EXTENSION OF FLOODING DATABASE FOR LARGE DIAMETER TUBE AT VARIABLE PRESSURE INCLUDING HYSTERESIS EFFECTS

A Thesis

by

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ABSTRACT

An experimental investigation into flooding phenomena was conducted to acquire data using steam/water and air/water fluid pairs at varying conditions within a large diameter vertical tube with annular flow. Experiments were performed to expand the database previously collected and verify correlations developed. Additionally, experimentation was conducted to determine hysteresis effects that may occur during flooding.

Experiments were completed in a previously established vertical test section. Flooding tests were conducted by forming an annular liquid film within the test section then injecting gas into the bottom of the test section until reversal of the annular film. Tests were performed at various gas inlet flow rates with water inlet flow rates ranging from 5 to 8 gallons per minute, and pressure varying from atmospheric pressure to 45 psig.

Data collected extends the range data beyond previous studies at the Nuclear Heat Transfer Systems laboratory. Data were collected in 0.5 GPM increments for the liquid mass flow rate range, filling out the data set previously collected. The additional data increases the reliability of the flooding database and flooding curves. Integration of the new data set with previous data enhances understanding of the effects of pressure, gas-liquid combination, and condensation effects of flooding phenomena.

Post-processing of data produced flooding curves to compare data sets. Integration of flooding data showed that when data is plotted as dimensionless

Kutateladze parameters showing that fluid-pair data overlay onto one another and a slight dependence on pressure of the system is present for steam/water data.

Hysteresis data was post-processed, and hysteresis curves produced, both gas-liquid systems exhibited hysteresis effects, namely as the gas flow rate was incrementally decreased, flooding occurred at a Kutateladze gas inlet parameter below that which is required to initiate flooding. The data suggests that higher carryover mass fraction can be sustained when the gas flow rate is being lowered from a flow rate beyond that needed to achieve the onset of flooding, effects were more dramatic at higher water inlet flow rates and pressures. Further, air/water mixtures showed more hysteresis than steam/water mixtures.

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The facility used in the study was designed and constructed by Nicole Williams (2009), with significant modifications and upgrades by Nick Wynne (2015). Additionally, data not collected during this study but included in the integrated data base in section 5, the operational procedures found in Appendix E, and experimental instrumentation data found in Appendix I were provided by Nick Wynne (2015) and Mathew Garza (2016). All other work reported in this thesis was completed by the student.

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NOMENCLATURE

ABBREVIATIONS

BWR	Boiling water reactor
CCFL	Countercurrent flow limitation
CFM	Cubic feet per minute
GPM	Gallons per minute
LOCA	Loss of Coolant Accident
NHTS	Nuclear Heat Transfer Systems
psia	Pounds per square inch absolute
psig	Pounds per square inch gauge
PWR	Pressurized water reactor
RCS	Reactor Coolant System
RCIC	Reactor core isolation cooling
gps	Grams per second

SYMBOLS

c	Constant in Wallis correlation
c_k	Constant in Kutateladze correlation
D	Diameter of the test section
D*	Bond number
f	Fraction of steam condensed

g	acceleration due to gravity
h_i	Enthalpy of phase *i*
j_i	Superficial velocity of phase *i*
j_i^*	Wallis parameter for the dimensionless superficial velocity of phase *i*
Ku_i	Kutateladze parameter of phase *i*
K_{ge}	Kutateladze effective gas flow rate
$\dot{m}_\iota$	Mass flow rate of phase *i*
Q	Volumetric flow rate
T_i	Temperature of phase *i*
T_s	Saturation temperature of working fluid
T_w	Temperature of the test section wall
V-x	Valve labeled with number x

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1. INTRODUCTION

The flooding phenomena is a limitation that is present in a countercurrent flow system. Countercurrent flow is phenomena that occurs when a liquid phase flows downwards as an annular ring along a pipe wall and a gas core flows upwards through the annular fluid ring. Flooding occurs when the gas phase reaches high enough velocities to impart enough momentum on the water phase that the water phase reverses flow direction, this is considered flooding or countercurrent flow limitation. The countercurrent flow limitation and flooding can be further defined as onset, partial, and full flow reversal by varying the gas phase mass flow rate in the system. This phenomenon and its challenges are present in many engineering applications including nuclear power reactors. Thus its study is of great interest in the nuclear field.

Like most instances of two-phase fluid flow these phenomena are complex leading to the of use empirical correlations to predict and model the behavior of flooding. These countercurrent flow correlations are often used in reactor safety codes to model flooding incidents in severe reactor accident scenarios. Thus there is a need in the reactor safety community for code validation to improve and provide more detailed models supported by experimental data.

1.1 Project Motivation

This study is the sixth installment of flooding investigation at the Nuclear Heat Transfer Systems (NHTS) laboratory at Texas A&M University. Flooding research began at the NHTS in response to analysis of a possible station blackout event that could potentially lead to flooding in the pressurizer surge line of a Pressurized Water Reactor (PWR) [1]. Since studies began at the NHTS, other hypothetical flooding limitations have been identified in Boiling Water Reactors (BWR). Thus the motivation for this research is to support and enhance the previous studies completed at the NHTS to better understand the flooding phenomena and to improve reactor safety codes used in severe accident analysis of nuclear reactors.

In a PWR, the primary coolant system, known as the Reactor Coolant System (RCS), is composed of various components designed to transfer heat away from the fuel core to a heat exchanger to produce power. This coolant, typically water, is pressurized so that the water stays in a liquid phase and is accomplished by controlling the system pressure. Two of these major components that allow control of the system pressure is the pressurizer and the pressurizer surge line. The pressurizer enables the system to change pressure via steam generation or steam quenching and release. At the top of the pressurizer, a relief valve is present to vent steam out of the pressurizer if the pressure exceeds a maximum threshold during normal operation. The pressurizer surge line is a system of piping that may include elbows, vertical and horizontal piping and associated connections of the pressurizer to rest of the system. Presented in Figure 1 is a general diagram of the components.

During a postulated accident scenario, large amounts steam may be generated in the core and travel through the surge line and vent out the relief valve. Previous work by Takeuchi, et al. found that flooding may occur in the pressurizer surge line leading to adverse system effects [2]. The concern is that as flooding occurs and high temperature steam replaces the water over long periods time, creep may cause failure of the pressurizer surge line or failure in the piping.

A second application of interest is in the emergency core cooling system (ECCS) of nuclear power reactors. The ECCS is a combination of systems that are meant to shut down a nuclear power plant after an accident safely. One of these systems in a BWR allows for the injection of cold water into the reactor core. Under an accident scenario, it is proposed that steam generation from the reactor core may be excessive leading to flooding or flow reversal reducing the effectiveness or failure of this system [3].

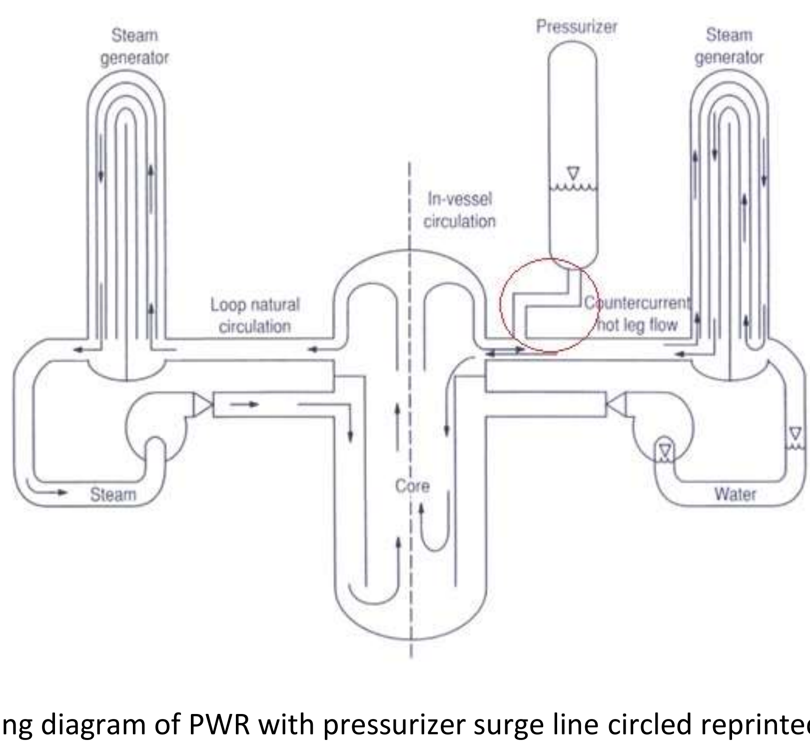

Figure 1: Piping diagram of PWR with pressurizer surge line circled reprinted from NUREG/CR-7110 Volume 2. [4].

1.2 Project Objectives

This study focuses on an experimental investigation into flooding of a large diameter vertical pipe at the onset of flooding and beyond onset flooding, and its associated hysteresis effects. An objective is to quantify this flooding phenomenon using air/water and steam/water mixtures to induce flooding within a preexisting test facility. Previous studies using the facility have been conducted to obtain onset of flooding data and various levels of flooding to compare air/water and steam/water tests. This current research will expand the data available, integrated data sets, and determine effects of flooding phenomena. Additionally, data was collected to identify hysteresis effects that occur in a flooded system after the gas inlet mass flow rate is reduced from the point at the onset of flooding or above.

The flooding data, much like previous studies were used to generate flooding correlations. The hysteresis data was analyzed based on conditions that allow the data to be compared to one another. This data will be useful in flooding models and reactor safety codes for post-flooding conditions.

1.3 Technical Approach

In previous installments of flooding at the NHTS flooding facility, Nick Wynne modified an existing facility designed by Nicole Ritchey [5]. These modifications allowed the facility to be pressurized up to 60 psia and for air/water or steam/water testing to be performed in the same test section, via common entrance and exit paths [6]. The facility was later modified by Matthew Garza to allow for water temperature, during steam/water tests, to be controlled via an additional heat exchanger [7]. These previous upgrades allow for direct data comparison of steam/water and air/water data with minimal effects to geometry and condensation [6][7]. This study will expand on the available data to enhance the understanding of the flooding phenomena and investigate the error produced during testing. Additional data sets were obtained to examine the hysteresis effects of flooding and are presented.

1.4 Thesis Organization

This thesis is divided into seven sections. The first section introduces the project motivation, objectives, and the general layout of this thesis. Section 2 contains a literature review of relevant flooding research covering significant correlations and flooding research performed outside of the NHTS Laboratory and flooding research conducted at the NHTS Laboratory. Section 3 describes the flooding facility at the NHTS Laboratory and explanations of design choices chosen by previous researchers. Within section 4, changes to previously established operational procedures to the NHTS flooding facility are presented. Section 5 presents results and discussion of flooding data. Within this section, analysis of raw data is displayed along with raw data conversion and plots to create flooding curves. The reduced data are then presented for steam/water and air/water flooding tests for newly collected data followed by integration of flooding data collected by Garza, Wynne, and the newly collected data [6] [7]. Section 6 presents hysteresis results for steam/water and air/water. Conclusions and future work suggestions are given in section 7. Appendices include reduced data collected for this study, additional flooding and hysteresis curves, operational procedures, raw data, MATLAB® scripts, and instrumentation details.

2. LITERATURE SURVEY

2.1 Initial Flooding Research

Initial experimental flooding research began in the mid-20th century by Wallis who reported findings from the experimentation of air/water flooding experiments [8]. In these experiments, Wallis tries to identify velocities in a vertical tube with an annular water film that will induce flooding [8]. Wallis proceeded to run experiments with different entrance and exit geometries concluding that the geometry of a test section affects the flooding velocities [8]. Using this information, Wallis determined a correlation, found in Equation 1, that matched well with his data and data obtained from a chemical packing tower experiments completed by Lobo and Sherwood [8] The correlation is a balance of forces using the densities of each phase, gravity, and the dimensions of the tube.

$$j_g^{*\frac{1}{2}} + m j_f^{*\frac{1}{2}} = c \qquad (1)$$

Where;

$$j_g^* = j_g \rho_g^{\frac{1}{2}} \left[gD\left(\rho_f - \rho_g\right) \right]^{-\frac{1}{2}} \qquad (2)$$

$$j_f^* = j_f \rho_f^{\frac{1}{2}} \left[gD\left(\rho_f - \rho_g\right) \right]^{-\frac{1}{2}} \qquad (3)$$

Where *m* and *c* in Equation 1 are constants associated with the specific test section geometry and j_i^* are the dimensionless parameters known as the Wallis parameters of the superficial velocity of phase *i*. Where in Equation 2 and 3 j_i, and ρ_i are the superficial velocity and the density of phase *i*, g is acceleration due to gravity, and D is the diameter of the test section.

From these equations, Wallis concluded that one could predict the gas velocity required for full flow reversal of water within the system by setting the superficial liquid velocity to zero [8]. Figure 1, presents the plot of equation 1 with respect to experimental data obtained from Lobo and Sherwood showing the fundamental trend that occurs in a flooding environment, he constants used for *c* and *m* are 0.775 and 1, respectively [8]. The underlying trend shows that as the superficial gas velocity, the y-axis, increases the superficial water velocity decreases, x-axis.

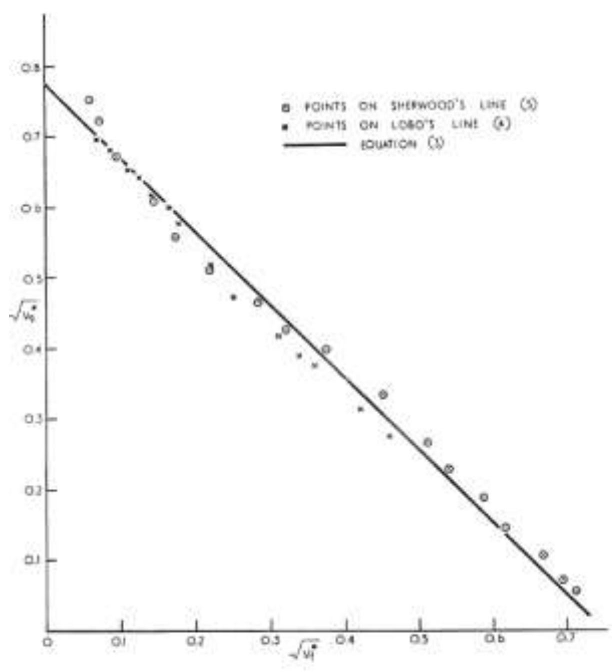

Figure 2: Wallis correlation plotted to experimental data obtained by Lobo and Sherwood reprinted from “Flooding velocities for air and water in vertical tubes” by Wallis [8].

Pushkina and Sorokin proceeded to experimentally study the Wallis correlation, Equation 1, and flooding by collecting data in test sections with diameters ranging from 6 to 309 mm [9]. Pushkina and Sorokin determined from their findings that the diameter, in Equation 1, played only a small roll in large diameter tubes; this results in inaccurate predictions when using the Wallis Correlation at large diameters. Further analysis determined that replacing the Wallis superficial velocities parameters, j_f^*, with Kutateladze (K) parameters, from prior work completed by Sorokin [9]. The Kutateladze parameters, Equation 4 and 5, for the respective phase proceeded to predicted flooding in large diameters more accurately.

$$Ku_g = \frac{j_g \rho_g^{\frac{1}{2}}}{[g\sigma(\rho_f - \rho_g)]^{\frac{1}{4}}} \tag{4}$$

$$Ku_f = \frac{j_f \rho_f^{\frac{1}{2}}}{[g\sigma(\rho_f - \rho_g)]^{\frac{1}{4}}} \tag{5}$$

Where Ku_i is the Kutateladze parameter for phase *i,* and σ is the surface tension of the liquid in annular flow.

Wallis further confirmed this and found that tubes above a certain diameter flooding prediction using the Kutateladze parameter yielded better results than his Wallis correlation [10]. Wallis concluded that much like his Wallis correlation the Kutateladze parameter is a balance of forces; however, it does not account for the dimensions of the test section but uses the viscosity of the fluid instead. Thus, Wallis determined a way of identifying whether a tube fits the large diameter criteria by use of the Bond number, Equation 6.

$$D^* = D\left[\frac{g(\rho_f - \rho_g)}{\sigma}\right]^{\frac{1}{2}} \quad (6)$$

The bond number is a dimensionless representation of the tube diameter concerning the density of the liquid and gas phases and surface tension of the liquid phase in the test section. Wallis found that if the bond number was greater than 30 the tube is considered large diameter and to apply the Kutateladze parameters, whereas if the bond number is less than 30 use the Wallis Correlation [10].

Vijayan later conducted an experimental investigation on into the effects of tube diameter on flooding determined that flooding occurs differently within a small diameter tube and that of a large diameter tube [11]. This same work further concluded that for large diameter tubes use of Kutateladze parameters would more accurately predict flooding behavior.

2.2 Flooding Research at Texas A&M University

Flooding research at the NHTS laboratory began with the work of Solmos who conducted fundamental flooding tests in an acrylic test section using air/water mixture at atmospheric pressure [12]. The test section Solmos designed was a scaled-down version of the 10-in diameter pipe found in a PWR surge line. Solmos' test section was a 3-in diameter acrylic tube that was determined to meet the large diameter criteria from the bond equation. This section became the prototype for the current test section revealing key design decisions required for flooding to be achieved. Solmos developed the methods used in the present test section to establish the annular liquid ring as well as optimized gas inlet conditions.

The second series of flooding experimentation followed directly from Solmos' prior work, where Ritchey conducted a similar scaling analysis using the design choices made by Solmos to construct a stainless-steel test section, closely resembling the test section built by Solmos [5]. The use of stainless steel allowed Ritchey to perform steam/water tests in a facility that closely mirrored the acrylic air/water facility, known to produce flooding. This stainless-steel test section is used in all proceeding flooding experiments at the NHTS laboratory. Flooding was initially observed and confirmed using air/water, and a benchmark was then obtained [5].

This benchmark data was then compared to steam/water data to begin understanding the effects condensation plays on flooding [13]. These steam/water tests were conducted at atmospheric pressure with a subcooling of 30°C with super-heated steam at 110°C, ensuring condensation. This data showed that flooding curves of air and steam with condensation would diverge from one another [13]. The Wallis parameter and Kutateladze parameters were both used to correlate the data and predict flooding; however, neither of these correlations accurately modeled the sub-cooled data, and a new correlation was developed using an energy balance to account for the losses of steam due to condensation from:

$$f = \frac{\dot{m}_f c_p (T_s - T_w)}{\dot{m}_g (h_g - h_f)} \tag{7}$$

where f is the fraction of steam that condenses, T_s is the saturation temperature, T_w is the inner tube wall temperature, m_i is the mass flow rates of the respective phases, and h_i is the enthalpy of the respective phases.

Applying equation 7 and the Kutateladze parameters a final correlation was developed to account for condensation:

$$\left(K_g(1-f)\right)^{0.5} + 0.56K_f^{0.5} = 1.45 \tag{8}$$

The third installment of flooding investigation was performed by Cullum to determine the effects of variable water subcooling at atmospheric pressure [14]. Work involved modification of the test section to allow for water inlet temperature to vary from 35°C to 97°C, for a subcooling range of 3°C up to 65°C. Data collected showed that as water subcooling increased the trend line would increasingly diverge from air/water data and that low water subcooling closely followed the air/water data [15].

Wynne began the fourth installment of flooding research at the NHTS laboratory by heavily modifying the entire test facility, this allowed for the testing of air/water and steam/water mixtures within the same test section under the same conditions. Modifications also included extensive work to allow for pressurized tests up to 45 psig. Additions included new sections of stainless-steel piping, high temperature pumps, high-volume air compressor, devices for pressure regulation, and heat exchangers for heat removal [6].

Wynne proceeded to conduct onset of flooding tests with steam/water up to 15 psig and air/water tests up 45 psig. This work concluded that at higher pressures a lower superficial gas velocity is needed to induce flooding due to the increase in gas density [6]. Flooding curves were generated using the Kutateladze parameters and when adjusted for condensation steam/water and air/water data was found to agree.

The fifth installment of flooding research followed and expanded upon Wynne's work at elevated pressures, Garza slightly modified the Wynne facility allowing for the temperature of the water entering the tests section to be controlled by the user during steam/water testing. Heating the inlet water was accomplished by the addition of a heat exchanger that uses steam to heat the incoming water from the water supply to the test section, allowing for more control on the amount of subcooling that would occur [7].

Garza proceeded to conduct onset of flooding tests with steam/water and air/water up to 45 psig while minimizing subcooling, less than 3℃ and began testing at various water inlet flow rates ranging from 5.5 GPM up to 7.0 GPM [7]. Flooding curves were produced from this dataset using the Kutateladze parameters for the fluid down test section and gas into the test section. Garza determined pressure had a minimal effect on the shape or placement of flooding data on the flooding curve and observed a small impact due to pressure; this was attributed to a random system error. Garza then determined a value f in equation 8 to account for subcooling to allow for a direct comparison of steam/water and air/water data [7].

3. FACILITY DESCRIPTION

The facility used in this study for flooding experiments is preexisting, and a culmination of work completed by Solmos [12], Williams [5], Cullum [14], Wynne [6], and Garza [7]. A brief overview of the facility will be provided for an understanding of how the facility is operated. Wynne provided an in-depth description of the facility, and no significant modifications have occurred since therefore much of the information presented here is presented in the Wynne thesis in detail [6]. A graphical representation of the facilities piping and instrumentation is provided on the proceeding page in Figure 3, as no changes have been made to the facility since Garza's work the P&ID presented is that presented in the Garza thesis [7].

3.1 Test Section

The test section is the same that was initially designed and built by Williams; the design drawing is presented in Figure 3 [5]. The design schematic introduced lists the component labels as steam, however, previous experiments updated the facility to use air in the same piping as steam. Thus the steam labels will be referred to as gas.

The test section assembly, labeled as 4 in Figure 3. is a 3-inch inner diameter stainless steel pipe, with a wall thickness of 0.25-inches, and is 72-inches long. At the ends of the test sections are Class 150 socket weld flanges, the top flange of the test section was placed well below the end of the pipe to allow the creation of a plenum for water to be collected and injected into the test section. At the bottom of the test

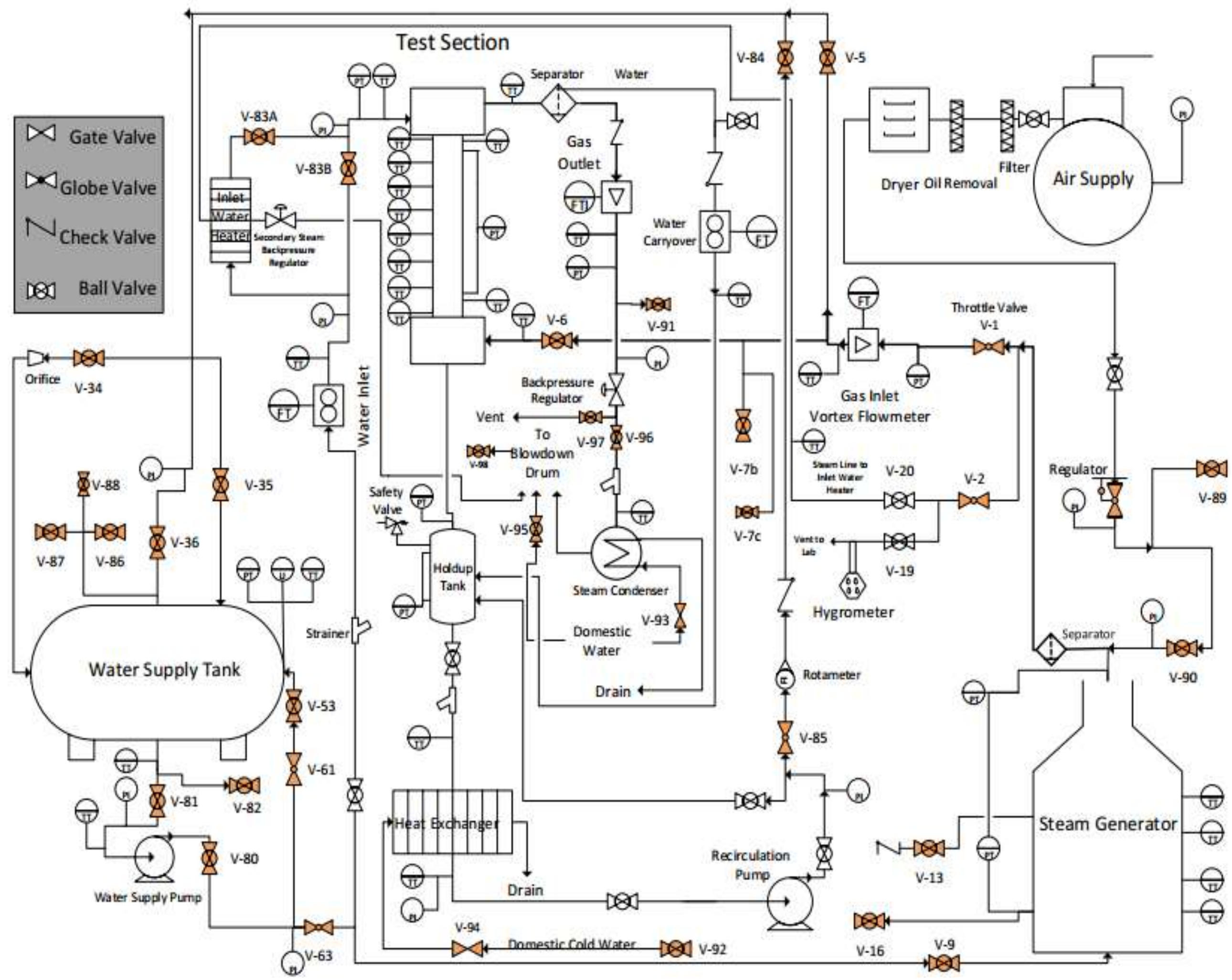

Figure 3: Facility piping and instrumentation diagram of the current flooding facility reprinted from Garza [7]. Highlighted valves are valves used during normal operation of the flooding facility.

section a water collection chamber is installed, item 5 in Figure 3, this allows water to collect below the test section and exit via four 1-inch holes in the flange below, item 6, without disturbing the incoming gas flow. A fifth hole is drilled into the same flange in the center allowing for gas to enter the test section undisturbed. This flange is constructed from a Class 150 blind flange with a 1.5-in national pipe thread (NPT) pipe section welded to center, which allows gas to enter the test section, the top of this pipe has a reducer installed to facilitate gas flow.

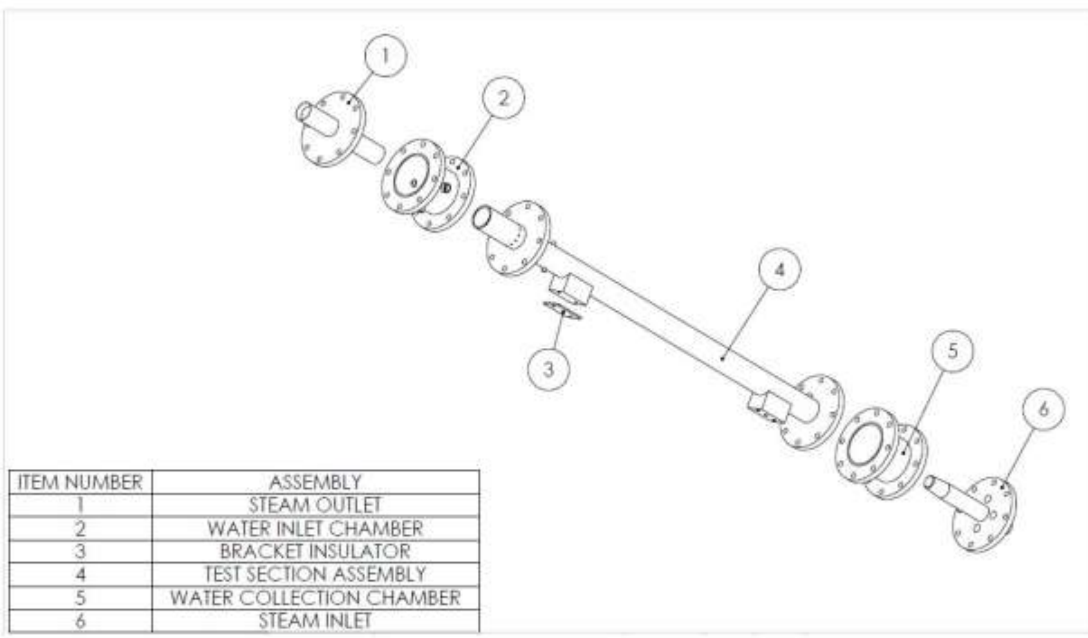

Figure 4: Design rendering of CCFL test section constructed by Williams reprinted from Williams work [5].

At the top of the test section is the water inlet chamber, item 2 in Figure 3, constructed of 6-inch NPS pipe and is attached via a Class 150 socket flange. The top of the test section, piece 4, protrudes into the 6-inch pipe creating a plenum for water to collect and allow for water to flow into the test section via twelve equally spaced 0.25-inch holes drilled into the circumference of the test section. Four equally spaced 0.75-inch water injection ports made from half couplings are welded into the 6-inch pipe to direct water into the plenum. For current testing, it was found that only two of the four water injection ports were needed for the flow rates used in tests [5].

Above the water inlet chamber, item 1 in Figure 3, is a Class 150 blind flange with a 2.75-inch outside diameter pipe and a wall thickness of 0.25-inch is welded to the center, this acts as an exit path for gas and for any two-phase mixture exiting the top of the test section without disturbing the water inlet flow. The gas outlet pipe was designed so that it fits into the 3-inch test section ending below the 12 water injection holes drilled into the test section, to facilitate the formation of an annular film along the test section walls. Inserting the gas outlet pipe into the test section forced the water film to have a thickness of 0.125-inches at this point [5]. The bottom of the steam outlet pipe is tapered 15˚ from the vertical axis to reduce vortices in the outlet flow two-phase mixture [5].

The test section has five 0.125-inch instrument ports three at the top of the test section and two at the bottom. Both bottom instrument ports are used for pressure measurements. At the top one port is currently unused, the second is used for centerline temperature measurement of the test section, and the final is used for pressure measurements. All materials used in the test section are made of austenitic Type 304 stainless steel [5].

3.2 Gas Flow Path

The current facility, due to modifications made by Wynne, allows for steam or air to enter the test section in common piping, and is controlled via a 1.5-inch globe valve and is referred to as the throttle valve, and is listed as V-1 in Figure 3. The gas travels through 1.5-inch NPS stainless steel piping into a Foxboro 83W Vortex Flow meter to obtain a mass flow rate of the gas.

Gas leaves the flow meter in 1.5-inch stainless steel pipe and routed to the bottom of the test section and injected upward into the test section. During testing, a two-phase gas/water mixture may leave the test section and must be separated. A multistage high efficiency, model LCCR-200-RL-SC separator manufactured by Anderson was procured by Wynne to accomplish this and can remove down to 1-micron droplets of water from the two-phase mixture.

After separation, the gas exits the separator in 1.5-inch stainless steel pipe, and the mass flow rate is measured via a Foxboro 84F Vortex flow meter. Once mass flow rate of the gas is obtained, the gas continues to flow through 1.5-inch stainless steel piping into a Jordan Mark 50 back pressure regulator allowing for pressure control of the system then allowed to exit the system.

While much of the path for both steam and air into and out of the test section are the same, they do differ in two places; before the throttle valve and after the back-pressure regulator. Steam is generated inside an ASME certified pressure vessel by boiling deionized water and is constructed of Schedule 10 Type 304 stainless steel with a maximum allowable pressure of 135 psig at 350 °F. Steam is generated inside the steam generator via six immersion electrical heaters produced by Watlow Process Systems, having a maximum power output of 157 kW. The heaters are wired to a control panel that allows the incremental operator control of the power level, giving the operator a way to control subcooling or superheating of the steam. Steam from the steam generator may have entrained water within it if testing is conducted below saturation, so an Anderson Type TL centrifugal high-efficiency separator was procured and installed above the steam generator to remove the entrained water as the steam leaves the steam generator [5]. Steam exits the separator into a T-valve, and then the throttle valve entering the common gas piping described previously.

At the exit of the facility, once the steam passes through the back-pressure regulator, it will be disposed of and removed from the system. If steam/water testings this is accomplished by condensing the steam with a steam condenser, an AlfaNova 27-34H plate type heat exchanger, procured by Wynne. Domestic water is supplied on the cold side of the heat exchanger and allowed to drain into domestic sewage. After the steam is condensed, it is gravity drained into a 50-gallon blowdown drum and eventually flowed into the domestic sewage line.

Air is supplied by a Quincy QT-15 air compressor procured and installed by Wynne. The compressor is a 15 HP reciprocating compressor with a 120-gallon capacity and a maximum output of 51 ACFM at 175 psig. The air leaving the air compressor is filtered through particulate and oil filters and then is dried, to remove entrained moisture, via a refrigerated dryer supplied by Quincy. After exiting the air dryer, the air is regulated via a pressure regulator and piped into the steam generator. The steam generator is emptied during air testing and is used as an air supply tank, the air then enters the test section in the same piping as steam. Once the air enters the test sections, is separated, and measured, it will pass into the back-pressure regulator and release from the system via a nylon braided hose to outside the lab.

A secondary gas side was initially installed by Wynne to measure the humidity of air during testing [6]. To accomplish this a tee was introduced before the gas throttle valve, V-1, and a second throttle valve was installed, called the secondary side throttle valve, V-2. Air was controlled via the secondary throttle valve and sent to a Dwyer HHT humidity/temperature transmitter, once air passes through the transmitter the air exits to the environment [6].

Garza modified the secondary side to allow steam to heat incoming water entering test section, by using steam from the steam generator allowing for more precise control of the water temperature entering the test section, allowing the user to reduce the amount of subcooling that may occur during steam testing [7]. The steam is controlled via the secondary throttle valve and is passed through an AlfaNova 27-30H plate type heat exchanger to heat the incoming water, procured by Garza [7]. This steam line has an addition Jordan Mark 60 pressure regulator to increase pressure in the secondary path for pressurized testing; this steam is disposed of via a blowdown drum where it can condense before being released to domestic sewer lines.

3.3 Water Flow Path

Water is stored in a 1400-gallon pressure vessel procured by Solom and is referred to as the water supply/RCIC tank [16]. The water supply/RCIC tank is made of Type 304 stainless steel and can maintain 88 psi at 400°F. Water is supplied to the flooding test section by one of two pumps located directly underneath the water supply/RCIC tank. The main pump used for flooding testing is referred to as the water supply pump and was procured by Wynne. The water supply pump is a 1.5 HP Liquidflo model 620 Century Series centrifugal pump capable of operating at 300 psig at 500°F [6]. The second pump, referred to as the RCIC pump, is a 0.75 HP Dayton five-stage centrifugal pump capable of operating at 93 psig at 194°F was procured by Solom [16]. Water from the pump enters a shared 1-inch stainless steel line with a 1-inch stainless steel globe valve used to adjust the water mass flow rate into the test section. After passing through the valve, the water enters a 0.5-inch Azbil MagneW 3000 magnetic flow meter to determine its mass flow rate. The water then flows into an AlfaNova 27-30H heat exchanger to heat water before it is sent to into the top of the test section during steam testing. If air testing is being performed the heat exchanger may be bypassed allowing water to flow directly into the top of the test section.

Water has one of two ways of leaving the test section: by either flowing down the walls of the test section or, after flow reversal occurs, out the top of the test section.

Water leaving the bottom of the test section is collected in a water hold up tank located below the test section. During testing if water is reversed, the water passes into the separator at the top of the test section and is separated from the gas; the separated water flows into a second .5-inch Azbil MagneW 3000 magnetic flow meter to determine the water carryover mass flow rate, then diverted into the holdup tank. The holdup tank is an 80-gallon stainless steel Type 316 pressure vessel capable of 150 psig at 400°F. As the size of the water hold up tank is small and to conserve water, the water is transferred back to the water supply/RCIC tank. Water from the holdup tank is sent into a second AlfaNova 27-30H plate type heat exchanger used to reduce the temperature of the water if steam testing is being conducted to avoid cavitation in the re-circulation pump, the cold side of the heat exchanger is supplied via the domestic water supply and disposed of via domestic sewage line. The water then enters a re-circulation pump and is returned to the water supply/RCIC tank and is a 1 HP Liquidflo model 620 Century Series centrifugal pump capable of operating at 300 psig at 500°F and was procured by Wynne [6].

Water is sourced from a domestic water supply and purified via a resin bed system provided by Culligan Water Treatment.

3.4 Instrumentation

The facility makes use of thermocouples, pressure transducers/transmitters, and flow meters so that identification of system characteristics, safe facility operation, and fluid parameters. Thermocouples are used extensively throughout the facility and used to measure axial temperature on the outside wall of the test section, monitor the water supply/RCIC tank temperature distribution, monitor temperatures entering the facilities pumps, holdup tank temperature, steam generator temperature, and the temperature at each flow rate detector [7] [13] [14]. Thermocouples are identified on the P&ID in Figure 3 and are labeled as “TT”. All thermocouples used in the facility are Type T copper constant thermocouples produced by Omega Engineering [7].

Flow meter locations and models pertaining direcnntly to testing are described previously. One additional 0.5-inch Azbil MagneW 3000 magnetic flow meter is used to identify the water flow rate entering or leaving the steam generator allowing the user to monitor fluid flow while emptying or filling the steam generator to or from the water supply/RCIC tank.

Three Honeywell ST3000 STD924 differential pressure transmitters are used in the facility: one used to measure the holdup tank water level, the second used to measure the steam generator water level, the third is installed on the test section and is used to identify when flooding occurs [1]. A Keller Valueline High Accuracy pressure transmitter is used to obtain the absolute pressure of the test section [6]. Honeywell ST3000 STA9400 pressure transmitters are installed to capture the absolute pressure of the steam generator and pressure conditions at the Foxboro vortex flow meters to determine gas mass flow rates [1].

Data is collected via a National Instruments SCXI 1000 Chassis and is recorded and monitored in LabVIEW. The LabVIEW VI is set to record 20 samples at a rate of 200 Hz, resulting in a 10 Hz output [6]. The LabVIEW VI allows the user to monitor the facility for safety, identify flooding events within the test section, and record data. Data from LabVIEW is output to .dat files; additional post-processing occurs in MATLAB®. Wynne compiled a table detailing operating range and accuracy associated with the instrumentation used in the flooding facility and is presented in Appendix I [6].

4. OPERATIONAL PROCEDURES

Safety is the primary concern when operating the flooding facility, as the use of pressurized temperature fluids and gases are present during operation. Proper use of the facility will also assist in maintaining consistent data across tests. Accordingly, operational procedures were created. The current facilities operating methods were initially developed by Wynne [6]. As modifications were made during Garza's work, the procedures were updated accordingly, as such the operational procedure follow very closely to the previous work and were updated for ease of use [7].

As most of the operational procedures for the flooding facility and associated subsystems were established in previous work and presented in Appendix E. Major changes to the procedure from Garza's work are given below and are reflected in the methods found in the Appendix E.

4.1 Changes to Operational Procedure

The operational procedure has been developed over two previous studies, with no additional equipment being included in this study. However, during maintenance of the air compressor, it was discovered that the oil level should be checked after the compressor has been started [17]. Following the previous procedures, an oil level check was done before starting the compressor if the oil level is tested at this point the level may appear to be high as the oil may have drained out of the heads of the compressor leading to an incorrect measurement of the oil level.

5. RESULTS OF NEW FLOODING DATA AND DATA SET INTEGRATION

Additional data were collected for this study to expand beyond the parameters of data collected by Wynne and Garza. Expansion of the dataset allows for a more extensive and more comprehensive flooding curve, that will lead to new insights into flooding of a vertical large diameter tube. Previous work performed at the NHTS collected 179 valid data points, newly conducted work obtained for this study added 285 data points. This new data focused on two areas; onset of flood and high carryover flow rate data, further details will be covered during data integration.

The proceeding sections summarize test parameters, newly collected data, analysis of data for this study, and analysis of an integrated database. Raw flooding data will be provided to explain the events of standard flooding test and explain why data reduction was conducted. The data reduction techniques will then be described, and the data set will be presented as flooding plots for steam/water and air/water tests. Finally, an error analysis was conducted and presented.

5.1 Test Range and Target Parameters

Test ranges for this study were established to compare to and extend the work by Garza; this leads to an operating pressure range from 1 to 45 psig. As 0 psig testing was not possible to obtain in the facility due to system design, low psi testing was conducted and was usually around 1.0 to 5.0 psig and will be referred to as ambient pressure. Pressure creep, a phenomenon that occurs due to pressure build up or losses in the system, developed in ambient and 15 psig testing at elevated gas mass inlet flow rates. The maximum pressure, 45 psig, was established by Wynne when he modified the facility for pressurized testing [6]. Garza proceeded to break the pressure operating range down into 15 psig intervals; the same convention is used here. Water mass flow rates obtained by Garza were limited, this study expanded on the data set Garza provided, by widening the range of mass inlet flow rates for water. The original water inlet mass flow rate range was based on the water flow rate operating range established by Williams [5]. Ritchie identified the water flow rates that the facility could adequately perform at were 4.5 to 12 GPM, initial testing for this study determined that 5.0 to 8.0 GPM should be conducted [13]. This range was chosen as the water inlet flow rates decreased below 5.0 GPM reasonable doubt of annular film creation of the water was being created. The upper limit restriction is due to pressure, and the water inlet mass flow rate, as both increases flow reversal is harder to achieve. Once this flow rate range was identified an increment of 0.5 GPM was chosen to define the water mass inlet flow rate range, testing at points that were already completed by Garza only occurred to verify, that results were repeatable with a new user.

Gas inlet mass flow rates were chosen to be at three different points the first being onset of flooding, or when countercurrent flow was first initiated in the test section. Due to the nature of flooding, this is dependent on the mass flow rate of the gas and the system pressure and was identified for each test. The second gas flow rate was roughly 10 grams per second (gps) above the onset mass flow rate; this was selected as it would ensure this target could be obtained for all testing. Finally, the last gas inlet mass flow rate was chosen as the gas flow rate required for full flow reversal. However, this was not attainable with the current facility due to lack of gas generation capabilities, and the pressure creep that developed as the mass inlet flow rate of the gas increased.

Water inlet and steam inlet temperatures for steam/water testing are determined by the saturation temperature required for the pressure of the test being performed, leading to a range from 100℃ up to 144℃. From Garza's work, it was established that the water temperature was to be within 3°C of saturation temperature [7]. The steam inlet temperature ideally was to be kept at the saturation temperature for the pressure being tested. However, it was found that this became quite difficult to control and maintain. Garza concluded that keeping the superheat to a minimum would achieve adequate results establishing that the steam inlet temperature should not exceed 10℃ above saturation temperature, leading to a steam temperature range of 100℃ to 154℃ [7]. The same approach is used in this study. However, care was taken to reduce the superheat as much as possible.

All testing parameters for flooding testing are summarized below for flooding testing in Table 1.

Table 1: Flooding test parameters.

Parameters	**Steam/Water Range**	**Air/Water Range**
Test Section Pressure [psig]	3-45	3-45
Gas Inlet Flow rate [gps]	25-66	35-75
Gas Inlet Temperature [°C]	100 – 154	15
Water Inlet Flow Rate [GPM]	5-8	5-8
Water Inlet Temperature [°C]	100 -144	25

5.2 Raw Data of a Typical Flooding Test

Data collection was completed using National Instruments LabVIEW with the raw data output as .dat files. A file collected all pertinent information for a test performed which included a variety of parameters such as mass flow rates, pressure, and temperatures at critical locations in the test section and facility so that a flooding profile was obtained. The data files for steam/water and air/water are similar with the caveat that for steam, additional data is collected for temperature as fluid and gas properties are affected by the temperature, some of this data was not collected for air/water testing, and it was assumed the effects of temperature would be minimal.

The purpose of a single test was to conduct a flooding test in which the user-controlled parameters are at a quasi-steady state. These parameters are water inlet mass flow rate and temperature, gas inlet mass flow rate and temperature, and system pressure. Testing was conducted for the onset of flooding and beyond onset of flooding.

A test is initiated by first allowing water to flow into the test section and stabilize at a predetermined water inlet mass flow rate, seen in Figure 5, from 0 to roughly 180 seconds. Typically, this flow rate and other system parameters are determined in a preliminary test, before a test is recorded.

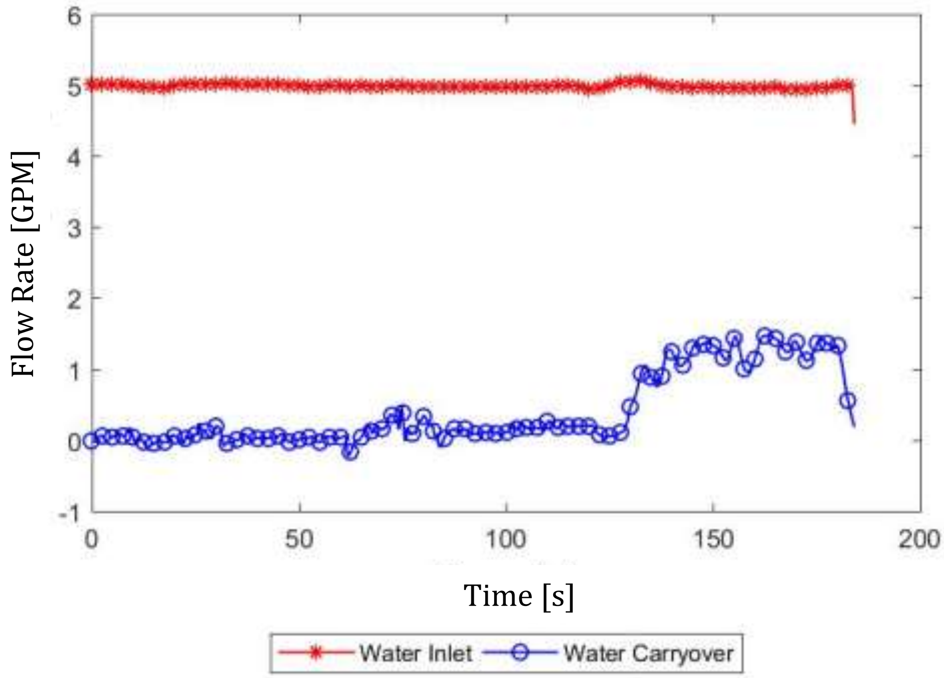

Figure 5: Water flow rates for a typical flooding test. This plot corresponds to test 2017_05_15_test_04.

After the predetermined water flow rate is established, the gas is allowed into the test section, shown in Figure 6, and slowly brought up to the point flooding will be initiated at, this is typically found and confirmed when establishing the water inlet flow rate.

Once the gas flow is initiated the system pressure begins to increase to the predefined pressure. This target pressure should be reached before flooding occurs.

The gas outlet flow rate will tend to lag the gas inlet flow rate. Ideally, the gas inlet and outlet flow rates should match, and typically do in air/water tests. However, it was found that during steam/water testing this was highly unlikely due condensation of the steam that may occur during testing. As a test progresses, the gas inlet and outlet flow rates tend to converge, although a test is limited to the amount of available gas and may end before a complete convergence of gas inlet mass flow rate and gas outlet mass flow rate appears.

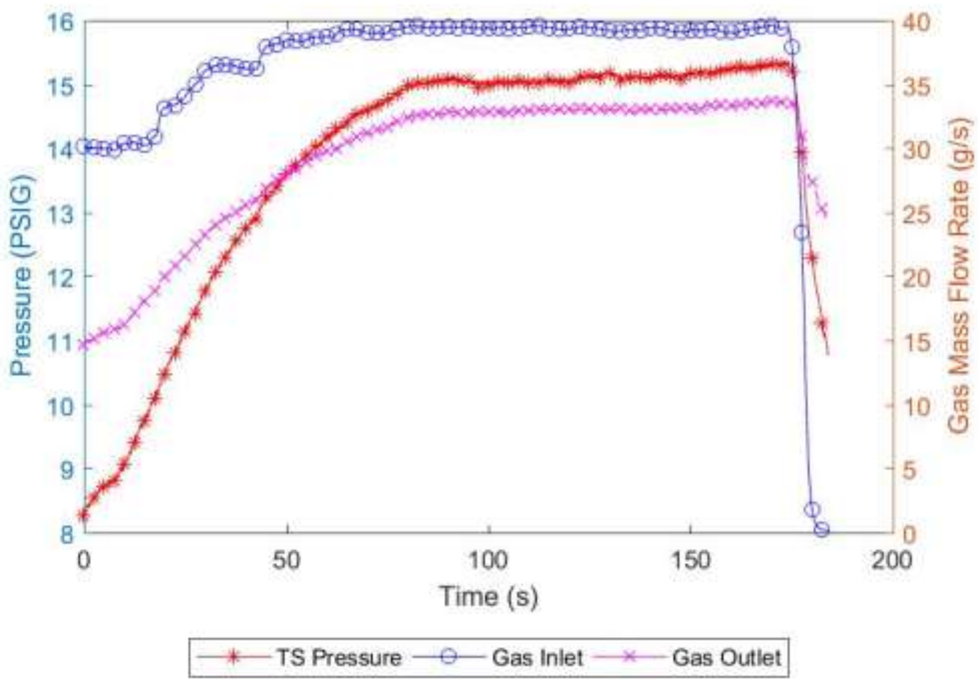

Figure 6: Gas flow rates and pressure for a typical flooding test. This plot corresponds to test 2017_05_15_test_04.

Once flooding is initiated the carryover flow rate appears, shown in Figure 4, carryover flow rate is a rate at which water is no longer flowing down the test section but is reversed by the gas and is exiting the top of the test section. This flow rate tends to follow a sinusoidal shape during a test.

Once a test is completed, the valve regulating the gas mass flow rate is closed causing pressure and gas inlet and outlet mass flow rates to fall immediately, in the case of gas flow rates to zero. The water inlet mass flow rate is then shut off and quickly drops to zero. The carryover mass flow rate typically will do that same unless large amounts of water are still present in the separator. The above parameters are monitored during testing and adjusted if needed manually.

Due to the non-opaque nature of the test section in use, direct visual confirmation of flooding is not possible. Therefore, flooding is identified in the LabVIEW VI using the test section differential pressure. From previous studies, it was determined that as flooding occurs, a significant drop in a test section differential pressure appears [11]. Further studies showed that this is due to a pressure wave forming the moment flooding is initiated and travels up the test section, creating a positive pressure at the low side port of the differential pressure transmitter, leading to an overall drop in the test section differential pressure.

A plot of differential pressure for the onset of flooding test is provided in Figure 7, as the test begins the test section differential pressure is approximately 55.75 in H_2O. Roughly 120 seconds into the test, test section differential pressure starts to deviate from the set point, informing the user that flooding has started to occur. Throughout the length of a test if flooding is occurring the differential pressure change is observed. At roughly 175 seconds the test is concluded, the gas flow is stopped, and a substantial differential pressure decrease is observed. This effect is from the remaining gas in system evacuating, causing a reduction in system pressure.

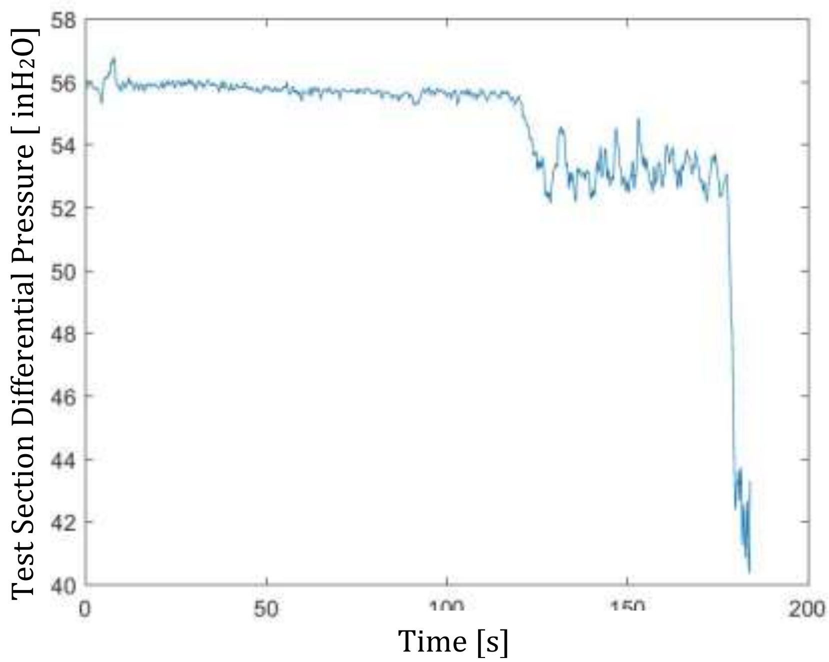

Figure 7: Test section differential pressure of a typical flooding test. This plot corresponds to test 2017_05_15_test_04.

The water temperature, gas inlet temperature, and the saturation temperature are also monitored and shown in Figure 8. Under ideal circumstances all three of these values should be identical for steam/water tests; with air/water testing the saturation temperature is neglected and gas inlet and outlet should be equal. For the test presented in Figure 8, it is observed that the gas inlet temperature is slightly higher, approximately

0.4°C, above the saturation temperature. The liquid inlet temperature started out high and was adjusted to below the saturation temperature before flooding occurs, and is kept constant, at roughly 2°C below the saturation temperature.

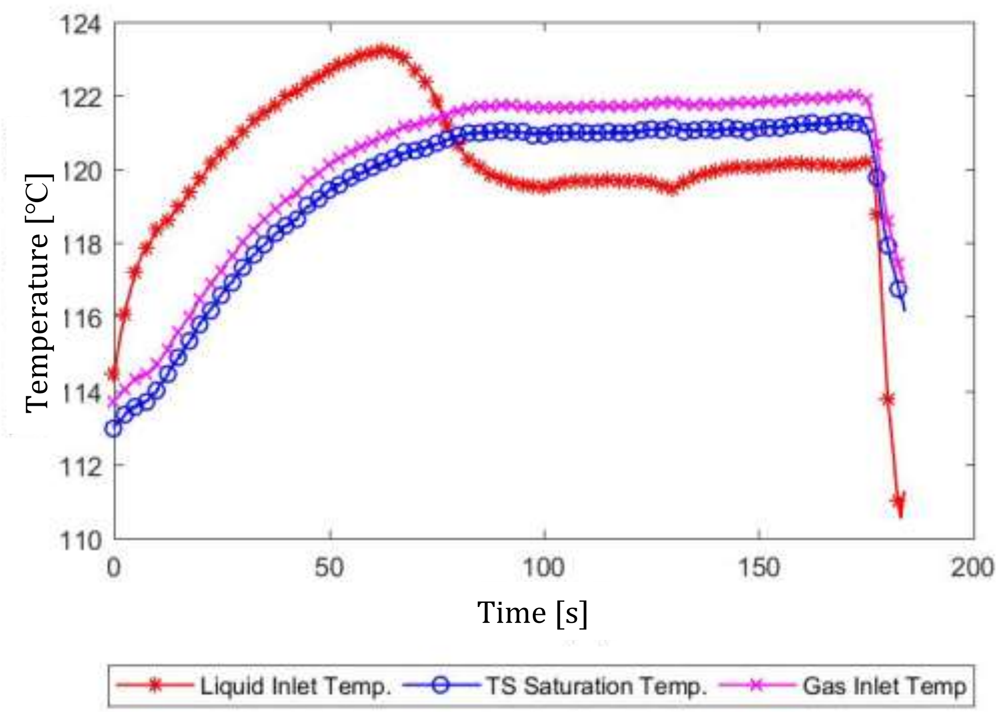

Figure 8: Gas inlet, saturation, and water inlet temperatures of a typical flooding test. This plot corresponds to test 2017_05_15_test_04.

5.3 Observations of Raw Data

Initial observations showed that a delay would appear from when the differential pressure transmitter indicates flooding to occur initially and when water carryover begins. From Figure 7 the time at which the differential pressure shows flooding to develop is roughly 120 seconds. Further, Figure 5 shows carryover flow rate doesn't appear until after 130 seconds; this is due to a delayed response from the magnetic flow meter that measures the carryover mass flow rate and the travel time required for the reversed water to pass into the flow meter.

During testing, it was observed that the gas mass flow rate to initiate flooding could be reduced by holding the gas inlet mass flow rate below the flow rate initially believed to cause the onset of flooding. Typically, this would usually occur 1 to 2 gps below the initially obtained value, doing so also corresponded to an increase in time from when this new mass inlet flow rate was reached, and when flooding would occur. This is observed in Figure 7, the differential pressure plot, showing flooding occurring at approximately 120 seconds when compared to the gas inlet flow rate, in figure 6, which indicates that the gas and pressure stabilize at roughly 85 seconds. Leaving approximately 35 seconds that the system was stable before flooding finally occurred. During this period the differential pressures transmitter begins to become erratic.

Finally, it was observed during testing the carryover mass flow rate followed a sinusoidal pattern shown, in Figure 9, for the onset of flooding and beyond onset of flooding. For tests completed well beyond onset, a gas inlet mass flow rate of 15 gps above the onset inlet mass flow rate was typically chosen, causing the water carryover mass flow rate average value to be higher. Which is to be expected due to increase momentum transfer from the higher gas flow rate to the liquid; this would coincide with an observed decrease in the amplitude of the sinusoidal peaks of the carryover mass flow rate, shown in Figure 10. This phenomenon is observed for both steam/water and air/water testing.

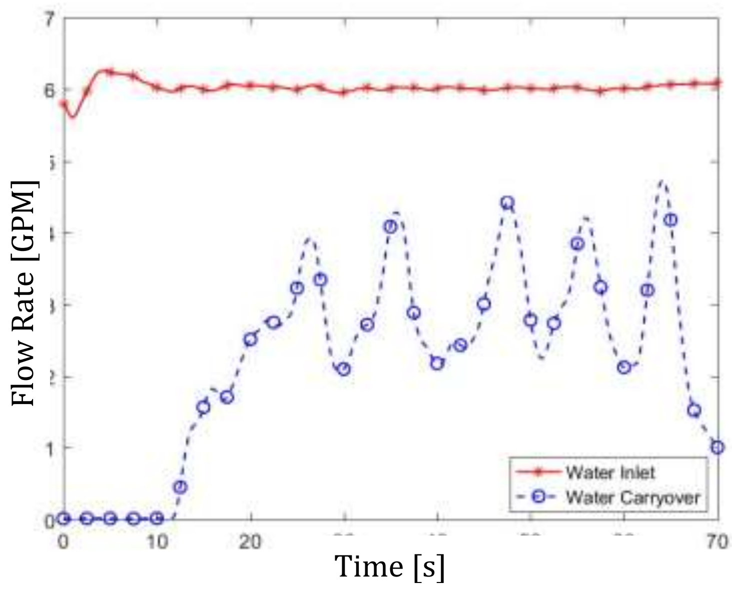

Figure 9: Test conducted with a water inlet mass flow rate of 6.0 GPM and air flow rate of 42 gps representative of an onset flooding test.

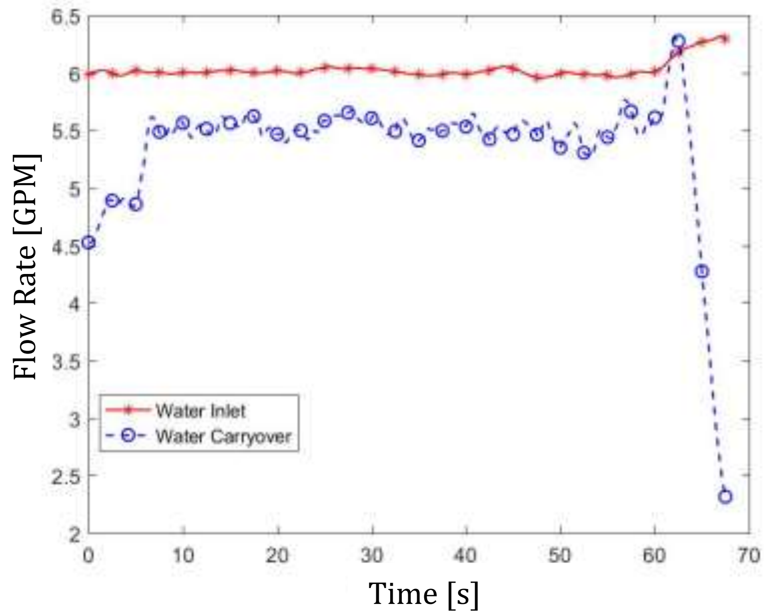

Figure 10: Test conducted with a water inlet mass flow rate of 6.0 GPM and air flow rate of 58 gps representative of a beyond onset test.

5.4 Data Reduction Method

To compare one test to another, the data was plotted using flooding curves, in terms of the square root of the Kutateladze parameters for gas flow into the test section and the fluid out the bottom of the test section. To do this each test needed to be averaged into a single data point over the time interval that flooding was occurring and completed by using sets of MATLAB® scripts for corresponding gas fluid pairs.

The first script "XXXX_Find_Range", where XXXX denotes the gas, loads a single .dat file and plots the gas inlet mass flow rate, test section pressure, carryover mass flow rate, and the test section differential pressure. These variables are used to identify the time interval at which flooding appears at a quasi-steady state condition and when it ends. The user locates this interval by identifying stable pressure, gas inlet flow rate, test section differential pressure drop, and carryover flow rate. Typically, this range was a minimum of 30 seconds. For high gas flow rates tests, this was not always possible and shorter time ranges were used, with no test allowed under 10 seconds. These values are then saved in an EXCEL document for later use.

Once a set of data had the flooding interval located a second script, called "XXXX_Reduced", takes the user identified ranges and averages all pertinent information over the time interval of interest for each test and calculated the superficial velocity, equations 2 and 3, and Kutateladze parameters, equations 4 and 5. Fluid properties were obtained using "XSteam" a freely available table of steam properties based on IAPWS IF-97 standards for MATLAB®[18]. This script was designed to loop through .dat files for batch processing. Pertinent information was output to an array of averaged and calculated values for all .dat files being processes; this output is saved into a master excel file for further analysis.

Within this excel file, each test is identified, and qualification criteria are applied. These criteria are the gas inlet flow rate doesn't deviate by more than ±1 gps, fluid temperature is no less than 3℃ subcooled, and that the pressure did not deviate by more than ±2 psi. Tests that passed these qualifications were then used to create Kutateladze flooding curves.

5.5 Observations from Reduced Newly Collected Data

Flooding curves were obtained by using the square root of Kutateladze parameters to analyze trends within the data set and will be referred to as the Kutateladze parameter for the respective condition of interest. Parameters used in this study for generation of flooding curves employed the fluid mass flow rate that exits the bottom of the test section, Ku_{fd}; this value is not directly measured by instrumentation, it is calculated during post-processing by using the fluid mass flow rate entering the test section minus the carryover mass flow rate.

Previous work by Garza identified that the water inlet mass flow rate had very little effect on a data points placement on a flowing curve. Thus the parameter for water mass flow rate down the test section is used [7]. The second parameters used is the Kutateladze gas parameter entering the test section, Ku_{gi}. Flooding curves presented plot the square root of Ku_{fd} on the x-axis, and the square root of Ku_{gi} on the y-axis and are obtained from equations 4 and 5. Interpretation of the flooding curve is intuitive, as the x-axis approaches zero, the Kutateladze fluid down parameter, a measure of the fluid forces due to the water going down the test section, decreases signifying less water is exiting the bottom of the test section. The y-axis is like the x-axis, an increase in the Kutateladze gas inlet parameter corresponds to an increase in the gas flow rate entering the test section.

A complete data set from newly collected data for this study is presented in Figure 11. Here each point on the curve represents an individual averaged flooding test and different symbols representing different parameters. Groups of tests were identified based on gas/liquid combination and pressure unless otherwise noted.

Initial observations show similar trends to previous studies performed at the NHTS laboratory and available literature, with a general data trend that a data point with a greater Ku_{gi} value the less the Ku_{fd} value tends to be. Fundamentally this should be the expected trend, as gas mass flow rate is increased into the test section, a decrease in water mass flow rate flowing down the pipe walls and out of the test section should occur.

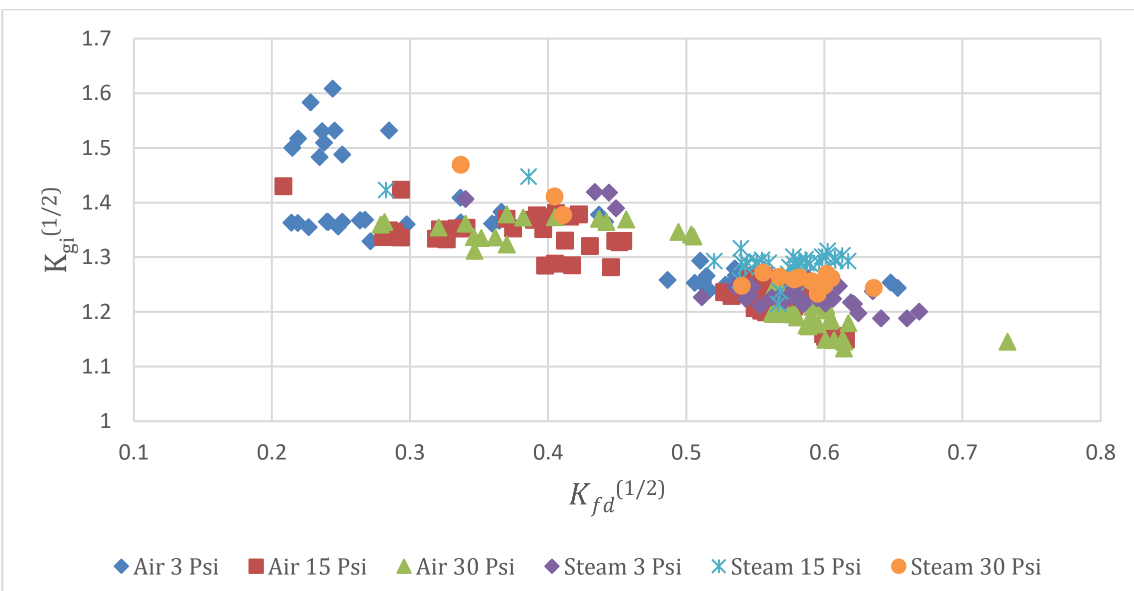

Figure 11: Kutateladze flooding diagram for ambient, 15, 30, and 45 psig for new data collected in this study.

To further analyze Figure 11, steam/water and air/water flooding curves were generated separately. Figure 12 presents a breakdown of only the steam data presented in Figure 11 and is divided into groups based on the target pressure ambient, 15, 30, and 45-psi. However, no 45 psig testing completed for this study passed qualification. A gap in the data set is observed at roughly 0.45 to 0.5 on the x-axis. This split in data separates the onset of flooding data from the beyond onset of flooding data during data collection. Beyond onset flooding was typically 10 to 15 gps above the onset of flooding, as this was kept close to 10 gps, a distinct separation appeared in the data.

Additionally, Figure 12, just as figure 11, shows the same general trend for the flooding curves. Garza noticed that pressure of the system appears to have a slight effect on where a data point is placed on the curve, the same phenomenon appears within the newly collected data as well [7]. While the slopes of each data set appear equal, higher pressure increases a datasets placement along the y-axis on the right-hand side of the curve, the onset of flooding data. However, this is a very slight difference and disappears when looking at the data on the left-hand side of the curve, the beyond onset of flooding data. Garza attributed this to error present within the system as the Kutateladze number inherently accounts for pressure via the density terms during calculations [7]. As this phenomenon doesn't appear for data on the left-hand side of the curve the cause of this phenomena may not be random error, additional insight was gained observing air/water curves.

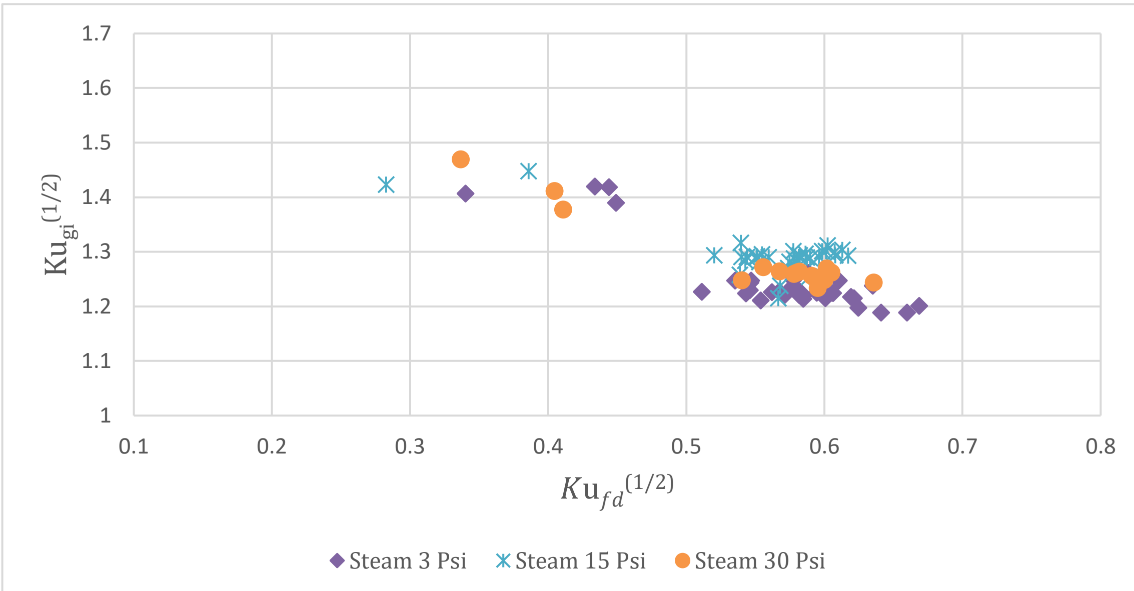

Figure 12: Complete steam/water Kutateladze flooding curve for ambient, 15, 30, and 45 psig for newly collected data.

Flooding curves for air/water were generated in the same manner as the steam/water curves, the first is presented in Figure 13, displaying the same general trend for flooding curves, as the Ku_{gi} increases the Ku_{fd} decreases. Here pressure is shown to have very little to no effect on the placement of the onset of flooding data, on the right-hand side of the curve, leading one to the conclusion that the Kutateladze parameters adequately account for pressure changes within the system of air/water curves at the onset of flooding. This insight leads one to dismiss earlier findings that the difference in placement along the y-axis is due to pressure effects for steam/water. During steam/water testing at higher pressures condensation of the steam appears to have a higher chance of occurring, this is due to user control of the water inlet temperature being slightly harder to control as pressure increases subsequently leading to a higher gas flow rate being required initiate flooding.

A second difference appears in the air/water dataset compared to steam data, below a Kutateladze fluid down parameter of 0.45 the data flattens out into an almost horizontal line, seen clearly in Figure 14, which removes ambient pressure tests from the flooding curve. Previous work by Vallèe's data also showed this leveling off of air data when using Kutateladze parameters, but no mention of it was discussed, and the test section was considerably different [19].

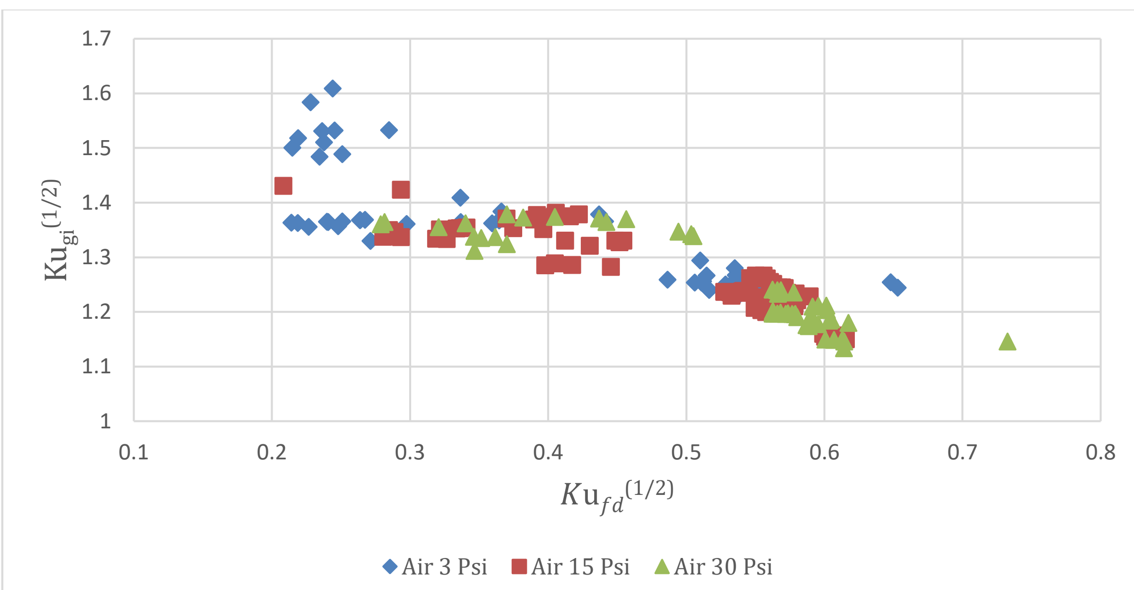

Figure 13: New air/water Kutateladze flooding curve for ambient, 15, 30 psig for data collected for this study.

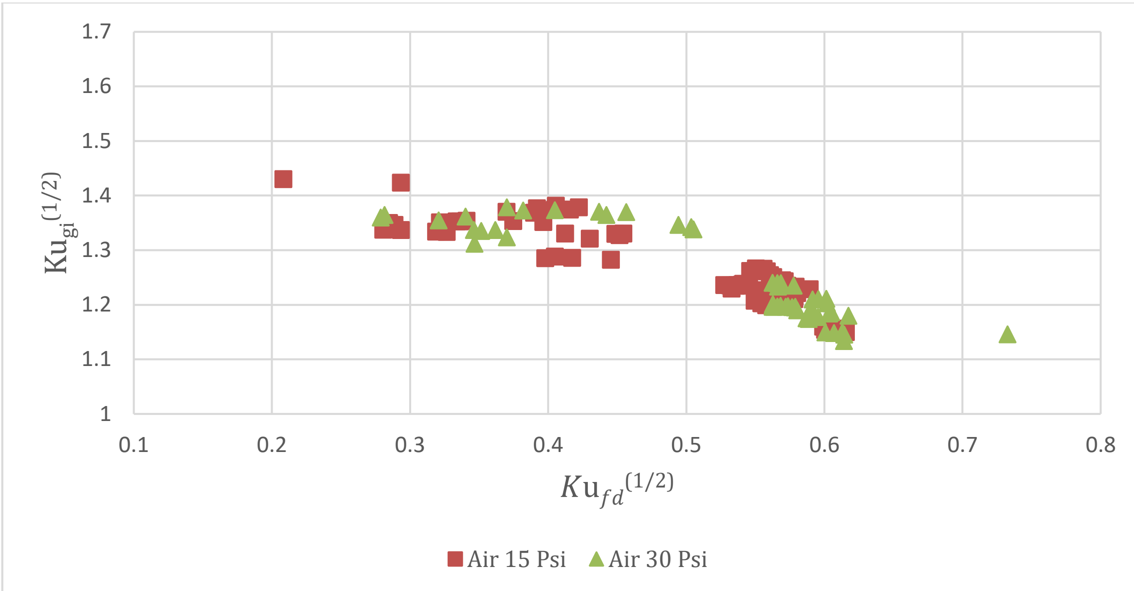

Figure 14: New air/water data for 15 and 30 psig collected for during this study.

Further investigation into the ambient air/water data set, shown in Figure 15, was carried out to identify the cause of this phenomena. Figure 15 is broken down by gas flow rate and appears to follow the expected trend of continuously increasing Kutateladze gas inlet parameter as Kutateladze gas inlet parameter decreases. However, for 50-55 gps the Kutateladze gas inlet parameter is roughly identical to one another with accompanying large changes in the Kutateladze fluid down parameter. If the air flow rate is increased well beyond 55 gps, as shown in the 65+ gps group, the plateau disappears. This plateau appeared in all air data, except for 45 psig and did not appear in the steam/water data sets. Data acquisition instrumentation was checked to identify possible malfunctioning. However, no issues were identified. The cause of this phenomena could not be identified in his study. Additional flooding curves for steam/water and air/water testing are provided in Appendix B.1 and Appendix C.1 for steam and air tests respectively and follow the same observations presented here.

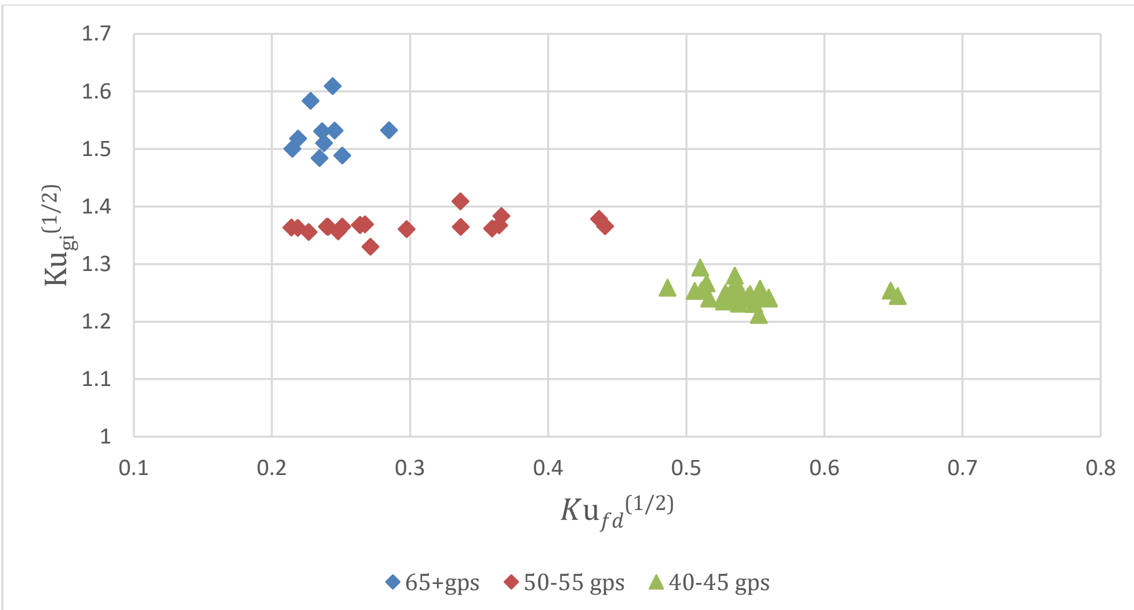

Figure 15: New ambient air/water data collected for this study broken down by gas flow rate.

5.6 Uncertainty and Repeatability of Newly Collected Data

The error associated with the testing was found to be caused from multiple sources: accuracy of instruments, the fluctuation due to random error, and error due to the conversion of an analog signal to digital signal.

Random error was obtained by repeating air/water and steam/water tests multiple times under the same conditions at selected pressures to determine the standard deviation of the Kutateladze parameters. Instrument error occurs from the accuracy limitations of the instrumentation used, these values are found in Appendix I and were obtained from the Wynne thesis who collected the values from instrument manuals [6]. For the Kutateladze parameters, the mass flow rate of the gas and water were found to be of most concern [6]. The error associated with analog to digital conversion was quite small and was considered negligible.

The error was calculated using standard error propagation techniques for each pressure and gas fluid pair and is summarized below in Table 2.

Table 2: Summary error for data collected for this study.

Gas/Fluid Pair	**Pressure [psig]**	**Ku_{fd} Error Percent**	**Ku_{gi} Error Percent**
Air/Water	3	2.187	0.529
Air/Water	15	1.618	0.308
Air/Water	30	1.624	0.293
Steam/Water	3	2.546	1.394
Steam/Water	15	1.929	0.508
Steam/Water	30	2.466	0.458

The Figures 16 and 17 show data collected for this study and include the associated errors in steam/water and air/water tests, respectively.

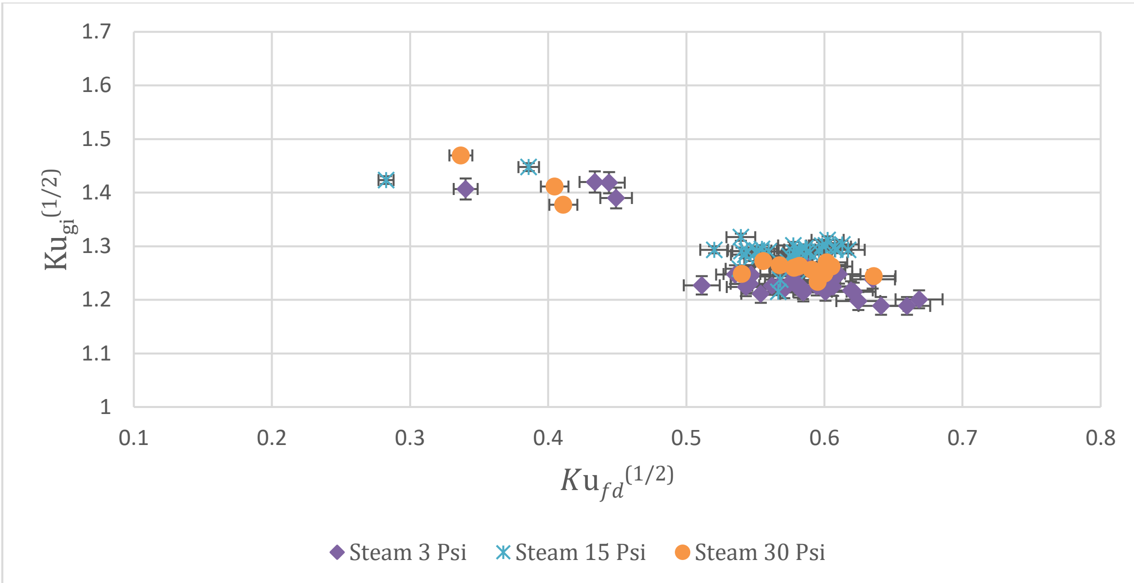

Figure 16: Newly collected steam/water data with associated error.

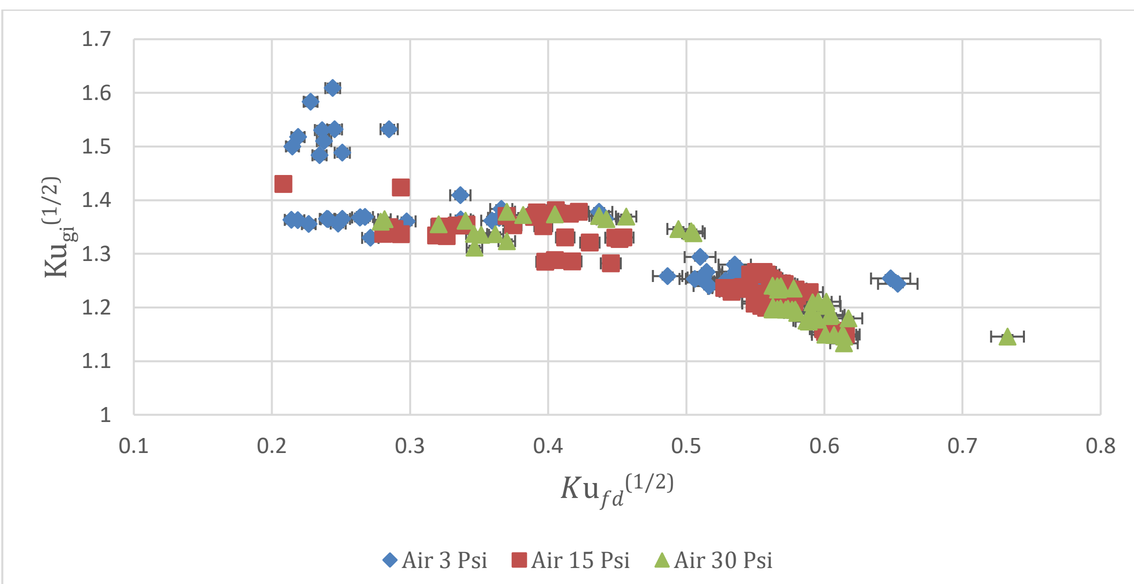

Figure 17: Newly collected air/water data with associated error.

To establish that the data are repeatable, air/water and steam/water tests were repeated with selected specific conditions. Each repeatability test included ten tests and post-processed. Averages for significant data were obtained from each set and checked against data qualification criteria. Table 3 shows the summary of the results. High repeatability is observed, with a slight decrease in repeatability of steam tests.

Table 3: Summary of repeatability results.

Fluid Pair	Pressure Range [psig]	Inlet Water Flow Rate Range [GPM]	Gas Inlet Flow Rate Range [gps]	Number of Tests Past
Steam/water	29.48-30.58	44.98-5.04	43.46-45.04	7
Steam/water	15.38-16.01	5.94-6.04	37.11-39.33	9
Steam/water	1.15-1.23	5.98-6.01	24.8-26.22	8
Air/water	30.44-30.21	64.53-65.3	6.00-6.04	10
Air/water	15.80-16.24	56.5-57.63	6.01-6.03	10
Air/water	1.118-1.24	40.85-42.29	6.00-6.04	9

Various other tests at other water inlet mass flow rates, pressures, and gas inlet flow rates were repeated as checks, but only two to four tests were completed instead of ten and are not considered repeatability tests.

5.7 Integration of Data Sets

Newly collected data during this study was to expand and enhance flooding curves previously produced at the NHTS. The newly collected data was to further complement current onset of flooding data, via pressure and water inlet flow rate combinations that had not been obtained. Newly collected data was to further expand into regimes beyond the onset of flooding so that high carryover or complete flow reversal was established. While complete flow reversal was not achieved during this study, degrees of high flow reversal that had not been reached previously were obtained.

Previously collected data by Wynne and Garza as well as the newly collected data is presented in flooding curve in Figure 18. The newly collected data, triangles, shows two very distinct locations on the flooding curve. First on the right-hand side at large Kutateladze fluid down parameters, representing the data collected at the onset of flooding, and trend very well with previously collected data. This newly collected data emphasizes new combinations of pressure and water flow rates that had not been previously collected. Above a Kutateladze fluid down parameter of 0.45 Wynne's, data square data points, disappear which is expected as his research focused on the establishment of the facility and initial onset of flooding data [6]. Garza's data, diamond data points, focused on the expansion of onset of flooding and initial beyond onset of flooding at elevated pressures. While Garza did obtain data at ambient pressures and beyond onset the data set was sparse leading to a nice trend of data up until a Kutateladze fluid down parameter of roughly 0.4 [7]. At and beyond this point a spread of Garza's data along the y-axis appears, much like the newly collected, but it is limited. The newly collected data, extend far into the lower range of Kutateladze fluid down parameter, representing data points that have a higher carryover then previously obtained, and is where the large spread of Kutateladze fluid down parameter appears.

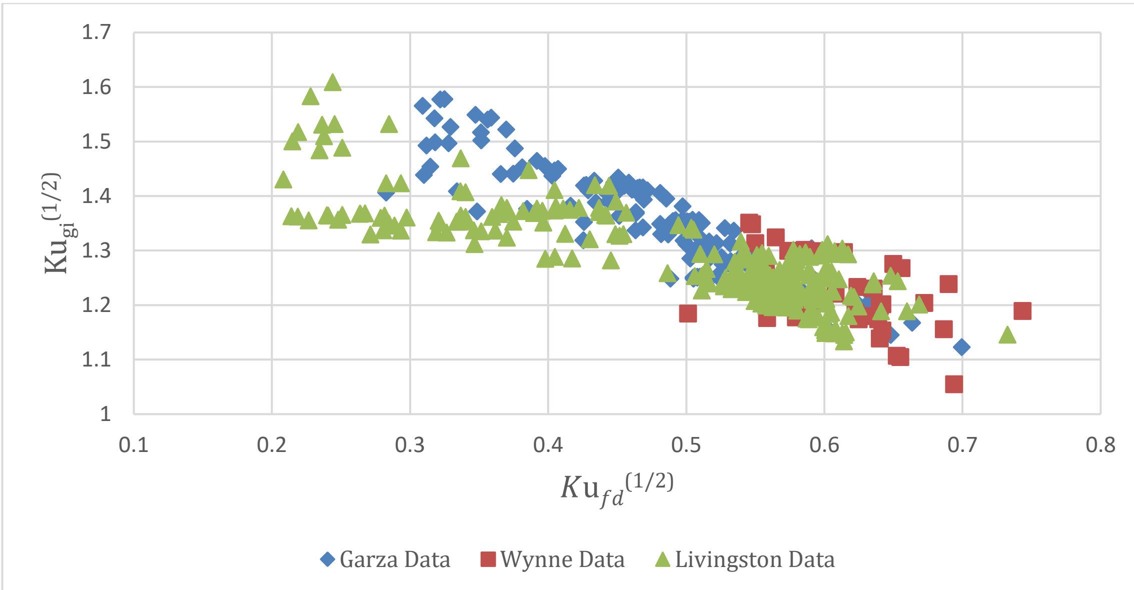

Figure 18: Data collected by Wynne, Garza, and Livingston at the NHTS flooding facility.

An additional objective of this study was to compare and validate the new data collected for this study to that of all data obtained using the current facility, the Wynne and Garzas data sets, and to further validate Garza's interpolation for the interchangeability of steam/water and air/water. However, during the analysis in this study improvement to the post-processing scripts identified an error in the processing of the previous data. All previous data points were subsequently reprocessed, and new flooding curves were created. The complete and integrated database is presented in Figure 19 and is broken down by pressure.

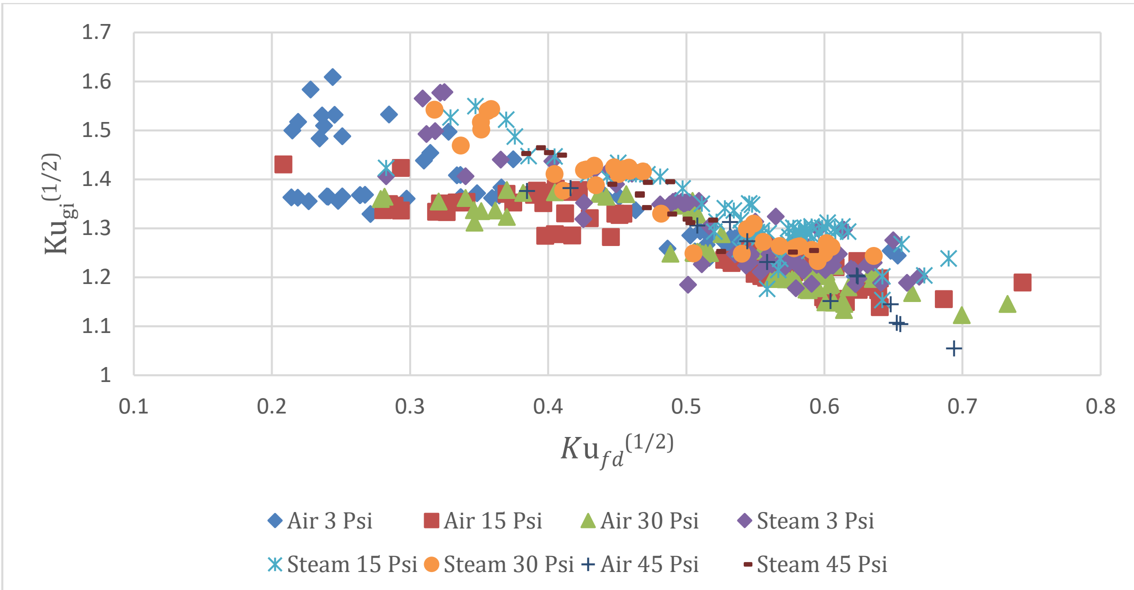

Figure 19: Integrated flooding curve constructed from Wynne, Garza, and Livingston datasets.

The complete database shows the same trend as other flooding literature and the previously presented flooding curves. However, once air/water tests are separated, displayed in Figure 20, the 15 and 30 psig data appear to level off, as discussed previously. Few data points are available for 45 psig air/water data it is unsure if this holds true for 45 psig air tests.

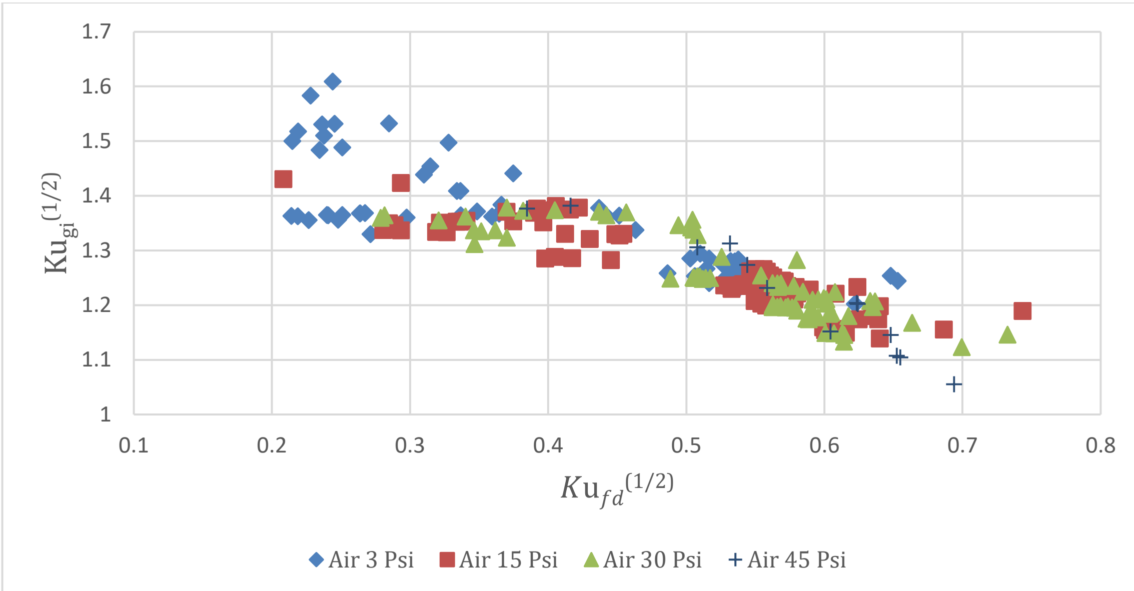

Figure 20: Integrated air data set collected at the NHTS using the current flooding facility.

Garza's work was to identify a correlation between steam/water and air/water data, Garza concluded that if condensation effects were accounted for in the steam/water tests the two sets of data would overlay onto one another [7]. Figure 21 shows the complete data set for ambient pressure broken down between steam/water and air/water test, showing only a slight difference between the two data sets, far less then what was observed by Garza and may be attributed to the issue discovered in post-processing. This nearly complete overlay of the data sets is attributed to the minimized subcooling that is achieved during testing which minimizes the condensation that will occur; this is reflected by the overlap between the steam/water and air/water data sets. Thus, a modified equation to account for condensation may not be needed when subcooling is minimized. However, with the flattening of the air curves that occurs beyond the onset of flooding direct correlation between steam/water and air/water curves may not yield accurate results. Figures 22 and 23 display the integrated database for 15 and 30 psig. Figure 22 shows that all low pressures the steam and air data sets lay directly on top of one another, while Figure 23 shows that the steam/water dataset trend is slightly higher than the air/water data which is attributed to increasing chances of subcooling at elevated pressures discussed previously. The 45 psig flooding curves can be found in Appendix C.1 and D.1 showing the same trend.

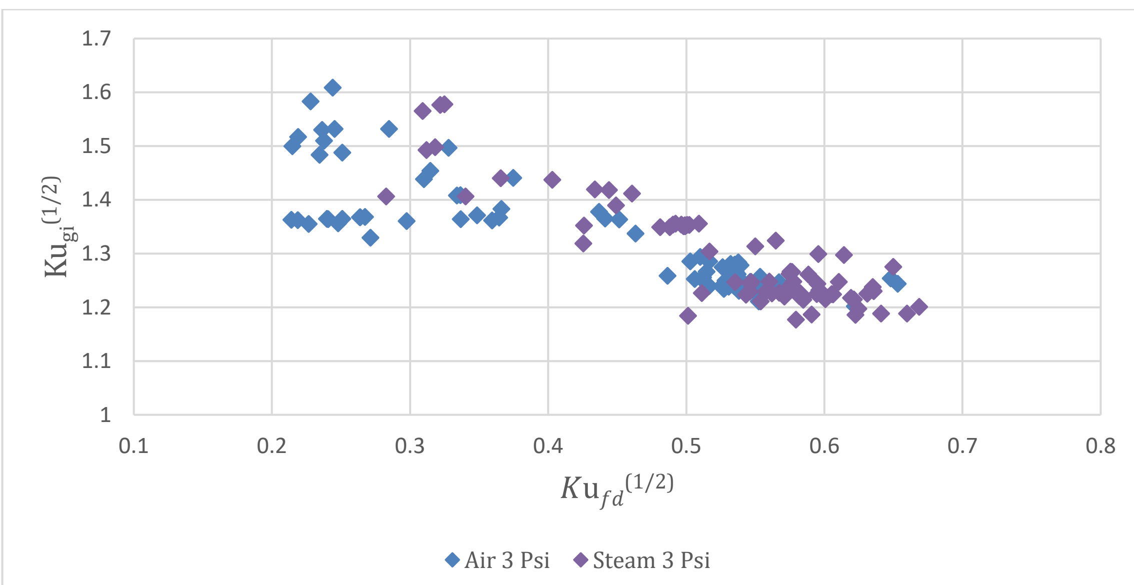

Figure 21: Integrated dataset for ambient pressure for steam/water and air/water tests.

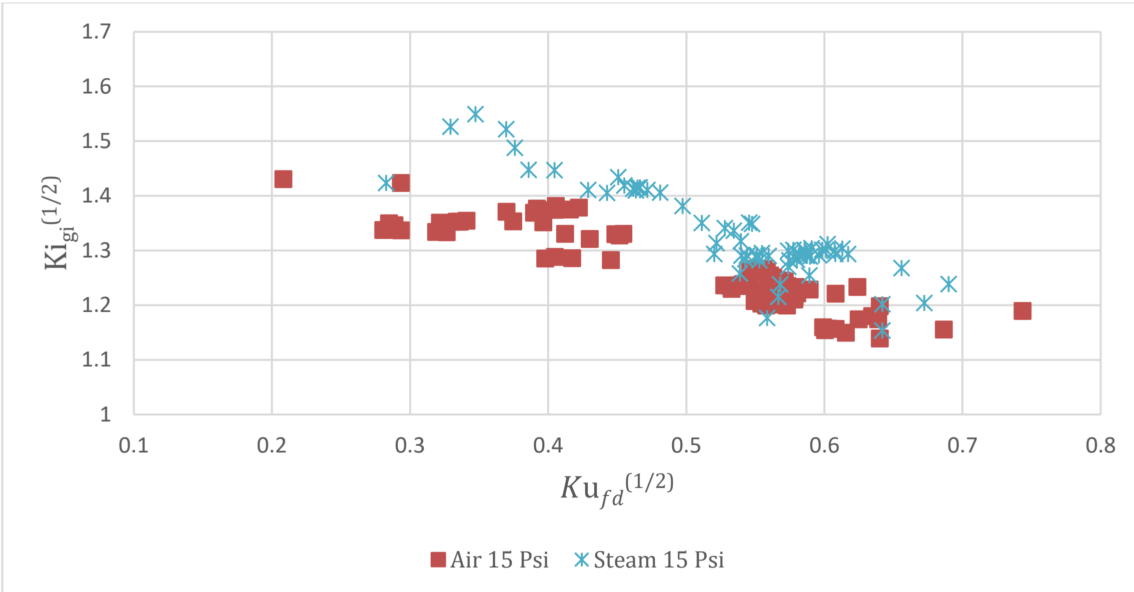

Figure 22: Integrated data set for 15 psig for steam/water and air/water tests.

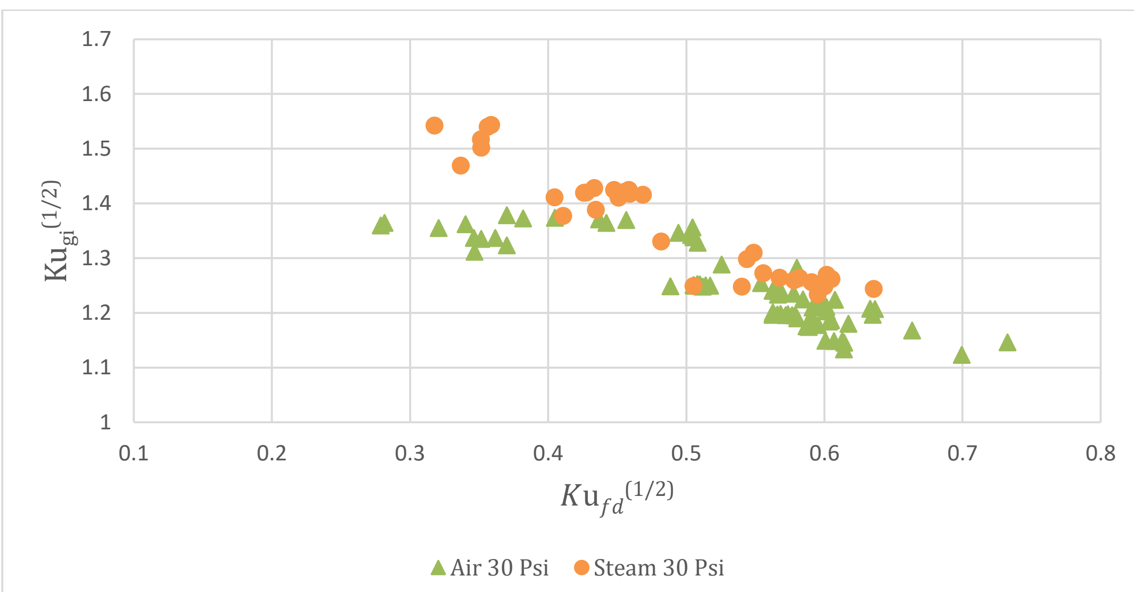

Figure 23: Integrated data set for 30 psig for steam/water and air/water tests.

Analysis of newly collected data found that steam/water testing at an elevated pressure increased a datasets position along the y-axis of a flooding curve for the onset of flooding data. Leading to the conclusion that this arises due to an increase of condensation at higher pressures; this is explored in the integrated dataset in Figure 24 and Figure 25. Figure 25 displays the flooding curves for steam/water data at varying pressures. Apart from 45 psig tests which are limited, the trend holds true that data on the right-hand side of the flooding curves, the onset of flooding, separate out based on an increase in pressure. For comparison, an integrated air/water data set, found in Figure 25, shows little if any separation effects due to pressure, supporting the conclusion that the separation in the steam/water data sets is due to condensation effects.

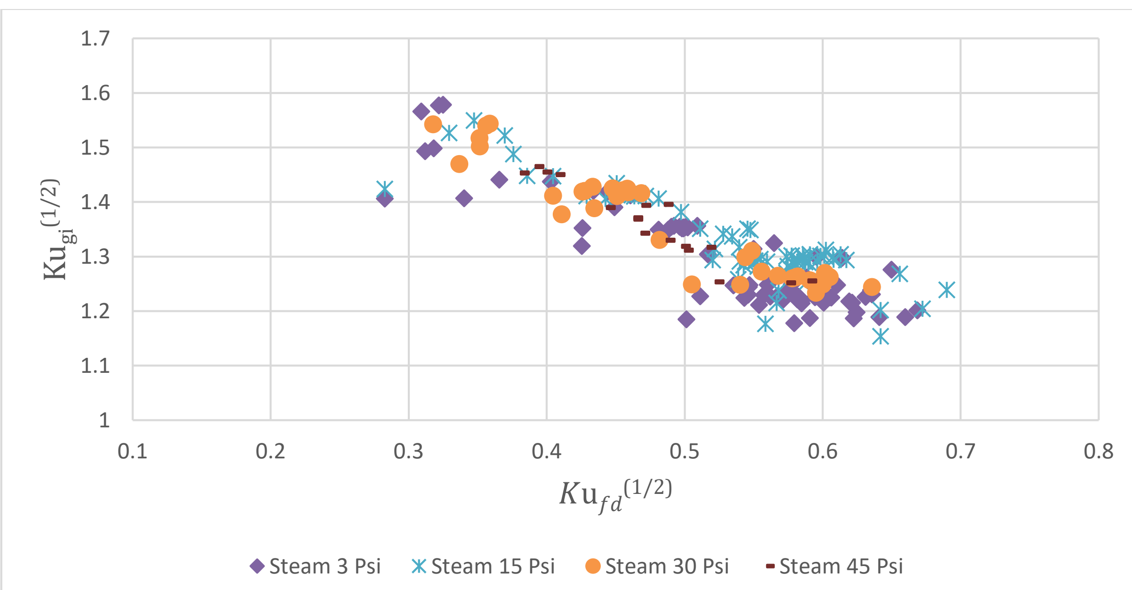

Figure 24: Integrated steam/water data set.

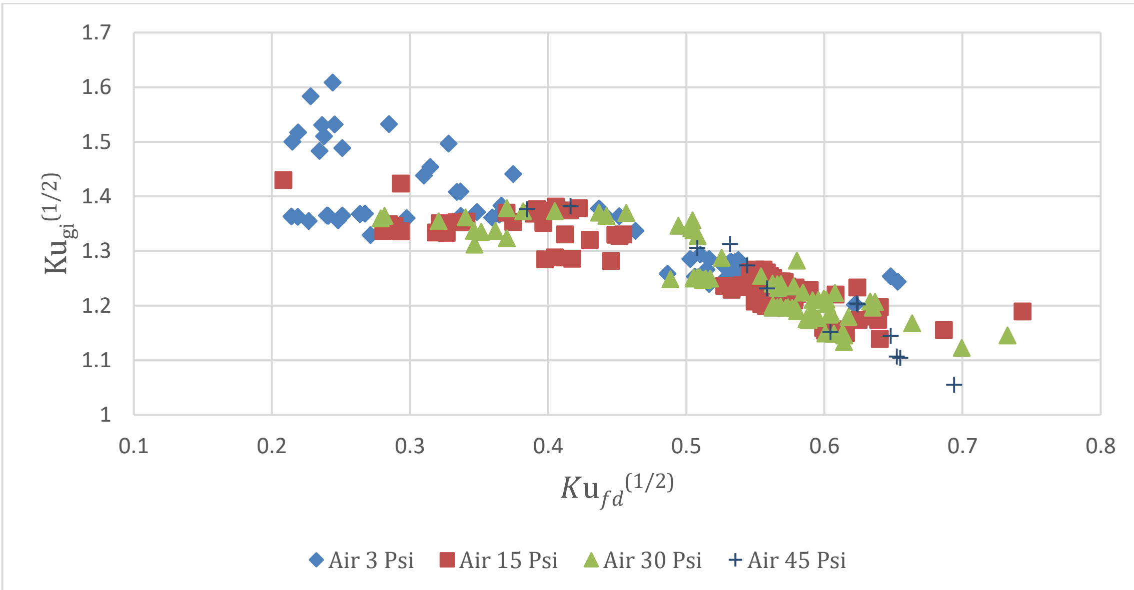

Figure 25: Integrated air/water data set.

6. RESULTS OF HYSTERESIS TESTS

Hysteresis effects of flooding were also explored in this study. Very little previous research was found on the hysteresis of flooding conditions. Govan observed hysteresis while conducting tests using different exit conditions although little analysis was performed of the hysteresis, was perform and limited to differences in exit conditions [20]. Understanding conditions post onset of a flooding event after gas mass flow rate is reduced beyond the onset condition will yield valuable information on when the flooding phenomena can be expected to occur in two-phase systems.

6. 1 Range and Parameters of Hysteresis Tests

As little previous research was obtained on flooding hysteresis, no benchmark could be established. Following the same parameters set forth for flooding tests presented above, hysteresis testing would be conducted from 1 to 45 psig with water inlet flow rates ranging from 5.0 to 7.5 GPM. During testing, it was discovered that the facility could not generate sustained gas flow rates needed for hysteresis testing with water inlet flow rates above 7.5 GPM and pressures above 30 psig. As no benchmark had been established, it was decided that 5.0, 6.0, and 7.0 GPM water inlet mass flow rates at ambient pressure, 15, and 30 psig would be used to conduct hysteresis testing.

6.2 Data Collection and Data Reduction Method of Hysteresis Tests

Hysteresis tests were completed by first determining the gas inlet mass flow rate required for the onset of flooding for a given pressure and water inlet mass flow rate. A new test was conducted by establishing the water inlet mass flow rate and injecting gas into the test section below the pre-determined gas mass flow rate required to initiate flooding and was typically a mass flow rate 15 gps below the onset of flooding mass flow rate. In the case of low-pressure steam/water tests, the gas flow rate to initiate flooding was low, and this difference was reduced. Once gas flow was established it was held at a quasi-steady state for a minimum of 30 seconds and then the gas mass flow rate was increased by 5 gps and again held at a quasi-steady state as before, then increased again; this repeated until well beyond the gas mass flow rate required to initial flooding, typically 15 gps above the onset of flooding gas mass flow rate. Once this maximum was reached the process was reversed, and gas mass flow was decreased in the same manner until flooding ceased.

Due to a limited supply of air, tests were completed in a piece-wise manner, of at least two data points per single test run. If a test only included one established data point and gas mass flow rate could not be sustained for a second point, the test was considered invalid for hysteresis consideration. The data allowed for a reconstruction of a full hysteresis diagram from these tests. Testing for hysteresis was performed at ambient pressure, 15, and 30 psig, 45-psig tests were attempted, but due to lack of adequate gas supply, these tests were not completed. Water flow rates were 5.0, 6.0, and 7.0 GPM. Table 4, below, list parameters for hysteresis testing.

Table 4: Parameters used for hysteresis tests.

Parameters	Steam/Water Range	Air/Water Range
Test Section Pressure [psig]	3-30	3-30
Gas Inlet Flow rate [g/s]	20-66	25-75
Gas Inlet Temperature [°C]	103 – 149	15
Water Inlet Flow Rate [GPM]	5-8	5-8
Water Inlet Temperature [°C]	100 -144	25

6.3 Observations from Hysteresis Data

After initial data collection, manual identification of steady state time intervals using a given pressure and water inlet mass flow rate were identified at each gas inlet mass flow rate step and recorded. Data sets were further processed to obtain averaged data points for the intervals of interest in the same manner as was done for the standard flooding tests. Each averaged data point was then compiled with data points containing the same pressure and water mass inlet flow rate to produce a hysteresis flooding curve for further analysis.

Hysteresis curves were constructed using the square root of the Kutateladze parameter for gas mass inlet flow rate, Ku_{gi}, allowing for representation of gas mass flow rate into the test section. The second parameter used was the carryover fraction, a unitless description of the liquid carryover, obtained by dividing the carryover mass flow rate by the water inlet mass flow rate.

Figure 26 shows a compiled steam hysteresis flooding curve for a water inlet mass flow rate at 5.0 GPM and ambient pressure. Diamond data points represent data collected as the gas flow rate was increasing and squares represent the data collected for decreasing gas flow rates, Interpretation of the hysteresis graph starts from the left and proceeds to the right and then reverses at the rightmost data point. Therefore, starting with the far-left diamond data point and moving right, the Kutateladze gas inlet parameter is increased, x-axis, a corresponding increase in the carryover fraction, the y-axis, should appear if flooding is occurring. Once the rightmost data point is reached the processes is reversed, and the gas flow is decreased and should correspond to a decrease in the carryover fraction.

The arrows in Figure 26 represent the increase and subsequent decrease in the data and the directions they are plotted. The lower arrow represents the data with increasing gas flow, diamond data points, and the upper arrow for data with decreasing gas flow rate, square data points. This convention is used on all following hysteresis plots.

The first two diamond data points in Figure 26 show zero to little carryover, so little that flooding is not considered to occur. Natural fluctuations in carryover mass flow rate are present in the system when both gas and water are both being allowed into the system. To verify the second point was not a flooding data point, analysis of the raw data showed that the second point is in fact not flooding, as no anlysis of the appearance of differential pressure drop occurred. The carryover is most likely occurring due to entrained droplets of water leaving the test section and being separated out. As the gas inlet Kutateladze parameter increases, flooding finally initiates at point 1, and water carryover fraction increases dramatically. Additional increases in the gas inlet

Kutateladze parameter beyond initial flooding point are accompanied with a higher carryover fraction.

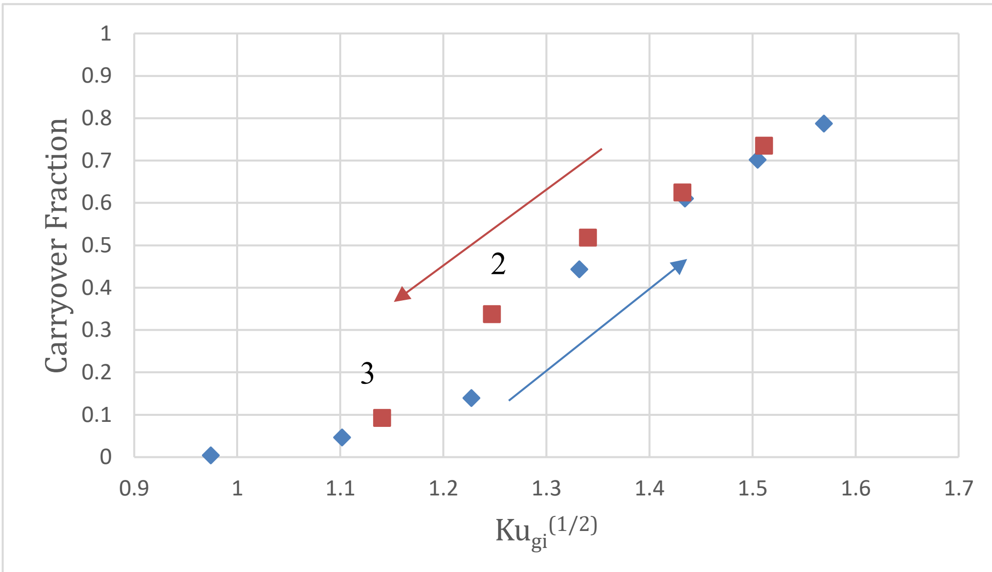

Figure 26: Compiled hysteresis graph for steam with a water flow rate of 5.0 GPM at ambient pressure. The bottom arrow represents increasing carryover as gas flow rate increases, and the upper arrow represents decreasing carryover as gas flow rate is decreased.

Once the final diamond point is reached, the procedure reverses to decrease the gas mass inlet flow rate. Beginning with the upper right square data point, the gas inlet Kutateladze parameter is incrementally decreased until flooding no longer occurs within the system, the same method for increasing mass inlet flow rate is used. The last square data point, point 3, shows a small hysteresis effect, implying that flooding is still occurring after the gas inlet Kutateladze parameter is reduced below the gas inlet Kutateladze parameter required to initiate flooding. Point 2 shows another effect of hysteresis, increased amounts of carryover when compared to the data point collected for flooding initiation, point 1. This general trend appears for steam/water tests at 5.0 GPM water flow rates and 15 and 30 psig, and for steam/water tests of 6.0 GPM and 7.0 GPM at ambient pressure.

As pressure and water inlet flow rate are increased hysteresis effects became more apparent corresponding to greater carryover when the gas inlet Kutateladze parameter is reduced below the initial flooding gas inlet Kutateladze parameter; this is shown in Figures 27and Figure 28. In both figures point 1 indicates the point where flooding is initiated while increasing the gas inlet Kutateladze parameter. With point 2 indicating a high degree of flooding occurring after the gas inlet Kutateladze parameter has been reduced below require gas inlet Kutateladze parameter to initiate flooding. For steam/water tests, increases in pressure and water inlet flow rate induced larger hysteresis effects in the system.

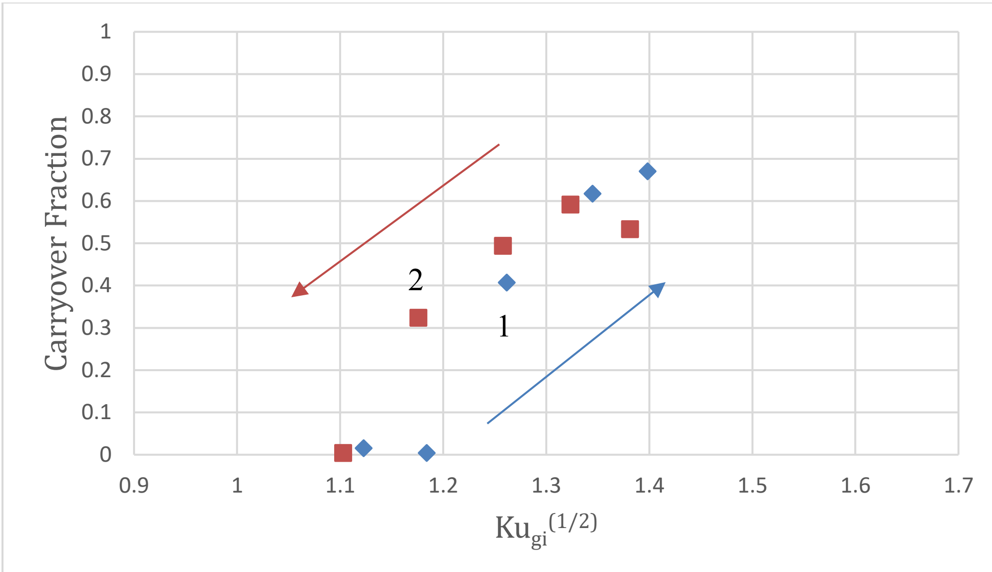

Figure 27: Hysteresis curve for steam/water testing with a flow rate of 6.0 GPM at 30 psig.

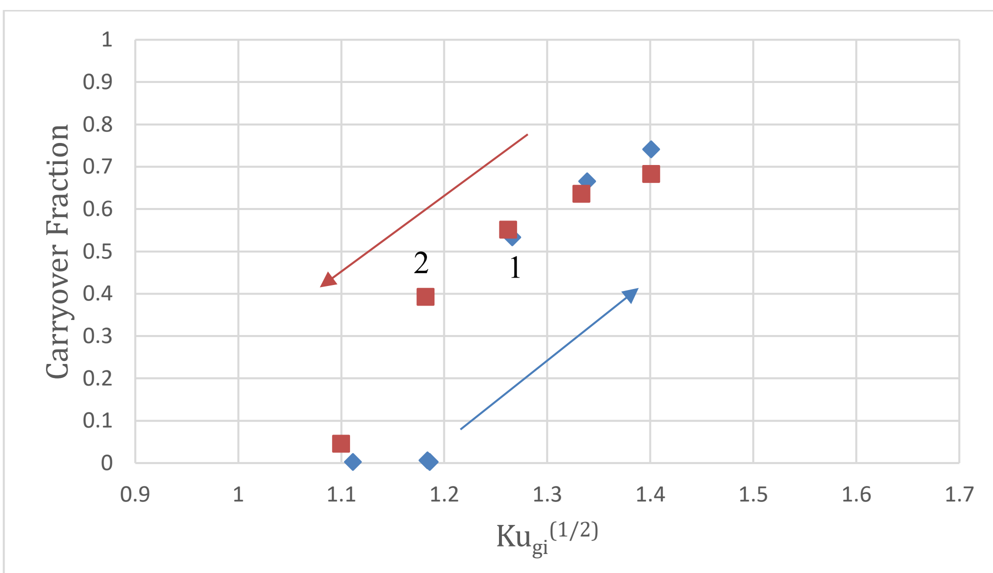

Figure 28: Hysteresis curve for steam/water testing with a flow rate of 7.0 GPM at 30 psig.

Hysteresis graphs for air/water test were constructed following the same procedure and followed the same progression as steam/water hysteresis testing. Tests conducted with air/water showed a greater extent of hysteresis than the steam/water tests throughout the entire pressure and water inlet mass flow rate ranges and is observed in Figure 29, for ambient pressure and 6.0 GPM water inlet mass flow rate. Point 1 indicates the location that flooding is first initiated at and point 2 indicates a high degree of flooding after the gas inlet Kutateladze parameter was raised beyond the initial flooding point and subsequently reduced to the same gas inlet Kutateladze parameter that initiated flooding. Once the gas inlet Kutateladze parameter is reduced to below what is required to initiate flooding, flooding continues to occur in the test section at points 3 and 4.

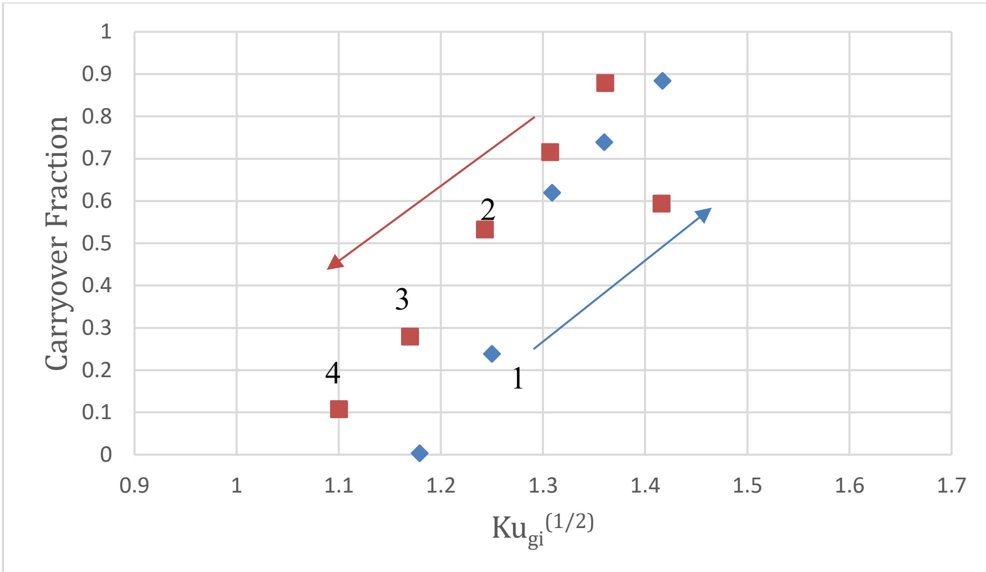

Figure 29: Hysteresis curve for air/water testing with a flow rate of 6.0 GPM at ambient pressure.

At elevated pressures and water inlet flow rates, hysteresis is sustained for much lower gas inlet Kutateladze parameters in air/water mixtures; this is demonstrated in Figure 30. Flooding first occurs at point 1, yet continues to occur through points 2-4, to a point well below the gas inlet Kutateladze parameter required to initiate flooding.

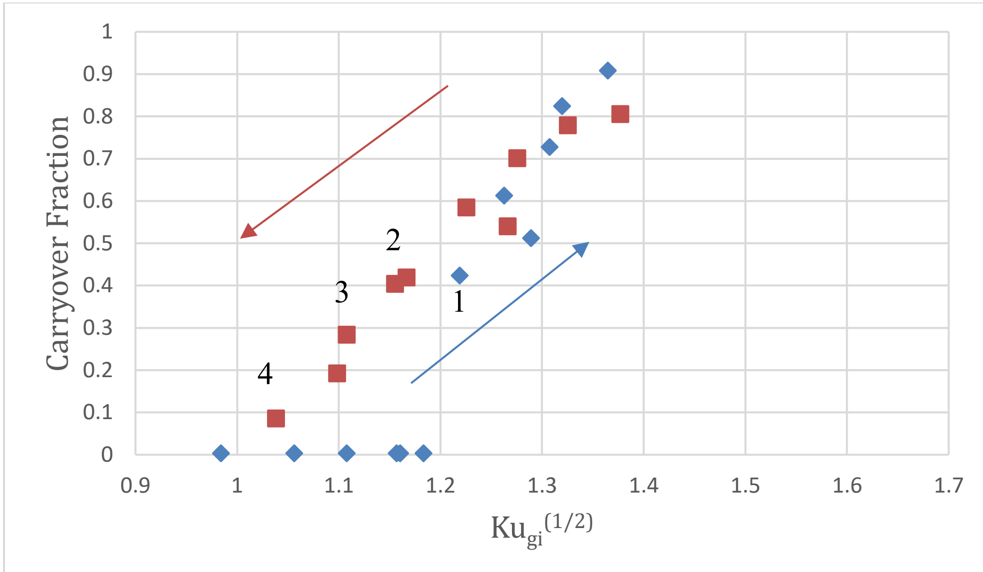

Figure 30: Hysteresis curve for air/water testing with a flow rate of 7.0 GPM at 15 psig.

The appearance of hysteresis in the data suggests that once the point of initial flooding is reached, the required momentum transfer to continue flooding is reduced. Therefore, a corresponding decrease in gas mass flow rate, lowering the Kutateladze gas inlet parameter, will sustain flooding within a tube at a velocity below that require initiating flooding. Data beyond the onset of flooding suggests that a higher carryover fraction appears after a gas velocity decrease occurs. Data at higher pressures suggests larger hysteresis effects.

6.4 Uncertainty within Hysteresis Data

Error analysis presented for flooding tests was also applied to the hysteresis tests. The error was propagated in the same manner; however, the error was also calculated for carryover fraction, error for each pressure and gas fluid combination is summarized below in Table 5.

Table 5: Error associated with hysteresis testing.

Gas/Fluid Pair	Pressure [psig]	Carryover Fraction Percent	Ku_{gi} Error Percent
Air/Water	3	3.188	0.529
Air/Water	15	0.179	0.308
Air/Water	30	0.136	0.293
Steam/Water	3	8.291	1.394
Steam/Water	15	7.881	0.508
Steam/Water	30	1.721	0.458

Figures 31 and 32 displays associated error in 5.0 GPM steam/water and air/water tests at ambient pressure, respectively.

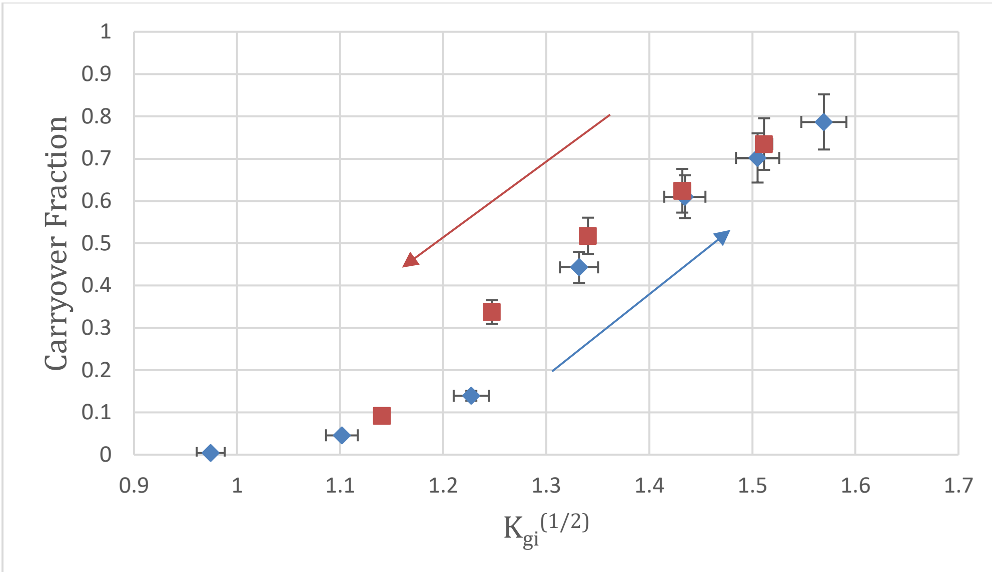

Figure 31: Hysteresis of steam/water at 5 GPM at ambient pressure with an associated error.

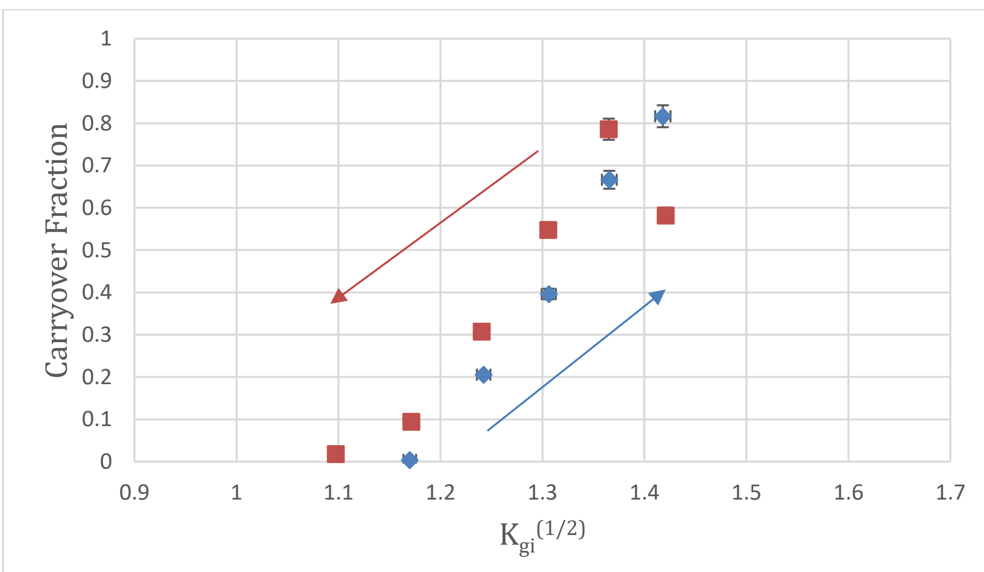

Figure 32: Hysteresis of air/water at 5 GPM at ambient pressure with an associated error.

7. CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

The flooding facility at the Nuclear Heat Transfer Systems Laboratory was employed for the current testing. An experimental investigation was conducted to expand the flooding database at elevated pressures using steam/water and air/water gas as the gas/liquid pairs. An experimental investigation into hysteresis inside a large diameter vertical tube was completed under the same parameters.

Flooding data were acquired from 5 to 8 GPM water inlet flow rates in 0.5 GPM increments, with incremental gas inlet mass flow rate increases at ambient pressure, 15, 30, and 45 psig for steam/water and air/water mixtures. The onset of flooding was obtained for each water flow rate and pressure, for both fluid pairs; additional data were collected beyond onset, of at least 10 gps above the gas flow rate to induce the onset of flooding. Conditions were held constant for at least 30 seconds to produce a quasi-steady state environment in the test section. Data were post-processed to reduce each test into a single data point, and non-dimensional Kutateladze parameters were calculated.

Kutateladze flooding curves were constructed using the parameters for water exiting the bottom of the test section and for gas entering the test section. Data collected for this study matched results from previous studies showing slight dependencies on pressure [3][6][7]. However, a flattening of the air/water curve at lower Kutateladze fluid down parameters was observed. The source of this flattening has not been identified. Data acquisition equipment was checked, and no issues were found. Steam/water and air/water datasets appear to compare and trend well to each other, with data sets laying nearly on top of each other and is attributed to low subcooling obtained while collecting data. This comparison is an important benchmark of air to steam data, and it suggests that the air data may be used when steam data are unavailable.

During steam/water data analysis, the pressure seemed to slightly affect where an onset of flooding data point would fall on the y-axis of a flooding curve; this was not seen in air/water data and is attributed to effects condensation will have at higher pressures, requiring a slightly higher gas inlet flow rate to initiate the onset of flooding. The same trend was observed in the integrated dataset.

The new data was compared to the earlier data sets collected by Garza and used to verify previous flooding correlation. Improvements to the post-processing scripts were made, and all data by Wynne and Garza were reprocessed. All data using the current NHTS flooding facility were combined into a single database, and flooding curves were generated. The integrated flooding curves were confirmed to follow the same trends as seen for data collected for this study.

This plateauing of the air data currently limits the direct comparisons of steam data to air data beyond the onset of flooding. Thus, further data at elevated gas flow rates for steam/water and air/water should be collected to establish a greater understanding of the phenomena that is occurring.

Data were collected to understand hysteresis within a large diameter vertical tube under flooding conditions at various pressures and water flow rates. Water flow rates obtained during hysteresis testing were 5.0, 6.0, and 7.0 GPM at pressures of ambient, 15, and 30 psig for steam/water and air/water.

Data was processed, and hysteresis curves were obtained using the Kutateladze parameter for the gas at the inlet and the water carryover mass fraction. Hysteresis was observed appearing as higher carryover fractions and flooding occurring at gas inlet flow rates far lower than those required to induce flooding for the incrementally increasing gas flow rate tests. Hysteresis appears in both steam/water and air/water combinations. Data at higher pressure and higher water inlet flow rates exhibited greater hysteresis effects, allowing flooding to continue after the gas flow has dropped below the rate needed to initiate flooding. Effects of hysteresis appear to be more severe for air tests than for steam tests.

Work presented here enhances the understanding of the phenomena within two-phase countercurrent flow known as flooding. This work can be implemented to improve and validate reactor safety codes for PWRs and BWRs.

7.2 Future Work

While this study did succeed in expanding the flooding database as well as enhancing our understanding of the flooding phenomena, many issues about flooding remain and are discussed below.

The number of steam/water and air/water data points at 45 psig is small. Expanding the data set of this pressure would provide for better comparisons of air to steam data. The current data set at 45-psig while does show some differences due to the different fluids, but it could be enhanced to allow for further investigation of the effects due to liquid and gas parameters.

Due to the flattening out of the air at high air mass flow rates further, steam testing is necessary to determine whether this trend happens for steam tests. Expansion of the steam/water data set at high gas flow rates to identify if the Kutateladze parameter for fluid in flattens out like air/water data should also be investigated.

Identification of the location of flooding within the test section remains elusive. For the acrylic air/water test section Solmos hypothesized that flooding occurs within the lower third of the test section [12]. However, this has not been confirmed in the stainless-steel test section. If the location of flow reversal could be identified, the conditions upon flooding occurrence could be more accurately identified.

Testing with subcooled water at elevated pressures should be performed. Cullum presented work with large degrees of subcooling. However, this was only obtained at atmospheric pressure. Furthermore, concerns of vacuum and condensation affect due to an open system shed doubt on the accuracy of the results. Producing a reliable subcooled dataset at elevated pressure would further enhance the understanding of flooding phenomena.

Currently, all air/water testing done at the NHTS has assumed that the no mass transfer occurs due to condensation, unlike steam tests in which steam condenses for a water temperature below saturation. However, to build a more accurate model and be able to accurately compare steam/water tests and air/water data, air/water testing should be performed with the inlet water temperature at or near saturation temperatures for a given pressure and the air also heated. Whether or not mass transfer appears may yield insightful information about the differences between steam/water and air/water testing due to differences in fluid parameters at saturation temperatures.

Previous and current work at the NHTS has not been able to produce full flow reversal of the liquid adequately. While flooding correlations and graphs have been produced, obtaining full flow reversal within the current test section would enable exploration of the two-phase configuration that is expected to be less turbulent or chaotic than that at the onset of flooding.

Regarding the hysteresis tests, an important disadvantage of the Texas A&M flooding system is that the air compressor does not have enough capacity to obtain all the data points for a flooding test in a single test run. To confirm data presented here and to obtain a more accurate understanding of flooding hysteresis in a vertical test section, testing should be conducted so that all data points can be collected on a single test. This may be possible if the lab can secure an air storage tank large enough for the said purpose.

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APPENDIX A

REDUCED STEAM/WATER FLOODING DATA

The proceeding section presents qualified reduced steam/water data collected in this study for flooding and hysteresis.

A.1 Reduced Steam/Water Flooding Data

The proceeding section presents qualified reduced steam/water flooding data; tests are listed by test name.

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	T_{sat} [°C]	Gas Inlet Flow rate [gps]	Gas Outlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2016_07_18_test_05	15.12	120.93	133.38	121.08	36.85	36.10	1.27	0.57	4.10	0.43	3.67
2016_07_19_test_02	15.47	120.74	138.54	121.46	48.29	45.93	1.45	0.39	5.08	3.42	1.66
2016_07_19_test_03	15.21	119.61	137.60	121.17	35.96	32.34	1.25	0.59	5.95	2.08	3.87
2016_07_19_test_05	15.49	120.75	136.29	121.47	35.18	33.50	1.24	0.57	6.54	2.95	3.59
2016_07_19_test_06	14.87	120.48	136.17	120.81	46.35	46.99	1.42	0.28	6.47	5.59	0.89
2016_07_20_test_01	15.46	118.95	134.14	121.45	34.01	31.20	1.21	0.57	7.47	3.89	3.57
2016_07_20_test_03	29.72	132.99	141.57	134.23	43.73	42.77	1.26	0.57	3.99	0.42	3.56
2016_07_20_test_04	29.28	133.08	143.77	133.89	58.99	58.42	1.47	0.34	3.98	2.73	1.25
2016_07_21_test_01	31.29	134.72	142.10	135.42	42.90	39.50	1.24	0.64	4.58	0.11	4.47
2016_07_21_test_02	30.01	133.01	143.70	134.45	52.23	49.52	1.38	0.41	4.48	2.62	1.87
2016_07_21_test_03	29.20	131.98	140.05	133.82	41.65	38.81	1.23	0.60	4.98	1.07	3.91
2016_07_21_test_04	29.84	131.99	145.20	134.32	54.66	51.59	1.41	0.40	5.00	3.19	1.81
2017_04_04_test_01	1.15	100.41	109.49	102.09	27.04	27.23	1.25	0.54	.99	1.75	3.24
2017_04_04_test_05	1.01	101.78	105.98	101.84	27.02	26.16	1.24	0.59	5.97	1.97	4.00
2017_04_04_test_06	1.78	102.52	103.89	103.21	35.05	31.99	1.39	0.45	5.99	3.72	2.28
2017_04_04_test_07	1.11	101.94	102.78	102.02	27.00	25.02	1.24	0.63	6.53	1.98	4.55
2017_04_04_test_08	1.81	102.80	103.95	103.26	36.43	32.80	1.42	0.44	6.49	4.27	2.22
2017_04_04_test_09	1.16	101.51	102.81	102.11	27.51	24.61	1.25	0.61	7.00	2.79	4.20
2017_04_04_test_10	1.88	102.34	104.06	103.37	36.60	32.66	1.42	0.43	6.99	4.87	2.12
2017_04_06_test_01	1.58	101.73	110.22	102.86	26.48	24.58	1.23	0.51	7.51	4.56	2.96
2017_04_06_test_02	2.57	103.30	110.99	104.54	36.04	35.17	1.41	0.34	7.51	6.20	1.31

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	T_{sat} [°C]	Gas Inlet Flow rate [gps]	Gas Outlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2017_04_06_test_03	1.59	101.90	106.79	102.87	26.30	24.94	1.22	0.57	7.50	3.82	3.68
2017_04_06_test_04	1.45	101.99	110.72	102.63	26.54	26.04	1.23	0.58	5.00	1.18	3.82
2017_04_06_test_05	1.49	102.29	110.29	102.69	26.93	26.05	1.23	0.60	5.00	0.99	4.01
2017_04_06_test_08	1.47	102.60	111.10	102.66	27.43	27.47	1.25	0.58	5.01	1.24	3.77
2017_04_06_test_12	1.35	102.19	103.95	102.46	28.44	27.39	1.27	0.58	5.02	1.26	3.76
2017_04_06_test_13	1.50	101.40	103.46	102.71	28.70	26.21	1.27	0.58	5.00	1.26	3.74
2017_04_06_test_14	1.38	101.21	103.19	102.50	28.34	25.31	1.26	0.59	4.98	1.07	3.91
2017_04_06_test_15	1.16	100.94	102.81	102.11	28.20	26.37	1.26	0.57	4.98	1.24	3.73
2017_04_17_test_01	1.31	101.68	111.02	102.38	27.04	26.42	1.25	0.55	5.99	2.61	3.39
2017_04_17_test_02	1.25	101.43	112.65	102.28	26.66	25.17	1.24	0.58	6.03	2.27	3.76
2017_04_17_test_03	1.26	101.60	113.16	102.30	26.26	25.43	1.23	0.58	6.00	2.17	3.83
2017_04_17_test_04	1.24	101.60	106.64	102.25	26.22	24.95	1.23	0.61	6.00	1.86	4.14
2017_04_17_test_05	1.22	101.57	107.45	102.23	25.96	24.81	1.22	0.62	5.99	1.66	4.33
2017_04_17_test_06	1.12	101.06	106.67	102.05	24.87	23.23	1.19	0.66	5.99	1.07	4.92
2017_04_21_test_01	1.22	102.17	112.54	102.23	26.02	25.75	1.23	0.56	6.00	2.42	3.57
2017_04_21_test_02	1.20	101.65	114.37	102.20	25.89	25.68	1.22	0.58	5.99	2.17	3.82
2017_04_21_test_03	1.22	101.67	113.14	102.23	25.86	25.66	1.22	0.58	5.99	2.13	3.86
2017_04_21_test_04	1.21	101.45	112.15	102.20	26.23	25.32	1.23	0.59	6.01	2.01	3.99
2017_04_21_test_05	1.15	100.83	112.05	102.11	25.86	24.50	1.22	0.62	6.00	1.64	4.36
2017_04_24_test_01	1.30	101.83	109.11	102.37	26.22	25.40	1.22	0.54	6.98	3.64	3.33
2017_04_24_test_02	1.32	101.69	108.24	102.40	26.52	25.39	1.23	0.55	7.01	3.65	3.37

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	T_{sat} [°C]	Gas Inlet Flow rate [gps]	Gas Outlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2017_04_24_test_03	1.21	101.92	104.29	102.20	26.00	23.92	1.22	0.60	7.01	2.94	4.07
2017_04_24_test_04	1.27	101.36	103.09	102.31	26.46	24.67	1.22	0.61	7.00	2.85	4.15
2017_05_11_test_01	1.33	101.77	106.60	102.42	25.80	25.32	1.21	0.55	7.00	3.53	3.47
2017_05_11_test_02	1.29	101.28	106.26	102.35	25.95	24.84	1.21	0.58	6.99	3.13	3.87
2017_05_11_test_03	1.16	100.27	108.40	102.12	25.25	22.79	1.20	0.62	7.03	2.62	4.41
2017_05_11_test_04	1.22	100.82	107.58	102.22	24.97	23.53	1.19	0.64	7.01	2.37	4.64
2017_05_11_test_05	1.19	100.68	106.77	102.17	25.55	22.69	1.20	0.67	7.04	1.99	5.05
2017_05_15_test_01	16.18	121.64	122.92	122.19	39.45	34.46	1.29	0.54	5.01	1.72	3.29
2017_05_15_test_02	15.35	120.91	122.04	121.33	39.33	35.41	1.30	0.55	5.03	1.60	3.43
2017_05_15_test_03	15.10	119.82	121.77	121.06	38.94	33.81	1.29	0.58	5.05	1.28	3.77
2017_05_15_test_04	15.19	120.04	121.85	121.16	39.28	33.26	1.29	0.58	4.97	1.20	3.77
2017_05_15_test_06	16.21	121.38	122.93	122.23	41.41	36.71	1.32	0.54	4.90	1.67	3.23
2017_05_16_test_01	1.16	101.88	111.20	102.11	26.82	26.10	1.24	0.55	5.01	1.63	3.38
2017_05_16_test_02	1.18	101.24	110.67	102.15	26.18	25.43	1.23	0.57	6.02	2.39	3.64
2017_05_16_test_03	15.56	119.45	126.65	121.55	38.32	35.55	1.28	0.55	5.22	1.81	3.42
2017_05_16_test_04	15.88	120.82	122.62	121.89	39.26	33.01	1.29	0.60	4.98	1.01	3.96
2017_05_16_test_05	16.49	121.52	123.23	122.51	40.10	33.96	1.30	0.59	4.98	1.16	3.83
2017_05_16_test_06	15.88	120.22	122.60	121.88	39.55	37.63	1.29	0.52	5.03	2.02	3.01
2017_05_16_test_10	15.38	119.42	122.08	121.36	37.11	33.11	1.26	0.54	5.99	2.75	3.24
2017_05_16_test_11	15.38	119.24	122.06	121.36	39.20	31.94	1.29	0.54	5.94	2.69	3.25
2017_05_16_test_12	15.68	119.06	122.37	121.67	39.32	32.37	1.29	0.55	5.99	2.61	3.38

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	T_{sat} [°C]	Gas Inlet Flow rate [gps]	Gas Outlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2017_05_16_test_13	15.98	120.86	122.69	121.99	39.41	33.04	1.29	0.58	5.99	2.27	3.72
2017_05_16_test_14	16.02	121.66	122.73	122.03	39.31	34.11	1.29	0.59	6.04	2.19	3.85
2017_05_16_test_15	15.68	120.34	122.38	121.67	39.32	32.40	1.29	0.61	5.99	1.86	4.12
2017_05_16_test_16	15.98	120.61	122.69	121.99	39.33	32.91	1.29	0.56	6.00	2.51	3.49
2017_05_16_test_17	15.99	120.42	122.70	122.00	39.00	32.92	1.28	0.58	5.99	2.24	3.75
2017_05_16_test_18	15.75	120.08	122.45	121.75	39.27	31.83	1.29	0.59	6.02	2.14	3.87
2017_05_16_test_19	16.02	120.02	122.72	122.03	39.15	33.10	1.28	0.54	5.97	2.69	3.28
2017_05_16_test_20	14.99	120.44	121.65	120.94	38.87	30.43	1.29	0.62	6.98	2.73	4.25
2017_05_16_test_21	15.27	120.11	121.97	121.24	39.51	30.63	1.30	0.60	7.03	3.00	4.03
2017_05_16_test_22	15.10	120.02	121.77	121.06	39.31	29.88	1.30	0.61	7.13	3.01	4.12
2017_05_16_test_23	16.22	120.33	122.94	122.24	39.06	32.11	1.28	0.57	7.02	3.34	3.68
2017_05_16_test_24	16.05	120.12	122.76	122.06	39.55	32.91	1.29	0.55	7.02	3.64	3.38
2017_05_16_test_26	13.96	119.42	120.54	119.83	39.38	30.40	1.31	0.60	7.04	2.99	4.05
2017_05_16_test_27	14.74	119.91	121.38	120.68	39.42	30.30	1.30	0.61	7.02	2.83	4.19
2017_05_16_test_28	14.90	119.57	121.55	120.85	39.46	30.40	1.30	0.60	7.04	3.05	3.99
2017_05_16_test_29	15.71	120.81	122.39	121.70	39.97	32.04	1.30	0.58	7.01	3.29	3.71
2017_05_17_test_09	30.23	132.99	135.35	134.62	44.28	40.09	1.26	0.58	5.05	1.33	3.72
2017_05_17_test_10	29.49	132.26	134.78	134.05	44.77	42.49	1.27	0.56	5.04	1.63	3.41
2017_05_17_test_11	30.23	132.65	135.35	134.62	44.46	39.10	1.26	0.61	5.02	0.98	4.05
2017_05_17_test_12	30.06	132.17	135.21	134.49	44.25	39.02	1.26	0.58	5.02	1.33	3.69
2017_05_17_test_13	30.48	132.22	135.54	134.81	44.32	38.89	1.26	0.60	5.02	1.04	3.98

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	T_{sat} [°C]	Gas Inlet Flow rate [gps]	Gas Outlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2017_05_17_test_14	29.94	132.26	135.13	134.40	44.50	39.88	1.26	0.58	5.06	1.32	3.74
2017_05_17_test_15	30.21	132.48	135.33	134.60	45.04	39.14	1.27	0.60	5.01	1.01	3.99
2017_05_18_test_02	30.71	132.98	135.74	134.98	43.49	40.98	1.25	0.54	4.99	1.77	3.22
2017_05_18_test_03	30.47	133.17	135.56	134.80	43.47	39.06	1.25	0.60	5.04	1.07	3.97
2017_05_18_test_06	30.30	132.25	135.39	134.68	44.09	38.65	1.26	0.59	6.01	2.15	3.86

A.2 Reduced Steam/Water Hysteresis Data

Below is the reduced data for steam/water hysteresis tests. The tests are displayed according to name and start with the first point associated with raising gas the gas mass flow rate up to a maximum and then back down. The column labeled direction signifies up (U) for increasing gas mass flow rate and down (D) for decreasing the mass flow rate.

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2016_08_23_test_01	14.60	117.47	123.74	16.25	0.84	0.70	5.44	0.02	0.00	U
2016_08_23_test_01	15.63	121.12	125.19	20.95	0.95	0.70	5.52	0.03	0.00	U
2016_08_23_test_01	16.00	120.79	127.01	26.60	1.07	0.70	5.52	0.02	0.00	U
2016_08_23_test_01	15.34	120.94	128.34	30.68	1.15	0.70	5.53	0.04	0.01	U
2016_08_23_test_01	16.29	120.10	132.39	40.95	1.32	0.51	5.51	2.63	0.48	U
2016_08_23_test_01	15.70	120.85	134.78	45.37	1.40	0.36	5.52	4.08	0.74	U
2016_08_23_test_01	16.02	121.63	135.68	50.26	1.47	0.38	5.50	3.88	0.71	U
2016_08_23_test_01	15.27	120.89	135.94	46.13	1.42	0.37	5.51	4.00	0.73	D
2016_08_23_test_01	14.12	119.94	135.76	40.62	1.34	0.44	5.51	3.35	0.61	D
2016_08_23_test_01	14.61	120.42	135.36	36.05	1.26	0.60	5.46	1.41	0.26	D
2016_08_23_test_01	14.45	119.07	134.97	31.04	1.17	0.69	5.51	0.15	0.03	D
2017_04_21_test_06	0.37	101.14	103.08	15.01	0.93	0.67	5.04	0.02	0.00	U
2017_04_21_test_06	0.56	101.29	103.99	20.00	1.07	0.66	5.00	0.02	0.00	U
2017_04_21_test_06	0.86	101.33	104.67	25.25	1.20	0.66	5.01	0.02	0.00	U
2017_04_21_test_06	1.36	102.06	103.58	29.43	1.29	0.52	5.01	1.98	0.40	U
2017_04_21_test_06	2.01	103.81	104.40	35.33	1.39	0.43	4.99	2.90	0.58	U
2017_04_21_test_06	2.43	105.19	106.09	40.44	1.48	0.37	5.00	3.47	0.69	U
2017_04_21_test_06	3.08	106.01	109.61	44.91	1.55	0.32	5.00	3.84	0.77	U
2017_04_21_test_07	2.06	103.06	104.38	39.27	1.47	0.38	5.01	3.42	0.68	D
2017_04_21_test_07	1.79	102.62	104.92	35.02	1.39	0.42	5.01	3.05	0.61	D
2017_04_21_test_07	1.42	102.28	107.94	30.02	1.30	0.50	5.00	2.22	0.44	D

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_04_21_test_07	1.05	101.85	108.12	25.67	1.21	0.58	5.00	1.21	0.24	D
2017_05_11_test_06	0.47	104.92	101.82	16.16	0.97	0.66	4.99	0.02	0.00	U
2017_05_11_test_06	0.76	106.00	107.98	20.89	1.10	0.65	5.00	0.23	0.05	U
2017_05_11_test_06	1.03	104.25	108.42	26.31	1.23	0.62	5.00	0.70	0.14	U
2017_05_11_test_06	1.40	102.19	106.19	31.55	1.33	0.50	5.00	2.22	0.44	U
2017_05_11_test_06	1.90	102.57	106.49	37.28	1.43	0.42	5.02	3.06	0.61	U
2017_05_11_test_06	2.51	104.48	108.48	41.81	1.51	0.36	5.02	3.52	0.70	U
2017_05_11_test_06	3.39	105.93	110.94	46.59	1.57	0.31	4.99	3.93	0.79	U
2017_05_11_test_07	2.51	104.21	105.26	42.08	1.51	0.34	5.00	3.67	0.73	D
2017_05_11_test_07	2.05	103.45	109.63	37.11	1.43	0.41	5.02	3.13	0.62	D
2017_05_11_test_07	1.57	102.48	110.72	31.96	1.34	0.46	5.02	2.60	0.52	D
2017_05_11_test_07	1.13	101.86	111.18	27.25	1.25	0.54	5.03	1.70	0.34	D
2017_05_11_test_07	0.76	101.60	111.22	22.47	1.14	0.64	5.03	0.46	0.09	D
2017_05_11_test_08	0.54	103.92	101.72	17.02	0.99	0.73	6.02	0.03	0.00	U
2017_05_11_test_08	0.86	104.23	102.43	21.87	1.12	0.72	6.01	0.16	0.03	U
2017_05_11_test_08	1.21	103.63	105.25	26.98	1.24	0.63	6.01	1.56	0.26	U
2017_05_11_test_08	1.58	101.33	104.11	32.13	1.34	0.51	6.01	3.11	0.52	U
2017_05_11_test_08	2.08	102.42	104.96	37.13	1.43	0.41	6.01	4.07	0.68	U
2017_05_11_test_08	2.94	104.49	109.10	42.95	1.52	0.34	6.03	4.76	0.79	U
2017_05_11_test_08	3.67	105.26	111.40	47.24	1.57	0.31	6.00	4.89	0.82	U
2017_05_11_test_09	2.97	104.56	106.97	42.41	1.51	0.31	6.02	4.90	0.82	D

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_05_11_test_09	2.35	103.45	111.30	36.71	1.42	0.37	6.01	4.50	0.75	D
2017_05_11_test_09	1.79	102.68	110.96	31.74	1.33	0.47	5.98	3.50	0.58	D
2017_05_11_test_09	1.33	101.95	108.75	26.98	1.24	0.54	5.99	2.74	0.46	D
2017_05_11_test_09	0.83	101.67	111.99	21.95	1.13	0.70	5.98	0.41	0.07	D
2017_05_11_test_10	0.79	104.36	108.36	17.69	1.01	0.79	7.01	0.05	0.01	U
2017_05_11_test_10	0.82	100.28	108.99	21.44	1.11	0.79	7.01	0.02	0.00	U
2017_05_11_test_10	1.25	101.21	109.59	26.90	1.24	0.67	7.01	1.91	0.27	U
2017_05_11_test_10	1.74	102.24	109.99	32.03	1.34	0.51	7.01	4.02	0.57	U
2017_05_11_test_10	2.34	103.49	110.32	36.58	1.41	0.39	7.00	5.25	0.75	U
2017_05_11_test_10	3.04	104.84	111.19	42.20	1.50	0.34	7.00	5.69	0.81	U
2017_05_11_test_10	3.91	105.96	112.37	47.11	1.57	0.32	7.00	5.84	0.83	U
2017_05_11_test_10	3.31	104.89	113.05	42.16	1.50	0.32	7.00	5.84	0.83	D
2017_05_11_test_10	2.67	104.37	113.22	36.95	1.42	0.42	7.02	5.06	0.72	D
2017_05_11_test_10	2.06	103.79	113.15	31.84	1.33	0.42	7.01	5.05	0.72	D
2017_05_11_test_10	1.50	102.79	112.90	27.09	1.24	0.54	7.00	3.66	0.52	D
2017_05_11_test_10	1.01	100.88	112.53	22.18	1.13	0.68	6.99	1.82	0.26	D
2017_05_11_test_11	2.90	104.33	105.88	41.77	1.50	0.34	7.01	5.72	0.82	D
2017_05_11_test_11	2.40	103.45	109.04	37.12	1.42	0.37	7.03	5.47	0.78	D
2017_05_11_test_11	1.88	102.86	110.09	31.75	1.33	0.46	7.02	4.65	0.66	D
2017_05_11_test_11	1.38	102.13	110.14	26.82	1.23	0.56	6.99	3.50	0.50	D
2017_05_11_test_11	0.81	101.49	109.98	21.64	1.12	0.74	6.99	0.76	0.11	D

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_05_17_test_01	14.76	118.14	123.62	29.04	1.12	0.67	5.00	0.03	0.01	U
2017_05_17_test_01	15.61	119.77	124.18	29.53	1.12	0.67	4.97	0.02	0.00	U
2017_05_17_test_01	15.52	119.37	123.58	34.67	1.22	0.62	5.02	0.76	0.15	U
2017_05_17_test_02	15.71	118.82	122.46	24.84	1.03	0.67	4.99	0.02	0.00	U
2017_05_17_test_02	15.64	120.24	122.52	29.70	1.12	0.67	4.99	0.02	0.00	U
2017_05_17_test_02	15.68	120.10	122.43	34.83	1.22	0.67	5.00	0.02	0.00	U
2017_05_17_test_02	15.77	120.18	122.51	39.74	1.30	0.56	4.99	1.53	0.31	U
2017_05_17_test_02	15.78	120.31	122.51	44.89	1.38	0.50	4.99	2.23	0.45	U
2017_05_17_test_02	16.06	120.42	122.80	50.31	1.46	0.40	4.98	3.16	0.63	U
2017_05_17_test_02	14.98	121.25	122.22	45.42	1.40	0.40	5.03	3.28	0.65	D
2017_05_17_test_02	15.97	121.42	124.84	39.36	1.29	0.56	4.95	1.41	0.29	D
2017_05_17_test_02	15.93	121.13	124.75	34.60	1.21	0.66	5.01	0.19	0.04	D
2017_05_17_test_03	15.10	120.69	121.76	29.57	1.13	0.67	5.03	0.03	0.00	U
2017_05_17_test_03	15.12	121.24	121.82	34.53	1.22	0.73	6.01	0.02	0.00	U
2017_05_17_test_03	14.66	120.22	121.34	39.22	1.30	0.59	6.00	2.12	0.35	U
2017_05_17_test_03	15.63	120.23	122.40	44.18	1.37	0.55	5.99	2.61	0.44	U
2017_05_17_test_03	15.38	120.38	122.28	50.32	1.46	0.44	6.02	3.86	0.64	U
2017_05_17_test_03	15.35	120.36	124.71	44.67	1.38	0.49	5.99	3.34	0.56	D
2017_05_17_test_03	15.89	120.23	124.88	38.90	1.28	0.53	6.00	2.83	0.47	D
2017_05_17_test_03	15.18	120.25	124.44	34.06	1.21	0.61	6.05	1.91	0.32	D
2017_05_17_test_04	15.35	116.35	122.03	29.39	1.12	0.79	6.99	0.02	0.00	U

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_05_17_test_04	14.85	119.93	121.52	34.93	1.23	0.79	7.01	0.02	0.00	U
2017_05_17_test_04	15.37	119.59	122.07	40.40	1.31	0.61	7.02	2.87	0.41	U
2017_05_17_test_04	15.31	120.20	122.00	44.45	1.38	0.51	6.98	4.11	0.59	U
2017_05_17_test_04	15.85	120.85	122.57	50.69	1.46	0.38	7.03	5.44	0.77	U
2017_05_17_test_04	14.64	120.63	121.32	44.23	1.38	0.51	7.00	4.15	0.59	D
2017_05_17_test_04	15.15	120.14	122.67	39.67	1.30	0.57	6.98	3.30	0.47	D
2017_05_17_test_05	15.38	119.97	122.07	44.31	1.37	0.55	6.98	3.58	0.51	D
2017_05_17_test_05	15.52	120.68	122.22	39.27	1.29	0.59	7.04	3.17	0.45	D
2017_05_17_test_05	15.95	120.11	122.68	34.16	1.20	0.77	7.01	0.48	0.07	D
2017_05_17_test_06	15.30	119.20	121.98	43.75	1.36	0.55	6.06	2.72	0.45	D
2017_05_17_test_06	15.54	119.41	122.24	38.30	1.28	0.55	5.96	2.58	0.43	D
2017_05_17_test_06	16.07	120.34	122.81	33.63	1.19	0.69	5.96	0.63	0.11	D
2017_05_18_test_04	27.74	130.28	133.39	33.94	1.12	0.67	4.99	0.03	0.01	U
2017_05_18_test_04	29.62	132.11	134.87	38.77	1.18	0.67	5.00	0.02	0.00	U
2017_05_18_test_04	29.45	133.41	134.74	43.81	1.26	0.58	5.00	1.25	0.25	U
2017_05_18_test_04	29.72	133.27	134.95	49.66	1.34	0.48	4.99	2.50	0.50	U
2017_05_18_test_04	29.85	133.49	135.05	54.08	1.39	0.43	4.99	2.95	0.59	U
2017_05_18_test_04	29.75	133.53	134.97	49.64	1.34	0.45	4.97	2.69	0.54	D
2017_05_18_test_04	30.00	133.64	135.16	43.74	1.25	0.56	4.99	1.55	0.31	D
2017_05_18_test_05	29.91	133.05	135.09	49.71	1.34	0.53	5.02	1.87	0.37	D
2017_05_18_test_05	30.14	133.11	135.26	44.43	1.26	0.58	5.00	1.32	0.26	D

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_05_18_test_05	30.79	132.35	135.76	39.47	1.19	0.65	4.99	0.29	0.06	D
2017_05_18_test_08	29.44	132.32	136.26	34.72	1.12	0.73	5.99	0.09	0.02	U
2017_05_18_test_08	29.63	132.60	135.99	38.68	1.18	0.74	6.01	0.03	0.00	U
2017_05_18_test_08	29.74	132.64	134.99	44.09	1.26	0.57	5.99	2.44	0.41	U
2017_05_18_test_08	29.62	132.98	134.88	50.09	1.35	0.46	6.02	3.72	0.62	U
2017_05_18_test_08	29.90	133.13	135.09	54.38	1.40	0.42	6.00	4.02	0.67	U
2017_05_18_test_08	29.91	133.59	135.99	49.39	1.33	0.46	6.00	3.63	0.61	D
2017_05_18_test_08	29.75	132.70	135.71	44.13	1.26	0.54	5.99	2.83	0.47	D
2017_05_18_test_08	30.17	132.42	135.70	39.41	1.19	0.61	5.89	1.73	0.29	D
2017_05_18_test_08	30.85	132.66	136.03	34.92	1.11	0.69	5.71	0.43	0.07	D
2017_05_22_test_02	30.97	134.68	135.91	53.30	1.38	0.50	5.97	3.18	0.53	D
2017_05_22_test_02	29.81	133.73	135.06	48.36	1.32	0.47	5.96	3.53	0.59	D
2017_05_22_test_02	30.16	133.21	136.10	43.90	1.26	0.52	5.99	2.96	0.49	D
2017_05_22_test_02	29.98	132.88	136.46	38.36	1.18	0.61	5.98	1.94	0.32	D
2017_05_22_test_02	30.27	133.96	136.01	33.86	1.10	0.74	6.06	0.03	0.00	D
2017_05_22_test_02	29.46	133.30	135.29	38.73	1.18	0.74	6.00	0.04	0.01	U
2017_05_22_test_04	29.92	132.56	135.12	34.27	1.11	0.79	6.99	0.02	0.00	U
2017_05_22_test_04	29.67	130.87	134.93	39.01	1.19	0.80	7.01	0.02	0.00	U
2017_05_22_test_04	29.68	133.37	134.91	44.35	1.27	0.54	7.01	3.74	0.53	U
2017_05_22_test_04	29.47	133.17	134.74	49.51	1.34	0.46	6.96	4.64	0.67	U
2017_05_22_test_04	30.15	133.20	135.27	54.70	1.40	0.40	6.95	5.15	0.74	U

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_05_22_test_05	30.48	134.82	135.56	54.45	1.40	0.45	6.99	4.78	0.68	D
2017_05_22_test_05	29.85	133.63	137.49	49.02	1.33	0.48	6.98	4.45	0.64	D
2017_05_22_test_05	29.91	133.42	137.96	44.02	1.26	0.53	6.97	3.85	0.55	D
2017_05_22_test_05	30.37	133.95	137.73	38.79	1.18	0.62	6.92	2.72	0.39	D
2017_05_22_test_05	30.90	133.52	137.48	33.83	1.10	0.78	7.03	0.32	0.05	D

APPENDIX B

REDUCED AIR/WATER DATA

The proceeding section presents qualified reduced air/water data collected in this study for flooding and hysteresis.

B.1 Reduced Air/Water Flooding Data

The proceeding section presents qualified reduced air/water flooding data; tests are listed by test name.

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2016_06_14_Test_06	15.36	25.12	13.33	58.37	1.25	0.56	4.42	0.72	3.70
2016_06_14_Test_07	15.38	25.19	13.72	59.02	1.26	0.56	4.47	0.80	3.67
2016_06_14_Test_08	15.54	25.28	13.36	59.20	1.26	0.55	4.48	0.96	3.52
2016_06_14_Test_09	15.64	25.37	13.64	59.71	1.27	0.55	4.48	0.91	3.57
2016_06_14_Test_10	15.57	25.41	14.03	59.63	1.27	0.56	4.48	0.84	3.64
2016_06_14_Test_11	15.87	25.55	13.96	58.43	1.25	0.56	4.98	1.24	3.73
2016_06_14_Test_12	15.59	25.59	14.44	57.59	1.24	0.57	4.98	1.16	3.82
2016_06_14_Test_13	15.55	25.71	14.54	57.41	1.24	0.57	4.99	1.15	3.84
2016_06_14_Test_14	15.58	25.82	14.64	57.53	1.24	0.57	4.98	1.20	3.78
2016_06_14_Test_15	14.83	25.92	12.51	69.50	1.37	0.42	5.06	3.02	2.04
2016_06_14_Test_16	15.17	25.98	12.66	70.13	1.38	0.39	5.04	3.23	1.81
2016_06_14_Test_17	14.82	26.02	12.56	69.86	1.38	0.42	5.04	2.94	2.10
2016_06_14_Test_18	14.98	26.10	12.66	70.34	1.38	0.41	5.03	3.09	1.94
2016_06_15_test_01	15.32	25.80	14.05	56.47	1.23	0.57	5.40	1.53	3.87
2016_06_15_test_02	14.99	25.88	14.20	55.02	1.22	0.58	5.46	1.52	3.94
2016_06_15_test_03	15.11	25.99	14.03	55.73	1.23	0.59	5.44	1.34	4.09
2016_06_15_test_04	15.32	26.02	13.60	56.37	1.23	0.58	5.44	1.49	3.95
2016_06_15_test_05	15.42	26.08	13.64	56.43	1.23	0.58	5.44	1.51	3.93
2016_06_15_test_06	15.84	26.24	11.67	70.82	1.37	0.41	5.49	3.56	1.93
2016_06_15_test_07	15.83	26.26	11.93	70.66	1.37	0.40	5.48	3.64	1.85
2016_06_15_test_08	15.83	26.31	11.94	70.38	1.37	0.37	5.50	3.89	1.61

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2016_06_15_test_09	15.81	26.35	11.96	70.15	1.37	0.39	5.50	3.71	1.79
2016_06_15_test_13	16.01	26.59	14.44	56.24	1.23	0.56	6.01	2.35	3.66
2016_06_15_test_14	15.69	26.63	14.44	56.32	1.23	0.56	6.00	2.30	3.70
2016_06_15_test_15	15.33	26.67	14.64	55.18	1.22	0.58	6.05	2.09	3.96
2016_06_15_test_16	15.47	26.69	14.90	55.78	1.23	0.58	6.01	2.10	3.91
2016_06_15_test_17	15.28	26.77	12.87	67.86	1.35	0.37	6.04	4.39	1.65
2016_06_15_test_19	15.64	26.88	12.65	68.06	1.35	0.40	6.01	4.16	1.85
2016_06_15_test_21	15.75	27.00	15.46	54.46	1.21	0.58	6.43	2.50	3.93
2016_06_15_test_22	15.72	27.07	14.58	54.95	1.22	0.57	6.46	2.61	3.85
2016_06_15_test_23	15.67	27.10	15.91	54.81	1.21	0.58	6.45	2.51	3.94
2016_06_15_test_25	15.56	27.15	15.20	54.35	1.21	0.58	6.49	2.59	3.90
2016_06_15_test_26	15.36	27.30	13.73	64.58	1.32	0.43	6.46	4.28	2.18
2016_06_15_test_27	15.60	27.38	13.54	65.44	1.33	0.45	6.45	4.05	2.40
2016_06_15_test_28	15.68	27.45	13.51	65.80	1.33	0.45	6.45	4.02	2.43
2016_06_15_test_29	15.65	27.51	13.64	65.72	1.33	0.45	6.45	4.08	2.37
2016_06_15_test_30	15.36	27.58	13.73	65.48	1.33	0.41	6.49	4.49	2.00
2016_06_16_test_01	15.68	26.71	14.31	54.23	1.21	0.56	6.96	3.27	3.69
2016_06_16_test_02	15.82	26.84	15.11	54.66	1.21	0.58	6.92	3.00	3.92
2016_06_16_test_03	15.95	26.95	14.30	54.85	1.21	0.57	6.93	3.08	3.85
2016_06_16_test_04	15.81	27.02	13.87	54.93	1.21	0.56	7.03	3.33	3.70
2016_06_16_test_05	15.51	27.21	12.60	67.51	1.35	0.29	7.01	6.03	0.98

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2016_06_16_test_06	15.75	27.28	12.24	68.25	1.35	0.32	7.01	5.80	1.22
2016_06_16_test_07	15.83	27.32	12.18	68.49	1.35	0.34	7.02	5.69	1.33
2016_06_16_test_08	15.78	27.40	12.14	68.41	1.35	0.33	7.04	5.73	1.31
2016_06_16_test_09	15.82	27.44	12.13	68.59	1.35	0.34	7.04	5.67	1.37
2016_06_16_test_10	15.94	27.57	14.28	53.99	1.20	0.55	7.40	3.78	3.62
2016_06_16_test_11	15.27	27.64	14.53	53.83	1.21	0.55	7.49	3.93	3.55
2016_06_16_test_12	14.96	27.72	14.32	52.82	1.20	0.56	7.52	3.86	3.66
2016_06_16_test_13	15.15	27.76	14.67	53.22	1.20	0.57	7.50	3.66	3.84
2016_06_16_test_14	14.76	27.85	12.47	65.55	1.34	0.29	7.50	6.49	1.01
2016_06_16_test_15	14.62	27.91	12.72	65.05	1.33	0.33	7.54	6.29	1.25
2016_06_16_test_16	14.58	27.95	12.99	65.07	1.33	0.32	7.51	6.31	1.20
2016_06_16_test_17	14.97	27.95	12.84	65.80	1.34	0.28	7.50	6.57	0.93
2016_06_16_test_18	14.24	28.09	14.49	47.82	1.15	0.62	8.14	3.68	4.46
2016_06_16_test_19	15.69	28.13	16.66	49.38	1.15	0.60	7.94	3.69	4.24
2016_06_16_test_20	15.73	28.17	15.62	49.60	1.16	0.61	7.96	3.61	4.35
2016_06_16_test_21	15.75	28.25	17.43	49.64	1.16	0.60	7.95	3.67	4.28
2016_06_16_test_22	15.80	28.32	17.45	49.92	1.16	0.60	7.93	3.71	4.22
2016_06_16_test_23	15.43	28.37	14.15	60.76	1.28	0.45	7.96	5.62	2.33
2016_06_16_test_24	15.56	28.42	14.09	61.48	1.29	0.40	7.96	6.04	1.93
2016_06_16_test_25	15.46	28.44	14.15	61.07	1.29	0.40	7.96	6.10	1.86
2016_06_16_test_26	15.50	28.50	14.18	61.17	1.29	0.42	7.97	5.92	2.05

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2016_06_22_test_08	30.10	25.41	14.46	68.77	1.23	0.57	4.50	0.72	3.78
2016_06_22_test_10	30.10	25.51	14.58	69.46	1.24	0.57	4.50	0.72	3.77
2016_06_22_test_11	30.68	25.58	13.82	82.06	1.34	0.50	4.50	1.51	2.99
2016_06_22_test_12	30.59	25.63	13.83	81.51	1.34	0.51	4.51	1.50	3.01
2016_06_22_test_13	30.91	25.69	13.80	82.80	1.35	0.49	4.48	1.60	2.88
2016_06_22_test_14	30.80	25.80	16.24	65.68	1.20	0.60	5.49	1.23	4.27
2016_06_22_test_15	30.95	25.89	16.99	66.74	1.21	0.60	5.42	1.16	4.26
2016_06_22_test_16	31.07	25.95	15.83	66.68	1.21	0.59	5.49	1.37	4.12
2016_06_22_test_17	31.06	25.99	15.87	66.76	1.21	0.60	5.47	1.29	4.18
2016_06_22_test_18	30.45	26.21	14.52	84.42	1.36	0.44	5.52	3.22	2.30
2016_06_22_test_19	30.62	26.23	14.47	85.23	1.37	0.46	5.47	3.02	2.45
2016_06_22_test_20	30.58	26.31	14.52	85.32	1.37	0.44	5.51	3.27	2.25
2016_06_22_test_21	30.99	26.47	16.20	64.24	1.19	0.59	6.45	2.36	4.09
2016_06_22_test_22	30.89	26.54	16.63	63.89	1.19	0.60	6.43	2.13	4.31
2016_06_22_test_23	30.87	26.57	16.30	63.61	1.18	0.60	6.47	2.18	4.29
2016_06_22_test_24	30.58	26.62	17.17	62.97	1.18	0.62	6.50	2.01	4.49
2016_06_22_test_25	29.78	26.76	14.89	85.43	1.38	0.37	6.53	4.92	1.61
2016_06_22_test_26	29.50	26.76	14.99	84.41	1.37	0.38	6.55	4.83	1.72
2016_06_22_test_27	29.52	26.78	14.90	84.53	1.37	0.40	6.50	4.57	1.93
2016_06_23_test_01	30.57	26.17	15.73	62.89	1.18	0.60	7.45	3.28	4.17
2016_06_23_test_02	30.53	26.19	15.56	62.53	1.17	0.59	7.46	3.38	4.08

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2016_06_23_test_03	30.63	26.21	14.96	62.76	1.18	0.59	7.45	3.39	4.06
2016_06_23_test_07	29.59	26.60	13.12	82.67	1.35	0.32	7.57	6.36	1.21
2016_06_23_test_08	29.60	26.61	13.34	83.52	1.36	0.34	7.55	6.19	1.36
2016_06_23_test_09	29.72	26.60	13.40	83.41	1.36	0.28	7.53	6.61	0.91
2016_06_23_test_10	29.92	26.60	13.48	84.14	1.36	0.28	7.54	6.61	0.93
2016_06_23_test_11	30.41	26.75	15.45	59.76	1.15	0.61	7.95	3.53	4.42
2016_06_23_test_12	30.48	26.80	15.29	59.80	1.15	0.60	7.93	3.68	4.25
2016_06_23_test_14	30.06	26.84	15.60	59.17	1.15	0.73	7.96	1.64	6.32
2016_06_23_test_15	30.43	26.98	14.61	80.98	1.34	0.36	7.96	6.42	1.54
2016_06_23_test_16	30.38	27.01	14.59	80.96	1.34	0.35	7.97	6.56	1.41
2016_06_23_test_17	30.36	27.04	14.56	80.72	1.34	0.35	7.97	6.51	1.45
2016_06_24_test_01	30.50	26.28	17.17	59.53	1.15	0.61	8.57	4.23	4.34
2016_06_24_test_02	30.39	26.26	16.81	59.19	1.15	0.61	8.57	4.13	4.44
2016_06_24_test_03	30.12	26.27	16.88	57.82	1.13	0.61	8.57	4.13	4.44
2016_06_24_test_04	31.09	26.34	14.97	79.95	1.32	0.37	8.47	6.86	1.61
2016_06_24_test_06	30.97	26.41	14.78	78.47	1.31	0.35	8.50	7.08	1.41
2016_07_13_test_24	30.38	26.63	17.23	69.28	1.24	0.57	4.47	0.67	3.80
2016_07_13_test_25	30.37	26.66	17.13	68.76	1.24	0.58	4.44	0.51	3.93
2016_07_13_test_26	30.81	26.72	16.86	69.66	1.24	0.56	4.59	0.86	3.72
2016_07_13_test_27	30.32	26.84	17.58	64.33	1.20	0.58	6.50	2.59	3.91
2016_07_13_test_28	30.19	26.88	17.54	63.94	1.19	0.59	6.48	2.37	4.10

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2016_07_13_test_29	30.15	26.97	20.61	63.56	1.19	0.58	6.51	2.55	3.96
2017_02_20_test_08	15.12	27.06	24.07	75.16	1.42	0.29	5.28	4.27	1.01
2017_02_23_test_01	15.91	26.06	24.86	53.62	1.20	0.57	7.61	3.74	3.87
2017_02_23_test_02	15.35	26.36	25.29	53.19	1.20	0.56	6.96	3.22	3.74
2017_02_23_test_03	15.30	26.42	25.38	53.29	1.20	0.57	7.00	3.21	3.79
2017_02_23_test_04	15.23	26.49	25.48	53.18	1.20	0.56	7.00	3.29	3.71
2017_02_27_test_01	16.17	25.05	24.05	68.20	1.35	0.28	7.00	6.04	0.96
2017_02_27_test_11	2.15	25.53	25.12	55.58	1.41	0.34	5.01	3.68	1.33
2017_02_27_test_12	1.07	25.56	25.21	42.35	1.25	0.65	4.99	0.04	4.95
2017_02_27_test_13	1.38	25.62	25.42	42.07	1.24	0.65	7.00	1.98	5.03
2017_02_27_test_10	1.29	25.52	25.05	44.47	1.28	0.54	5.00	1.63	3.37
2017_02_27_test_11	3.02	25.53	25.13	63.77	1.49	0.25	4.98	4.24	0.74
2017_02_27_test_12	3.54	25.52	25.22	68.72	1.53	0.28	5.03	4.07	0.96
2017_02_27_test_13	3.91	25.64	25.42	64.86	1.48	0.23	7.01	6.36	0.65
2017_02_27_test_12	4.30	25.51	25.23	75.11	1.58	0.23	5.03	4.41	0.61
2017_02_27_test_13	4.56	25.65	25.43	70.50	1.53	0.25	6.98	6.28	0.71
2017_02_27_test_05	15.43	25.31	24.56	76.01	1.43	0.21	6.98	6.47	0.51
2017_02_27_test_09	4.48	25.47	24.83	67.39	1.50	0.21	5.02	4.48	0.54
2017_02_27_test_09	1.96	25.49	24.98	53.26	1.38	0.37	4.99	3.41	1.58
2017_03_03_test_01	1.65	23.89	22.99	45.87	1.29	0.51	4.50	1.43	3.07
2017_03_03_test_02	1.49	23.94	22.98	43.07	1.26	0.55	4.51	0.89	3.61

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2017_03_03_test_03	1.52	24.00	23.01	43.63	1.26	0.54	4.50	1.10	3.40
2017_03_03_test_04	1.47	23.97	22.98	42.07	1.24	0.56	4.99	1.30	3.69
2017_03_03_test_05	1.53	24.00	23.04	42.35	1.24	0.55	5.49	1.90	3.59
2017_03_03_test_06	1.55	24.01	23.08	42.47	1.24	0.54	6.00	2.50	3.50
2017_03_03_test_07	1.61	24.03	23.13	42.49	1.24	0.53	6.49	3.22	3.27
2017_03_03_test_08	1.65	24.05	23.19	42.35	1.24	0.52	7.00	3.85	3.15
2017_03_03_test_09	1.70	24.06	23.25	42.56	1.24	0.55	7.50	3.99	3.51
2017_03_03_test_10	1.62	24.09	23.32	40.30	1.21	0.55	8.02	4.42	3.60
2017_03_03_test_02	1.98	23.98	22.98	51.89	1.37	0.44	4.50	2.20	2.29
2017_03_03_test_03	2.05	24.03	23.01	53.11	1.38	0.44	4.50	2.25	2.25
2017_03_03_test_04	2.12	23.99	22.99	52.29	1.37	0.36	4.98	3.42	1.57
2017_03_03_test_05	2.18	24.02	23.05	52.05	1.36	0.36	5.50	3.98	1.52
2017_03_03_test_06	2.31	24.01	23.09	52.49	1.36	0.34	6.00	4.67	1.34
2017_03_03_test_07	2.39	24.03	23.15	52.32	1.36	0.30	6.49	5.45	1.04
2017_03_03_test_08	2.50	24.05	23.20	52.08	1.36	0.23	6.99	6.39	0.61
2017_03_03_test_09	2.61	24.07	23.27	52.31	1.36	0.25	7.50	6.77	0.73
2017_03_03_test_10	2.50	24.10	23.33	50.02	1.33	0.27	7.99	7.12	0.87
2017_03_13_test_01	1.41	24.17	24.60	43.45	1.27	0.54	5.00	1.61	3.38
2017_03_13_test_02	3.68	24.22	24.59	68.54	1.53	0.24	5.00	4.34	0.66
2017_03_13_test_03	4.85	24.29	24.58	78.54	1.61	0.24	5.01	4.31	0.70
2017_03_13_test_05	1.55	24.41	24.58	43.90	1.27	0.51	6.01	2.89	3.12

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2017_03_13_test_06	3.98	24.44	24.58	68.22	1.52	0.22	6.00	5.44	0.56
2017_03_13_test_09	1.64	24.63	24.57	43.60	1.26	0.49	6.99	4.20	2.79
2017_03_13_test_10	4.40	24.60	24.57	68.42	1.51	0.24	7.01	6.35	0.67
2017_03_24_test_01	1.36	24.36	23.32	42.26	1.25	0.53	5.99	2.70	3.29
2017_03_24_test_02	1.40	24.44	23.36	42.60	1.25	0.51	6.00	2.93	3.08
2017_03_24_test_03	1.40	24.52	23.39	42.80	1.26	0.51	6.00	2.91	3.09
2017_03_24_test_04	1.39	24.56	23.41	42.64	1.25	0.51	5.98	2.96	3.02
2017_03_24_test_05	2.17	24.59	23.45	52.26	1.37	0.26	6.00	5.18	0.82
2017_03_24_test_06	2.16	24.64	23.47	52.36	1.37	0.27	5.98	5.14	0.84
2017_03_24_test_07	2.15	24.69	23.50	52.31	1.37	0.26	6.01	5.19	0.82
2017_03_24_test_08	2.15	24.71	23.53	52.15	1.37	0.25	6.00	5.26	0.74
2017_03_24_test_09	2.41	24.74	23.56	52.38	1.36	0.21	7.02	6.48	0.54
2017_03_24_test_10	2.37	24.79	23.66	52.44	1.36	0.24	6.99	6.31	0.68
2017_03_24_test_11	2.40	24.76	23.61	52.33	1.36	0.22	7.01	6.45	0.56
2017_03_24_test_12	2.39	24.81	23.70	52.50	1.37	0.24	7.00	6.33	0.68
2017_03_24_test_13	1.21	24.87	23.73	41.69	1.24	0.55	5.00	1.42	3.58
2017_03_24_test_14	1.24	24.86	23.76	42.20	1.25	0.55	5.00	1.48	3.52
2017_03_24_test_15	1.19	24.86	23.82	41.62	1.24	0.56	5.00	1.31	3.69
2017_03_24_test_16	1.24	24.88	23.88	42.46	1.25	0.54	5.00	1.57	3.43
2017_04_03_test_01	1.18	24.41	21.76	40.85	1.23	0.54	6.03	2.61	3.41
2017_04_03_test_02	1.22	24.42	21.81	41.46	1.24	0.53	6.04	2.72	3.32

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2017_04_03_test_03	1.22	24.43	21.84	41.52	1.24	0.53	6.00	2.63	3.37
2017_04_03_test_04	1.22	24.46	21.88	41.70	1.24	0.53	6.02	2.70	3.31
2017_04_03_test_05	1.21	24.50	21.91	41.53	1.24	0.53	6.02	2.74	3.28
2017_04_03_test_06	1.22	24.53	21.98	41.51	1.24	0.54	6.03	2.63	3.40
2017_04_03_test_07	1.18	24.58	22.03	40.97	1.23	0.55	6.02	2.46	3.56
2017_04_03_test_08	1.21	24.62	22.09	41.30	1.23	0.53	6.01	2.74	3.28
2017_04_03_test_09	1.24	24.66	22.14	42.35	1.25	0.53	6.02	2.68	3.33
2017_04_03_test_10	1.18	24.73	22.19	41.61	1.24	0.54	6.03	2.58	3.44
2017_04_03_test_11	15.88	24.86	22.51	56.55	1.23	0.53	6.03	2.68	3.35
2017_04_03_test_12	16.21	24.89	22.62	57.34	1.23	0.55	6.01	2.50	3.51
2017_04_03_test_13	16.24	24.96	22.72	57.48	1.24	0.53	6.01	2.73	3.28
2017_04_03_test_14	16.12	24.99	22.84	57.39	1.24	0.54	6.03	2.58	3.45
2017_04_03_test_15	16.11	25.04	22.97	57.32	1.24	0.53	6.03	2.70	3.33
2017_04_03_test_16	16.02	25.07	23.04	57.26	1.24	0.54	6.02	2.62	3.40
2017_04_03_test_17	16.01	25.10	23.13	57.22	1.24	0.53	6.02	2.64	3.37
2017_04_03_test_18	15.96	25.18	23.22	57.11	1.24	0.54	6.01	2.63	3.38
2017_04_03_test_19	16.20	25.18	23.32	57.63	1.24	0.54	6.03	2.58	3.45
2017_04_03_test_20	16.05	25.24	23.39	57.34	1.24	0.54	6.01	2.57	3.44
2017_04_03_test_21	30.28	25.49	24.00	64.61	1.20	0.57	6.02	2.16	3.85
2017_04_03_test_22	30.33	25.50	24.08	64.87	1.20	0.56	6.00	2.28	3.73
2017_04_03_test_23	30.34	25.53	24.19	64.67	1.20	0.58	6.03	2.08	3.95

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Q_{fd} [GPM]
2017_04_03_test_24	30.31	25.60	24.28	64.71	1.20	0.56	6.04	2.29	3.74
2017_04_03_test_25	30.21	25.67	24.38	64.70	1.20	0.57	6.04	2.27	3.77
2017_04_03_test_26	30.27	25.80	24.66	64.53	1.20	0.58	6.04	2.09	3.94
2017_04_03_test_27	30.44	25.80	24.70	65.31	1.20	0.56	6.02	2.30	3.73
2017_04_03_test_28	30.31	25.87	24.70	64.83	1.20	0.57	6.02	2.15	3.87
2017_04_03_test_29	30.16	25.86	24.77	64.63	1.20	0.56	6.03	2.31	3.72
2017_04_03_test_30	30.32	25.90	24.81	64.94	1.20	0.57	6.02	2.22	3.80

B.2 Reduced Air/Water Hysteresis Data

Below is the reduced data for air/water hysteresis tests. The tests are displayed according to name and start with the first point associated with raising gas the gas mass flow rate up to a maximum and then back down. The column labeled direction signifies up (U) for increasing gas mass flow rate and down (D) for decreasing the mass flow rate.

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2016_08_26_test_01_01	15.84	51.20	18.05	28.46	0.88	0.69	5.51	0.02	0.00	U
2016_08_26_test_01_02	15.07	51.17	16.88	33.69	0.97	0.68	5.44	0.02	0.00	U
2016_08_26_test_01_03	15.13	51.15	16.67	37.58	1.02	0.69	5.52	0.02	0.00	U
2016_08_26_test_01_04	15.03	51.15	18.62	42.73	1.09	0.69	5.54	0.02	0.00	U
2016_08_26_test_01_05	15.14	51.15	19.28	47.95	1.15	0.69	5.53	0.02	0.00	U
2016_08_26_test_02_01	15.33	50.91	16.57	48.12	1.15	0.69	5.54	0.02	0.00	U
2016_08_26_test_02_02	15.29	50.93	17.85	52.98	1.21	0.63	5.53	0.83	0.15	U
2016_08_26_test_02_03	15.49	50.96	17.27	58.13	1.26	0.58	5.50	1.58	0.29	U
2016_08_26_test_03_01	16.17	50.81	15.01	62.97	1.31	0.56	5.54	1.86	0.34	D
2016_08_26_test_04_01	16.23	50.57	16.38	54.10	1.21	0.61	5.51	1.12	0.20	D
2016_08_26_test_04_02	14.82	50.62	17.47	48.18	1.16	0.68	5.53	0.18	0.03	D
2016_08_26_test_05_01	14.59	50.56	17.41	49.66	1.18	0.64	5.50	0.69	0.13	D
2017_03_03_test_11_01	1.04	24.16	23.36	36.87	1.17	0.65	5.00	0.02	0.00	U
2017_03_03_test_11_02	1.46	24.17	23.37	42.22	1.24	0.58	5.00	1.03	0.21	U
2017_03_03_test_11_03	1.71	24.18	23.38	47.13	1.31	0.51	5.00	1.98	0.40	U
2017_03_03_test_11_04	2.07	24.17	23.39	52.19	1.37	0.38	5.00	3.33	0.67	U
2017_03_03_test_11_05	2.50	24.17	23.40	57.12	1.42	0.28	4.99	4.08	0.82	U
2017_03_03_test_12_01	2.47	24.20	23.47	57.28	1.42	0.42	4.98	2.90	0.58	D
2017_03_03_test_12_02	2.16	24.19	23.47	52.30	1.37	0.30	5.06	3.98	0.79	D
2017_03_03_test_12_03	1.73	24.19	23.47	47.14	1.31	0.44	5.05	2.77	0.55	D
2017_03_03_test_12_04	1.43	24.20	23.48	42.08	1.24	0.54	5.01	1.54	0.31	D

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_03_03_test_12_05	1.16	24.19	23.48	37.14	1.17	0.62	5.00	0.47	0.09	D
2017_03_03_test_12_06	0.83	24.19	23.49	32.19	1.10	0.65	5.01	0.09	0.02	D
2017_03_03_test_13_01	1.05	24.20	23.52	37.51	1.18	0.71	5.96	0.02	0.00	U
2017_03_03_test_13_02	1.49	24.19	23.52	42.80	1.25	0.62	5.98	1.43	0.24	U
2017_03_03_test_13_03	1.88	24.20	23.53	47.58	1.31	0.44	6.03	3.74	0.62	U
2017_03_03_test_13_04	2.24	24.20	23.54	52.01	1.36	0.36	6.00	4.43	0.74	U
2017_03_03_test_13_05	2.79	24.20	23.54	57.49	1.42	0.24	6.01	5.31	0.88	U
2017_03_03_test_14_01	2.65	24.23	23.58	57.17	1.42	0.45	5.97	3.54	0.59	D
2017_03_03_test_14_02	2.35	24.20	23.58	52.24	1.36	0.25	6.05	5.32	0.88	D
2017_03_03_test_14_03	1.89	24.21	23.58	47.45	1.31	0.38	6.02	4.30	0.72	D
2017_03_03_test_14_04	1.56	24.23	23.59	42.42	1.24	0.49	6.02	3.21	0.53	D
2017_03_03_test_14_05	1.25	24.23	23.60	37.12	1.17	0.61	6.01	1.68	0.28	D
2017_03_03_test_14_06	0.86	24.23	23.61	32.40	1.10	0.68	6.03	0.65	0.11	D
2017_03_03_test_15_01	1.03	24.22	23.65	37.58	1.18	0.77	7.04	0.02	0.00	U
2017_03_03_test_15_02	1.60	24.22	23.65	42.31	1.24	0.62	7.01	2.46	0.35	U
2017_03_03_test_15_03	2.09	24.22	23.65	47.32	1.30	0.36	7.00	5.46	0.78	U
2017_03_03_test_15_04	2.52	24.22	23.66	52.17	1.36	0.23	7.00	6.39	0.91	U
2017_03_03_test_15_05	3.12	24.22	23.67	57.42	1.41	0.21	6.98	6.46	0.93	U
2017_03_03_test_16_01	3.03	24.27	23.72	57.45	1.41	0.31	6.91	5.78	0.84	D
2017_03_03_test_16_02	2.63	24.25	23.72	52.58	1.36	0.21	7.03	6.53	0.93	D
2017_03_03_test_16_03	2.07	24.24	23.72	47.23	1.30	0.34	7.03	5.70	0.81	D

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_03_03_test_16_04	1.64	24.25	23.73	42.19	1.24	0.47	7.03	4.40	0.63	D
2017_03_03_test_16_05	1.33	24.25	23.74	37.18	1.17	0.57	6.99	3.10	0.44	D
2017_03_03_test_16_06	1.01	24.24	23.75	32.09	1.09	0.69	6.98	1.44	0.21	D
2017_03_27_test_01_01	14.68	24.36	23.62	39.77	1.05	0.65	5.00	0.01	0.00	U
2017_03_27_test_01_02	15.50	24.35	23.60	45.45	1.11	0.65	5.03	0.02	0.00	U
2017_03_27_test_01_03	15.86	24.36	23.61	49.59	1.16	0.65	5.01	0.02	0.00	U
2017_03_27_test_01_04	16.00	24.38	23.62	54.66	1.21	0.65	5.02	0.02	0.00	U
2017_03_27_test_02_01	15.69	24.47	23.75	55.14	1.22	0.65	5.00	0.01	0.00	U
2017_03_27_test_02_02	16.06	24.44	23.70	60.10	1.27	0.60	5.01	0.84	0.17	U
2017_03_27_test_02_03	16.23	24.44	23.69	65.08	1.32	0.50	4.99	2.06	0.41	U
2017_03_27_test_02_04	16.21	24.46	23.70	69.32	1.36	0.41	5.05	3.09	0.61	U
2017_03_27_test_03_01	16.36	24.54	23.84	70.04	1.36	0.48	5.01	2.32	0.46	U
2017_03_27_test_03_02	16.27	24.51	23.80	74.76	1.41	0.29	5.04	4.04	0.80	U
2017_03_27_test_04_01	14.89	24.60	23.92	74.29	1.42	0.49	5.00	2.15	0.43	D
2017_03_27_test_04_02	14.68	24.57	23.88	70.47	1.39	0.33	5.03	3.76	0.75	D
2017_03_27_test_05_01	14.48	24.61	23.94	69.90	1.38	0.34	5.01	3.67	0.73	D
2017_03_27_test_05_02	14.44	24.62	23.92	64.69	1.33	0.44	4.99	2.74	0.55	D
2017_03_27_test_06_01	14.96	24.66	24.00	60.16	1.28	0.51	5.00	1.96	0.39	D
2017_03_27_test_06_02	15.47	24.66	23.99	54.75	1.22	0.57	5.01	1.25	0.25	D
2017_03_27_test_06_03	15.34	24.67	24.00	49.68	1.16	0.61	5.00	0.58	0.12	D
2017_03_27_test_07_01	15.03	24.72	24.17	35.41	0.98	0.71	6.04	0.02	0.00	U

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_03_27_test_07_02	15.31	24.72	24.15	40.49	1.05	0.71	6.04	0.02	0.00	U
2017_03_27_test_07_03	15.64	24.73	24.16	44.94	1.10	0.71	6.01	0.02	0.00	U
2017_03_27_test_08_01	15.68	24.82	24.33	45.21	1.10	0.71	6.01	0.02	0.00	U
2017_03_27_test_08_02	15.87	24.76	24.24	50.44	1.16	0.71	6.01	0.02	0.00	U
2017_03_27_test_08_03	15.85	24.77	24.24	54.91	1.21	0.64	6.00	1.15	0.19	U
2017_03_27_test_08_04	15.53	24.77	24.26	57.04	1.24	0.51	6.04	2.99	0.49	U
2017_03_27_test_09_01	16.14	24.84	24.42	59.86	1.26	0.56	5.93	2.17	0.37	U
2017_03_27_test_09_02	15.73	24.81	24.36	65.26	1.32	0.41	6.02	4.00	0.66	U
2017_03_27_test_09_03	15.82	24.82	24.37	69.27	1.36	0.30	6.00	4.96	0.83	U
2017_03_27_test_11_01	16.15	24.87	24.51	69.84	1.36	0.38	6.00	4.34	0.72	D
2017_03_27_test_11_02	15.35	24.85	24.48	64.84	1.32	0.39	6.02	4.18	0.70	D
2017_03_27_test_11_03	15.59	24.85	24.50	60.08	1.27	0.47	6.00	3.41	0.57	D
2017_03_27_test_12_01	16.03	24.90	24.66	60.23	1.27	0.56	6.01	2.32	0.39	D
2017_03_27_test_12_02	14.65	24.87	24.61	54.75	1.22	0.53	5.99	2.67	0.45	D
2017_03_27_test_12_03	15.15	24.87	24.62	49.49	1.16	0.62	6.00	1.49	0.25	D
2017_03_27_test_12_04	15.28	24.87	24.64	44.20	1.09	0.67	6.00	0.63	0.10	D
2017_03_27_test_13_01	15.10	24.91	24.79	35.56	0.98	0.76	6.87	0.02	0.00	U
2017_03_27_test_13_02	14.78	24.91	24.78	40.75	1.06	0.77	7.02	0.02	0.00	U
2017_03_27_test_13_03	14.96	24.93	24.79	44.99	1.11	0.77	7.01	0.02	0.00	U
2017_03_27_test_13_04	15.09	24.92	24.80	49.51	1.16	0.77	7.01	0.02	0.00	U
2017_03_27_test_13_05	15.63	24.92	24.80	51.94	1.18	0.77	6.99	0.02	0.00	U

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_03_27_test_14_01	16.08	24.99	25.00	49.96	1.16	0.77	6.98	0.02	0.00	U
2017_03_27_test_14_02	16.03	24.95	24.95	55.51	1.22	0.59	7.01	2.97	0.42	U
2017_03_27_test_14_03	16.08	24.96	24.96	59.66	1.26	0.48	7.01	4.29	0.61	U
2017_03_27_test_14_04	16.15	24.96	24.98	64.09	1.31	0.40	6.98	5.08	0.73	U
2017_03_27_test_15_01	14.30	25.02	25.13	60.35	1.29	0.54	6.97	3.57	0.51	U
2017_03_27_test_15_02	15.72	24.98	25.09	64.83	1.32	0.32	6.99	5.76	0.82	U
2017_03_27_test_15_03	15.86	24.99	25.09	69.57	1.36	0.23	7.01	6.36	0.91	U
2017_03_27_test_16_01	15.35	25.03	25.22	70.20	1.38	0.34	6.99	5.63	0.81	D
2017_03_27_test_16_02	15.25	25.02	25.21	64.91	1.33	0.36	6.97	5.43	0.78	D
2017_03_27_test_16_03	14.76	25.02	25.23	59.61	1.28	0.42	7.02	4.92	0.70	D
2017_03_27_test_17_01	16.10	25.02	25.35	59.99	1.27	0.52	7.01	3.79	0.54	D
2017_03_27_test_17_02	14.60	25.02	25.35	54.79	1.23	0.50	6.98	4.08	0.58	D
2017_03_27_test_17_03	14.69	25.03	25.37	49.68	1.17	0.59	7.02	2.94	0.42	D
2017_03_27_test_17_04	15.17	25.03	25.41	44.38	1.10	0.69	7.00	1.35	0.19	D
2017_03_27_test_18_01	16.29	25.08	25.55	50.01	1.16	0.60	7.04	2.84	0.40	D
2017_03_27_test_18_02	15.09	25.06	25.54	45.04	1.11	0.65	7.00	1.99	0.28	D
2017_03_27_test_18_03	15.53	25.06	25.56	39.82	1.04	0.74	7.02	0.60	0.09	D
2017_03_31_test_01_01	29.74	24.77	22.69	45.27	1.00	0.65	4.99	0.01	0.00	U
2017_03_31_test_01_02	30.47	24.76	22.68	49.66	1.05	0.65	5.03	0.01	0.00	U
2017_03_31_test_01_03	29.90	24.77	22.69	55.17	1.11	0.65	5.02	0.02	0.00	U
2017_03_31_test_01_04	29.42	24.77	22.71	59.87	1.16	0.65	5.07	0.02	0.00	U

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_03_31_test_02_01	30.20	24.81	22.83	59.86	1.15	0.65	5.00	0.02	0.00	U
2017_03_31_test_02_02	29.94	24.79	22.81	65.02	1.20	0.59	5.03	0.95	0.19	U
2017_03_31_test_03_01	30.22	24.85	22.96	65.58	1.20	0.65	4.97	0.02	0.00	U
2017_03_31_test_03_02	29.80	24.81	22.92	70.05	1.25	0.57	5.03	1.20	0.24	U
2017_03_31_test_03_03	30.49	24.82	22.92	74.92	1.28	0.51	5.01	1.89	0.38	U
2017_03_31_test_04_01	30.37	24.88	23.08	75.23	1.29	0.59	5.00	0.96	0.19	D
2017_03_31_test_04_02	30.02	24.85	23.04	69.98	1.25	0.54	5.01	1.57	0.31	D
2017_03_31_test_05_01	30.65	24.90	23.13	70.11	1.24	0.59	5.01	0.98	0.20	D
2017_03_31_test_05_02	29.45	24.90	23.13	64.72	1.20	0.58	4.98	1.02	0.20	D
2017_03_31_test_06_01	30.10	24.96	23.26	65.11	1.20	0.65	5.01	0.02	0.00	D
2017_03_31_test_06_02	29.51	24.92	23.25	59.33	1.15	0.62	5.02	0.48	0.09	D
2017_03_31_test_07_01	29.50	24.97	23.36	59.90	1.16	0.62	5.02	0.52	0.10	D
2017_03_31_test_07_02	29.55	24.97	23.37	55.30	1.11	0.64	5.00	0.22	0.04	D
2017_03_31_test_08_01	30.49	24.98	23.48	45.29	1.00	0.71	6.01	0.02	0.00	U
2017_03_31_test_08_02	29.51	24.97	23.48	49.79	1.05	0.71	6.01	0.02	0.00	U
2017_03_31_test_08_03	30.33	24.99	23.50	55.36	1.11	0.71	6.00	0.02	0.00	U
2017_03_31_test_09_01	29.98	25.01	23.61	60.11	1.16	0.65	6.04	1.02	0.17	U
2017_03_31_test_09_02	30.11	25.01	23.61	64.78	1.20	0.55	6.00	2.39	0.40	U
2017_03_31_test_10_01	30.14	25.02	23.72	70.22	1.25	0.52	6.03	2.83	0.47	U
2017_03_31_test_10_02	29.77	25.02	23.72	74.34	1.29	0.48	6.05	3.36	0.56	U
2017_03_31_test_11_01	29.81	25.06	23.86	74.83	1.29	0.51	5.99	2.96	0.49	D

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_03_31_test_11_02	29.56	25.06	23.83	69.62	1.25	0.51	5.99	2.95	0.49	D
2017_03_31_test_12_01	29.25	25.07	23.95	69.61	1.25	0.52	6.00	2.78	0.46	D
2017_03_31_test_12_02	29.89	25.07	23.93	64.80	1.20	0.56	6.00	2.27	0.38	D
2017_03_31_test_13_01	30.34	25.10	24.04	64.99	1.20	0.56	5.98	2.28	0.38	D
2017_03_31_test_13_02	30.27	25.10	24.05	59.75	1.15	0.62	5.99	1.46	0.24	D
2017_03_31_test_14_01	29.89	25.12	24.14	59.81	1.15	0.62	6.00	1.53	0.25	D
2017_03_31_test_14_02	30.92	25.13	24.16	55.11	1.10	0.68	6.00	0.59	0.10	D
2017_03_31_test_14_03	29.96	25.15	24.19	49.58	1.05	0.70	6.01	0.19	0.03	D
2017_04_03_test_31_01	29.66	25.92	24.87	45.38	1.01	0.77	6.93	0.02	0.00	U
2017_04_03_test_31_02	29.86	25.93	24.79	50.41	1.06	0.77	7.04	0.02	0.00	U
2017_04_03_test_31_03	30.14	25.98	24.75	54.74	1.10	0.77	7.00	0.02	0.00	U
2017_04_03_test_32_01	29.66	25.97	24.82	59.66	1.15	0.62	7.01	2.48	0.35	U
2017_04_03_test_32_02	29.83	26.00	24.79	64.73	1.20	0.54	7.00	3.63	0.52	U
2017_04_03_test_33_01	30.28	26.15	25.10	69.66	1.24	0.50	7.03	4.09	0.58	U
2017_04_03_test_33_02	31.52	26.16	25.11	73.98	1.27	0.49	6.97	4.19	0.60	U
2017_04_03_test_34_01	30.80	26.17	25.22	74.94	1.28	0.52	7.01	3.85	0.55	D
2017_04_03_test_34_02	30.36	26.19	25.14	69.53	1.24	0.48	7.00	4.25	0.61	D
2017_04_03_test_35_01	30.33	26.20	25.26	70.10	1.24	0.55	7.02	3.41	0.49	D
2017_04_03_test_35_02	30.21	26.19	25.14	64.64	1.20	0.53	7.03	3.77	0.54	D
2017_04_03_test_35_03	30.06	26.21	25.16	59.73	1.15	0.56	7.01	3.30	0.47	D
2017_04_03_test_37_01	30.74	26.28	25.41	59.80	1.15	0.63	7.04	2.43	0.34	D

Test Name	TS Pressure (psig)	T_fi [°C]	T_gi [°C]	Gas Inlet Flow rate [gps]	$K_{gi}^{1/2}$	$K_{fd}^{1/2}$	Q_{fi} [GPM]	Q_{fc} [GPM]	Carryover Fraction	Direction
2017_04_03_test_37_02	30.84	26.30	25.28	54.79	1.10	0.63	7.01	2.30	0.33	D
2017_04_03_test_37_03	30.45	26.33	25.27	49.70	1.05	0.71	7.00	1.01	0.14	D
2017_04_03_test_37_04	30.86	26.34	25.31	44.86	0.99	0.77	7.00	0.10	0.01	D

APPENDIX C

KUTATELADZE FLOODING CURVES

C.1 Kutateladze Curves for Data Collected in this Study

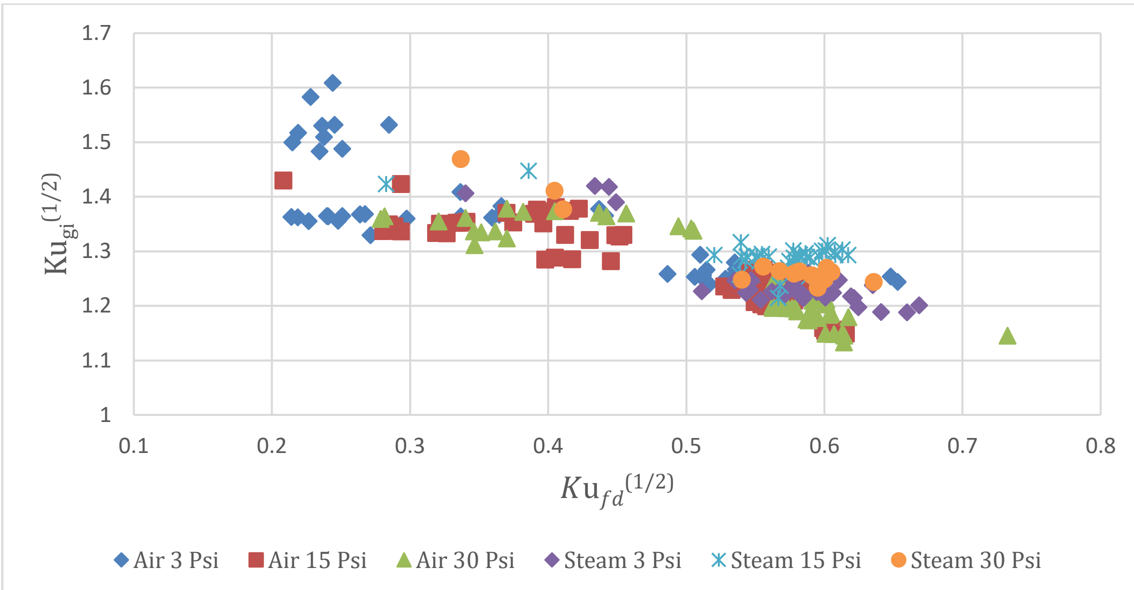

Figure C1: Complete flooding curve for data collected during this study.

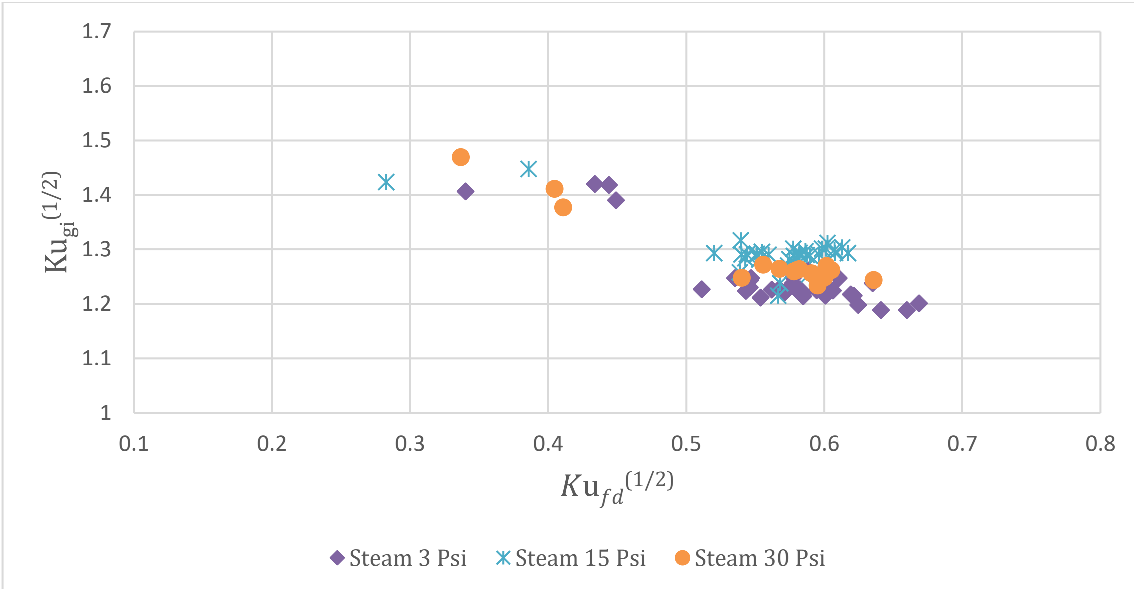

Figure C2: Complete steam data flooding curve for data collected for this study.

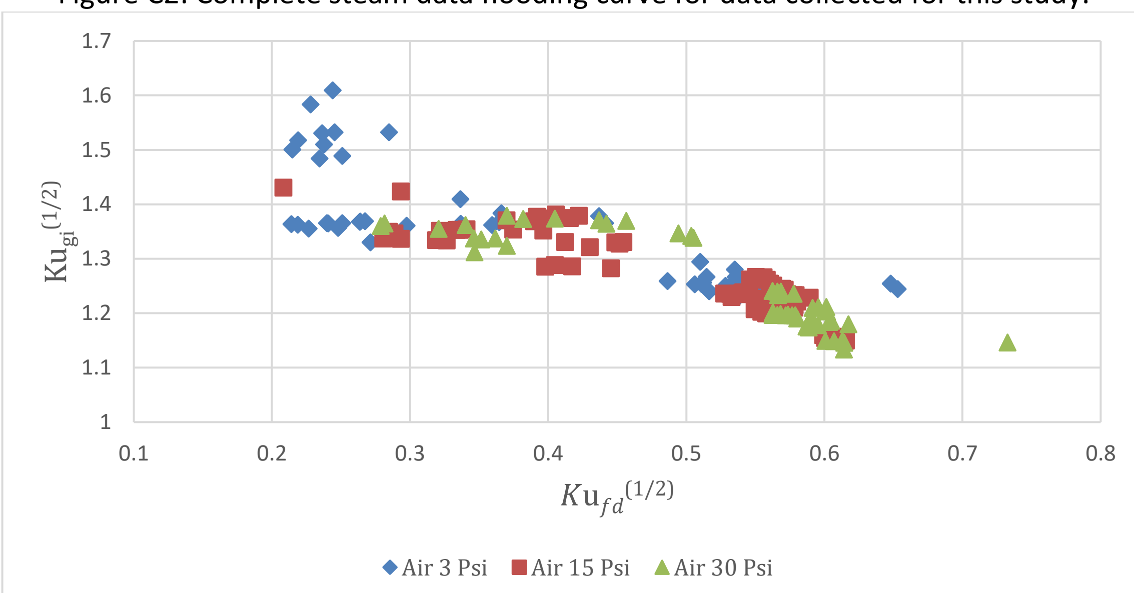

Figure C3: Complete air data flooding curve for data collected for this study.

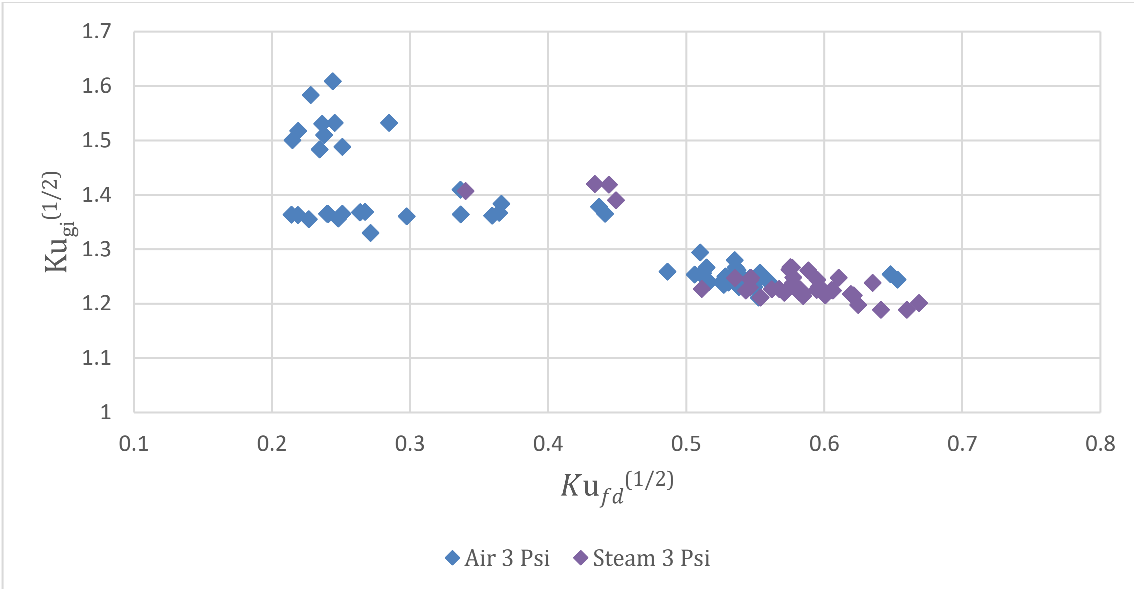

Figure C4: Ambient pressure steam and air flooding curve for data collected in this study.

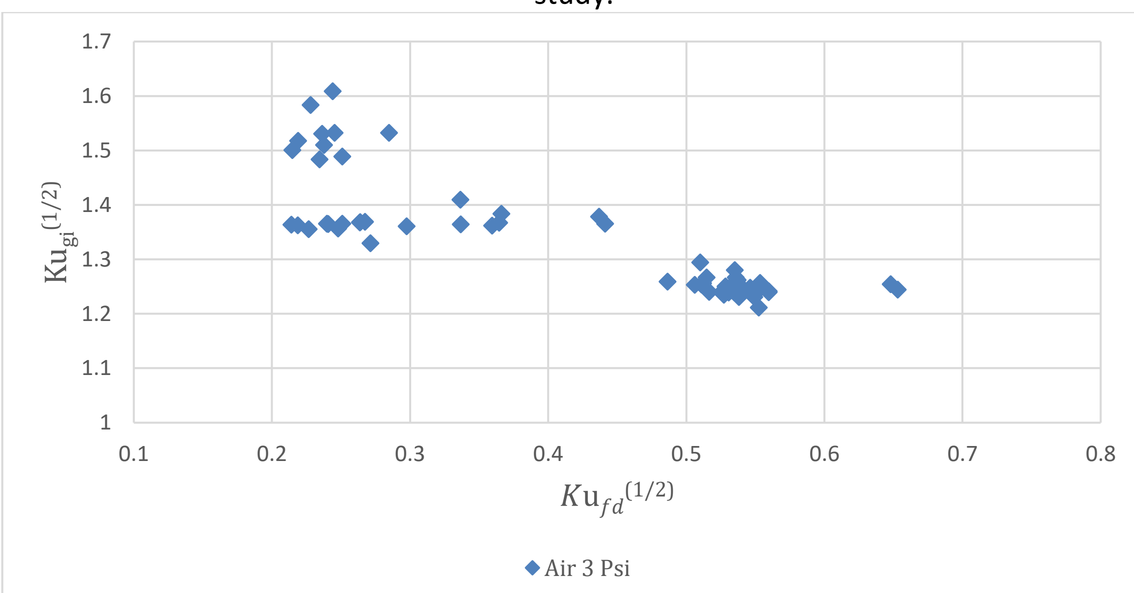

Figure C5: Ambient air flooding curve for data collected in this study.

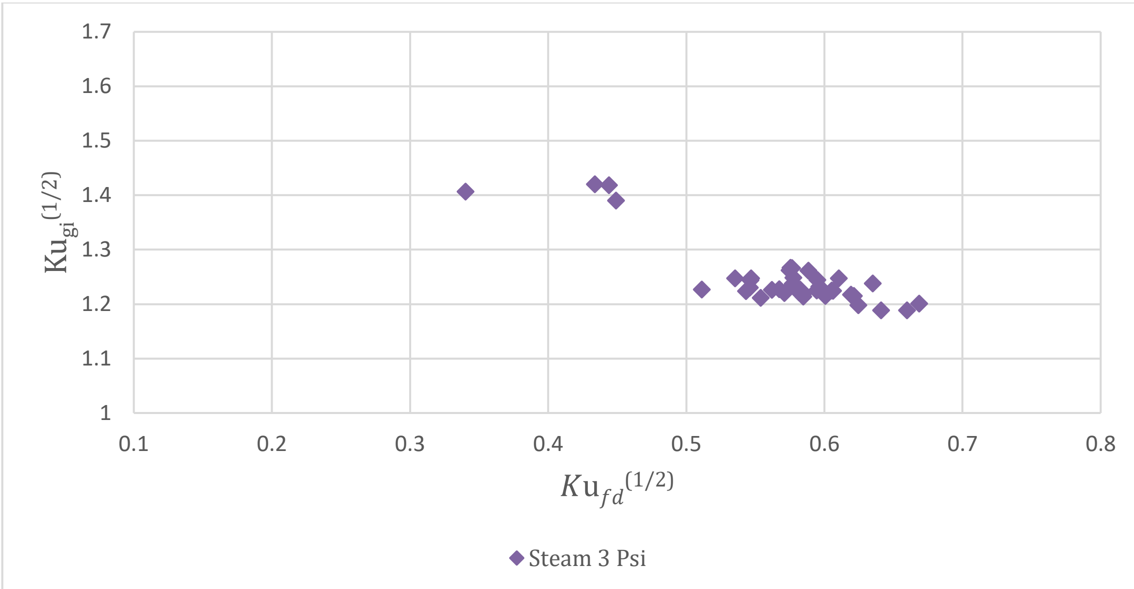

Figure C6: Ambient steam flooding curve for data collected in this study.

