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A NOVEL TWO-PHASE GAS\LIQUID SLUG FLOW MEASUREMENT SYSTEM USING A T-JUNCTION SEPARATOR AND ULTRASONIC MEASUREMENTS

Khalifa M. Khalifa and Mike L. Sanderson
Cranfield University
Cranfield MK43 0AL, Bedfordshire, UK

ABSTRACT

Over the last decade, the development and deployment of in-line multiphase flow metering systems has been a major focus worldwide. Accurate measurement of multiphase flow in the oil and gas industry is difficult because it occurs in wide range of flow regimes and multiphase meters do not generally perform well under the intermittent slug flow conditions which commonly occur in oil production.

A novel ultrasonic multiphase metering concept has been proposed and investigated which measures the flow rates of the liquid and gas phases from ultrasonic measurements made in two different flow regimes – partially separated and homogeneous - in the same measurement system and fuses the data from the different flow regimes to obtain improved overall measurement accuracy. The system employs a partial gas/liquid separation using a T-junction configuration and a combination of Doppler and cross correlation. The partially separated flow regimes uses ultrasonic cross correlation measurement for the liquid flow measurement which has gas entrained within it. The homogeneous regime employs ultrasonic Doppler method.

This approach has been tested on water/air flows on a 50mm facility in the Department of Process and Systems Engineering. The liquid and gas flowrate measurements using the proposed techniques were compared with a reference measurement and good agreements between these two measurements were obtained with error ranging from ± 2 % and 10%, respectively. Such a performance offers the potential for an in-line multiphase flowmeter with improved performance.

Keywords: (slug flow, mixture flowrate, T-junction separation, ultrasonic Doppler and ultrasonic cross-correlation).

1. INTRODUCTION

The measurement of multiphase flows of oil/water/gas is a critical element of oil exploration and production processes. Nevertheless, an accurate measurement of multiphase slug flow is still far way from fulfilling this industry development needs. The conventional separating methods of measuring a multiphase flow using in oil and gas industry are still very costly, time consuming and involved bulky equipment when the purpose of measurement is to monitor, control and test the oil and gas production field. However, this method is still ideal when the purpose of separation is for fiscal measurement. As a result in-line measurement using accurate multi-phase flow meters are emerging employing partial separation, homogenization and pattern recognition. These methods can also be used in volume allocations for companies producing from the same reservoir or injecting into the same pipeline.

1. .TWO-PHASE FLOW IDENTIFICATION

Multiphase flow is where more than one phase or component exists in a flow; this can be liquid/liquid such as water/oil, or liquid/gas such as oil, gas, water or solid/liquid such as sand/oil/water or all the phases are existed together in a pipeline as gas/oil/water/sand. There is no specific method to identify two phase flow regimes in a pipeline. However, several methods have been used to gather accurate information that can reflect the true flow regimes. These methods are as the following:

- Direct methods. It is based on directly identify the flow regime, these methods such as visual inspection, the high speed photography and attenuation system.
- Indirect methods, these methods are illustrated in statistical analyses of measured signals, which can reflect the fluctuant characteristic of two phase flows, and flow regimes are identified as a result.[1]

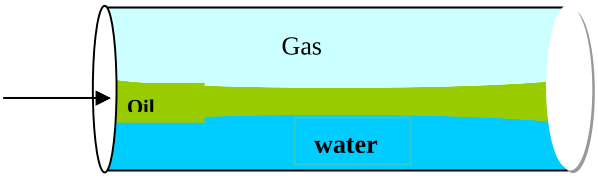

FIGURE 1, MULTI-PHASE FLOW IN A HORIZONTAL PIPE ADOPTED FROM BABELI (2002)[2]

Moreover, there are several patterns for multiphase flow occurs in a horizontal pipe line, such as, stratified smooth or wavy flow, annular mist flow, bubble flow, slug flow, and dispersed flow.[3]

2. THE USED MEASUREMENT TECHNIQUES

The used ultrasonic measurements techniques for two phase flow can be categorized into the following: Transit time, Doppler, and cross correlation[4]. However, ultrasonic transit-time is proposed to be used in separated gas measurement in the future.

1. *Ultrasonic Transit-Time*

As it can see from the figure 2, in the transit time method the difference between the time of flight of ultrasonic waves transmitted upstream and downstream as a consequence of flow are measured.

The fluid velocity v along the ultrasonic path in a pipe of diameter d in meters at an angle θ to the flow direction is given as the following:

$$v = \frac{Ld\partial\tau}{2\tau_1\tau_2 \sin\theta\cos\theta} \qquad (1)$$

Where τ_1 is the time to flight in seconds for upstream path Lu, τ_2 is the time of flight in seconds for downstream path Ld and $\partial\tau$ is the difference between τ_1 and τ_2.[5]

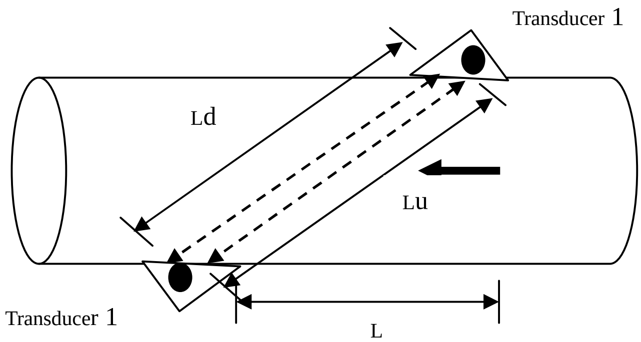

FIGURE 2, BASIC ULTRASONIC TRANSIT TIME

2. *Ultrasonic Doppler Flowmeter*

The Doppler ultrasonic flow meter principle is based on the reflection of acoustic waves from a moving scatterer back to the source; the frequency shift is proportional to the velocity component of the object parallel to the acoustic beam. The frequency shift is given as:

$$\Delta f = 2