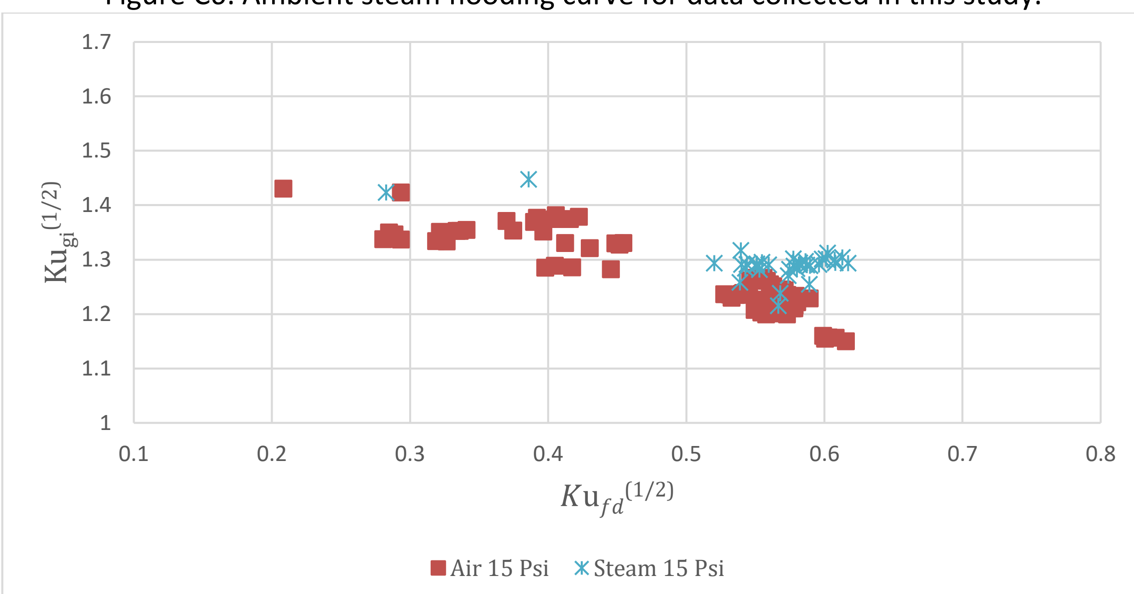

Figure C7: Air and steam flooding curves for 15 psig for data collected in this study.

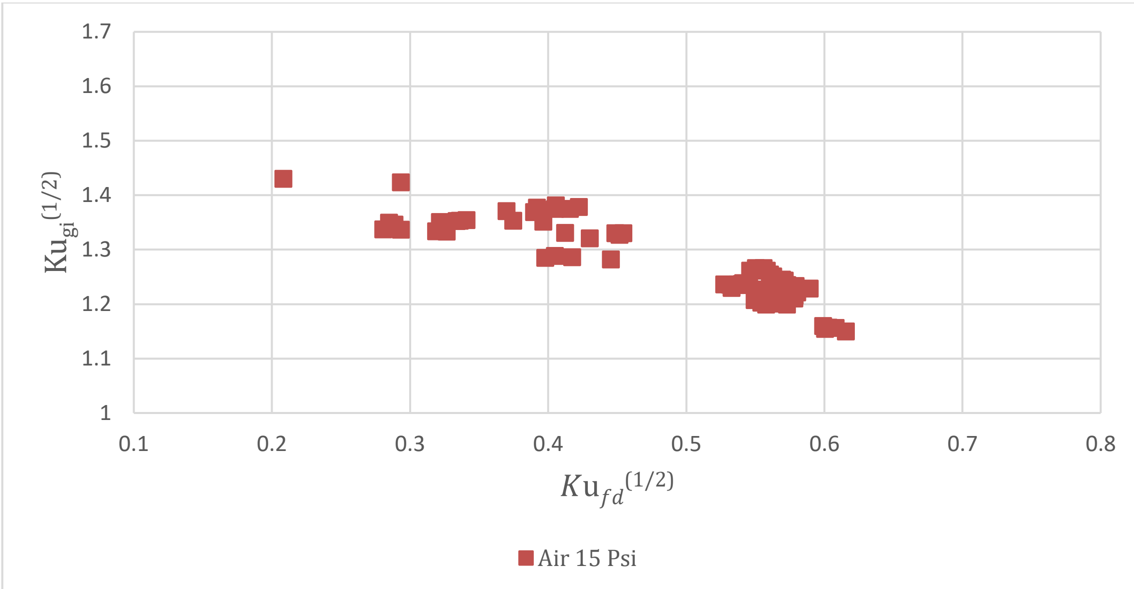

Figure C8: Air flooding curves for 15 psig for data collected in this study.

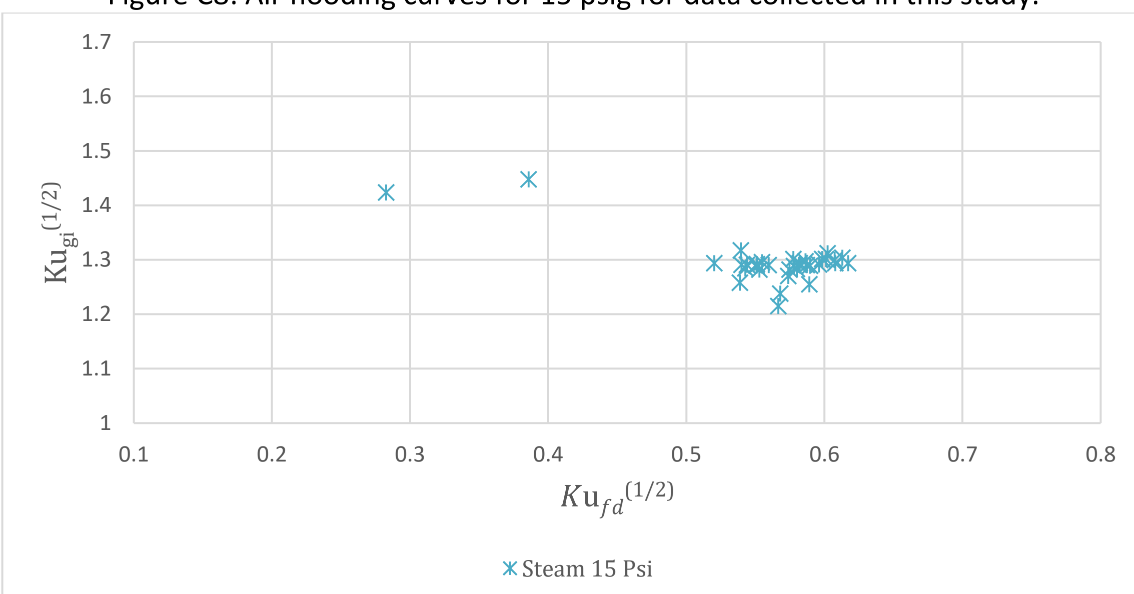

Figure C9: Steam flooding curves for 15 psig for data collected in this study.

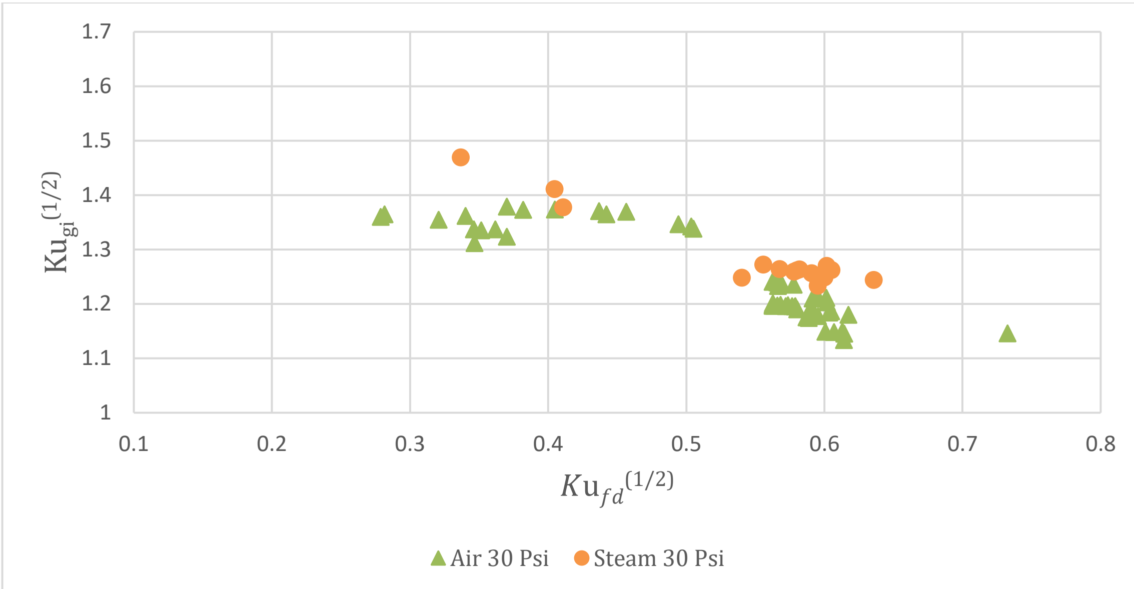

Figure C10: Air and steam flooding curves for 30 psig for data collected in this study.

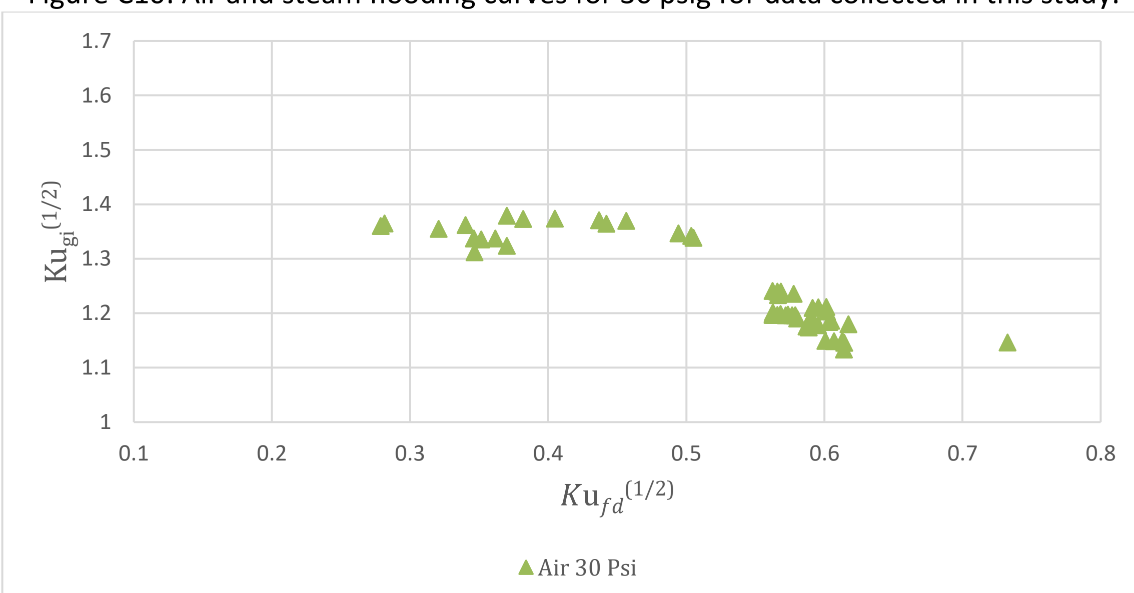

Figure C11: Air flooding curves for 30 psig for data collected in this study.

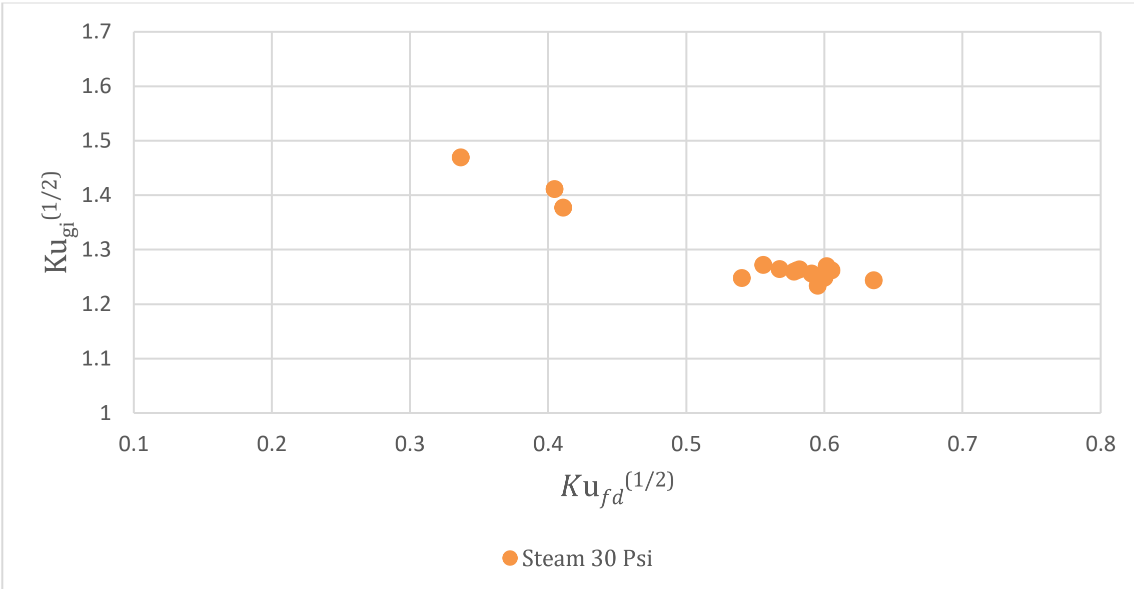

Figure C12: Steam flooding curves for 30 psig for data collected in this study.

C.2 Integrated Kutateladze Curves: Includes Wynne and Garza Data

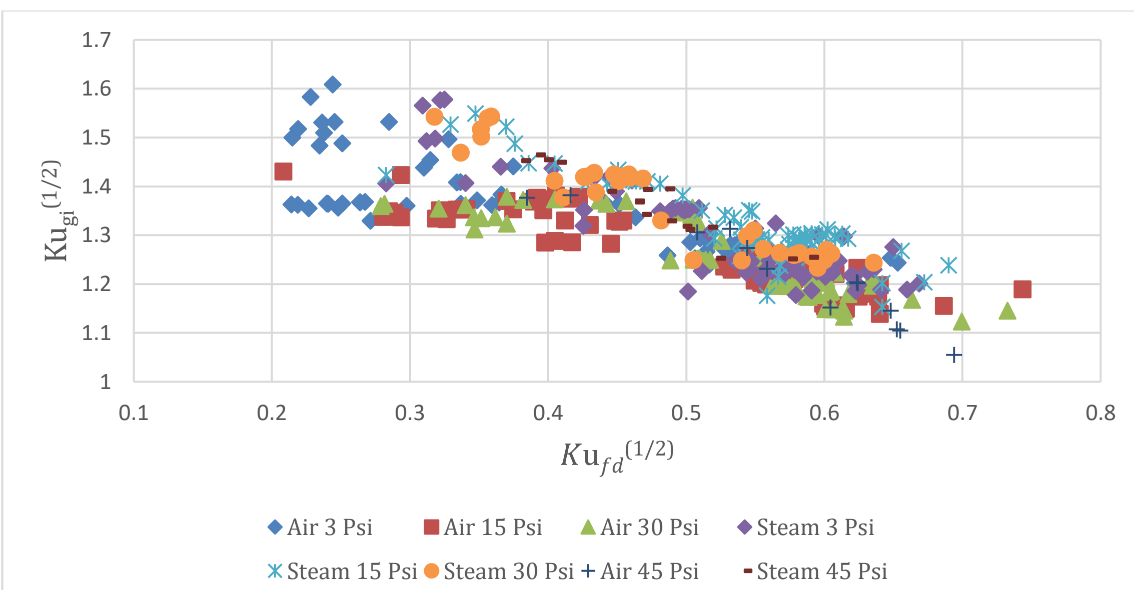

Figure C13: Complete integrated flooding curve.

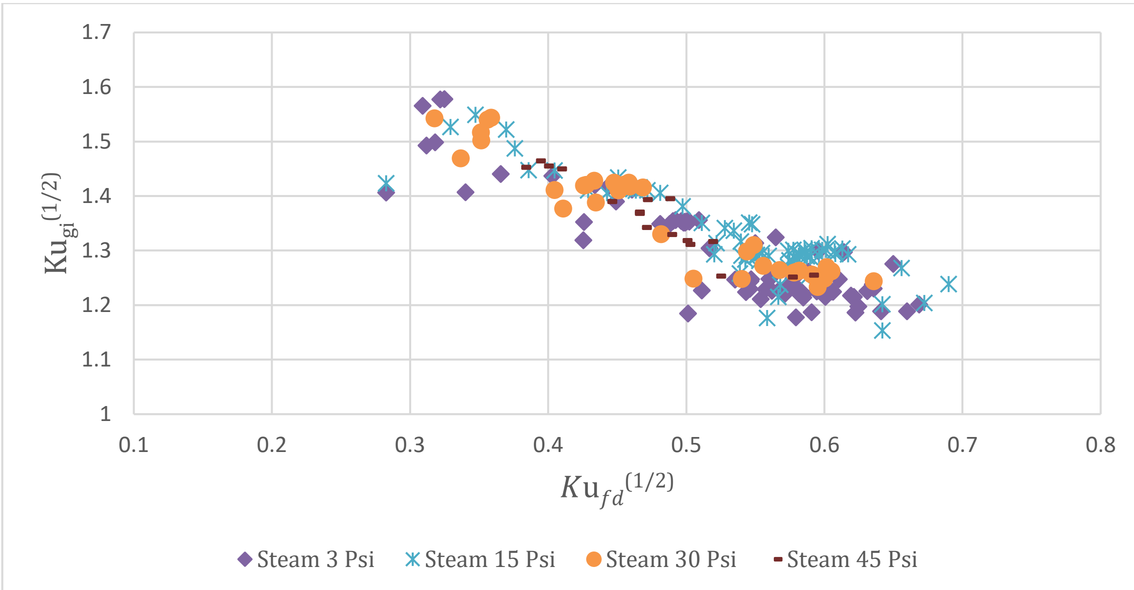

Figure C14: Integrated flooding dataset for steam.

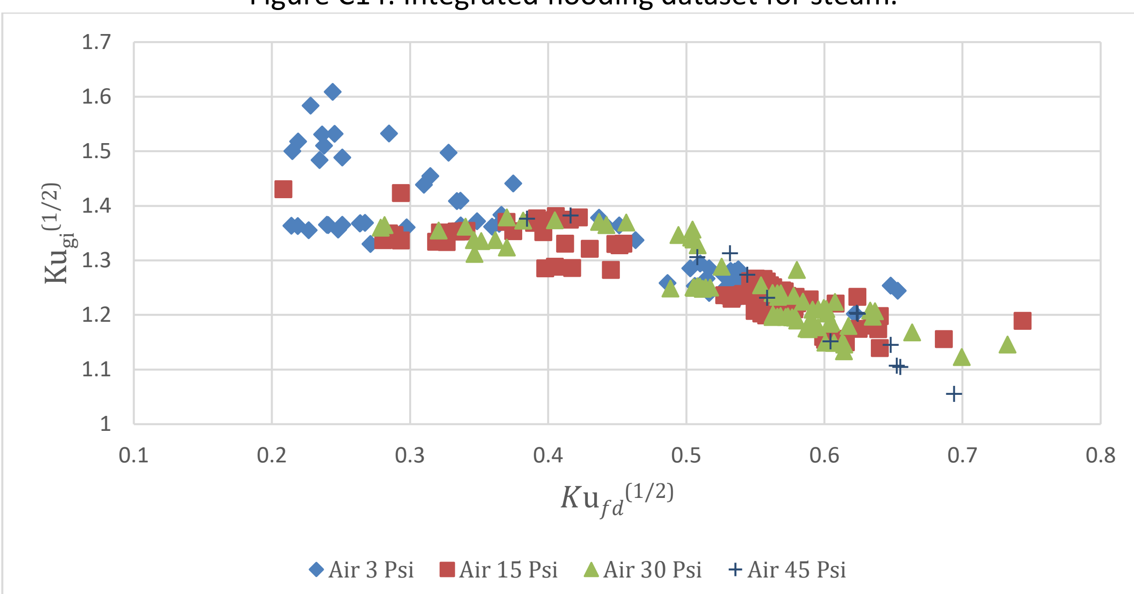

Figure C15: Integrated flooding dataset for air.

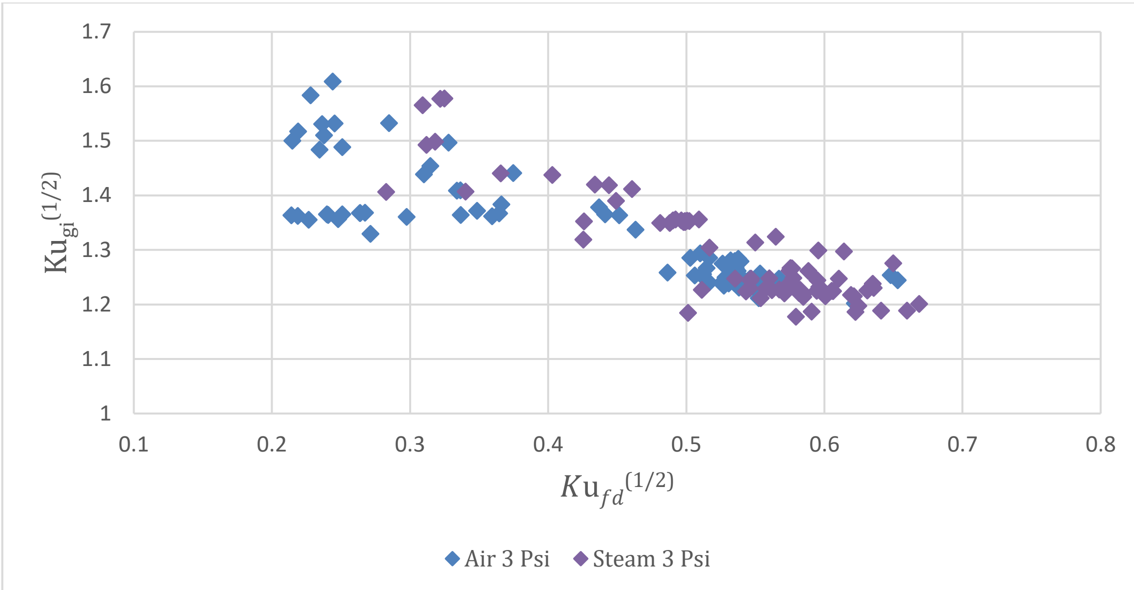

Figure C16: Integrated air and steam flooding curve for ambient pressure.

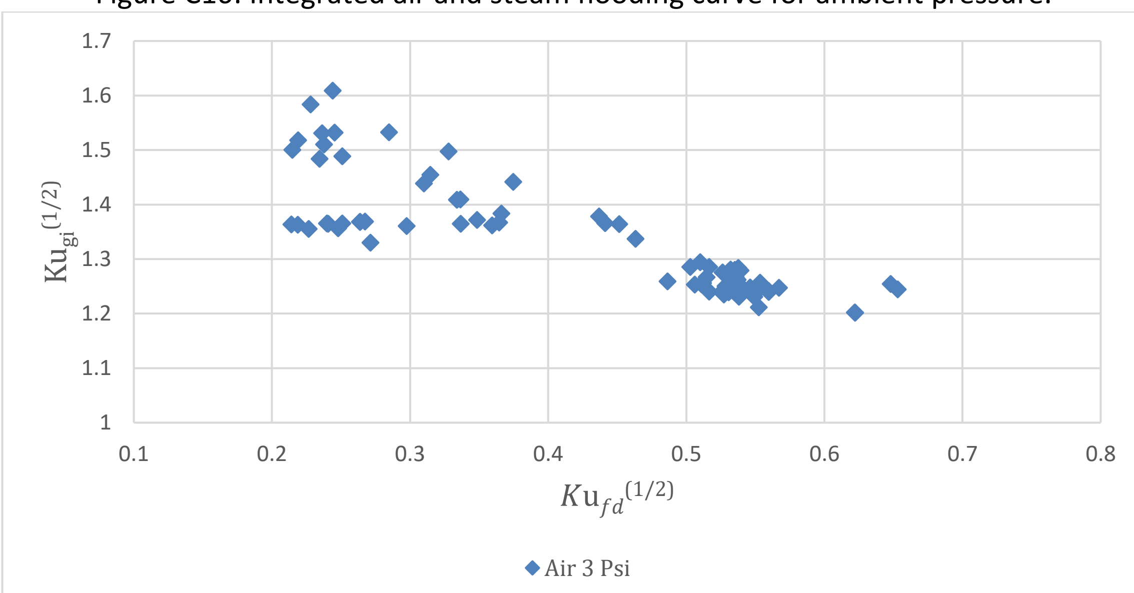

Figure C17: Integrated air flooding curve for ambient pressure.

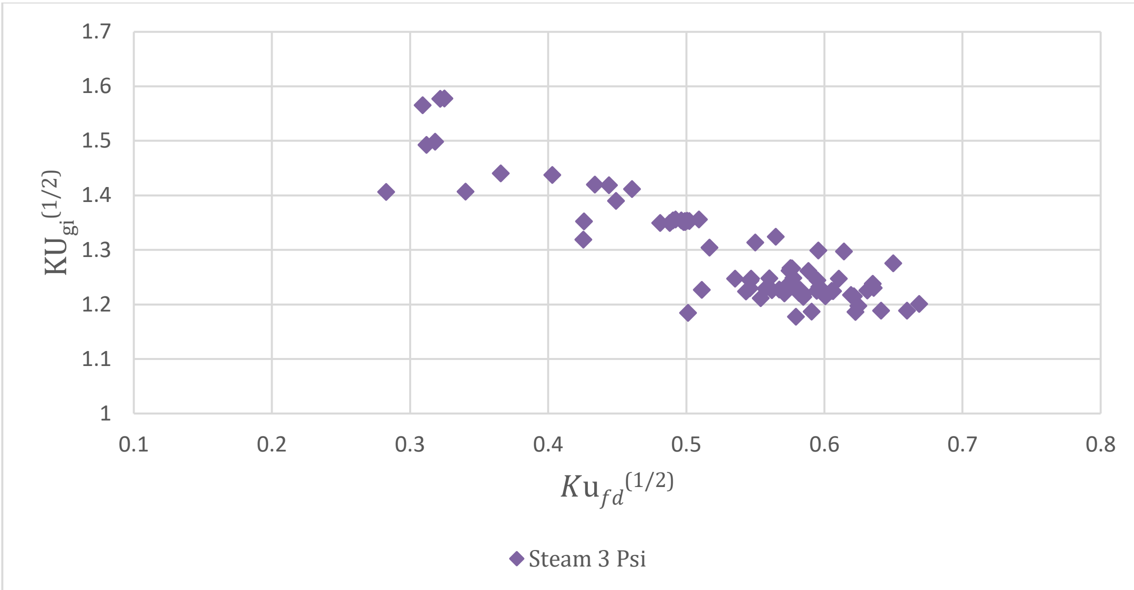

Figure C18: Integrated steam flooding curve for ambient pressure.

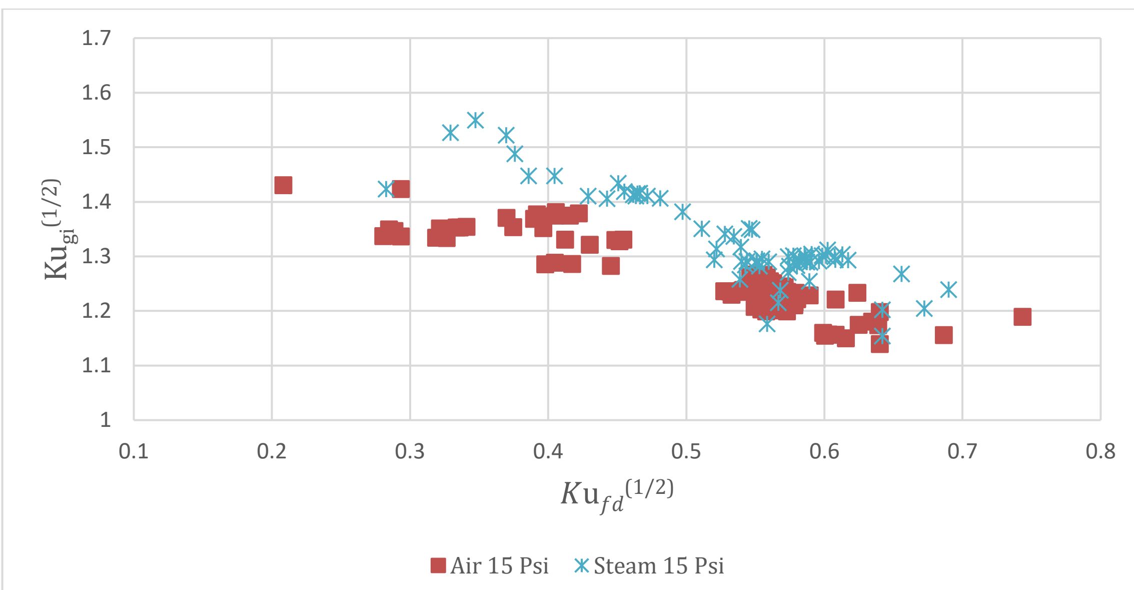

Figure C19: Integrated air and steam flooding curve for 15 psig.

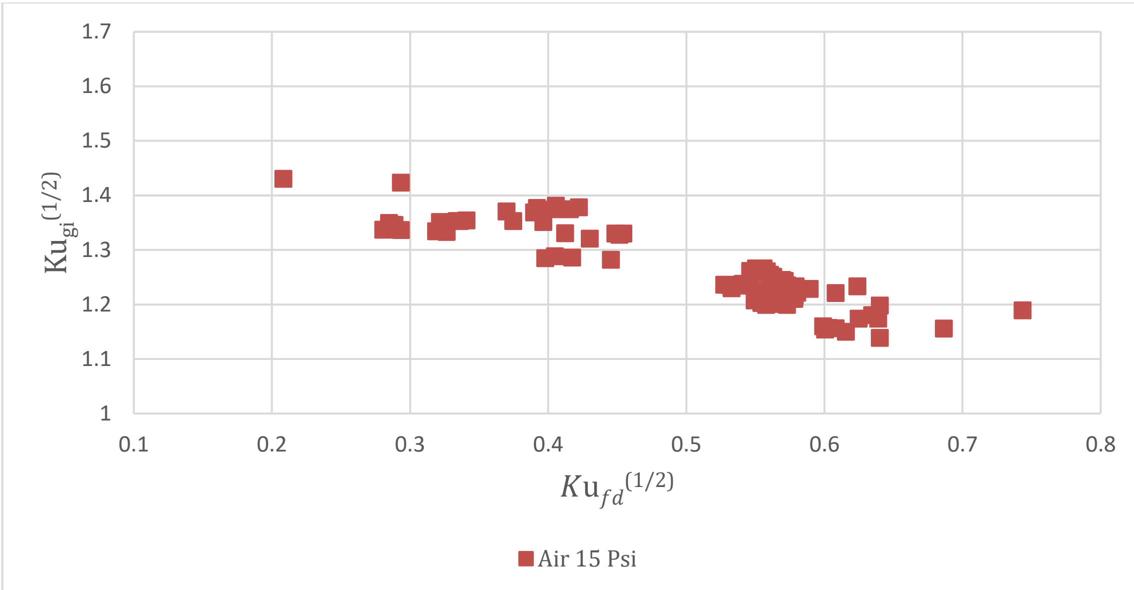

Figure C20: Integrated air flooding curve for 15 psig.

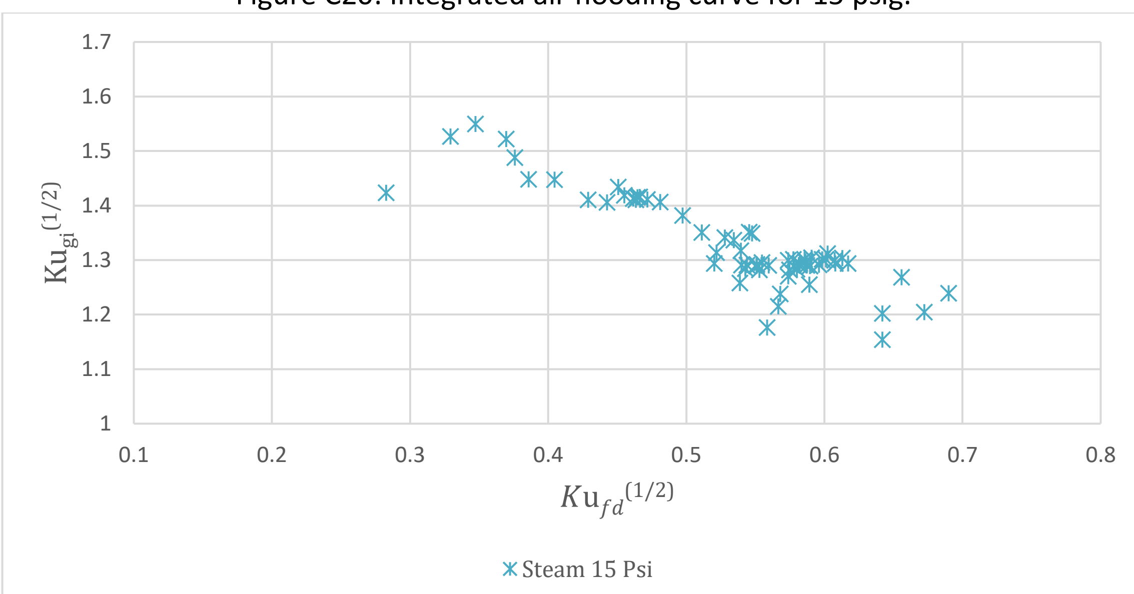

Figure C21: Integrated steam flooding curve for 15 psig.

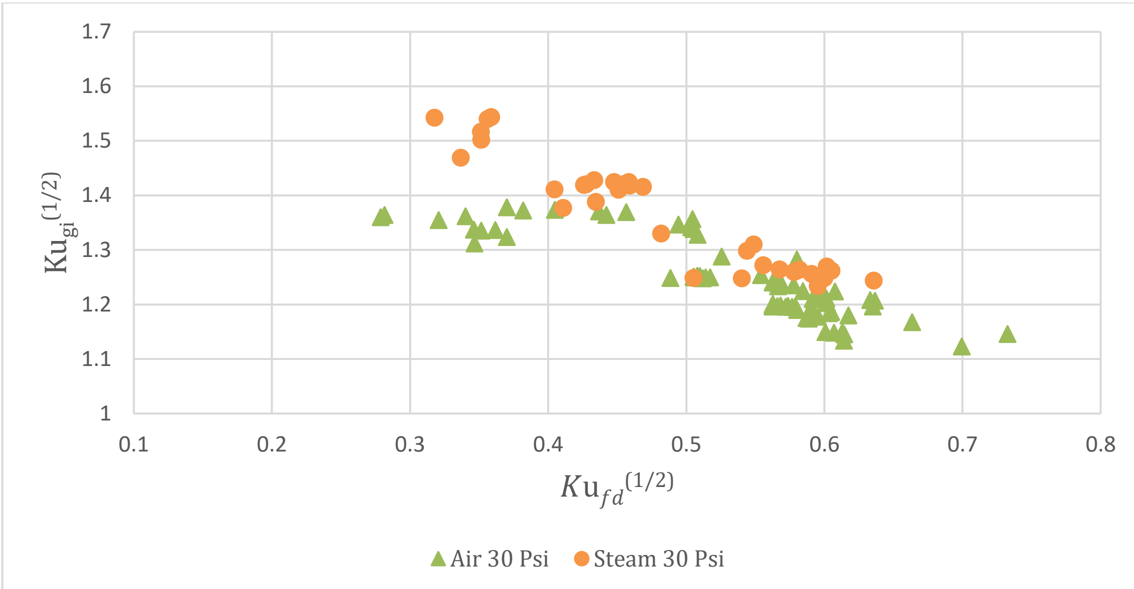

Figure C22: Integrated air and steam flooding curve for 30 psig.

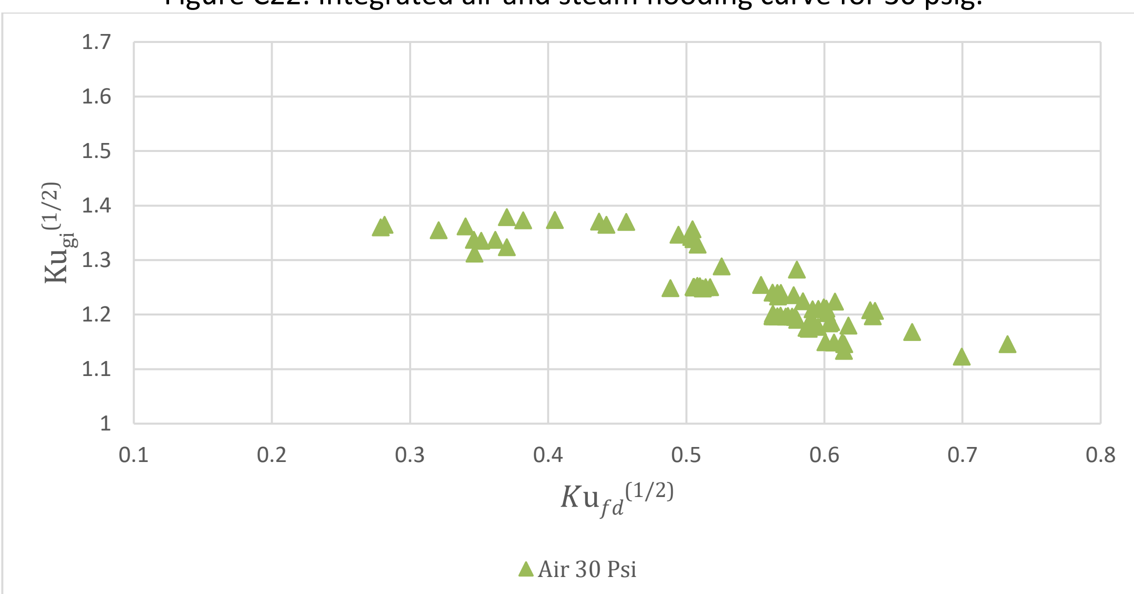

Figure C23: Integrated air flooding curve for 30 psig.

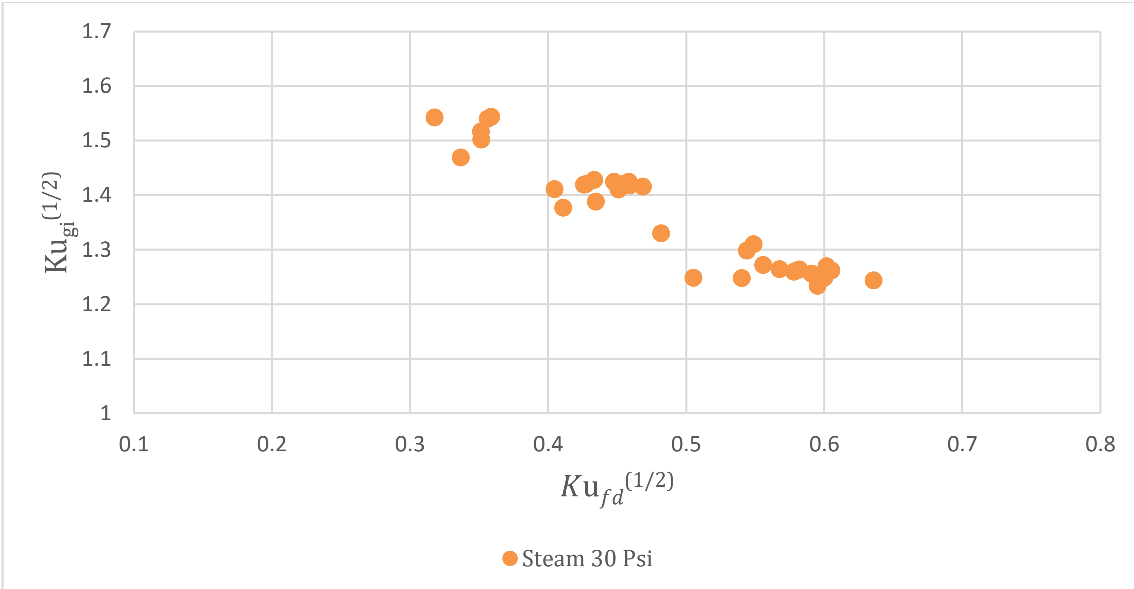

Figure C24: Integrated steam flooding curve for 30 psig.

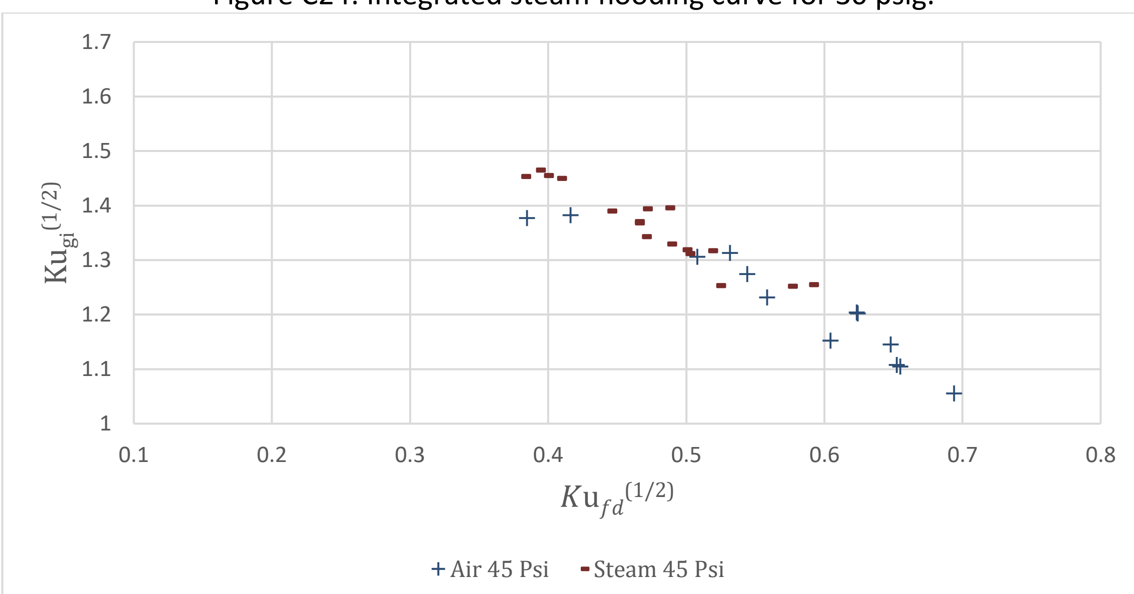

Figure C25: Integrated air and steam flooding curve for 45 psig.

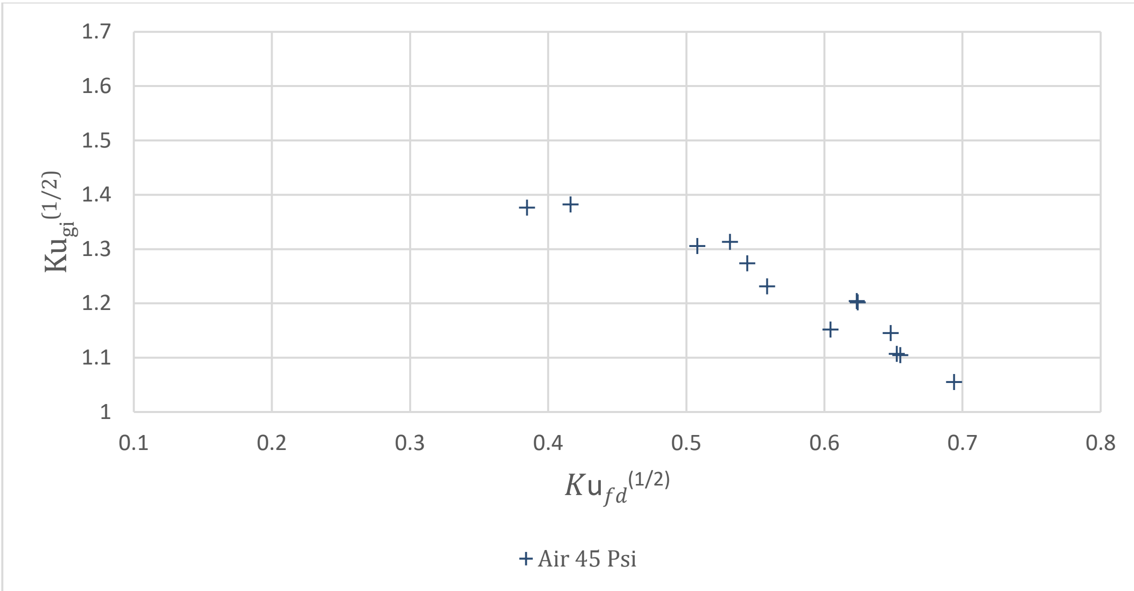

Figure C26: Integrated air flooding curve for 45 psig.

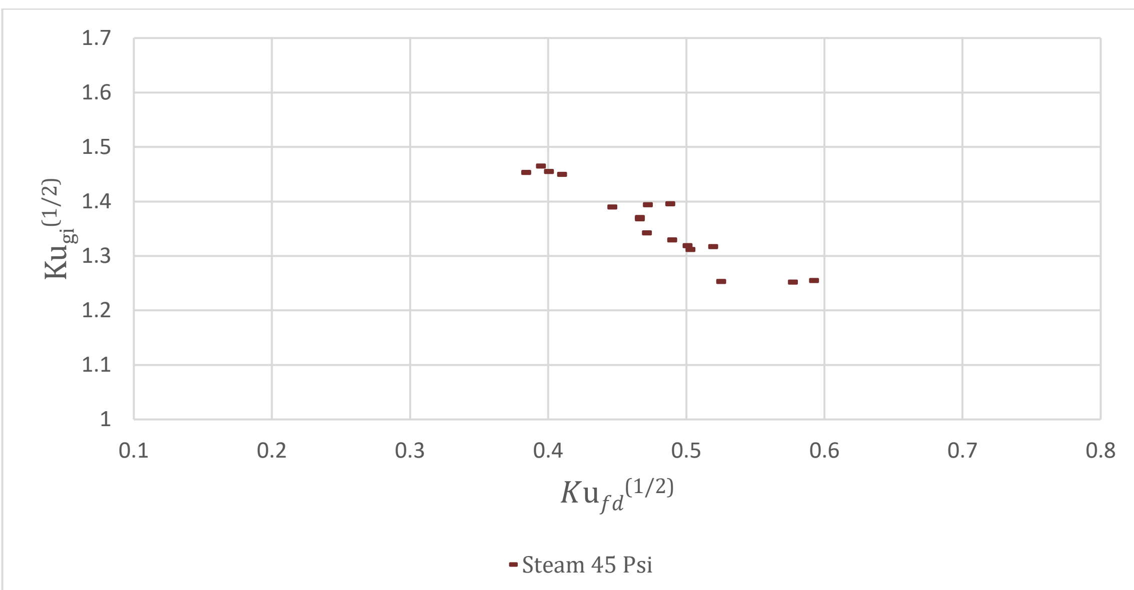

Figure C27: Integrated steam flooding curve for 45 psig.

APPENDIX D

FLOODING HYSTERESIS CURVES

D.1 Air/Water Hysteresis Curves

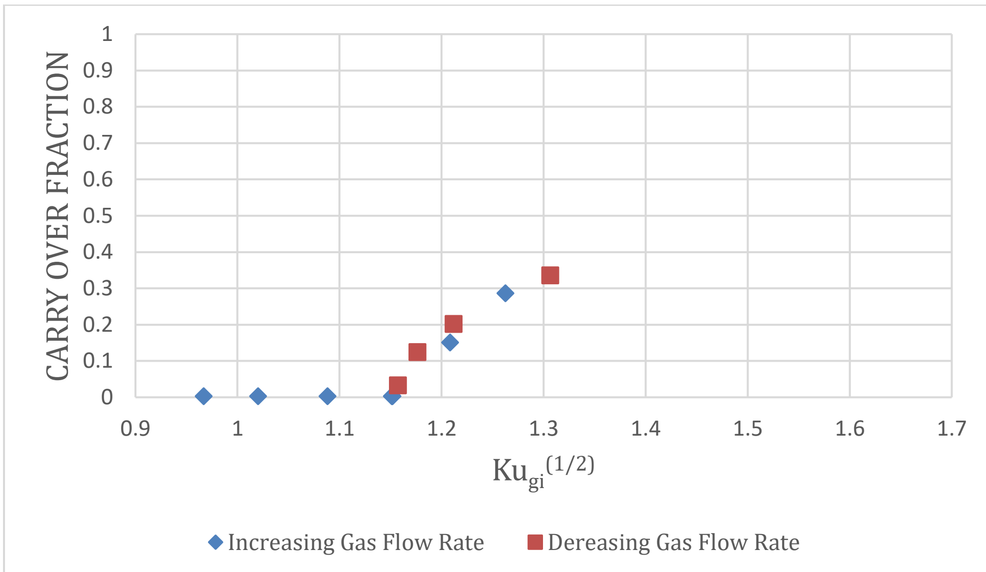

Figure D33: Hysteresis curve for air/water testing with a flow rate of 5.0 GPM at ambient pressure.

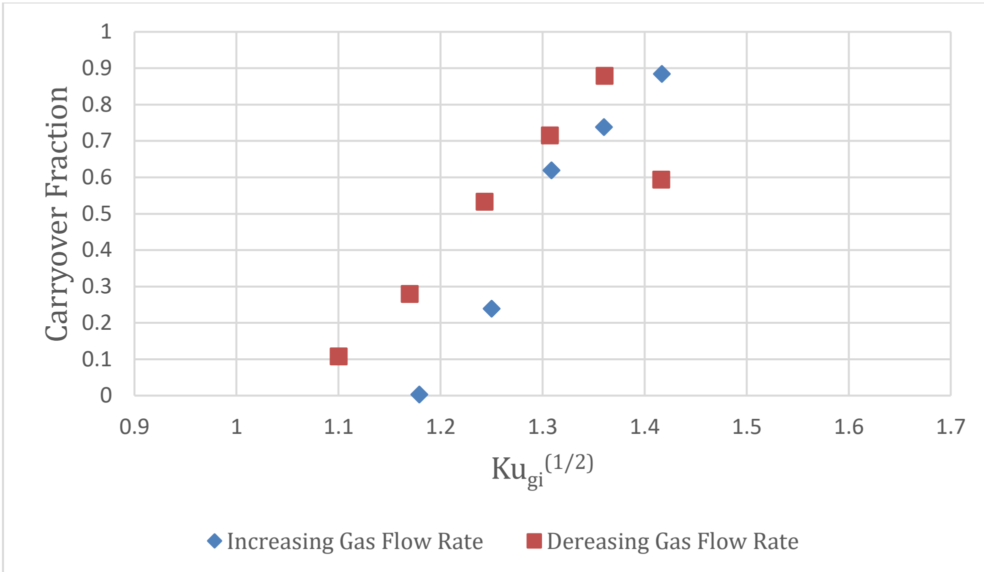

Figure D34: Hysteresis curve for air/water testing with a flow rate of 6.0 GPM at ambient pressure

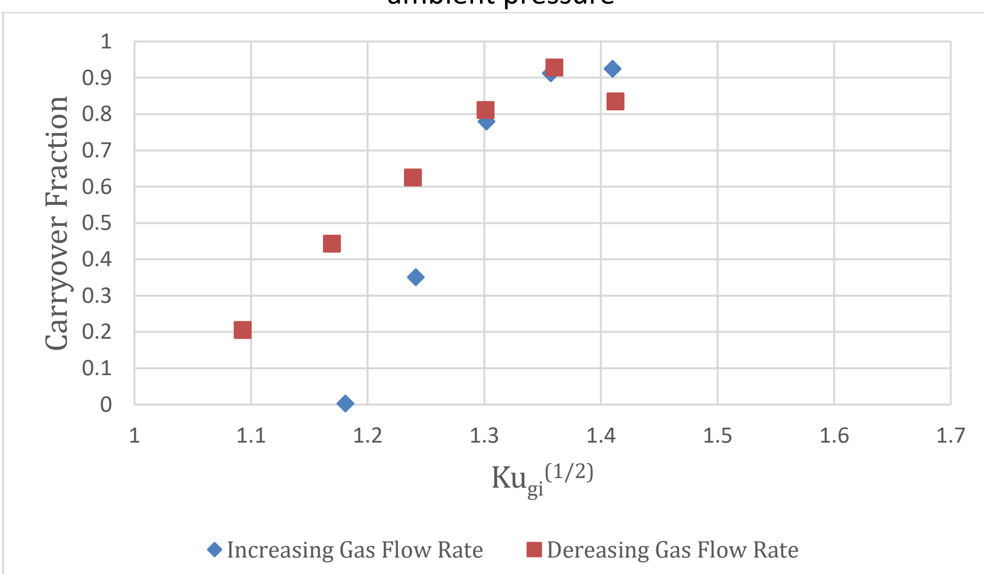

Figure D35: Hysteresis curve for air/water testing with a flow rate of 7.0 GPM at ambient pressure.

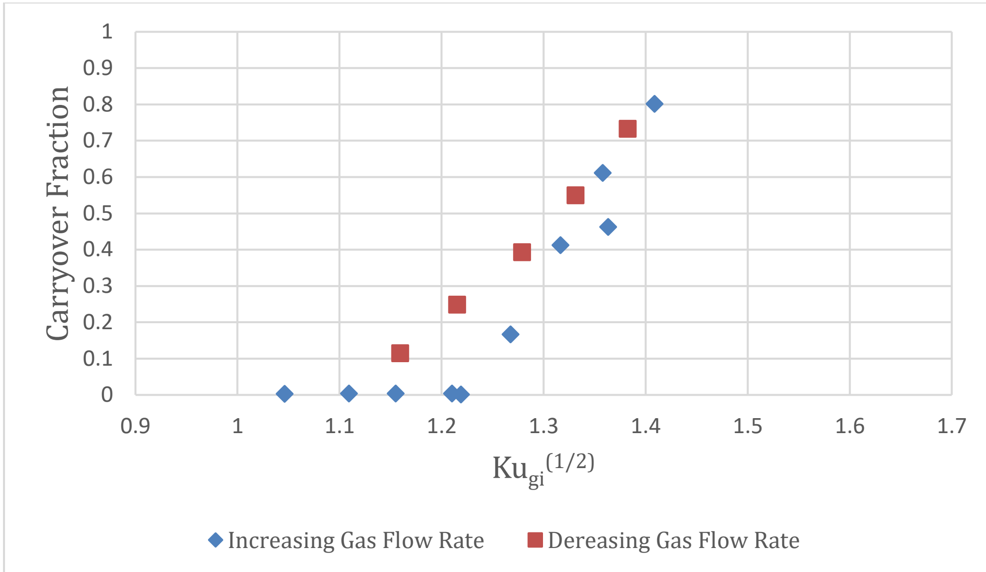

Figure D36: Hysteresis curve for air/water testing with a flow rate of 5.0 GPM at 15 psig.

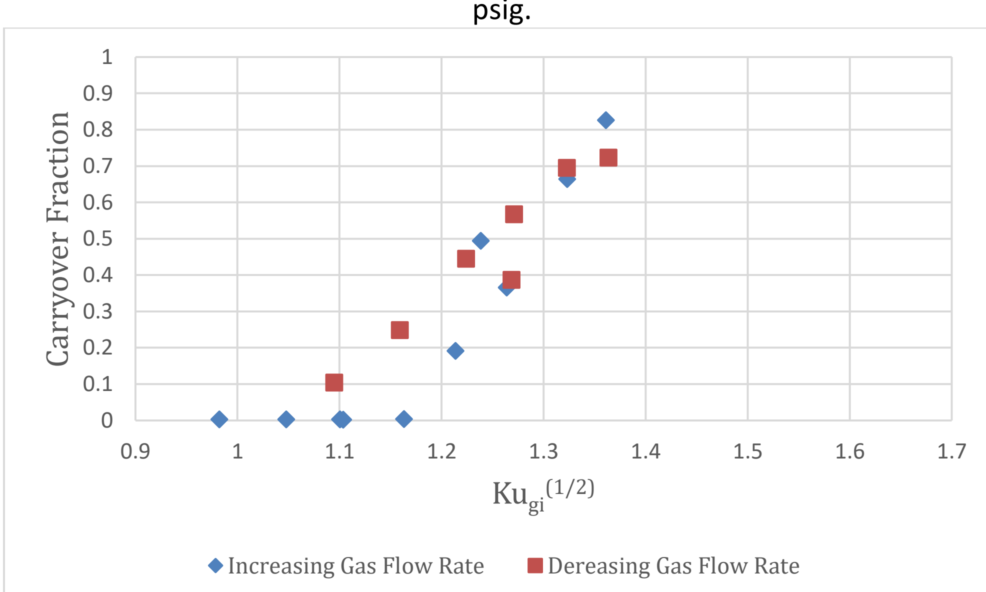

Figure D37: Hysteresis curve for air/water testing with a flow rate of 6.0 GPM at 15 psig.

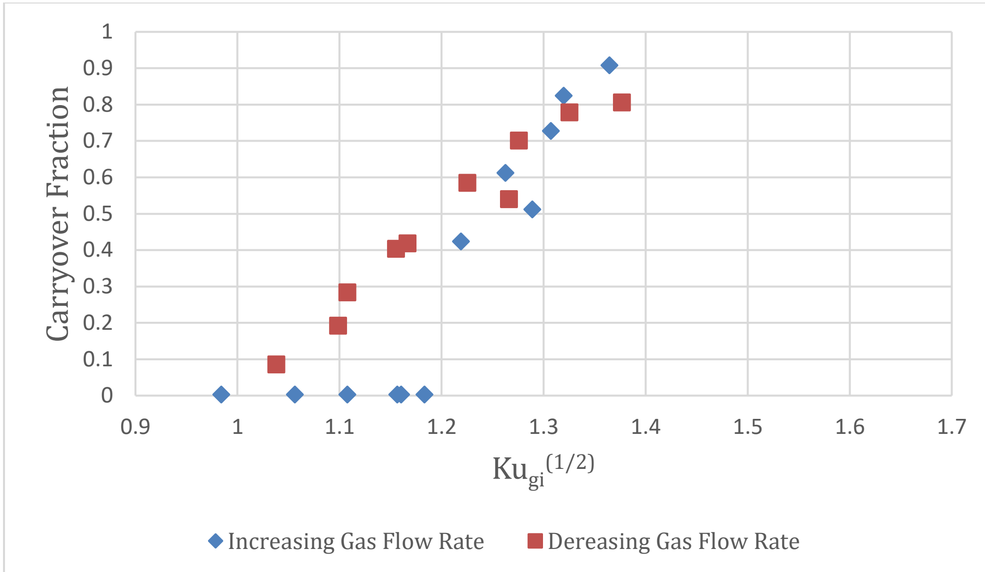

Figure D38: Hysteresis curve for air/water testing with a flow rate of 7.0 GPM at 15 psig.

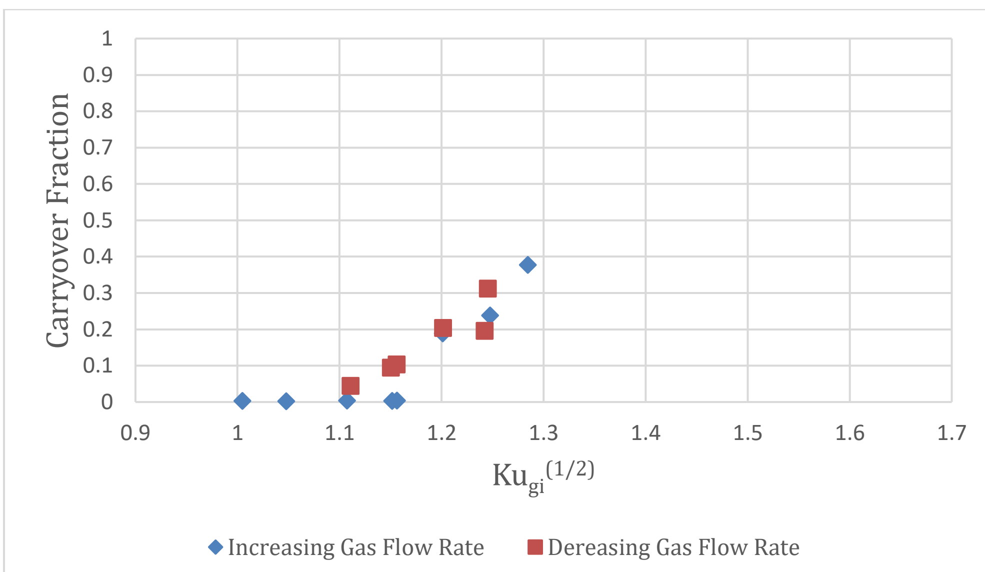

Figure D39: Hysteresis curve for air/water testing with a flow rate of 5.0 GPM at 30 psig.

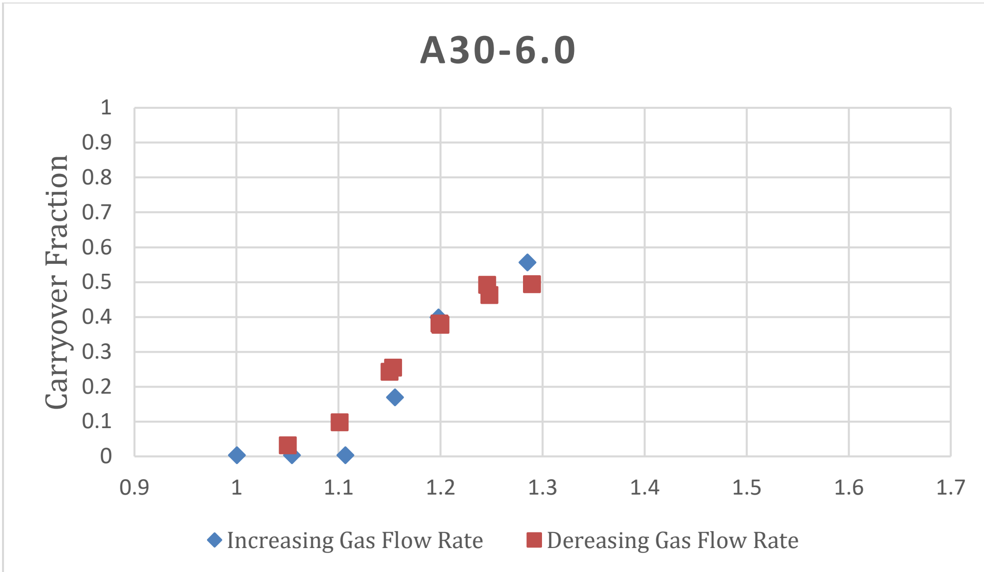

Figure D40: Hysteresis curve for air/water testing with a flow rate of 6.0 GPM at 30 psig.

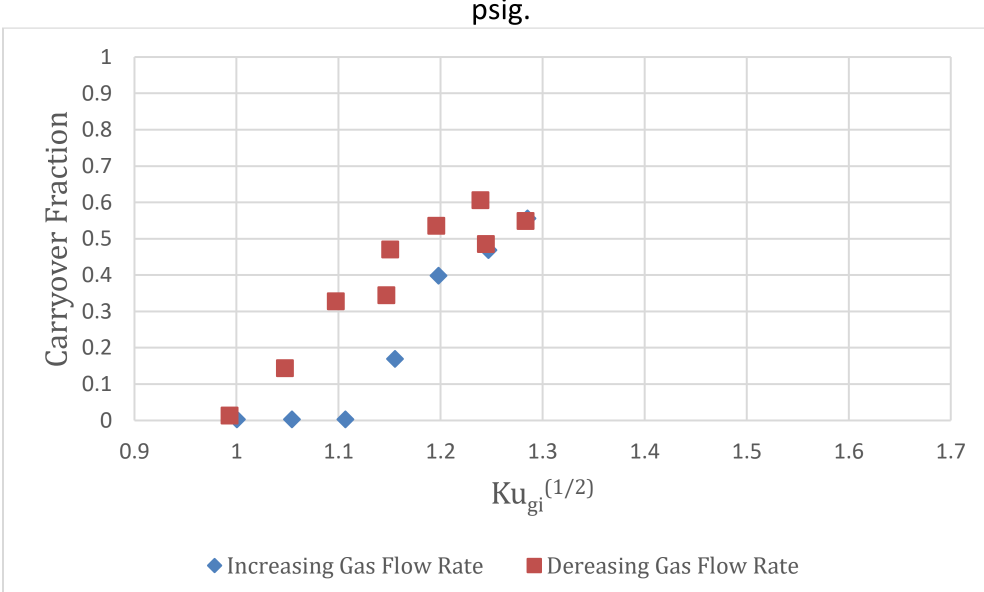

Figure D41: Hysteresis curve for air/water testing with a flow rate of 7.0 GPM at 30 psig.

D.2 Steam/Water Hysteresis Curves

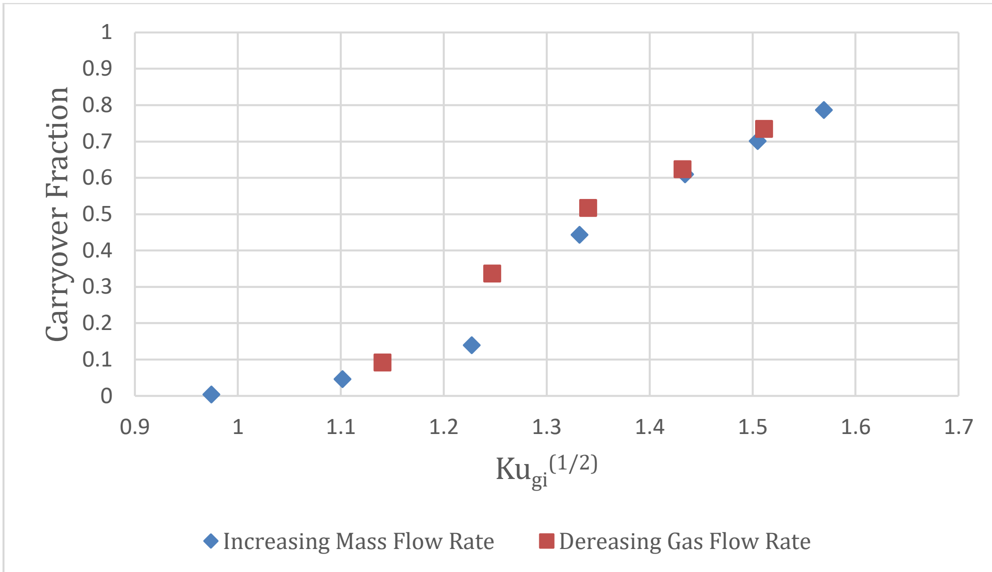

Figure D42: Hysteresis curve for steam/water testing with a flow rate of 5.0 GPM at ambient pressure.

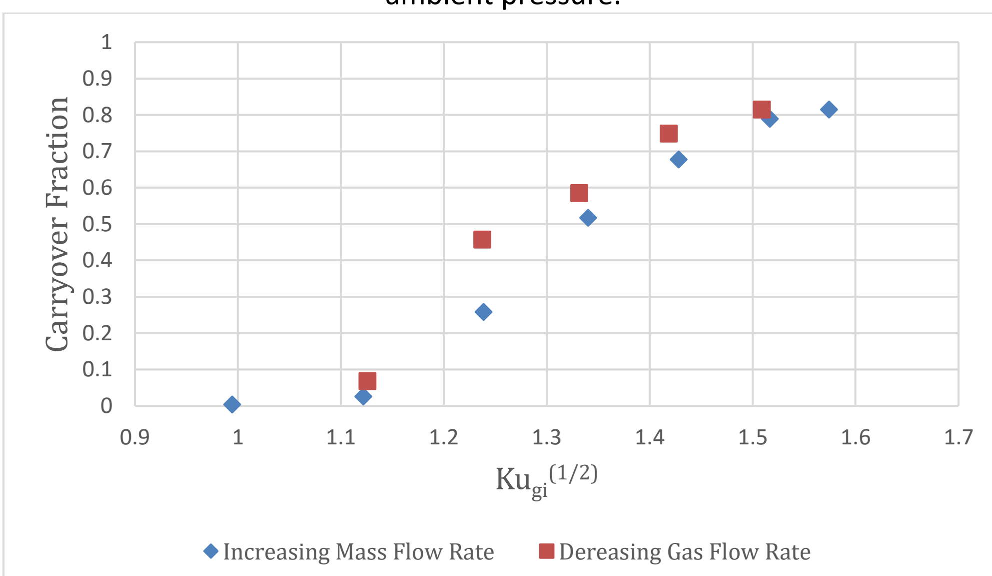

Figure D43: Hysteresis curve for steam/water testing with a flow rate of 6.0 GPM at ambient pressure.

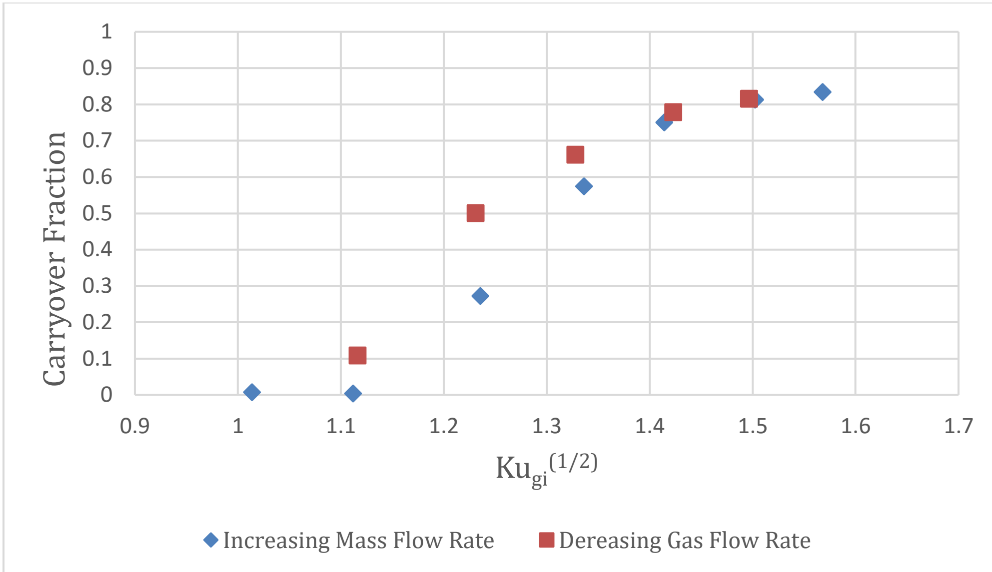

Figure D44: Hysteresis curve for steam/water testing with a flow rate of 7.0 GPM at ambient pressure.

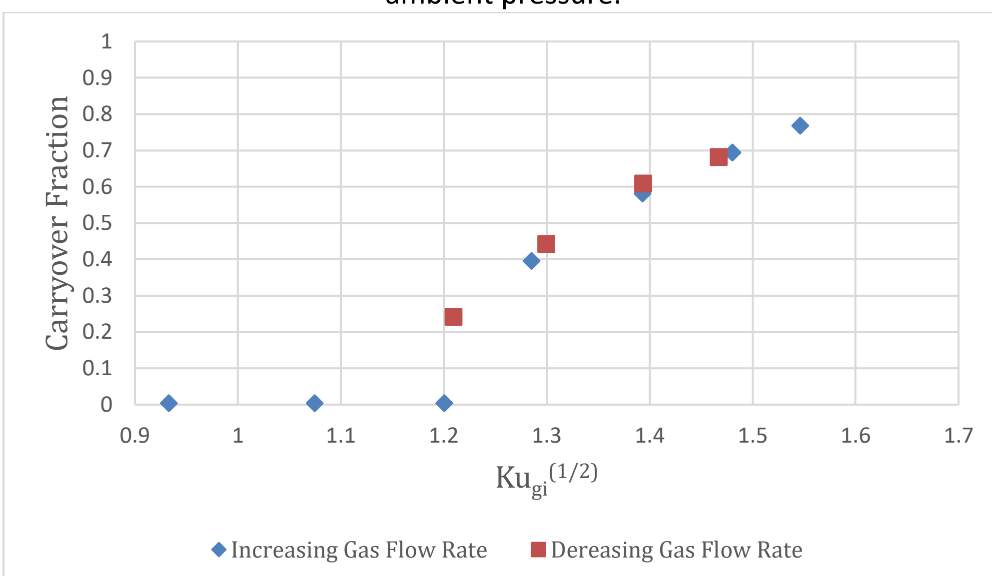

Figure D45: Hysteresis curve for steam/water testing with a flow rate of 5.0 GPM at 15 psig.

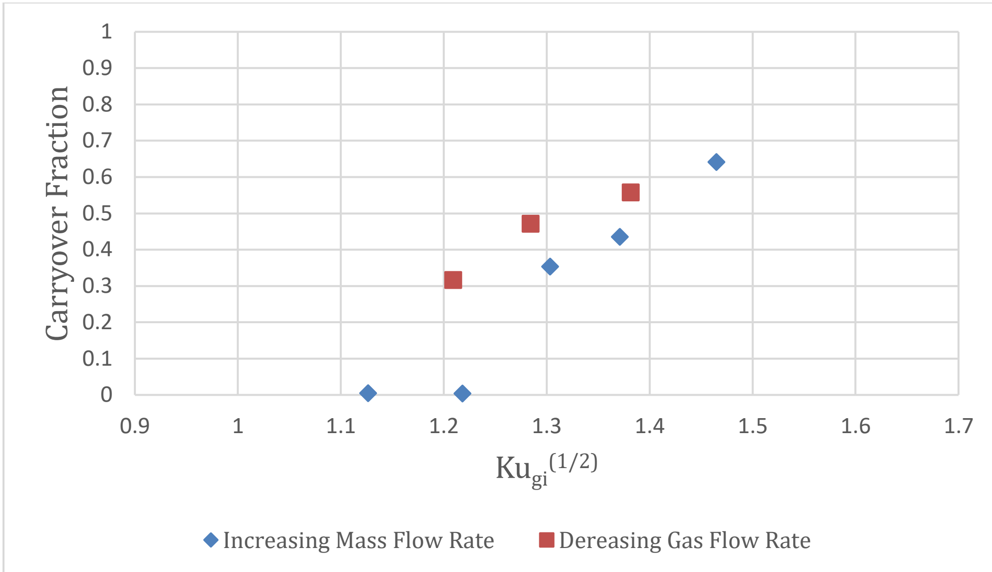

Figure D46: Hysteresis curve for steam/water testing with a flow rate of 6.0 GPM at 15 psig.

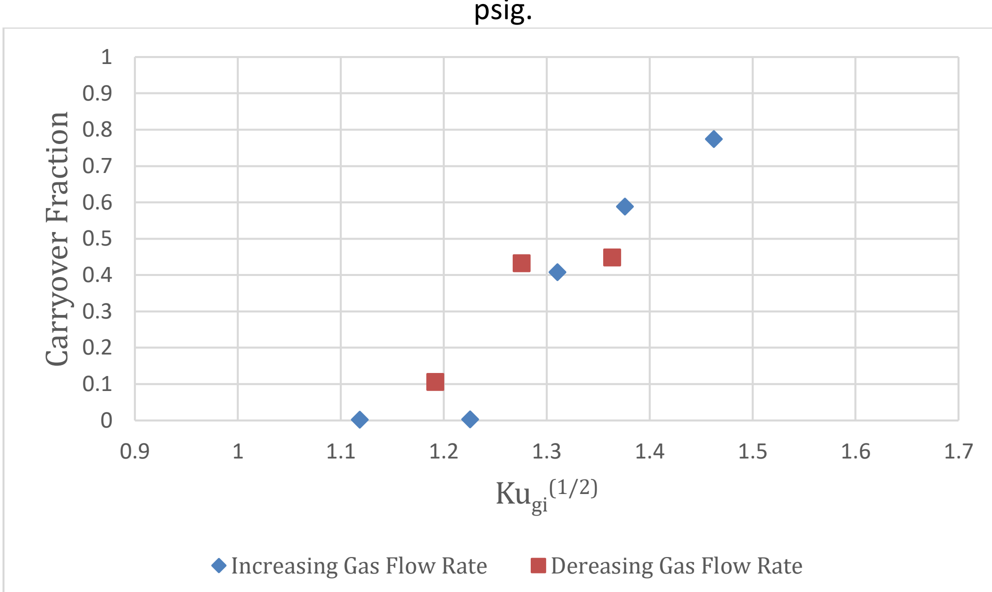

Figure D47: Hysteresis curve for steam/water testing with a flow rate of 7.0 GPM at 15 psig.

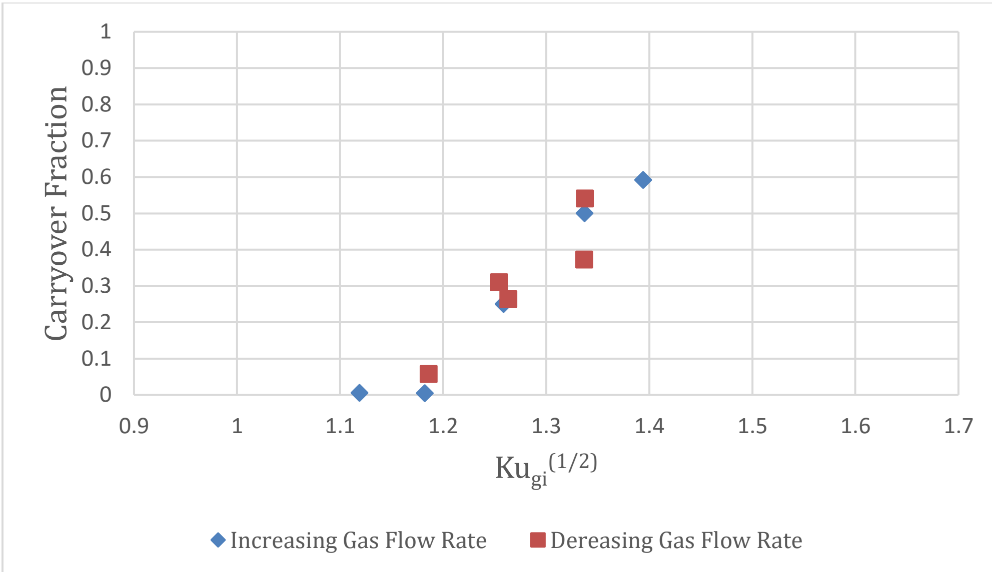

Figure D48: Hysteresis curve for steam/water testing with a flow rate of 5.0 GPM at 30 psig.

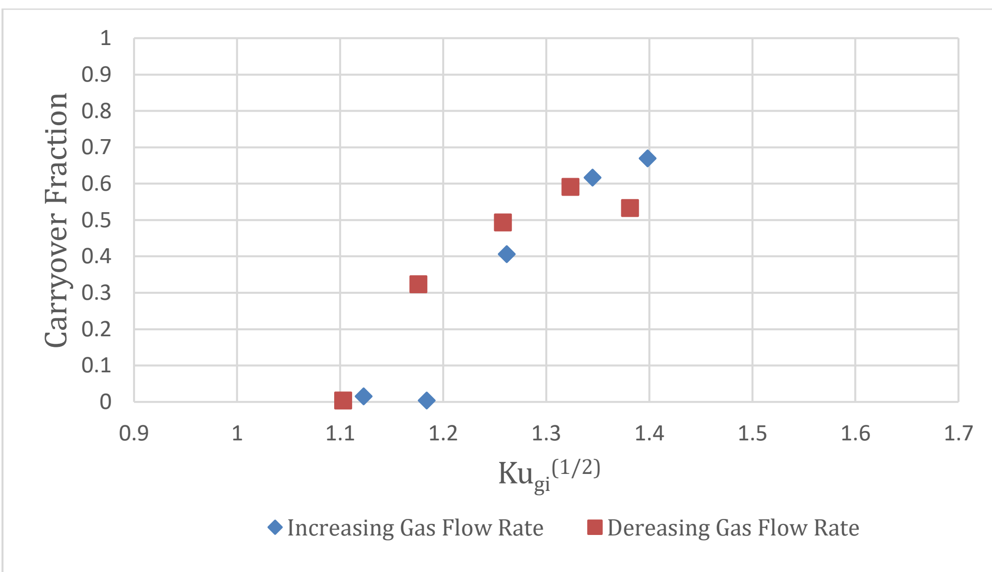

Figure D49: Hysteresis curve for steam/water testing with a flow rate of 6.0 GPM at 30 psig.

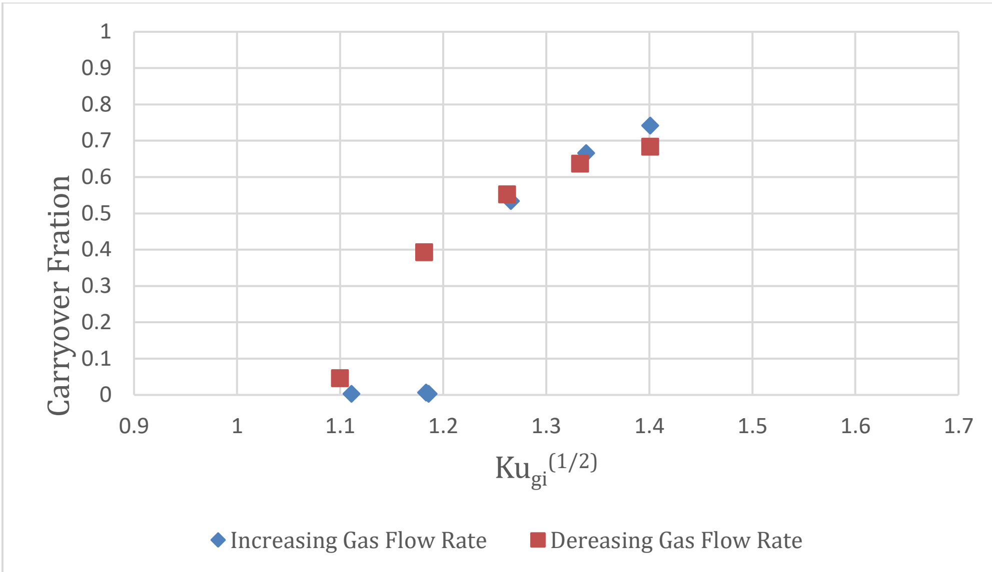

Figure D50: Hysteresis curve for steam/water testing with a flow rate of 7.0 GPM at 30 psig.

APPENDIX E

OPERATIONAL PROCEDURE

E.1 Data Acquisition System

The data acquisition system is used to record data and monitor facility conditions, while data may not be recorded the data acquisition system should always be operating if the facility is being operated.

1. Startup and/or login to data acquisition computer.*
2. Power ON the remote monitor near the throttle valve.*
3. Power ON the remote monitor near water flow control valve. *
4. Open *D:\...\SteamFlooding_Version5.vi* for steam/water tests. *

   Open *D:\...\AirFlooding_Version4.vi* for air/water tests. *
5. Turn ON the DC power supply, verify that the voltage displays 24.0 V.
6. Turn ON the National Instruments SCXI chassis. *
7. Click “Run” button in LabVIEW’s top ribbon bar to start actively monitoring the facility. *
8. Verify that the instruments are reporting expected values if irregularities are present identify and correct the error. *
   a. The test section differential pressure transmitter should output 55.75 inches H_2O with ± 5% while no gas or water is flowing. * If the

displayed output is outside this range purging of the lines will be necessary, refer to section E.13 for instructions. *

b. The outlet gas vortex flow meter needs to be set for the appropriate gas being used f the meter is not set for the appropriate gas the density, temperature, and viscosity must be changed directly on the flow meter panel. * The appropriate fluid parameters for steam and air and instructions are marked in the Foxboro user manual. *

9. Fill in the filename with the appropriate date and test number for the data to be recorded. *
    a. The naming scheme used for this work follows that presented by Garza and is *"YYYY_MM_DD_Test_##.dat"*.
10. Turn the Write Data toggle switch on the LabVIEW front panel to "YES". *
11. Select the "START" button on the LabVIEW front panel to begin writing data to the file. *
12. After completing a test select the "End Execution" button on the front panel to end data recording, this will stop/freeze the LabVIEW front panel.*
13. Select the "Run" button on the top ribbon to allow monitoring of the facility.
14. Repeat steps 9-14 for subsequent testing.

*Obtained from Wynne thesis [6].

E.2 Air Supply Operation

An air compressor is used to supply air flow for air/water testing. To increase the volume of air available, the steam generator should be drained of most of the water, refer to Section E.11 for the procedure on how to properly drain the steam generator. When pressurizing the steam generator with air, slow pressurization should occur and best done together with pressurization of the air compressor.

1. Turn the refrigeration dryer switch to ON at least 5 minutes before turning on the air compressor to ensure that the piping is free of condensate. *
    - Dryer must always be ON when the compressor is in use. *
2. Plug in the electric drain valve. *
    - The condensate filter of the auto drain must be inspected and cleaned once a month. For periods of heavy use double, the maintenance frequency. *
    - Condenser fins must be inspected and cleaned once a month. *
3. Inspect the air compressor for any visual obstructions and issues. Verify that all guards and shields are locked in place. *
4. Visually inspect the drive belt checking to see that it is free of cracks, frays, and tears. *
    - Every 160 hours' tension of the belts must be checked; a belt tension gauge is supplied. *
5. Verify that the isolation valves leading up to the pressure regulator are open.
6. Verify that the air hose valve, V-89, is closed. *

7. Open the steam generator isolation valve, V-90. *
8. Verify that the throttle valve, V-1, is closed.
9. Verify that the steam generator vent, V-16, is closed.
10. Close the vacuum breaker valve, V-13. *
11. Turn on the 30A breaker in the 480 VAC electrical panel to ON to start the compressor. *
12. Before pressurizing ensure that the regulator is set to less than 110 psig. The steam generators pressure release valves will activate at 135 psig. *
13. Monitor the air compressor and steam generator pressure during initial pressurization.
    - The air compressor is set to turn off at 175 psig automatically. *
    - After initial pressurization, it is common to hear air hissing out of the air compressor for a short time. This is due to air exiting the regulating valve and usually lasts a few minutes. *
    - The electronic drain valve will vent condensate every 45 minutes. *
14. After initial pressurization has finished check that the lubricant level is within the high/ low-level marks on the dipstick.
    - If lubricant is below the low-level mark drain and replace, refer to user manual for replacement oil instructions, capacity, and viscosity. *
    - Additionally, the lubricant should be replaced every 500 hours of operation.*

    The air supply system is now pressurized and ready to use.

E.3 Steam Generator Operation

The steam generator is used to generate steam for steam/water tests. The steam is also used to heat the supply/RCIC tank water so that the water entering the test section is at or close to saturation conditions. To operate the steam generator at least two people must be present in the lab.

1. Verify that the steam generator level is at 60 cm on the magnetic level indicator.* If it does not, follow the procedures in section E.11 fill the steam generator with water.
2. Isolate the steam generator by verifying that valves V-1, V-2, V-9, V-13, V-16, and V-90 are closed.*
3. Unlock the steam generator control padlock.*
4. Turn the steam generator breaker to ON in the 480 VAC electrical panel.*
5. Switch the steam generator control switch to ON.*
6. Turn on the appropriate number of heaters depending on the operation being performed.*
7. Monitor the steam generator pressure and temperatures in the LabVIEW VI.
    a. During initial heat up, at 30 psia open the steam generator vent valve, V-16, for 30 seconds. This will evacuate the non-condensable gases in the steam generator and promote mixing in the steam generator lower the temperature differentials that will appear in the steam generator.*

   b. This may need to be repeated multiple times until the temperature gradient is no longer seen before initiating a test. *

8. Continue monitoring the steam generator during heat up.
9. Turn off the steam generator heaters when the desired pressure is reached.*
   a. Do not let the steam generator pressurize above 130 psia.*

E.4 Water Supply Heat Up for Steam/Water Testing

For steam/water flooding tests the water supply inside the supply/RCIC tank needs to be heated by using steam from the steam generator so that the water inlet is raised close to saturation conditions. If conducting air/water tests this will not need to be accomplished and skip to sections E.5.

1. Purge water from the common pipeline:
   a. Close the throttle valve, V-1.*
   b. Close the common pipeline valve, V-5.*
   c. Close the water re-circulation valve, V-84.*
   d. Close the RCIC sparger valve, V-34.*
   e. Verify that the SRV sparger valve, V-36, is closed.*
   f. Open the airspace sparger valve, V-35.*
   g. Isolate the test section by closing the test section gas inlet valve, V-6.*
   h. Drain the condensate from valve V-7b, close once complete.*
   i. Set the air regulator to 50 psig.*
   j. Slowly open the air purge valve, V-7c to 50%.*

k. Slowly open the common pipeline valve, V-5.*

l. Close the air purge valve, V-7c, when the supply/RCIC tank pressure increases 0.5 psi.*

2. Water supply heat up:

    a. Always complete the water purge before conducting water supply heat up.*

    b. Start up the steam generator by following section E.3.

    c. Confirm that the common pipeline valve, V-5, is closed.*

    d. Confirm that the test section isolation valve, V-6, is closed.*

    e. Confirm that the airspace sparger valve, V-35, is open.*

    f. Confirm that the water supply return valve is closed, V-84.

    g. Open the SRV sparger valve, V-36.*

    h. If the water supply/ RCIC tank is at ambient conditions open the water supply tank vent valve, V-86.* If reheating the supply/RCIC tank, verify that the valve is closed.*

    i. Open the gas throttle valve, V-1, to initiate steam flow. Limit this steam flow to 7-10 gps.*

    j. Open the test section condensate trap valve, V-7b, to remove condensed steam, close when water is evacuated.*

    k. Close the airspace sparger valve, V-35, when:

        i. The water supply/RCIC tank pressure increases.*

ii. The water supply tank airspace temperatures begin to increase.*

iii. Audible popping occurs from the water supply/RCIC tank.*

l. Increase the steam flow rate by adjusting the gas throttle valve, V-1. The maximum steam flow rate is 65 gps with all heater turned on.* The typical heating flow rate is 40 gps. Refill the steam generator when necessary by following the steps in section E.10.

m. Close the water supply tank vent valve, V-86, when the average water supply/RCIC tank temperature reaches 94 ℃.* This has been found to allow for the water supply/RCIC tank to pressure up to approximately 5 psig above saturation pressures.*

n. Continue heating water to saturation conditions for testing that will be conducted, closing the gas throttle valve, V-1, when reached.

o. Shut off steam generator heaters.

3. Purge steam from the common pipeline:

   a. Ensure that valves V-1, V-5, V-6, V-34, and V-36 are closed.*

   b. Open the air sparger valve, V-35.*

   c. Set the air regulator to 50 psig.*

   d. Slowly open the air purge valve, V-7c to 50%.*

   e. Slowly open the common pipeline valve, V-5.*

f. Close the air purge valve, V-7c, when the supply/RCIC tank pressure increases 0.5 psi.*

g. Close the common pipeline valve, V-5.*

h. Open the test section condensate trap valve, V-7b, to evacuate the remaining air from the piping, close when complete.*

E.5 Setting Test Section Pressure

During all elevated pressure testing the test section and water supply/RCIC pressures must be appropriately set. For the test section, the back-pressure regulator set point determines the pressure. This must be initially set before a test can be started. This is done by allowing gas to pass through the regulator at roughly the same flow rate for the test to be conducted and adjusting the regulator until the target pressure is acquired. The test section will begin depressurizing once the flow rate is stopped leading to a higher pressure in the water supply/RCIC tank. This may lead to higher water flow rates in the test section if water is still flowing into or not being able to return water from the holdup tank to the water supply/RCIC tank. Air/water and steam/water test section pressure procedure differ slightly and will be covered separately. The preceding section will cover how to set the water supply/RCIC pressure

1. Setting the test section pressure for air/water tests:

   a. Verify that valves V-5, V-7b, V-7c, V-91, and V-96 are closed.*

   b. If the water supply/RCIC tank is not pressurized close the water re-circulation isolation valve, V-85.*

c. Open the test section isolation valve, V-6.*

d. Open the air exhaust vent valve, V-97.*

e. If the air exhaust vent hose is stowed, direct it outside through the overhead door.*

f. Inject are into the test section by opening the gas throttle valve, V-1, and adjust to desired mass flow rate.*

g. Adjust the back-pressure regulator with a half inch wrench until the desired pressure is approximately reached.* During a test, this may need to be adjusted slightly.

h. Close the gas throttle valve, V-1.*

i. If conducting low-pressure tests open the exhaust condensation trap valve, V-91.* Attach an additional vent hose and direct the exhaust to the outside. Ensure that the back-pressure regulator is fully backed out.

2. Setting the test section pressure for steam/water tests:

    a. Verify that the common pipeline valve, V-5, is closed.*

    b. Open the test section condensation trap. V-7b.*

    c. Open the exhaust condensation trap, V-91.*

    d. Verify that the air purge valve, V-7c, is closed.*

    e. Verify that the air exhaust valve, V-97, is closed.*

    f. Open the steam exhaust valve, V-96.*

g. Heat up the primary steam flow path:

    i. Open the gas throttle valve, V-1, allowing 10-15 gps of steam to flow.*

    ii. When steam exits the test section condensation trap close valve V-7b.*

    iii. When steam exits the exhaust condensation trap close valve V-91.*

h. Adjust the gas throttle valve, V-1, to the desired flow rate.*

i. Adjust the back-pressure regulator with a half inch wrench until the desired pressure is approximately reached. During an actual test, this may need to be adjusted slightly.*

j. Close the gas throttle valve, V-1.*

k. Adjust the back pressure of the water inlet heat exchanger.

    i. Verify that the hygrometer isolation valve, V-19, is closed.†

    ii. If steam flows through the hygrometer, it can damage the instrument.† It is best practice to close this valve unless in use.

    iii. Open the water inlet heat exchanger isolation valve, V-20. †

    iv. Open the secondary side throttle valve, V-2 to an appropriate level to send steam to the water inlet heat exchanger. †

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† Obtained from Garza thesis [7].

v. Adjust the secondary side back pressure regulator with a 5/8-inch wrench to adjust above the pressure for the remainder of the test. During the first use of the day of the secondary side pressure regulator, large popping noises may be generated inside the regulator. † This is normal and is due to condensate being created and traveling through the back-pressure regulator, once heated the noise will cease. †

E.6 Setting the Water Supply/RCIC Tank Pressure

Before running a test, and ideally, before setting the test section pressure, the water supply/RCIC pressure must be set allowing for a lower pressure differential between the water supply source and the test section. This, in turn, allows for more precise control of the water flow rate and reduces the chances of cavitation in the supply and RCIC pumps. As the supply and RCIC pumps are run the pressure will be reduced in the supply/RCIC tank, reducing the ability to control the water flow rate and increase the pressure difference between the test section and the water supply/RCIC tank, therefore throughout testing the procedure may need to be completed when the pressure in the water supply/RCIC tank.

1. Close both water inlet valves, V-83a and V83b.*
2. Connect the 0.75-inch red air house from the quick connect air tap to the water supply tank quick connect.*
3. Verify that the air hose vent valve, V-86, is closed.*

4. Verify that the supply tank vent valve, V-86, is closed.*
5. Slightly open the air hose fill valve, V-89, and set the pressure regulator to a pressure above the desired operating pressure.*
6. Slightly open the water supply/RCIC tank fill valve, V-87. Air will now be entering the water supply/RCIC tank.*
7. Close the water supply/RCIC tank fill valve, V-87, when the desired pressure is reached. This has been observed that 5 psi above the test section operating pressure works well to reduce cavitation and allows for an extended testing period.*
8. When done close the air hose fill valve, V-89, and vent the air hose by slowly opening V-88. The 0.75-inch red air house is now ready to be disconnected if desired.*
9. Repeat steps 5-8 as needed.

During steam testing air pressurization to the water supply/RCIC tank may not be needed, as the pressurization of the RCIC tank can be completed by heater the water inside the supply/RCIC tank. When the pressure gets too low, this is accompanied by a lowering of the water temperature and will usually need to be reheated, where you can also re-pressurize via heating, refer to section E.4 for water supply/RCIC tank heat up operations.

E.7 Water Supply Operation

The water supply is sent to the test section by either the water supply pump or the RCIC pump. For flooding testing it is customary to use the water supply pump, this section will cover its proper operation. The water flow rate is controlled via the water flow control valve, V63, and the water bypass valve, V-61. During operation it is best to run a preliminary test to set up the valves so that during recording only slight adjustments of the valves are needed, allowing for a consistent water inlet flow rate. The water inlet flow rate is highly dependent on the pressure difference between the test section pressure and the water supply/RCIC tank pressure refer to sections E.6 directions on supply/RCIC pressurizing the water supply/RCIC tank for steam/water testing and for air/water testing.

1. Verify that that the test section pressure and water supply/RCIC tank pressures are set. Refer to section E.5 and E.6 as needed.
2. Open the water supply pump suction valve, V-81.*
3. Verify that the RCIC pump suction valve, V-82, is closed. *
4. Open the water supply discharge valve, V-80. *
5. Verify that the water bypass isolation valve, V-53 is open. *
6. Turn on the water supply pump. *
7. Slowly open the water inlet valve:
    a. Valve V-83A for steam/water tests. *
    b. Valve V-83B for air/water tests. *

8. Adjust the water inlet control valves, V63 and V-61 to obtain the desired water inlet flow rate. *
    a. During testing adjust may need to be made to the gas inlet flow rate, water inlet flow rate, and back pressure regulator as a test progresses.*

E.8 Re-circulation Pump Operations

During normal operations when water is sent to the test sections water is collected in the water hold up tank below the test section, and it is necessary to send this collected water back to the water supply/RCIC tank and that the water hold up tank is maintained to appropriate levels. During steam/water testing it is also necessary to maintain an appropriate water temperature going into the re-circulation pump, so that cavitation and failure of the pump do not occur, this is accomplished by adjusting the water flow rate entering the water re-circulation heat exchanger.

1. Verify that the common pipeline has been evacuated of steam, follow part 3 of section E.4.
2. Verify that the re-circulation valve, V-84, is open. *
3. Verify that the common pipeline valve, V-5, is closed. *
4. Verify the SRV sparger valve, V-36 is closed. *
5. Verify the airspace sparger valve, V-35, is closed. *
6. Verify the RCIC sparger valve, V-34, is open. *
7. Turn on the re-circulation pump. *

8. Monitor the re-circulation flow rate through the rotameter, adjust the re-circulation throttle valve, V85, if necessary. *
    a. If no flow is visible through the rotameter the pressure difference between the test section and the water supply/RCIC tank may be too great.* This normally caused by a higher pressure in the water supply/RCIC tank, which will need to be depressurized by opening the water supply/RCIC vent valve, V-86. *
    b. During air/water testing air may escape into the pump and lead to no water flow through the rotameter. * To resolve this, a valve has been installed at the top of the pump. Run the pump for 2 seconds, open the valve to let air escape, repeat until continuous stream of water is observed.*
9. For steam/water tests cavitation may occur in the re-circulation pump, and the heat exchanger will need to be employed.* To operate the heat exchanger:
    a. Verify the cold side heat exchanger exhaust is vented outside of the lab or to a water drain.*
    b. Connect the domestic water fill line to the blowdown drum.*
    c. Open the auxiliary domestic water supply valve, V-95.*
    d. Open the primary domestic water supply valve, V-92.*
    e. Close the auxiliary domestic water supply valve, V-95.*

f. When water is observed to enter the blowdown drum close the auxiliary domestic water supply valve, V-95.* The auxiliary domestic water supply allows for water to easily exit the water supply piping reducing hammering that will occur in the piping.*

g. Open the heat exchanger domestic water supply valve, V-94 to send water into the re-circulation heat exchanger.* Adjust V-94 as necessary to adequately cool water entering the re-circulation pump.*

10. Monitor the holdup tank level in the LabVIEW VI, keeping the water level between 20% and 80%*
11. Shut off the re-circulation pump when complete.*

E.9 Flooding Procedure

1. Determine the type of testing to be conducted either steam/water or air/water test at ambient pressure or elevated pressure.
2. Follow sections E.1 through E.8, using the appropriate sections when necessary, to properly set up the facility for tests being completed.
3. If air/water tests are to be conducted:
    a. Close the water inlet heat exchanger isolation valve, V-20.*
    b. Open the hygrometer isolation valve, V-19.*
    c. Purge to hygrometer opening the secondary side isolation valve, V-2.*
4. If steam/water tests conducted:
    a. Verify that the hygrometer isolation valve, V-19, is closed.*

b. Verify that the water inlet heat exchanger valve, V-20, is open.*

c. Turn on the domestic water supply, by following the instructions in section 4.8.*

i. Open steam condenser isolation valve, V-93. This allows domestic cold water into the steam condenser heat exchanger.* Adjust V-93 as necessary to condense steam from the test section.*

ii. Verify the secondary side exhaust hose to the steam condenser heat exchanger is directed in the water drain.†

5. Verify the LabVIEW VI is recording data.*

6. Follow section E.7 to begin sending water into the test section.*

7. Open the gas throttle valve, V-2.*

a. For steam, tests turn on the appropriate number of heaters for testing.*

8. Slowly increase the gas flow rate by continuing to open the gas throttle valve V-2 to the desired amount.*

a. If onset of flooding testing is to be performed monitor the LabVIEW VI's "Test Section DP". When flooding occurs, a large differential will appear. The gas flow rate this occurs at will need to be kept steady.

9. Once the appropriate gas flow rate is reached minor adjustments will be made to the gas throttle valve, back pressure regulator, and water inlet flow rate for the remainder of the test.

a. For steam testing the water inlet temperature is to be kept within 3℃ of the saturation temperature, this is accomplished by adjusting the secondary side throttle valve, V-2, and will need to be adjusted throughout a test.*

10. If the water level in the holdup tank is to great turn on the water re-circulation pump and turn off as needed.*
11. When the system is no longer able to be kept in a steady state condition, close the gas throttle valve, V-1.*
    a. If steam/water tests are being performed close the secondary side throttle valve, V-2.*
    b. If steam/water tests are being performed turn off all the steam generator heaters.*
    c. A typical test will be recorded at steady state for a minimum of 30 seconds.*
    d. Close the water inlet valve, V-83a/b.*
    e. Shut off the water supply pump.*
12. Stop data collection and prepare the facility for the next test or begin facility shut down.*

E.10 Facility Shutdown

Once testing is completed the facility must be depressurized, all vessels must be subcooled if steam testing was conducted, and all electronics shut off before the user can leave the facility. The shutdown procedure for steam/water and air/water is the same, air/water shutdown will not need to reduce temperature and will not need the steam generator to be shut down.

1. Turn OFF the 30A breaker in the 480 VAC electrical panel OFF to secure the air compressor.*
2. Shut down the steam generator.
    a. Turn OFF power to all steam generator heaters.*
    b. Turn the heater power switch to OFF, lockout the switch using the padlock.*
    c. Turn OFF the 200A breaker in the 480 VAC electrical panel.*
    d. Open the steam generator vent valve, V-16, to blow down the steam generator. Steam generator thermocouples must be below 100^{o}C.*
    e. Blown down the air compressor by slowly opening the air compressor isolation valve, V-90.*
    f. Blow down the test section by opening the throttle valve, V-1.*
    g. When blowdown is complete, and the steam generators bulk temperature is below 100 ^{o}C close the steam generator vent valve, V-16.*
    h. Open the vacuum breaker valve, V-13; the steam generator is now secured.*
3. Close the RCIC sparger valve, V-34.*

4. Open the airspace valve, V-35.*
5. Operate the water supply and re-circulation pumps until the bulk water supply temperatures in the holdup tank are below 100^{o}C.*
6. Once complete secure both pumps.*
7. Depressurize the test section by opening the condensate traps, V-7b and V-91.*
8. Depressurize the supply/RCIC tank by opening the water supply tank vent, V-86.*
9. Secure the heat exchanger and steam condenser by closing valves, V-93 and V-94.*
10. Close the domestic water supply valve, V-92.*
11. Verify that both pressure regulators have been backed out.*
12. Turn OFF and unplug the magnetic flow meters.*
13. Power OFF the remote monitor near the throttle valve V-1.*
14. Power OFF the remote monitor near water flow control valve V-63.*
15. Verify that all pressures are at atmospheric conditions.*
16. Verify that temperatures at below saturation conditions.*
17. Close the condensate valves, V-7b and V-91.*
18. Close LabVIEW.*
19. Turn OFF the National Instruments SCXI chassis.*
20. Turn OFF the DC power supply.*

21. Log out of the data acquisition PC.*

E.11 Filling the Steam Generator

Before producing steam in the steam generator, the water level inside the steam generator must be filled to a minimum level to ensure that the immersion heaters are covered with water preventing damage to the generator. There are two main reasons why you may need to fill the steam generator first during steam generator operation. During steam generator operation the level of the water in the steam generator will decrease from use, a reed switch was placed at roughly 35 cm on the magnetic level indicator. When the water drops below this level, the reed switch opens the circuit turning off the heaters, ensuring that the level of water is sufficient to cover the heaters. The second reason is that the steam generator has been evacuated of water for various reasons such as maintenance of the steam generator or air testing and must be filled.

Filling the steam generator can be accomplished one of two ways and are dependent on the amount of water that is needed in the water supply/RCIC tank. If this level is low, it is best to fill the steam generator with fresh water from the deionization system. However, during normal operation or if the water supply/RCIC tank level is sufficient, it is best to use water from the water supply/RCIC tank.

1. Verify that the supply/RCIC tank level is adequate.
2. If the water level is low:
    a. open the valve leading from the DI system to the water hold up tank.
    b. Open the DI water supply valve, V-28.*

c. Fill the steam generator until the magnetic level meter is registering roughly 60 cm.
d. Close the DI water supply valve, V-28. *
e. Close the DI system valve.*
f. The steam generator is now ready to use.

3. If the water level is adequate or during testing:
    a. Verify that the steam generator is below 90 psia. This is the maximum pressure that the steam generator can be filled.*
        i. If the pressure inside the steam generator is above 90 psia open the steam generator vent valve, V-16, to decrease the pressure to an appropriate level.
    b. Close the supply pump discharge valve, V-80.
    c. Open the RCIC pump suction valve, V-82.*
    d. Confirm that the re-circulation valve, V-53, is open.*
    e. Open the bypass valve, V-61.*
    f. Open the water flow control valve, V-63.* It is best practice to crack this valve such that slight positive flow of water is permitted into the steam generator. However, this is based on the water supply/RCIC tank pressure and the steam generator pressure.
    g. Turn on the RCIC pump fan.
    h. Turn on the RCIC pump.*

i. Slowly open the steam generator fill valve, V-9, allowing water to flow into the steam generator.

j. Quickly verify that water is being transferred to the steam generator, adjust the water flow control valves, V-61 and V-63, as necessary.

k. Fill the steam generator to roughly 60 cm on the magnetic level indicator.

    i. If the steam generator is being used for testing the water entering the steam generator may be cooler than that in the steam generator. This will most likely cause a temperature gradient to occur in the steam generator. Thus, throughout filling the steam generator it is best to open the steam generator vent valve, V-16 once or twice to promote mixing and reduce the temperature gradient.

l. Close the steam generator fill valve, V-9.*

m. Turn off the RCIC pump and the RCIC pump fan.*

During the normal operation, the supply/RCIC tank may contain heated water; this may cause issues with the RCIC pump as the thermal limits on the pump may be reached. This is accompanied by a “whining” coming from the pump, due to cavitation occurring within the pump. This effect may damage the pump, the pump must be shut off quickly, however filling may still need to occur in the steam generator and switching to the water supply pump will be necessary. The water supply pump has a lower head;

thus, the steam generator must have a lower pressure and may not be turned on during the process.

1. If “whining” occurs close the steam generator fill valve, V-9.*
2. Turn off the RCIC pump. *
3. Depressurize the steam generator such that the supply/RCIC tank and the steam generator pressures are roughly equal by opening steam generator vent valve, V-16.*
4. Open the supply-discharge valve, V-80.*
5. Close the RCIC pump suction valve, V-82.*
6. Turn on the water supply pump.*
7. Slowly open the steam generator fill valve, V-9.
8. Quickly verify that water is being transferred to the steam generator.
9. If the water is not being transferred to the steam generator close the steam generator fill valve and reduce the pressure of the steam generator.
10. Fill the steam generator to roughly 60 cm on the magnetic level indicator.
11. Close the steam generator supply valve, V-9.
12. Turn of the water supply pump.*

E.12 Draining the Steam Generator

During water testing, it is best to drain the steam generator of most water so that available air supply is maximized by using the steam generator as a pressure vessel for air, or if the supply/RCIC tank is low on water.

1. Complete the air supply operation procedure section E.2, pressuring the steam generator to 40 psig.
2. Close the pump supply and discharge valves, V80 and V-82.*
3. Completely open valve V-63.*
4. Completely open the bypass valve, V-61.*
5. Verify that the re-circulation valve, V-53, is open.
6. Slowly open the steam generator supply valve, V-9.*
7. Monitor the LabVIEW VI and close the steam generator supply valve, V-9, when the VI displays less than 24 inches.
8. Isolate the air compressor from the steam generator by closing the steam generator isolation valve, V-90.*
9. Depressurize the steam generator by opening the steam generator vent valve, V-16.*

E.13 Purging Differential Pressure Transmitters

On occasion, the impulse tubing of the differential pressure transmitters may need to be purged. Caution must be taken during the procedure so that damage to detectors diaphragm do not occur. Below, in Figure 40 a reference of the valves used in the process is provided.

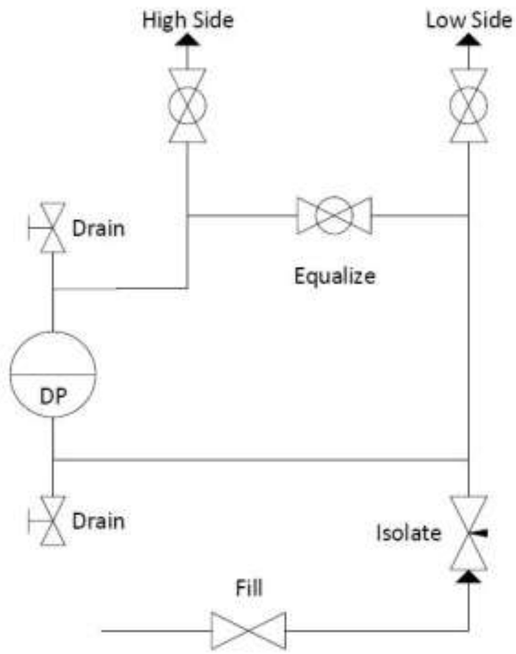

Figure E1: Rudimentary tubing and valve design for a differential pressure transmitter [6].*

1. Full the pump sprayer with deionized water from the deionized water source.*
2. Verify that the fill valve in Figure 40, this is attached to the pump sprayer is closed.*
3. Pump sprayer up to a reasonable pressure, if over pressurized a relief valve will engage. This may need to be done multiple times while purging.
4. Attach fill valve to compression fitting impulse tubing located near the isolation valve.*

5. Close the high side valve.*
6. Verify that the equalization valve is closed.*
7. Verify the low side valve is open.*
8. Open the isolation valve.*
9. Open the fill valve allowing water to purge any air out of the low side of the differential pressure transmitter.
10. Open the low side drain, located underneath the transmitter, do not let water to contact transmitter electronics as this may damage them.
11. Close the low side drain when a continuous stream of water is exiting the drain.
12. Close the fill valve.*
13. Close the low side valve.*
14. Open the high side valve.*
15. Open the equalizing valve.*
16. Open the fill valve to allow water to purge air out of high side and equalizer tubing. After a few seconds, audible dripping should be heard from inside the test section.
17. Open the high side drain, do not let water contact transmitter electronics as this may damage them.
18. Close the fill valve.*
19. Close the Equalizing valve.*

20. Open the low side valve.*
21. Close the isolation valve.*
22. Verify in LabVIEW that the transmitter is outputting an adequate reading, if not repeat steps 5-21.*
23. Disconnect the compression fitting from the impulse tubing.*

APPENDIX F

RAW STEAM/WATER DATA

This appendix contains the raw data images for all qualified steam/water tests performed for this study, presented in Appendix A.1.

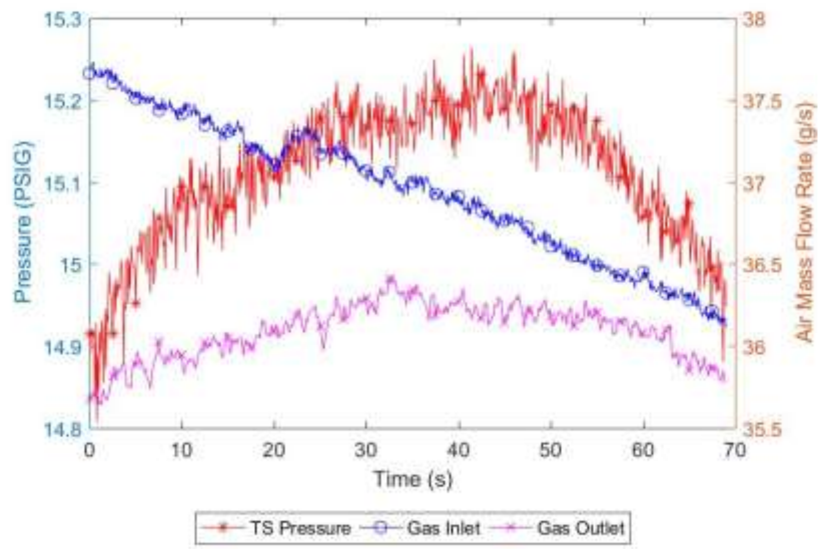

Figure F51: Pressure and gas inlet and outlet mass flow rate for test 2016_07_18_test_05.

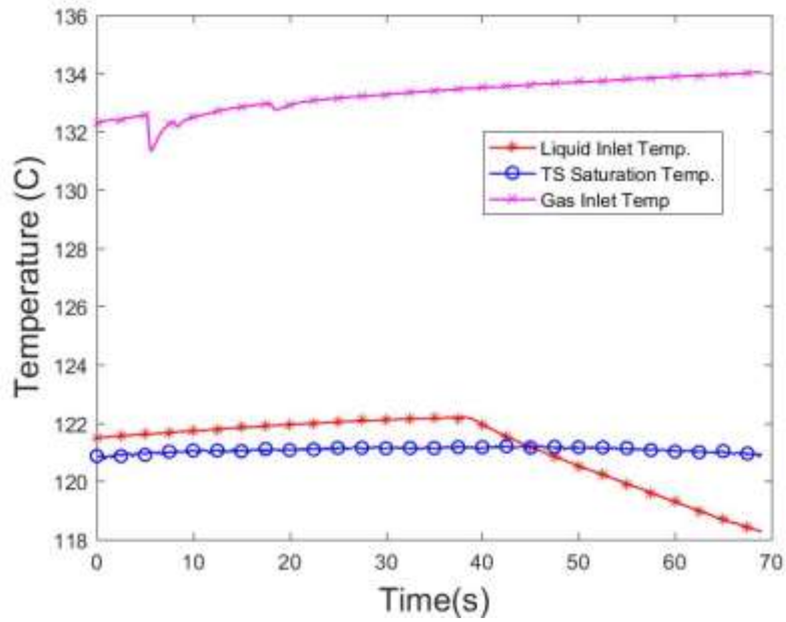

Figure F52: Temperature Profiles for test 2016_07_18_test_05.

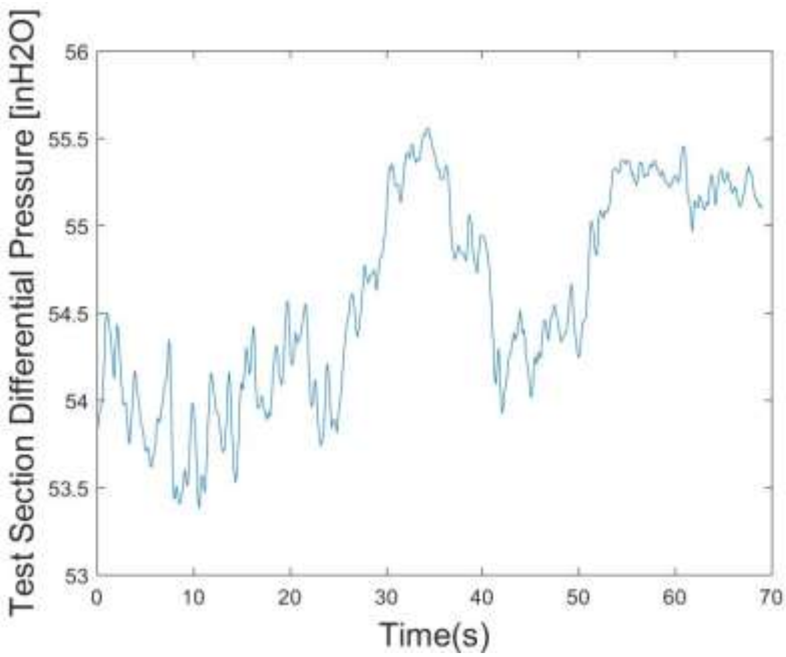

Figure F53: Test section differential pressure for 2016_07_18_test_05.

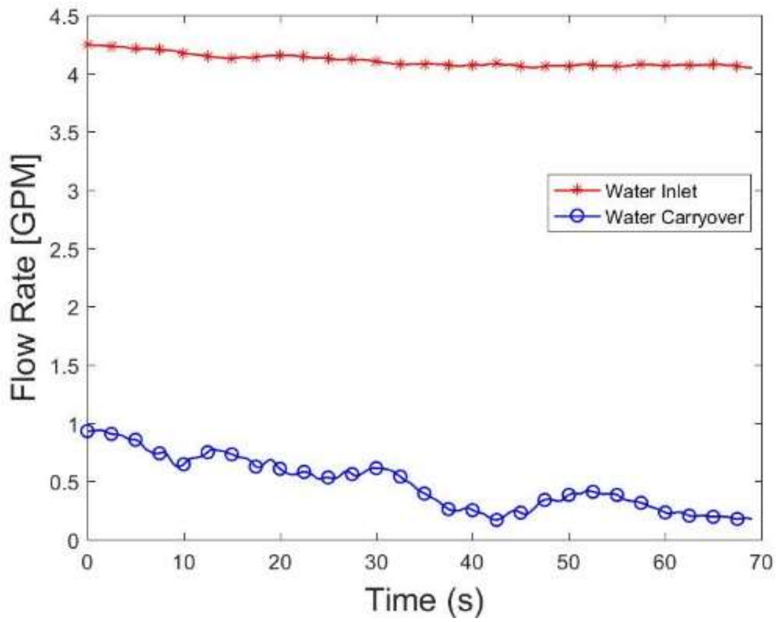

Figure F54: Water flow rates for2016_07_18_test_05.

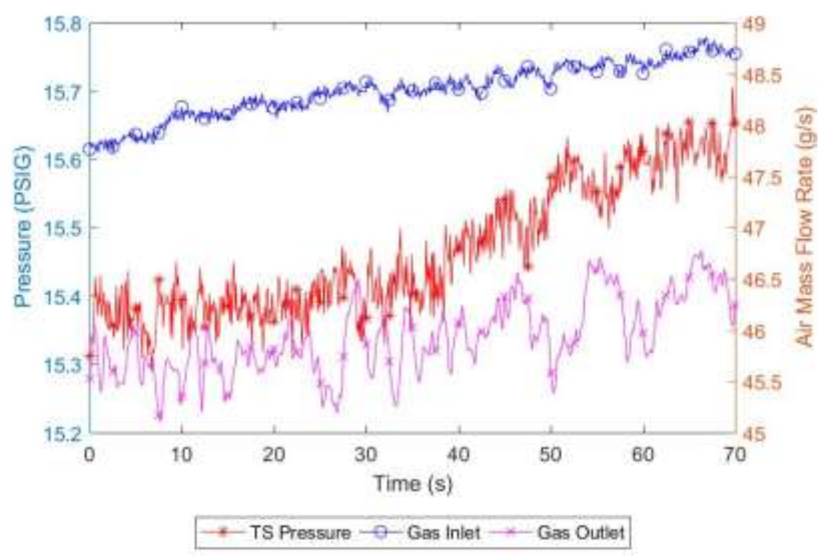

Figure F5: Pressure and gas inlet and outlet mass flow rate for test 2016_07_19_test_02.

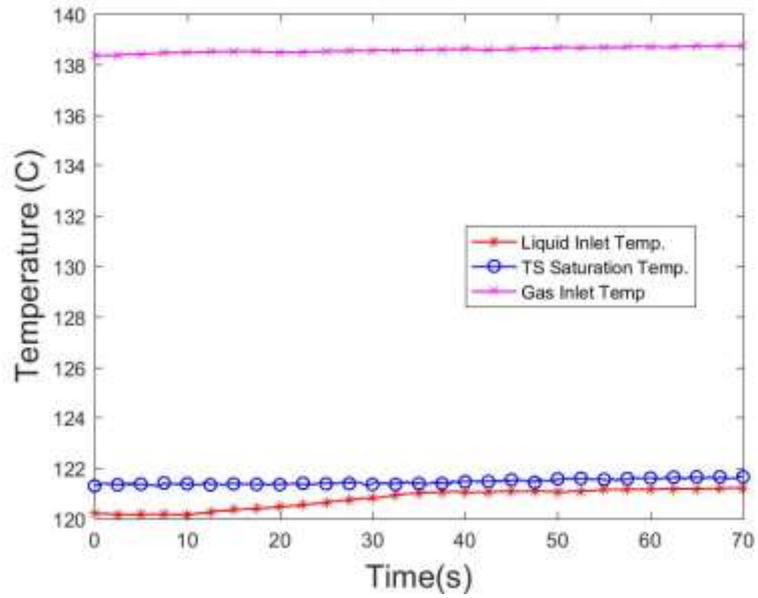

Figure F55: Temperature Profiles for test 2016_07_19_test_02.

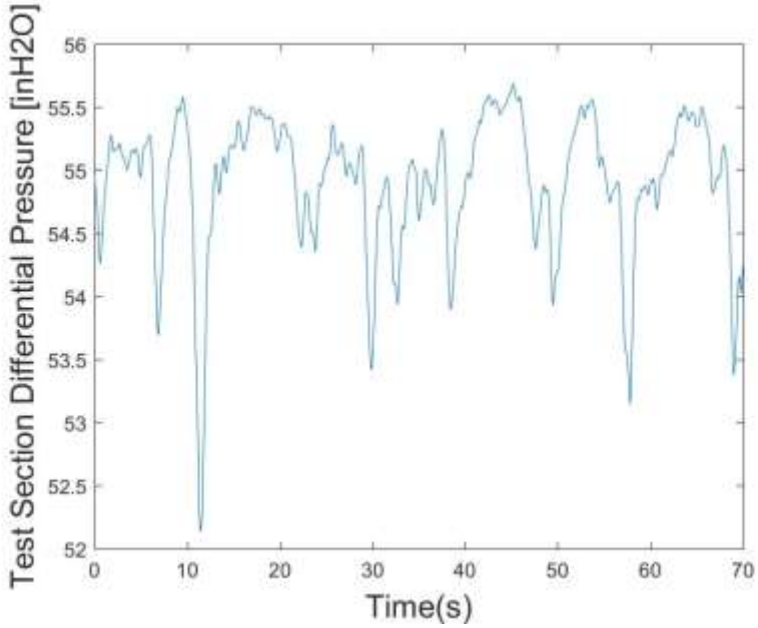

Figure F56: Test section differential pressure for test 2016_07_19_test_02.

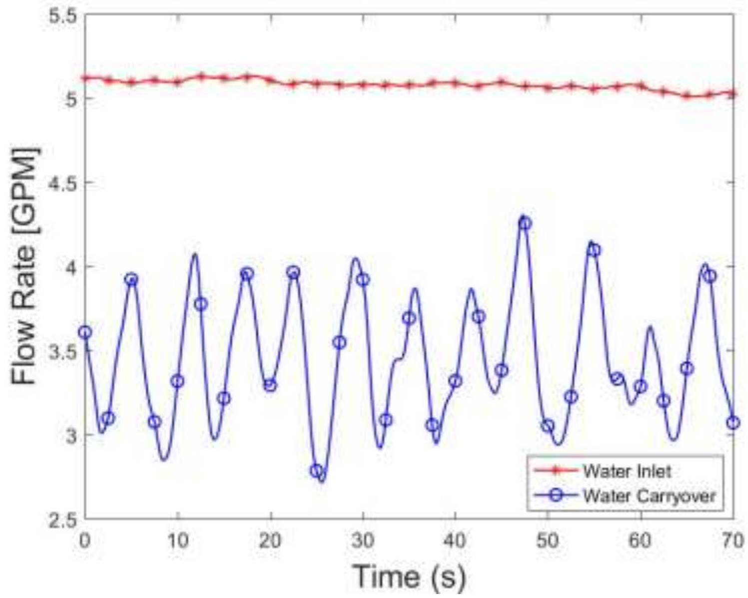

Figure F57: Water flow rates for2016_07_19_test_02.

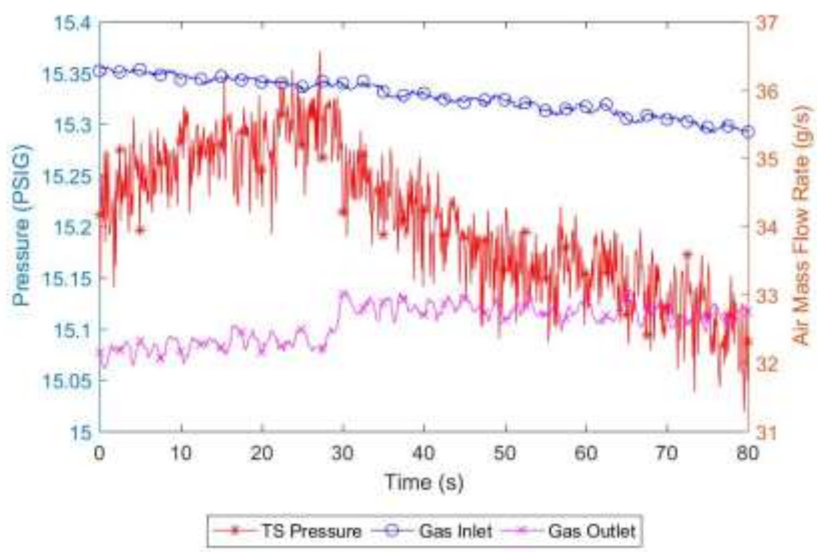

Figure F58: Pressure and gas inlet and outlet mass flow rate for test 2016_07_19_test_03.

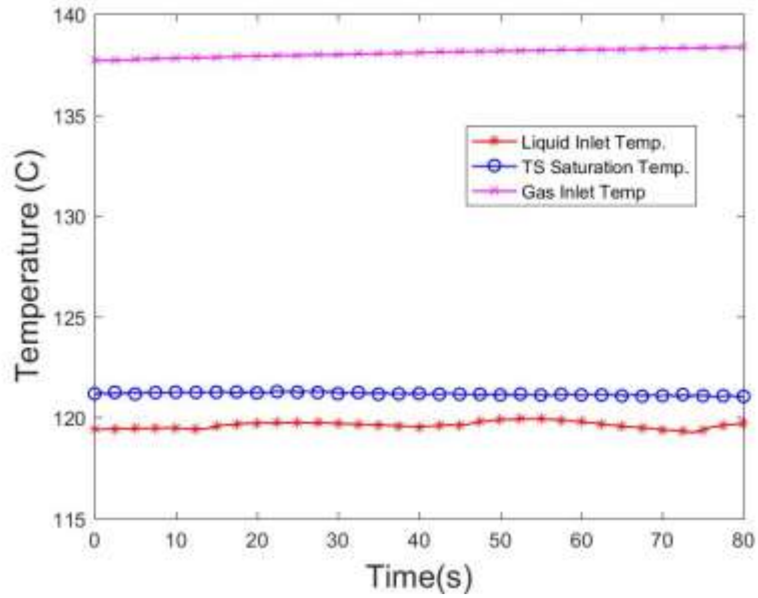

Figure F59: Temperature Profiles for test 2016_07_19_test_03.

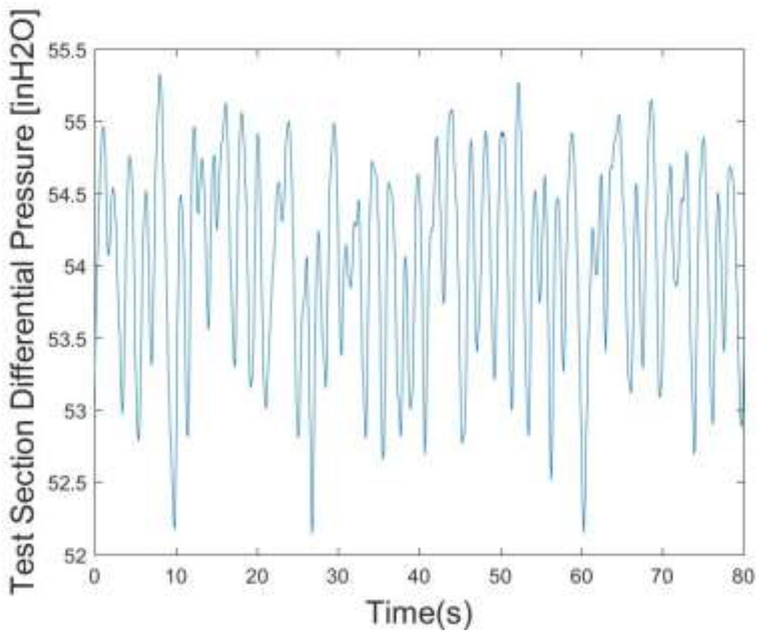

Figure F60: Test section differential pressure for 2016_07_19_test_03.

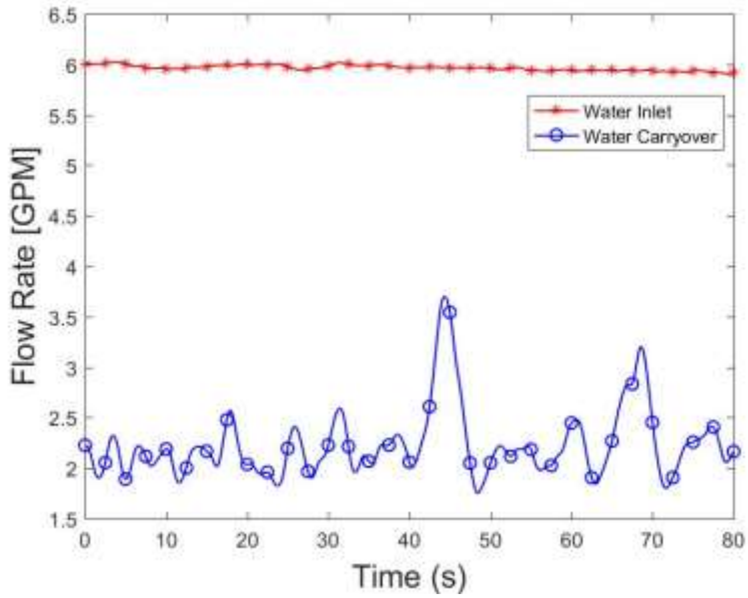

Figure F61: Water flow rates for2016_07_19_test_03.

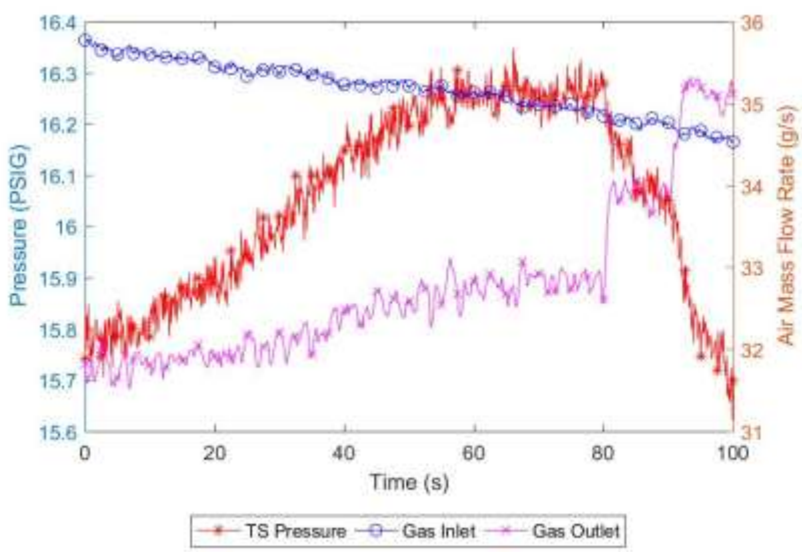

Figure F62: Pressure and gas inlet and outlet mass flow rate for test 2016_07_19_test_05.

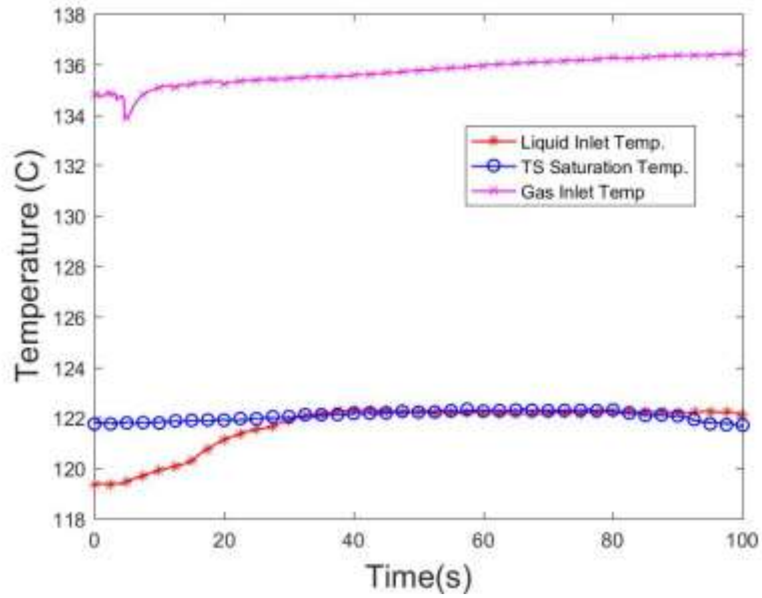

Figure F63: Temperature Profiles for test 2016_07_19_test_05.

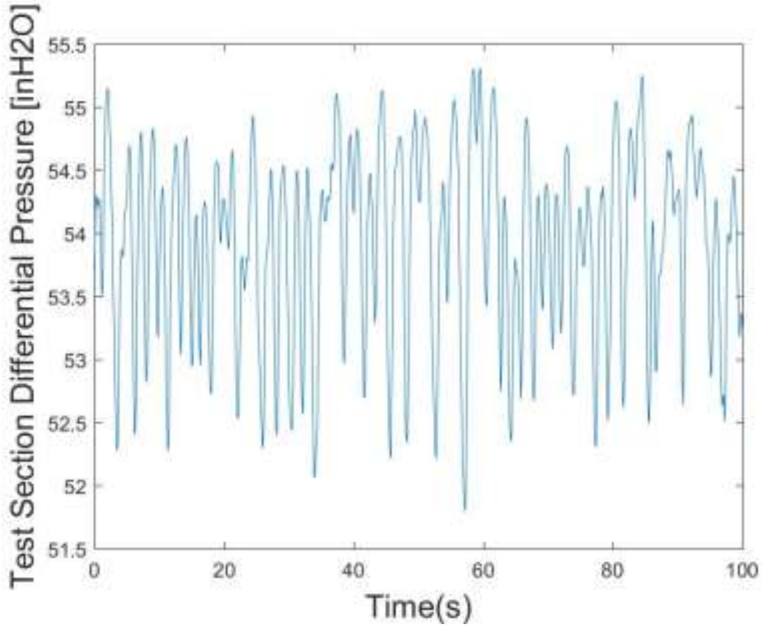

Figure F64: Test section differential pressure for 2016_07_19_test_05.

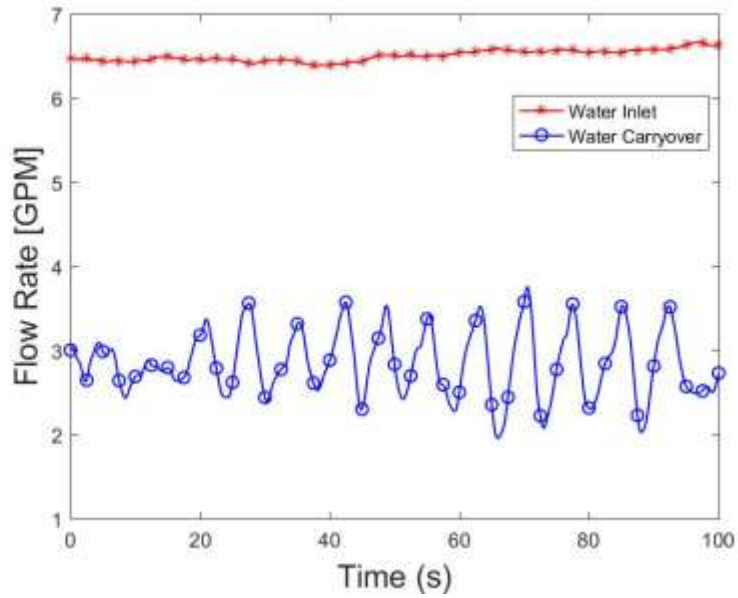

Figure F65: Water flow rates for2016_07_19_test_05.

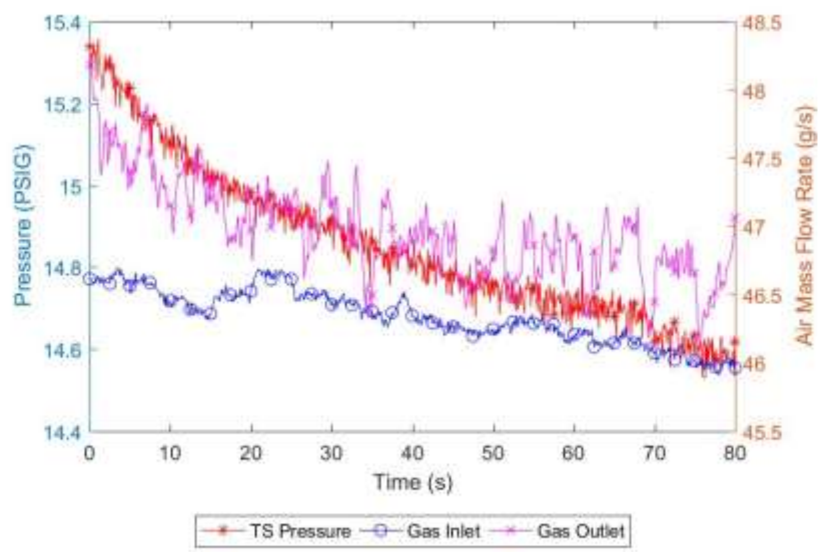

Figure F66: Pressure and gas inlet and outlet mass flow rate for test 2016_07_19_test_06.

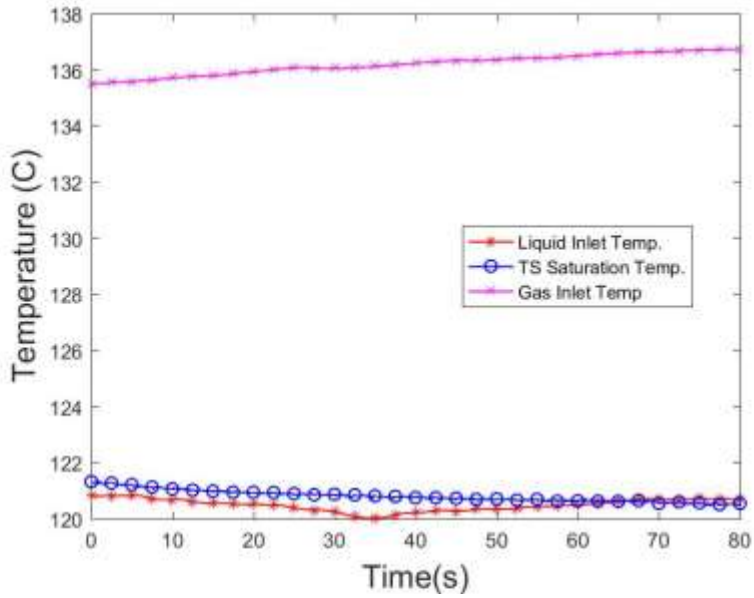

Figure F67: Temperature Profiles for test 2016_07_19_test_06.

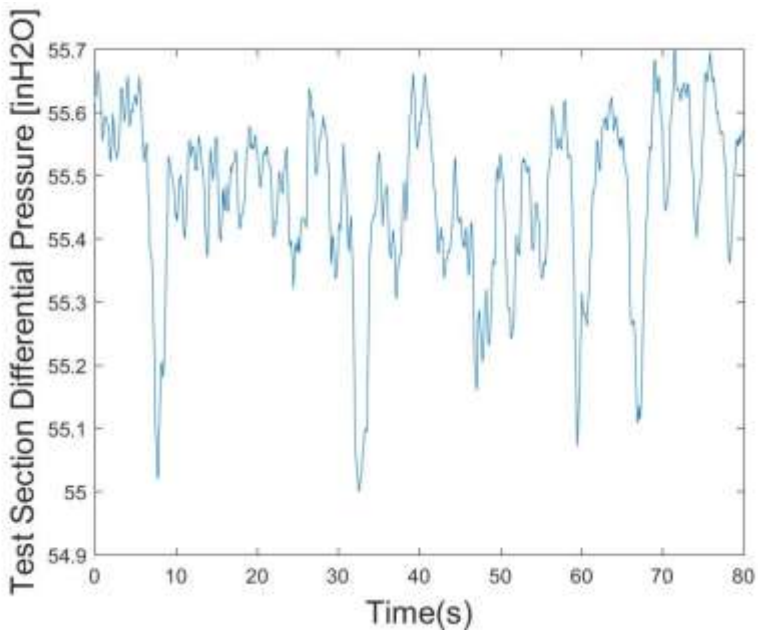

Figure F68: Test section differential pressure for test 2016_07_19_test_06.

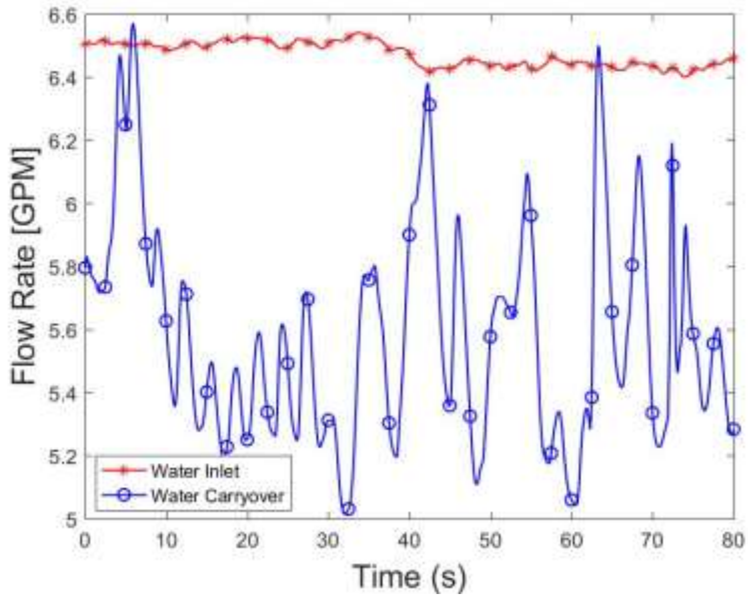

Figure F69: Water flow rates for2016_07_19_test_06.

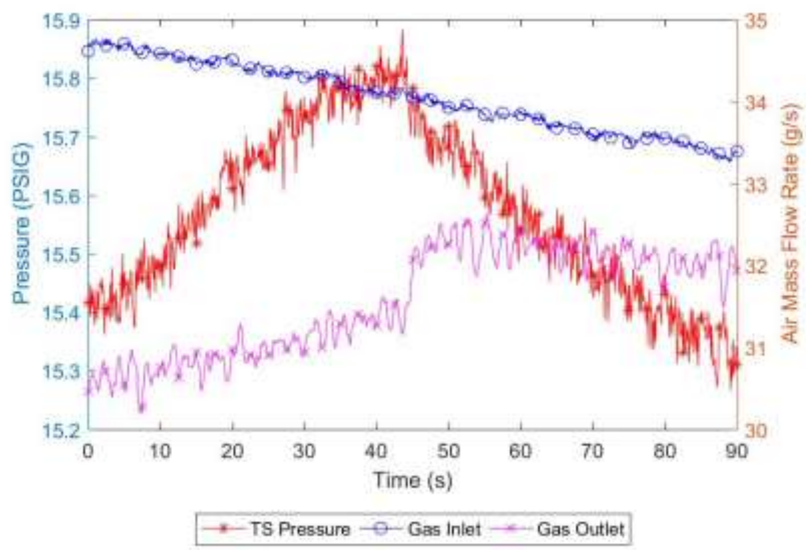

Figure F70: Pressure and gas inlet and outlet mass flow rate for test 2016_07_20_test_01.

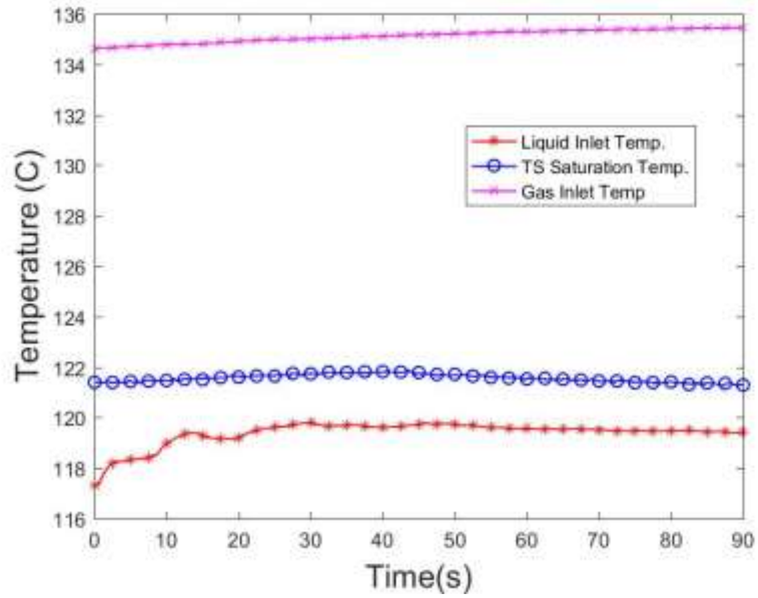

Figure F71: Temperature Profiles for test 2016_07_20_test_01.

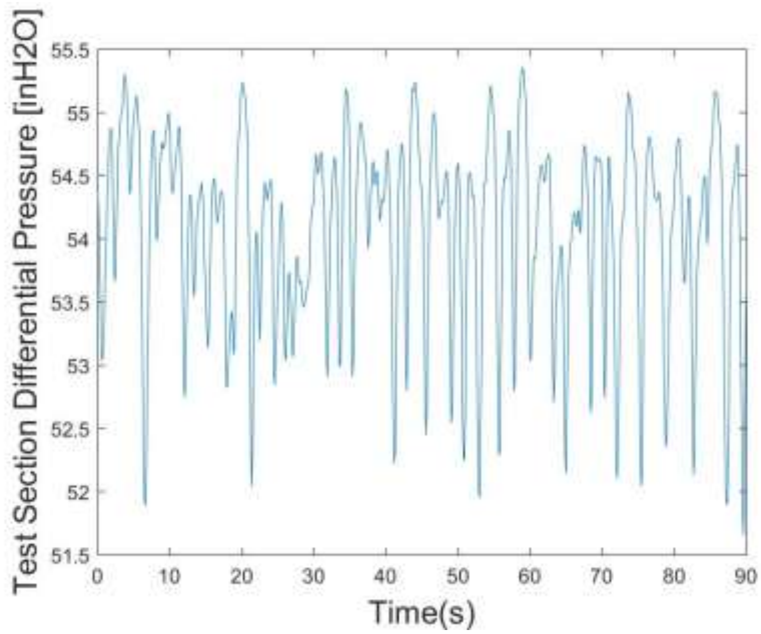

Figure F72: Test section differential pressure for test 2016_07_20_test_01.

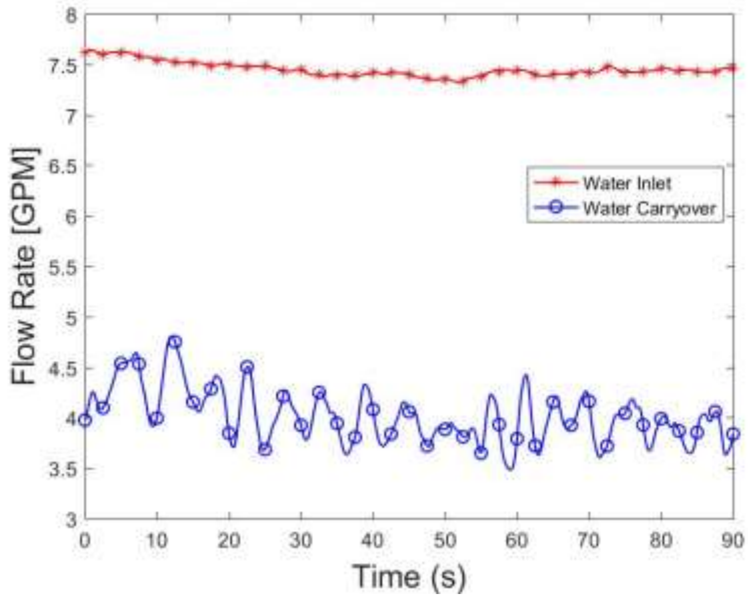

Figure F73: Water flow rates for2016_07_20_test_01.

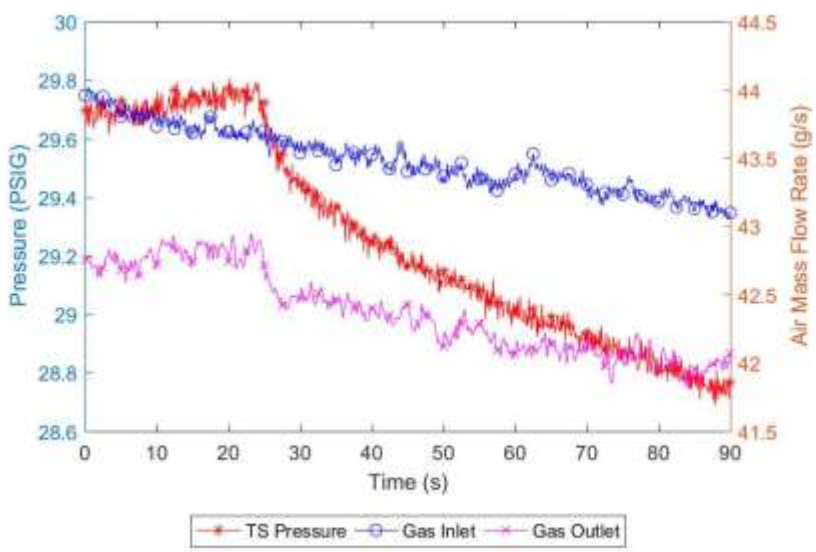

Figure F74: Pressure and gas inlet and outlet mass flow rate for test 2016_07_20_test_03.

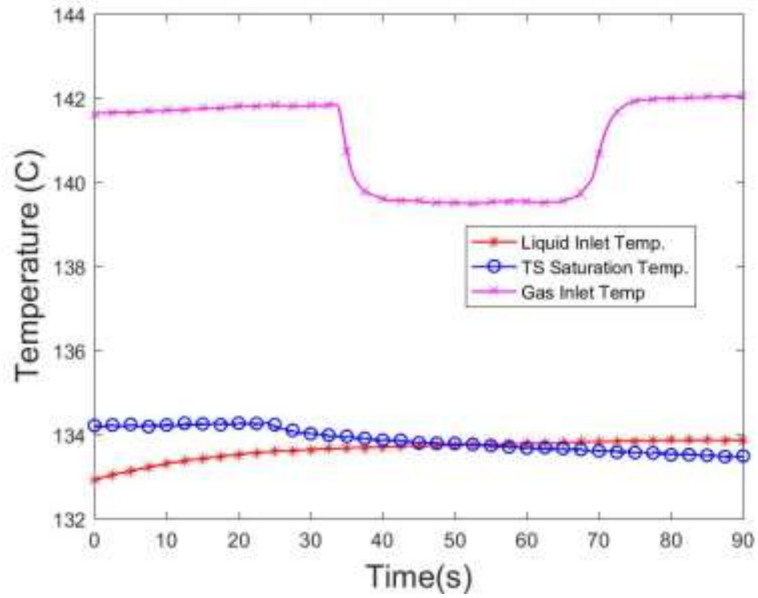

Figure F75: Temperature Profiles for test 2016_07_20_test_03.

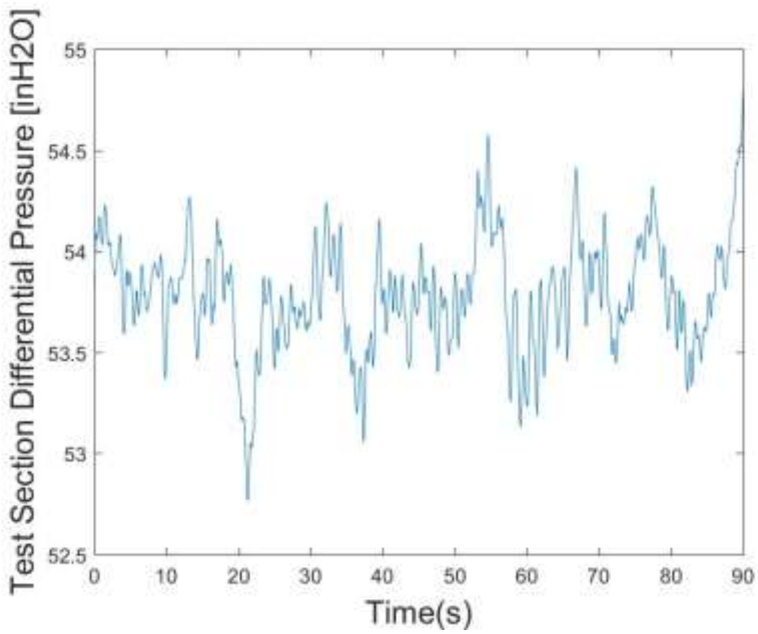

Figure F76: Test section differential pressure for test 2016_07_20_test_03.

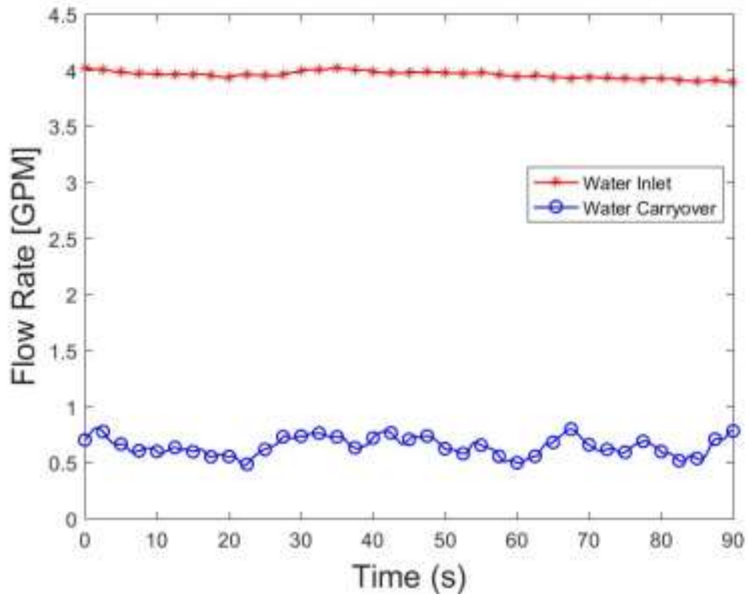

Figure F77: Water flow rates for2016_07_20_test_03.

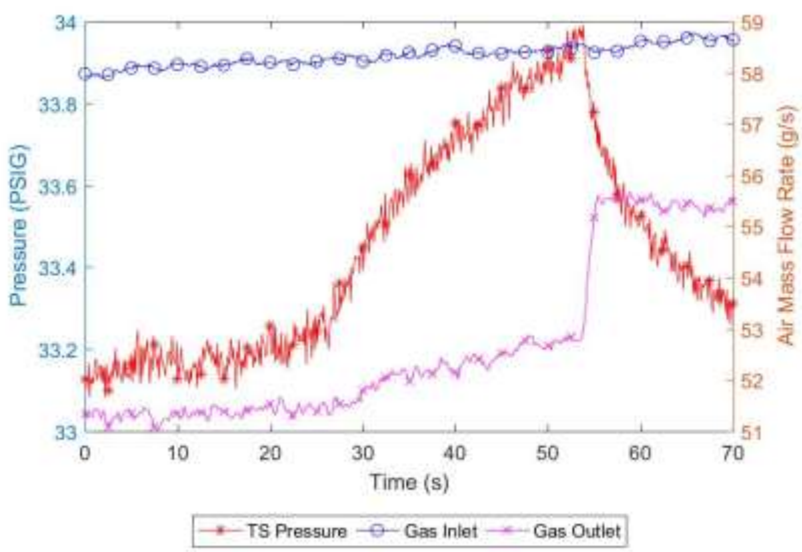

Figure F78: Pressure and gas inlet and outlet mass flow rate for test 2016_07_20_test_04.

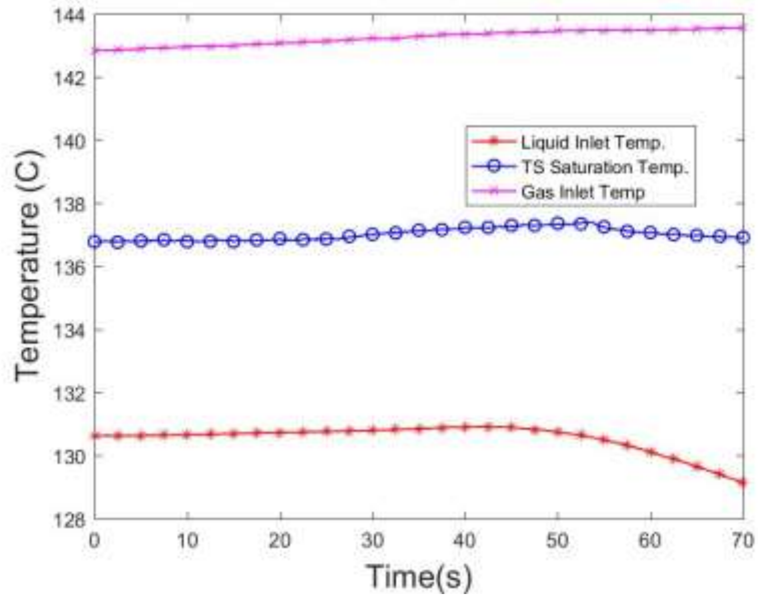

Figure F79: Temperature Profiles for test 2016_07_20_test_04.

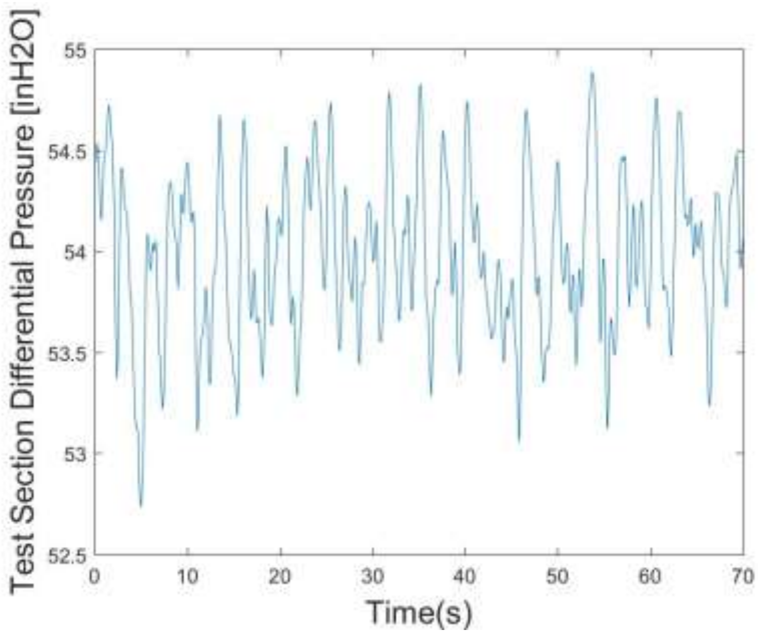

Figure F80: Test section differential pressure for test 2016_07_20_test_04.

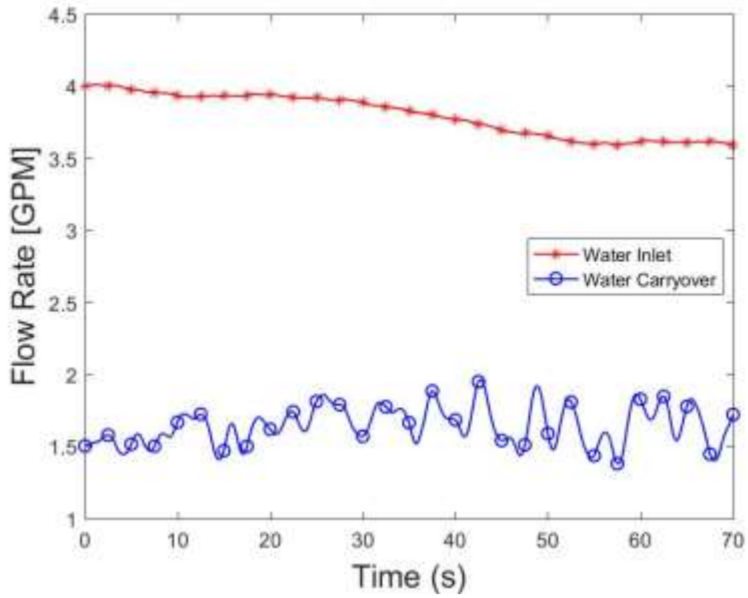

Figure F81: Water flow rates for2016_07_20_test_04.

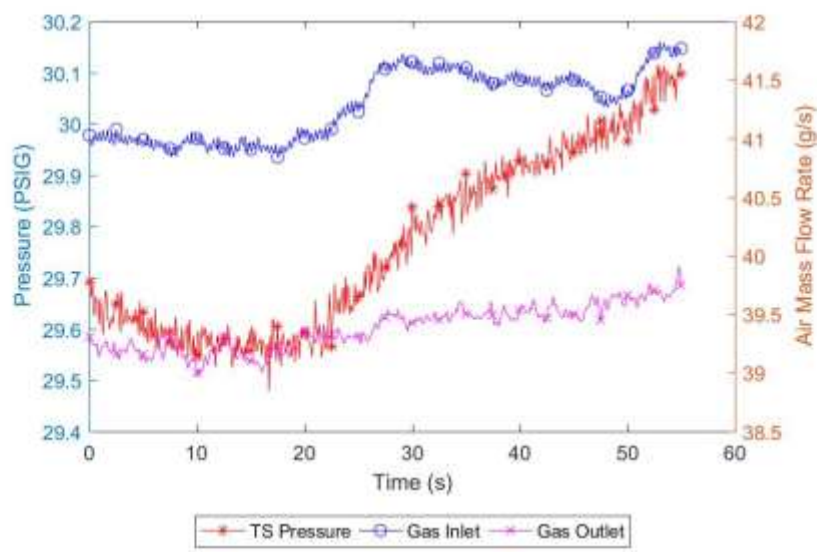

Figure F82: Pressure and gas inlet and outlet mass flow rate for test 2016_07_21_test_01.

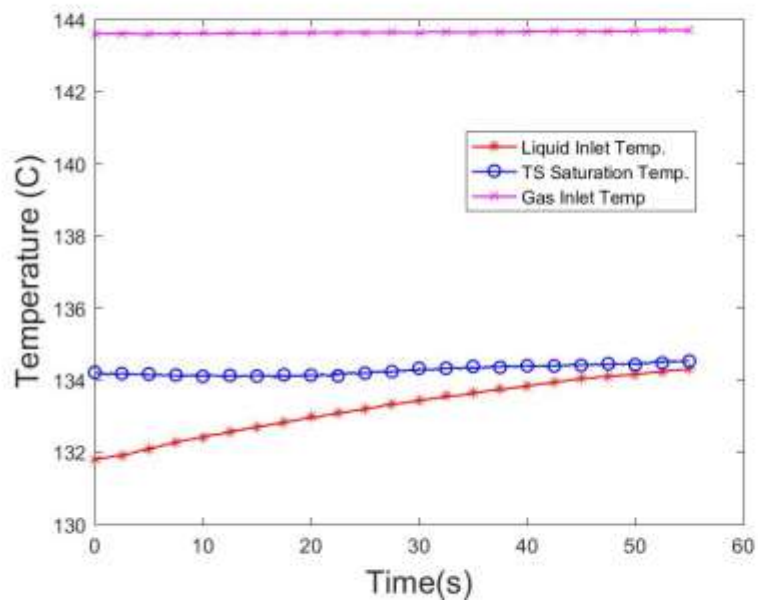

Figure F83: Temperature Profiles for test 2016_07_21_test_01.

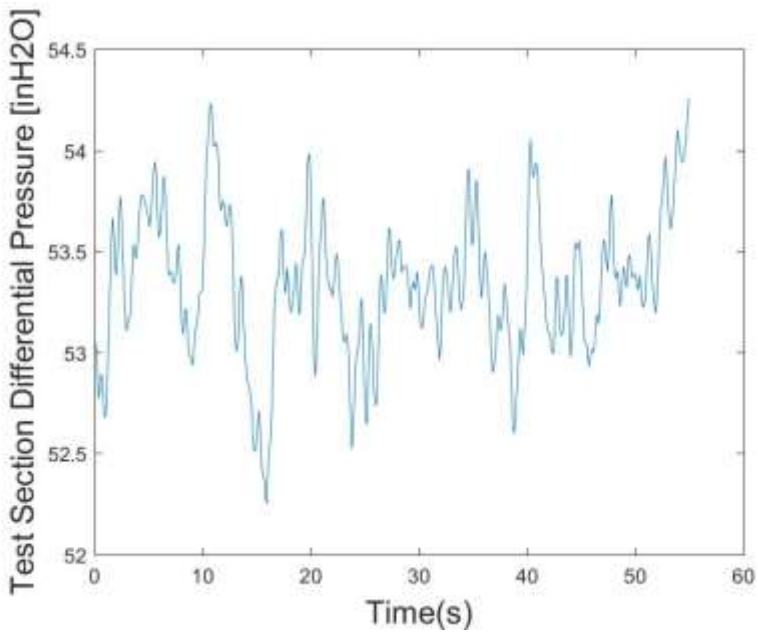

Figure F84: Test section differential pressure for test 2016_07_21_test_01.

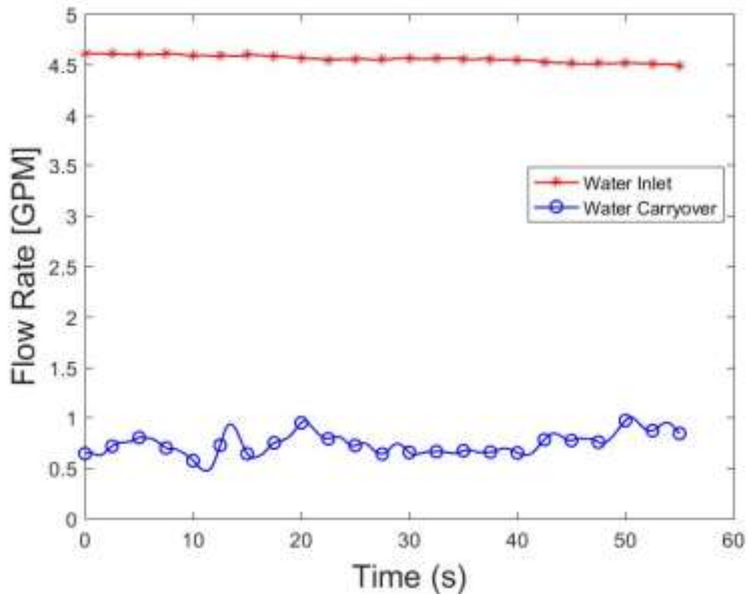

Figure F85: Water flow rates for2016_07_21_test_01.

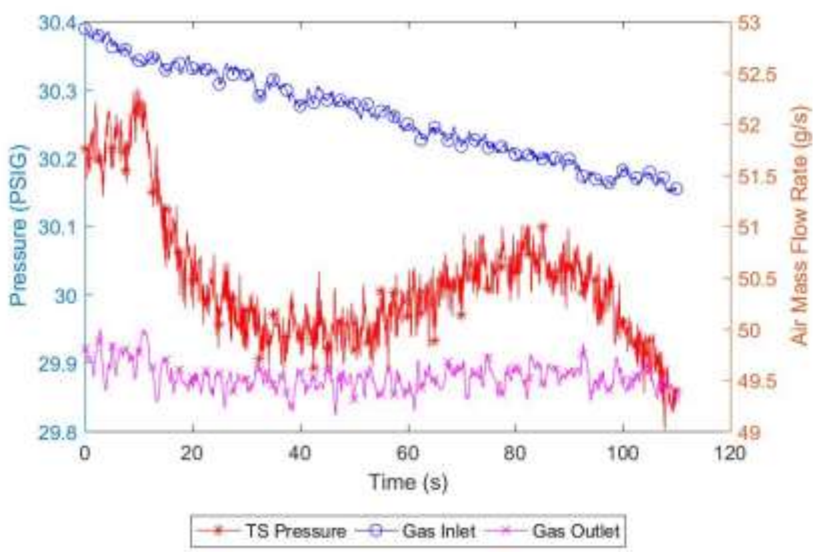

Figure F86: Pressure and gas inlet and outlet mass flow rate for test 2016_07_21_test_02.

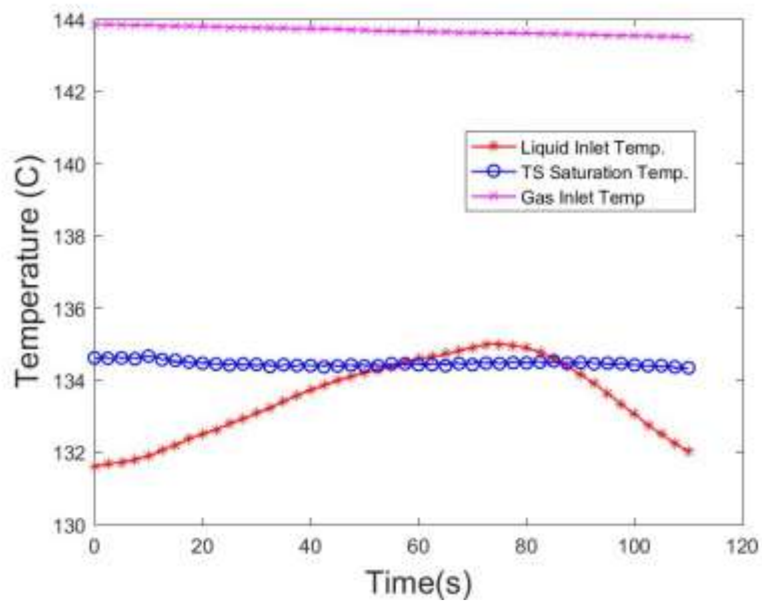

Figure F87: Temperature Profiles for test 2016_07_21_test_02.

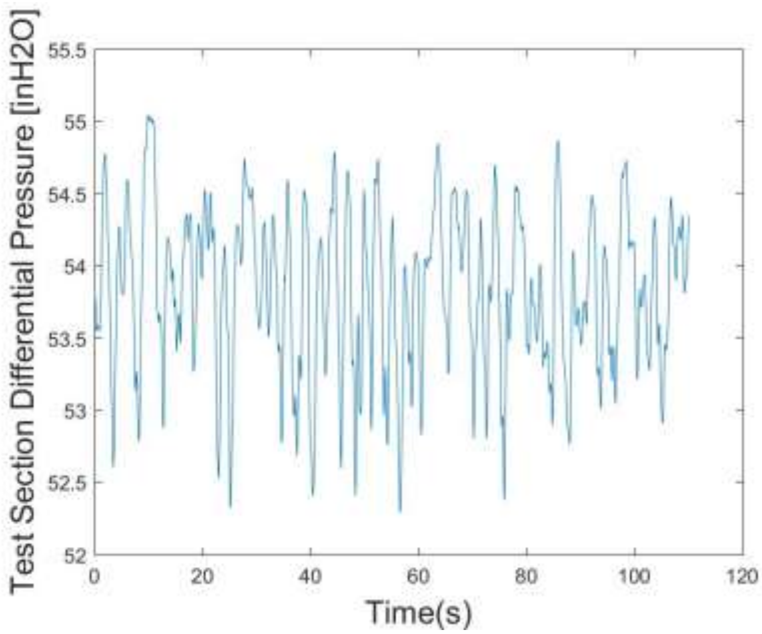

Figure F88: Test section differential pressure for test 2016_07_21_test_02.

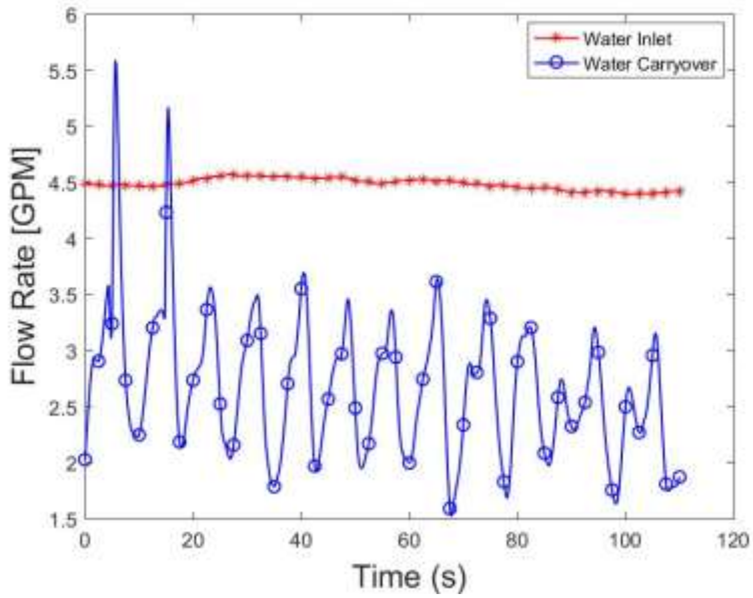

Figure F89: Water flow rates for2016_07_21_test_02.

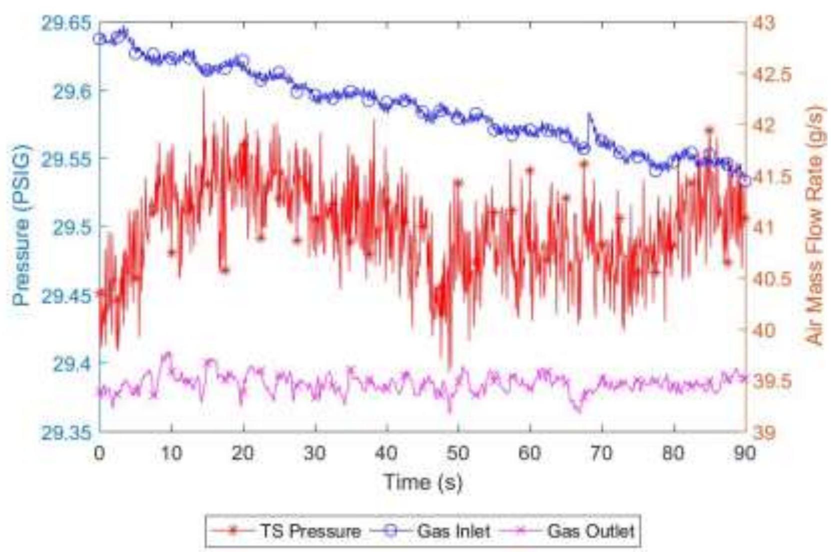

Figure F90: Pressure and gas inlet and outlet mass flow rate for test 2016_07_21_test_03.

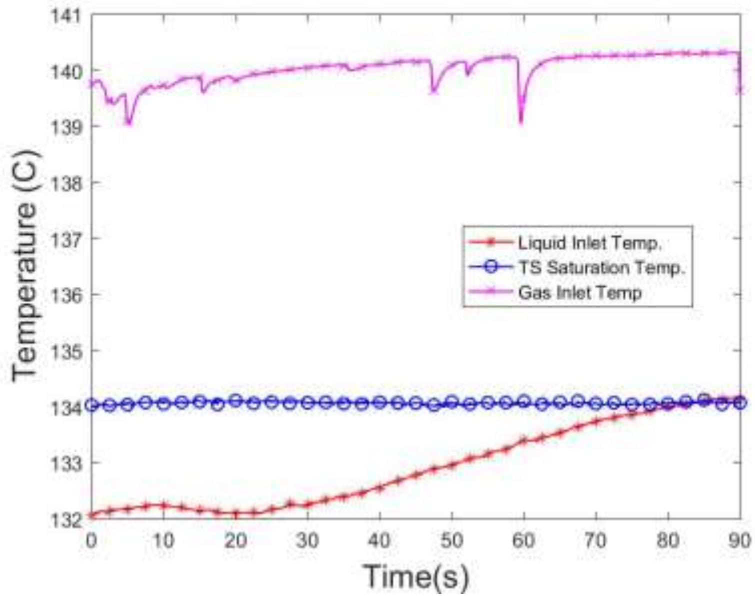

Figure F91: Temperature Profiles for test 2016_07_21_test_03.

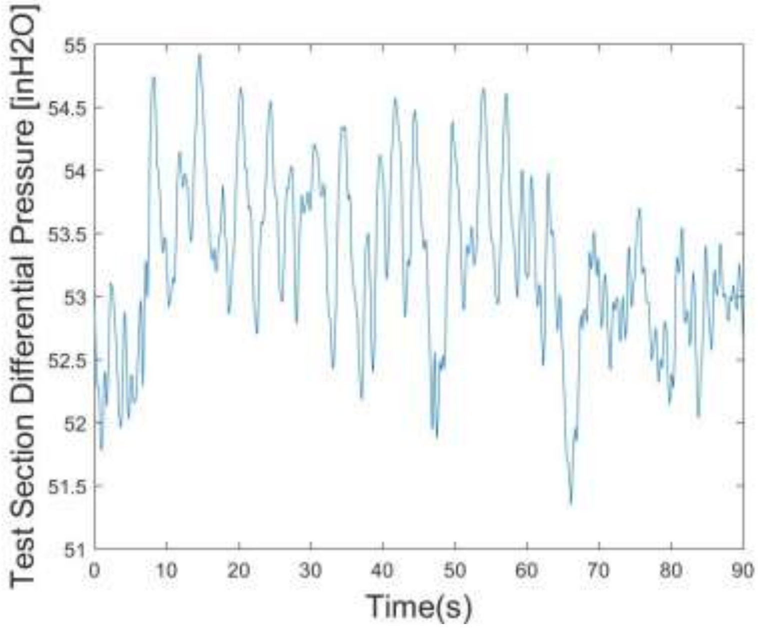

Figure F92: Test section differential pressure for test 2016_07_21_test_03.

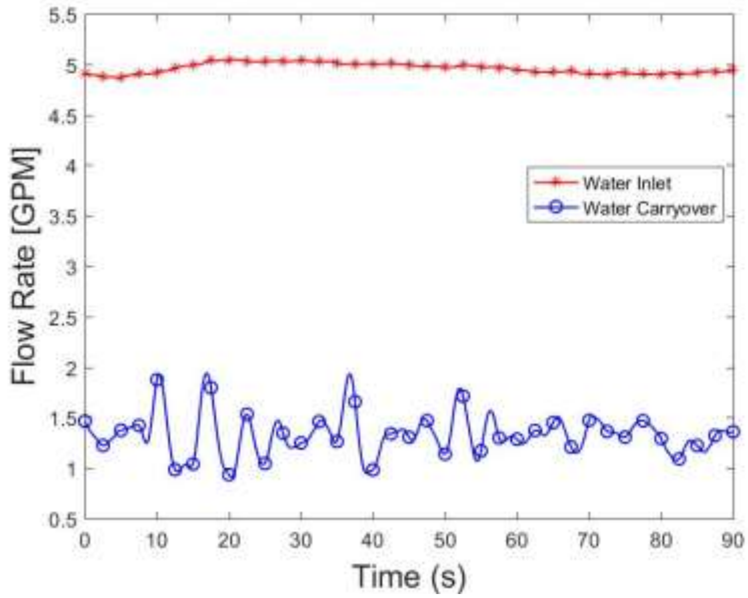

Figure F93: Water flow rates for2016_07_21_test_03

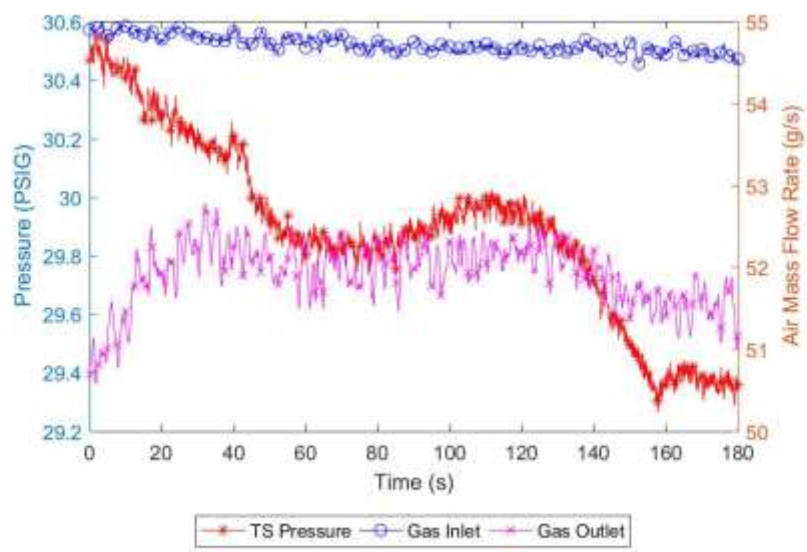

Figure F94: Pressure and gas inlet and outlet mass flow rate for test 2016_07_21_test_04.

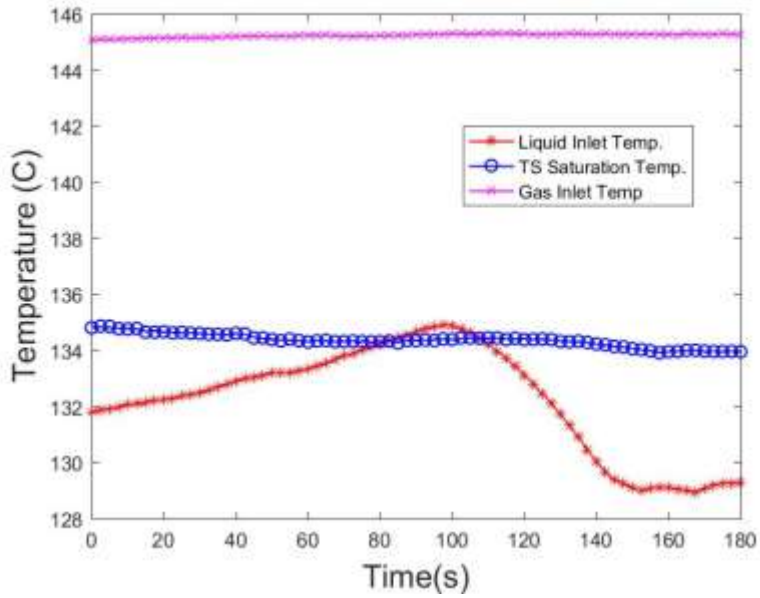

Figure F95: Temperature Profiles for test 2016_07_21_test_04.

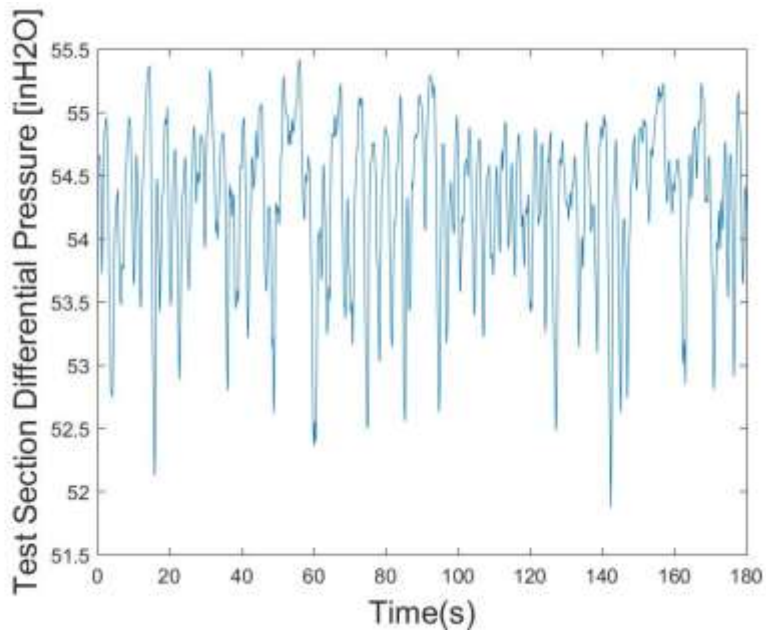

Figure F96: Test section differential pressure for test 2016_07_21_test_04.

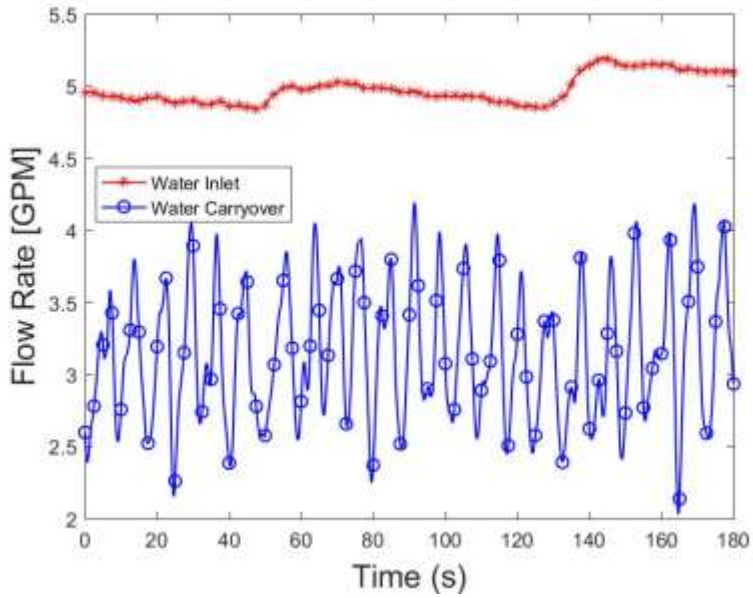

Figure F97: Water flow rates for2016_07_21_test_04.

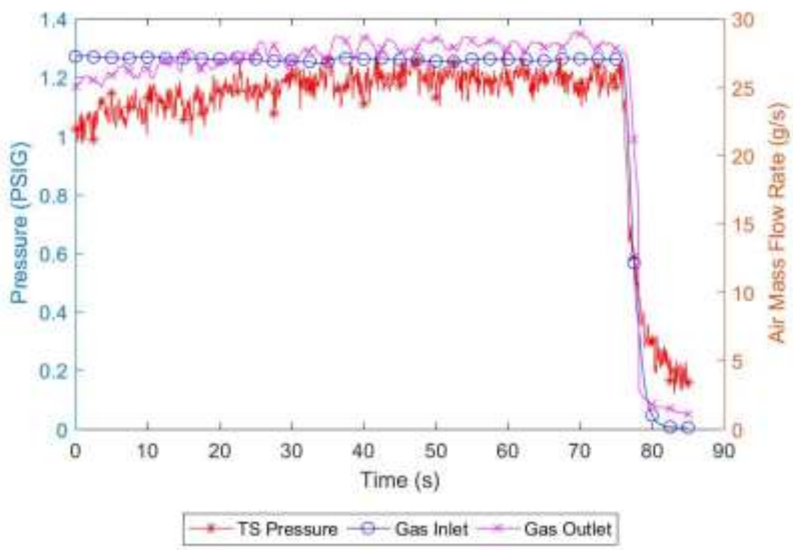

Figure F98: Pressure and gas inlet and outlet mass flow rate for test 2017_04_04_test_01.

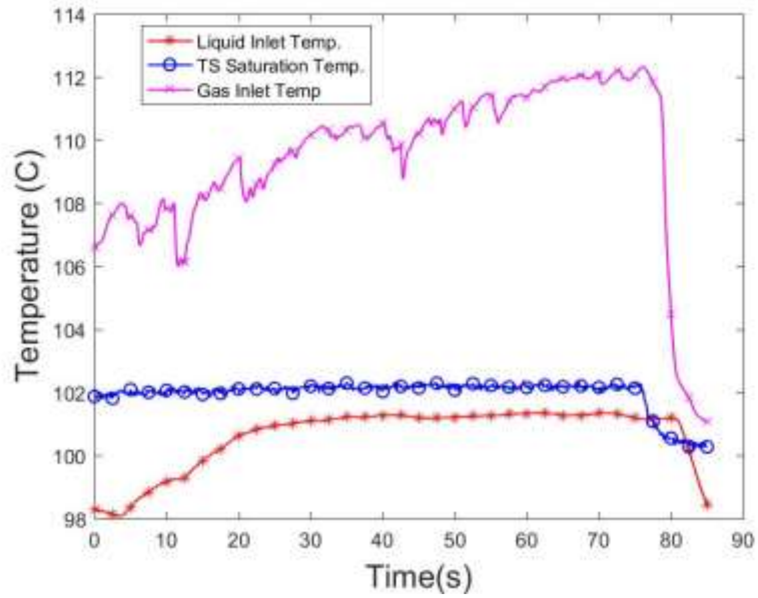

Figure F99: Temperature Profiles for test 2017_04_04_test_01.

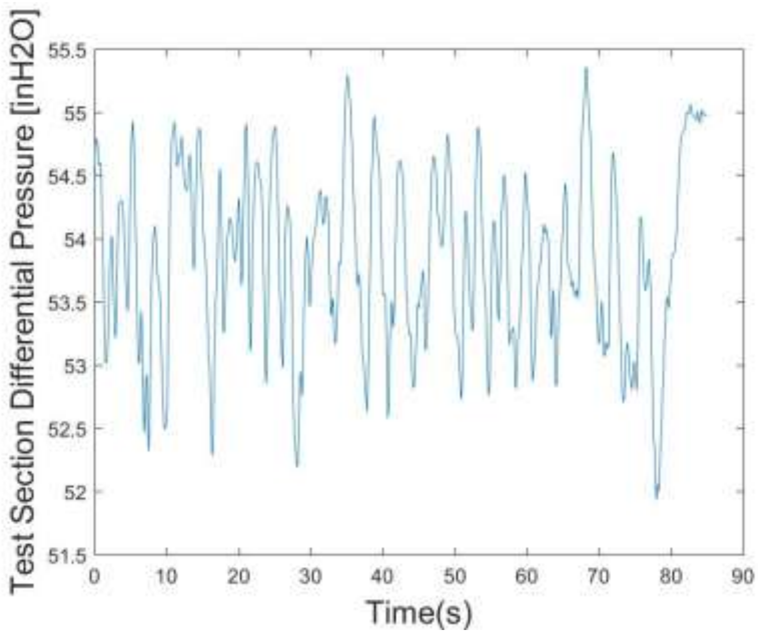

Figure F100: Test section differential pressure for test 2017_04_04_test_01.

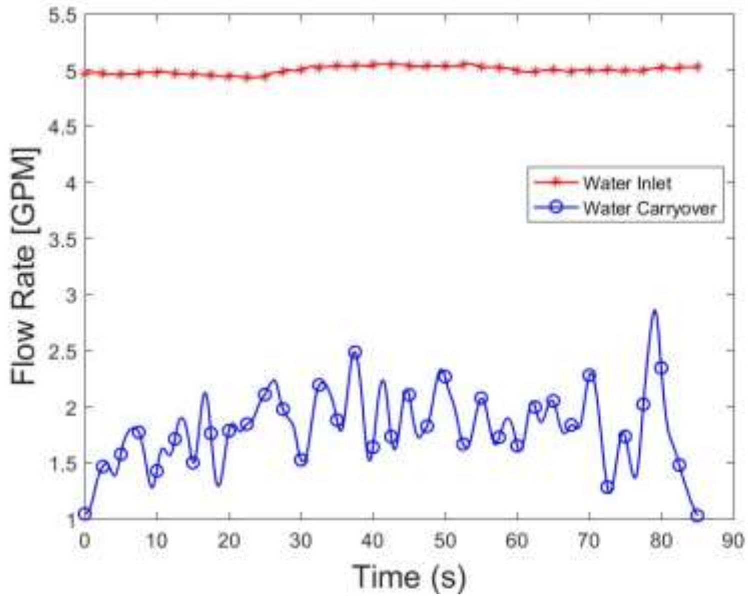

Figure F101: Water flow rates for 2017_04_04_test_01.

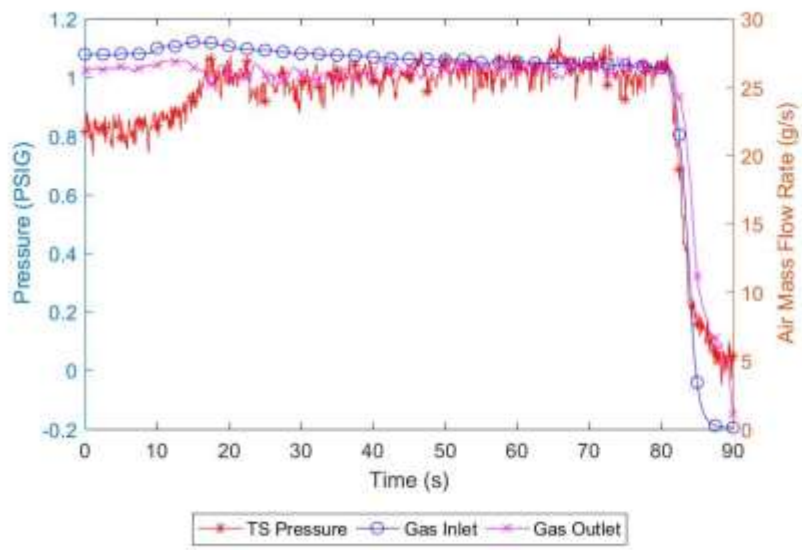

Figure F102: Pressure and gas inlet and outlet mass flow rate for test 2017_04_04_test_05.

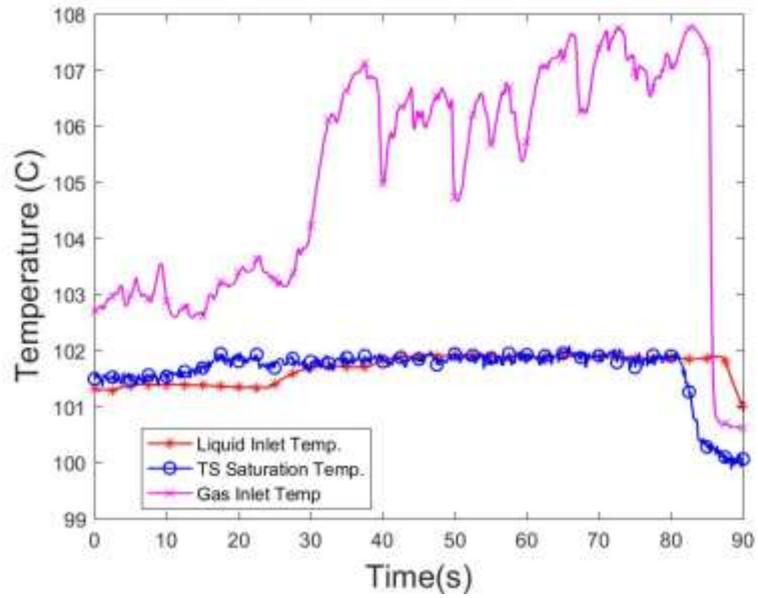

Figure F103: Temperature Profiles for test 2017_04_04_test_05.

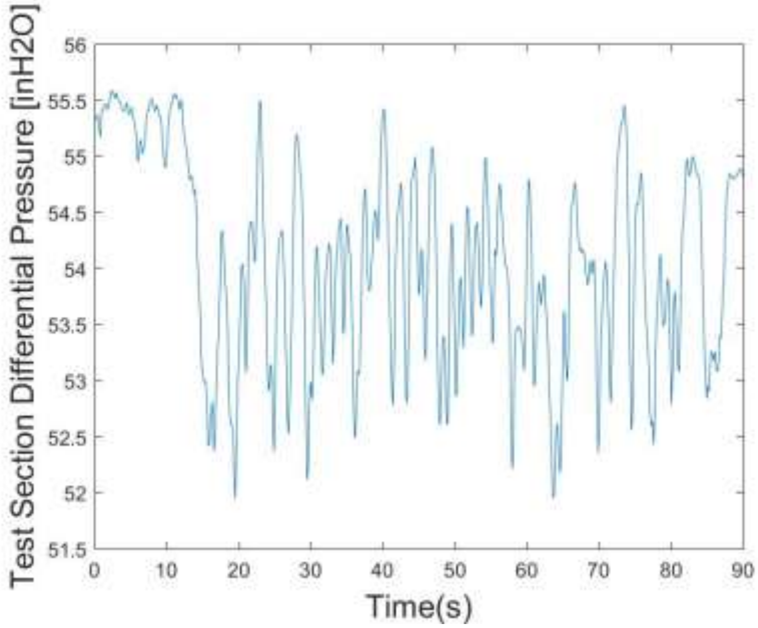

Figure F104: Test section differential pressure for test 2017_04_04_test_05.

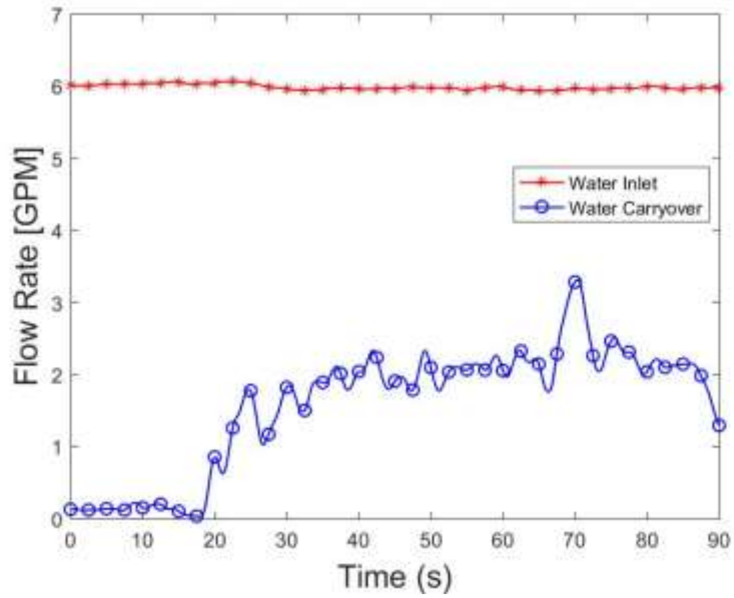

Figure F105: Water flow rates for 2017_04_04_test_05.

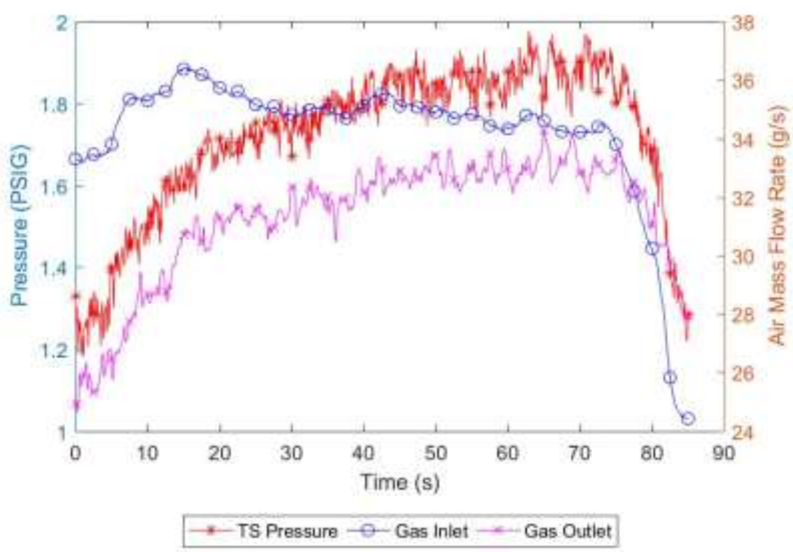

Figure F106: Pressure and gas inlet and outlet mass flow rate for test 2017_04_04_test_06.

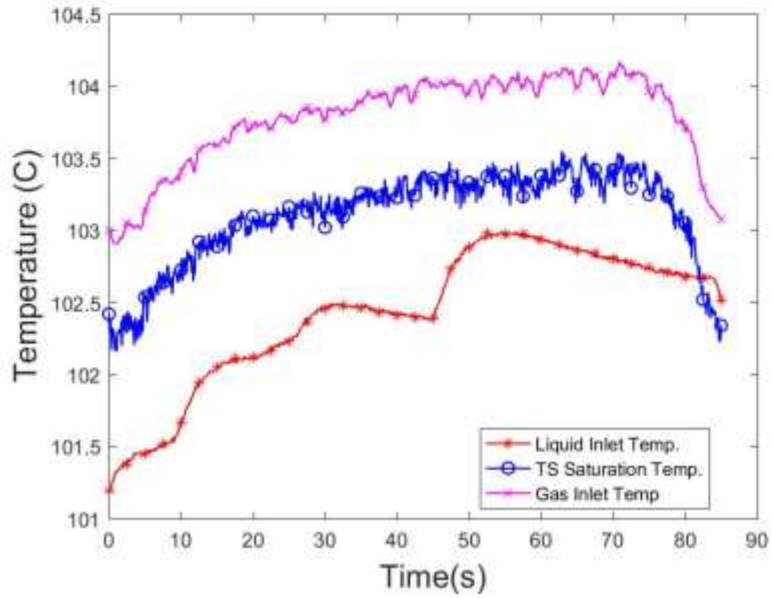

Figure F107: Temperature Profiles for test 2017_04_04_test_06.

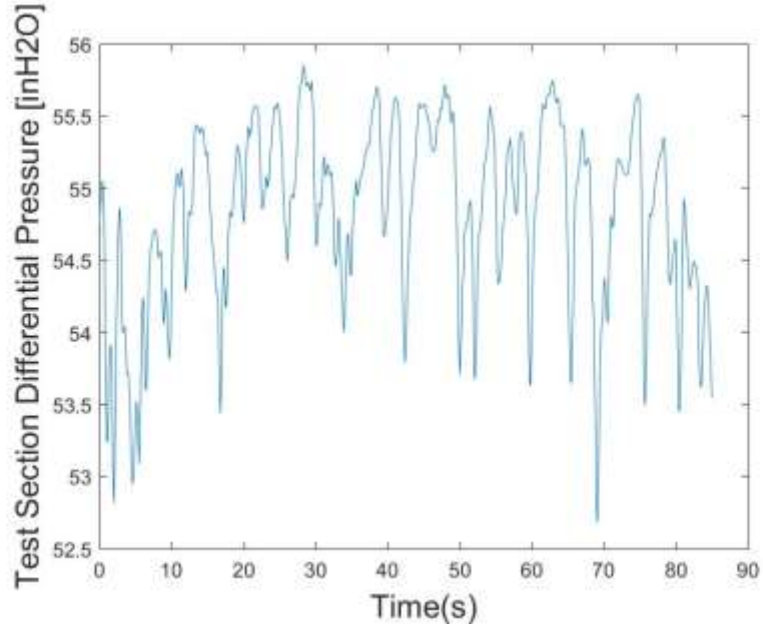

Figure F108: Test section differential pressure for test 2017_04_04_test_06.

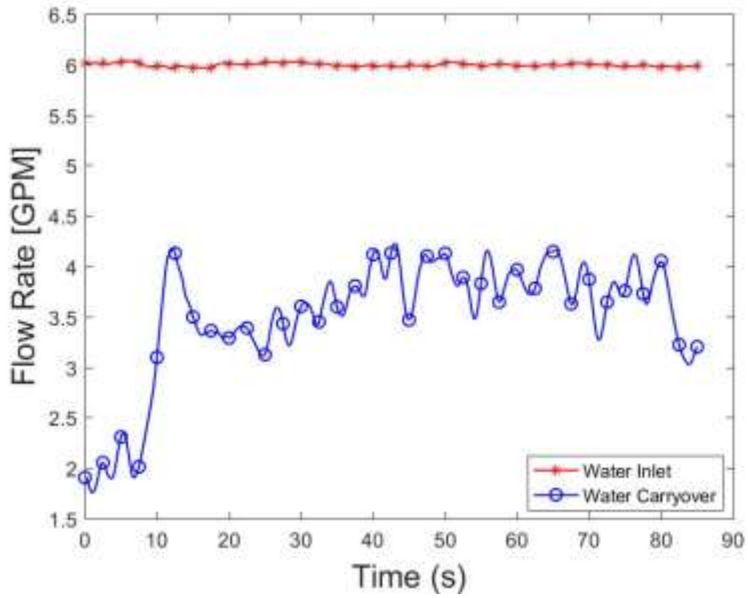

Figure F109: Water flow rates for 2017_04_04_test_06.

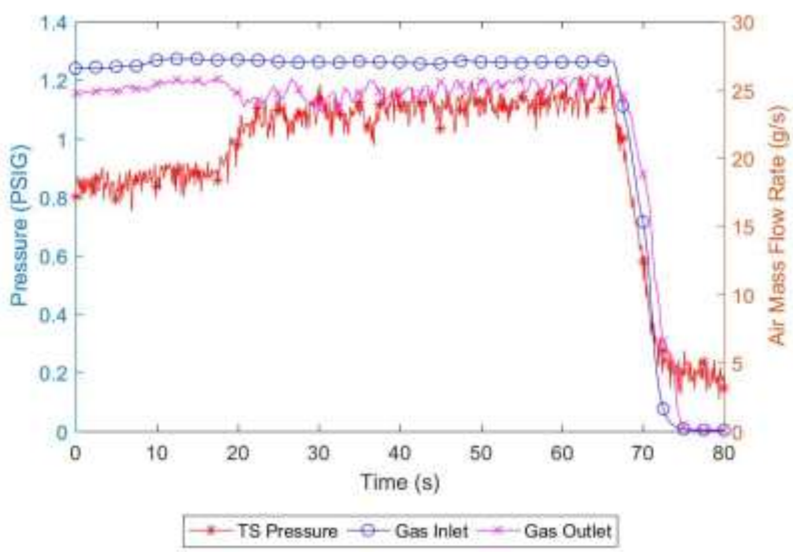

Figure F110: Pressure and gas inlet and outlet mass flow rate for test 2017_04_04_test_07.

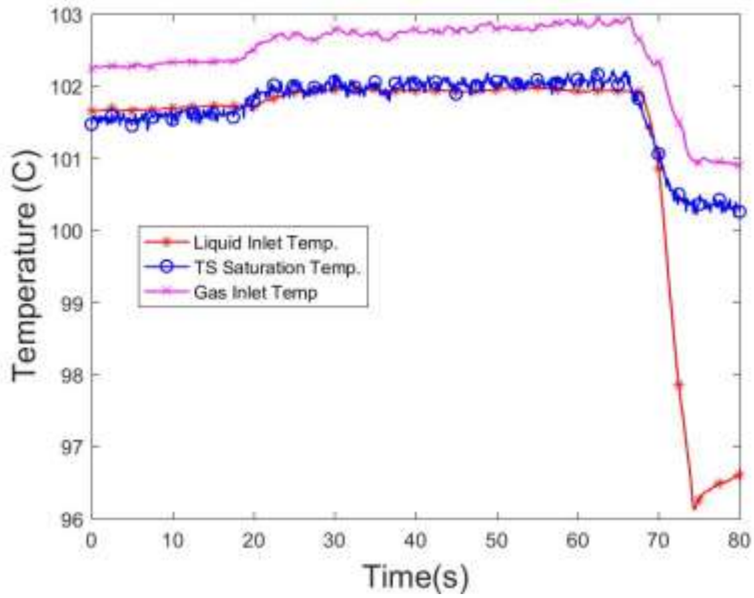

Figure F111: Temperature Profiles for test 2017_04_04_test_07.

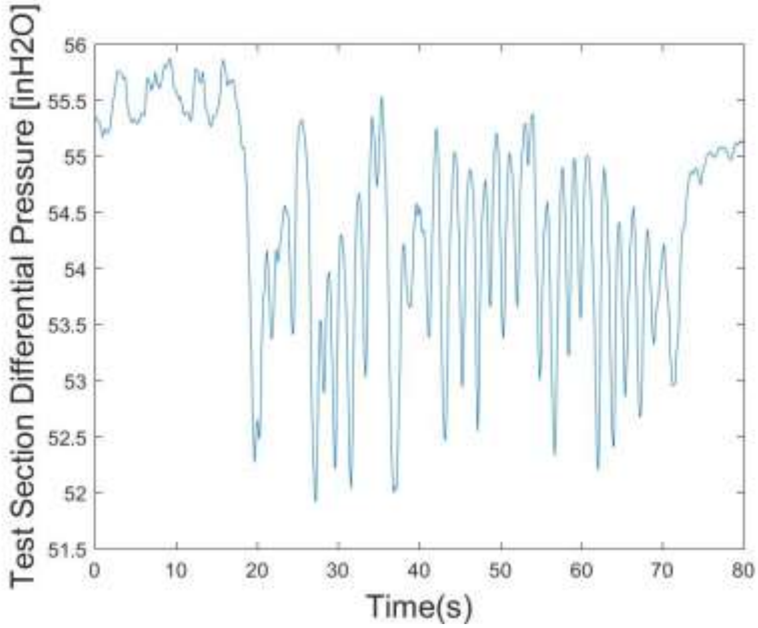

Figure F112: Test section differential pressure for test 2017_04_04_test_07.

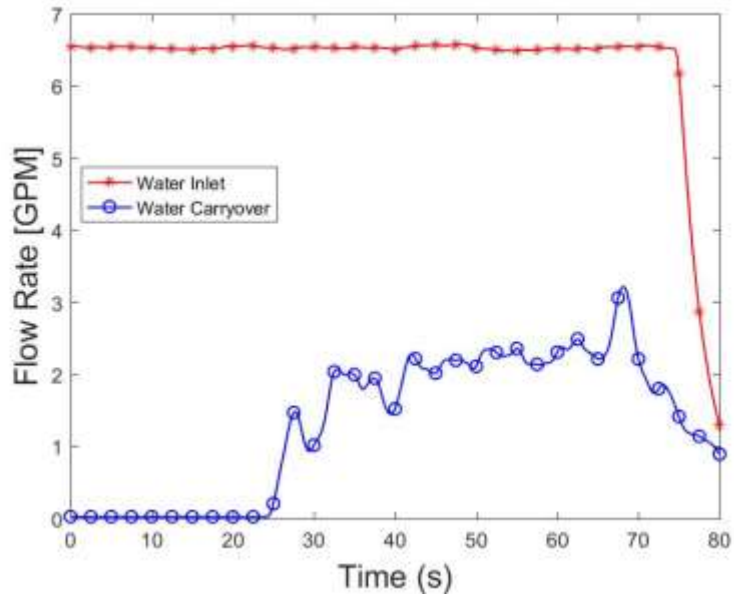

Figure F113: Water flow rates for 2017_04_04_test_07.

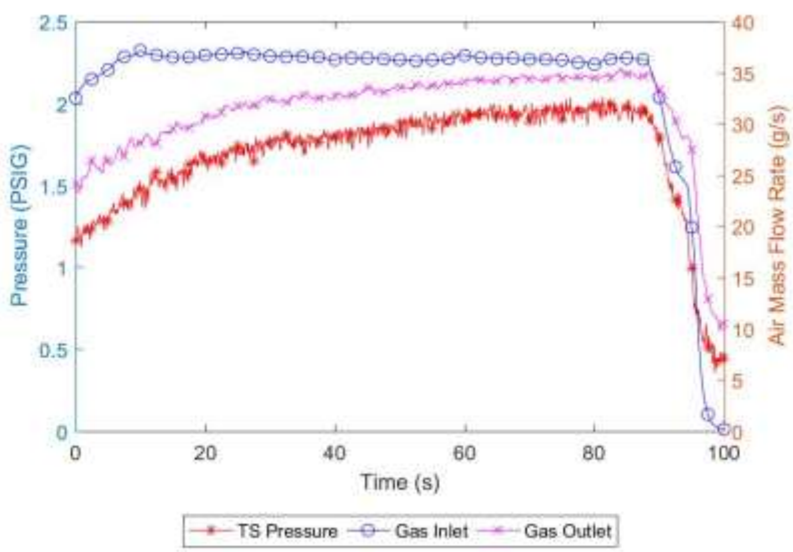

Figure F114: Pressure and gas inlet and outlet mass flow rate for test 2017_04_04_test_08.

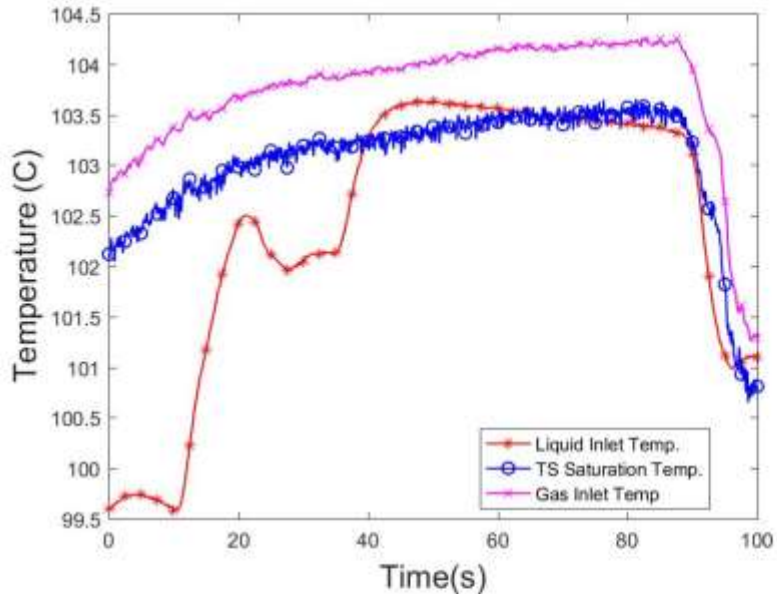

Figure F115: Temperature Profiles for test 2017_04_04_test_08.

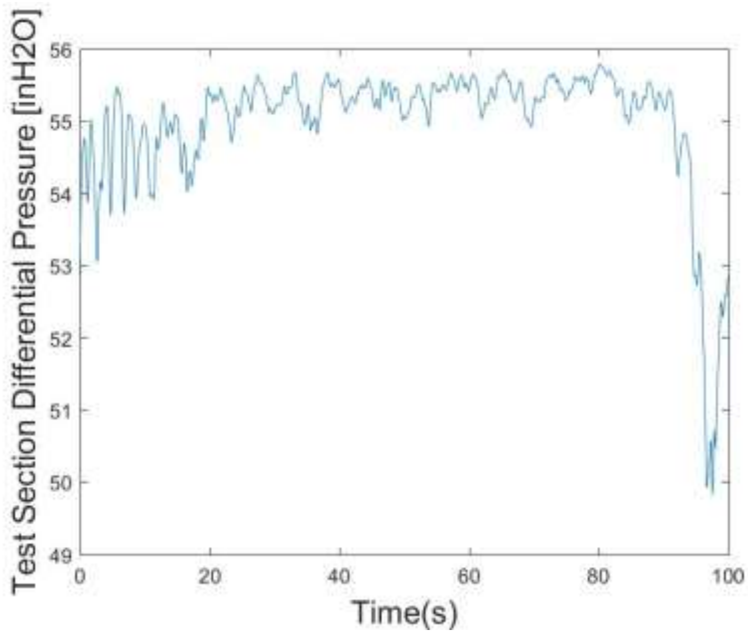

Figure F116: Test section differential pressure for test 2017_04_04_test_08.

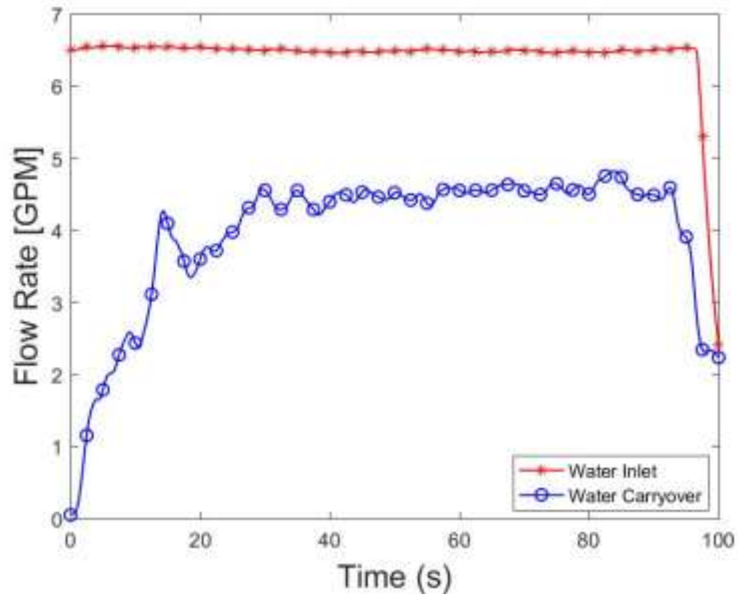

Figure F117: Water flow rates for 2017_04_04_test_08.

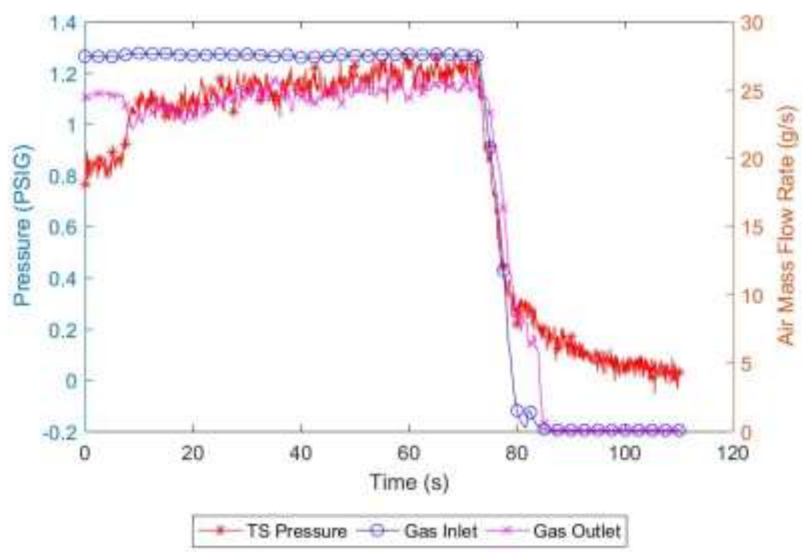

Figure F118: Pressure and gas inlet and outlet mass flow rate for test 2017_04_04_test_09.

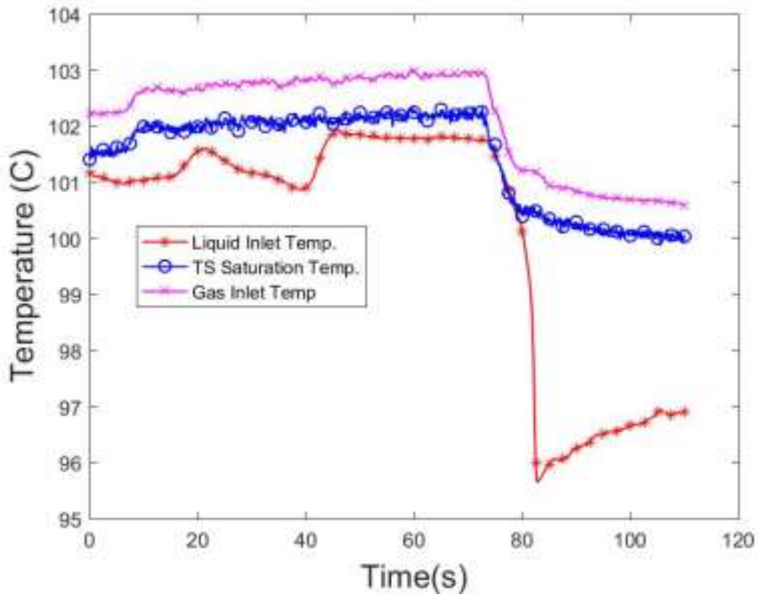

Figure F119: Temperature Profiles for test 2017_04_04_test_09.

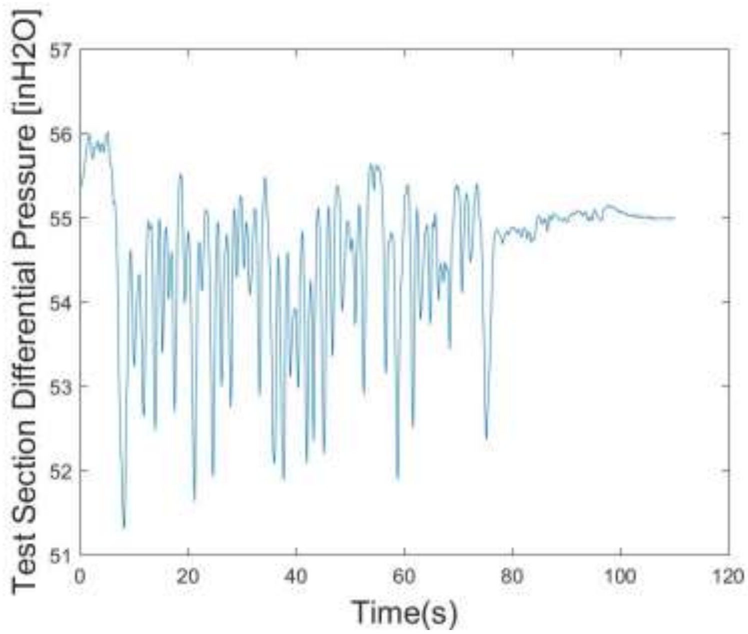

Figure F120: Test section differential pressure for test 2017_04_04_test_09.

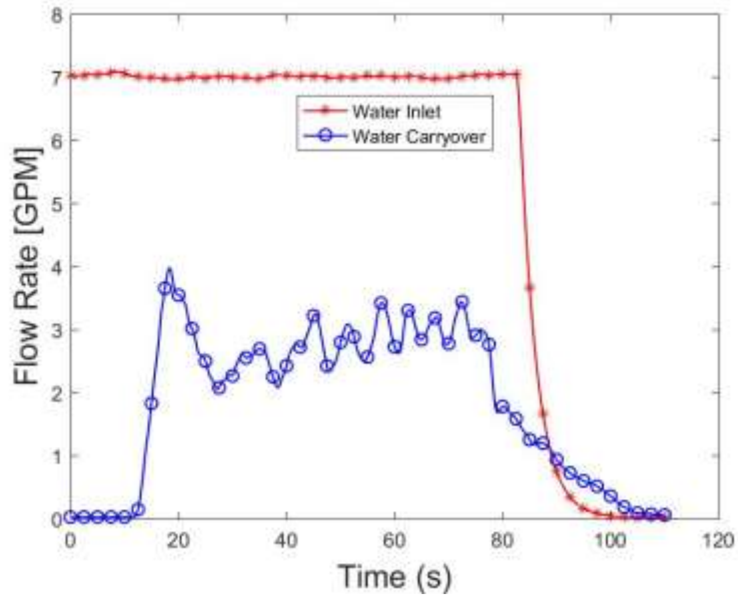

Figure F121: Water flow rates for 2017_04_04_test_09.

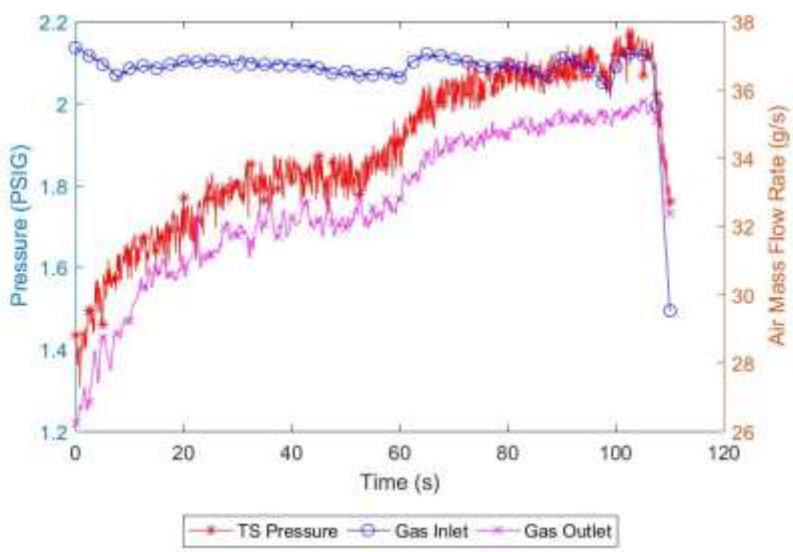

Figure F122: Pressure and gas inlet and outlet mass flow rate for test 2017_04_04_test_10.

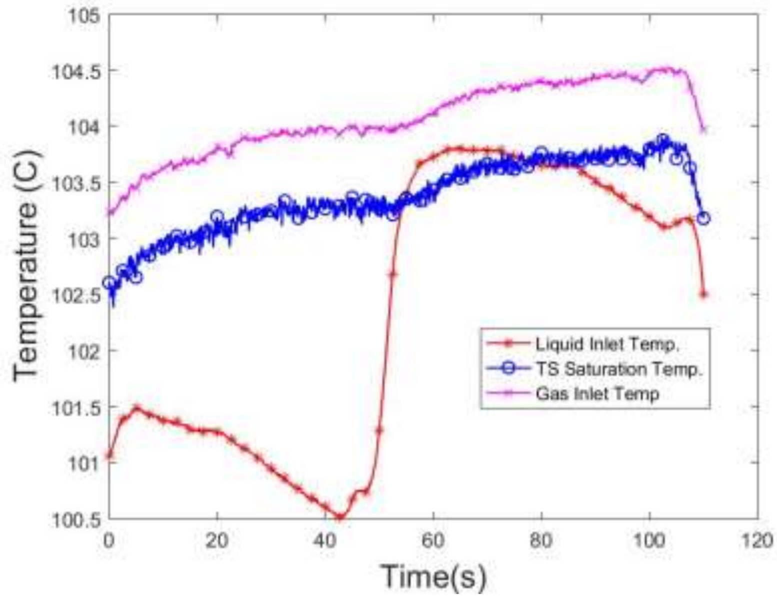

Figure F123: Temperature Profiles for test 2017_04_04_test_10.

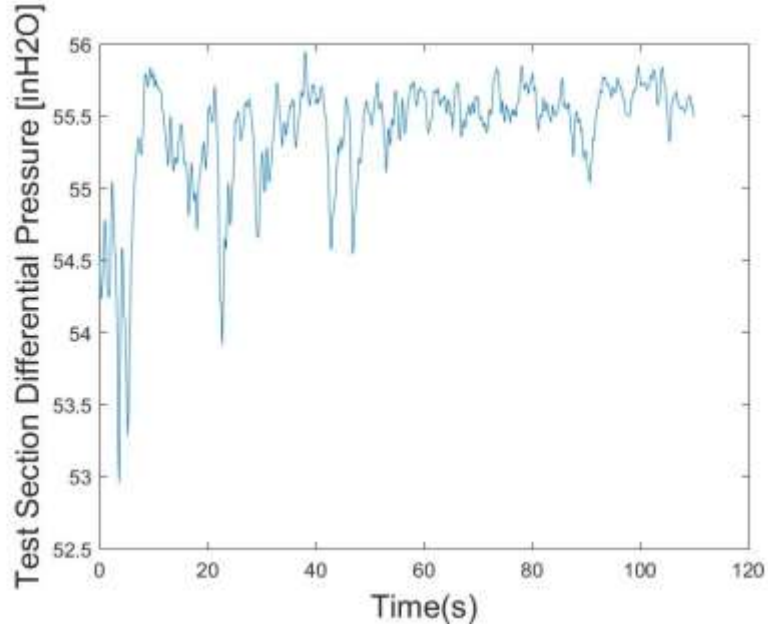

Figure F124: Test section differential pressure for test 2017_04_04_test_10.

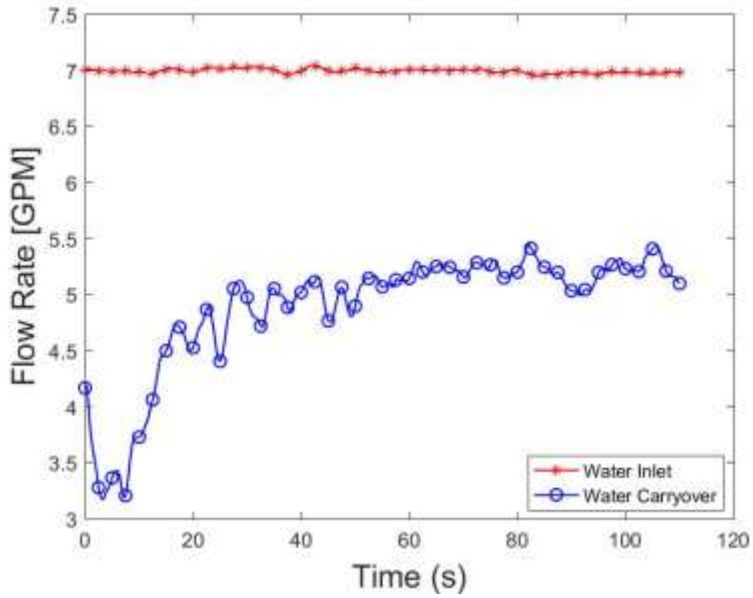

Figure F125: Water flow rates for 2017_04_04_test_10.

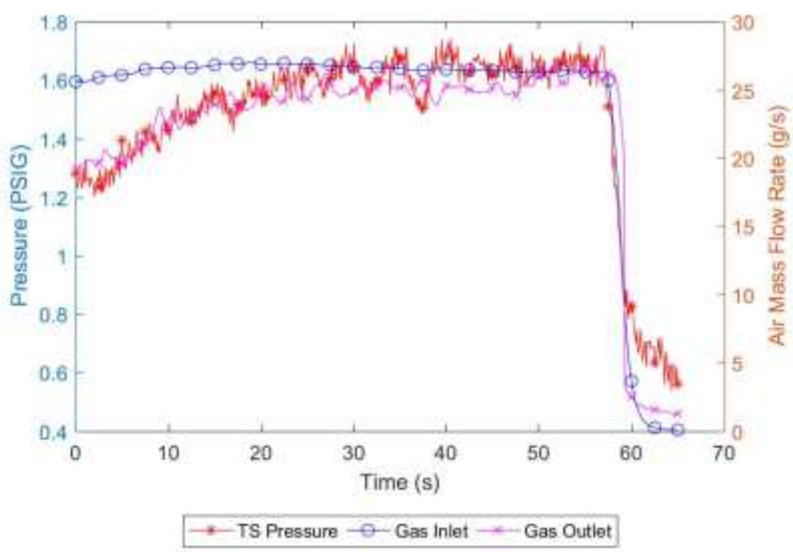

Figure F126: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_01.

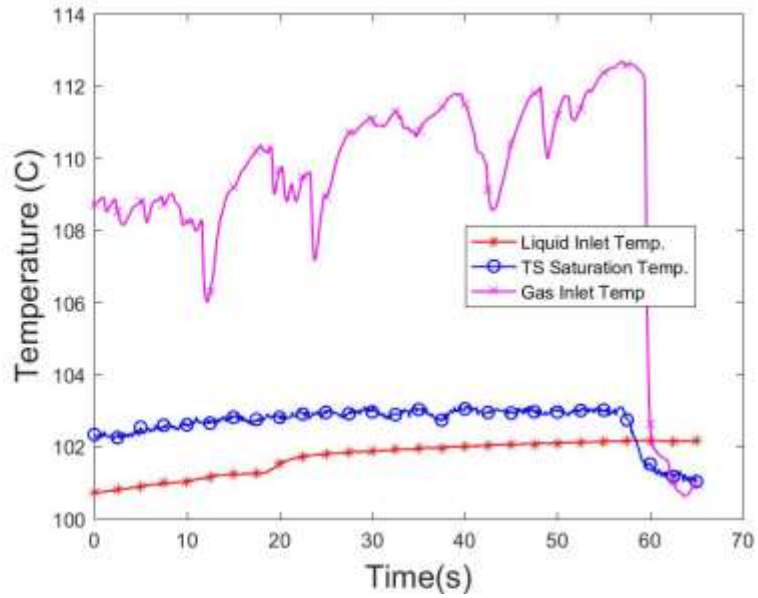

Figure F127: Temperature Profiles for test 2017_04_06_test_01.

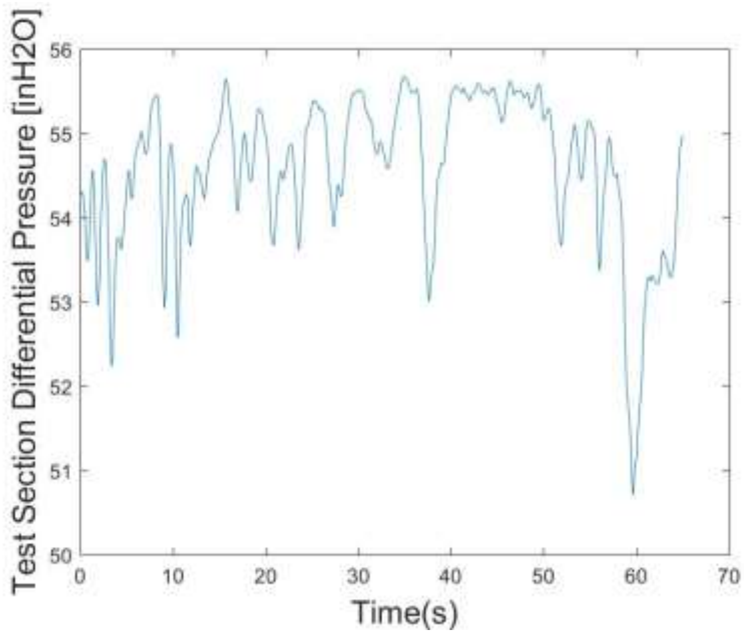

Figure F128: Test section differential pressure for test 2017_04_06_test_01.

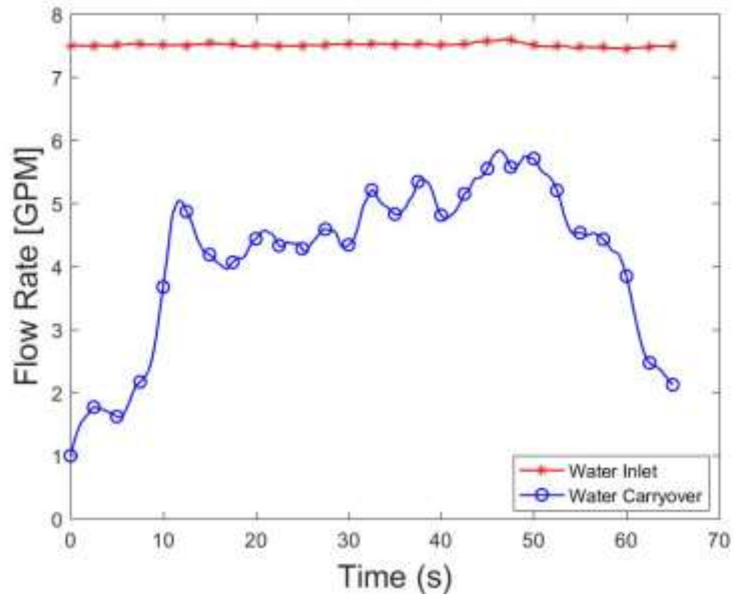

Figure F129: flow rates for 2017_04_06_test_01.

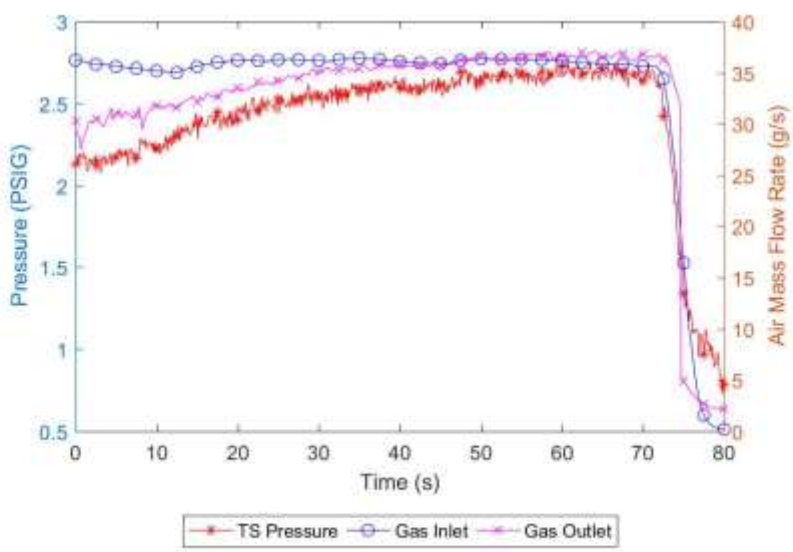

Figure F130: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_02.

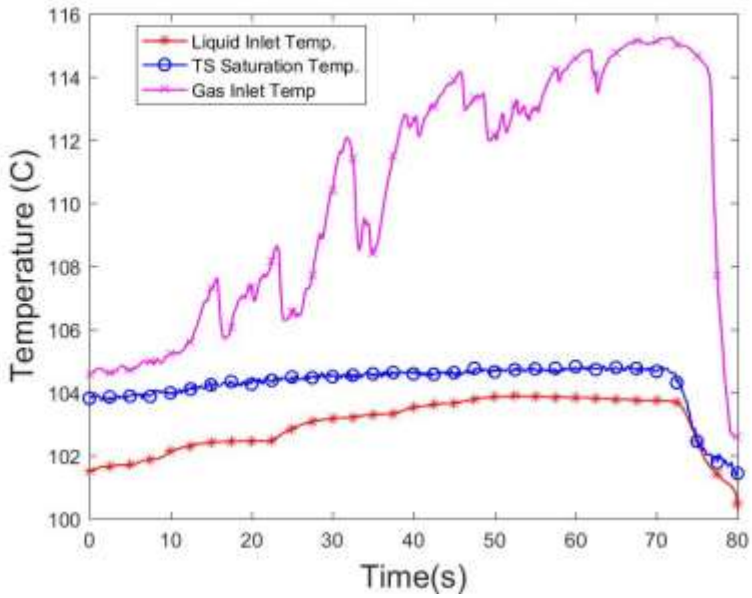

Figure F131: Temperature Profiles for test 2017_04_06_test_02.

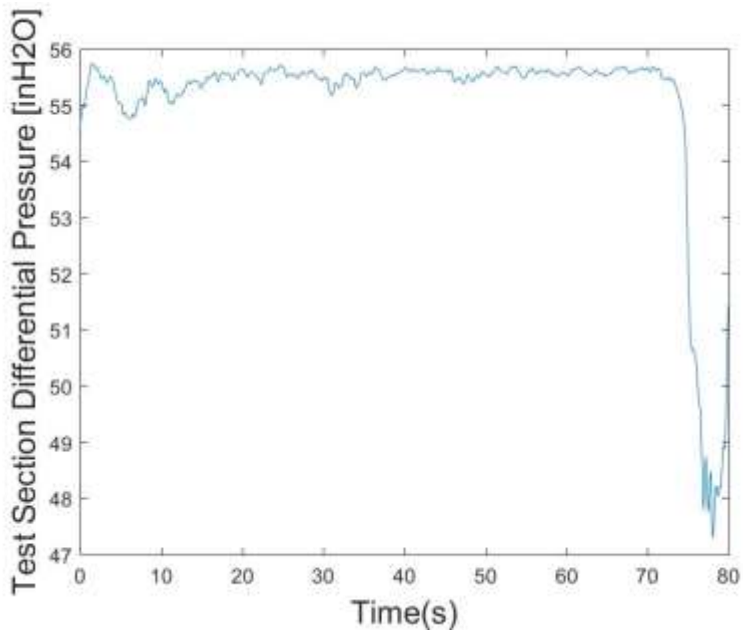

Figure F132: Test section differential pressure for test 2017_04_06_test_02.

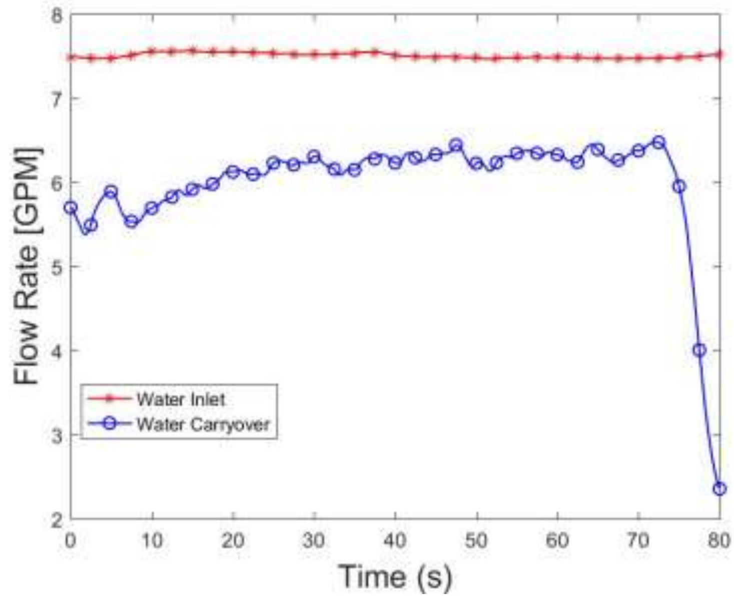

Figure F133: flow rates for 2017_04_06_test_02.

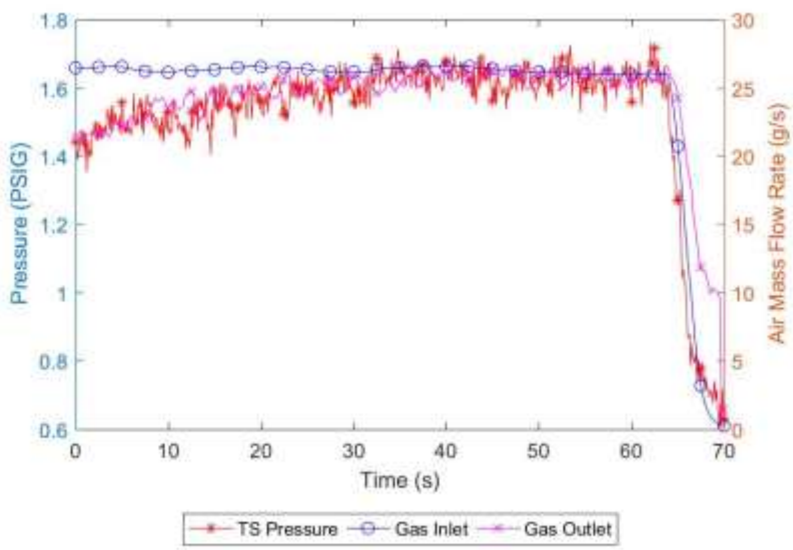

Figure F134: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_03.

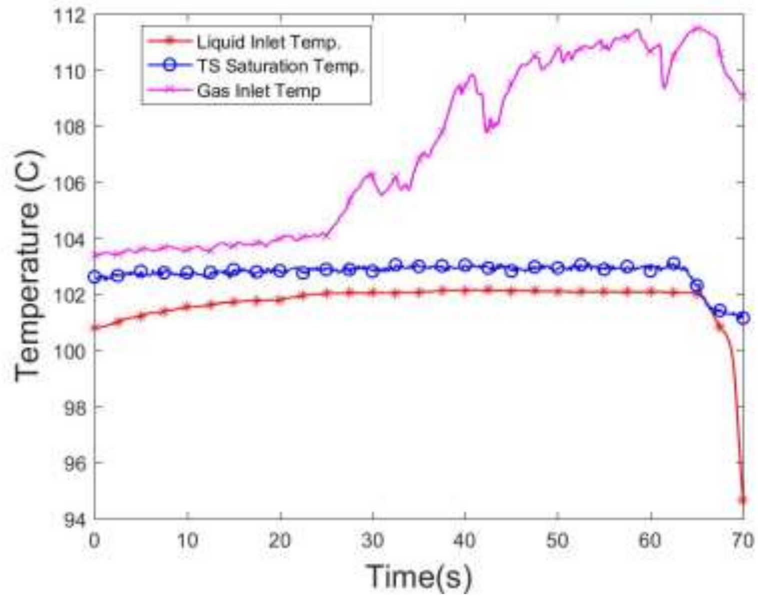

Figure F135: Temperature Profiles for test 2017_04_06_test_03.

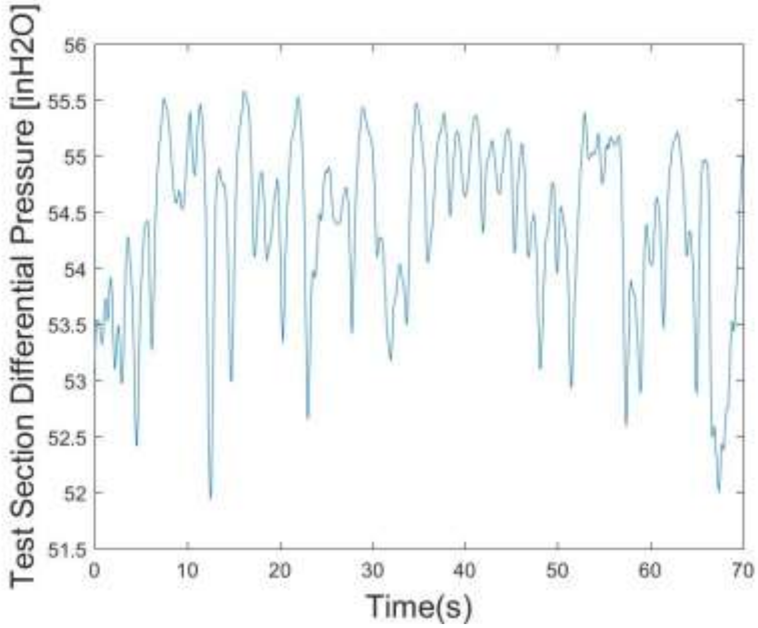

Figure F136: Test section differential pressure for test 2017_04_06_test_03.

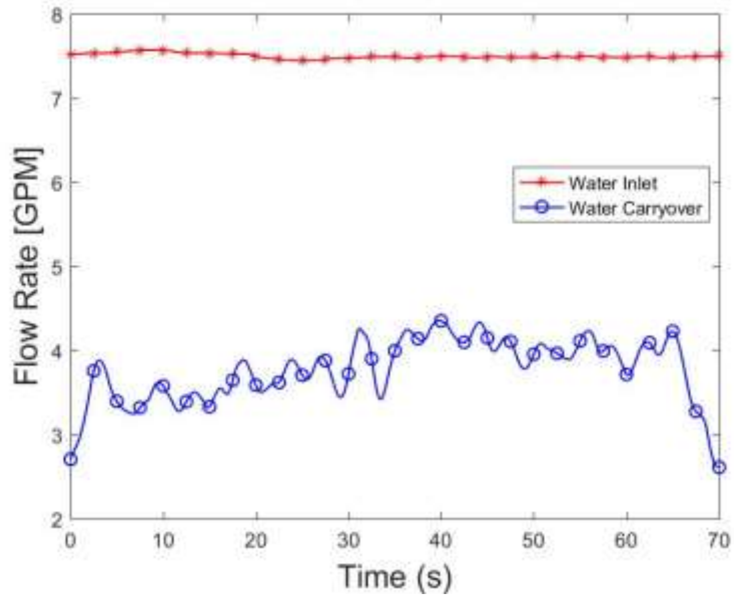

Figure F137: flow rates for 2017_04_06_test_03.

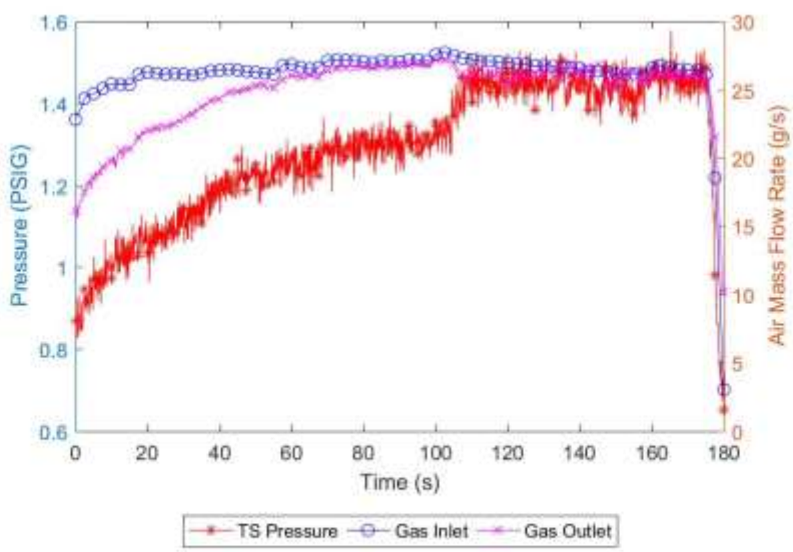

Figure F138: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_04.

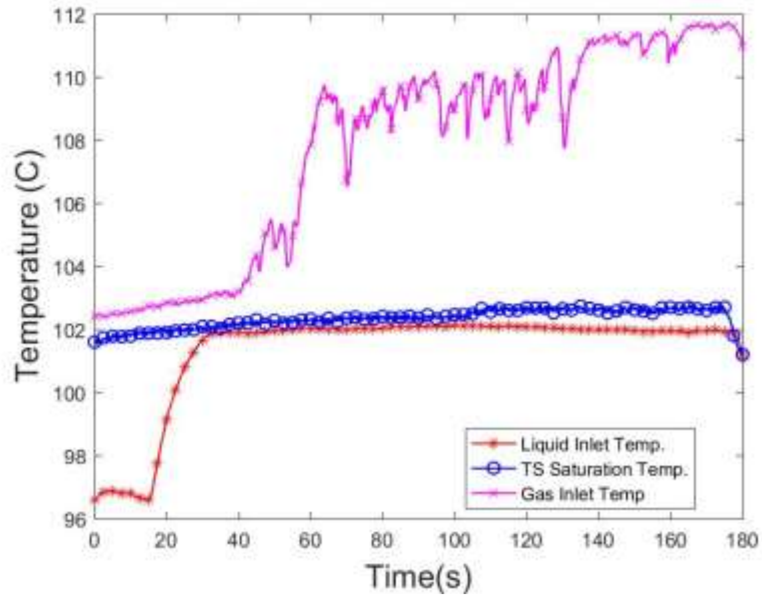

Figure F139: Temperature Profiles for test 2017_04_06_test_04.

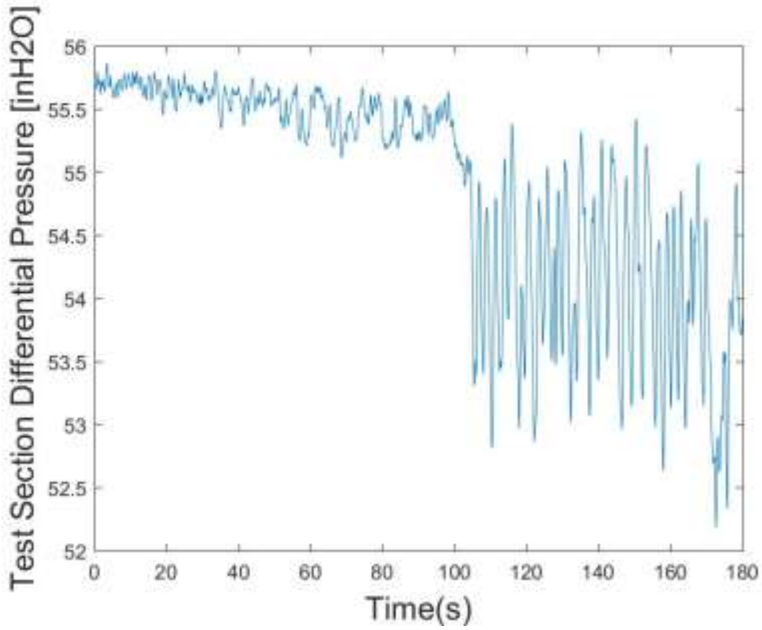

Figure F140: Test section differential pressure for test 2017_04_06_test_04.

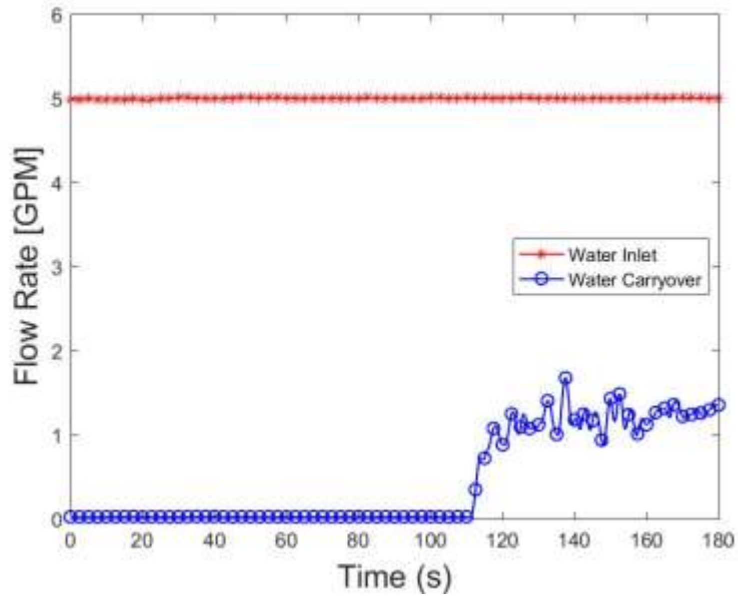

Figure F141: flow rates for 2017_04_06_test_04.

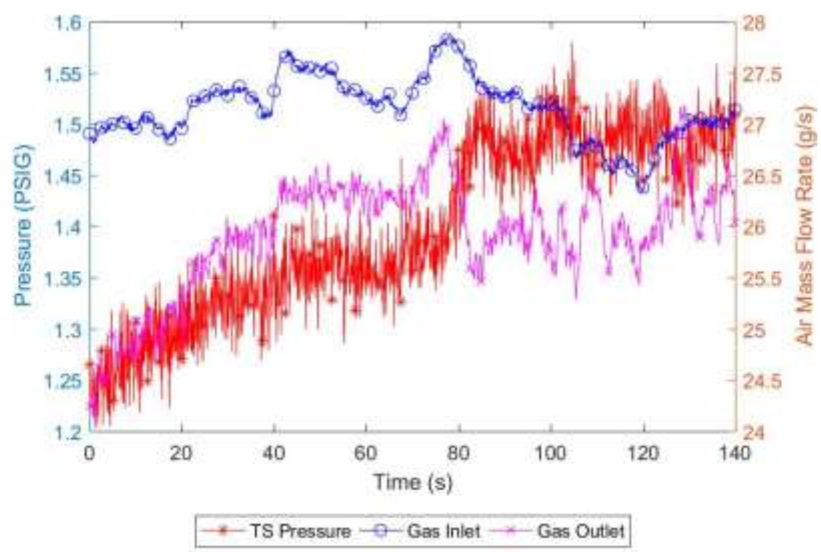

Figure F142: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_05.

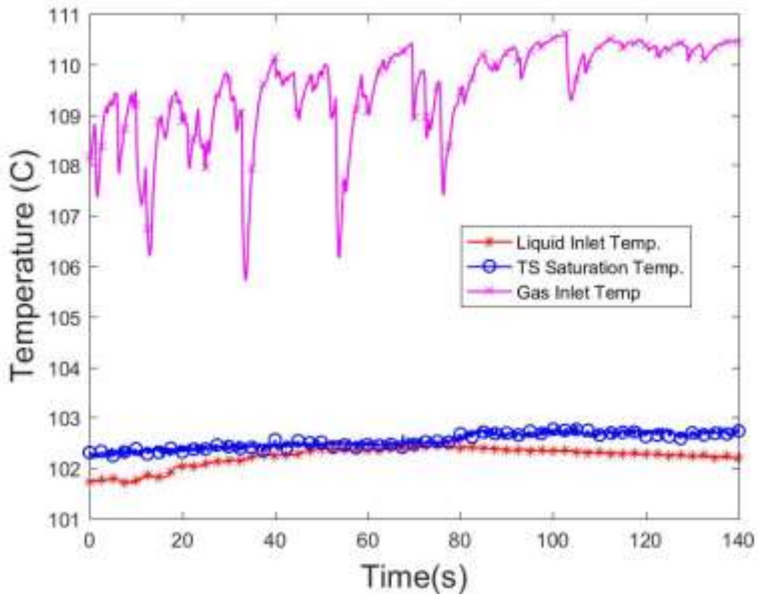

Figure F143: Temperature Profiles for test 2017_04_06_test_05.

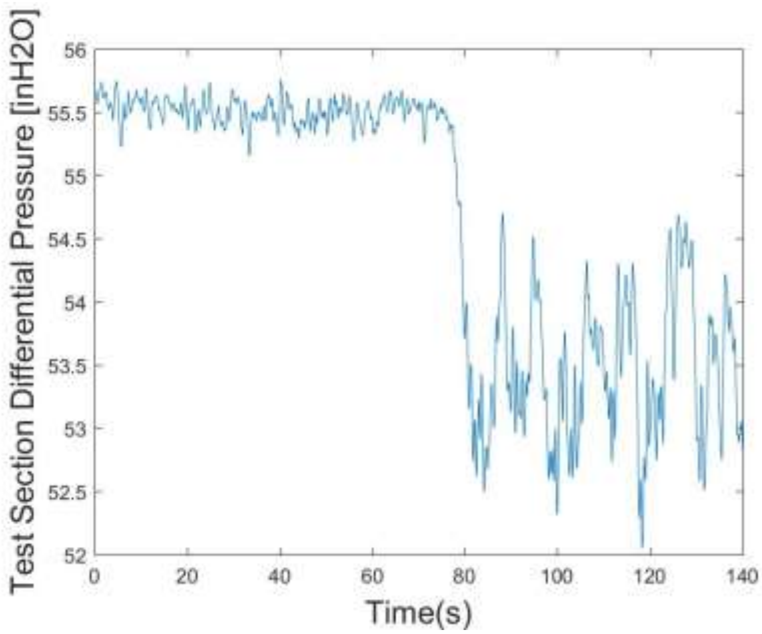

Figure F144: Test section differential pressure for test 2017_04_06_test_05.

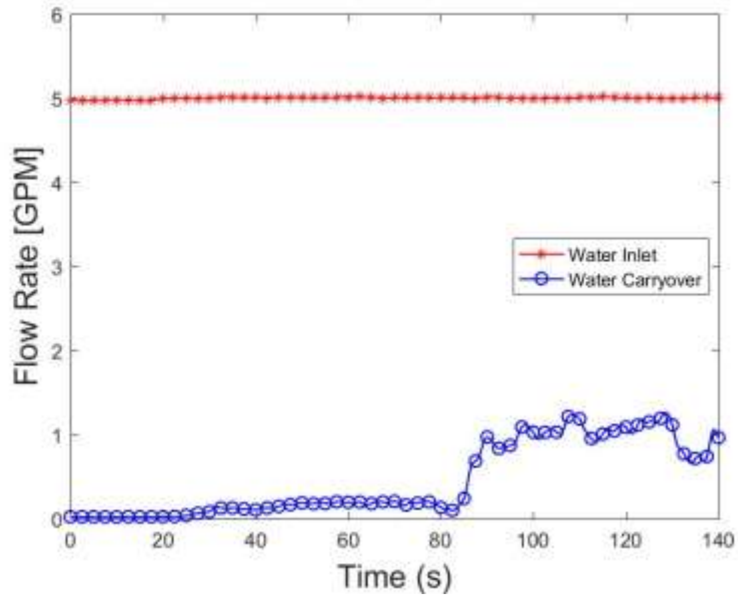

Figure F145: flow rates for 2017_04_06_test_05.

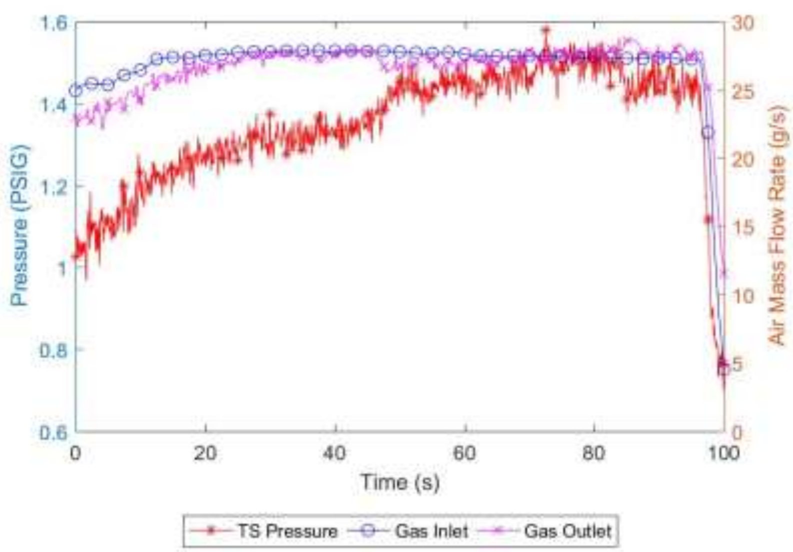

Figure F146: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_08.

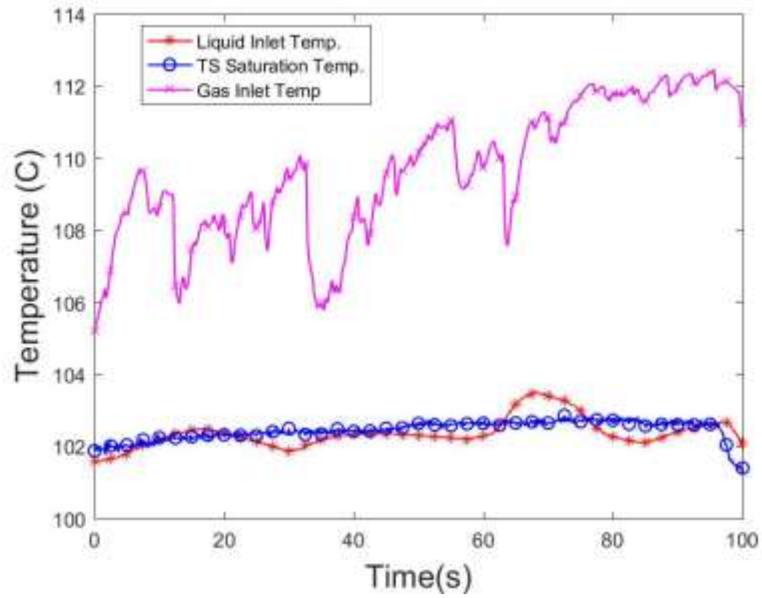

Figure F147: Temperature Profiles for test 2017_04_06_test_08.

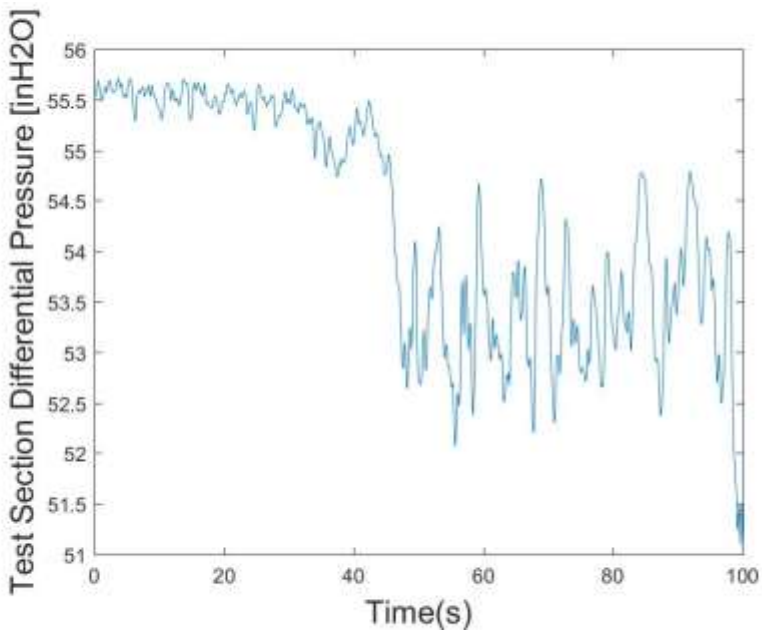

Figure F148: Test section differential pressure for test 2017_04_06_test_08.

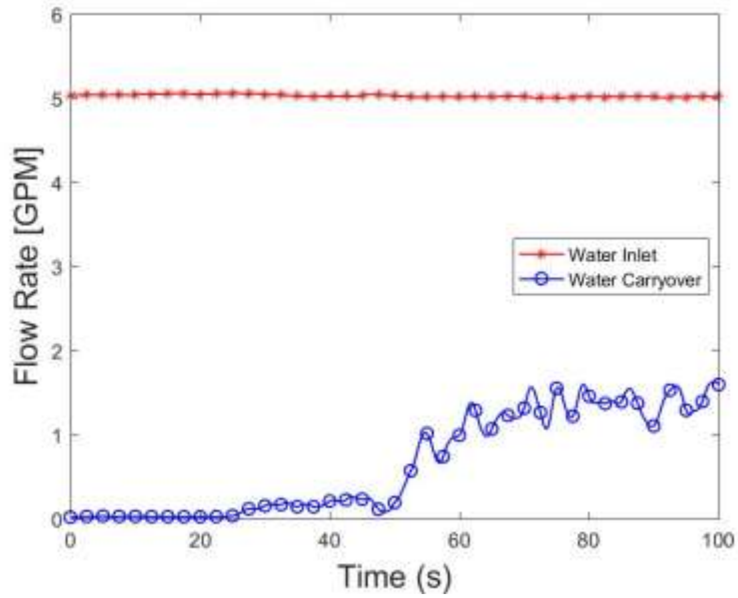

Figure F149: flow rates for 2017_04_06_test_08.

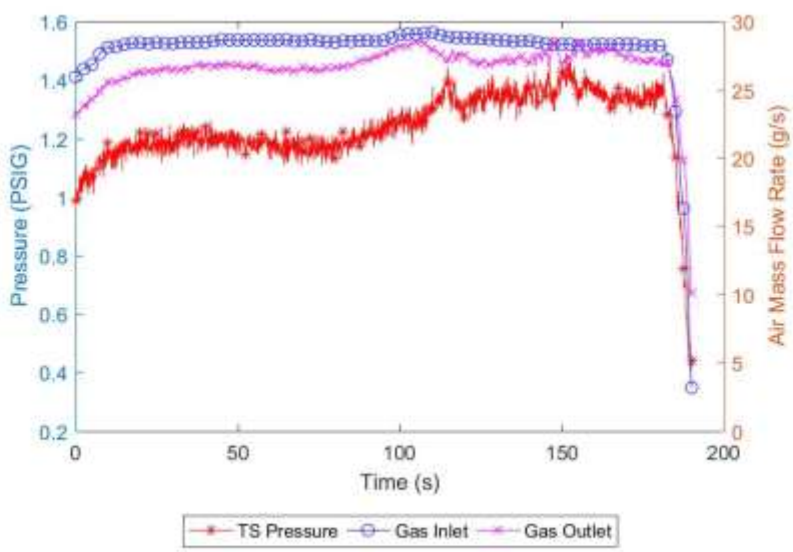

Figure F150: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_12.

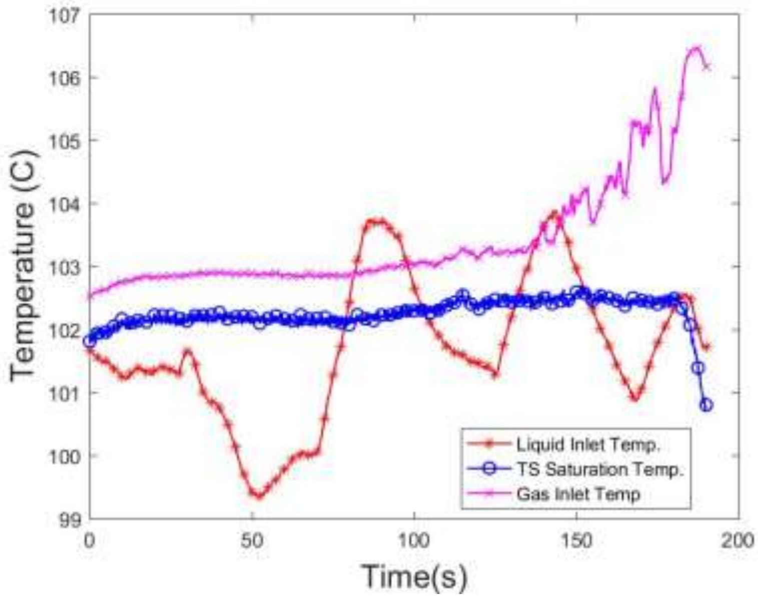

Figure F151: Temperature Profiles for test 2017_04_06_test_12.

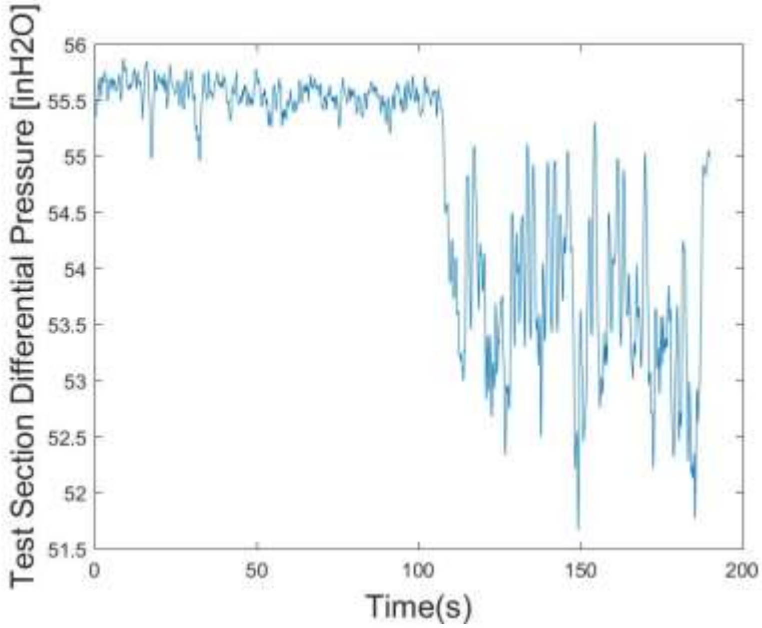

Figure F152: Test section differential pressure for test 2017_04_06_test_12.

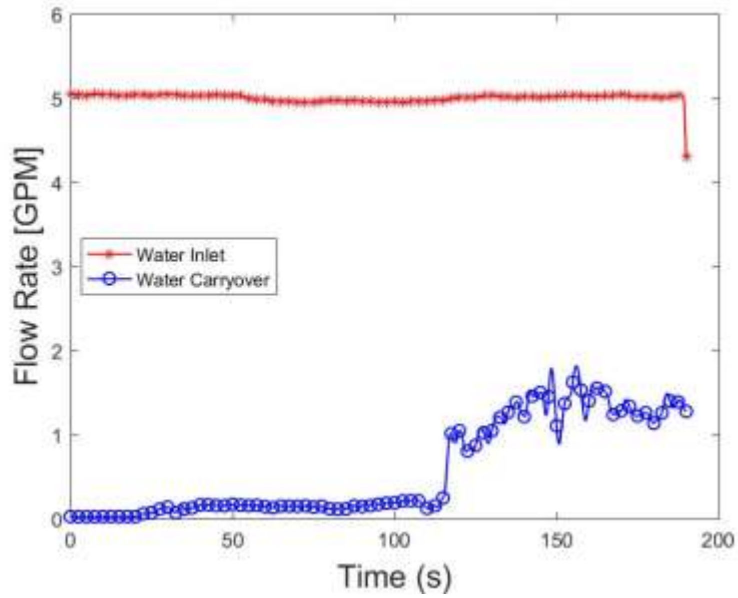

Figure F153: flow rates for 2017_04_06_test_12.

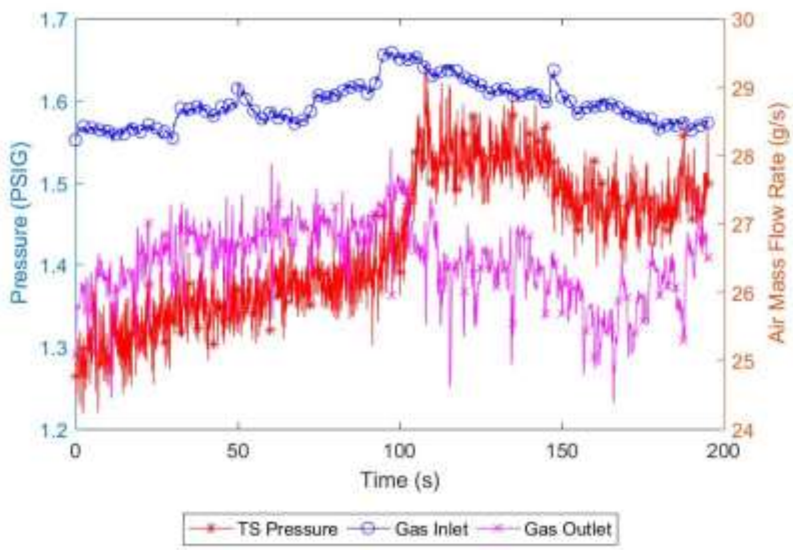

Figure F154: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_13.

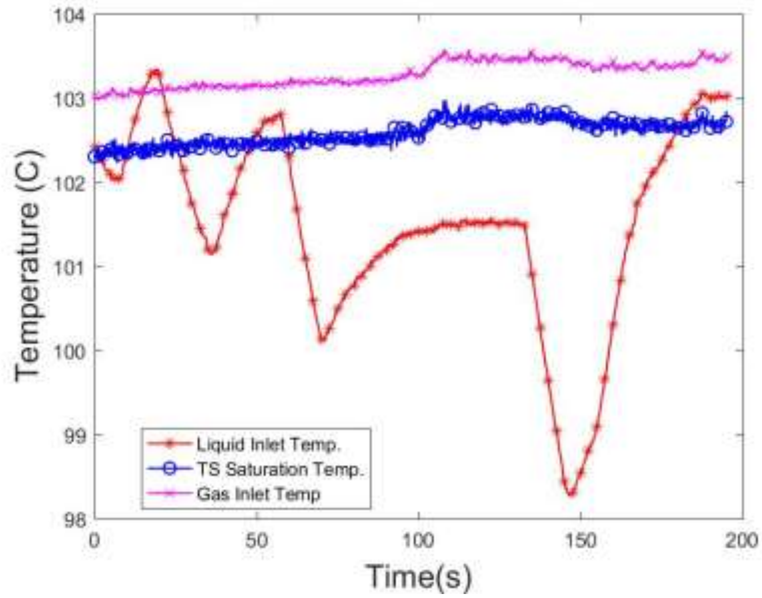

Figure F155: Temperature Profiles for test 2017_04_06_test_13.

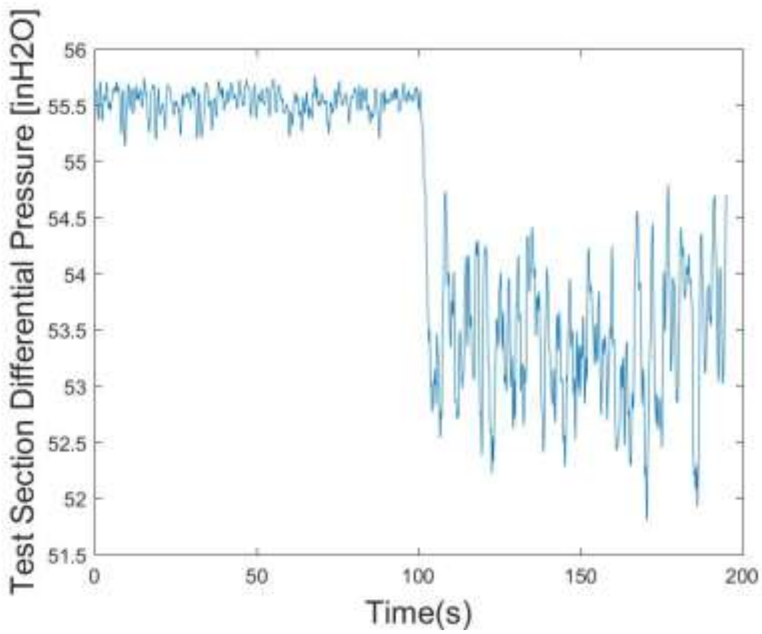

Figure F156: Test section differential pressure for test 2017_04_06_test_13.

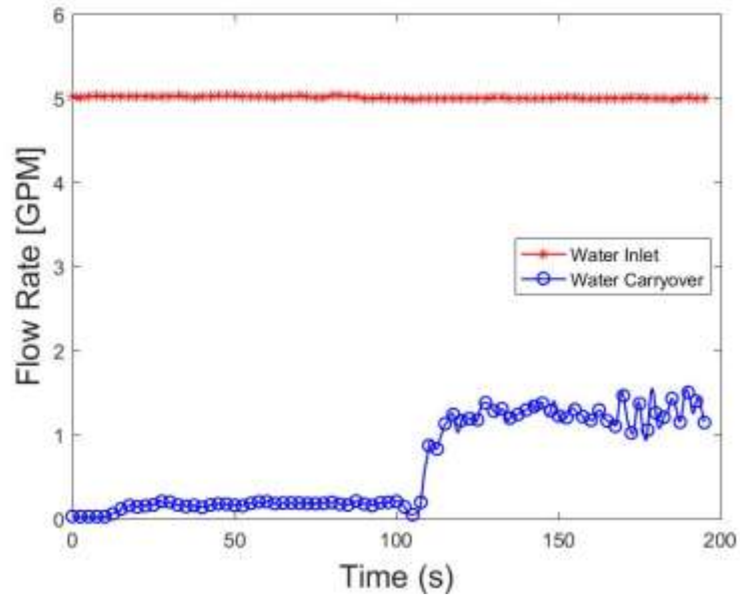

Figure F157: flow rates for 2017_04_06_test_13.

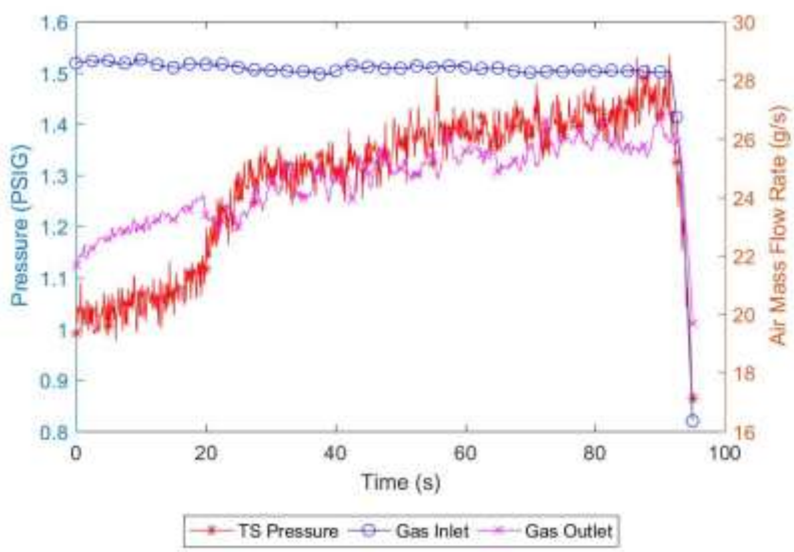

Figure F158: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_14.

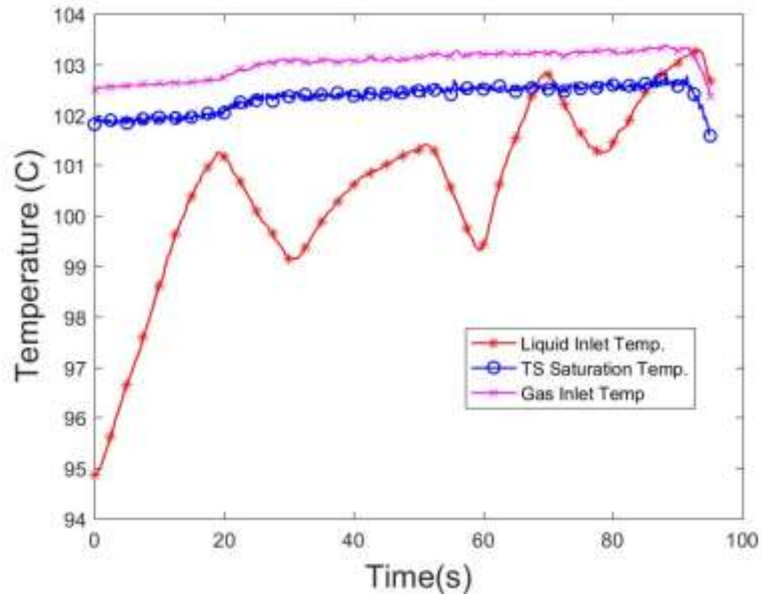

Figure F159: Temperature Profiles for test 2017_04_06_test_14.

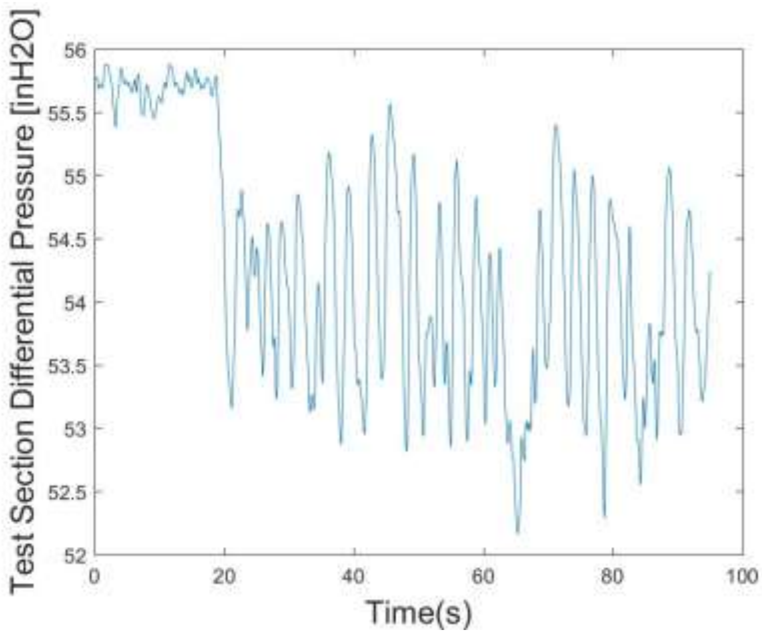

Figure F160: Test section differential pressure for test 2017_04_06_test_14.

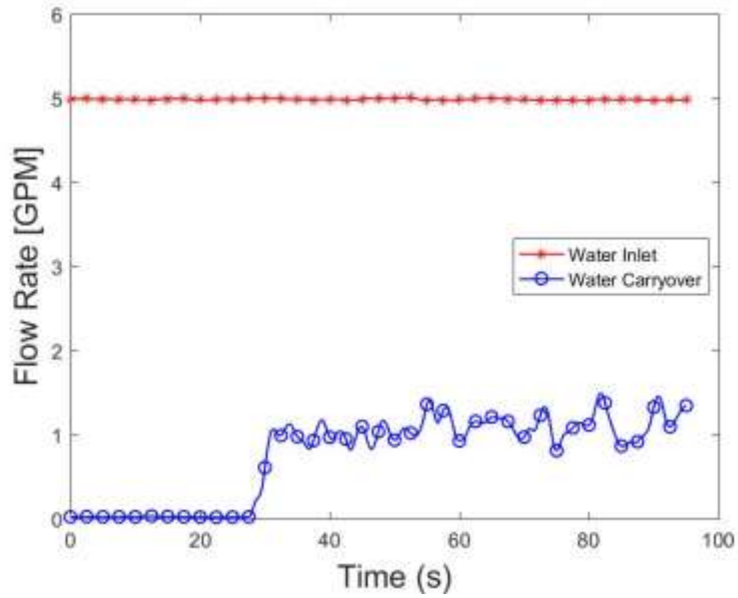

Figure F161: flow rates for 2017_04_06_test_14.

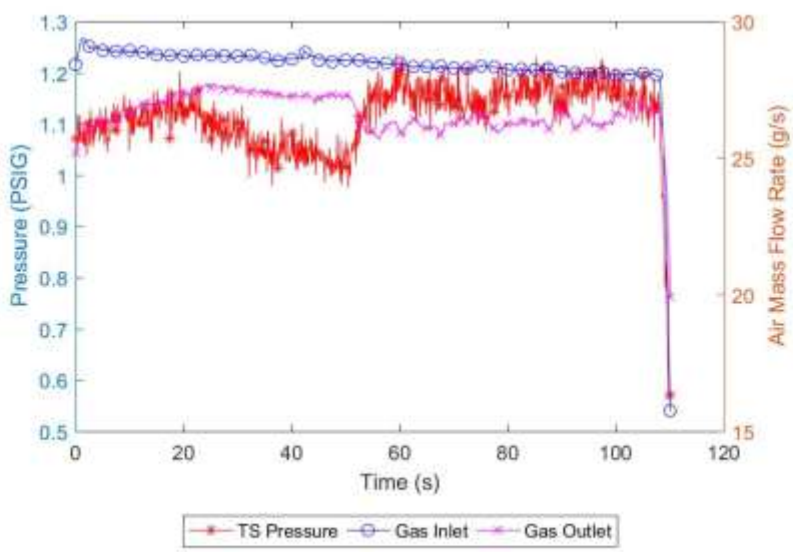

Figure F162: Pressure and gas inlet and outlet mass flow rate for test 2017_04_06_test_15.

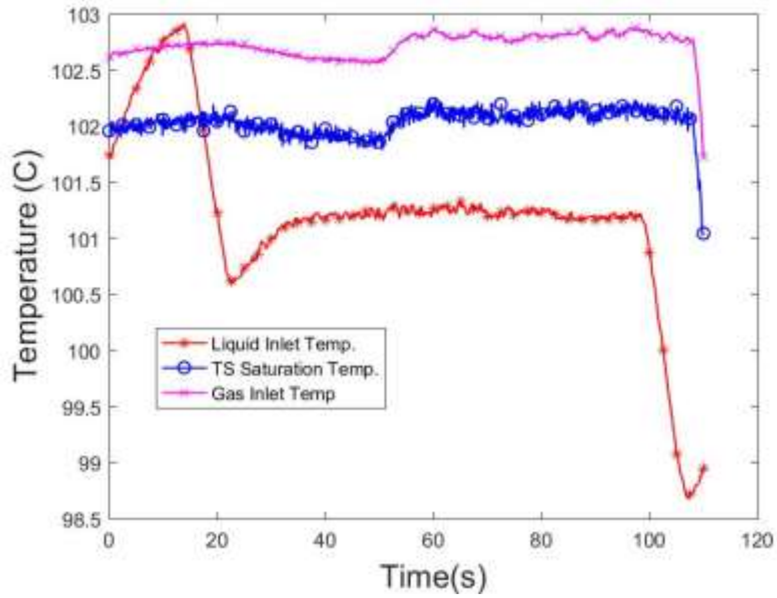

Figure F163: Temperature Profiles for test 2017_04_06_test_15.

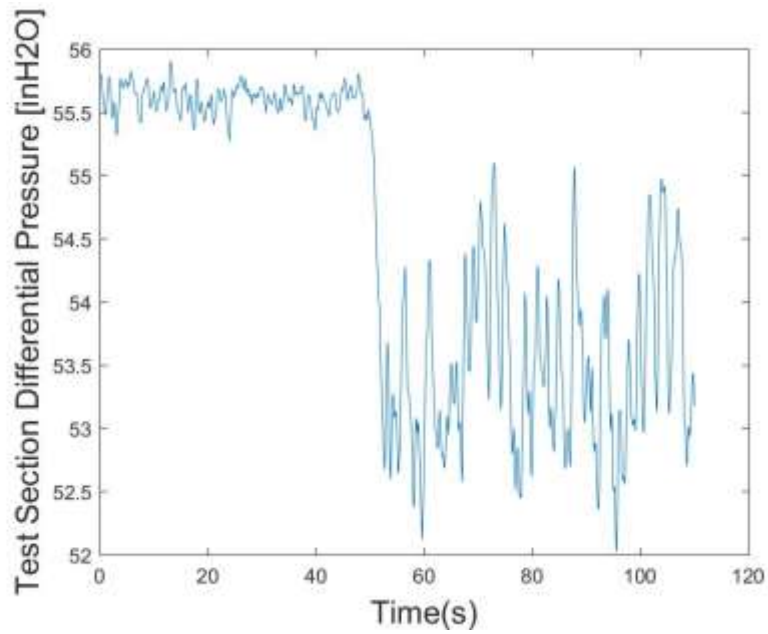

Figure F164: Test section differential pressure for test 2017_04_06_test_15.

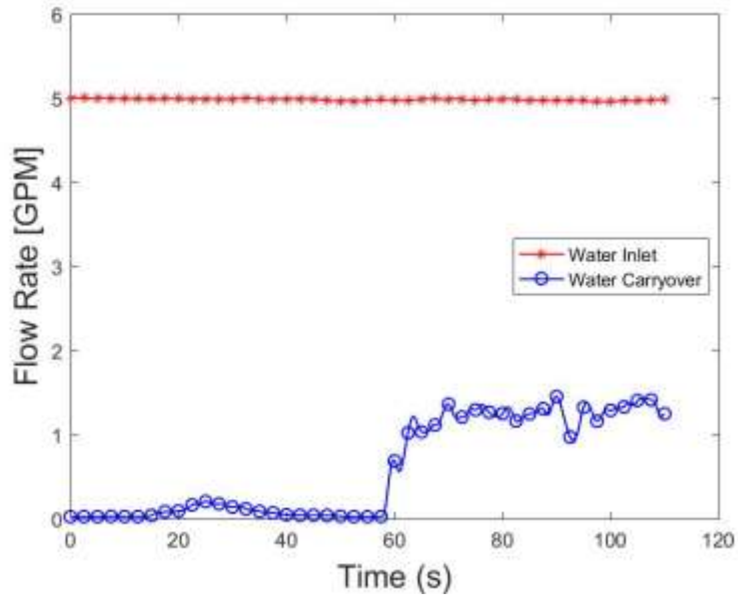

Figure F165: flow rates for 2017_04_06_test_15.

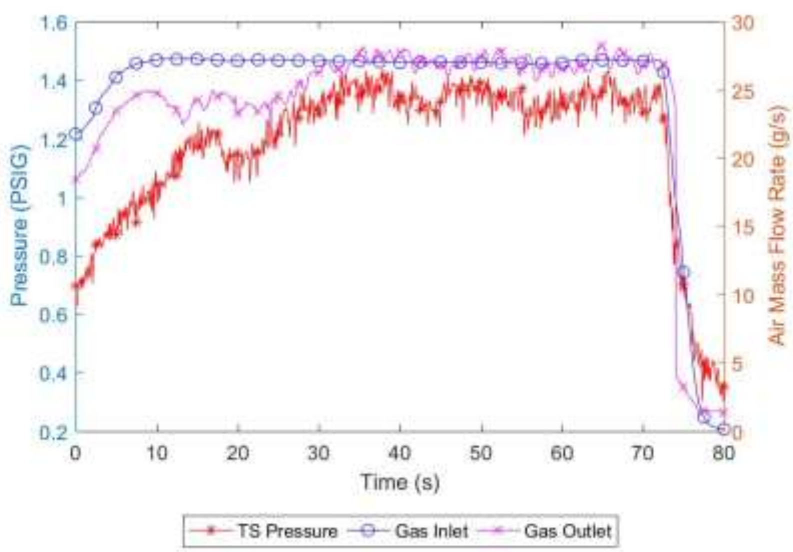

Figure F166: Pressure and gas inlet and outlet mass flow rate for test 2017_04_17_test_01.

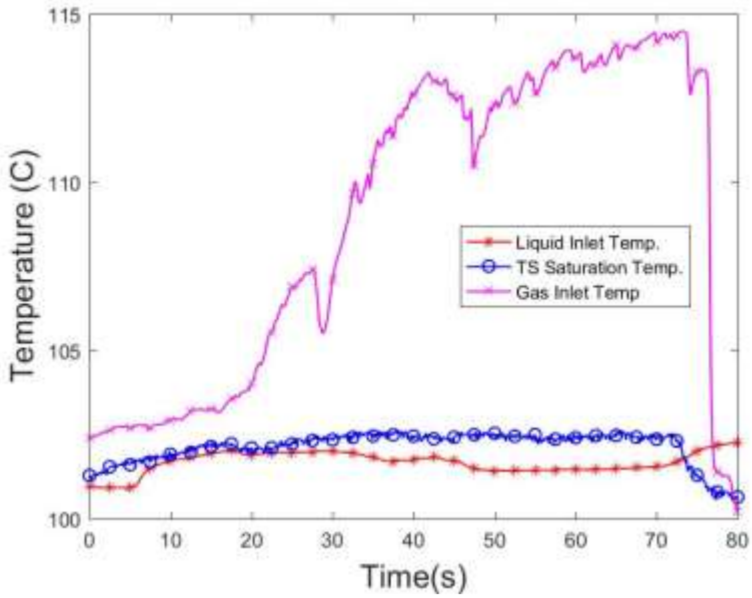

Figure F167: Temperature Profiles for test 2017_04_17_test_01.

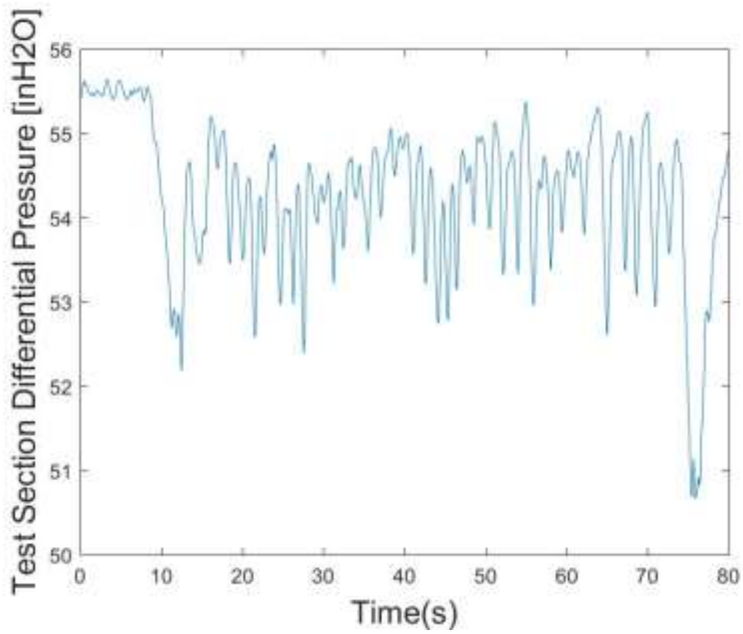

Figure F168: Test section differential pressure for test 2017_04_17_test_01.

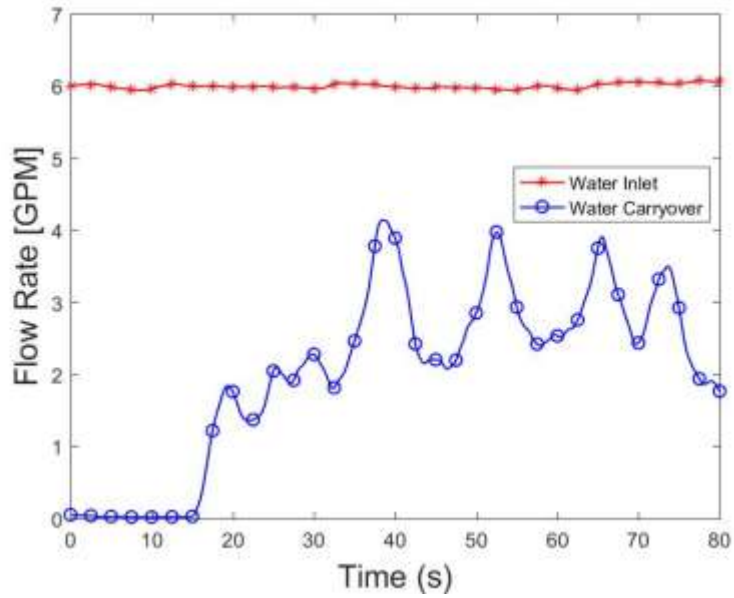

Figure F169: Water flow rates for 2017_04_17_test_01

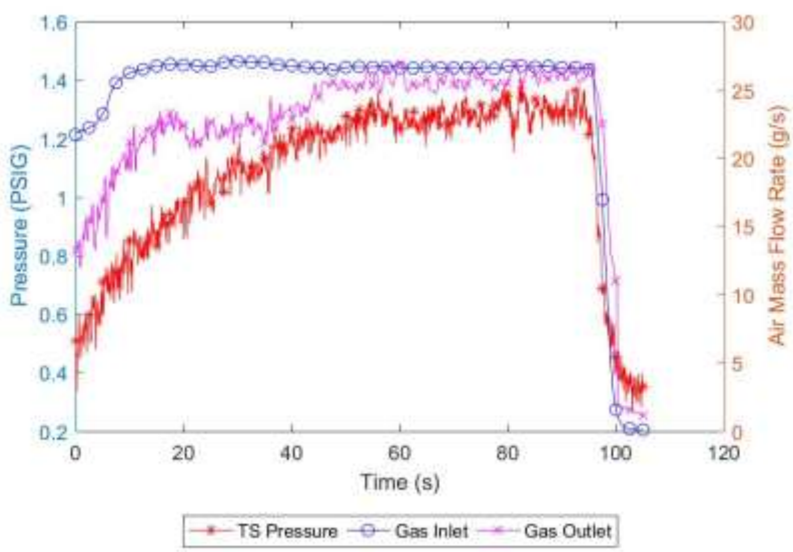

Figure F170: Pressure and gas inlet and outlet mass flow rate for test 2017_04_17_test_02.

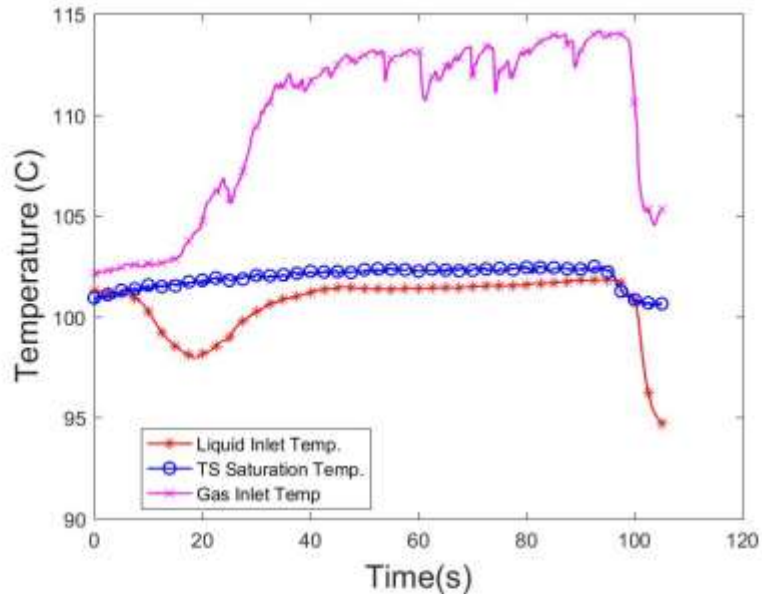

Figure F171: Temperature Profiles for test 2017_04_17_test_02.

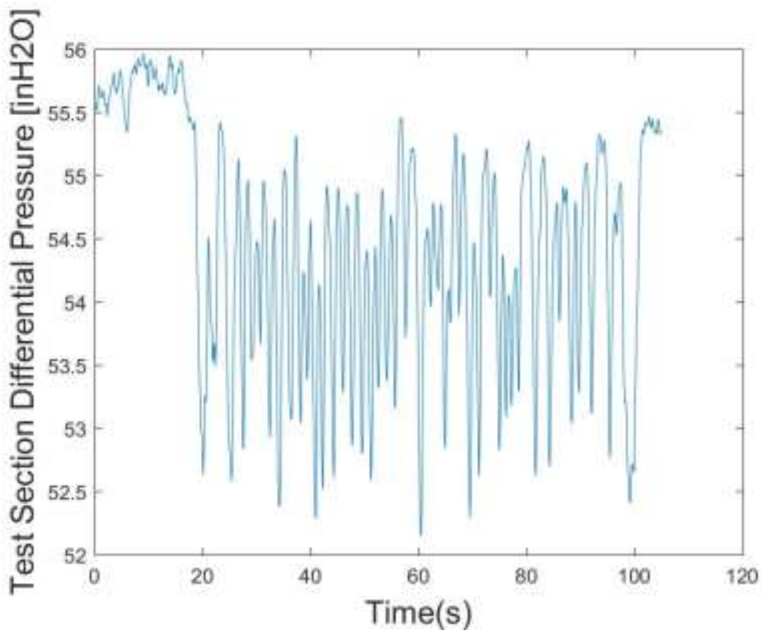

Figure F172 C: Test section differential pressure for test 2017_04_17_test_02.

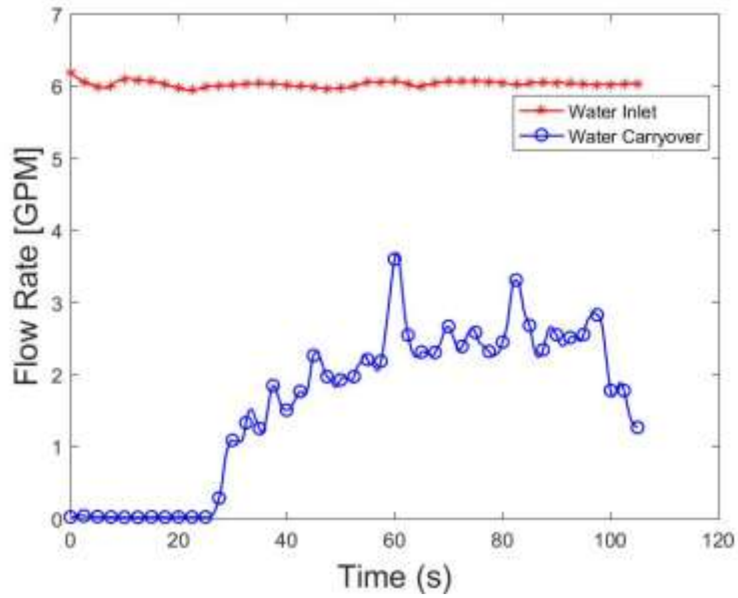

Figure F173: Water flow rates for 2017_04_17_test_02.

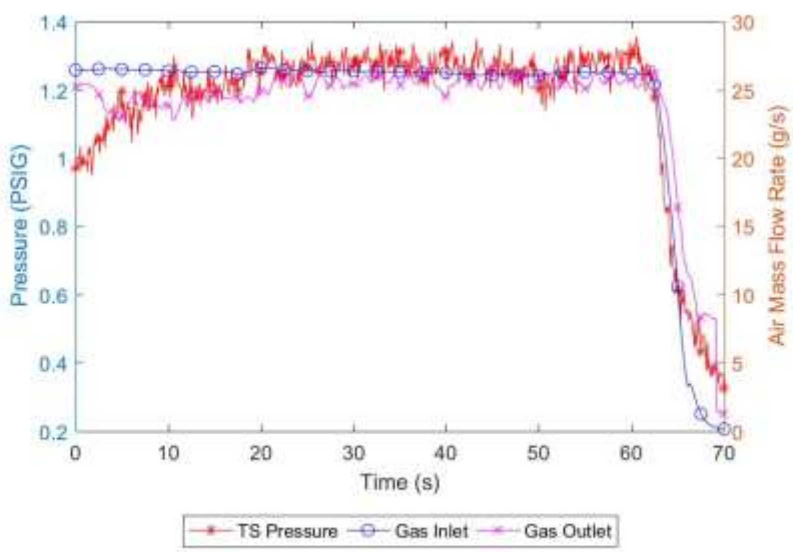

Figure F174: Pressure and gas inlet and outlet mass flow rate for test 2017_04_17_test_03.

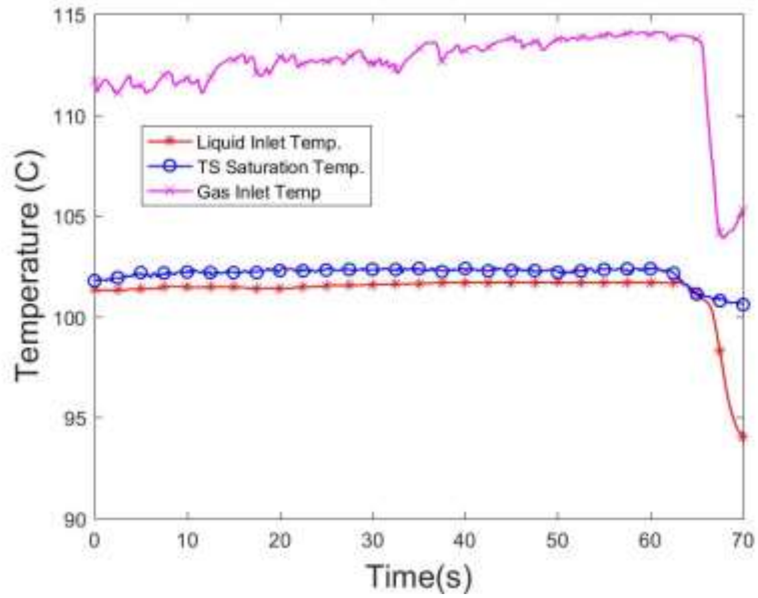

Figure F175: Temperature Profiles for test 2017_04_17_test_03.

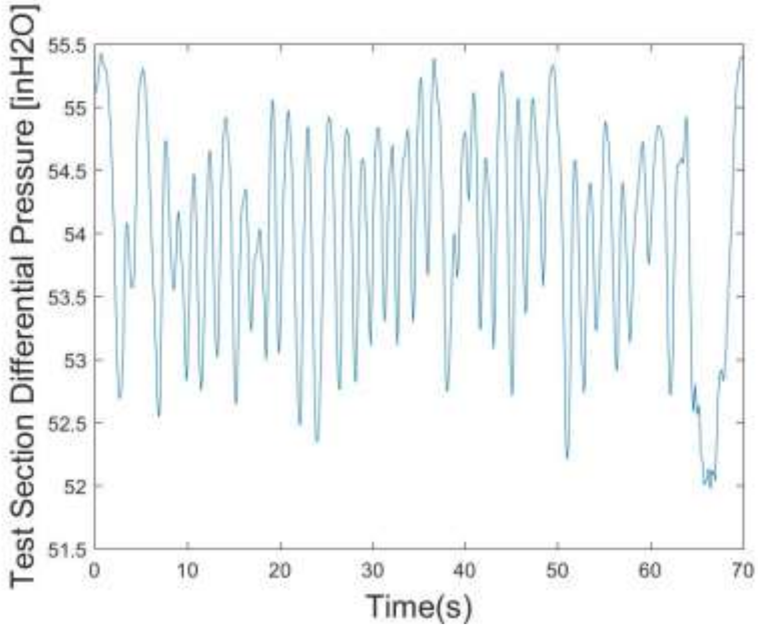

Figure F176: Test section differential pressure for test 201704_17_test_03.

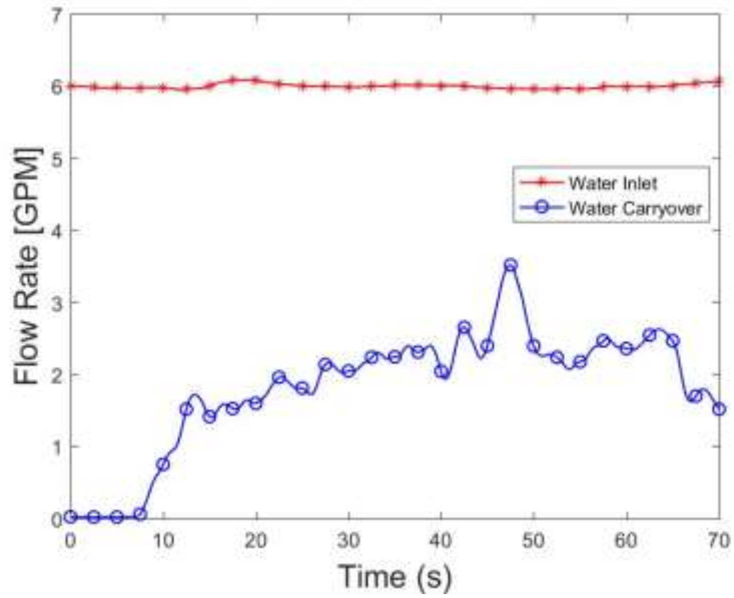

Figure F177: Water flow rates for 2017_04_17_test_03.

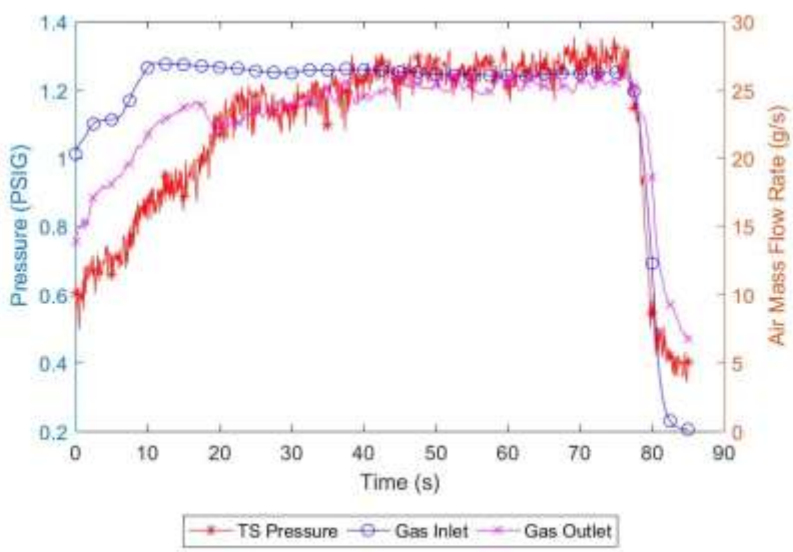

Figure F178: Pressure and gas inlet and outlet mass flow rate for test 2017_04_17_test_04.

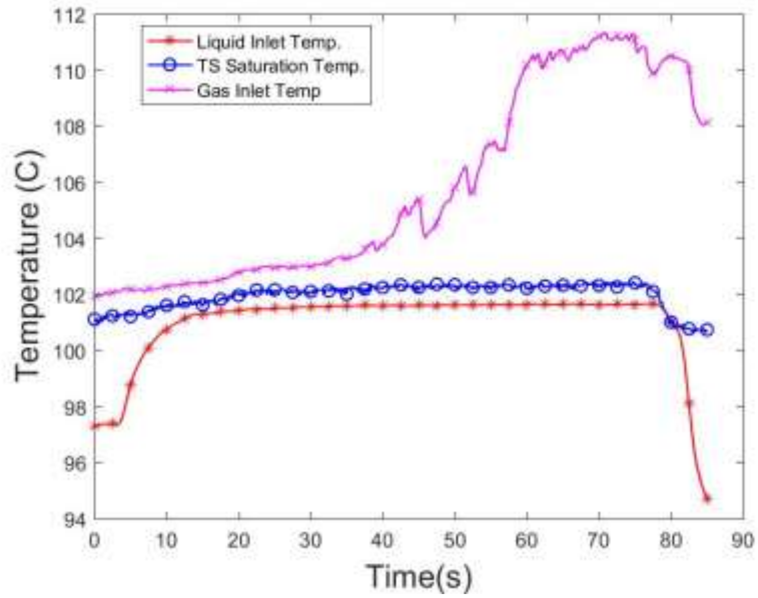

Figure F179: Temperature Profiles for test 2017_04_17_test_04.

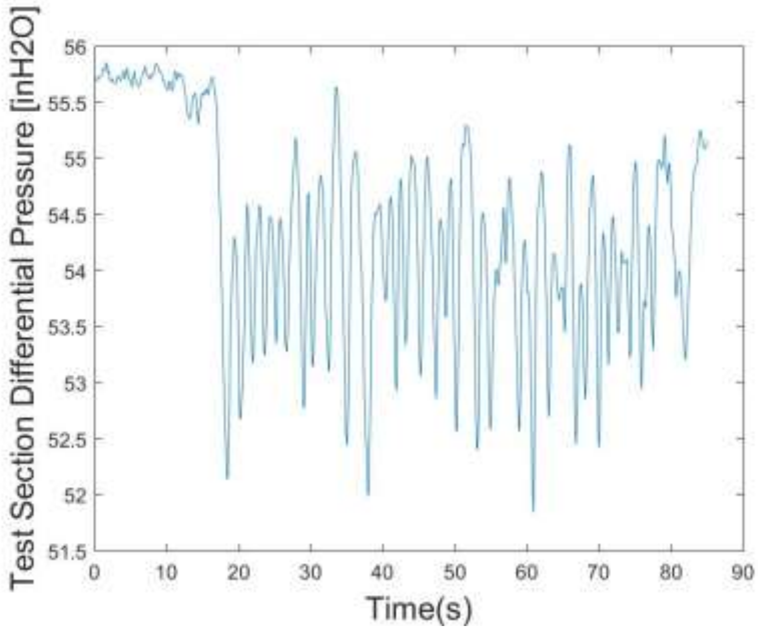

Figure F180: Test section differential pressure for test 2017_04_17_test_04.

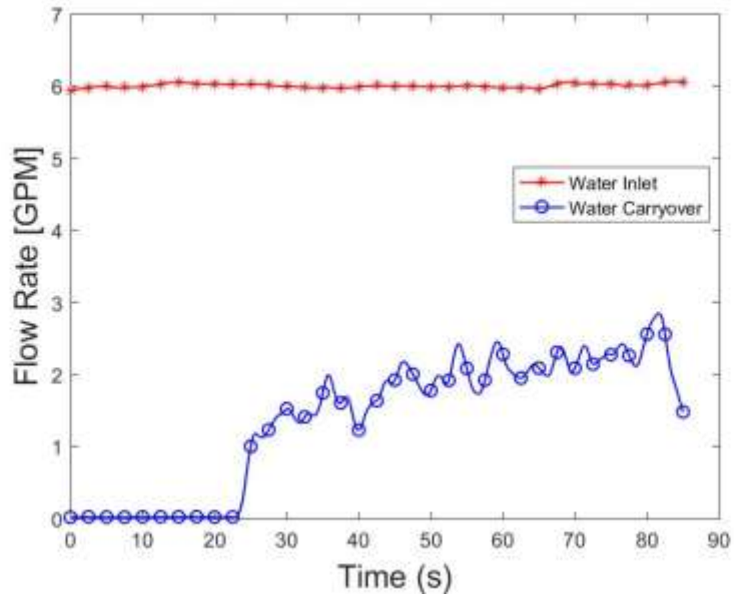

Figure F181: Water flow rates for 2017_04_17_test_04.

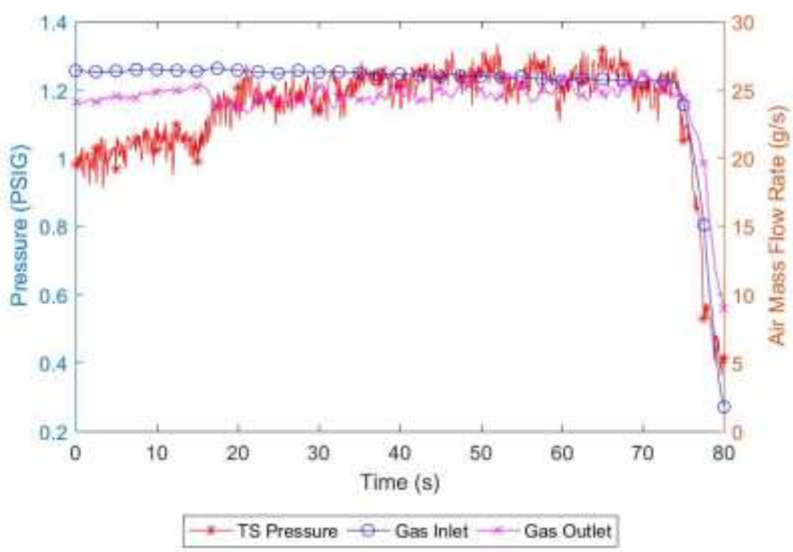

Figure F182: Pressure and gas inlet and outlet mass flow rate for test 2017_04_17_test_05.

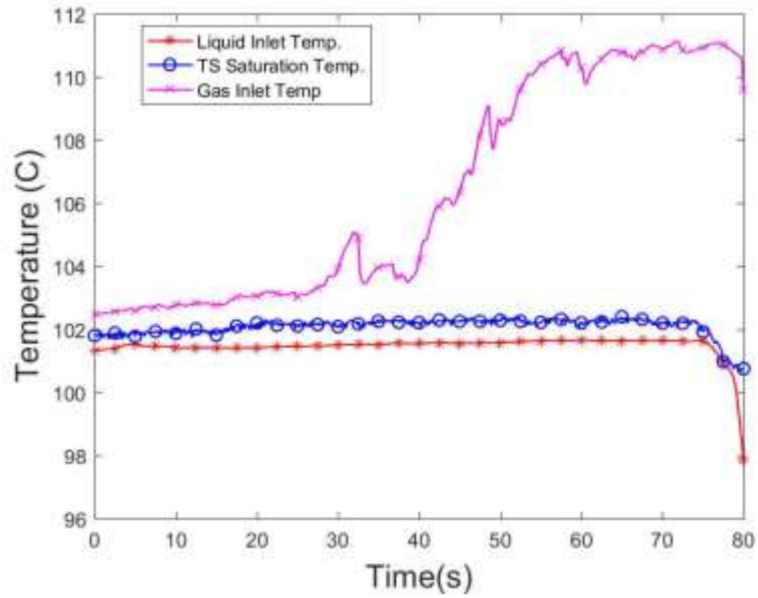

Figure F183: Temperature Profiles for test 2017_04_17_test_05.

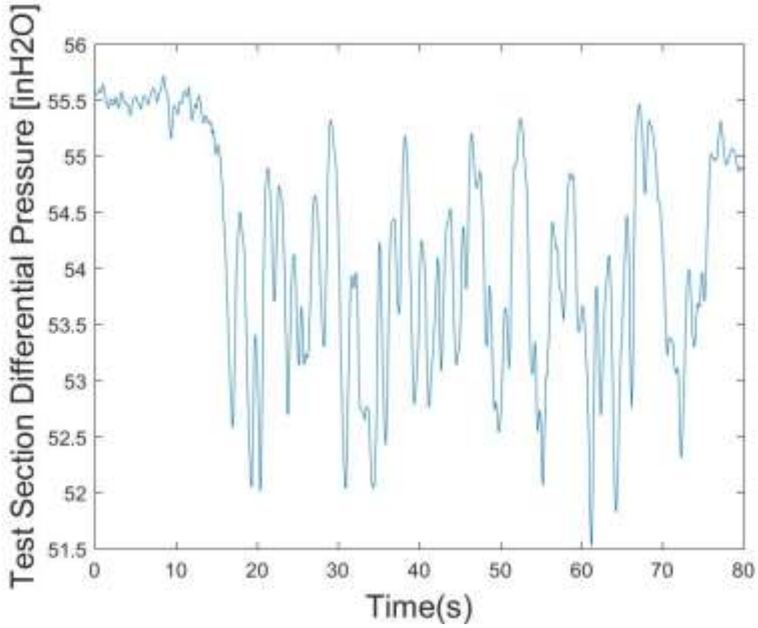

Figure F184: Test section differential pressure for test 2017_04_17_test_05.

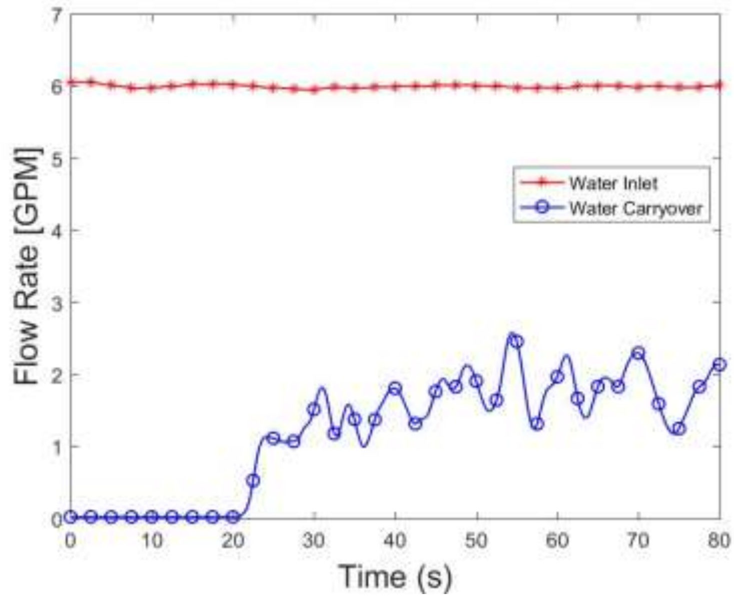

Figure F185: Water flow rates for 2017_04_17_test_05.

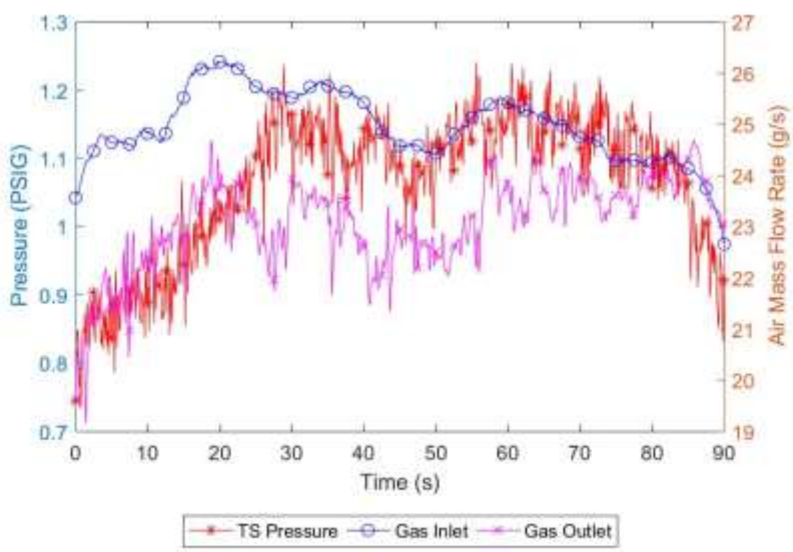

Figure F186: Pressure and gas inlet and outlet mass flow rate for test 2017_04_17_test_06.

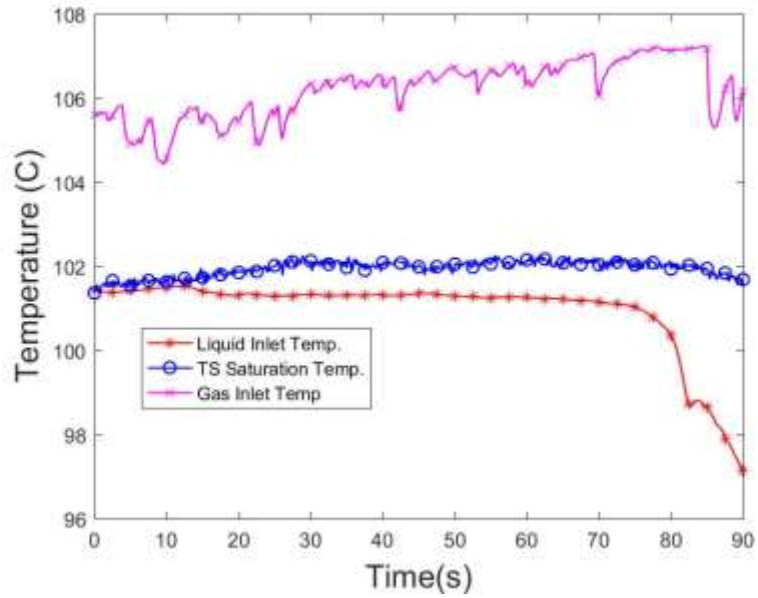

Figure F187: Temperature Profiles for test 2017_04_17_test_06.

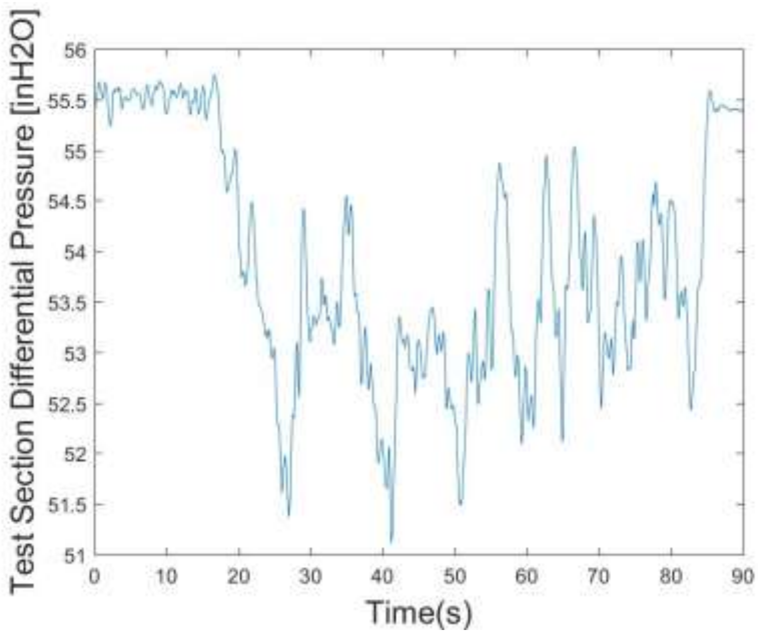

Figure F188: Test section differential pressure for test 2017_04_17_test_06.

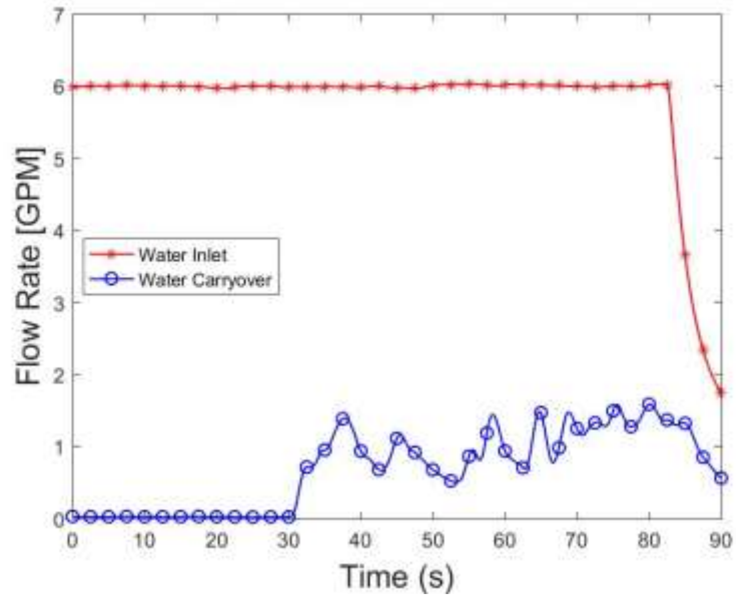

Figure F189: Water flow rates for 2017_04_17_test_06.

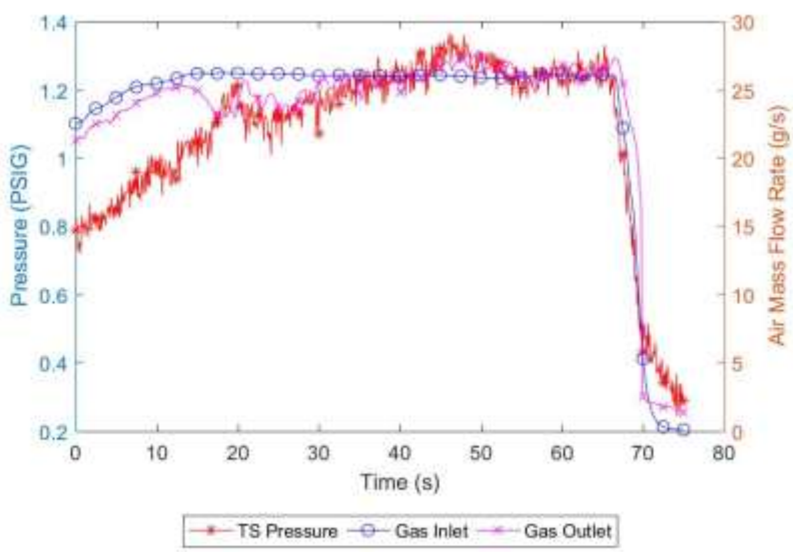

Figure F190: Pressure and gas inlet and outlet mass flow rate for test 2017_04_21_test_01.

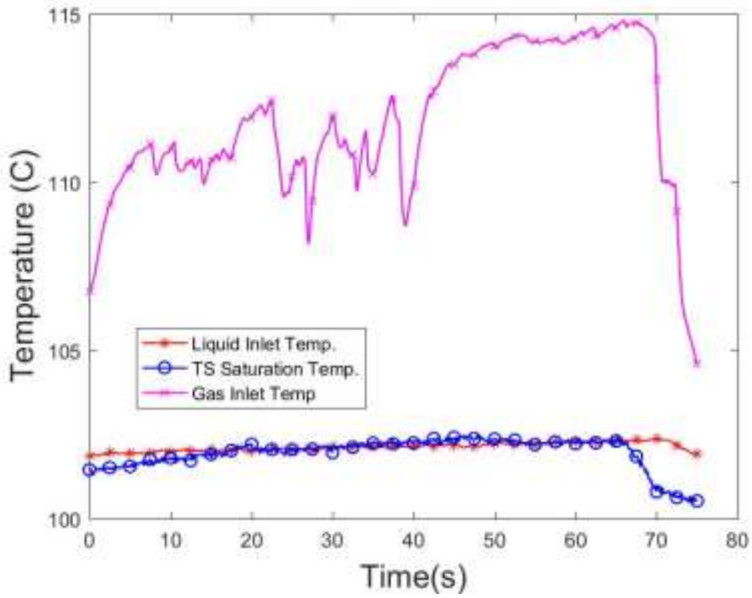

Figure F191: Temperature Profiles for test 2017_04_21_test_01.

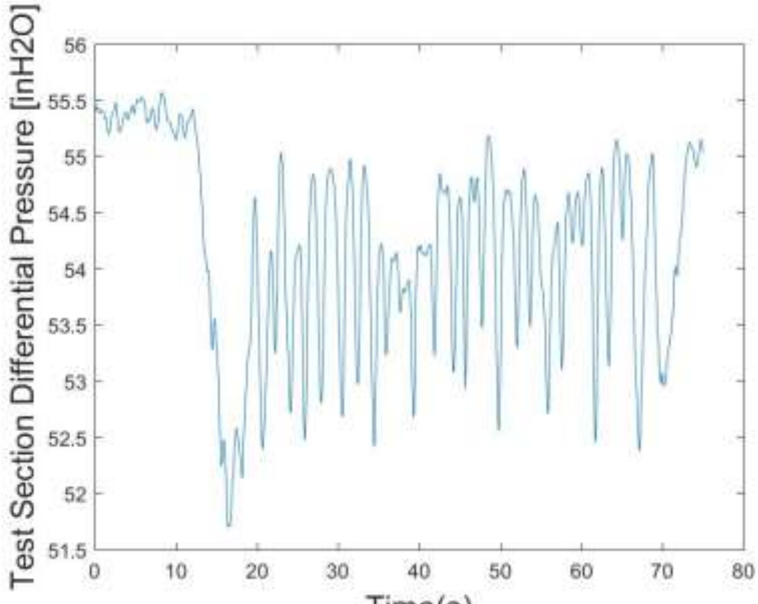

Figure F192: Test section differential pressure for test 2017_04_21_test_01.

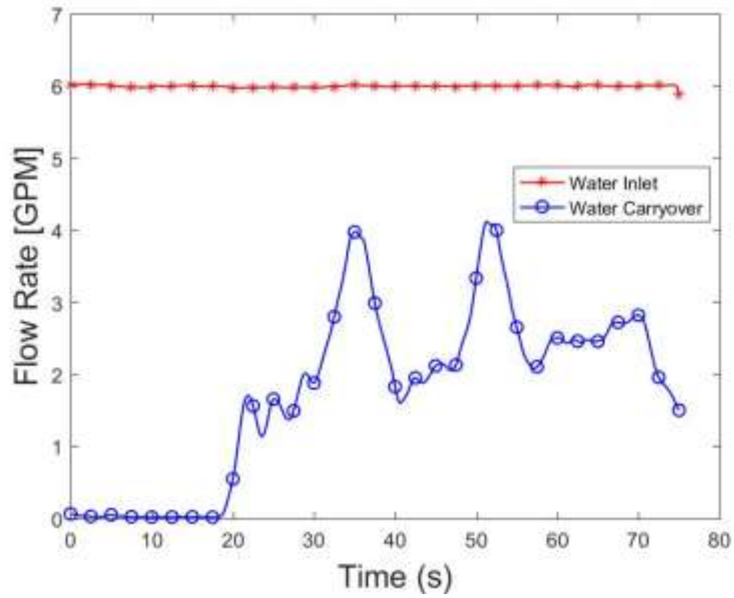

Figure F193: Water flow rates for 2017_04_21_test_01.

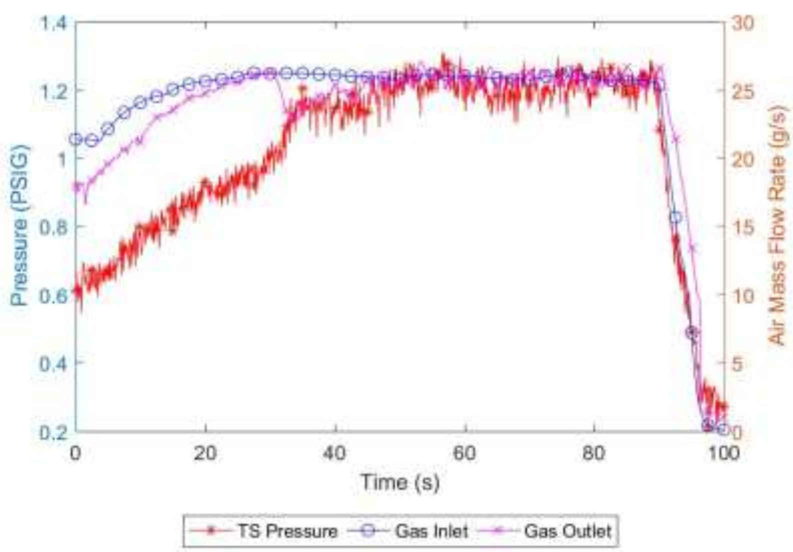

Figure F194: Pressure and gas inlet and outlet mass flow rate for test 2017_04_21_test_02.

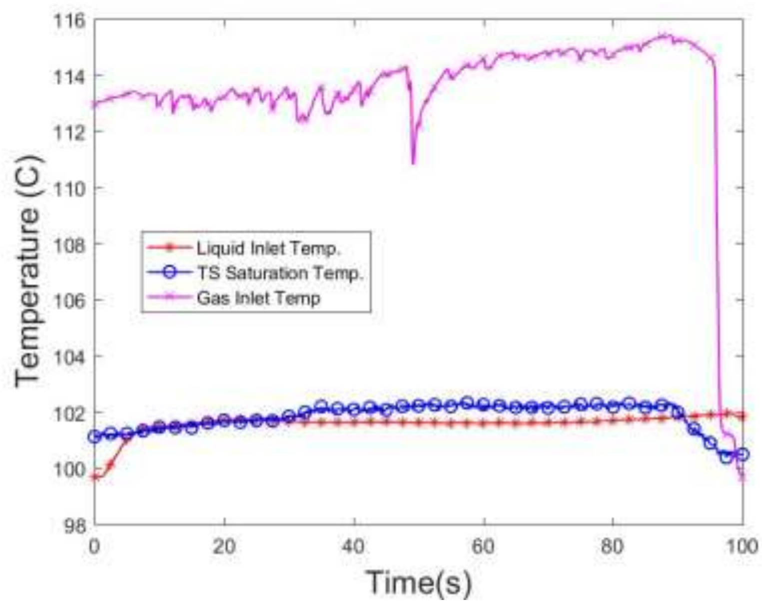

Figure F195: Temperature Profiles for test 2017_04_21_test_02.

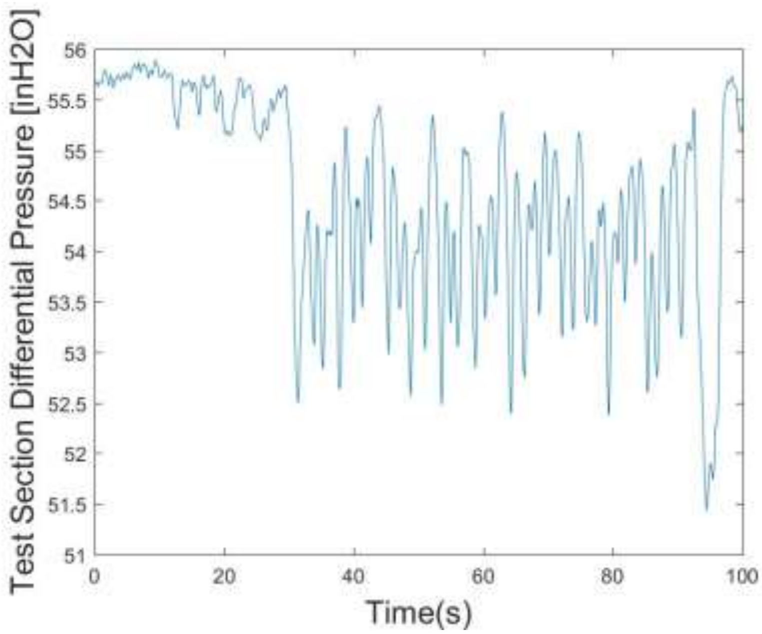

Figure F196: Test section differential pressure for test 2017_04_21_test_02.

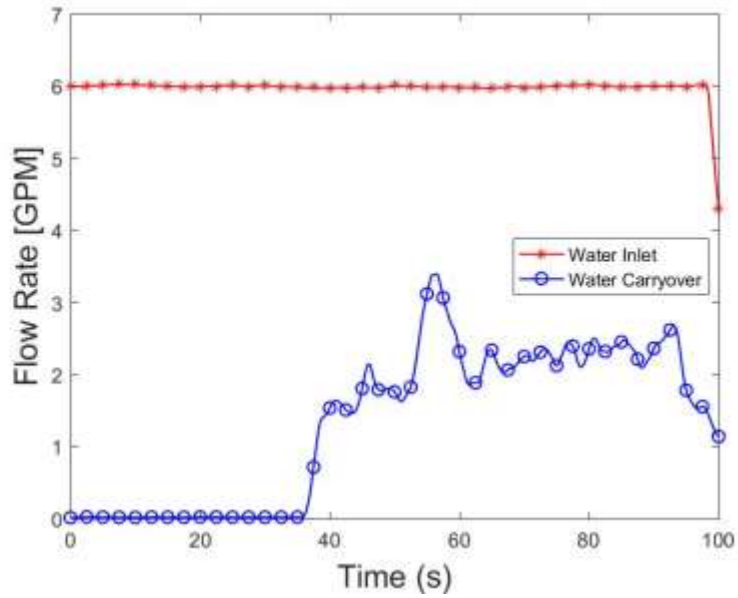

Figure F197: Water flow rates for 2017_04_21_test_02.

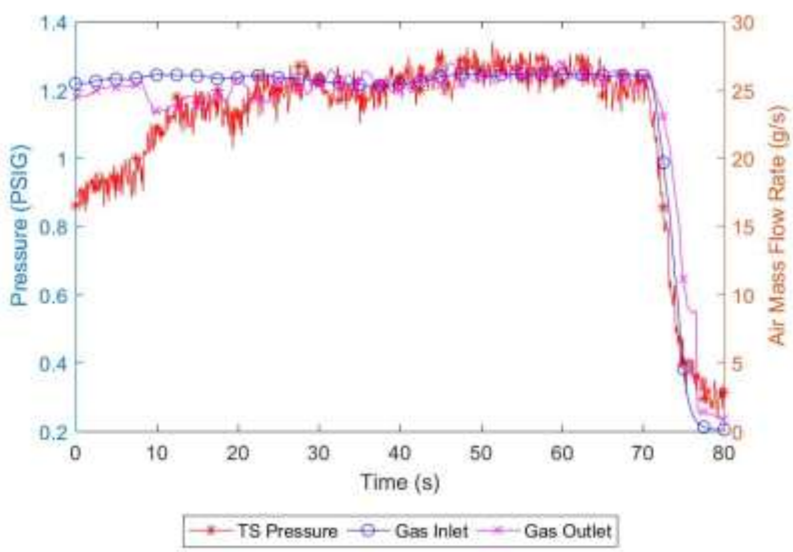

Figure F198: Pressure and gas inlet and outlet mass flow rate for test 2017_04_21_test_03.

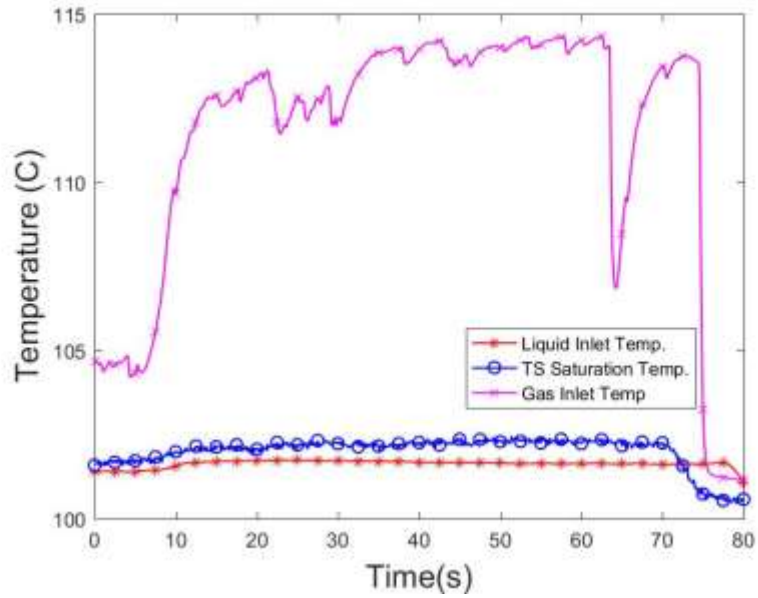

Figure F199: Temperature Profiles for test 2017_04_21_test_03.

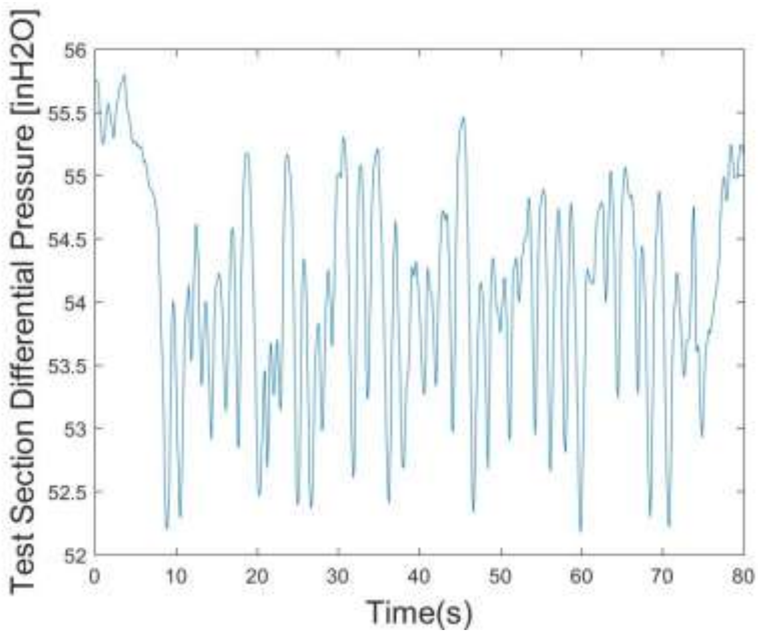

Figure F200: Test section differential pressure for test 2017_04_21_test_03.

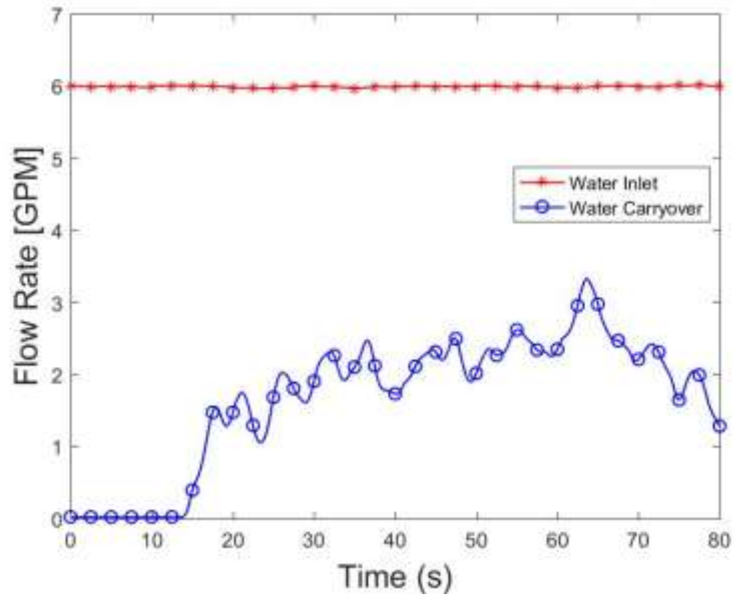

Figure F201: Water flow rates for 2017_04_21_test_03.

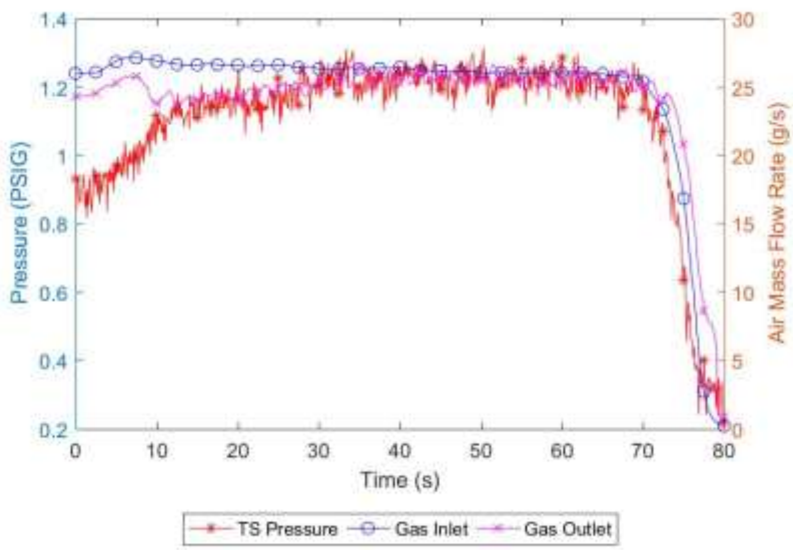

Figure F202: Pressure and gas inlet and outlet mass flow rate for test 2017_04_21_test_04.

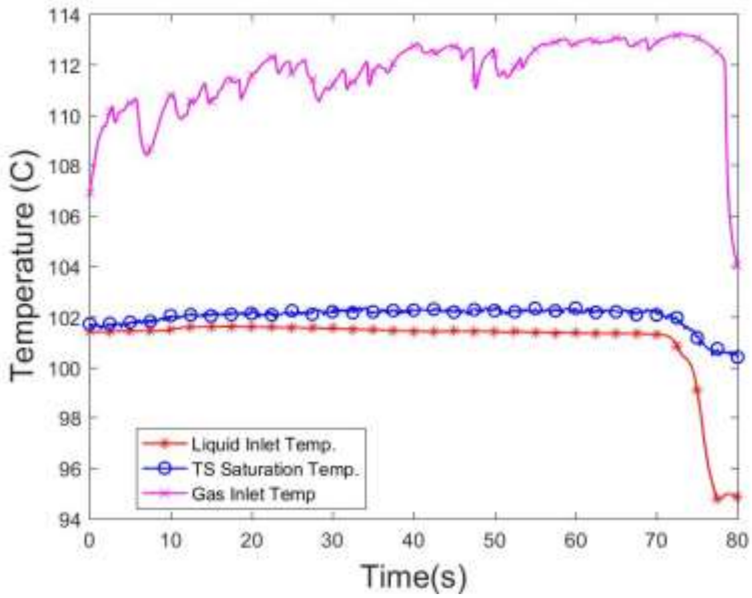

Figure F203: Temperature Profiles for test 2017_04_21_test_04.

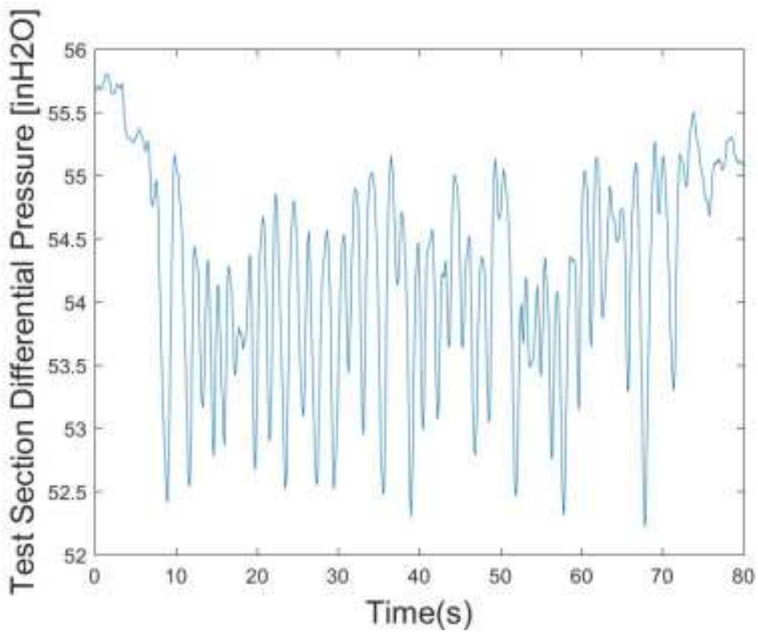

Figure F204: Test section differential pressure for test 2017_04_21_test_04.

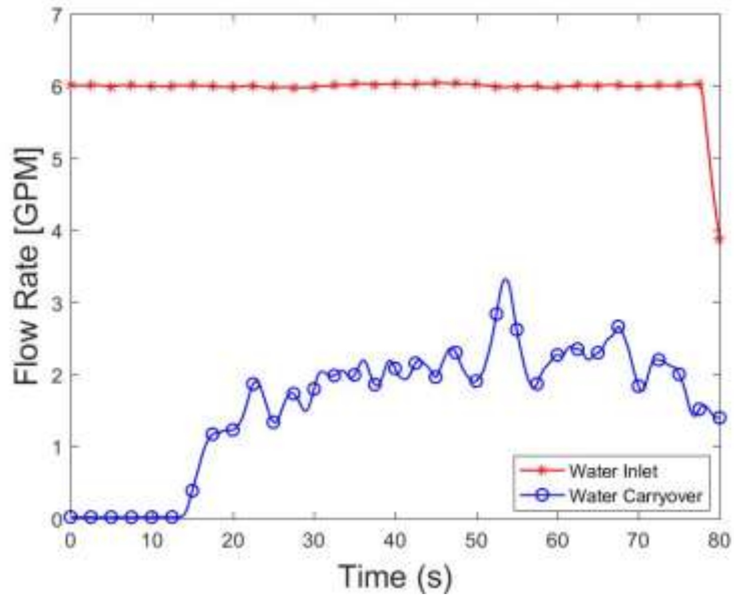

Figure F205: Water flow rates for 2017_04_21_test_04.

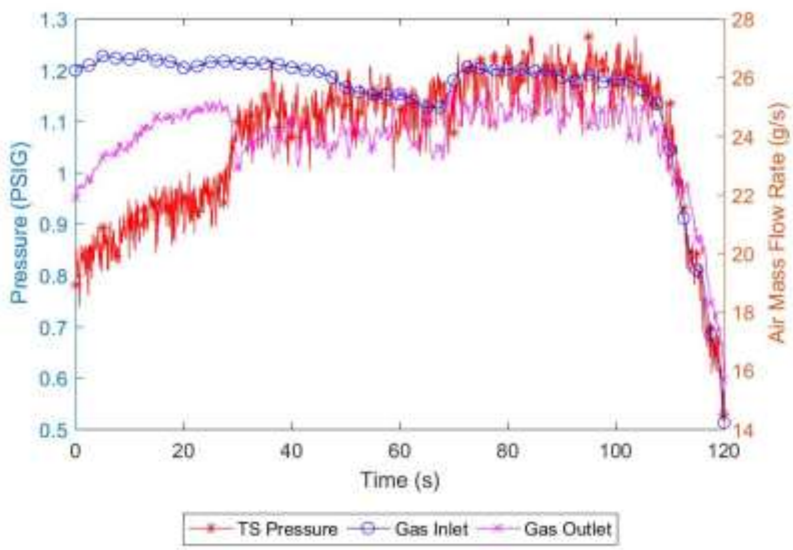

Figure F206: Pressure and gas inlet and outlet mass flow rate for test 2017_04_21_test_05.

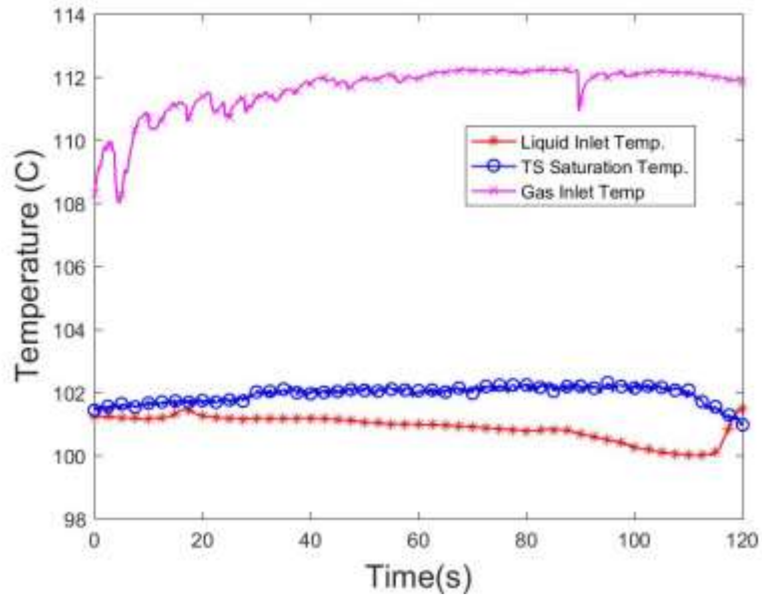

Figure F207: Temperature Profiles for test 2017_04_21_test_05.

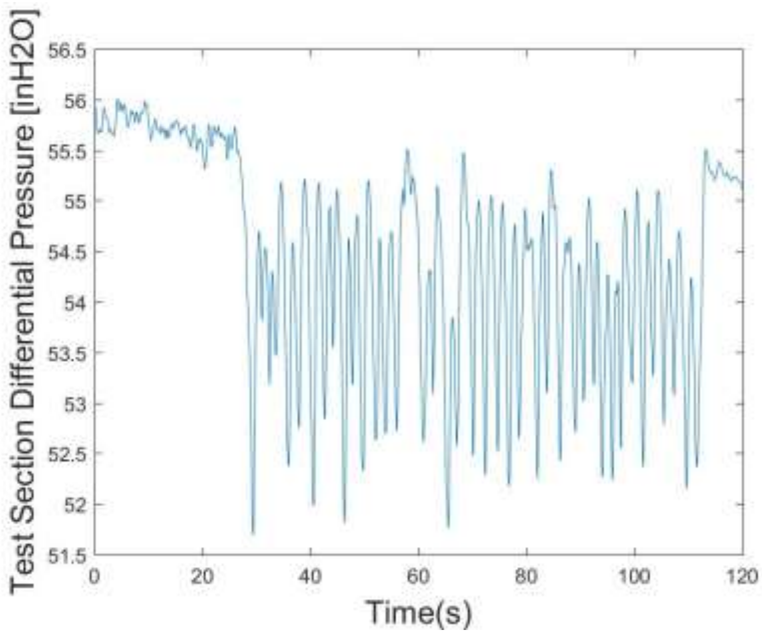

Figure F208: Test section differential pressure for test 2017_04_21_test_05.

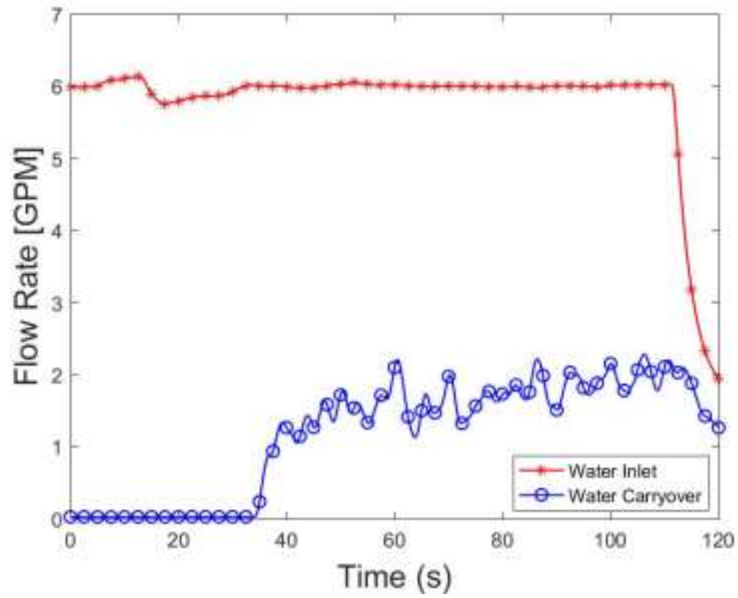

Figure F209: Water flow rates for 2017_04_21_test_05.

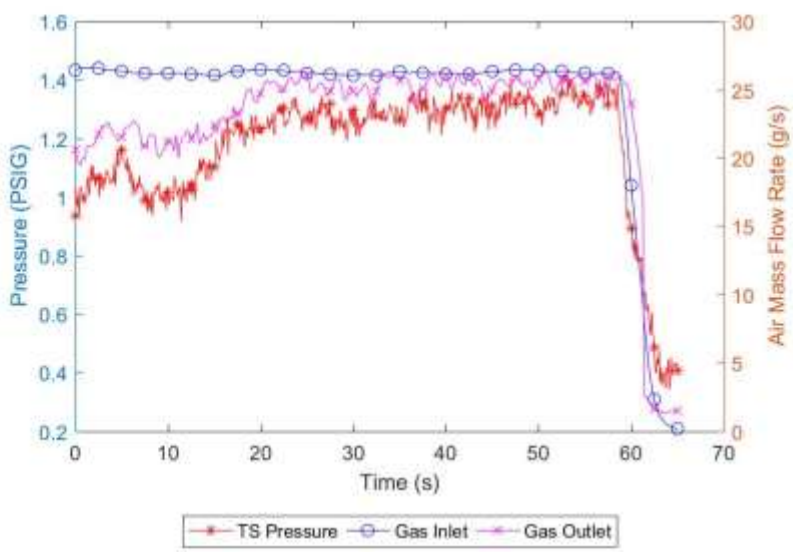

Figure F210: Pressure and gas inlet and outlet mass flow rate for test 2017_04_24_test_01.

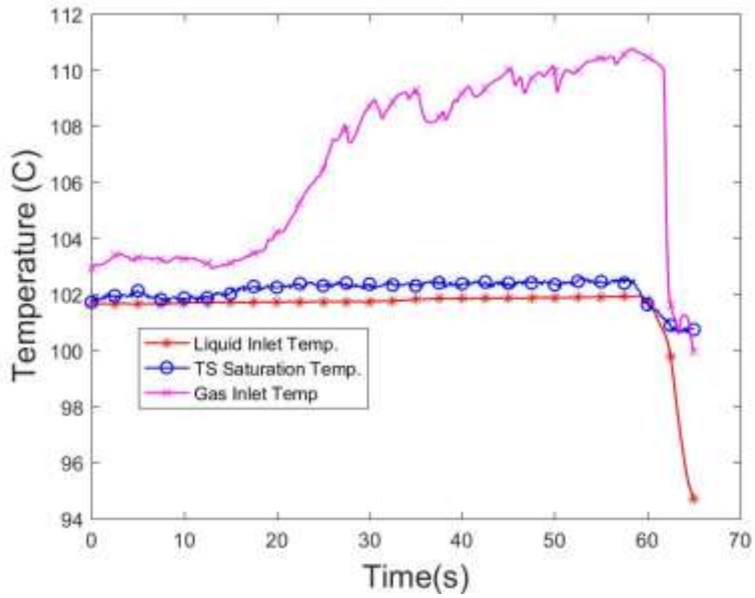

Figure F211: Temperature Profiles for test 2017_04_24_test_01.

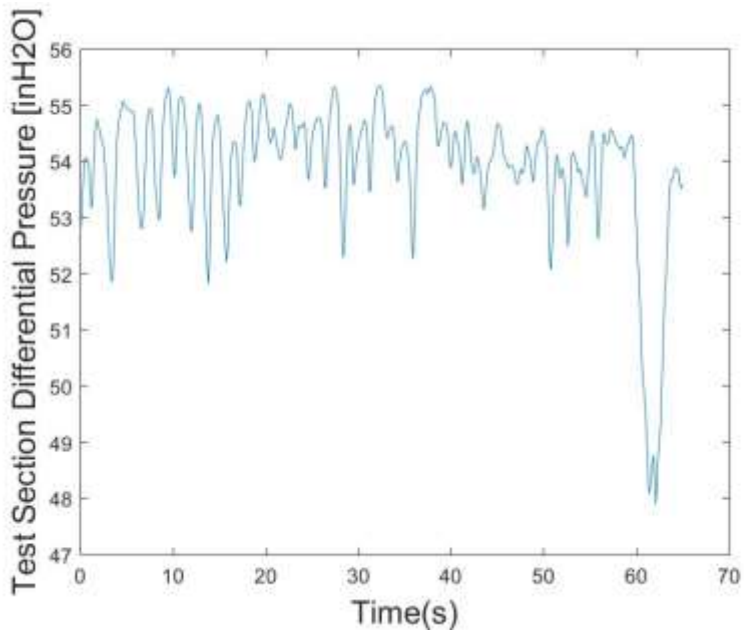

Figure F212: Test section differential pressure for test 2017_04_24_test_01.

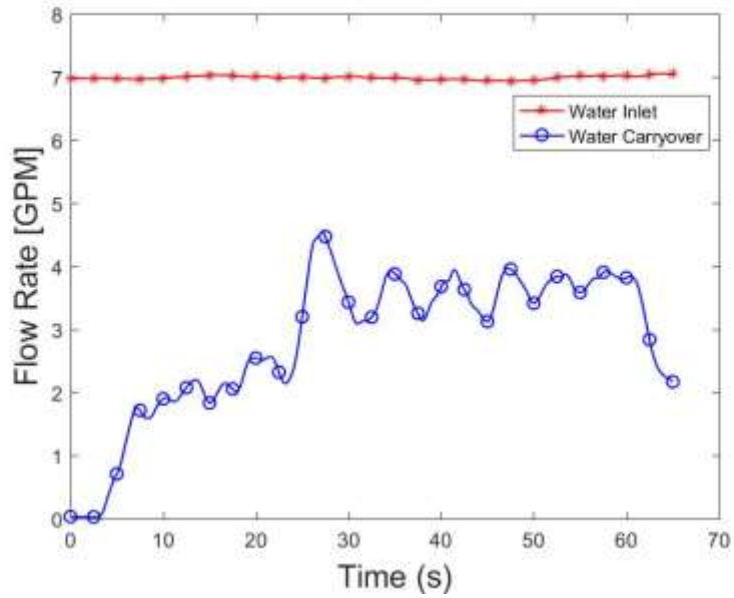

Figure F213: Water flow rates for 2017_04_24_test_01.

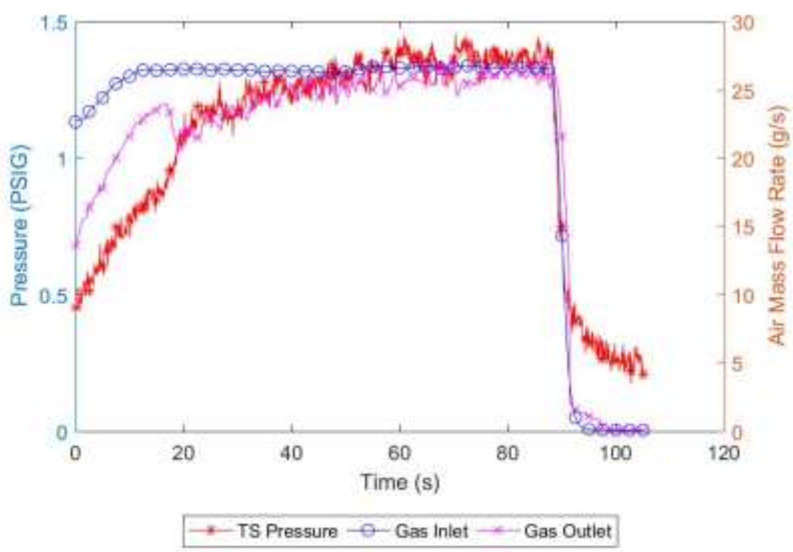

Figure F214: Pressure and gas inlet and outlet mass flow rate for test 2017_04_24_test_02.

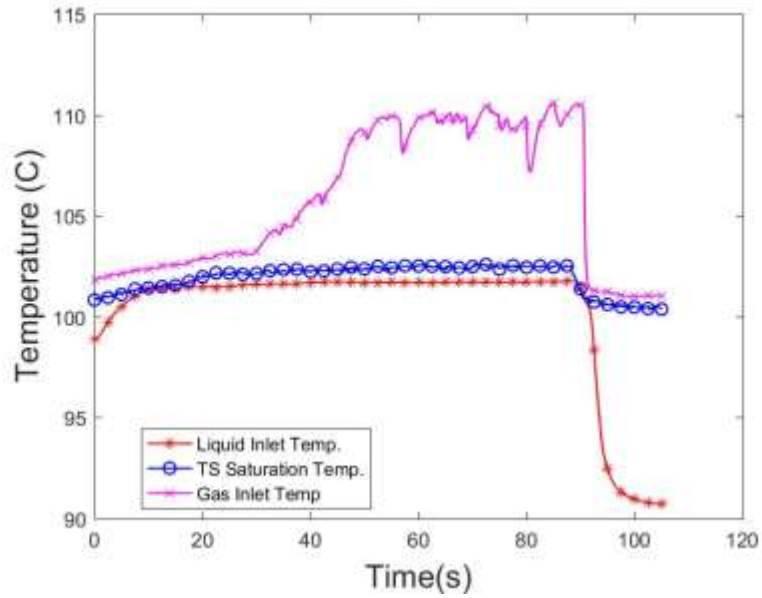

Figure F215: Temperature Profiles for test 2017_04_24_test_02.

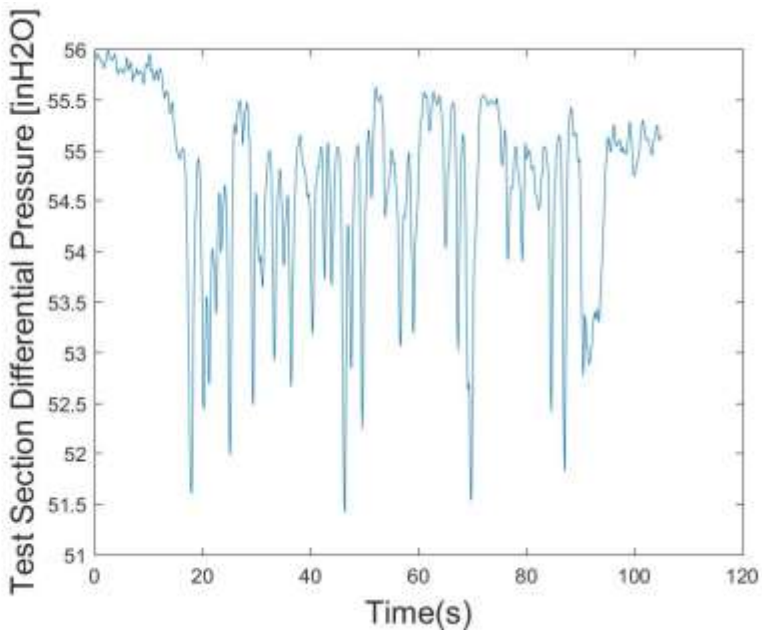

Figure F216: Test section differential pressure for test 2017_04_24_test_02.

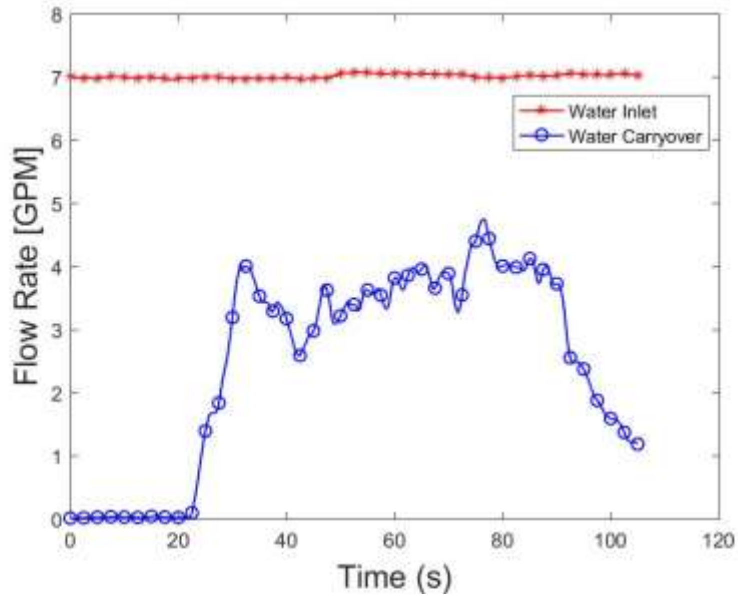

Figure F217: Water flow rates for 2017_04_24_test_02.

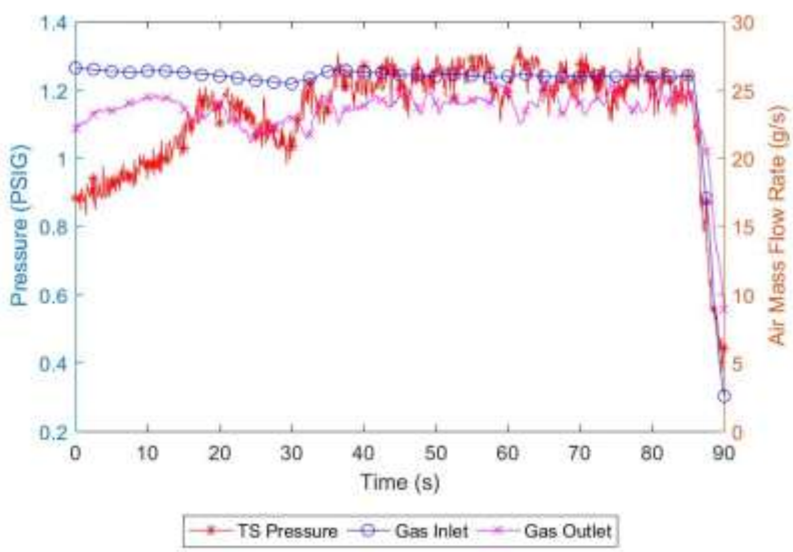

Figure F218: Pressure and gas inlet and outlet mass flow rate for test 2017_04_24_test_03.

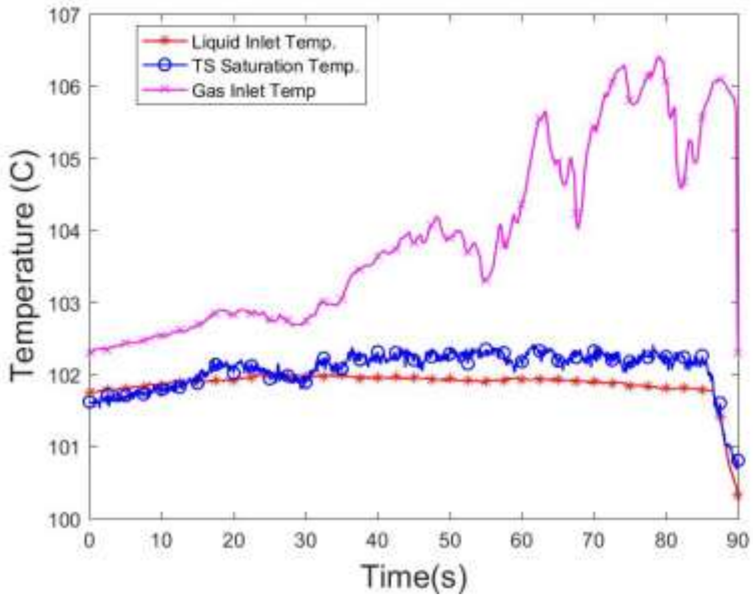

Figure F219: Temperature Profiles for test 2017_04_24_test_03.

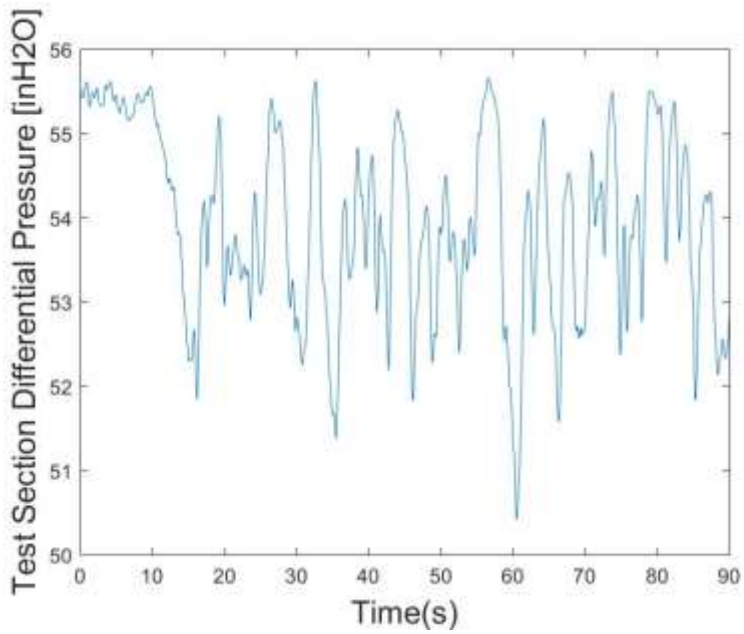

Figure F220: Test section differential pressure for test 2017_04_24_test_03.

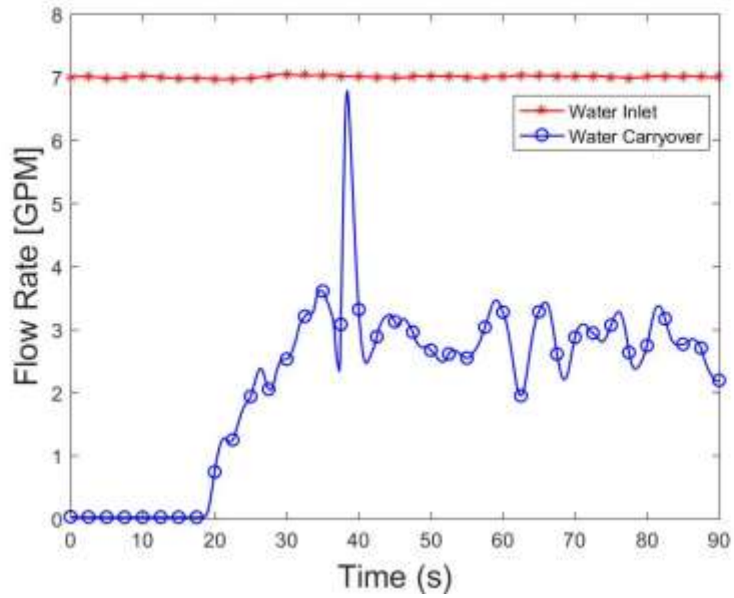

Figure F221: Water flow rates for 2017_04_24_test_03.

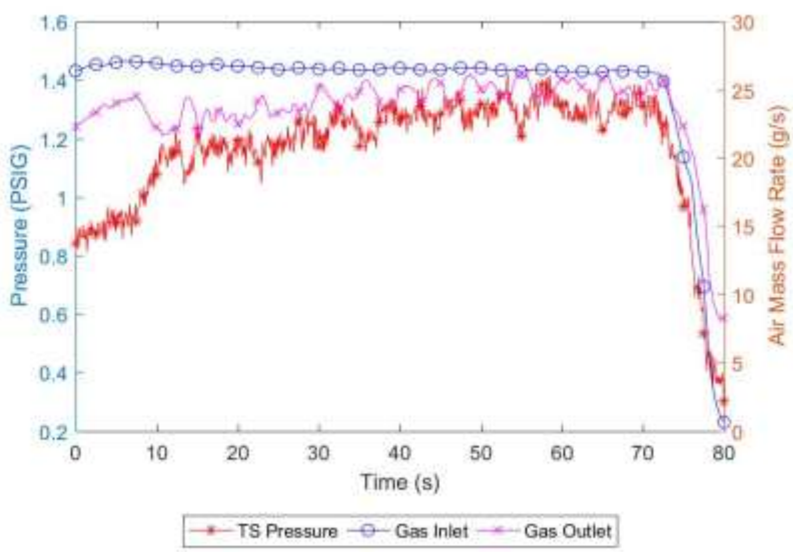

Figure F222: Pressure and gas inlet and outlet mass flow rate for test 2017_04_24_test_04.

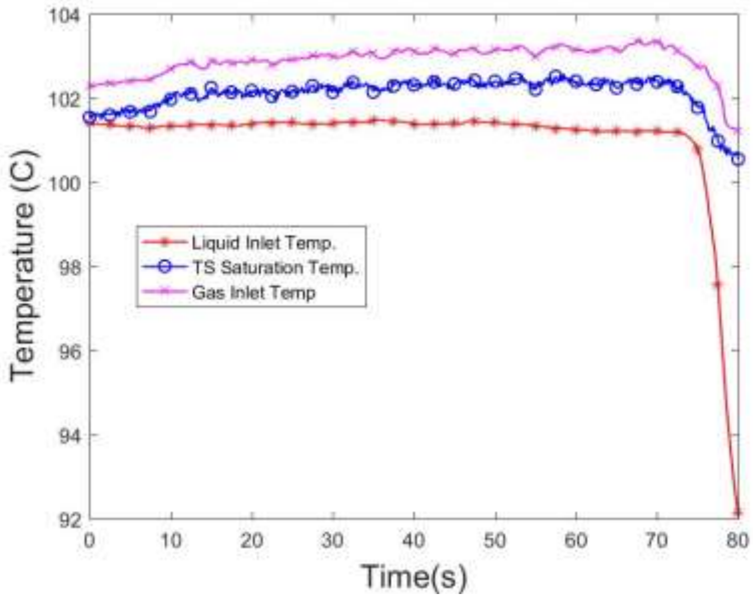

Figure F223: Temperature Profiles for test 2017_04_24_test_04.

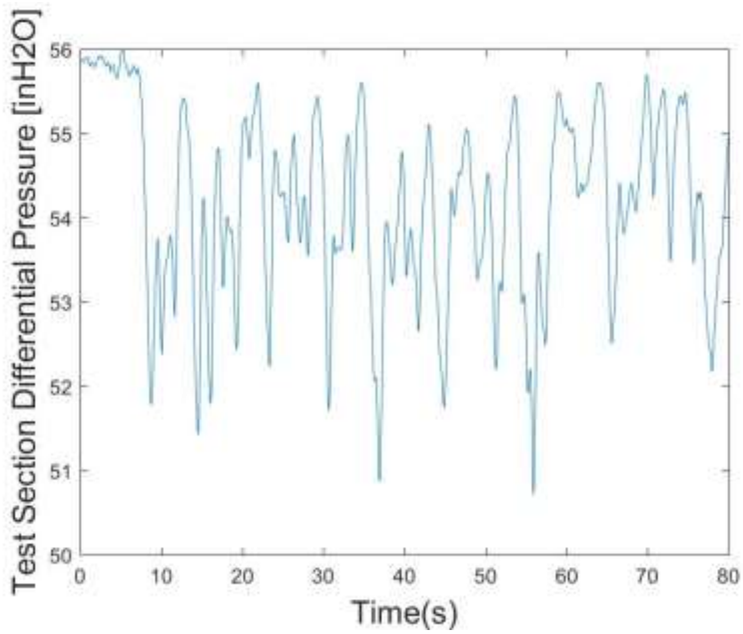

Figure F224: Test section differential pressure for test 2017_04_24_test_04.

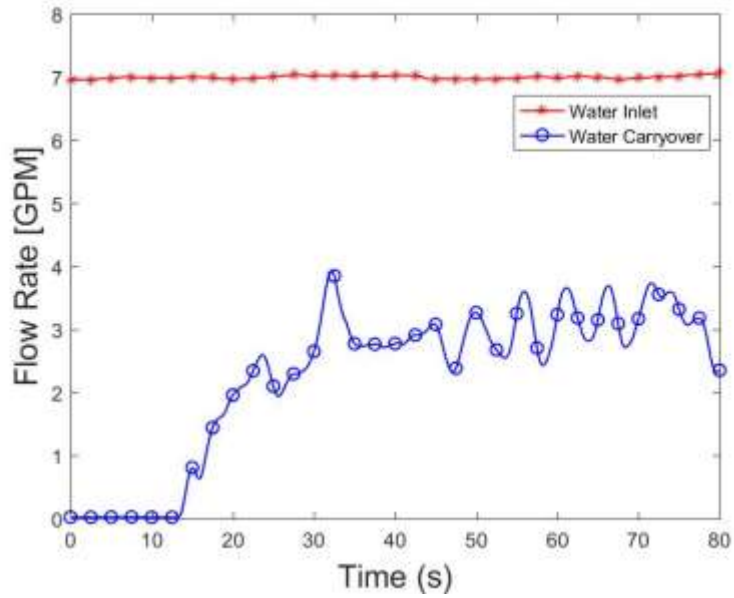

Figure F225: Water flow rates for 2017_04_24_test_04.

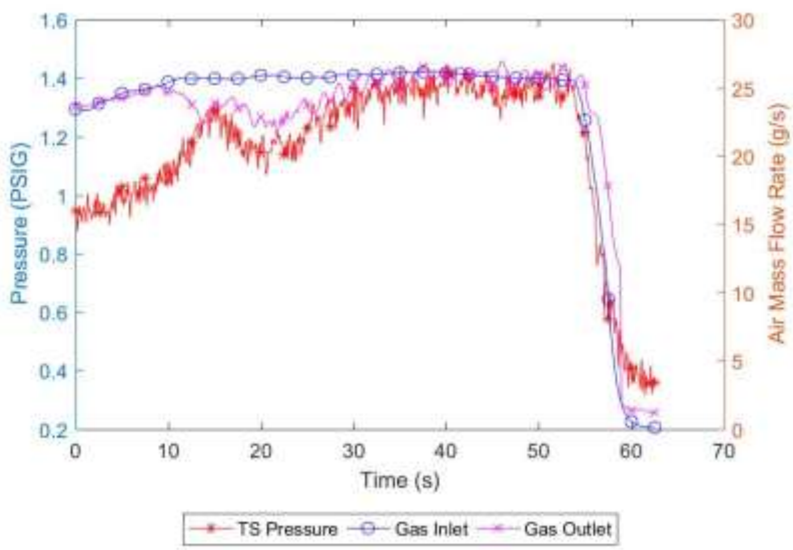

Figure F226: Pressure and gas inlet and outlet mass flow rate for test 2017_05_11_test_01.

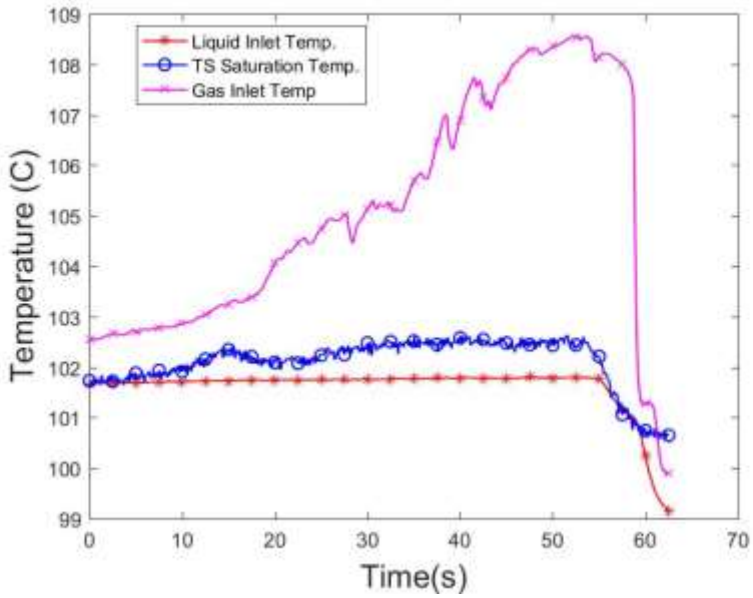

Figure F227: Temperature Profiles for test 2017_05_11_test_01.

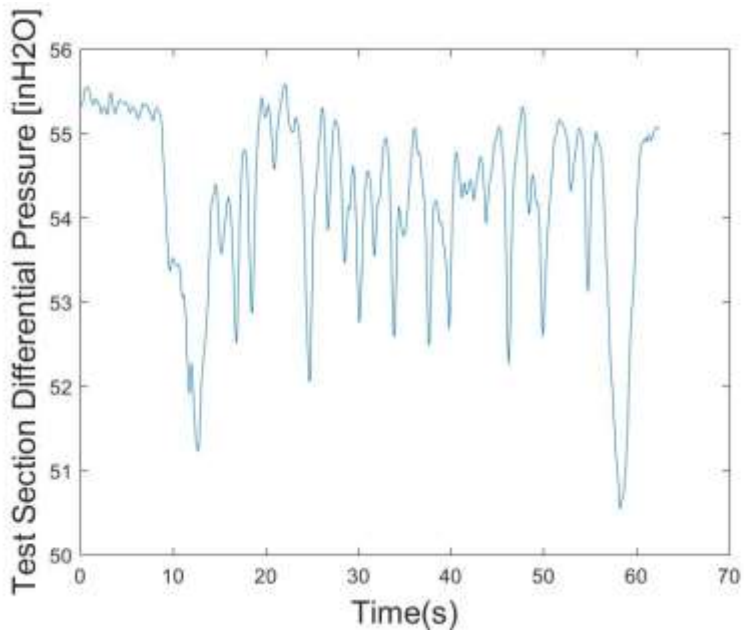

Figure F228: Test section differential pressure for test 2017_05_11_test_01.

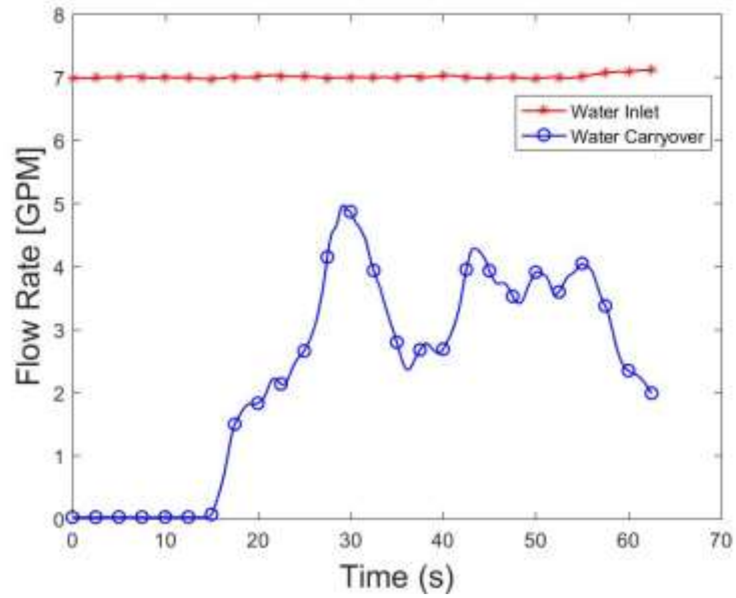

Figure F229: Water flow rates for 2017_05_11_test_01.

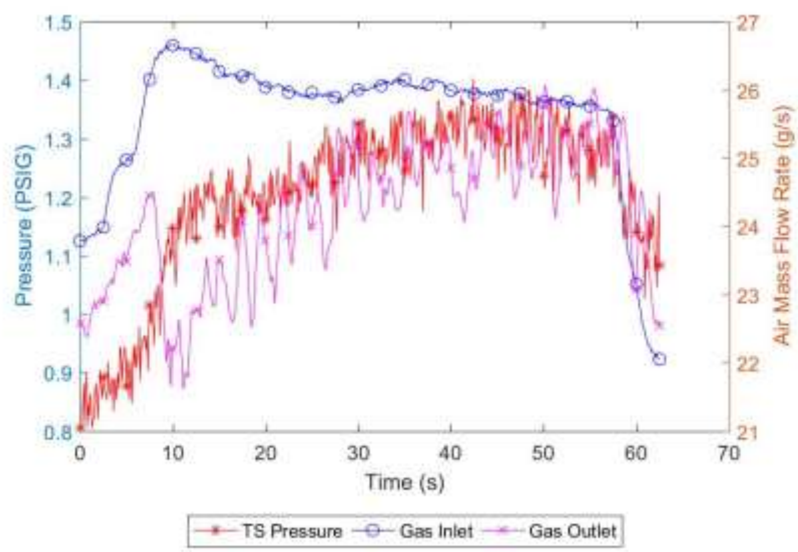

Figure F230: Pressure and gas inlet and outlet mass flow rate for test 2017_05_11_test_02.

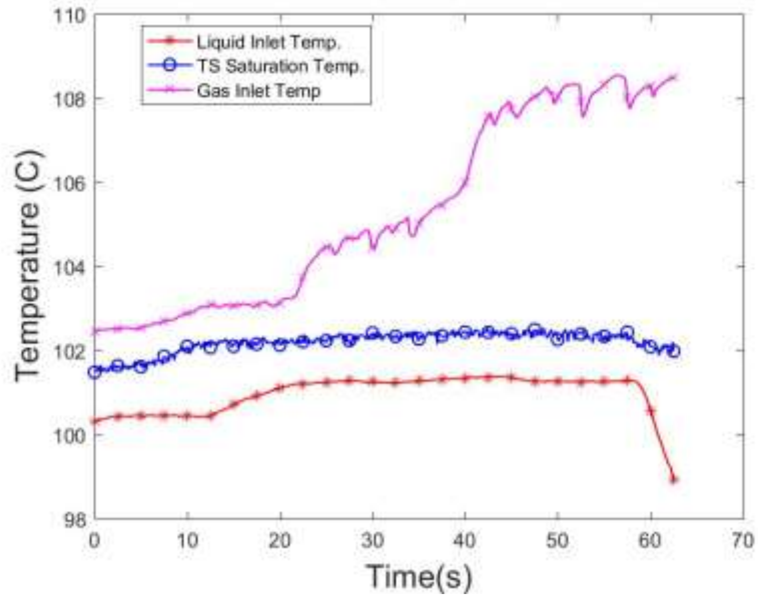

Figure F231: Temperature Profiles for test 2017_05_11_test_02.

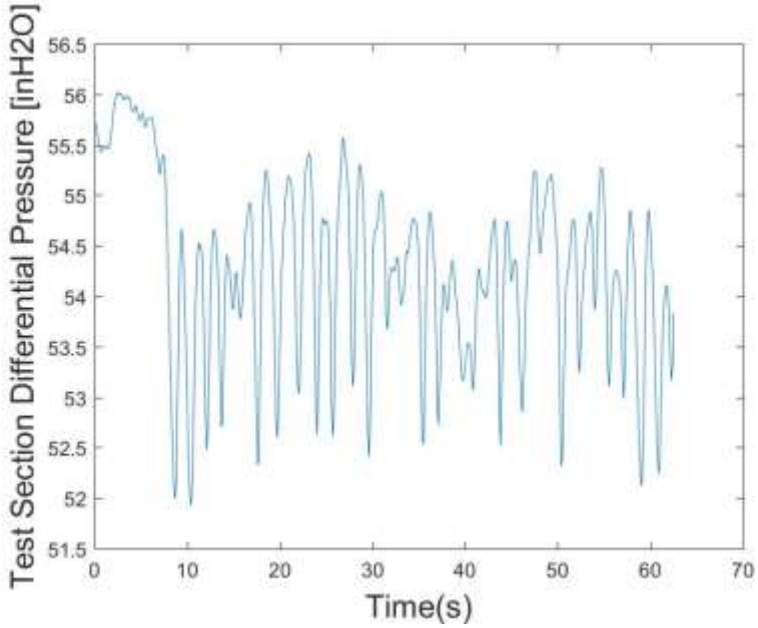

Figure F232: Test section differential pressure for test 2017_05_11_test_02.

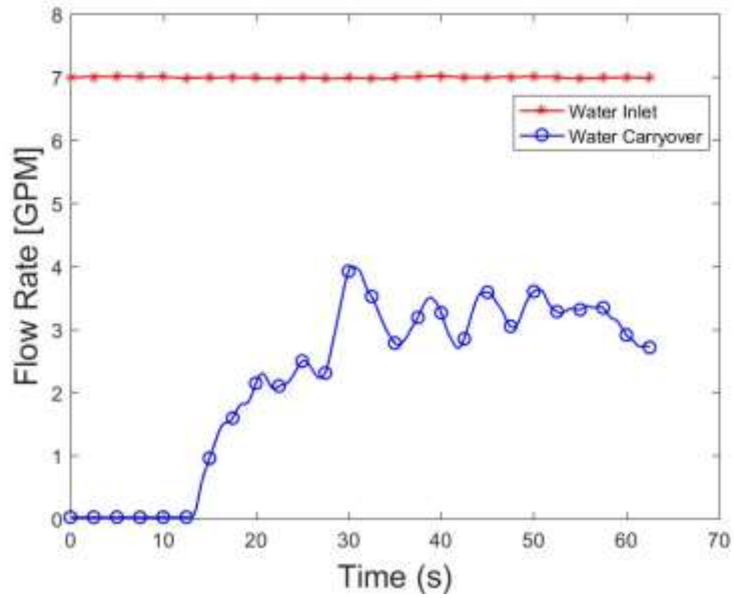

Figure F233: Water flow rates for 2017_05_11_test_02.

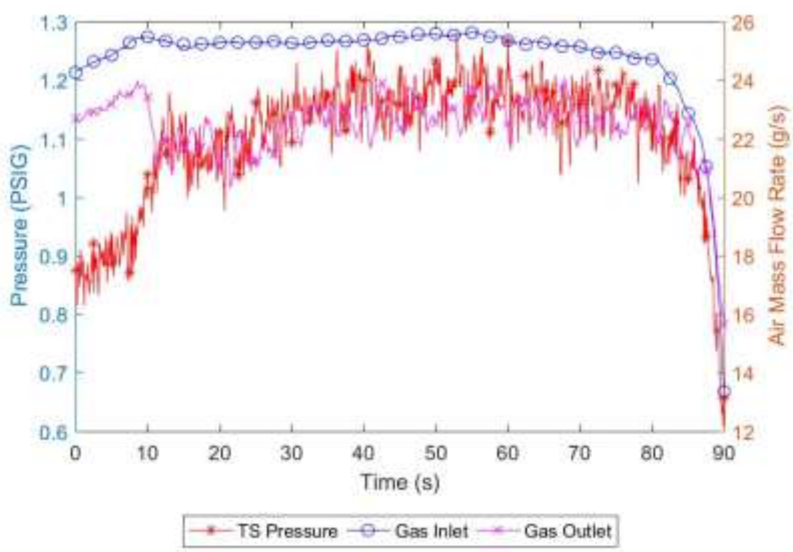

Figure F234: Pressure and gas inlet and outlet mass flow rate for test 2017_05_11_test_03.

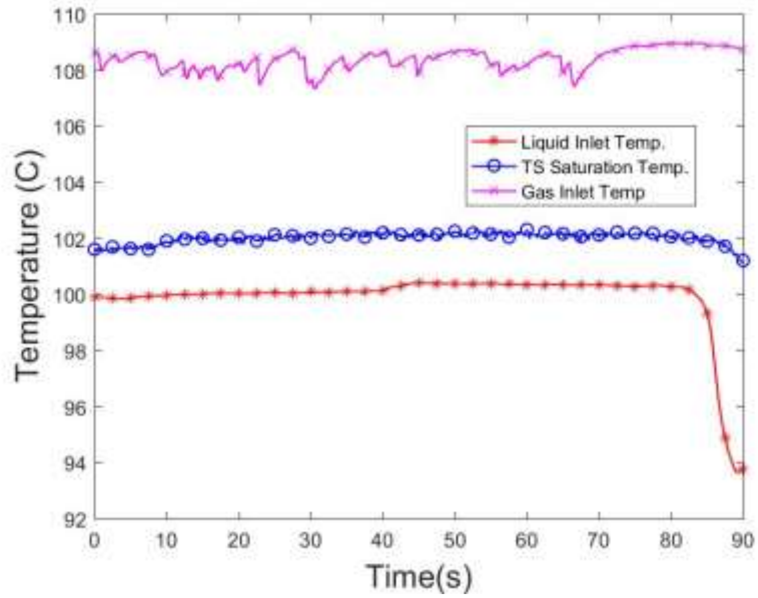

Figure F235: Temperature Profiles for test 2017_05_11_test_03.

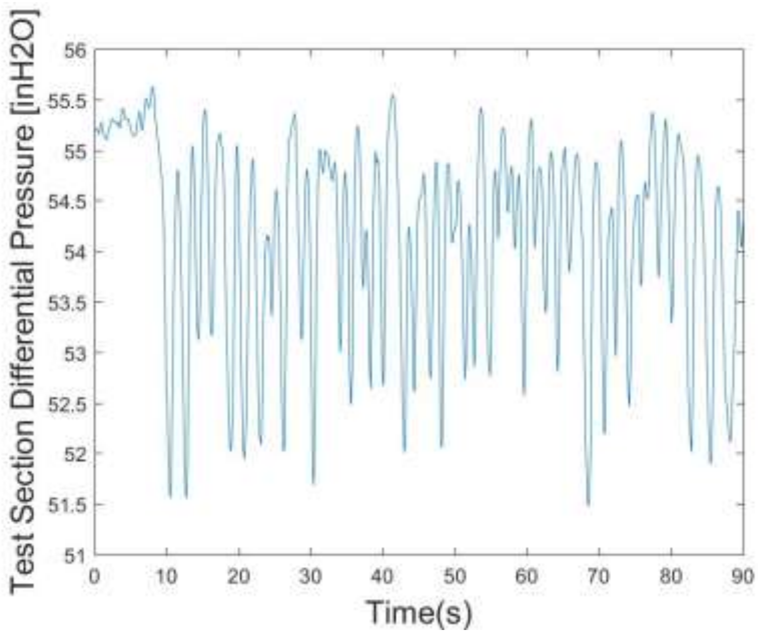

Figure F236: Test section differential pressure for test 2017_05_11_test_03.

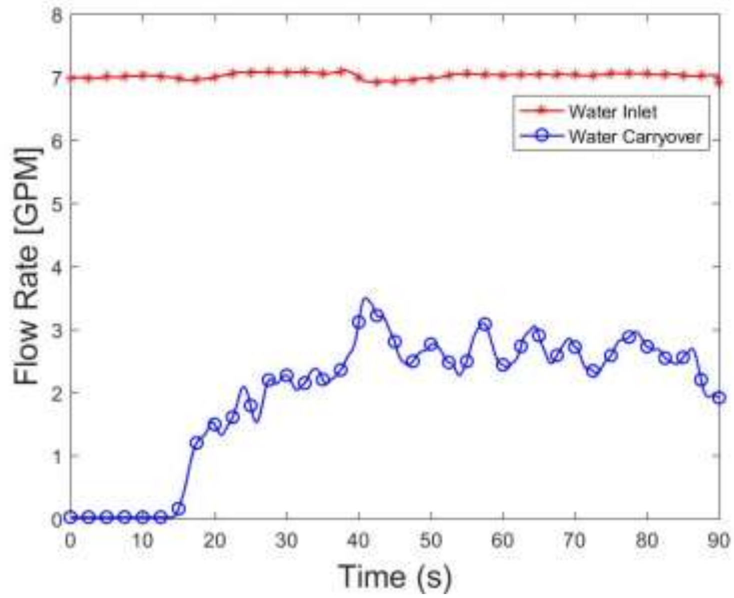

Figure F237: Water flow rates for 2017_05_11_test_03.

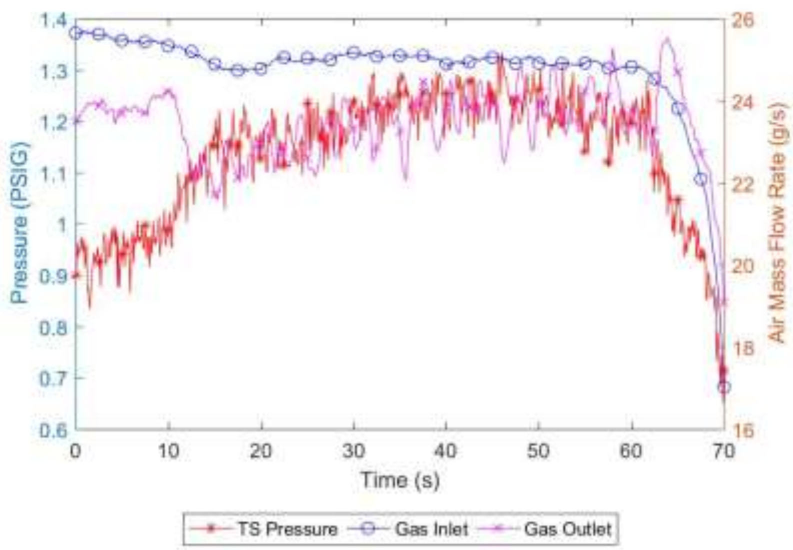

Figure F238: Pressure and gas inlet and outlet mass flow rate for test 2017_05_11_test_04.

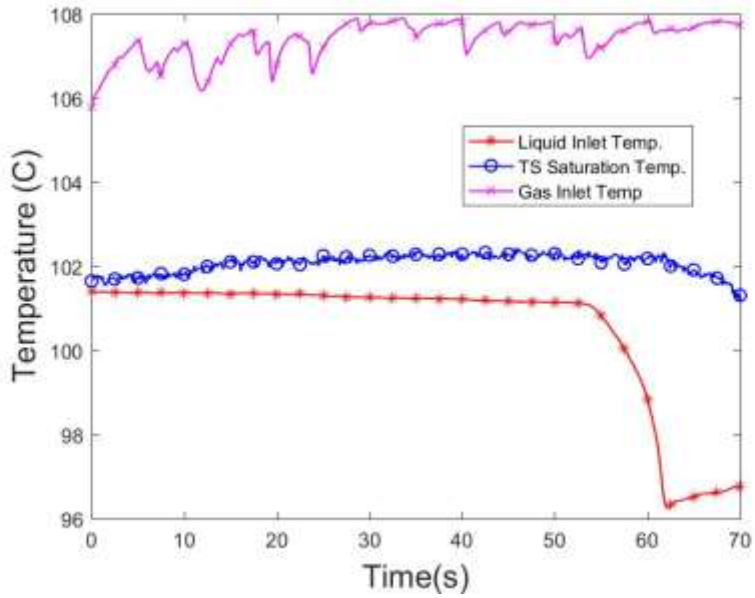

Figure F239: Temperature Profiles for test 2017_05_11_test_04.

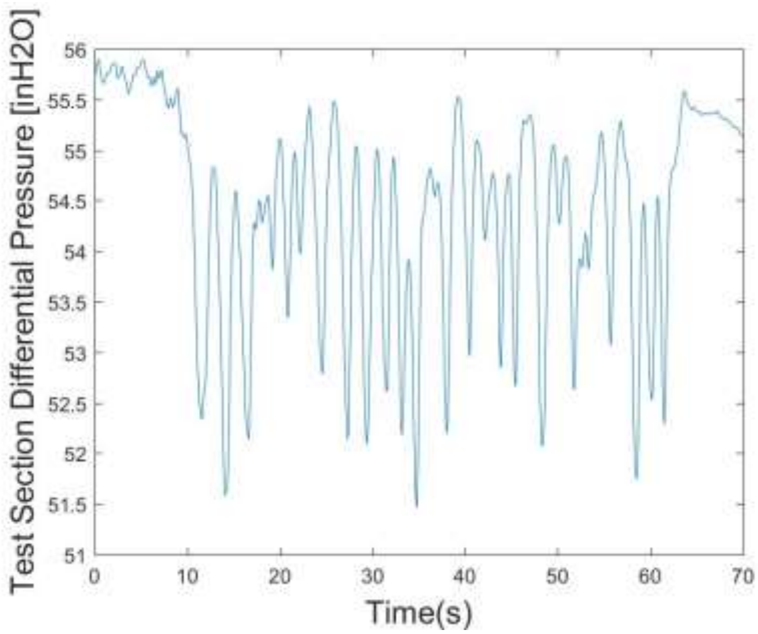

Figure F240: Test section differential pressure for test 2017_05_11_test_04.

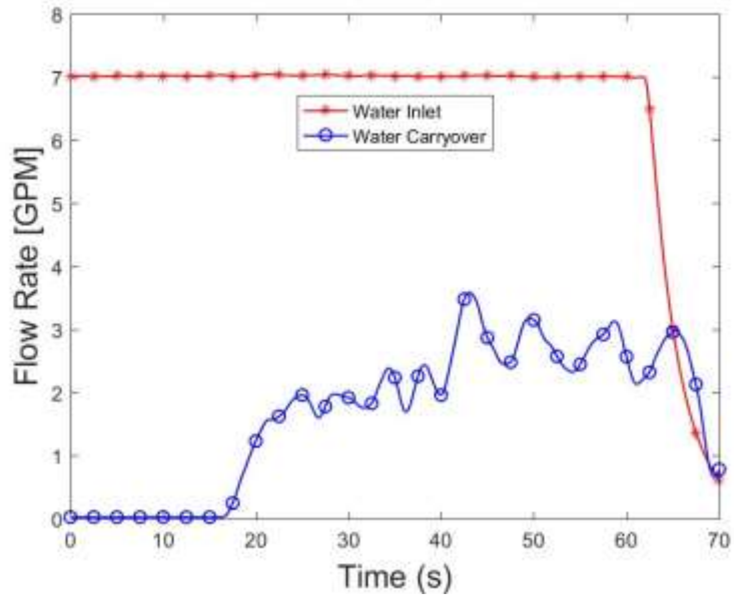

Figure F241: Water flow rates for 2017_05_11_test_04.

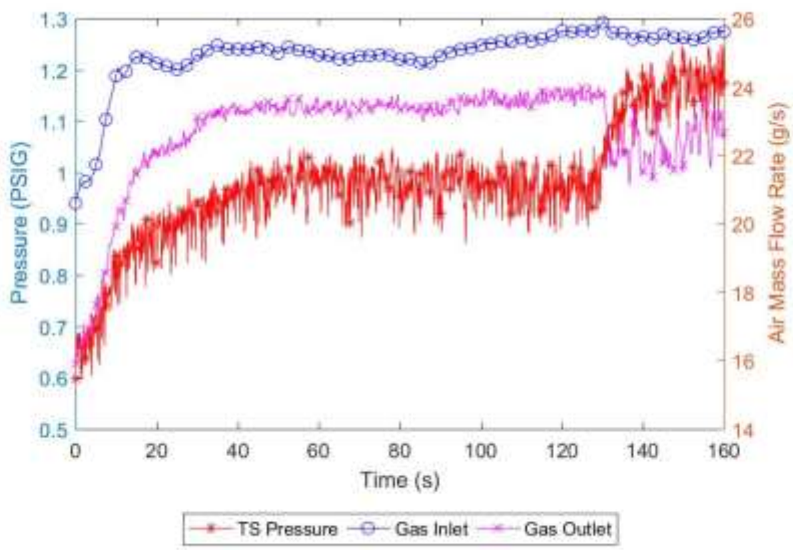

Figure F242: Pressure and gas inlet and outlet mass flow rate for test 2017_05_11_test_05.

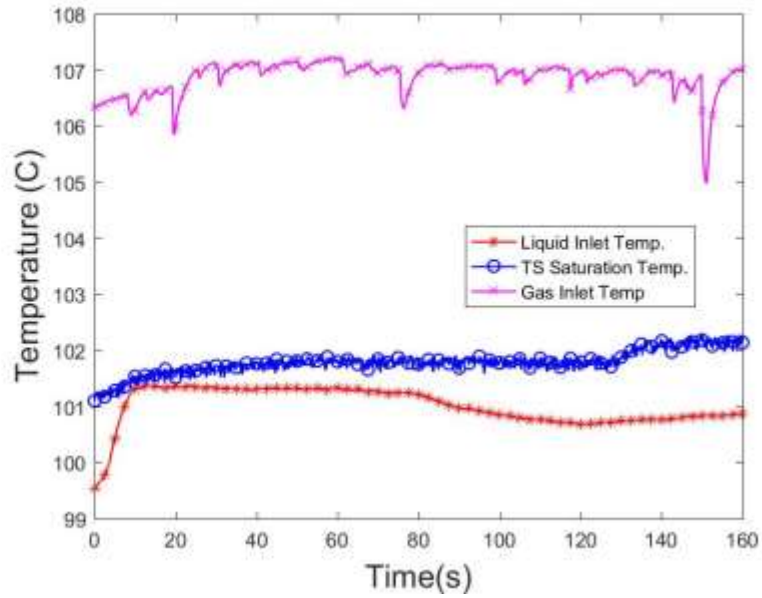

Figure F243: Temperature Profiles for test 2017_05_11_test_05.

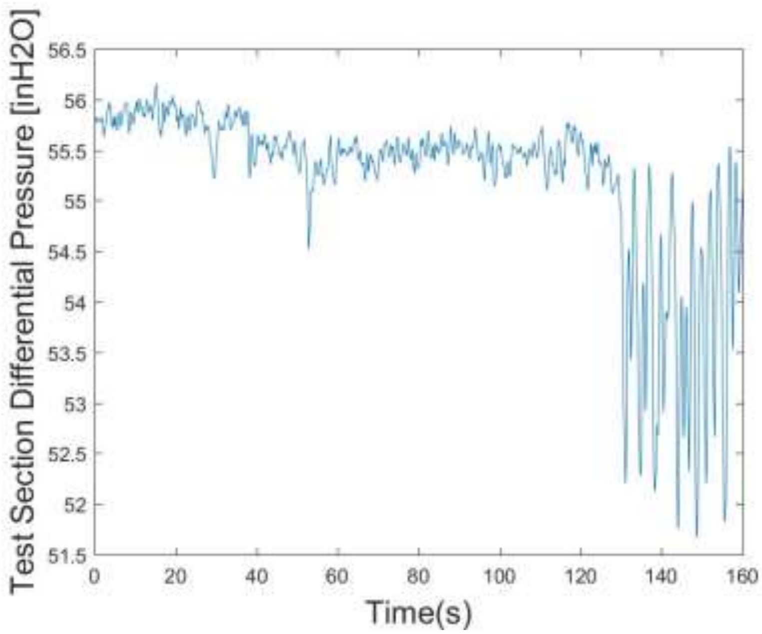

Figure F244: Test section differential pressure for test 2017_05_11_test_05.

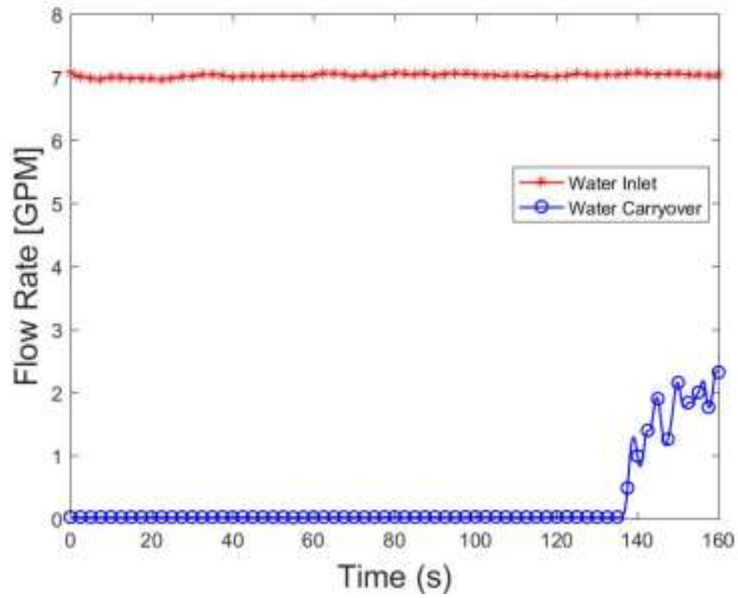

Figure F245: Water flow rates for 2017_05_11_test_05.

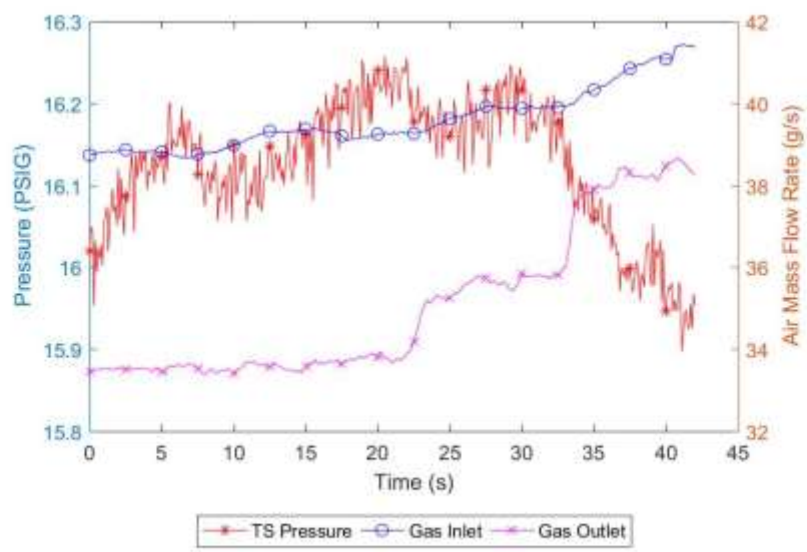

Figure F246: Pressure and gas inlet and outlet mass flow rate for test 2017_05_15_test_01.

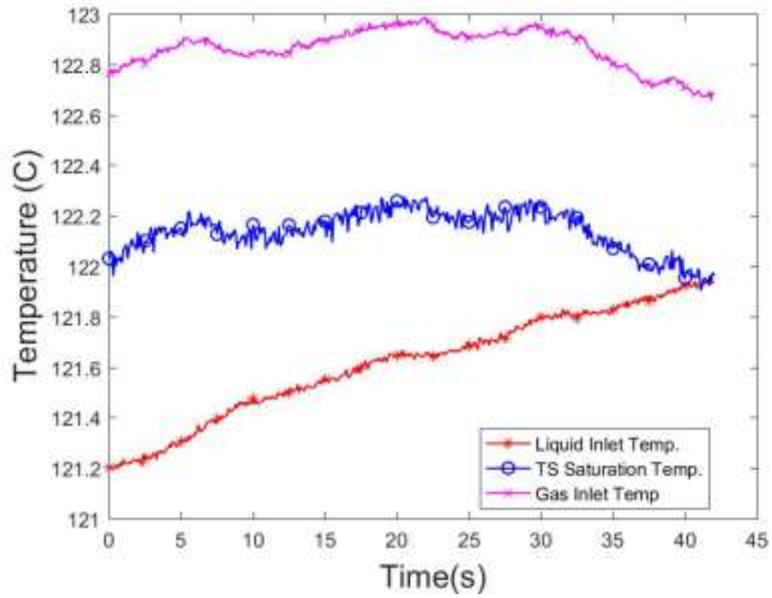

Figure F247: Temperature Profiles for test 2017_05_15_test_01.

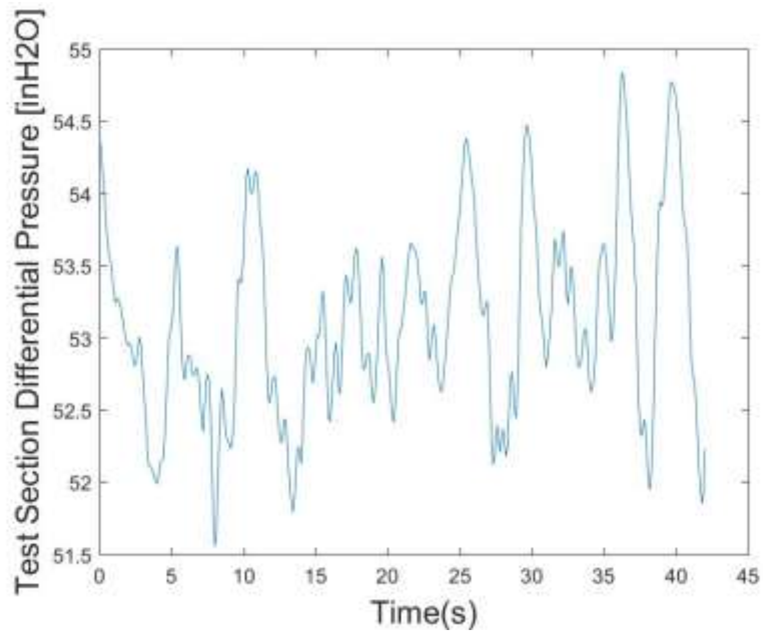

Figure F248: Test section differential pressure for test 2017_05_15_test_01.

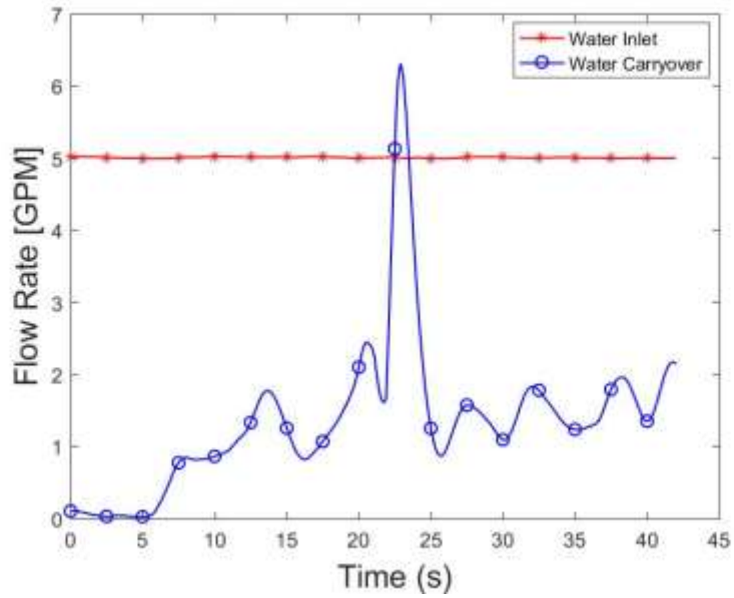

Figure F249: Water flow rates for 2017_05_15_test_01.

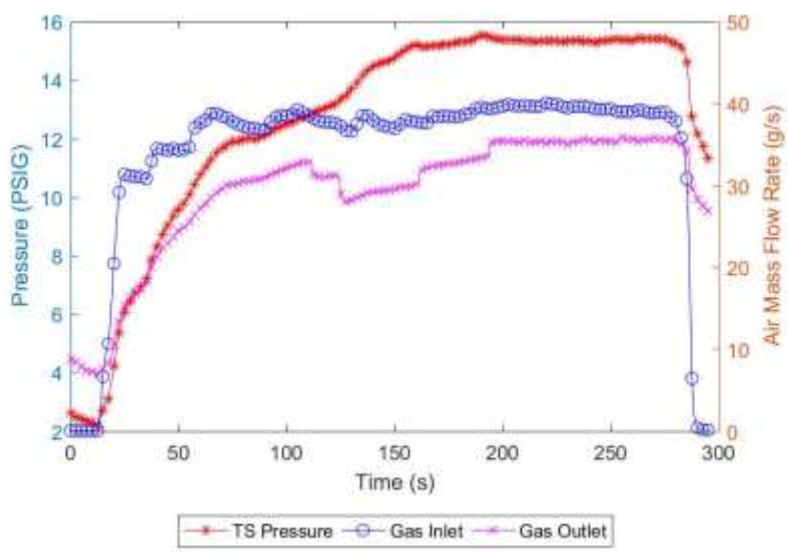

Figure F250: Pressure and gas inlet and outlet mass flow rate for test 2017_05_15_test_02.

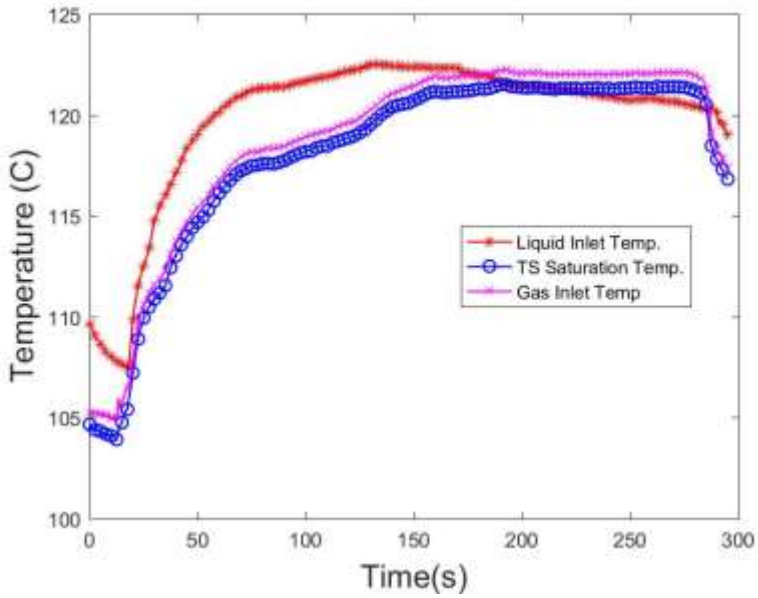

Figure F251: Temperature Profiles for test 2017_05_15_test_02.

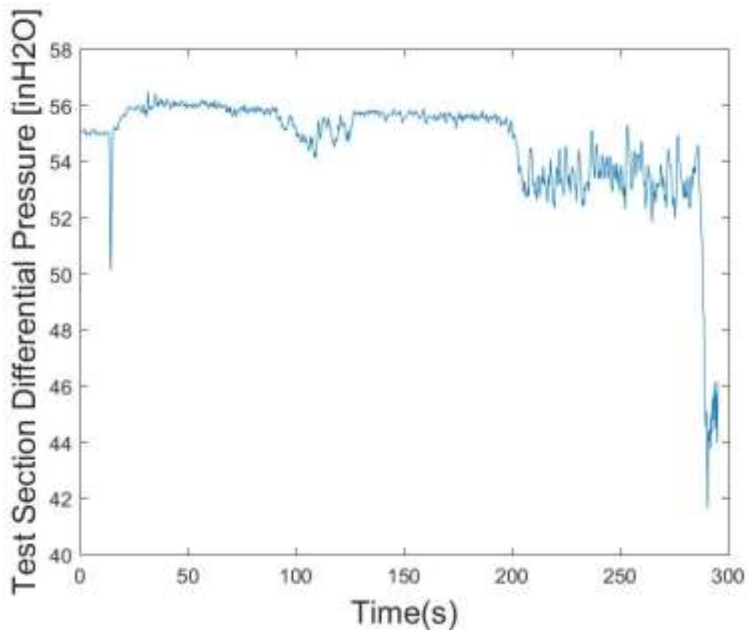

Figure F252: Test section differential pressure for test 2017_05_15_test_02.

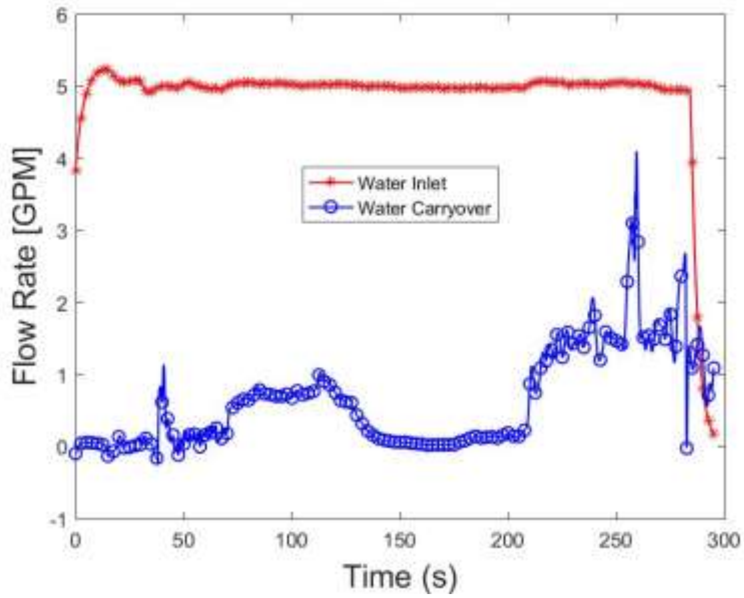

Figure F253: Water flow rates for 2017_05_15_test_02.

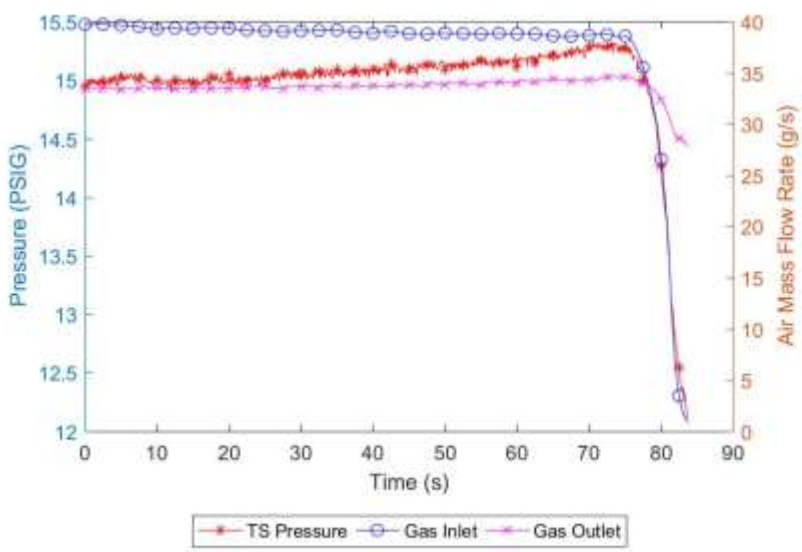

Figure F254: Pressure and gas inlet and outlet mass flow rate for test 2017_05_15_test_03.

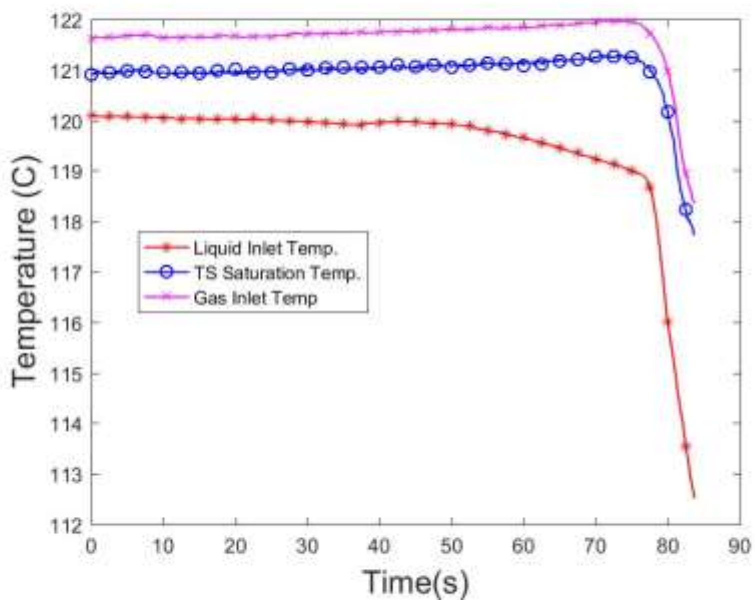

Figure F255: Temperature Profiles for test 2017_05_15_test_03.

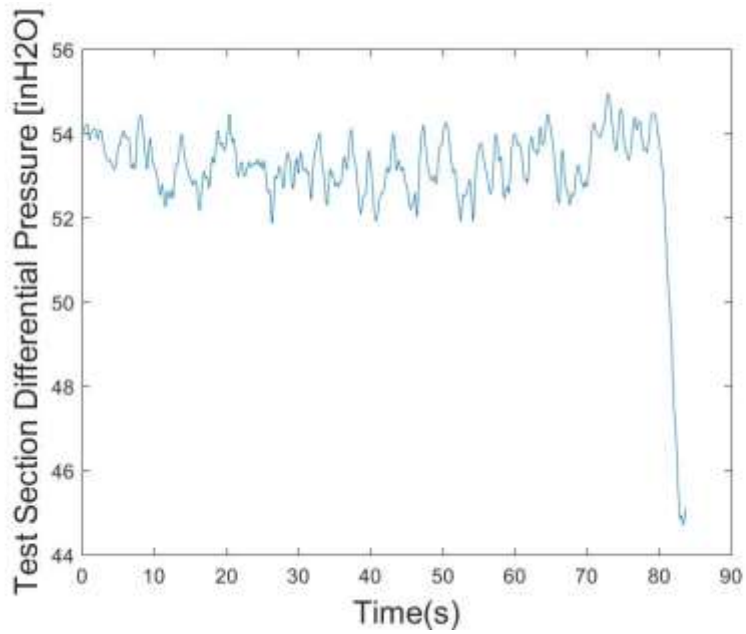

Figure F256: Test section differential pressure for test 2017_05_15_test_03.

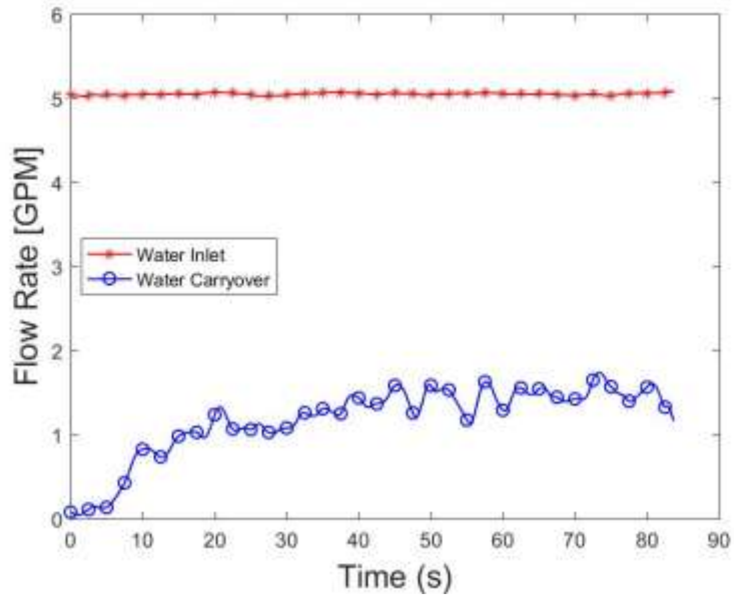

Figure F257: Water flow rates for 2017_05_15_test_03.

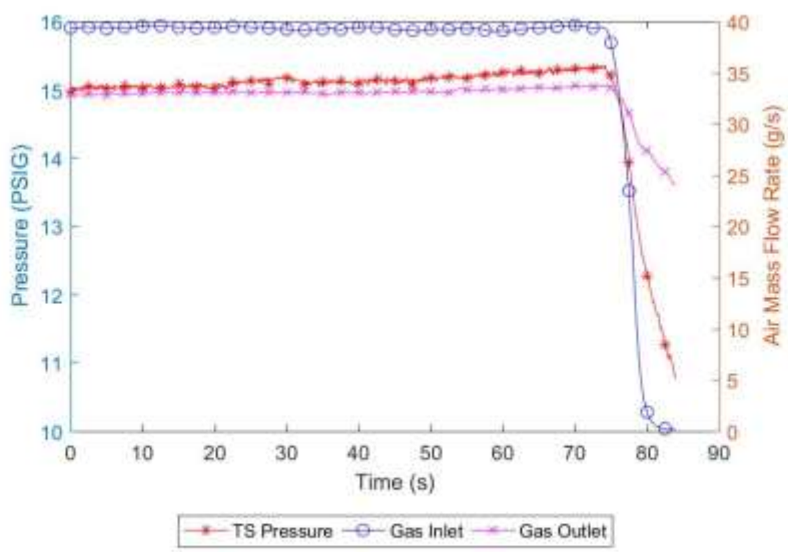

Figure F258: Pressure and gas inlet and outlet mass flow rate for test 2017_05_15_test_04.

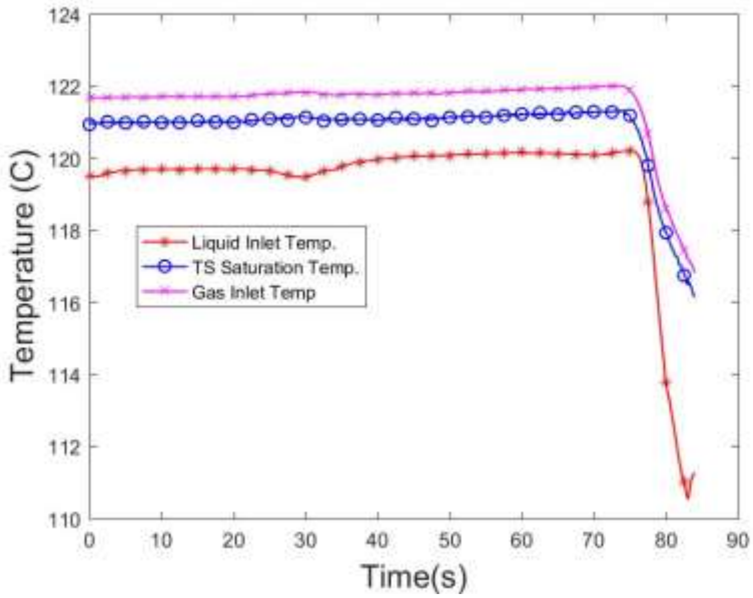

Figure F259: Temperature Profiles for test 2017_05_15_test_04.

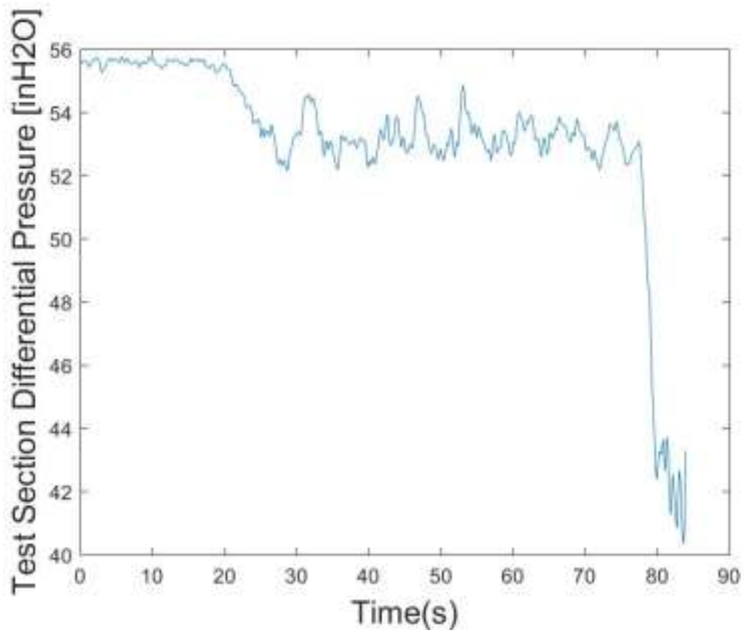

Figure F260: Test section differential pressure for test 2017_05_15_test_04.

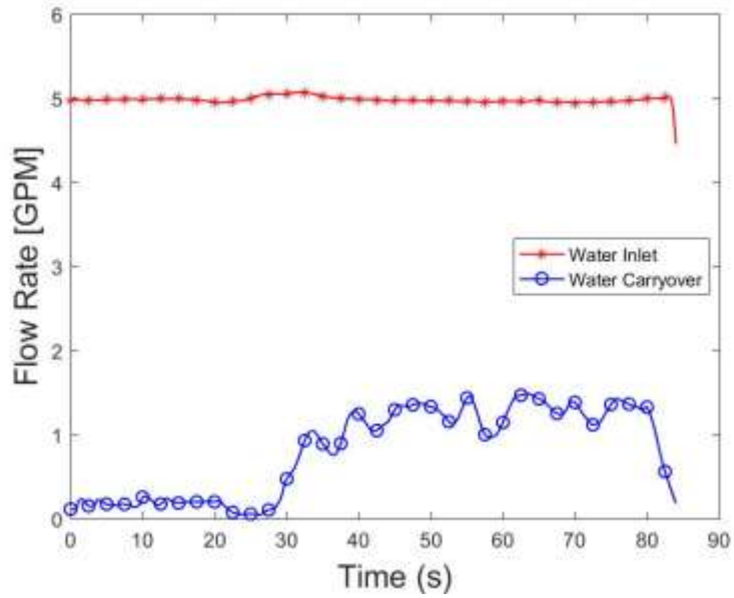

Figure F261: Water flow rates for 2017_05_15_test_04.

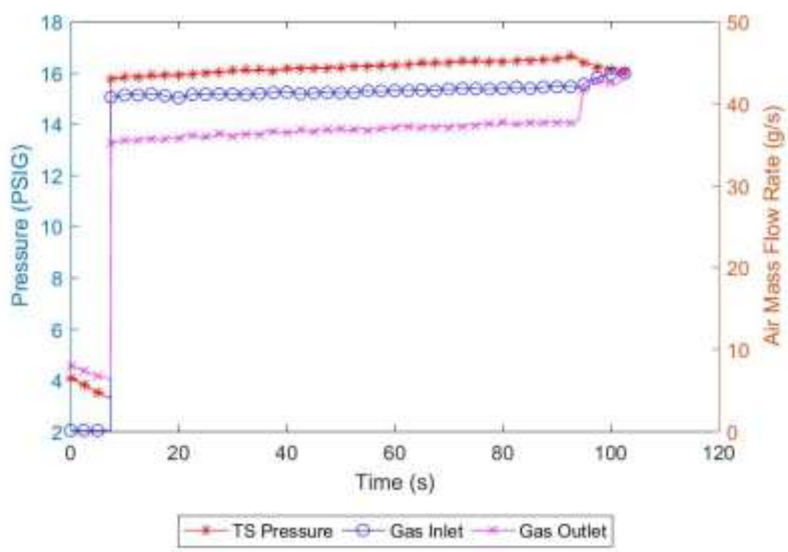

Figure F262: Pressure and gas inlet and outlet mass flow rate for test 2017_05_15_test_06.

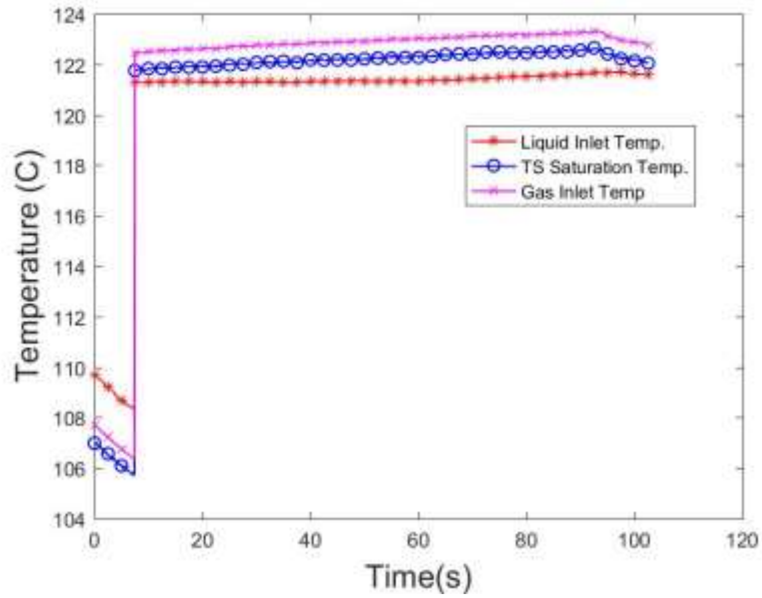

Figure F263: Temperature Profiles for test 2017_05_15_test_06.

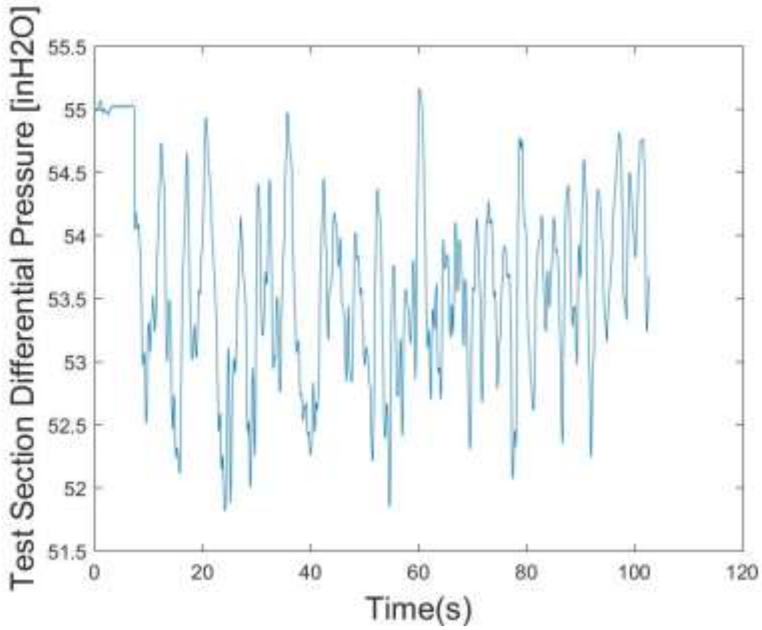

Figure F264: Test section differential pressure for test 2017_05_15_test_06.

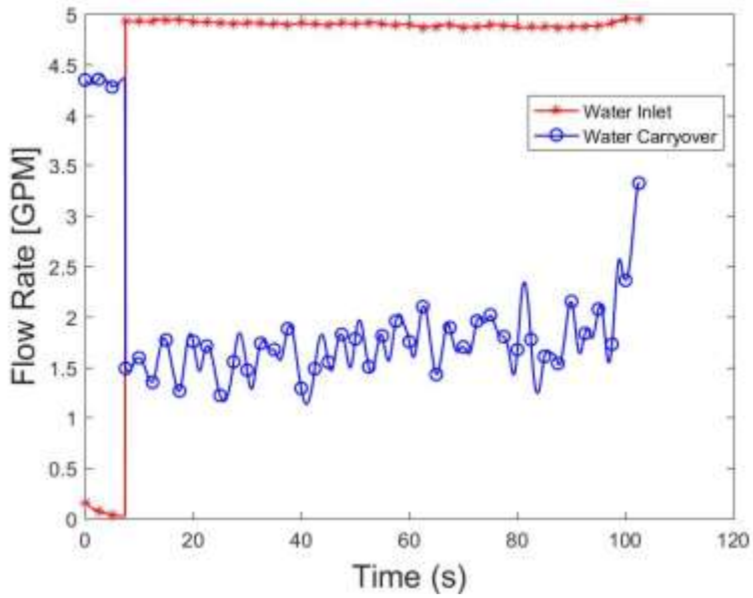

Figure F265: Water flow rates for 2017_05_15_test_06.

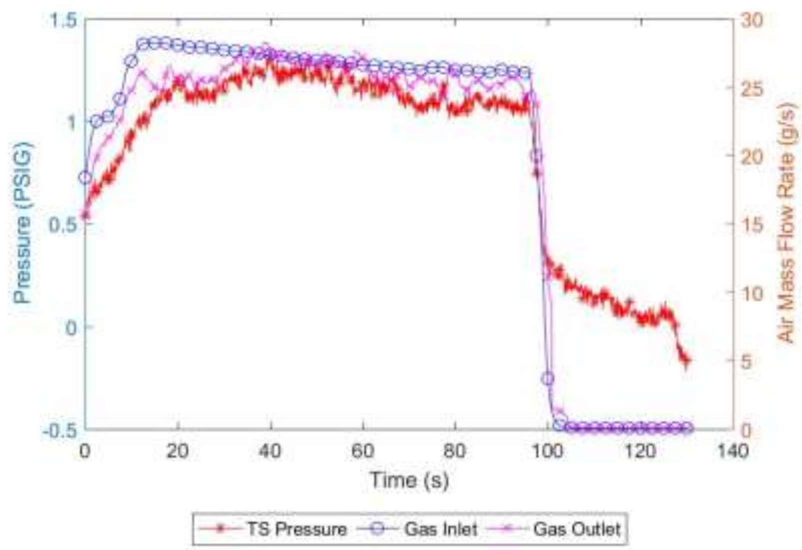

Figure F266: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_01.

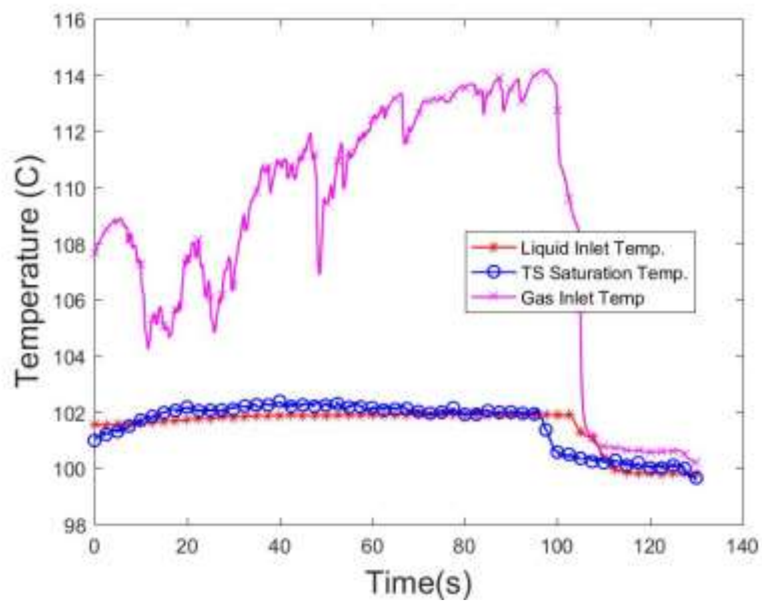

Figure F267: Temperature Profiles for test 2017_05_16_test_01.

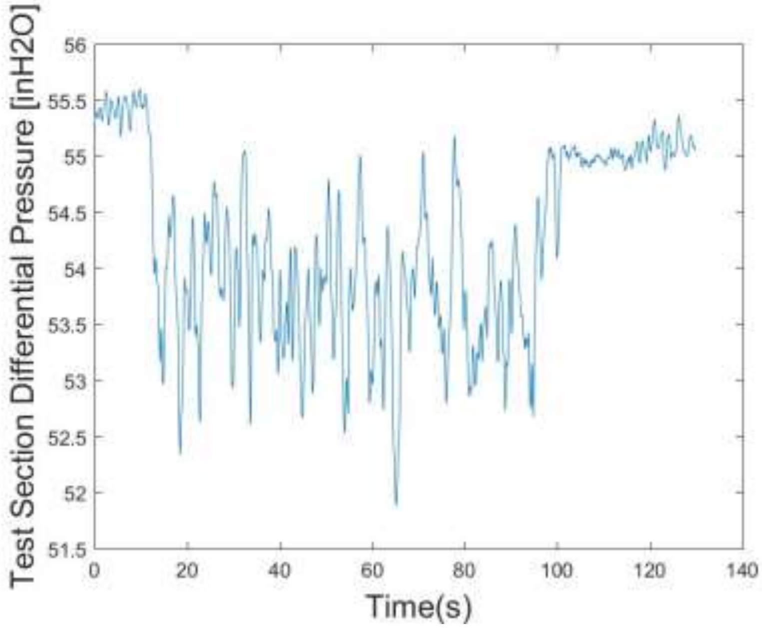

Figure F268: Test section differential pressure for test 2017_05_16_test_01.

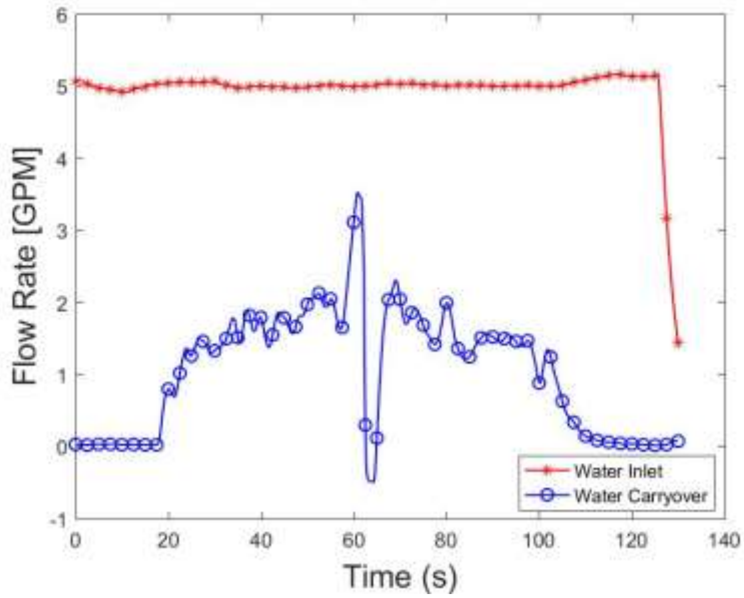

Figure F269: Water flow rates for 2017_05_16_test_01.

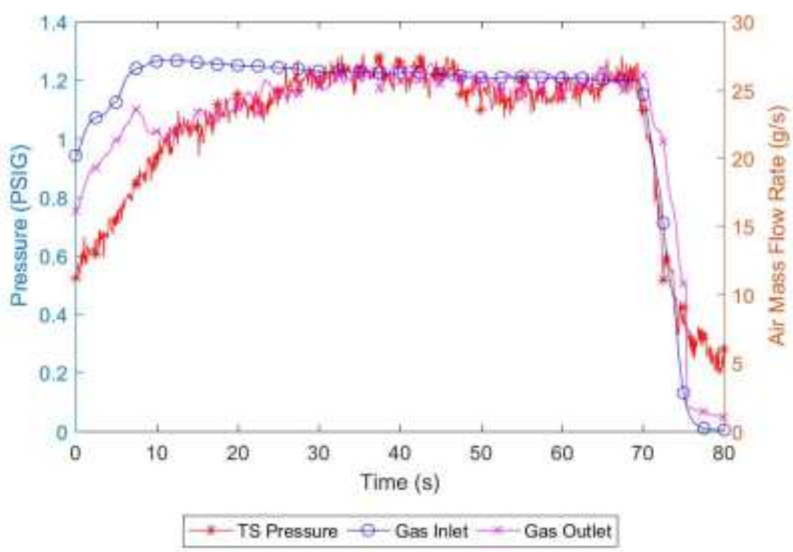

Figure F270: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_02.

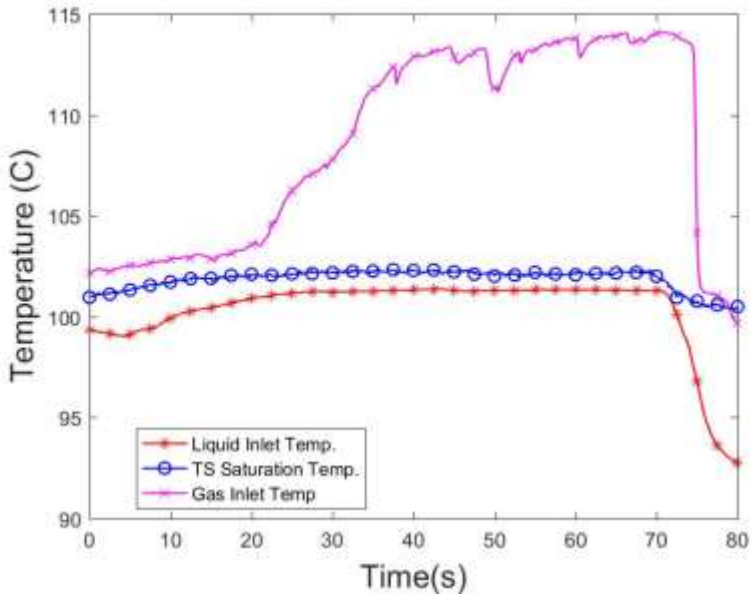

Figure F271: Temperature Profiles for test 2017_05_16_test_02.

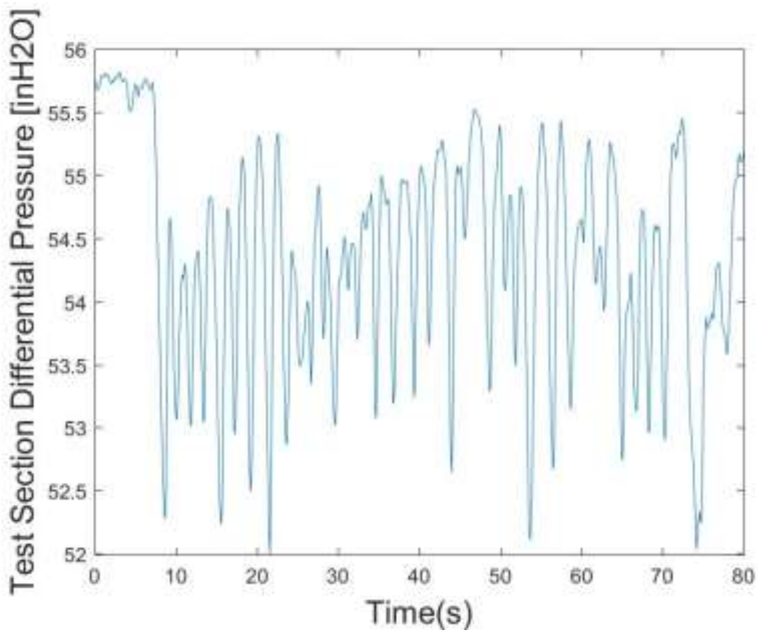

Figure F272: Test section differential pressure for test 2017_05_16_test_02.

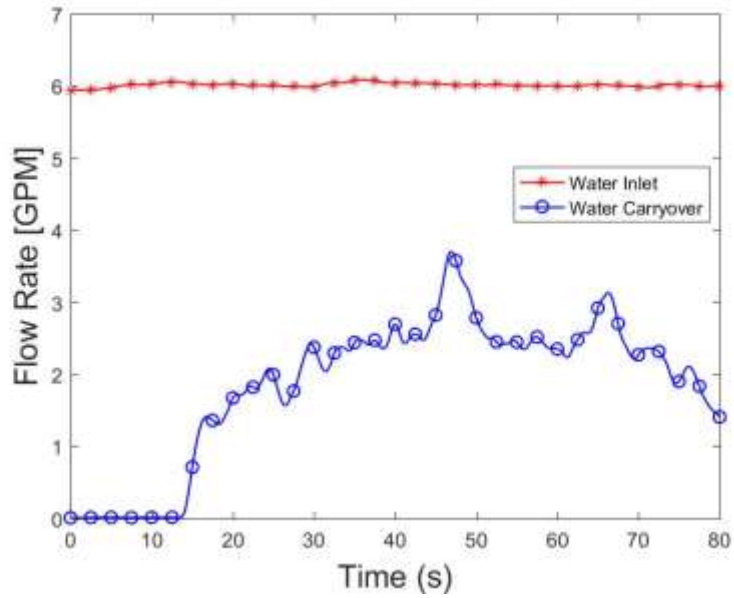

Figure F273: Water flow rates for 2017_05_16_test_02.

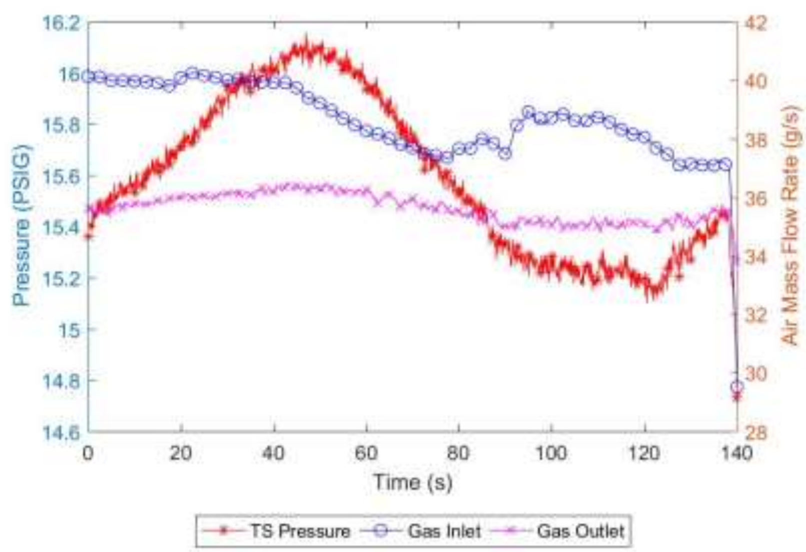

Figure F274: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_03.

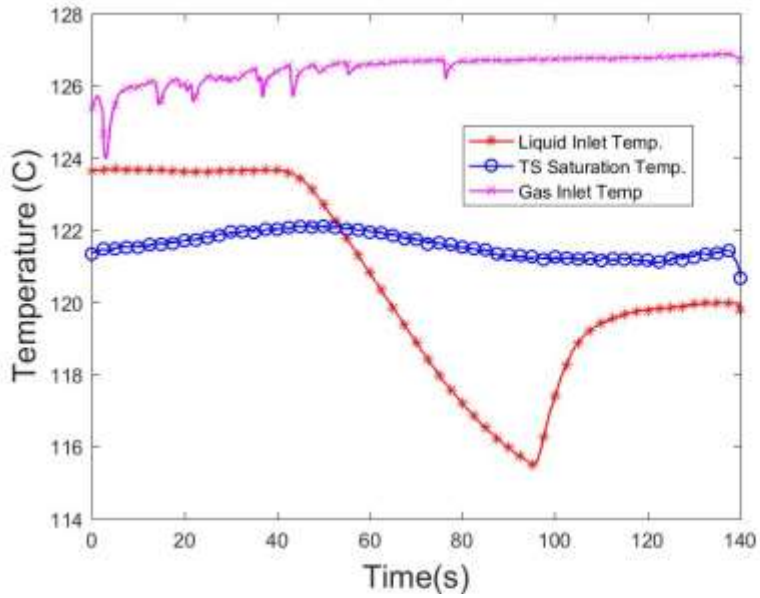

Figure F275: Temperature Profiles for test 2017_05_16_test_03.

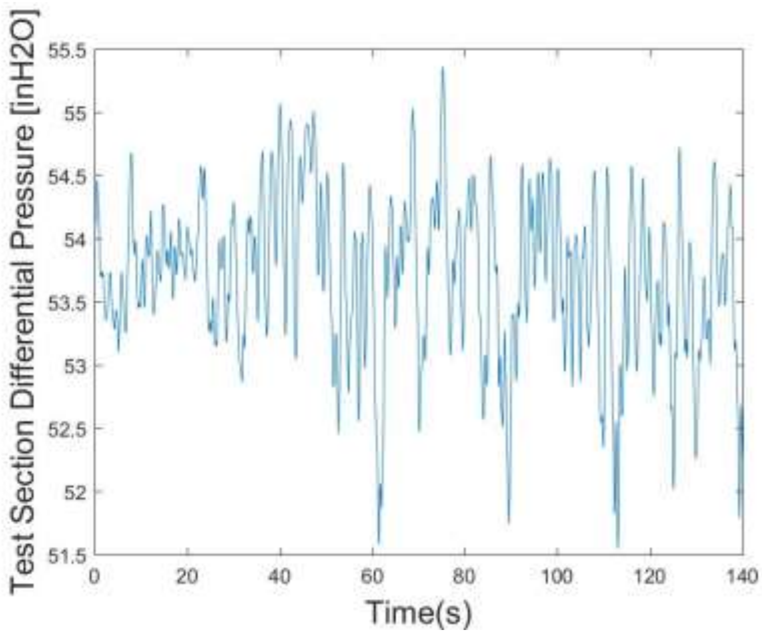

Figure F276: Test section differential pressure for test 2017_05_16_test_03.

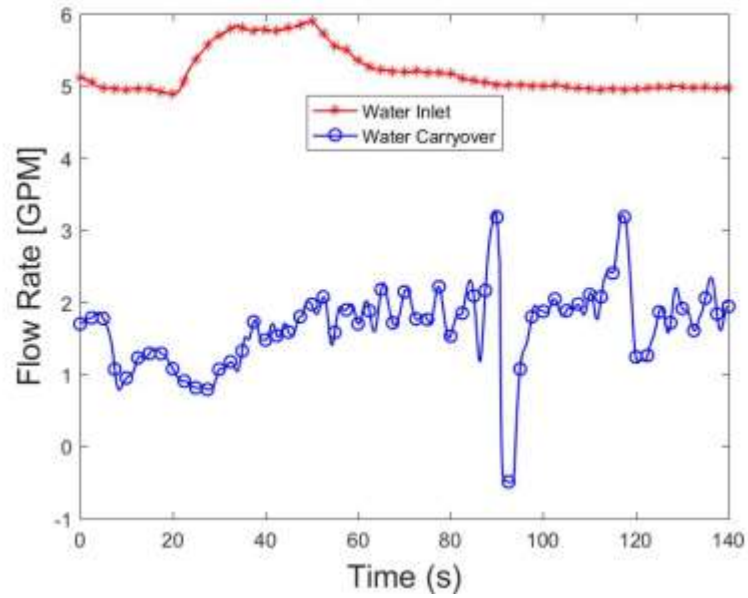

Figure F277: Water flow rates for 2017_05_16_test_03.

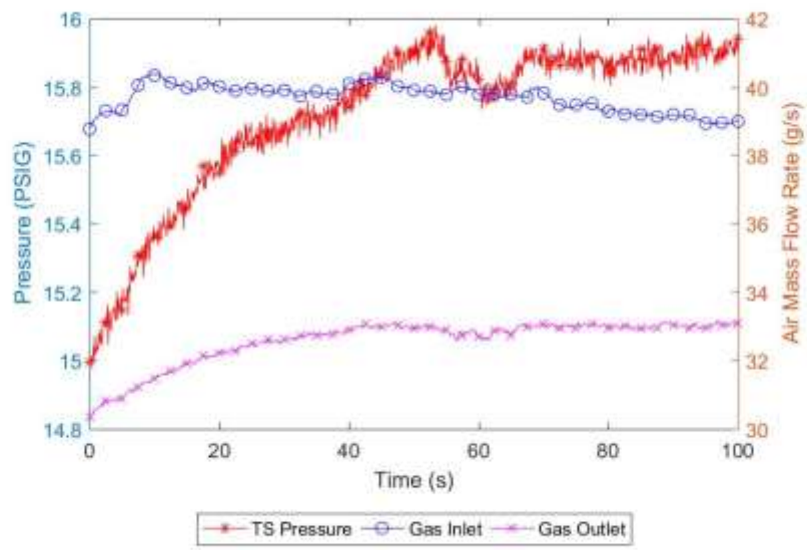

Figure F278: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_04.

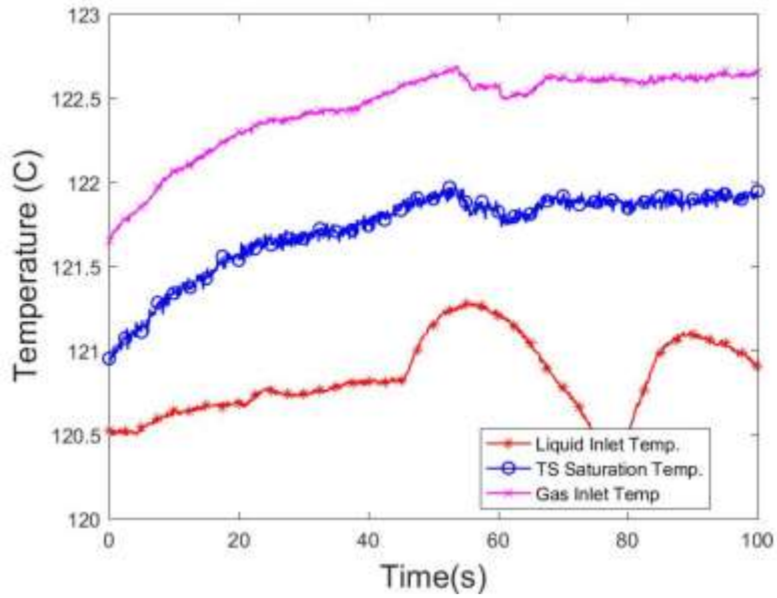

Figure F279: Temperature Profiles for test 2017_05_16_test_04.

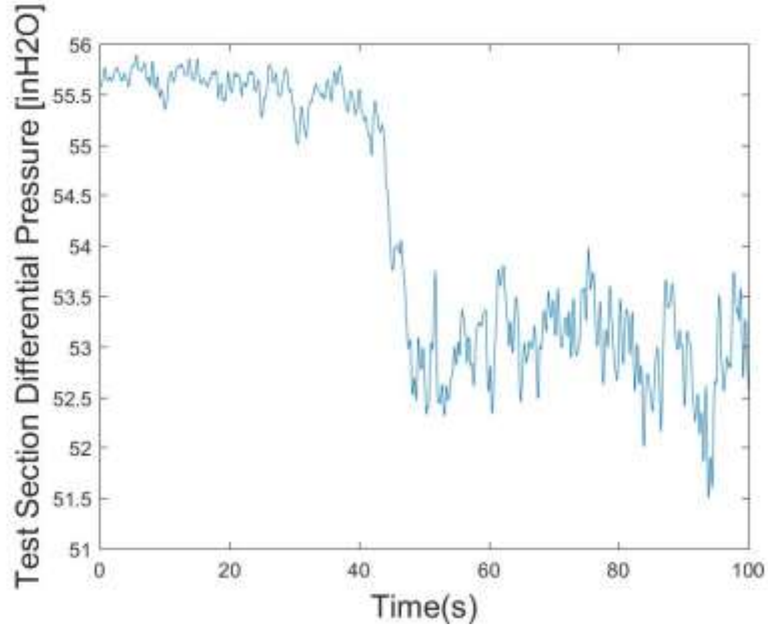

Figure F280: Test section differential pressure for test 2017_05_16_test_04.

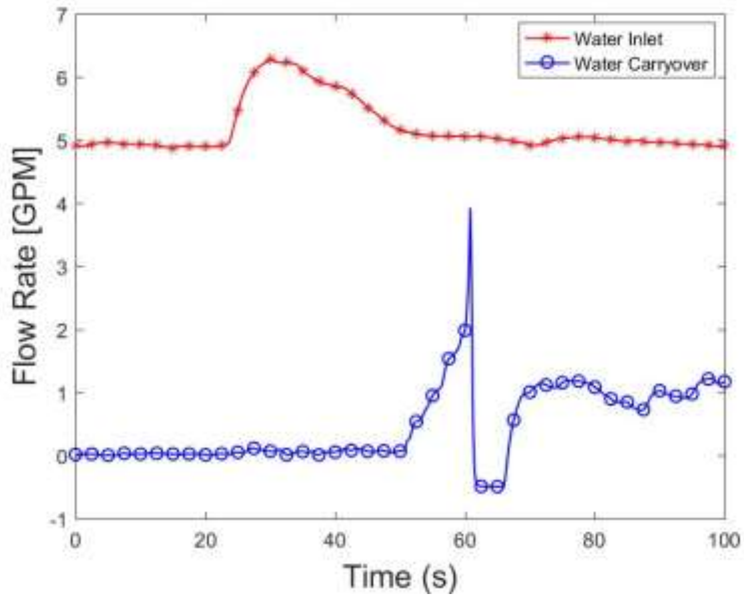

Figure F281: Water flow rates for 2017_05_16_test_04.

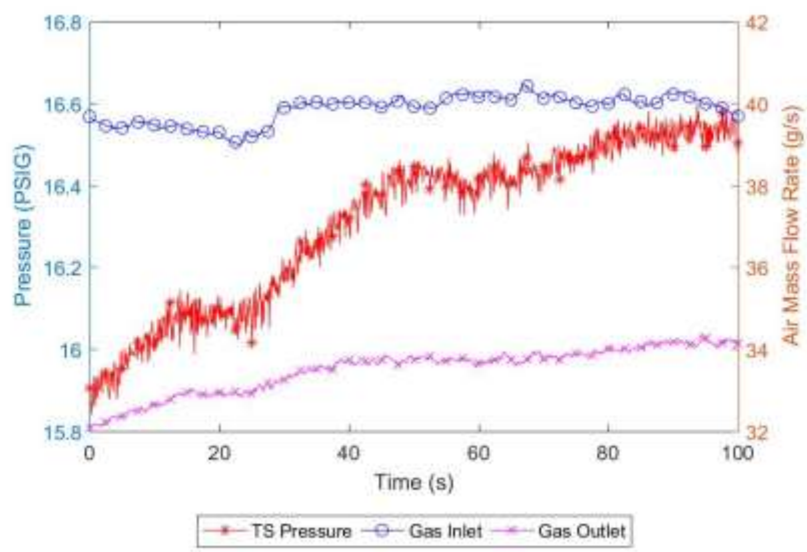

Figure F282: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_05.

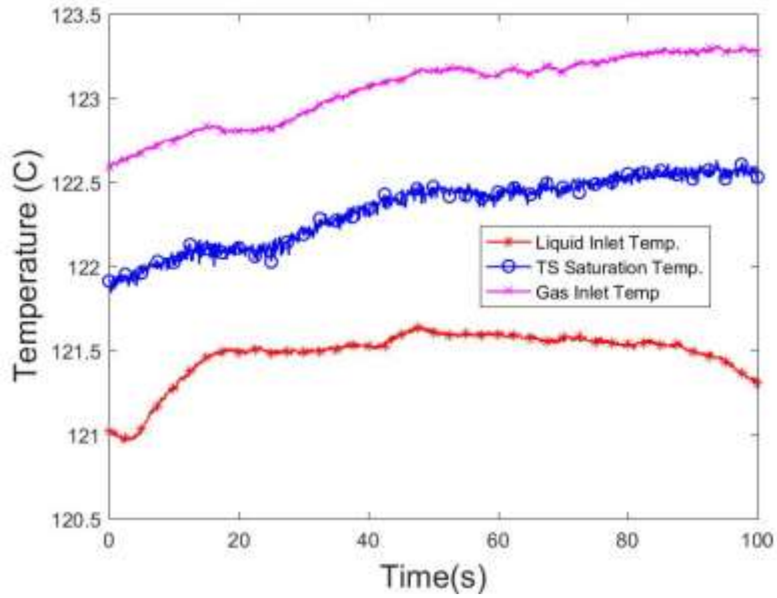

Figure F283: Temperature Profiles for test 2017_05_16_test_05.

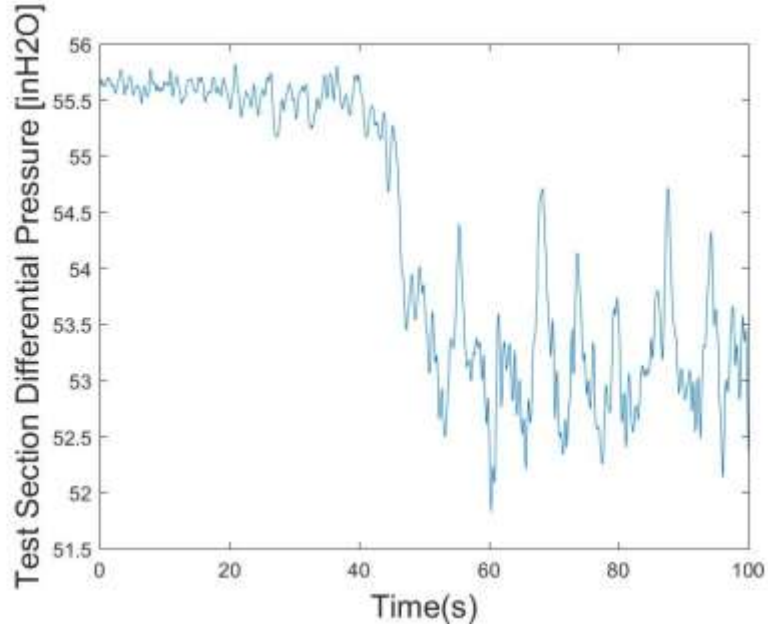

Figure F284: Test section differential pressure for test 2017_05_16_test_05.

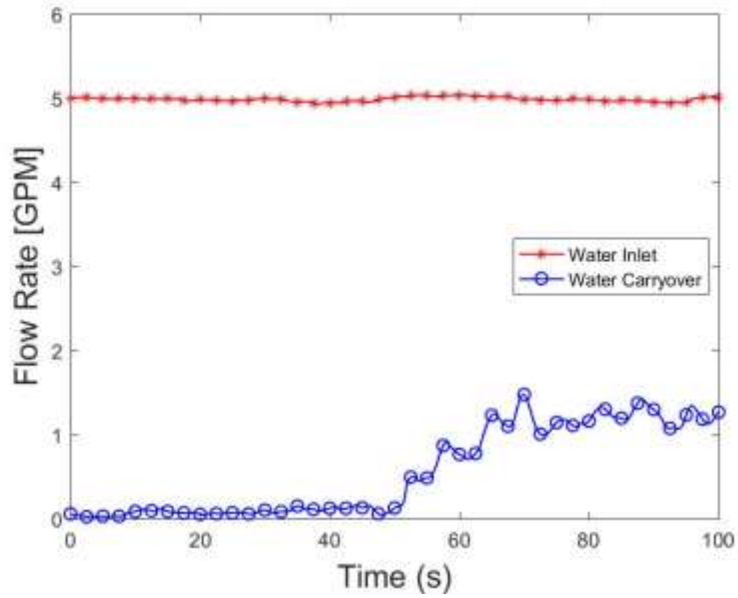

Figure F285: Water flow rates for 2017_05_16_test_05.

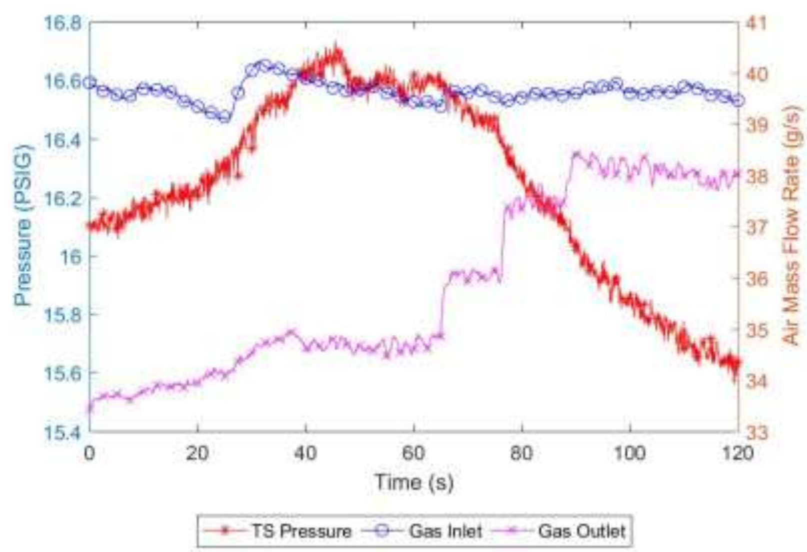

Figure F286: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_06.

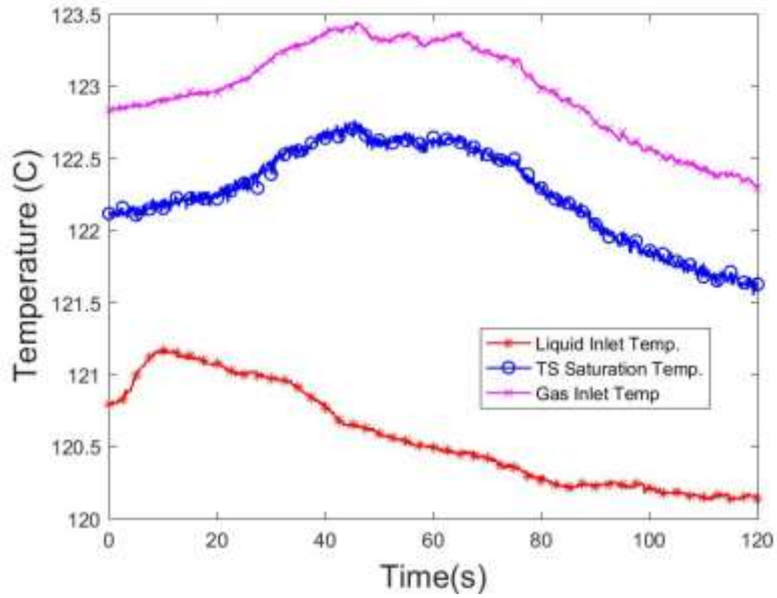

Figure F287: Temperature Profiles for test 2017_05_16_test_06.

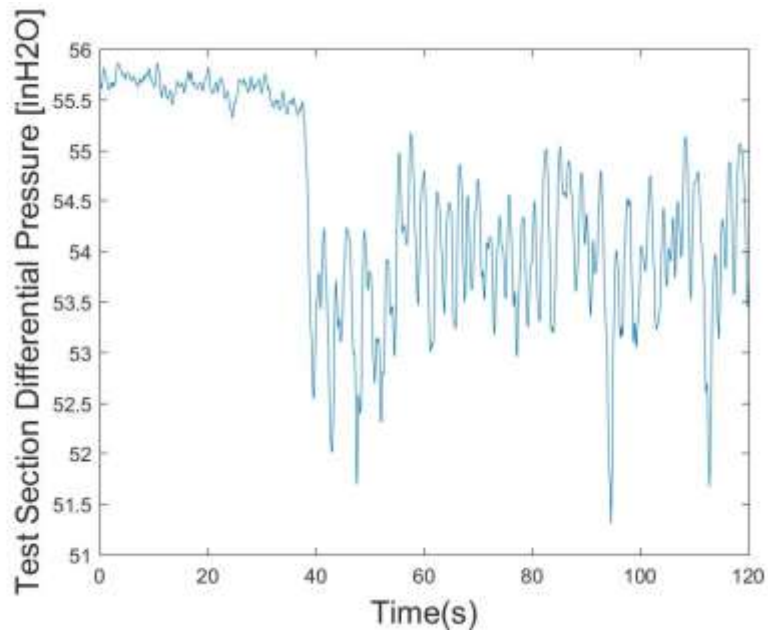

Figure F288: Test section differential pressure for test 2017_05_16_test_06.

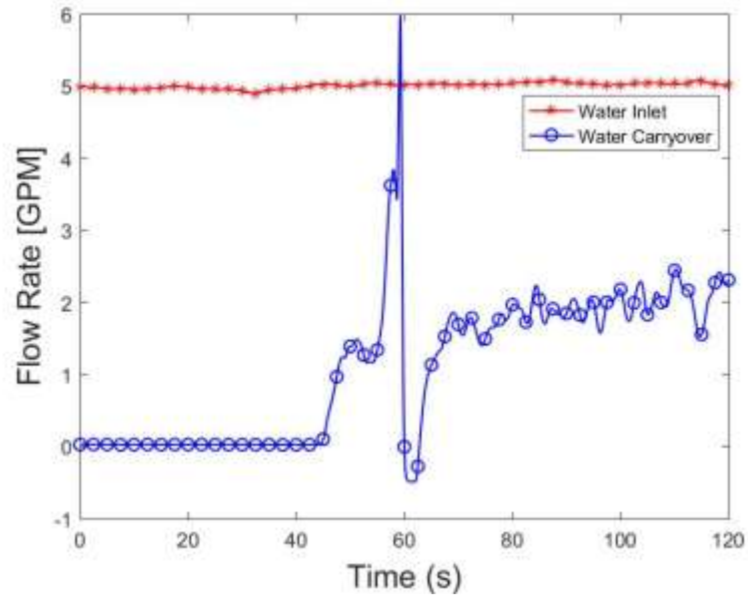

Figure F289: Water flow rates for 2017_05_16_test_06.

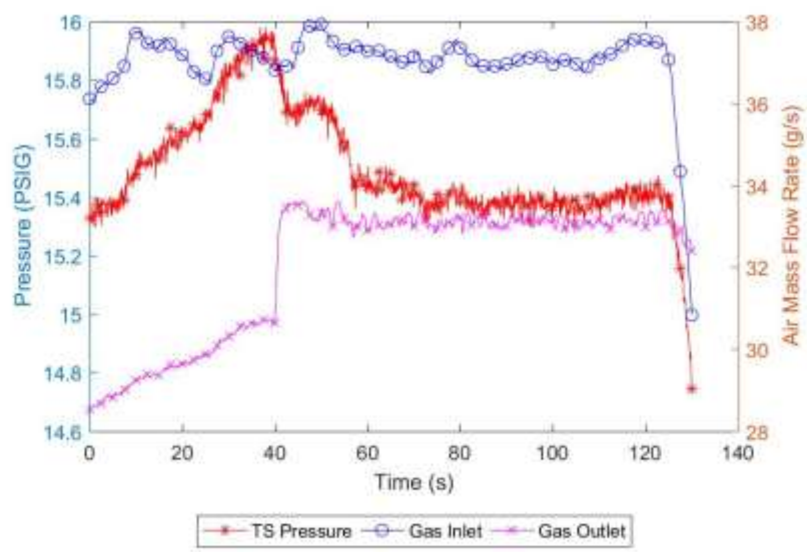

Figure F290: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_10.

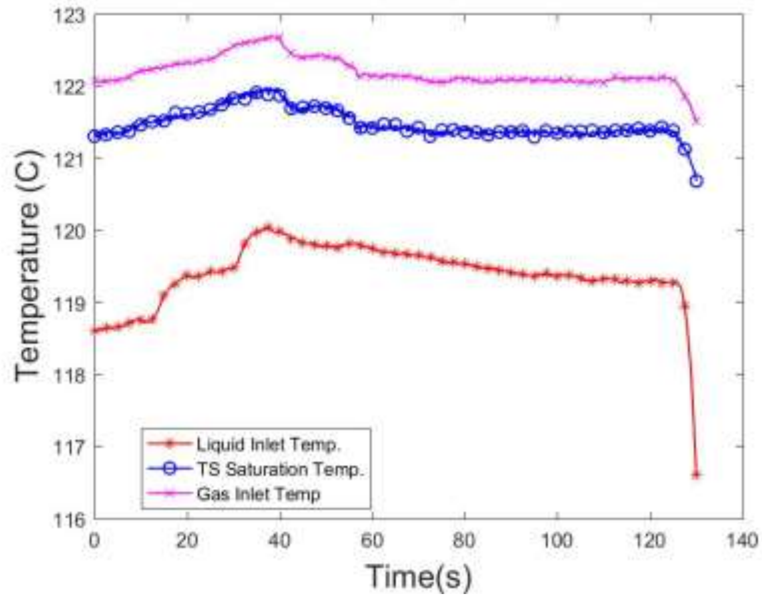

Figure F291: Temperature Profiles for test 2017_05_16_test_10.

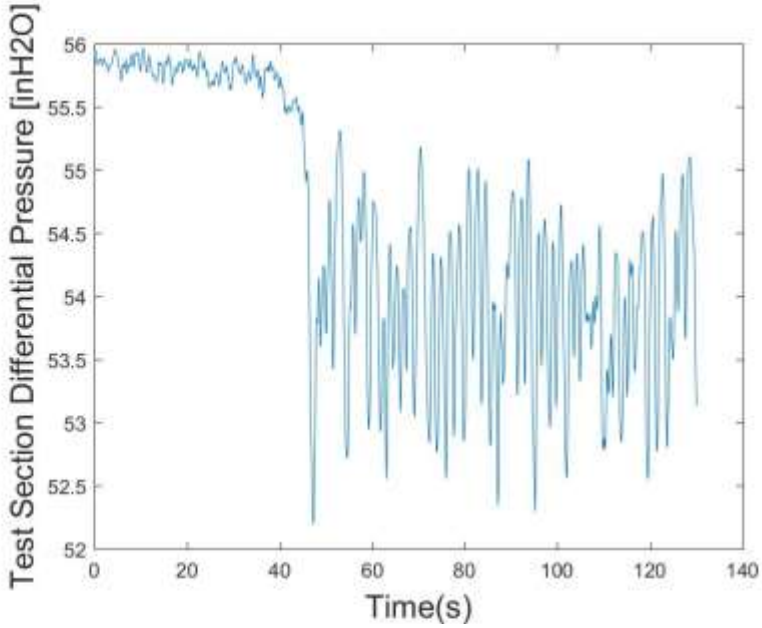

Figure F292: Test section differential pressure for test 2017_05_16_test_10.

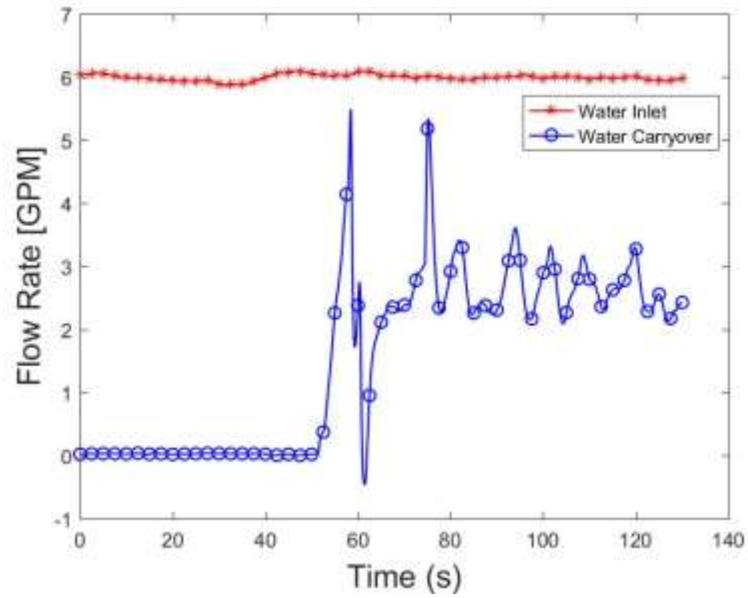

Figure F293: Water flow rates for 2017_05_16_test_10.

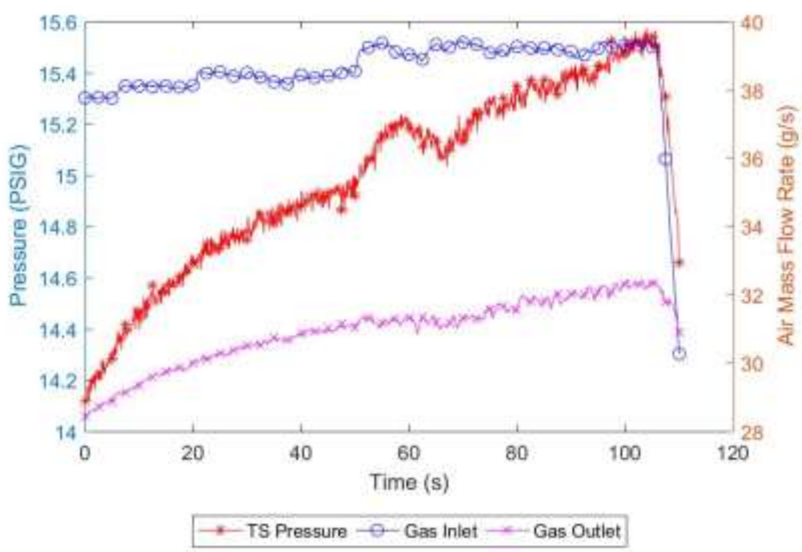

Figure F294: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_11.

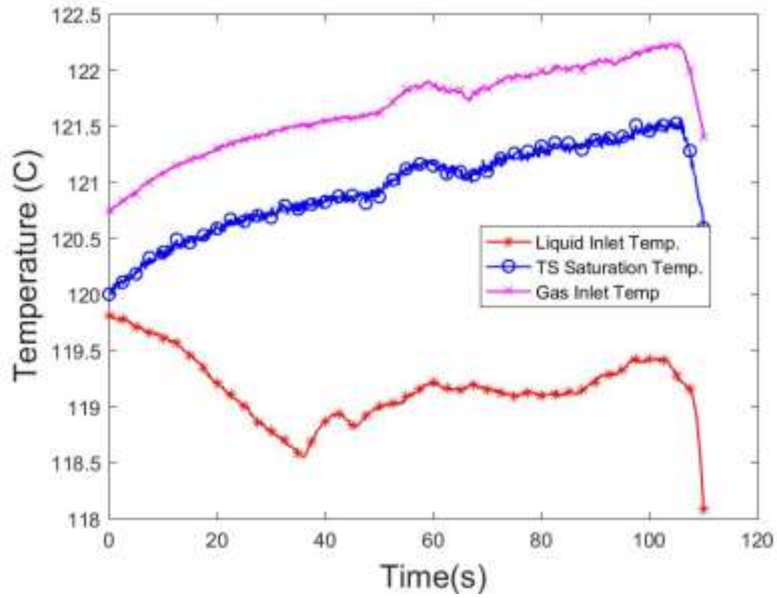

Figure F295: Temperature Profiles for test 2017_05_16_test_11.

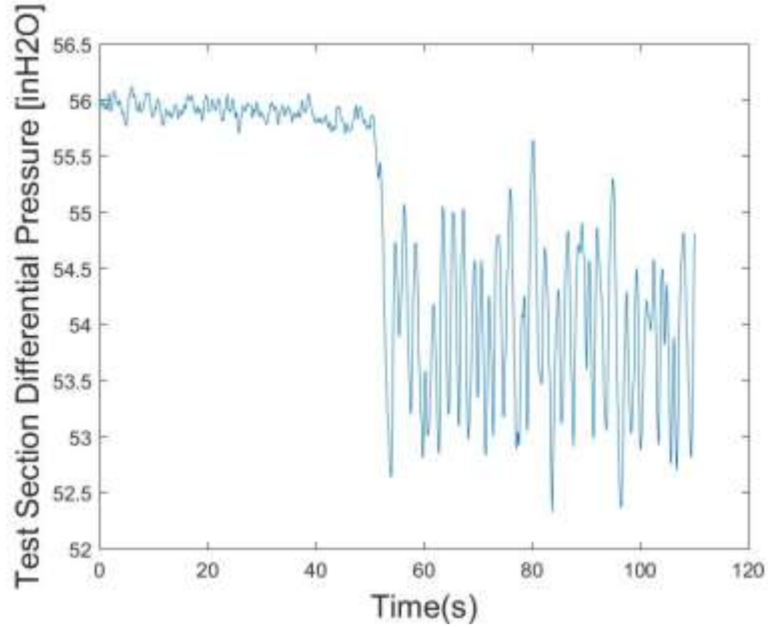

Figure F296: Test section differential pressure for test 2017_05_16_test_11.

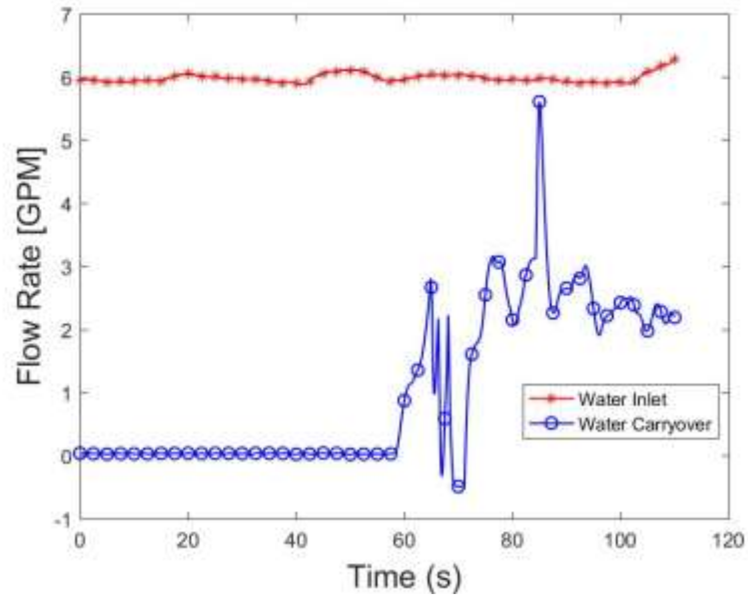

Figure F297: Water flow rates for 2017_05_16_test_11.

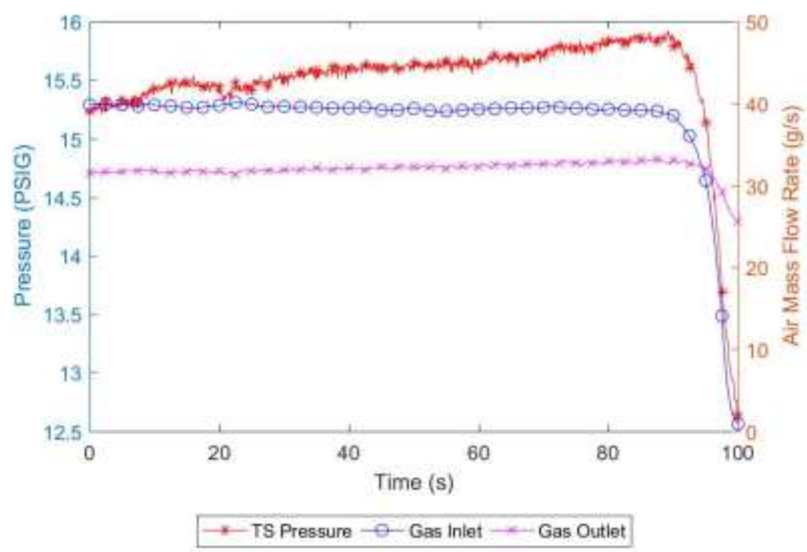

Figure F298: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_12.

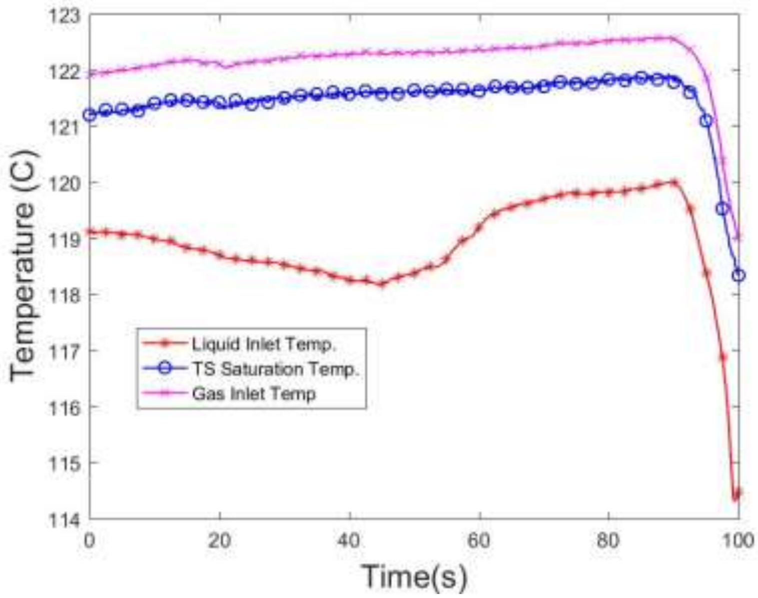

Figure F299: Temperature Profiles for test 2017_05_16_test_12.

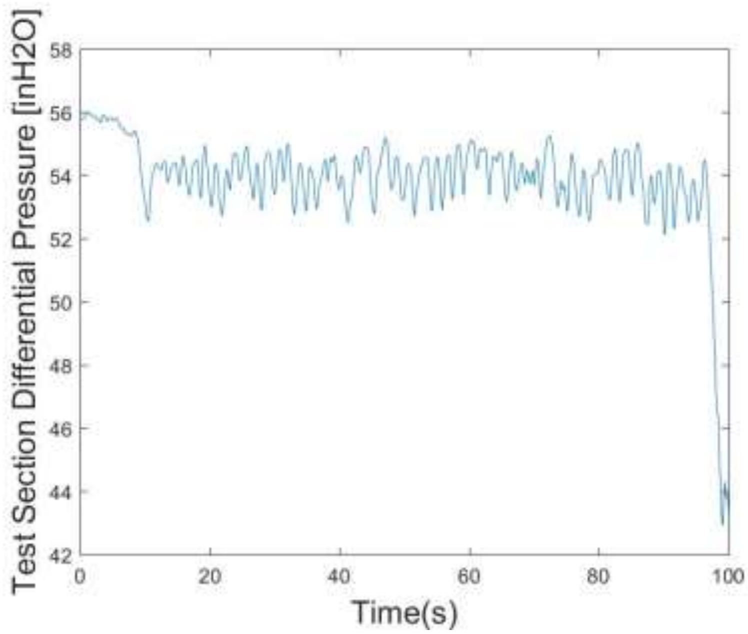

Figure F300: Test section differential pressure for test 2017_05_16_test_12.

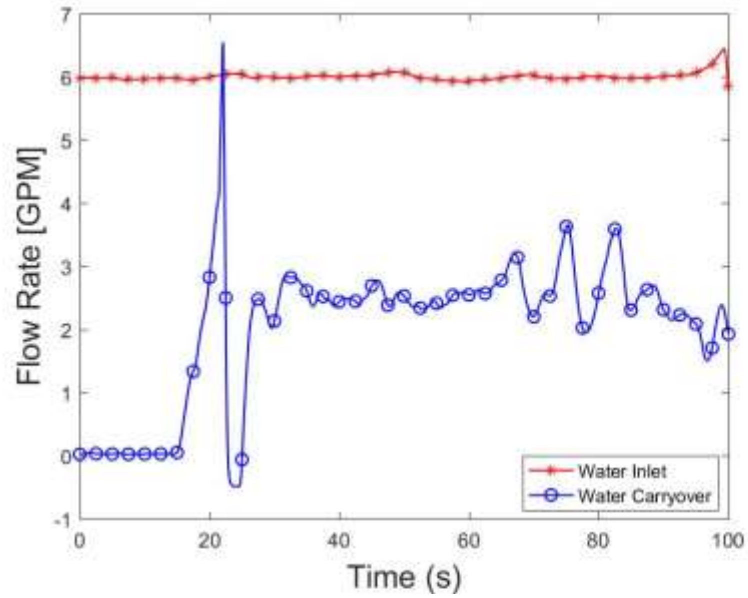

Figure F301: Water flow rates for 2017_05_16_test_12.

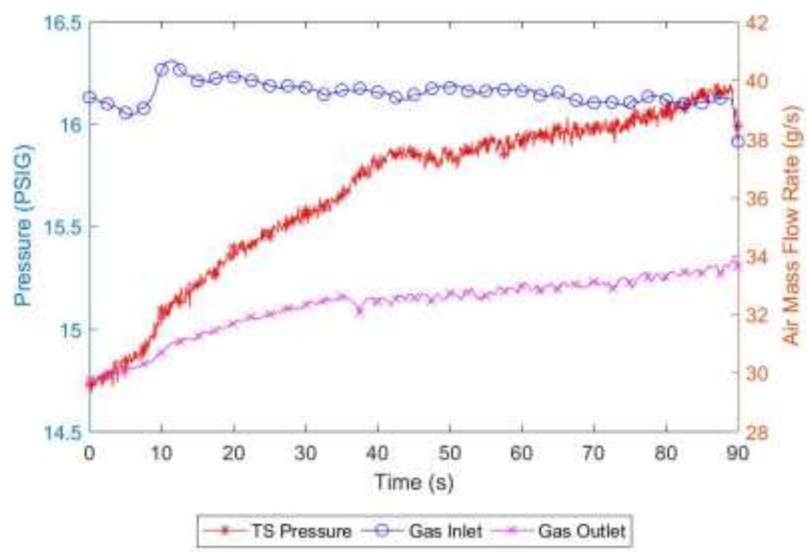

Figure F302: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_13.

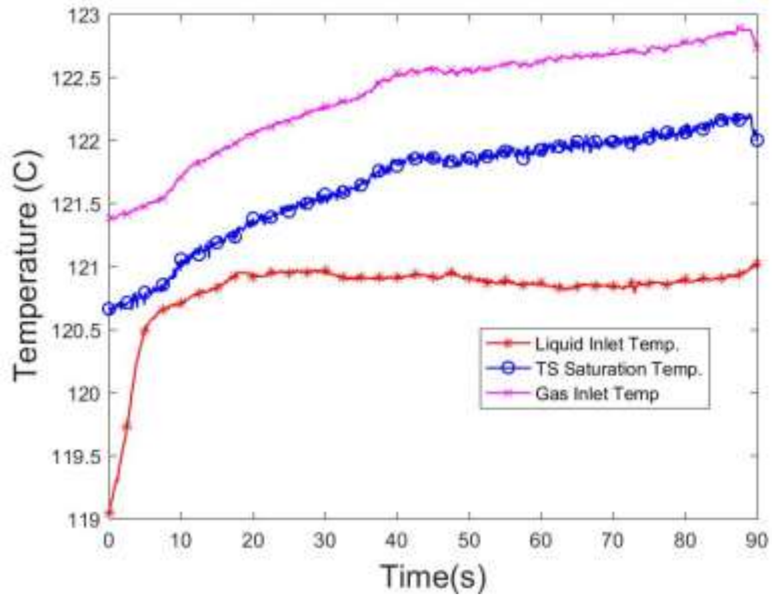

Figure F303: Temperature Profiles for test 2017_05_16_test_13.

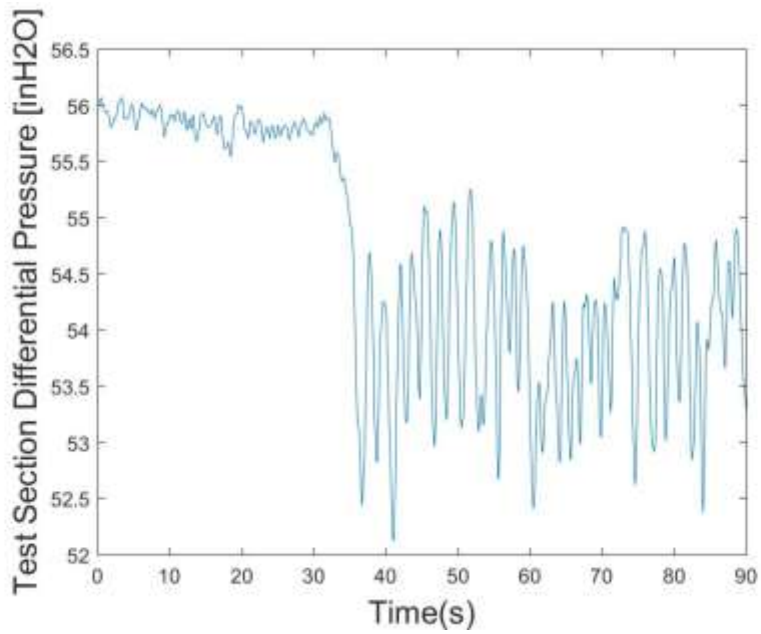

Figure F304: Test section differential pressure for test 2017_05_16_test_13.

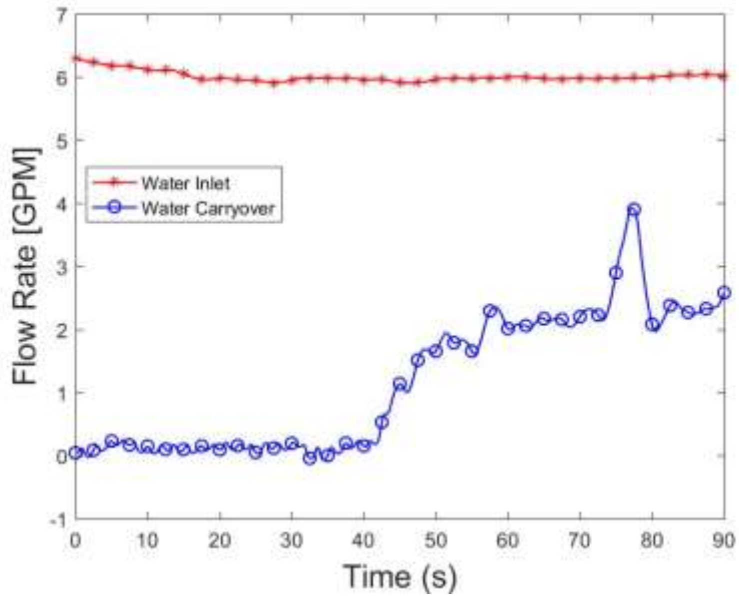

Figure F305: Water flow rates for 2017_05_16_test_13.

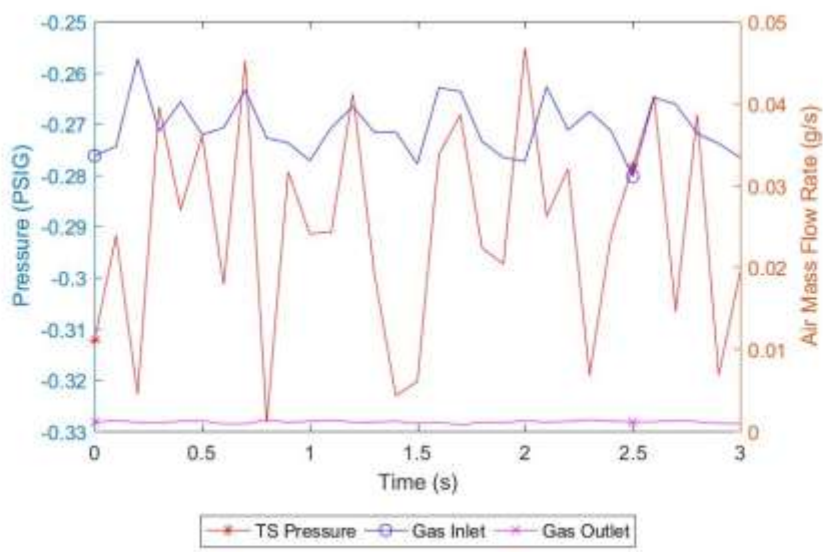

Figure F306: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_14.

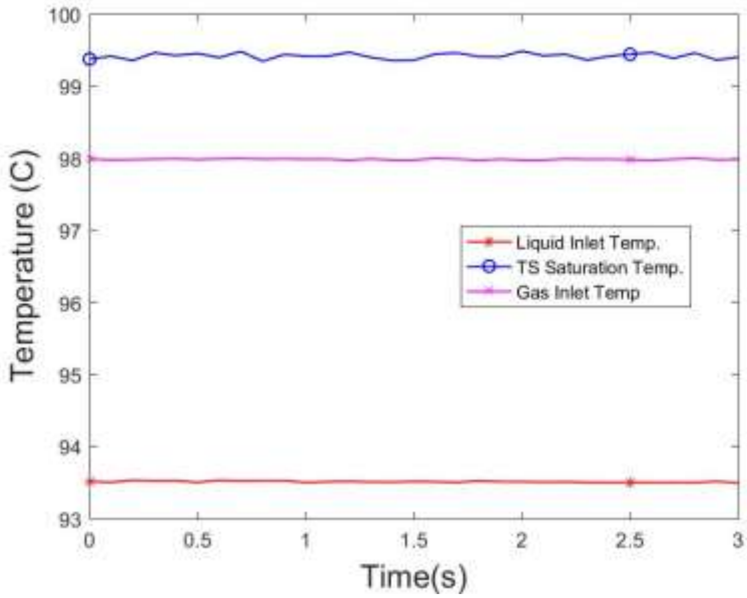

Figure F307: Temperature Profiles for test 2017_05_16_test_14.

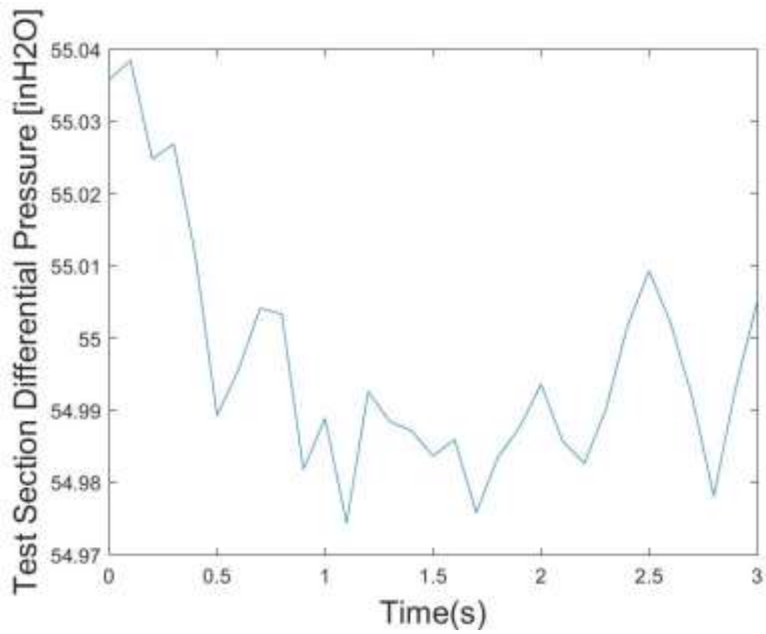

Figure F308: Test section differential pressure for test 2017_05_16_test_14.

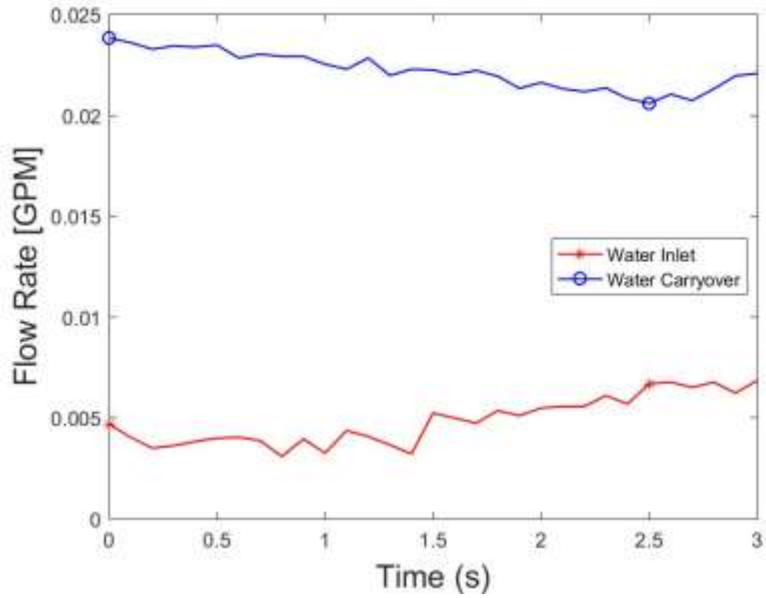

Figure F309: Water flow rates for 2017_05_16_test_14.

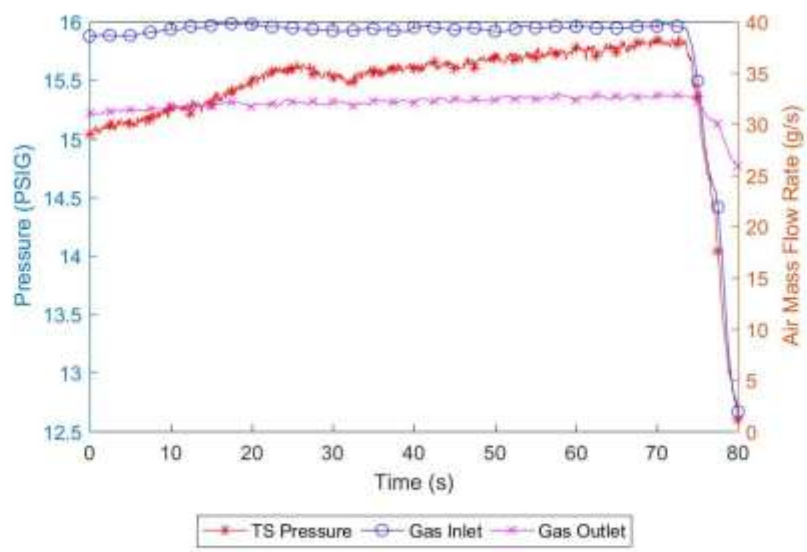

Figure F310: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_15.

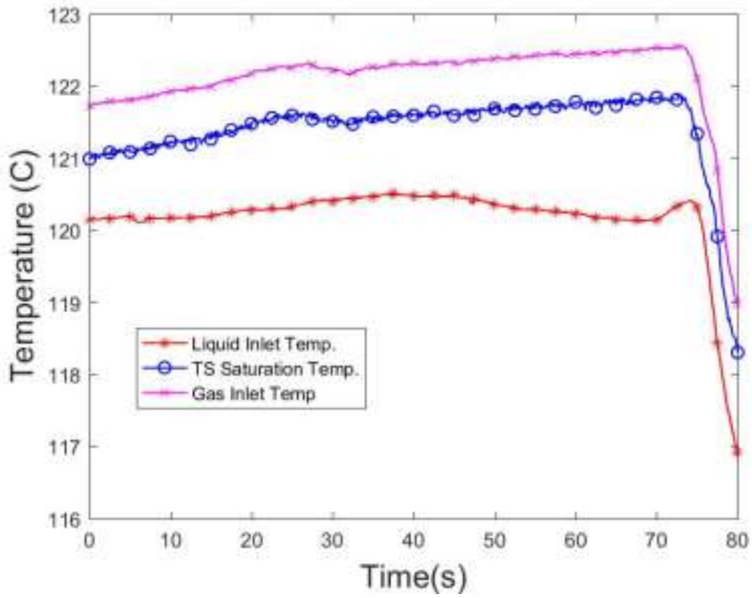

Figure F311: Temperature Profiles for test 2017_05_16_test_15.

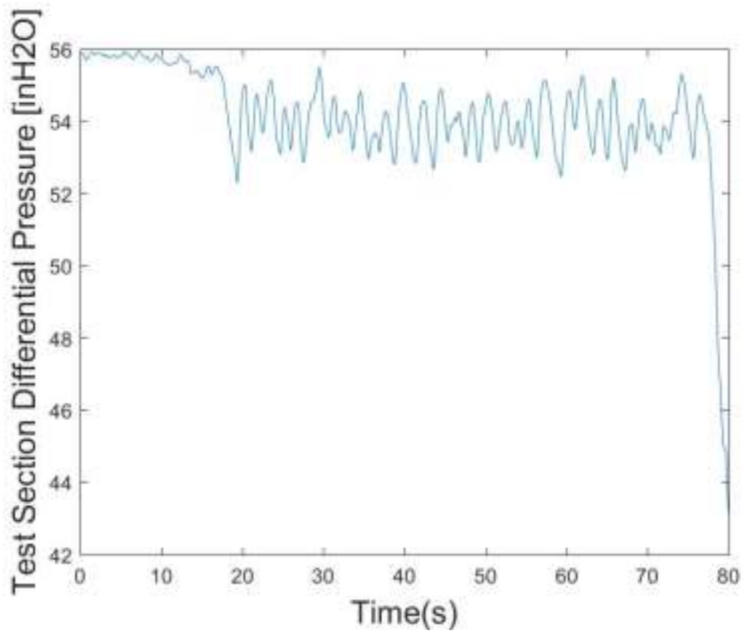

Figure F312: Test section differential pressure for test 2017_05_16_test_15.

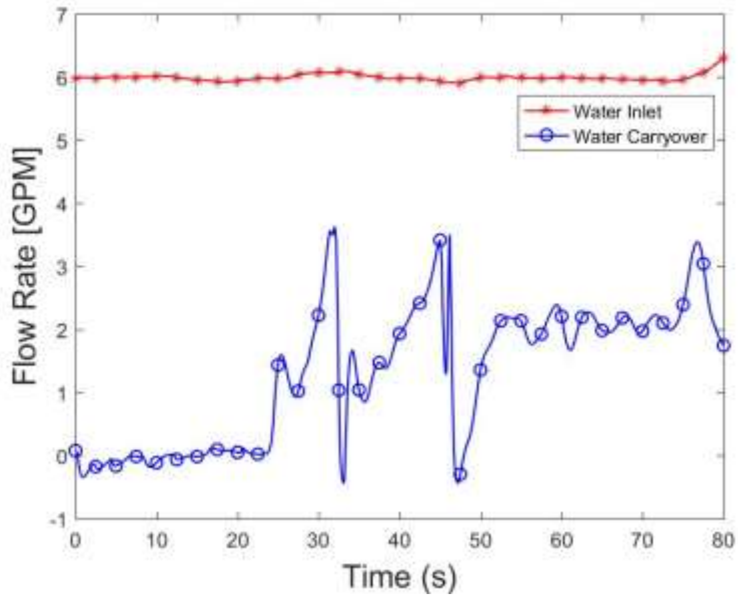

Figure F313: Water flow rates for 2017_05_16_test_15.

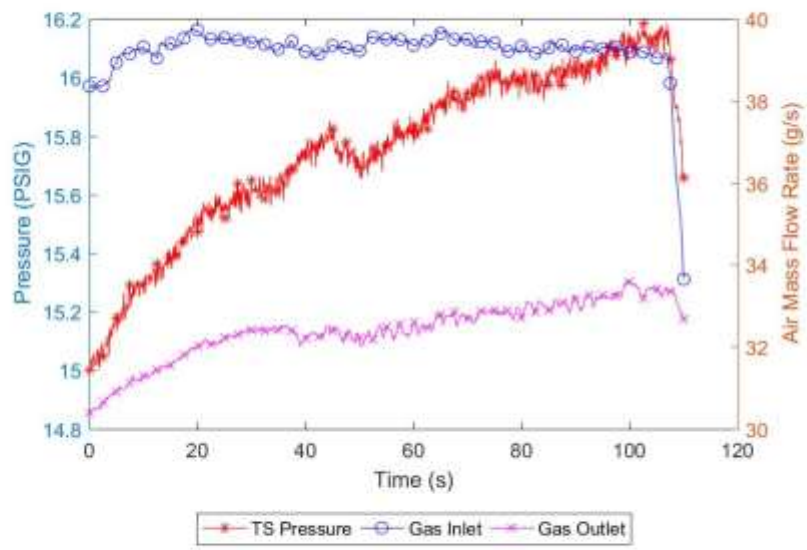

Figure F314: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_16.

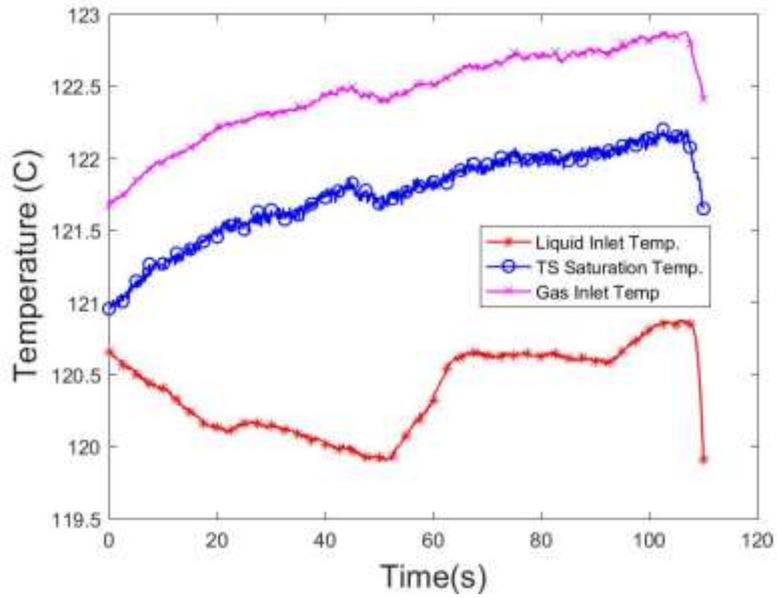

Figure F315: Temperature Profiles for test 2017_05_16_test_16.

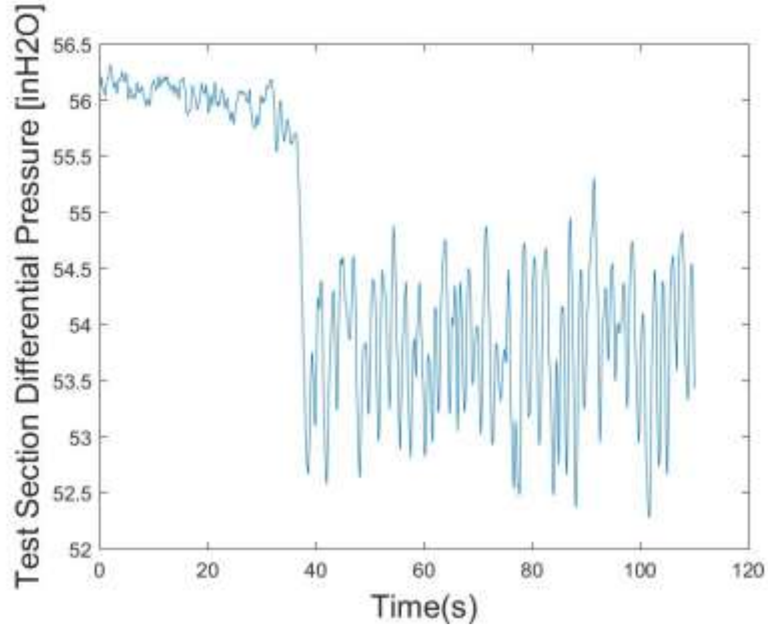

Figure F316: Test section differential pressure for test 2017_05_16_test_16.

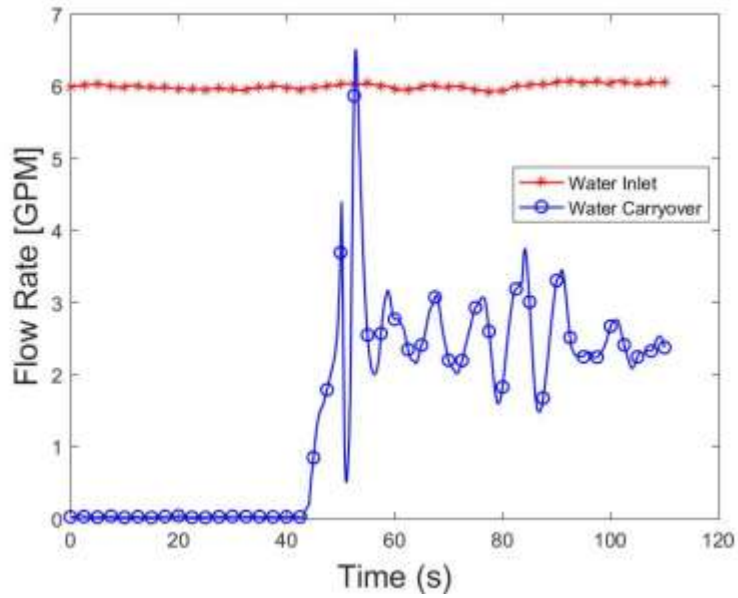

Figure F317: Water flow rates for 2017_05_16_test_16.

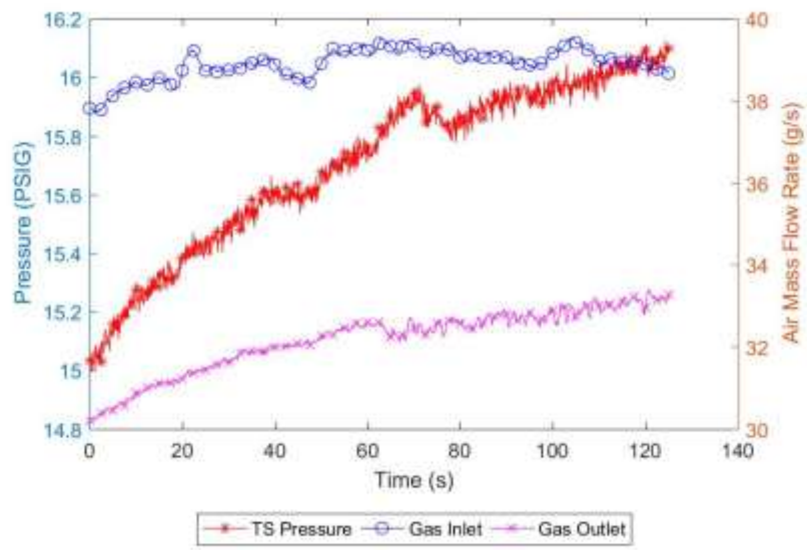

Figure F318: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_17.

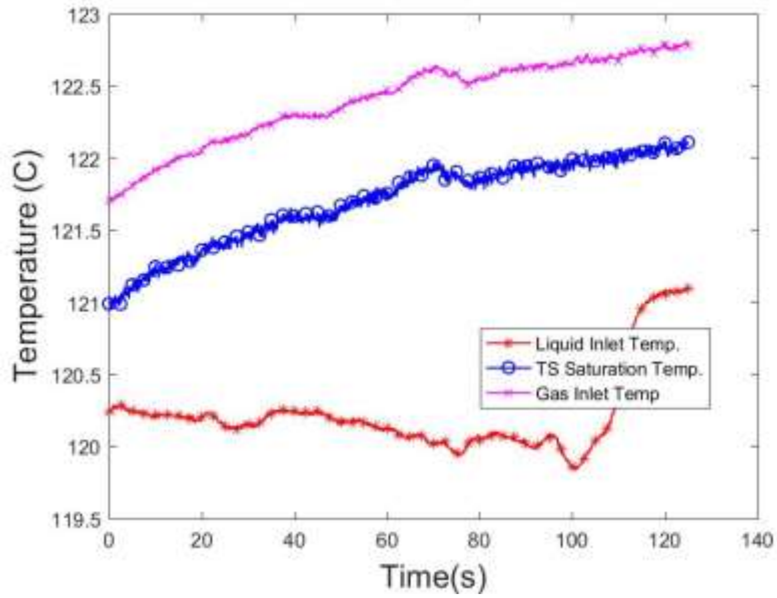

Figure F319: Temperature Profiles for test 2017_05_16_test_17.

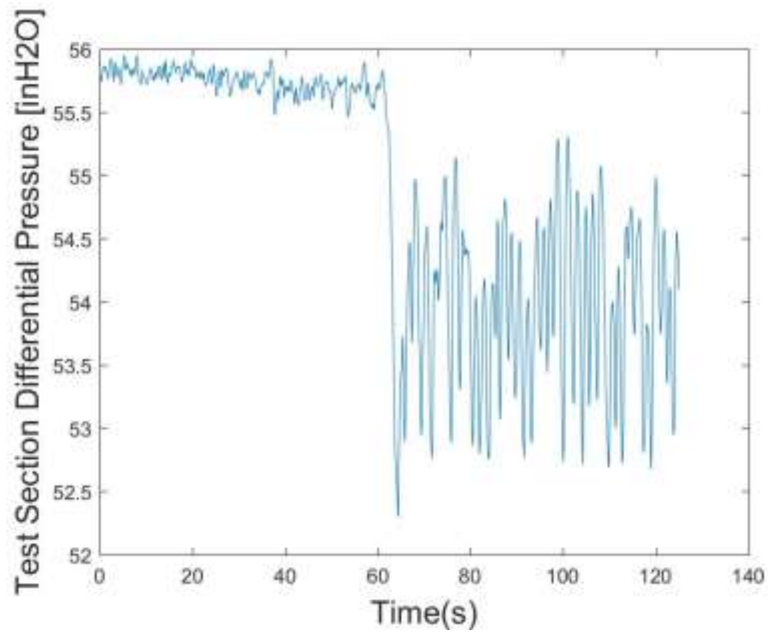

Figure F320: Test section differential pressure for test 2017_05_16_test_17.

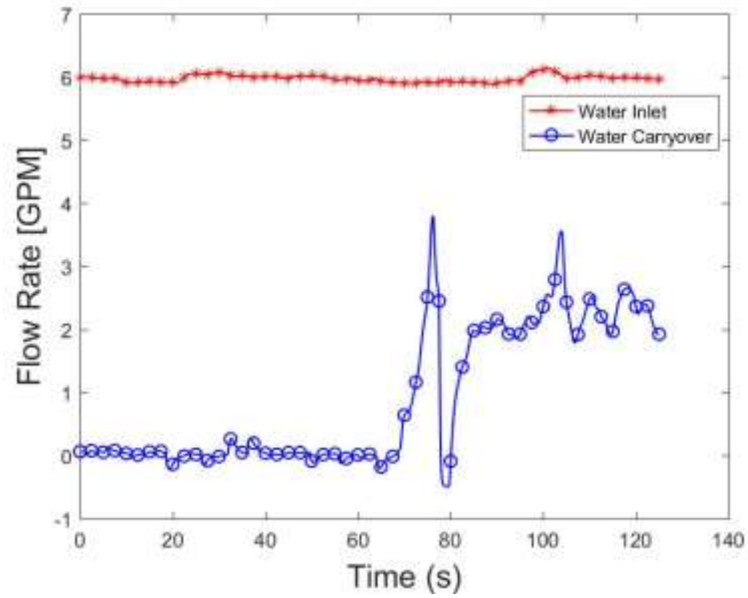

Figure F321: Water flow rates for 2017_05_16_test_17.

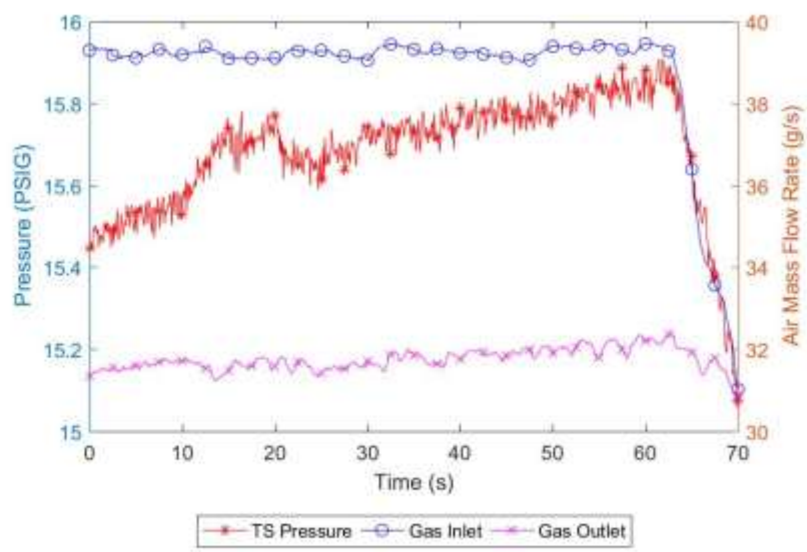

Figure F322: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_18.

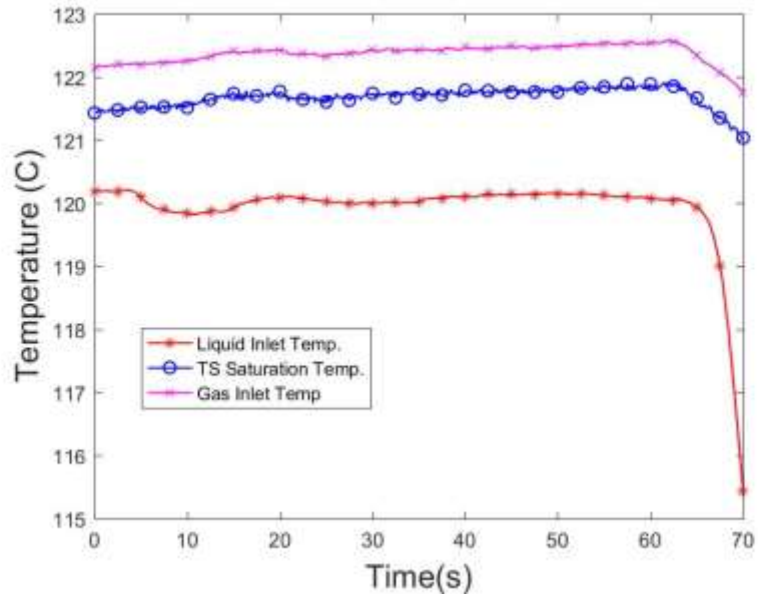

Figure F323: Temperature Profiles for test 2017_05_16_test_18.

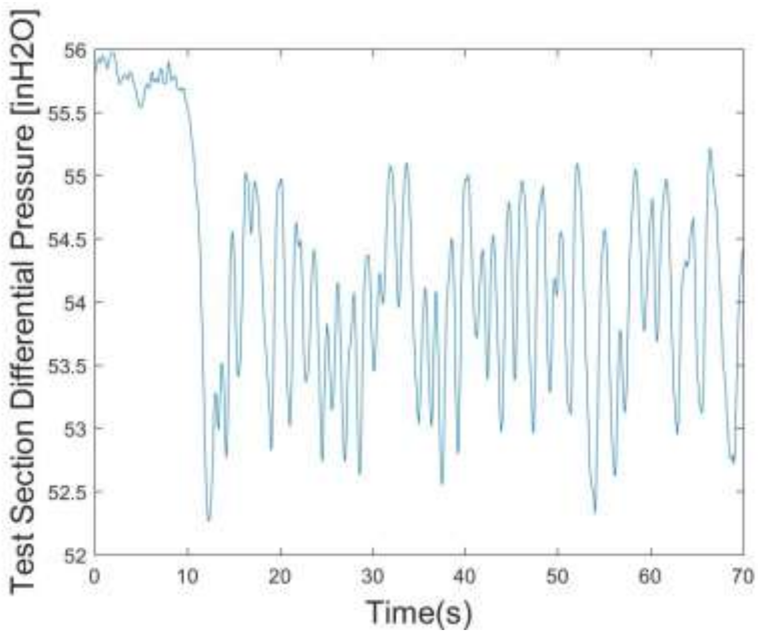

Figure F324: Test section differential pressure for test 2017_05_16_test_18.

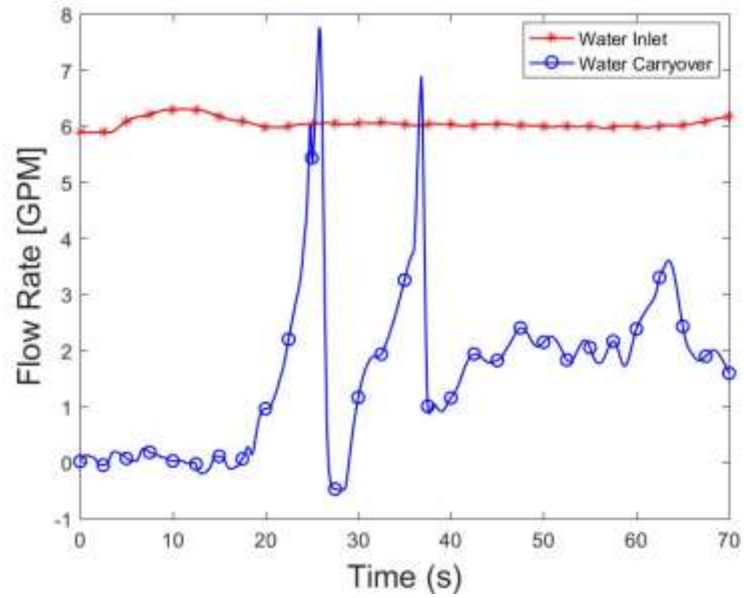

Figure F325: Water flow rates for 2017_05_16_test_18.

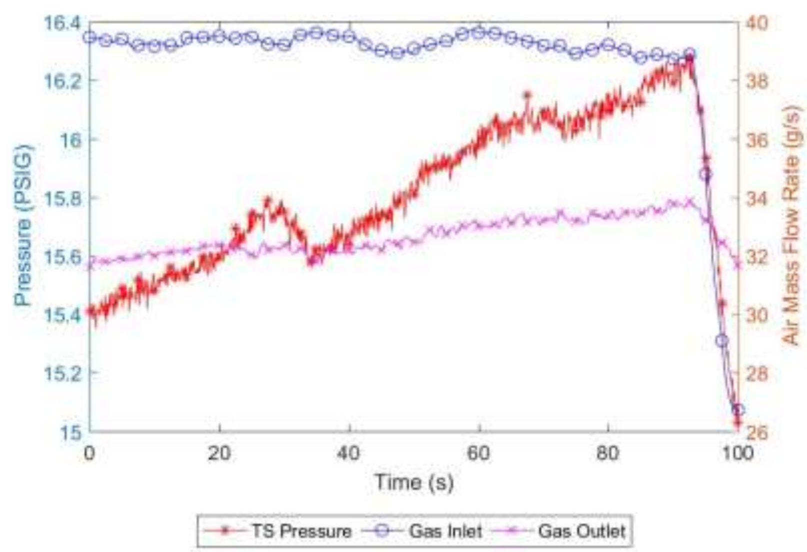

Figure F326: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_19.

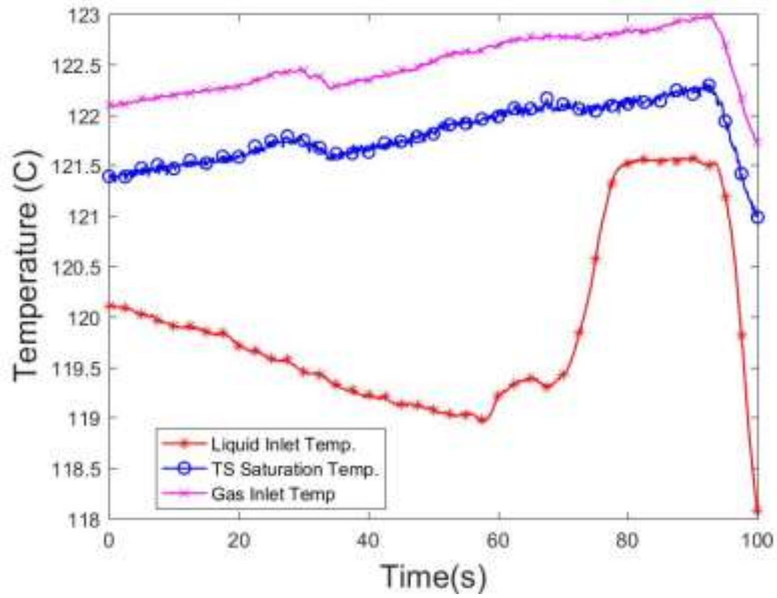

Figure F327: Temperature Profiles for test 2017_05_16_test_19.

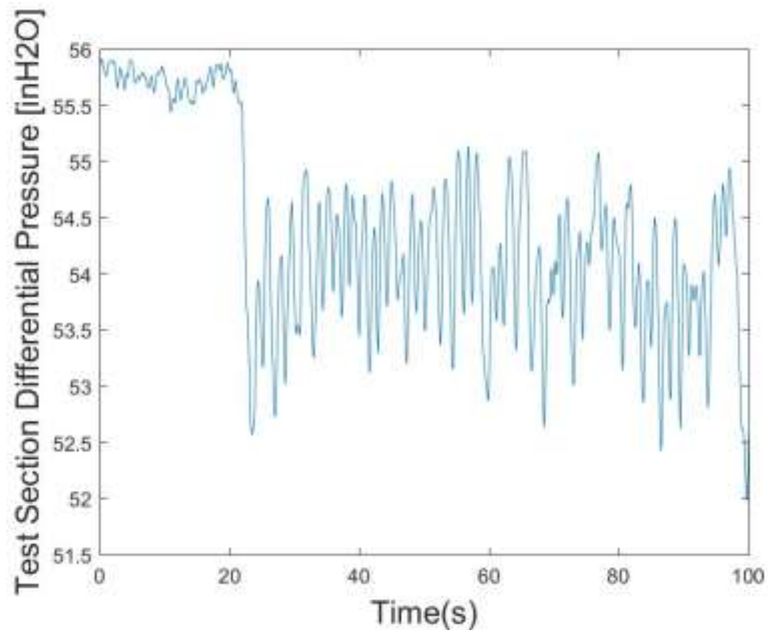

Figure F328: Test section differential pressure for test 2017_05_16_test_19.

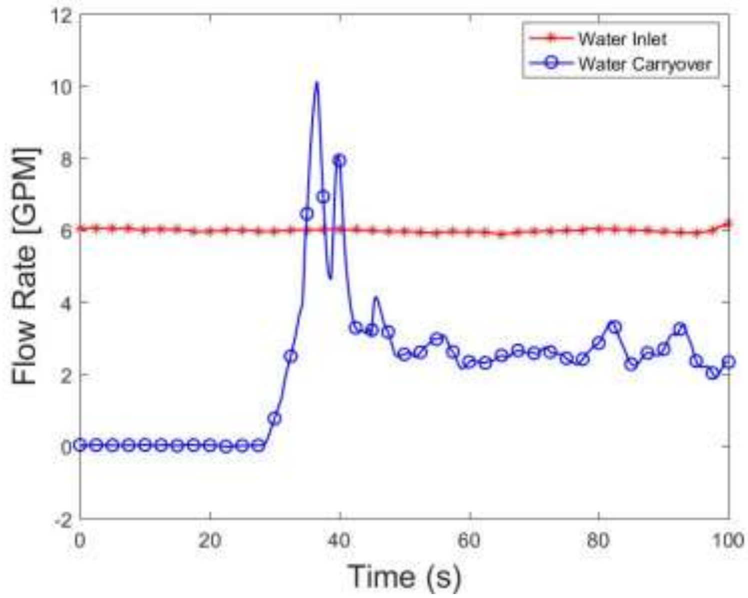

Figure F329: Water flow rates for 2017_05_16_test_19.

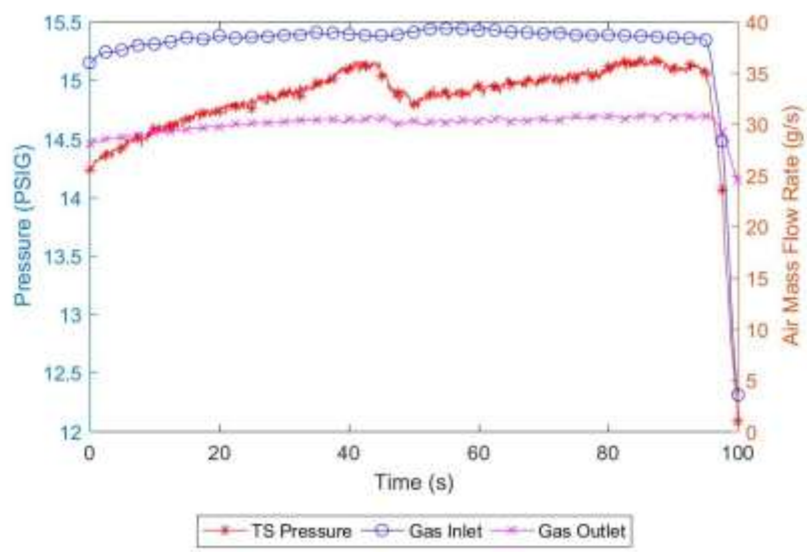

Figure F330: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_20.

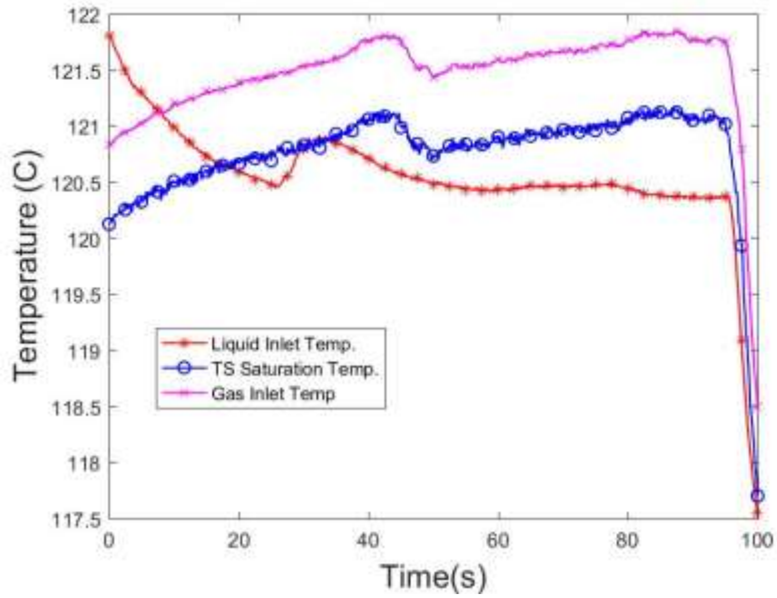

Figure F331: Temperature Profiles for test 2017_05_16_test_20.

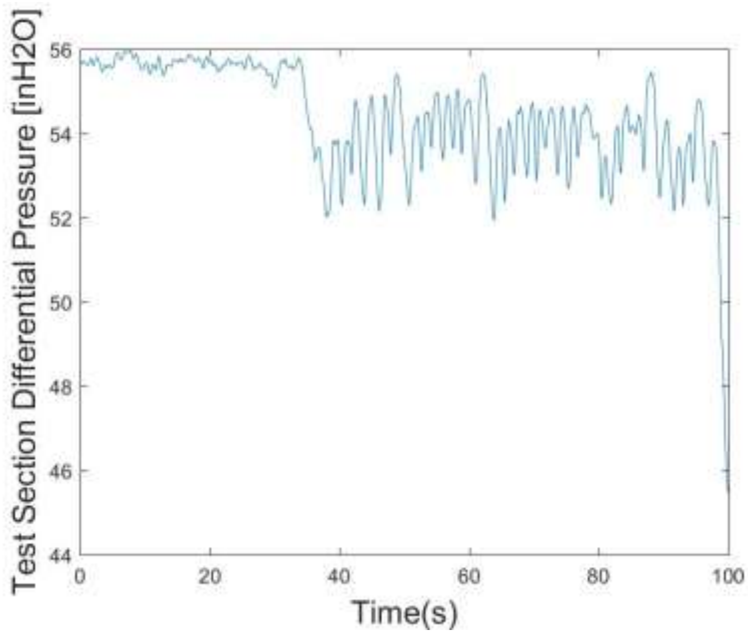

Figure F332: Test section differential pressure for test 2017_05_16_test_20.

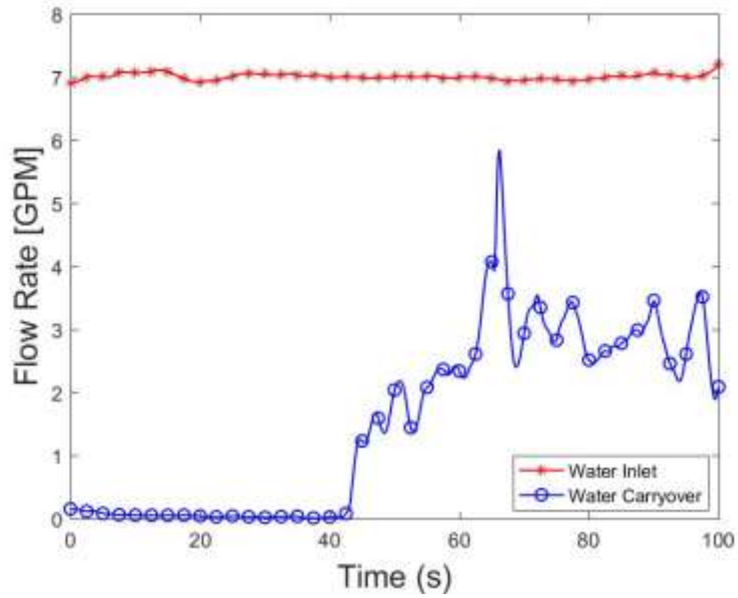

Figure F333: Water flow rates for 2017_05_16_test_20.

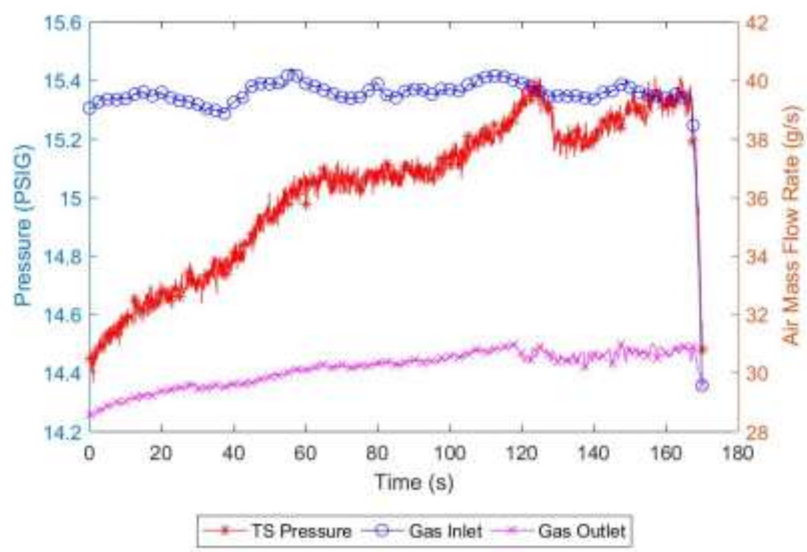

Figure F334: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_21.

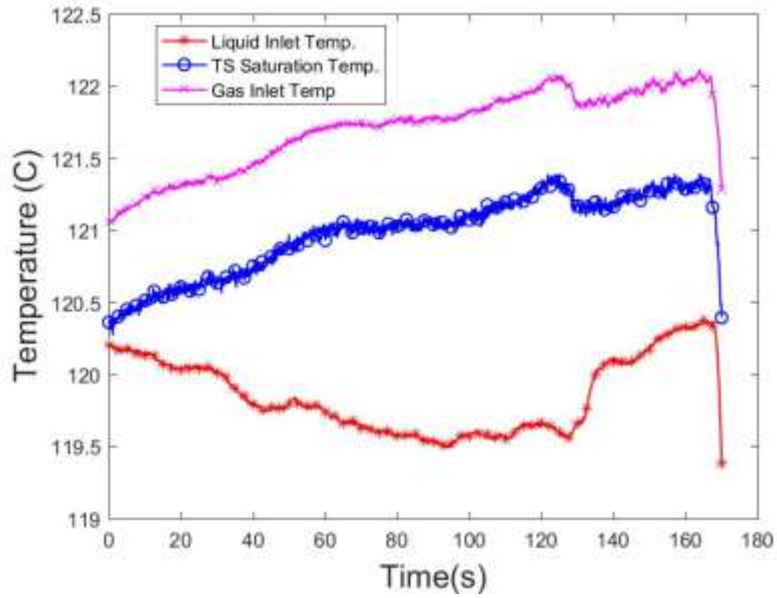

Figure F335: Temperature Profiles for test 2017_05_16_test_21.

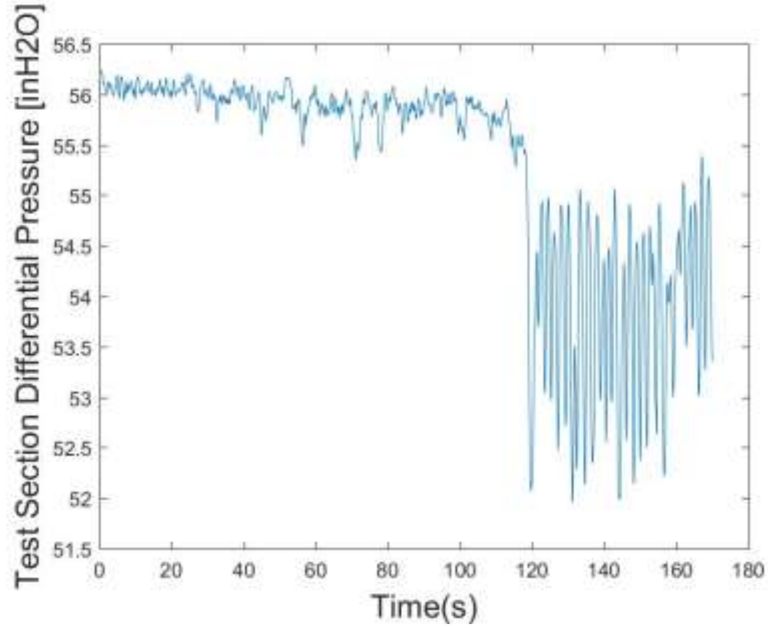

Figure F336: Test section differential pressure for test 2017_05_16_test_21.

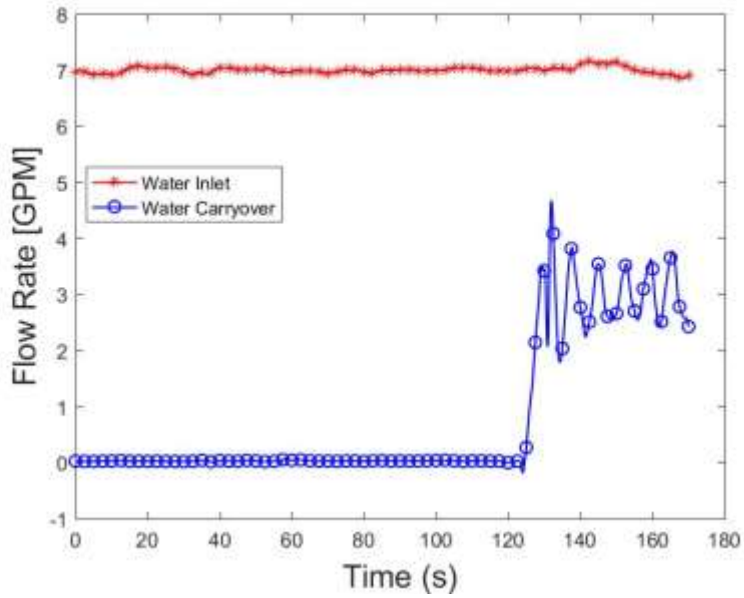

Figure F337: Water flow rates for 2017_05_16_test_21.

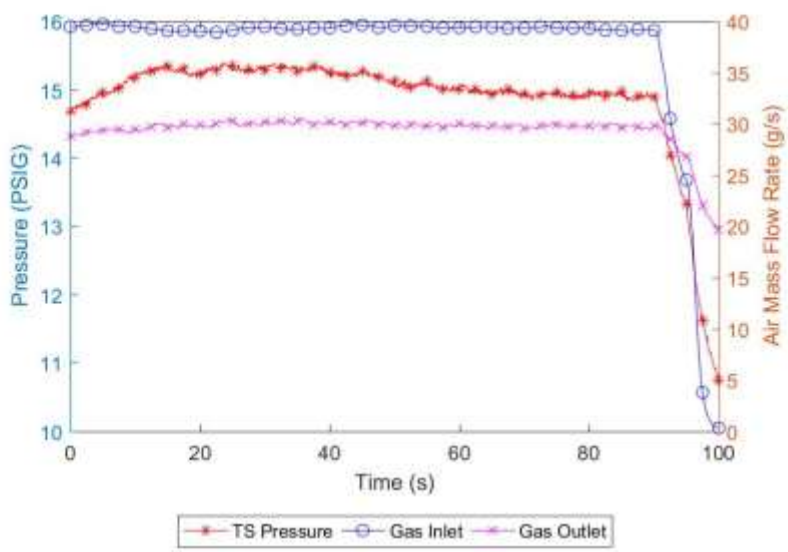

Figure F338: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_22.

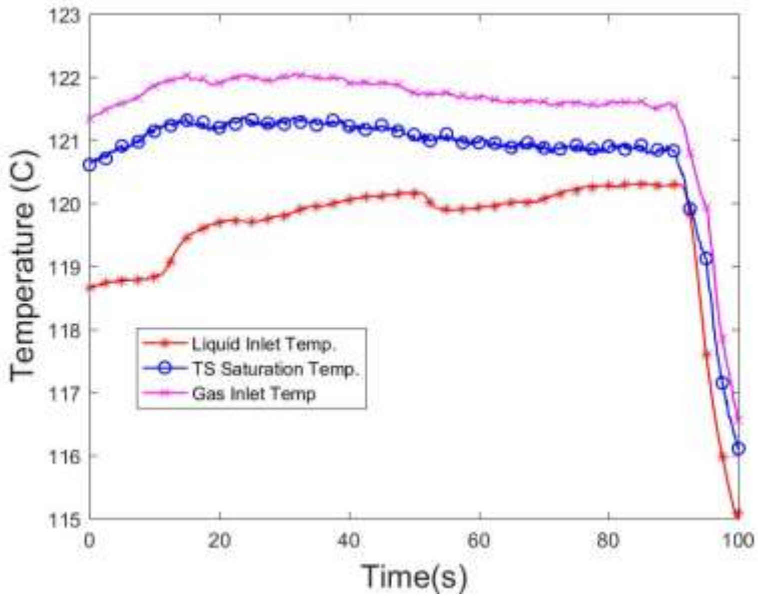

Figure F339: Temperature Profiles for test 2017_05_16_test_22.

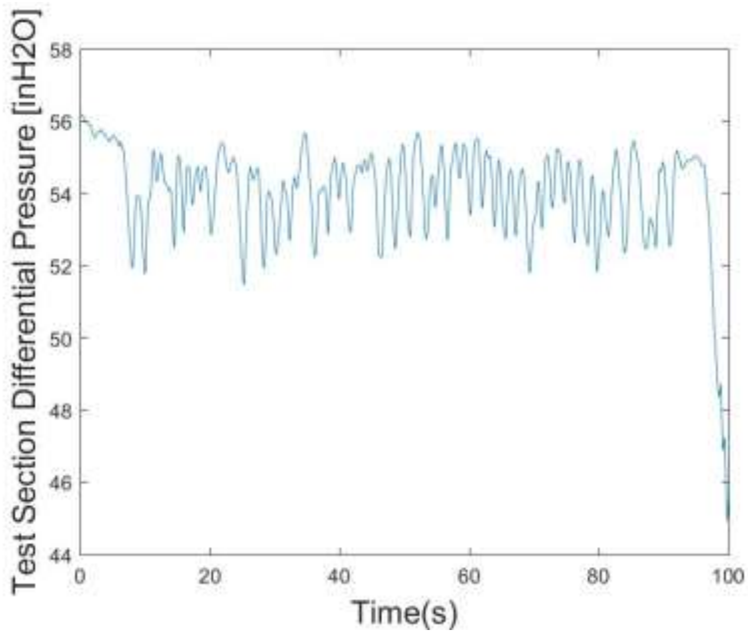

Figure F340: Test section differential pressure for test 2017_05_16_test_22.

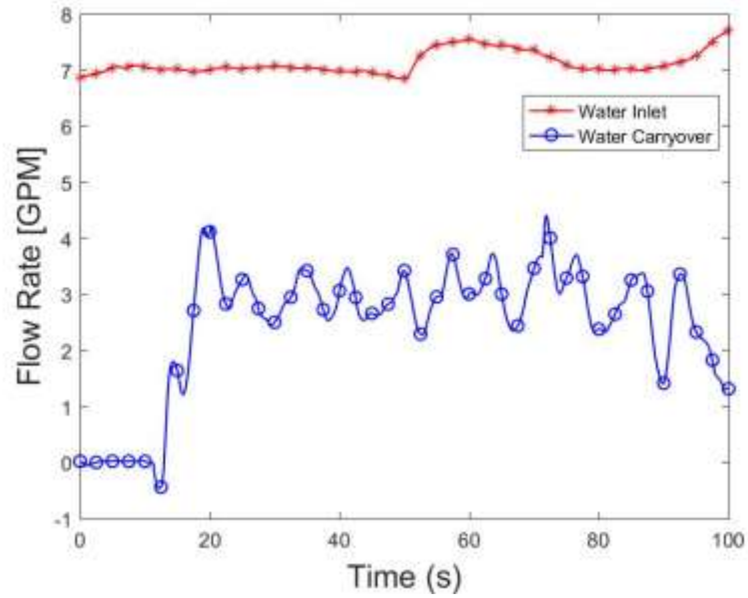

Figure F341: Water flow rates for 2017_05_16_test_22.

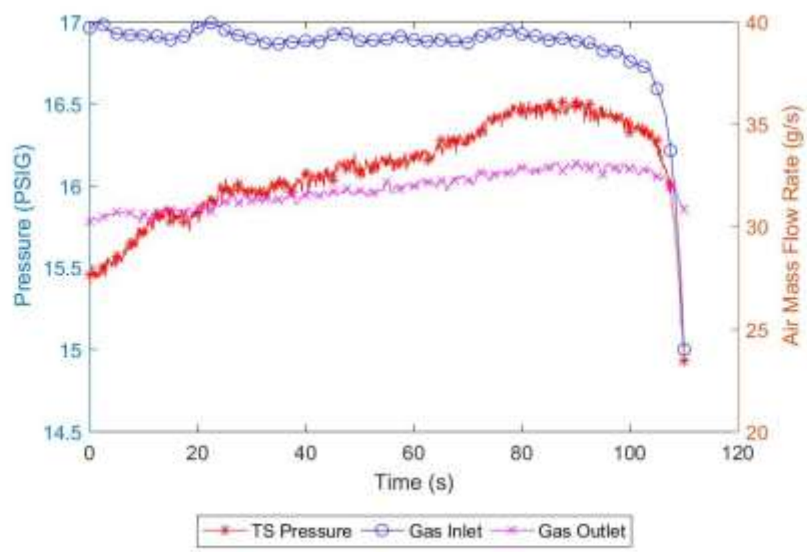

Figure F342: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_23.

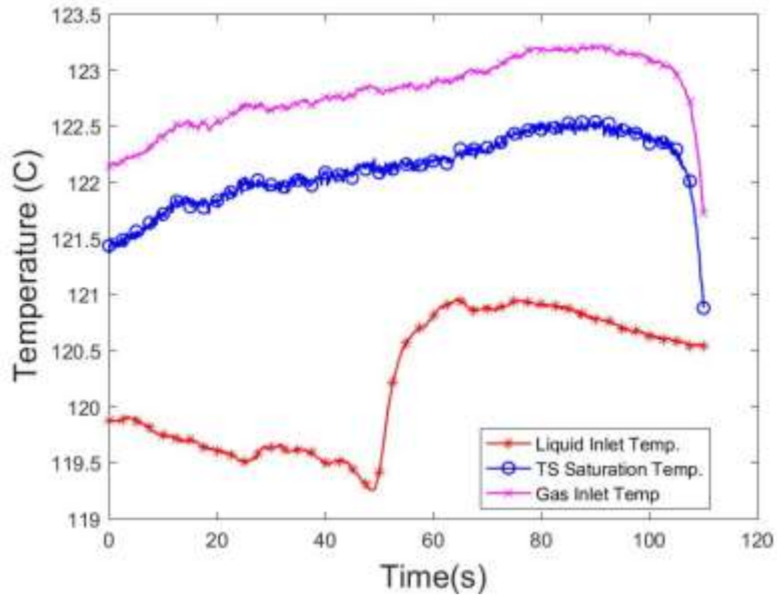

Figure F343: Temperature Profiles for test 2017_05_16_test_23.

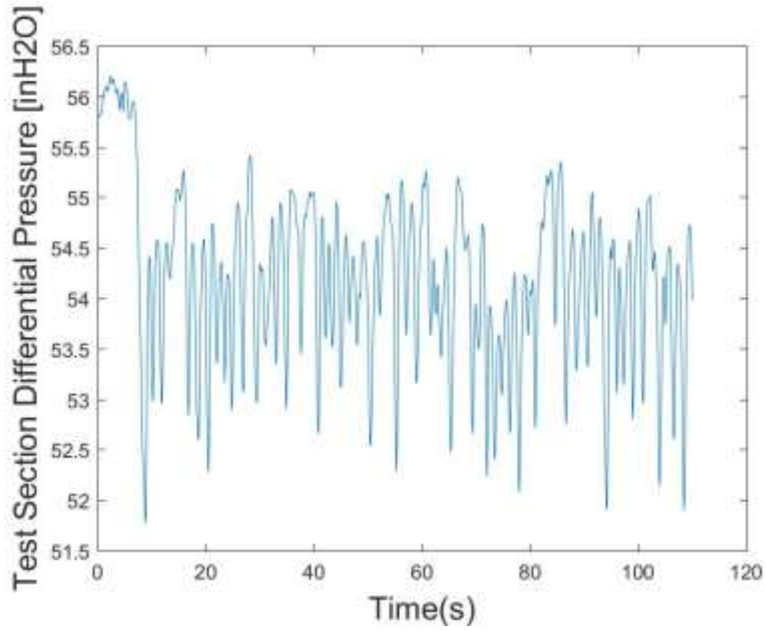

Figure F344: Test section differential pressure for test 2017_05_16_test_23.

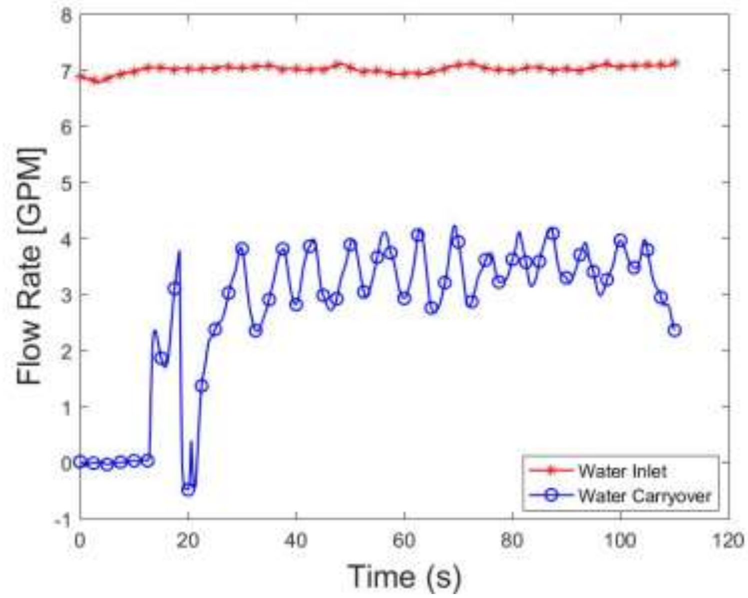

Figure F345: Water flow rates for 2017_05_16_test_23.

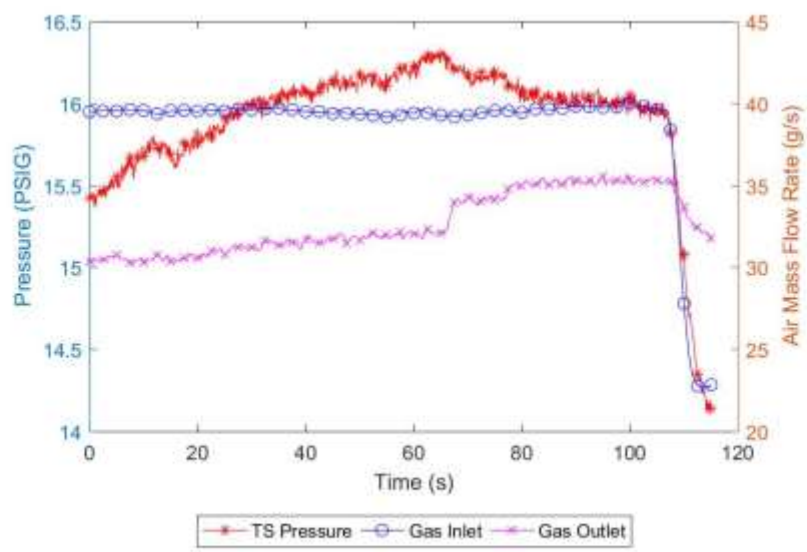

Figure F346: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_24.

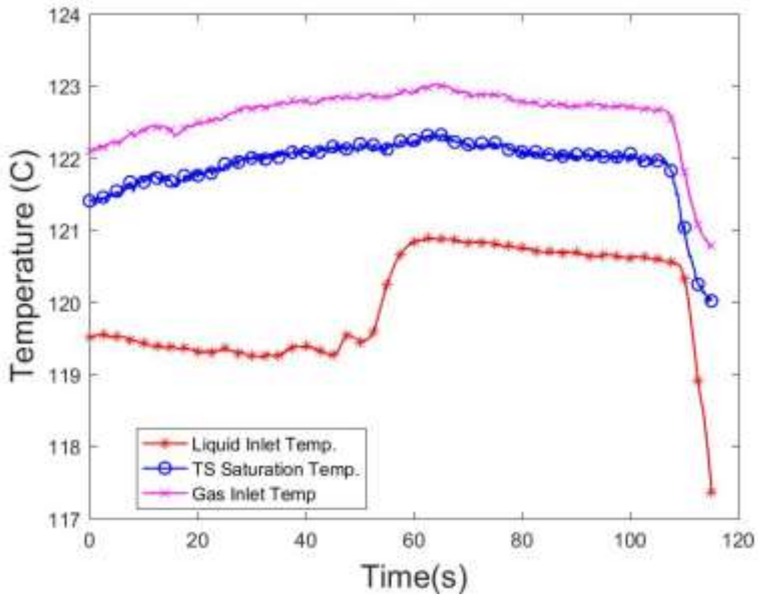

Figure F347: Temperature Profiles for test 2017_05_16_test_24.

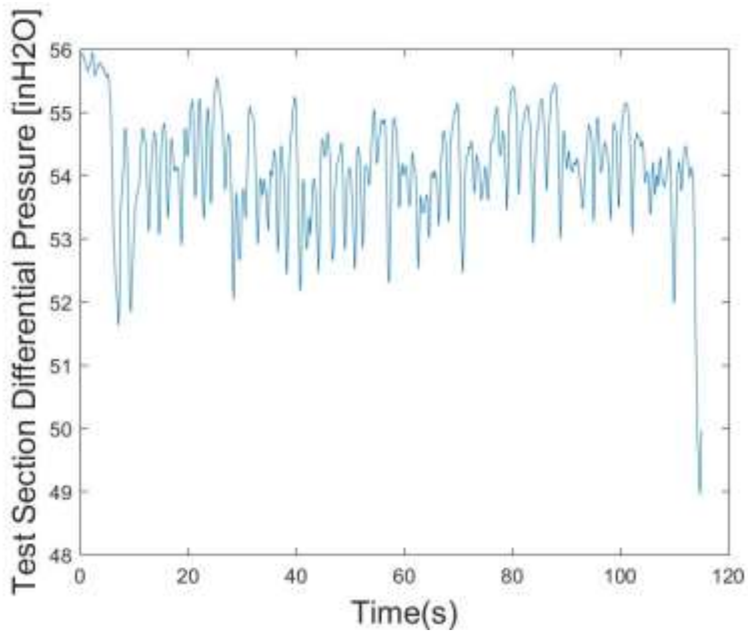

Figure F348: Test section differential pressure for test 2017_05_16_test_24.

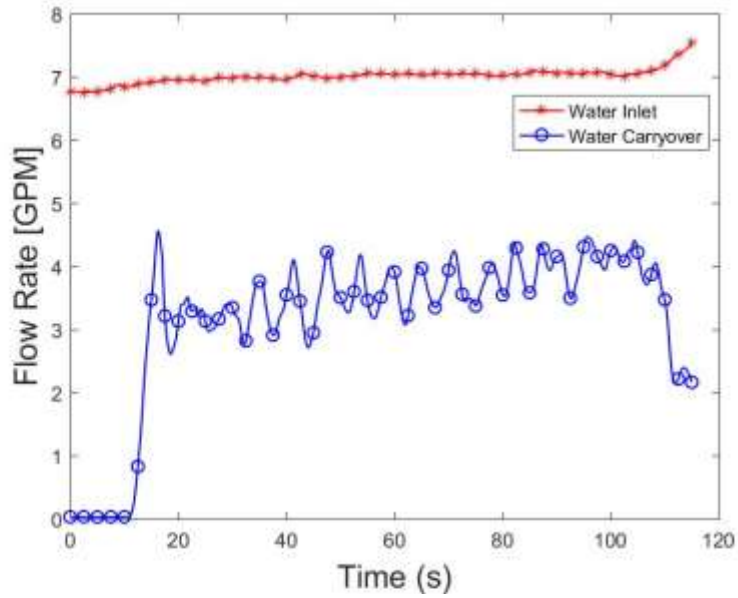

Figure F349: Water flow rates for 2017_05_16_test_24.

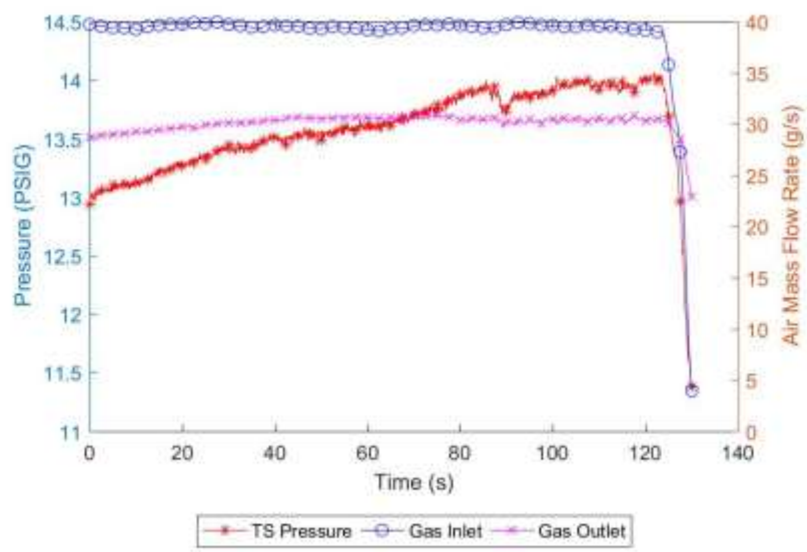

Figure F350: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_26.

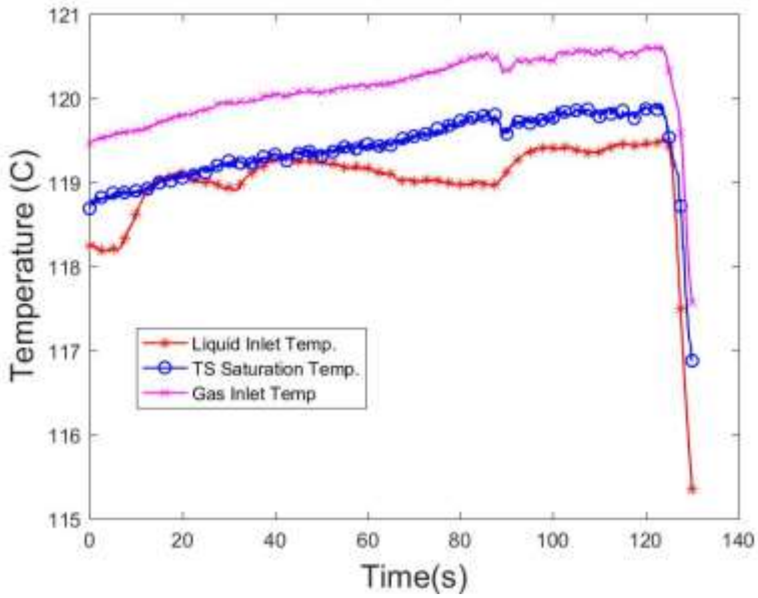

Figure F351: Temperature Profiles for test 2017_05_16_test_26.

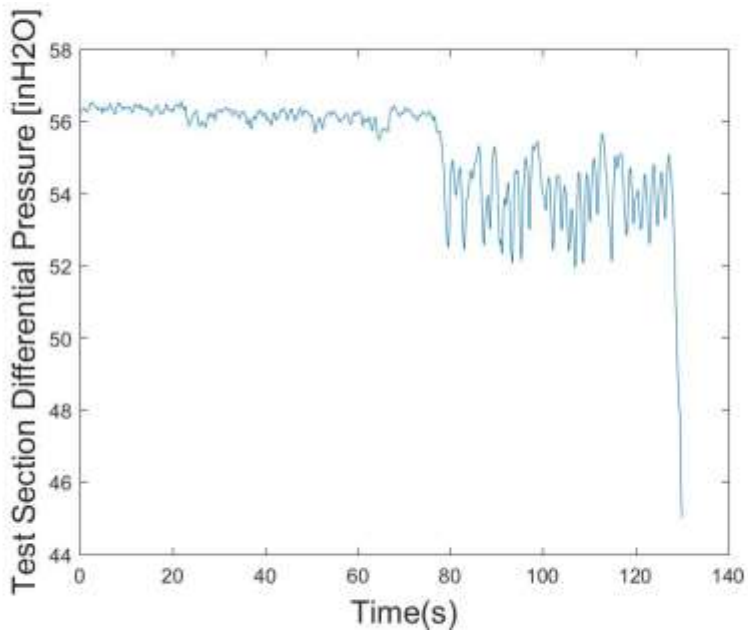

Figure F352: Test section differential pressure for test 2017_05_16_test_26.

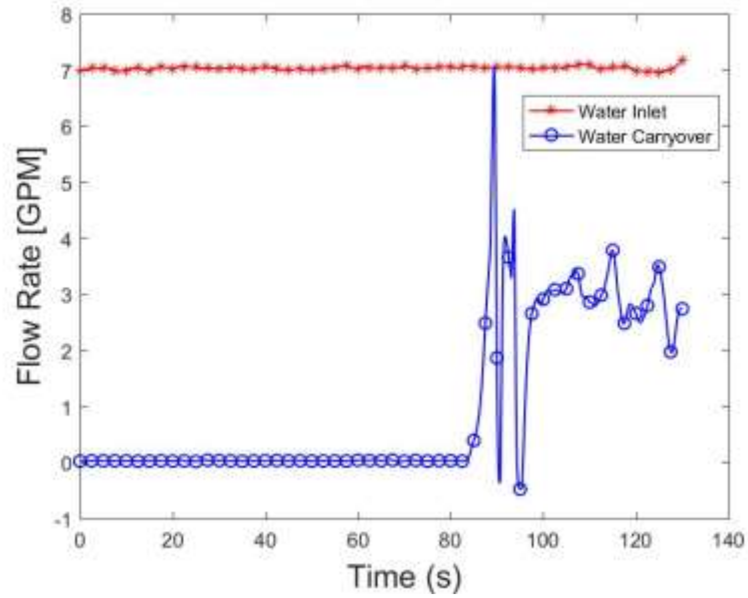

Figure F353: Water flow rates for 2017_05_16_test_26.

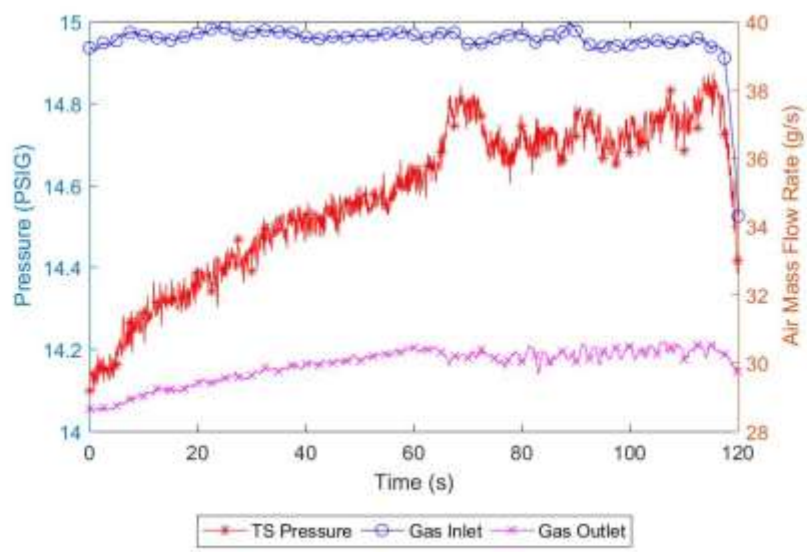

Figure F354: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_27.

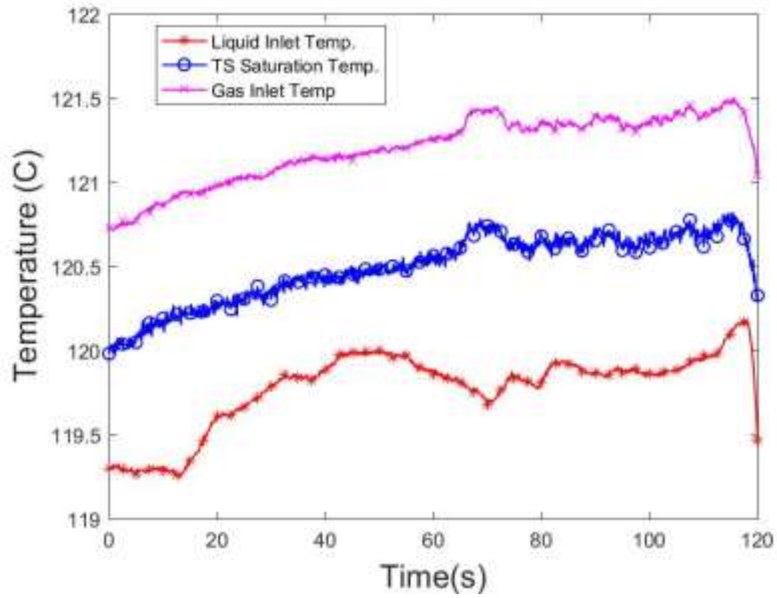

Figure F355: Temperature Profiles for test 2017_05_16_test_27.

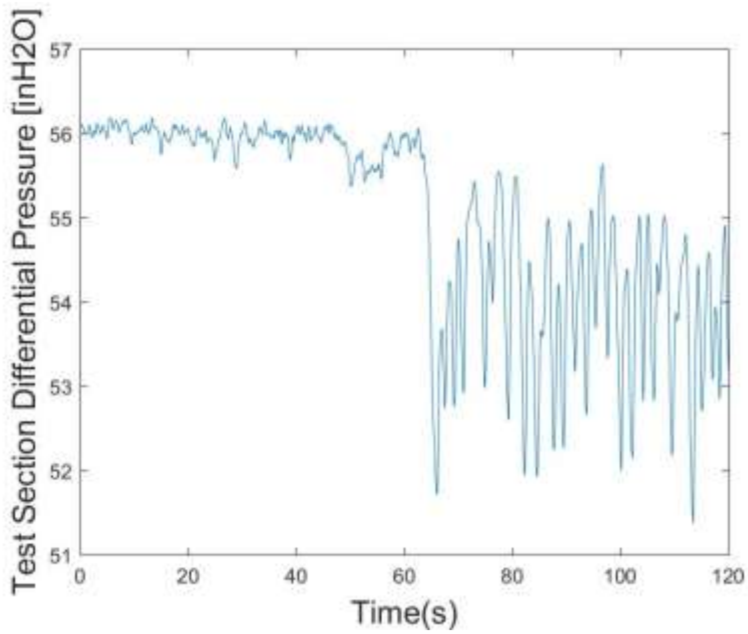

Figure F356: Test section differential pressure for test 2017_05_16_test_27.

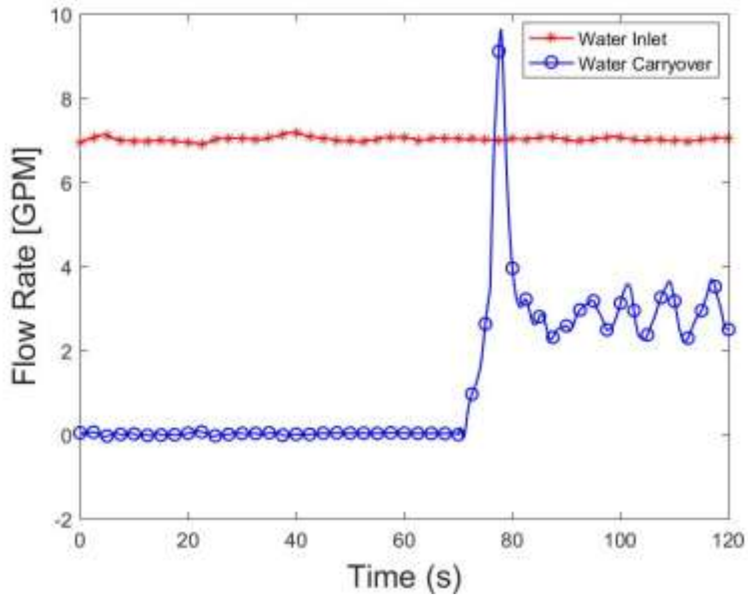

Figure F357: Water flow rates for 2017_05_16_test_27.

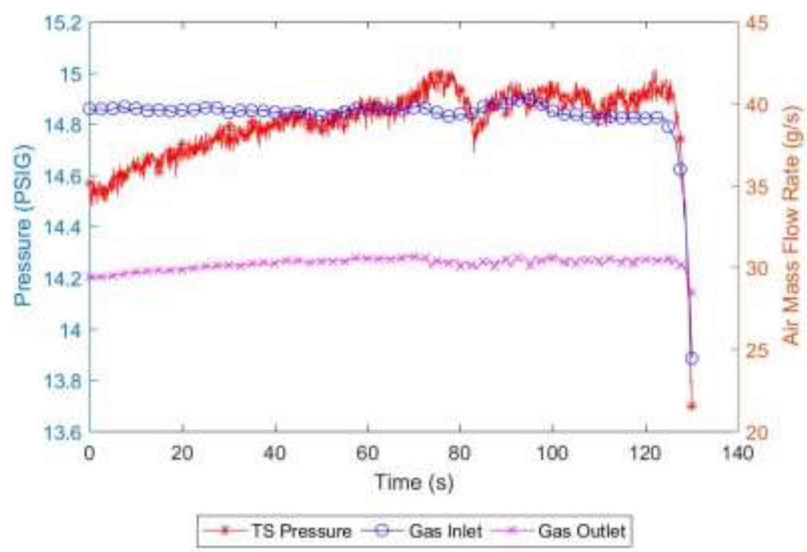

Figure F358: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_28.

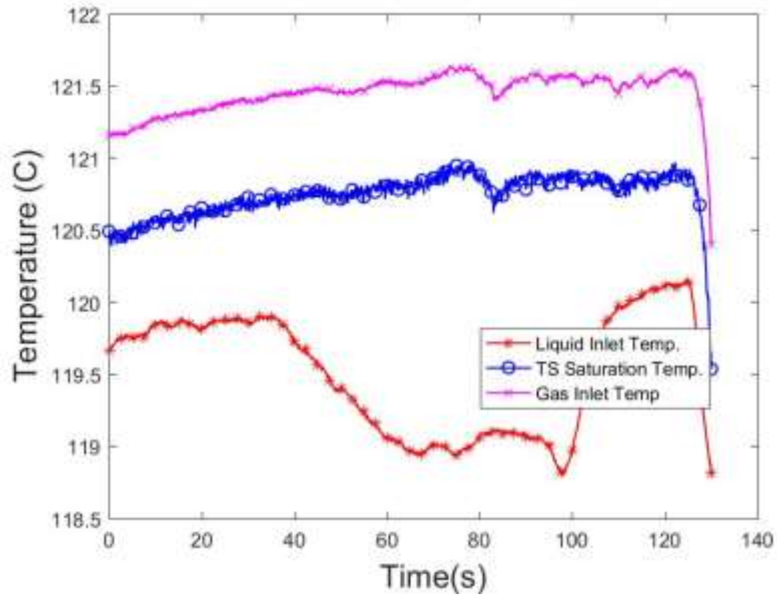

Figure F359: Temperature Profiles for test 2017_05_16_test_28.

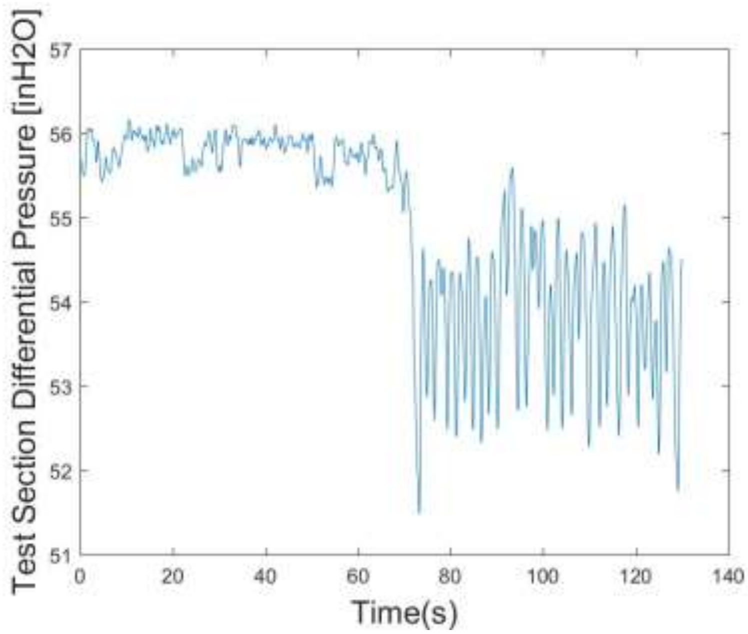

Figure F360: Test section differential pressure for test 2017_05_16_test_28.

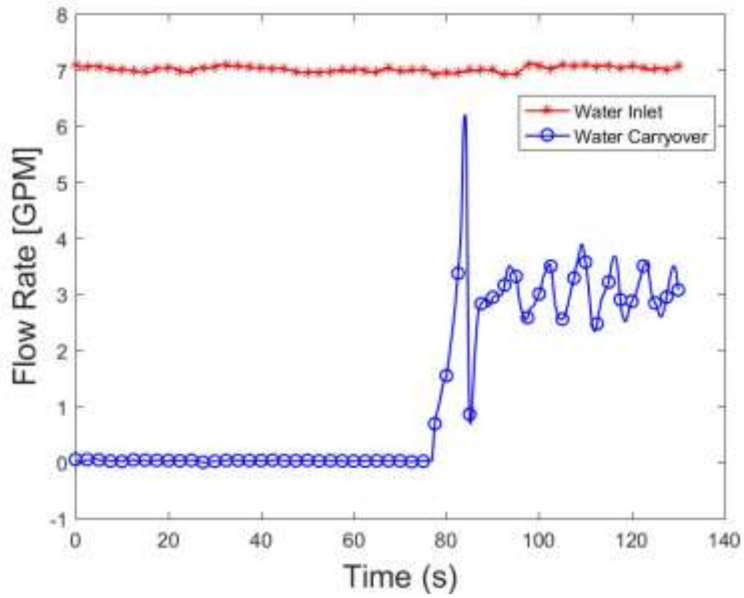

Figure F361: Water flow rates for 2017_05_16_test_28.

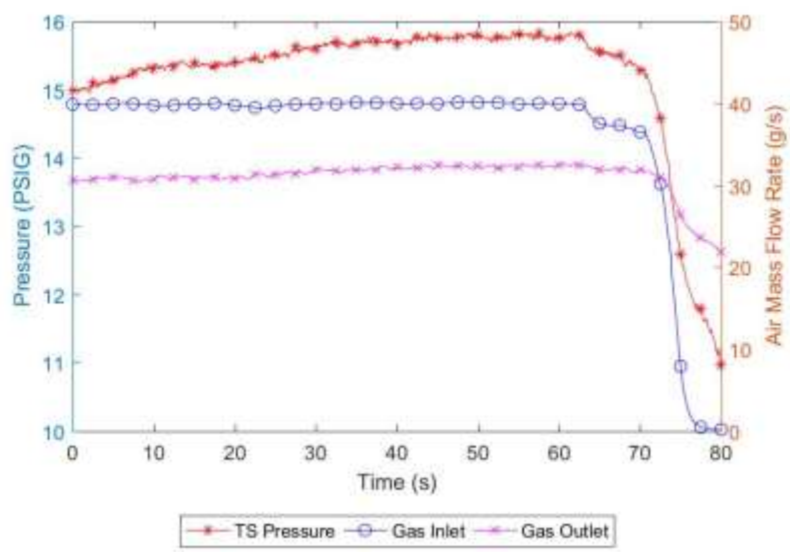

Figure F362: Pressure and gas inlet and outlet mass flow rate for test 2017_05_16_test_29.

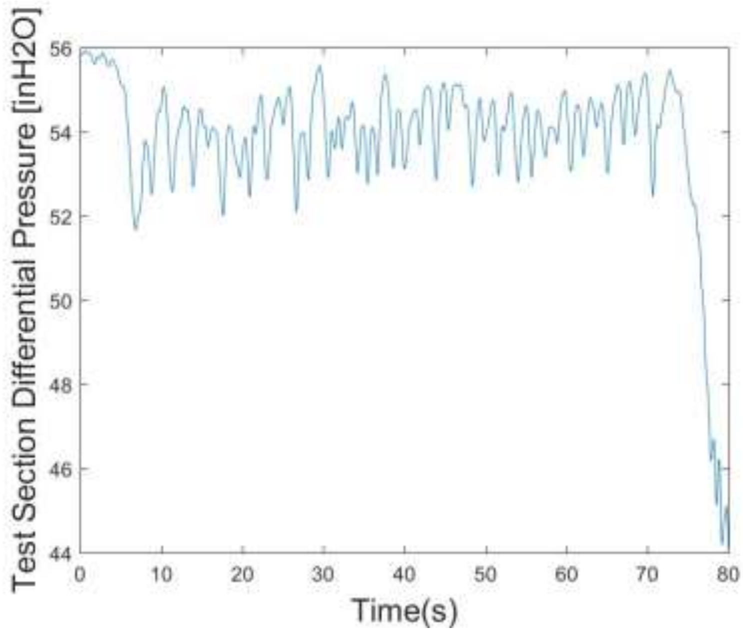

Figure F363: Test section differential pressure for test 2017_05_16_test_29.

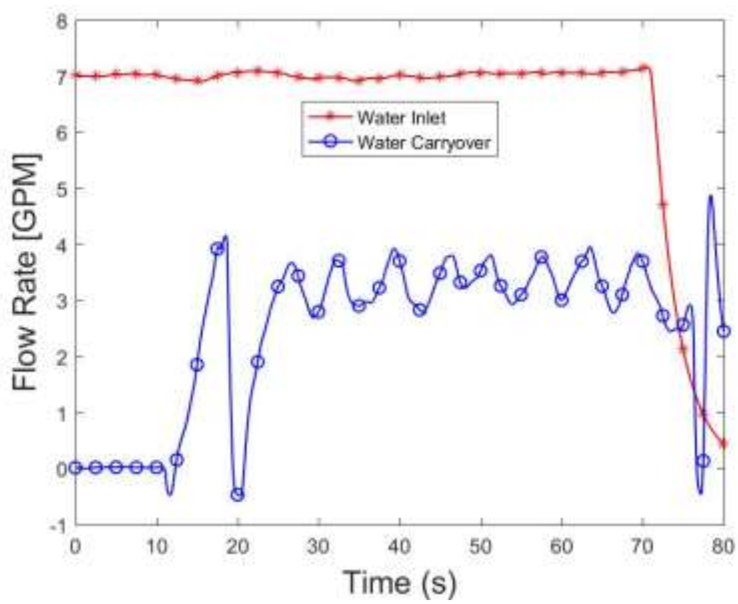

Figure F364: Water flow rates for 2017_05_16_test_29

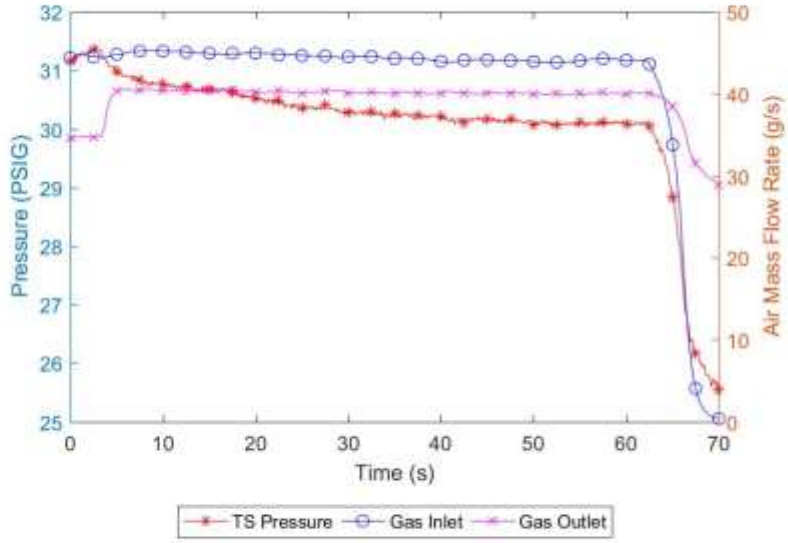

Figure F365:Pressure and gas inlet and outlet mass flow rate for test 2017_05_17_test_09.

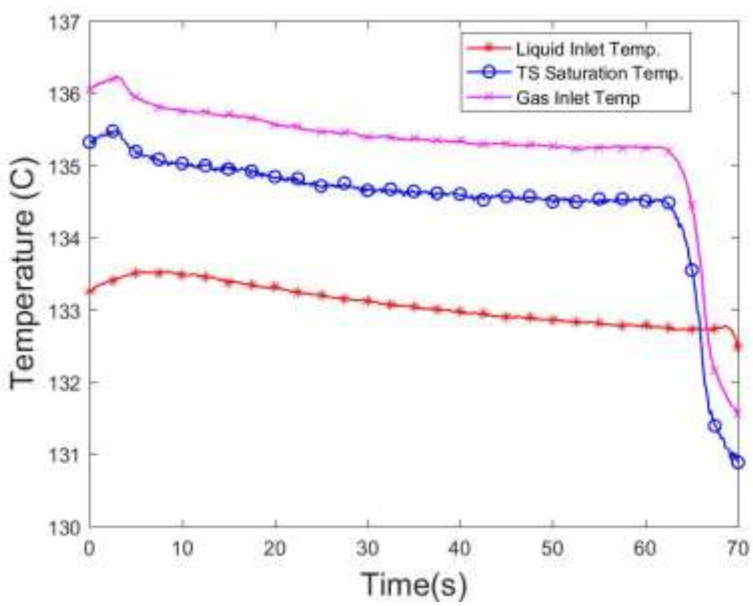

Figure F366:Temperature Profiles for test 2017_05_17_test_09.

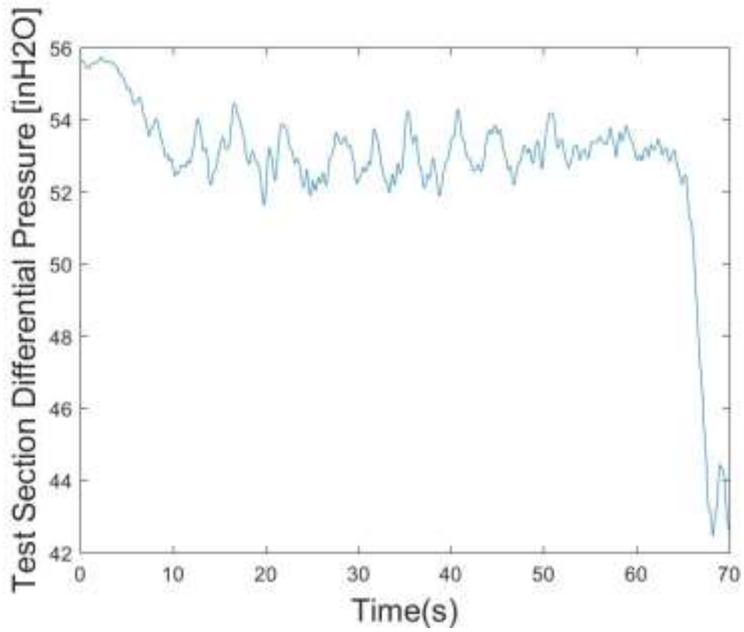

Figure F367: Test section differential pressure for test 2017_05_17_test_09.

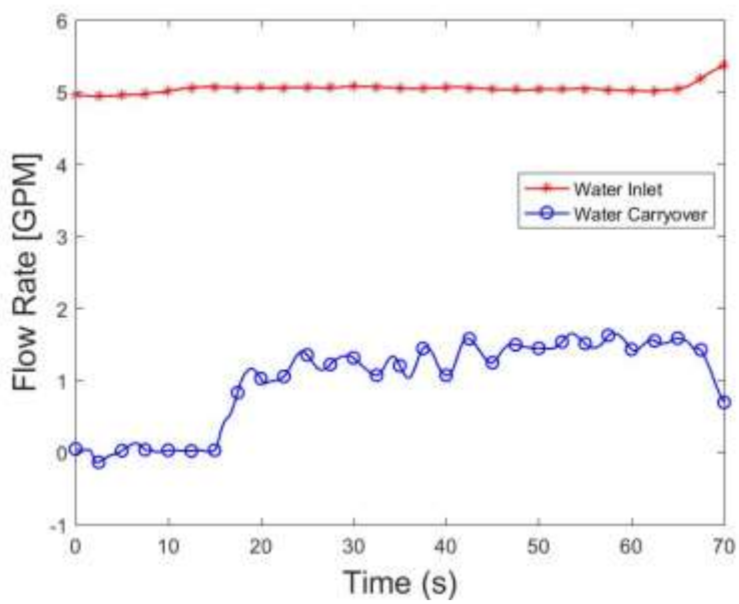

Figure F368 Water flow rates for 2017_05_17_test_09

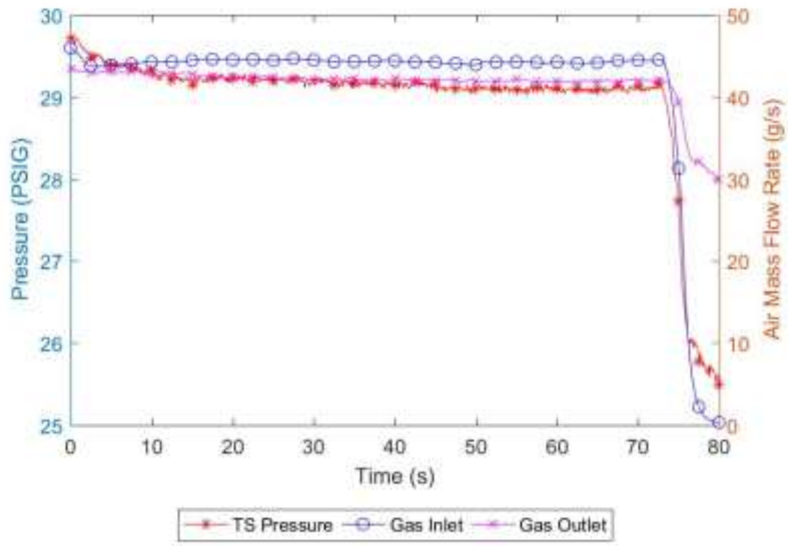

Figure F369:Pressure and gas inlet and outlet mass flow rate for test 2017_05_17_test_10.

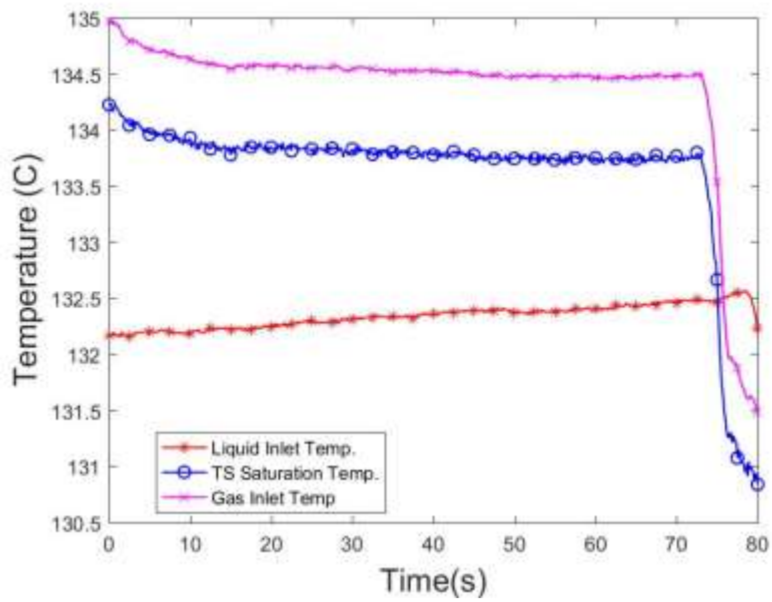

Figure F370:Temperature Profiles for test 2017_05_17_test_10.

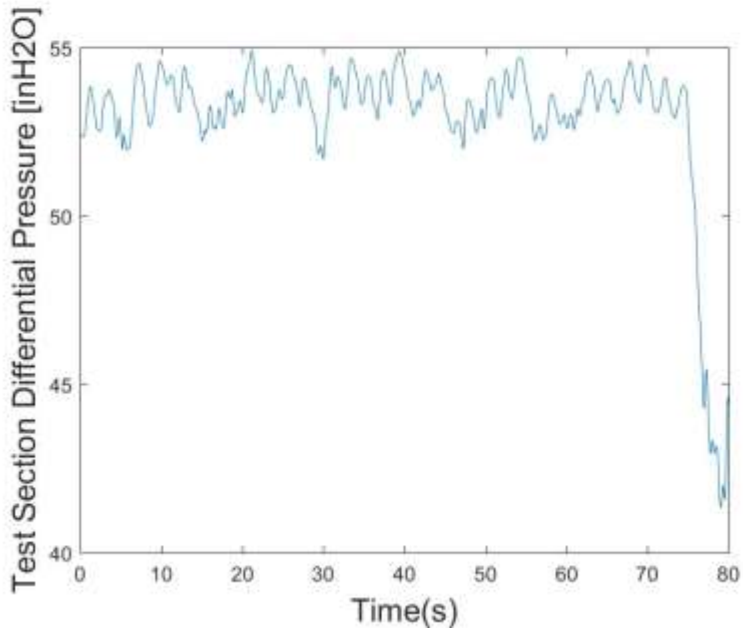

Figure F371: Test section differential pressure for test 201705_17_test_10.

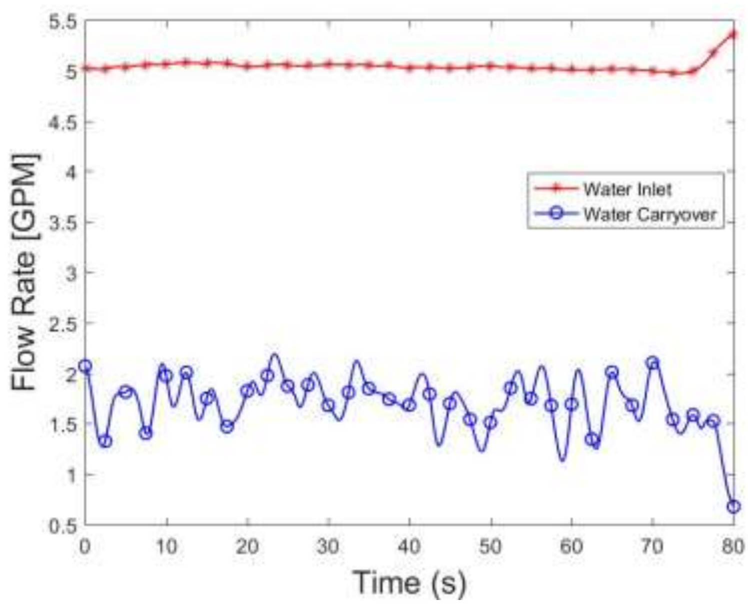

Figure F372: Water flow rates for 2017_05_17_test_10

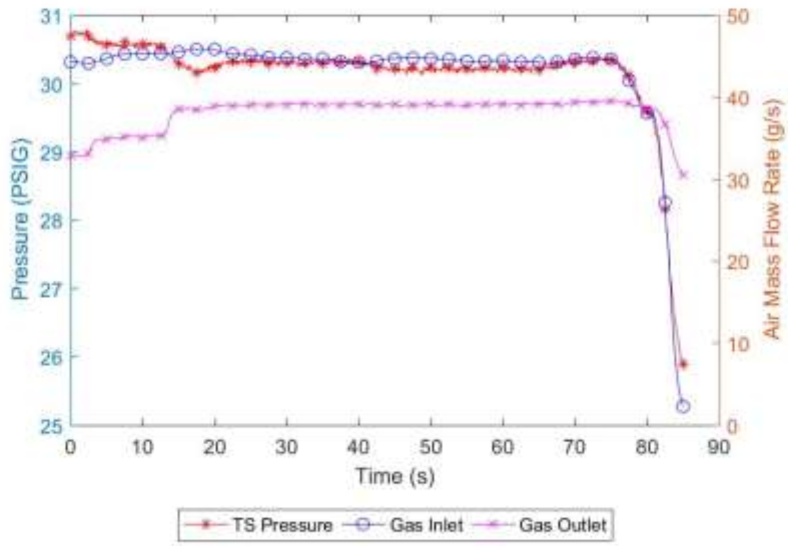

Figure F373: Pressure and gas inlet and outlet mass flow rate for test 2017_05_17_test_11.

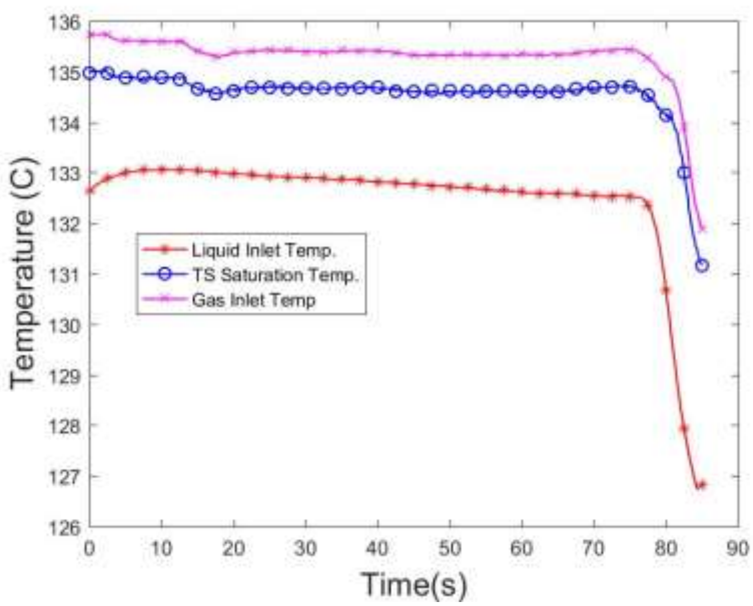

Figure F374: Temperature Profiles for test 2017_05_17_test_11.

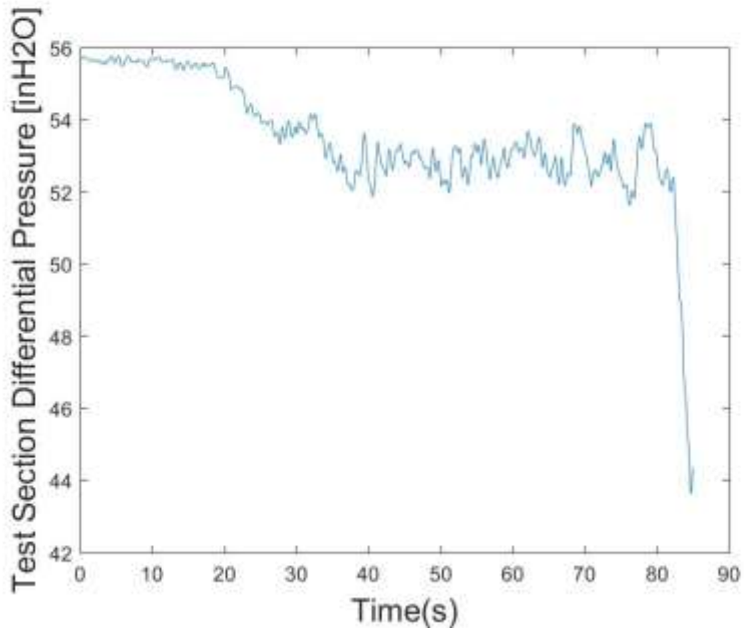

Figure F375: Test section differential pressure for test 2017_05_17_test_11.

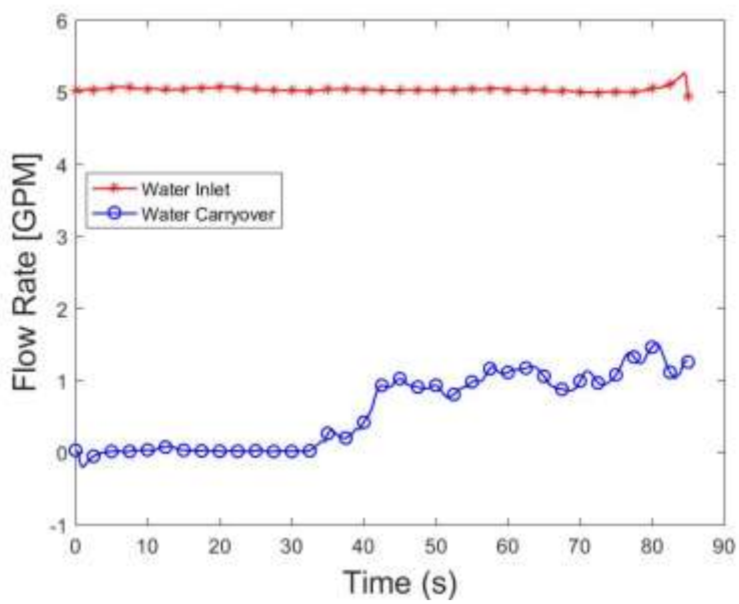

Figure F376: Water flow rates for 2017_05_17_test_11

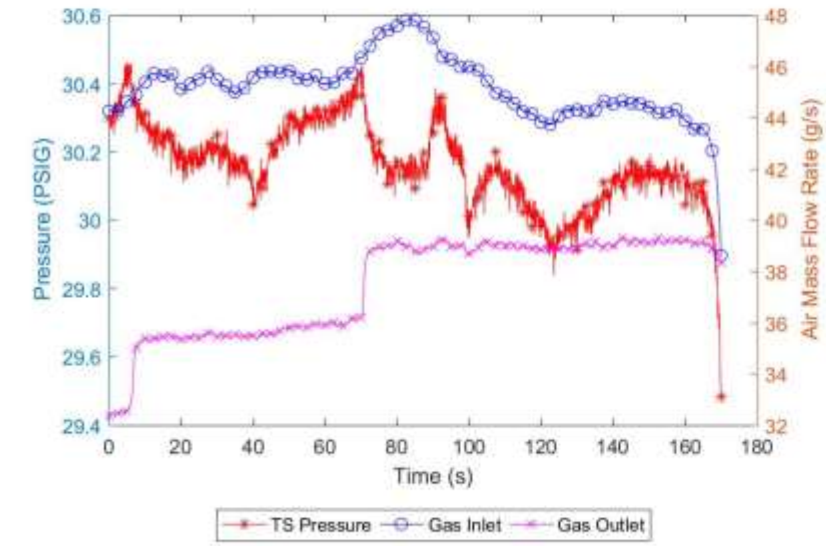

Figure F377: Pressure and gas inlet and outlet mass flow rate for test 2017_05_17_test_12.

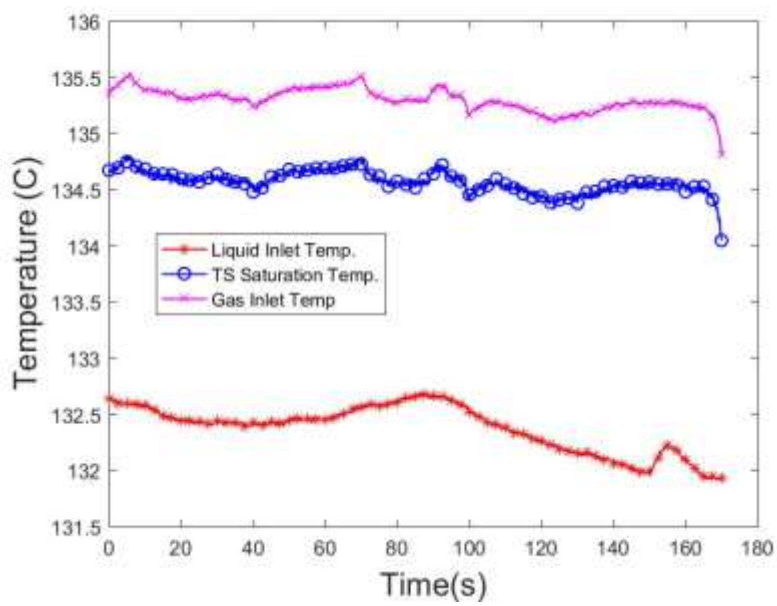

Figure F378: Temperature Profiles for test 2017_05_17_test_12.

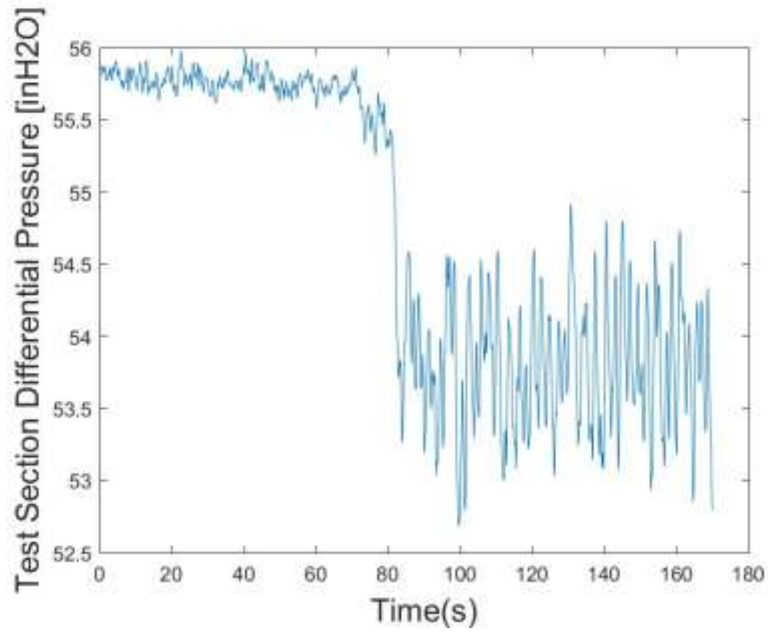

Figure F379: Test section differential pressure for test 2017_05_17_test_12.

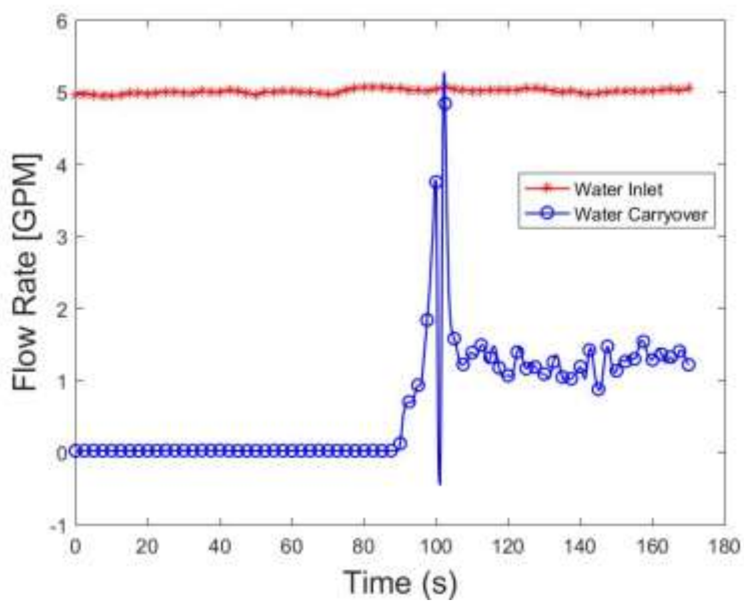

Figure F380: Water flow rates for 2017_05_17_test_12.

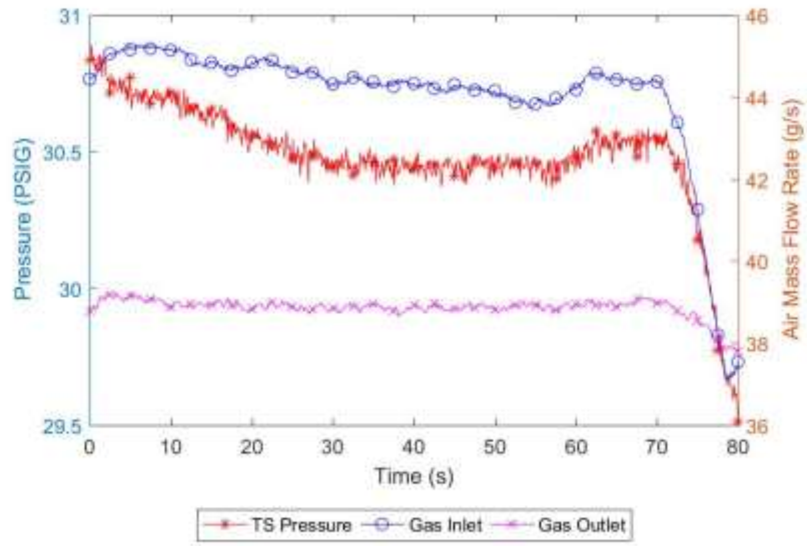

Figure F381: Pressure and gas inlet and outlet mass flow rate for test 2017_05_17_test_13.

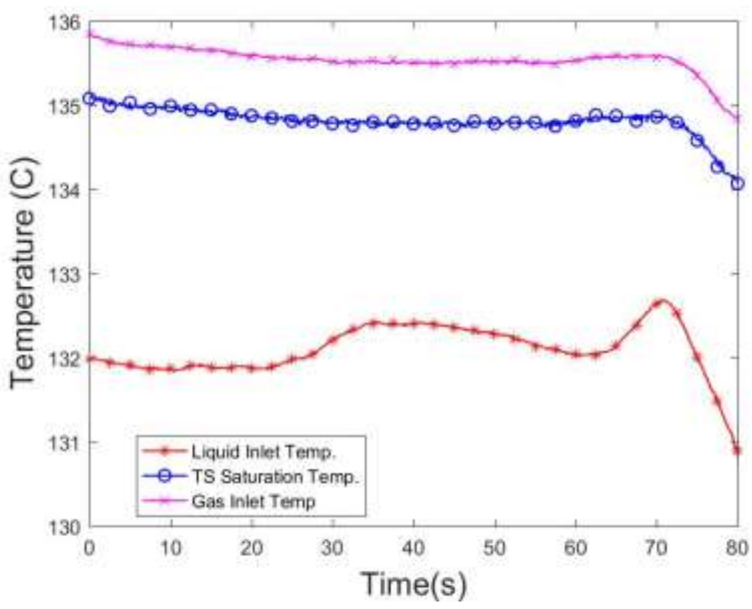

Figure F382:Temperature Profiles for test 2017_05_17_test_13.

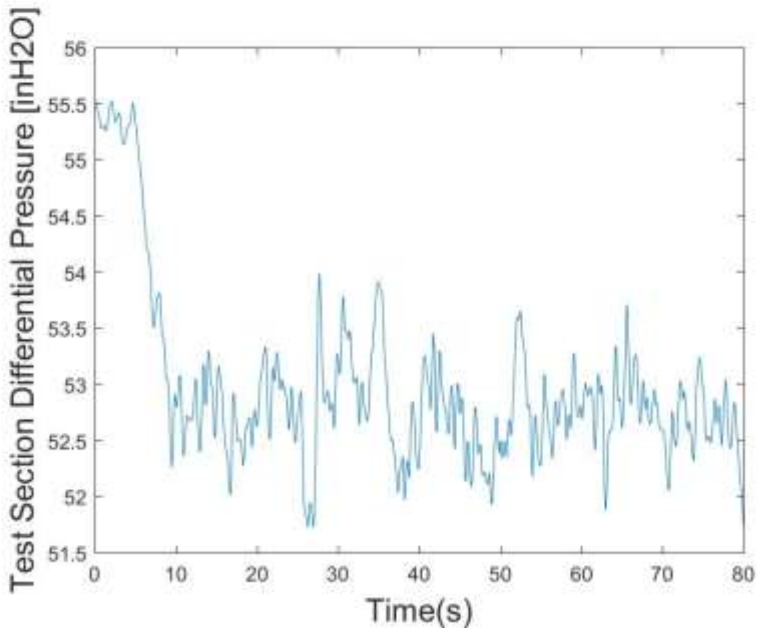

Figure F383: Test section differential pressure for test 2017_05_17_test_13.

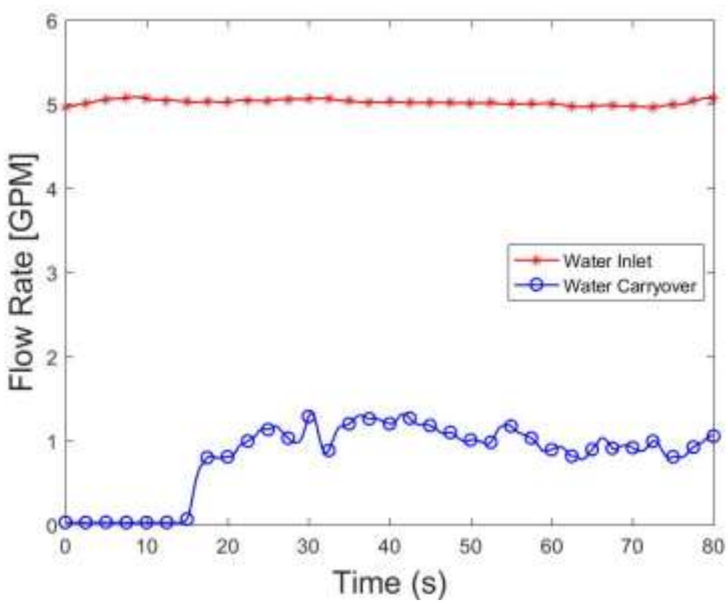

Figure F384: Water flow rates for 2017_05_17_test_13

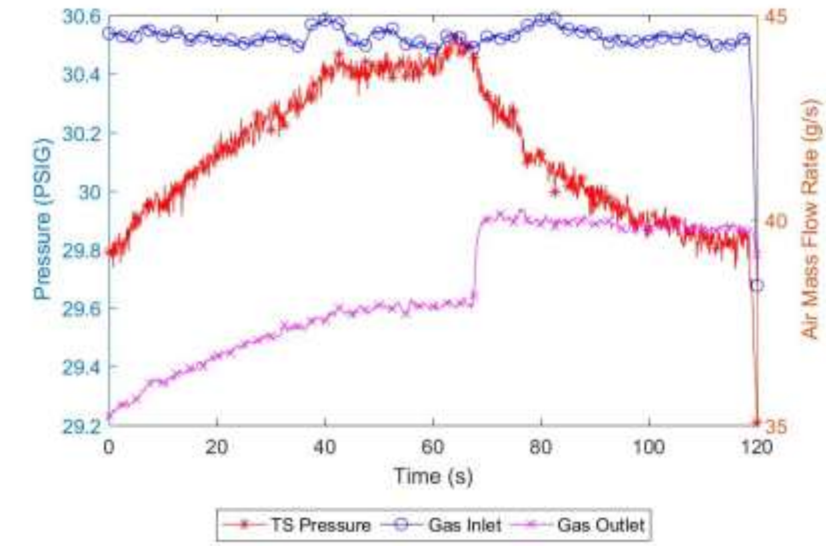

Figure F385: Pressure and gas inlet and outlet mass flow rate for test 2017_05_17_test_14.

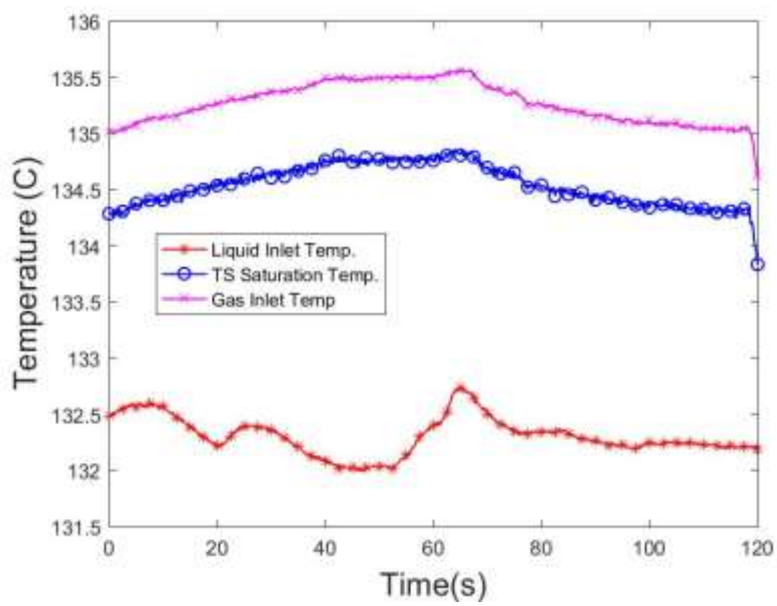

Figure F386: Temperature Profiles for test 2017_05_17_test_14.

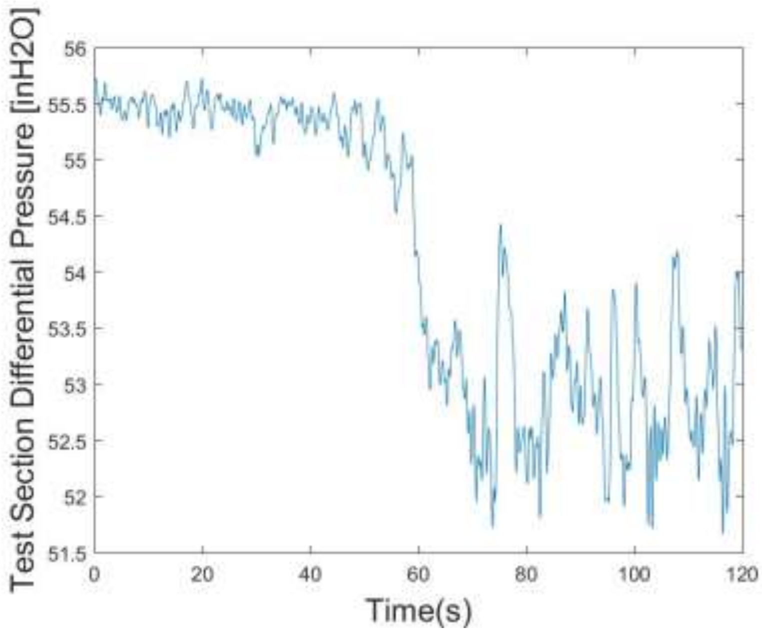

Figure F387: Test section differential pressure for test 2017_05_17_test_14.

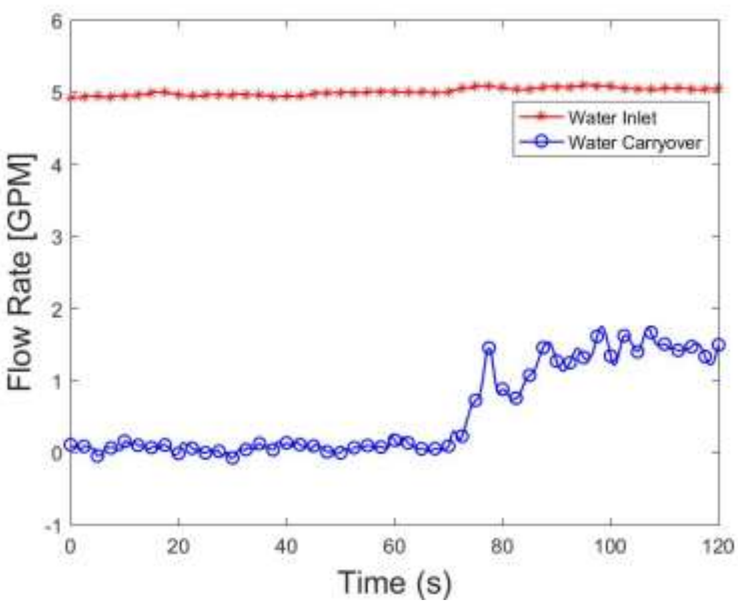

Figure F388: Water flow rates for 2017_05_17_test_14

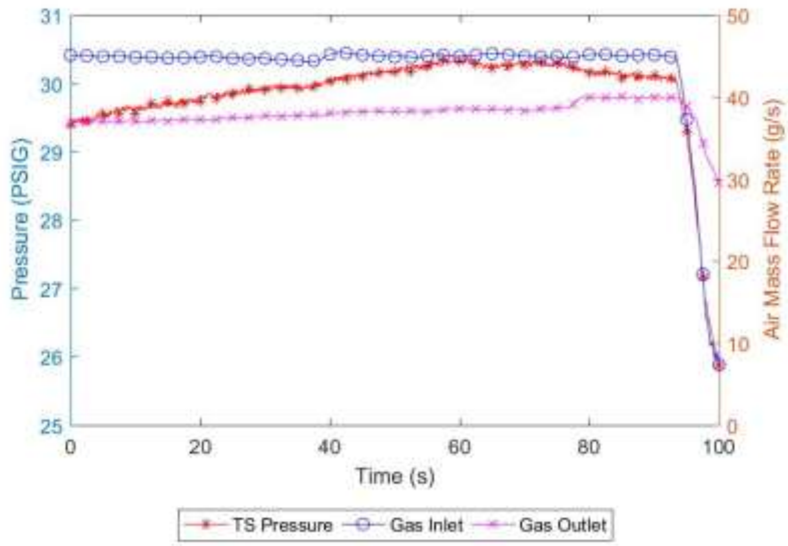

Figure F389: Pressure and gas inlet and outlet mass flow rate for test 2017_05_17_test_15.

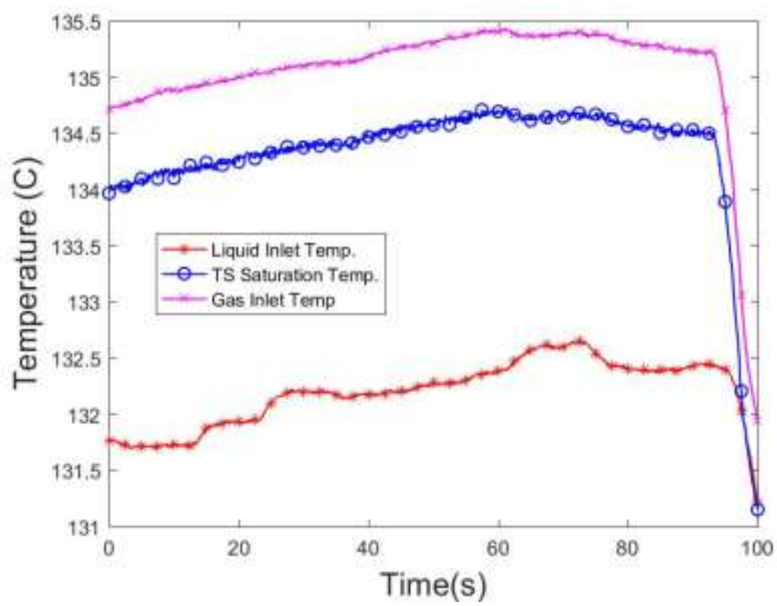

Figure F390: Temperature Profiles for test 2017_05_17_test_15.

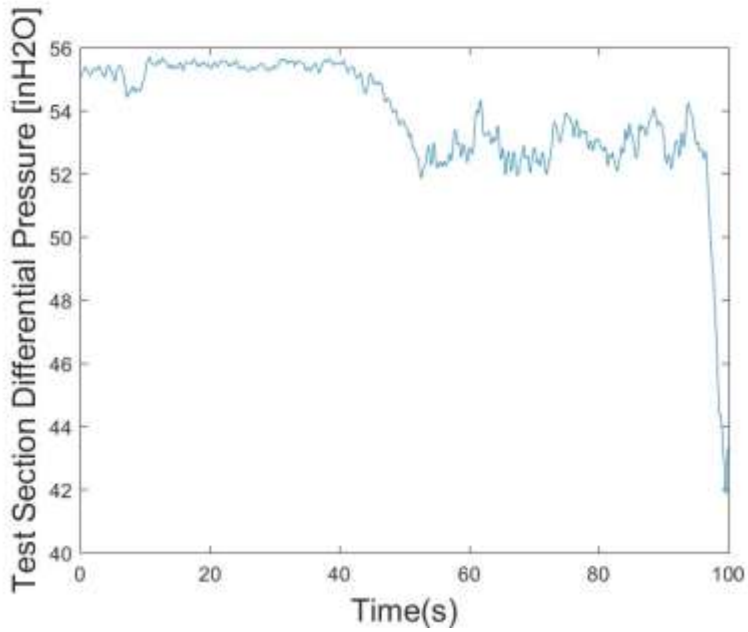

Figure F391: Test section differential pressure for test 2017_05_17_test_15.

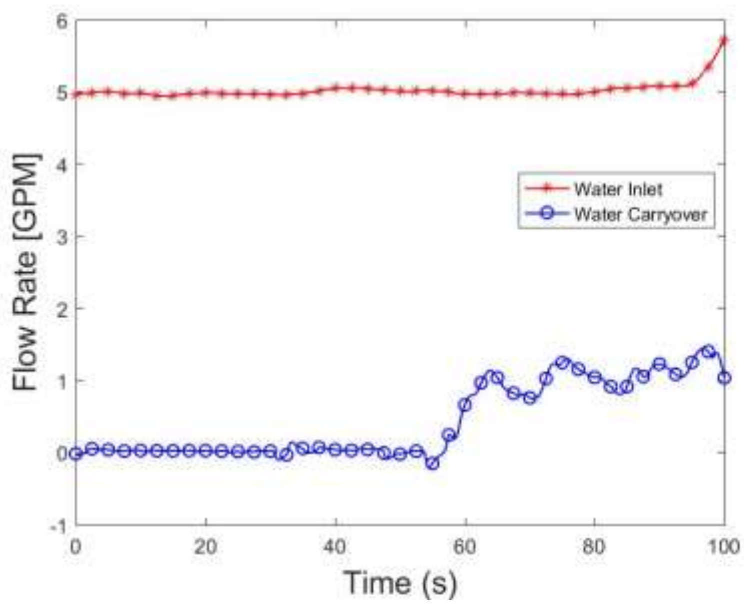

Figure F392: Water flow rates for 2017_05_17_test_15

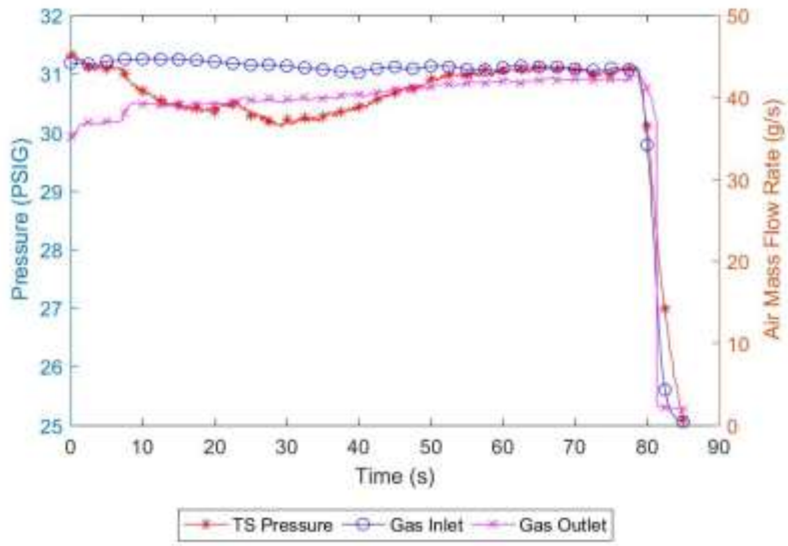

Figure F393: Pressure and gas inlet and outlet mass flow rate for test 2017_05_18_test_02.

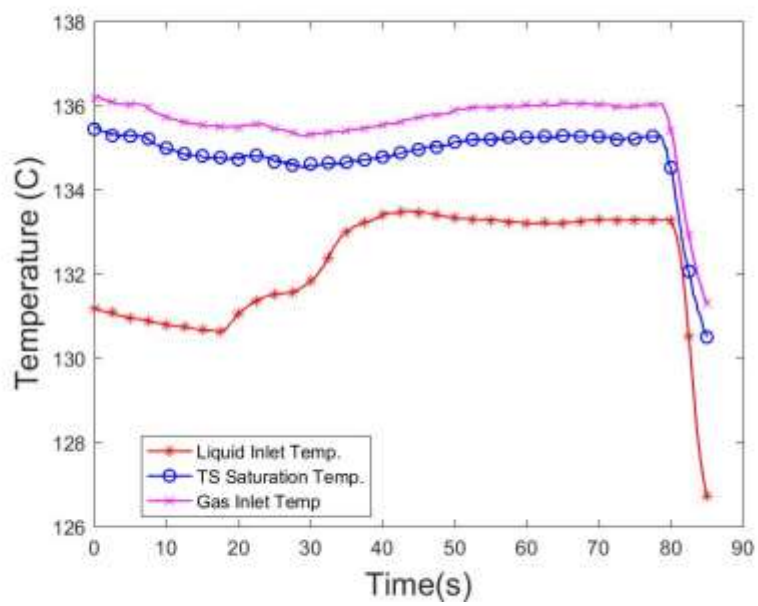

Figure F394: Temperature Profiles for test 2017_05_18_test_02.

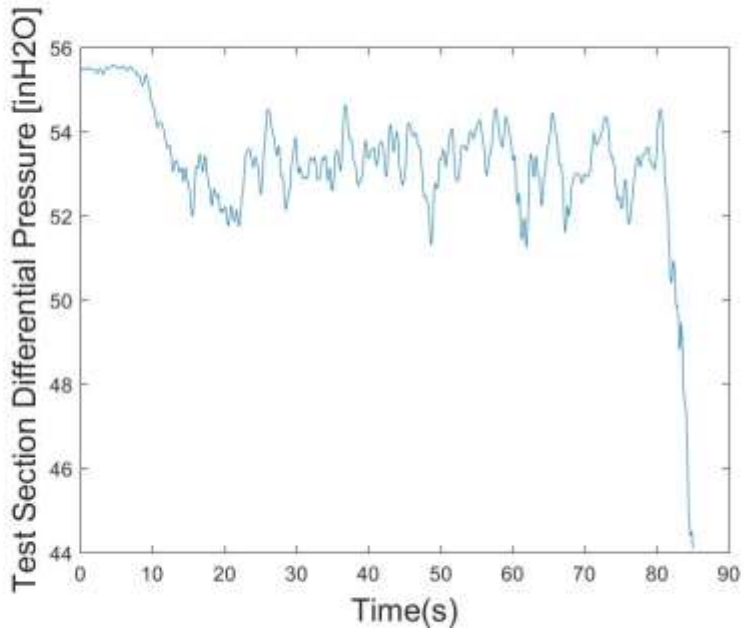

Figure F395: Test section differential pressure for test 2017_05_18_test_02.

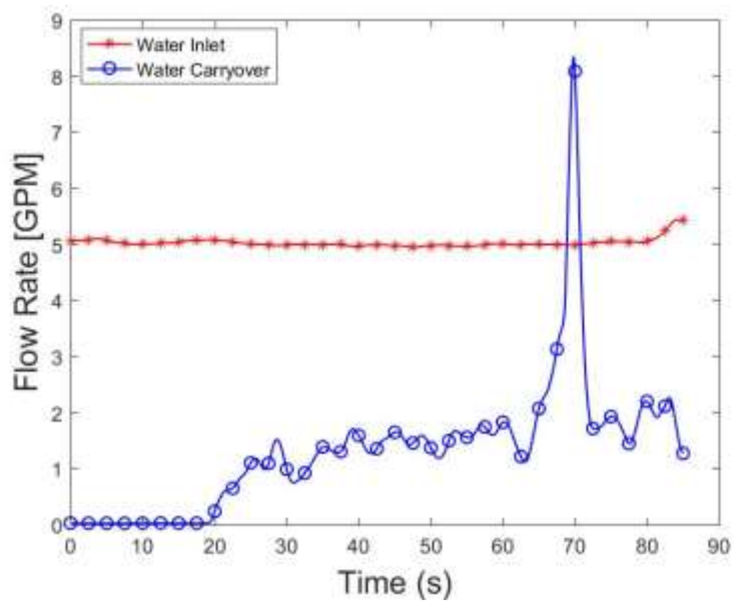

Figure F396: Water flow rates for 2017_05_18_test_02

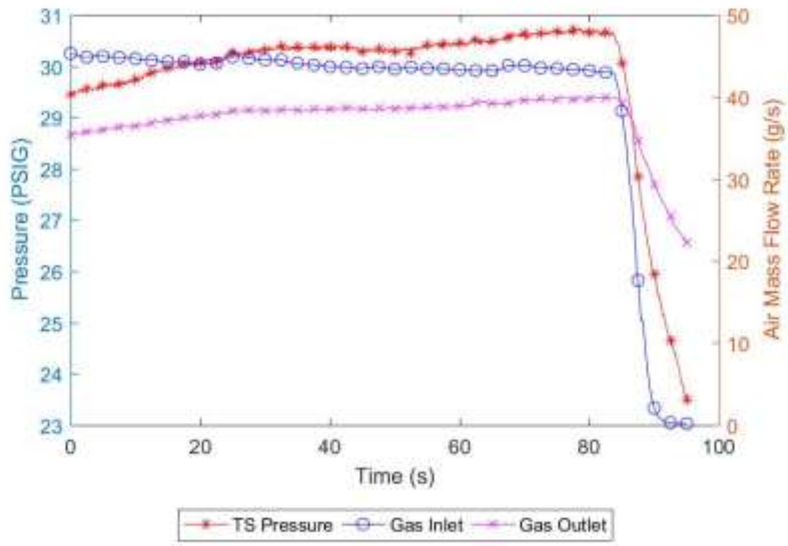

Figure F397: Pressure and gas inlet and outlet mass flow rate for test 2017_05_18_test_03.

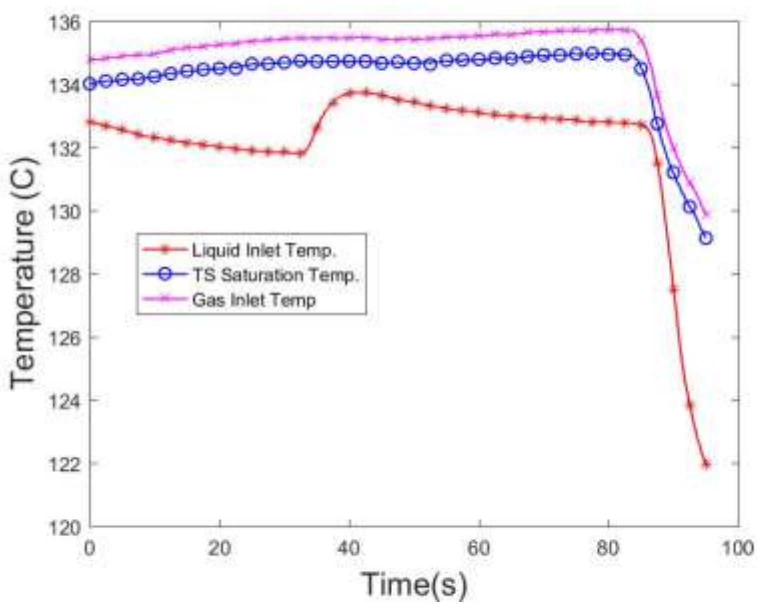

Figure F398: Temperature Profiles for test 2017_05_18_test_03.

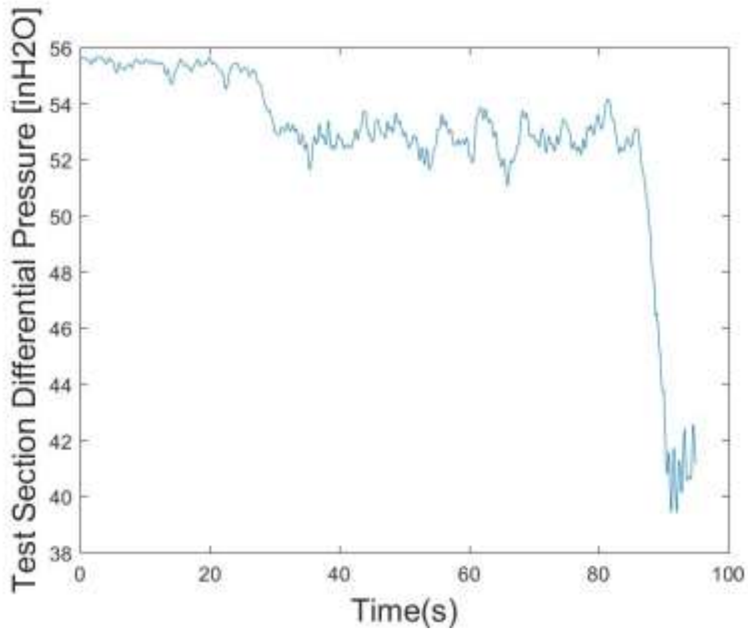

Figure F399: Test section differential pressure for test 2017_05_18_test_03.

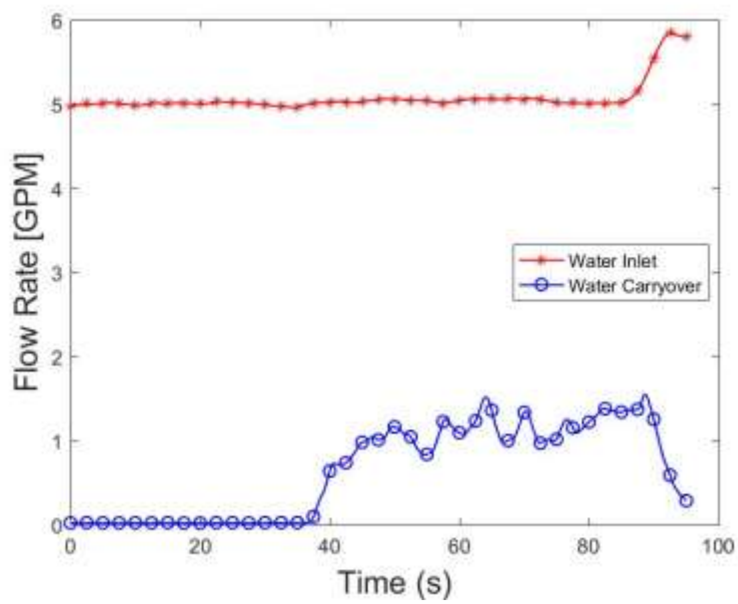

Figure F400: Water flow rates for 2017_05_18_test_03.

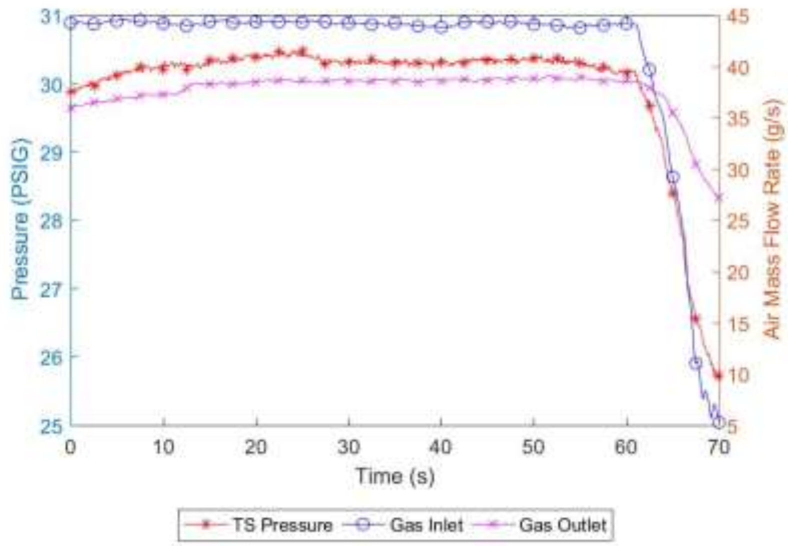

Figure F401: Pressure and gas inlet and outlet mass flow rate for test 2017_05_18_test_06.

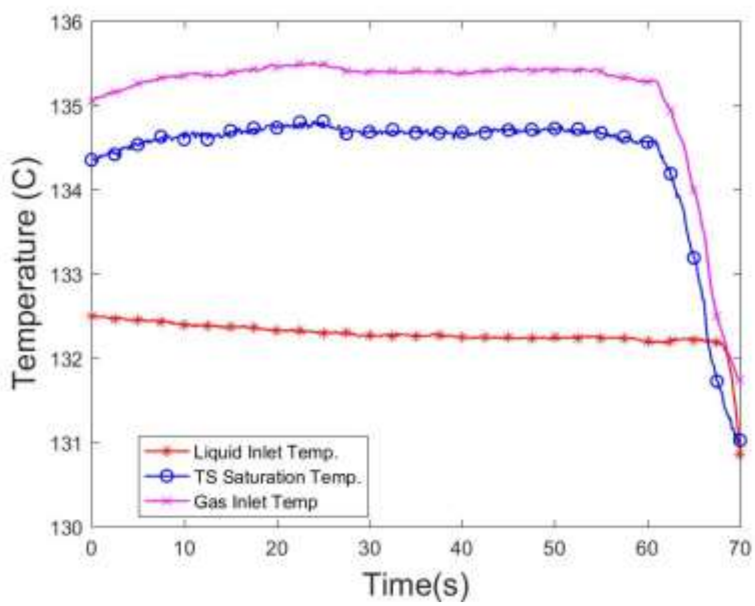

Figure F402: Temperature Profiles for test 2017_05_18_test_06.

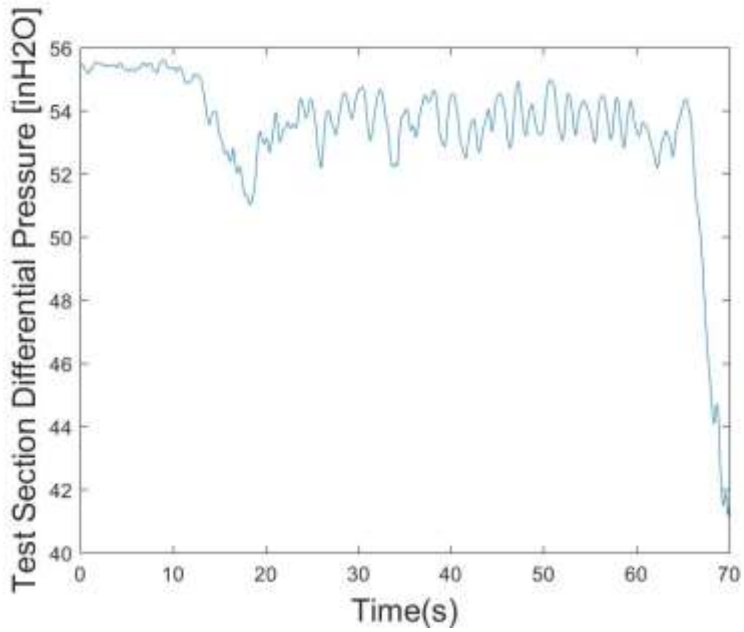

Figure F403: Test section differential pressure for test 2017_05_18_test_06.

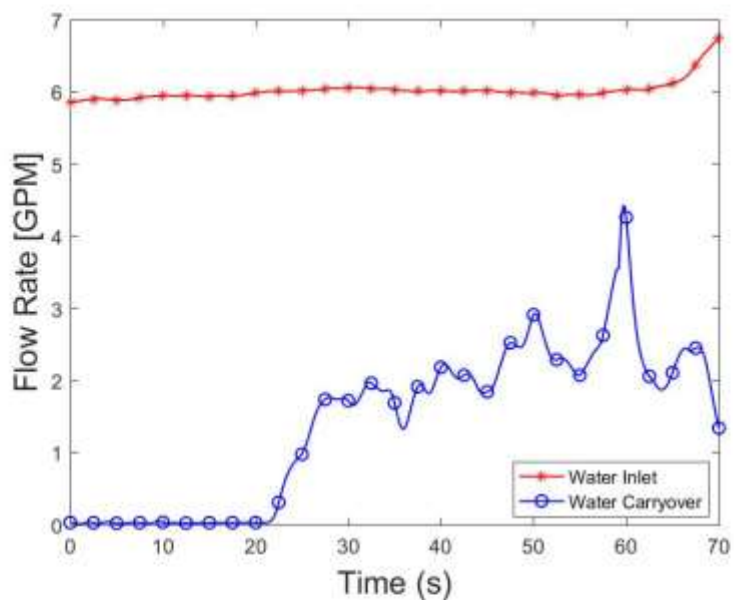

Figure F404: Water flow rates for 2017_05_18_test_06.

APPENDIX G

RAW AIR/WATER DATA

This appendix contains the raw data images for all qualified air/water tests performed for this study, presented in Appendix B.1.

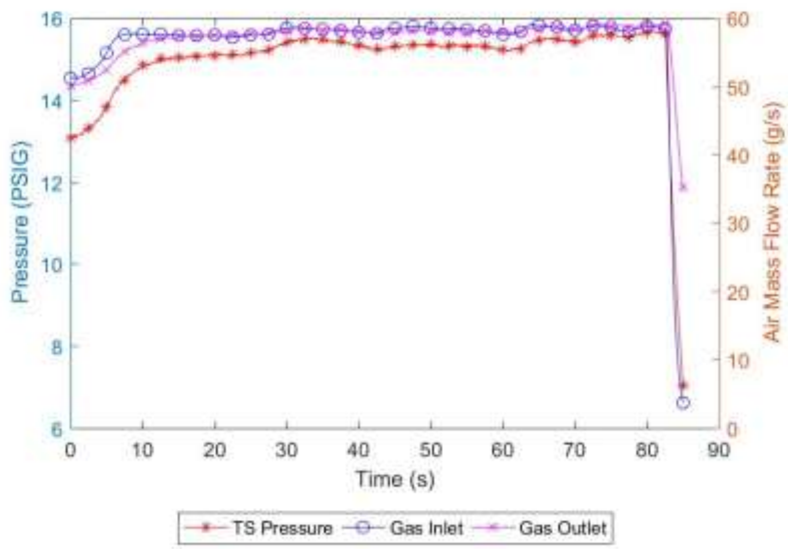

Figure G405: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_06.

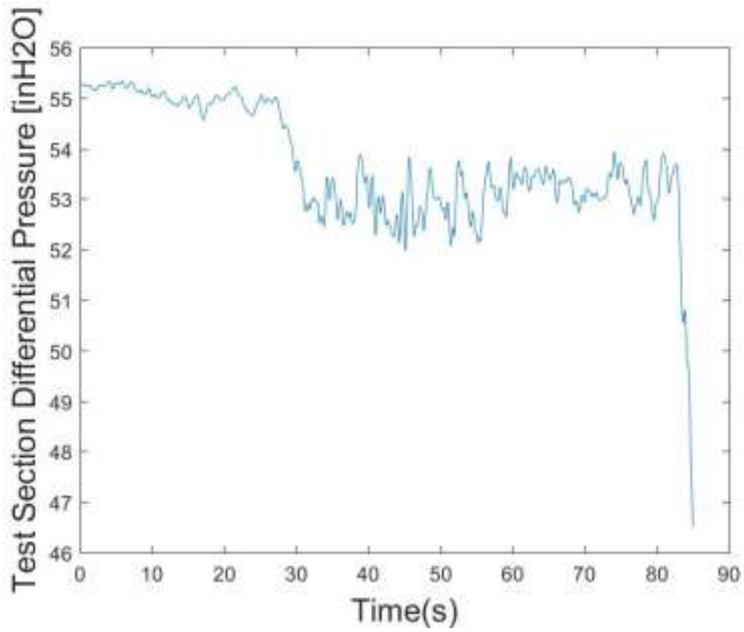

Figure G406: Test section differential pressure for test 2016_06_14_test_06.

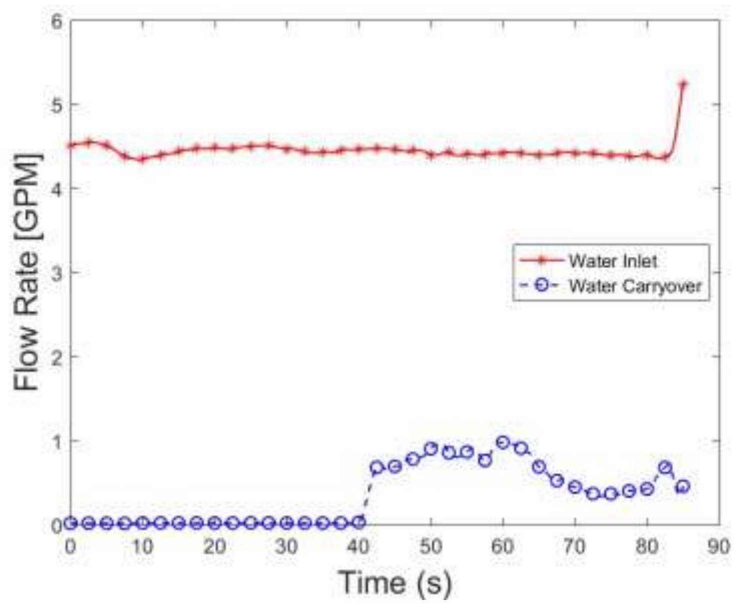

Figure G407: Water flow rates for test 2016_06_14_test_06.

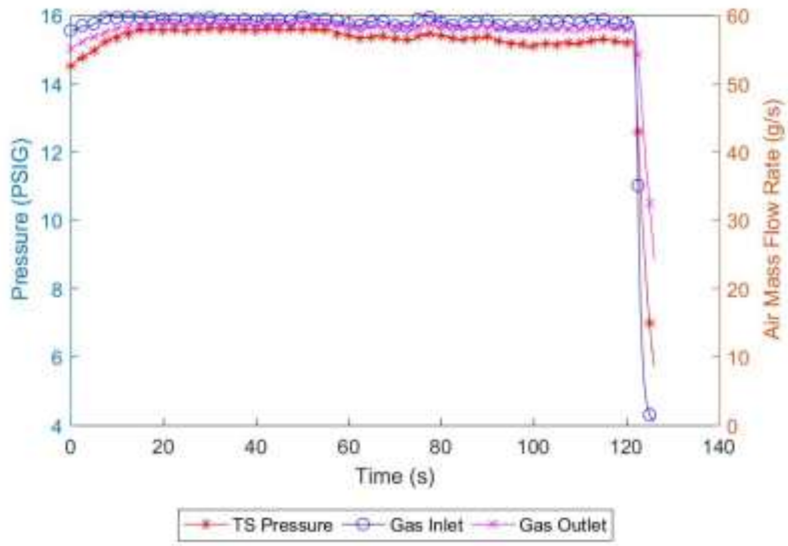

Figure G408: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_07.

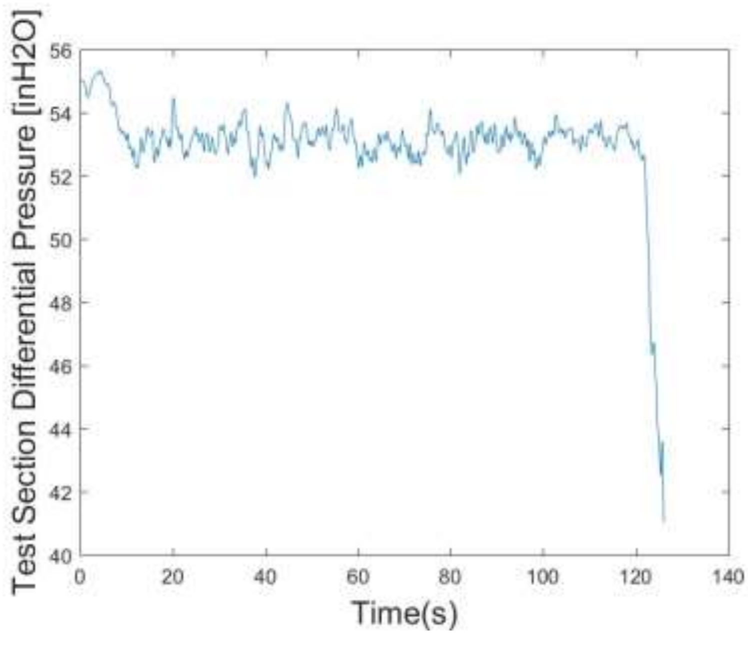

Figure G409: Test section differential pressure for test 2016_06_14_test_07.

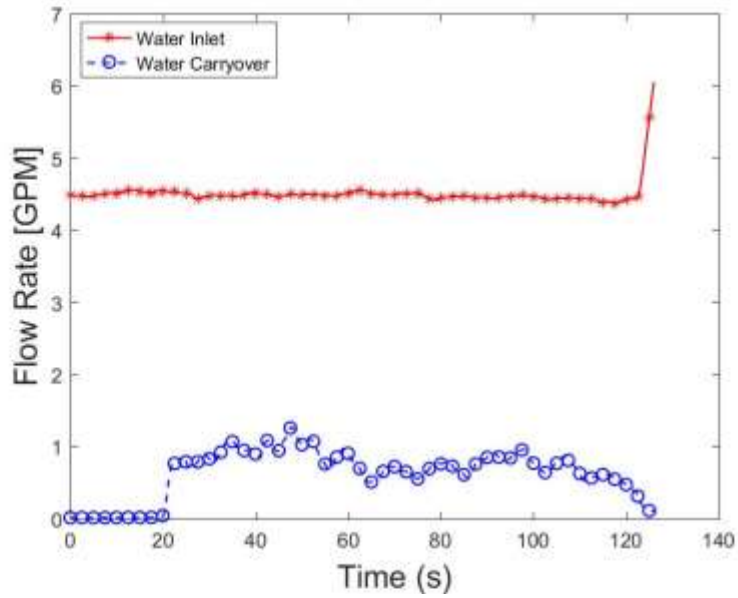

Figure G410: Water flow rates for test 2016_06_14_test_07.

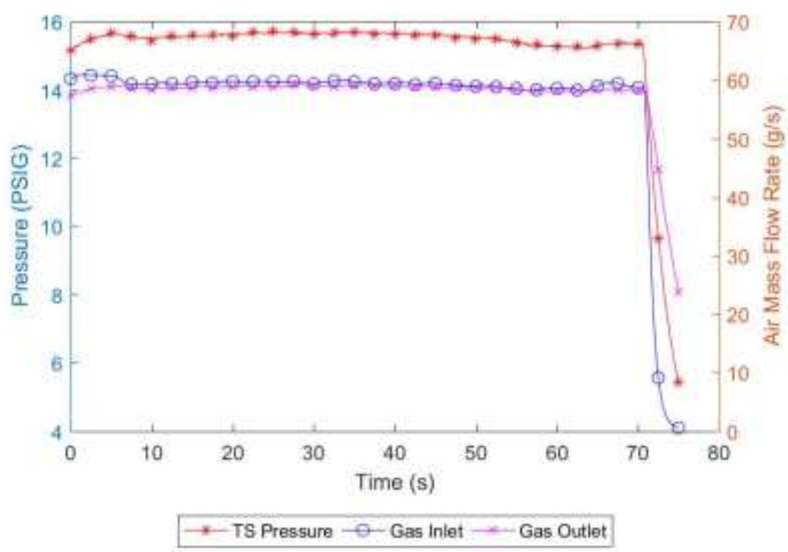

Figure G411: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_08.

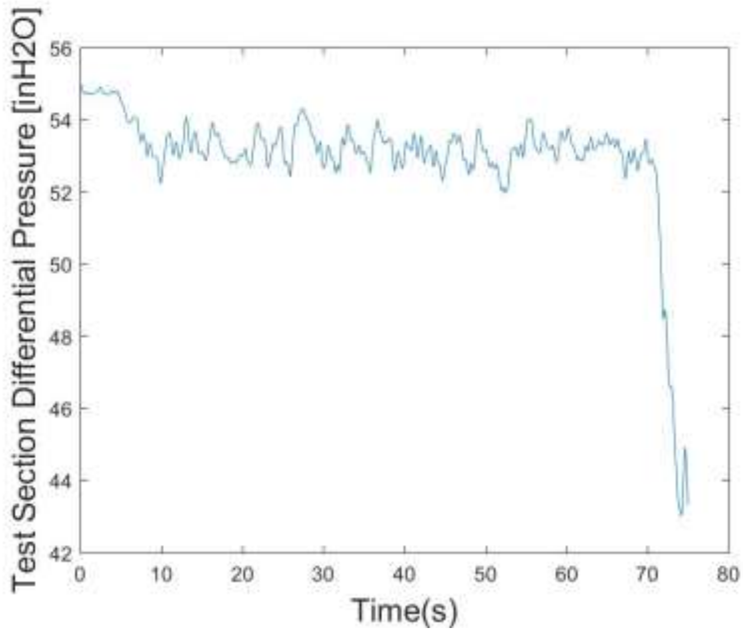

Figure G412: Test section differential pressure for test 2016_06_14_test_08.

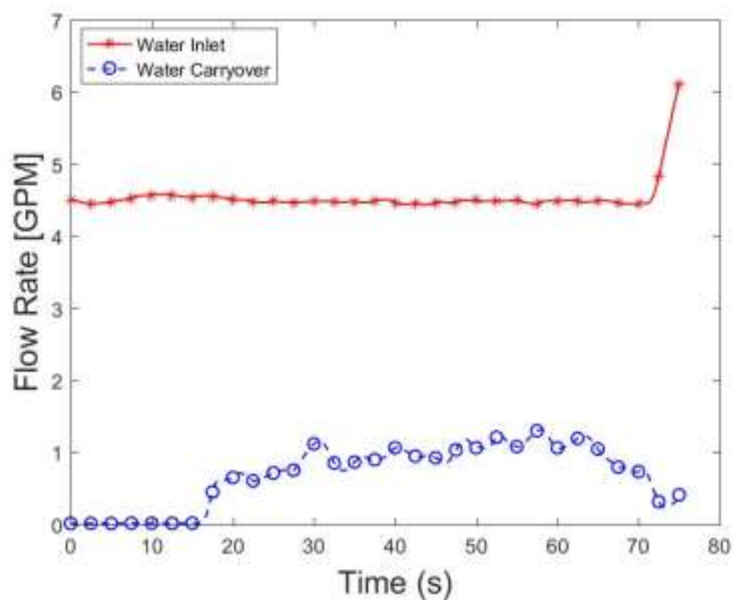

Figure G413: Water flow rates for test 2016_06_14_test_08.

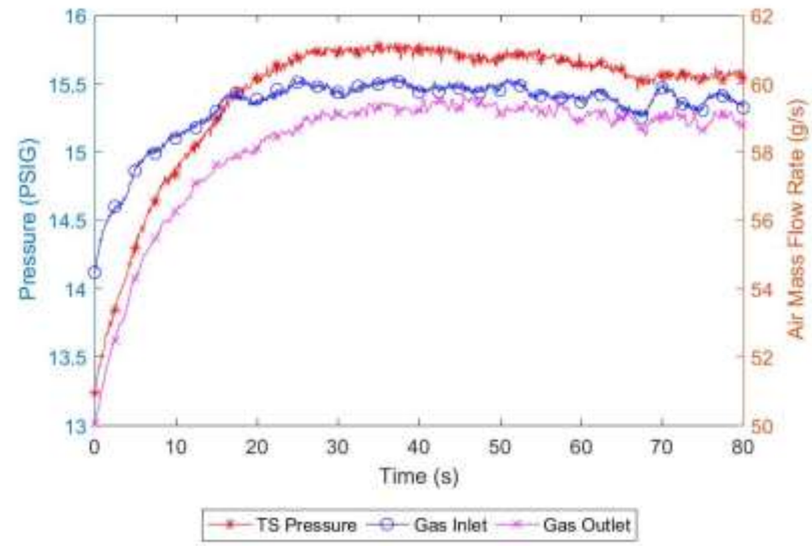

Figure G414: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_09.

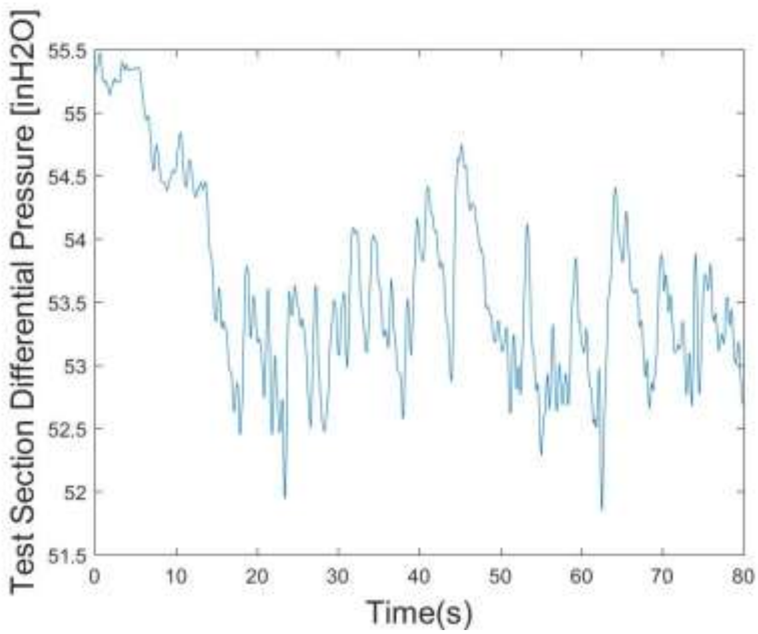

Figure G415: Test section differential pressure for test 2016_06_14_test_09.

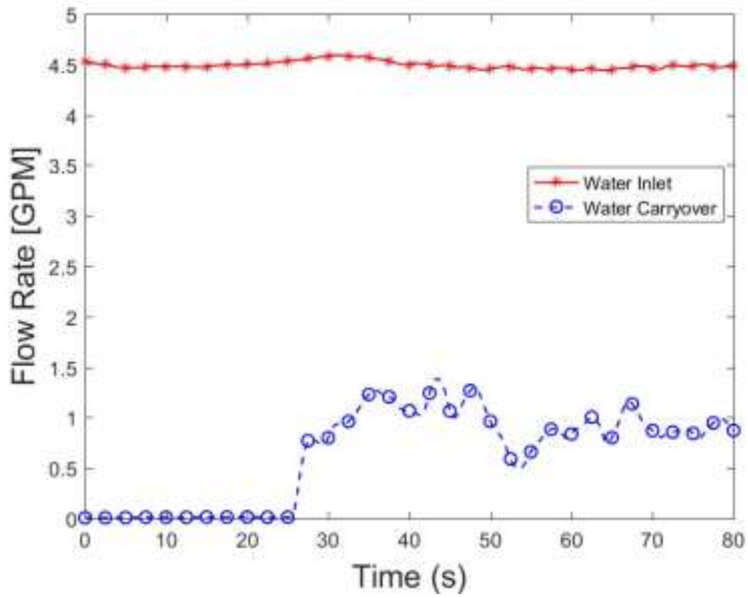

Figure G416: Water flow rates for test 2016_06_14_test_09.

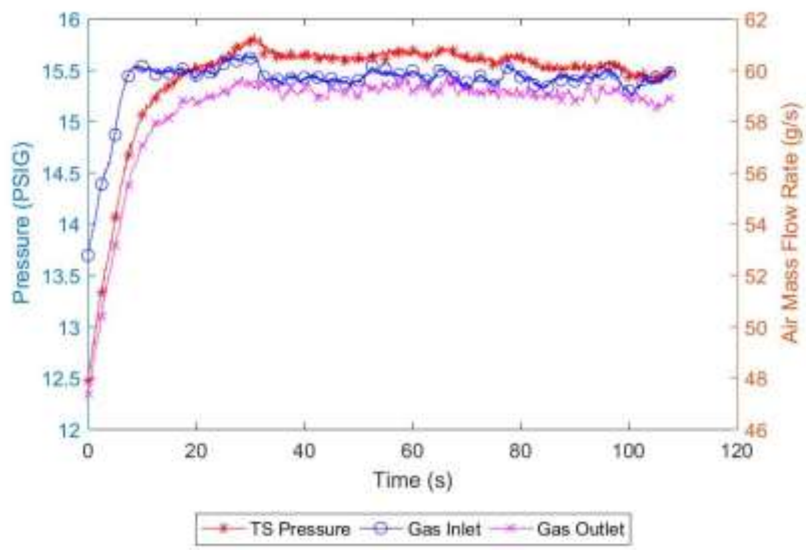

Figure G417: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_10.

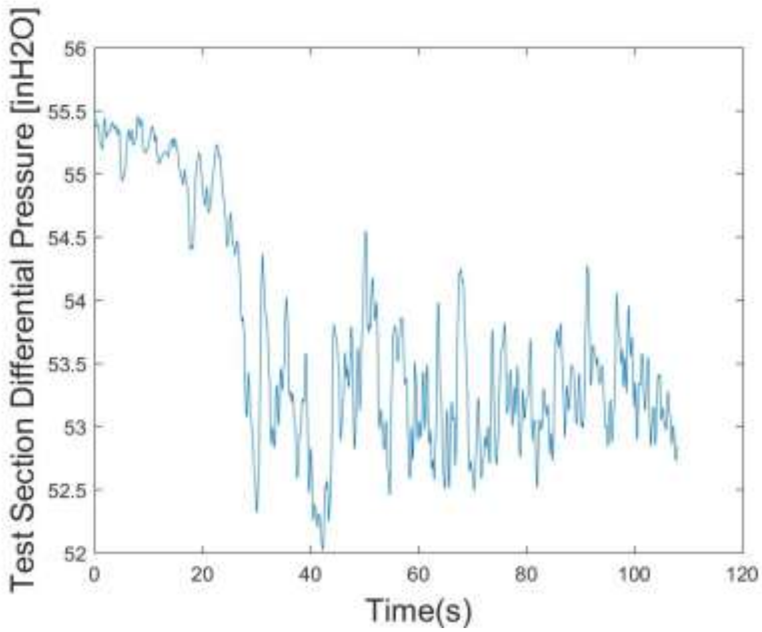

Figure G418: Test section differential pressure for test 2016_06_14_test_10.

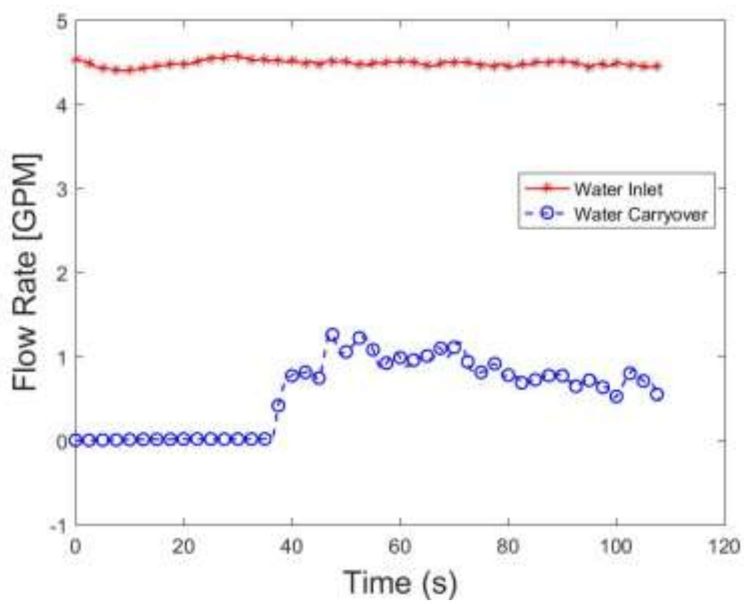

Figure G419: Water flow rates for test 2016_06_14_test_10.

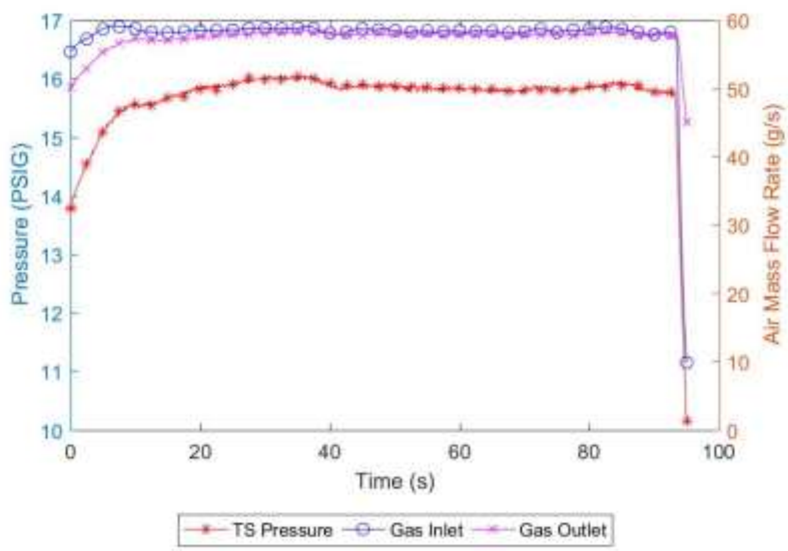

Figure G420: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_11.

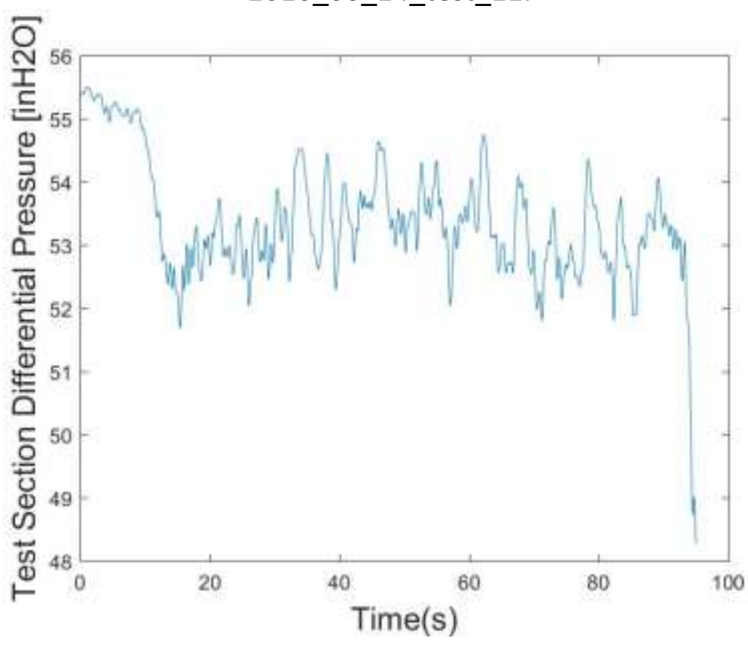

Figure G421: Test section differential pressure for test 2016_06_14_test_11.

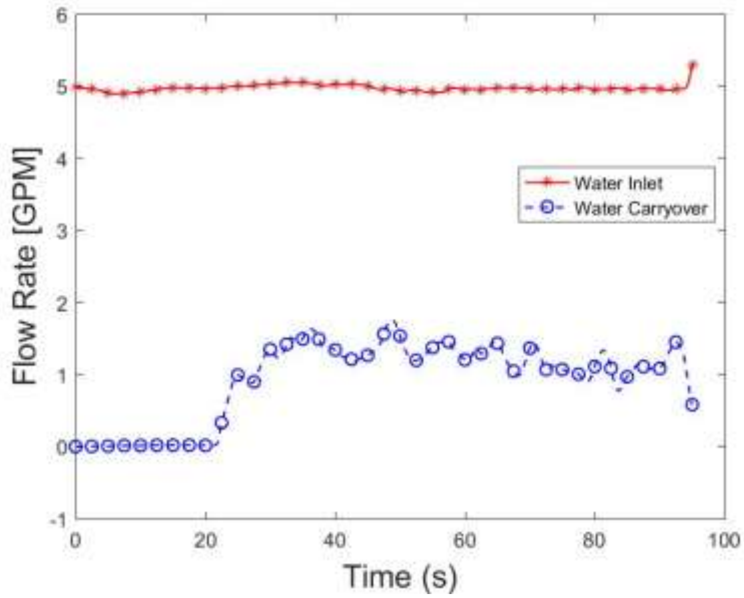

Figure G422: Water flow rates for test 2016_06_14_test_11.

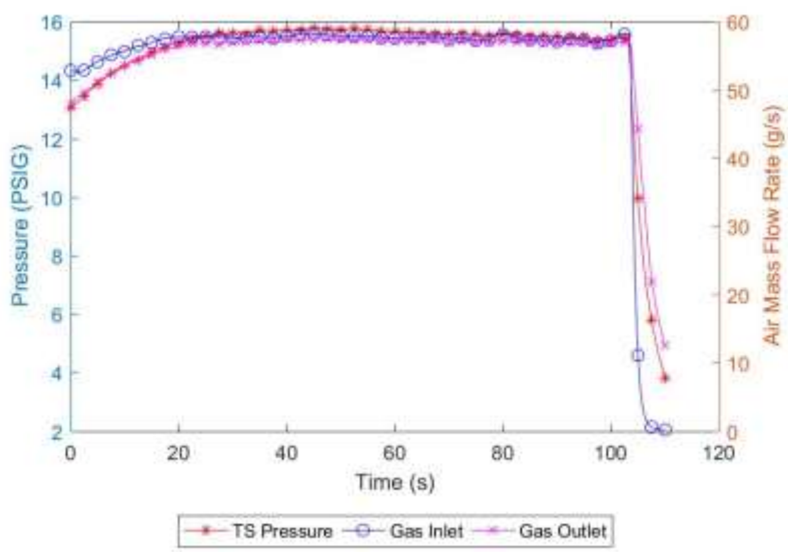

Figure G423: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_12.

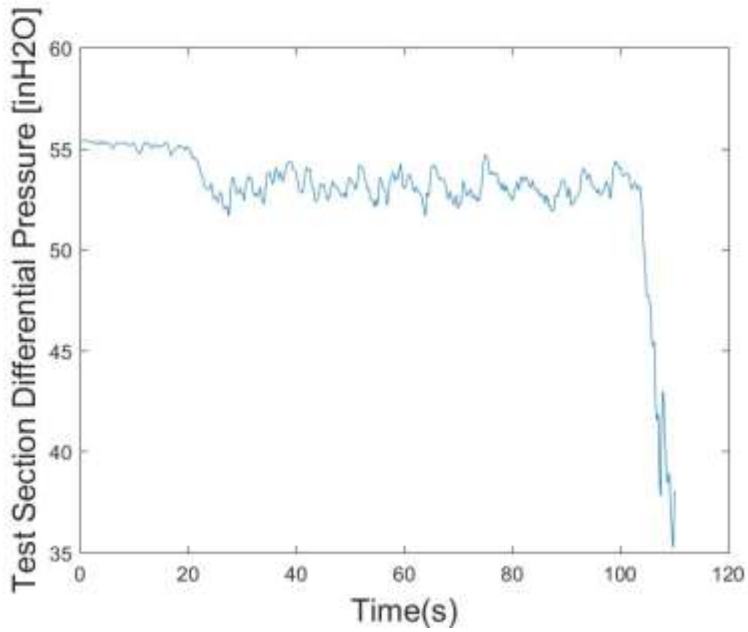

Figure G424: Test section differential pressure for test 2016_06_14_test_12.

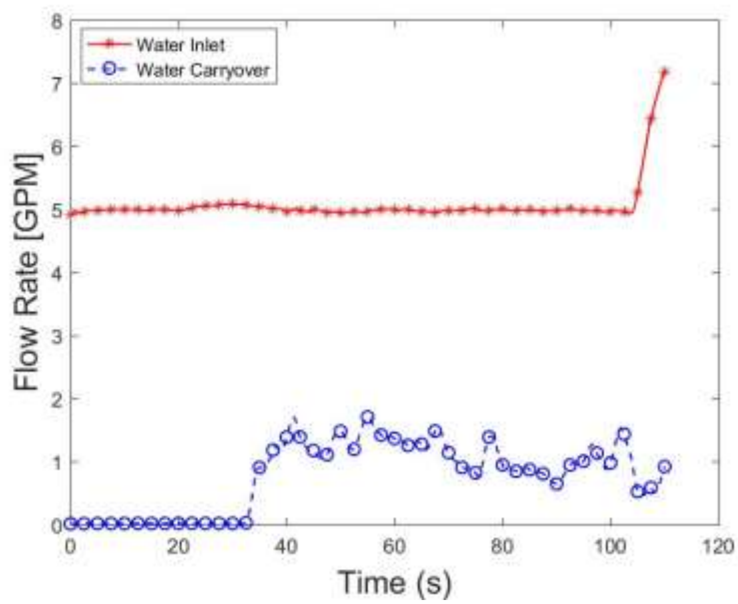

Figure G425: Water flow rates for test 2016_06_14_test_12.

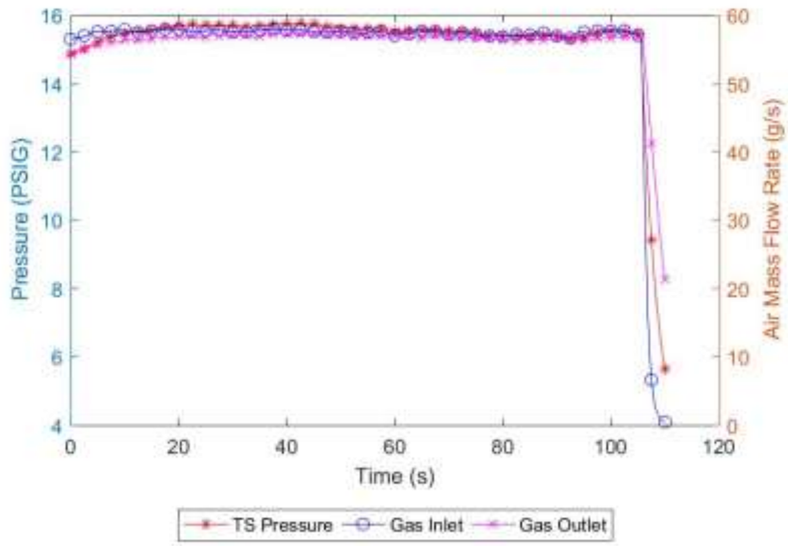

Figure G426: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_13.

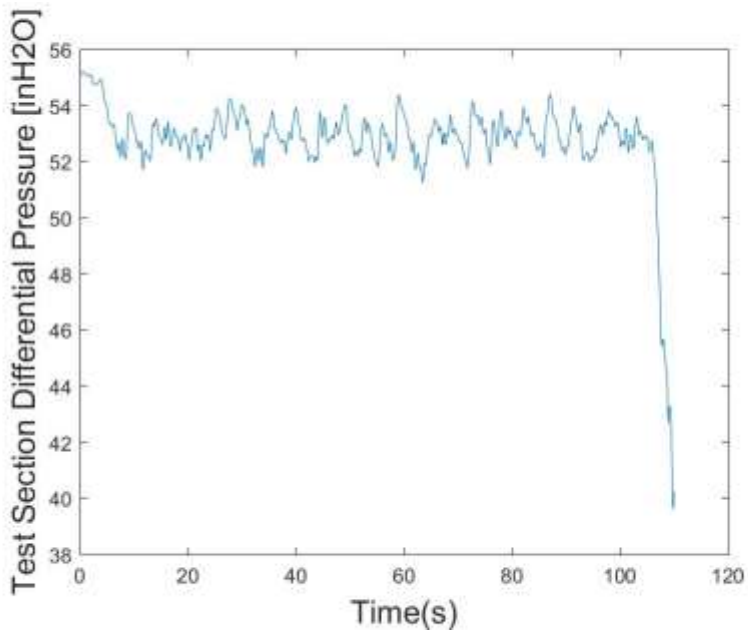

Figure G427: Test section differential pressure for test 2016_06_14_test_13.

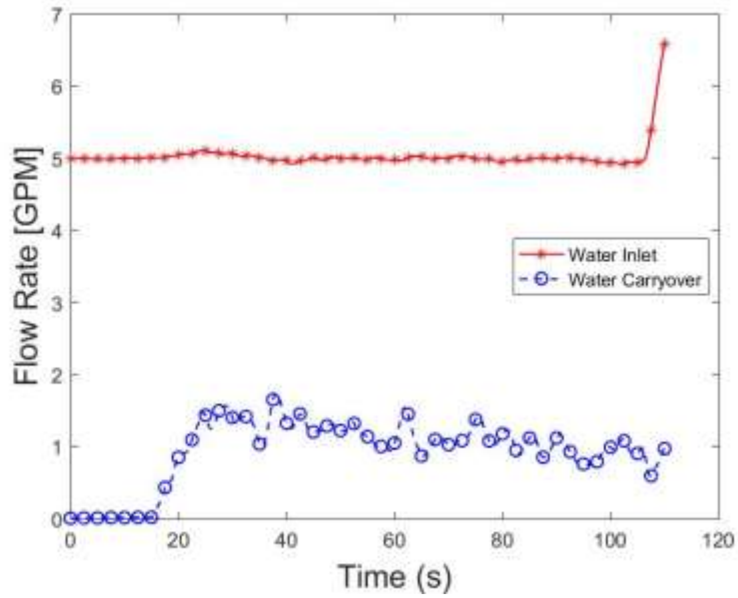

Figure G428: Water flow rates for test 2016_06_14_test_13.

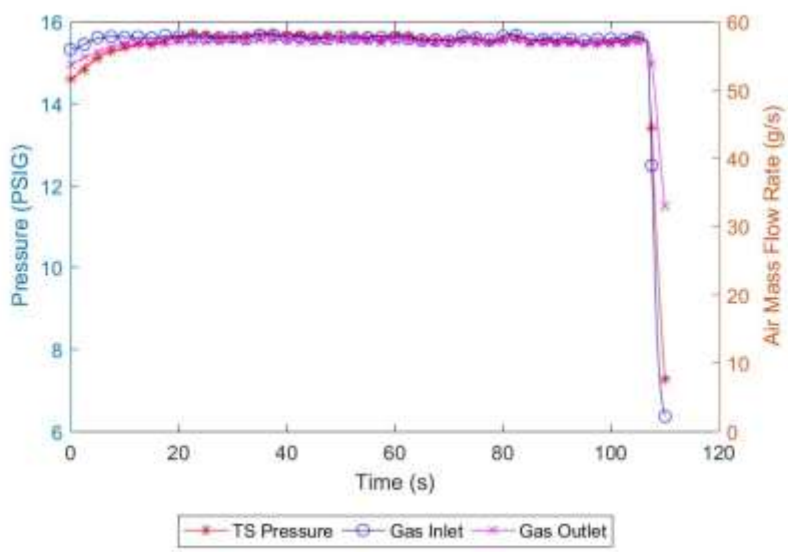

Figure G429: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_14.

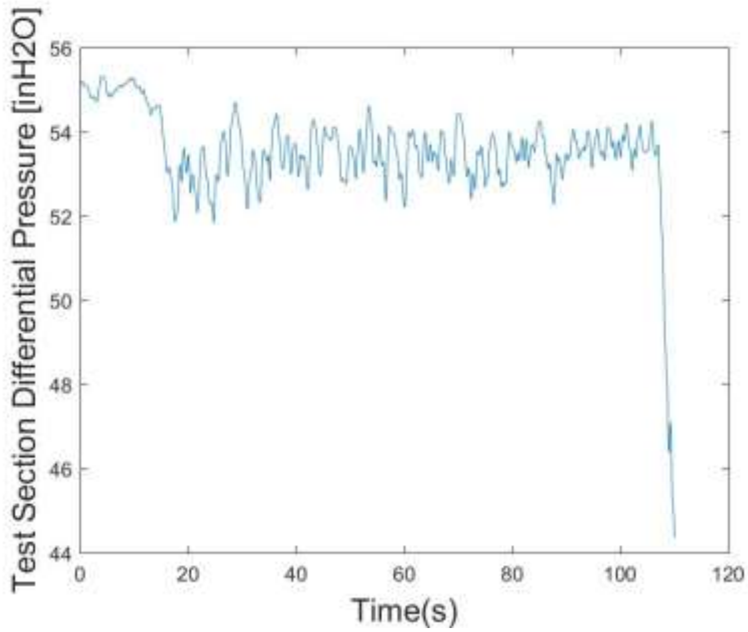

Figure G430: Test section differential pressure for test 2016_06_14_test_14.

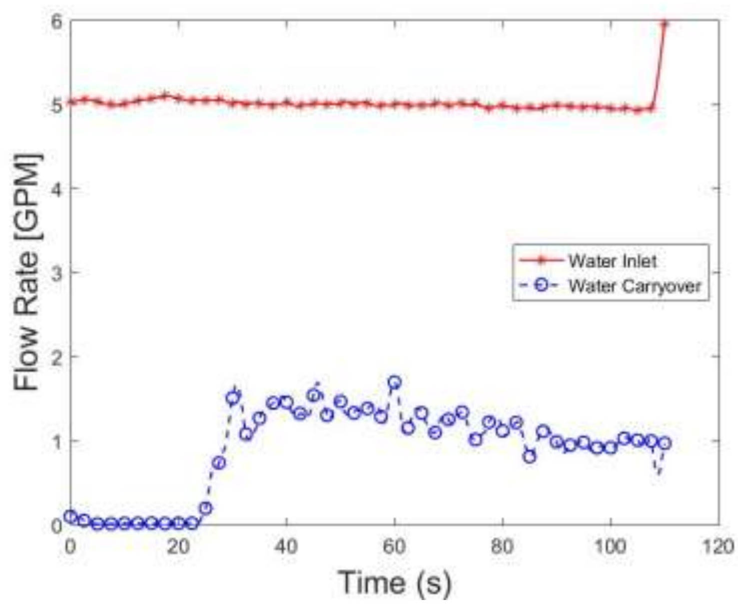

Figure G431: Water flow rates for test 2016_06_14_test_14.

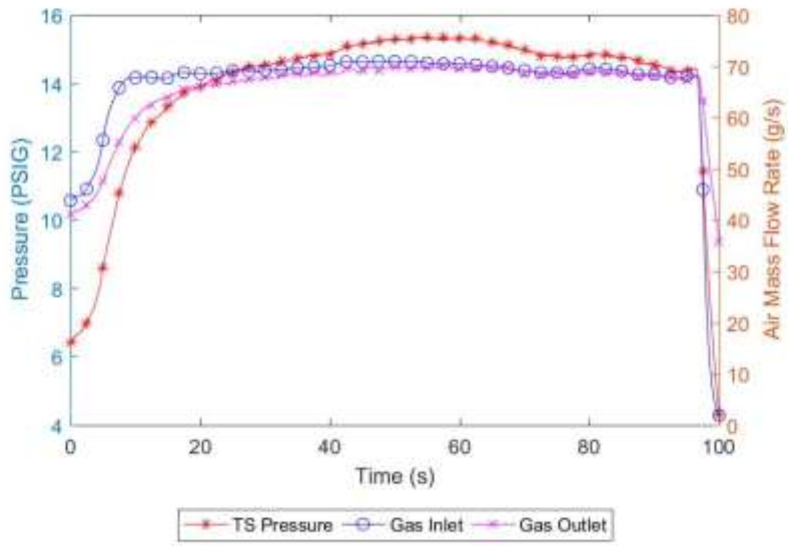

Figure G432: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_15.

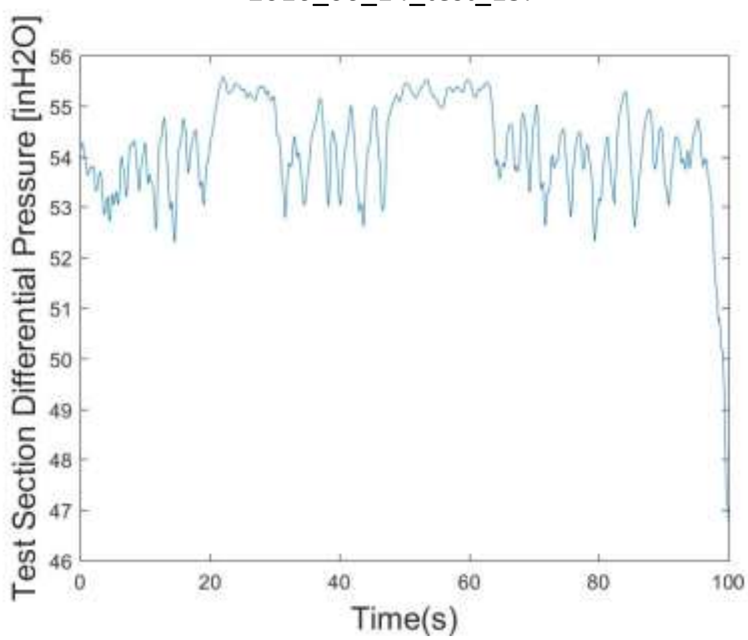

Figure G433: Test section differential pressure for test 2016_06_14_test_15.

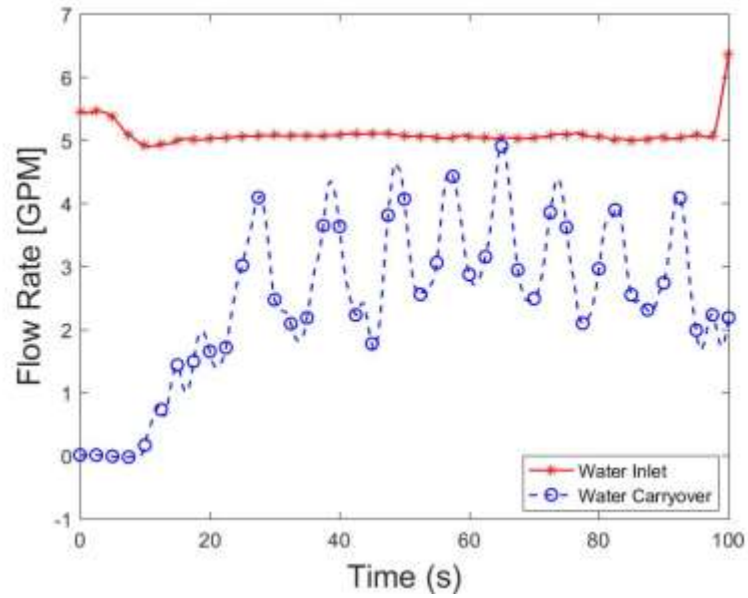

Figure G434: Water flow rates for test 2016_06_14_test_15.

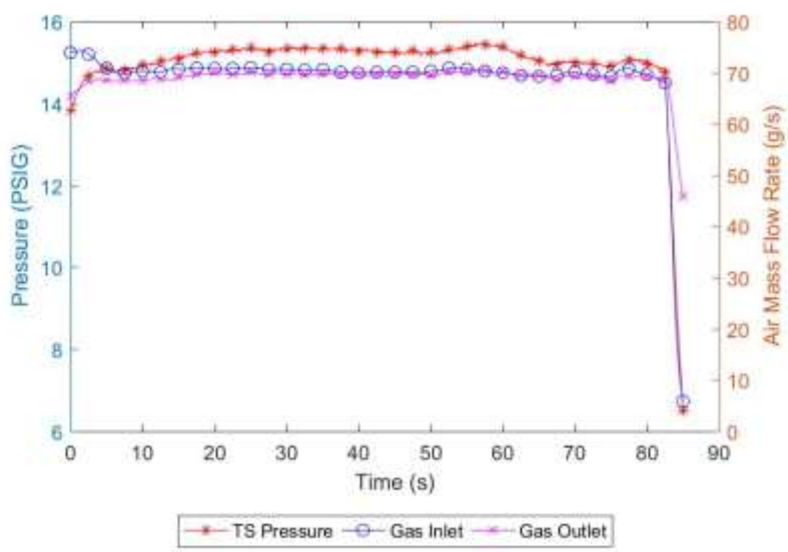

Figure G435: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_16.

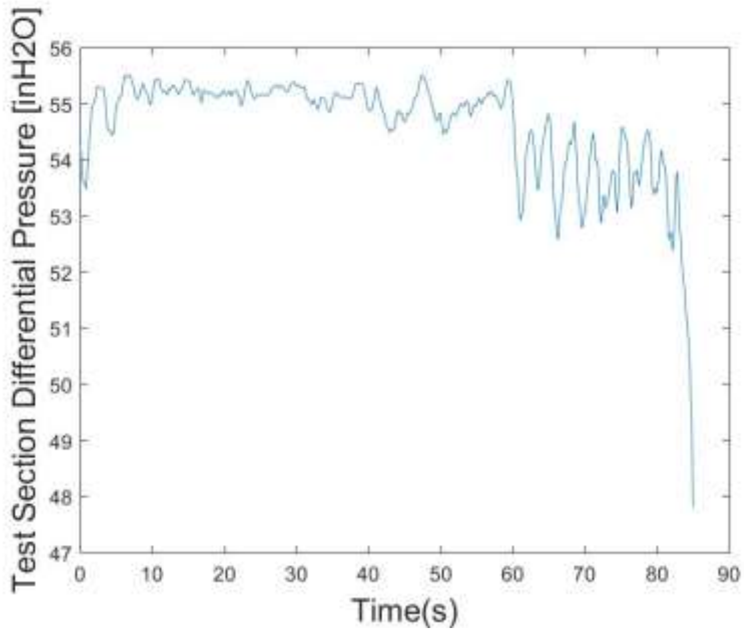

Figure G436: Test section differential pressure for test 2016_06_14_test_16.

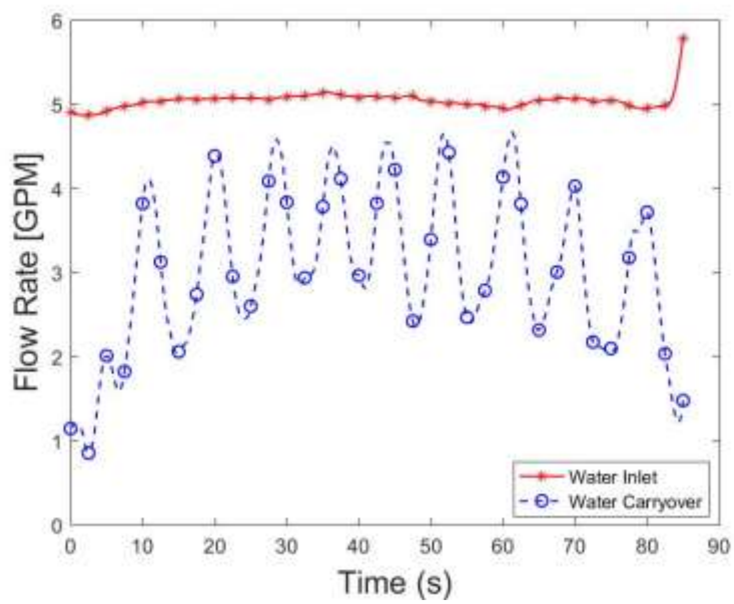

Figure G437: Water flow rates for test 2016_06_14_test_16.

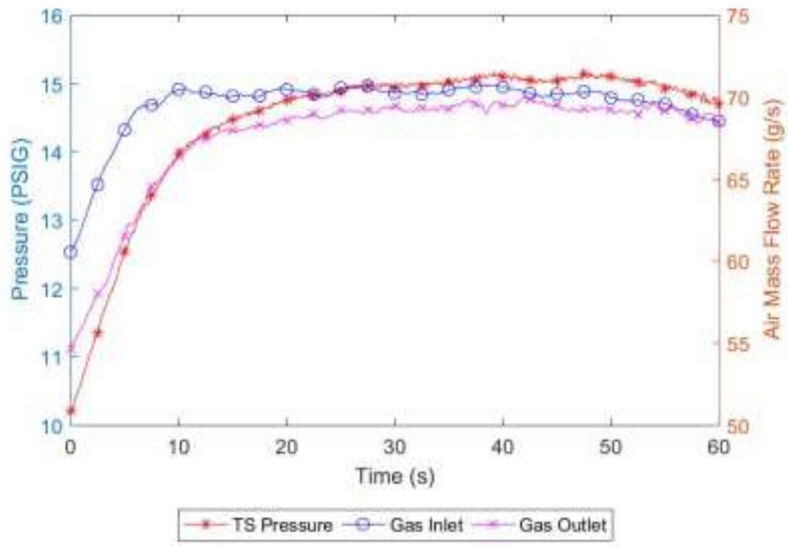

Figure G438: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_17.

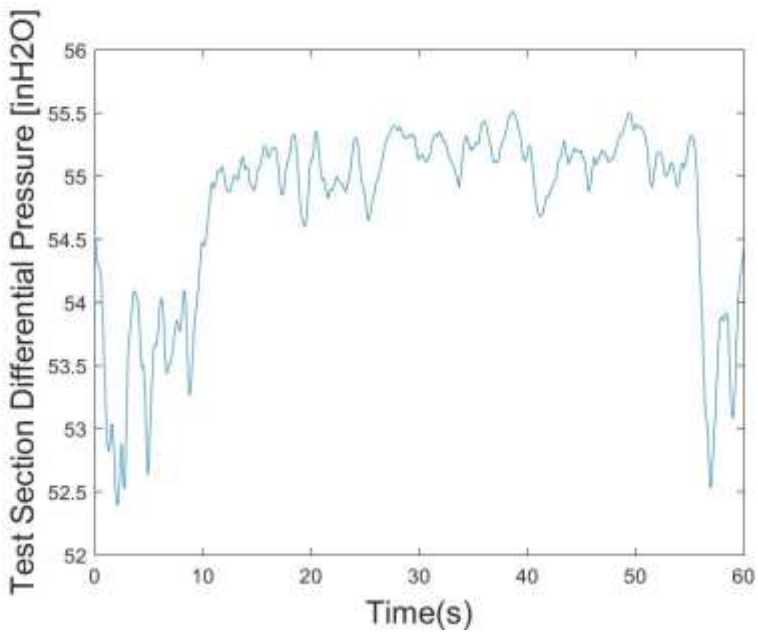

Figure G439: Test section differential pressure for test 2016_06_14_test_17.

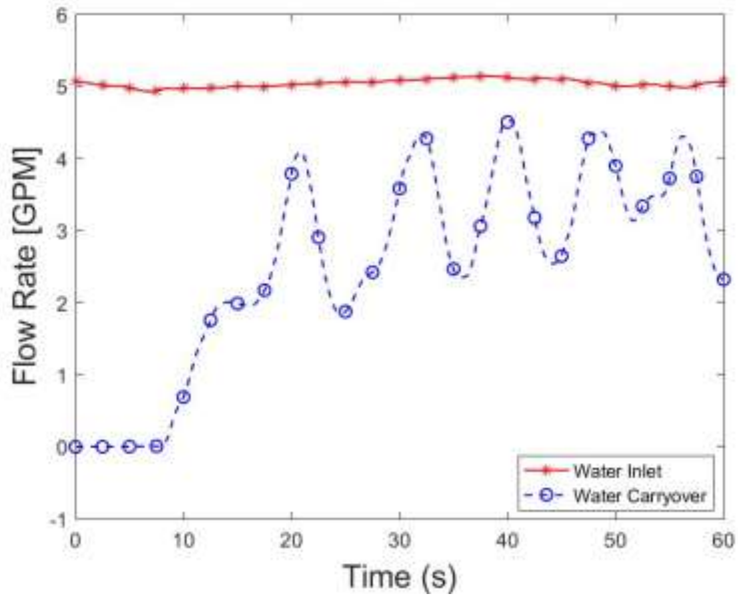

Figure G440: Water flow rates for test 2016_06_14_test_17.

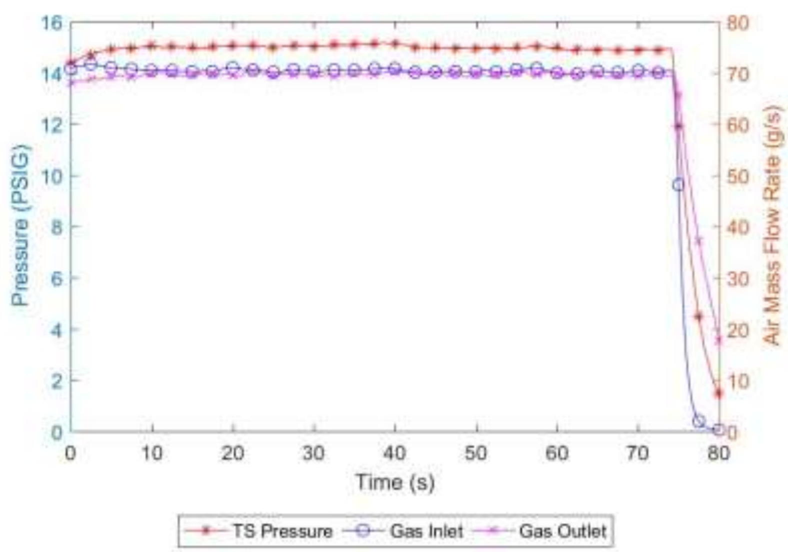

Figure G441: Pressure and gas inlet and outlet mass flow rates for test 2016_06_14_test_18.

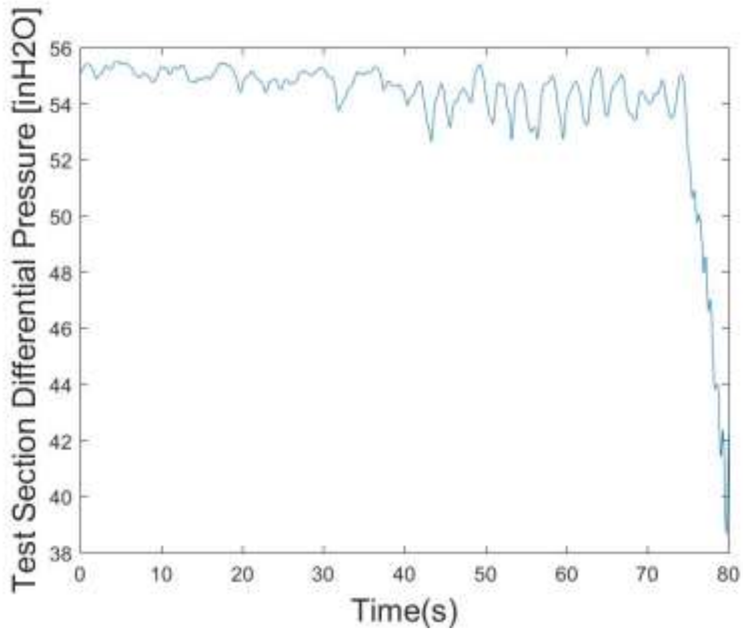

Figure G442: Test section differential pressure for test 2016_06_14_test_18.

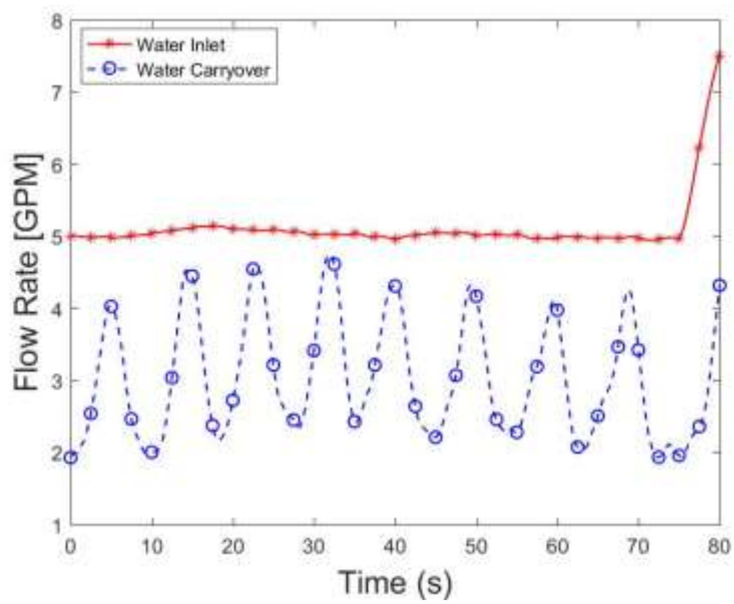

Figure G443: Water flow rates for test 2016_06_14_test_18.

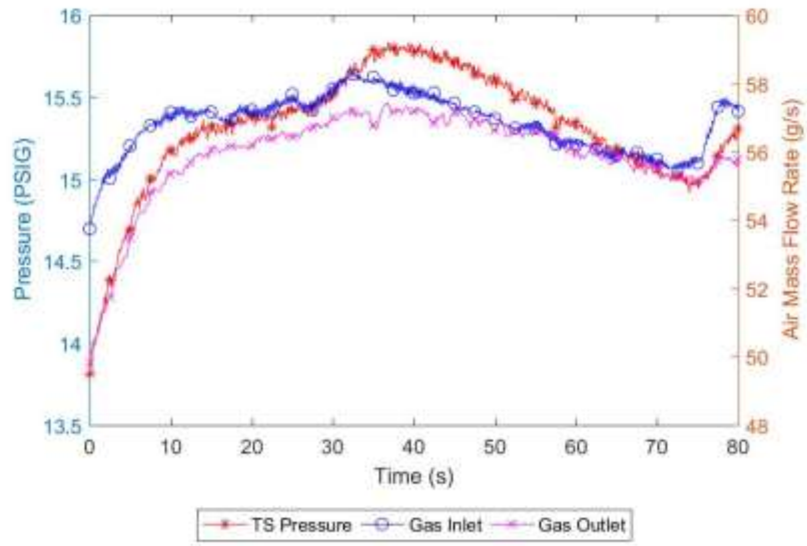

Figure G444: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_01.

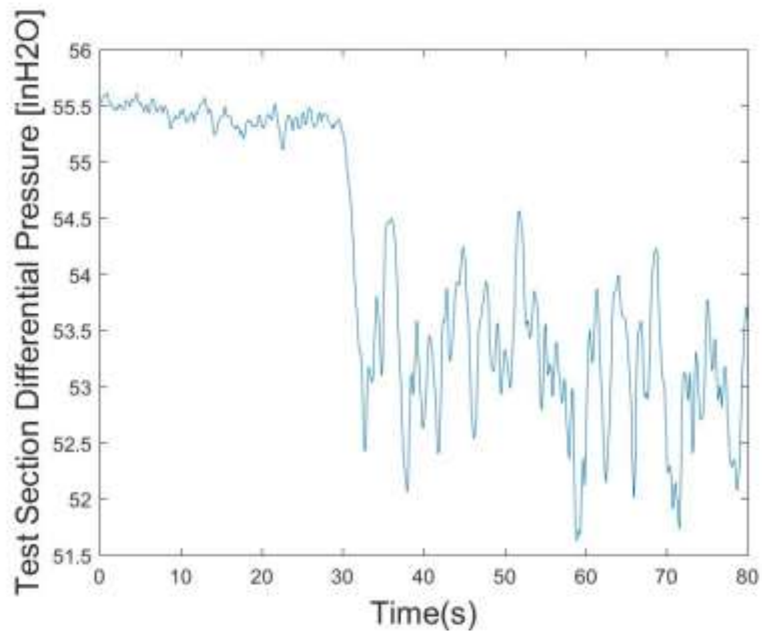

Figure G445: Test section differential pressure for test 2016_06_15_test_01.

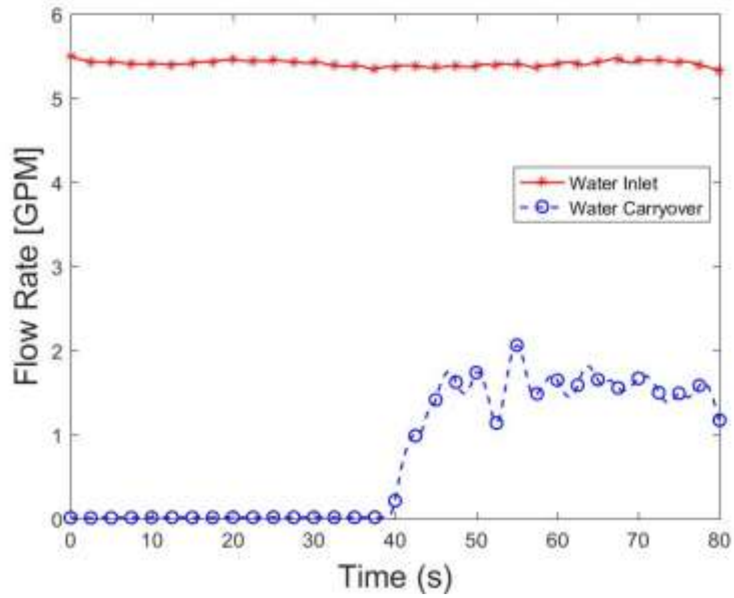

Figure G446: Water flow rates for test 2016_06_15_test_01.

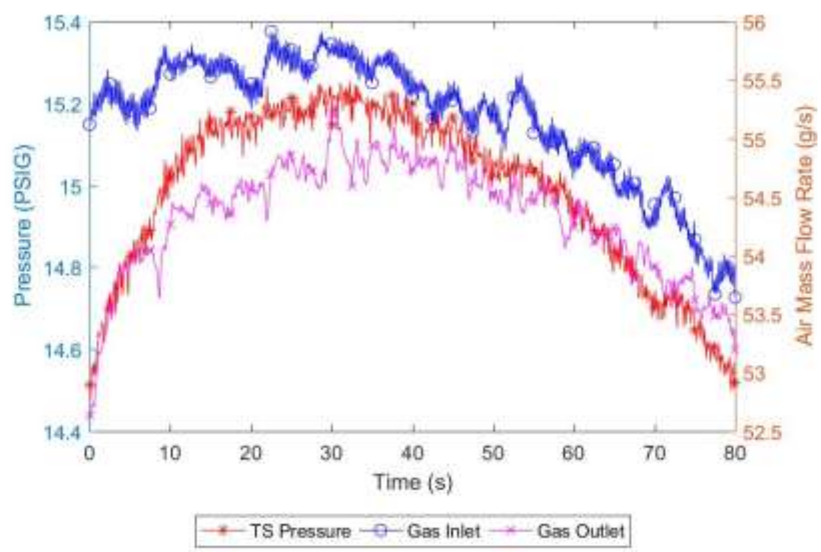

Figure G447: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_02.

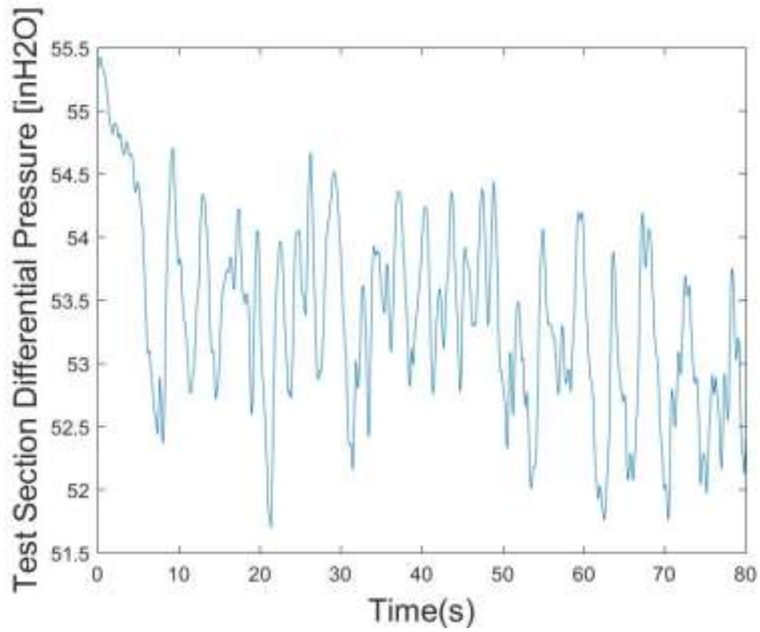

Figure G448: Test section differential pressure for test 2016_06_15_test_02.

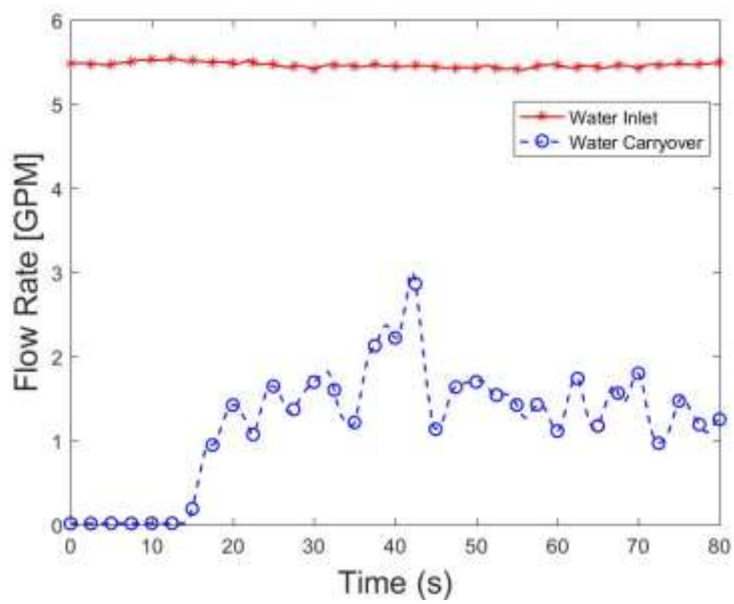

Figure G449: Water flow rates for test 2016_06_15_test_02.

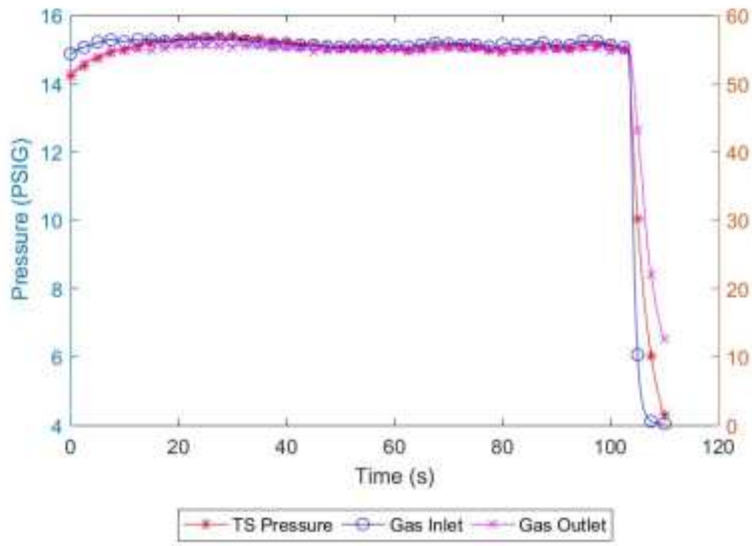

Figure G450: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_03.

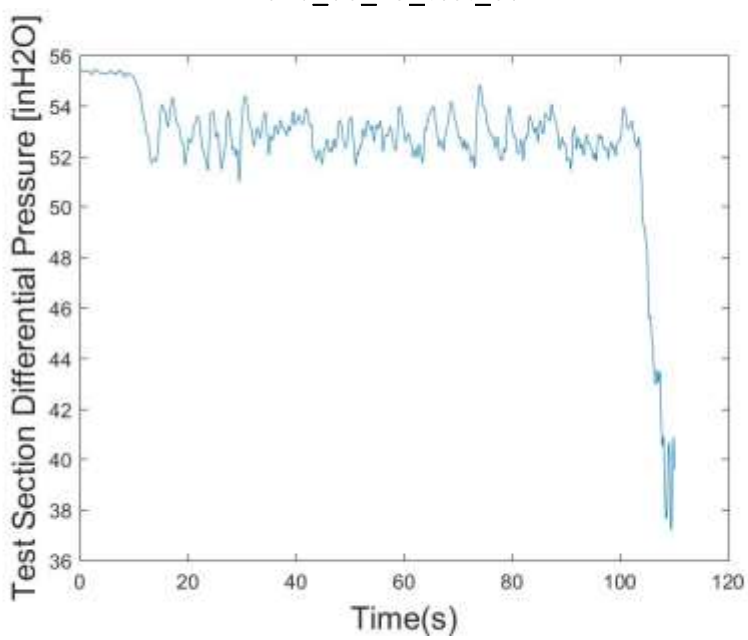

Figure G451: Test section differential pressure for test 2016_06_15_test_03.

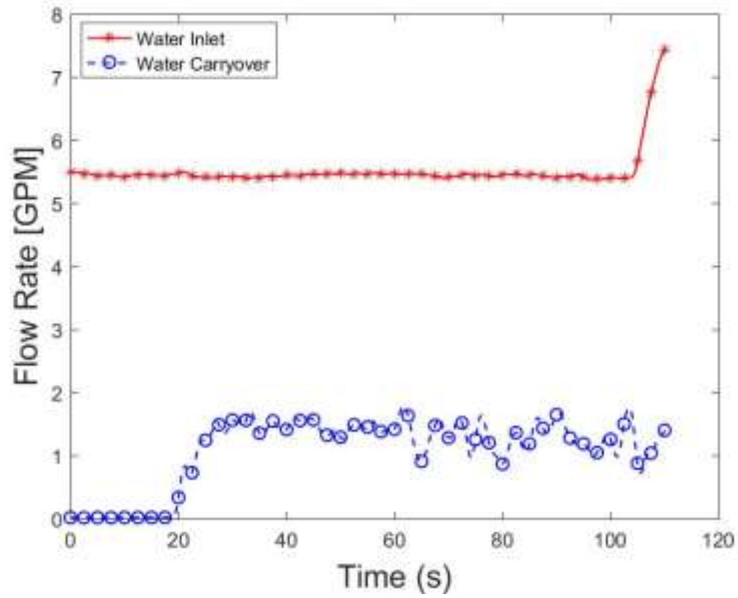

Figure G452: Water flow rates for test 2016_06_15_test_03.

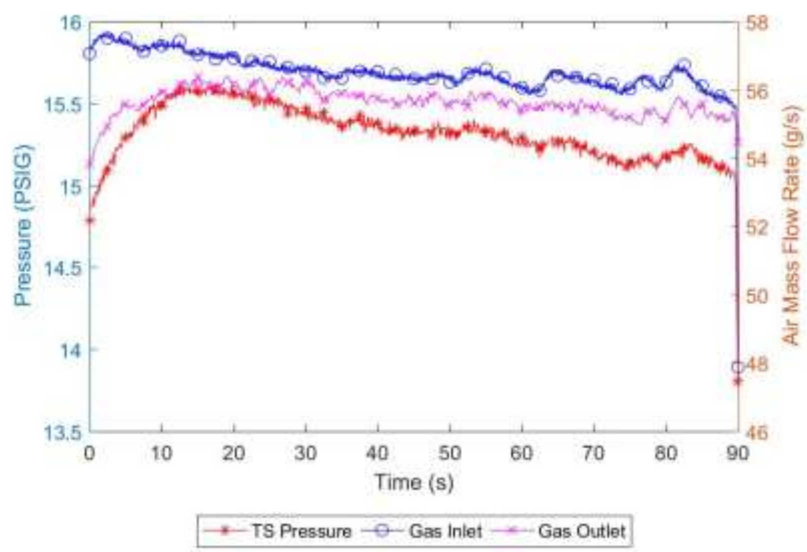

Figure G453: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_04.

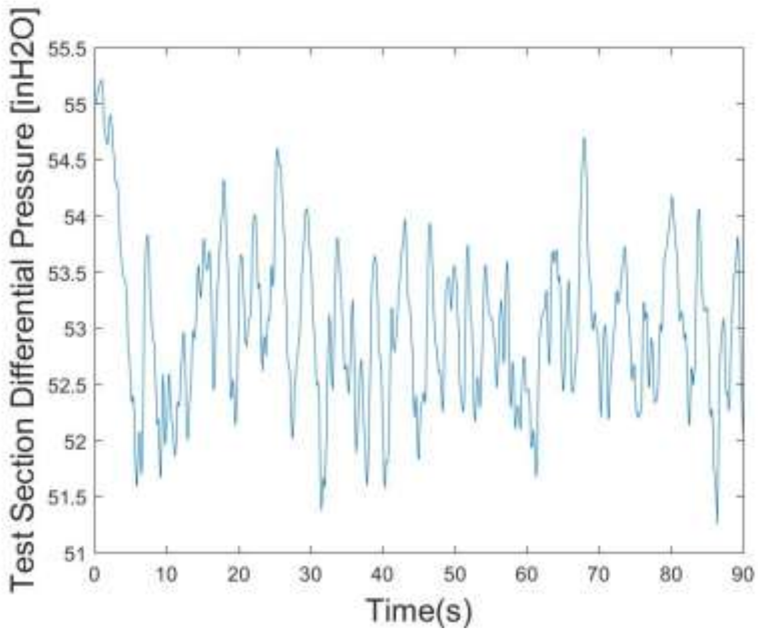

Figure G454: Test section differential pressure for test 2016_06_15_test_04.

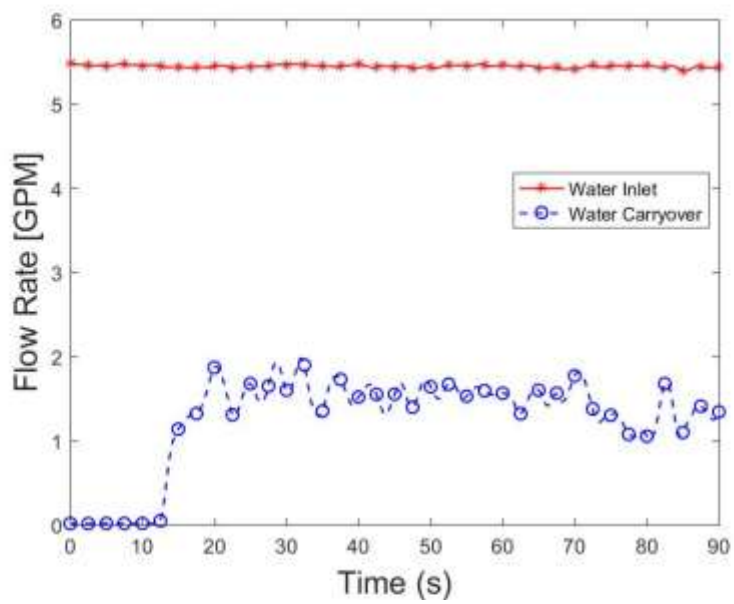

Figure G455: Water flow rates for test 2016_06_15_test_04.

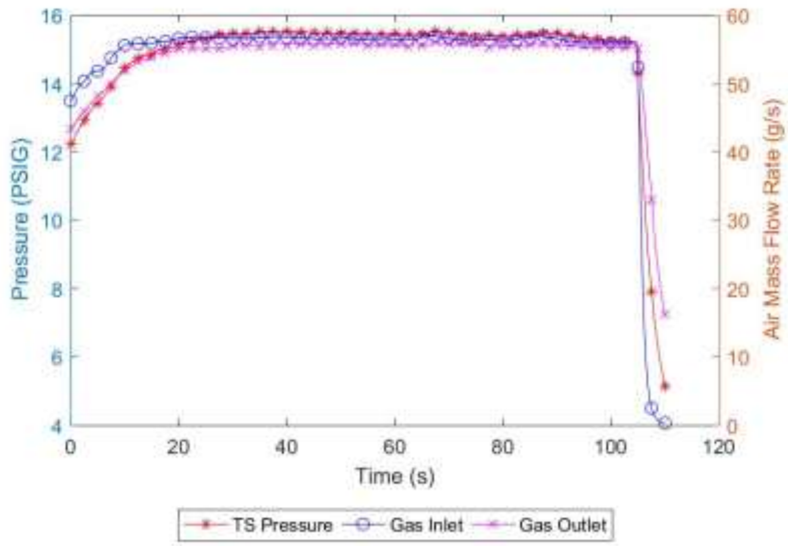

Figure G456: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_05.

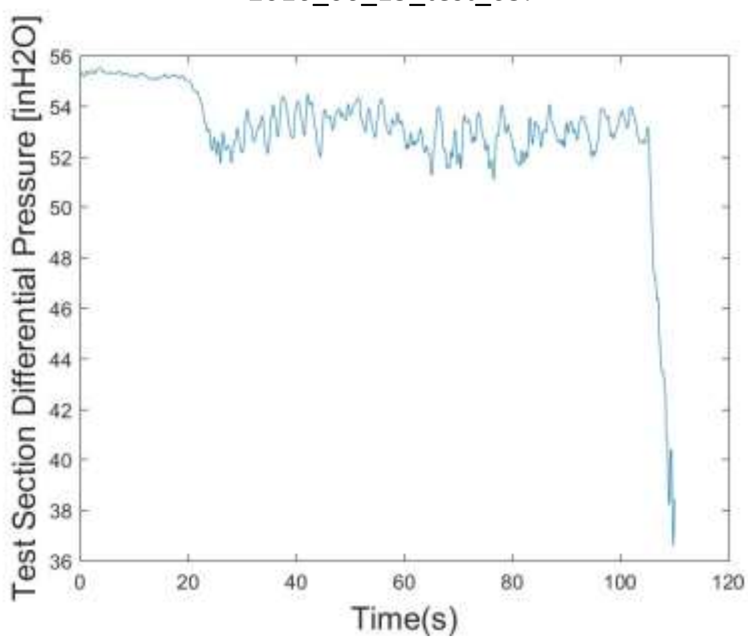

Figure G457: Test section differential pressure for test 2016_06_15_test_05.

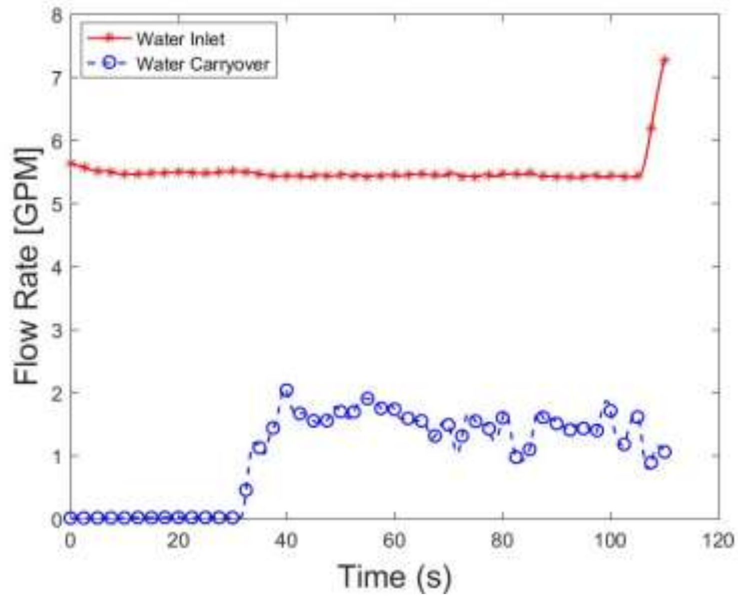

Figure G458: Water flow rates for test 2016_06_15_test_05.

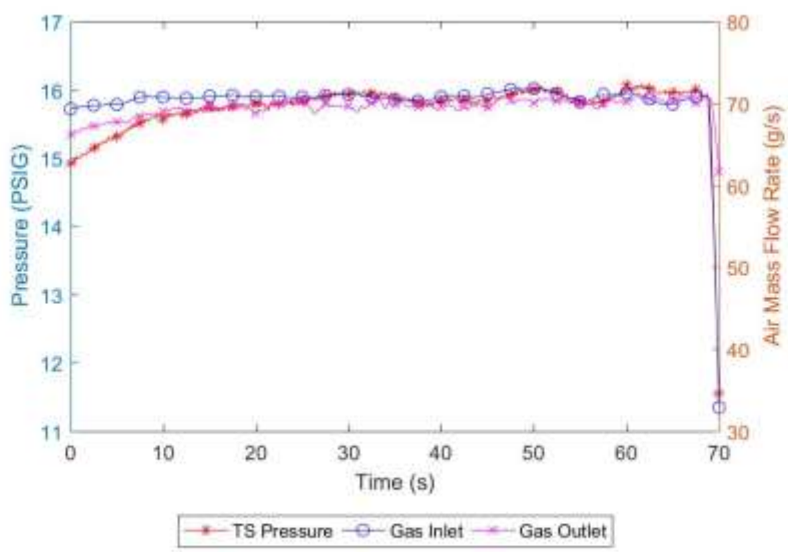

Figure G459: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_06.

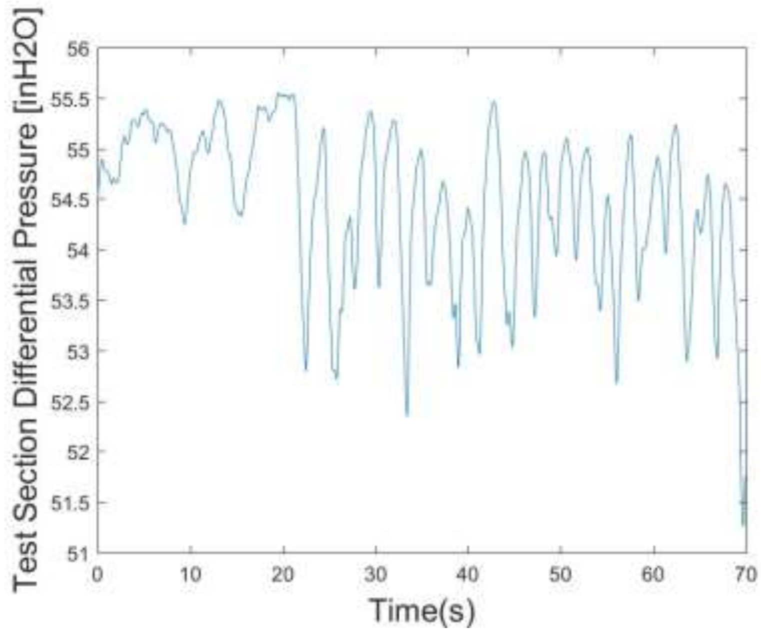

Figure G460: Test section differential pressure for test 2016_06_15_test_06.

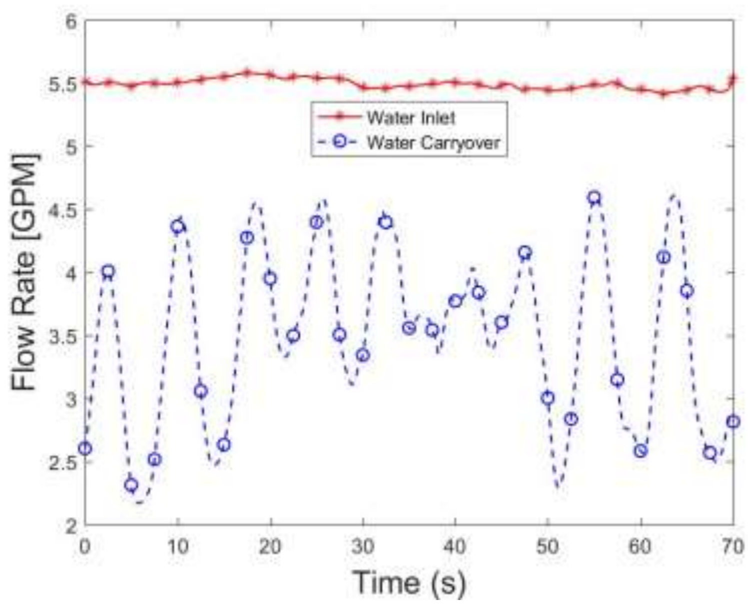

Figure G461: Water flow rates for test 2016_06_15_test_06.

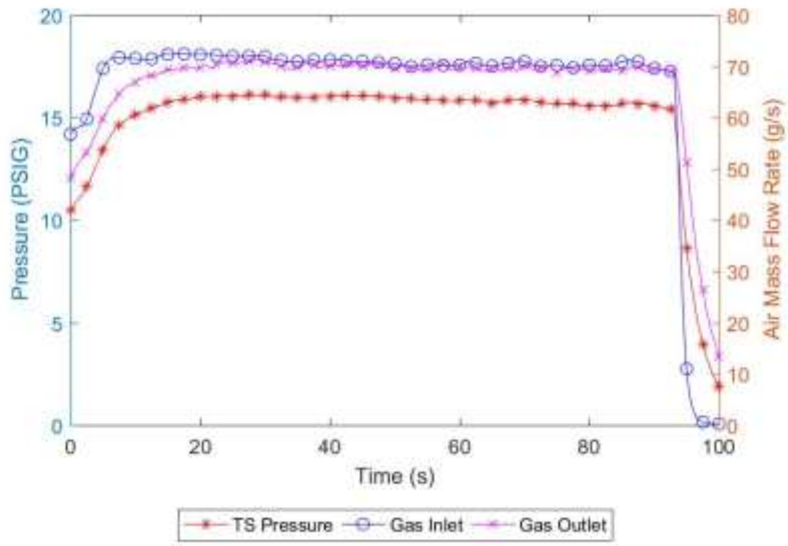

Figure G462: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_07.

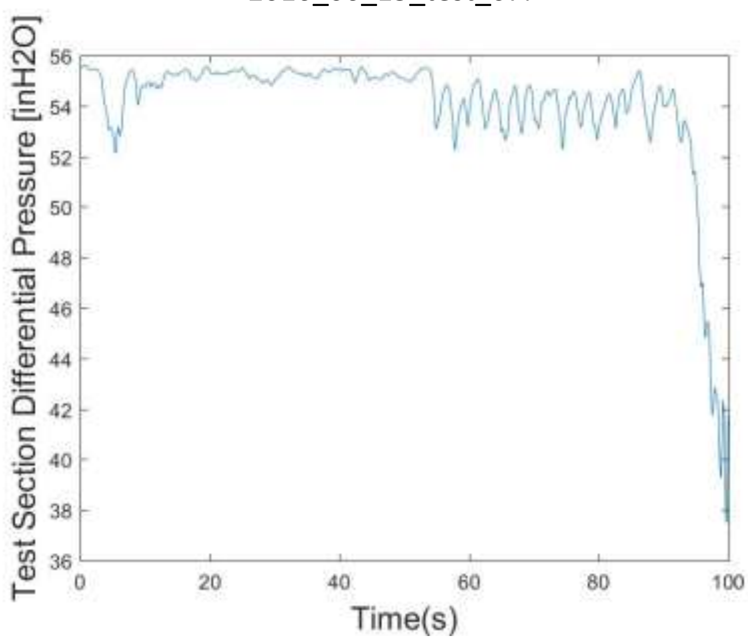

Figure G463: Test section differential pressure for test 2016_06_15_test_07.

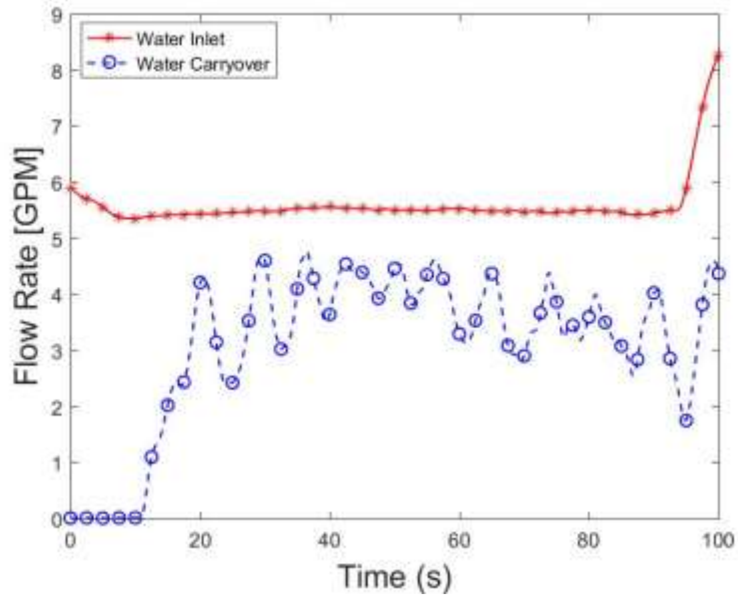

Figure G464: Water flow rates for test 2016_06_15_test_07.

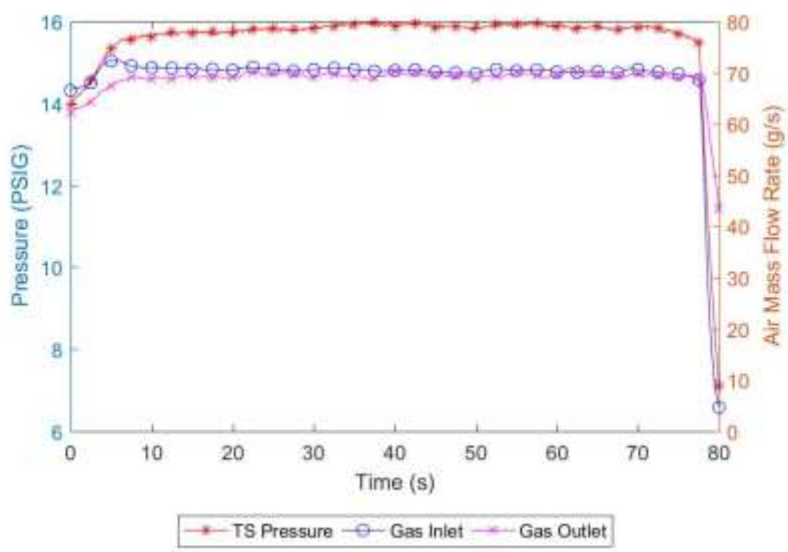

Figure G465: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_08.

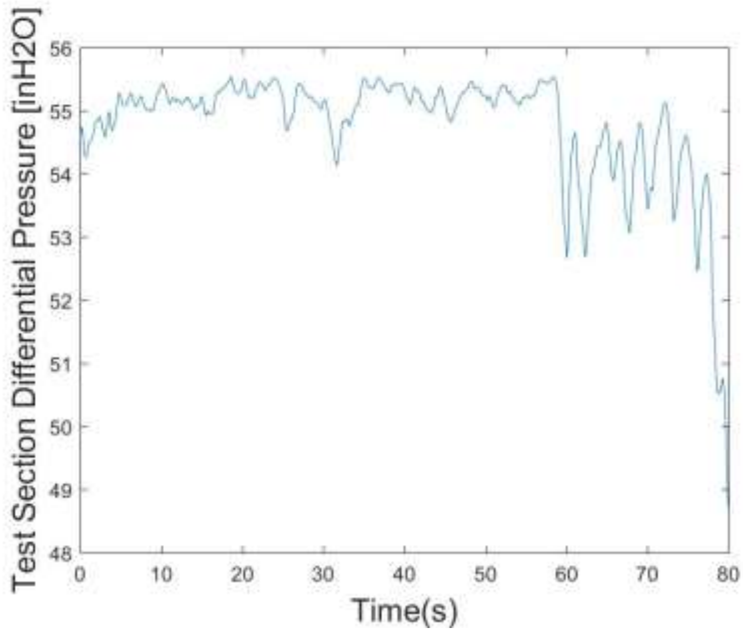

Figure G466: Test section differential pressure for test 2016_06_15_test_08.

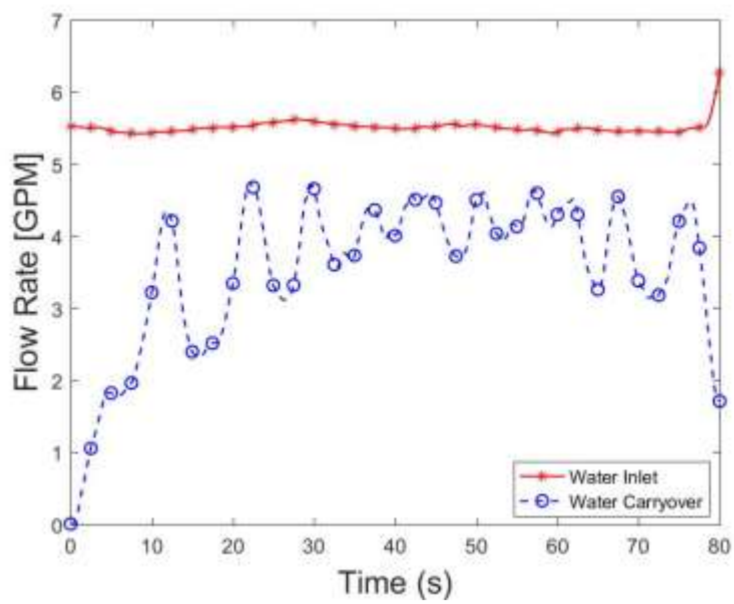

Figure G467: Water flow rates for test 2016_06_15_test_08.

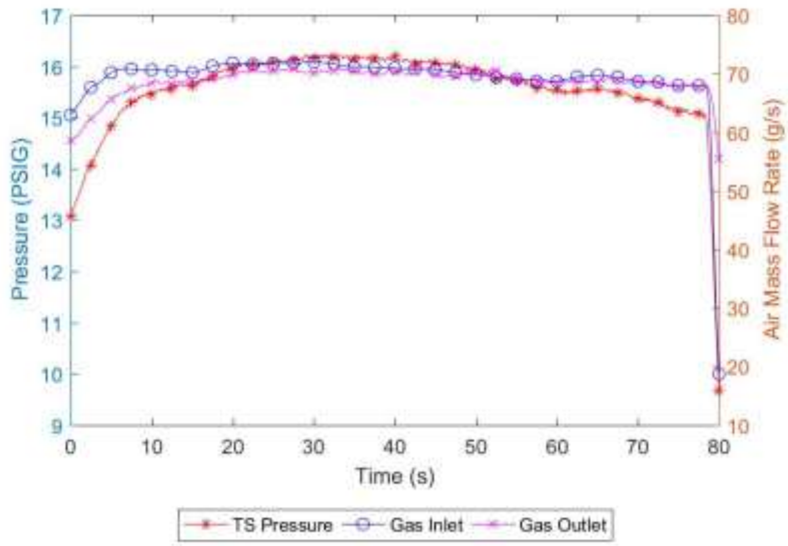

Figure G468: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_09.

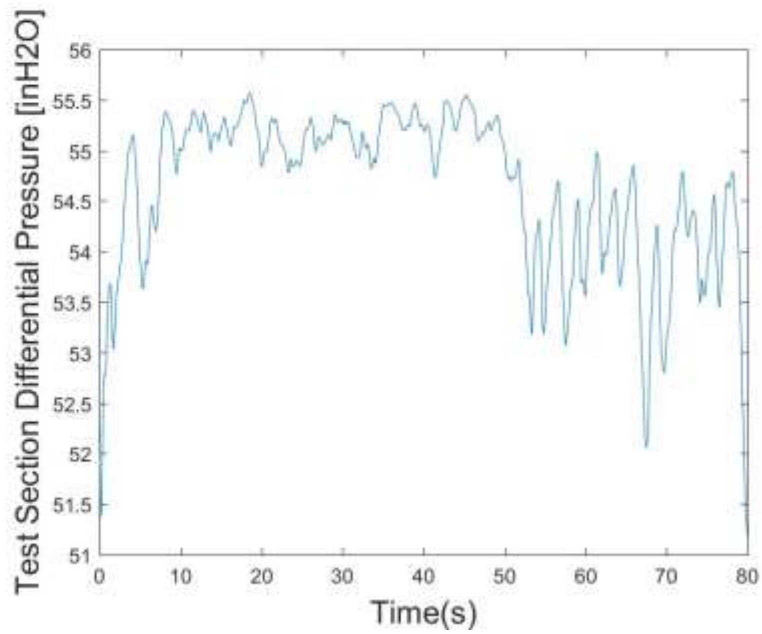

Figure G469: Test section differential pressure for test 2016_06_15_test_09.

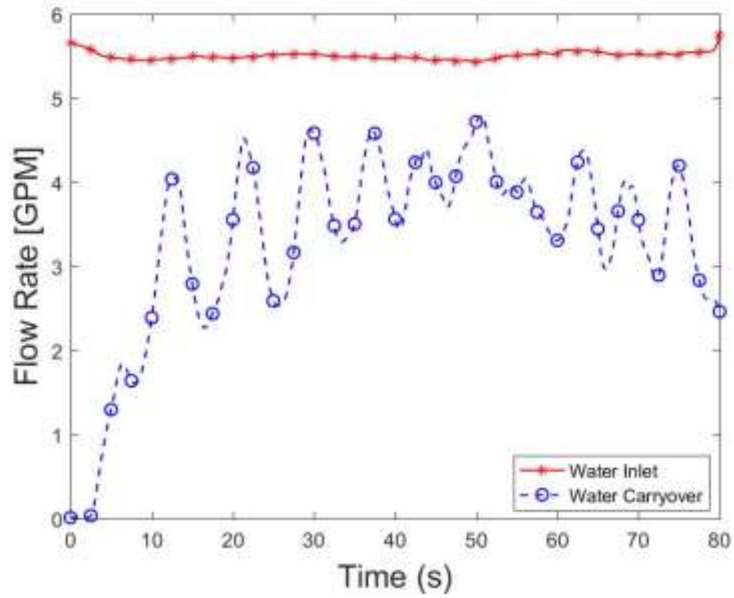

Figure G470: Water flow rates for test 2016_06_15_test_09.

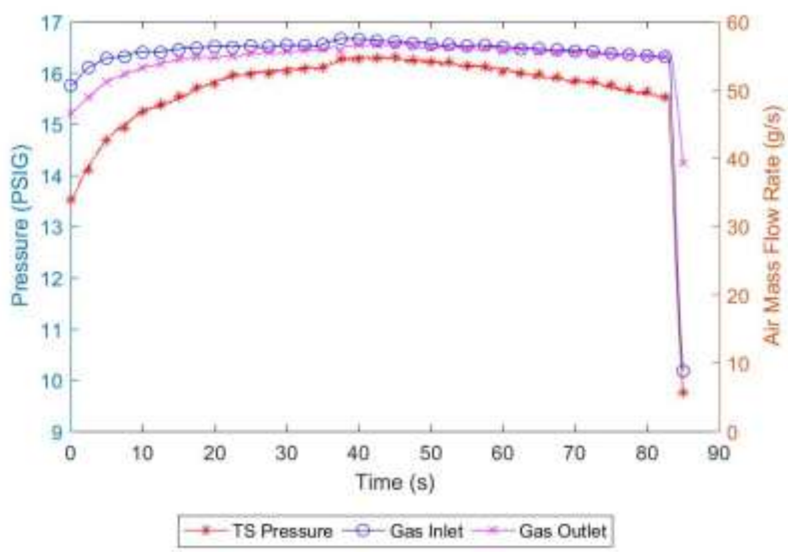

Figure G471: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_13.

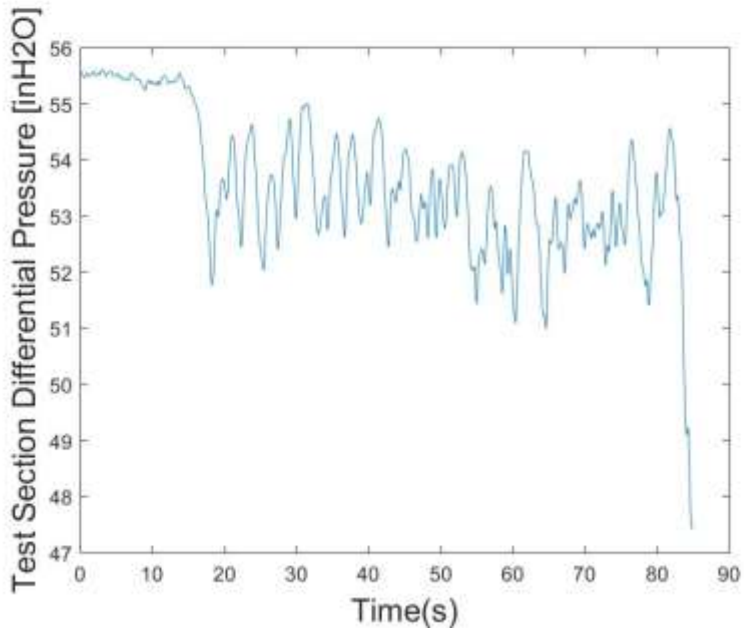

Figure G472: Test section differential pressure for test 2016_06_15_test_13.

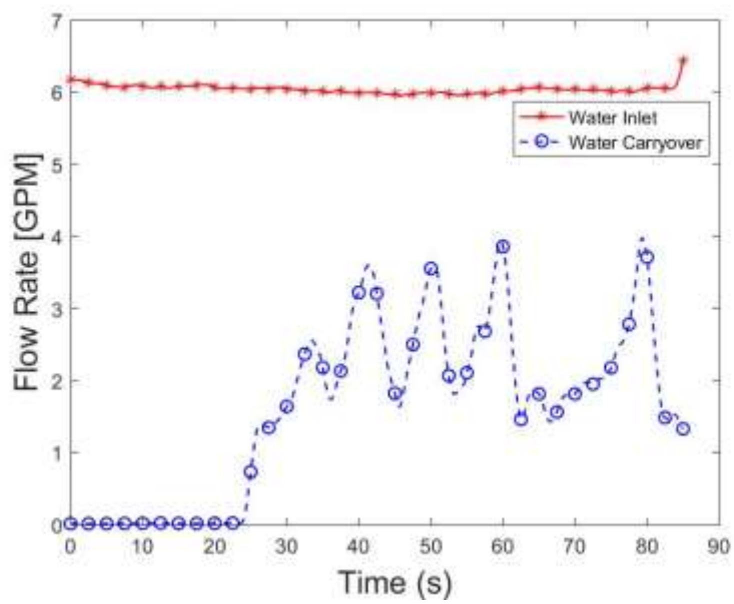

Figure G473: Water flow rates for test 2016_06_15_test_13.

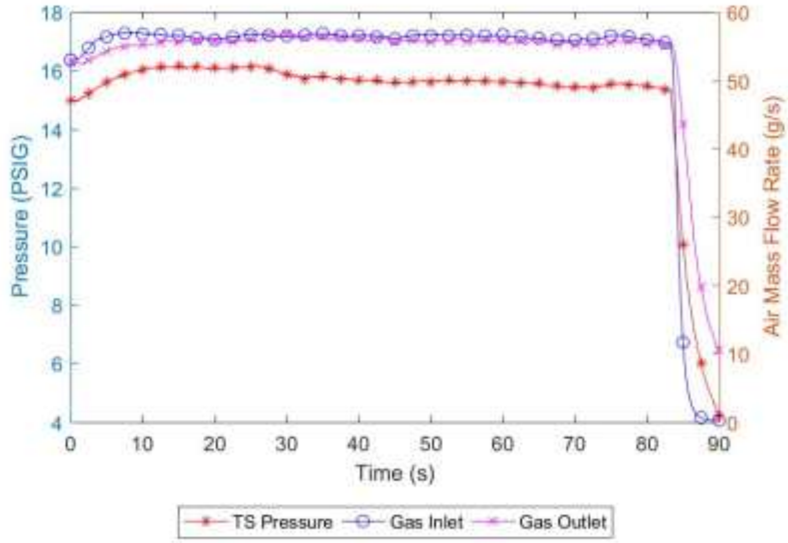

Figure G474: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_14.

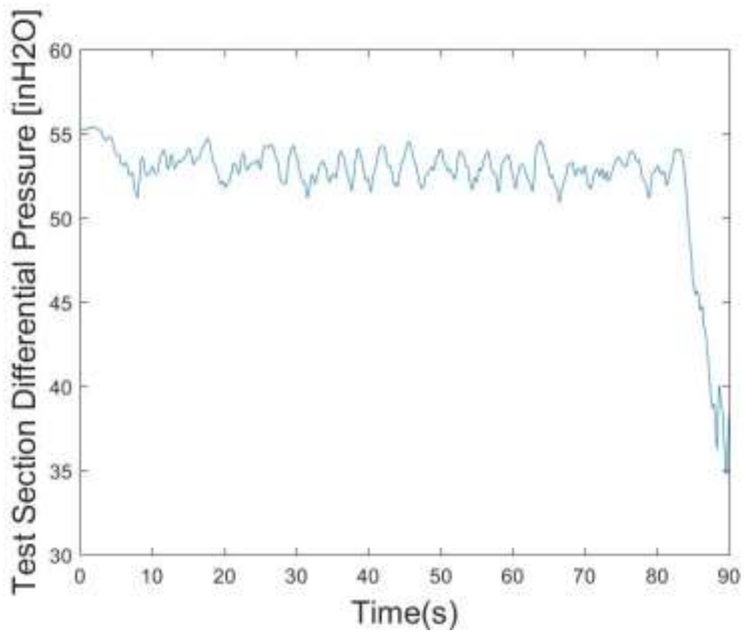

Figure G475: Test section differential pressure for test 2016_06_15_test_14.

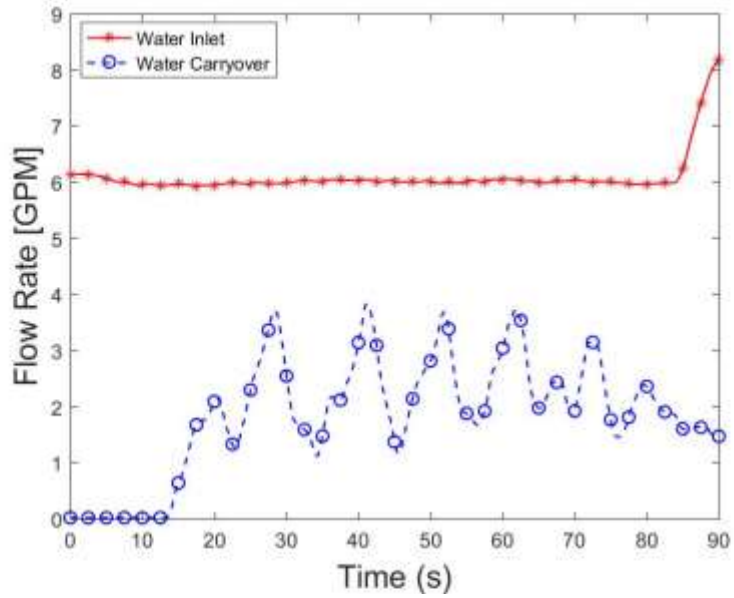

Figure G476: Water flow rates for test 2016_06_15_test_14.

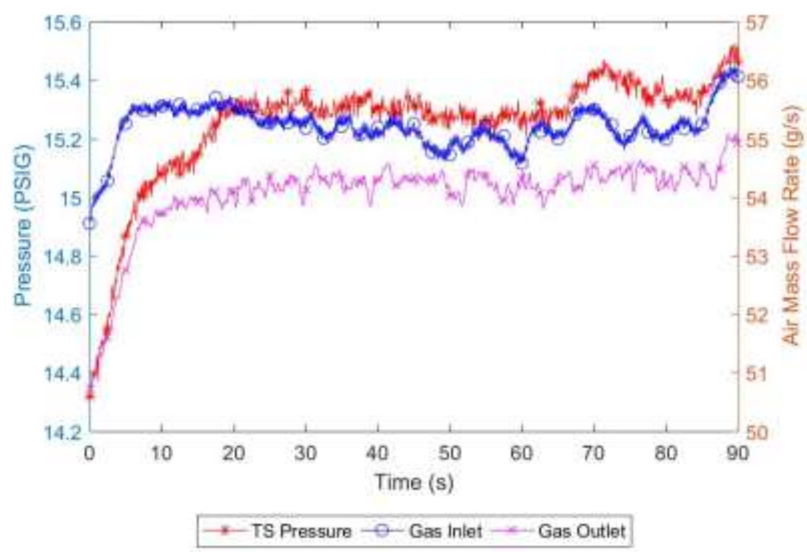

Figure G477: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_15.

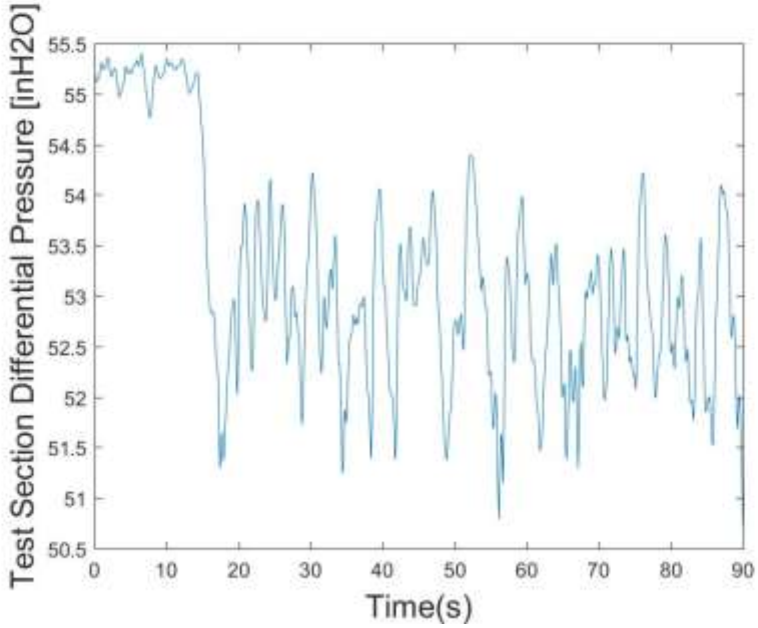

Figure G478: Test section differential pressure for test 2016_06_15_test_15.

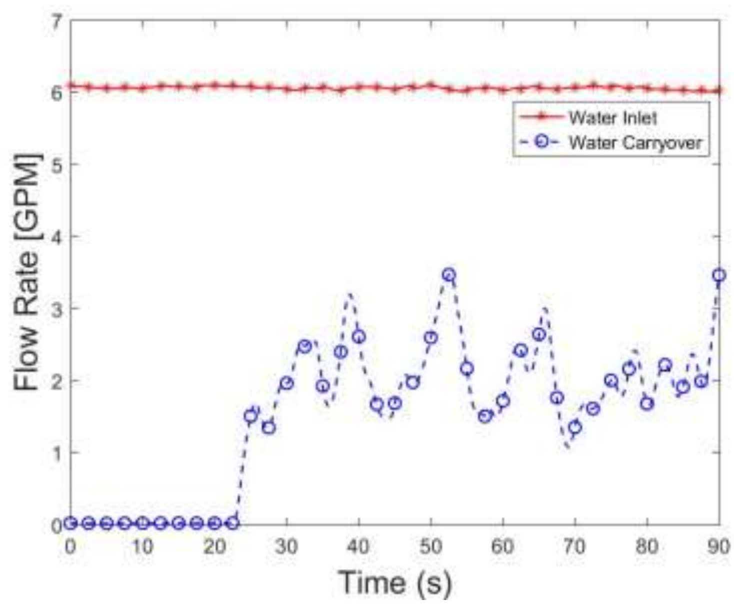

Figure G479: Water flow rates for test 2016_06_15_test_15.

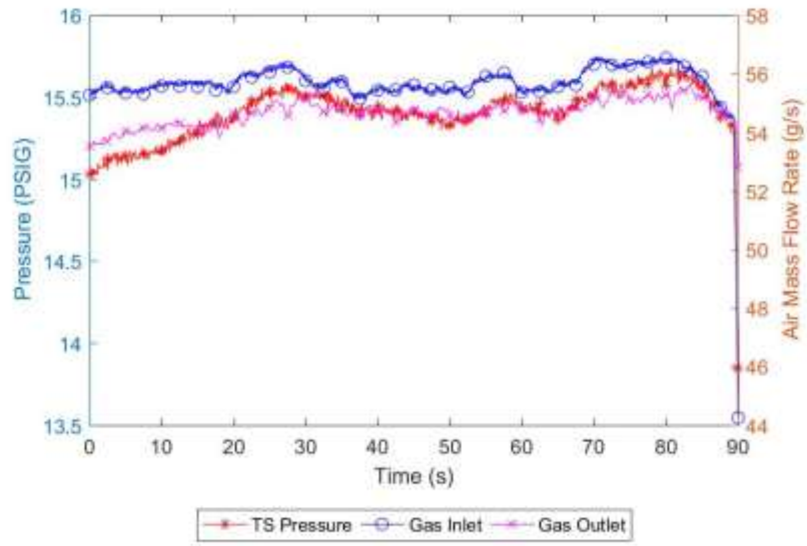

Figure G480: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_16.

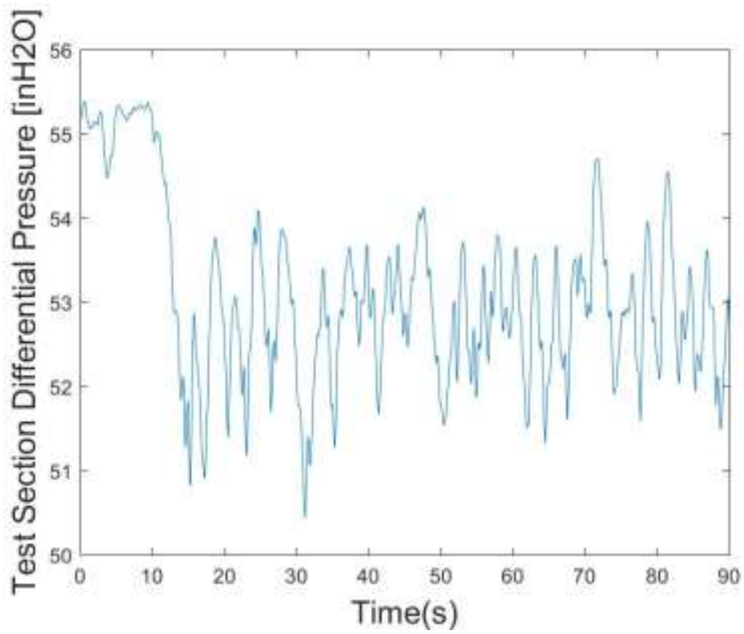

Figure G481: Test section differential pressure for test 2016_06_15_test_16.

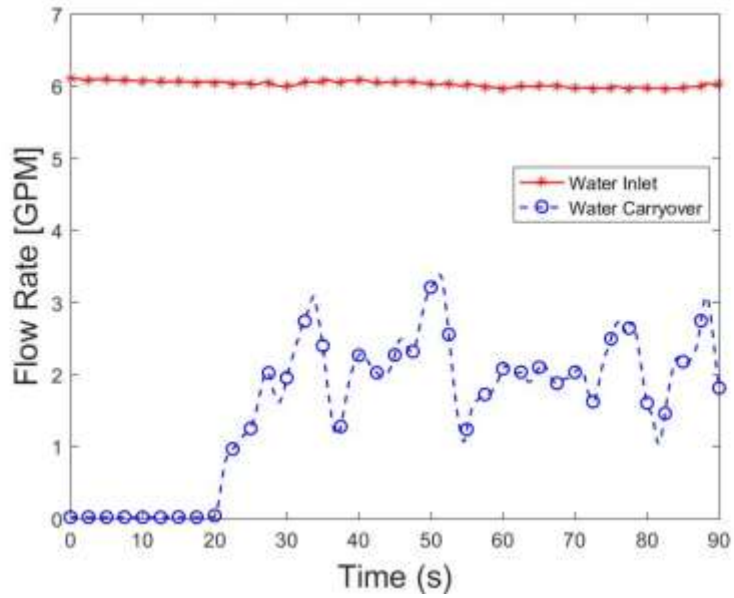

Figure G482: Water flow rates for test 2016_06_15_test_16.

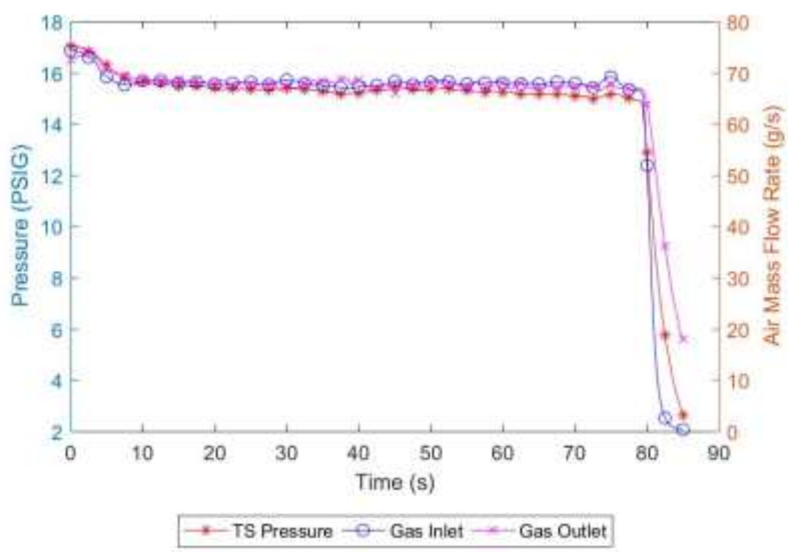

Figure G483: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_17.

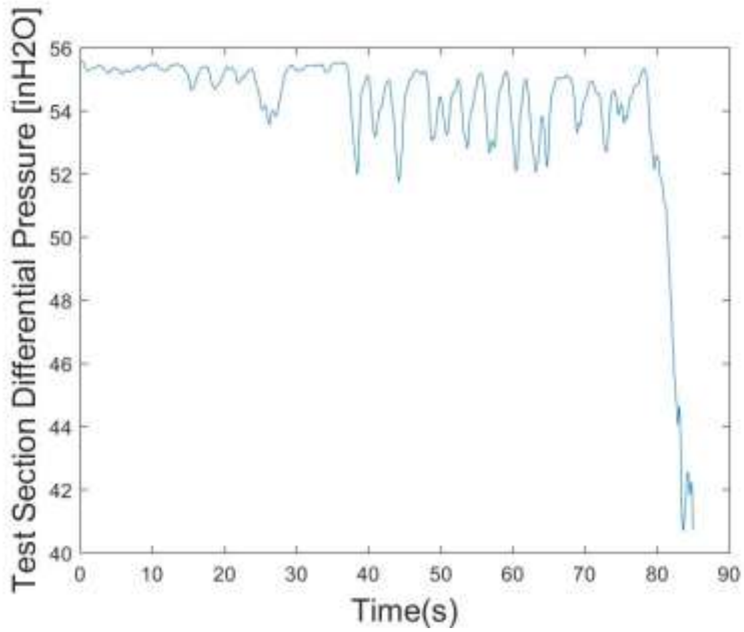

Figure G484: Test section differential pressure for test 2016_06_15_test_17.

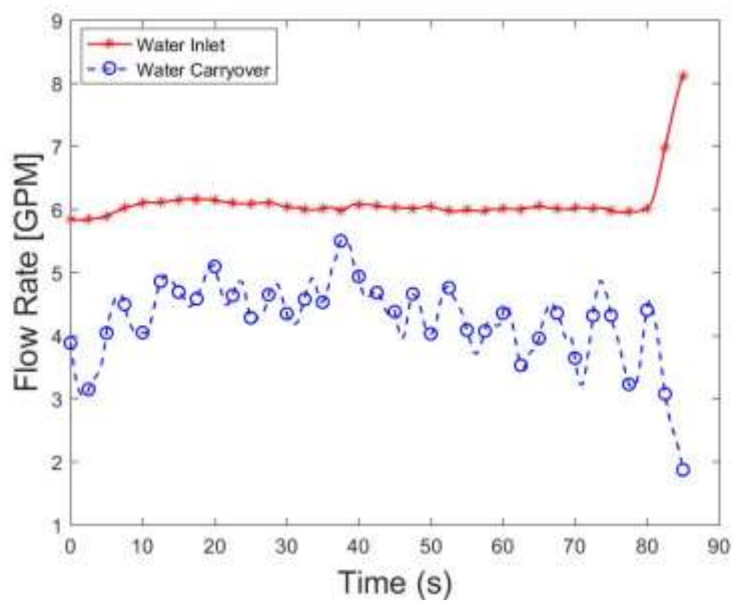

Figure G485: Water flow rates for test 2016_06_15_test_17.

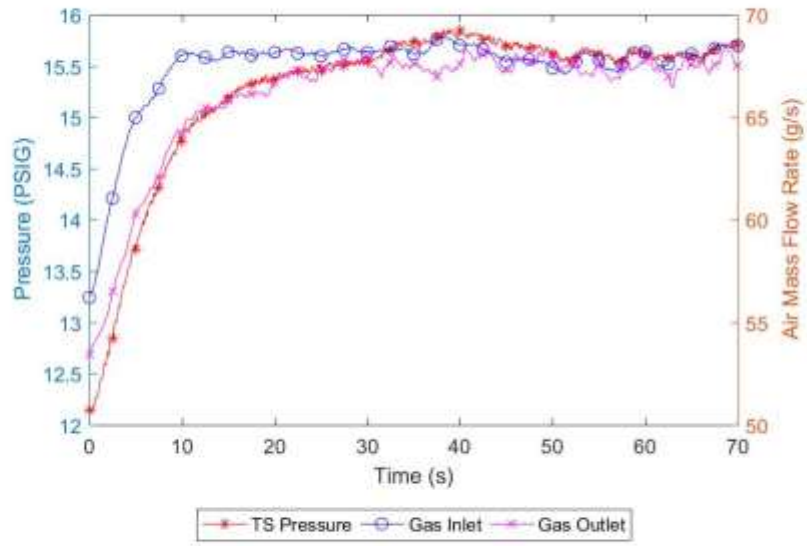

Figure G486: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_19.

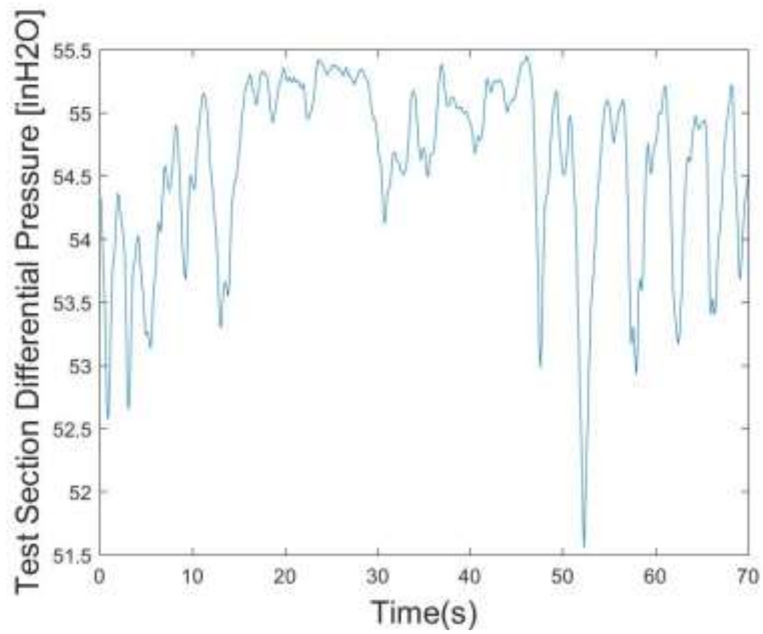

Figure G487: Test section differential pressure for test 2016_06_15_test_19.

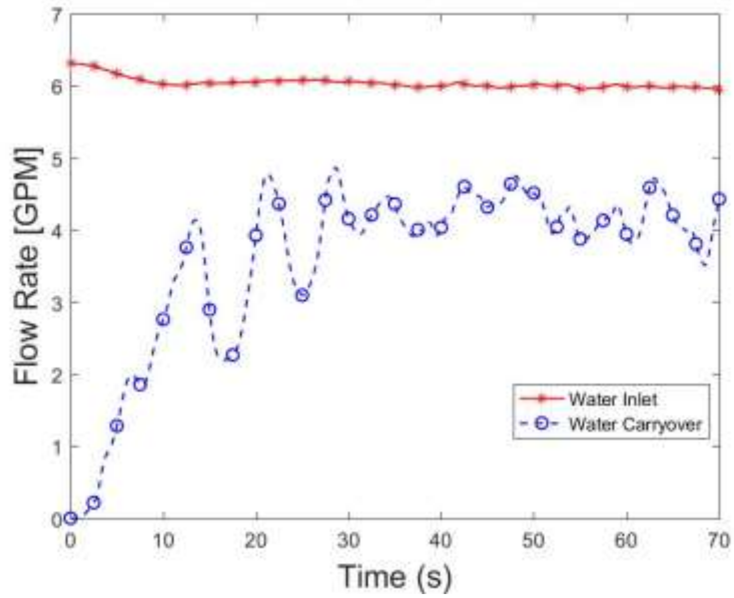

Figure G488: Water flow rates for test 2016_06_15_test_19.

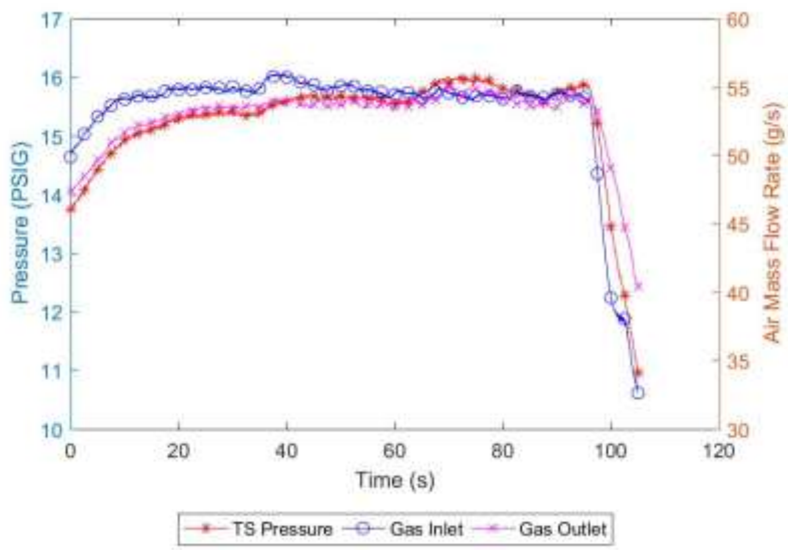

Figure G489: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_21.

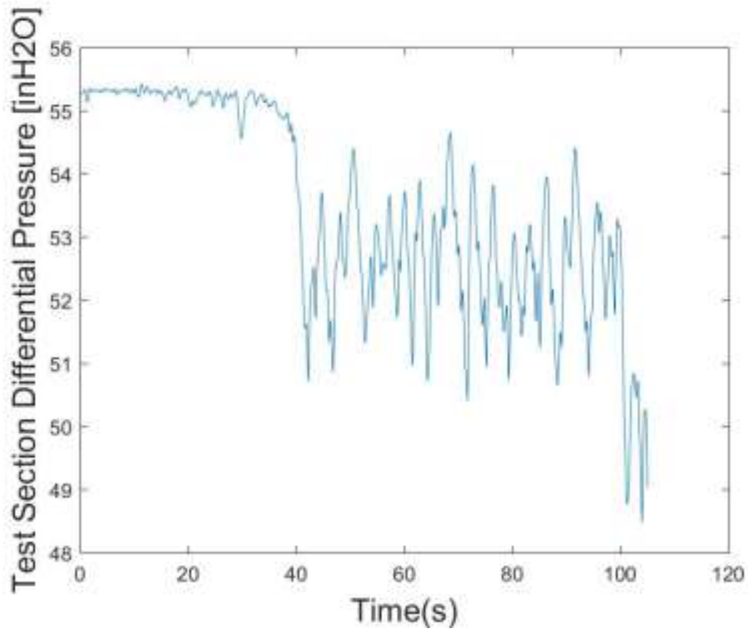

Figure G490: Test section differential pressure for test 2016_06_15_test_21.

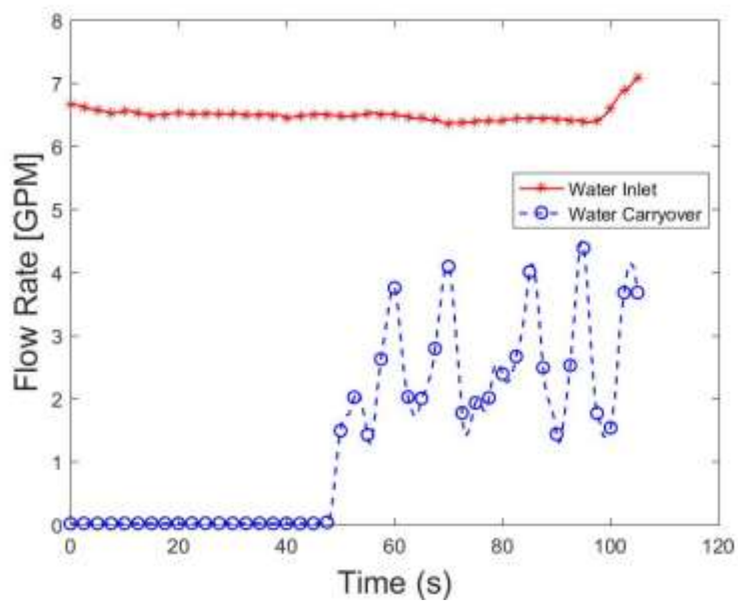

Figure G491: Water flow rates for test 2016_06_15_test_21.

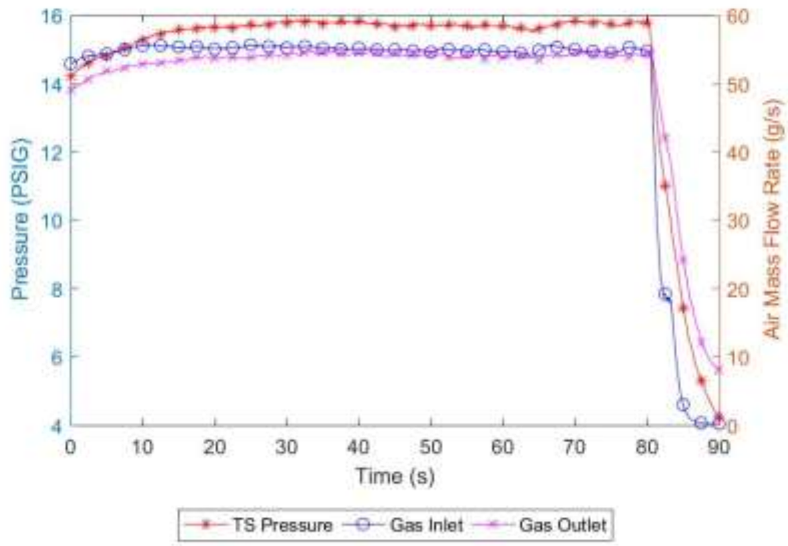

Figure G492: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_22.

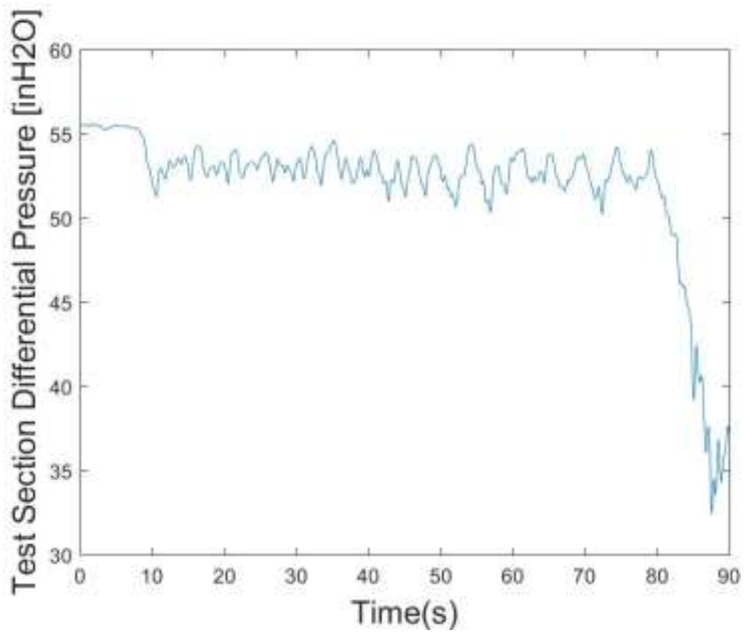

Figure G493: Test section differential pressure for test 2016_06_15_test_22.

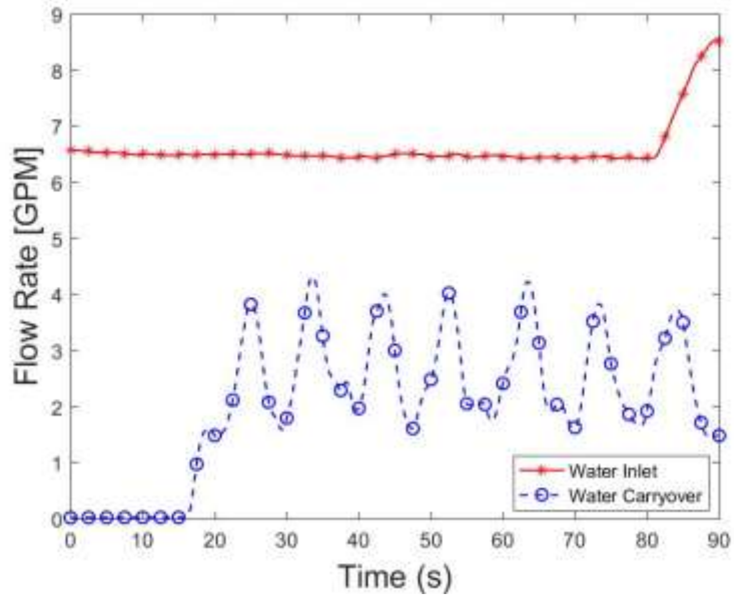

Figure G494: Water flow rates for test 2016_06_15_test_22.

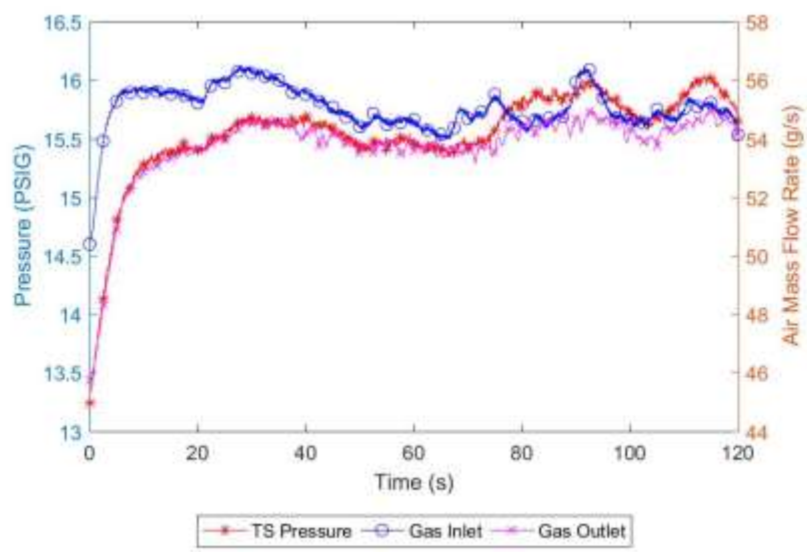

Figure G495: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_23.

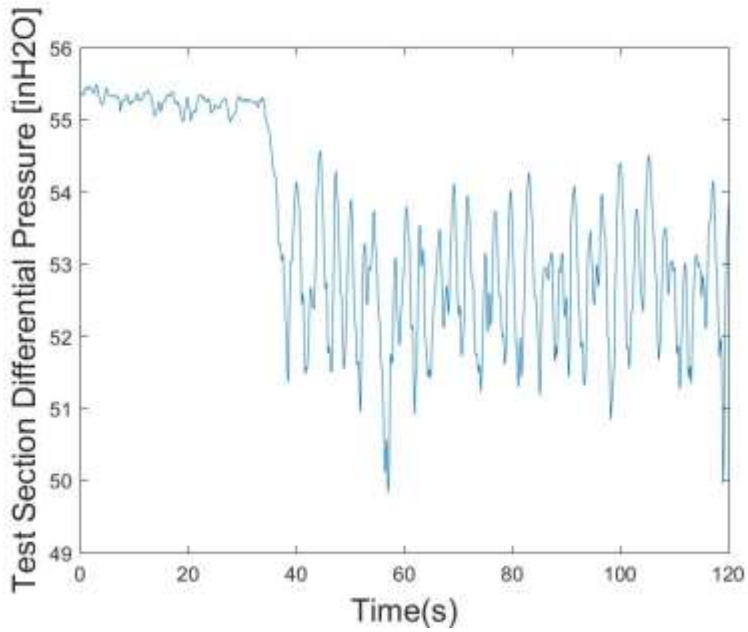

Figure G496: Test section differential pressure for test 2016_06_15_test_23.

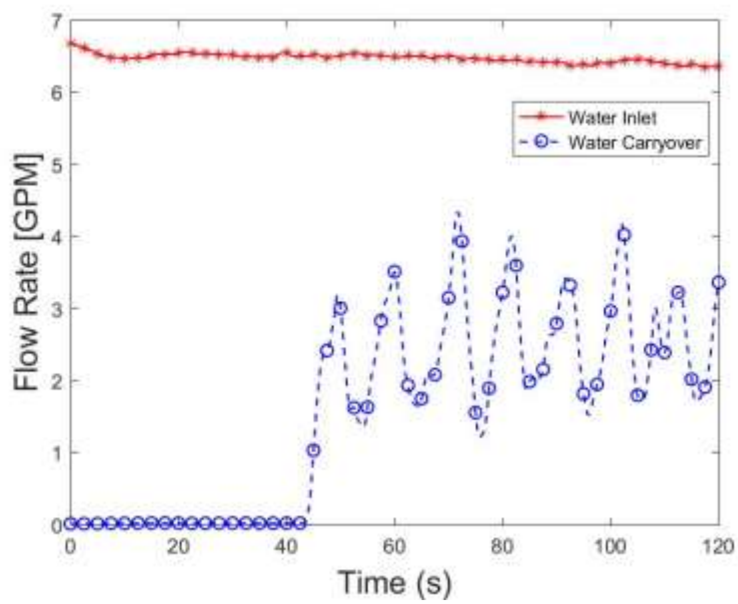

Figure G497: Water flow rates for test 2016_06_15_test_23.

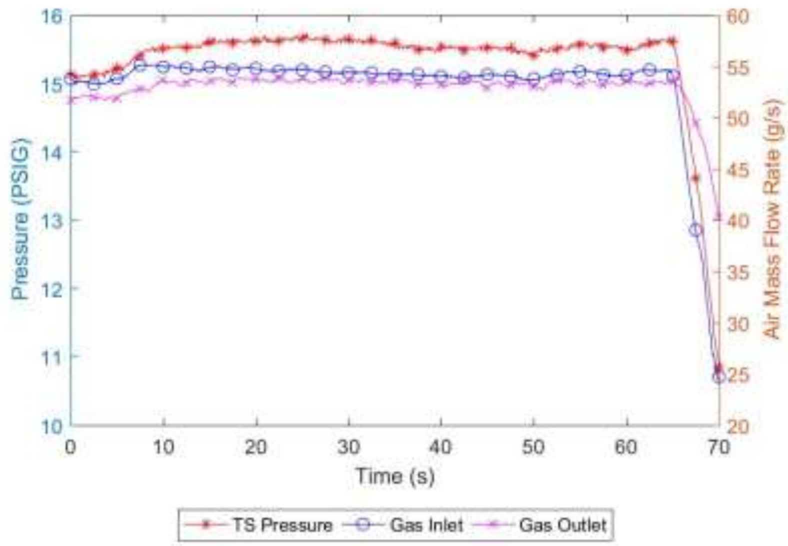

Figure G498: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_25.

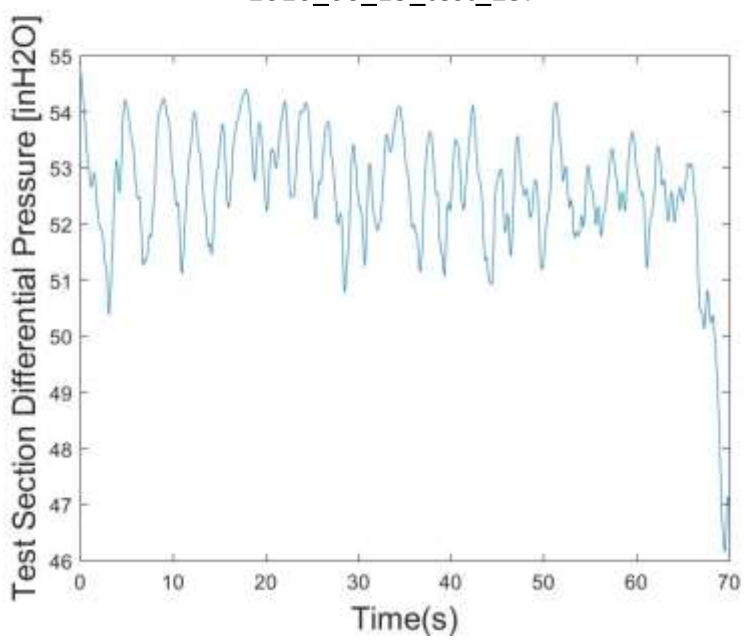

Figure G499: Test section differential pressure for test 2016_06_15_test_25.

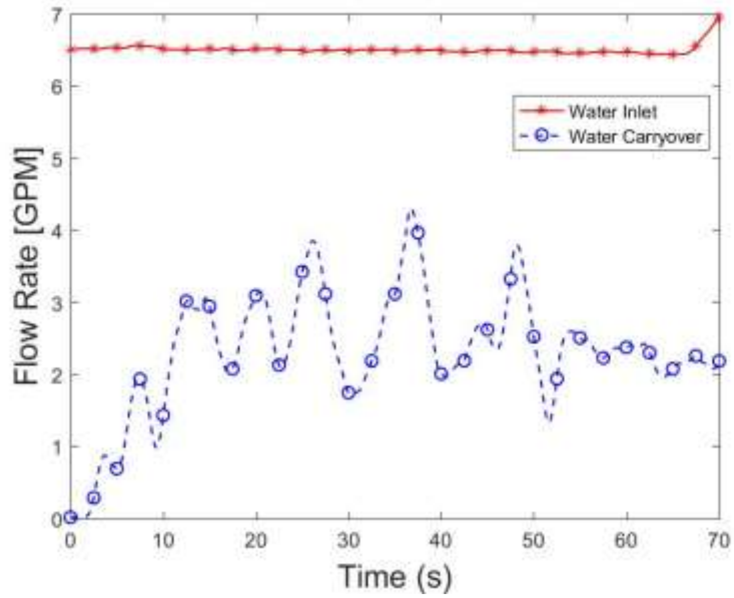

Figure G500: Water flow rates for test 2016_06_15_test_25.

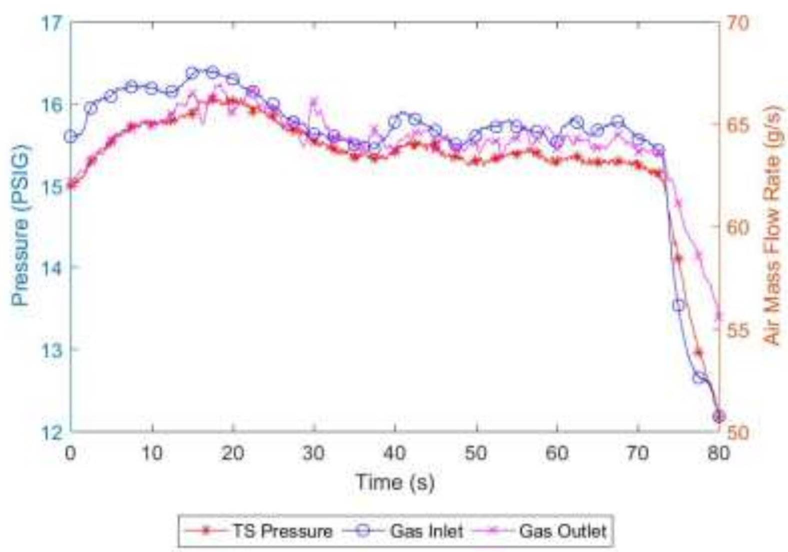

Figure G501: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_26.

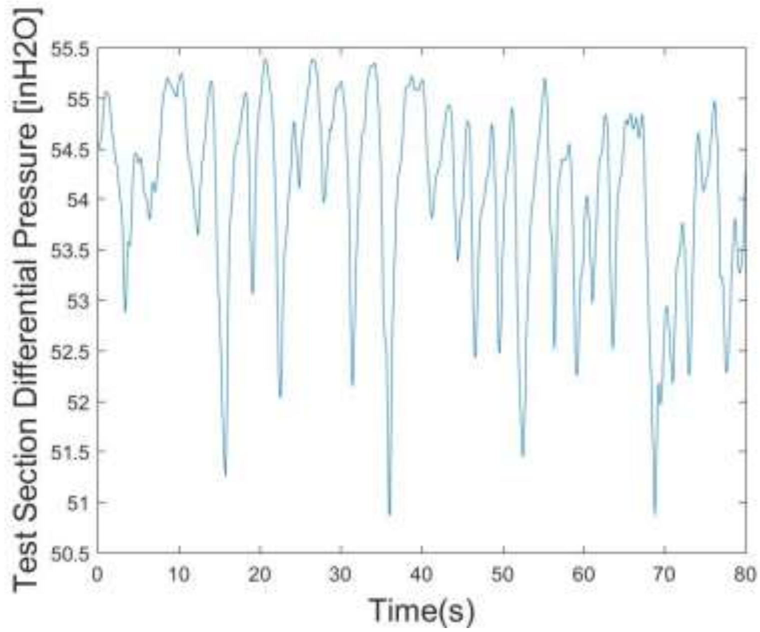

Figure G502: Test section differential pressure for test 2016_06_15_test_26.

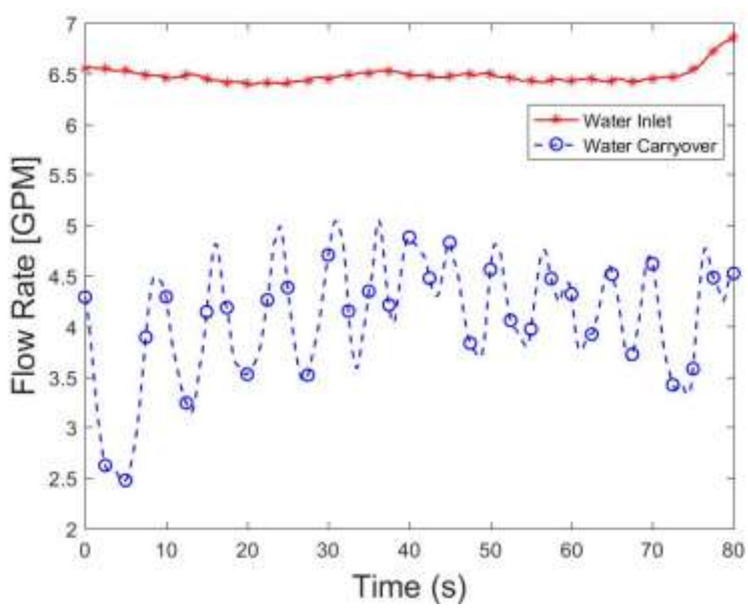

Figure G503: Water flow rates for test 2016_06_15_test_26.

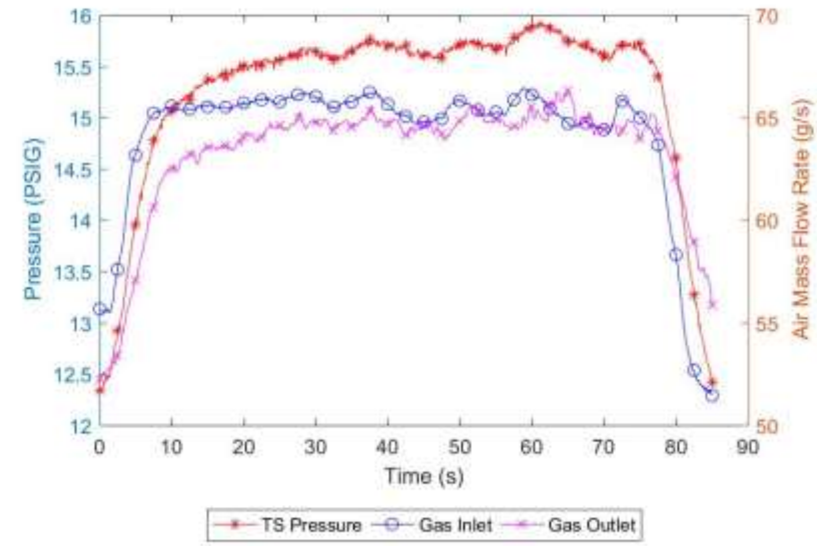

Figure G504: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_27.

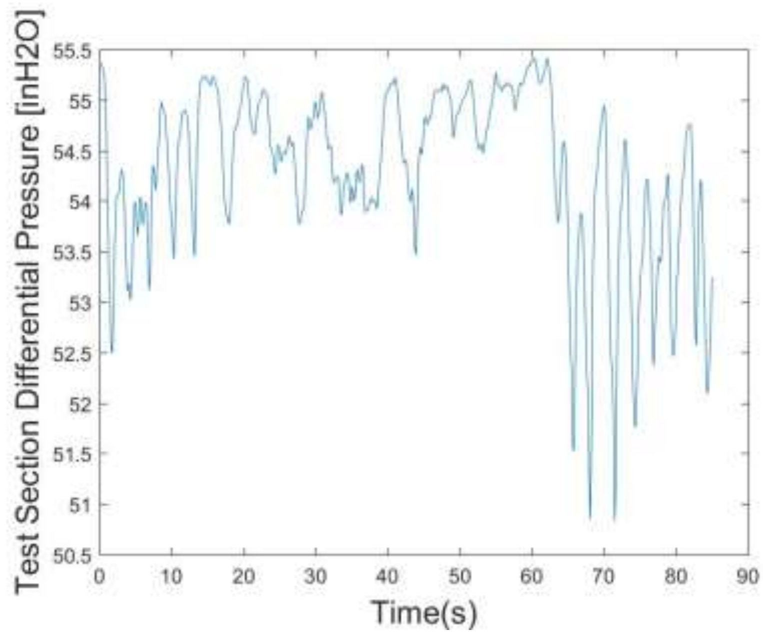

Figure G505: Test section differential pressure for test 2016_06_15_test_27.

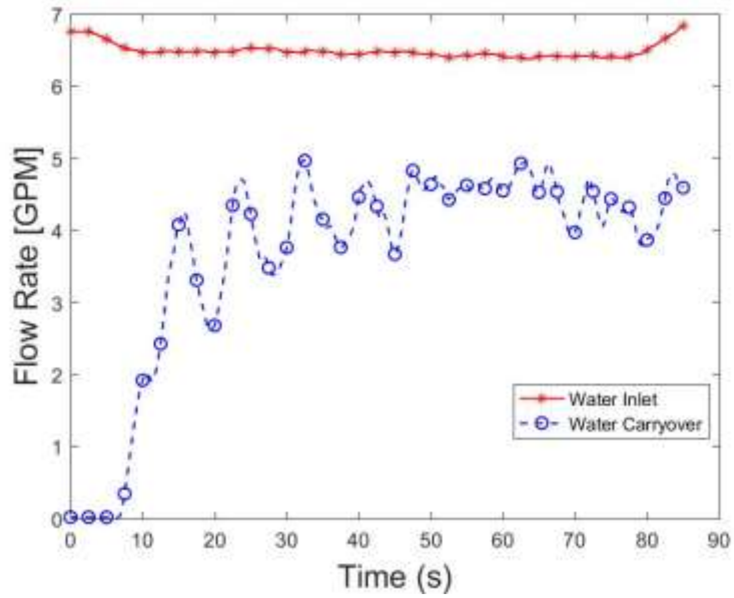

Figure G506: Water flow rates for test 2016_06_15_test_27.

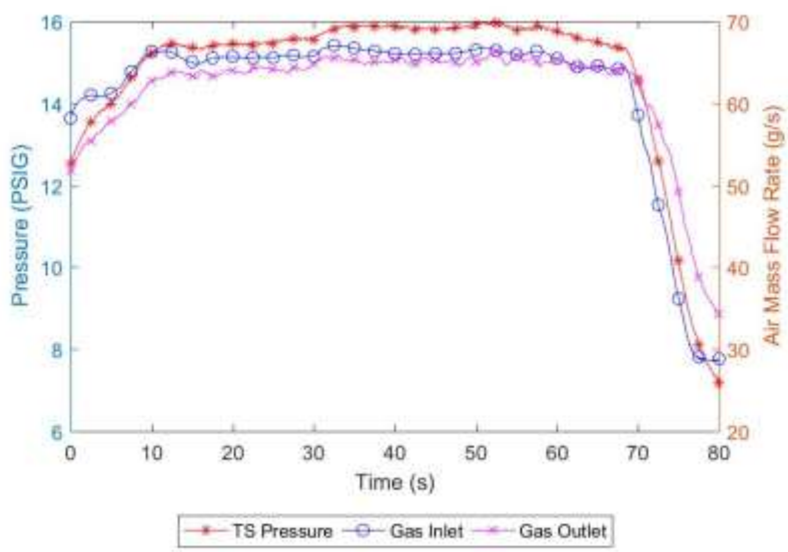

Figure G507: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_28.

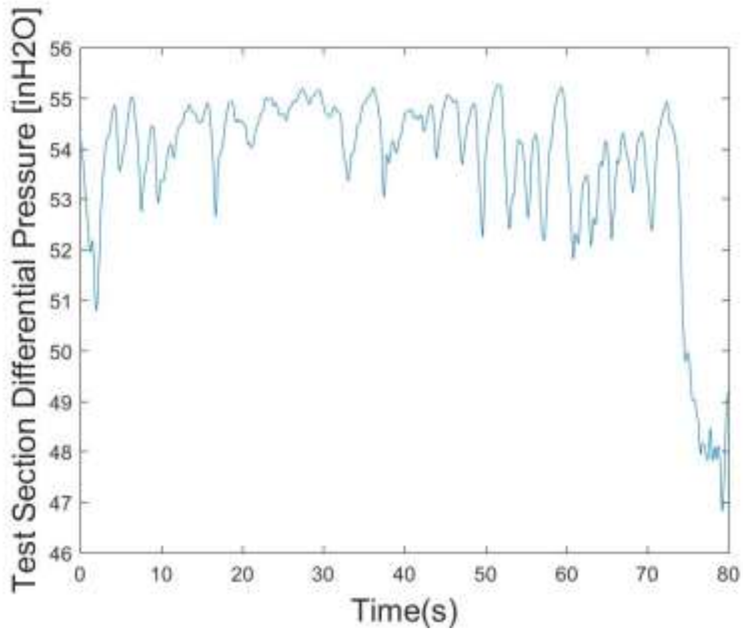

Figure G508: Test section differential pressure for test 2016_06_15_test_28.

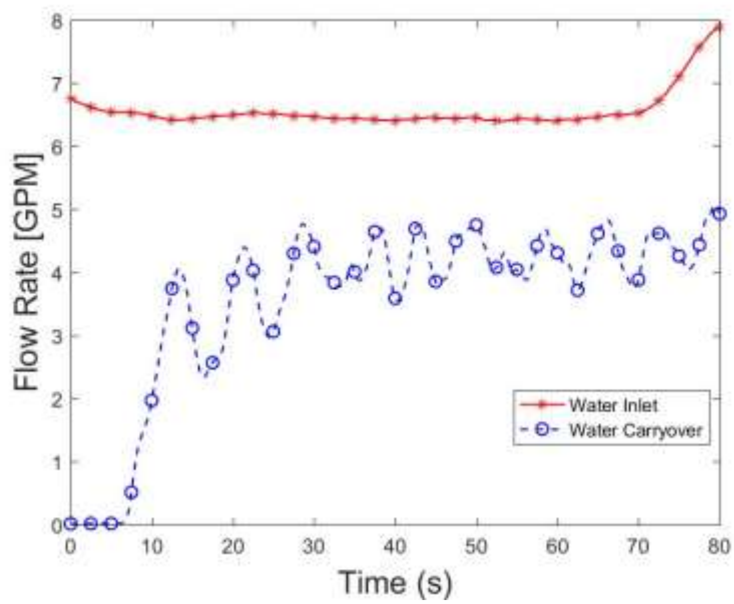

Figure G509: Water flow rates for test 2016_06_15_test_28.

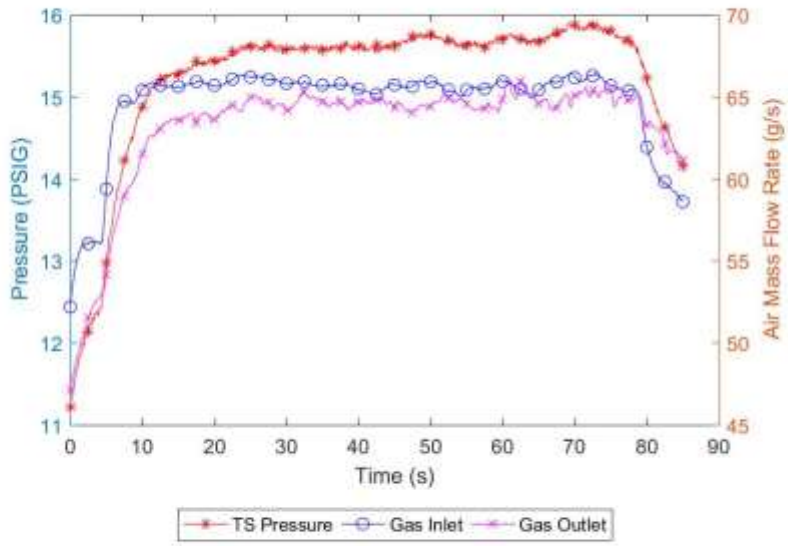

Figure G510: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_29.

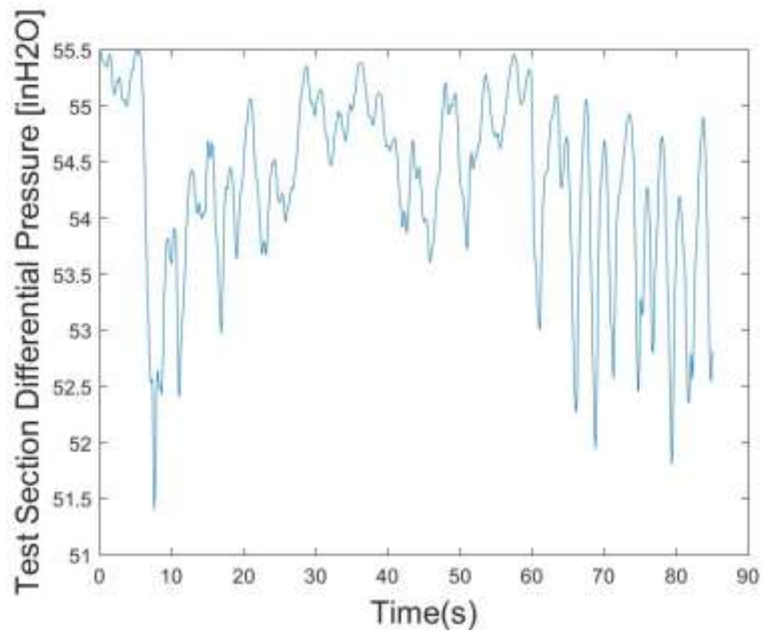

Figure G511: Test section differential pressure for test 2016_06_15_test_29.

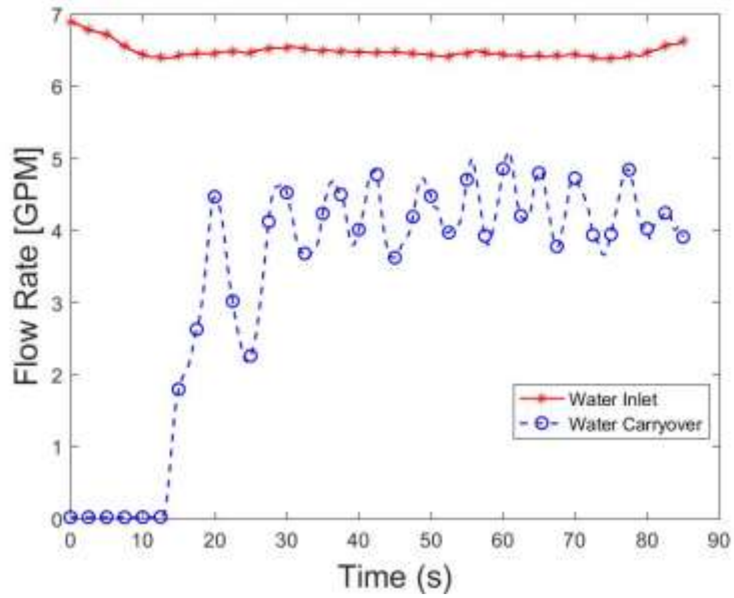

Figure G512: Water flow rates for test 2016_06_15_test_29.

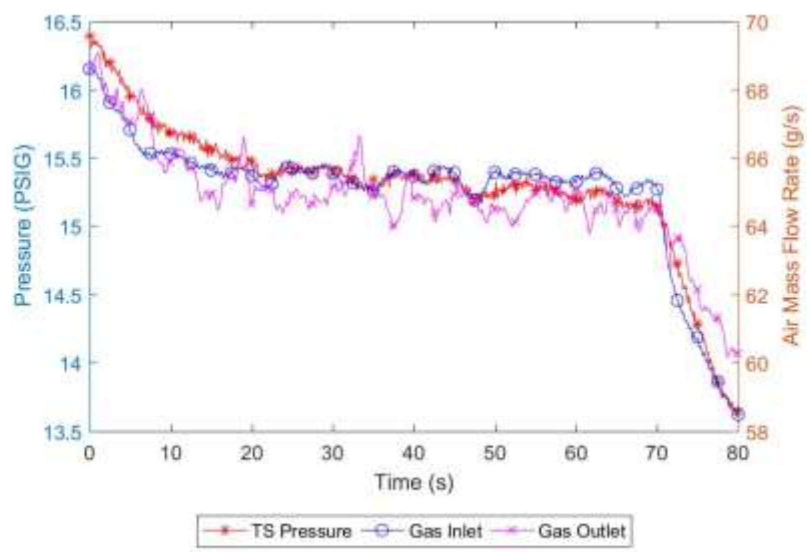

Figure G513: Pressure and gas inlet and outlet mass flow rates for test 2016_06_15_test_30.

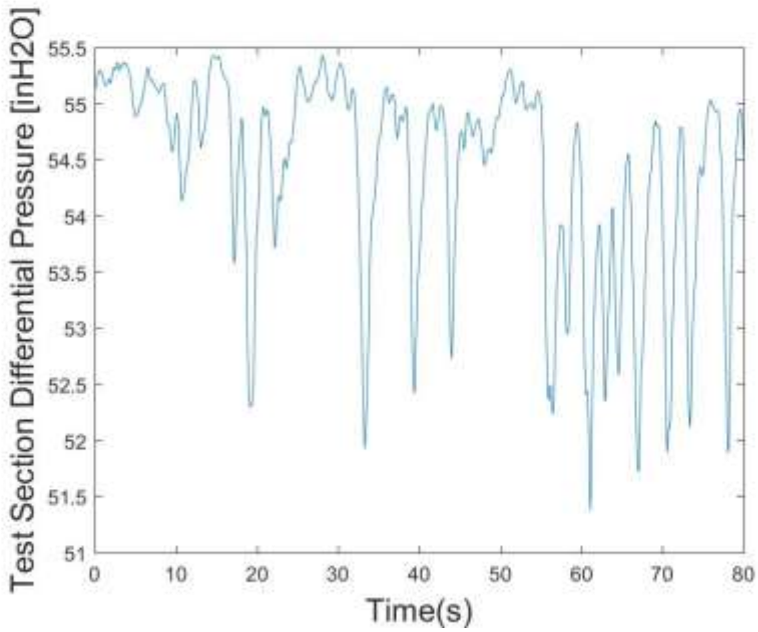

Figure G514: Test section differential pressure for test 2016_06_15_test_30.

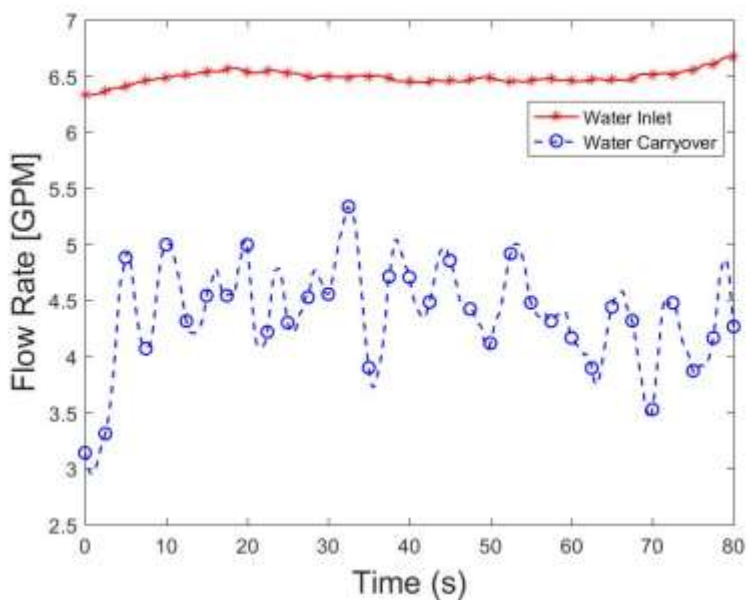

Figure G515: Water flow rates for test 2016_06_15_test_30.

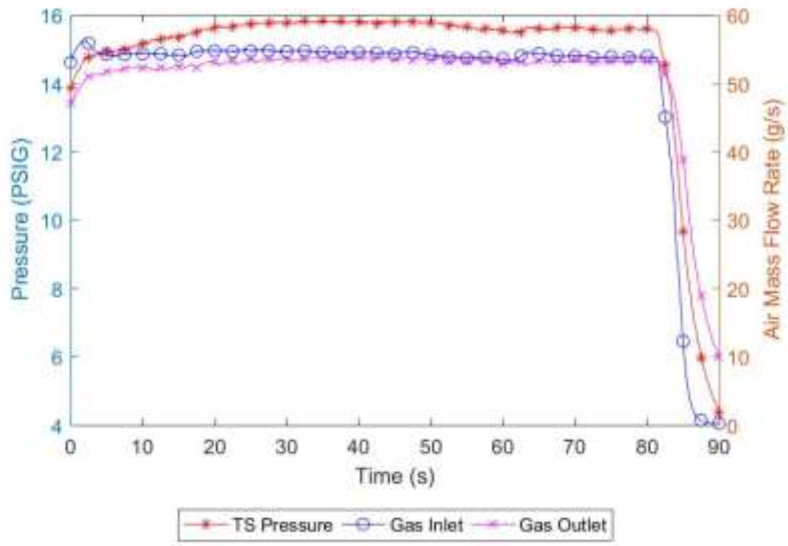

Figure G516: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_01.

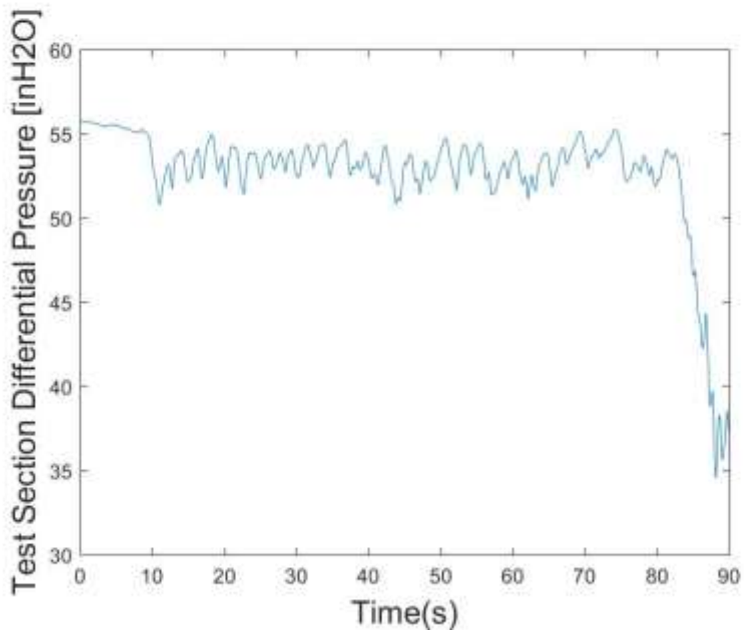

Figure G517: Test section differential pressure for test 2016_06_16_test_01.

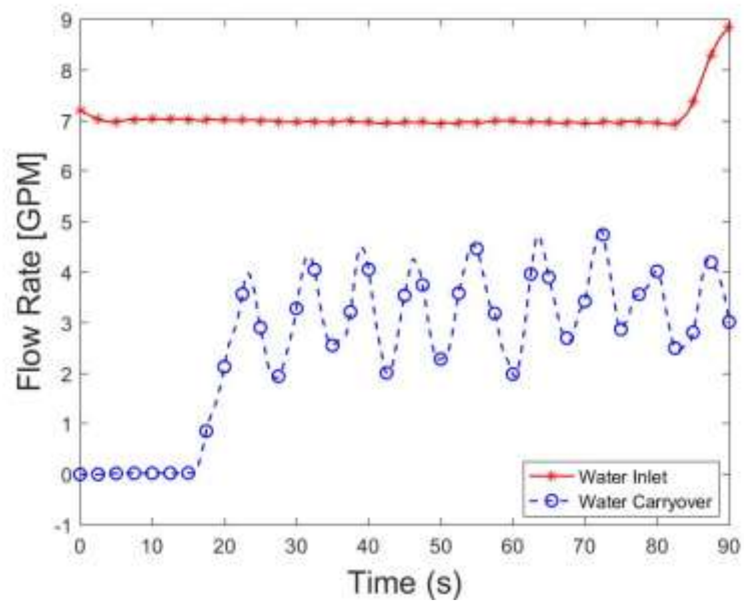

Figure G518: Water flow rates for test 2016_06_16_test_01.

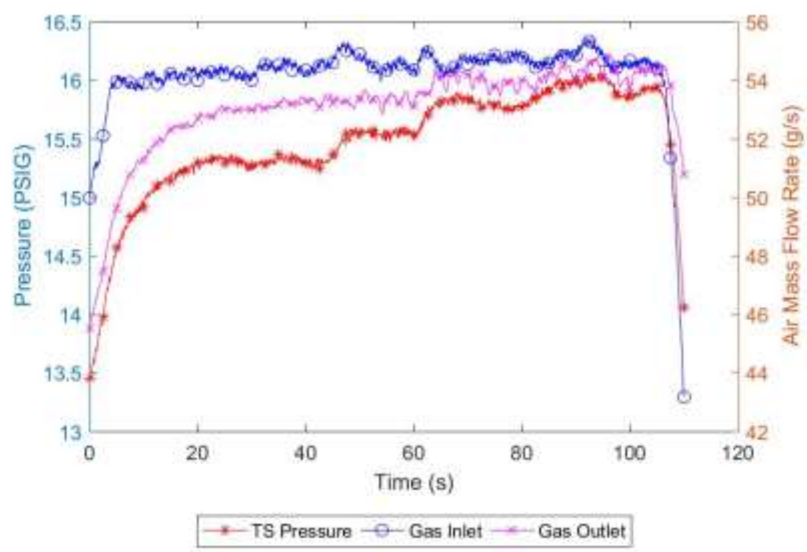

Figure G519: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_02.

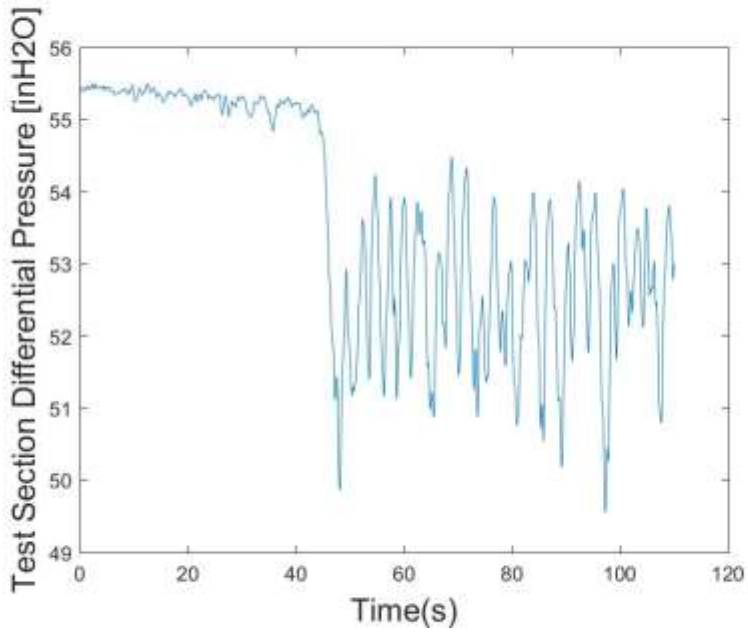

Figure G520: Test section differential pressure for test 2016_06_16_test_02.

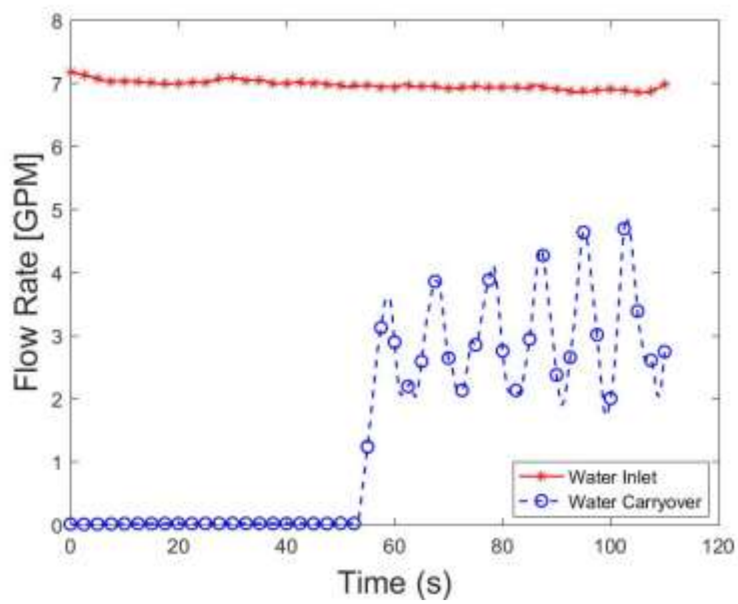

Figure G521: Water flow rates for test 2016_06_16_test_02.

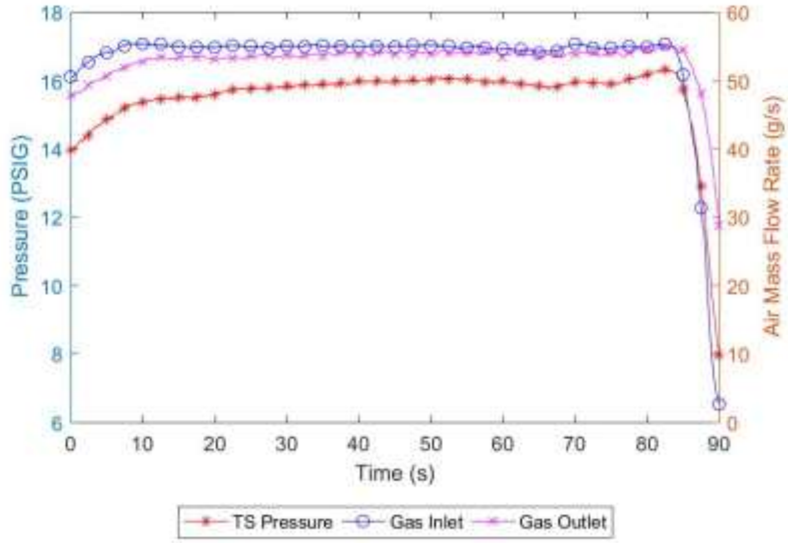

Figure G522: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_03.

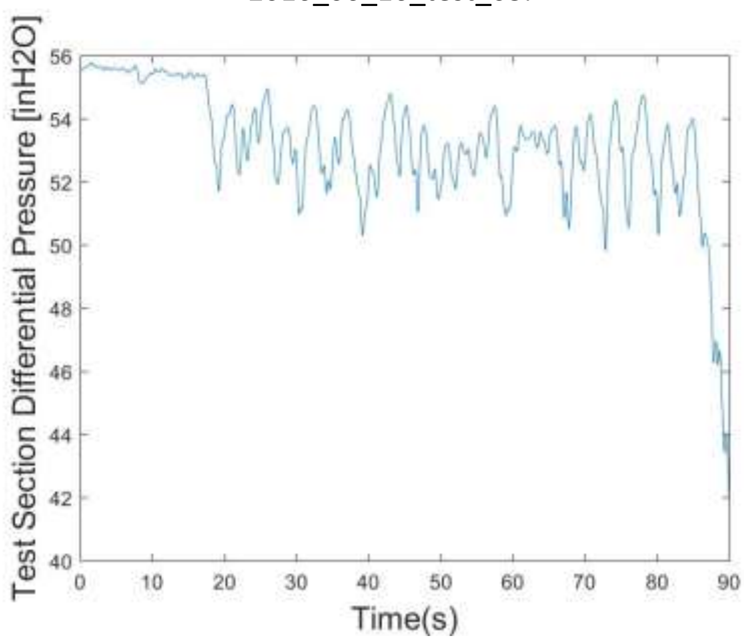

Figure G523: Test section differential pressure for test 2016_06_16_test_03.

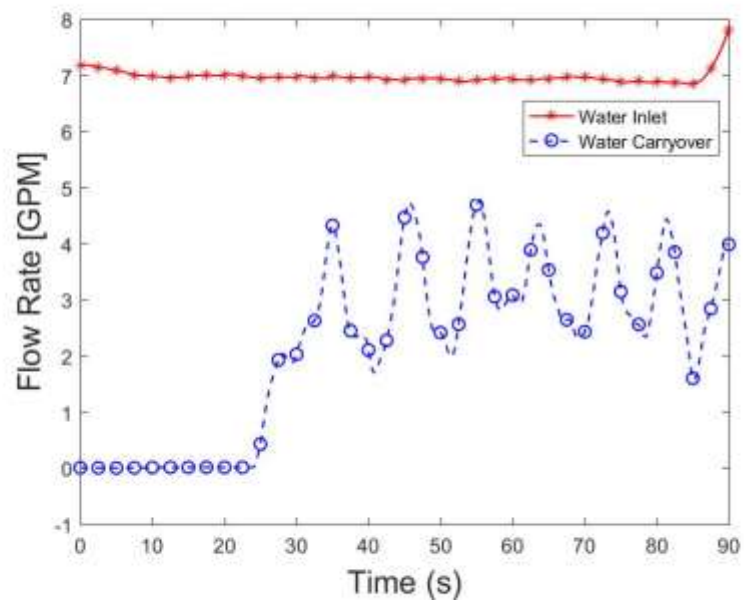

Figure G524: Water flow rates for test 2016_06_16_test_03.

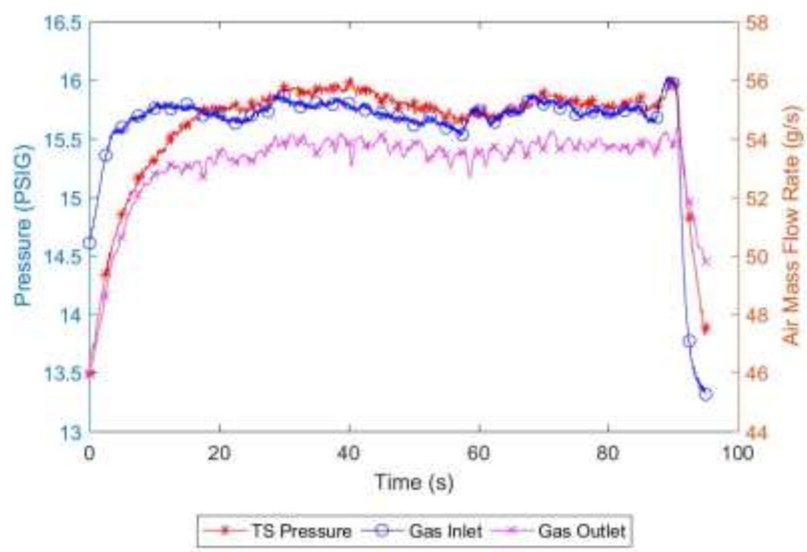

Figure G525: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_04.

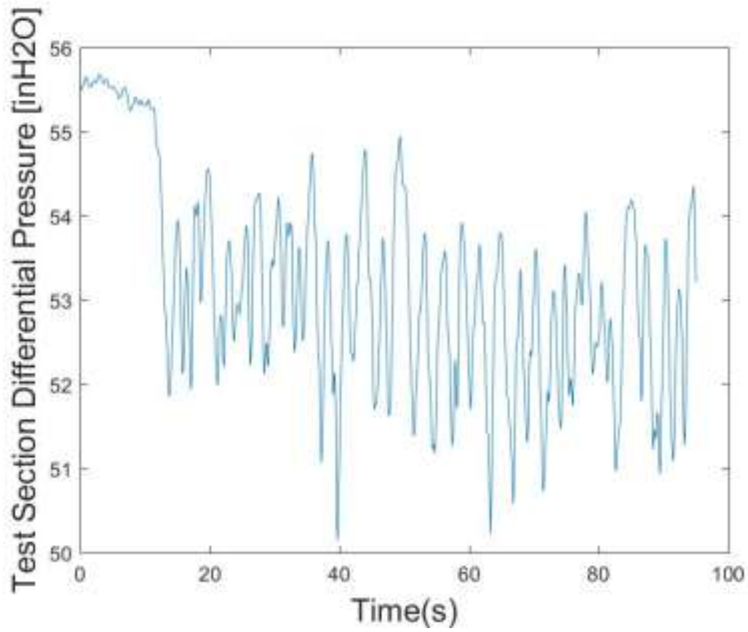

Figure G526: Test section differential pressure for test 2016_06_16_test_04.

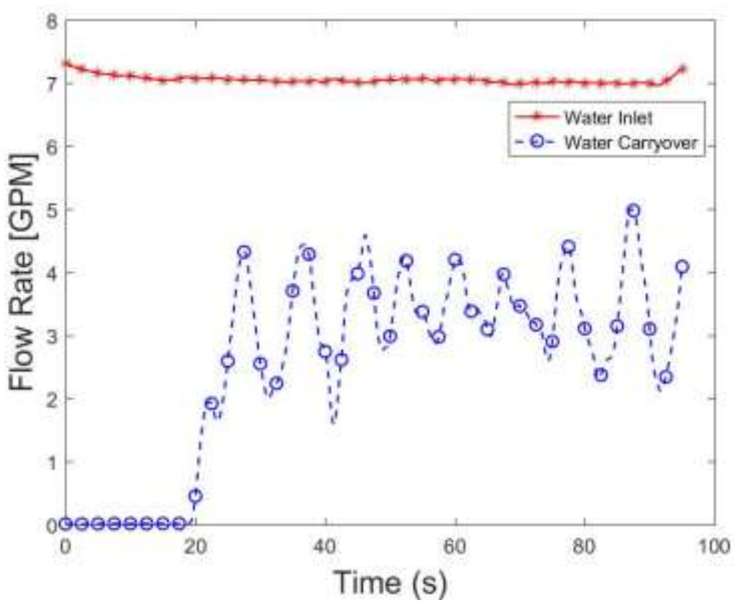

Figure G527: Water flow rates for test 2016_06_16_test_04.

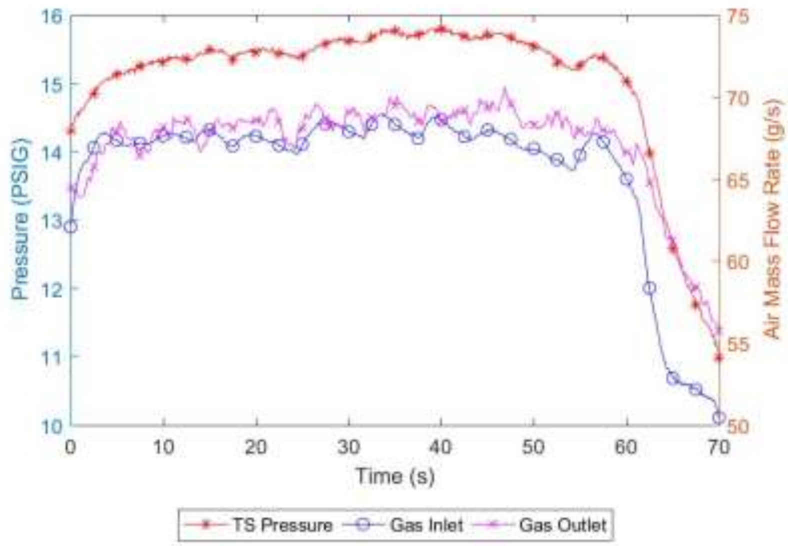

Figure G528: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_05.

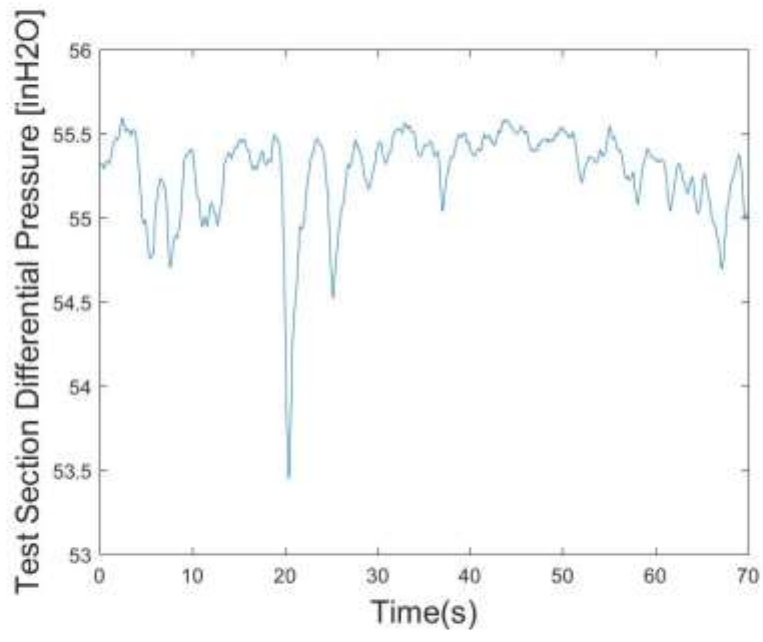

Figure G529: Test section differential pressure for test 2016_06_16_test_05.

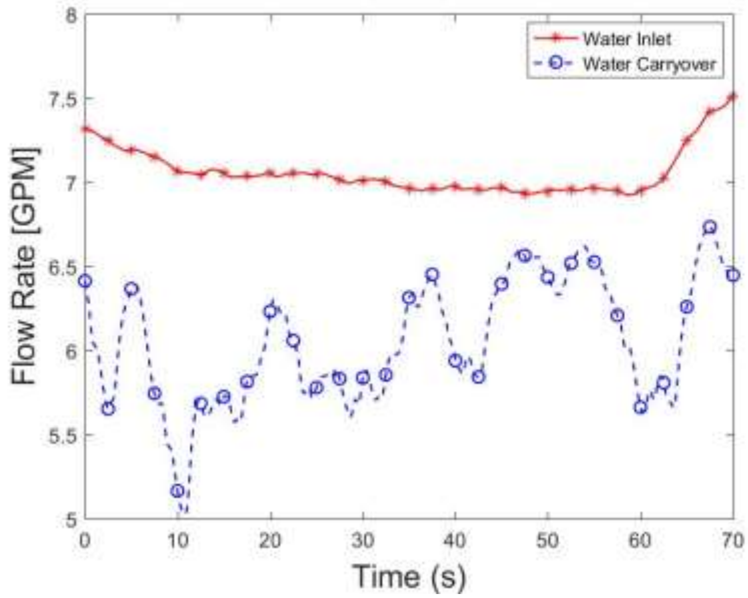

Figure G530: Water flow rates for test 2016_06_16_test_05.

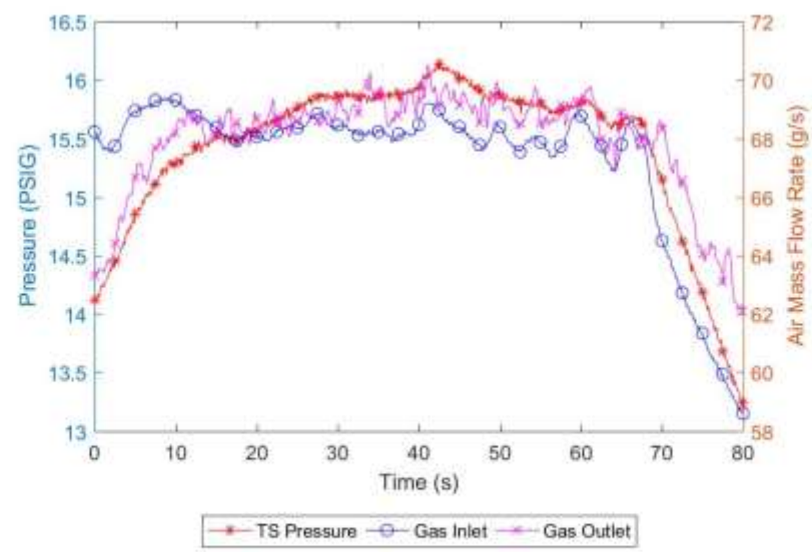

Figure G531: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_06.

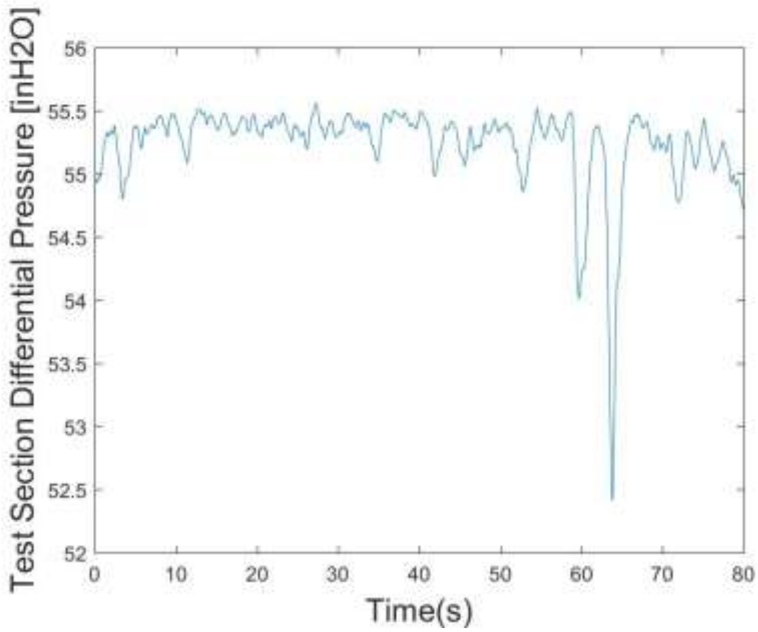

Figure G532: Test section differential pressure for test 2016_06_16_test_06.

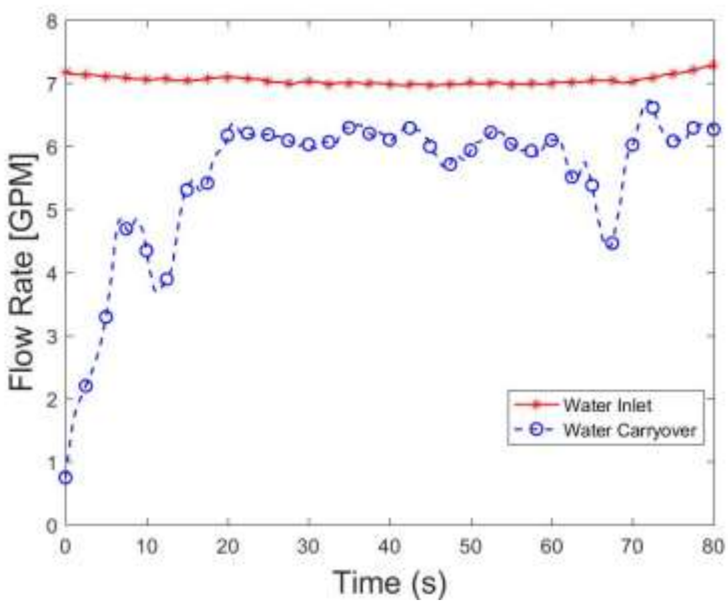

Figure G533: Water flow rates for test 2016_06_16_test_06.

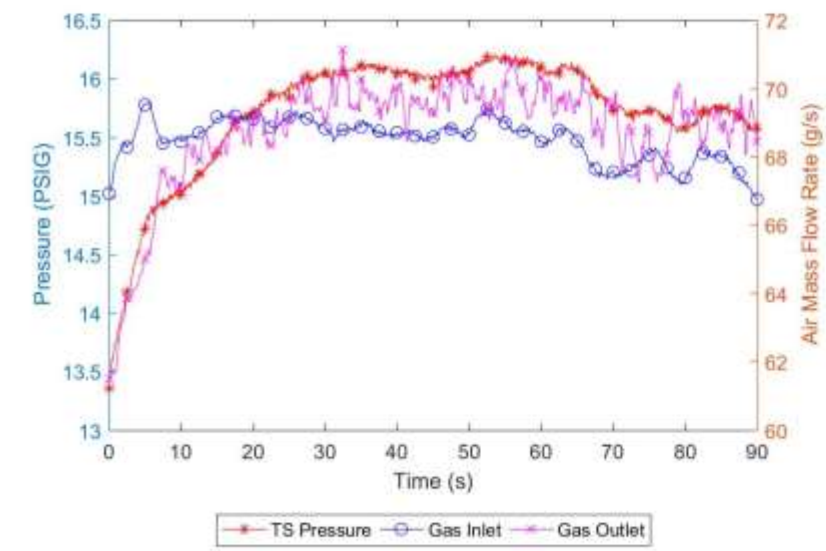

Figure G534: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_07.

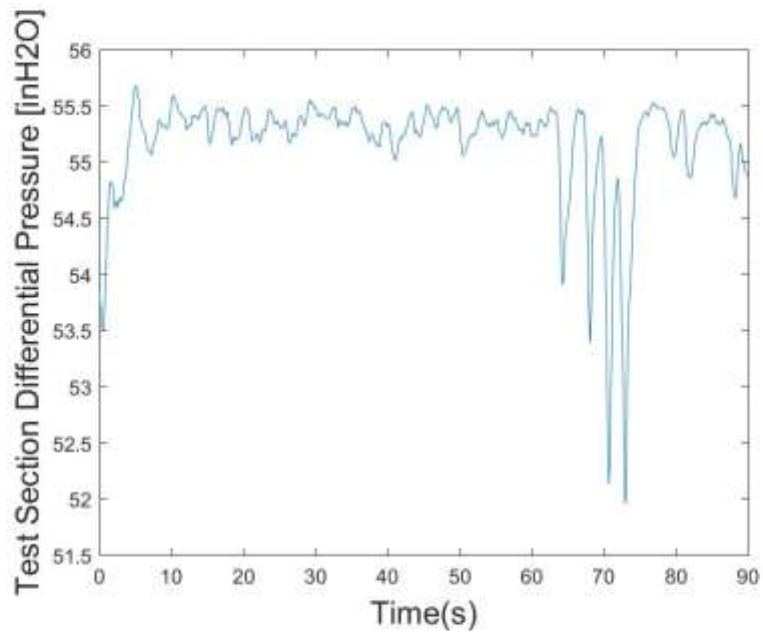

Figure G535: Test section differential pressure for test 2016_06_16_test_07.

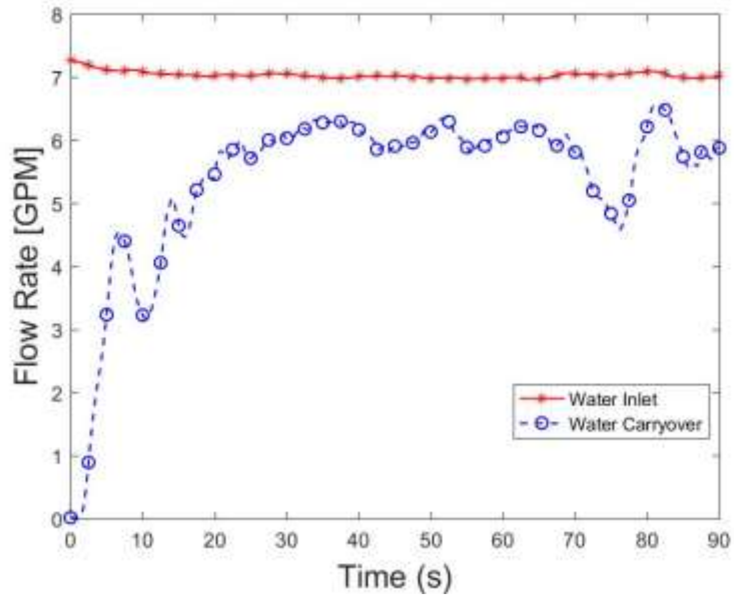

Figure G536: Water flow rates for test 2016_06_16_test_07.

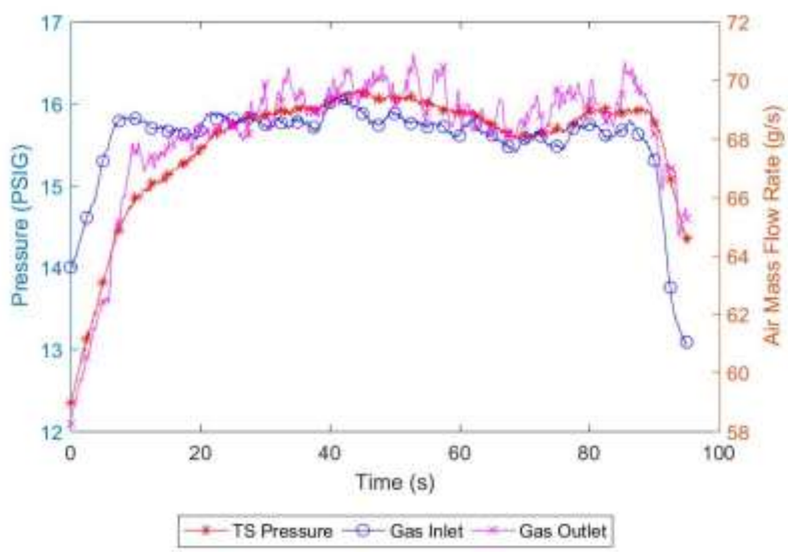

Figure G537: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_08.

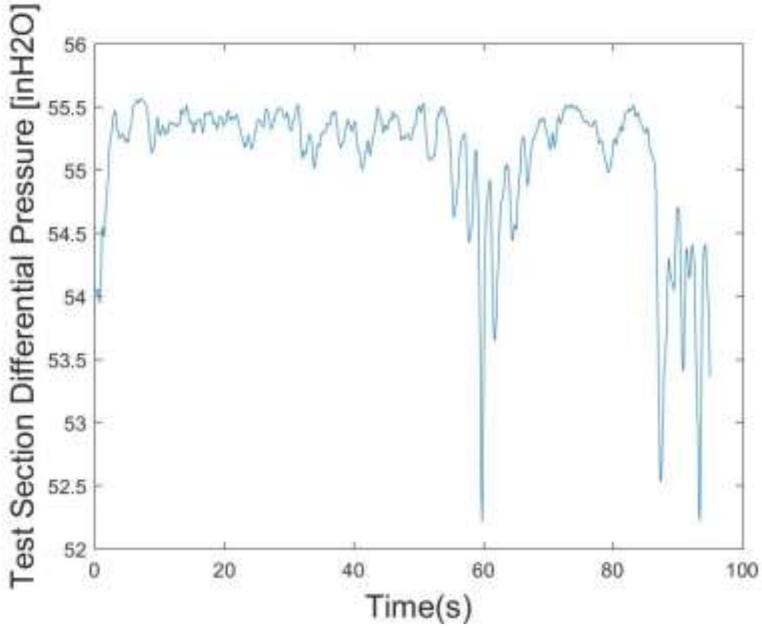

Figure G538: Test section differential pressure for test 2016_06_16_test_08.

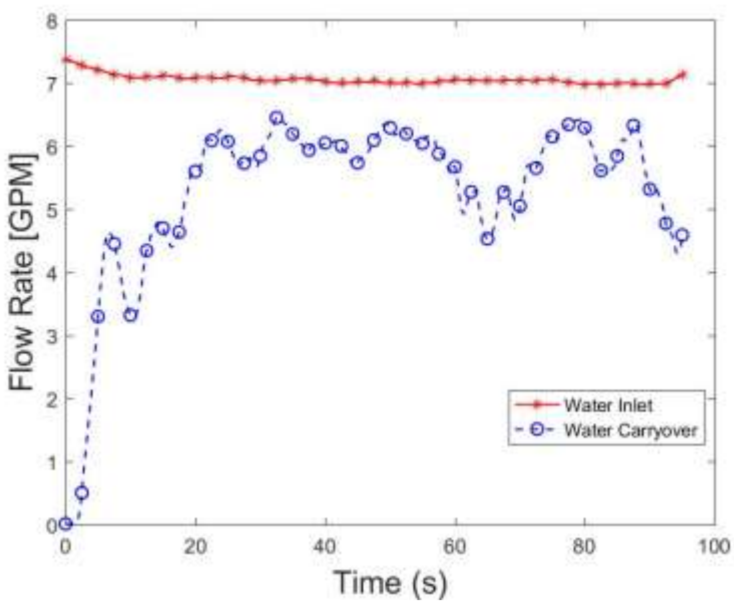

Figure G539: Water flow rates for test 2016_06_16_test_08.

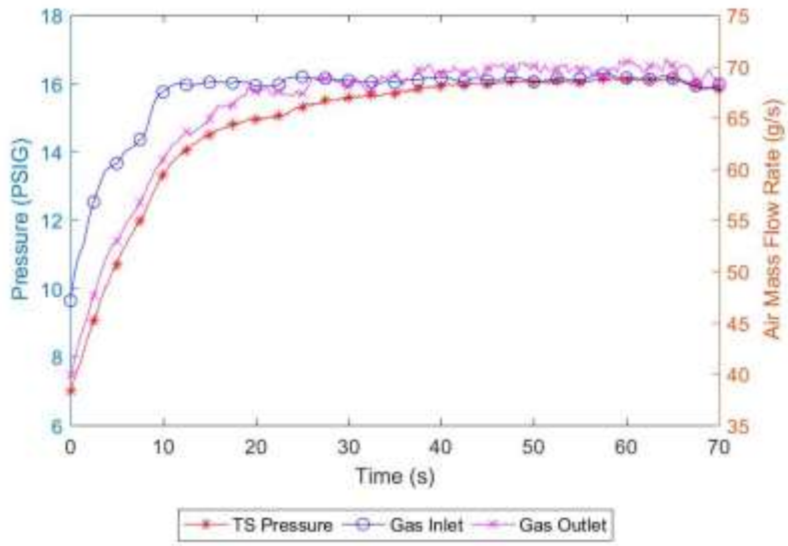

Figure G540: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_09.

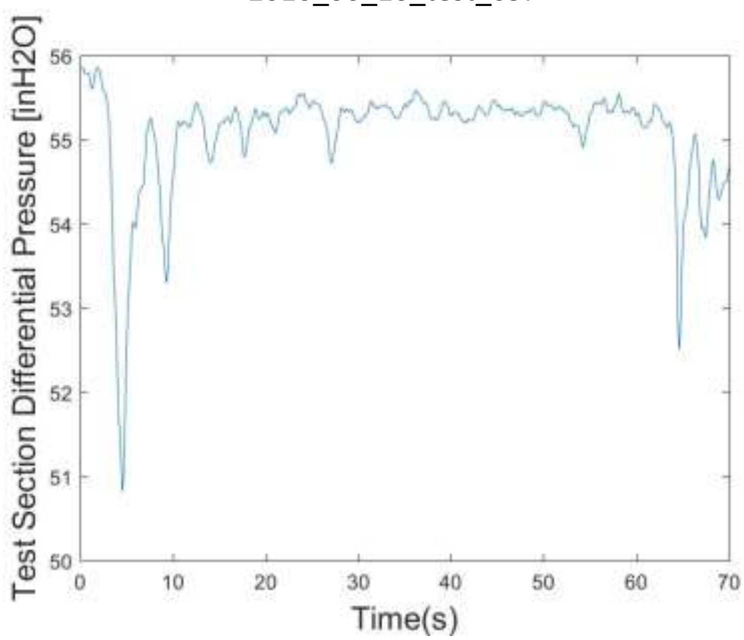

Figure G541: Test section differential pressure for test 2016_06_16_test_09.

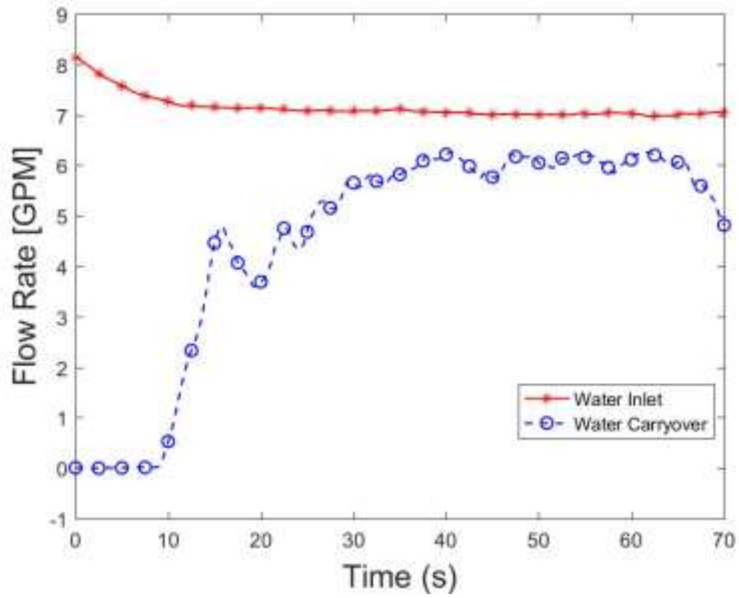

Figure G542: Water flow rates for test 2016_06_16_test_09.

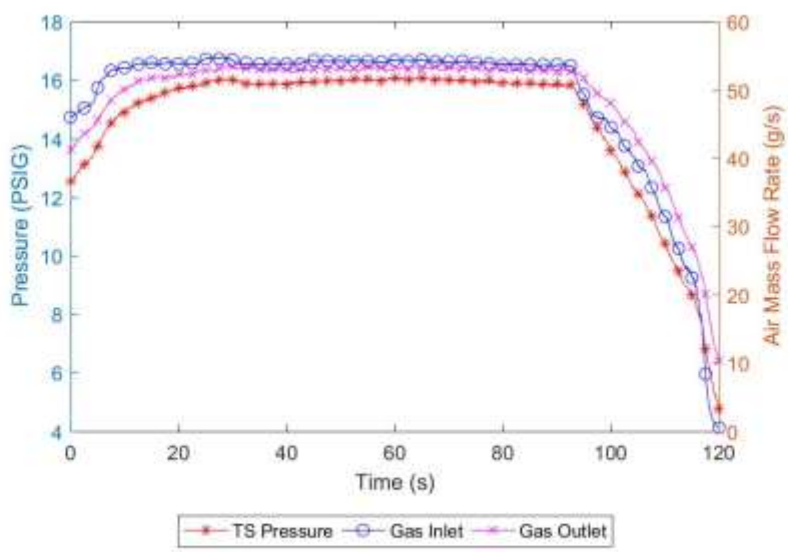

Figure G543: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_10.

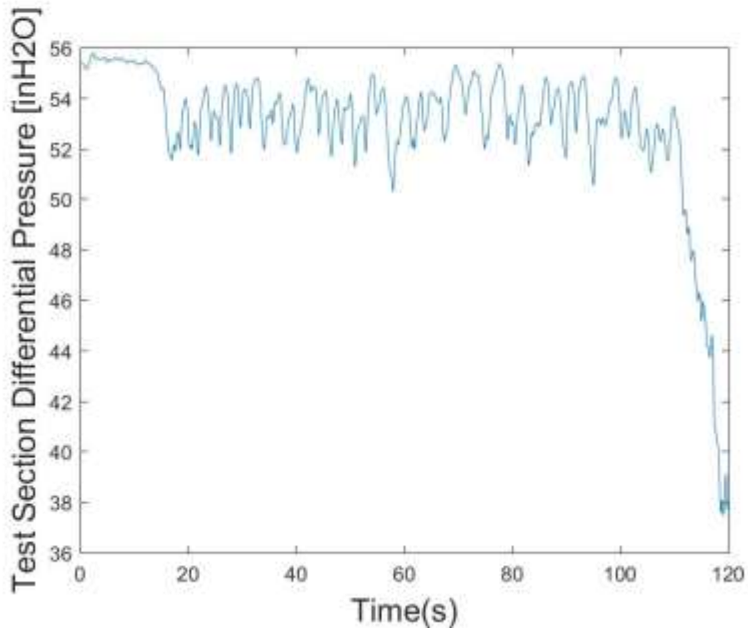

Figure G544: Test section differential pressure for test 2016_06_16_test_10.

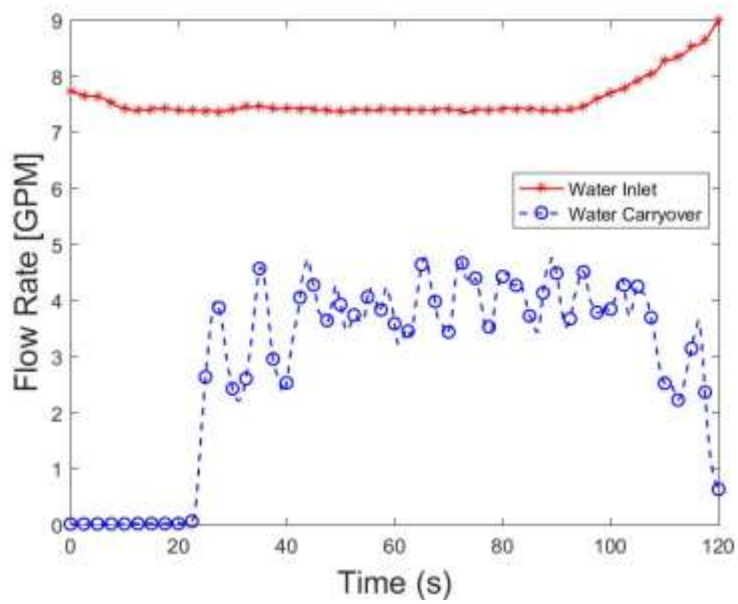

Figure G545: Water flow rates for test 2016_06_16_test_10.

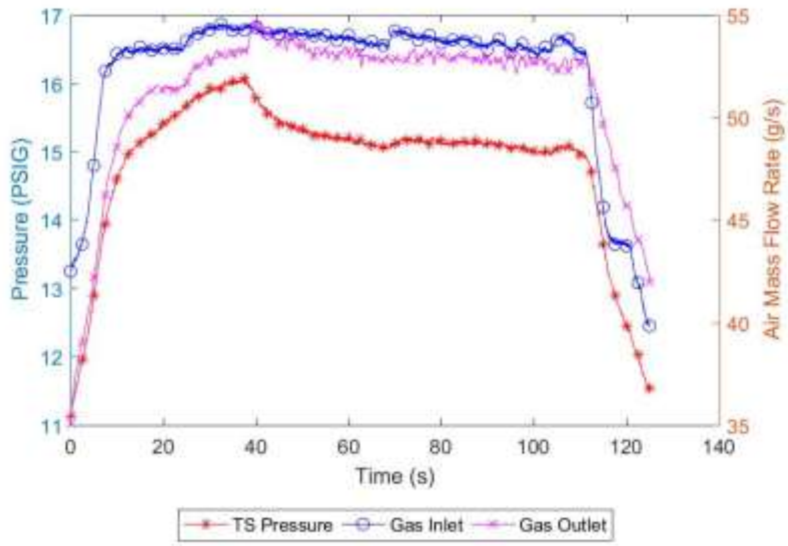

Figure G546: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_11.

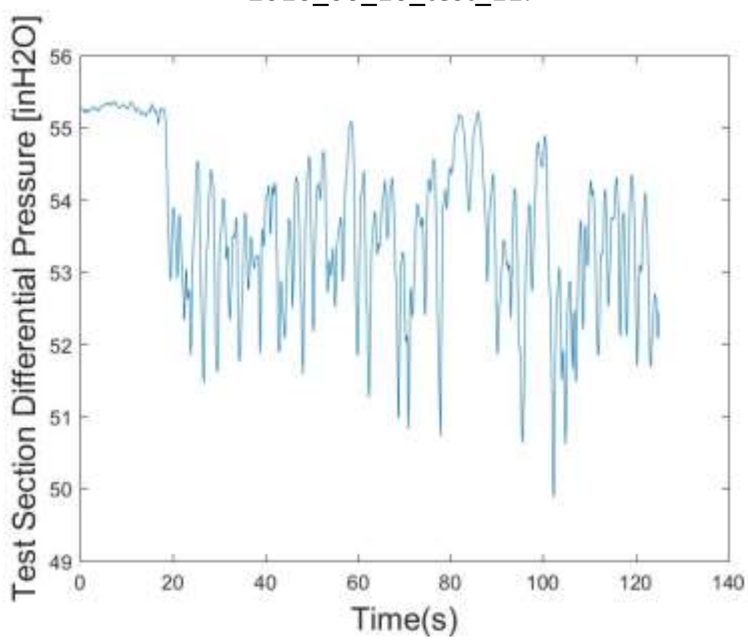

Figure G547: Test section differential pressure for test 2016_06_16_test_11.

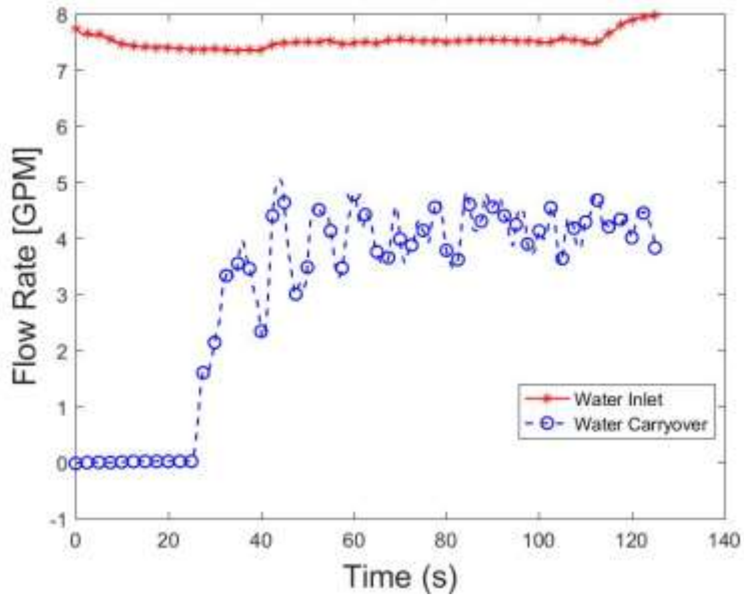

Figure G548: Water flow rates for test 2016_06_16_test_11.

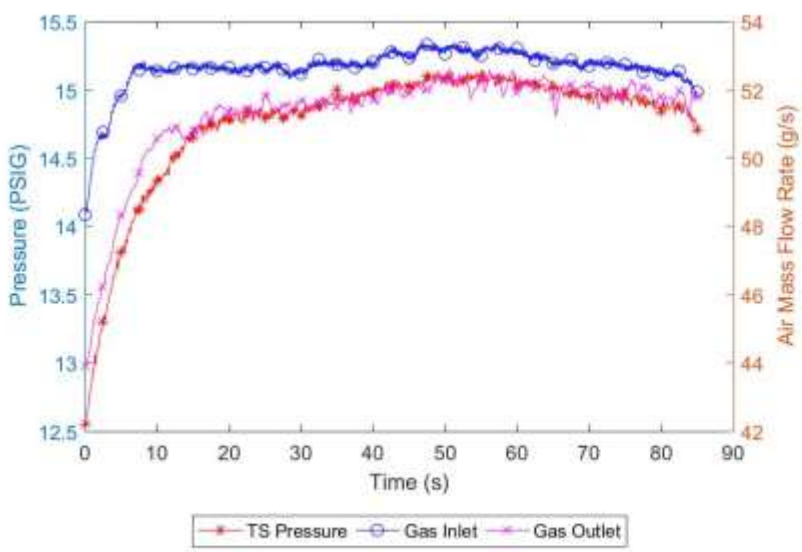

Figure G549: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_12.

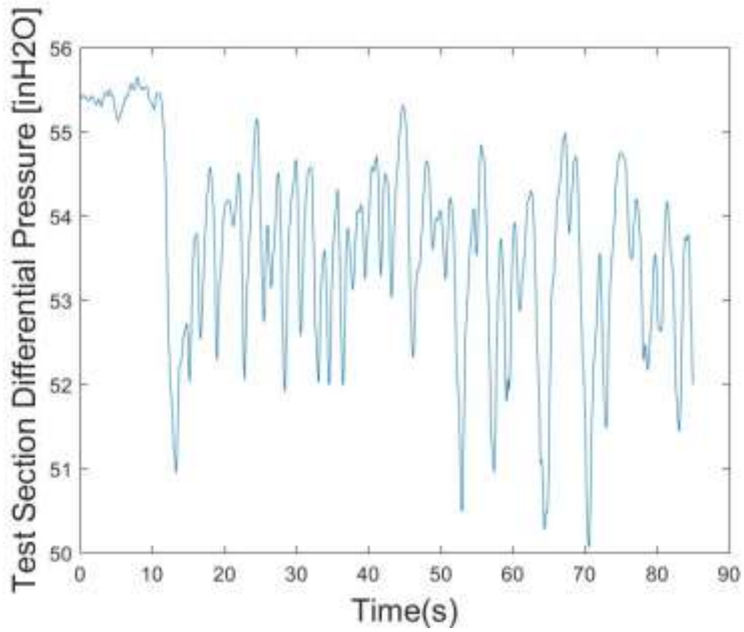

Figure G550: Test section differential pressure for test 2016_06_16_test_12.

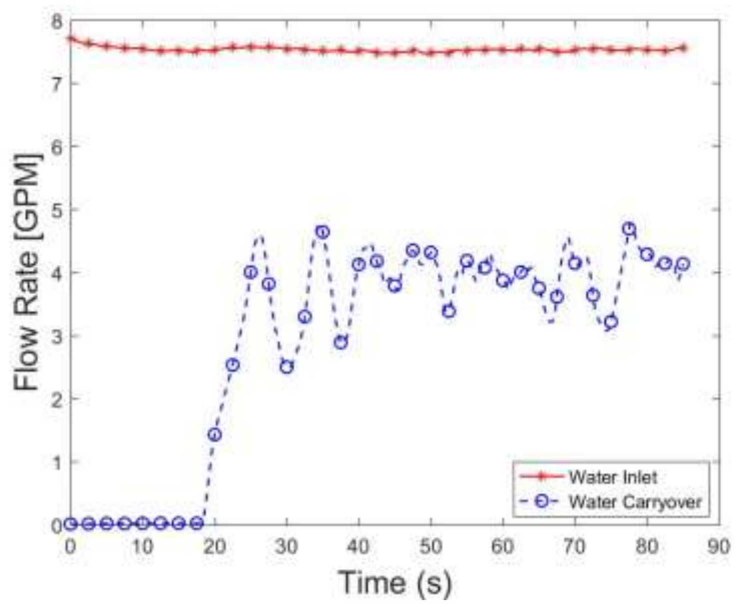

Figure G551: Water flow rates for test 2016_06_16_test_12.

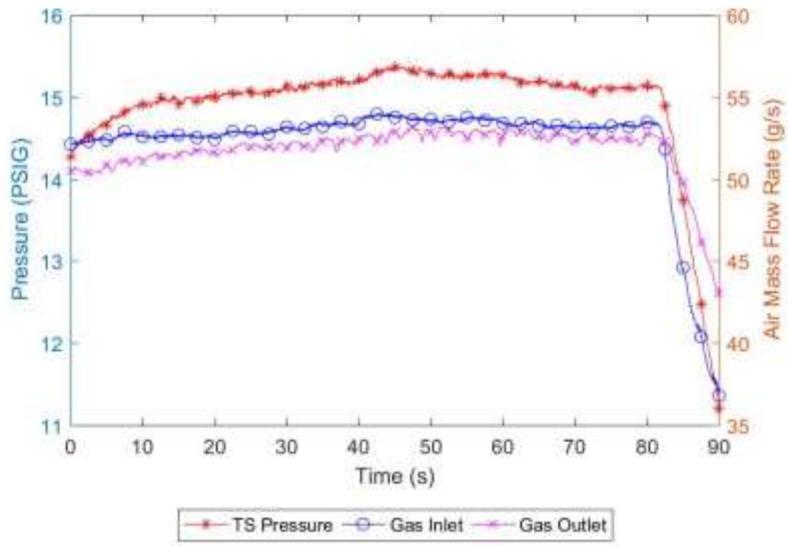

Figure G552: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_13.

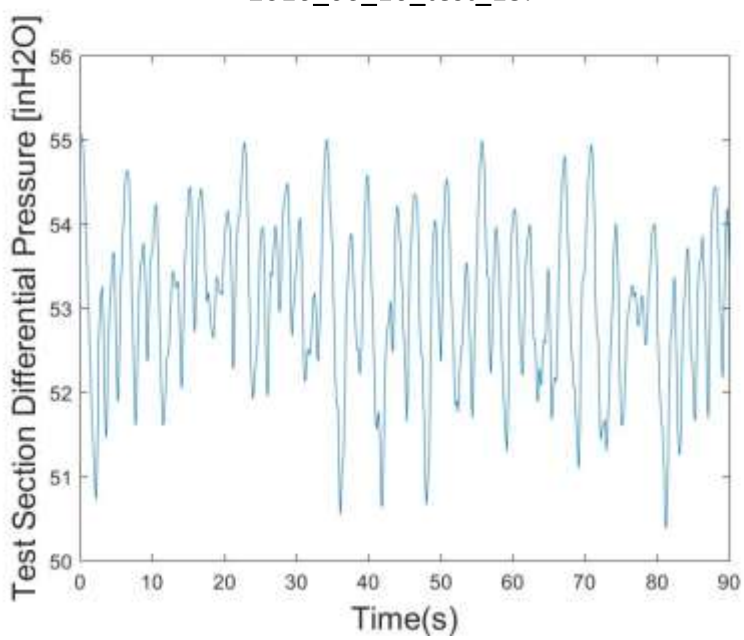

Figure G553: Test section differential pressure for test 2016_06_16_test_13.

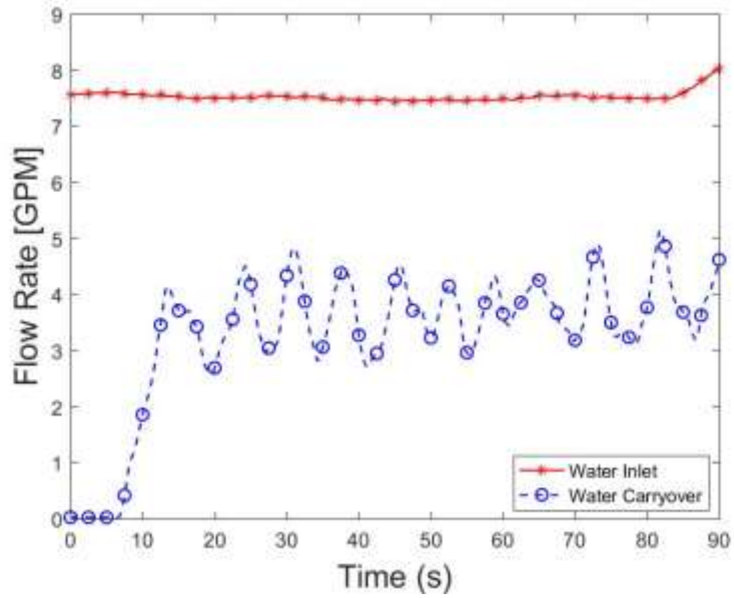

Figure G554: Water flow rates for test 2016_06_16_test_13.

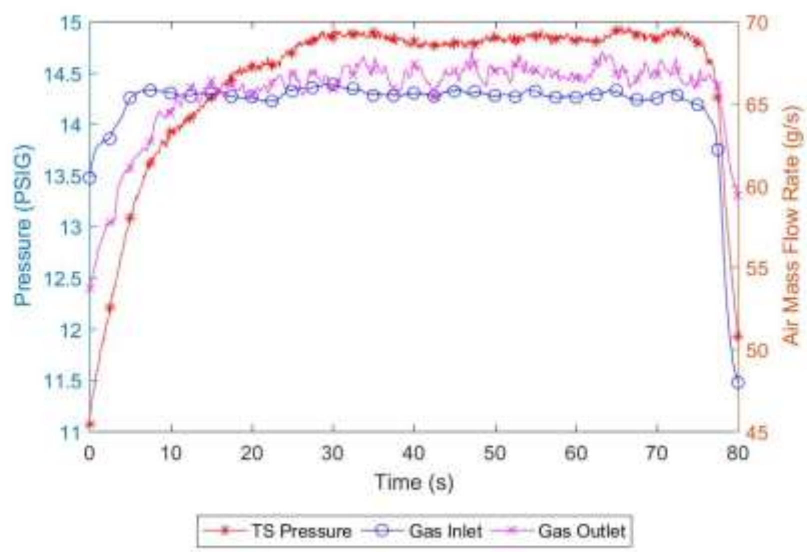

Figure G555: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_14.

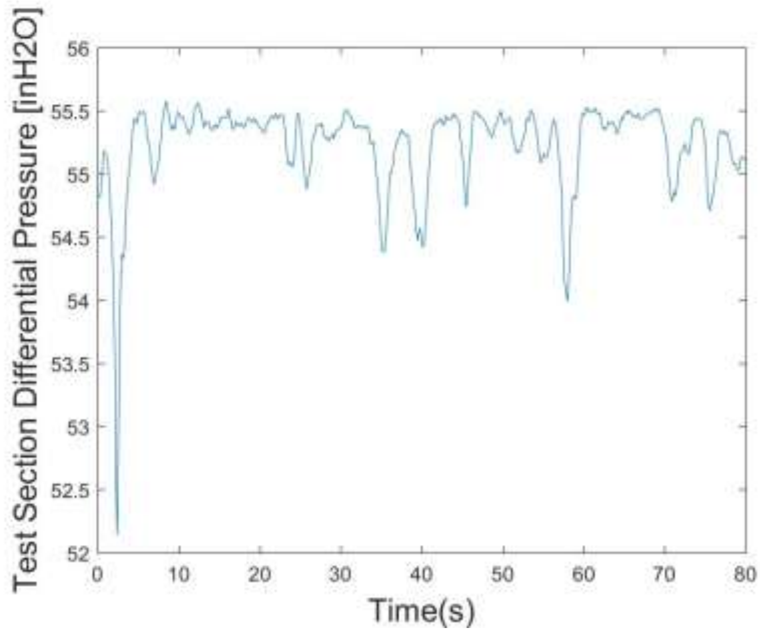

Figure G556: Test section differential pressure for test 2016_06_16_test_14.

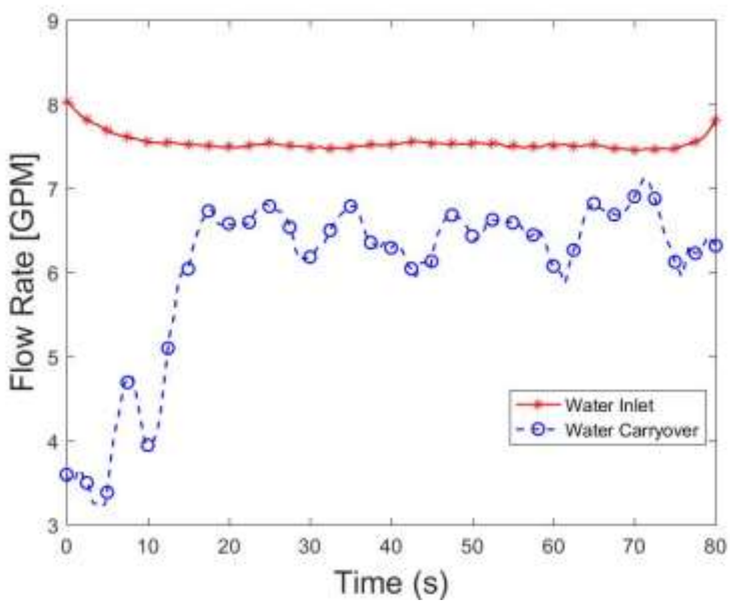

Figure G557: Water flow rates for test 2016_06_16_test_14.

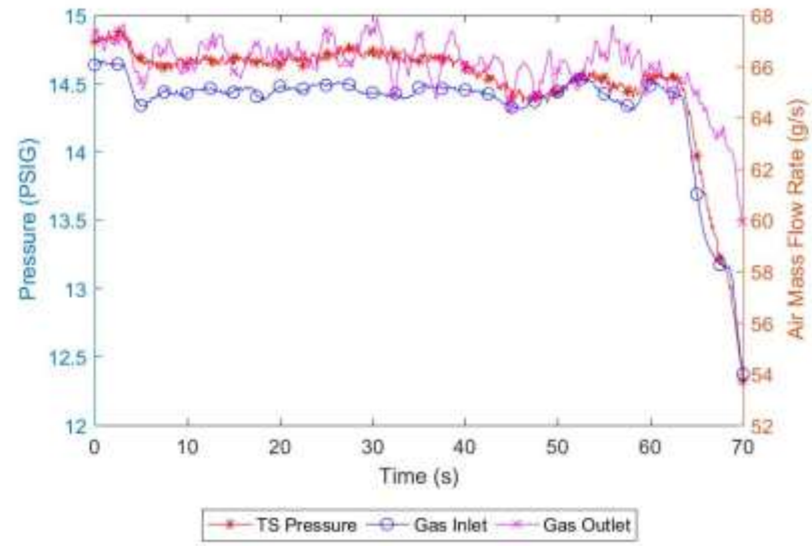

Figure G558: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_15.

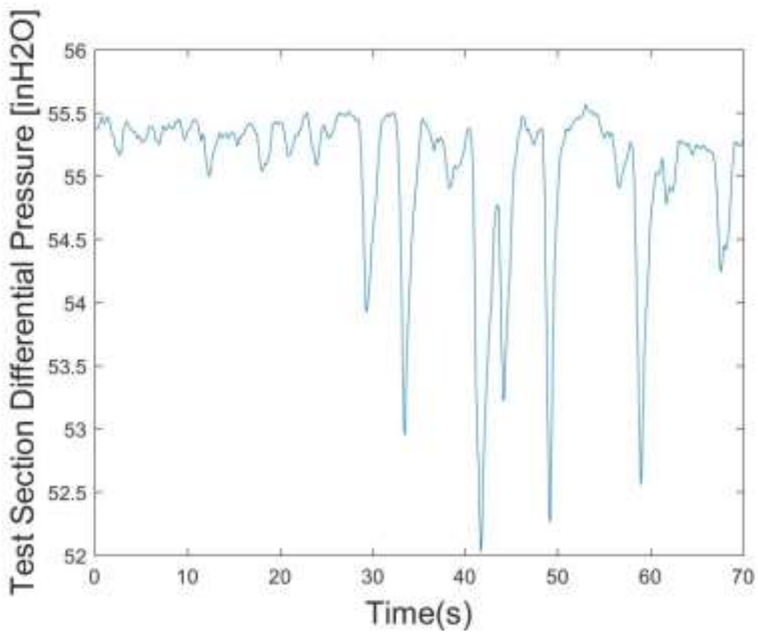

Figure G559: Test section differential pressure for test 2016_06_16_test_15.

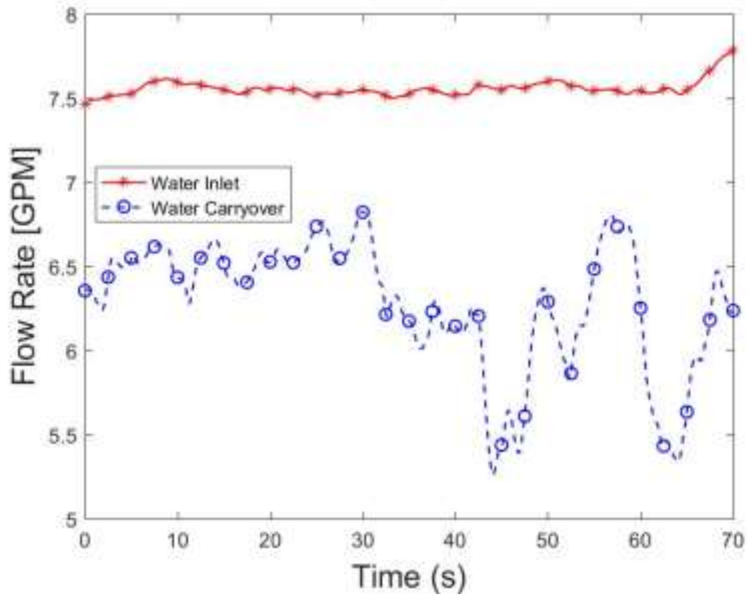

Figure G560: Water flow rates for test 2016_06_16_test_15.

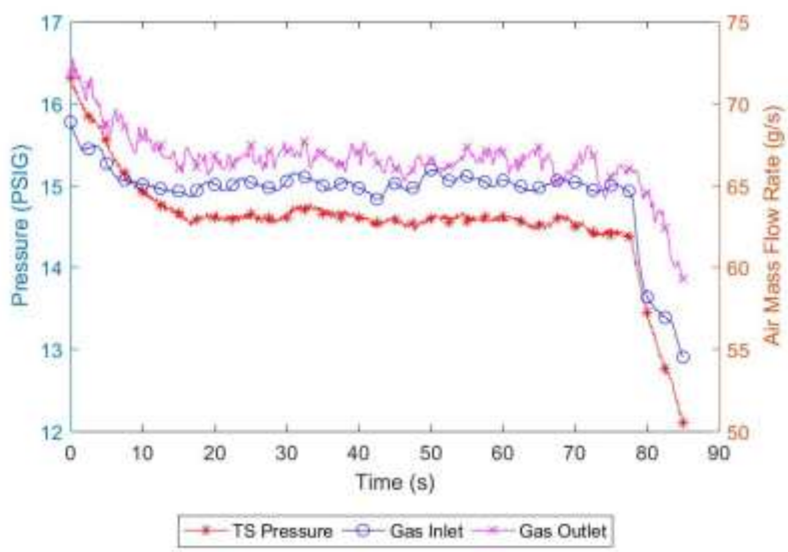

Figure G561: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_16.

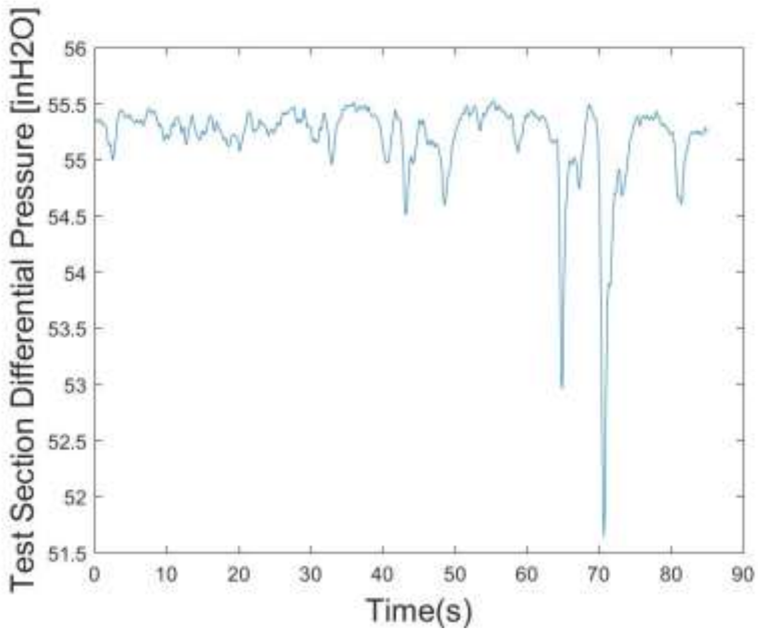

Figure G562: Test section differential pressure for test 2016_06_16_test_16.

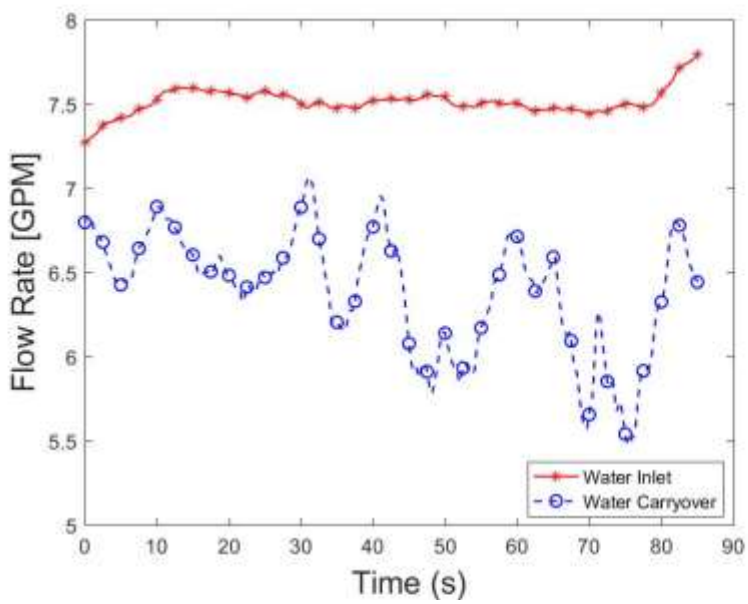

Figure G563: Water flow rates for test 2016_06_16_test_16.

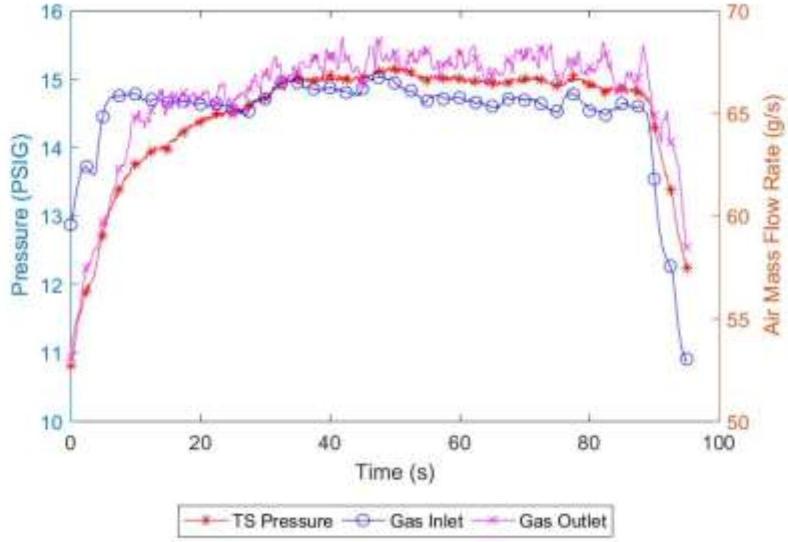

Figure G564: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_17.

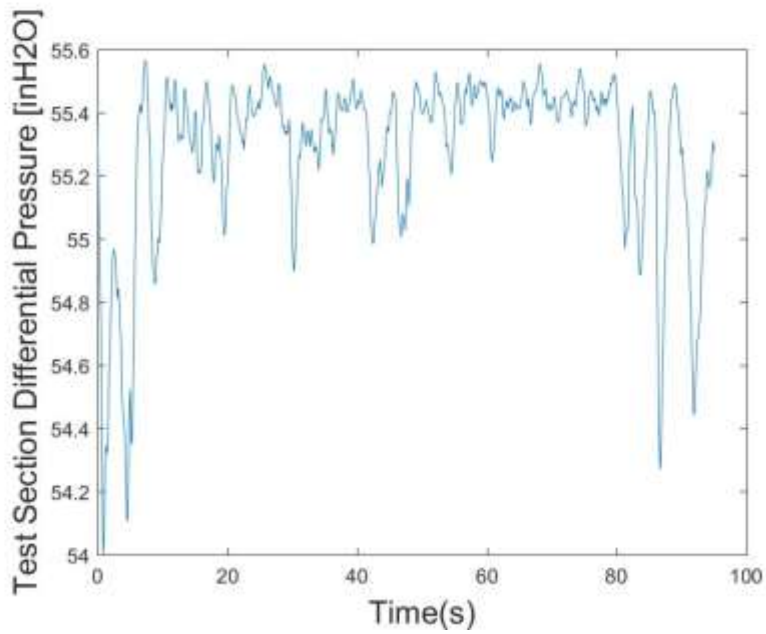

Figure G565: Test section differential pressure for test 2016_06_16_test_17.

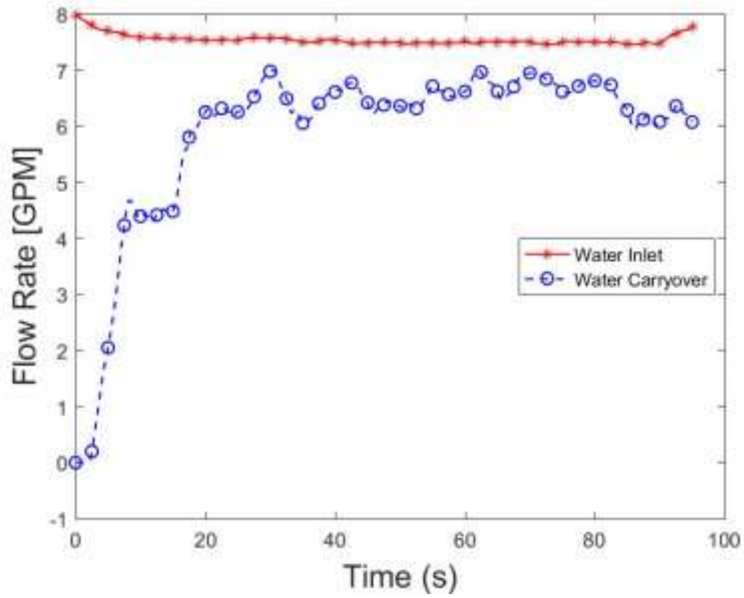

Figure G566: Water flow rates for test 2016_06_16_test_17.

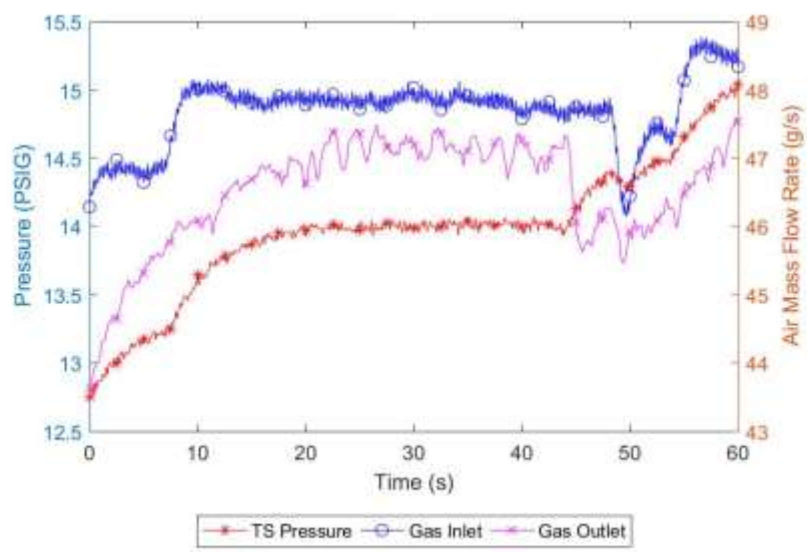

Figure G567: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_18.

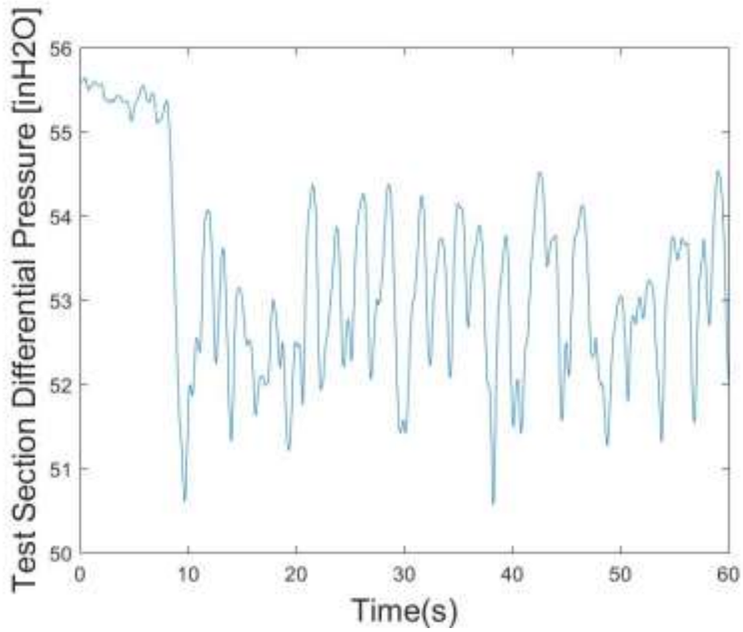

Figure G568: Test section differential pressure for test 2016_06_16_test_18.

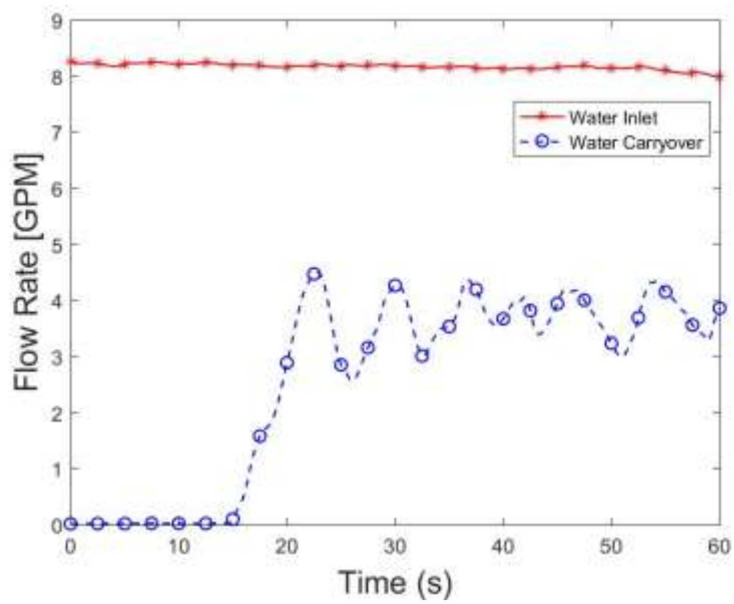

Figure G569: Water flow rates for test 2016_06_16_test_18.

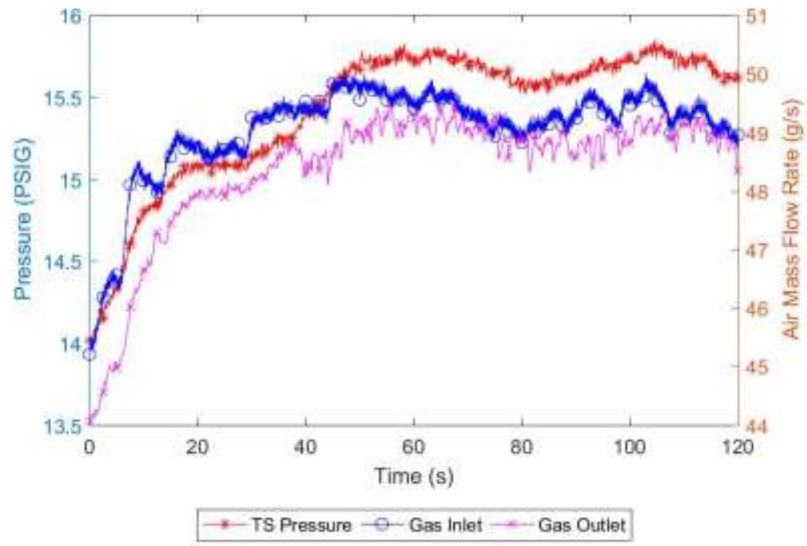

Figure G570: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_19.

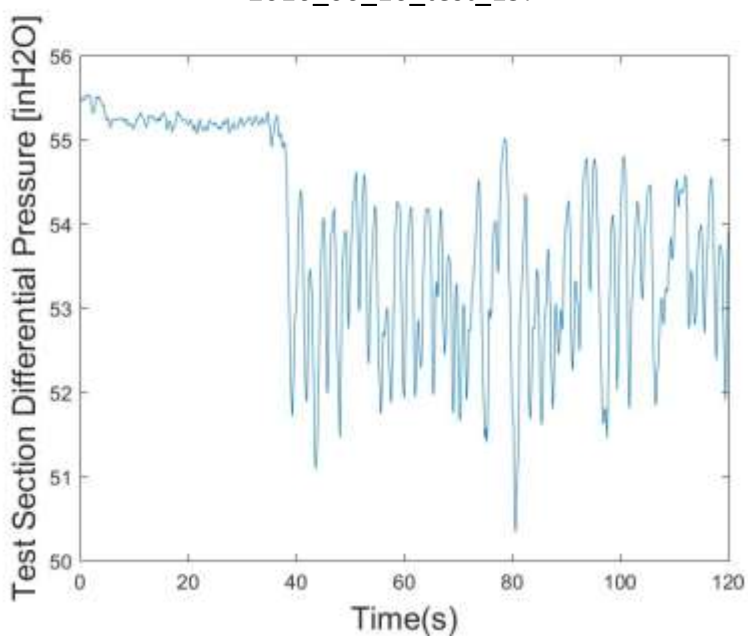

Figure G571: Test section differential pressure for test 2016_06_16_test_19.

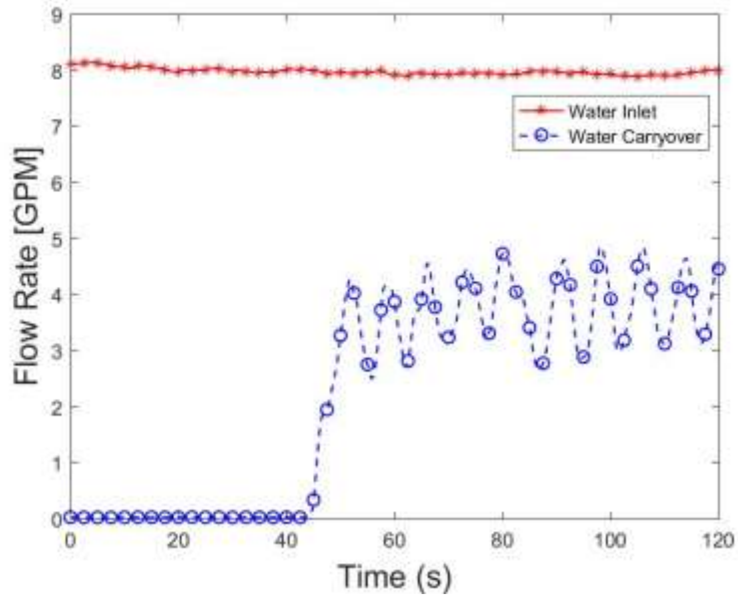

Figure G572: Water flow rates for test 2016_06_16_test_19.

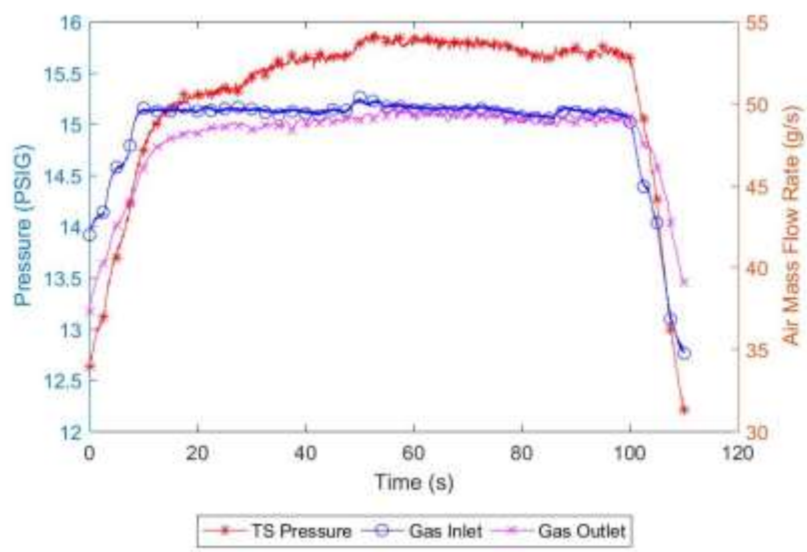

Figure G573: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_20.

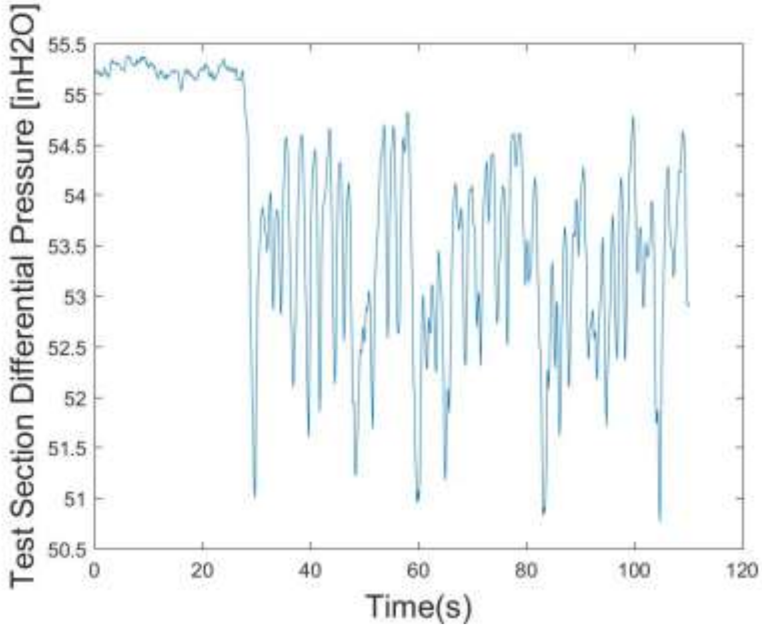

Figure G574: Test section differential pressure for test 2016_06_16_test_20.

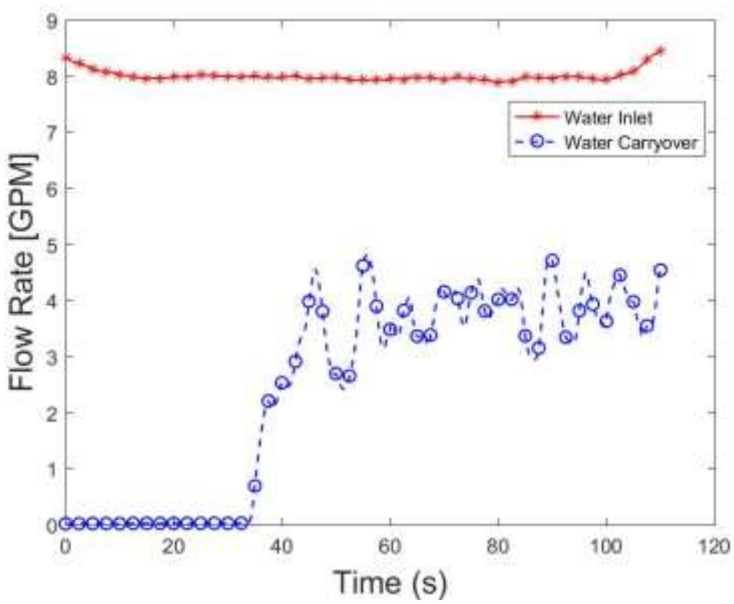

Figure G575: Water flow rates for test 2016_06_16_test_20.

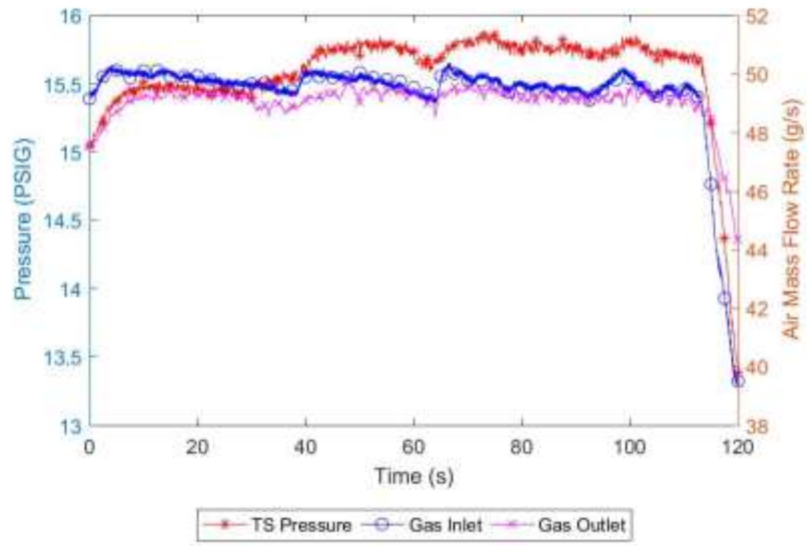

Figure G576: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_21.

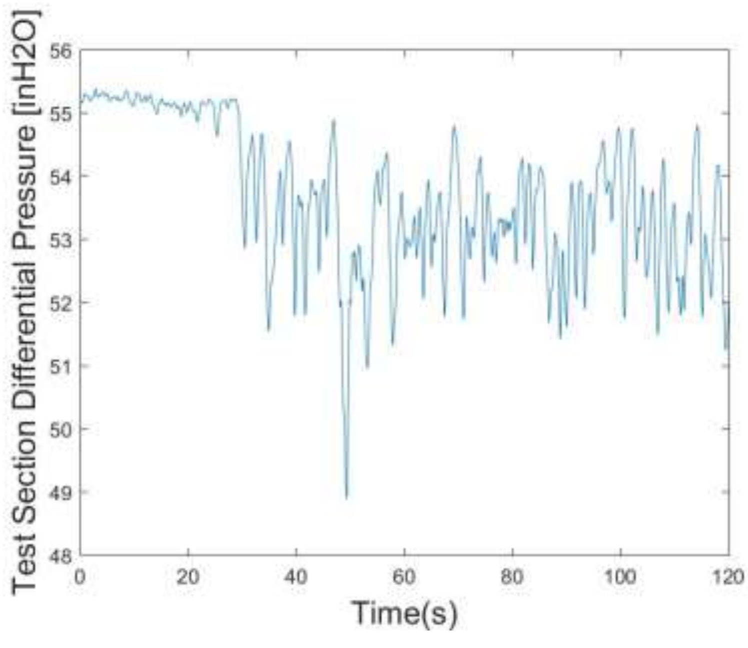

Figure G577: Test section differential pressure for test 2016_06_16_test_21.

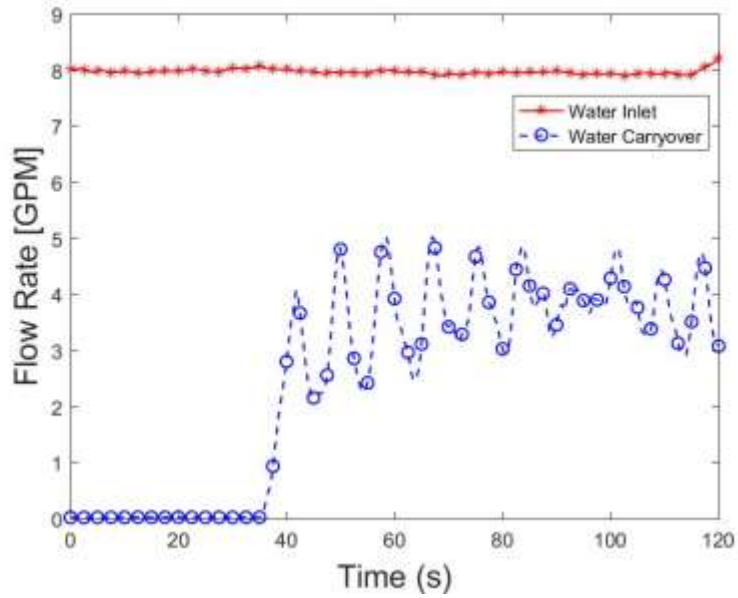

Figure G578: Water flow rates for test 2016_06_16_test_21.

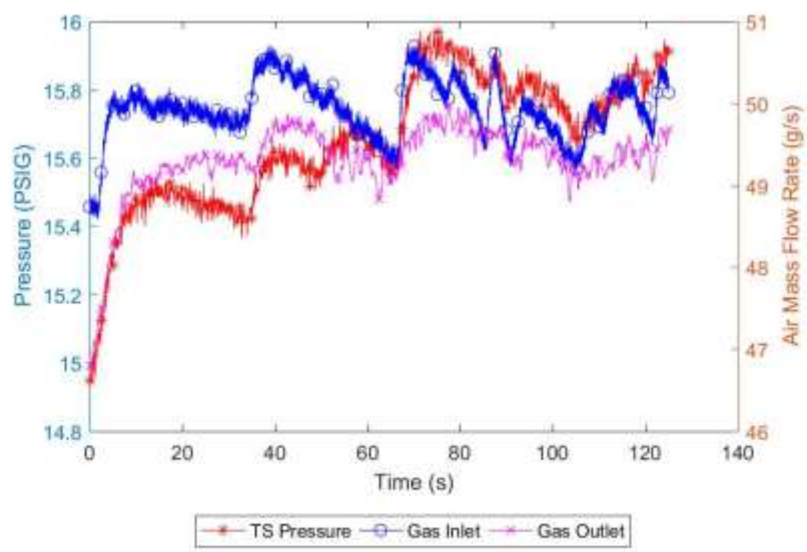

Figure G579: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_22.

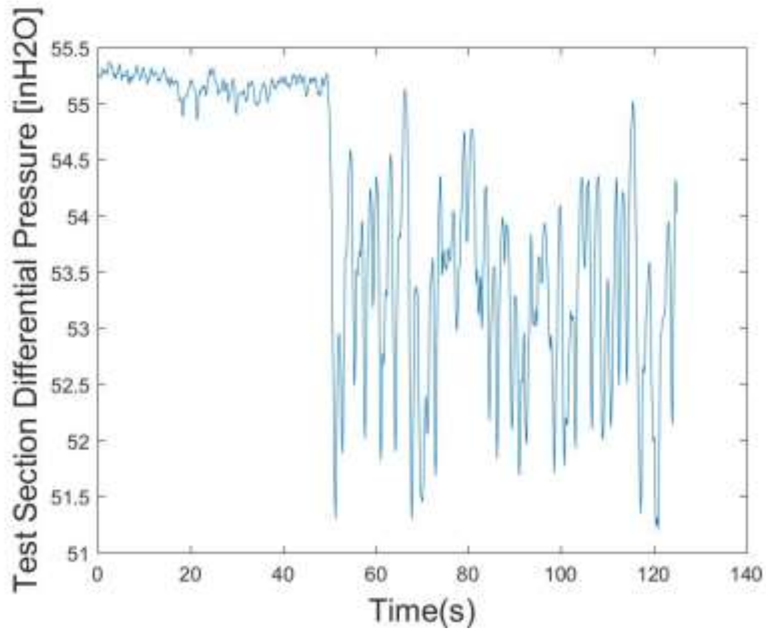

Figure G580: Test section differential pressure for test 2016_06_16_test_22.

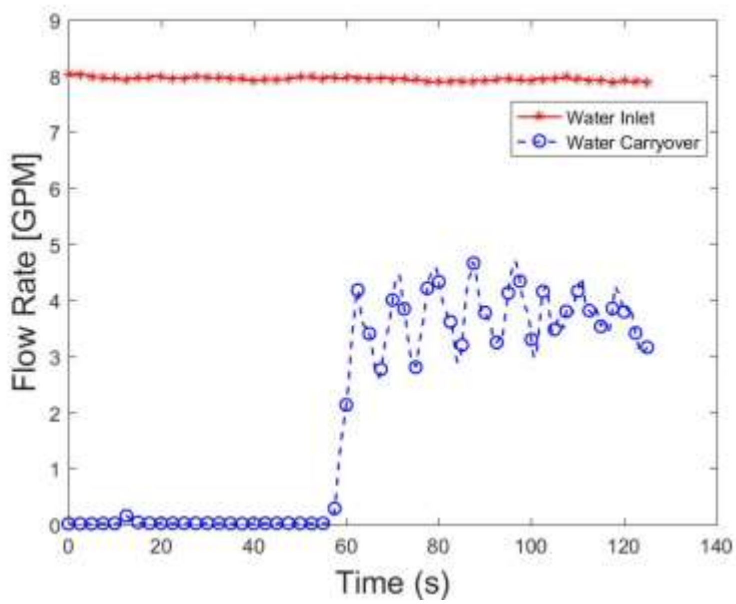

Figure G581: Water flow rates for test 2016_06_16_test_22.

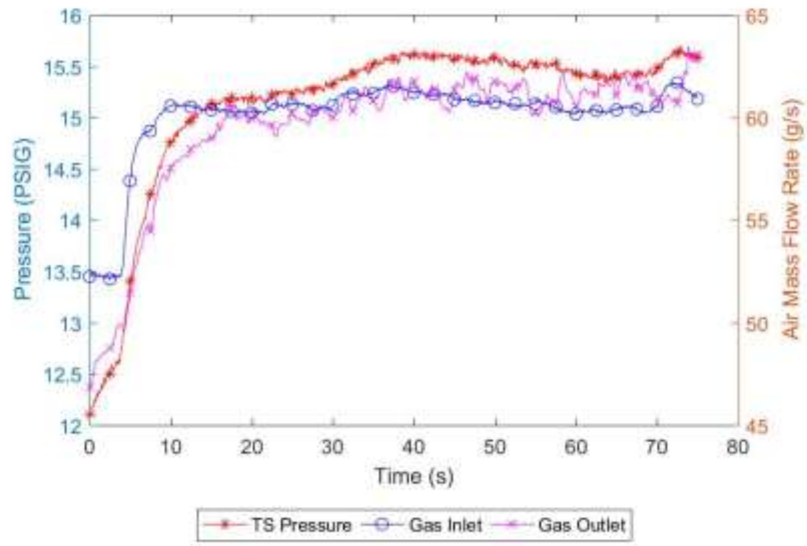

Figure G582: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_23.

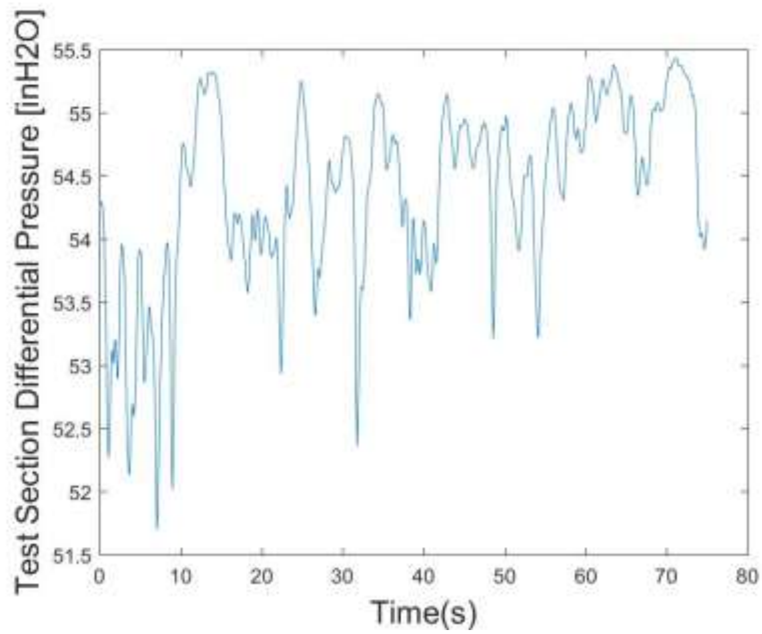

Figure G583: Test section differential pressure for test 2016_06_16_test_23.

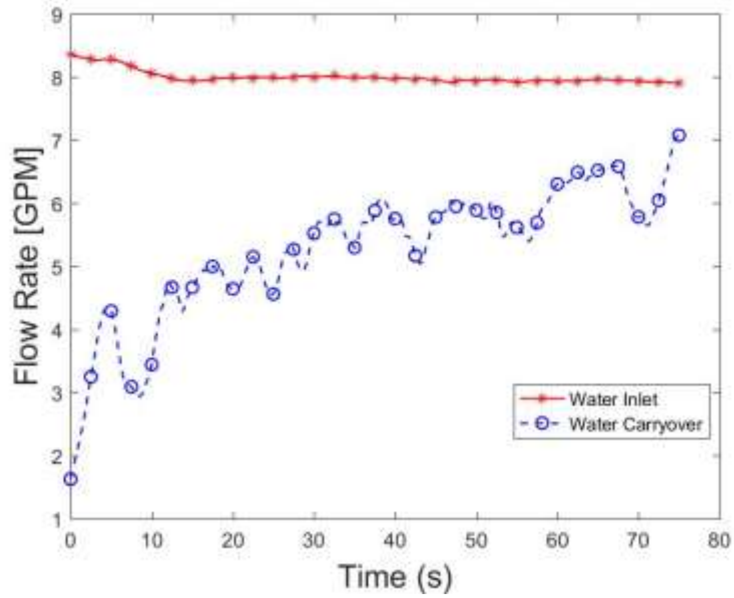

Figure G584: Water flow rates for test 2016_06_16_test_23.

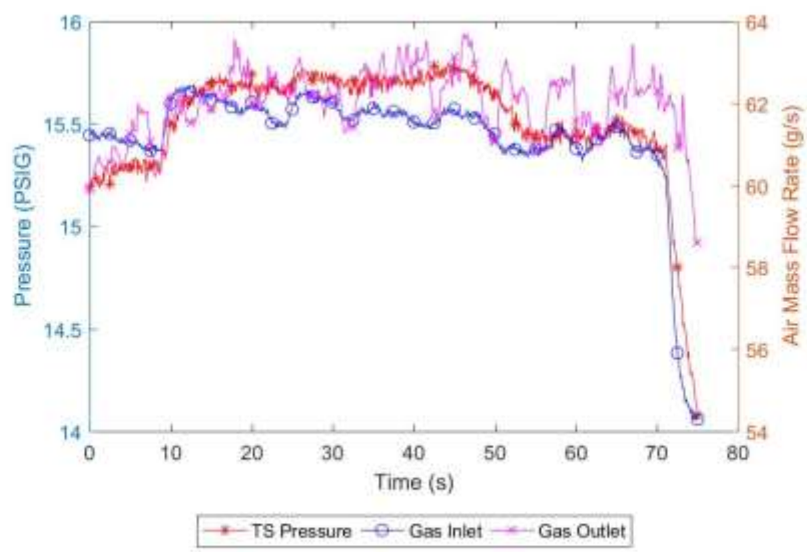

Figure G585: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_24.

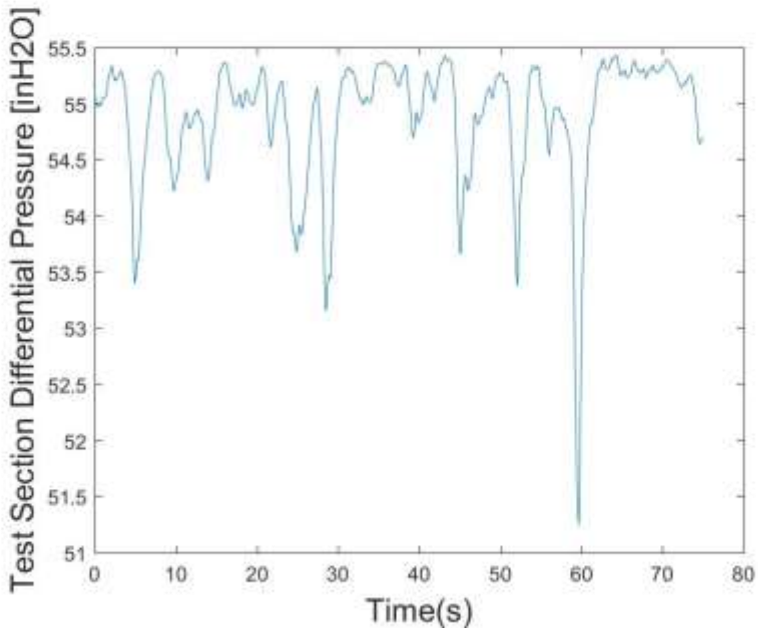

Figure G586: Test section differential pressure for test 2016_06_16_test_24.

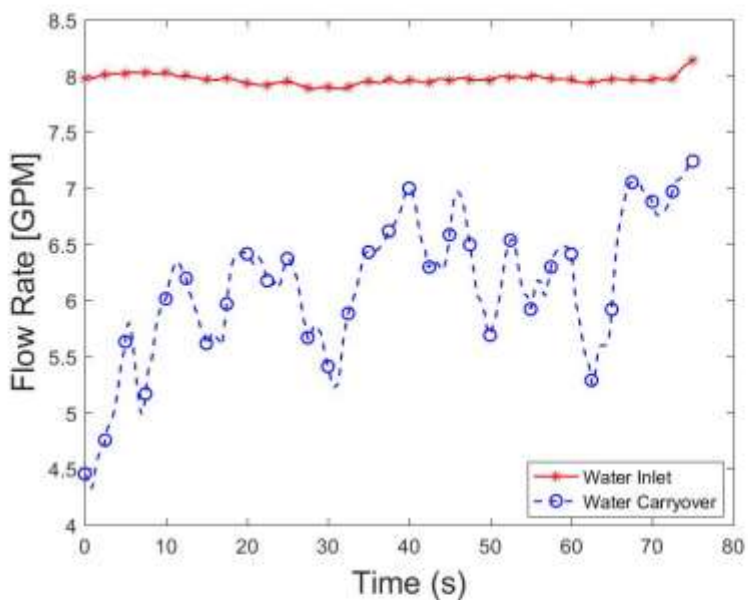

Figure G587: Water flow rates for test 2016_06_16_test_24.

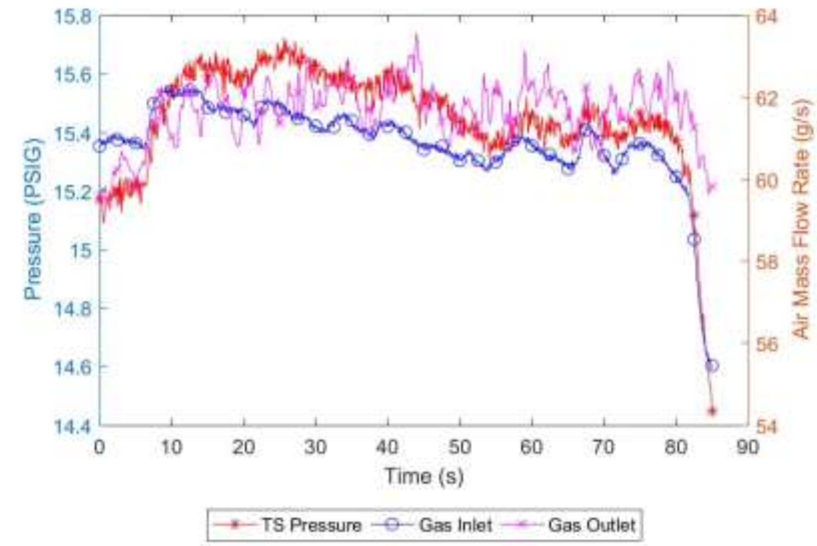

Figure G588: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_25.

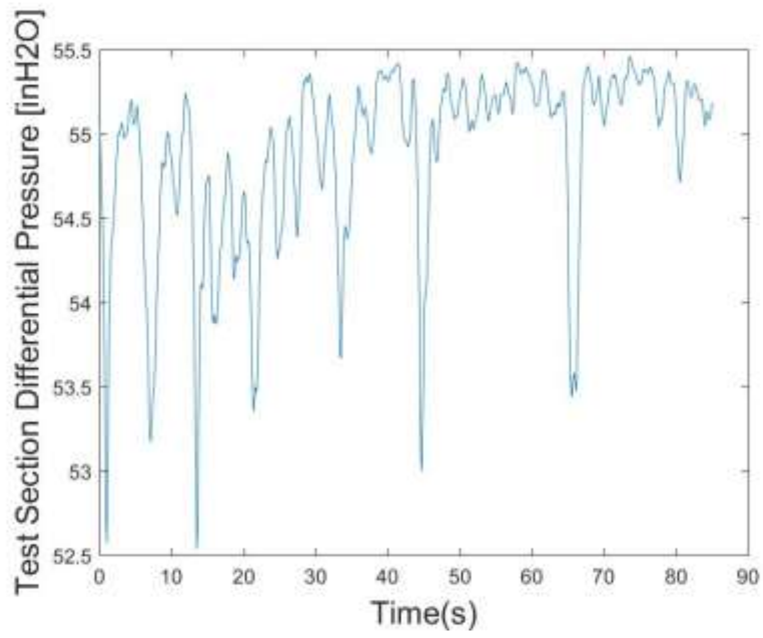

Figure G589: Test section differential pressure for test 2016_06_16_test_25.

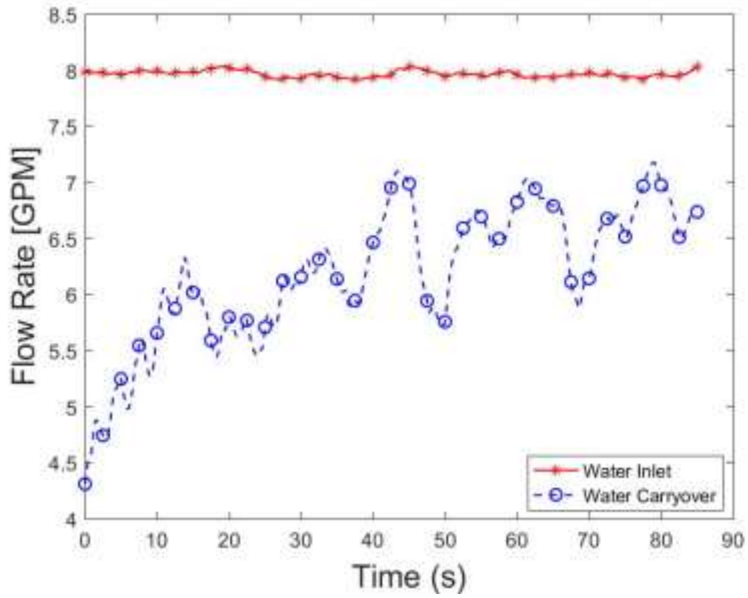

Figure G590: Water flow rates for test 2016_06_16_test_25.

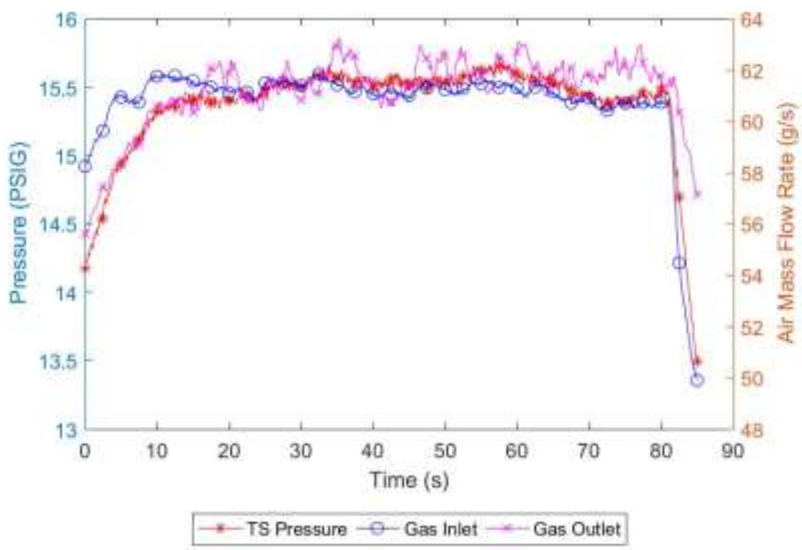

Figure G591: Pressure and gas inlet and outlet mass flow rates for test 2016_06_16_test_26.

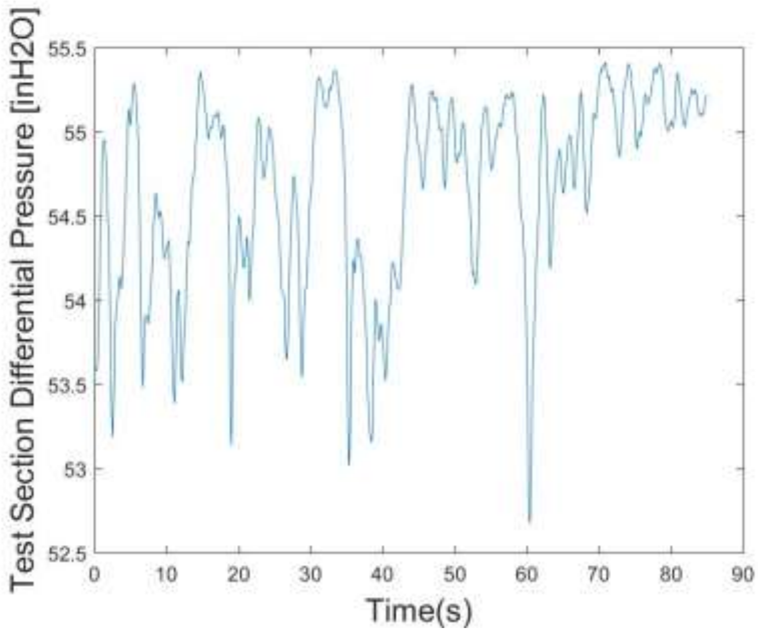

Figure G592: Test section differential pressure for test 2016_06_16_test_26.

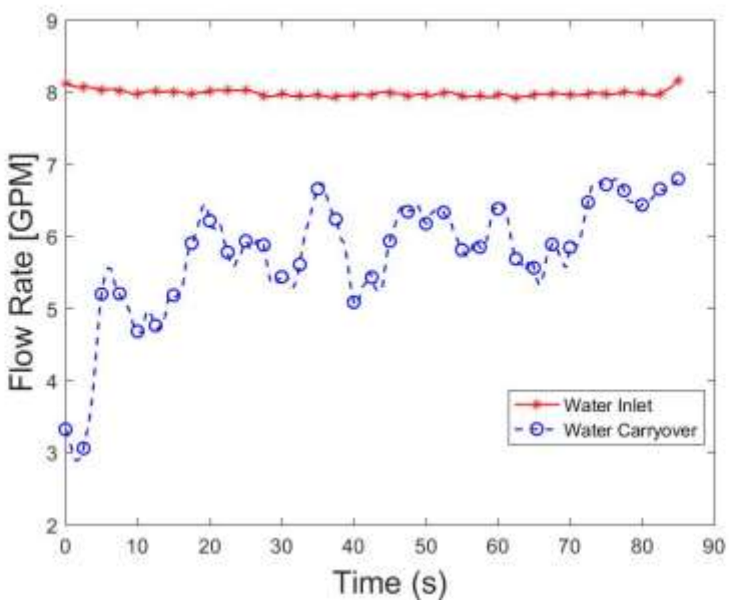

Figure G593: Water flow rates for test 2016_06_16_test_26.

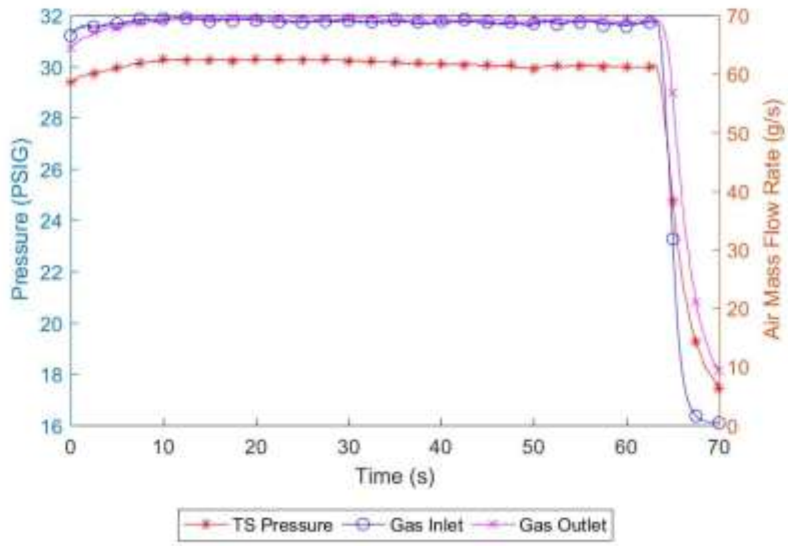

Figure G594: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_08.

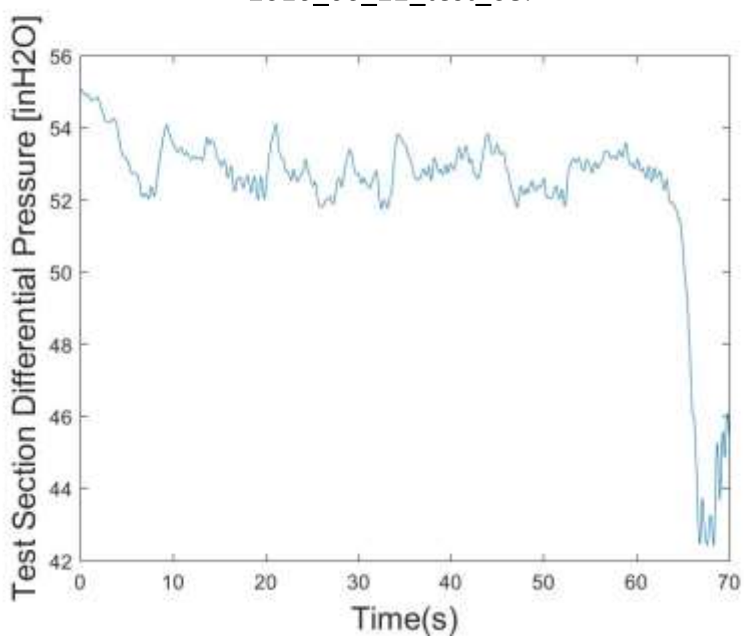

Figure G595: Test section differential pressure for test 2016_06_22_test_08.

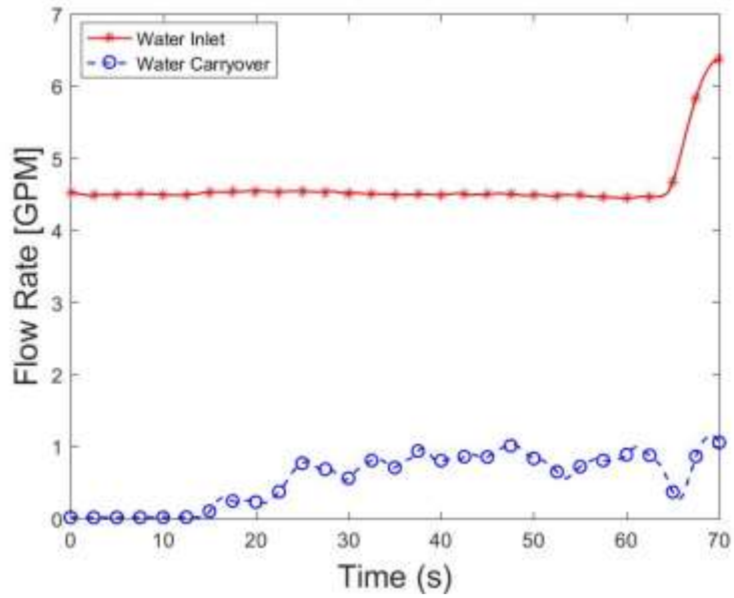

Figure G596: Water flow rates for test 2016_06_22_test_08.

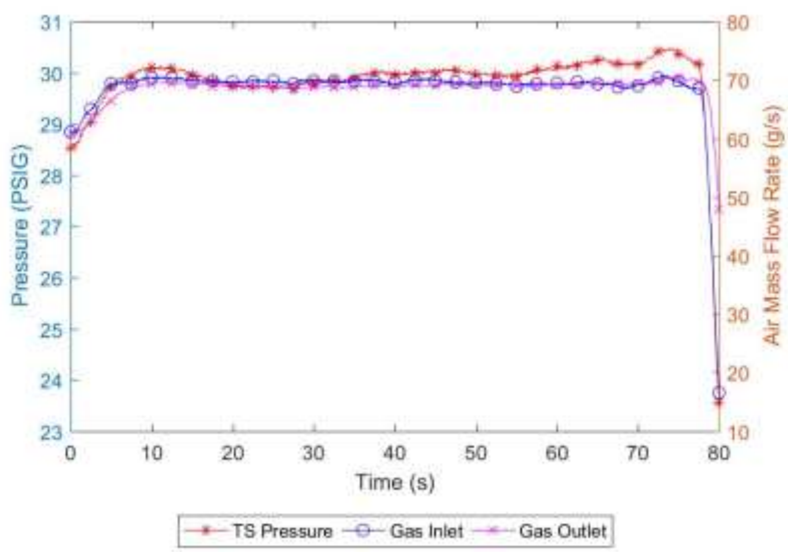

Figure G597: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_10.

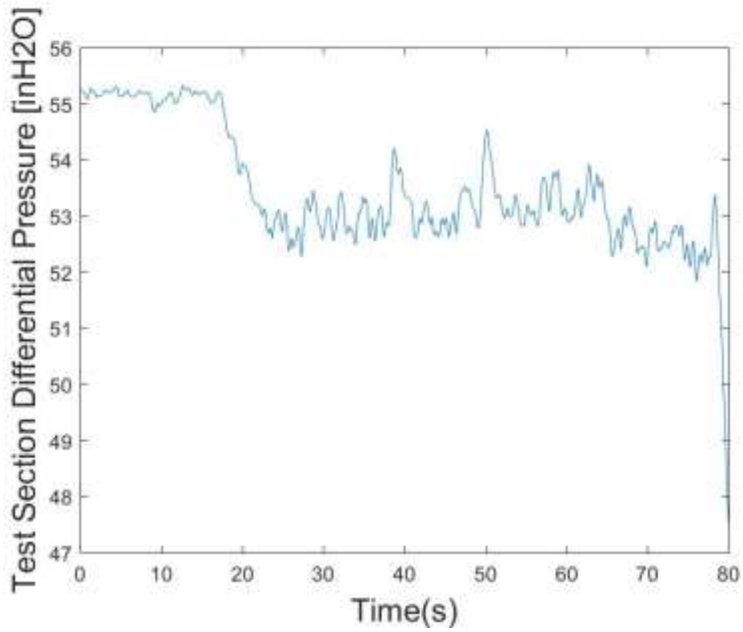

Figure G598: Test section differential pressure for test 2016_06_22_test_10.

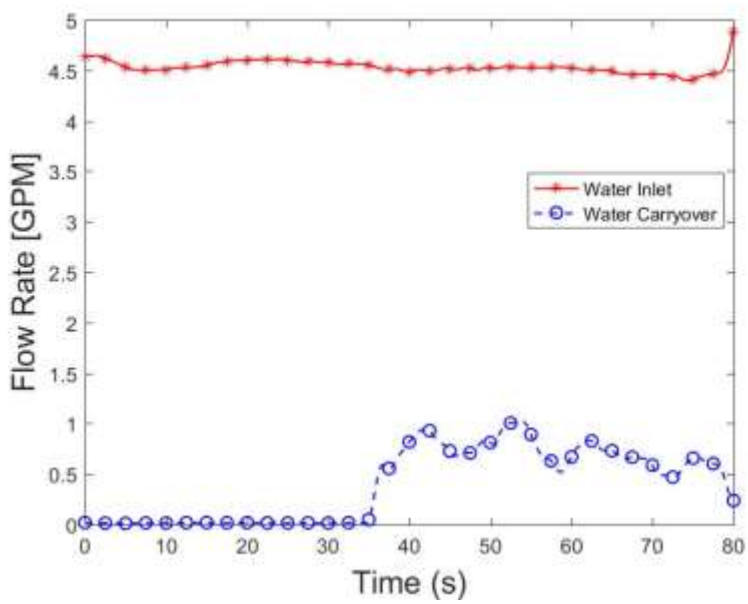

Figure G599: Water flow rates for test 2016_06_22_test_10.

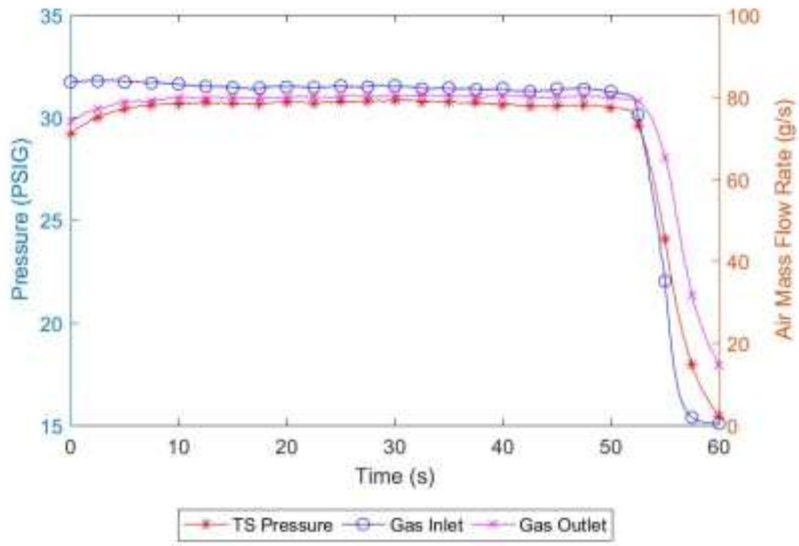

Figure G600: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_11.

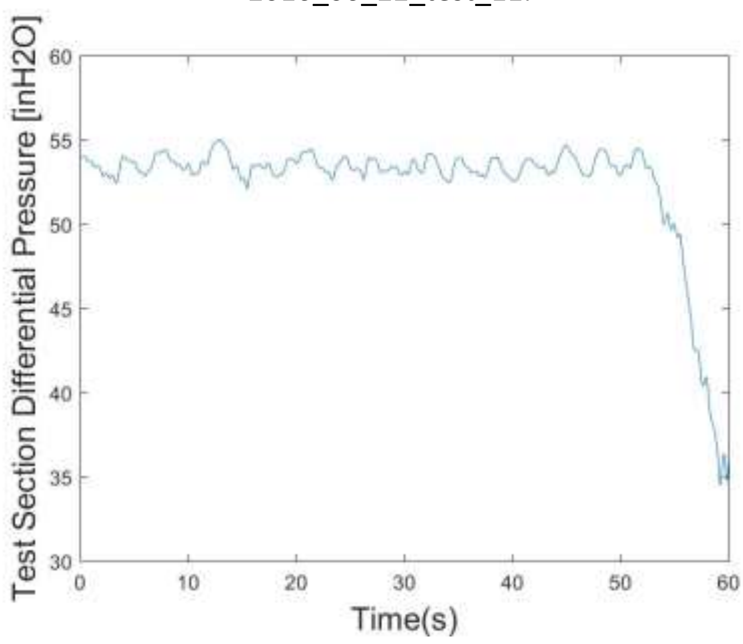

Figure G601: Test section differential pressure for test 2016_06_22_test_11.

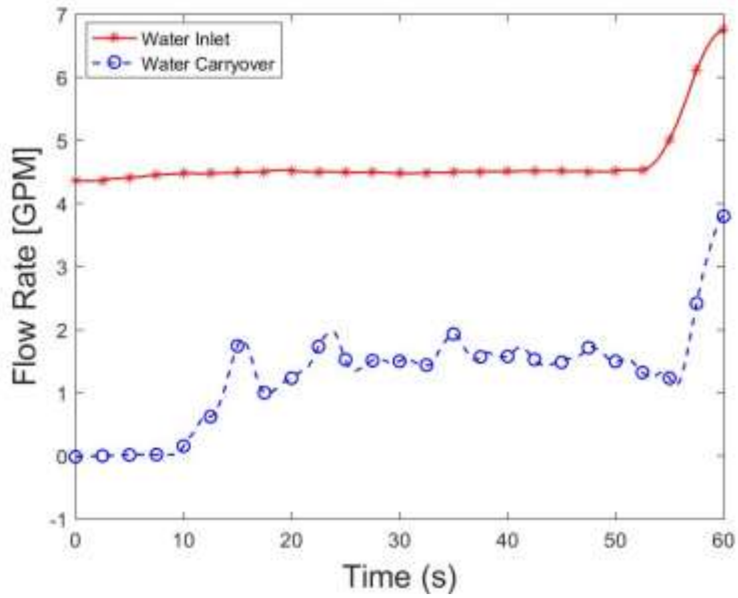

Figure G602: Water flow rates for test 2016_06_22_test_11.

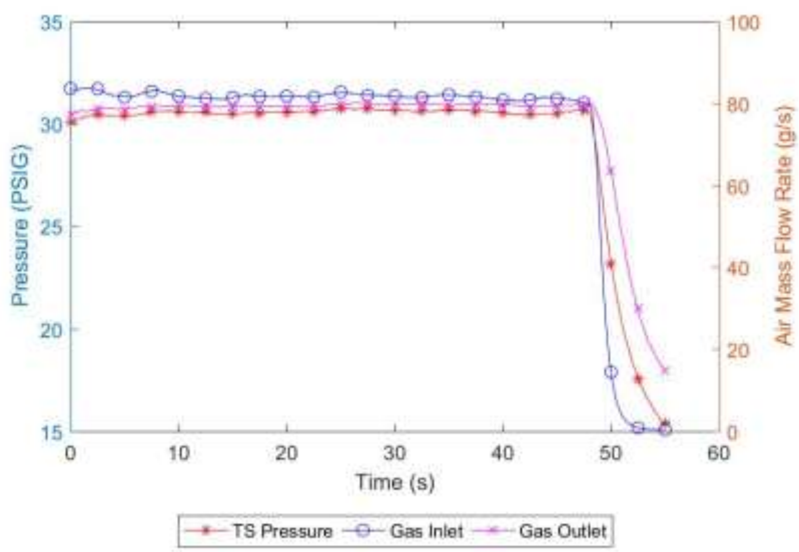

Figure G603: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_12.

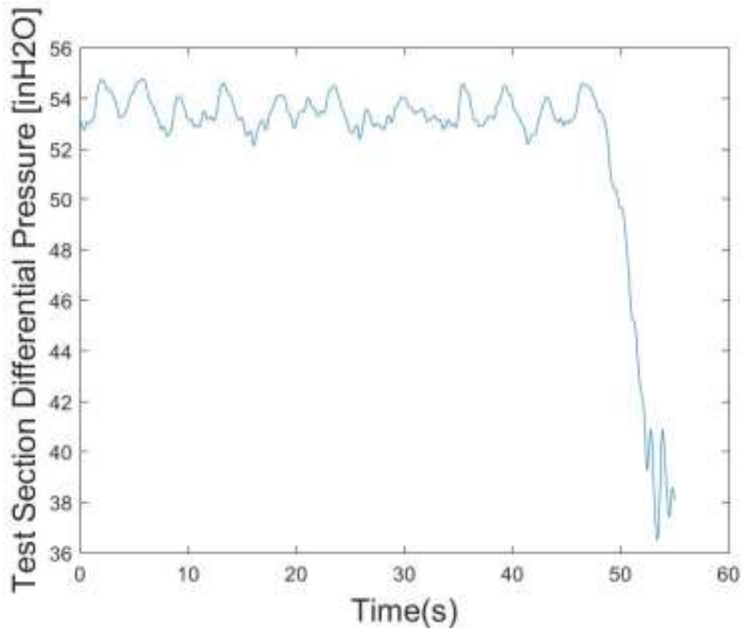

Figure G604: Test section differential pressure for test 2016_06_22_test_12.

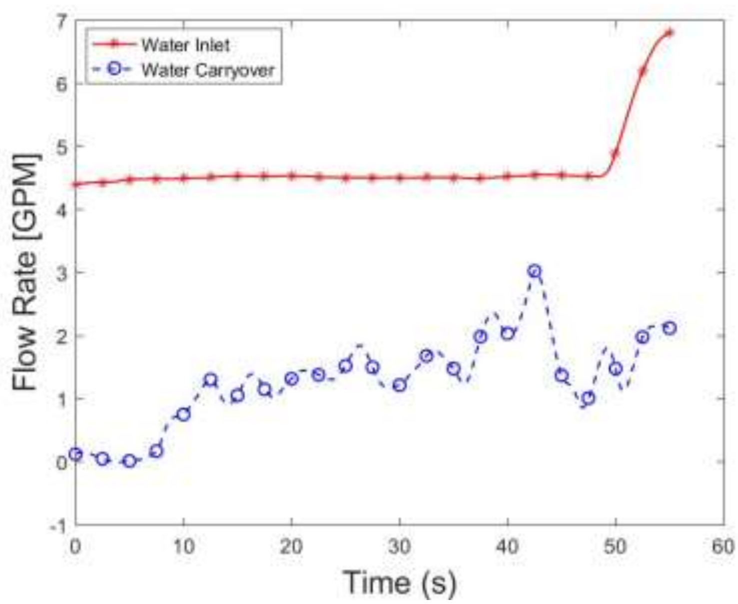

Figure G605: Water flow rates for test 2016_06_22_test_12.

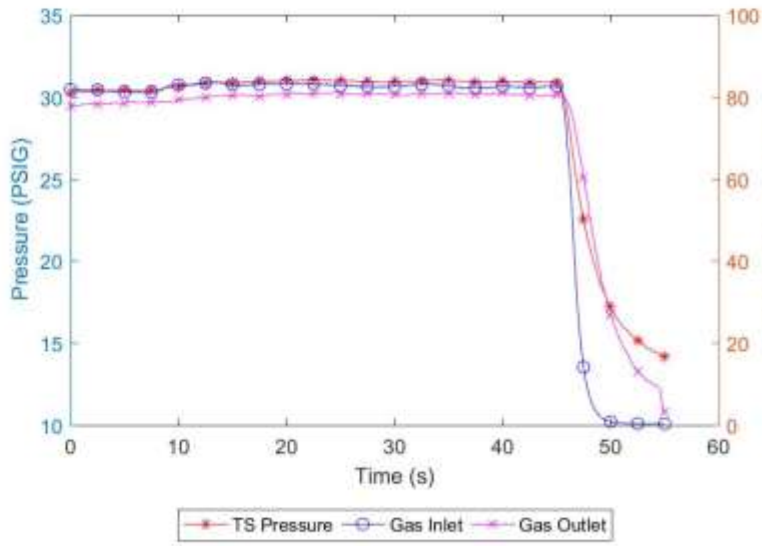

Figure G606: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_13.

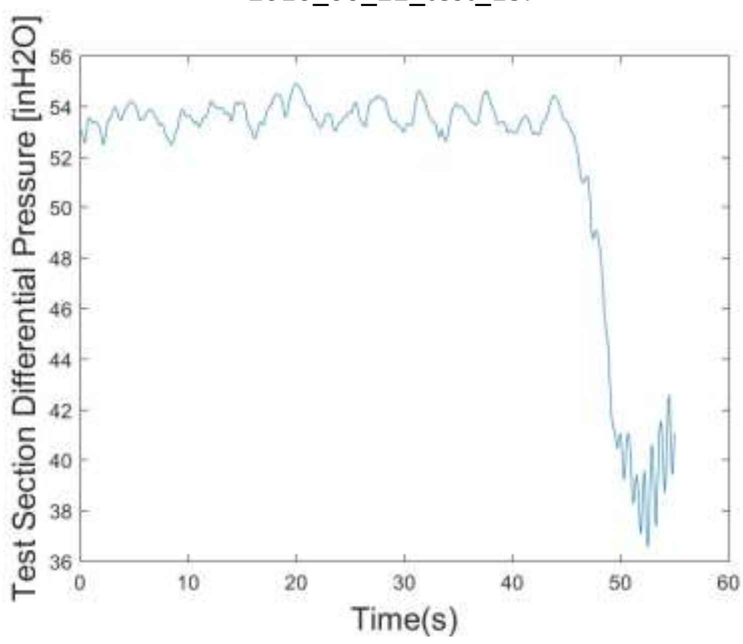

Figure G607: Test section differential pressure for test 2016_06_22_test_13.

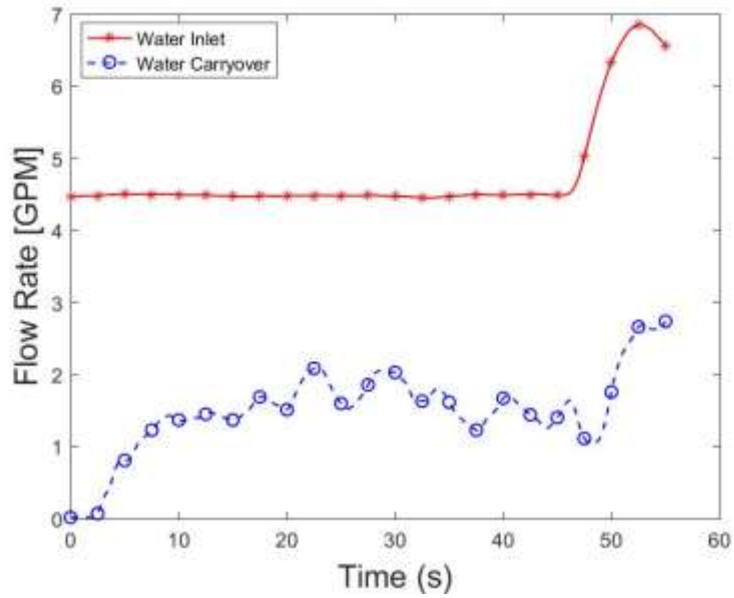

Figure G608: Water flow rates for test 2016_06_22_test_13.

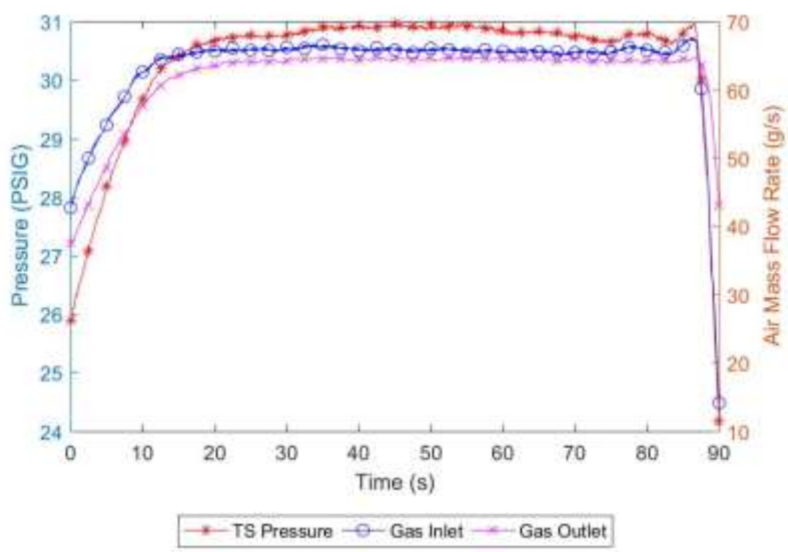

Figure G609: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_14.

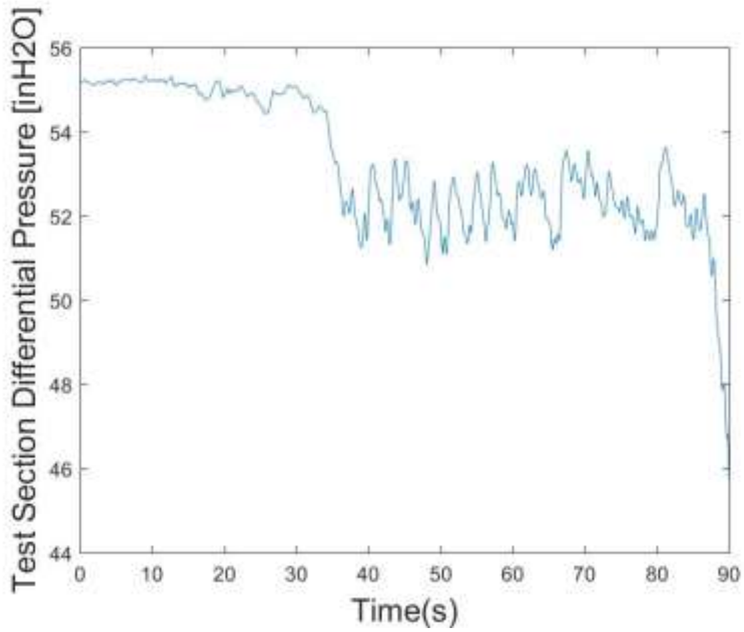

Figure G610: Test section differential pressure for test 2016_06_22_test_14.

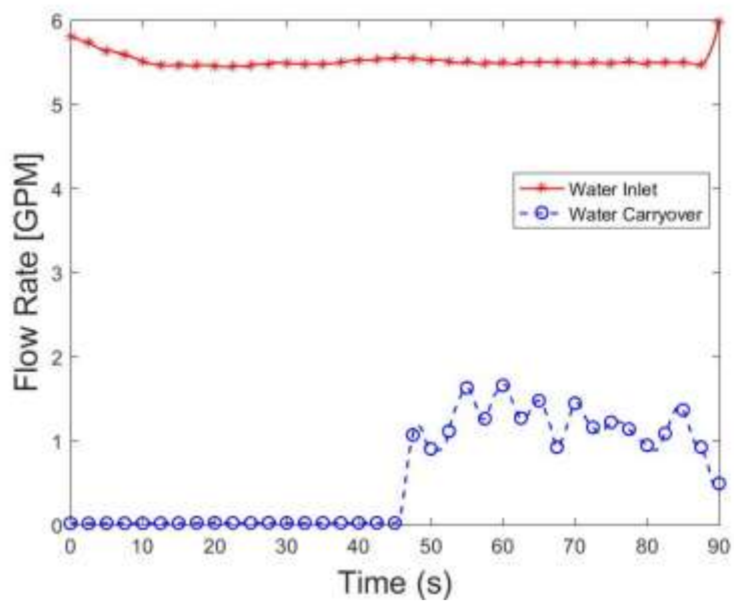

Figure G611: Water flow rates for test 2016_06_22_test_14.

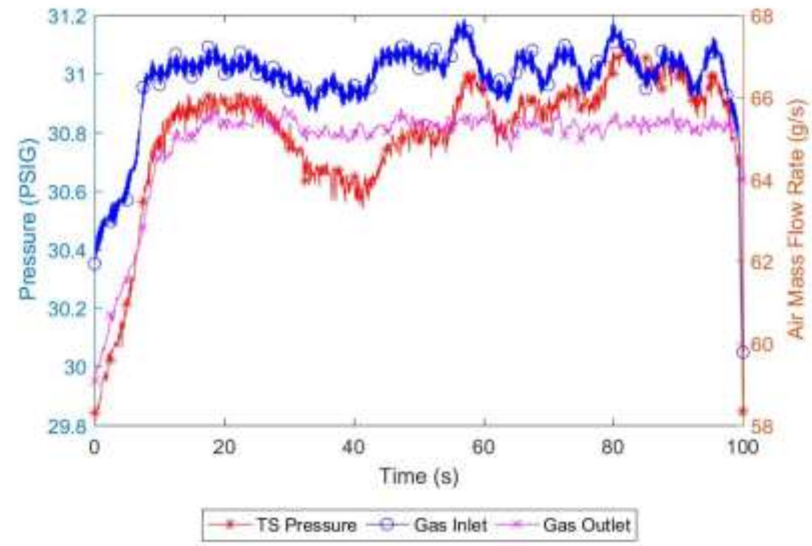

Figure G612: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_15.

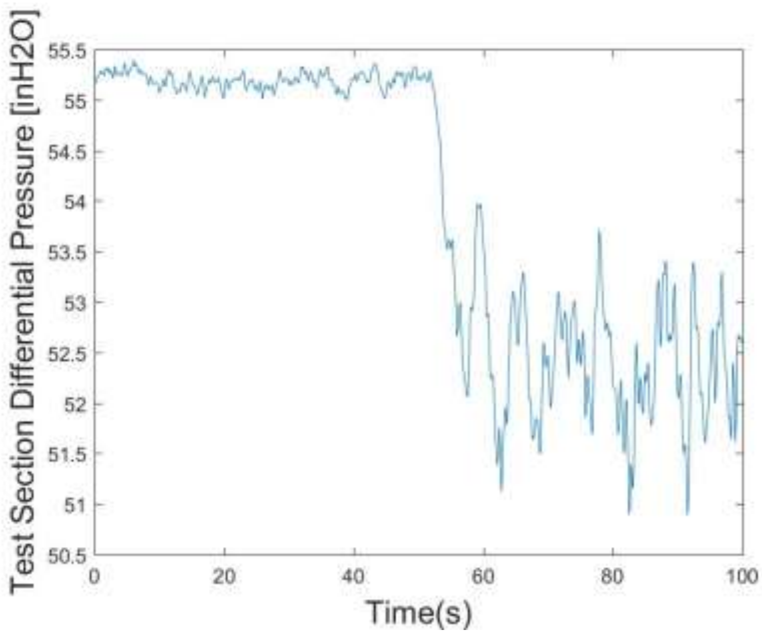

Figure G613: Test section differential pressure for test 2016_06_22_test_15.

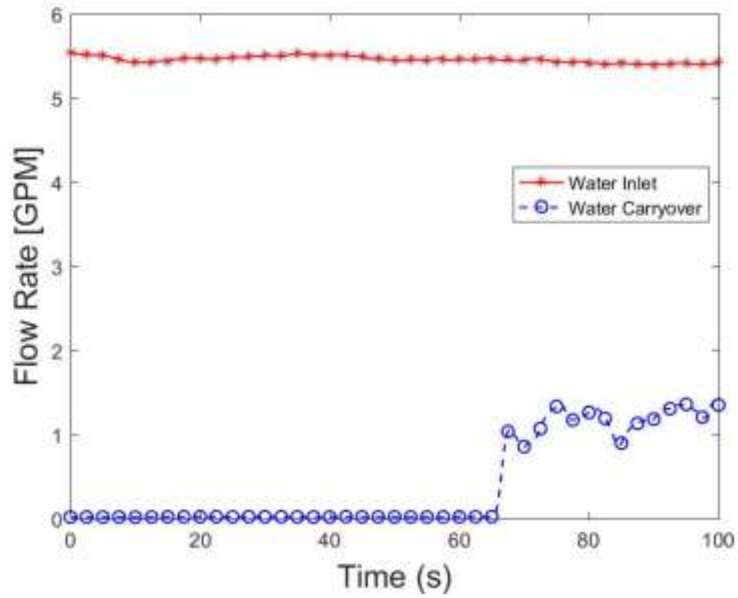

Figure G614: Water flow rates for test 2016_06_22_test_15.

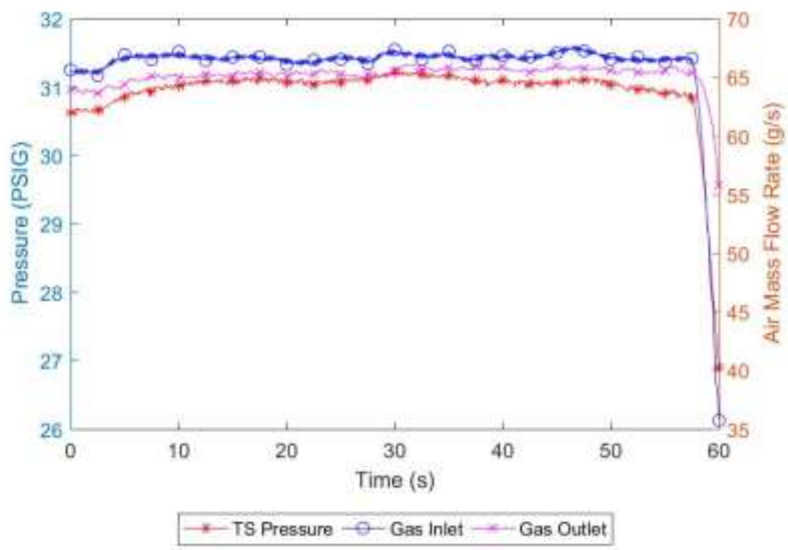

Figure G615: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_16.

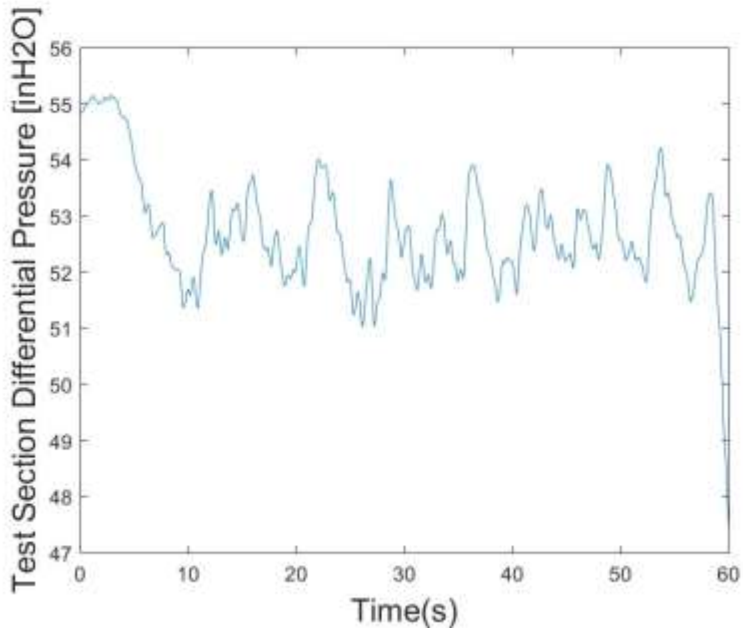

Figure G616: Test section differential pressure for test 2016_06_22_test_16.

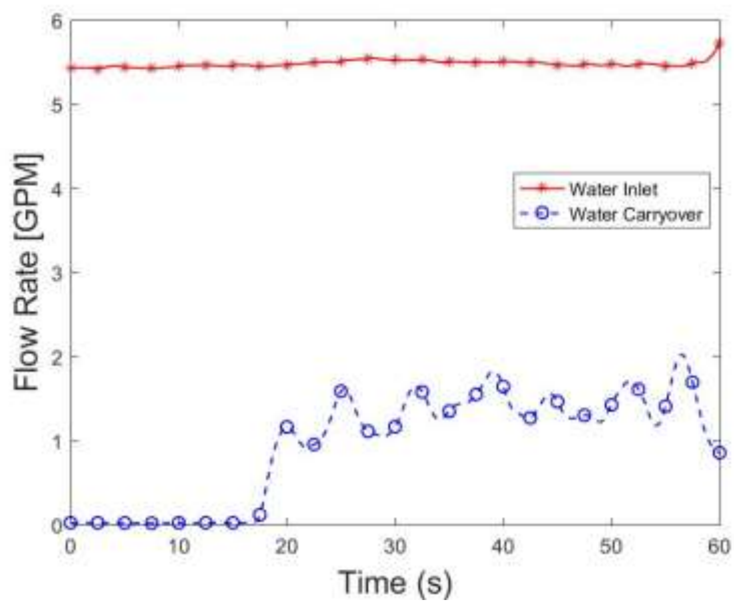

Figure G617: Water flow rates for test 2016_06_22_test_16.

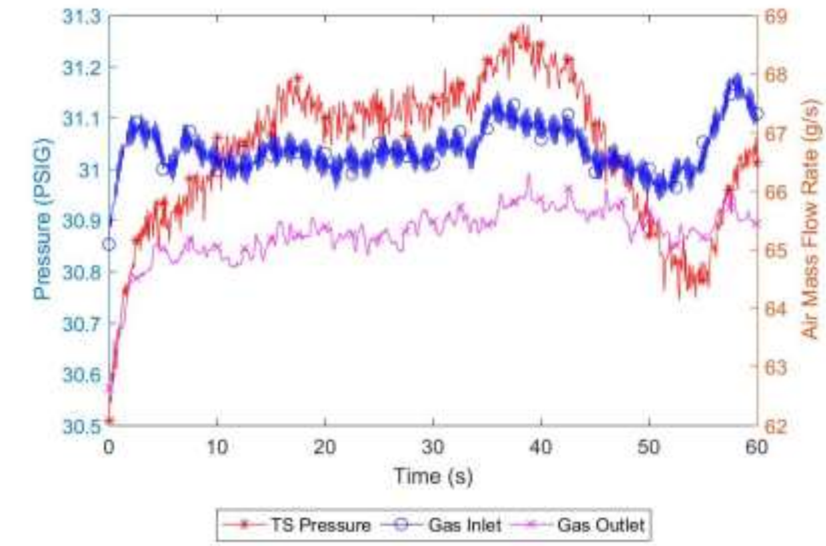

Figure G618: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_17.

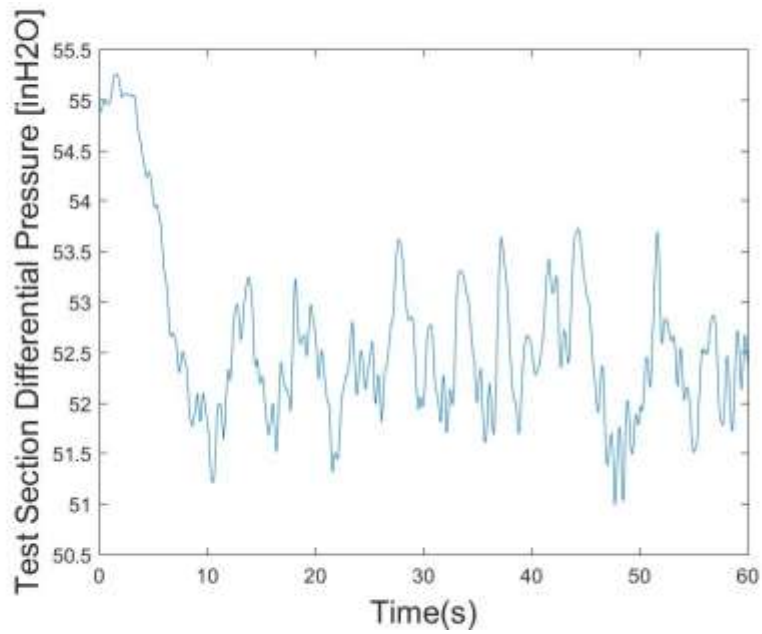

Figure G619: Test section differential pressure for test 2016_06_22_test_17.

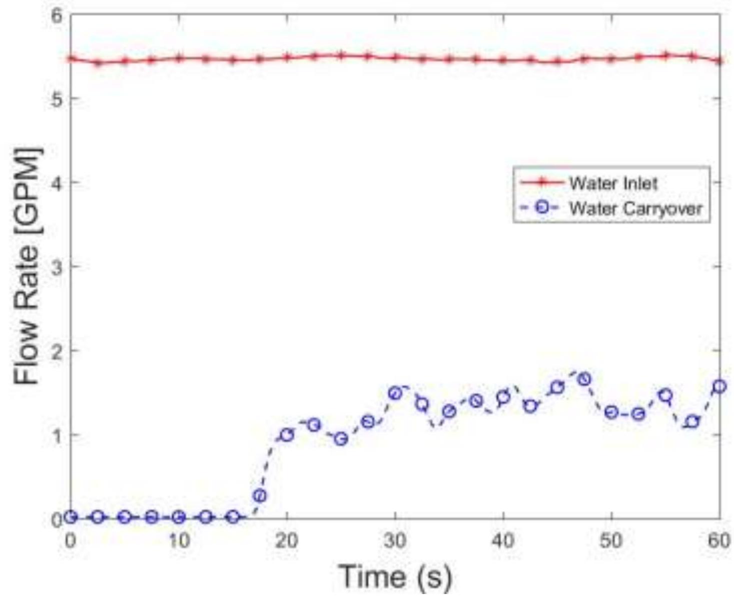

Figure G620: Water flow rates for test 2016_06_22_test_17.

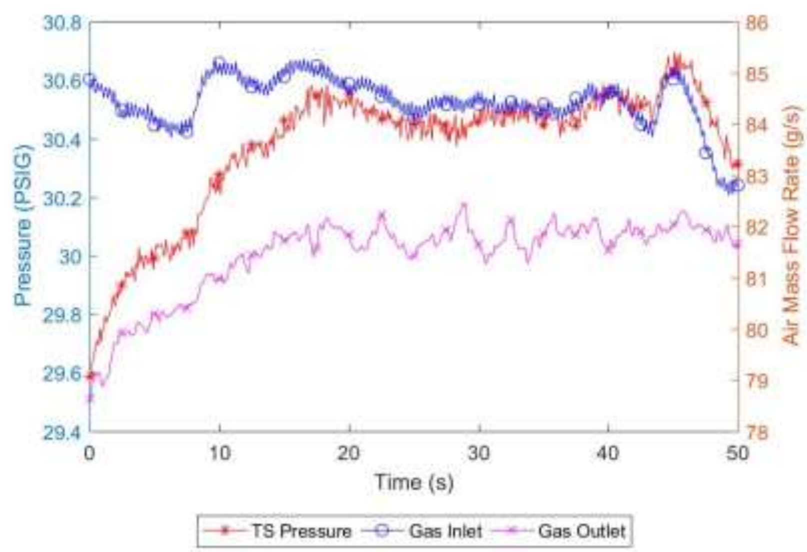

Figure G621: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_18.

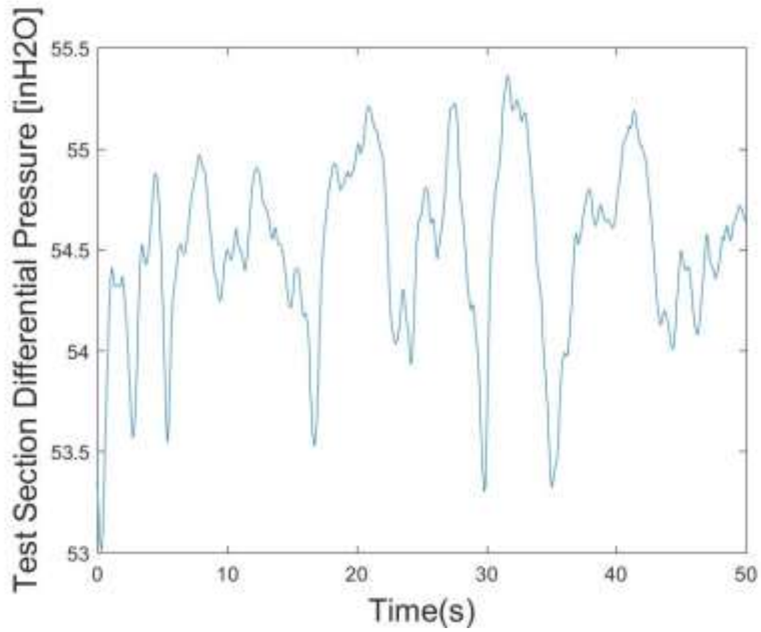

Figure G622: Test section differential pressure for test 2016_06_22_test_18.

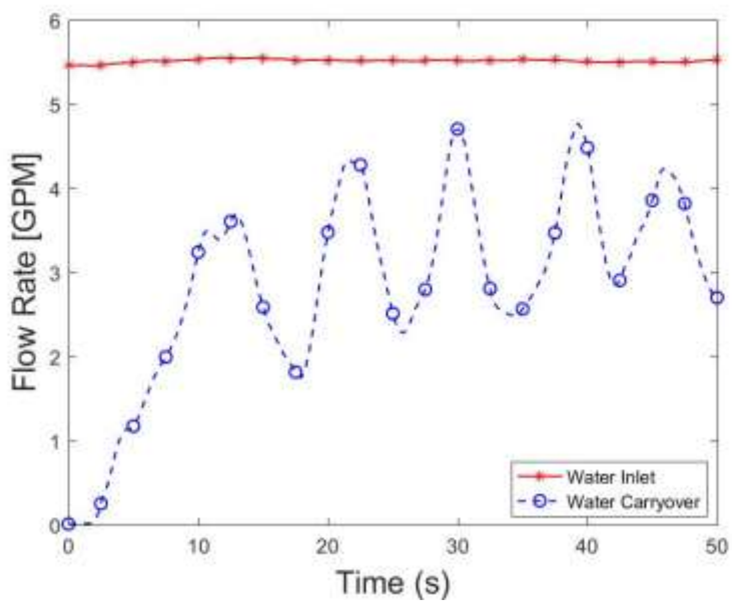

Figure G623: Water flow rates for test 2016_06_22_test_18.

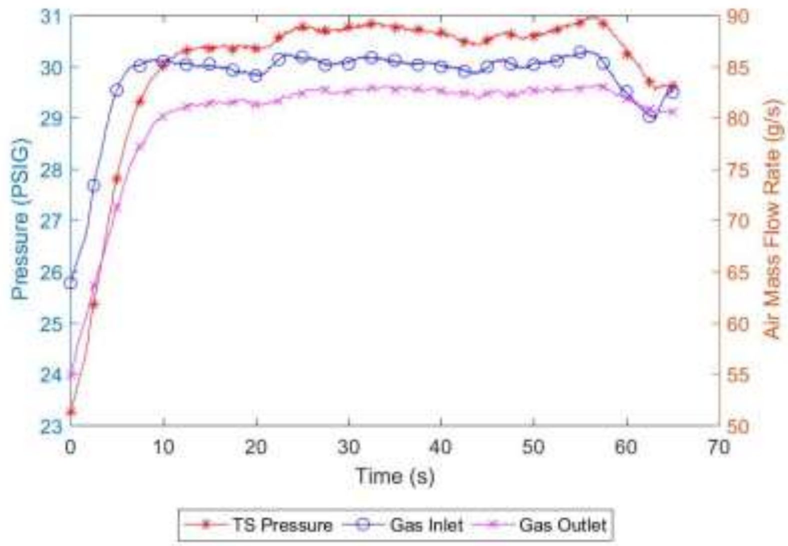

Figure G624: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_19.

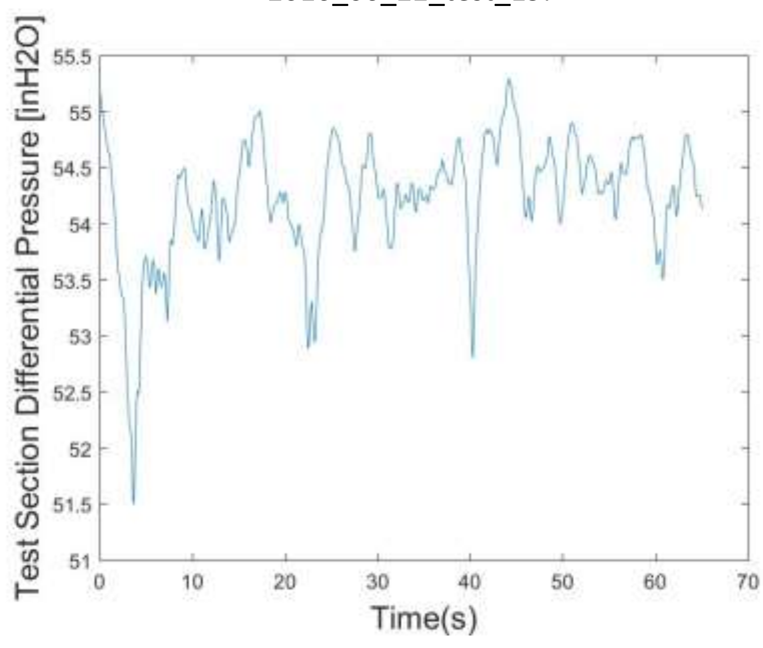

Figure G625: Test section differential pressure for test 2016_06_22_test_19.

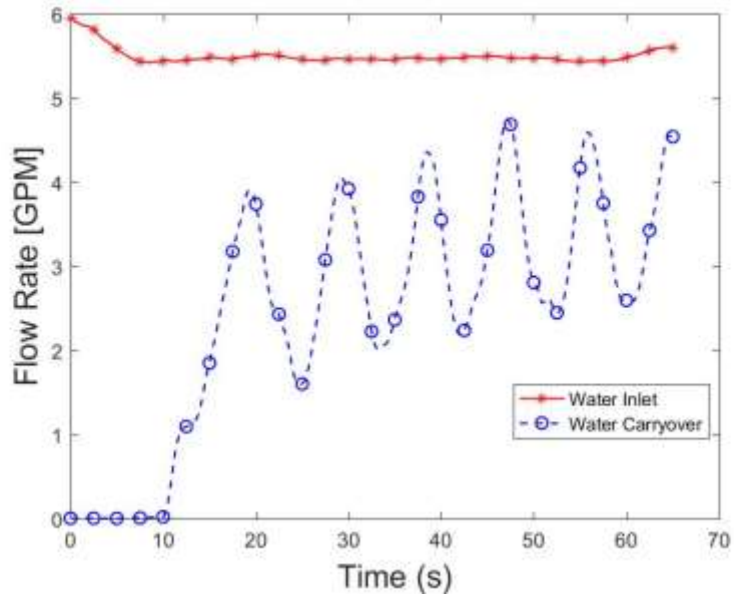

Figure G626: Water flow rates for test 2016_06_22_test_19.

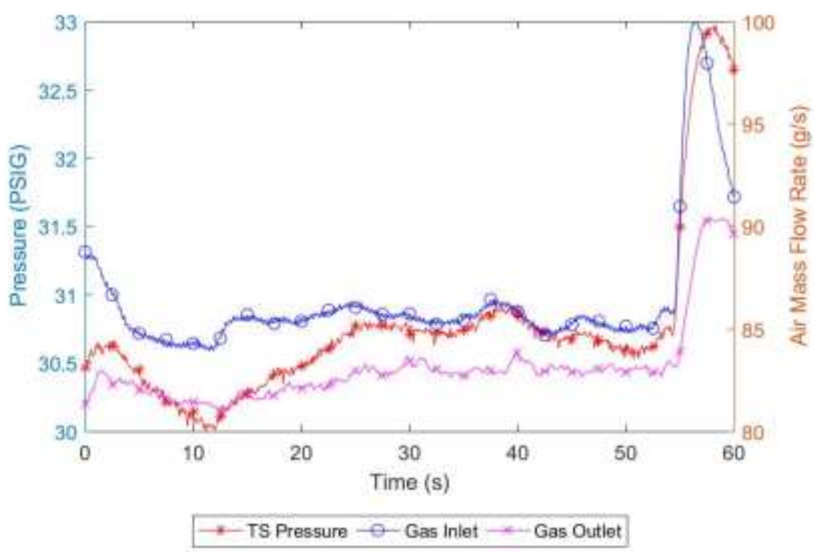

Figure G627: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_20.

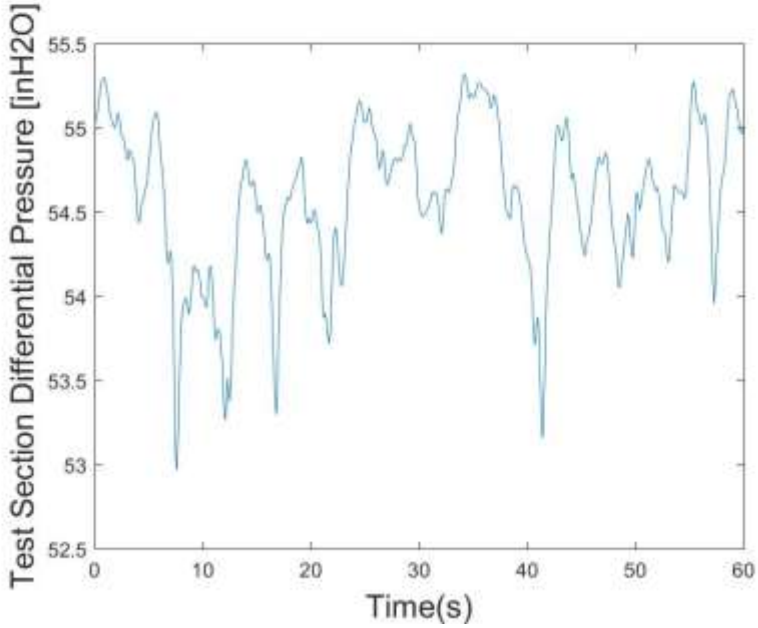

Figure G628: Test section differential pressure for test 2016_06_22_test_20.

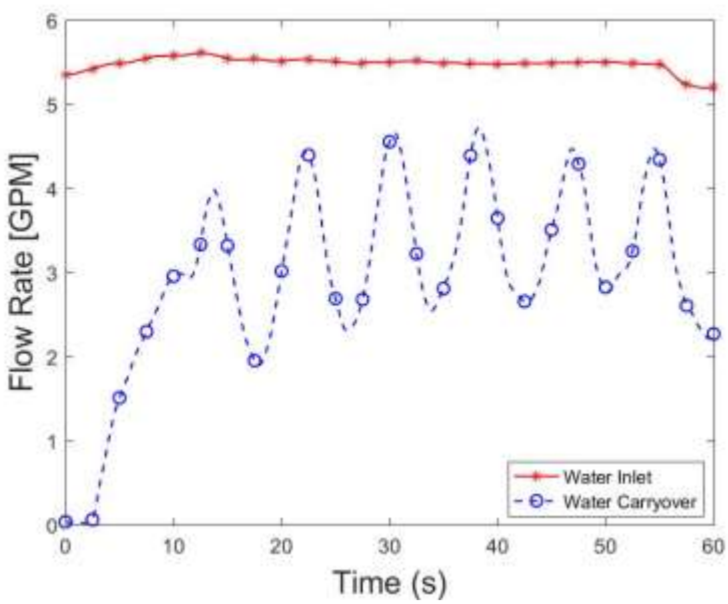

Figure G629: Water flow rates for test 2016_06_22_test_20.

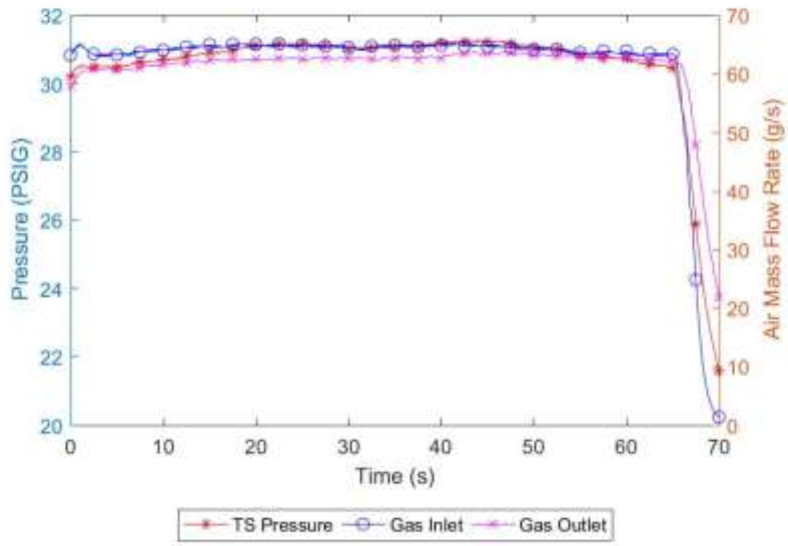

Figure G630: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_21.

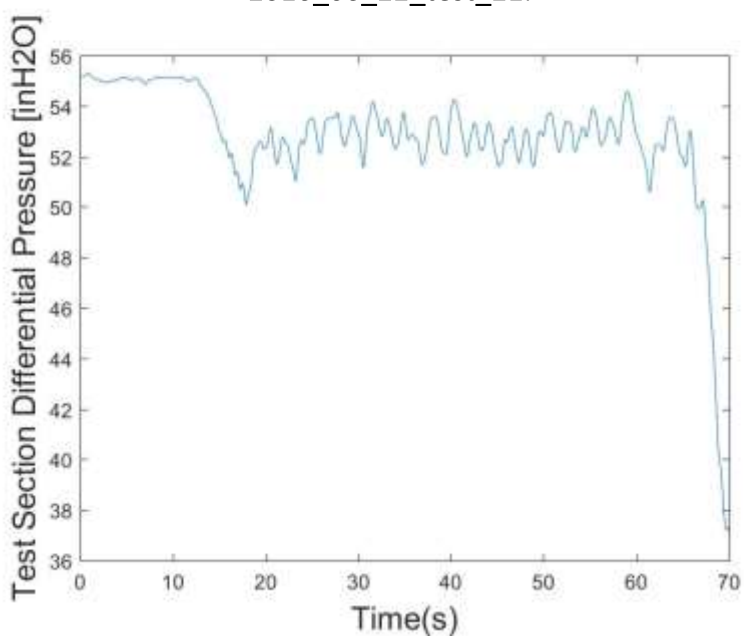

Figure G631: Test section differential pressure for test 2016_06_22_test_21.

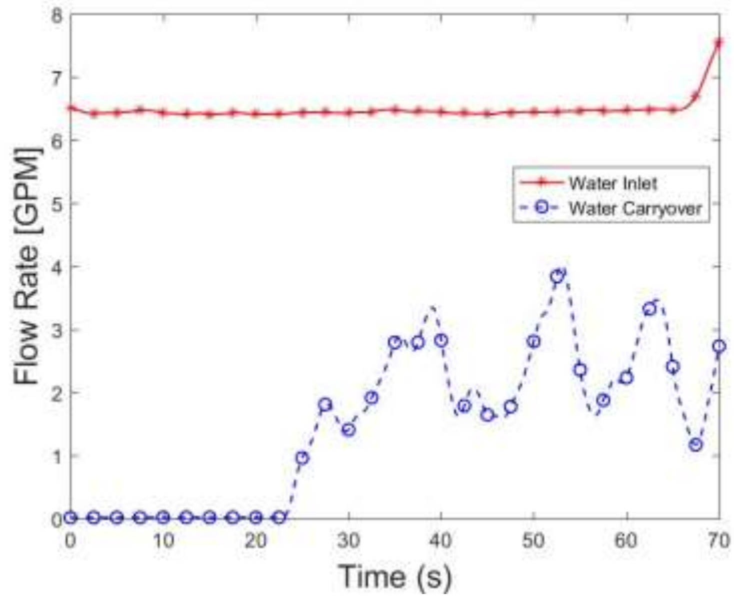

Figure G632: Water flow rates for test 2016_06_22_test_21.

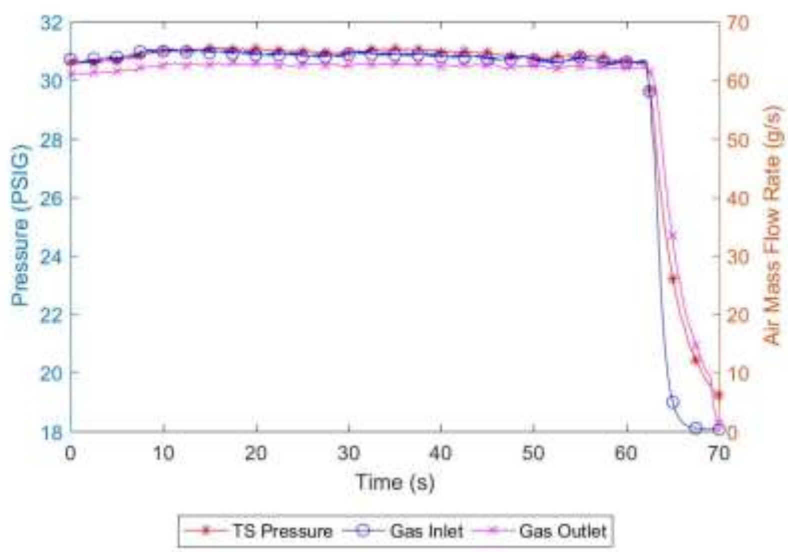

Figure G633: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_22.

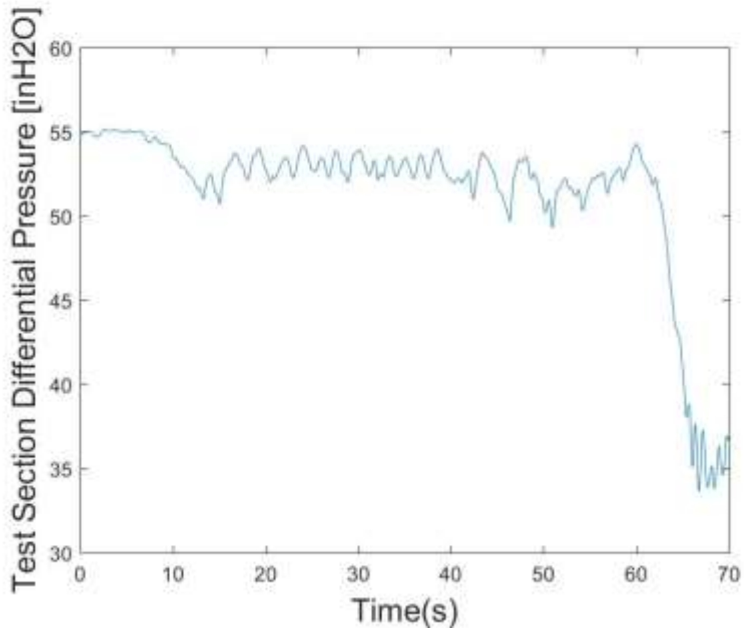

Figure G634: Test section differential pressure for test 2016_06_22_test_22.

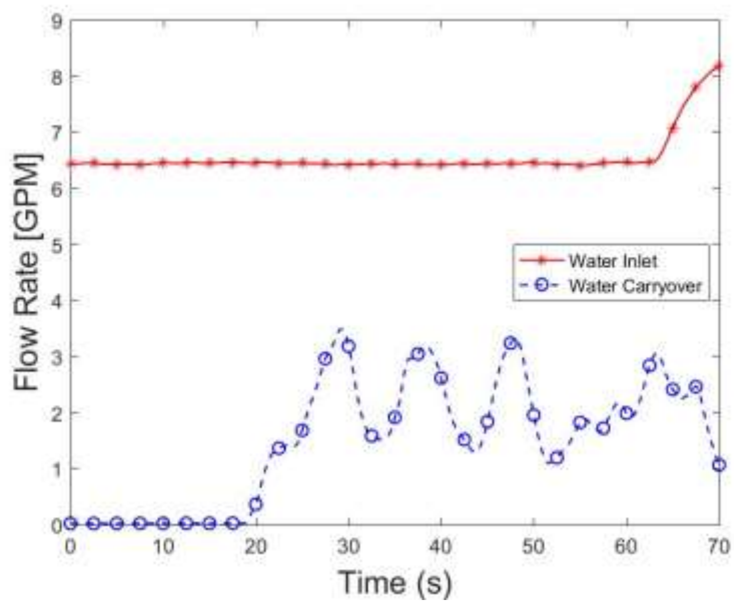

Figure G635: Water flow rates for test 2016_06_22_test_22.

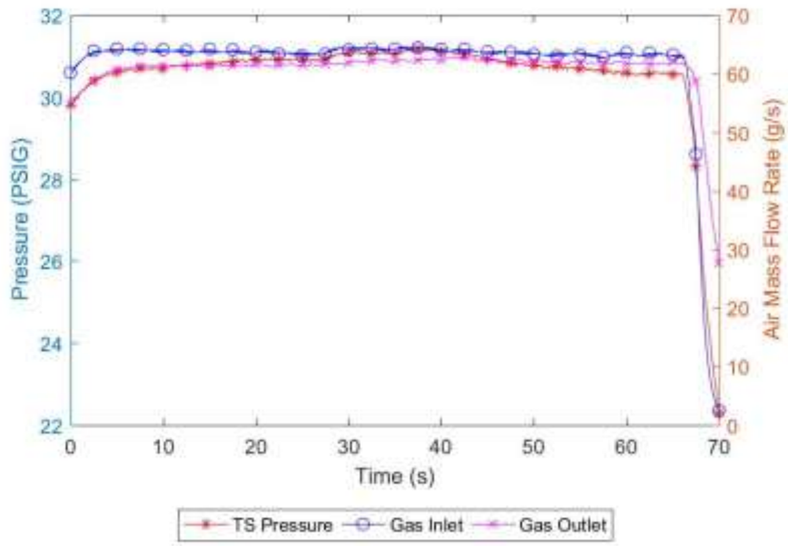

Figure G636: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_23.

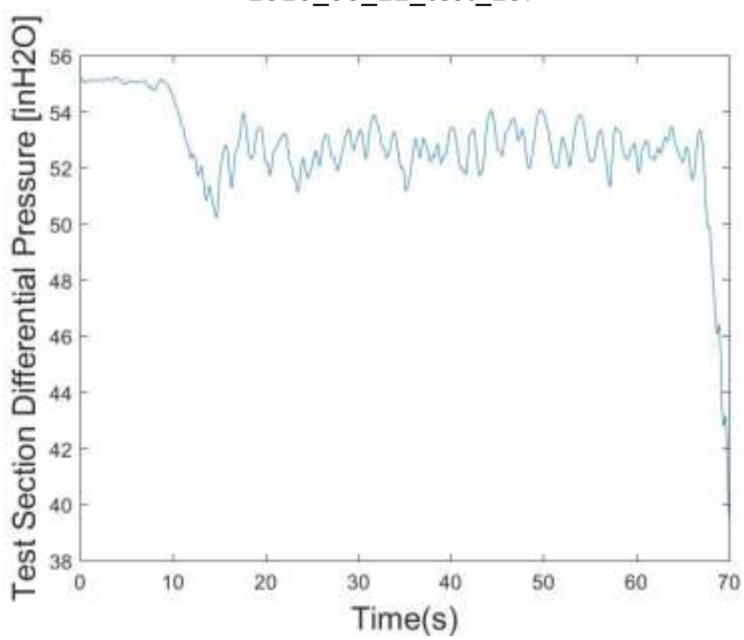

Figure G637: Test section differential pressure for test 2016_06_22_test_23.

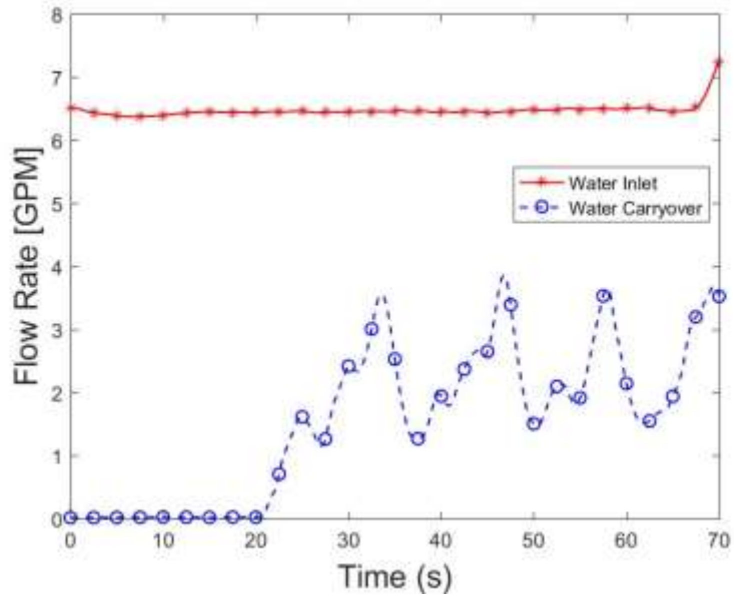

Figure G638: Water flow rates for test 2016_06_22_test_23.

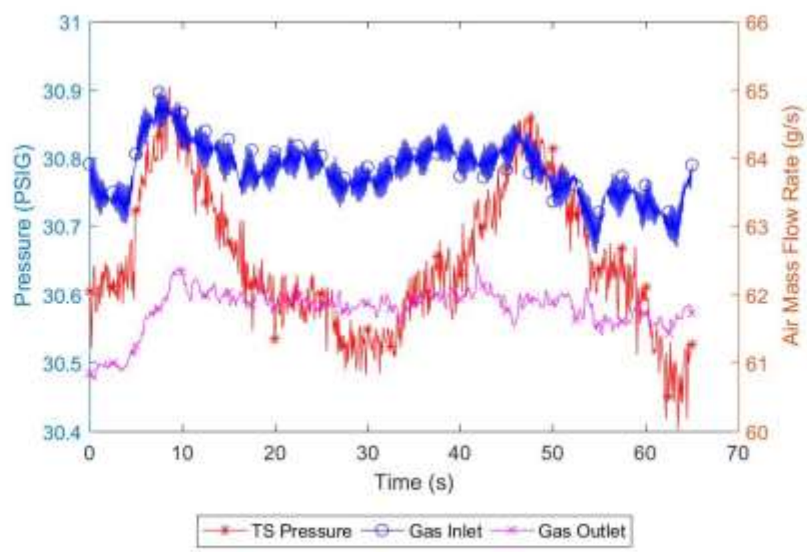

Figure G639: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_24.

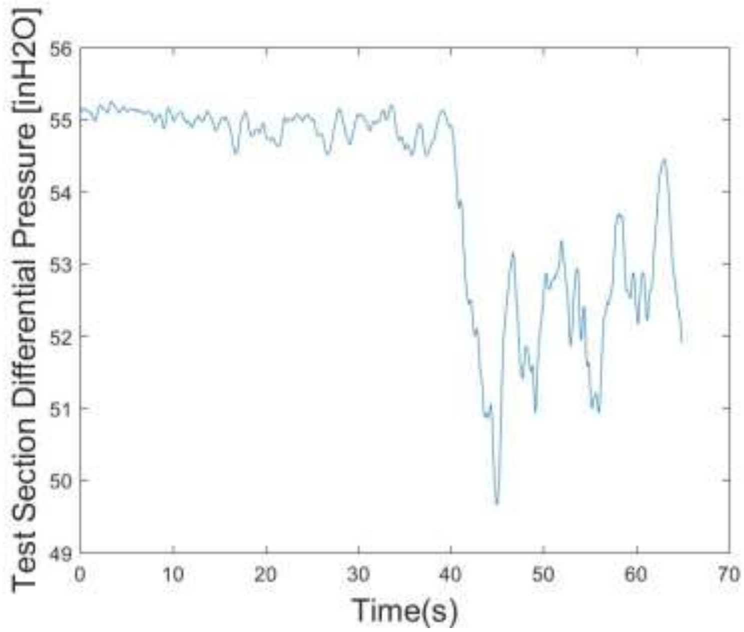

Figure G640: Test section differential pressure for test 2016_06_22_test_24.

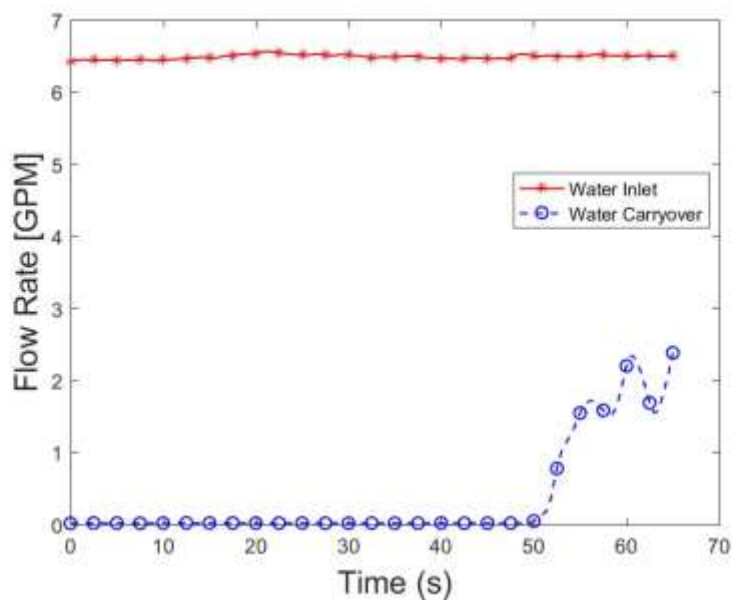

Figure G641: Water flow rates for test 2016_06_22_test_24.

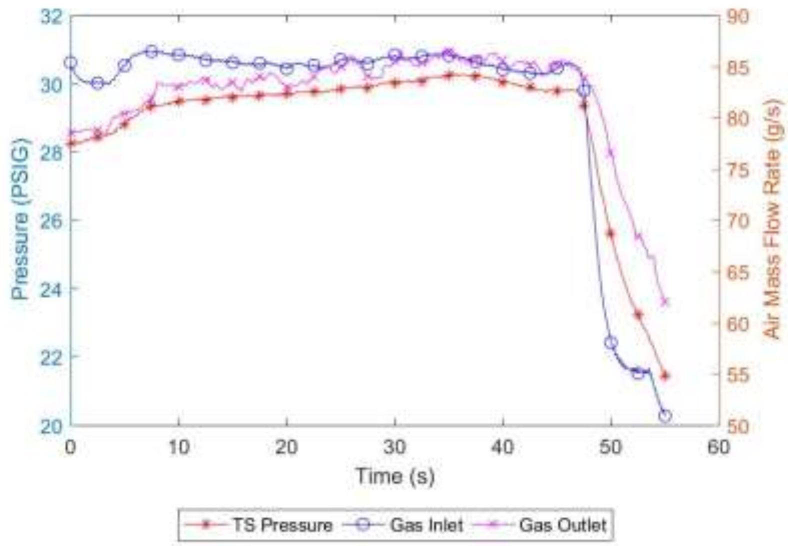

Figure G642: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_25.

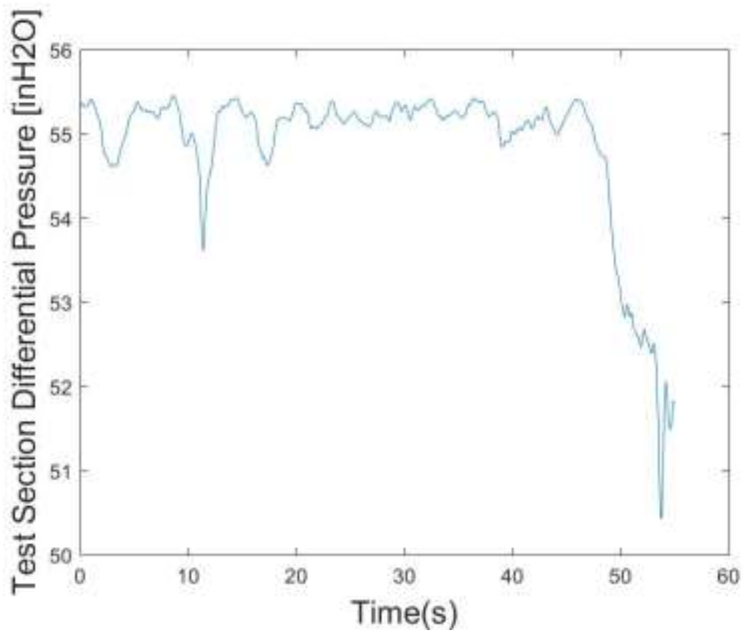

Figure G643: Test section differential pressure for test 2016_06_22_test_25.

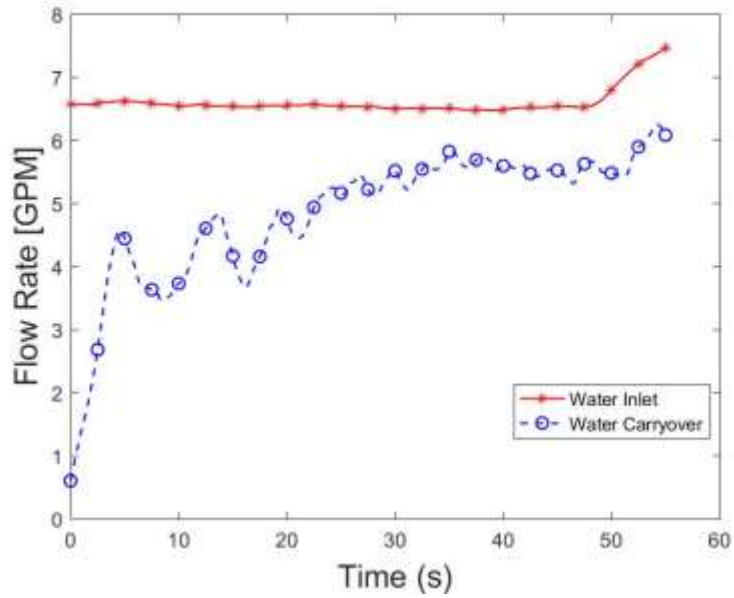

Figure G644: Water flow rates for test 2016_06_22_test_25.

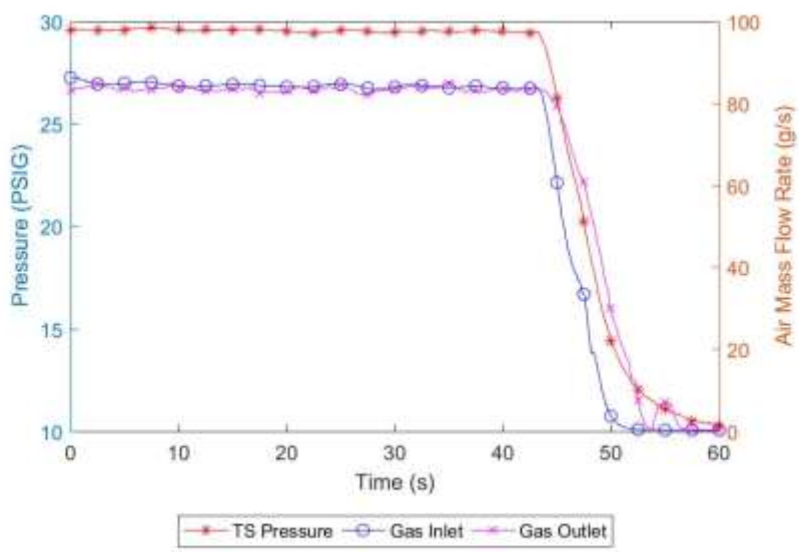

Figure G645: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_26.

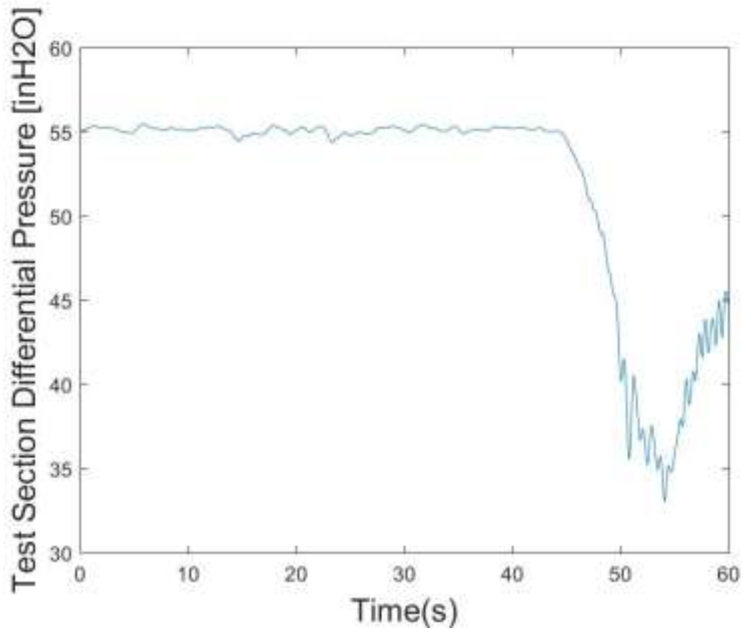

Figure G646: Test section differential pressure for test 2016_06_22_test_26.

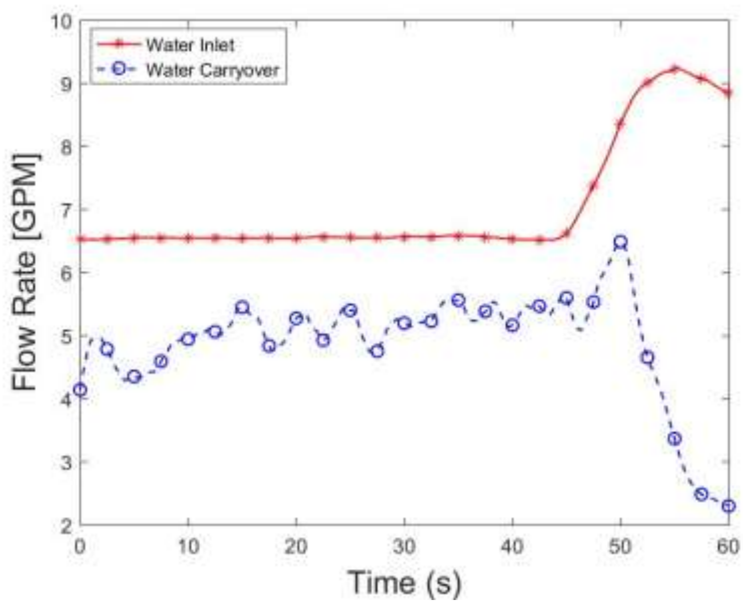

Figure G647: Water flow rates for test 2016_06_22_test_26.

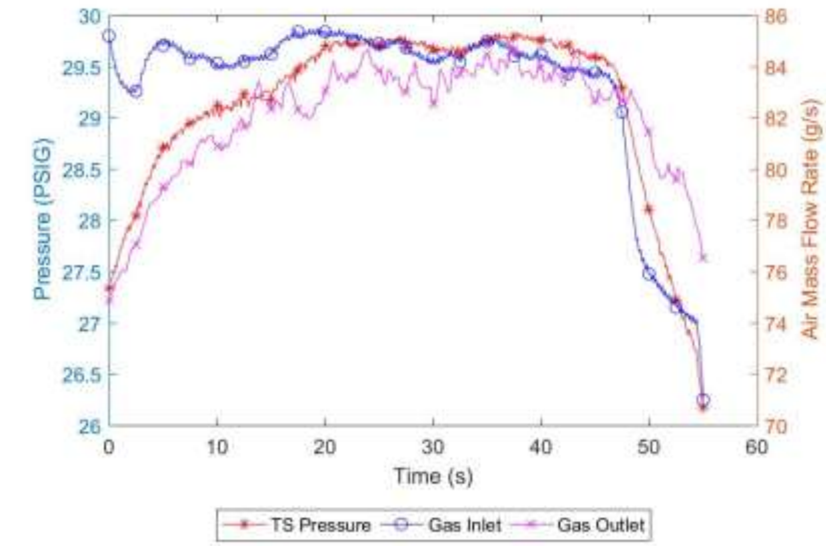

Figure G648: Pressure and gas inlet and outlet mass flow rates for test 2016_06_22_test_27.

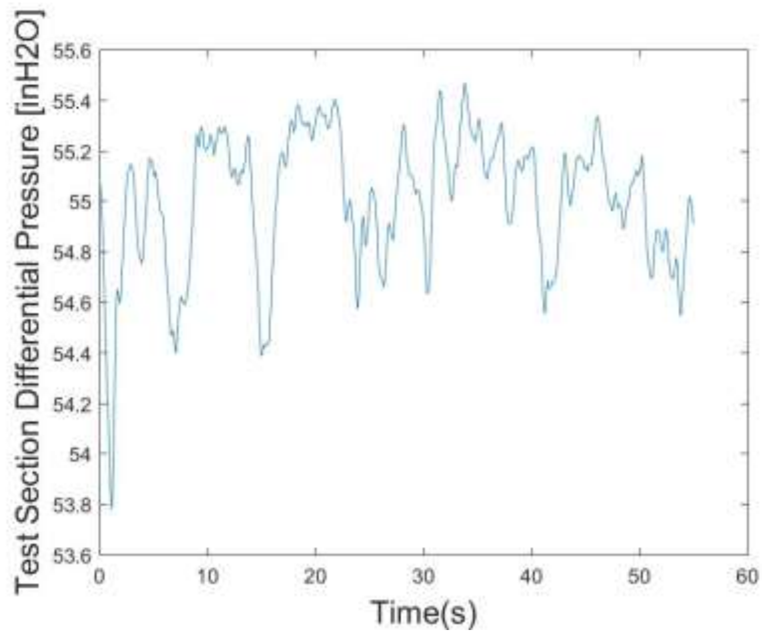

Figure G649: Test section differential pressure for test 2016_06_22_test_27.

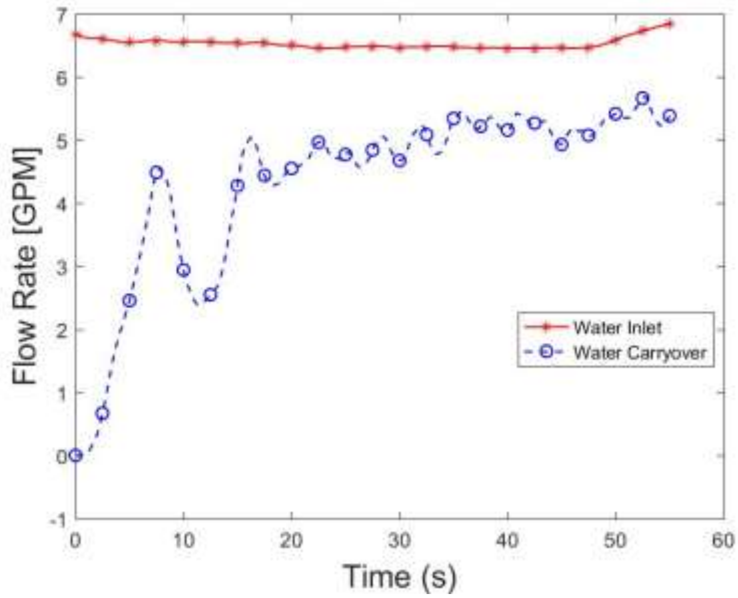

Figure G650: Water flow rates for test 2016_06_22_test_27.

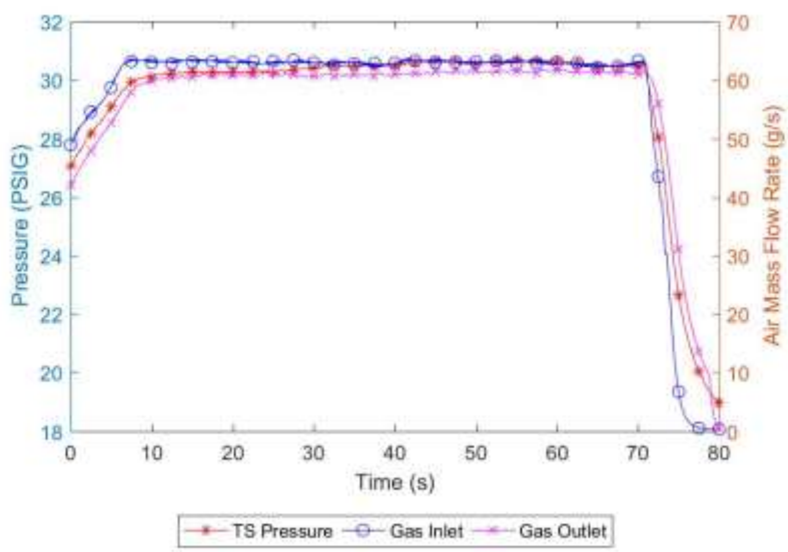

Figure G651: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_01.

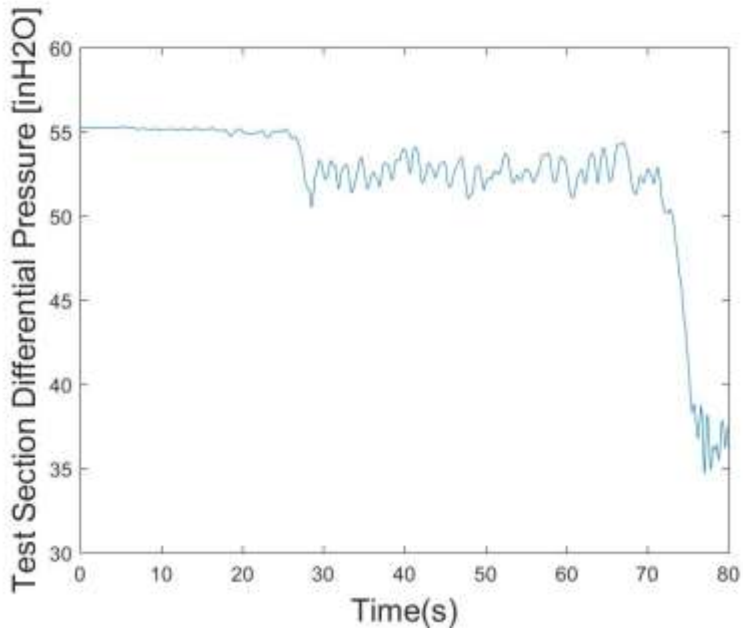

Figure G652: Test section differential pressure for test 2016_06_23_test_01.

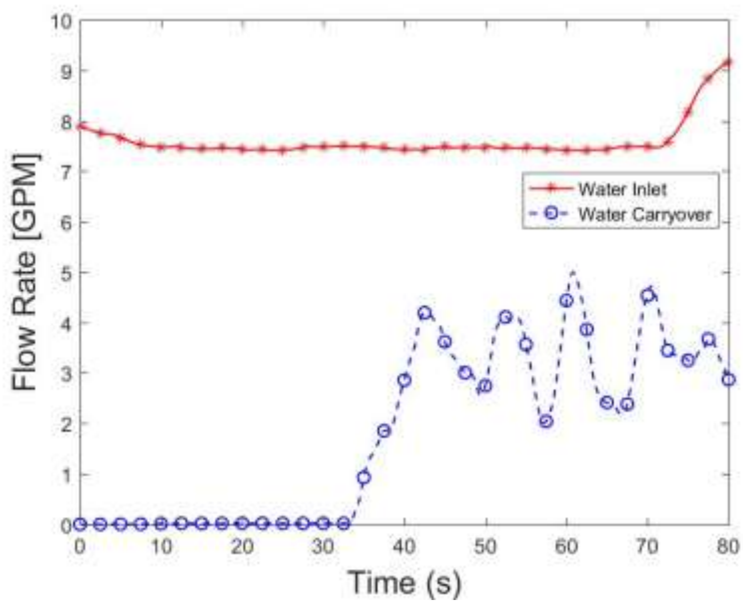

Figure G653: Water flow rates for test 2016_06_23_test_01.

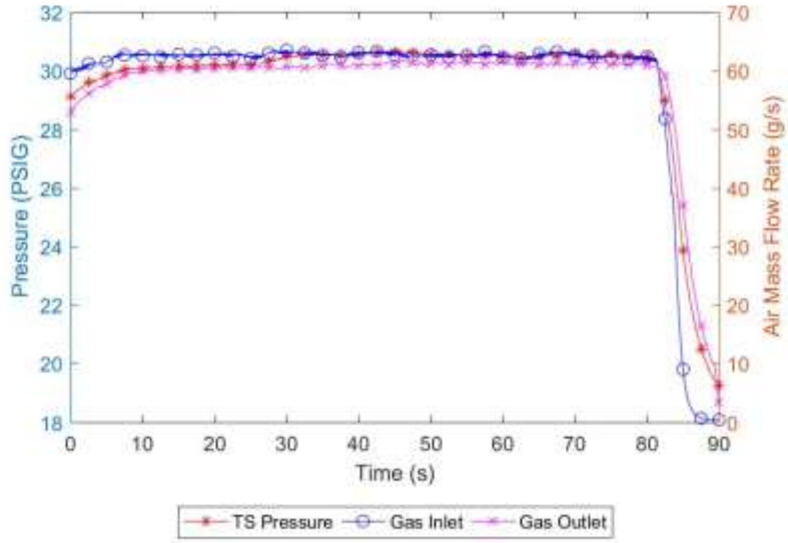

Figure G654: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_02.

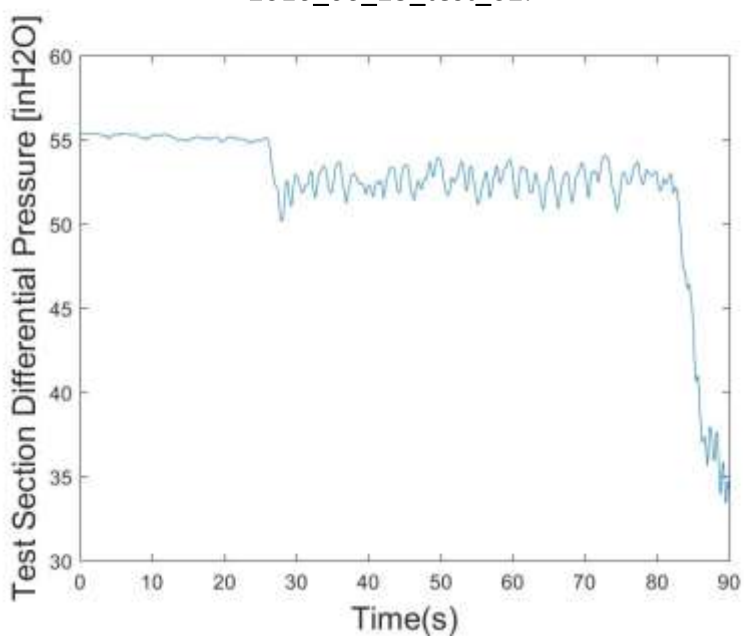

Figure G655: Test section differential pressure for test 2016_06_23_test_02.

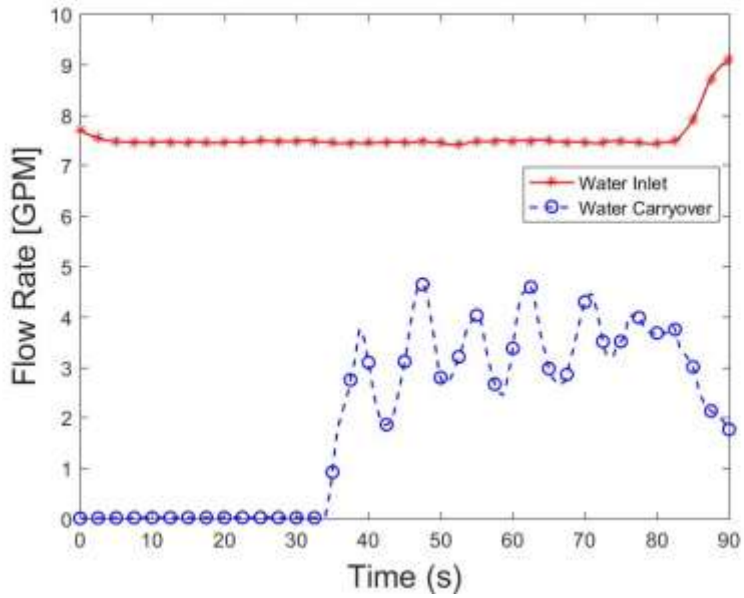

Figure G656: Water flow rates for test 2016_06_23_test_02.

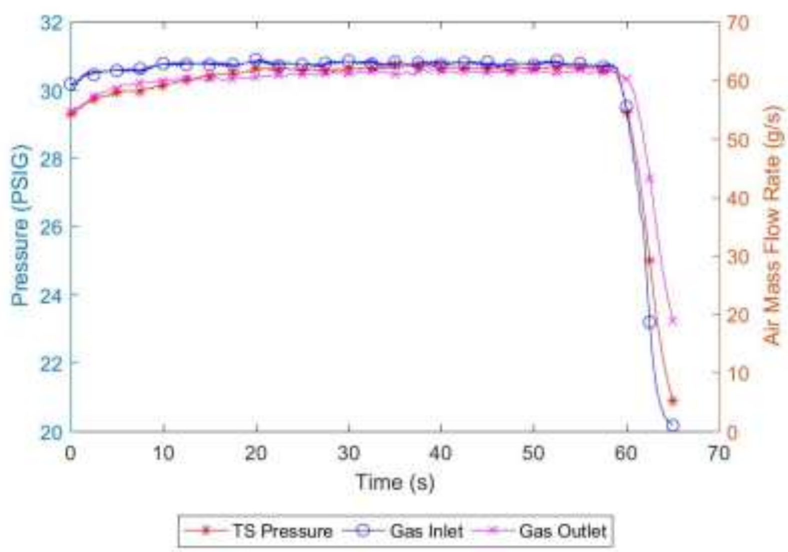

Figure G657: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_03.

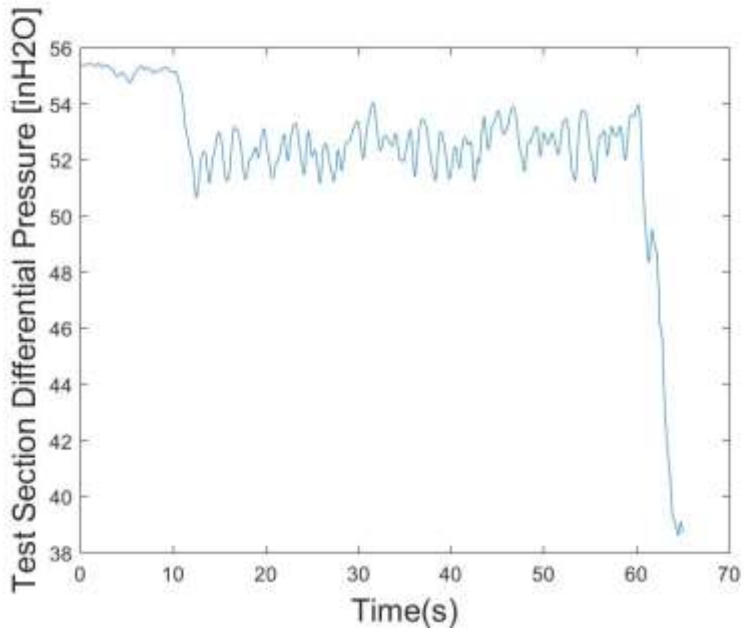

Figure G658: Test section differential pressure for test 2016_06_23_test_03.

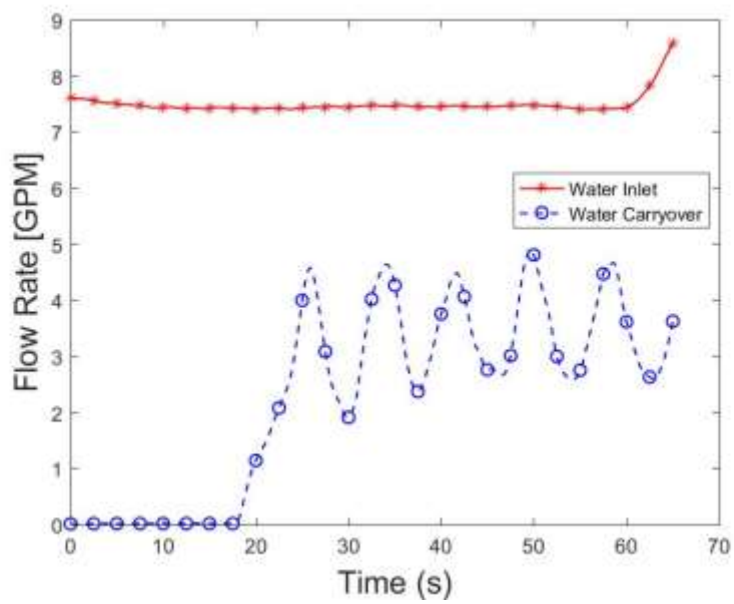

Figure G659: Water flow rates for test 2016_06_23_test_03.

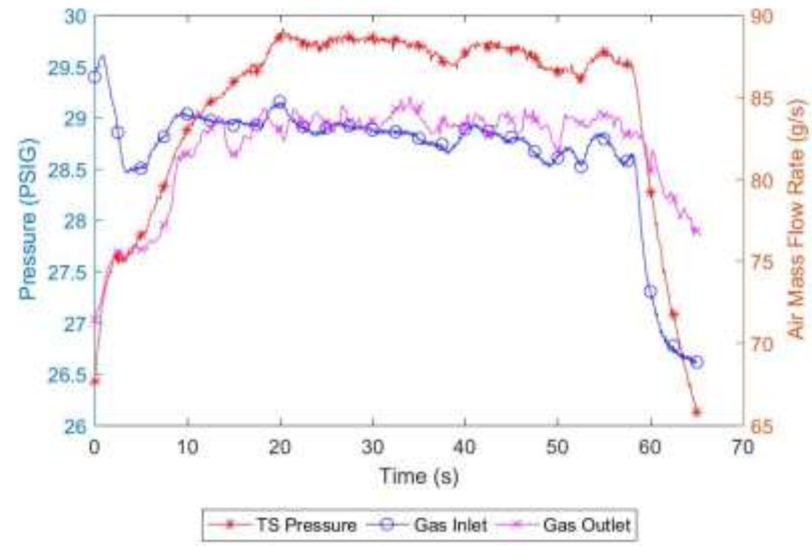

Figure G660: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_07.

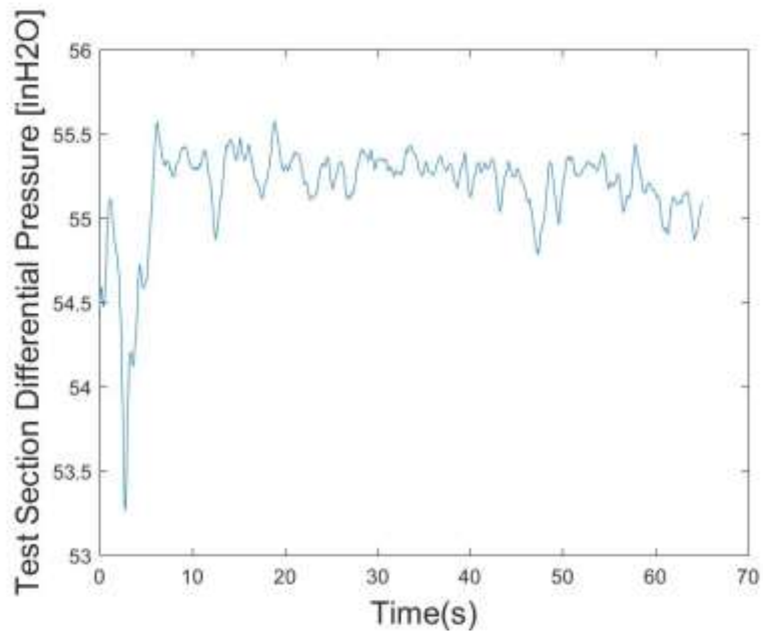

Figure G661: Test section differential pressure for test 2016_06_23_test_07.

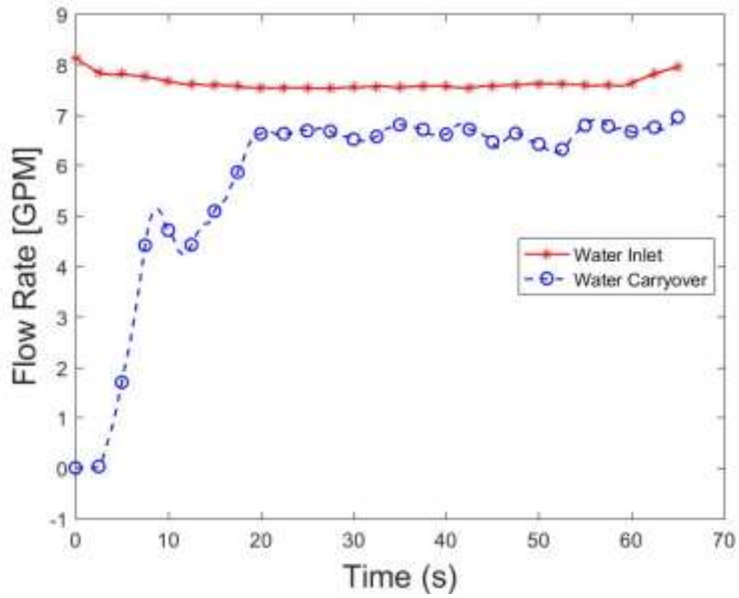

Figure G662: Water flow rates for test 2016_06_23_test_07.

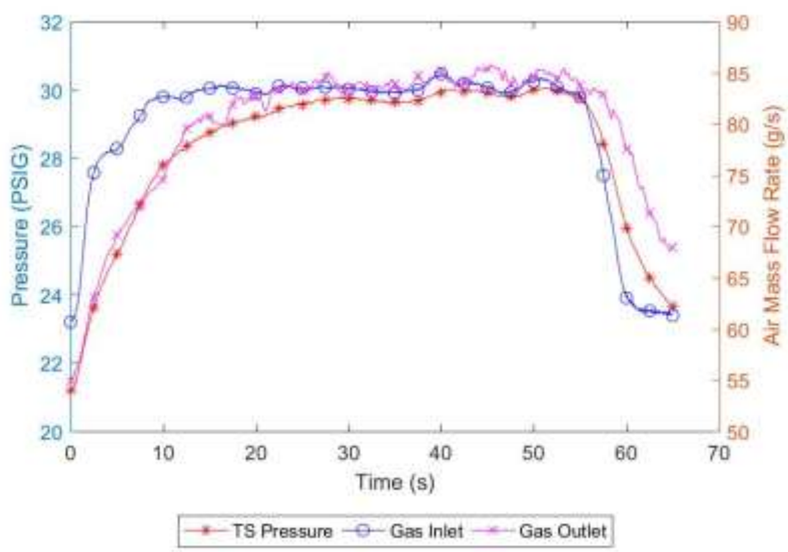

Figure G663: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_08.

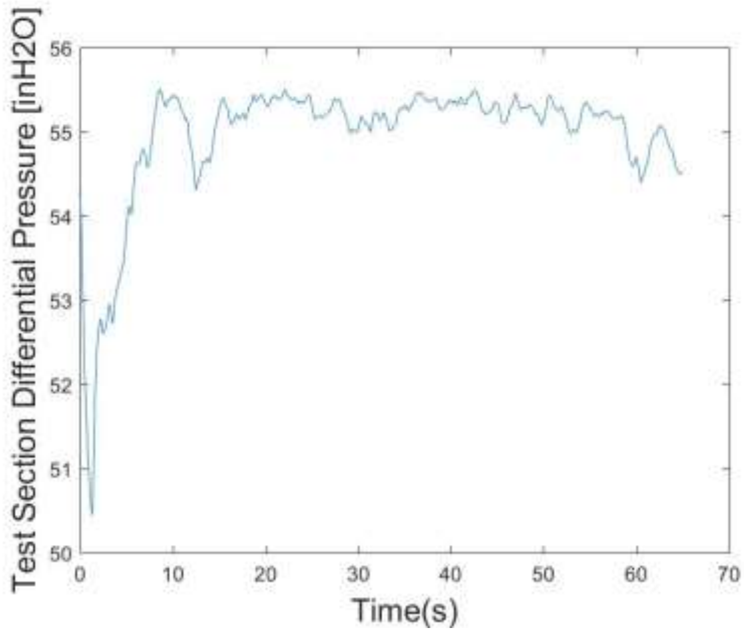

Figure G664: Test section differential pressure for test 2016_06_23_test_08.

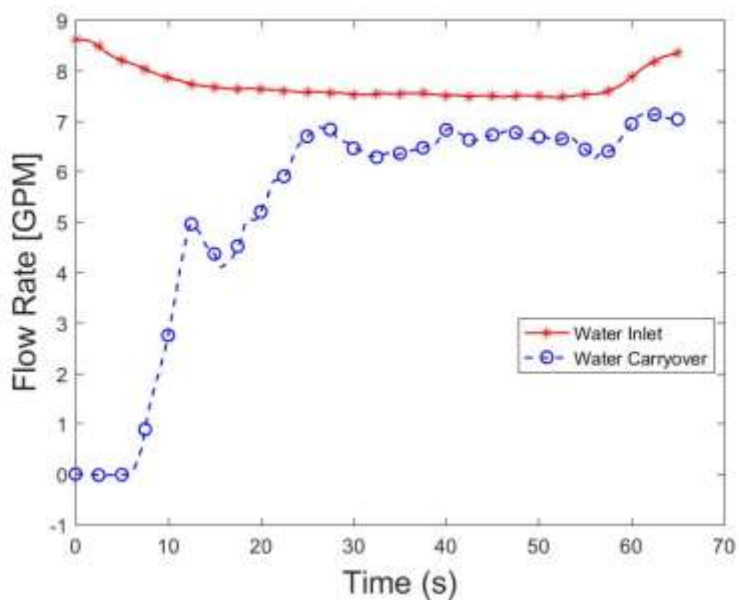

Figure G665: Water flow rates for test 2016_06_23_test_08.

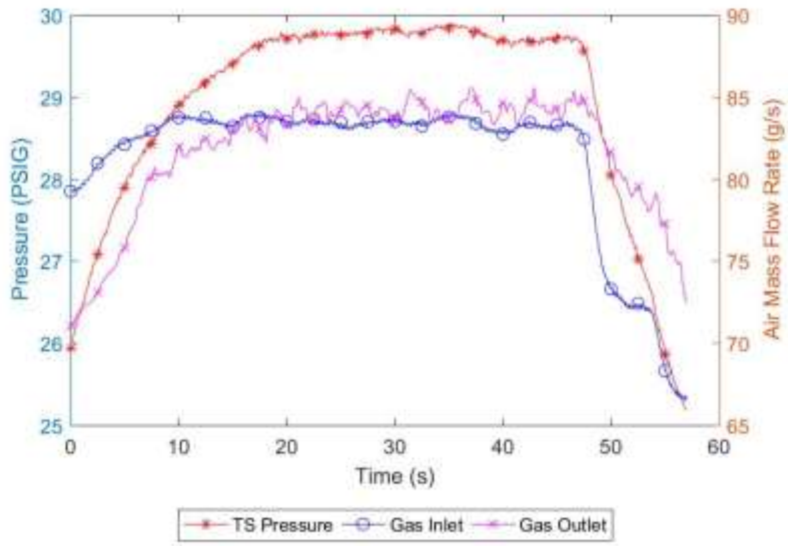

Figure G666: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_09.

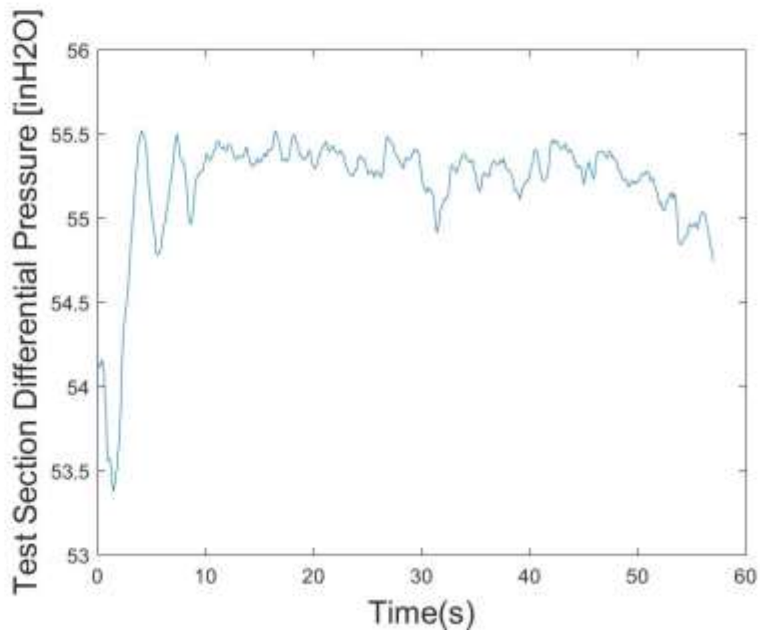

Figure G667: Test section differential pressure for test 2016_06_23_test_09.

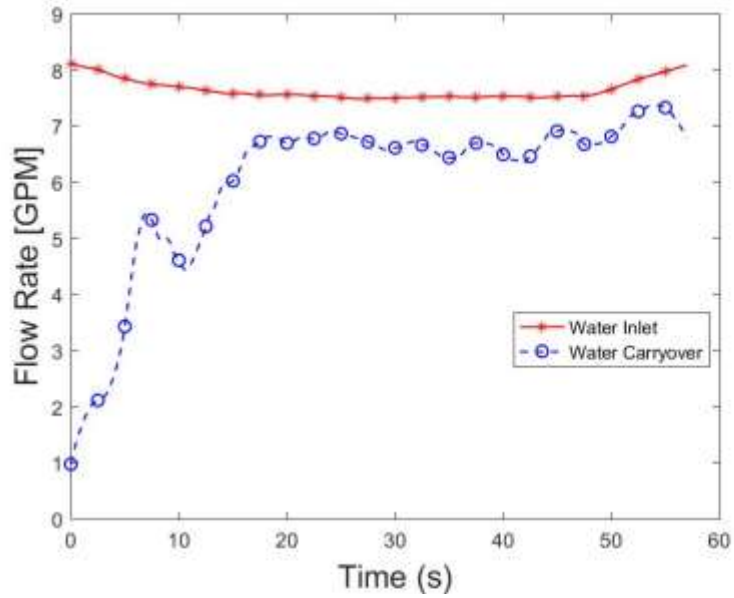

Figure G668: Water flow rates for test 2016_06_23_test_09.

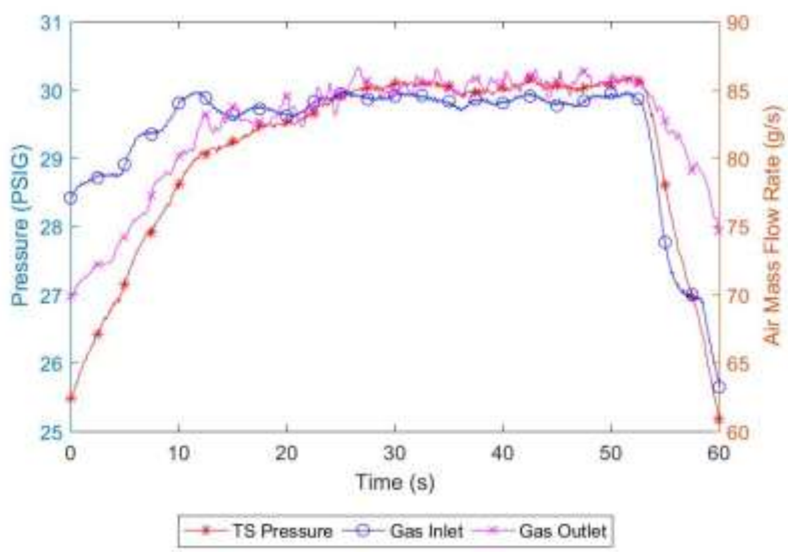

Figure G669: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_10.

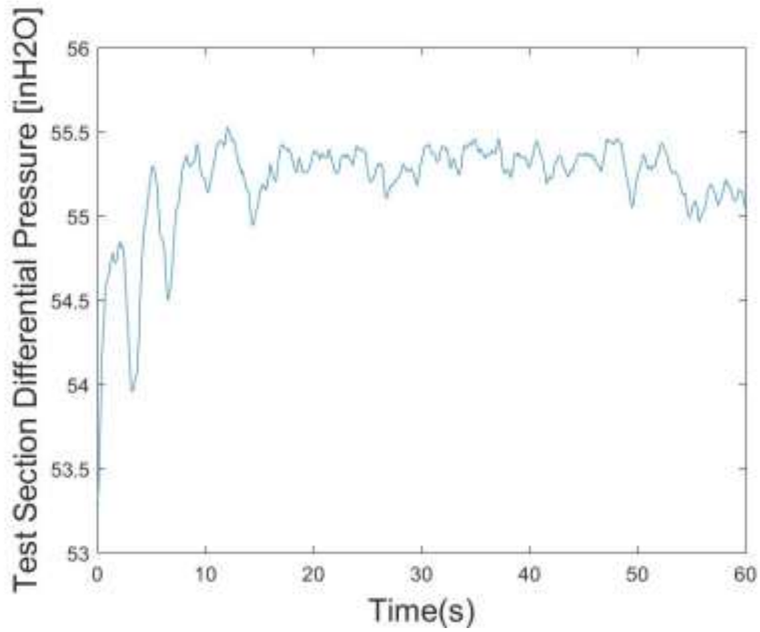

Figure G670: Test section differential pressure for test 2016_06_23_test_10.

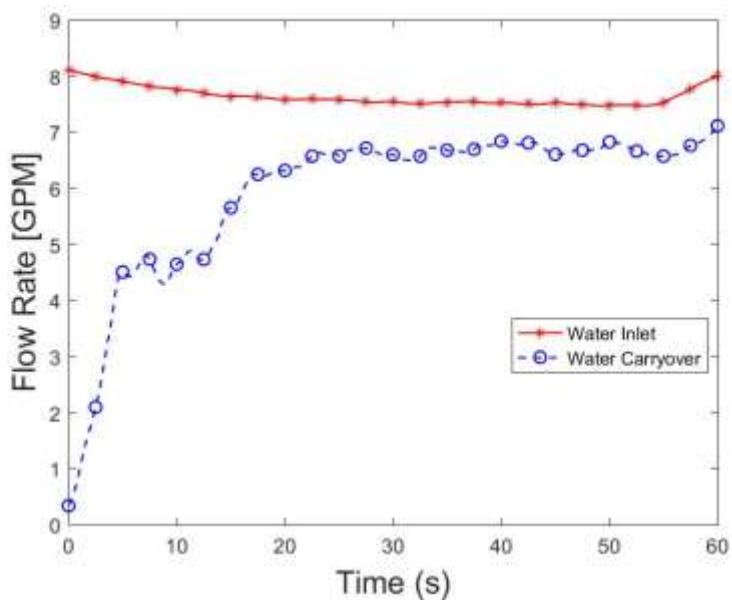

Figure G671: Water flow rates for test 2016_06_23_test_10.

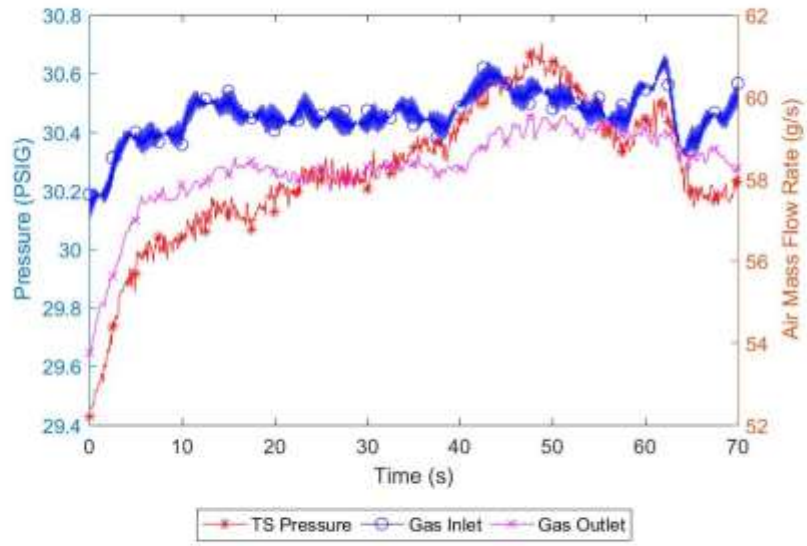

Figure G672: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_11.

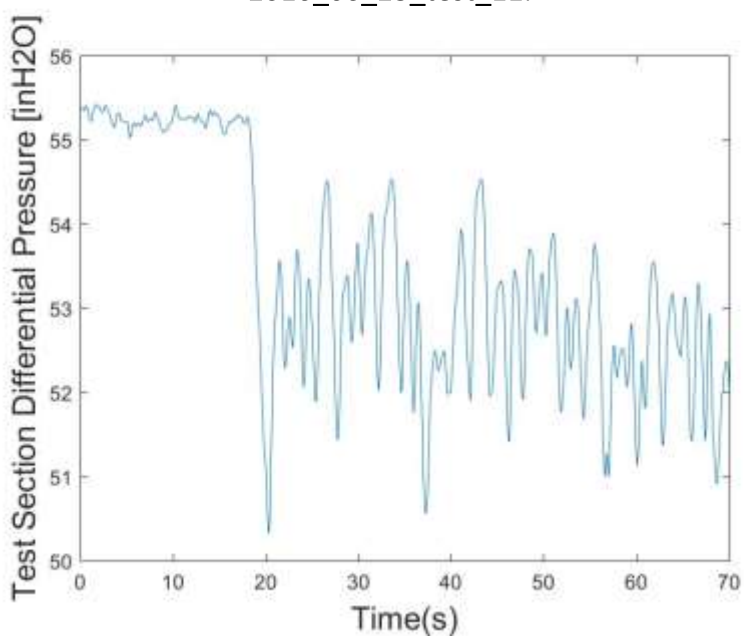

Figure G673: Test section differential pressure for test 2016_06_23_test_11.

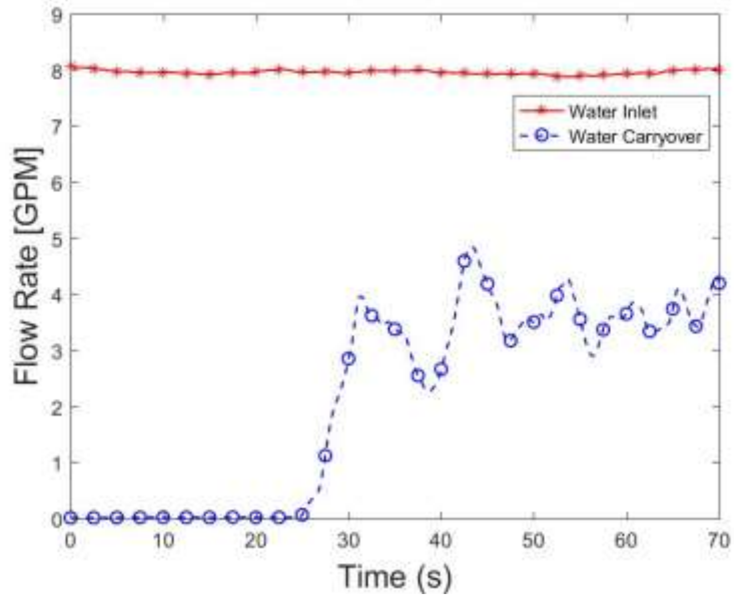

Figure G674: Water flow rates for test 2016_06_23_test_11.

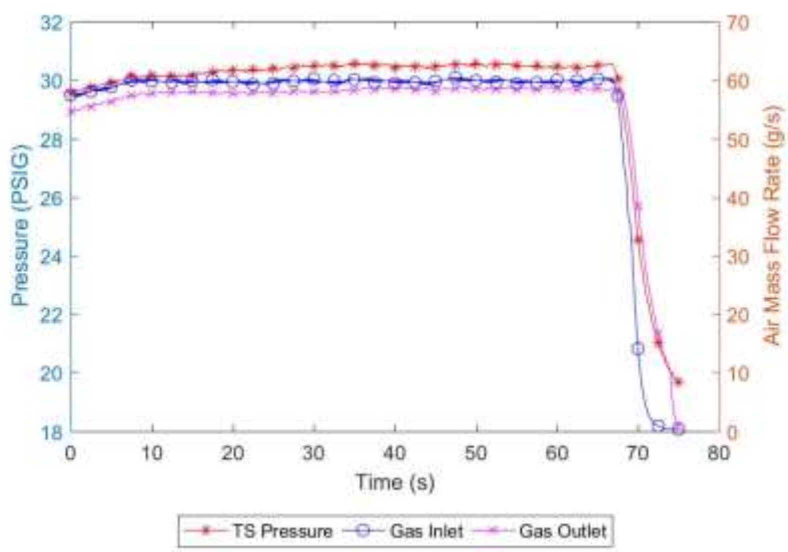

Figure G675: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_12.

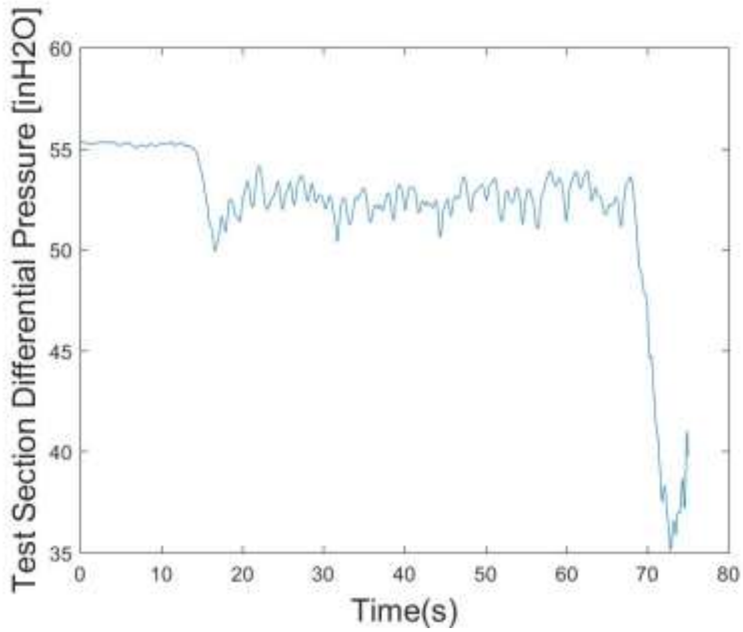

Figure G676: Test section differential pressure for test 2016_06_23_test_12.

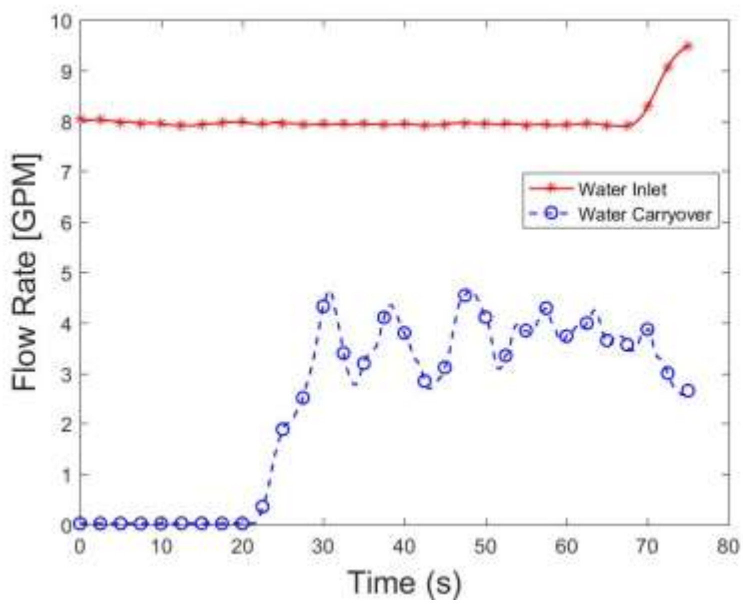

Figure G677: Water flow rates for test 2016_06_23_test_12.

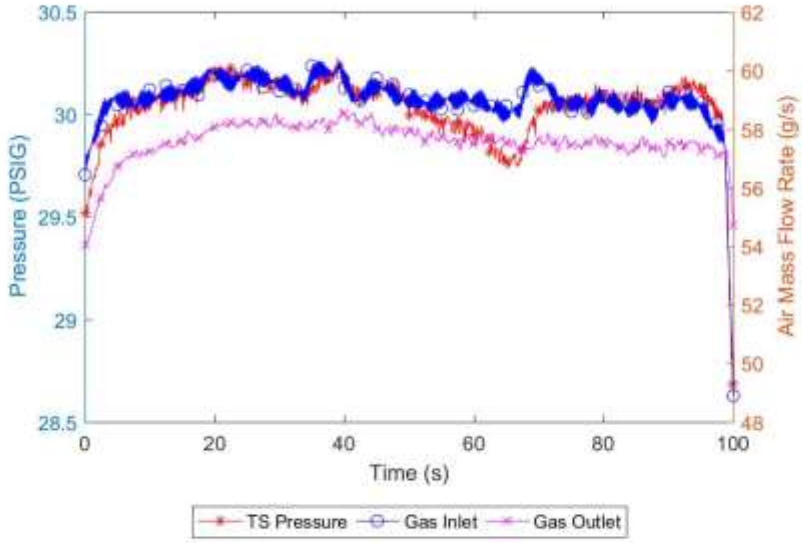

Figure G678: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_14.

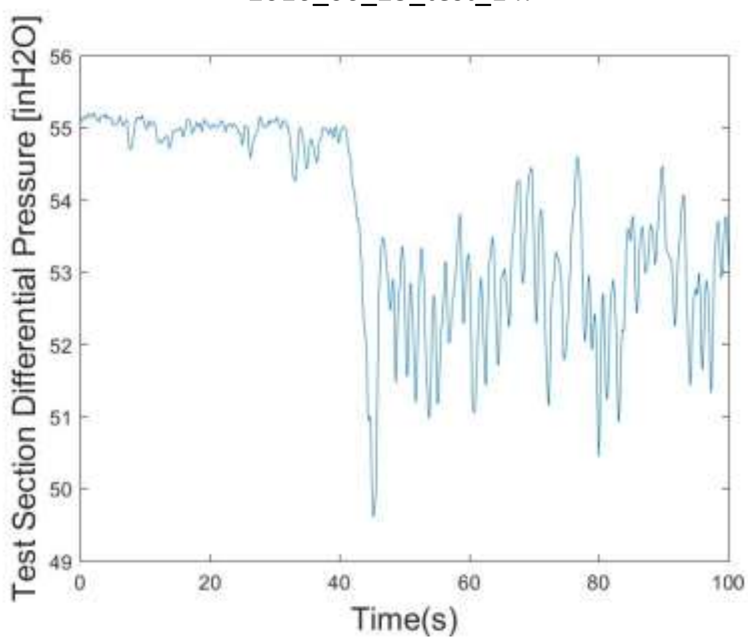

Figure G679: Test section differential pressure for test 2016_06_23_test_14.

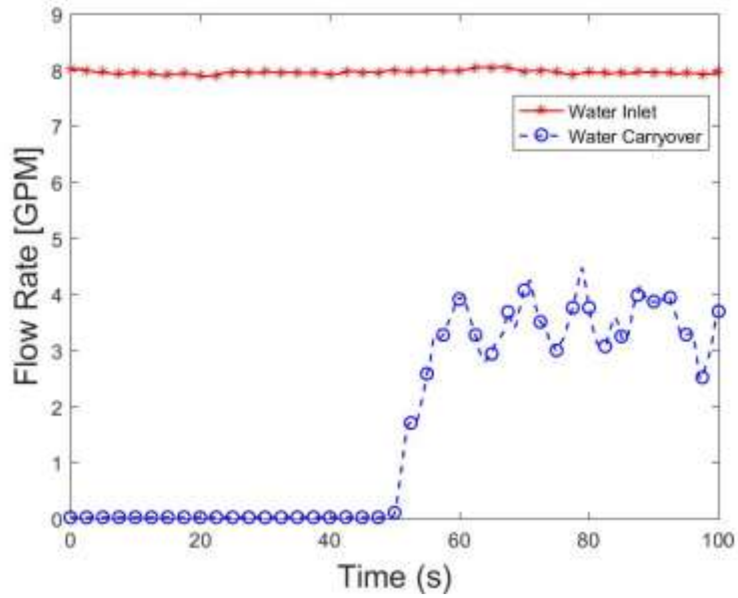

Figure G680: Water flow rates for test 2016_06_23_test_14.

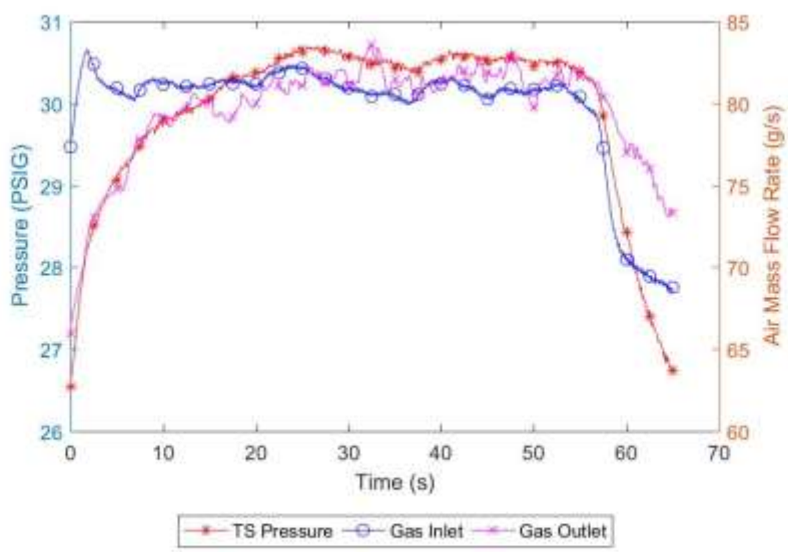

Figure G681: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_15.

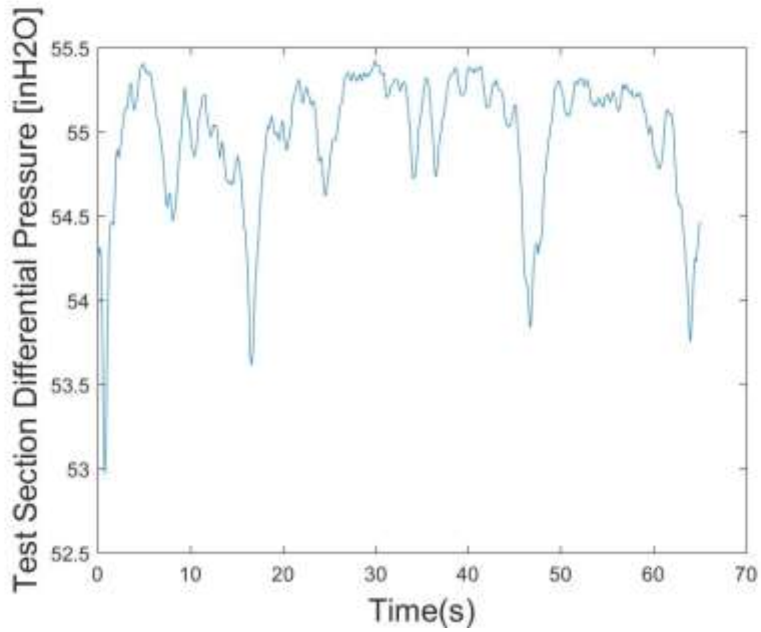

Figure G682: Test section differential pressure for test 2016_06_23_test_15.

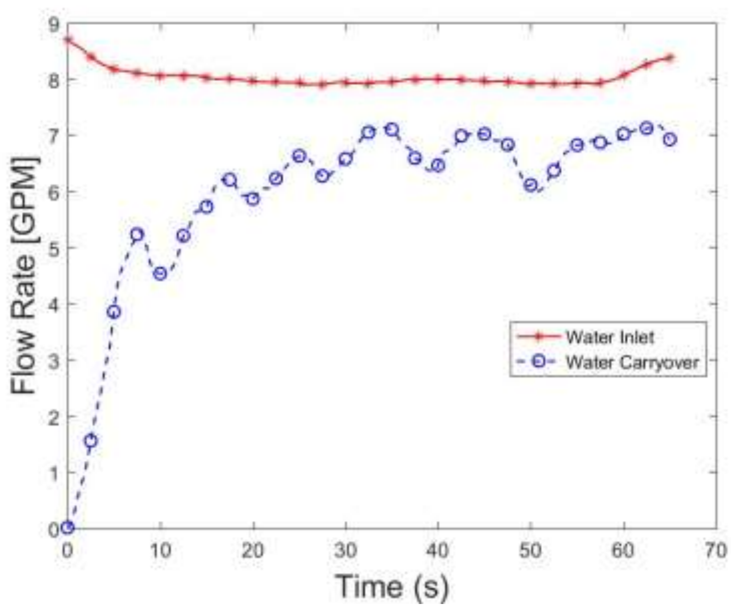

Figure G683: Water flow rates for test 2016_06_23_test_15.

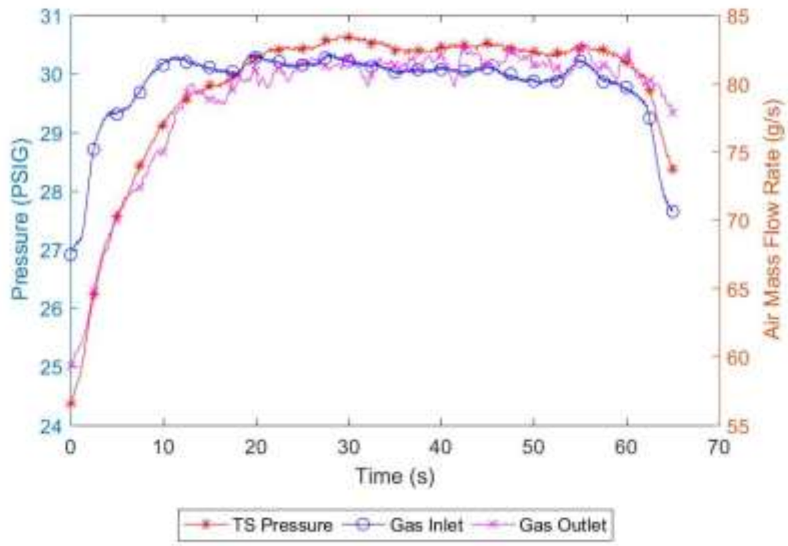

Figure G684: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_16.

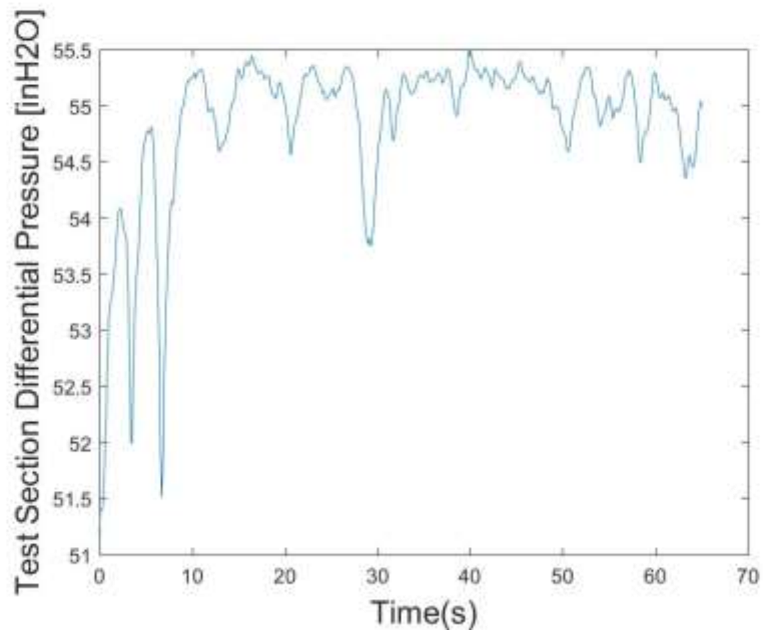

Figure G685: Test section differential pressure for test 2016_06_23_test_16.

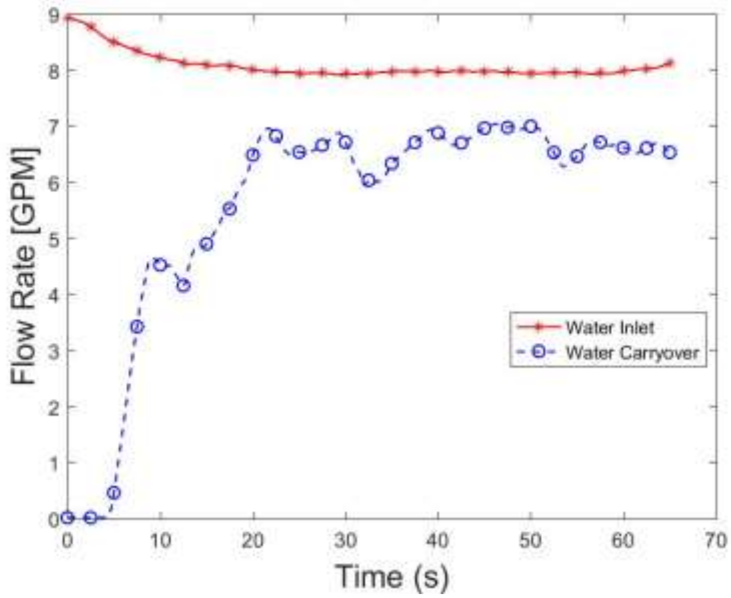

Figure G686: Water flow rates for test 2016_06_23_test_16.

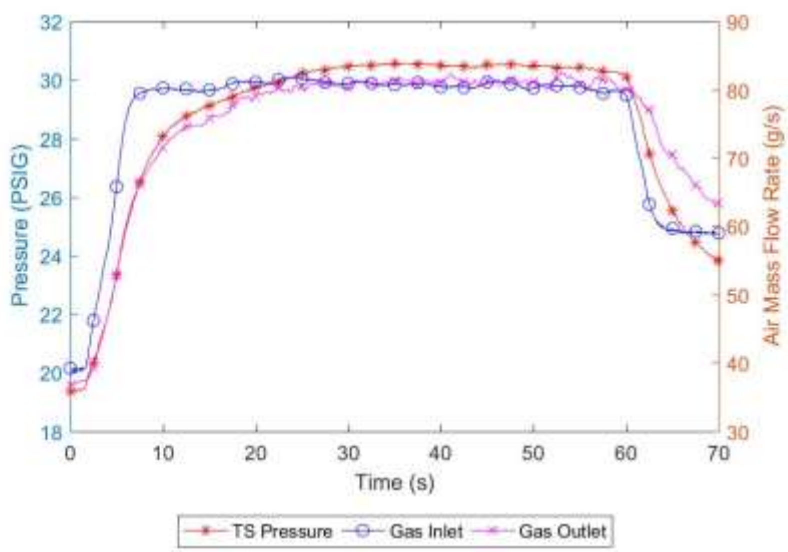

Figure G687: Pressure and gas inlet and outlet mass flow rates for test 2016_06_23_test_17.

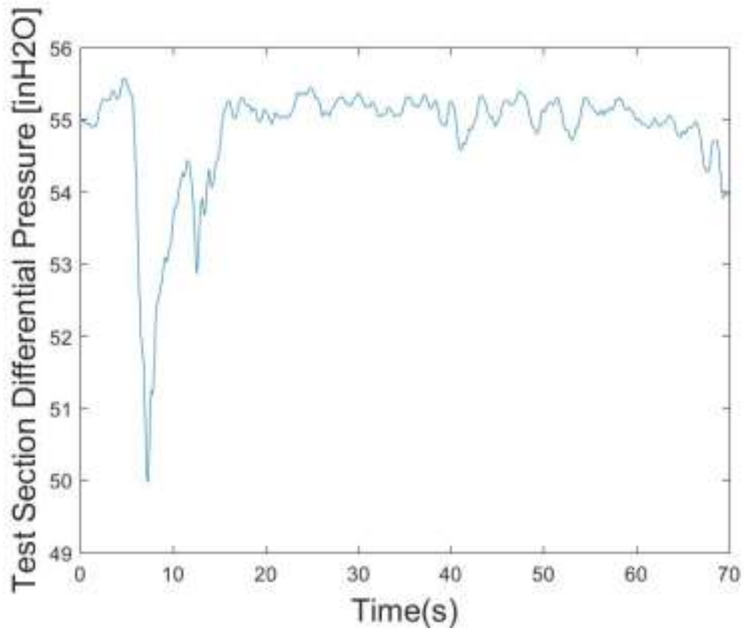

Figure G688: Test section differential pressure for test 2016_06_23_test_17.

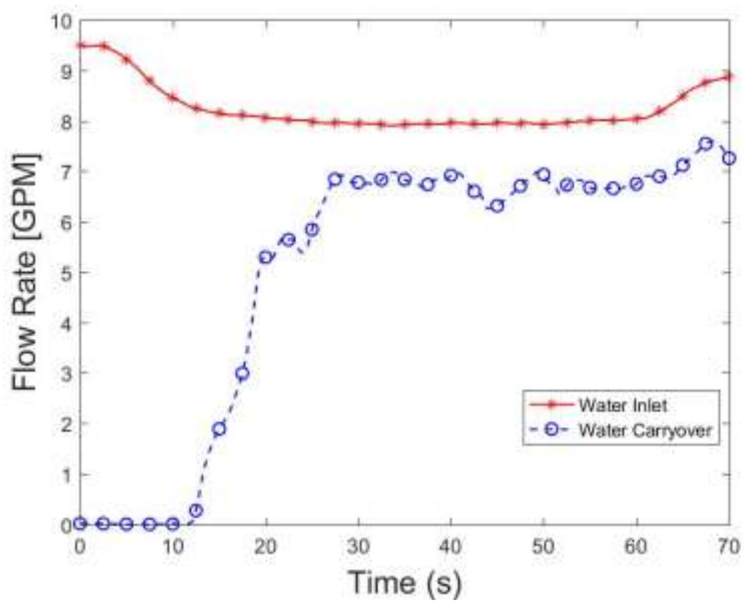

Figure G689: Water flow rates for test 2016_06_23_test_17.

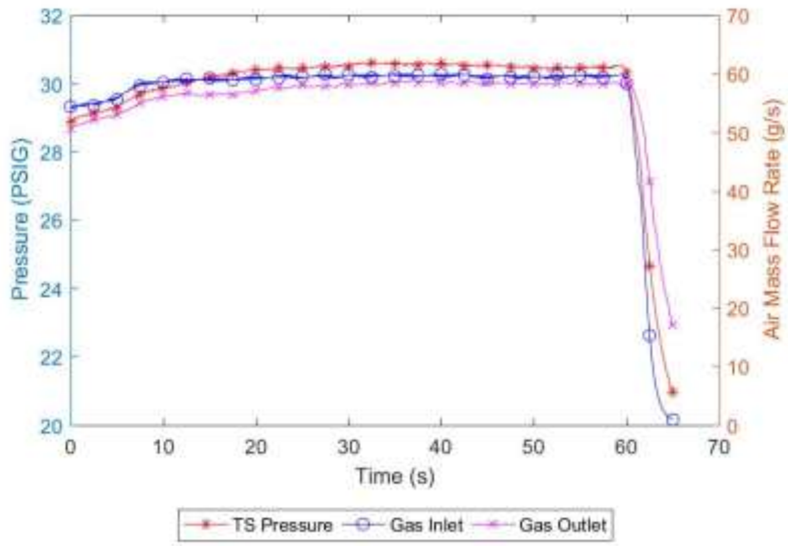

Figure G690: Pressure and gas inlet and outlet mass flow rates for test 2016_06_24_test_01.

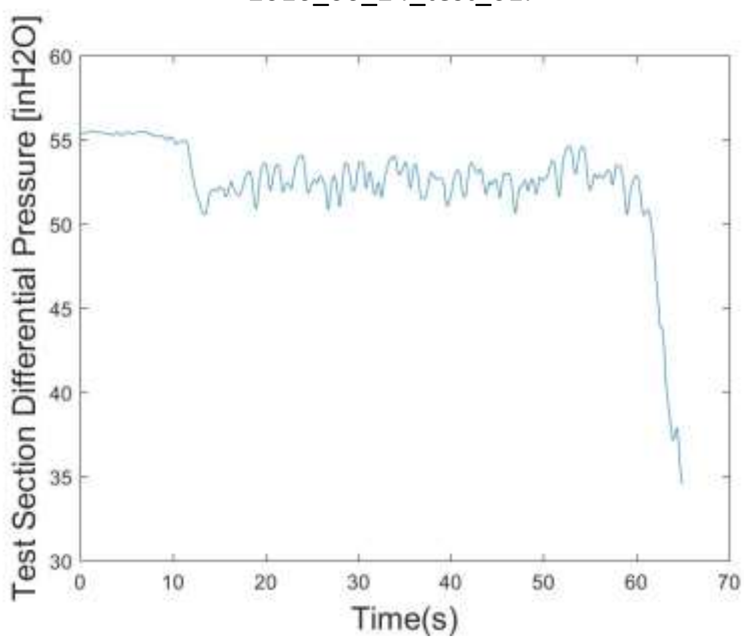

Figure G691: Test section differential pressure for test 2016_06_24_test_01.

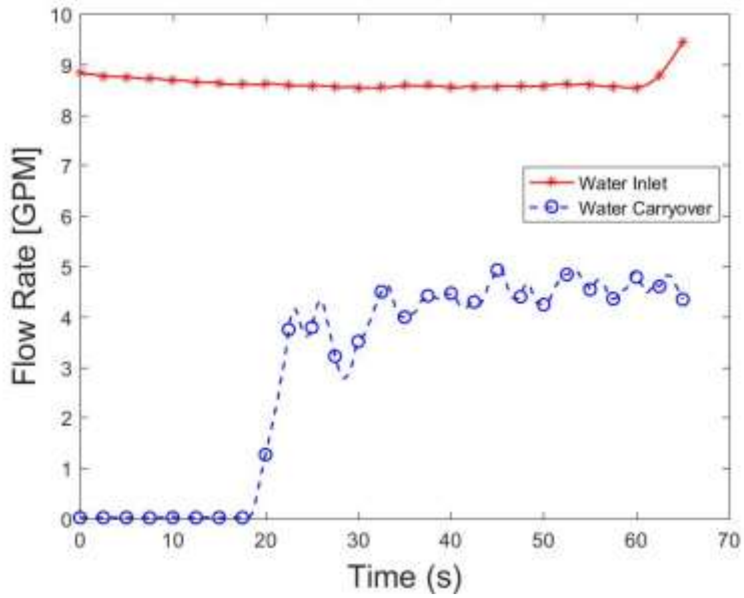

Figure G692: Water flow rates for test 2016_06_24_test_01.

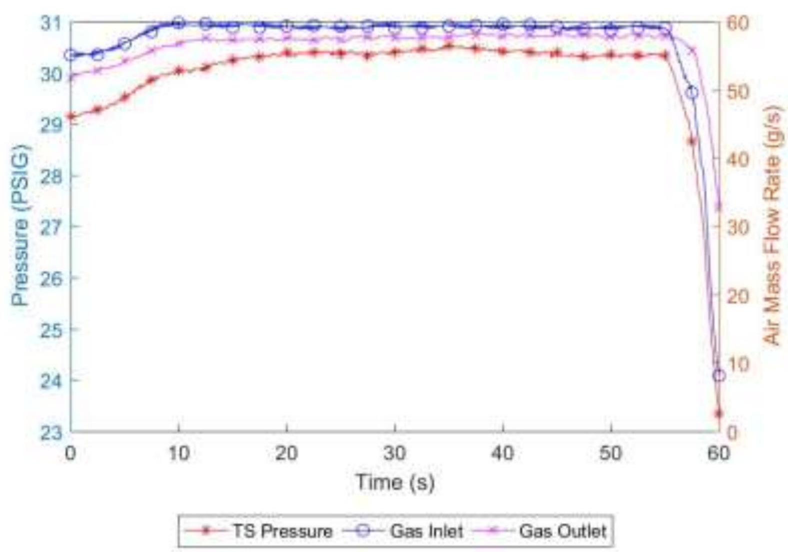

Figure G693: Pressure and gas inlet and outlet mass flow rates for test 2016_06_24_test_02.

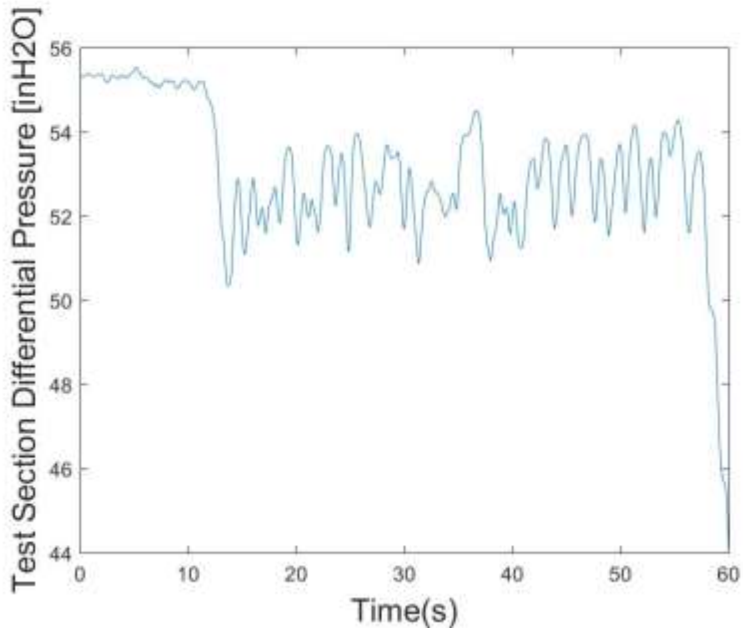

Figure G694: Test section differential pressure for test 2016_06_24_test_02.

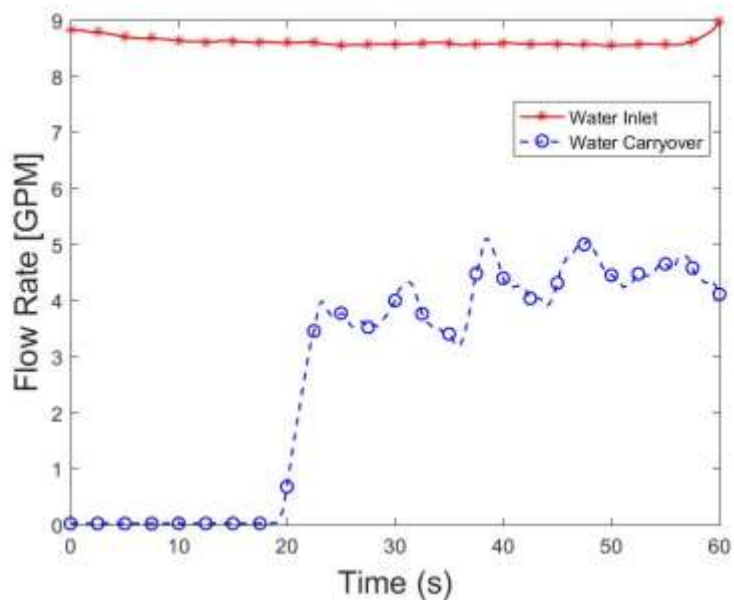

Figure G695: Water flow rates for test 2016_06_24_test_02.

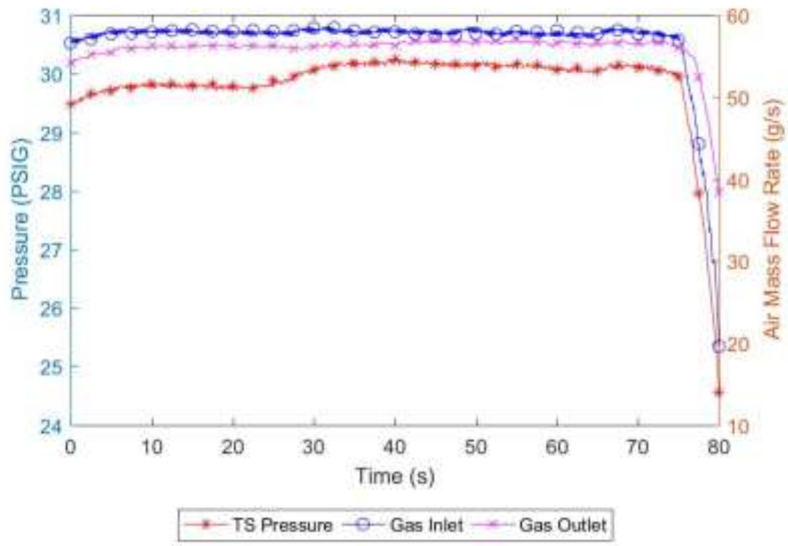

Figure G696: Pressure and gas inlet and outlet mass flow rates for test 2016_06_24_test_03.

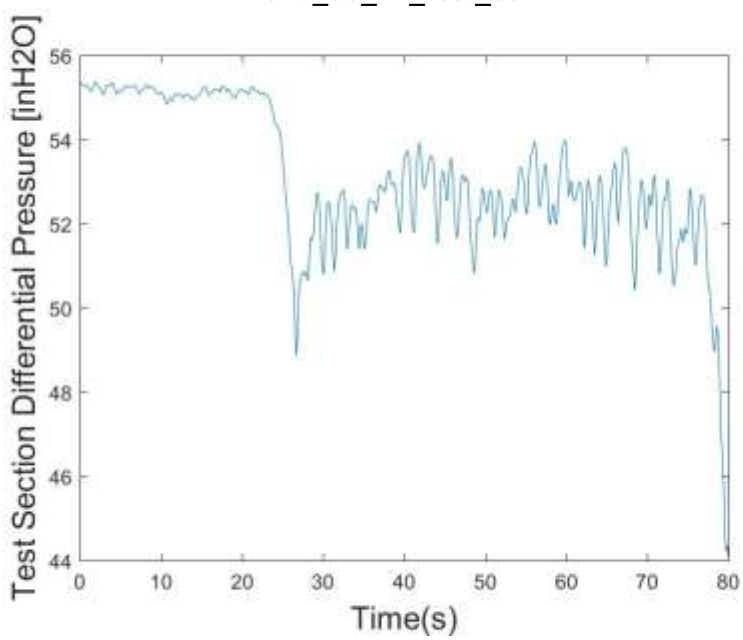

Figure G697: Test section differential pressure for test 2016_06_24_test_03.

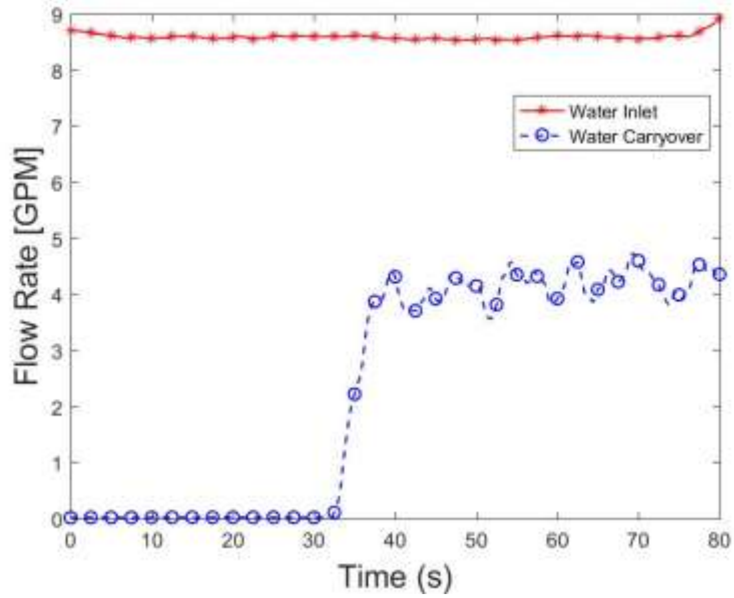

Figure G698: Water flow rates for test 2016_06_24_test_03.

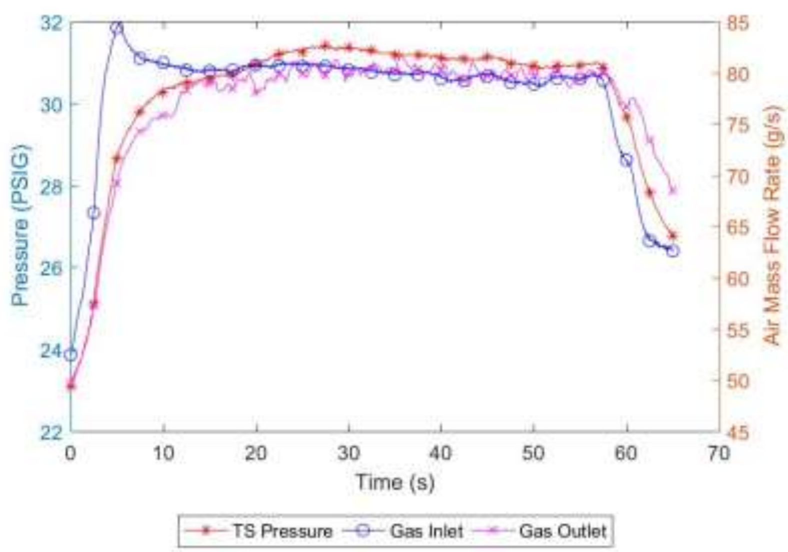

Figure G699: Pressure and gas inlet and outlet mass flow rates for test 2016_06_24_test_04.

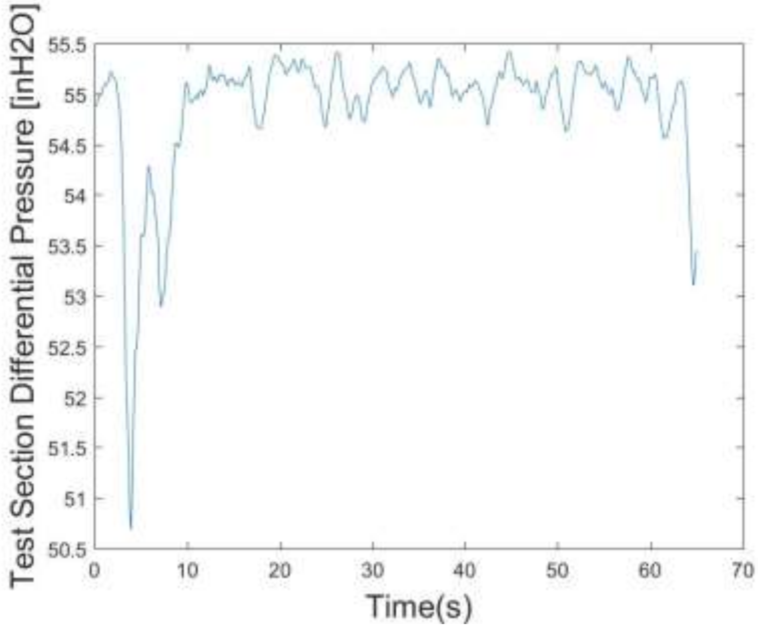

Figure G700: Test section differential pressure for test 2016_06_24_test_04.

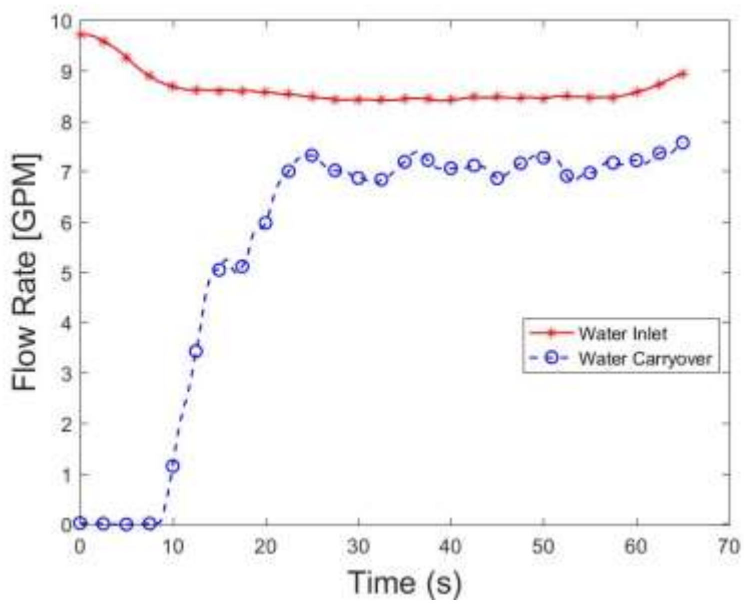

Figure G701: Water flow rates for test 2016_06_24_test_04.

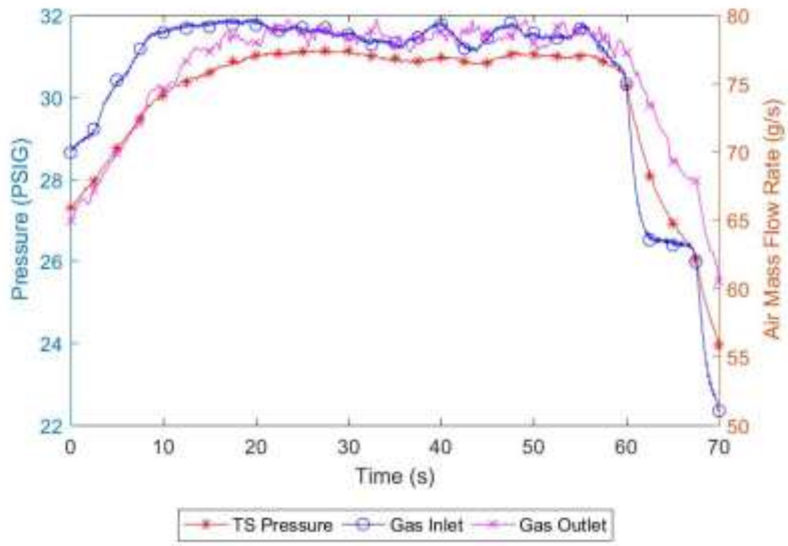

Figure G702: Pressure and gas inlet and outlet mass flow rates for test 2016_06_24_test_06.

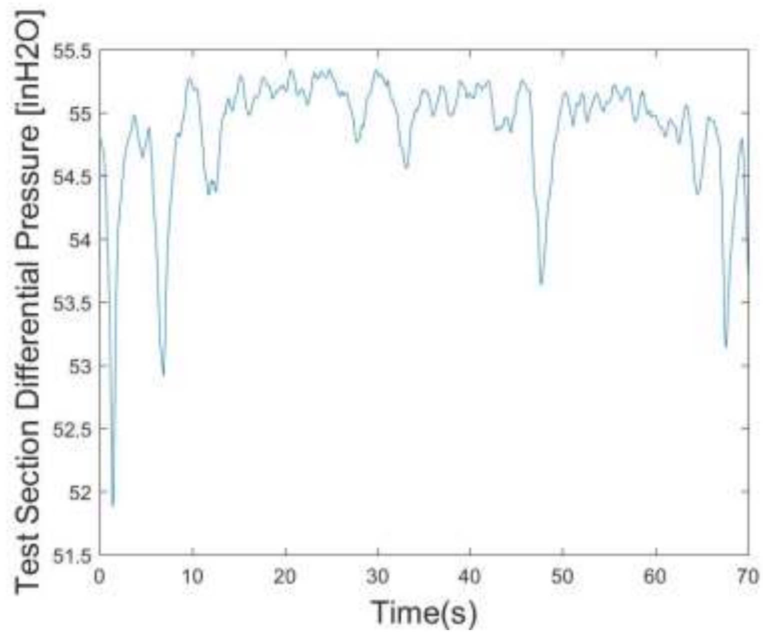

Figure G703: Test section differential pressure for test 2016_06_24_test_06.

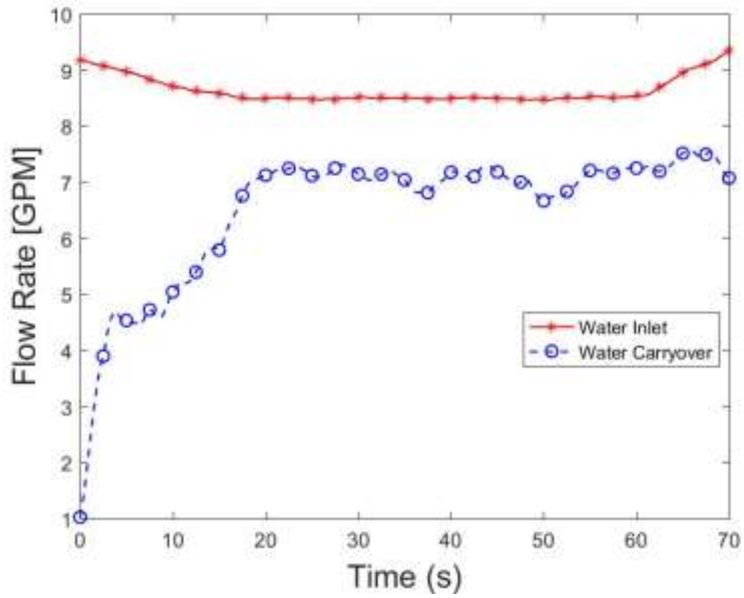

Figure G704: Water flow rates for test 2016_06_24_test_06.

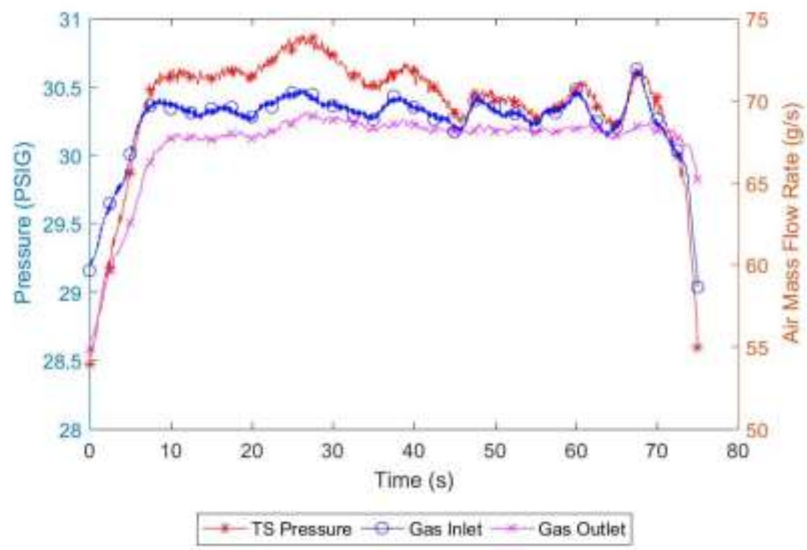

Figure G705: Pressure and gas inlet and outlet mass flow rates for test 2016_07_13_test_24.

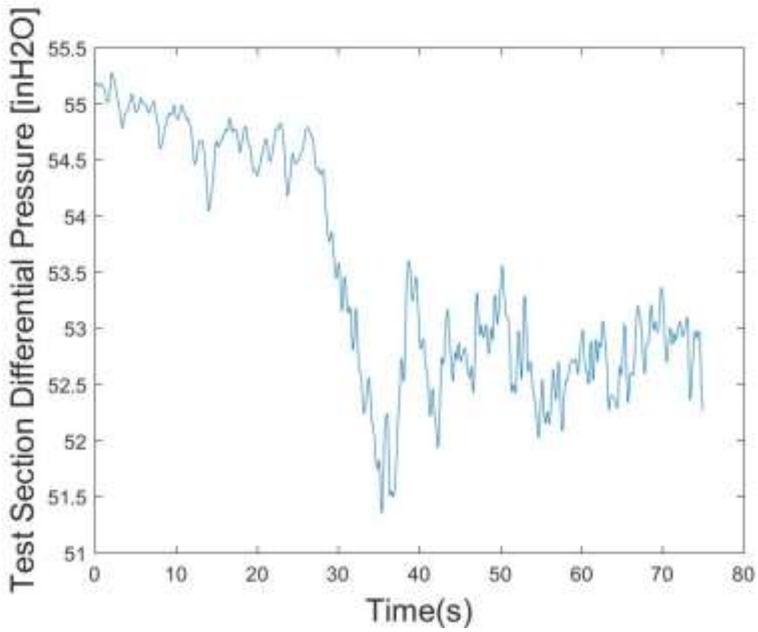

Figure G706: Test section differential pressure for test 2016_07_13_test_24.

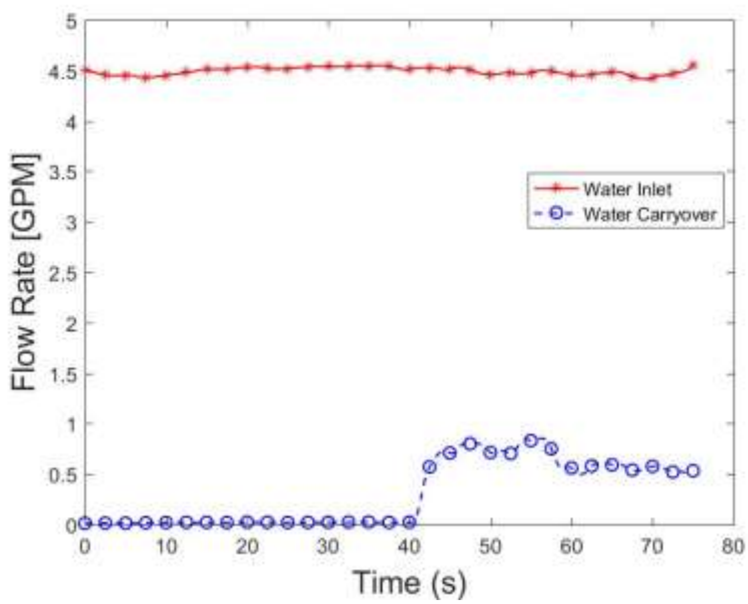

Figure G707: Water flow rates for test 2016_07_13_test_24.

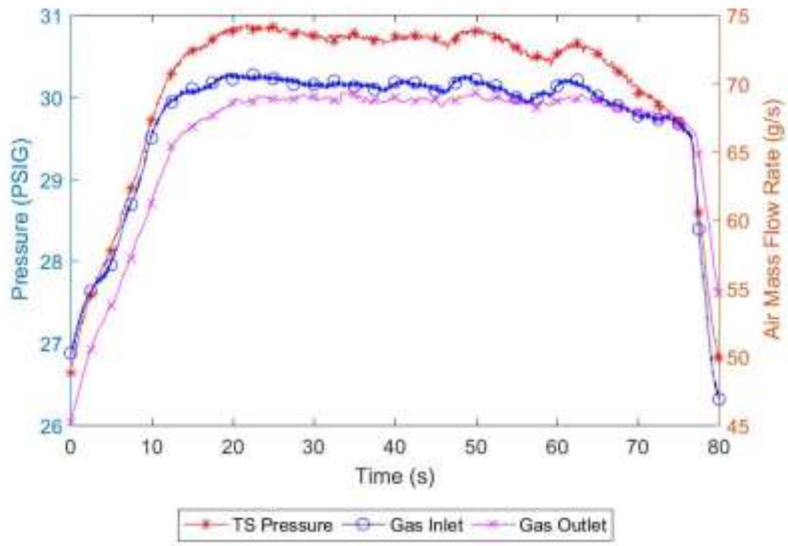

Figure G708: Pressure and gas inlet and outlet mass flow rates for test 2016_07_13_test_25.

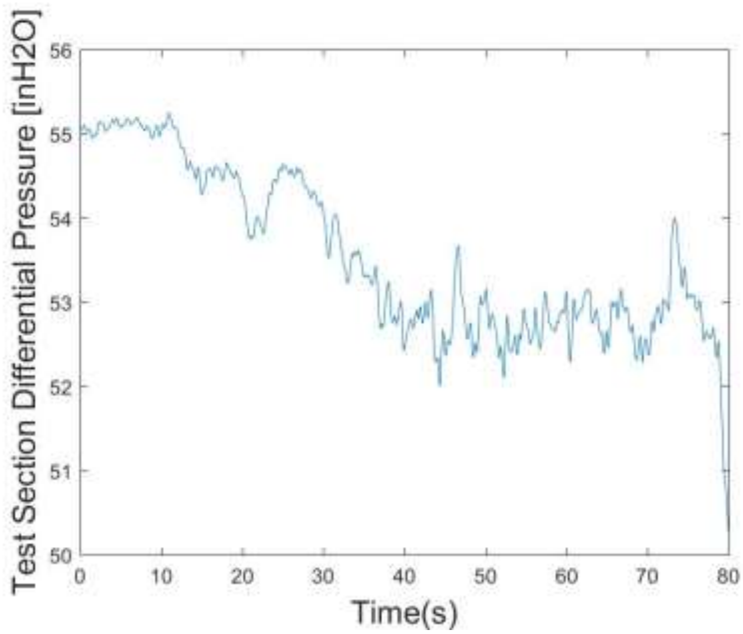

Figure G709: Test section differential pressure for test 2016_07_13_test_25.

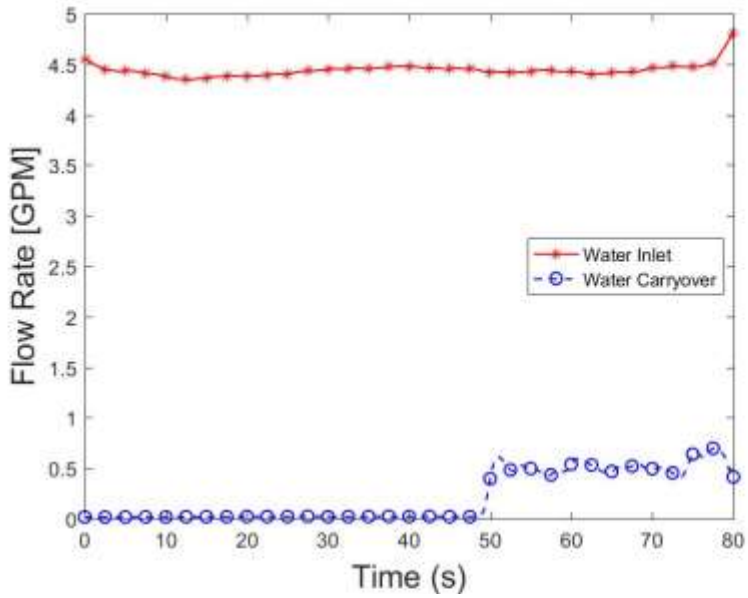

Figure G710: Water flow rates for test 2016_07_13_test_25.

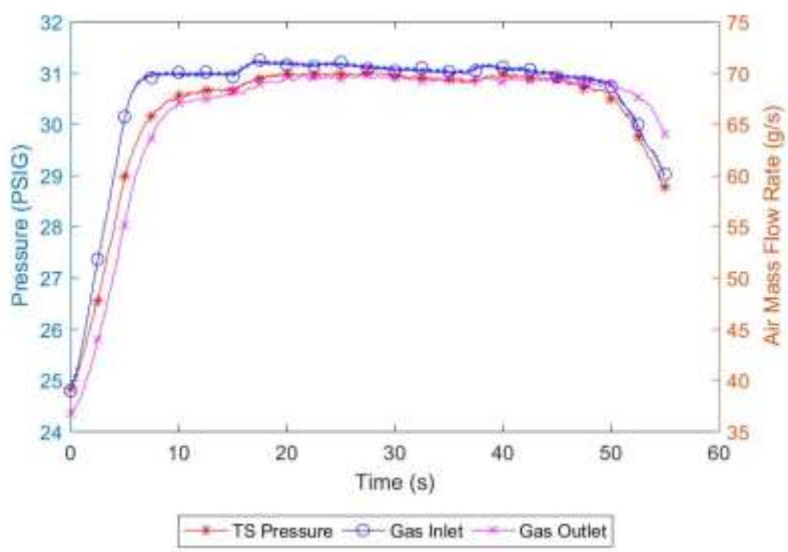

Figure G711: Pressure and gas inlet and outlet mass flow rates for test 2016_07_13_test_26.

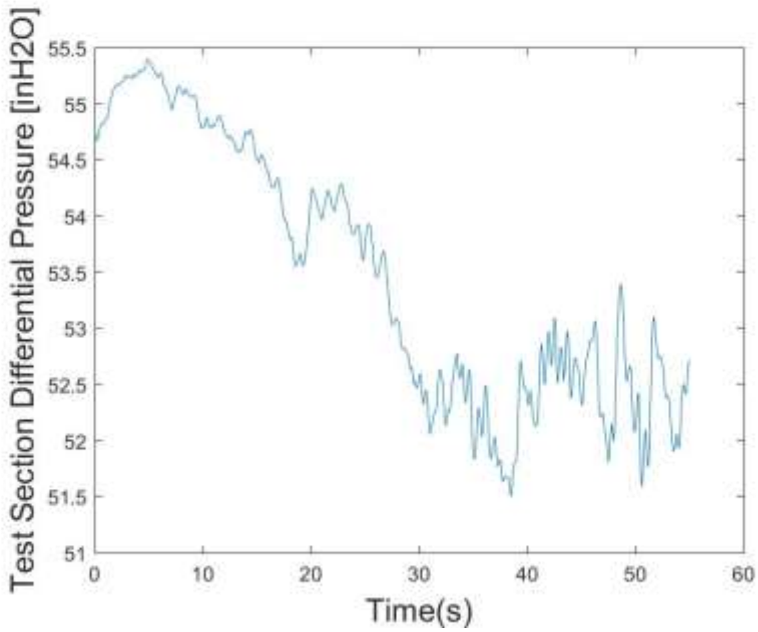

Figure G712: Test section differential pressure for test 2016_07_13_test_26.

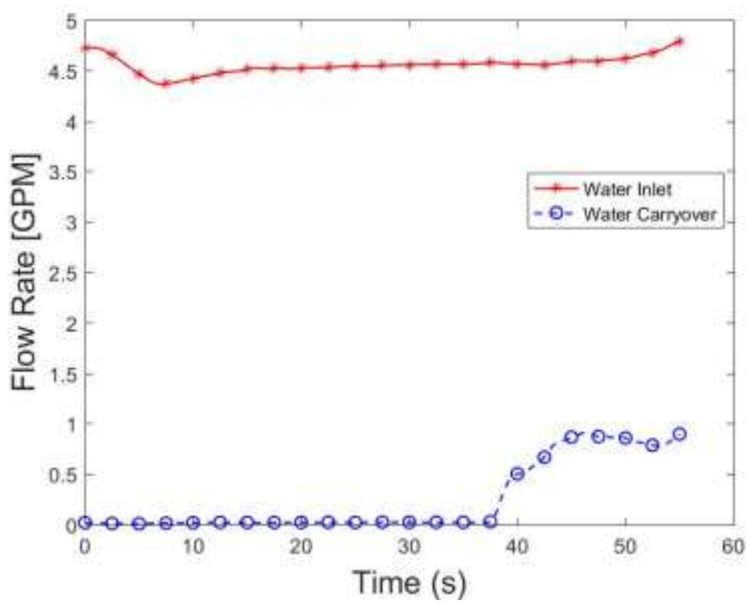

Figure G713: Water flow rates for test 2016_07_13_test_26.

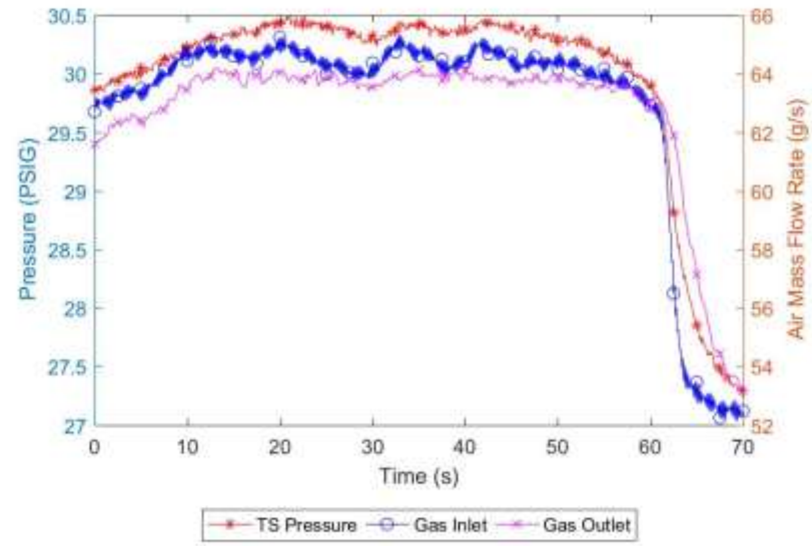

Figure G714: Pressure and gas inlet and outlet mass flow rates for test 2016_07_13_test_27.

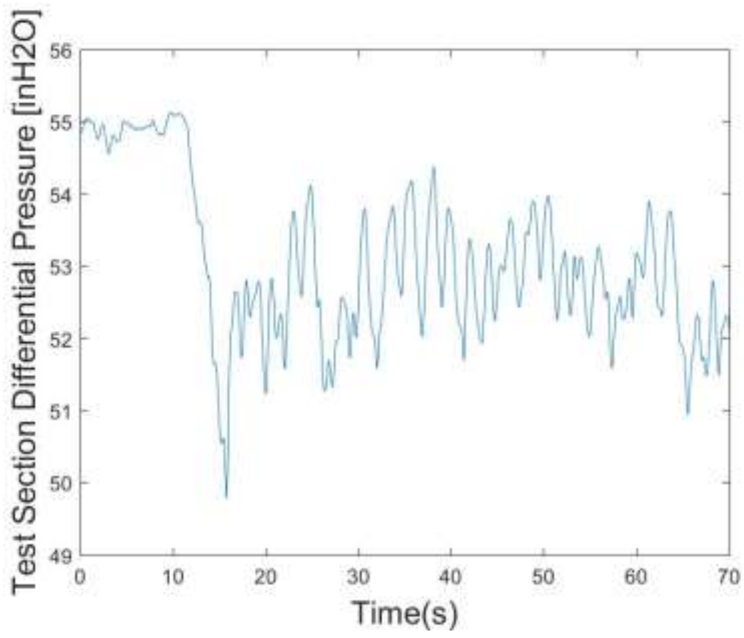

Figure G715: Test section differential pressure for test 2016_07_13_test_27.

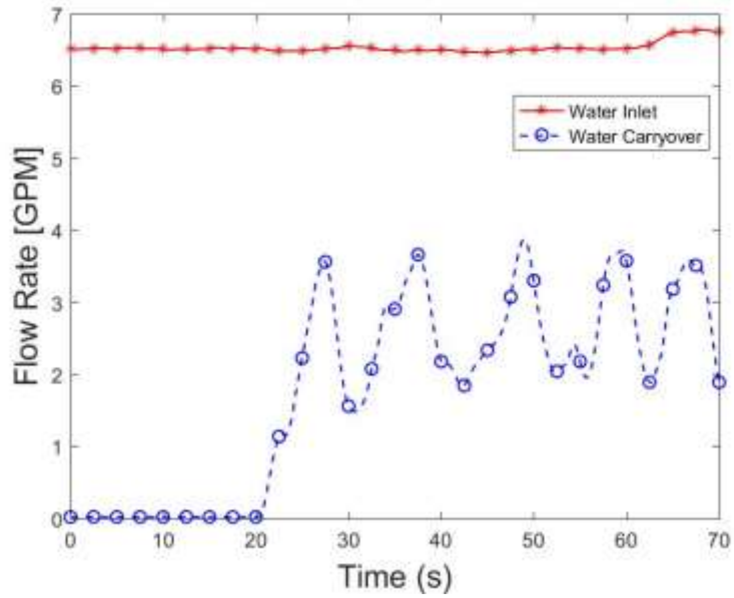

Figure G716: Water flow rates for test 2016_07_13_test_27.

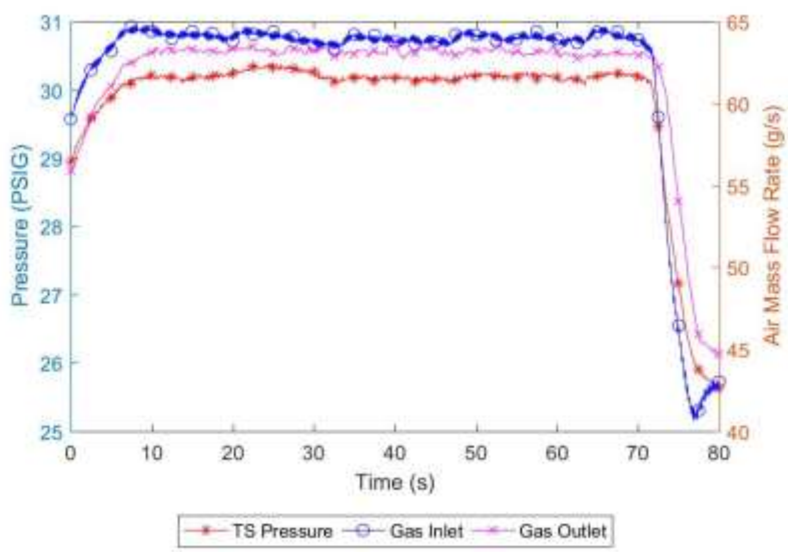

Figure G717: Pressure and gas inlet and outlet mass flow rates for test 2016_07_13_test_28.

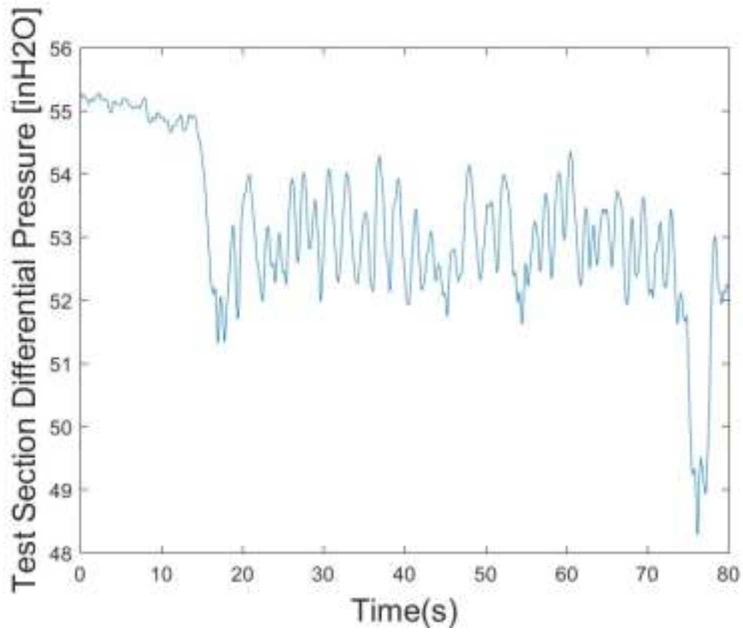

Figure G718: Test section differential pressure for test 2016_07_13_test_28.

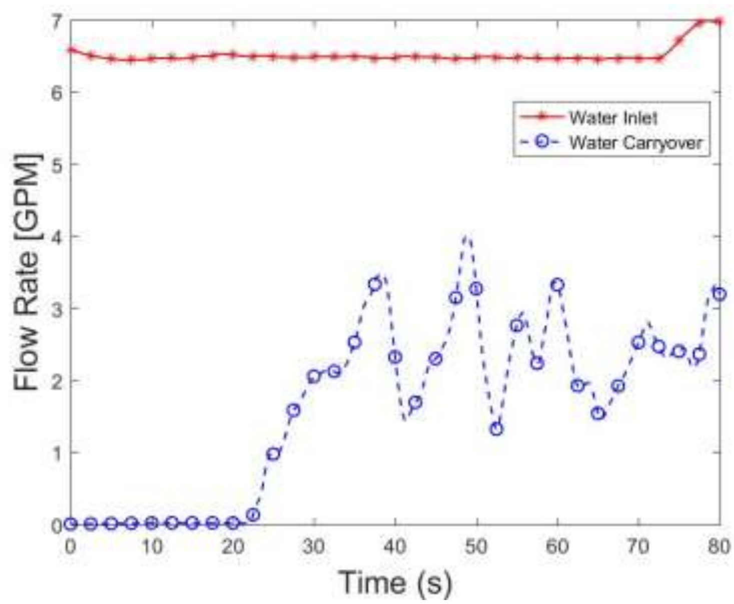

Figure G719: Water flow rates for test 2016_07_13_test_28.

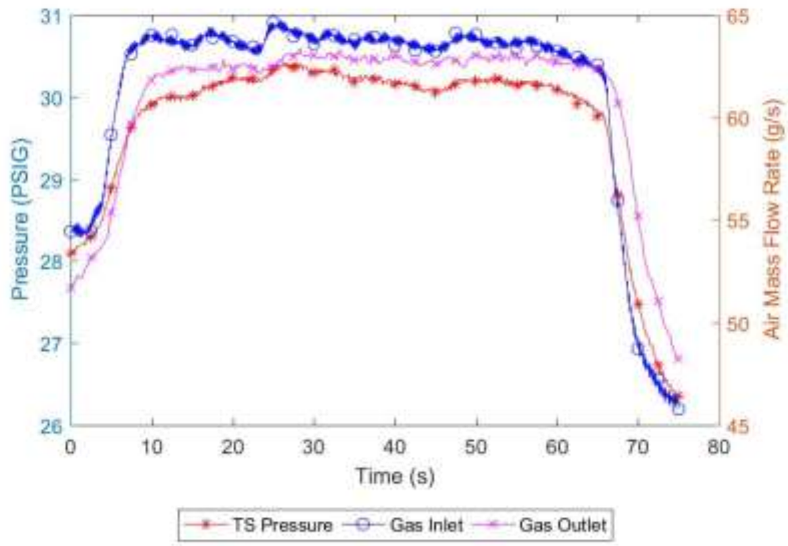

Figure G720: Pressure and gas inlet and outlet mass flow rates for test 2016_07_13_test_29.

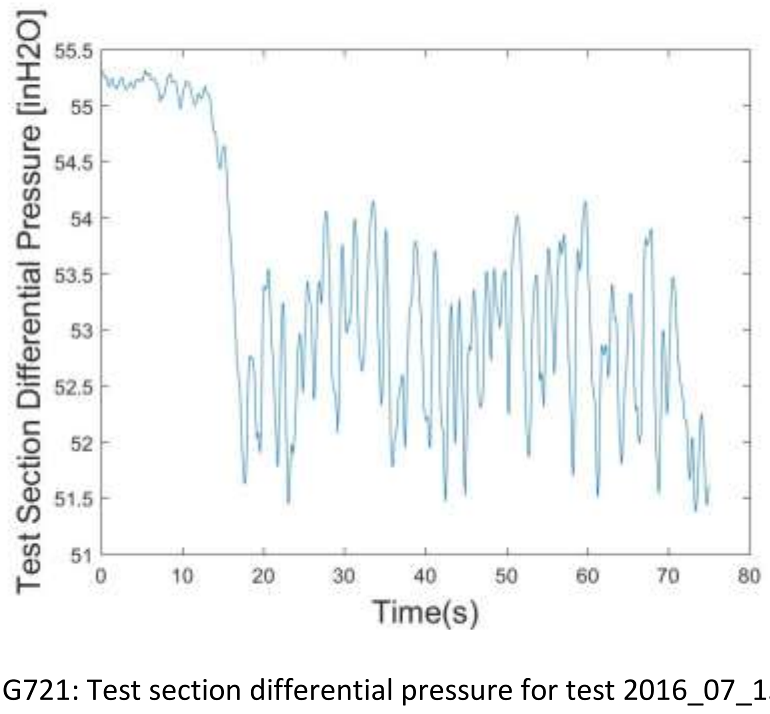

Figure G721: Test section differential pressure for test 2016_07_13_test_29.

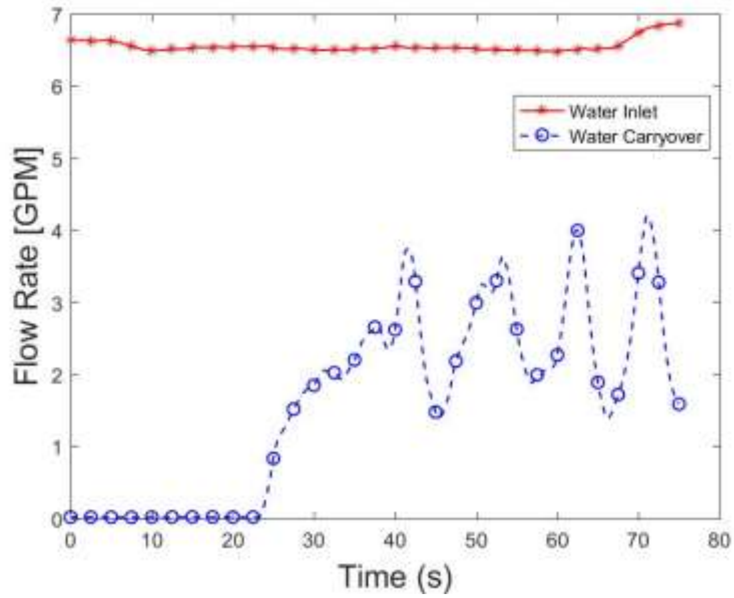

Figure G722: Water flow rates for test 2016_07_13_test_29.

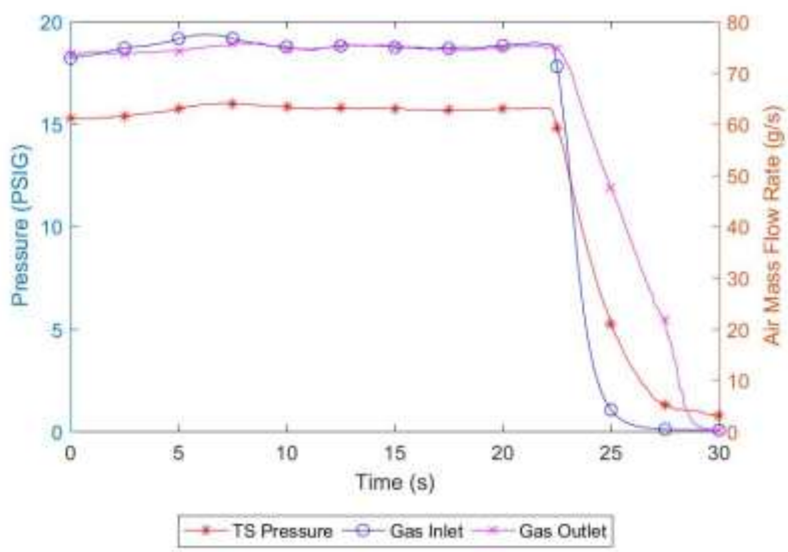

Figure G723: Pressure and gas inlet and outlet mass flow rates for test 2017_02_20_test_08.

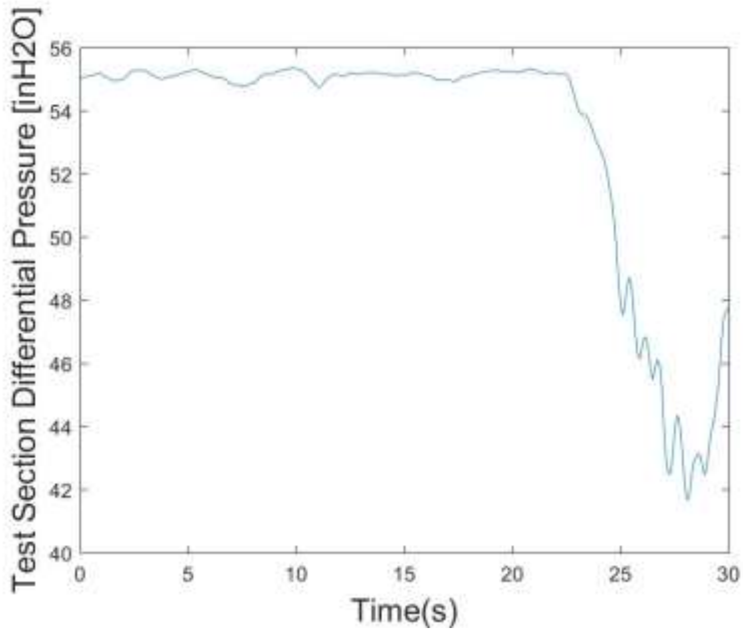

Figure G724: Test section differential pressure for test 2017_02_20_test_08.

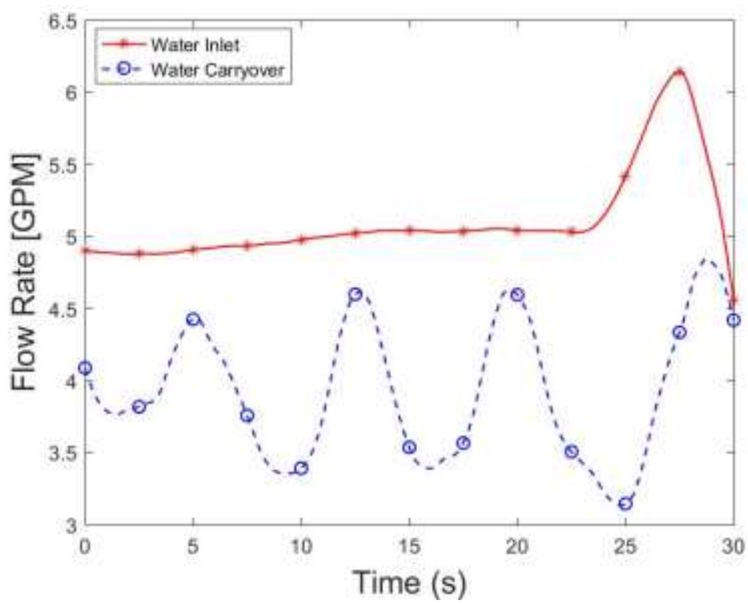

Figure G725: Water flow rates for test 2017_02_20_test_08.

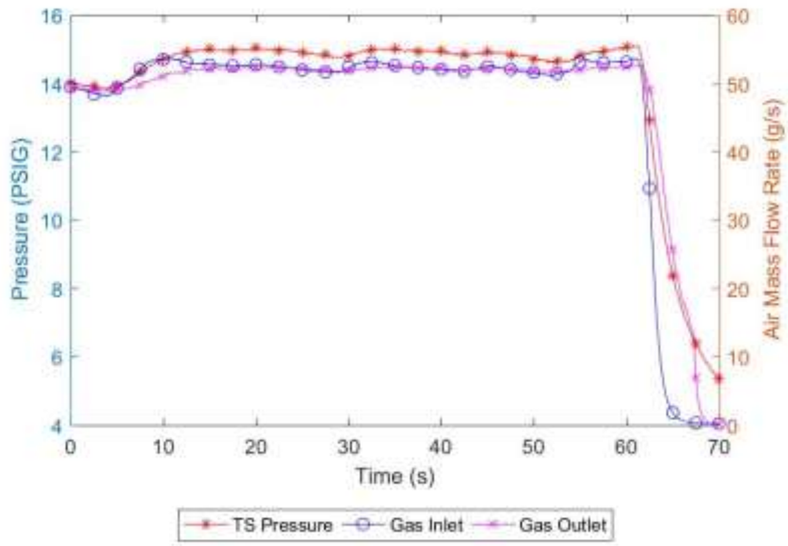

Figure G726: Pressure and gas inlet and outlet mass flow rates for test 2017_02_23_test_01.

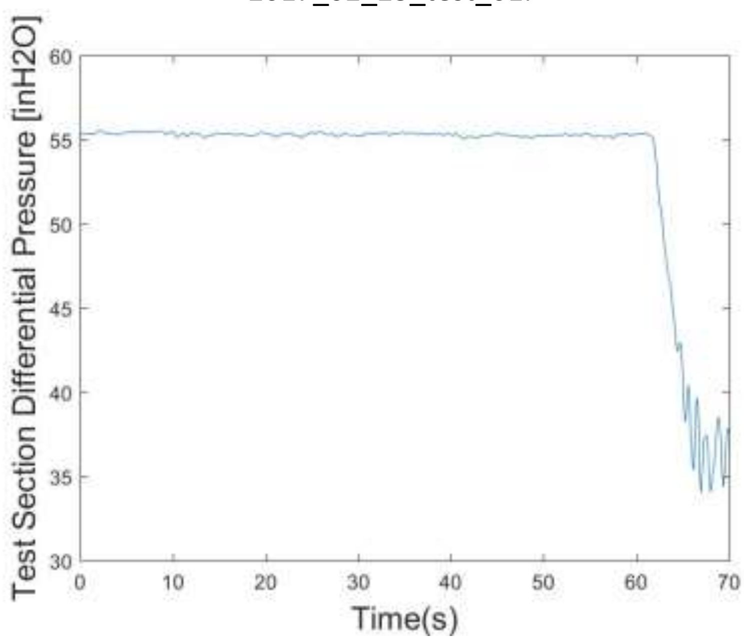

Figure G727: Test section differential pressure for test 2017_02_23_test_01.

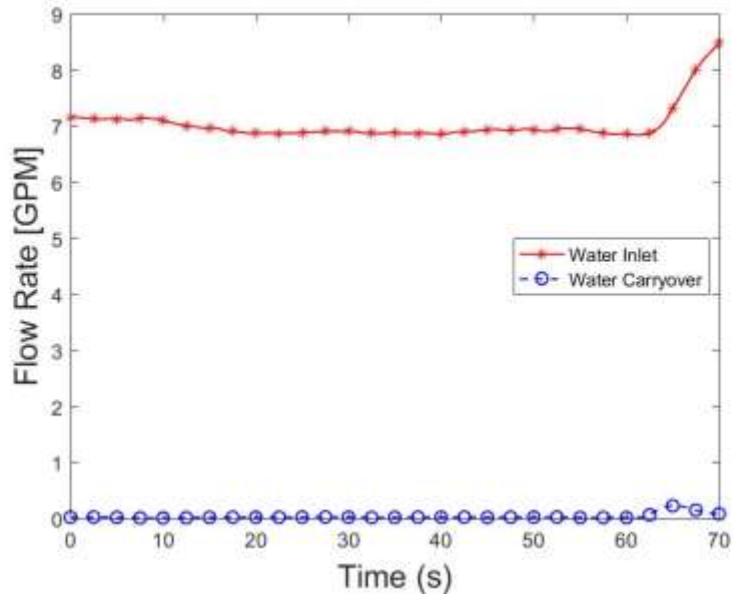

Figure G728: Water flow rates for test 2017_02_23_test_01.

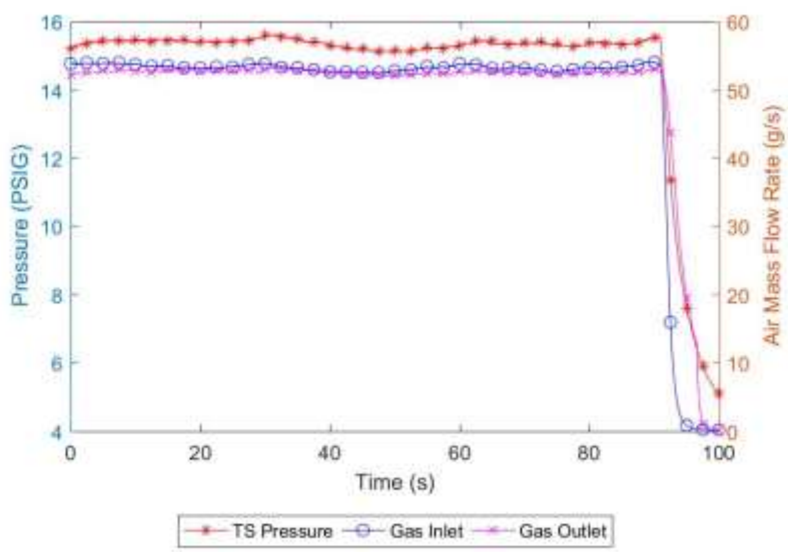

Figure G729: Pressure and gas inlet and outlet mass flow rates for test 2017_02_23_test_02.

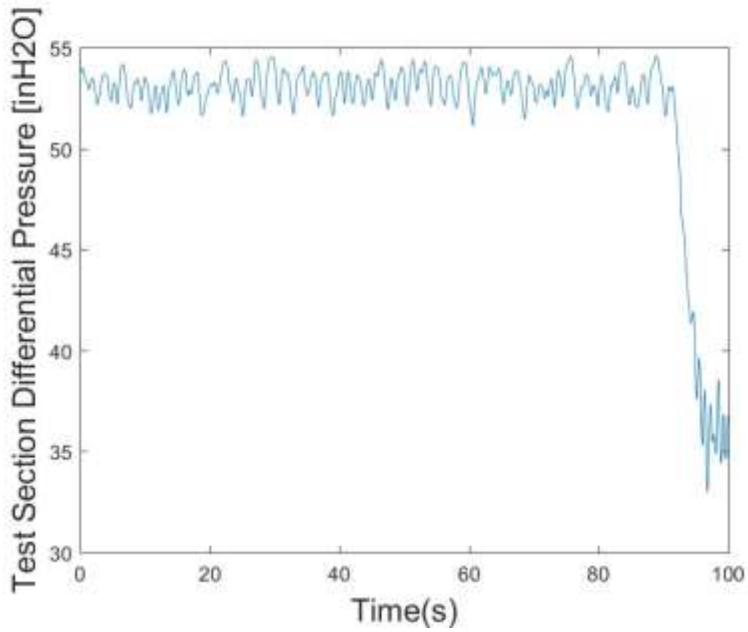

Figure G730: Test section differential pressure for test 2017_02_23_test_02.

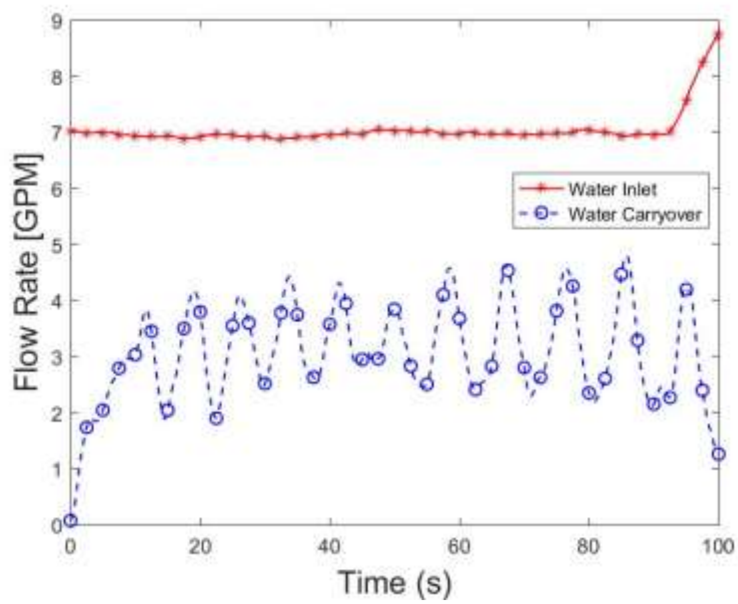

Figure G731: Water flow rates for test 2017_02_23_test_02.

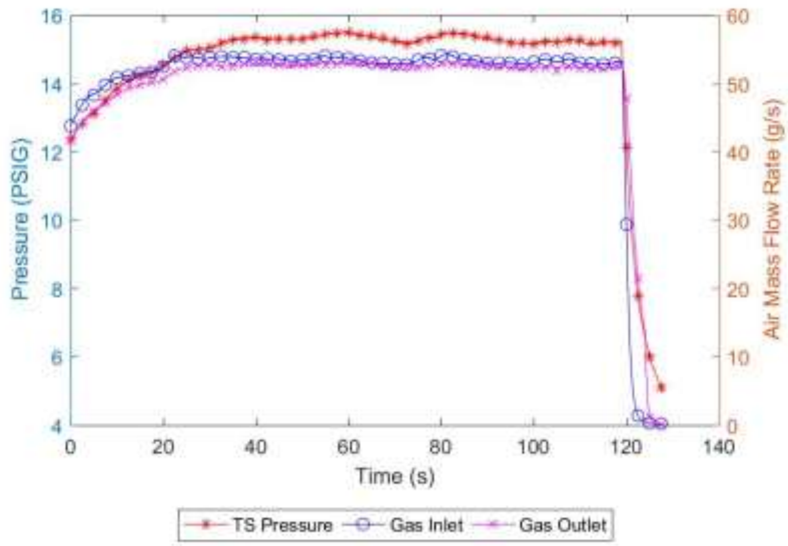

Figure G732: Pressure and gas inlet and outlet mass flow rates for test 2017_02_23_test_03.

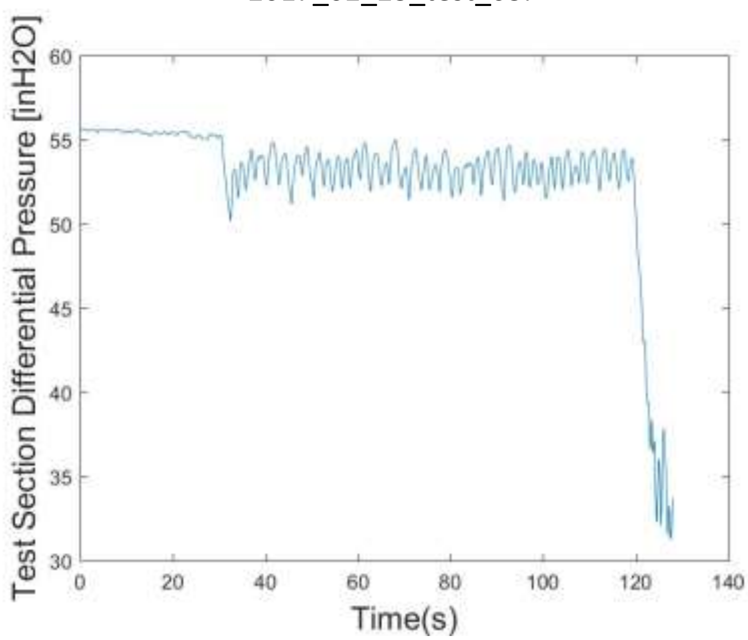

Figure G733: Test section differential pressure for test 2017_02_23_test_03.

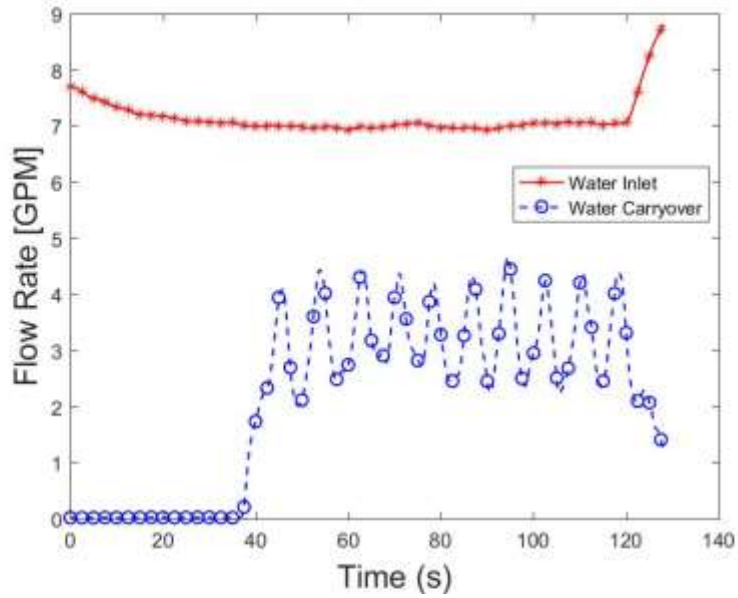

Figure G734: Water flow rates for test 2017_02_23_test_03.

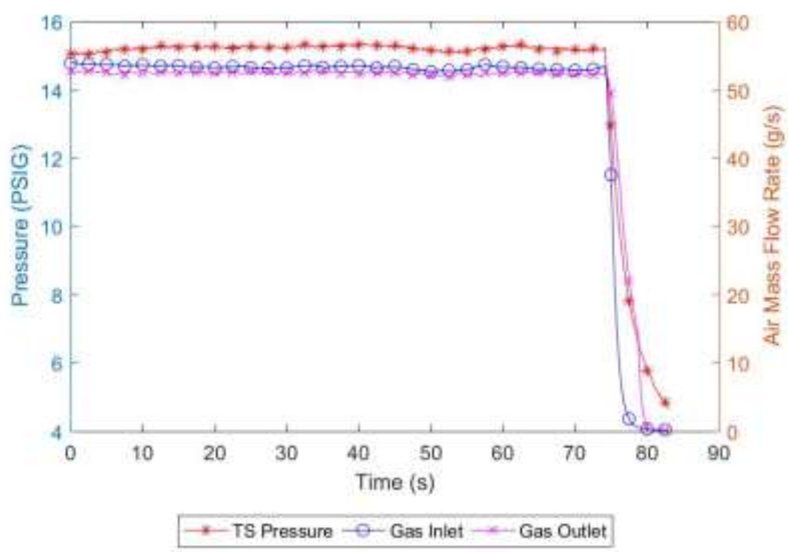

Figure G735: Pressure and gas inlet and outlet mass flow rates for test 2017_02_23_test_04.

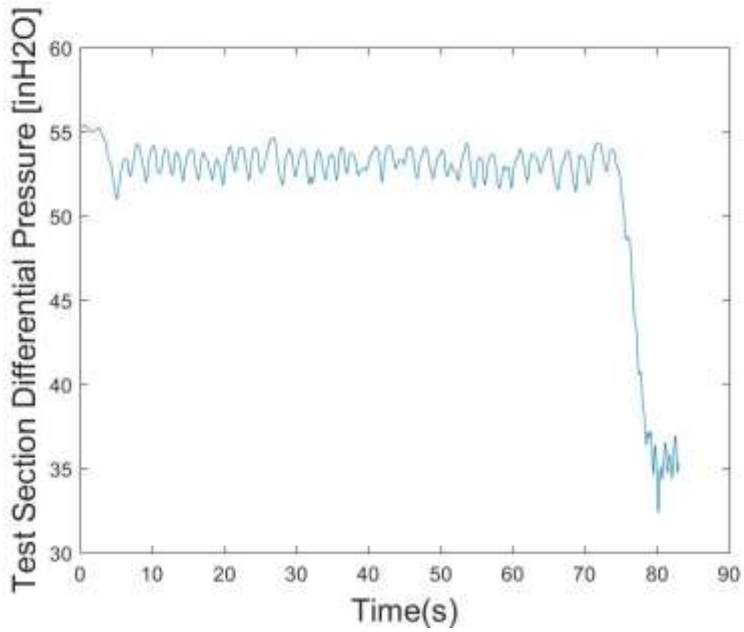

Figure G736: Test section differential pressure for test 2017_02_23_test_04.

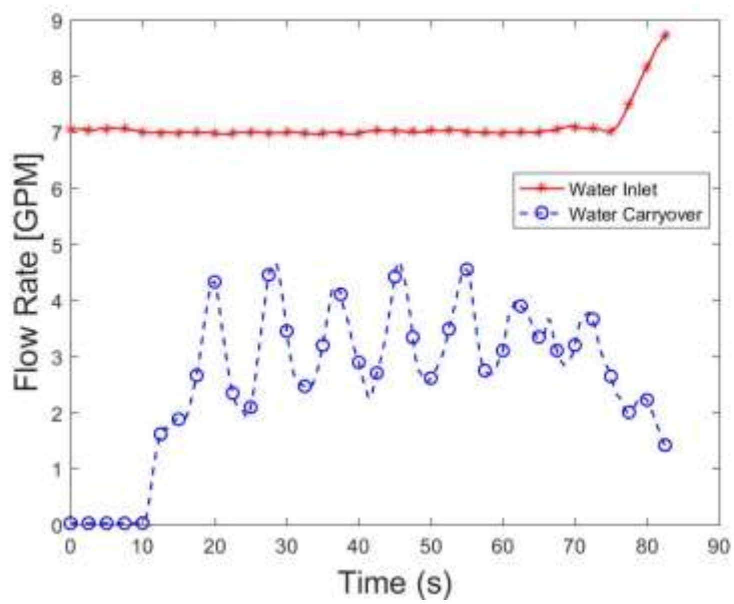

Figure G737: Water flow rates for test 2017_02_23_test_04.

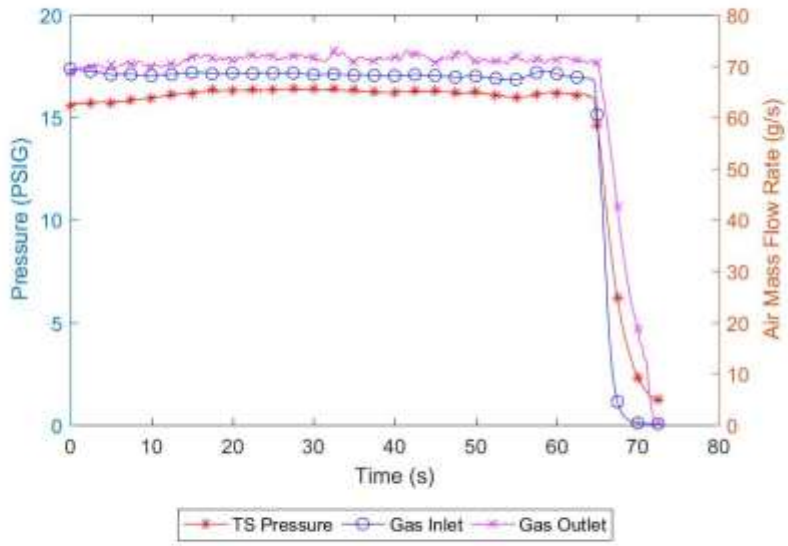

Figure G738: Pressure and gas inlet and outlet mass flow rates for test 2017_02_27_test_01.

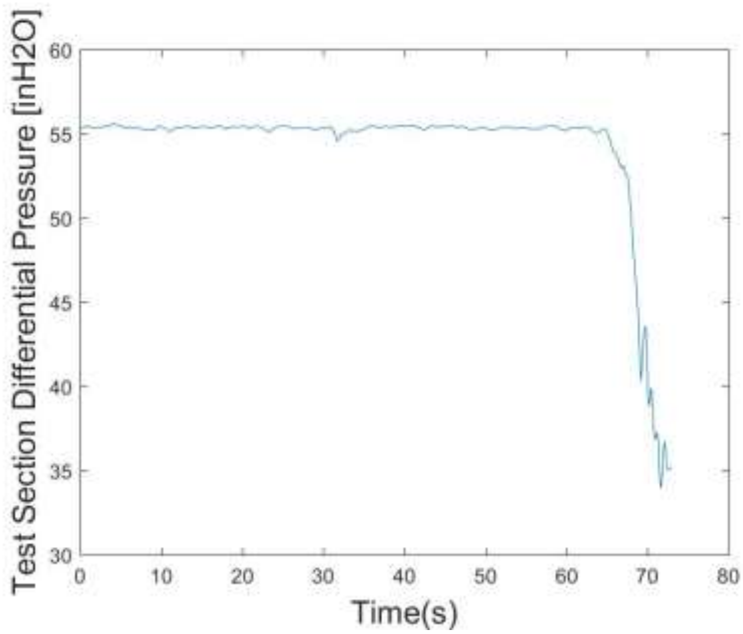

Figure G739: Test section differential pressure for test 2017_02_27_test_01.

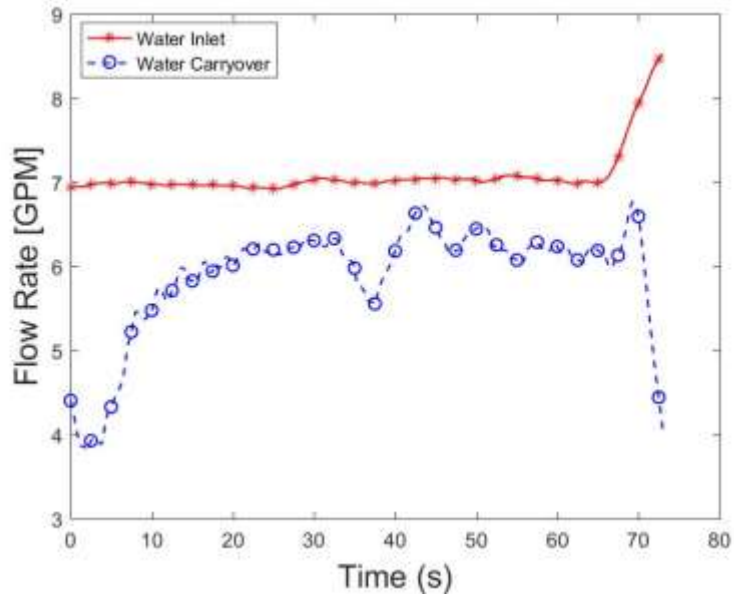

Figure G740: Water flow rates for test 2017_02_27_test_01.

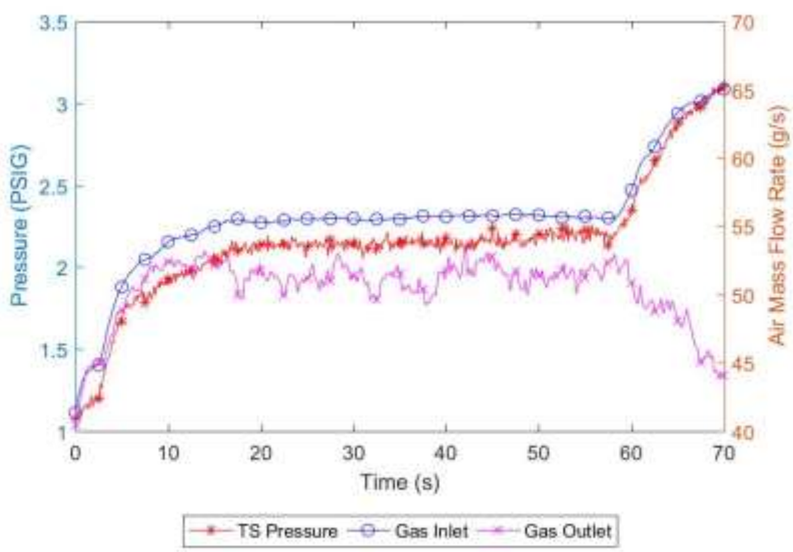

Figure G741: Pressure and gas inlet and outlet mass flow rates for test 2017_02_27_test_11.

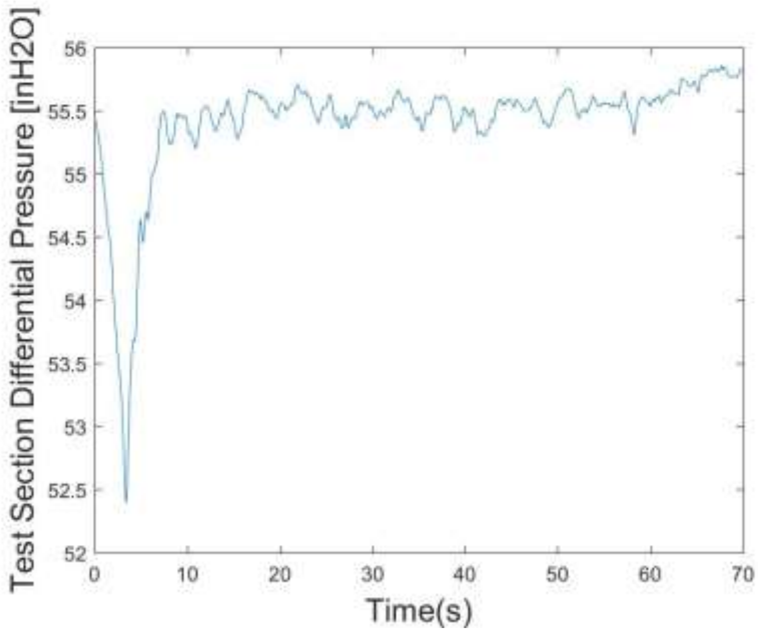

Figure G742: Test section differential pressure for test 2017_02_27_test_11.

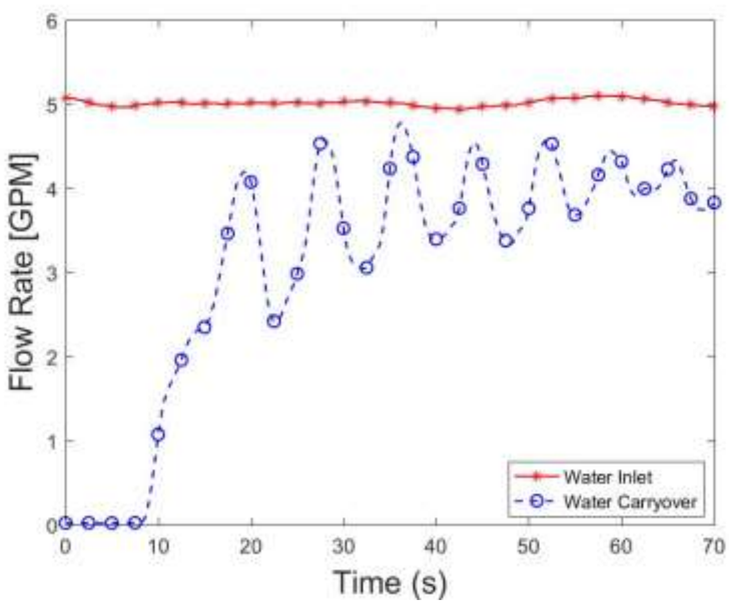

Figure G743: Water flow rates for test 2017_02_27_test_11.

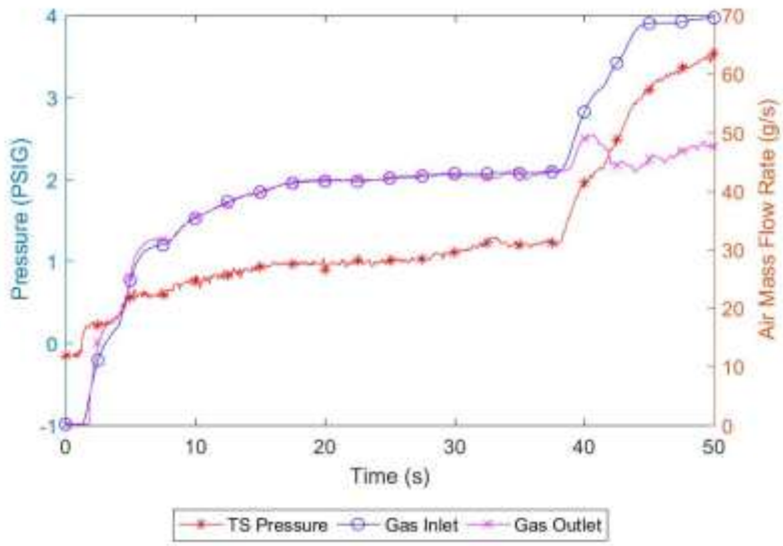

Figure G744: Pressure and gas inlet and outlet mass flow rates for test 2017_02_27_test_12.

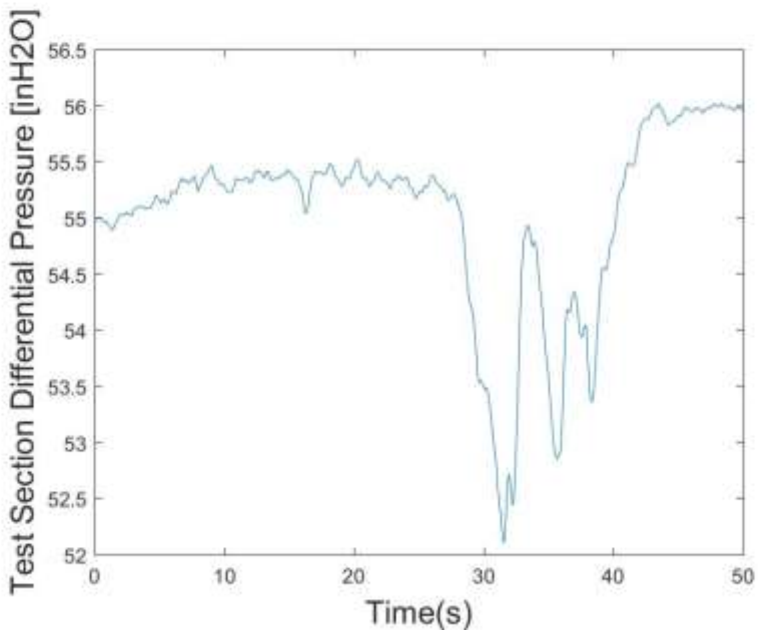

Figure G745: Test section differential pressure for test 2017_02_27_test_12.

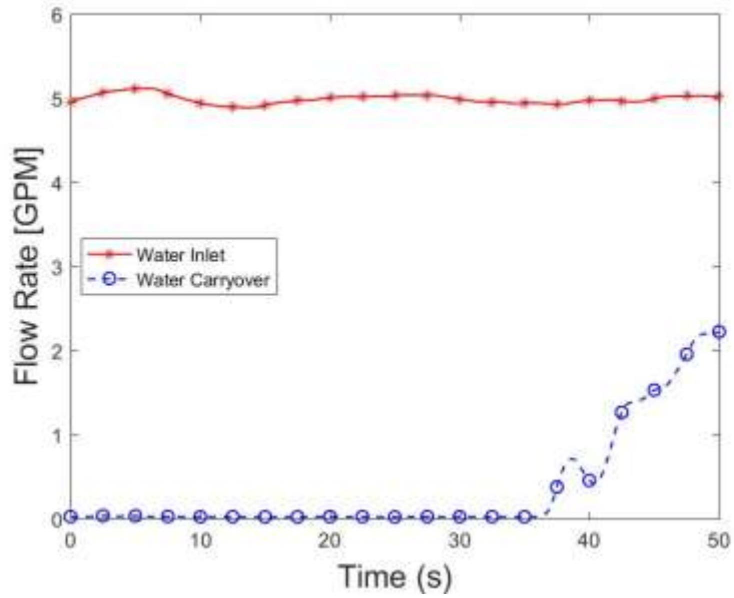

Figure G746: Water flow rates for test 2017_02_27_test_12.

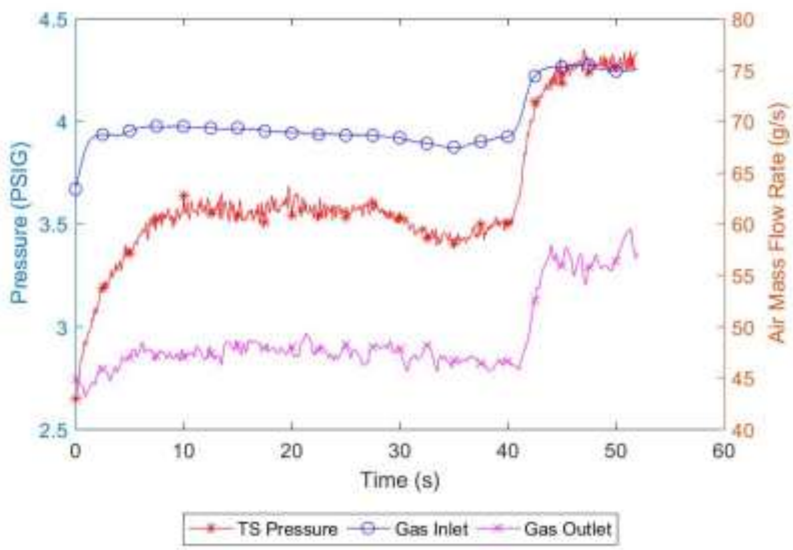

Figure G747: Pressure and gas inlet and outlet mass flow rates for test 2017_02_27_test_12b.

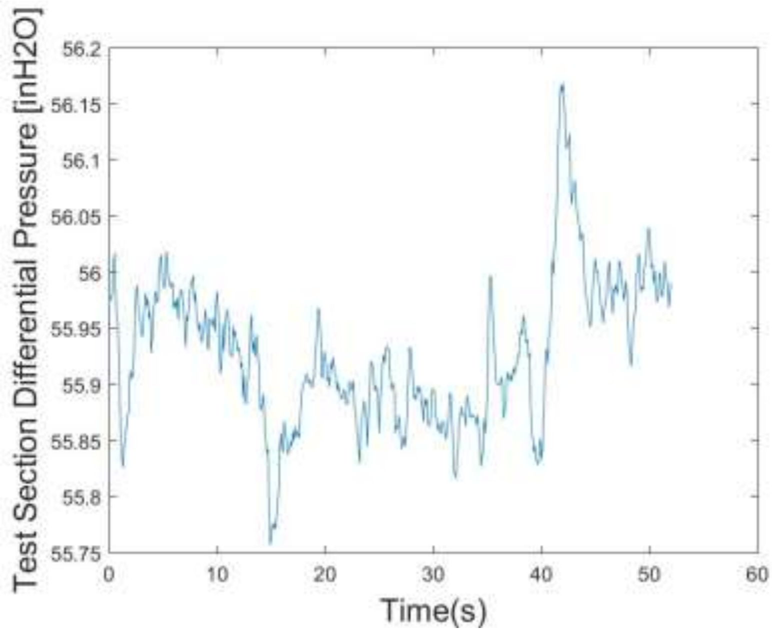

Figure G748: Test section differential pressure for test 2017_02_27_test_12b.

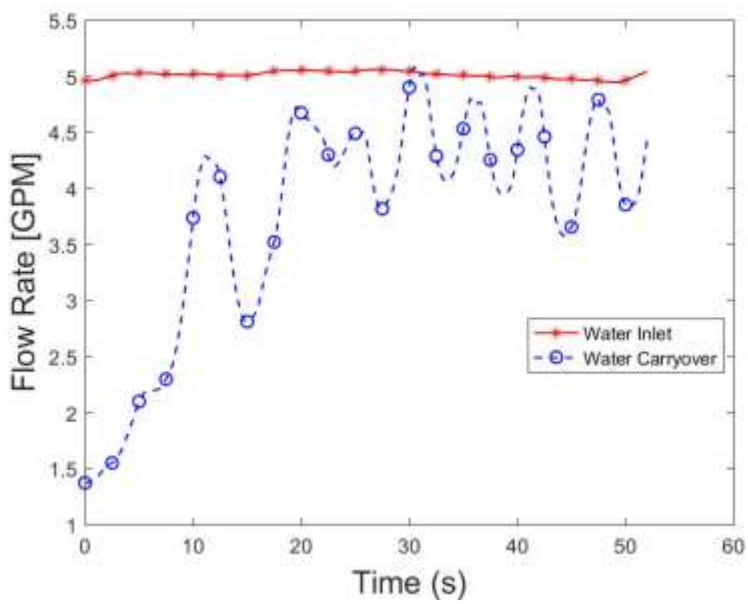

Figure G749: Water flow rates for test 2017_02_27_test_12b.

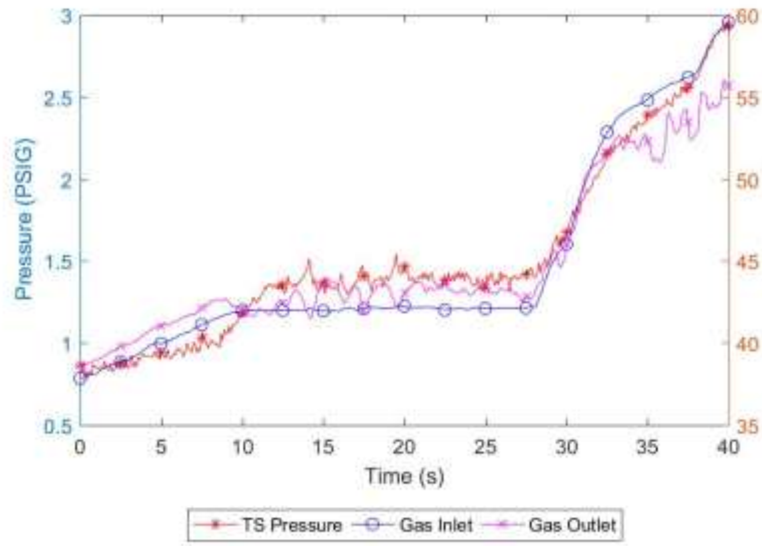

Figure G750: Pressure and gas inlet and outlet mass flow rates for test 2017_02_27_test_13.

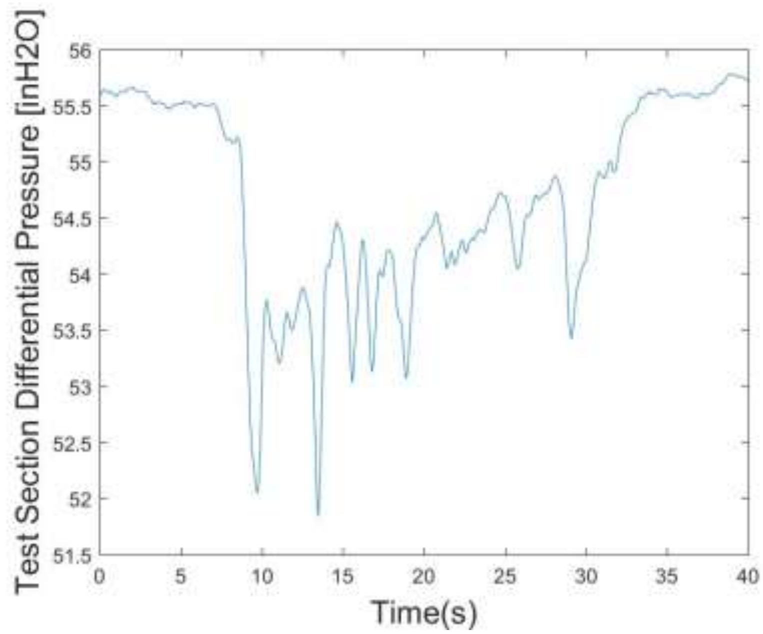

Figure G751: Test section differential pressure for test 2017_02_27_test_13.

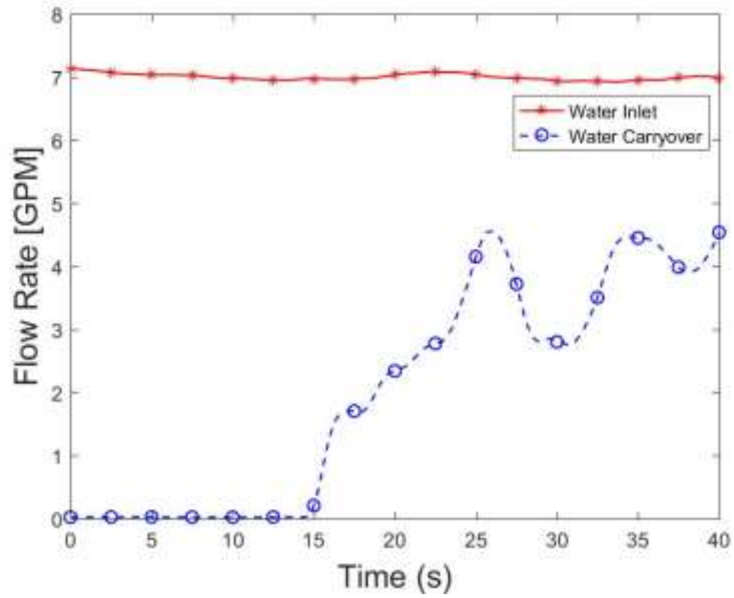

Figure G752: Water flow rates for test 2017_02_27_test_13.

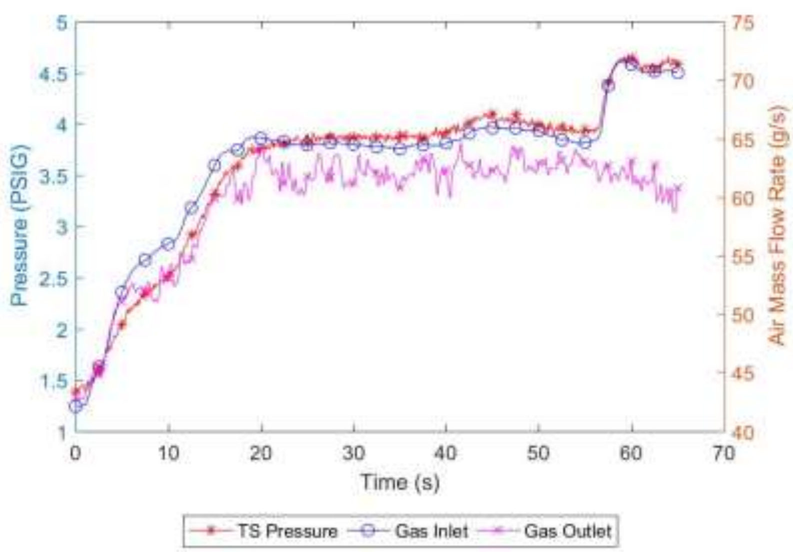

Figure G753: Pressure and gas inlet and outlet mass flow rates for test 2017_02_27_test_13b.

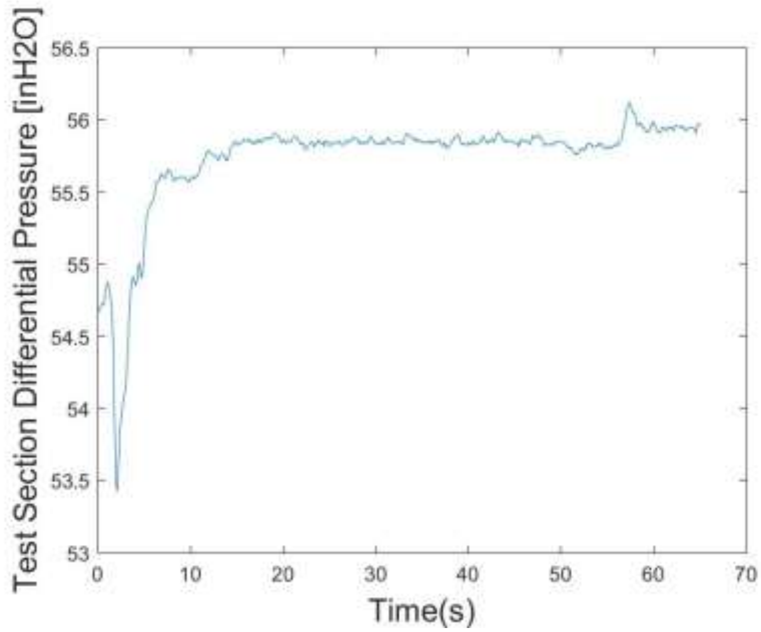

Figure G754: Test section differential pressure for test 2017_02_27_test_13b.

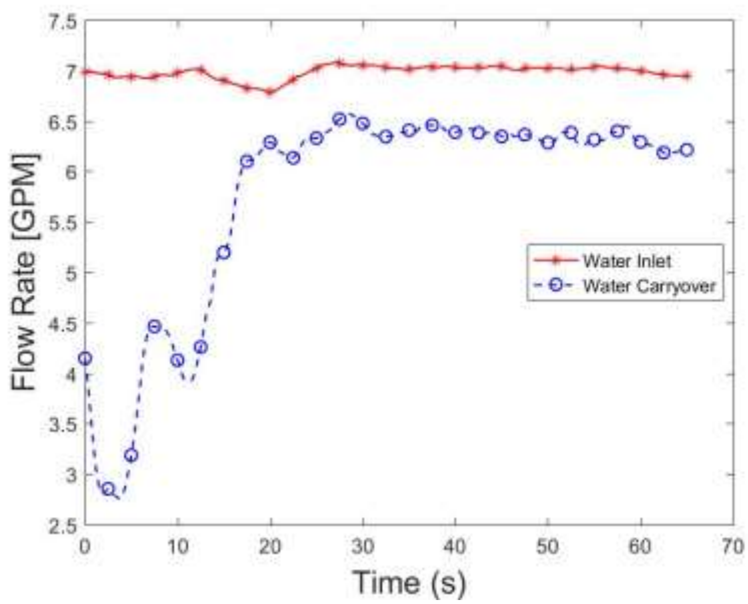

Figure G755: Water flow rates for test 2017_02_27_test_13b.

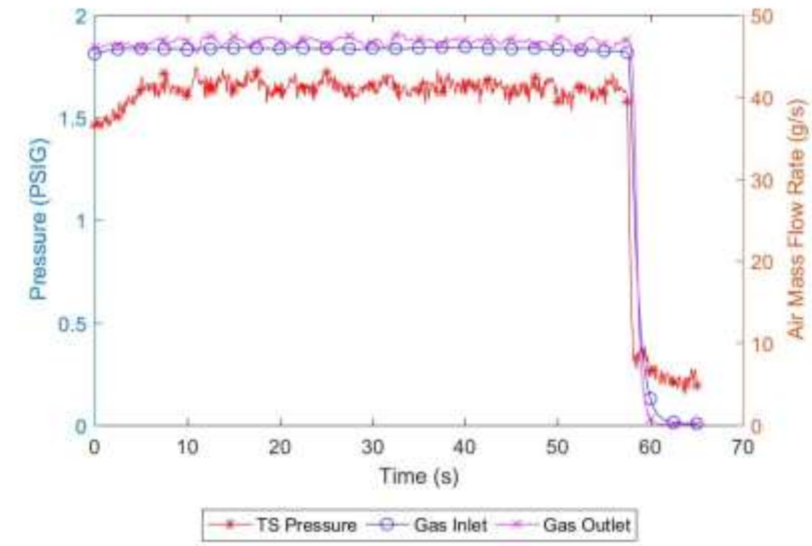

Figure G756: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_01a.

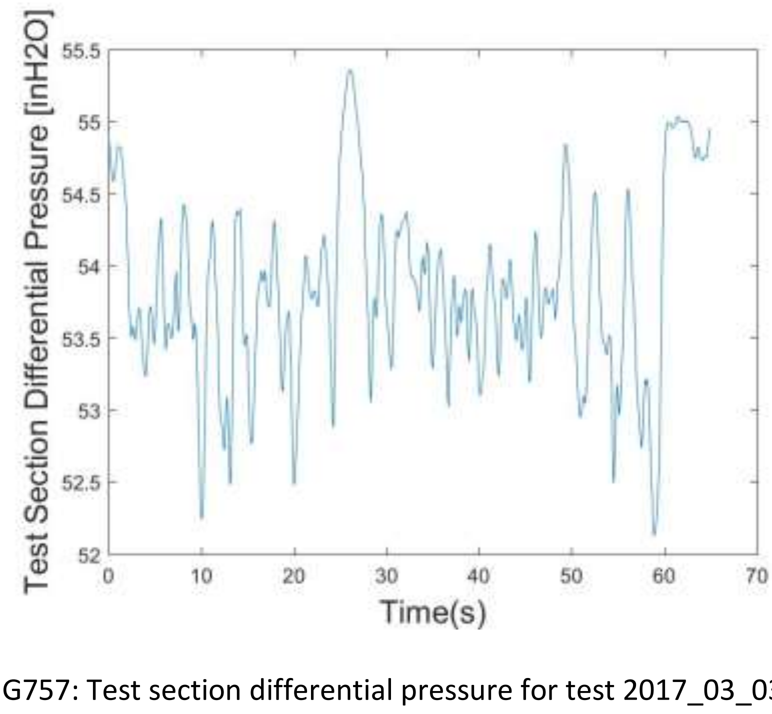

Figure G757: Test section differential pressure for test 2017_03_03_test_01a.

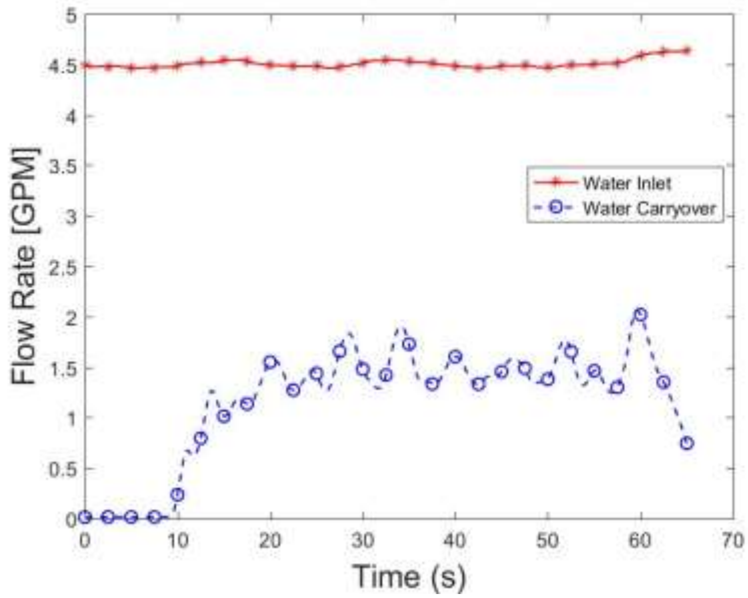

Figure G758: Water flow rates for test 2017_03_03_test_01a.

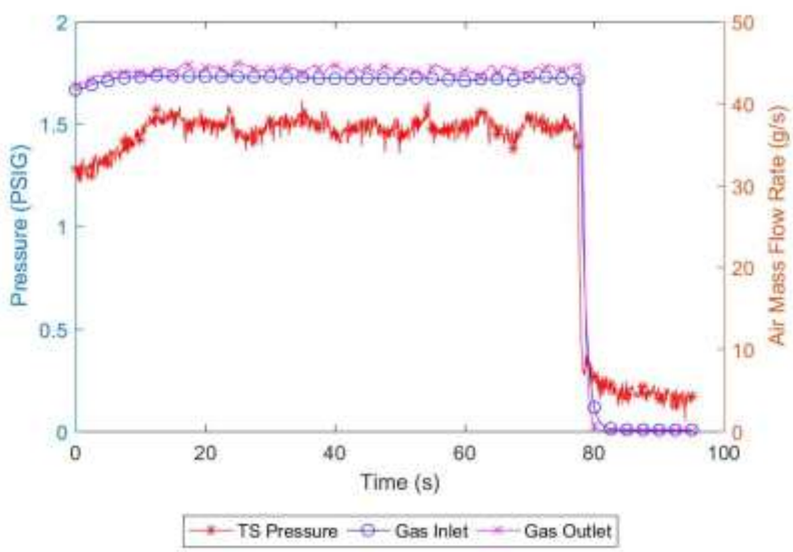

Figure G759: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_02a.

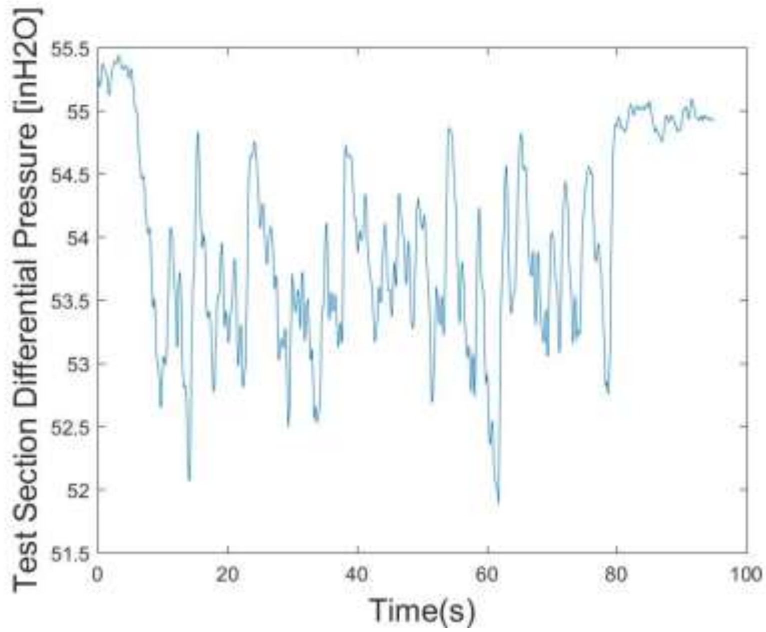

Figure G760: Test section differential pressure for test 2017_03_03_test_02a.

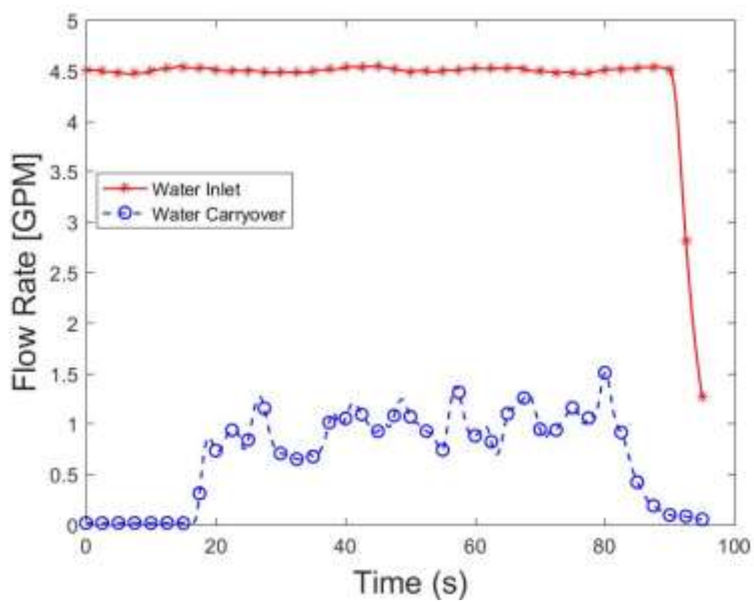

Figure G761: Water flow rates for test 2017_03_03_test_02a.

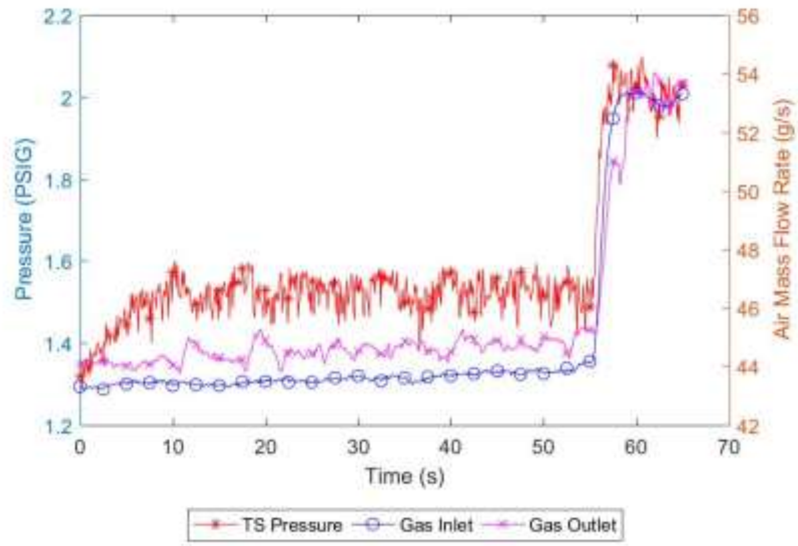

Figure G762: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_03a.

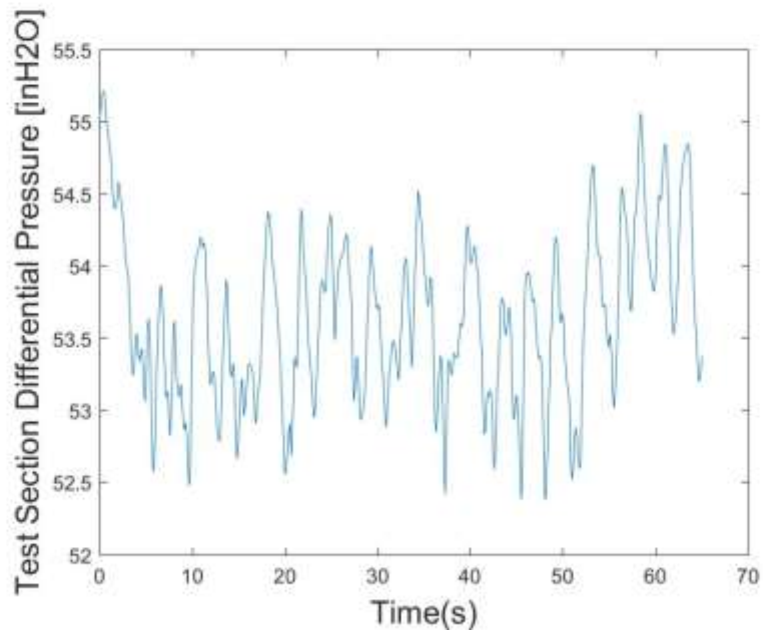

Figure G763: Test section differential pressure for test 2017_03_03_test_03a.

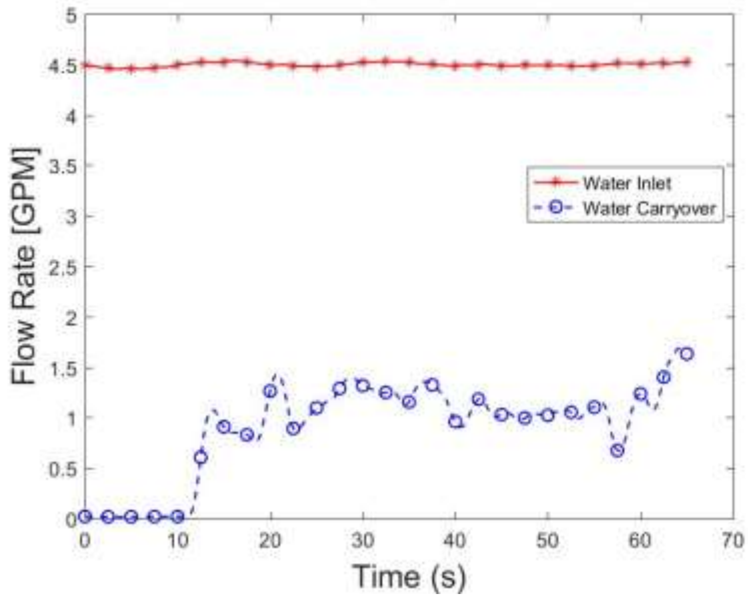

Figure G764: Water flow rates for test 2017_03_03_test_03a.

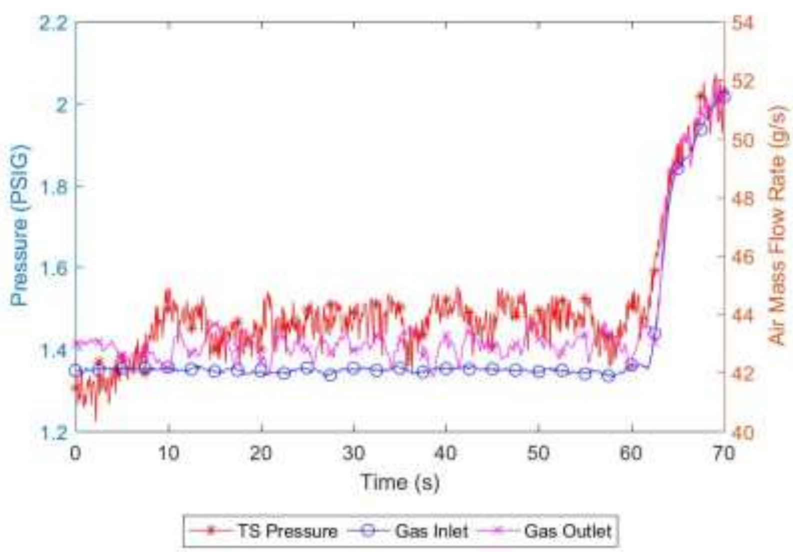

Figure G765: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_04a.

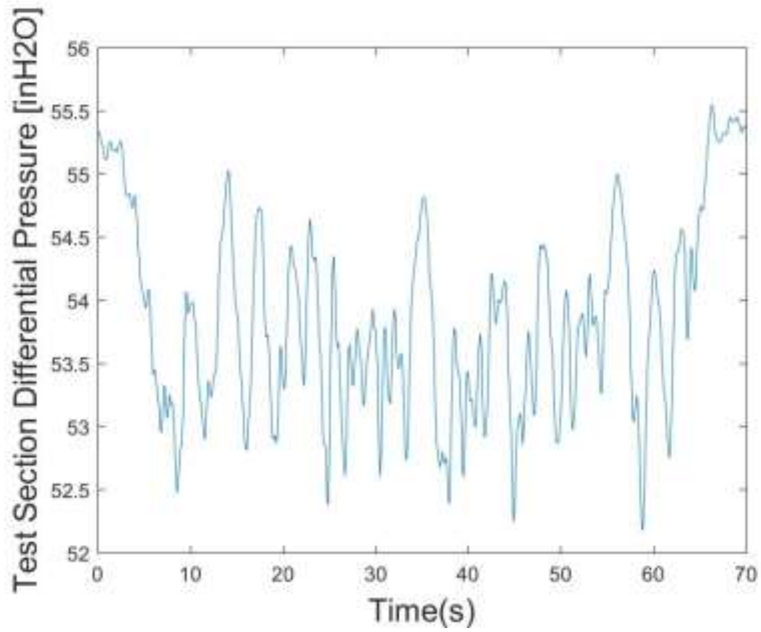

Figure G766: Test section differential pressure for test 2017_03_03_test_04a.

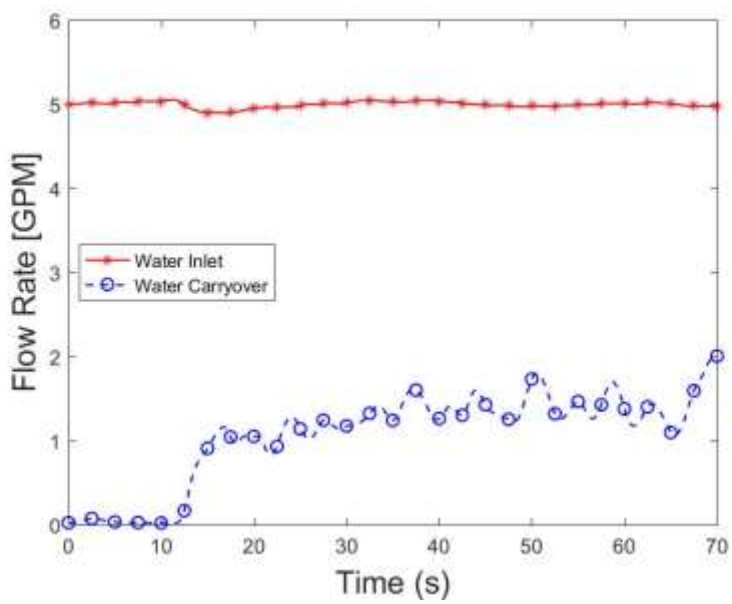

Figure G767: Water flow rates for test 2017_03_03_test_04a.

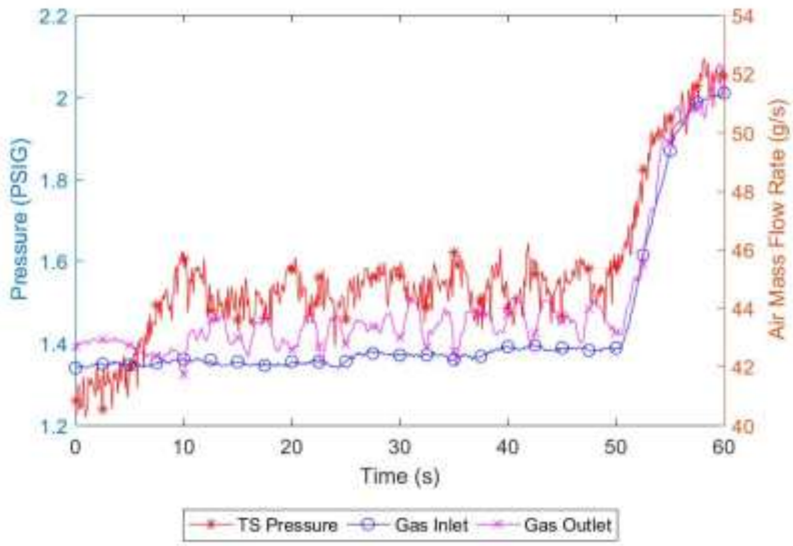

Figure G768: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_05a.

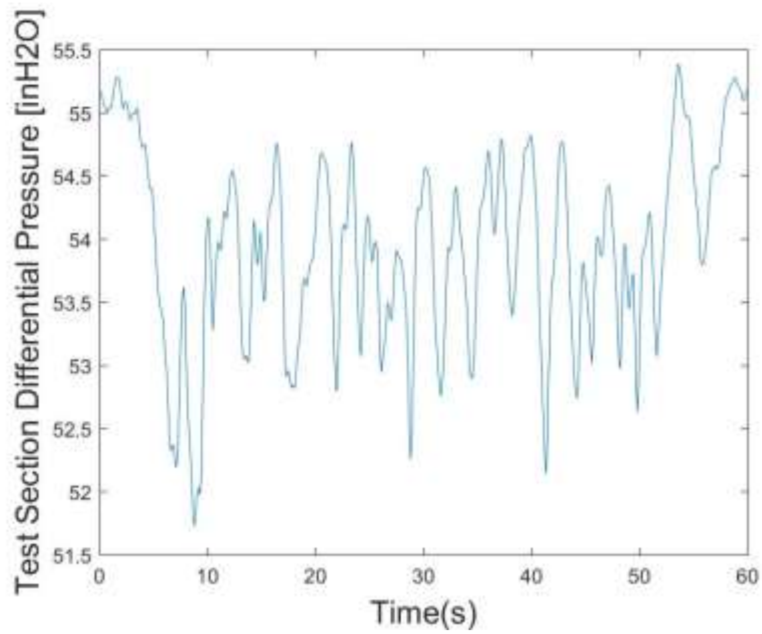

Figure G769: Test section differential pressure for test 2017_03_03_test_05a.

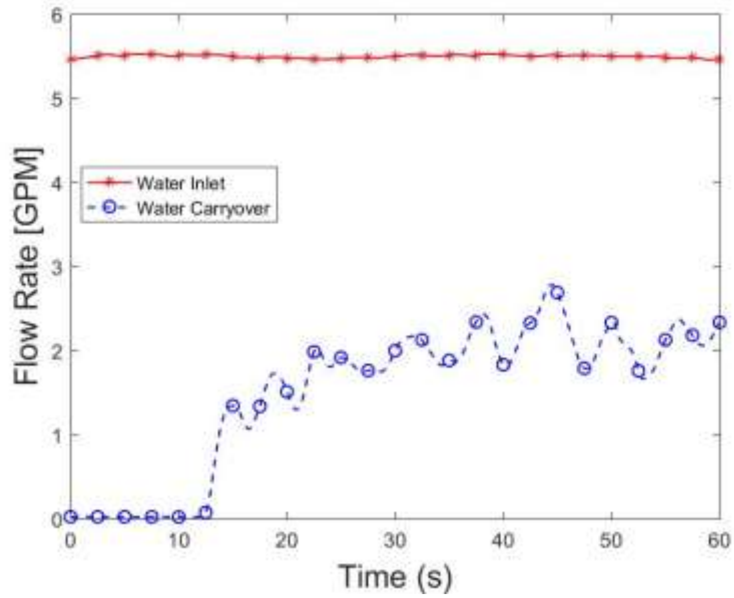

Figure G770: Water flow rates for test 2017_03_03_test_05a.

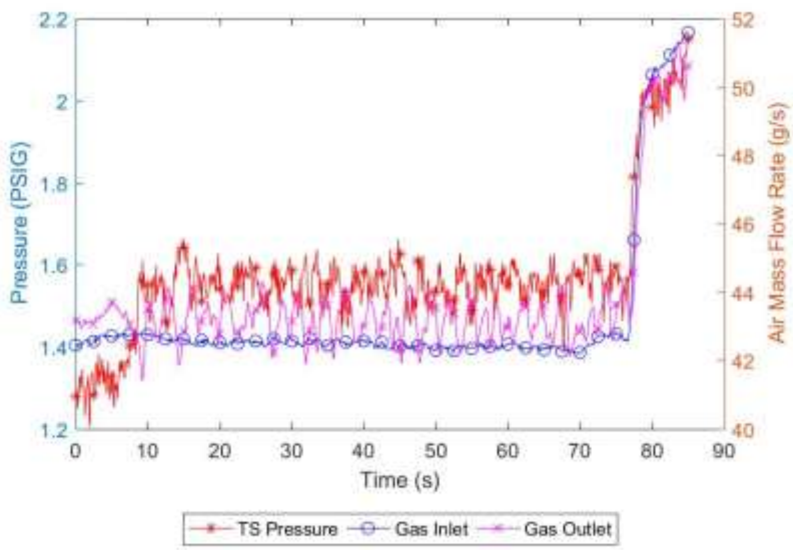

Figure G771: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_06a.

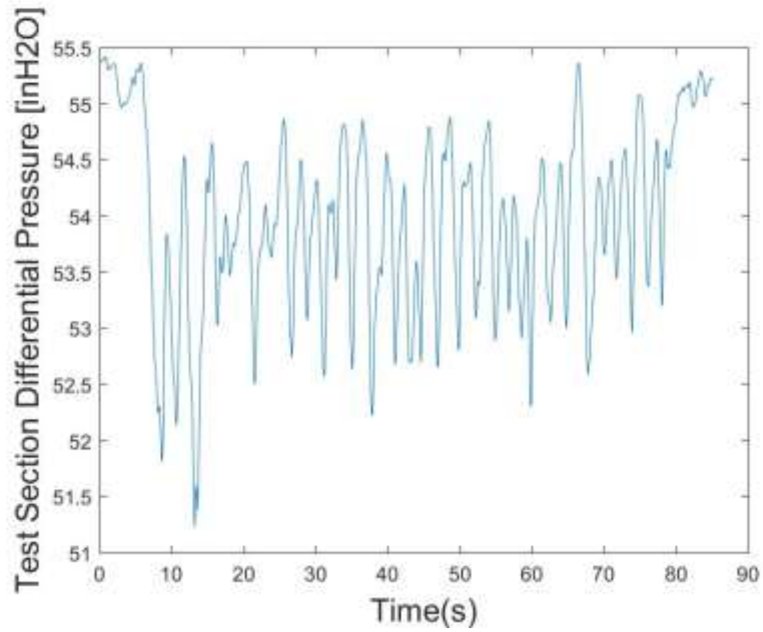

Figure G772: Test section differential pressure for test 2017_03_03_test_06a.

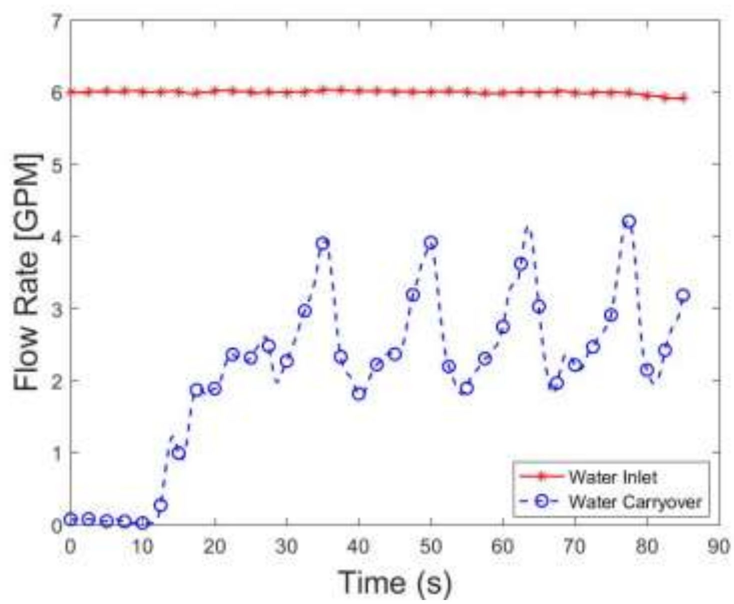

Figure G773: Water flow rates for test 2017_03_03_test_06a.

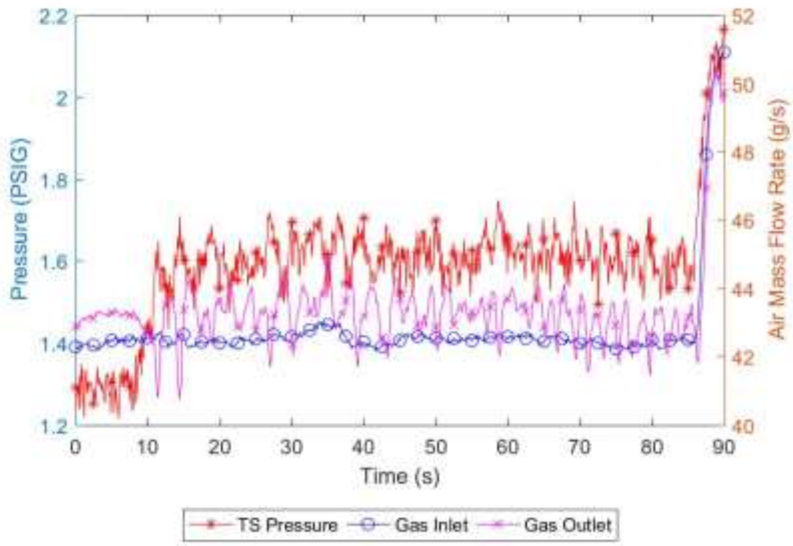

Figure G774: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_07a.

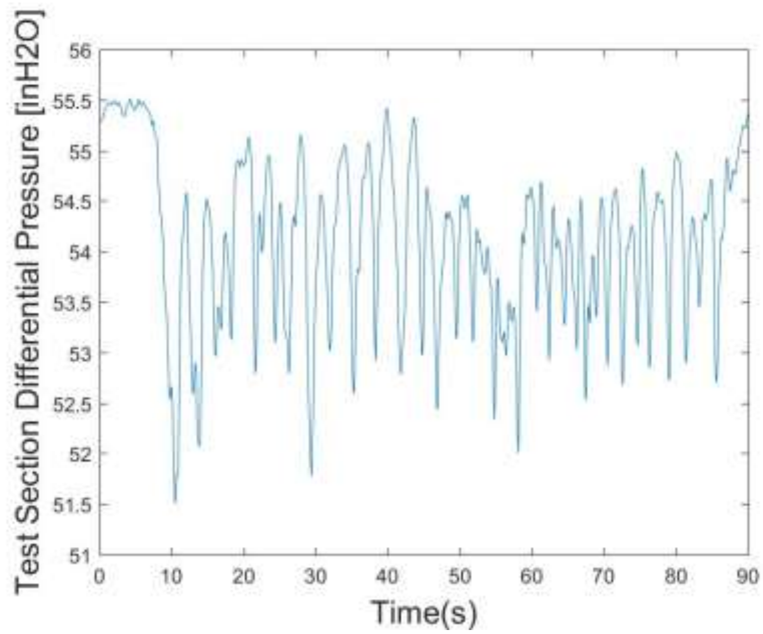

Figure G775: Test section differential pressure for test 2017_03_03_test_07a.

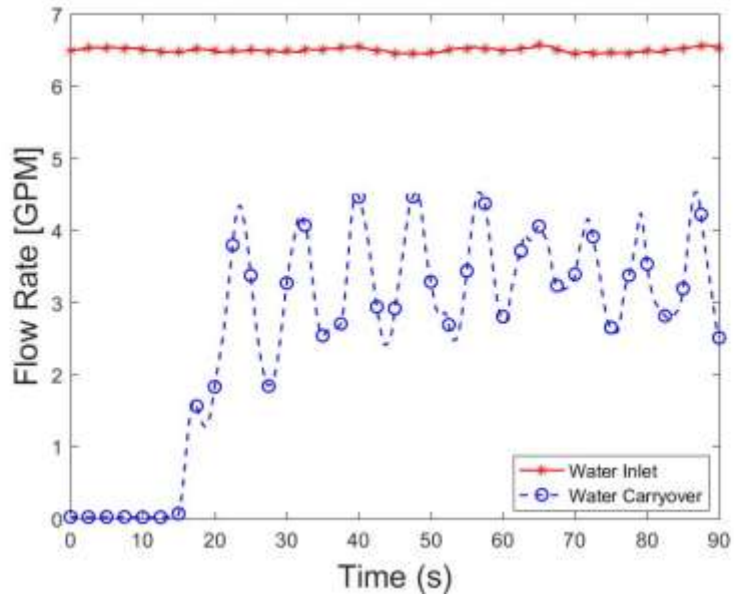

Figure G776: Water flow rates for test 2017_03_03_test_07a.

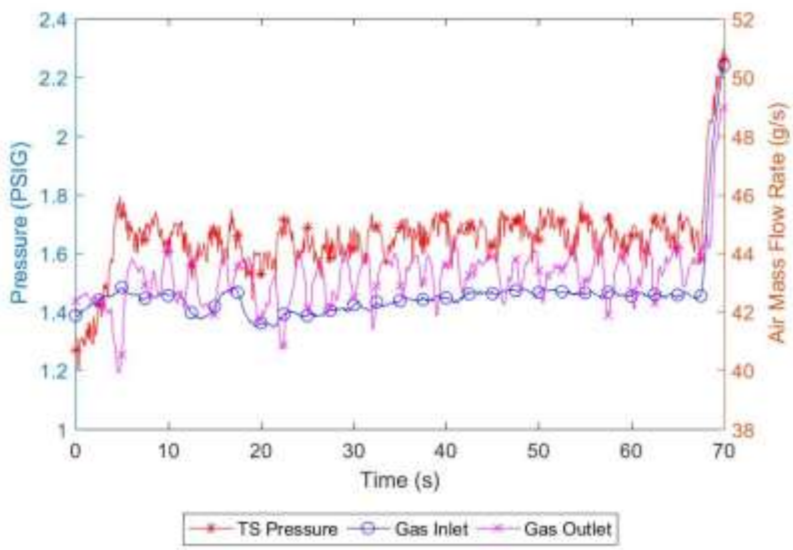

Figure G777: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_08a.

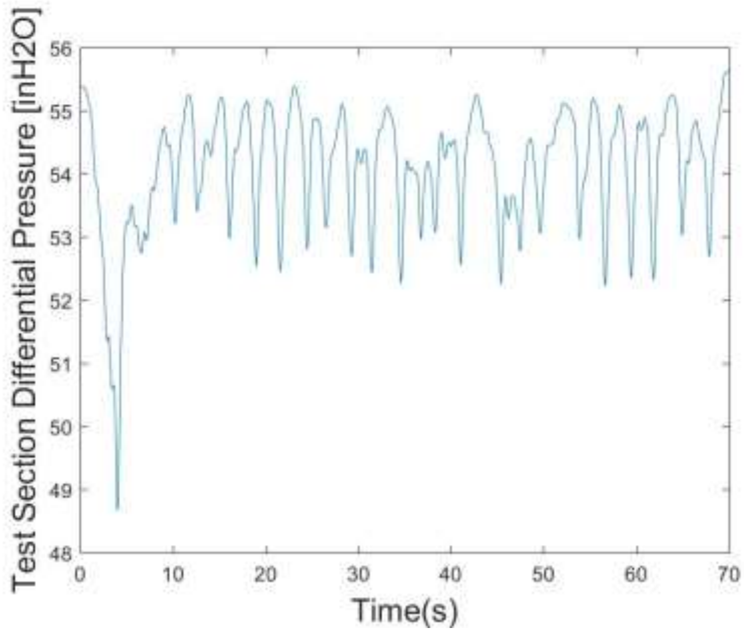

Figure G778: Test section differential pressure for test 2017_03_03_test_08a.

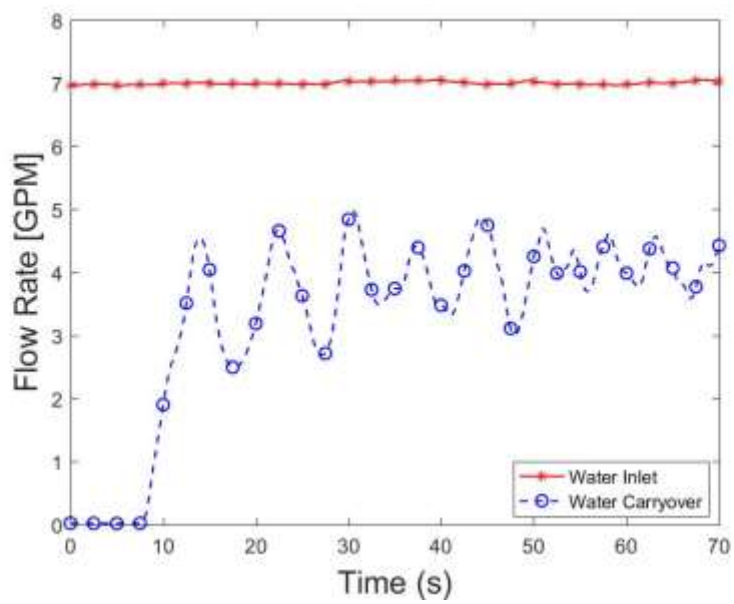

Figure G779: Water flow rates for test 2017_03_03_test_08a.

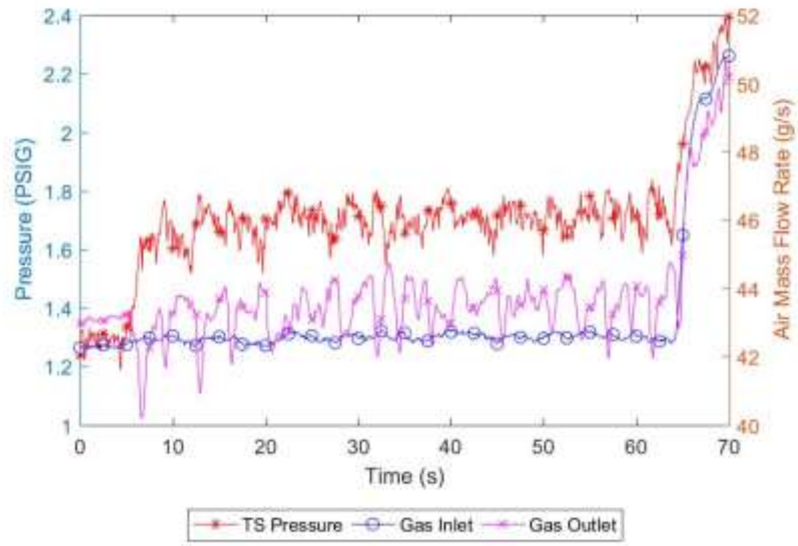

Figure G780: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_09a.

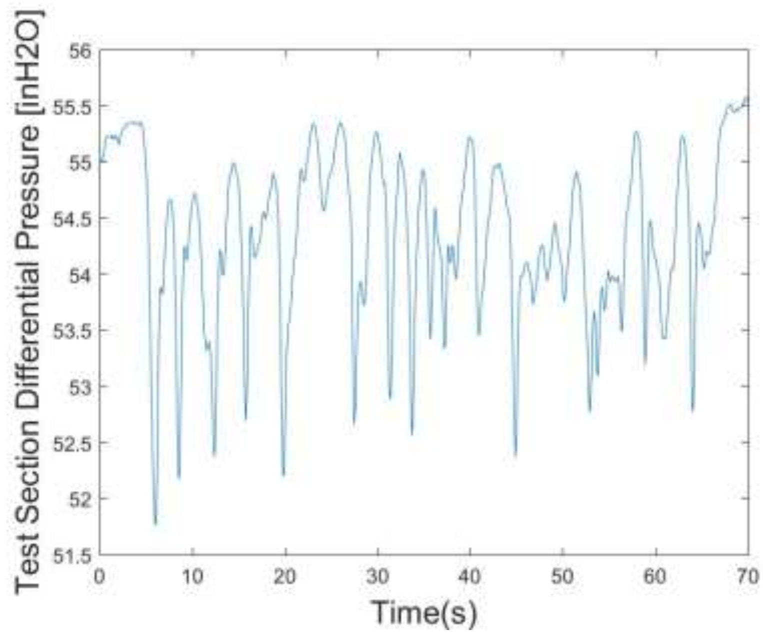

Figure G781: Test section differential pressure for test 2017_03_03_test_09a.

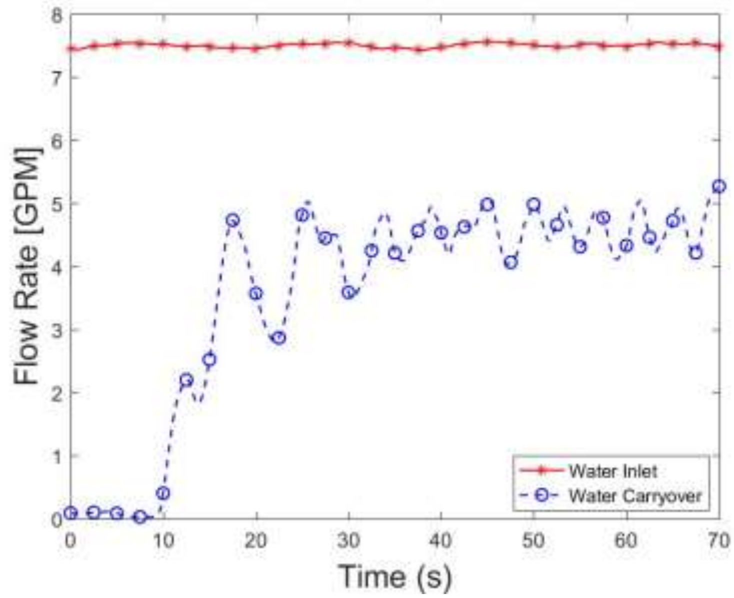

Figure G782: Water flow rates for test 2017_03_03_test_09a.

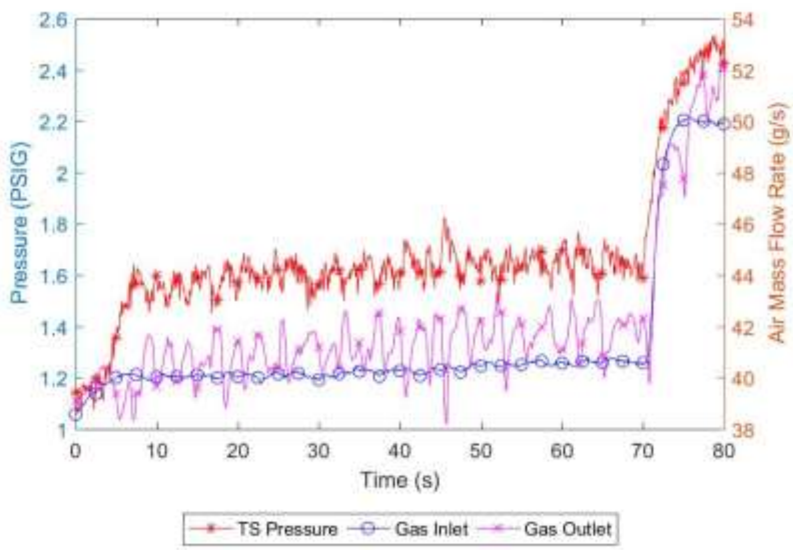

Figure G783: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_10a.

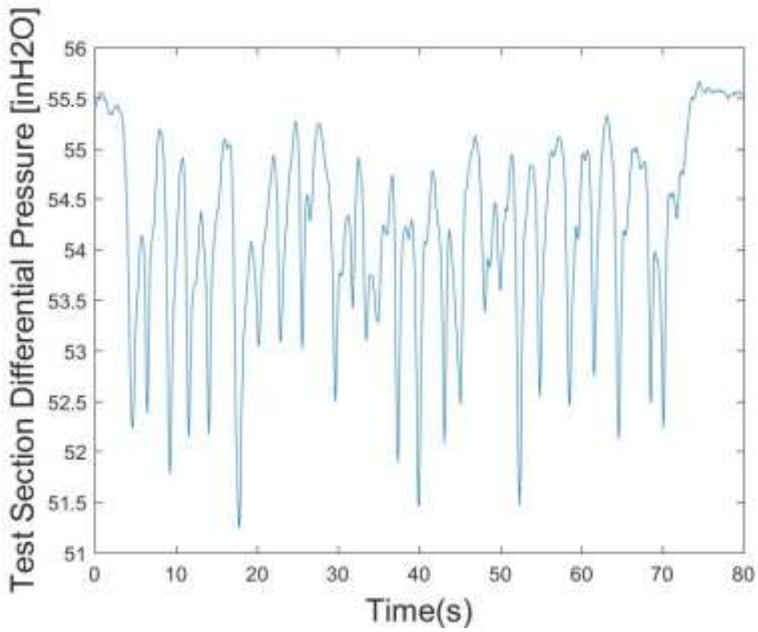

Figure G784: Test section differential pressure for test 2017_03_03_test_10a.

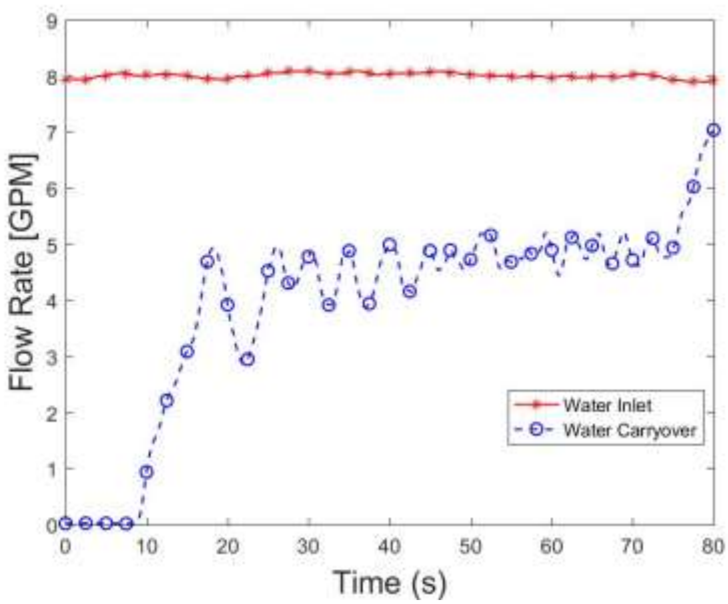

Figure G785: Water flow rates for test 2017_03_03_test_10a.

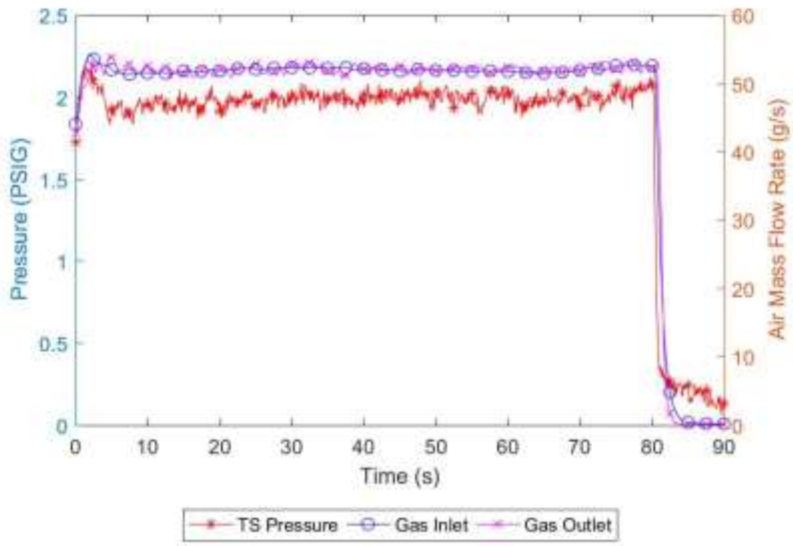

Figure G786: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_02b.

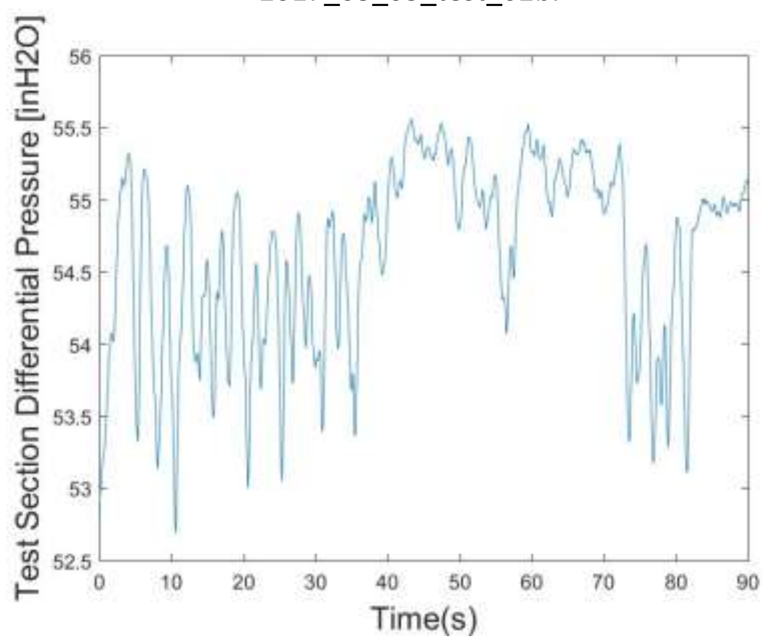

Figure G787: Test section differential pressure for test 2017_03_03_test_02b.

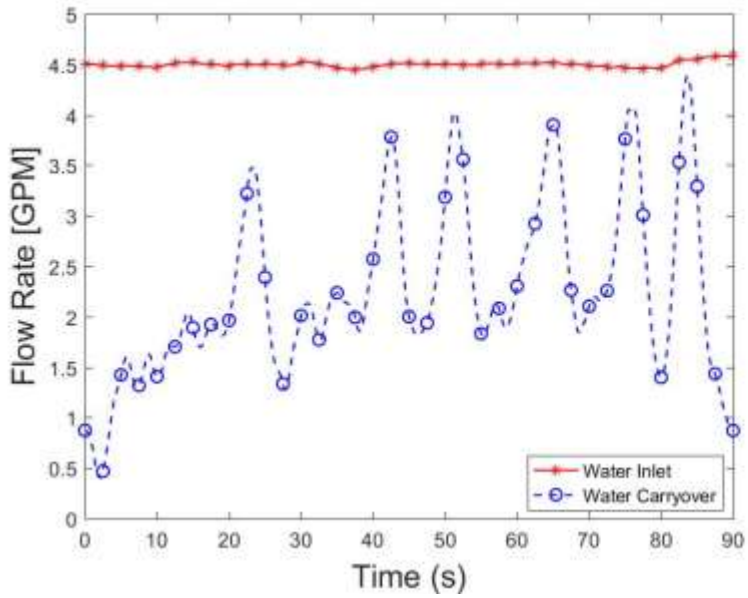

Figure G788: Water flow rates for test 2017_03_03_test_02b.

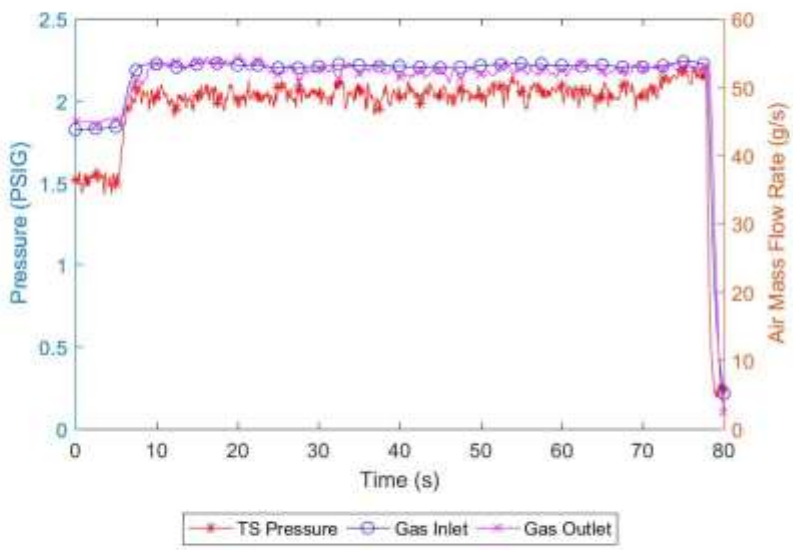

Figure G789: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_03b.

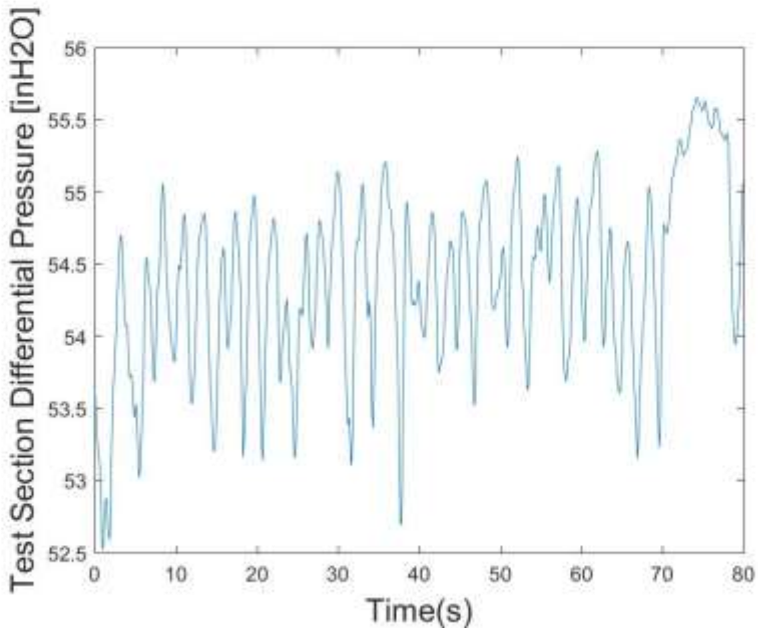

Figure G790: Test section differential pressure for test 2017_03_03_test_03b.

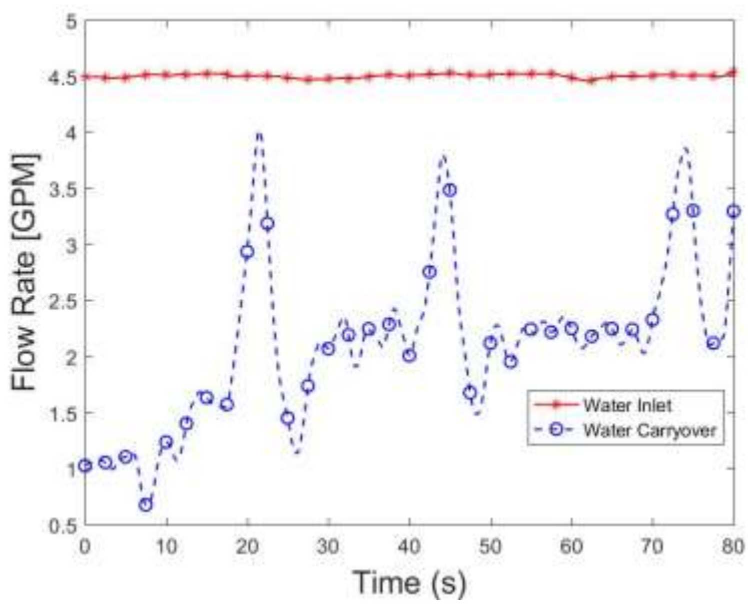

Figure G791: Water flow rates for test 2017_03_03_test_03b.

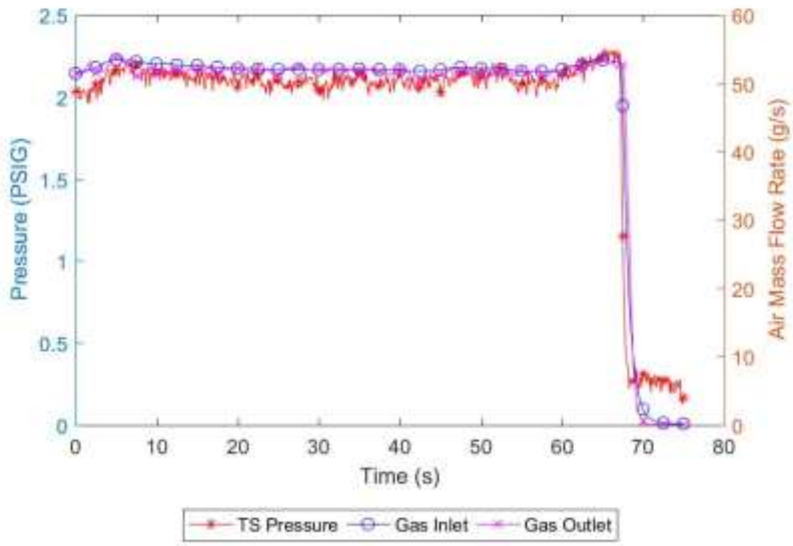

Figure G792: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_04b.

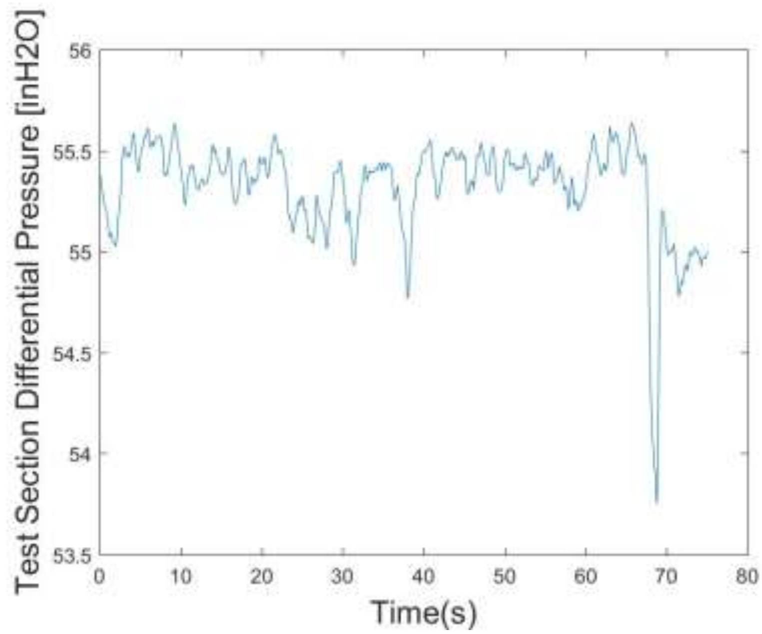

Figure G793: Test section differential pressure for test 2017_03_03_test_04b.

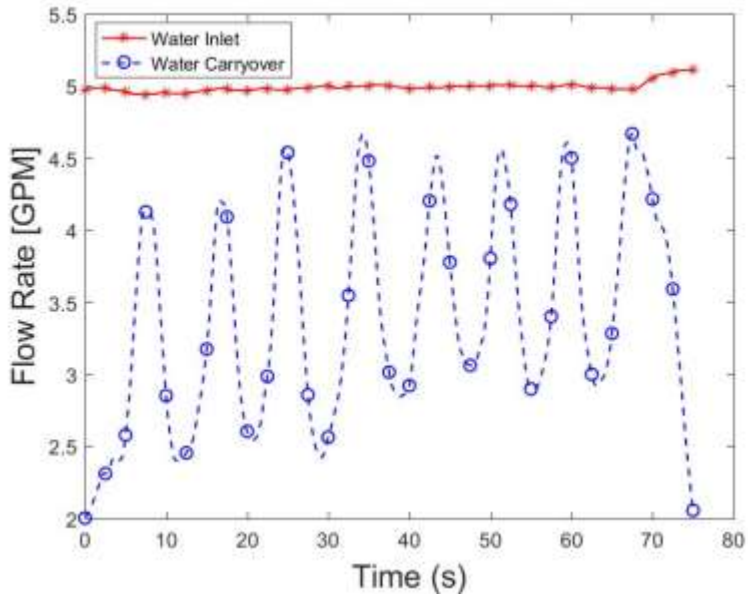

Figure G794: Water flow rates for test 2017_03_03_test_04b.

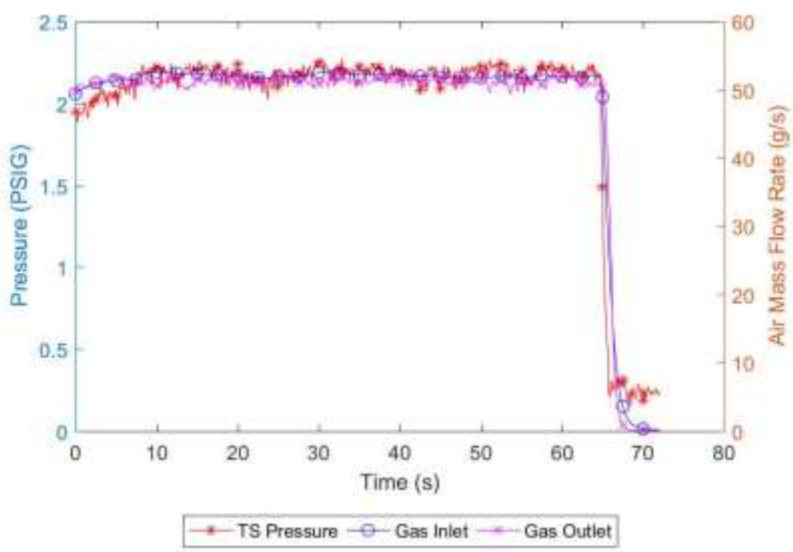

Figure G795: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_05b.

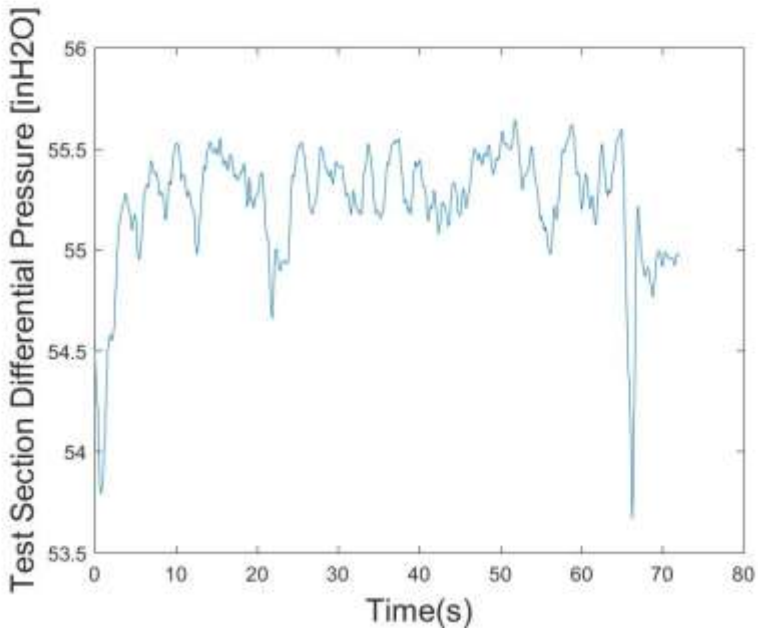

Figure G796: Test section differential pressure for test 2017_03_03_test_05b.

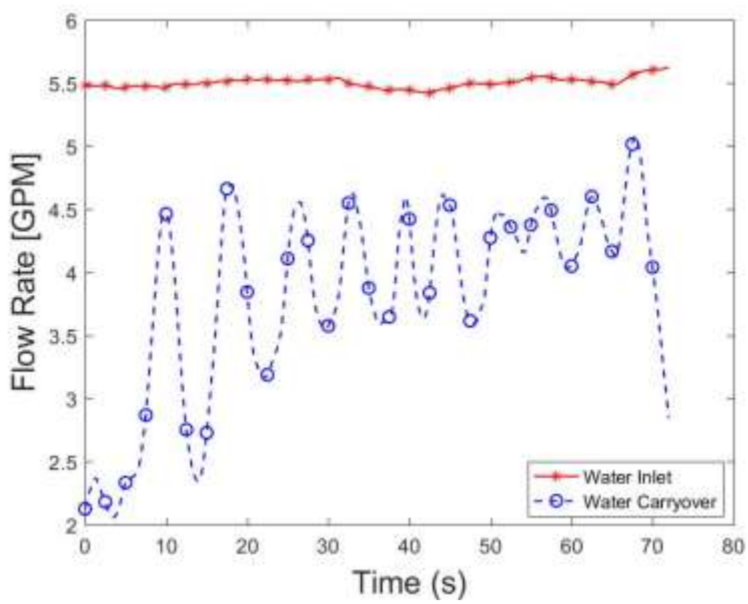

Figure G797: Water flow rates for test 2017_03_03_test_05b.

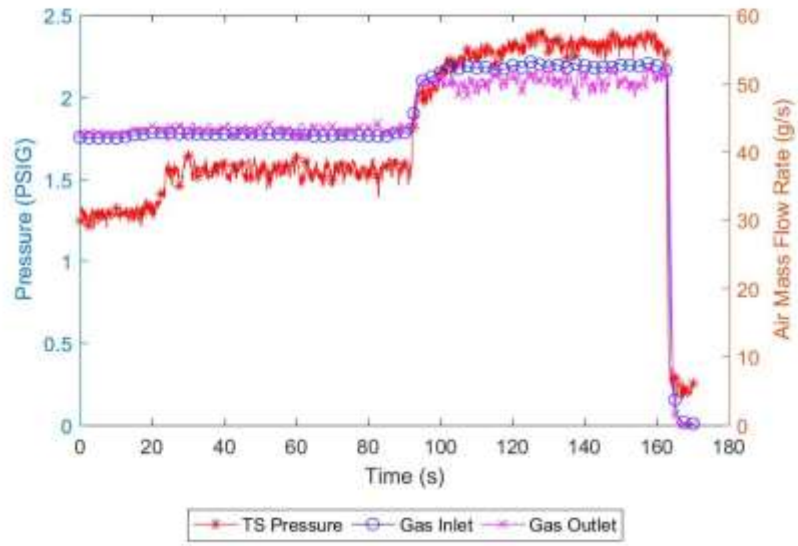

Figure G798: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_06b.

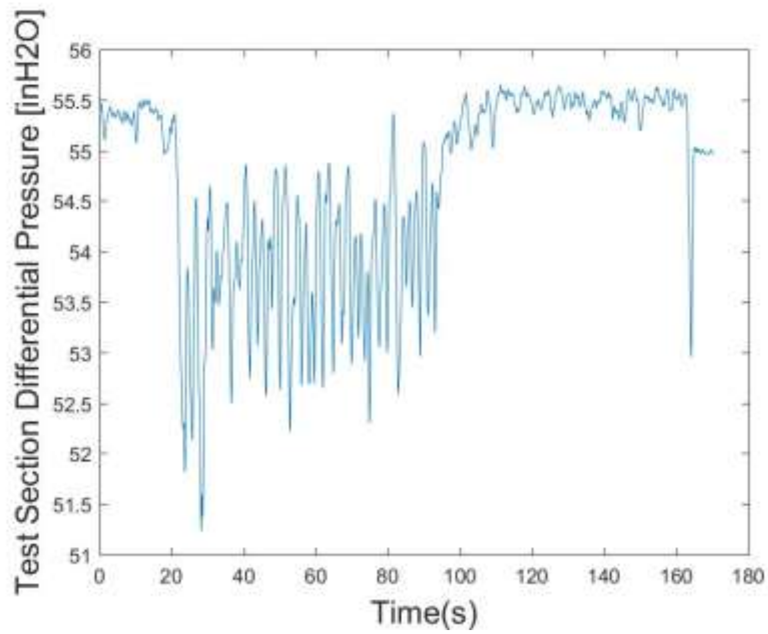

Figure G799: Test section differential pressure for test 2017_03_03_test_06b.

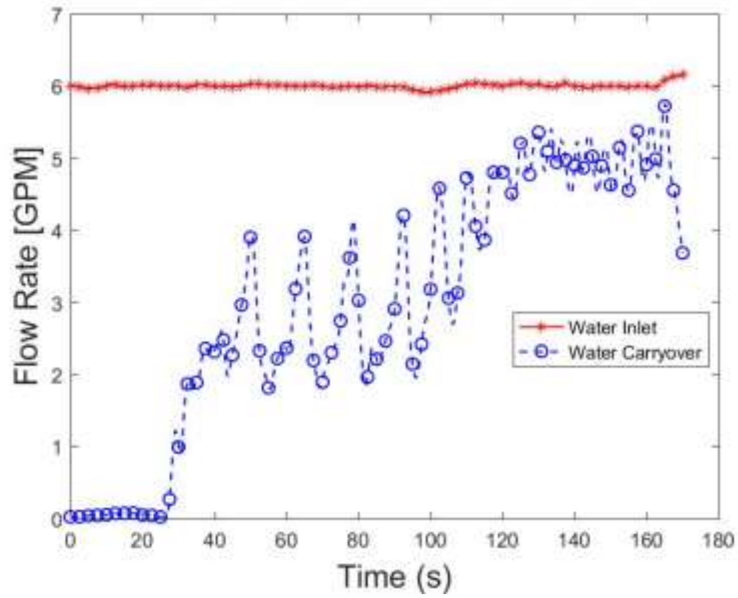

Figure G800: Water flow rates for test 2017_03_03_test_06b.

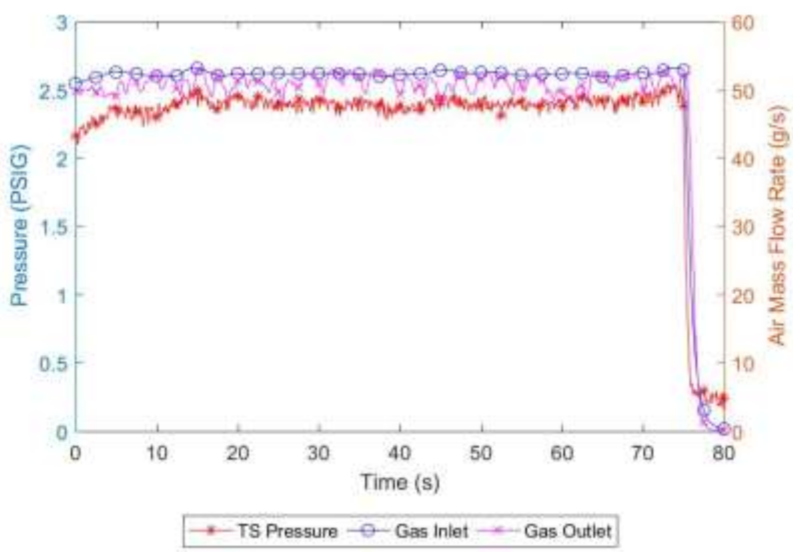

Figure G801: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_07b.

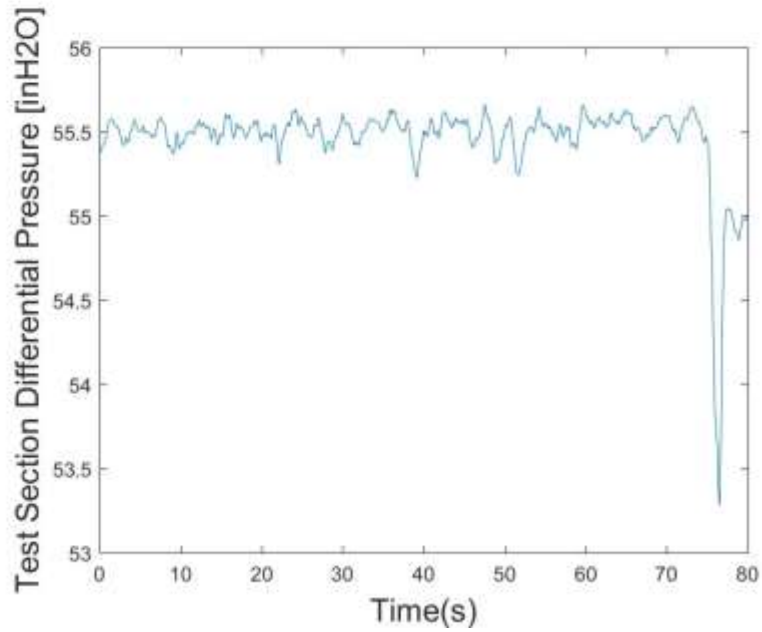

Figure G802: Test section differential pressure for test 2017_03_03_test_07b.

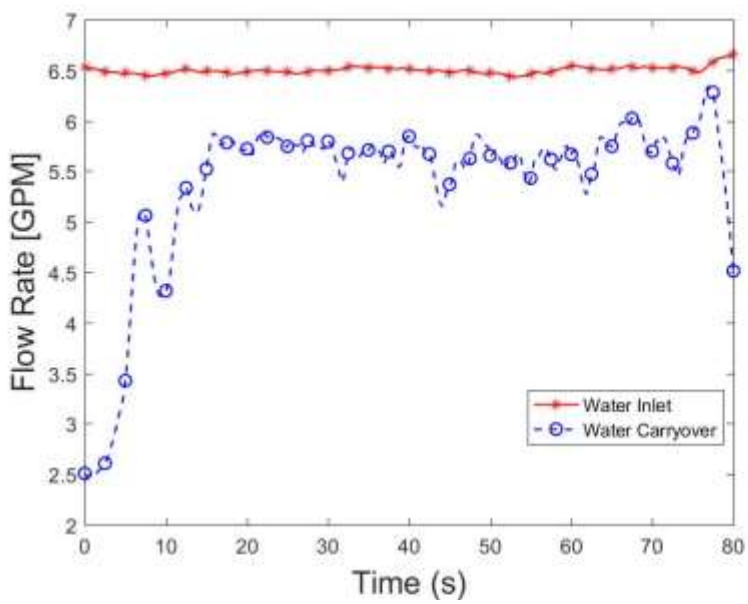

Figure G803: Water flow rates for test 2017_03_03_test_07b.

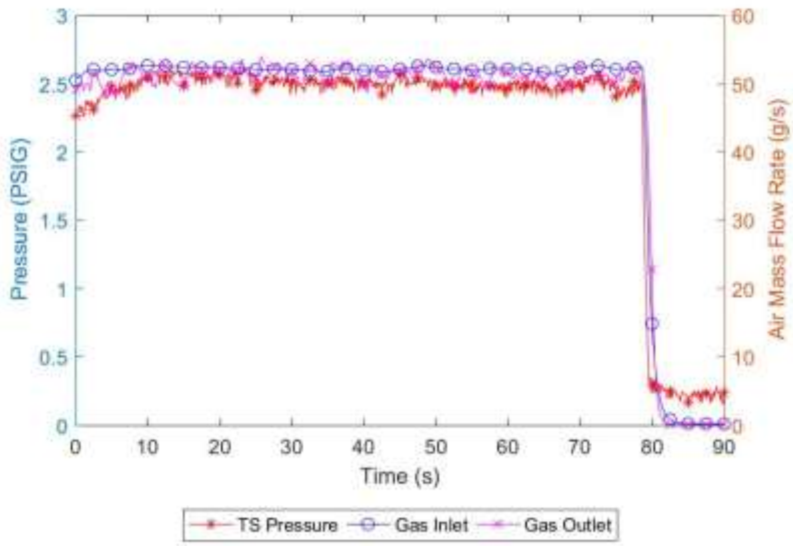

Figure G804: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_08b.

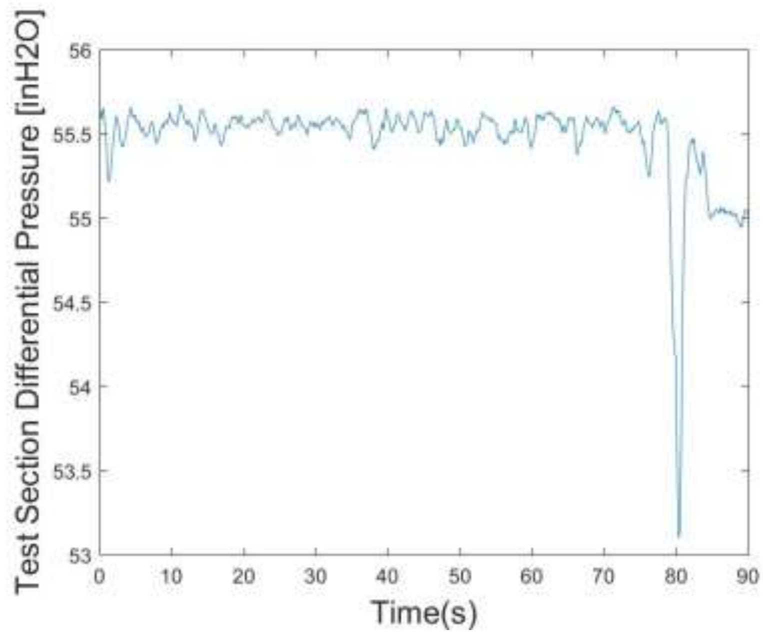

Figure G805: Test section differential pressure for test 2017_03_03_test_08b.

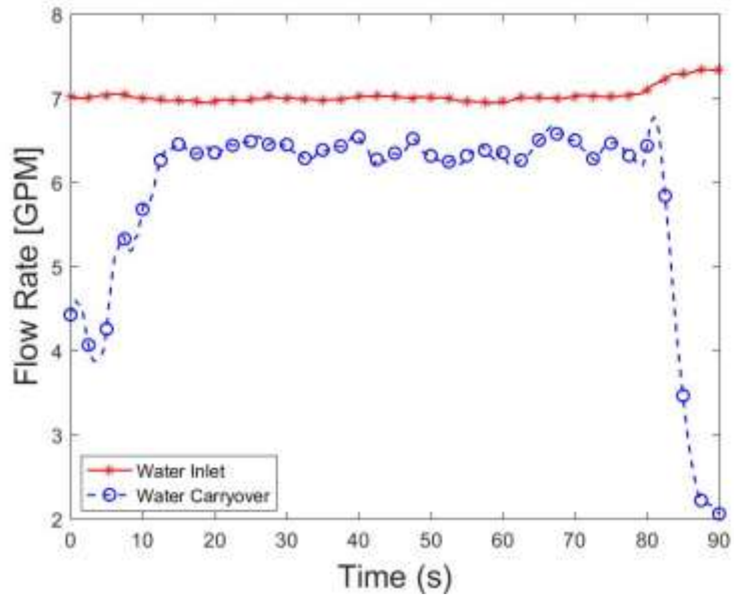

Figure G806: Water flow rates for test 2017_03_03_test_08b.

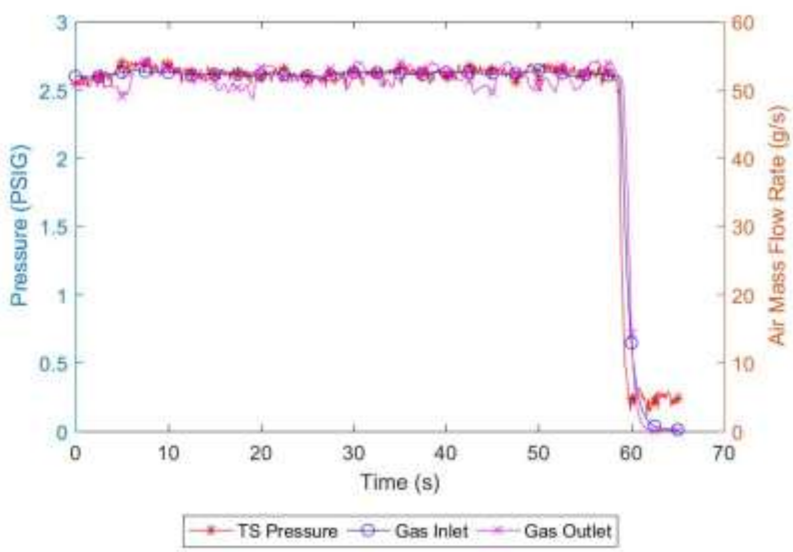

Figure G807: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_09b.

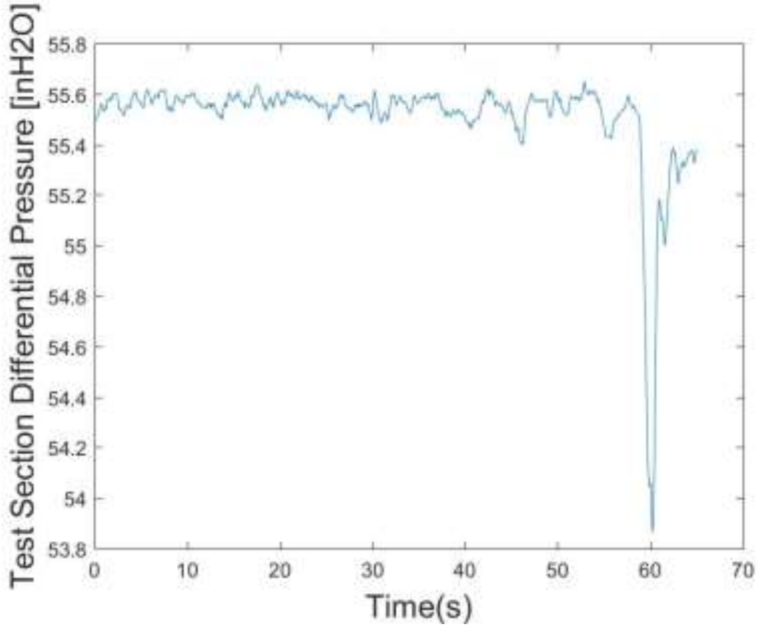

Figure G808: Test section differential pressure for test 2017_03_03_test_09b.

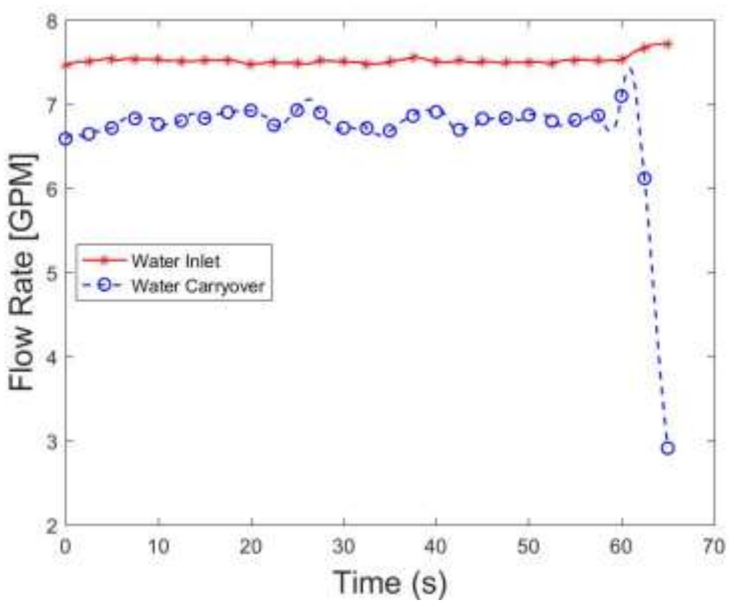

Figure G809: Water flow rates for test 2017_03_03_test_09b.

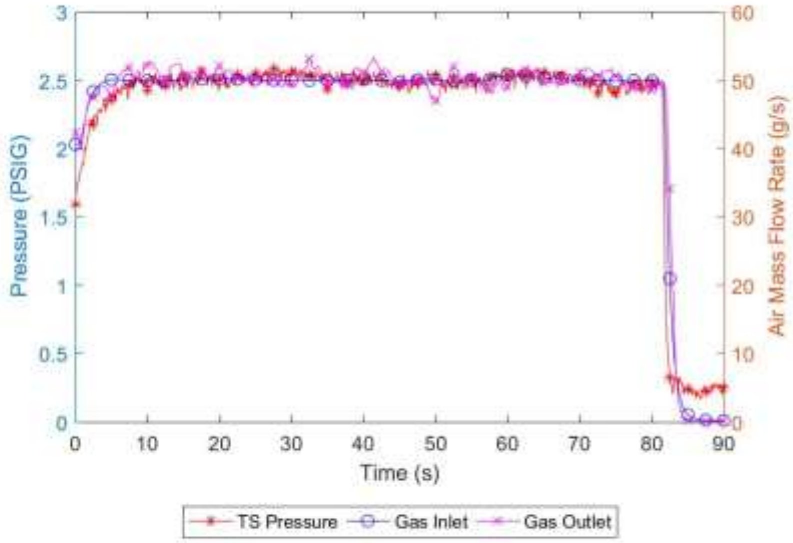

Figure G810: Pressure and gas inlet and outlet mass flow rates for test 2017_03_03_test_10b.

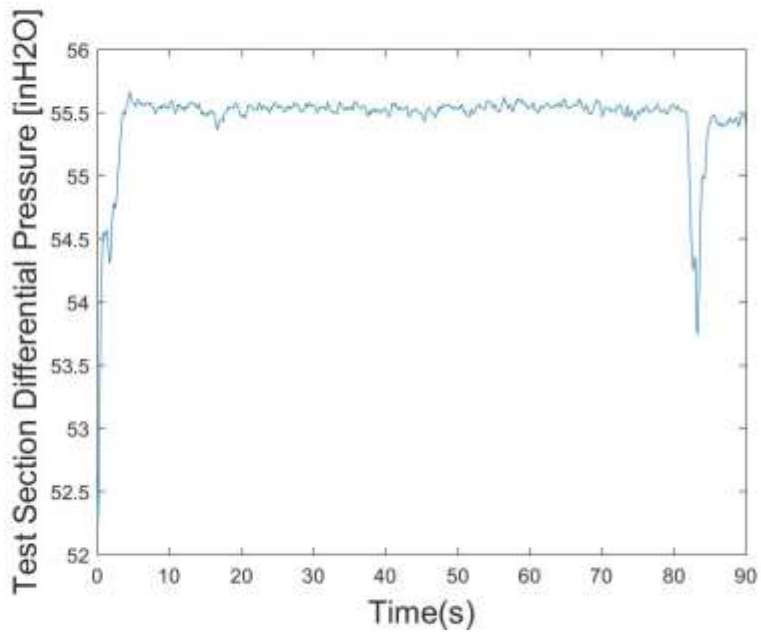

Figure G811: Test section differential pressure for test 2017_03_03_test_10b.

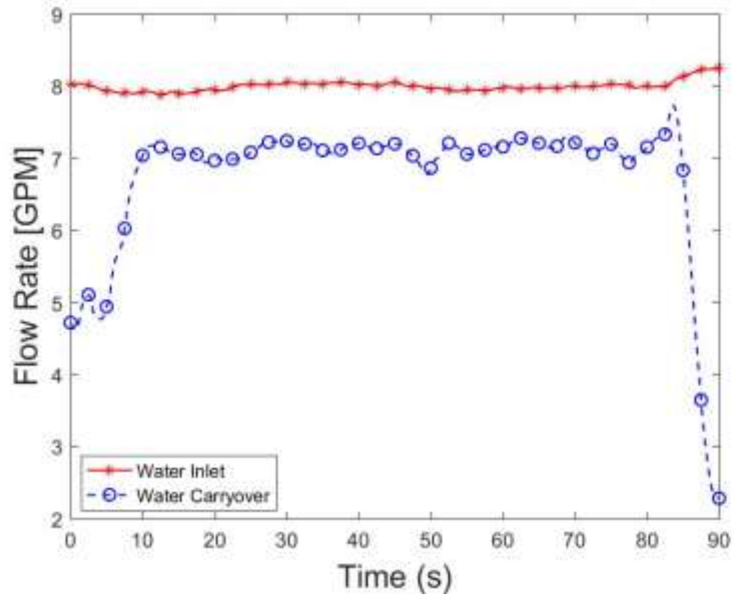

Figure G812: Water flow rates for test 2017_03_03_test_10b.

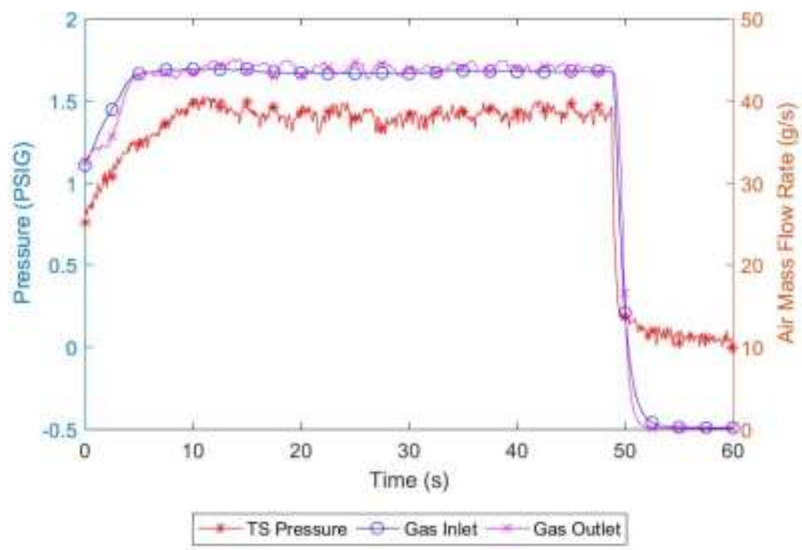

Figure G813: Pressure and gas inlet and outlet mass flow rates for test 2017_03_13_test_01.

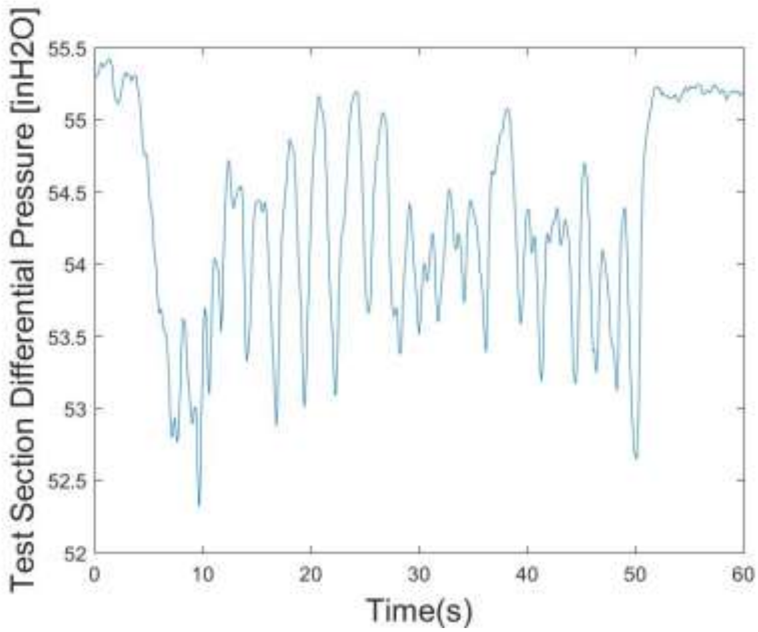

Figure G814: Test section differential pressure for test 2017_03_13_test_01.

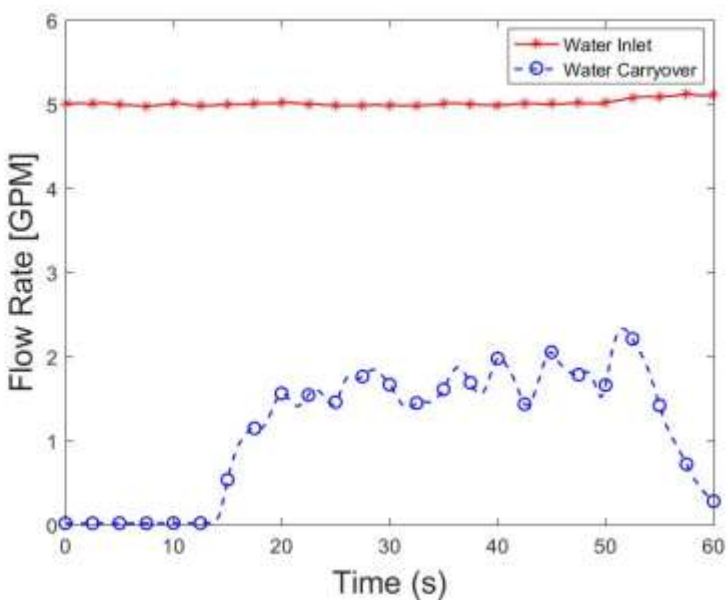

Figure G815: Water flow rates for test 2017_03_13_test_01.

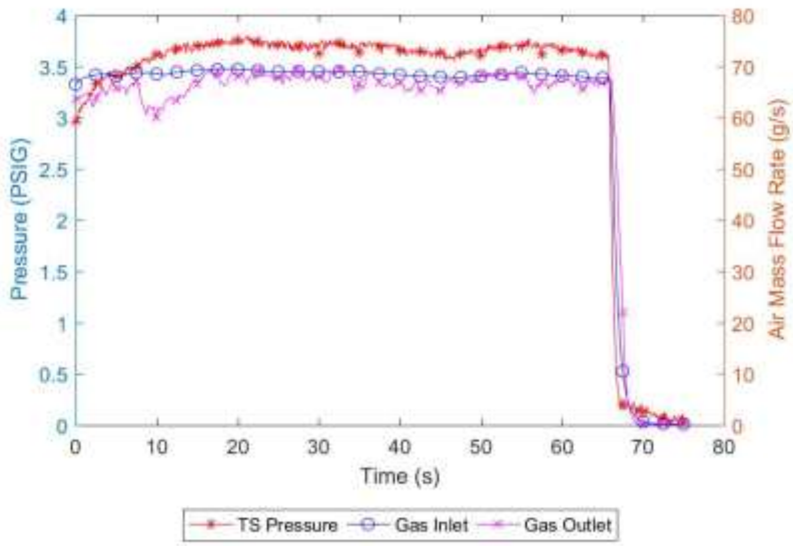

Figure G816: Pressure and gas inlet and outlet mass flow rates for test 2017_03_13_test_02.

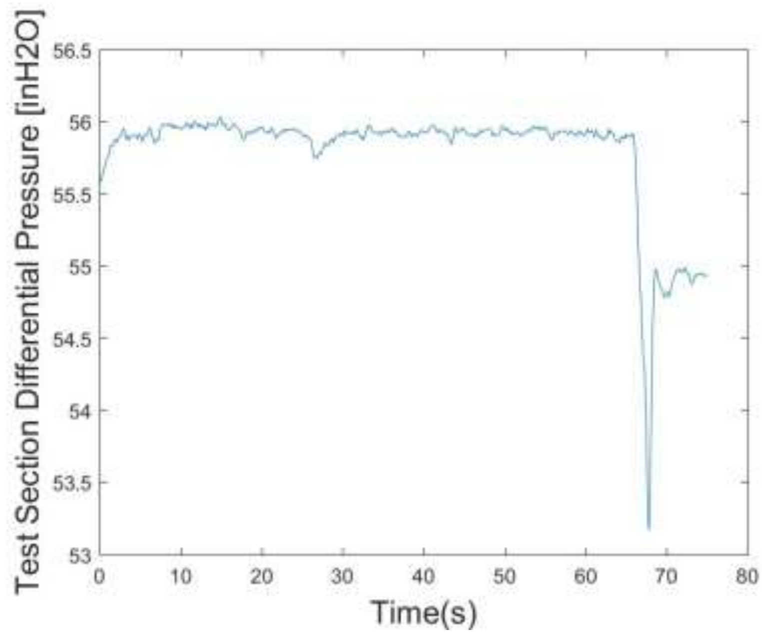

Figure G817: Test section differential pressure for test 2017_03_13_test_02.

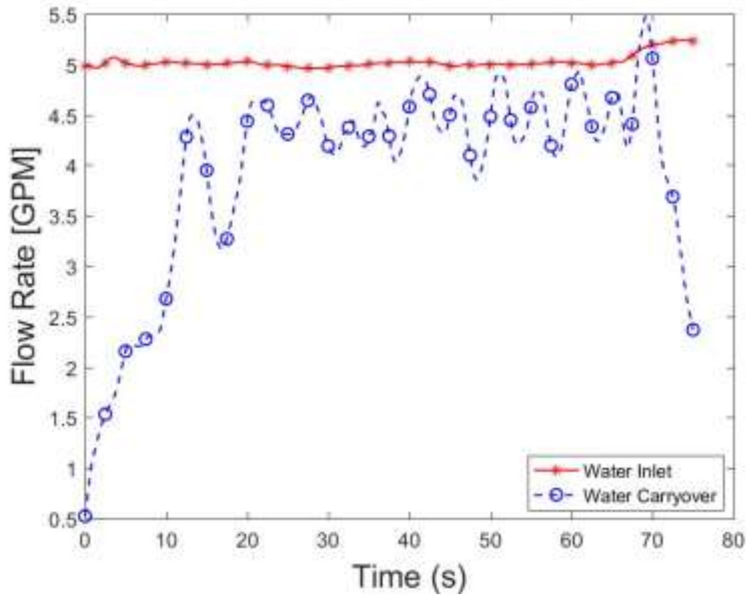

Figure G818: Water flow rates for test 2017_03_13_test_02.

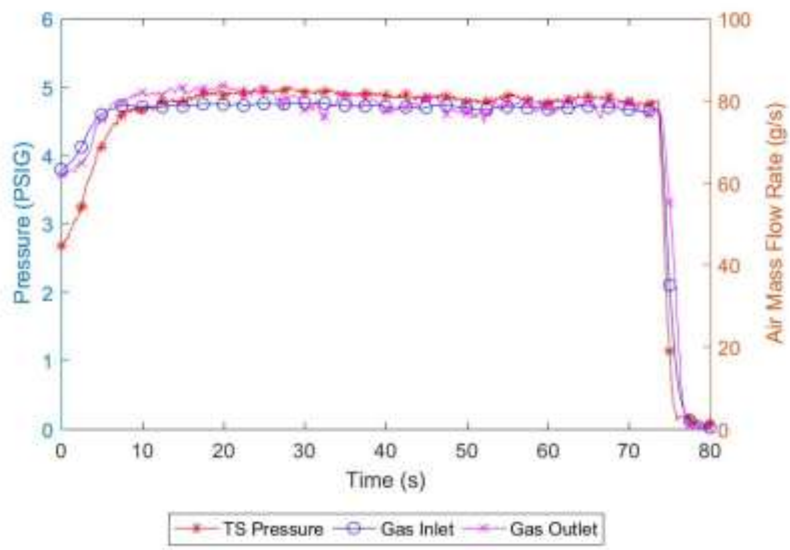

Figure G819: Pressure and gas inlet and outlet mass flow rates for test 2017_03_13_test_03.

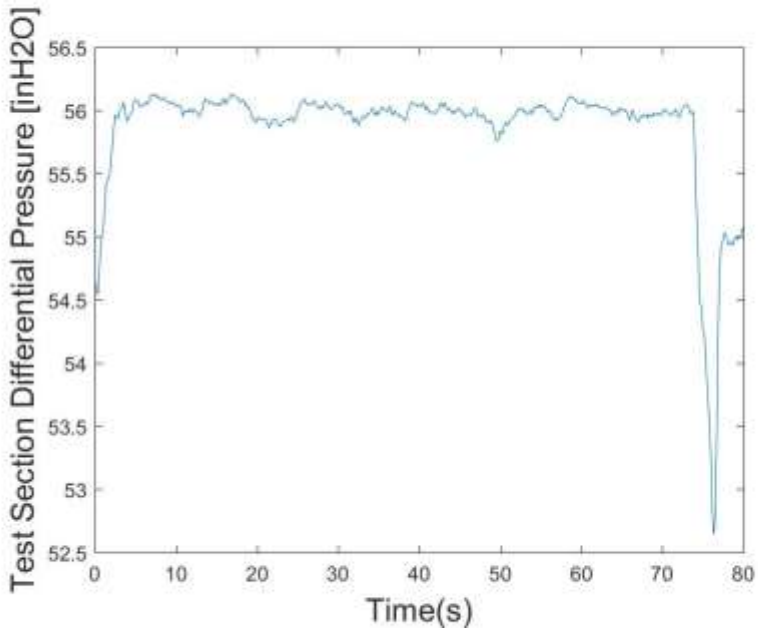

Figure G820: Test section differential pressure for test 2017_03_13_test_03.

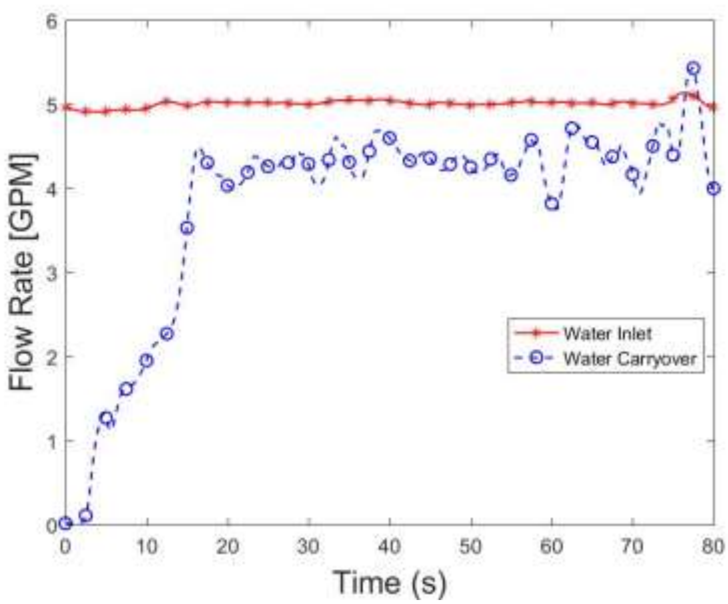

Figure G821: Water flow rates for test 2017_03_13_test_03.

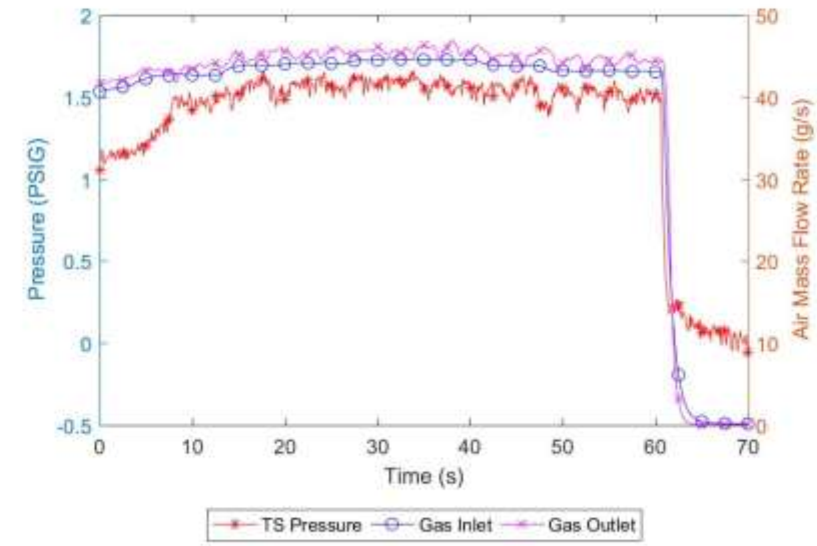

Figure G822: Pressure and gas inlet and outlet mass flow rates for test 2017_03_13_test_05.

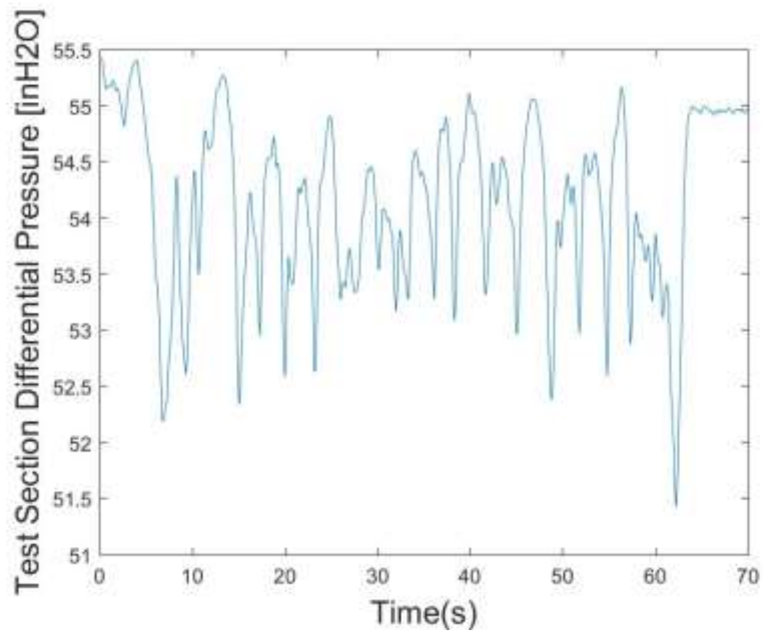

Figure G823: Test section differential pressure for test 2017_03_13_test_05.

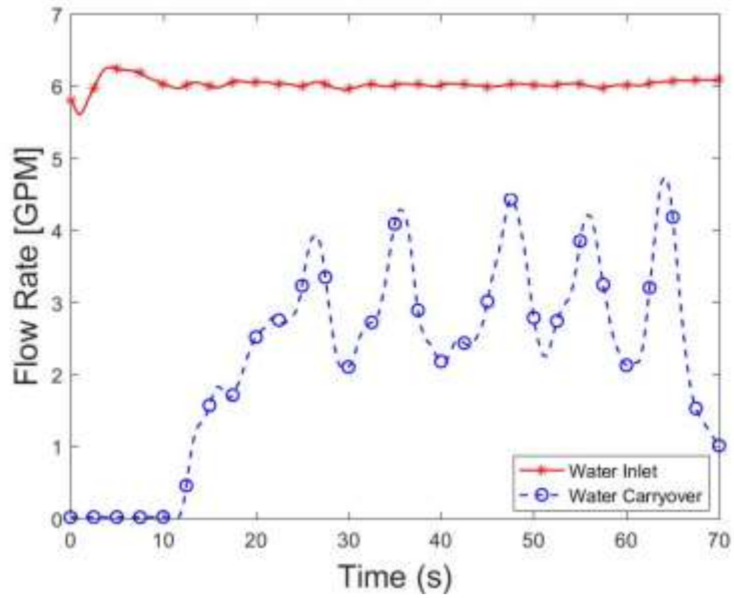

Figure G824: Water flow rates for test 2017_03_13_test_05.

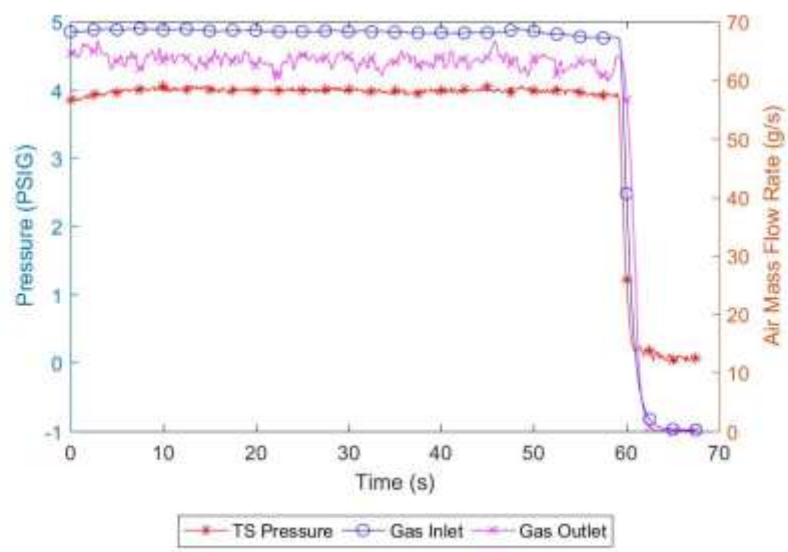

Figure G825: Pressure and gas inlet and outlet mass flow rates for test 2017_03_13_test_06.

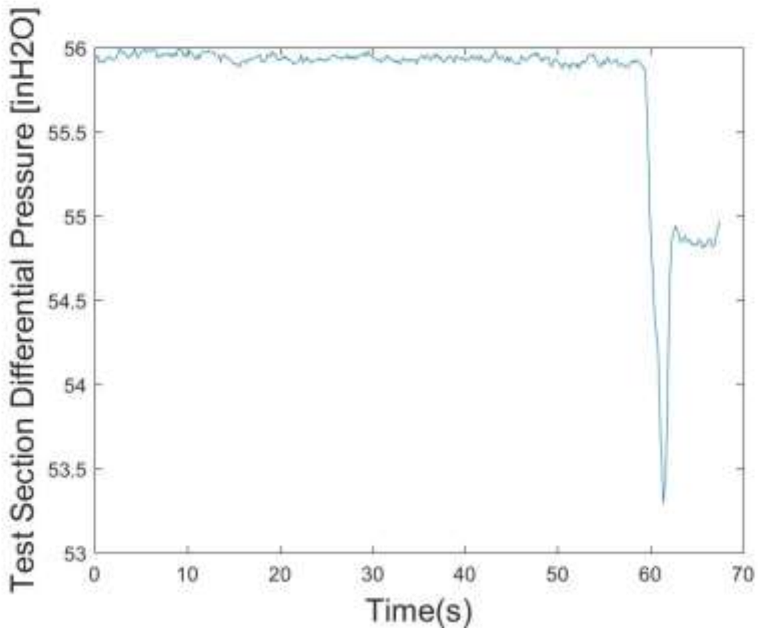

Figure G826: Test section differential pressure for test 2017_03_13_test_06.

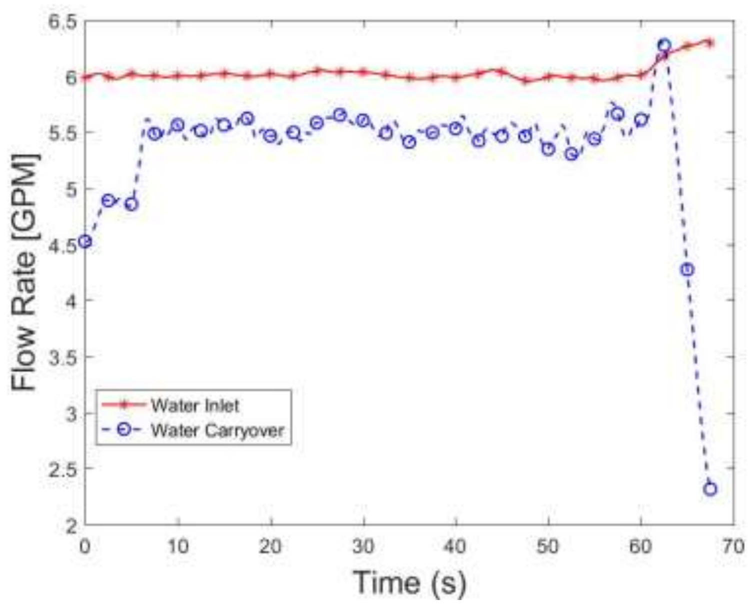

Figure G827: Water flow rates for test 2017_03_13_test_06.

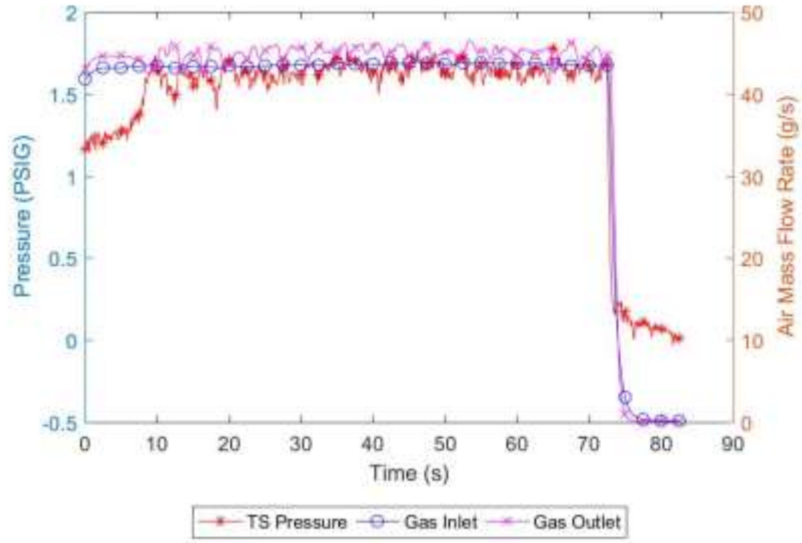

Figure G828: Pressure and gas inlet and outlet mass flow rates for test 2017_03_13_test_09.

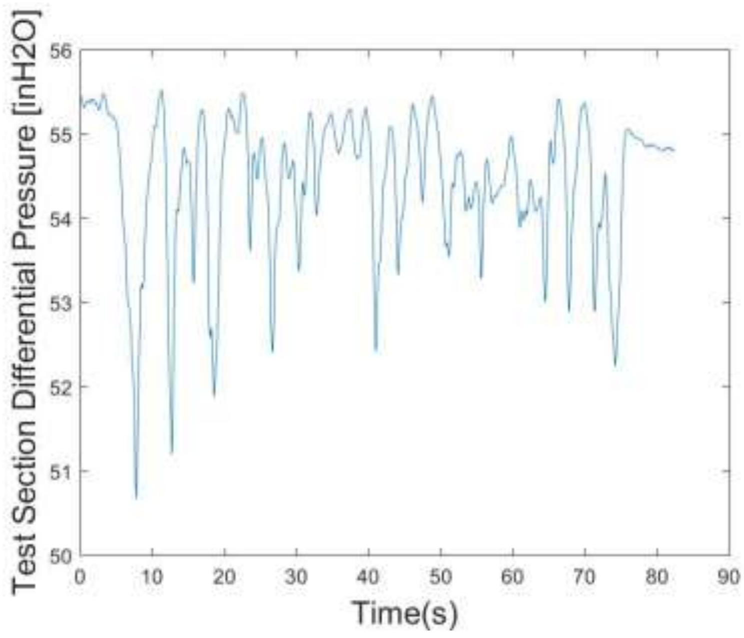

Figure G829: Test section differential pressure for test 2017_03_13_test_09.

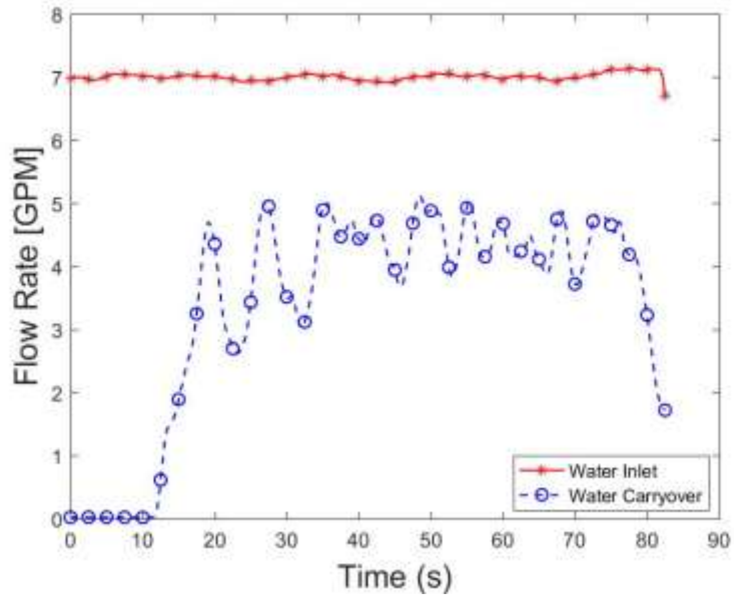

Figure G830: Water flow rates for test 2017_03_13_test_09.

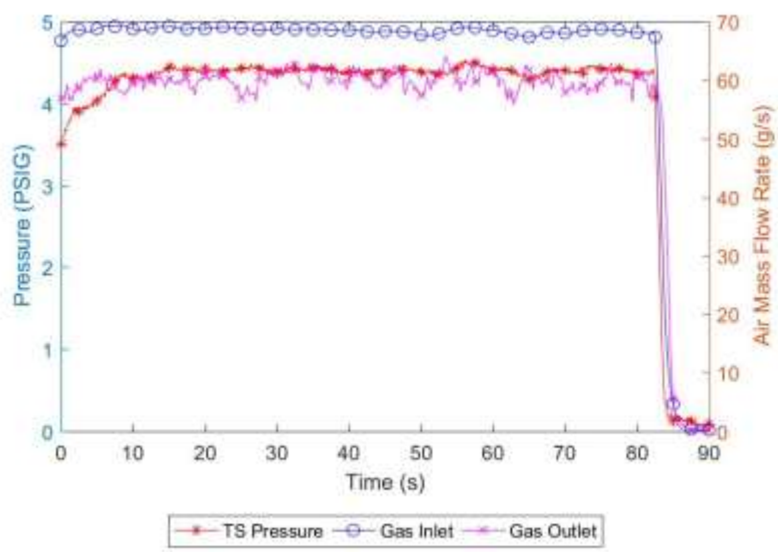

Figure G831: Pressure and gas inlet and outlet mass flow rates for test 2017_03_13_test_10.

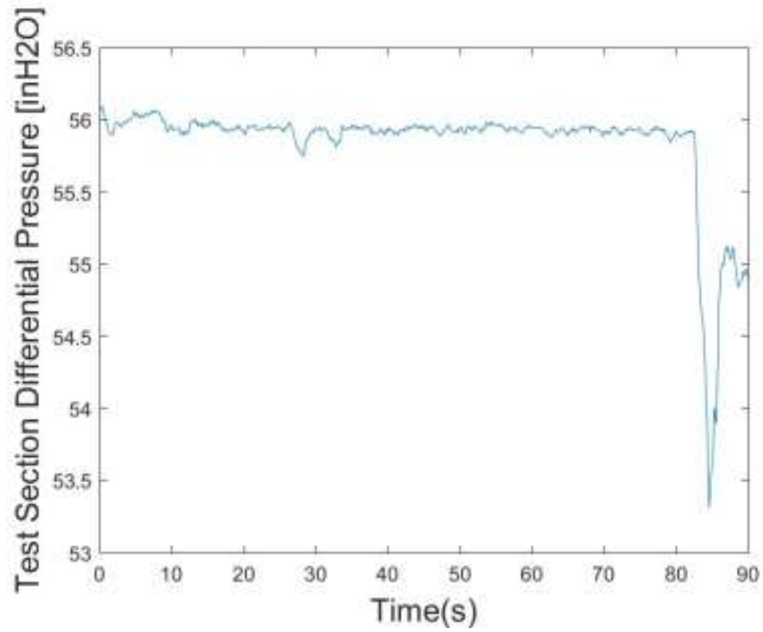

Figure G832: Test section differential pressure for test 2017_03_13_test_10.

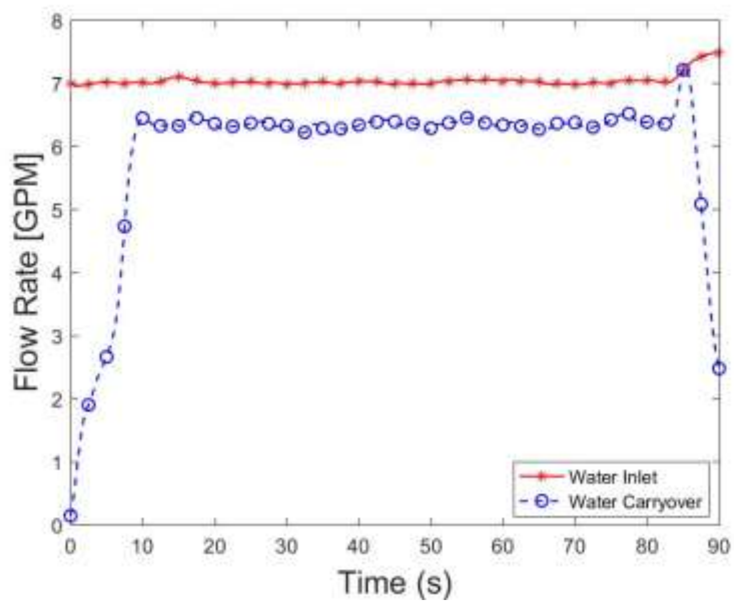

Figure G833: Water flow rates for test 2017_03_13_test_10.

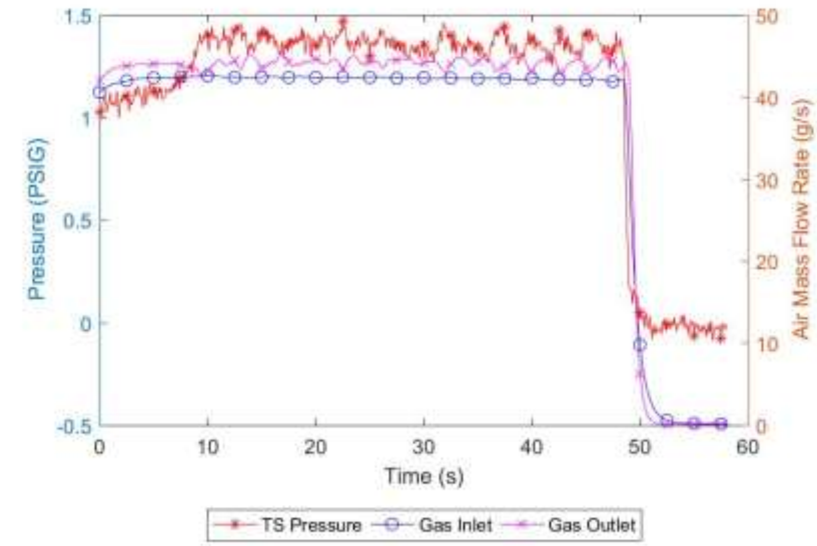

Figure G834: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_01.

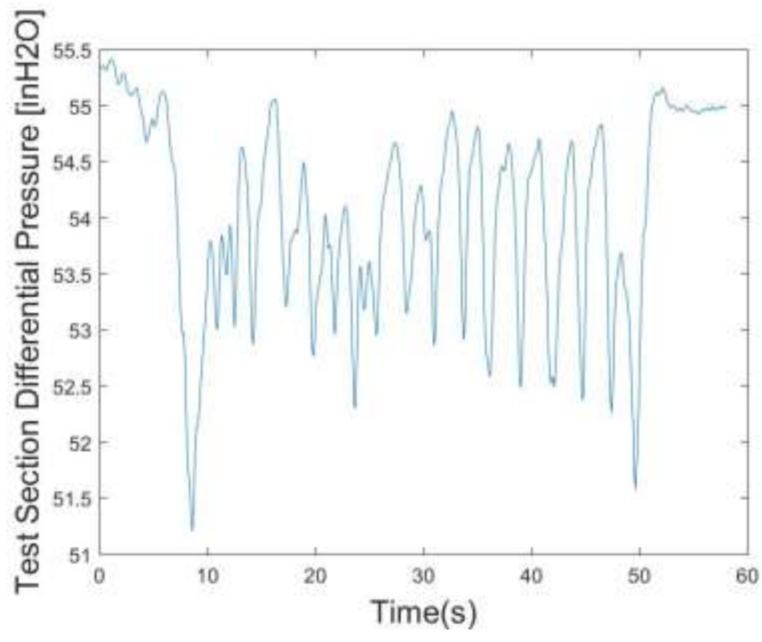

Figure G835: Test section differential pressure for test 2017_03_24_test_01.

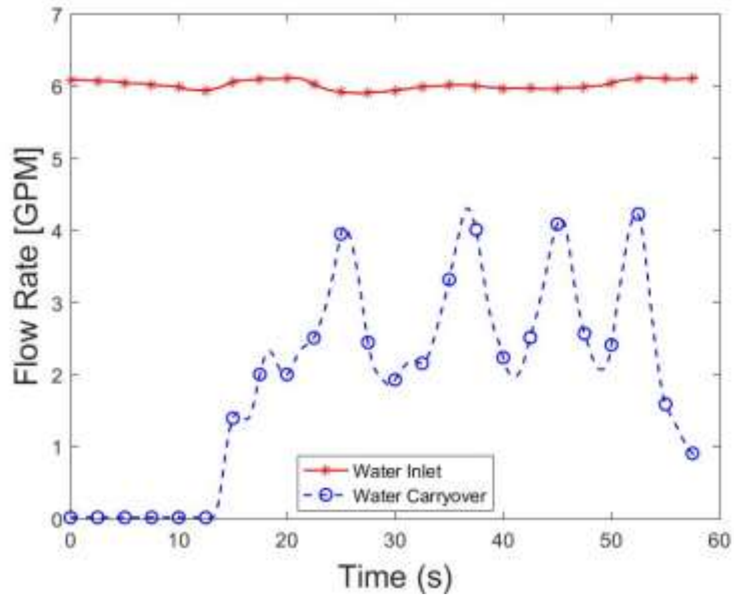

Figure G836: Water flow rates for test 2017_03_24_test_01.

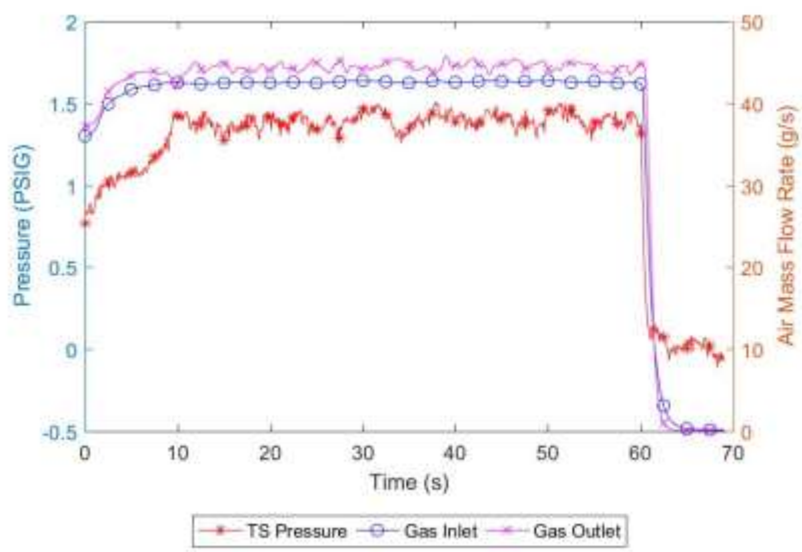

Figure G837: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_02.

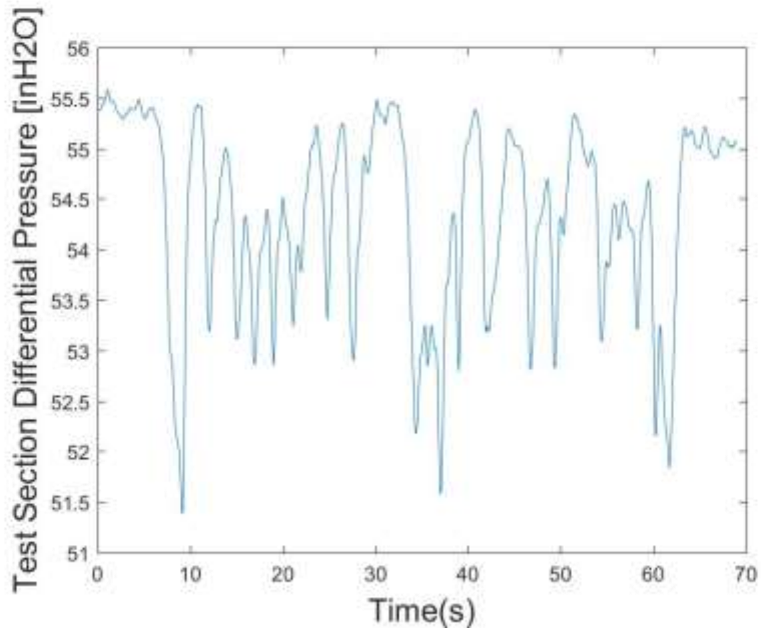

Figure G838: Test section differential pressure for test 2017_03_24_test_02.

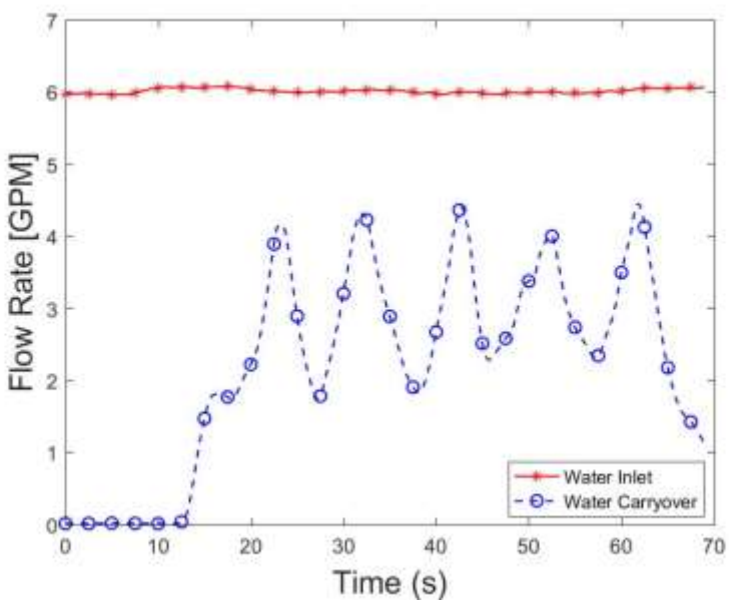

Figure G839: Water flow rates for test 2017_03_24_test_02.

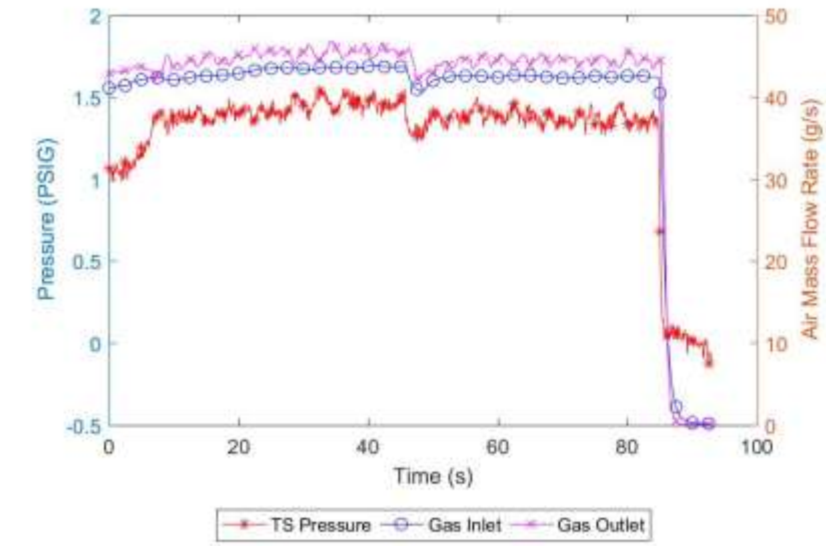

Figure G840: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_03.

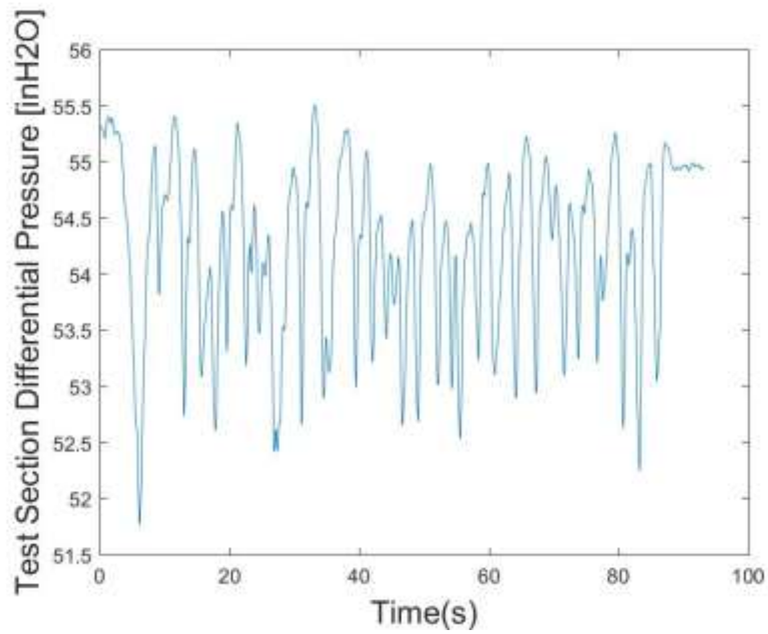

Figure G841: Test section differential pressure for test 2017_03_24_test_03.

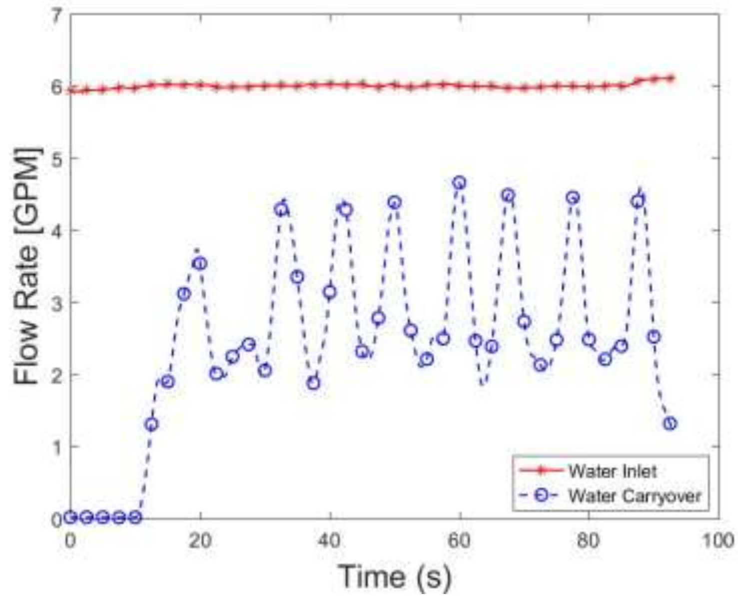

Figure G842: Water flow rates for test 2017_03_24_test_03.

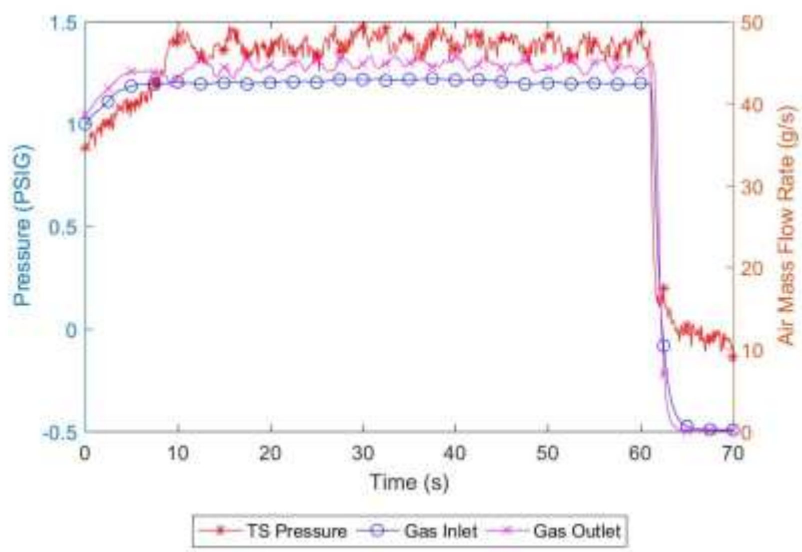

Figure G843: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_04.

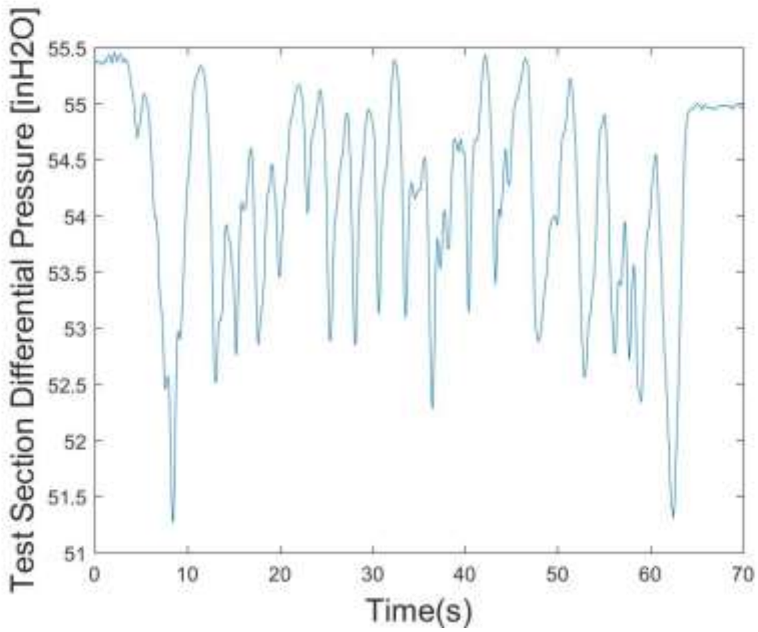

Figure G844: Test section differential pressure for test 2017_03_24_test_04.

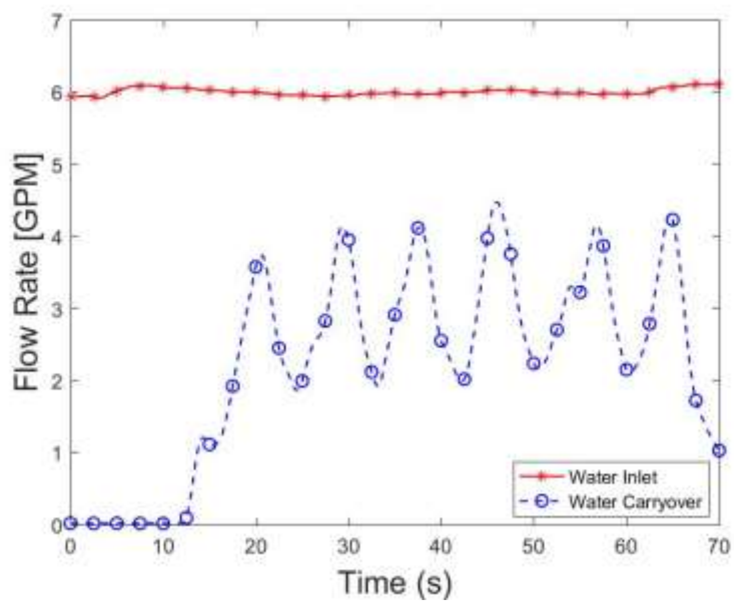

Figure G845: Water flow rates for test 2017_03_24_test_04.

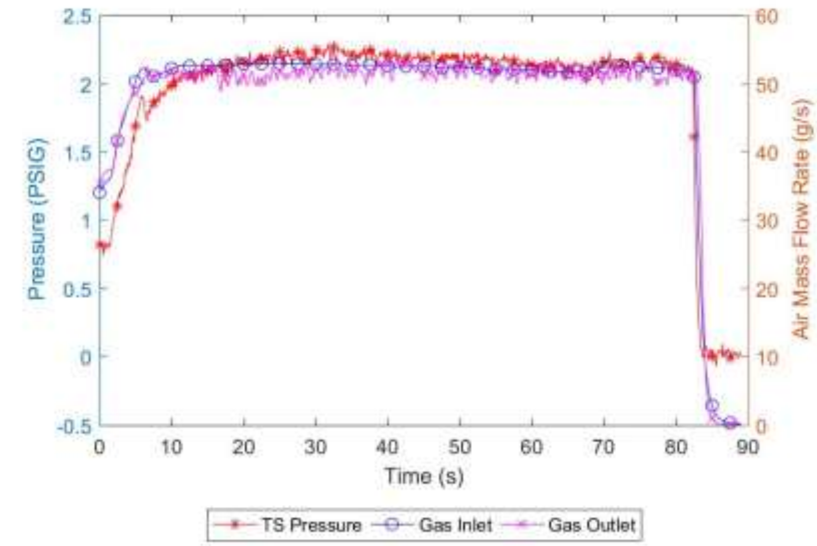

Figure G846: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_05.

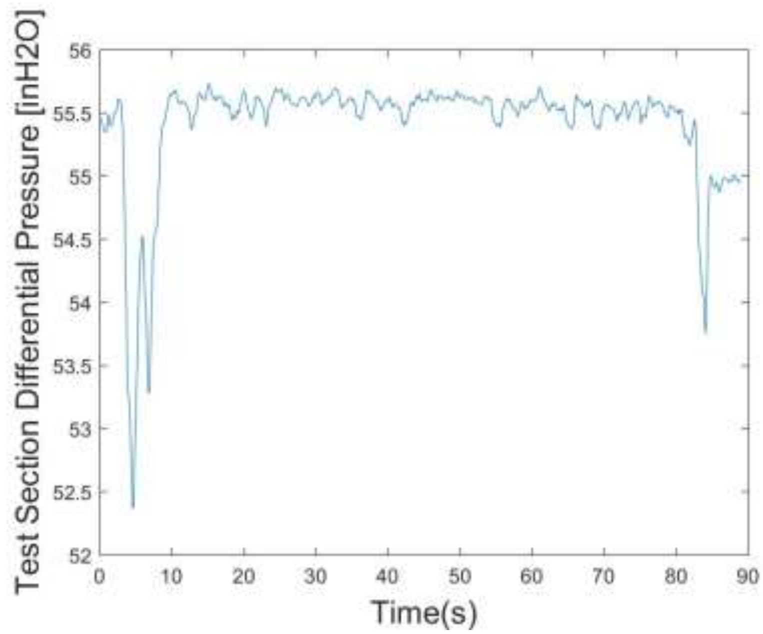

Figure G847: Test section differential pressure for test 2017_03_24_test_05.

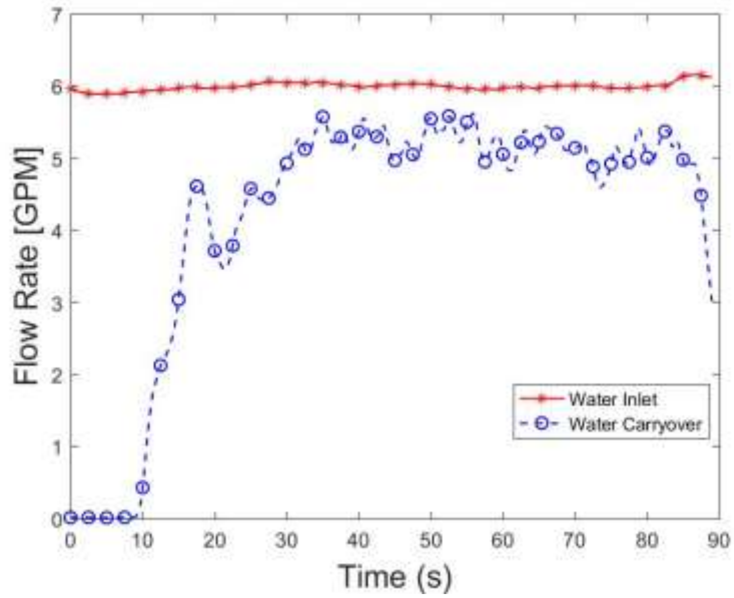

Figure G848: Water flow rates for test 2017_03_24_test_05.

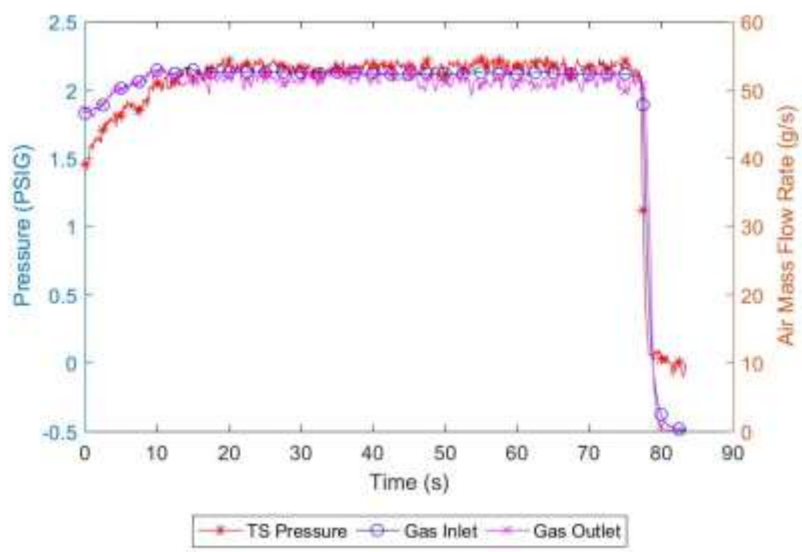

Figure G849: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_06.

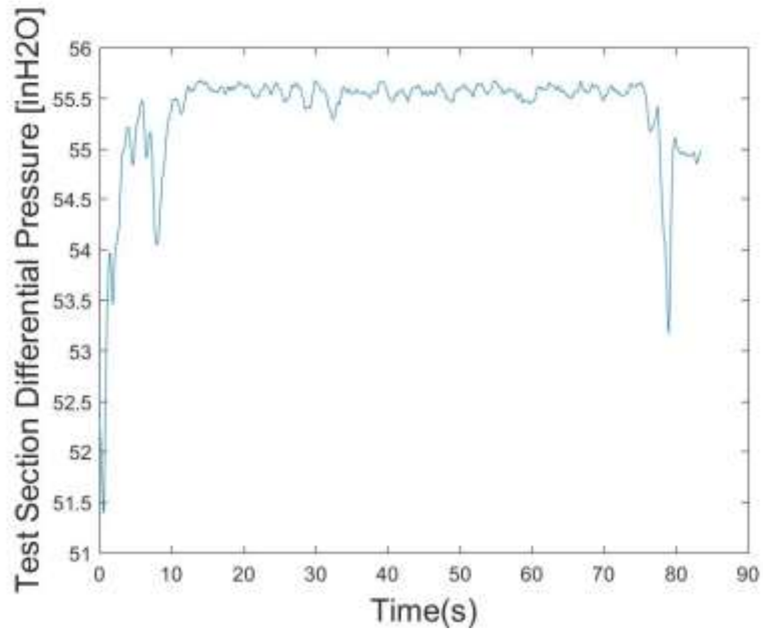

Figure G850: Test section differential pressure for test 2017_03_24_test_06.

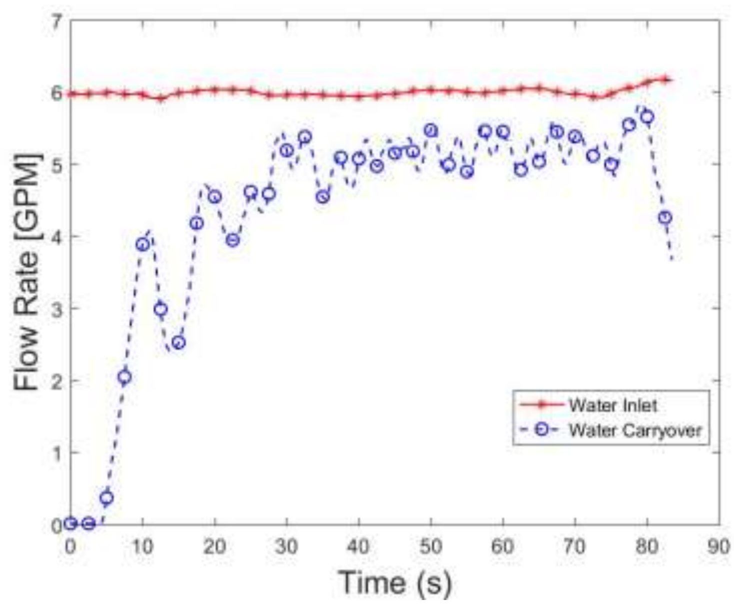

Figure G851: Water flow rates for test 2017_03_24_test_06.

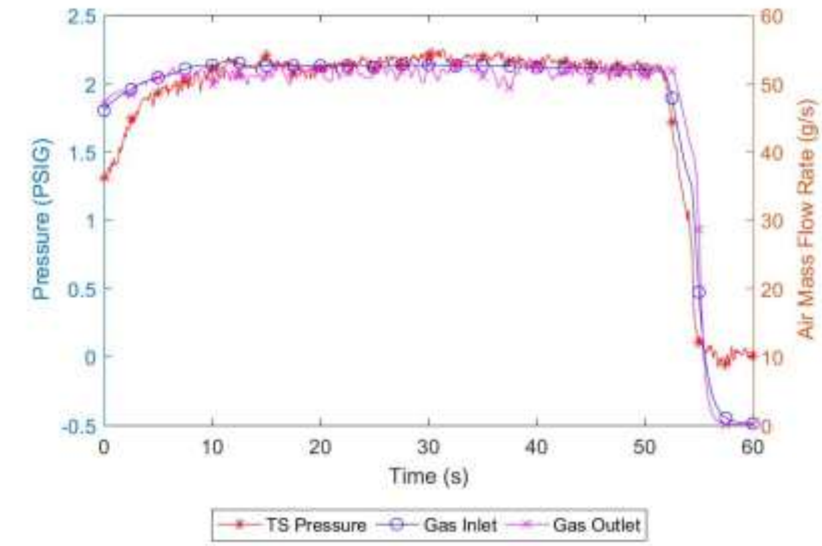

Figure G852: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_07.

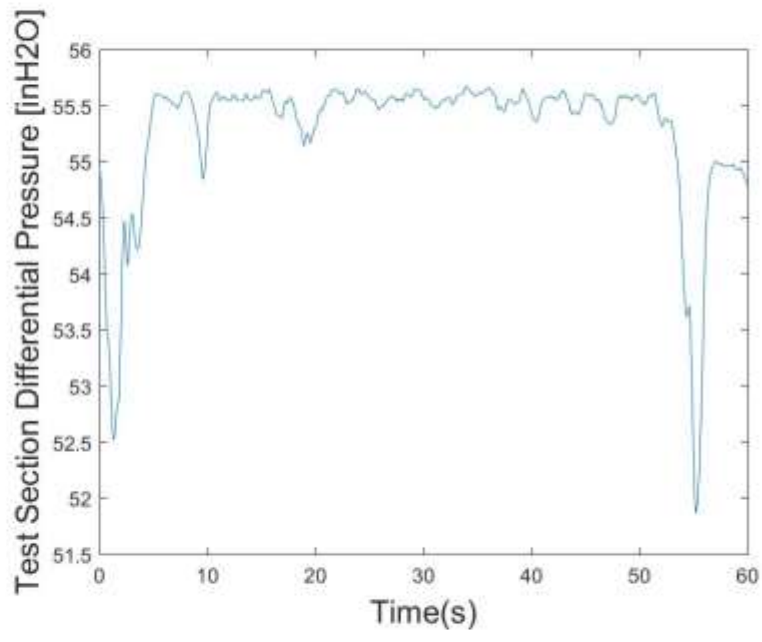

Figure G853: Test section differential pressure for test 2017_03_24_test_07.

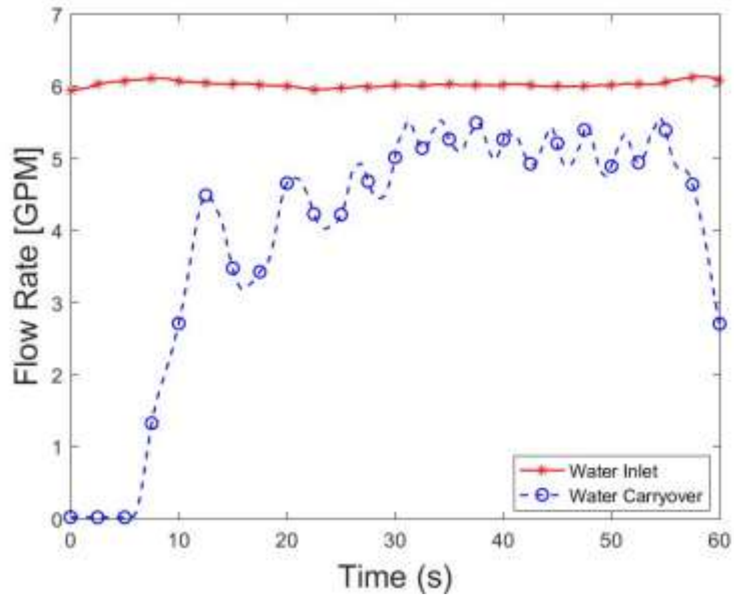

Figure G854: Water flow rates for test 2017_03_24_test_07.

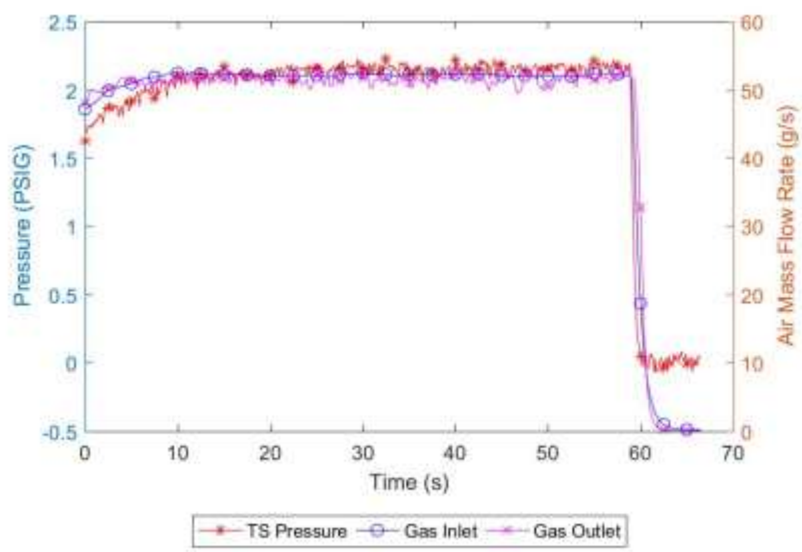

Figure G855: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_08.

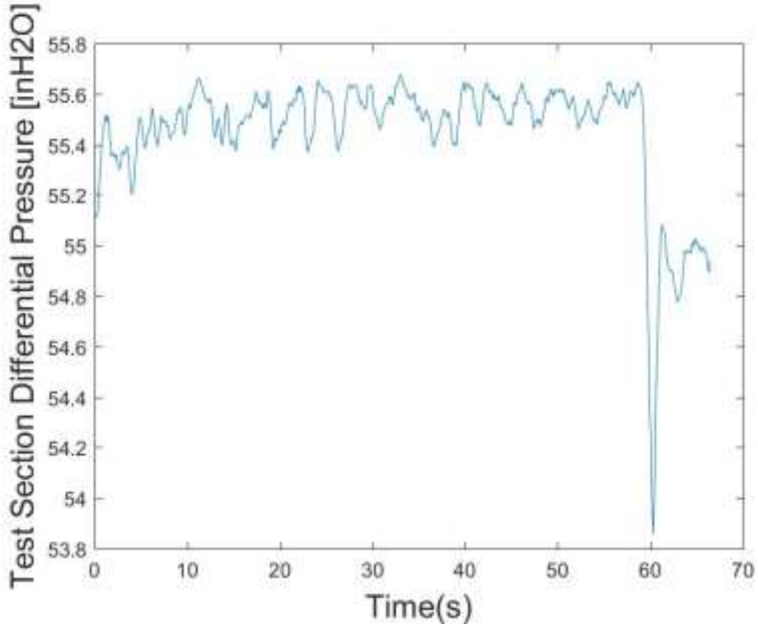

Figure G856: Test section differential pressure for test 2017_03_24_test_08.

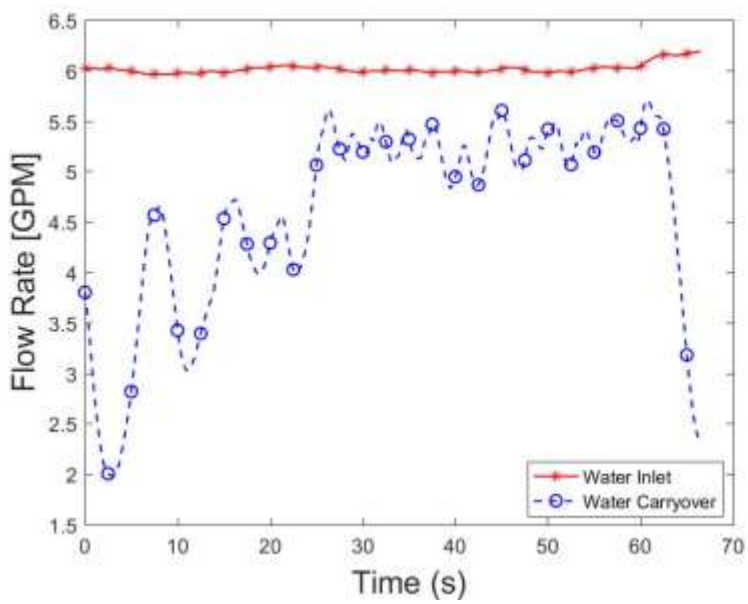

Figure G857: Water flow rates for test 2017_03_24_test_08.

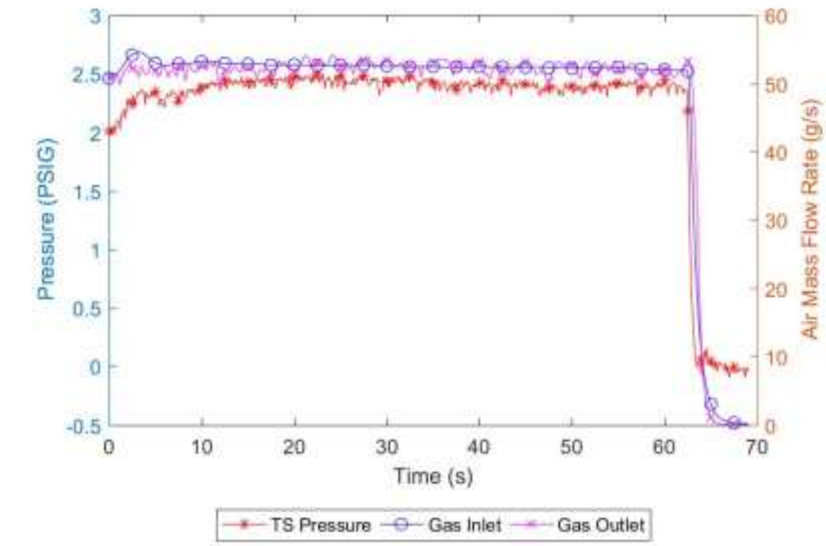

Figure G858: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_09.

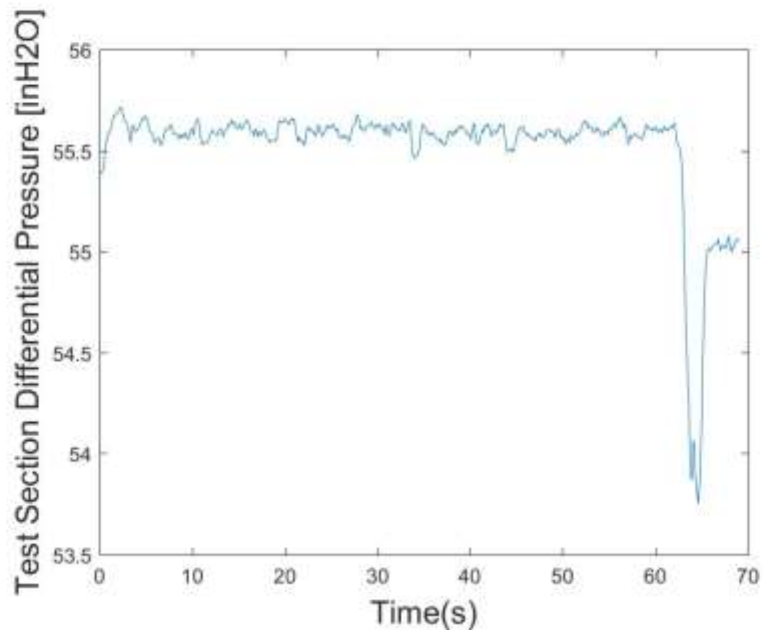

Figure G859: Test section differential pressure for test 2017_03_24_test_09.

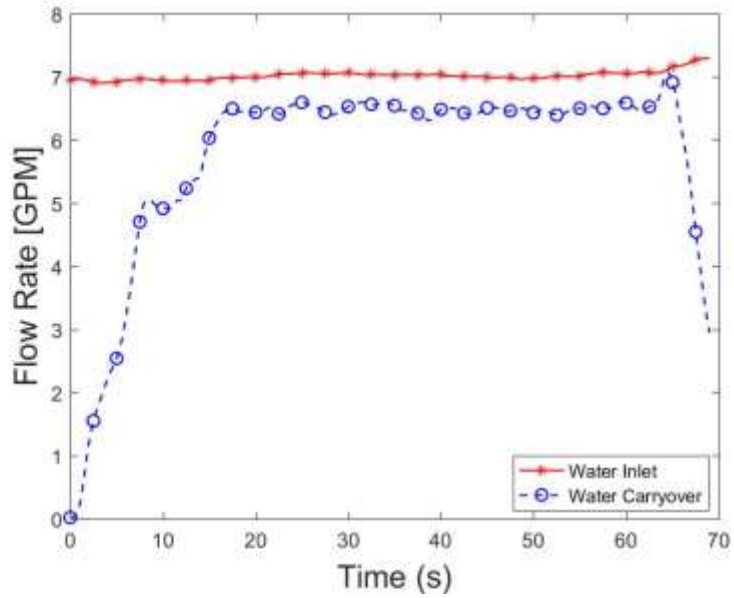

Figure G860: Water flow rates for test 2017_03_24_test_09.

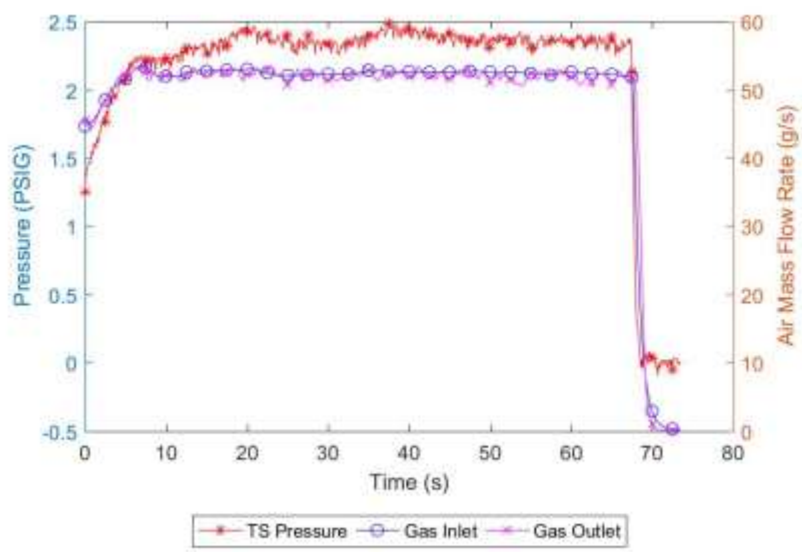

Figure G861: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_10.

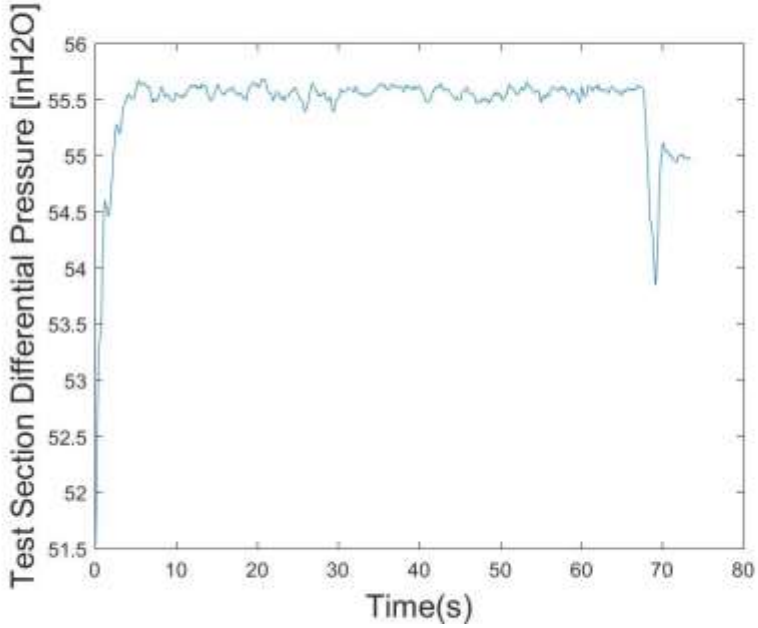

Figure G862: Test section differential pressure for test 2017_03_24_test_10.

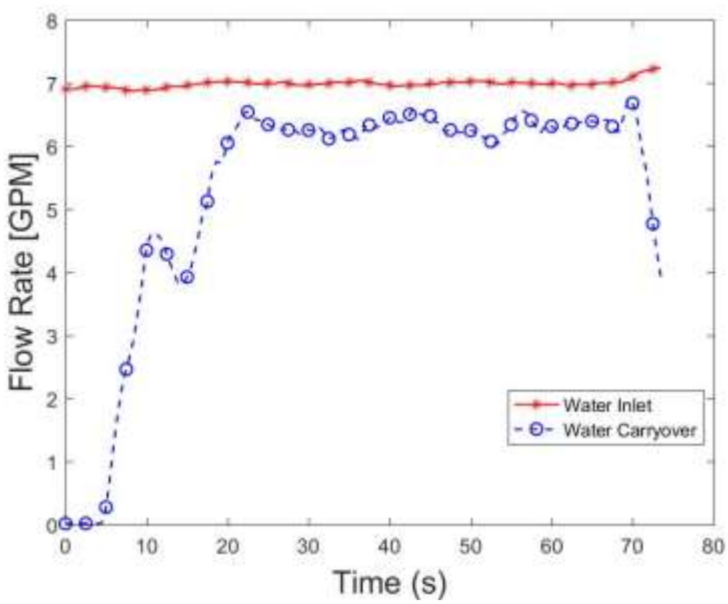

Figure G863: Water flow rates for test 2017_03_24_test_10.

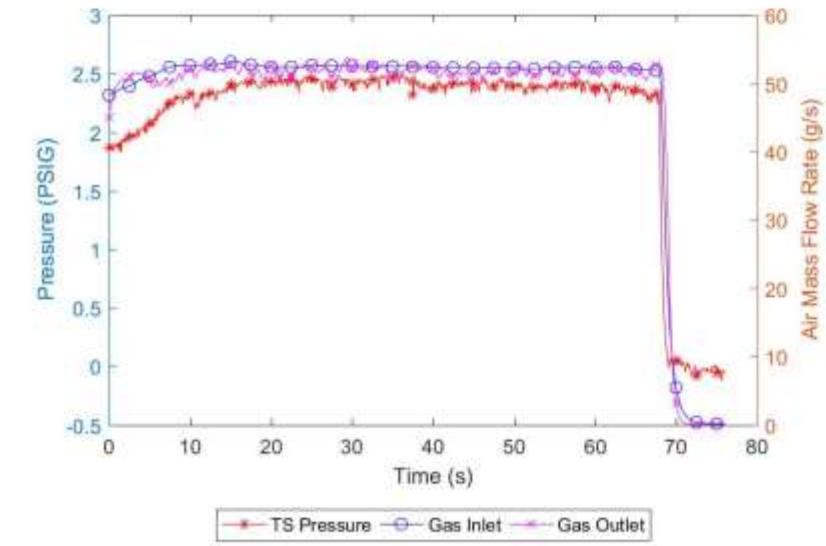

Figure G864: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_11.

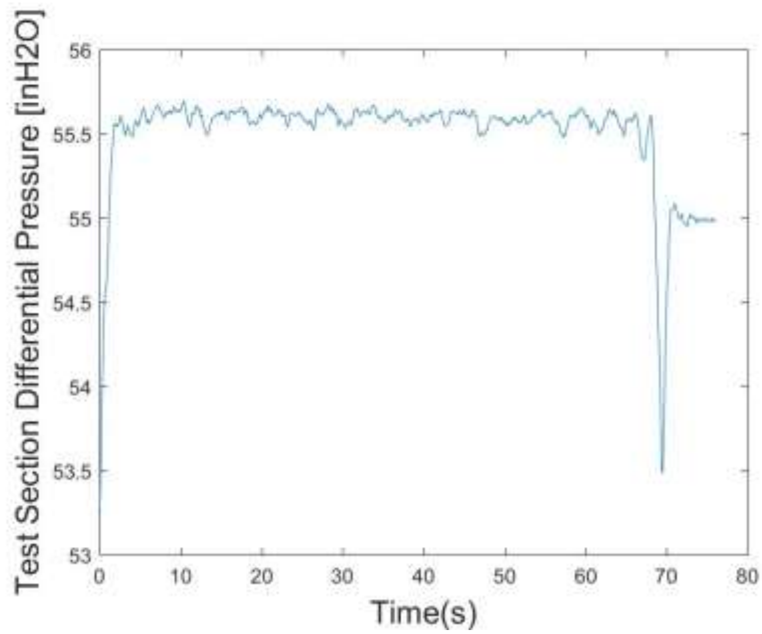

Figure G865: Test section differential pressure for test 2017_03_24_test_11.

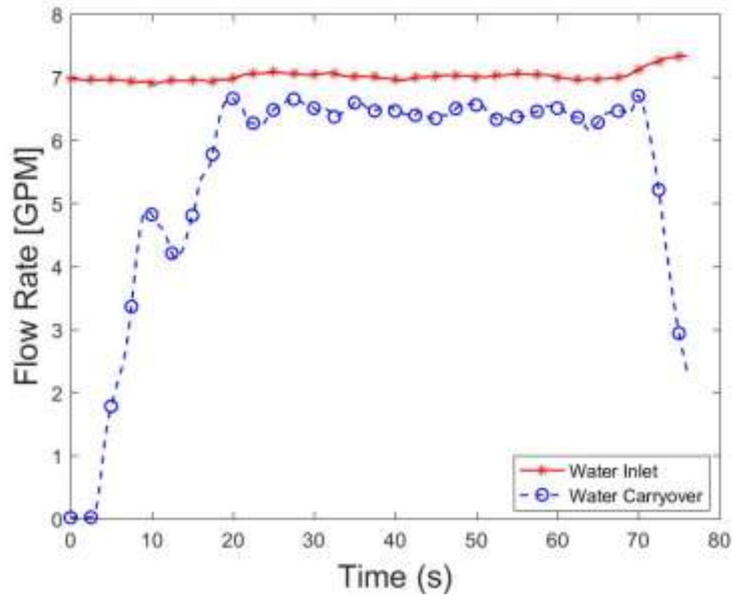

Figure G866: Water flow rates for test 2017_03_24_test_11.

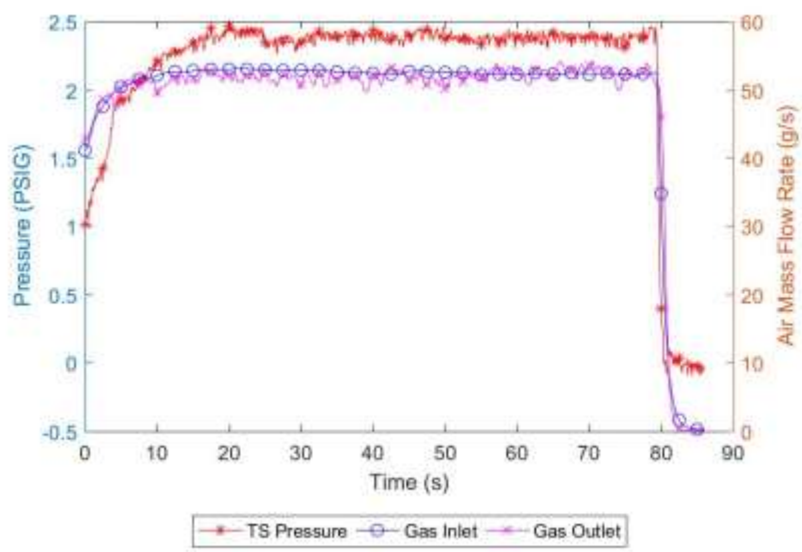

Figure G867: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_12.

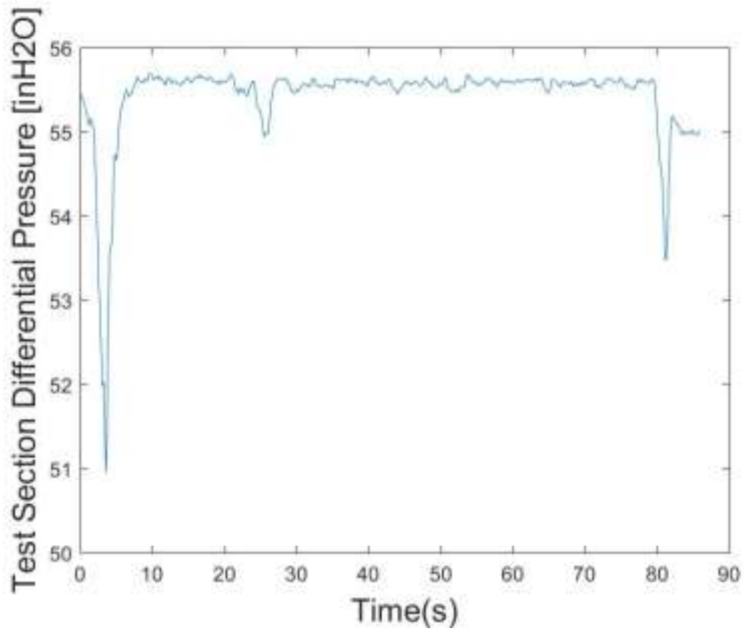

Figure G868: Test section differential pressure for test 2017_03_24_test_12.

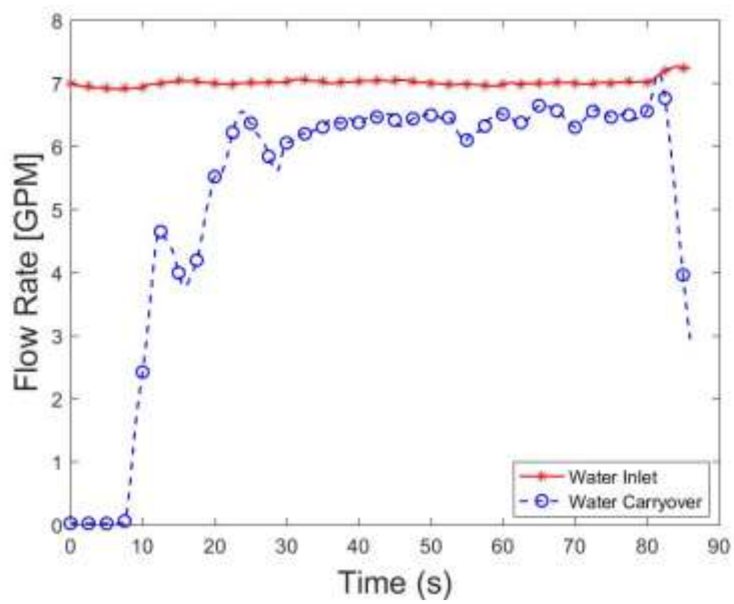

Figure G869: Water flow rates for test 2017_03_24_test_12.

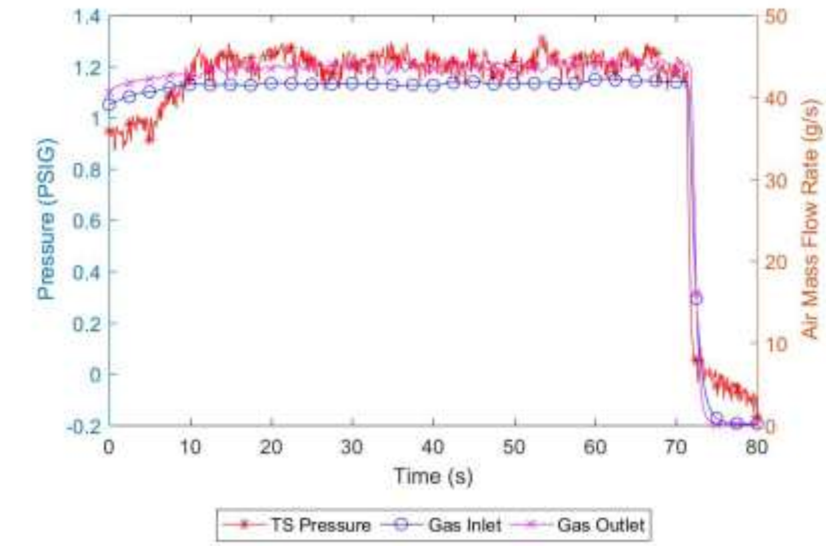

Figure G870: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_13.

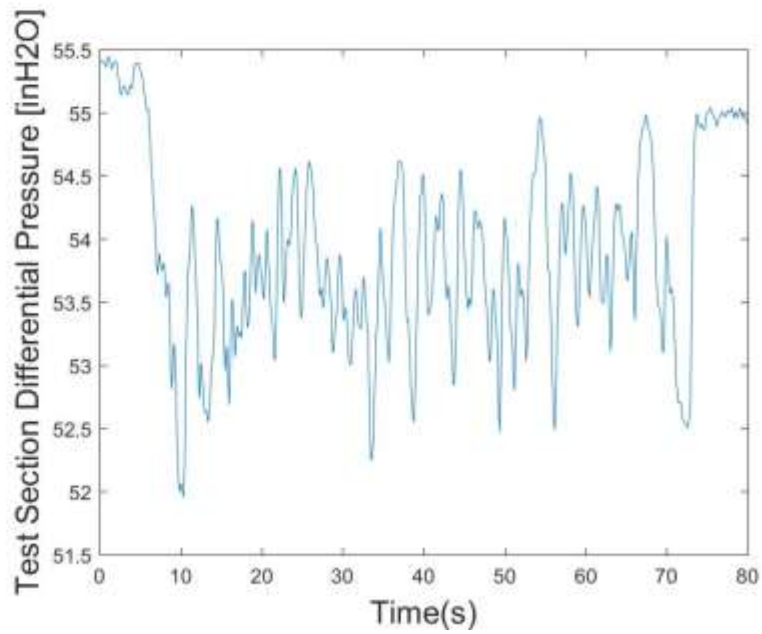

Figure G871: Test section differential pressure for test 2017_03_24_test_13.

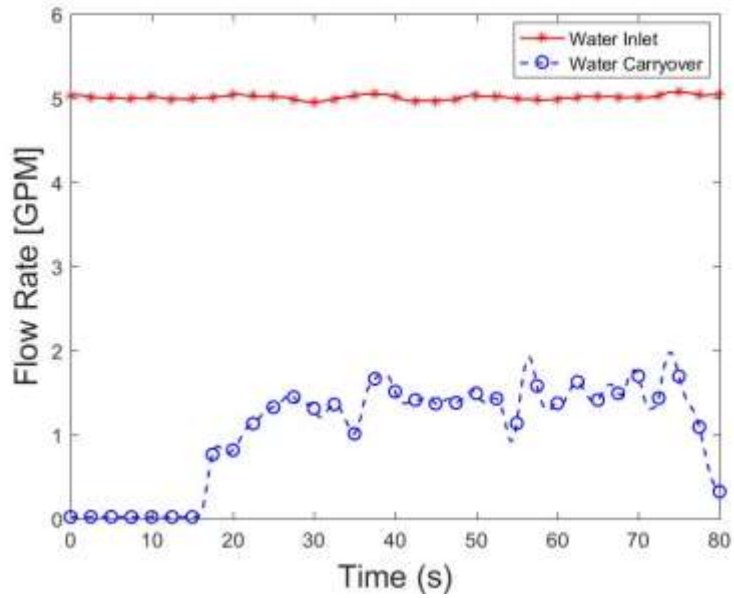

Figure G872: Water flow rates for test 2017_03_24_test_13.

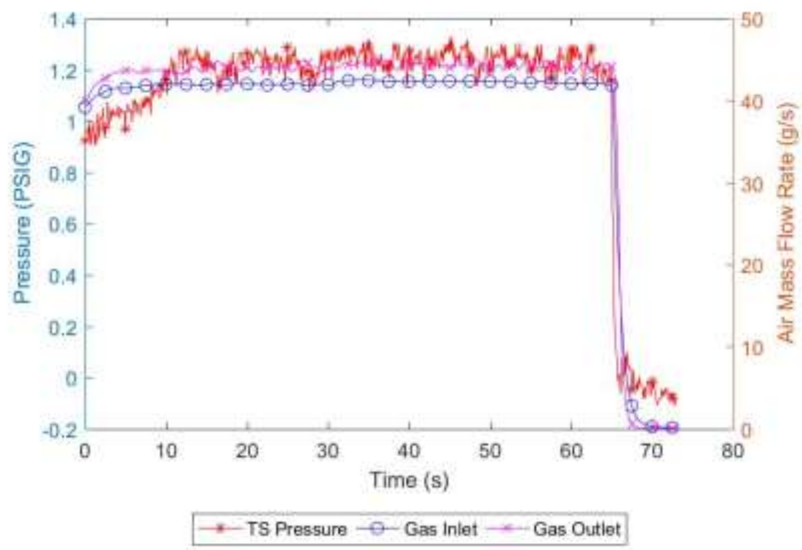

Figure G873: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_14.

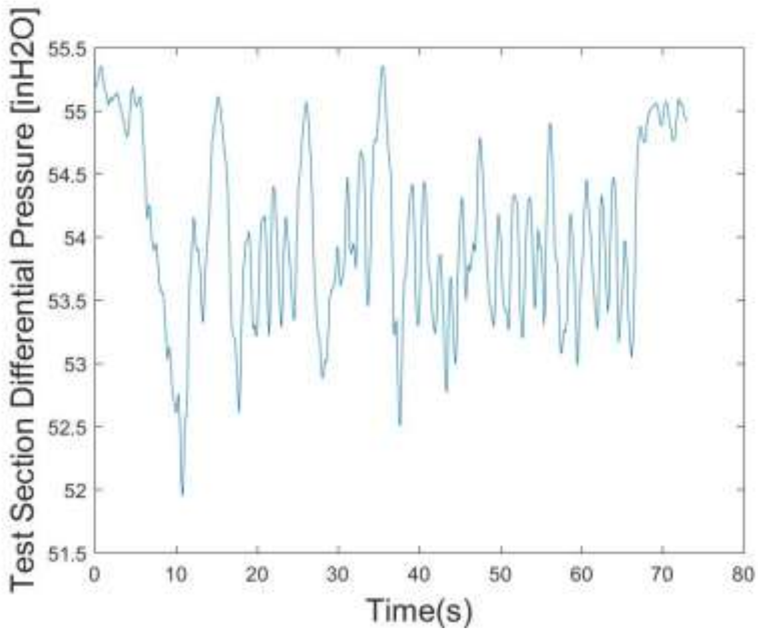

Figure G874: Test section differential pressure for test 2017_03_24_test_14.

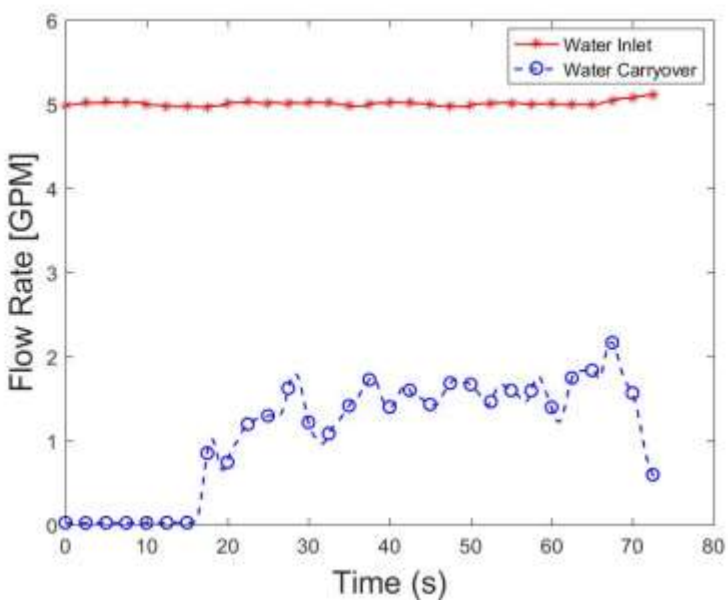

Figure G875: Water flow rates for test 2017_03_24_test_14.

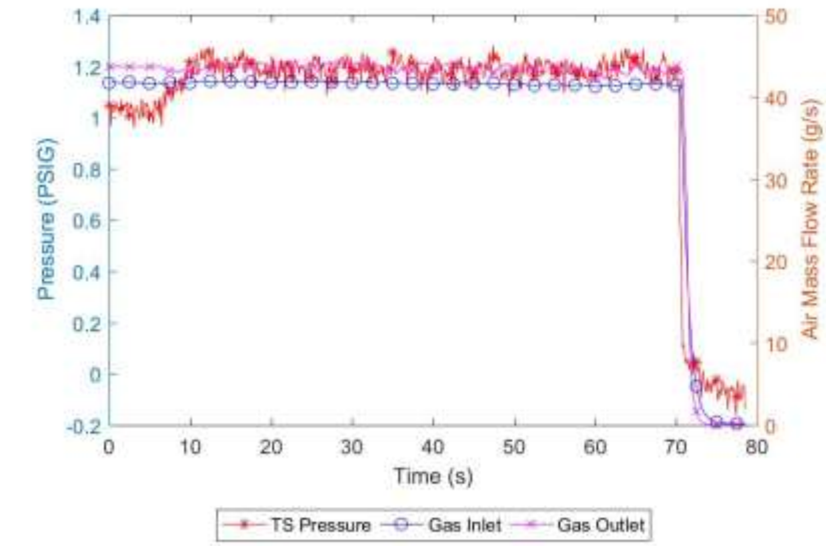

Figure G876: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_15.

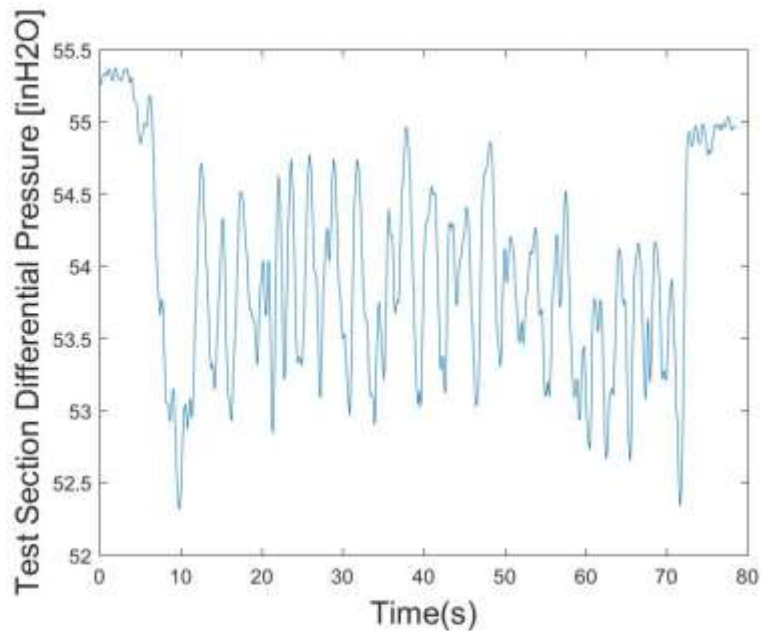

Figure G877: Test section differential pressure for test 2017_03_24_test_15.

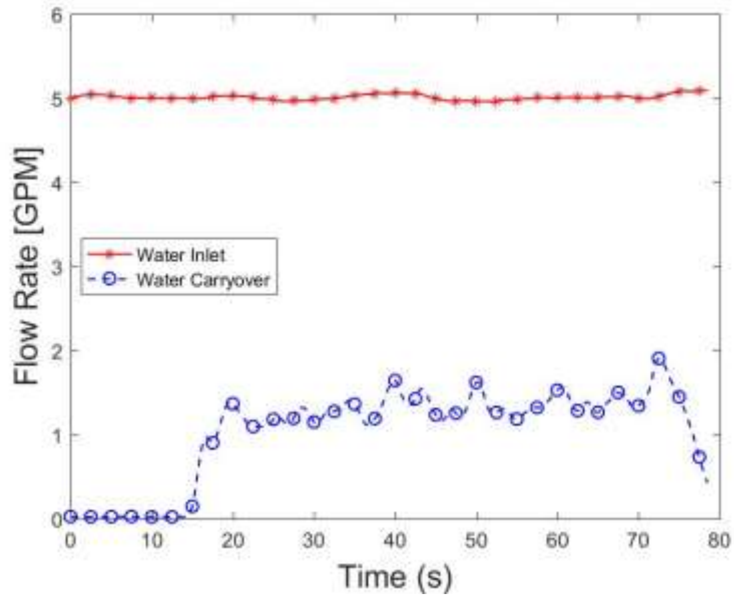

Figure G878: Water flow rates for test 2017_03_24_test_15.

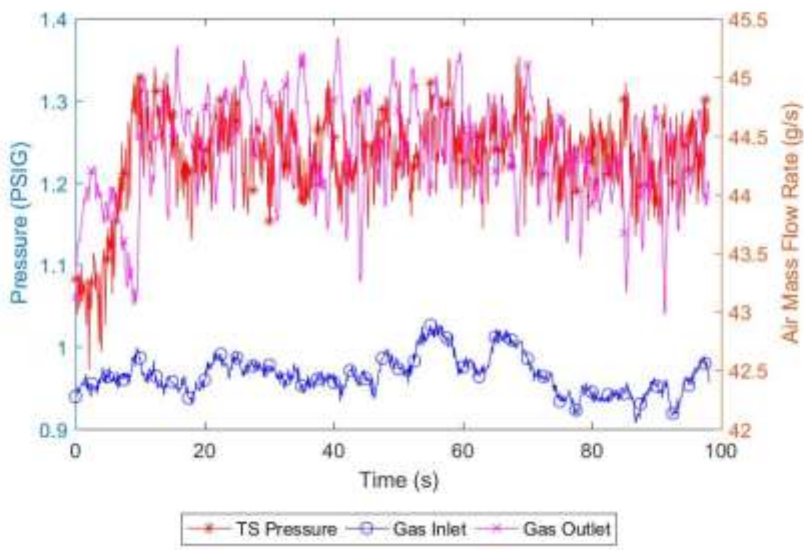

Figure G879: Pressure and gas inlet and outlet mass flow rates for test 2017_03_24_test_16.

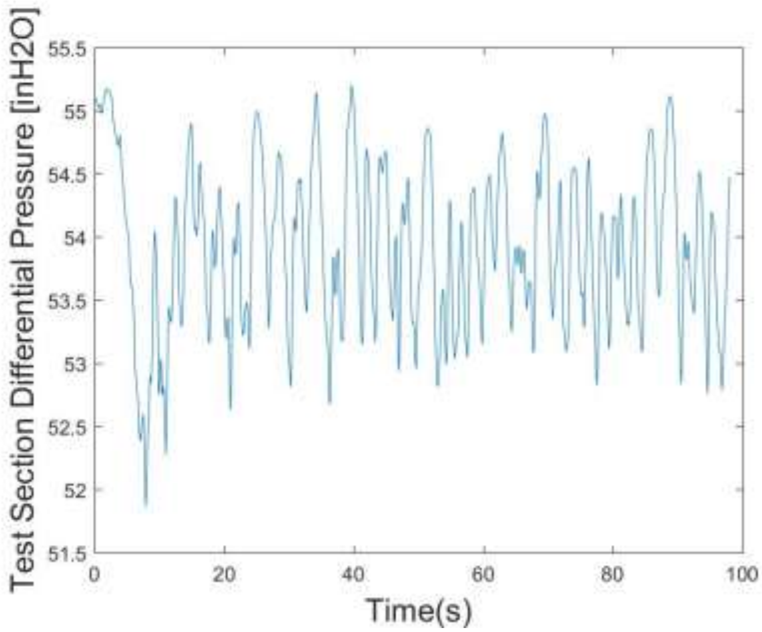

Figure G880: Test section differential pressure for test 2017_03_24_test_16.

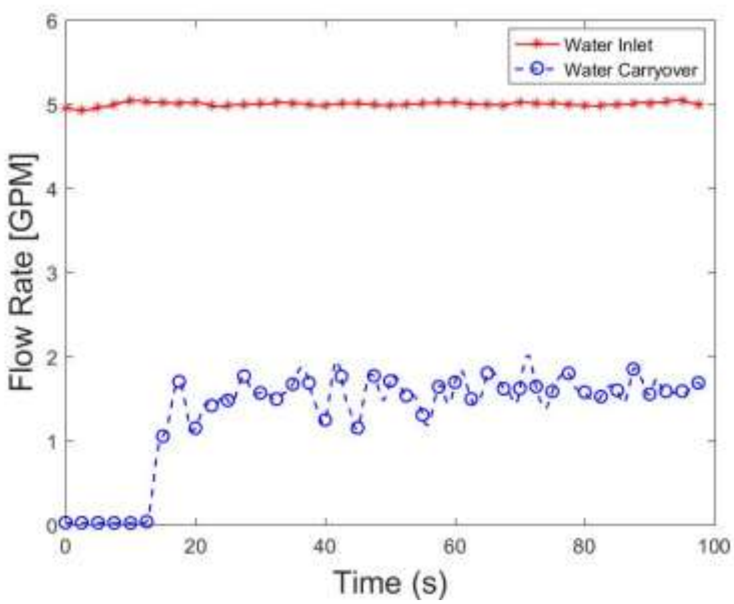

Figure G881: Water flow rates for test 2017_03_24_test_16.

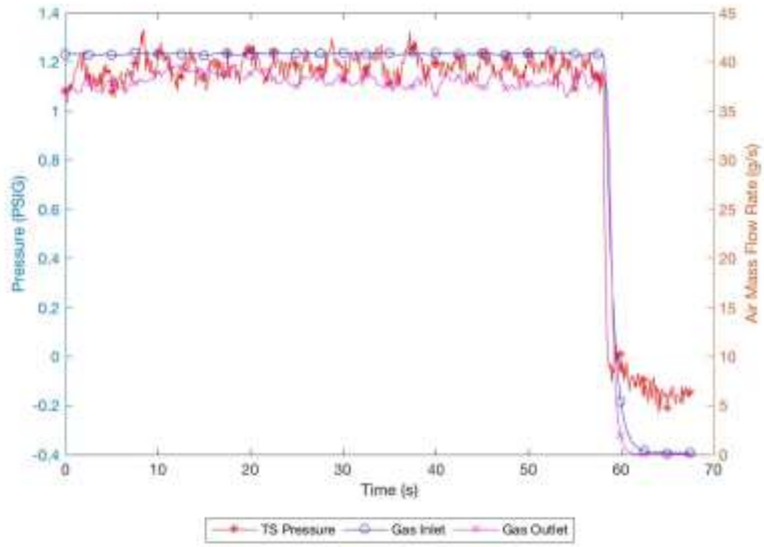

Figure G882: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_01.

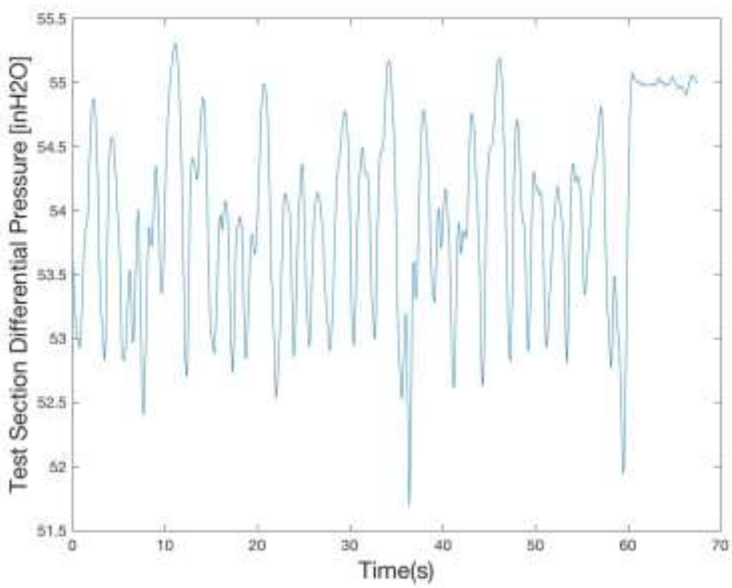

Figure G883: Test section differential pressure for test 2017_04_03_test_01.

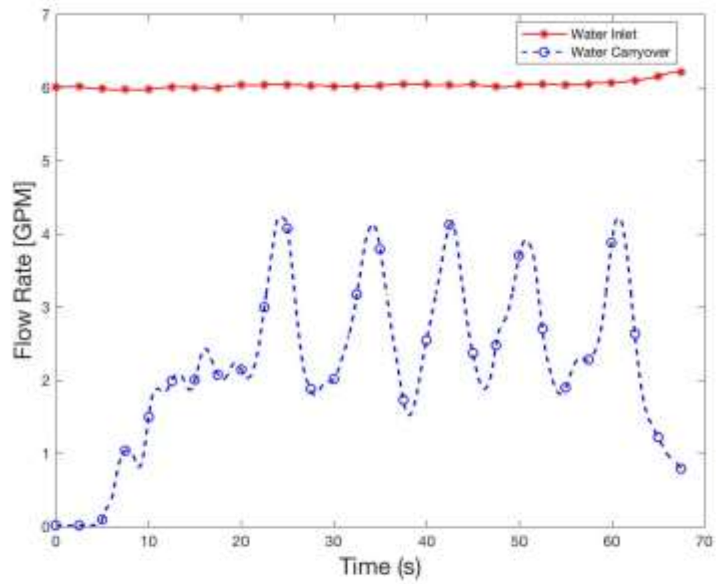

Figure G884: Water flow rates for test 2017_04_03_test_01.

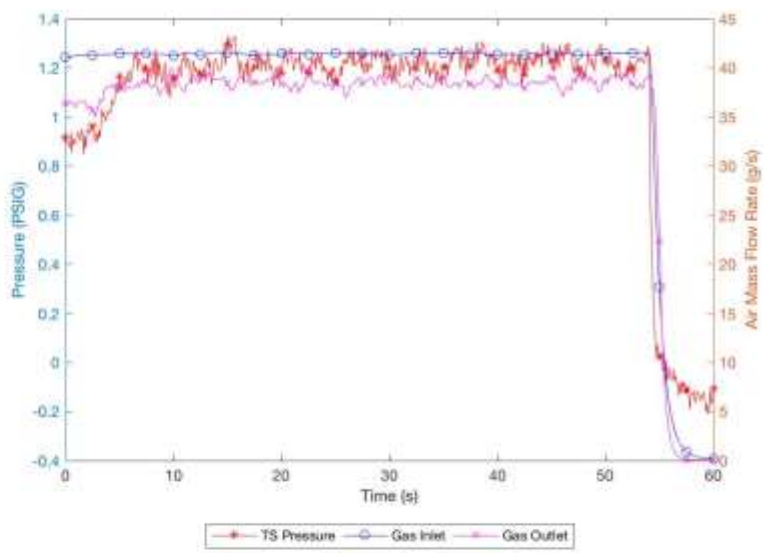

Figure G885: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_02.

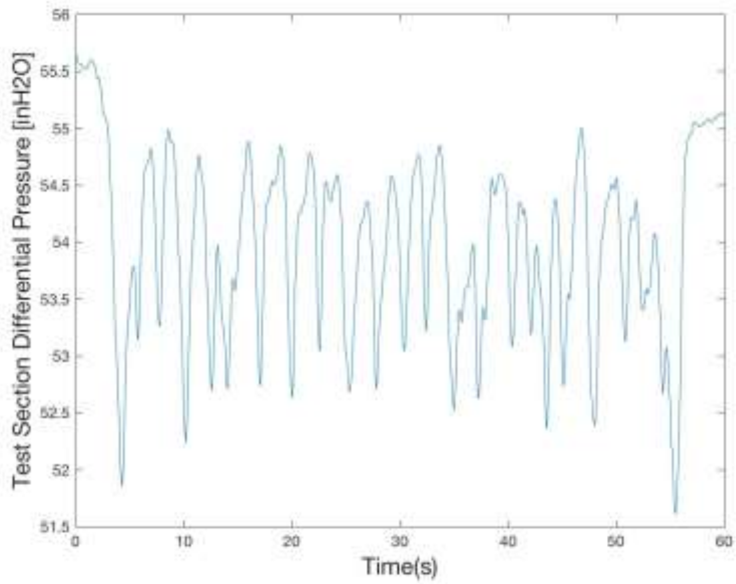

Figure G886: Test section differential pressure for test 2017_04_03_test_02.

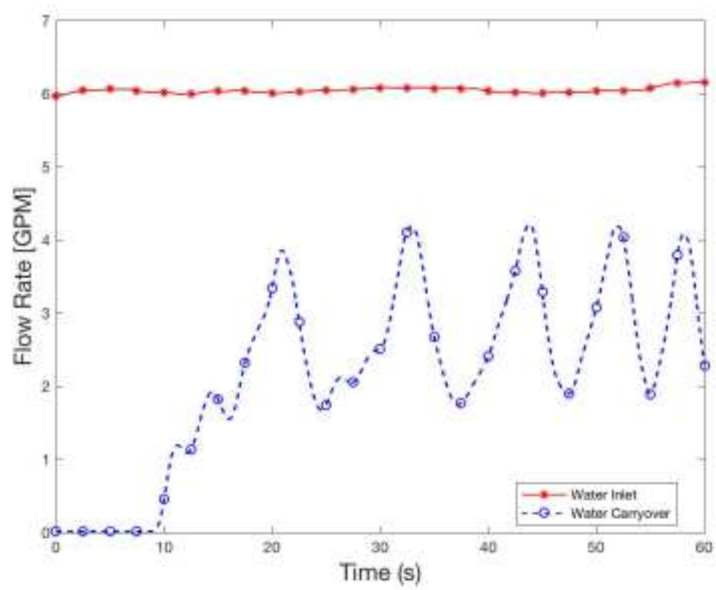

Figure G887: Water flow rates for test 2017_04_03_test_02.

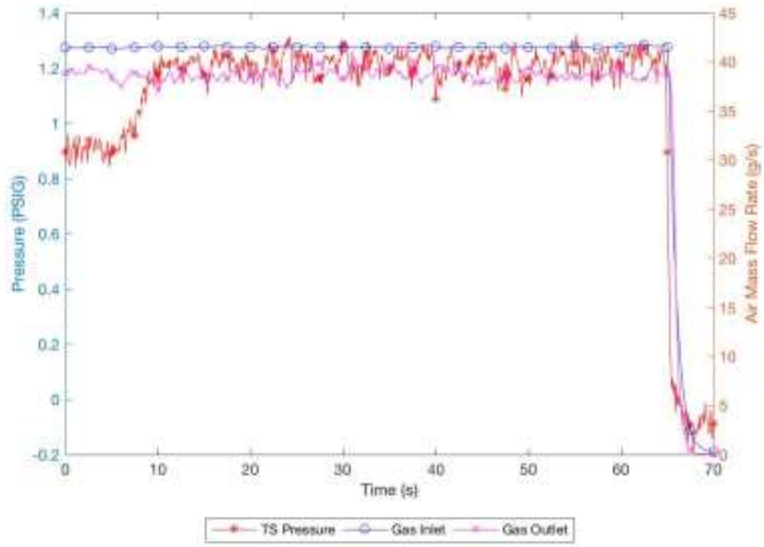

Figure G888: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_03.

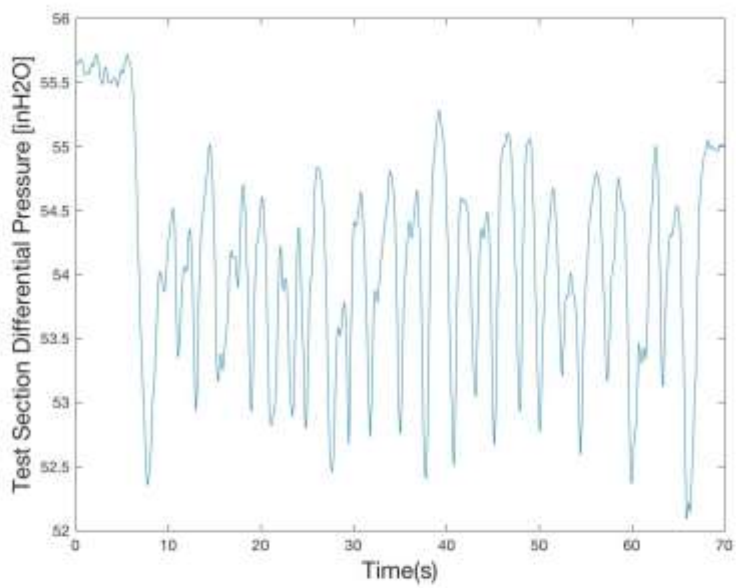

Figure G889: Test section differential pressure for test 2017_04_03_test_03.

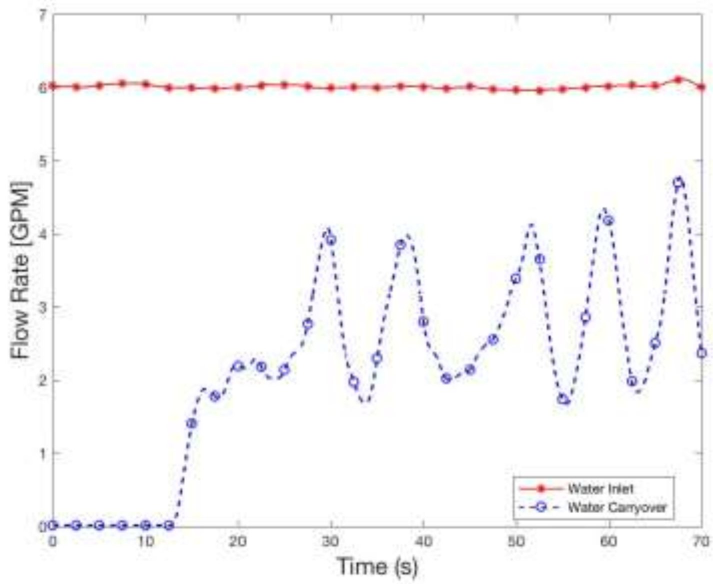

Figure G890: Water flow rates for test 2017_04_03_test_03.

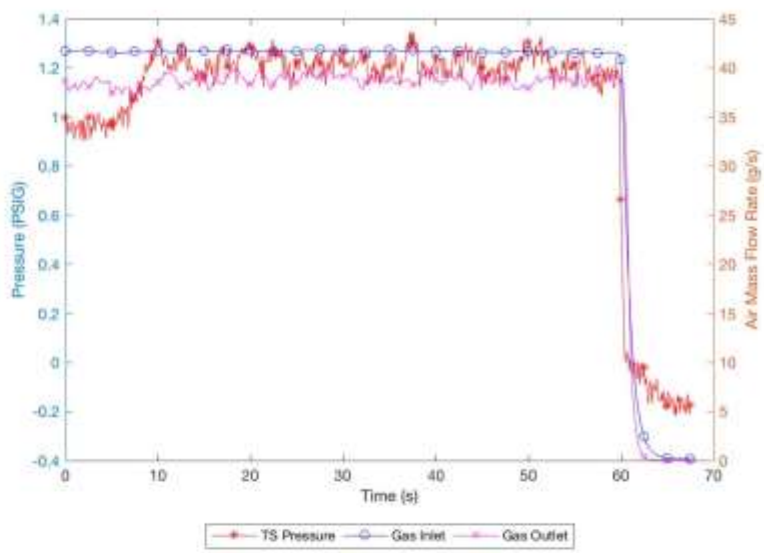

Figure G891: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_04.

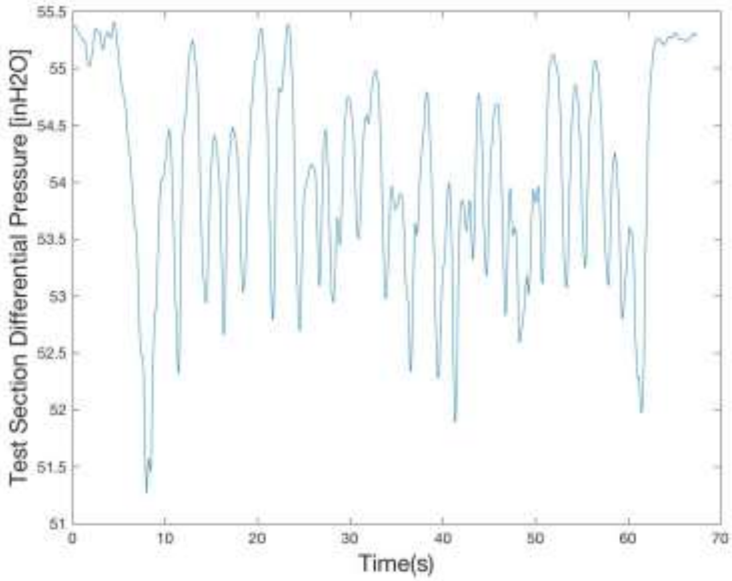

Figure G892: Test section differential pressure for test 2017_04_03_test_04.

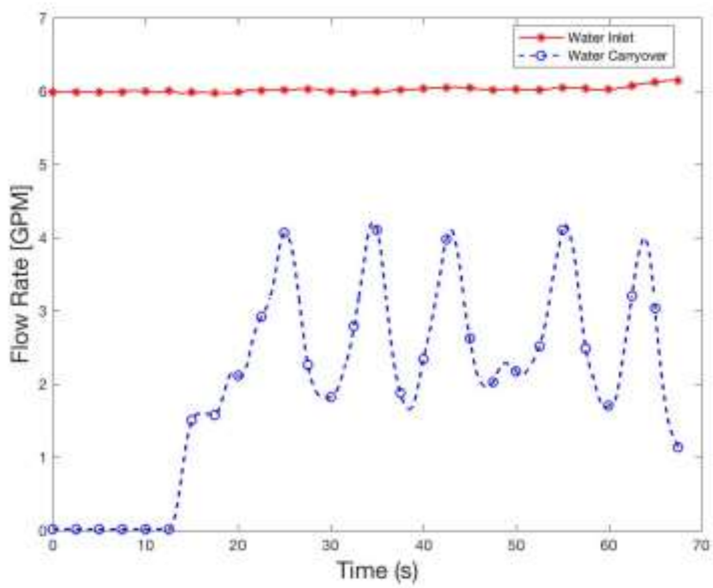

Figure G893: Water flow rates for test 2017_04_03_test_04.

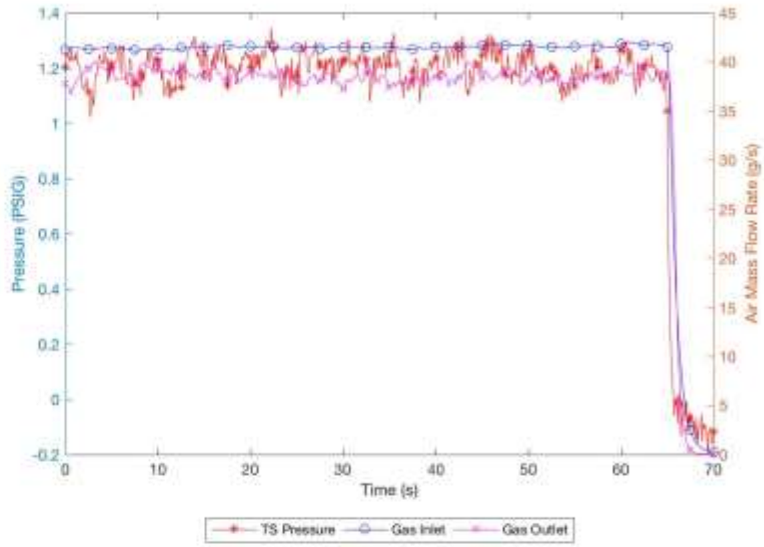

Figure G894: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_05.

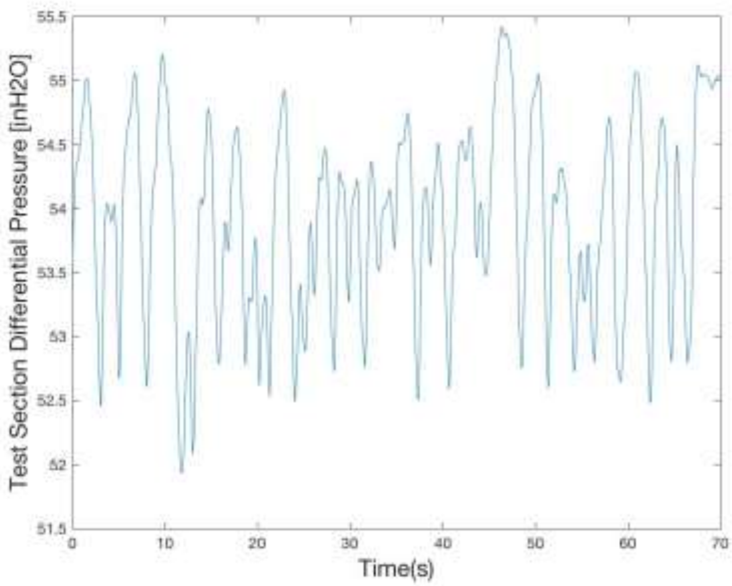

Figure G895: Test section differential pressure for test 2017_04_03_test_05.

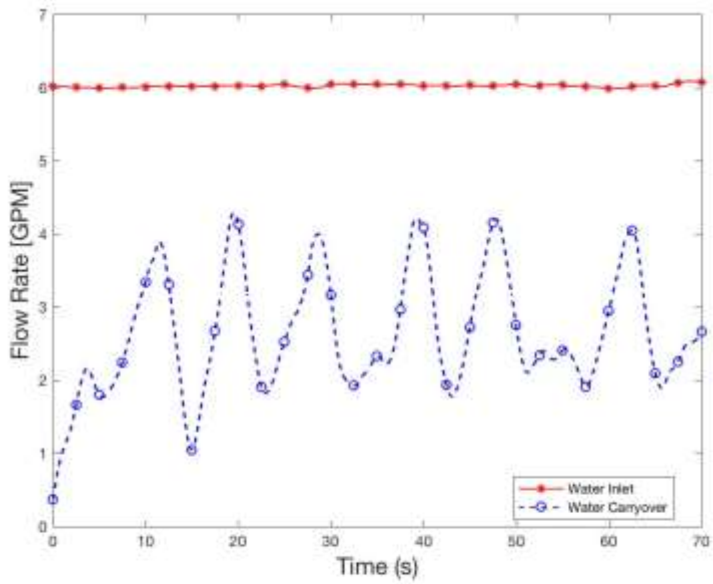

Figure G896: Water flow rates for test 2017_04_03_test_05.

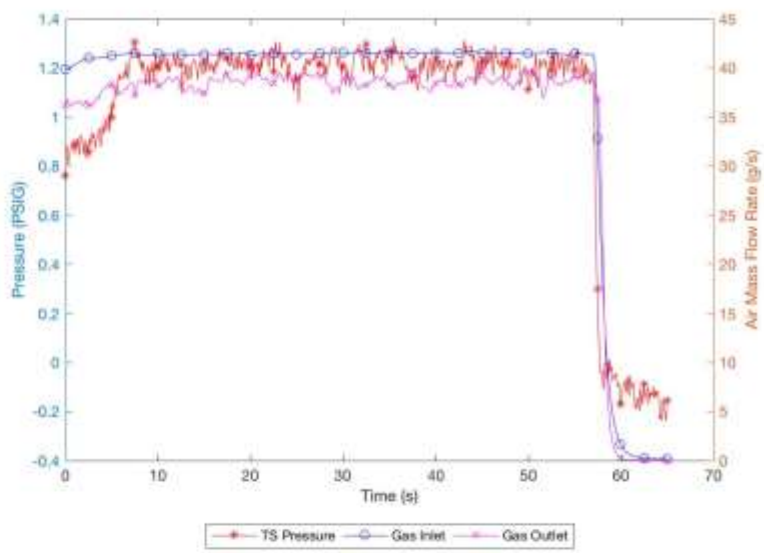

Figure G897: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_06.

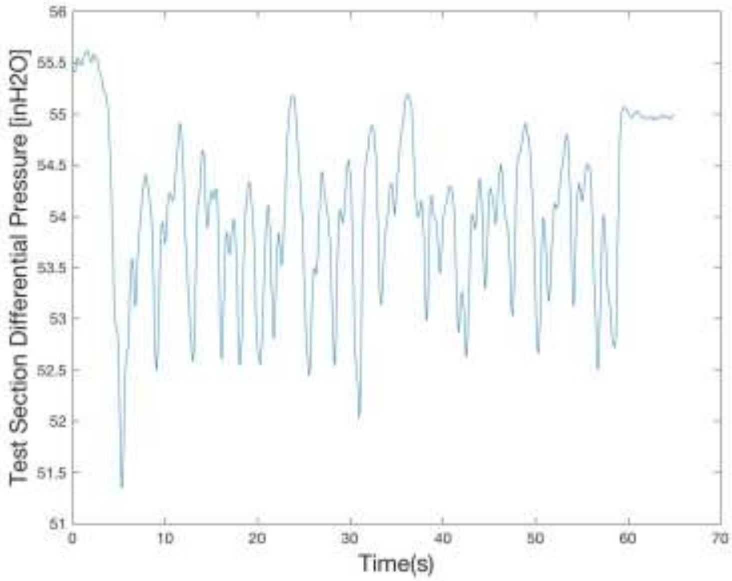

Figure G898: Test section differential pressure for test 2017_04_03_test_06.

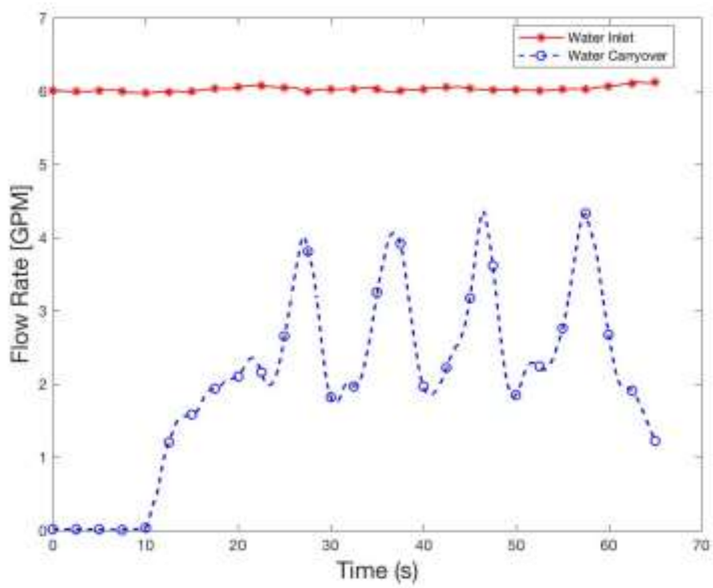

Figure G899: Water flow rates for test 2017_04_03_test_06.

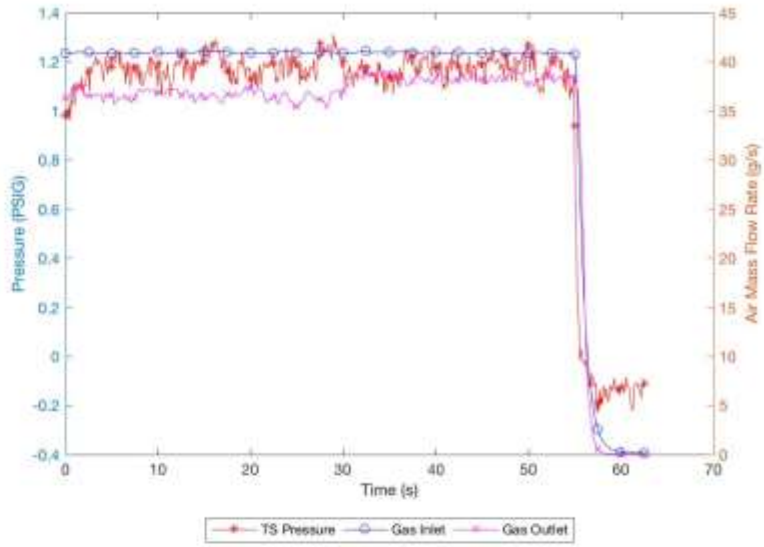

Figure G900: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_07.

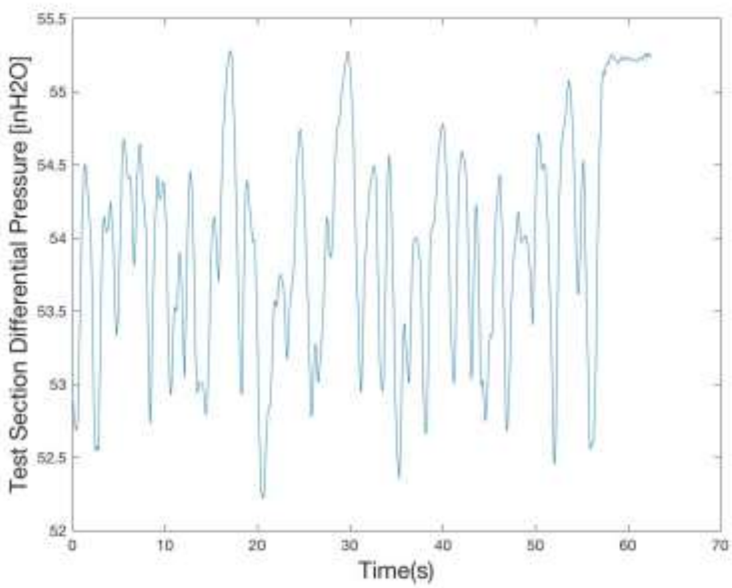

Figure G901: Test section differential pressure for test 2017_04_03_test_07.

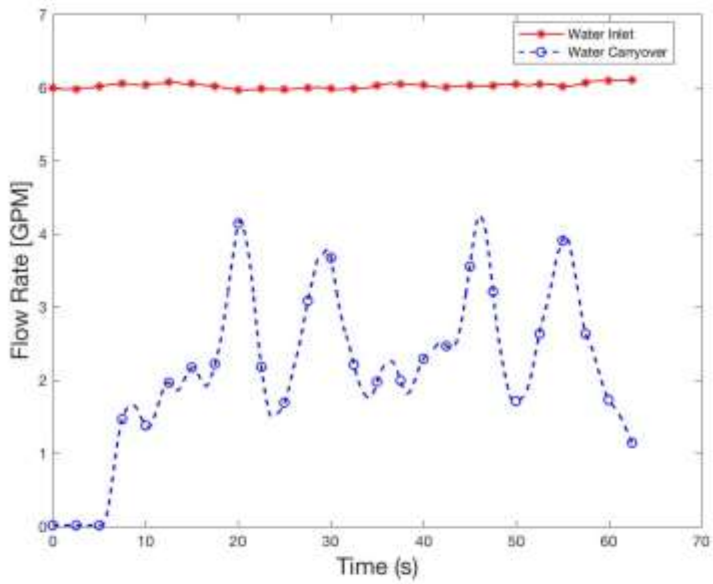

Figure G902: Water flow rates for test 2017_04_03_test_07.

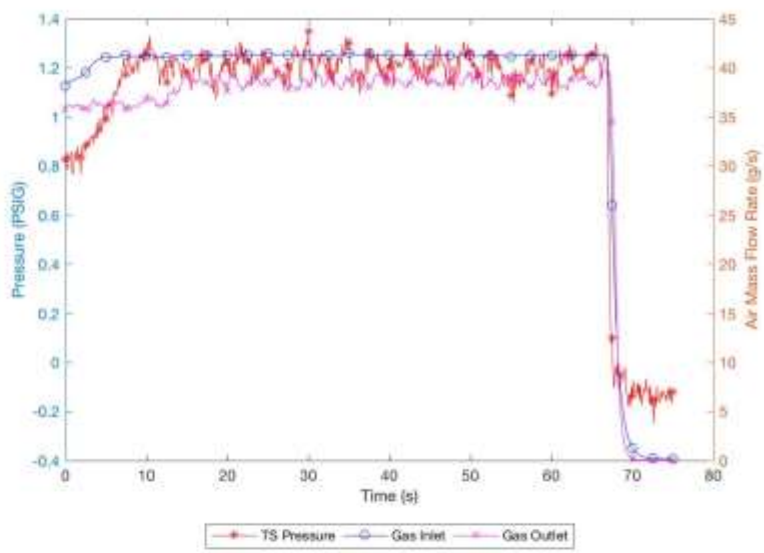

Figure G903: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_08.

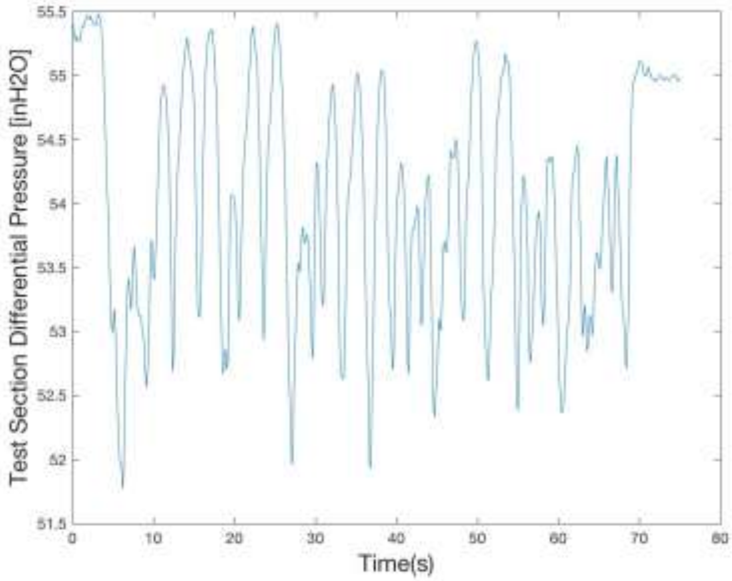

Figure G904: Test section differential pressure for test 2017_04_03_test_08.

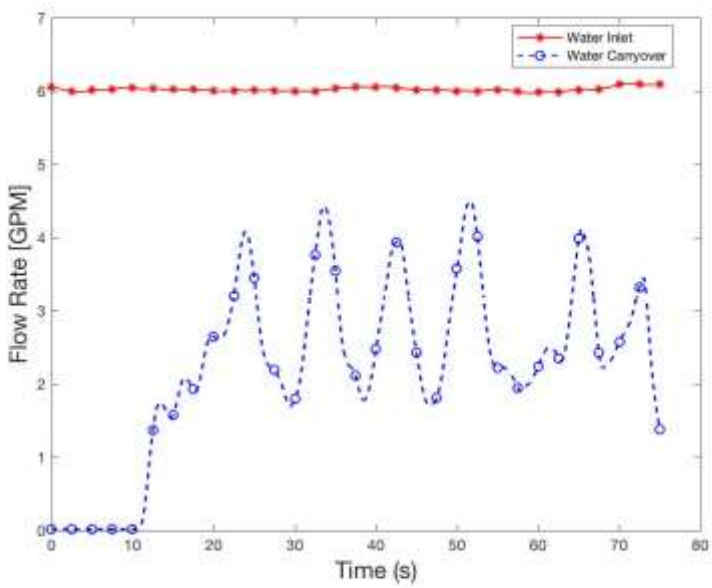

Figure G905: Water flow rates for test 2017_04_03_test_08.

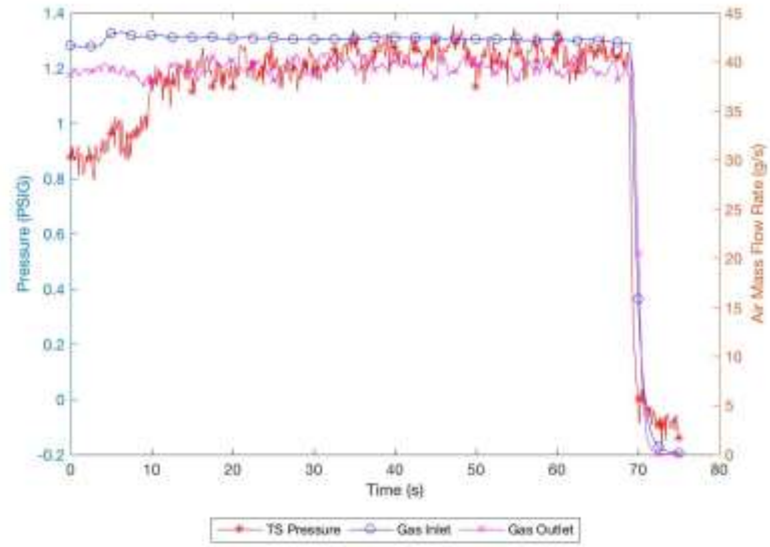

Figure G906: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_09.

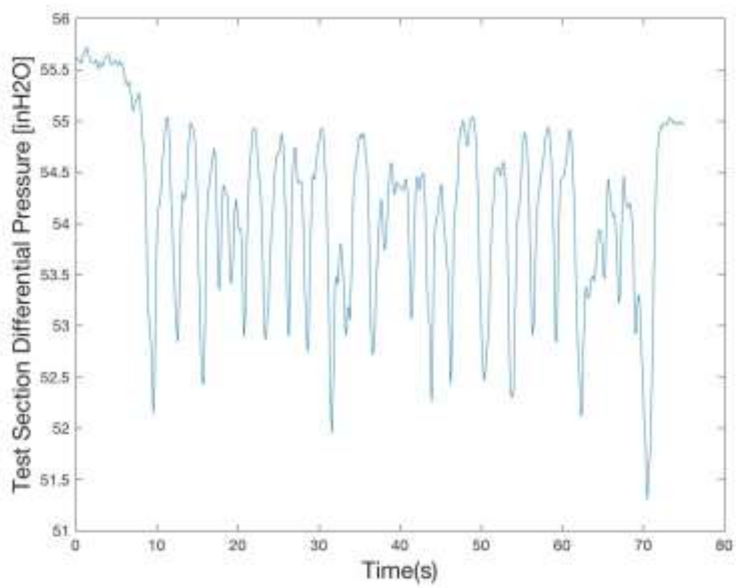

Figure G907: Test section differential pressure for test 2017_04_03_test_09.

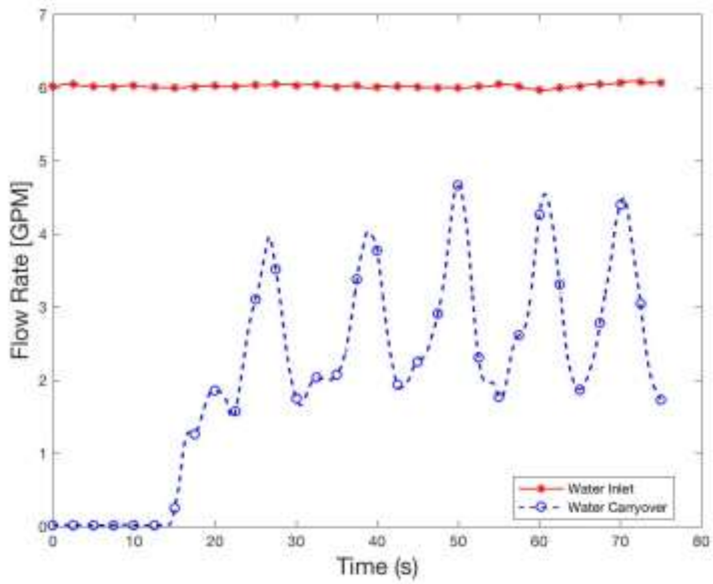

Figure G908: Water flow rates for test 2017_04_03_test_09.

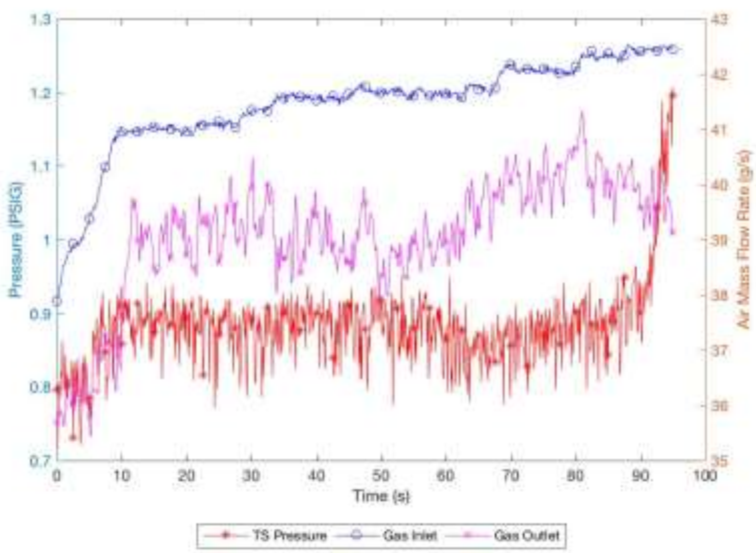

Figure G909: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_10.

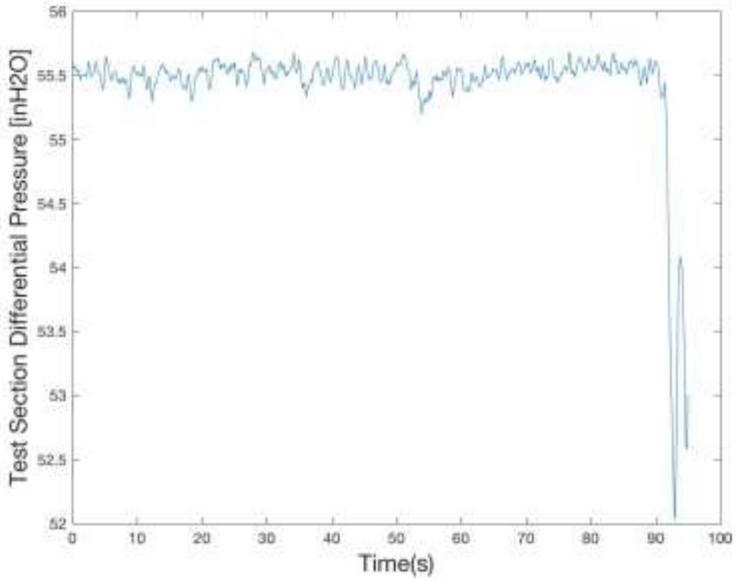

Figure G910: Test section differential pressure for test 2017_04_03_test_10.

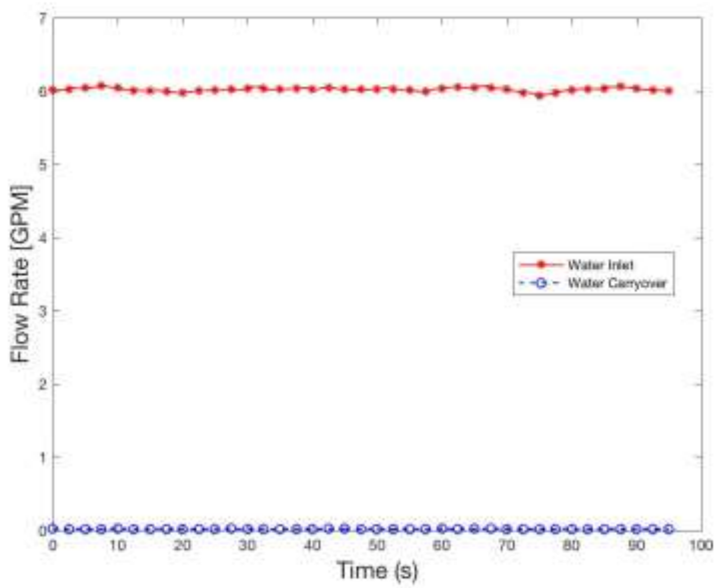

Figure G911: Water flow rates for test 2017_04_03_test_10.

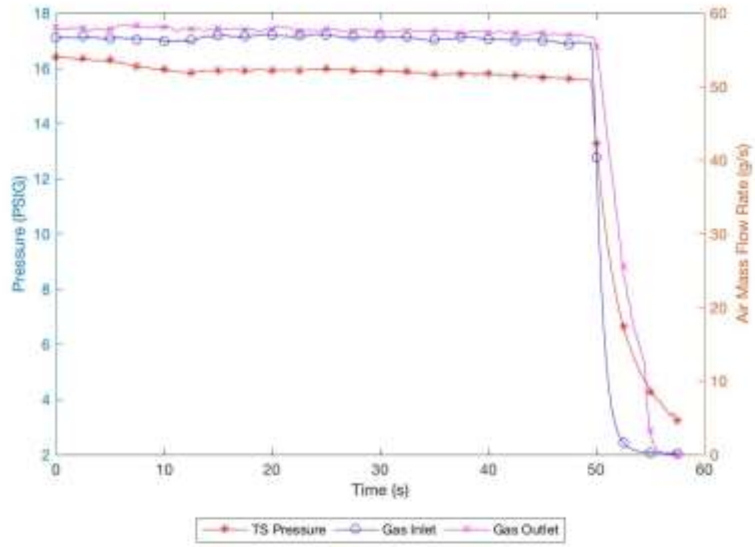

Figure G912: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_11.

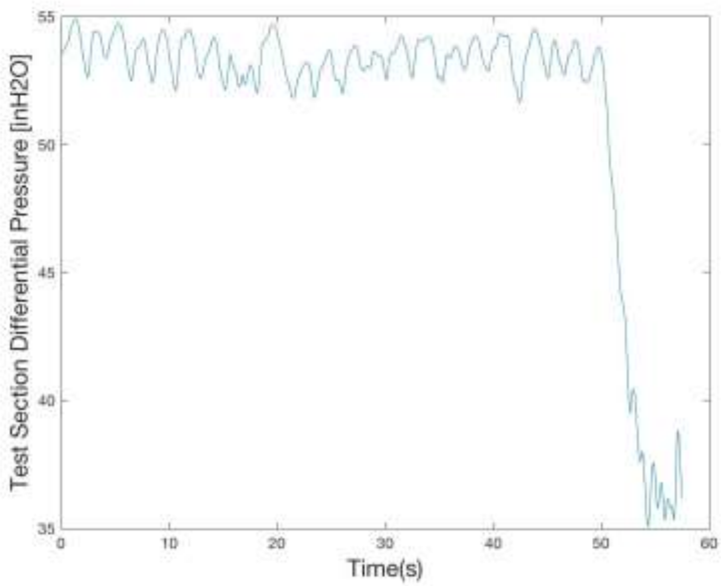

Figure G913: Test section differential pressure for test 2017_04_03_test_11.

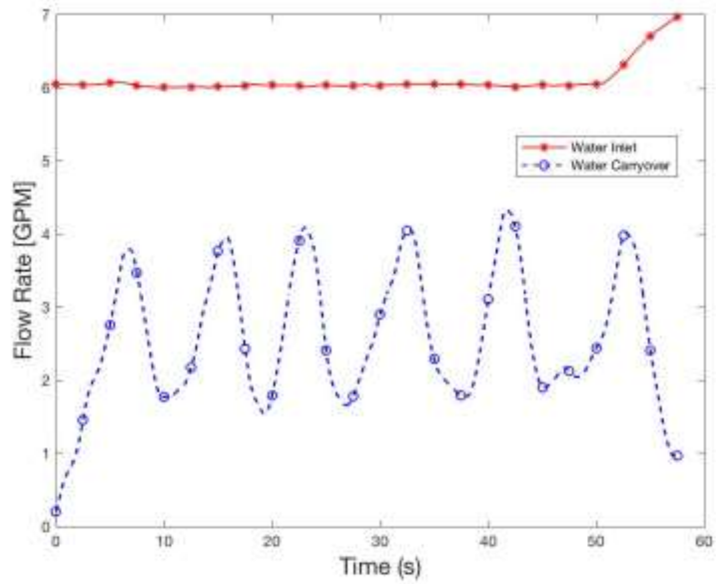

Figure G914: Water flow rates for test 2017_04_03_test_11.

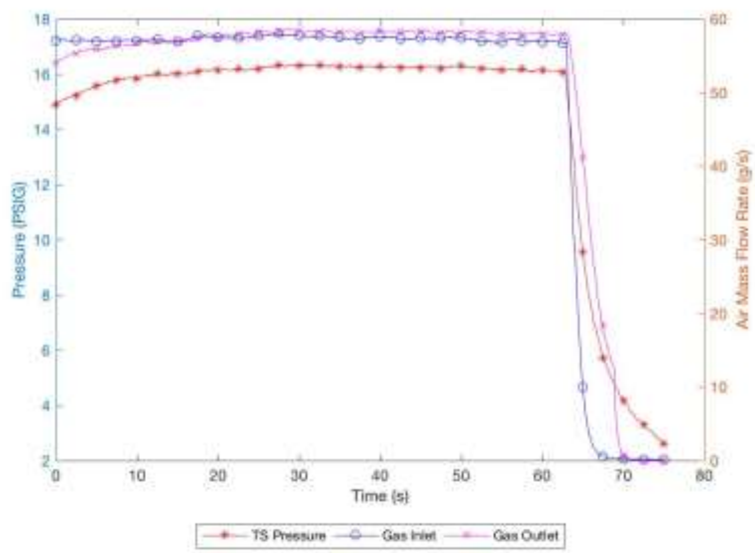

Figure G915: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_12.

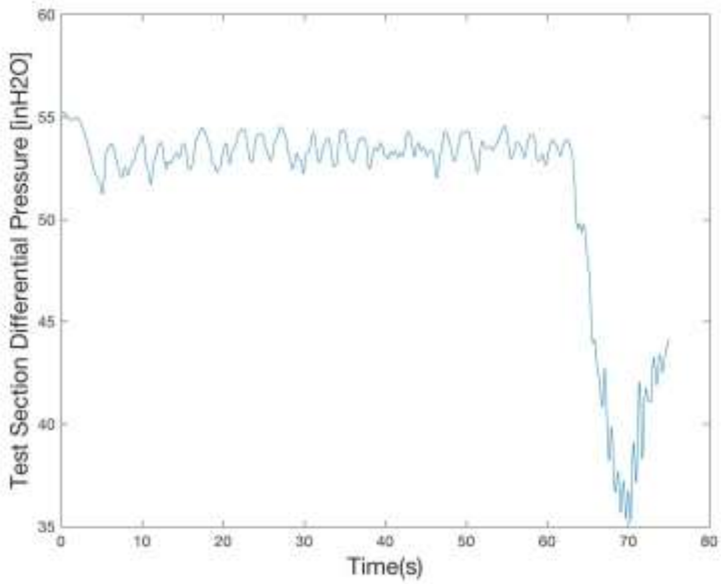

Figure G916: Test section differential pressure for test 2017_04_03_test_12.

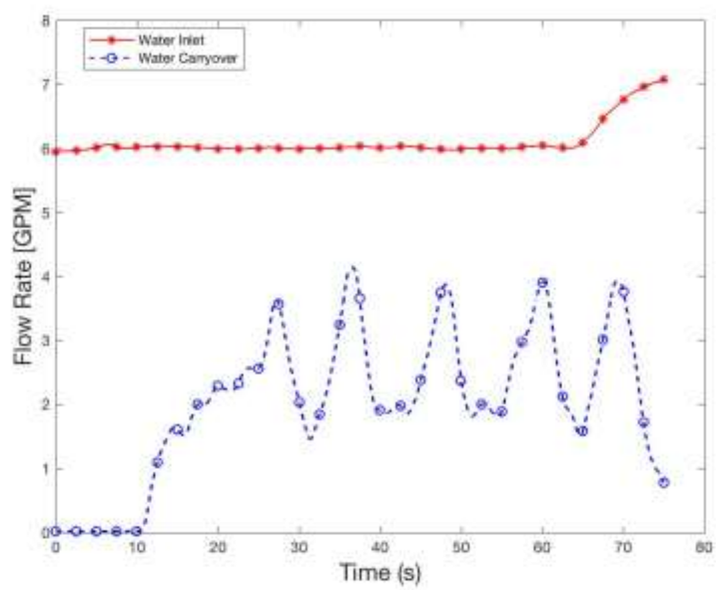

Figure G917: Water flow rates for test 2017_04_03_test_12.

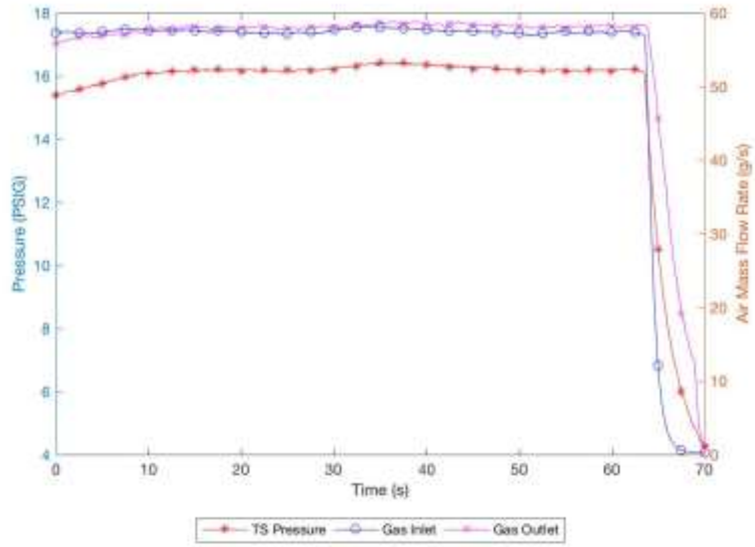

Figure G918: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_13.

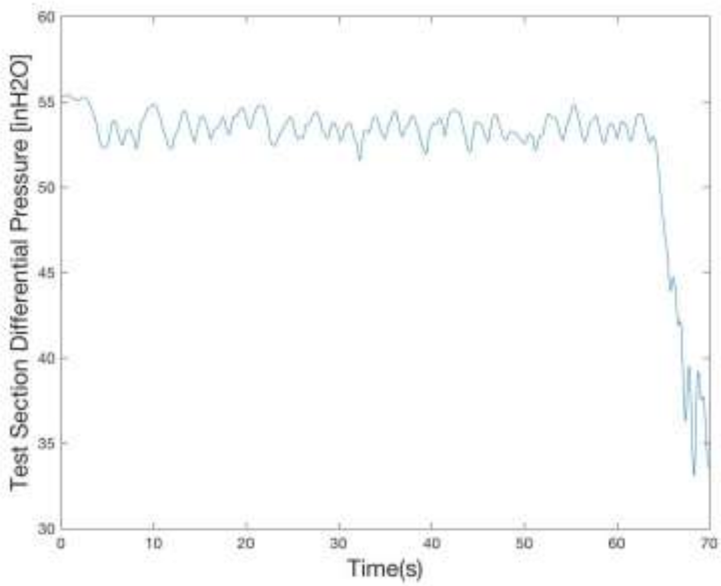

Figure G919: Test section differential pressure for test 2017_04_03_test_13.

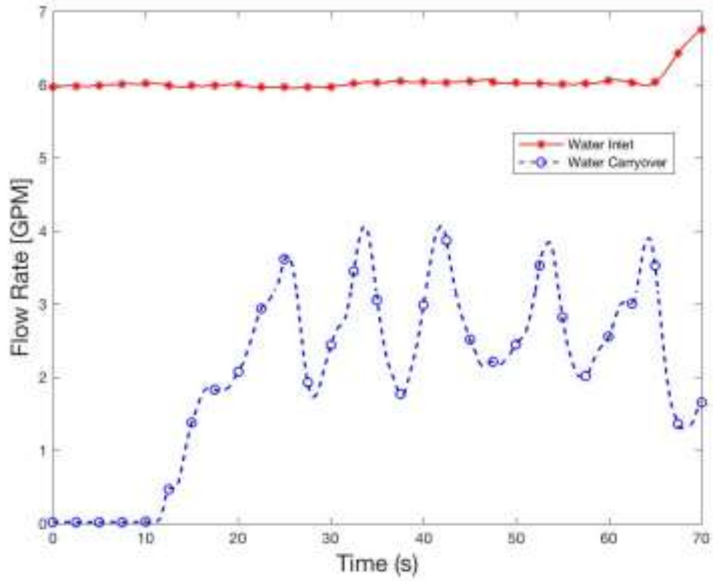

Figure G920: Water flow rates for test 2017_04_03_test_13.

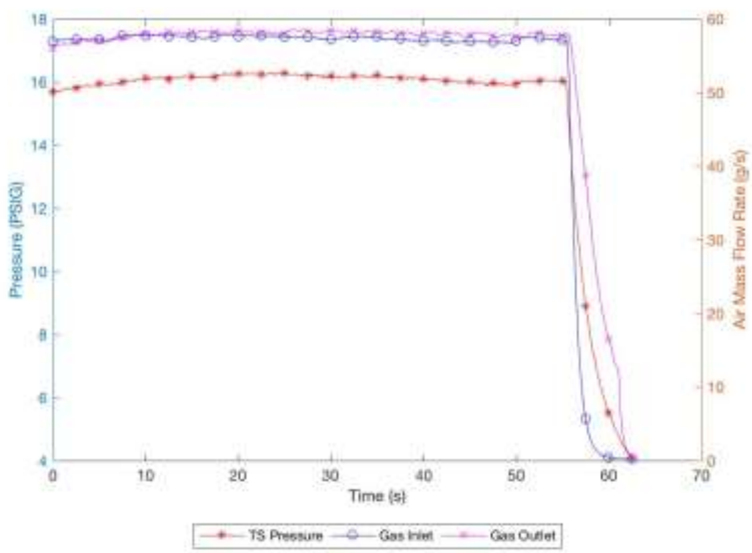

Figure G921: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_14.

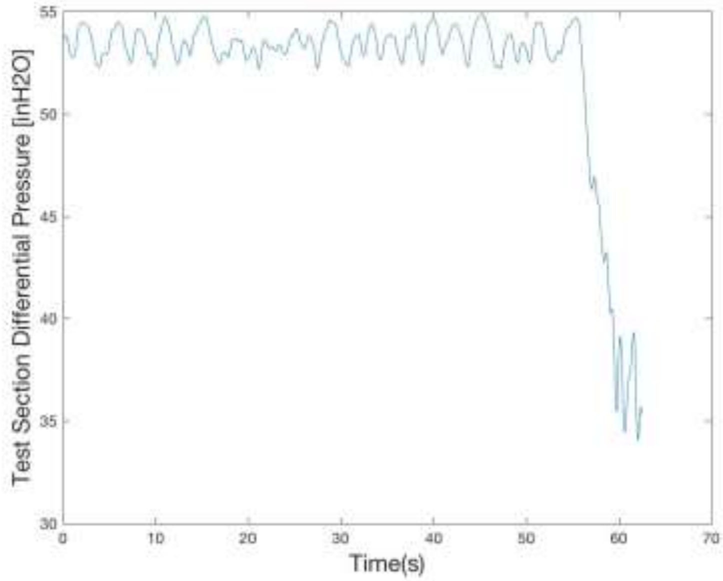

Figure G922: Test section differential pressure for test 2017_04_03_test_14.

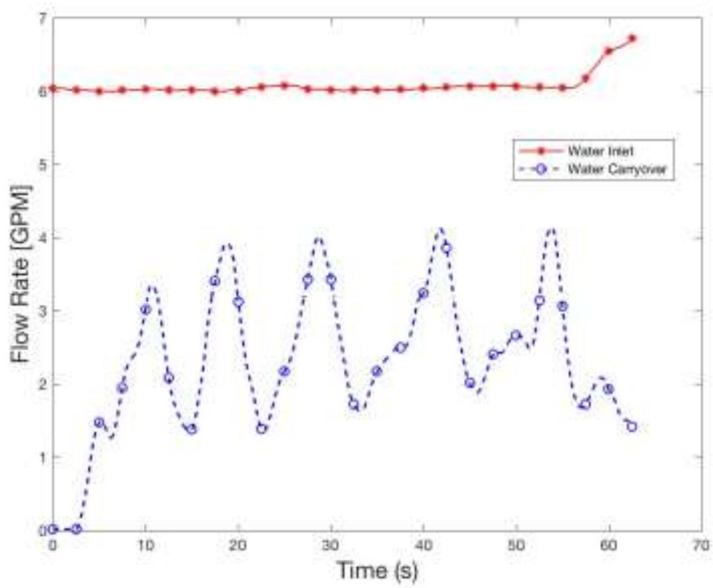

Figure G923: Water flow rates for test 2017_04_03_test_14.

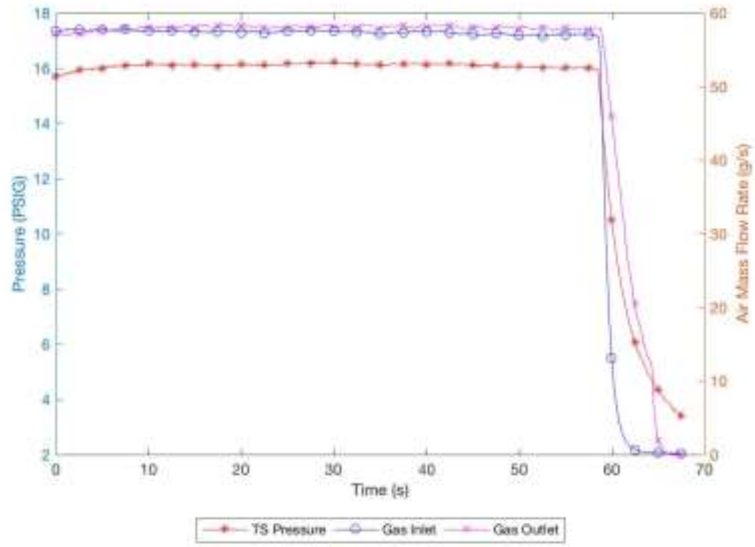

Figure G924: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_15.

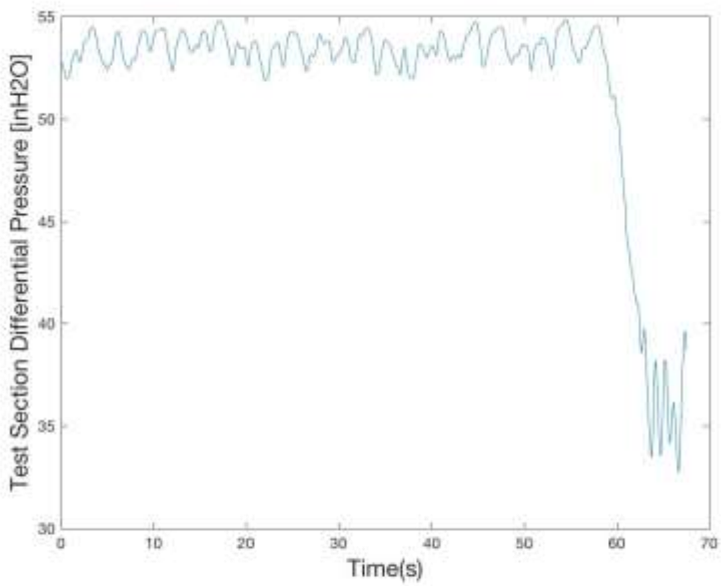

Figure G925: Test section differential pressure for test 2017_04_03_test_15.

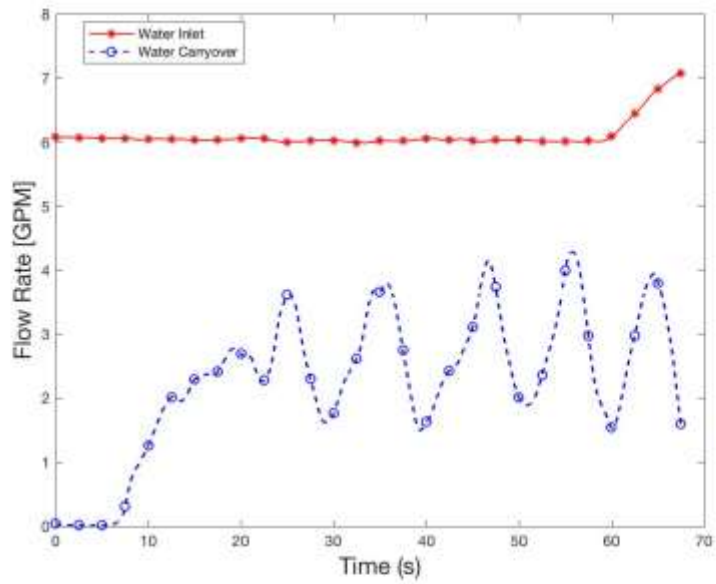

Figure G926: Water flow rates for test 2017_04_03_test_15.

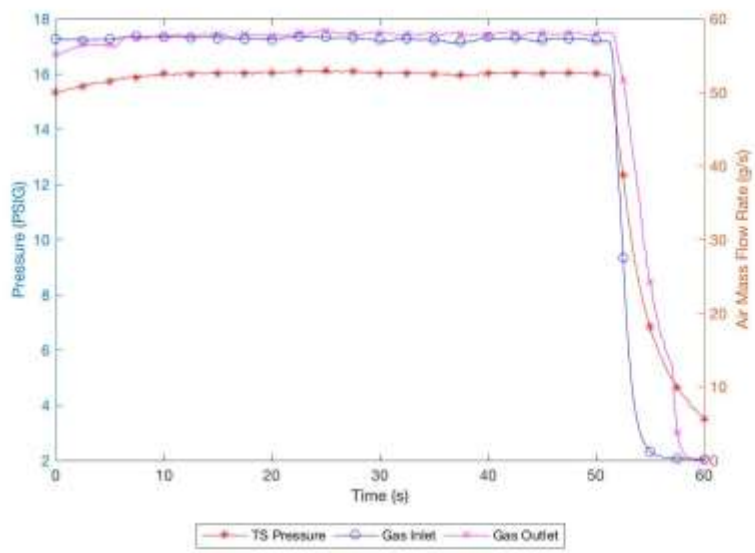

Figure G927: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_16.

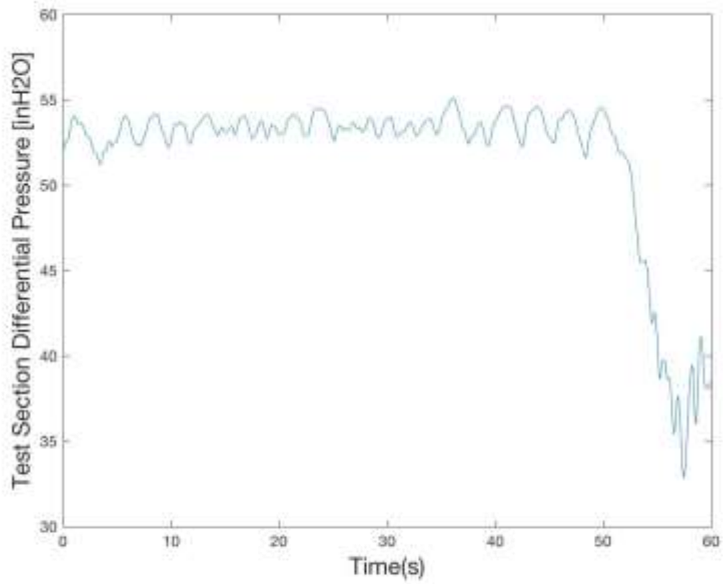

Figure G928: Test section differential pressure for test 2017_04_03_test_16.

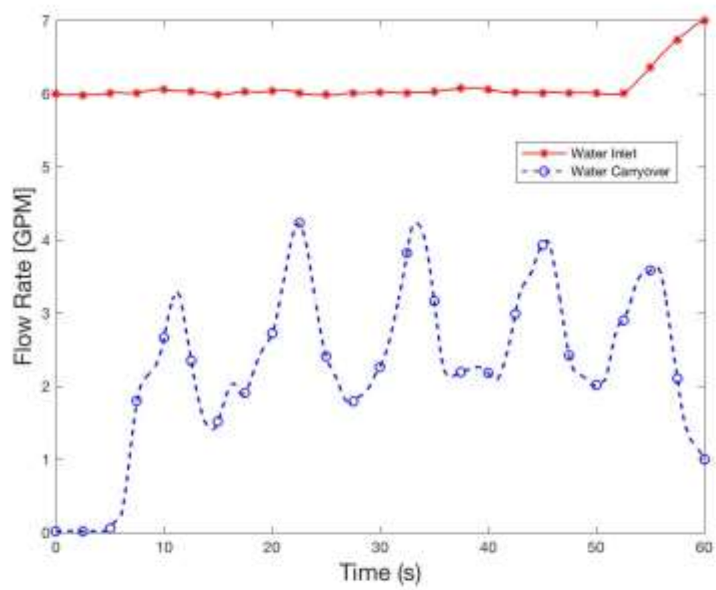

Figure G929: Water flow rates for test 2017_04_03_test_16.

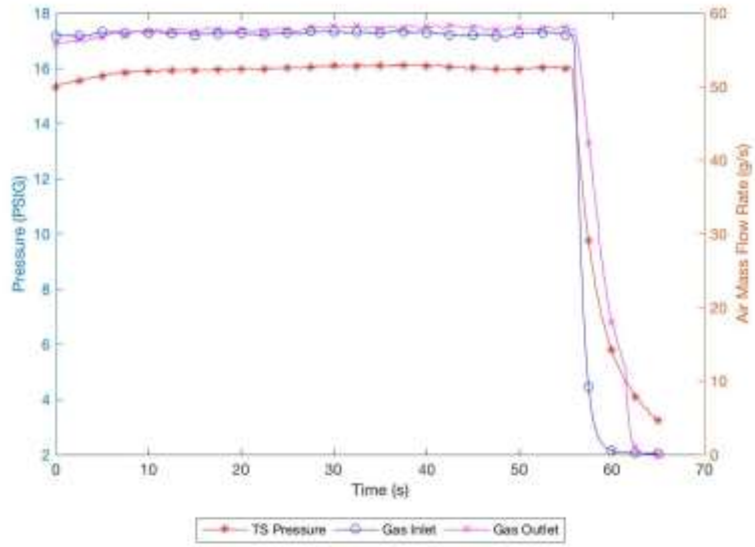

Figure G930: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_17.

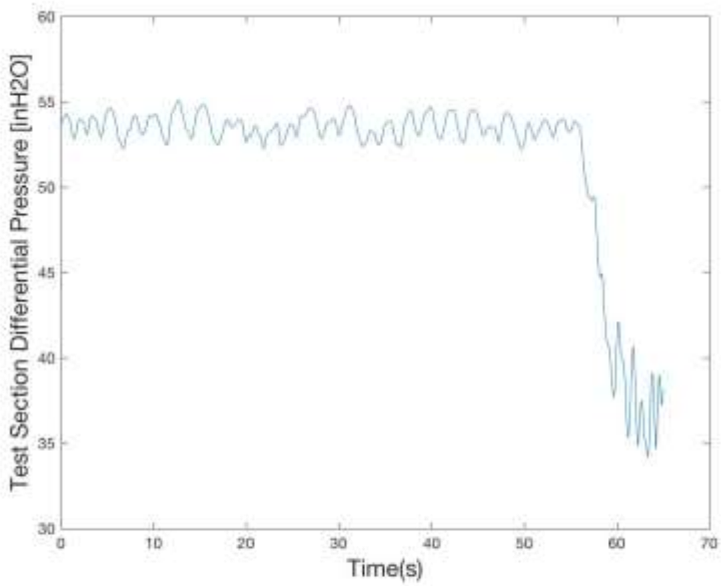

Figure G931: Test section differential pressure for test 2017_04_03_test_17.

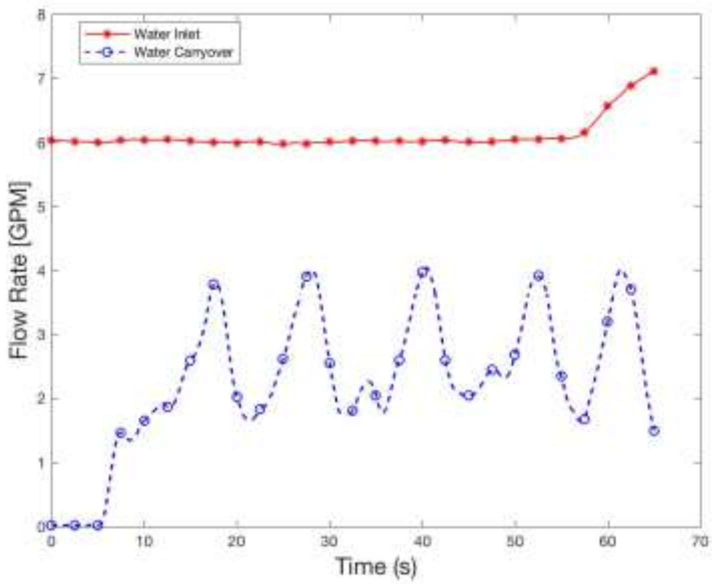

Figure G932: Water flow rates for test 2017_04_03_test_17.

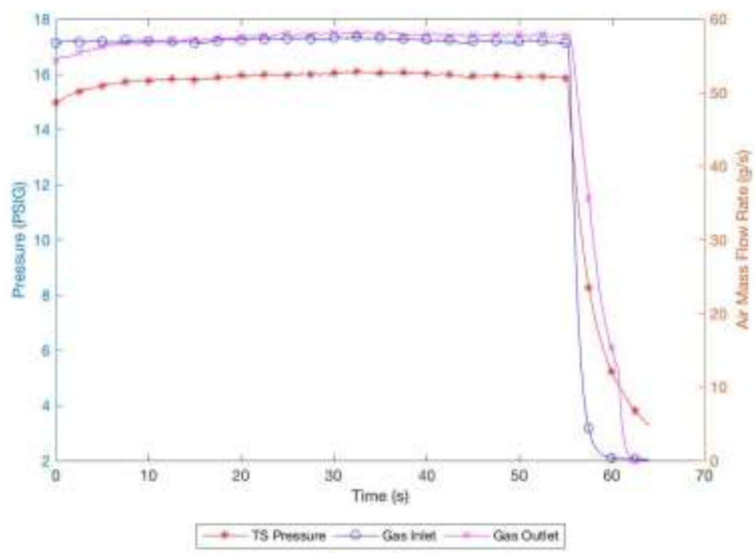

Figure G933: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_18.

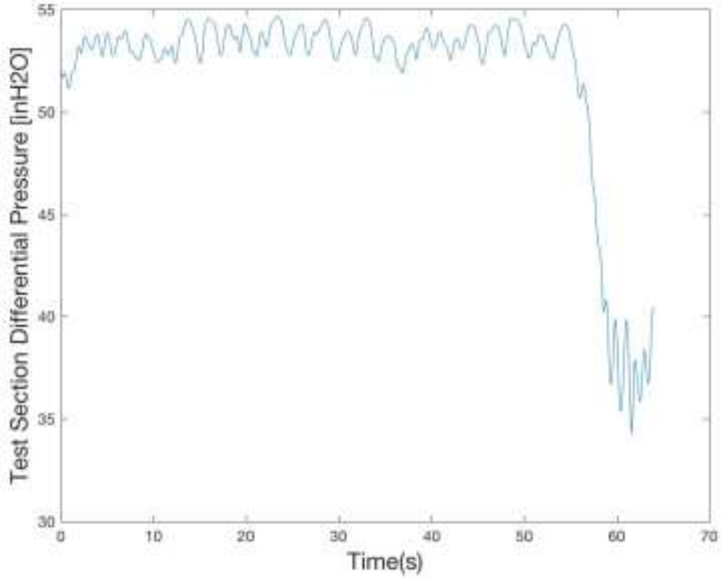

Figure G934: Test section differential pressure for test 2017_04_03_test_18.

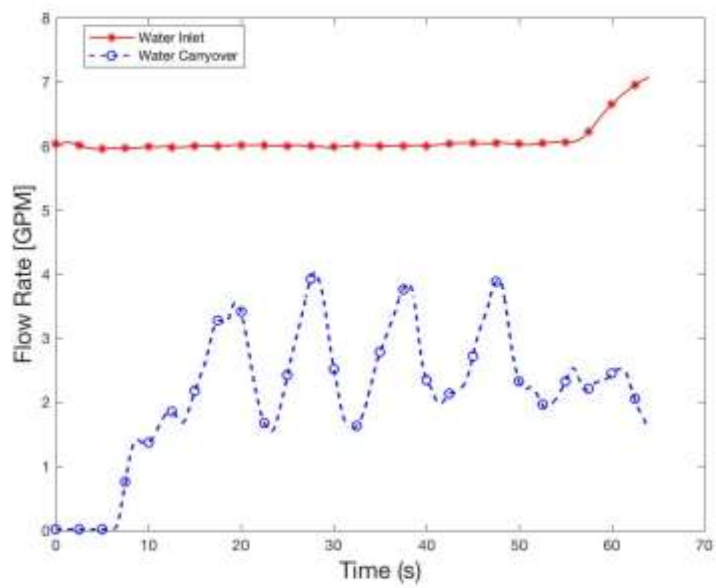

Figure G935: Water flow rates for test 2017_04_03_test_18.

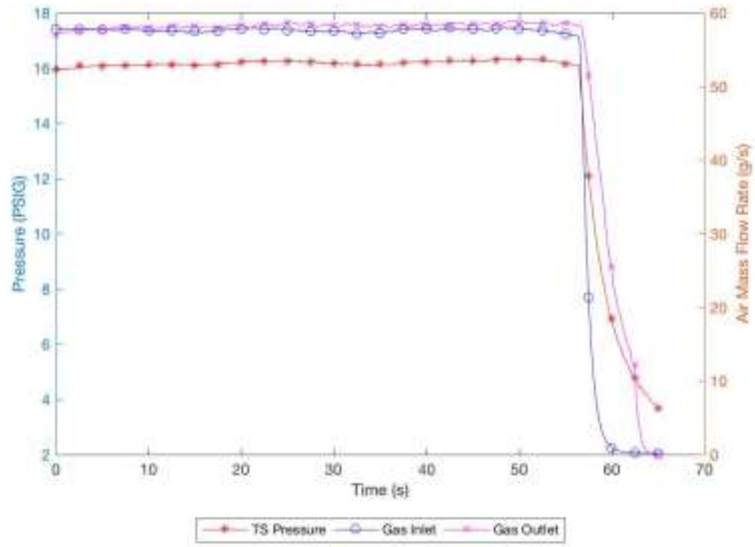

Figure G936: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_19.

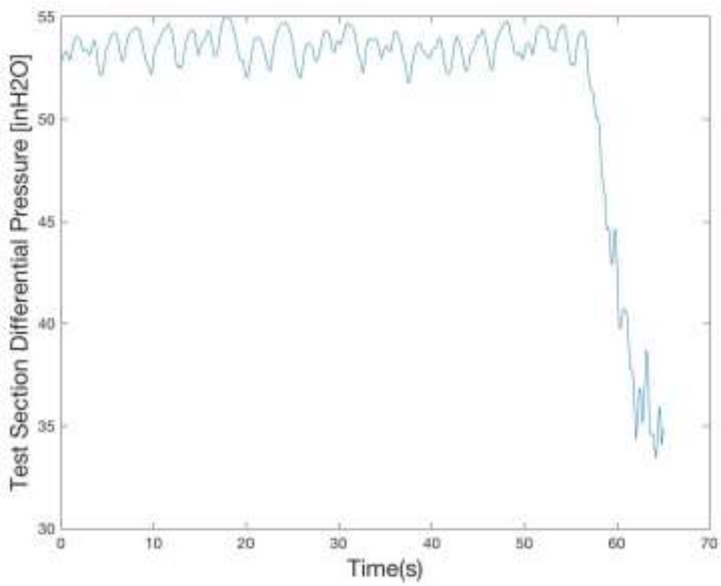

Figure G937: Test section differential pressure for test 2017_04_03_test_19.

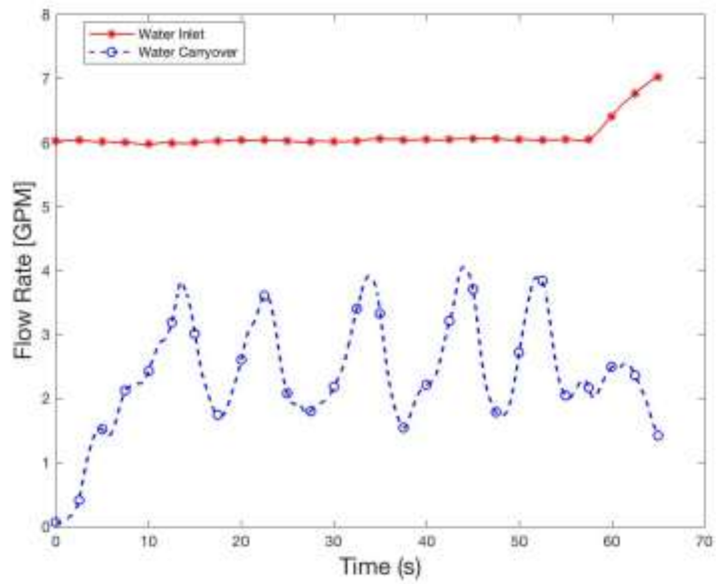

Figure G938: Water flow rates for test 2017_04_03_test_19.

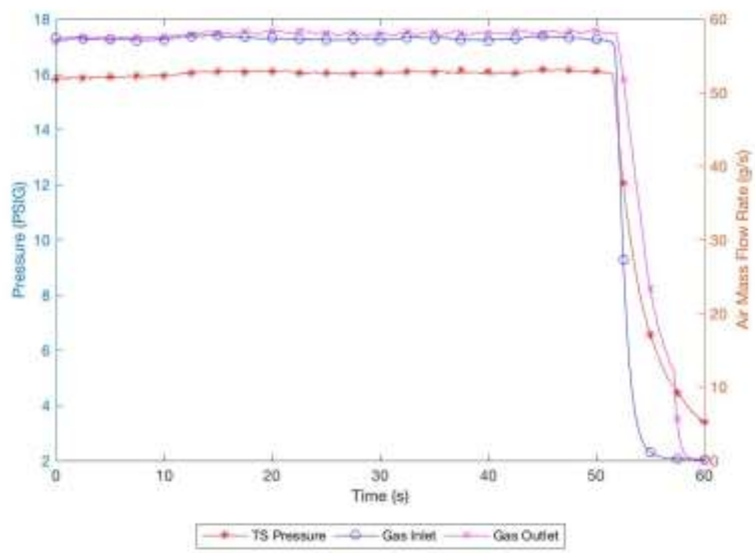

Figure G939: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_20.

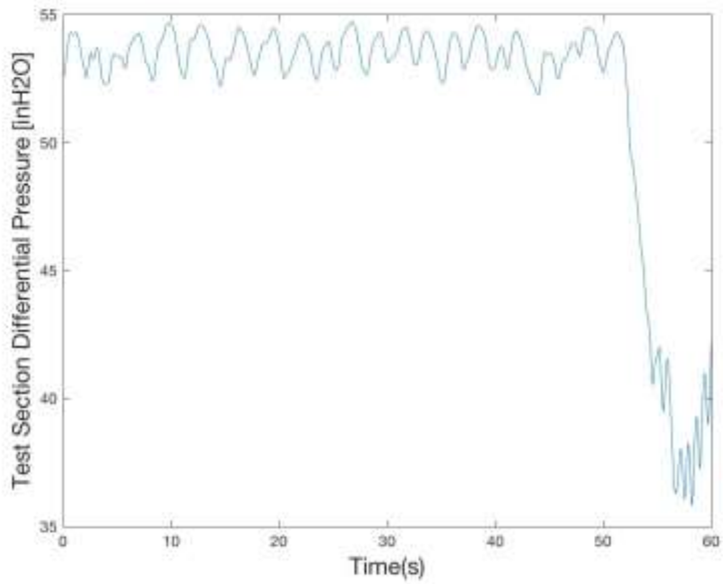

Figure G940: Test section differential pressure for test 2017_04_03_test_20.

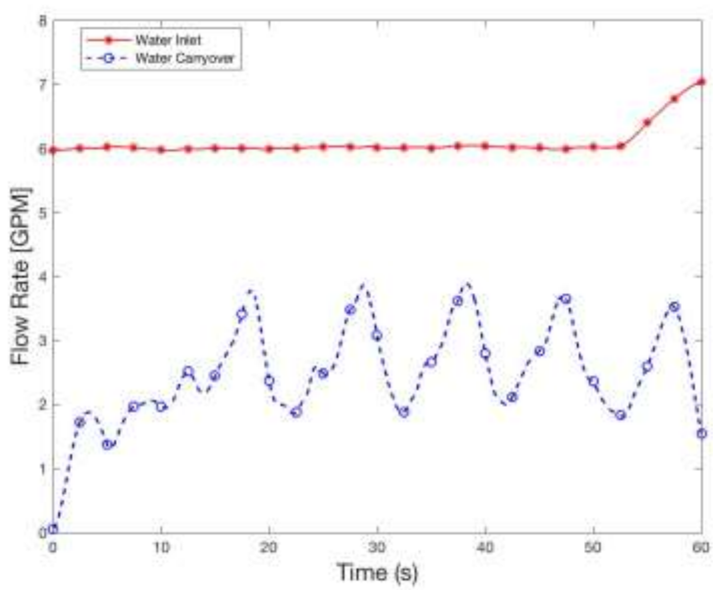

Figure G941: Water flow rates for test 2017_04_03_test_20.

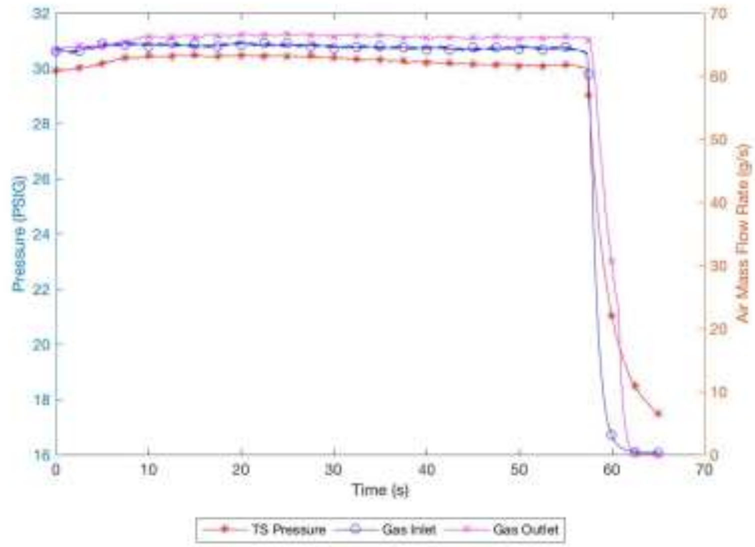

Figure G942: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_21.

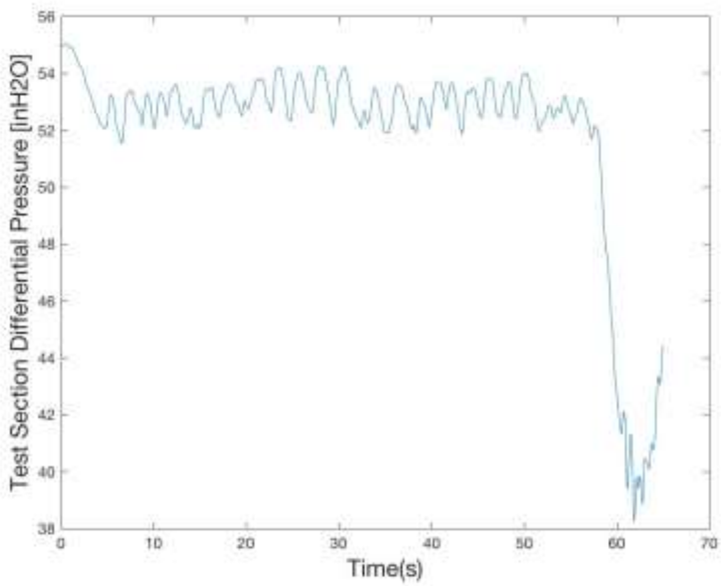

Figure G943: Test section differential pressure for test 2017_04_03_test_21.

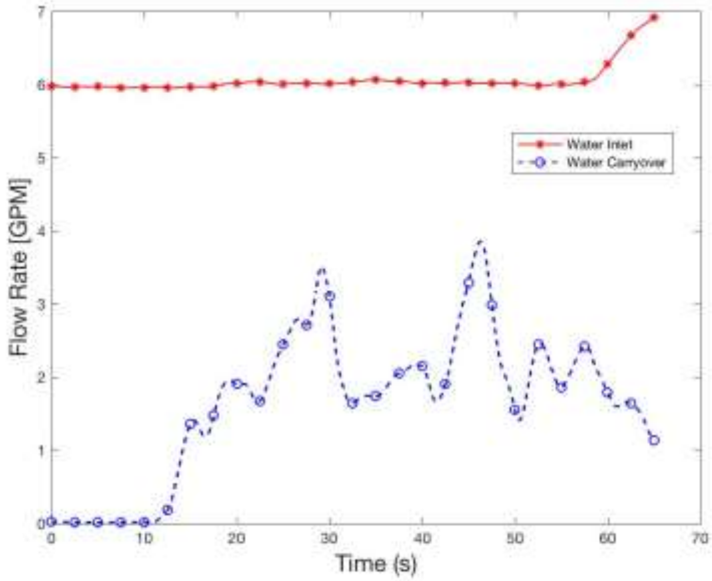

Figure G944: Water flow rates for test 2017_04_03_test_21.

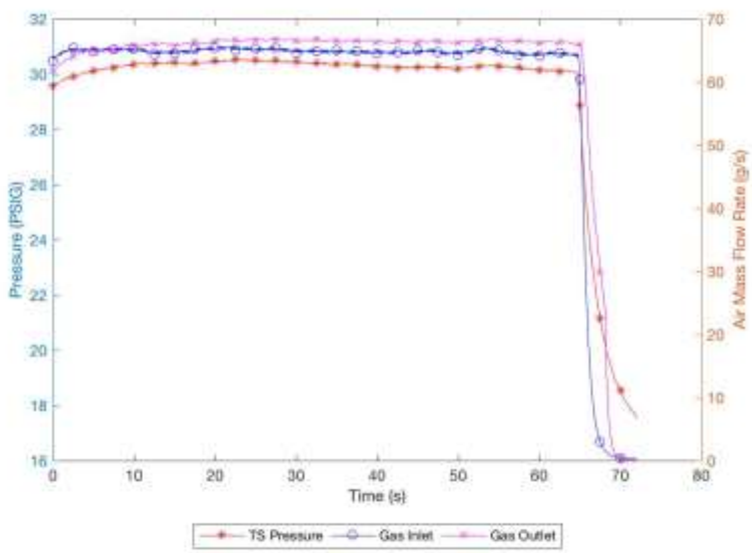

Figure G945: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_22.

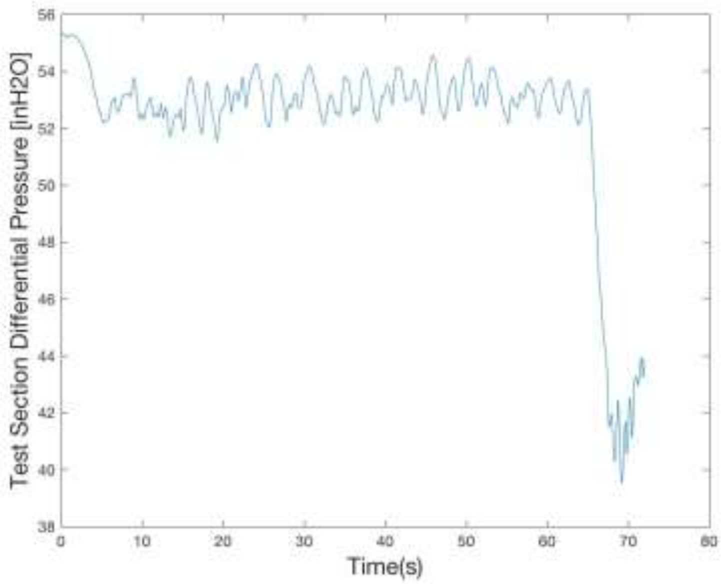

Figure G946: Test section differential pressure for test 2017_04_03_test_22.

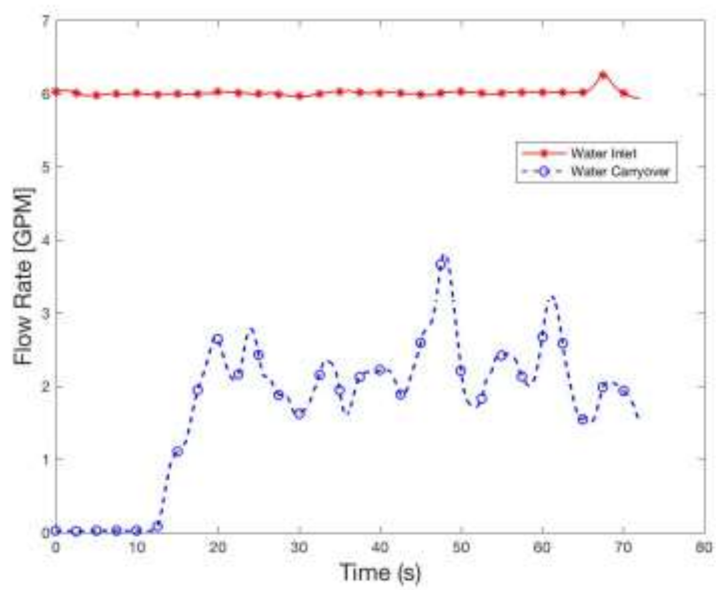

Figure G947: Water flow rates for test 2017_04_03_test_22.

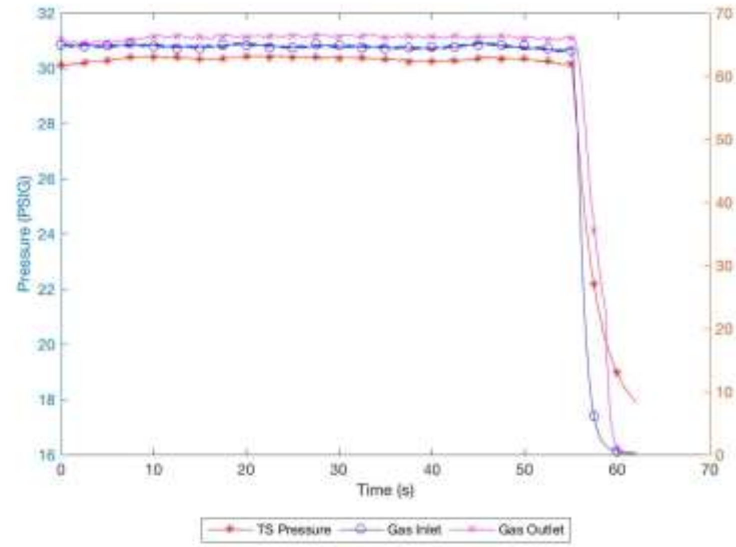

Figure G948: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_23.

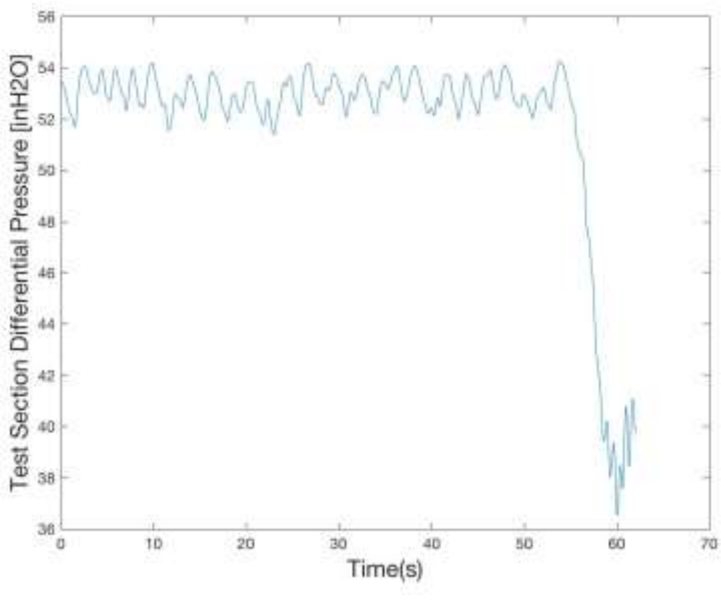

Figure G949: Test section differential pressure for test 2017_04_03_test_23.

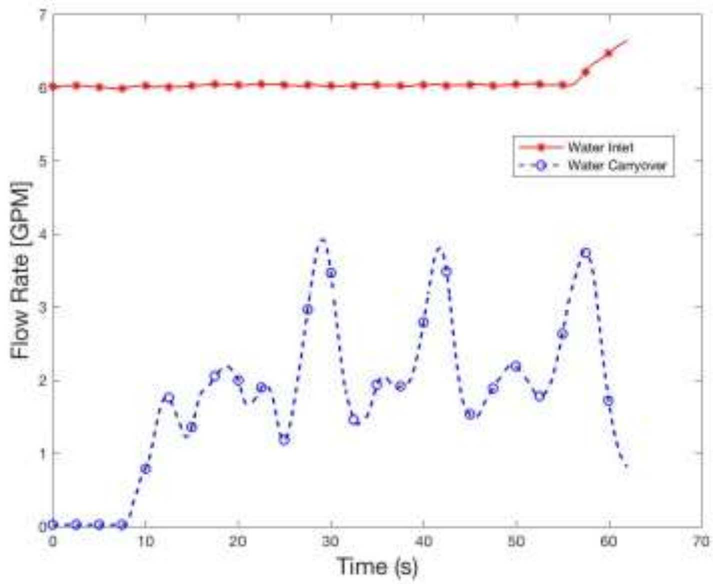

Figure G950: Water flow rates for test 2017_04_03_test_23.

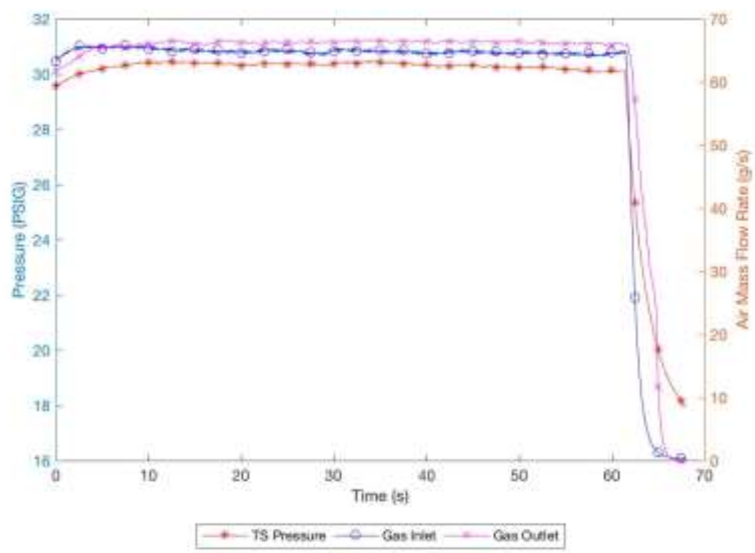

Figure G951: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_24.

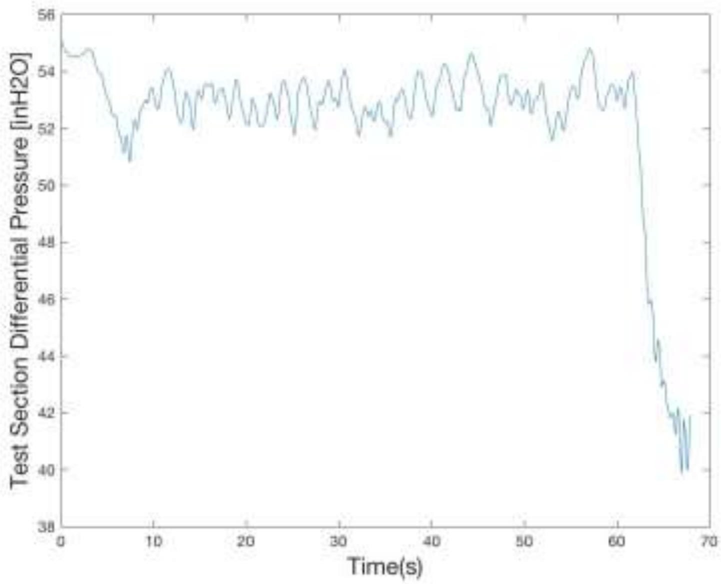

Figure G952: Test section differential pressure for test 2017_04_03_test_24.

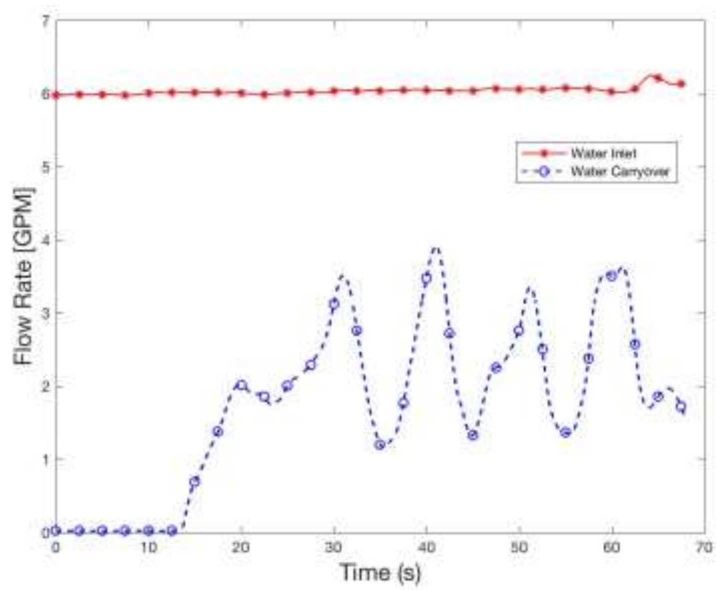

Figure G953: Water flow rates for test 2017_04_03_test_24.

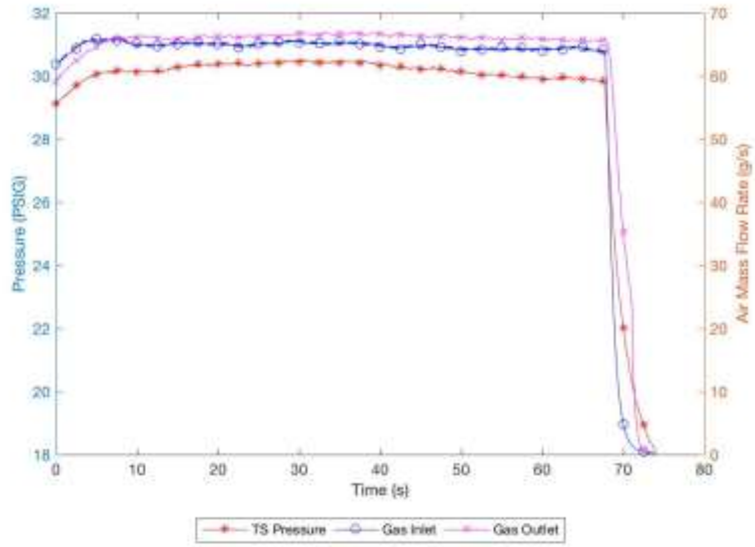

Figure G954: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_25.

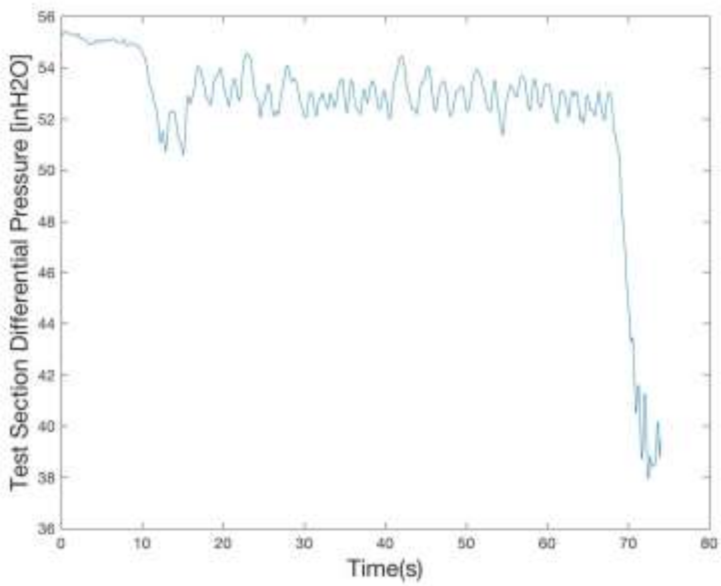

Figure G955: Test section differential pressure for test 2017_04_03_test_25.

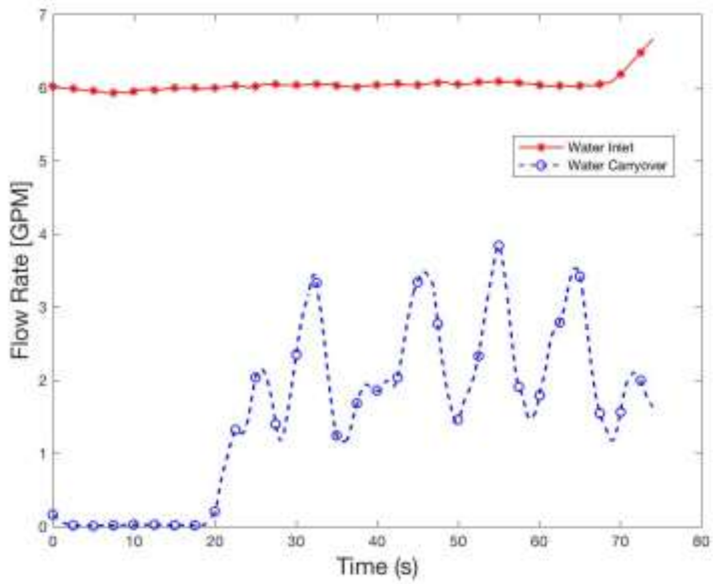

Figure G956: Water flow rates for test 2017_04_03_test_25.

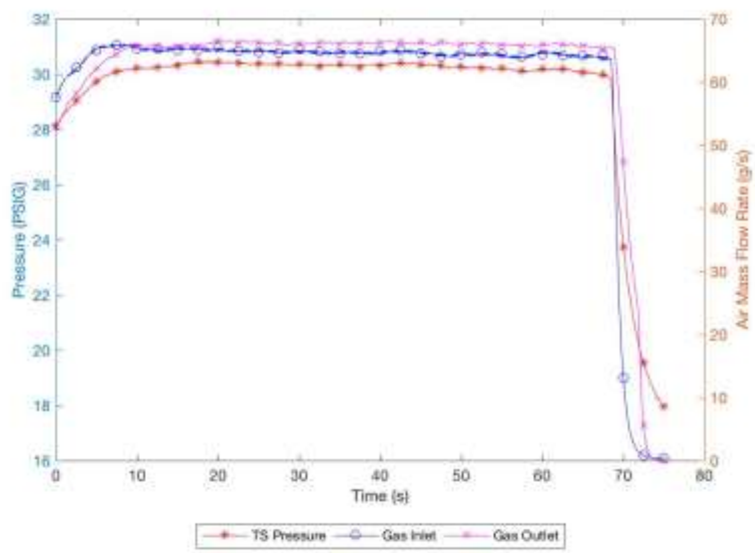

Figure G957: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_26.

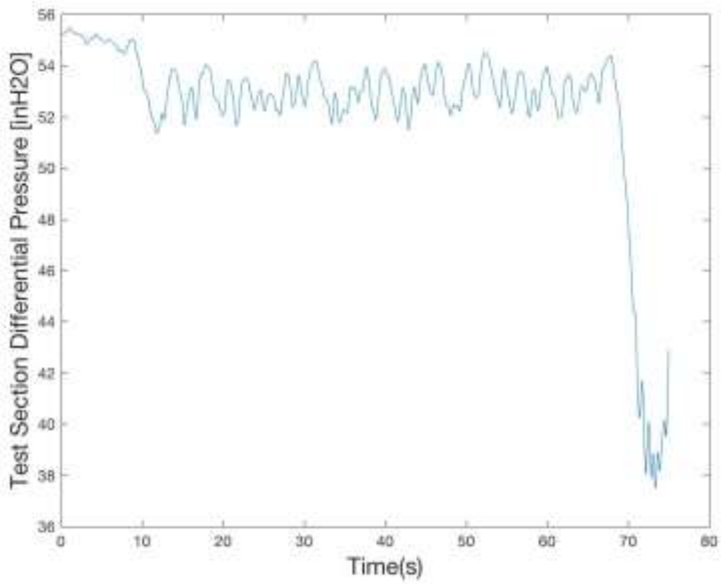

Figure G958: Test section differential pressure for test 2017_04_03_test_26.

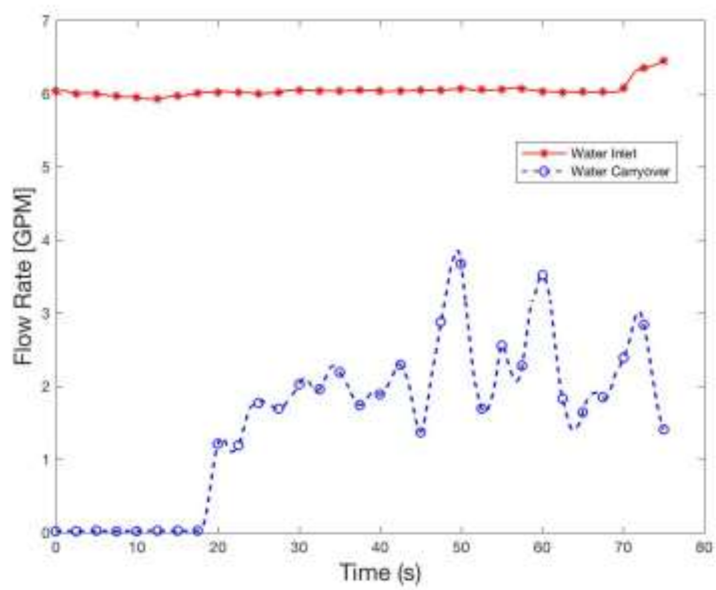

Figure G959: Water flow rates for test 2017_04_03_test_26.

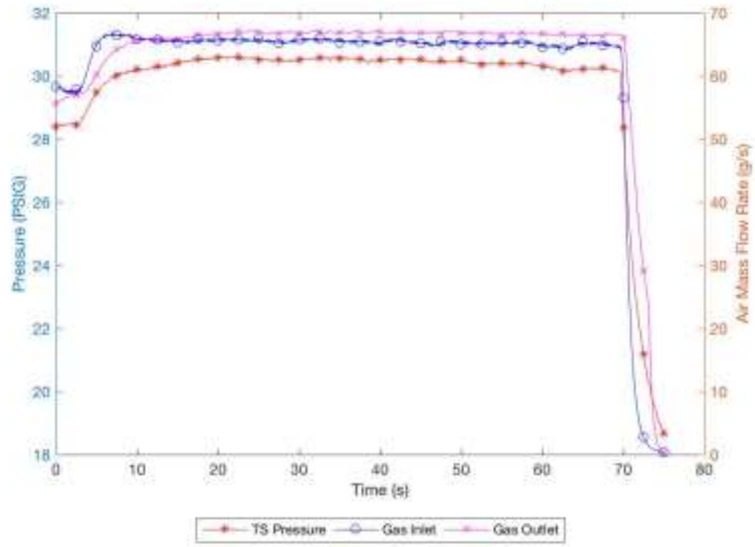

Figure G960: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_27.

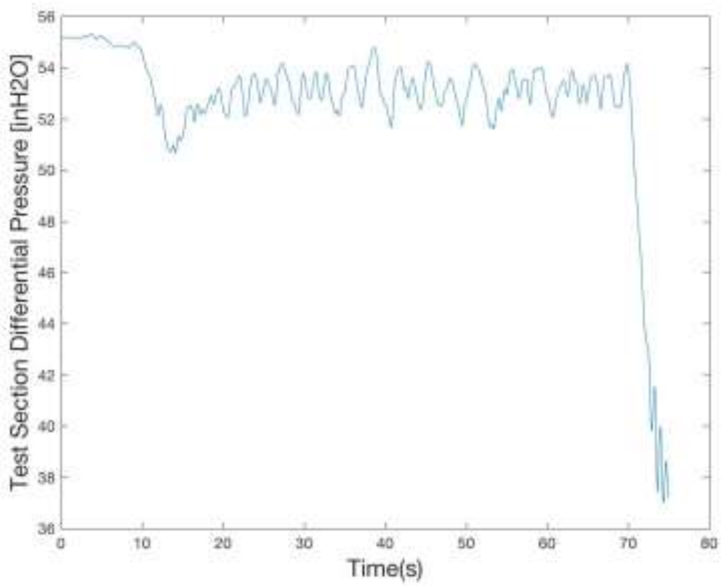

Figure G961: Test section differential pressure for test 2017_04_03_test_27.

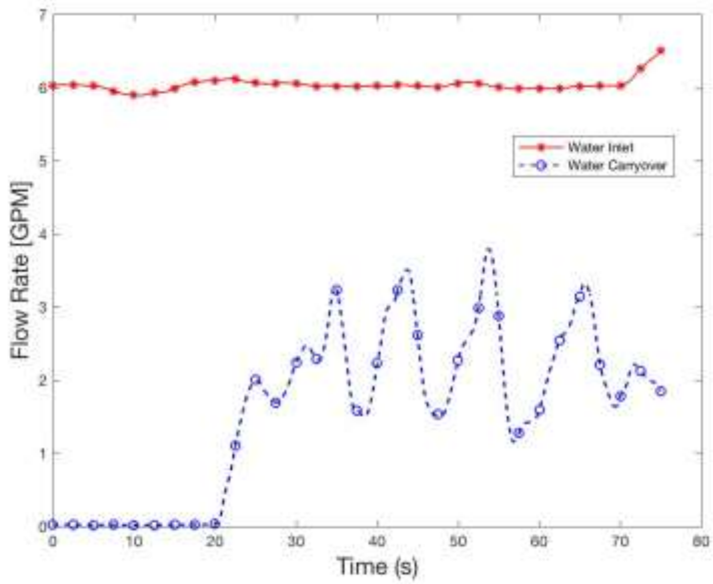

Figure G962: Water flow rates for test 2017_04_03_test_27.

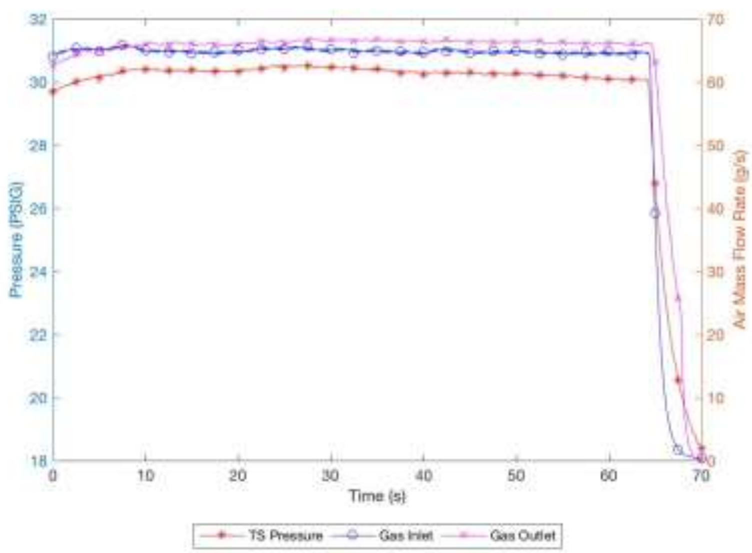

Figure G963: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_28.

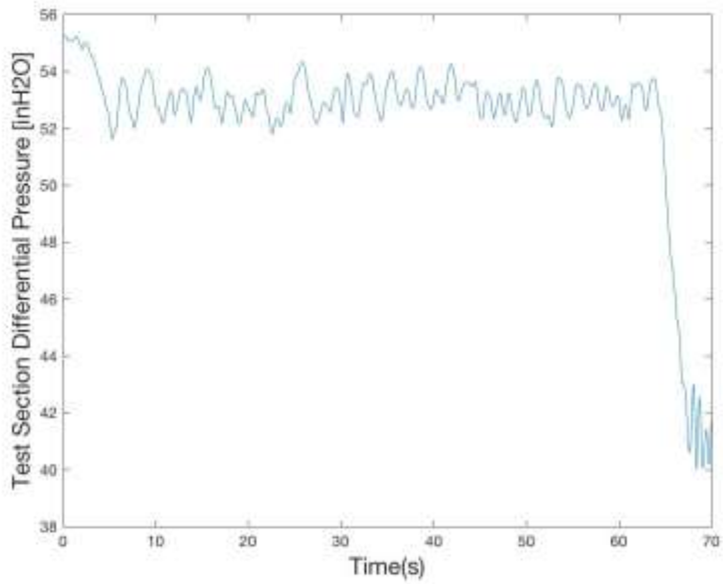

Figure G964: Test section differential pressure for test 2017_04_03_test_28.

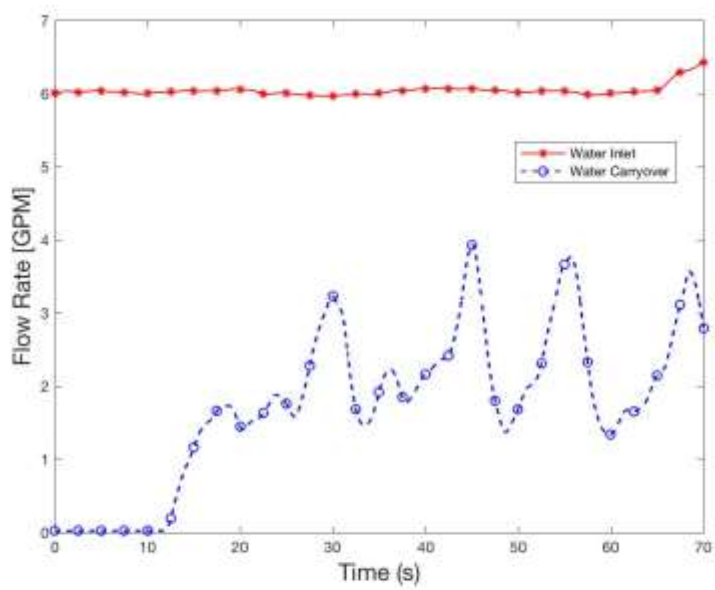

Figure G965: Water flow rates for test 2017_04_03_test_28.

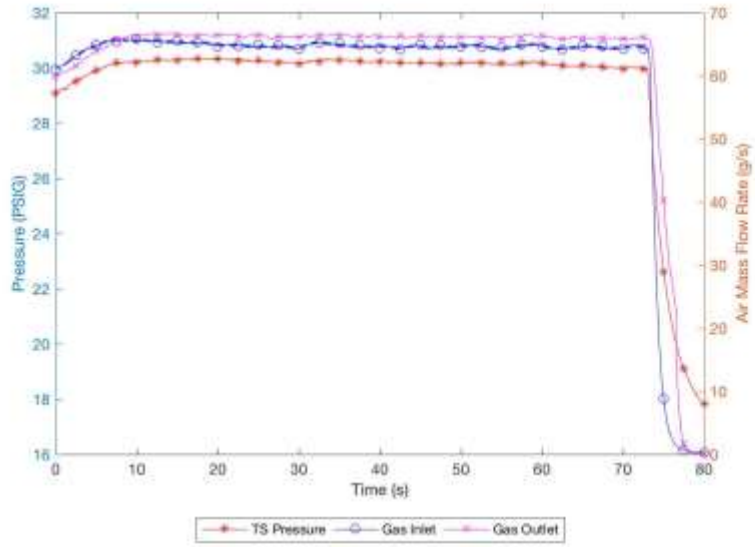

Figure G966: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_29.

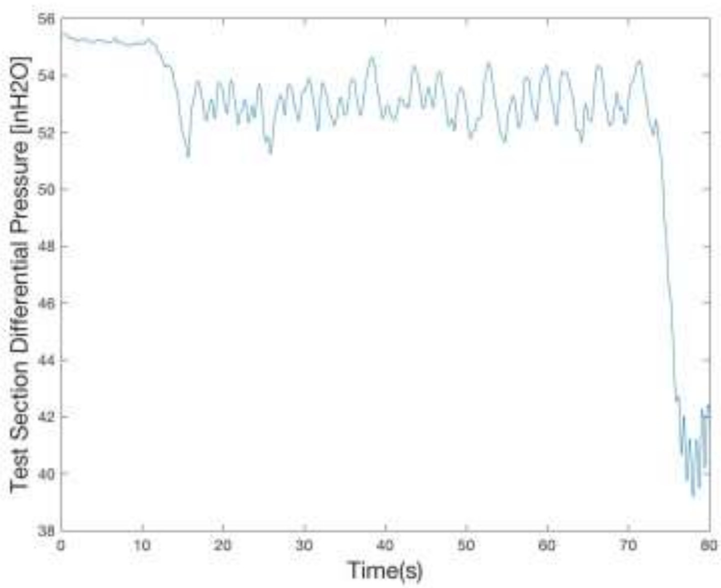

Figure G967: Test section differential pressure for test 2017_04_03_test_29.

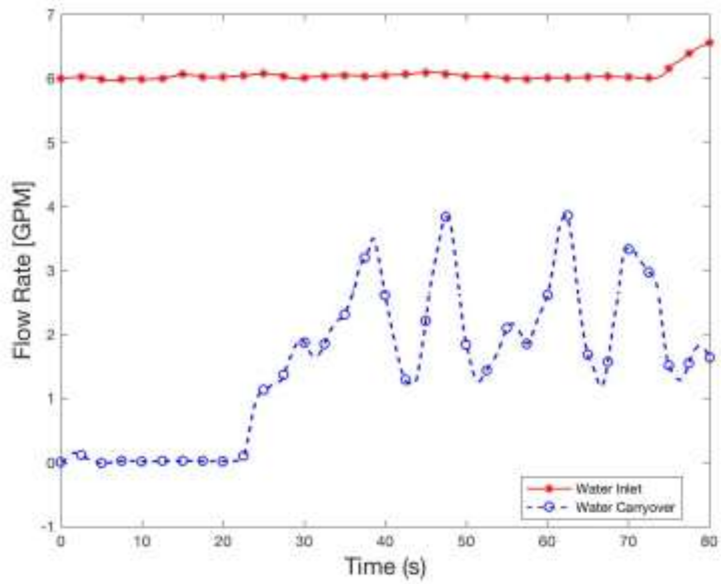

Figure G968: Water flow rates for test 2017_04_03_test_29.

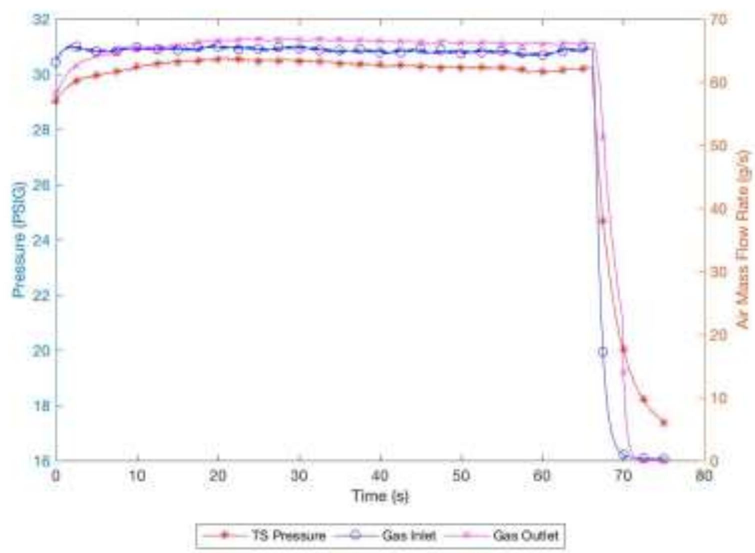

Figure G969: Pressure and gas inlet and outlet mass flow rates for test 2017_04_03_test_30.

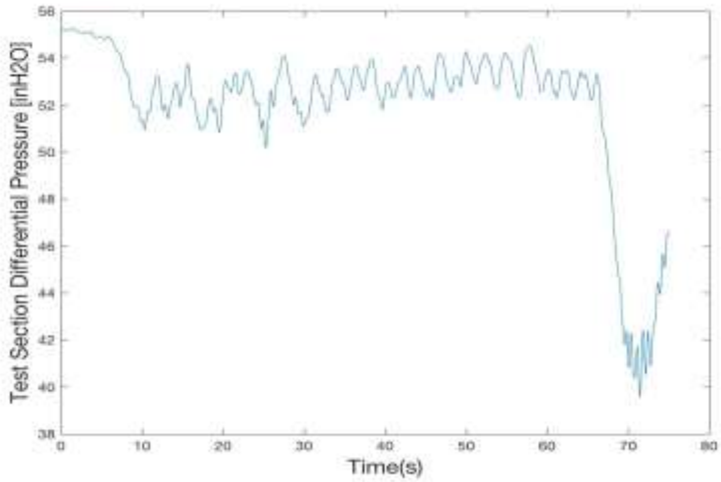

Figure G970: Test section differential pressure for test 2017_04_03_test_30.

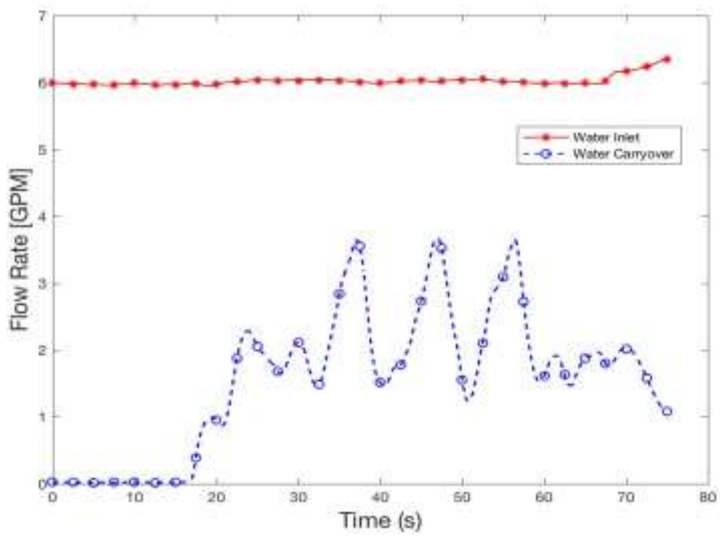

Figure G971: Water flow rates for test 2017_04_03_test_30.

APPENDIX H

MATLAB® SCRIPTS

This appendix includes the MATLAB® scripts used to locate the time defendant raw flooding data, average the raw time-dependent data, and plot the raw data. The MATLAB® scripts are modified from those created and used by Garza. The MATLAB® scripts used for steam/water and air/water are nearly identical, except select column numbers in the data matrices as water some information is not needed, only the steam scripts are only presented for steam/water.

H.1 Find Range Script

Below, is the script used to obtain and identify the times where flooding occurs.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% Find Test Range and Field of Study STEAM%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%The purpose of this script is to load steam
%test data and plot certain parameters as
%needed to be able to determine the test
%range and the field of study range

clc;
%clf(1);clf(2);  %This will guarantee that the graphs will clear if present, if not comment out
%to produce the first set of graphs

cvin=load('C:\Users\"filename".dat');

gasflowin=cvin(:,84)*10^3;     %Steam is 84 for [kg/s, for air this is 83 for [g/s]
gasflowout=cvin(:,92);   %[g/s]
tsdp=cvin(:,111);             %[in H2O]
tsabsp=cvin(:,101);           %[psia]
carryover=cvin(:,77);         %[GPM]
tsgp=tsabsp-14.6959494;       %[psig]
timeend=0.1*(length(gasflowout)-1);
```

```
time=0:0.1:timeend;
time=time';
input = 0;                  %places input matrix for next set of code

figure(1)
yyaxis left
plot(gasflowin)%plot one of the above parameters and manually manipulate
ylabel('Gas Flow In')
yyaxis right
plot(tsgp)
ylabel('TS P')

figure(2)
yyaxis left
plot(carryover)
ylabel('Carryover')
yyaxis right
plot(tsdp)
ylabel('TSDP')
```

H.2 Reducing Script

Below is the script used to batch process the time dependent flooding data into a single data point per test, by averaging the data over the time interval of flooding.

```
%This file takes the pertinent information in the .dat files for a given
 %folder and reduces (averages) the variables into a single data point over
 %the beginning and ending times selected from the previous script

 %Basic constants for test section
ts_d=0.0762; %Test Section Diameter [m]
ts_area=((ts_d/2)^2)*pi; %Test Section Flow Area [m^2]
g=9.81; %Constant for gravity [m/s^2]

%Initialize array, use the directory where your .dat files are located
my_files = dir('C:\Users\.....\*.dat');

[numoffiles, one] = size(my_files);
Final = zeros(numoffiles,36);

%Pull start and end times from input array! need to create
BFOS = input(:,1);
EFOS = input(:,2);
%loop iterating through each file in the folder. This will not skip files
%and need to be in consecutive order starting with 01,
%02,...,10,11,12,...,n
```

```
for k=1:numoffil
  disp(k);
  cvin = load(my_files(k).name);       %loads .dat file
  currentfile = my_files(k).name;
  %load specific columns for calculations
  TSDP=cvin(:,111);           %need to verify this had 110 [which is listed at sigma]/although not used in the
script
  T_fi=cvin(:,56);
  T_gi=cvin(:,28);
  T_go=cvin(:,50);
  T_satTS=cvin(:,102);
  T_wall=cvin(:,40);
  Q_fmagmi=cvin(:,72);
  Q_fc=cvin(:,77);
  mdot_gi=cvin(:,84);
  mdot_go=(cvin(:,92))*10^(-3);
  P_TSpsia=cvin(:,101);
  P_TSpsig=cvin(:,101)-14.6959494;
  rho_gi=cvin(:,82);
  rho_go=cvin(:,91);
  rho_fmagmi=cvin(:,73);

  SSP=BFOS(k);
  ESP=EFOS(k);

 %average variables to obtain single data points
  AvgT_fi=mean(T_fi(SSP:ESP));             %Temp of Water In [C]
  AvgT_gi=mean(T_gi(SSP:ESP));             %Temp of Gas In   [C]
  AvgT_go=mean(T_go(SSP:ESP));             %Temp of Gas Out  [C]
  AvgT_satTS=mean(T_satTS(SSP:ESP));       %Saturation Temp in TS [C]
  AvgT_wall=mean(T_wall(SSP:ESP));         %Temp of wall [C]
  AvgQ_fmagmi=mean(Q_fmagmi(SSP:ESP));     %Water In Flow Rate at Mag Meter[GPM]
  AvgQ_fc=mean(Q_fc(SSP:ESP));             %Water carryover flow rate [GPM]
  Avgmdot_gi=mean(mdot_gi(SSP:ESP));       %Mass flow rate of gas in [kg/s]
  Avgmdot_go=mean(mdot_go(SSP:ESP));       %Mass flow rate of gas out [kg/s]
  AvgP_TSpsia=mean(P_TSpsia(SSP:ESP));     %Pressure in TS [psia]
  AvgP_TSpsig=mean(P_TSpsig(SSP:ESP));     %Pressure in TS [psig]
  Avgrho_gi=mean(rho_gi(SSP:ESP));         %Density of gas in [kg/m^3]
  Avgrho_go=mean(rho_go(SSP:ESP));         %Density of gas out [kg/m^3]
  Avgrho_fmagmi=mean(rho_fmagmi(SSP:ESP)); %Density of water in at mag flow meter [kg/m^3]

  AvgP_TSbar=(AvgP_TSpsia)/(14.5037738007); %Average Pressure of TS in bar
   %Use XSteam to look up necessary gas and liquid parameters
  Avgsigma_f=XSteam('st_T',AvgT_fi); %Average surface tension of water in TS [N/m]
  Cp=XSteam('Cp_pT',AvgP_TSbar,AvgT_fi); %Specific isobaric heat capacity of water in TS [kJ/(kg C)]
  h_sti=XSteam('h_pT',AvgP_TSbar,AvgT_gi); %Enthalpy of steam entering TS [kJ/kg]
  h_sto=XSteam('h_pT',AvgP_TSbar,AvgT_go); %Enthalpy of steam exiting TS [kJ/kg]
  h_f=XSteam('h_pt',AvgP_TSbar,AvgT_fi); %Enthalpy of water entering TS [kJ/kg]
```

```
%Changed this to AvgQ_fmagmi: Ideally this should not change as the only
%exit for this is through the test section (ie mass conservation)
%The issue that is causing the large AvgQ_fi is from Avgrho
Avgrho_f= Avgrho_fmagmi; %Changes rho to that at mag meter

%Calculates the actual volumetric flow rate of water going into the test
%section accounting for the density change from the water going through
%the inlet water heater.
AvgQ_fi=(AvgQ_fmagmi*Avgrho_fmagmi)/(Avgrho_f); %Average Water In flow rate [GPM]

%Calculates the volumetric flow rate of the water going down the tube by
%subtracting the avg water carryover from the average water in. This
%assumes that the density of the water doesn't change much from entering
%and exiting the test section.
AvgQ_fd=AvgQ_fi-AvgQ_fc; %Average water down flow rate [GPM]

%Calculate the superficial velocities for the inlet gas outlet gas and
%water falling down the test section.

Avgj_gi=(Avgmdot_gi)/(Avgrho_gi*ts_area); %Superficial Velocity of gas entering TS [m/s]
Avgj_go=(Avgmdot_go)/(Avgrho_go*ts_area); %Superficial Velocity of gas leaving TS [m/s]
Avgj_fd=(AvgQ_fd*(0.00006309))/(ts_area); %Superficial Velocity of water falling down test section
[m/s]
Avgj_fi=(AvgQ_fi*(0.00006309))/(ts_area);
Avgj_fc=(AvgQ_fc*(0.00006309))/(ts_area);
%Calculate the kutateladze parameter for gas in, gas out, and water down.
%Kutateladze Parameter of Gas In to test section [unitless]
K_gi=(((Avgrho_gi)^(1/2))*(Avgj_gi))/(g*Avgsigma_f*(Avgrho_f-Avgrho_gi))^(1/4);
%Kutateladze Parameter of Gas Out of test section [unitless]
K_go=(((Avgrho_go)^(1/2))*(Avgj_go))/(g*Avgsigma_f*(Avgrho_f-Avgrho_go))^(1/4);
%Kutateladze Parameter of water down test section [unitless]
K_fd=(((Avgrho_f)^(1/2))*(Avgj_fd))/(g*Avgsigma_f*(Avgrho_f-Avgrho_gi))^(1/4);

K_fi=(((Avgrho_f)^(1/2))*(Avgj_fi))/(g*Avgsigma_f*(Avgrho_f-Avgrho_gi))^(1/4);
K_fc=(((Avgrho_f)^(1/2))*(Avgj_fc))/(g*Avgsigma_f*(Avgrho_f-Avgrho_gi))^(1/4);
%Calculate the square root of the Kutateladze parameters as that is how
%they will be plotted.
K_gisqr=sqrt(K_gi);
K_gosqr=sqrt(K_go);
K_fdsqr=sqrt(K_fd);
K_fisqr=sqrt(K_fi);
K_fcsqr=sqrt(K_fc);

k_fc_over_k_fi=(K_fcsqr)/(K_fisqr);
k_fi_over_k_fc=(K_fisqr)/(K_fcsqr);

%Set the values in a final array that can be used for plotting
```

```
  %or recording
  Final(k,1)=AvgP_TSpsig;
  Final(k,2)=AvgT_fi;
  Final(k,3)=AvgT_gi;
  Final(k,4)=AvgT_go;
  Final(k,5)=AvgT_satTS;
  Final(k,8)=K_gisqr;
  Final(k,9)=K_fdsqr;
  Final(k,10)=AvgT_wall;
  Final(k,11)=AvgQ_fmagmi;
  Final(k,12)=AvgQ_fi;
  Final(k,13)=AvgQ_fc;
  Final(k,14)=AvgQ_fd;
  Final(k,16)=Avgmdot_gi;
  Final(k,17)=Avgmdot_go;
  Final(k,18)=Avgrho_f;
  Final(k,19)=Avgrho_fmagmi;
  Final(k,20)=Avgrho_gi;
  Final(k,21)=Avgrho_go;
  Final(k,22)=Avgsigma_f;
  Final(k,23)=Avgj_gi;
  Final(k,24)=Avgj_go;
  Final(k,25)=Avgj_fd;
  Final(k,26)=Cp;
  Final(k,27)=h_sti;
  Final(k,28)=h_sto;
  Final(k,29)=h_f;
  Final(k,30)=K_gi;
  Final(k,31)=K_go;
  Final(k,32)=K_fd;
  Final(k,33)=K_gosqr;
%   Final(k,31)=f_i_williams;
%   Final(k,32)=f_o_williams;
%   Final(k,33)=K_ge_i;
%   Final(k,34)=K_ge_isqr;
%   Final(k,35)=K_ge_o;
%   Final(k,36)=K_ge_osqr;
  Final(k,52)=K_fi;
  Final(k,53)=K_fc;
  Final(k,54)=K_fisqr;
  Final(k,55)=K_fcsqr;
  Final(k,56)=k_fc_over_k_fi;
  Final(k,57)=k_fi_over_k_fc;
  Final(k,58)=std(P_TSpsig(SSP:ESP));
  Final(k,59)=std(mdot_gi(SSP:ESP));
  Final(k,61)=std(Q_fmagmi(SSP:ESP));

end
```

H.3 Graphing Script

Below is the script used to graph the raw data.

```
% initialize the cell array
my_files = dir('C:\...\*.dat'); % structure containing your *.dat files
[numoffiles one]=size(my_files);
Final=zeros(numoffiles,36);
numoffiles
TS_D=0.0762; %Test Section Diameter [m]
TS_Area=((TS_D/2)^2)*pi; %Test Section Flow Area [m^2]
g=9.81; %Constant for gravity [m/s^2]
%Loop to load data and make calculations
fontsize=16;
legendfontsize=12;
for k=1:numoffiles
  k
  cvin= load(my_files(k).name); % load .dat file recursively
  CurrentFile=my_files(k).name
  testdateandname=regexp(my_files(k) .name, '\w*test\w*', 'match');
  fileID=testdateandname(1);

  %Pull specific parameters that need to be plotted from the dat files.
  TSDP=cvin(:,111);
  TSDPfulltest=TSDP(SOT(k):EOT(k));
  TSDPtrimmedplot=TSDP(BFOS(k):EFOS(k));
  T_fi=cvin(:,56);
  T_fi_ft=T_fi(SOT(k):EOT(k));
  T_fi_tp=T_fi(BFOS(k):EFOS(k));
  T_gi=cvin(:,28);
  T_gi_ft=T_gi(SOT(k):EOT(k));
  T_gi_tp=T_gi(BFOS(k):EFOS(k));
  T_go=cvin(:,50);
  T_go_ft=T_go(SOT(k):EOT(k));
  T_go_tp=T_go(BFOS(k):EFOS(k));
  T_satTS=cvin(:,102);
  T_satTS_ft=T_satTS(SOT(k):EOT(k));
  T_satTS_tp=T_satTS(BFOS(k):EFOS(k));
  Q_fmagmi=cvin(:,72);
  Q_fmagmi_ft=Q_fmagmi(SOT(k):EOT(k));
  Q_fmagmi_tp=Q_fmagmi(BFOS(k):EFOS(k));
  Q_fc=cvin(:,77);
  Q_fc_ft=Q_fc(SOT(k):EOT(k));
```

```
Q_fc_tp=Q_fc(BFOS(k):EFOS(k));
mdot_gi=cvin(:,84)*10^3;
mdot_gi_ft=mdot_gi(SOT(k):EOT(k));
mdot_gi_tp=mdot_gi(BFOS(k):EFOS(k));
mdot_go=(cvin(:,92));
mdot_go_ft=mdot_go(SOT(k):EOT(k));
mdot_go_tp=mdot_go(BFOS(k):EFOS(k));
P_TSpsig=cvin(:,101)-14.6959494;
P_TSpsig_ft=P_TSpsig(SOT(k):EOT(k));
P_TSpsig_tp=P_TSpsig(BFOS(k):EFOS(k));
Q_fd=Q_fmagmi-Q_fc;
Q_fd_ft=Q_fd(SOT(k):EOT(k));
Q_fd_tp=Q_fd(BFOS(k):EFOS(k));
SOTtime=SOT(k)/10;
EOTtime=EOT(k)/10;
BFOStime=BFOS(k)/10;
EFOStime=EFOS(k)/10;
time=0:0.1:EOTtime-SOTtime;
trimmedtime=BFOStime-SOTtime:0.1:(EFOStime-SOTtime);
time=time';
trimmedtime=trimmedtime';
%Set the name for the specific plots to change with each test.
nameTSDP=char(strcat(fileID, '_TSDP.jpg'));
nameTemps=char(strcat(fileID, '_Temps.jpg'));
nameWaterFlow=char(strcat(fileID, '_waterflow.jpg'));
namePandGasIn=char(strcat(fileID, '_PandGasIn.jpg'));


%TSDP Plots

  TSDPplot=plot(time,TSDPfulltest);
  xlabel('Time(s)', 'fontsize', fontsize);
  ylabel('Test Section Differential Pressure [inH2O]', 'fontsize', fontsize);
  print('-djpeg', nameTSDP);

  clf('reset'); %clears figure of all data

%Temps Plots

  plot(time,T_fi_ft,'r','LineWidth',1);
  hold on;
   plot(time(1:25:end),T_fi_ft(1:25:end),'r*','LineWidth',1);
   p1=plot(time(1),T_fi_ft(1),'-r*','LineWidth',1);
  plot(time,T_satTS_ft,'b','LineWidth',1);
   plot(time(1:25:end),T_satTS_ft(1:25:end),'bo','LineWidth',1);
   p2=plot(time(1),T_satTS_ft(1),'-bo','LineWidth',1);
  plot(time,T_gi_ft,'m','LineWidth',1);
   plot(time(1:25:end),T_gi_ft(1:25:end),'mx','LineWidth',1);
```

```
 p3=plot(time(1),T_gi_ft(1),'-mx','LineWidth',1);
legend([p1,p2,p3], 'Liquid Inlet Temp.', 'TS Saturation Temp.','Gas Inlet Temp','Location','Best');
xlabel('Time(s)','fontsize',fontsize);
ylabel('Temperature (C)','fontsize',fontsize);
hold off;
print('-djpeg', nameTemps);

clf('reset'); %clears figure of all data

%Water Flow Rate Plots
    plot(time,Q_fmagmi_ft,'r','LineWidth',1);
  hold on;
   plot(time(1:25:end),Q_fmagmi_ft(1:25:end),'r*','LineWidth',1);
   p1=plot(time(1),Q_fmagmi_ft(1),'-r*','LineWidth',1);
  plot(time,Q_fc_ft,'b','LineWidth',1);
   plot(time(1:25:end),Q_fc_ft(1:25:end),'bo','LineWidth',1);
   p2=plot(time(1),Q_fc_ft(1),'-bo','LineWidth',1);
  hold off;
  xlabel('Time (s)','fontsize',fontsize);
  ylabel('Flow Rate [GPM]','fontsize', fontsize);
  legend([p1,p2],'Water Inlet','Water Carryover','Location','Best');
  print('-djpeg',nameWaterFlow);

  clf('reset'); %clears figure of all data

% Pressure and Gas Flow Rate Plots
  yyaxis left
    plot (time, P_TSpsig_ft,'r');
    hold on;
     plot (time(1:25:end), P_TSpsig_ft(1:25:end),'r*');
     p1=plot (time(1), P_TSpsig_ft(1),'-r*');
    xlabel('Time (s)')
    ylabel('Pressure (PSIG)')

   yyaxis right
    plot (time, mdot_gi_ft, 'b');
     plot (time(1:25:end), mdot_gi_ft(1:25:end), 'bo')
     p2=plot (time(1), mdot_gi_ft(1), '-bo')
    plot (time, mdot_go_ft, 'm')
     plot (time(1:25:end), mdot_go_ft(1:25:end), 'mx')
     p3=plot (time(1), mdot_go_ft(1), '-mx')
    ylabel('Air Mass Flow Rate (g/s)')
    legend([p1,p2,p3],'TS Pressure','Gas Inlet','Gas Outlet')
    legend([p1,p2,p3],'location','southoutside','Orientation','horizontal')
    hold off;
    print('-djpeg', namePandGasIn);

    clf('reset');
```

```
end
```

APPENDIX I

EXPERIMENTAL INSTRUMENTATION

Below, in Table 6, location, manufacturer, model, range, and accuracy of the instrumentation used for this study. As no new instruments were used all information contained in the table was collected by Wynne and originally presented in the Wynne thesis ranges and accuracy information were obtained from manufacture manuals [6]. The table has been updated to address formatting, visual issues, and update all units to a unified format.

Table 6: Instrumentation used in the flooding facility reprinted and updated from Wynne [6].

Instrument	Location	Manufacturer/Model	Range	Accuracy
Thermocouple	Throughout Facility	Omega/Type T	-250 -350℃	0.5℃
Absolute Pressure Transmitter	Gas Inlet	Honeywell/ST3000ST A940	0-115 psig	0.1% Span
Absolute Pressure Transmitter	Gas Outlet	Honeywell/ST3000ST A940	0-85 psig	0.1% Span
Absolute Pressure Transmitter	Steam Generator	Honeywell/ST3000ST A940	0-135 psig	0.1% Span
Absolute Pressure Transmitter	Test Section	Keller/Valueline	0-135 psig	0.1% Span
Differential Pressure Transmitter	Steam Generator Level	Honeywell/ST3000ST D924	0-110 inH_2O	0.075% Span
Differential Pressure Transmitter	Water Supply/RCIC Tank Level	Honeywell/ST3000ST D924	0-80 inH_2O	0.075% Span
Differential Pressure Transmitter	Test Section	Honeywell/ST3000ST D924	0-100 inH_2O	0.075% Span
Differential Pressure Transmitter	Hold Up Tank Level	Rosemount/3051S	0-25 inH_2O	0.035% Span
Gauge Pressure Transmitter	Hold Up Tank	Dwyer/673-7	0-100 psig	0.25% Span
Gauge Pressure Transmitter	Water Supply/RCIC Tank	Dwyer/673-7	0-100 psig	0.25% Span
Gauge Pressure Transmitter	Water Inlet	Dwyer/673-7	0-100 psig	0.25% Span
Vortex Flow Meter	Gas Inlet	Foxboro/Model 83W-A	0-2400 Hz	1% Value
Vortex Flow Meter	Gas Outlet	Foxboro Model 84F	0-140 CFM	1% Value
Magnetic Flow Meter	Water Inlet	Azbil/MagneW 3000 Plus	0-20 GPM	0.5% Value
Magnetic Flow Meter	Water Carryover	Azbil/MagneW 3000 Plus	0-10 GPM	0.5% Value
Hygrometer	Secondary Gas Side	Dwyer/HHT	0-100% RH	2% Value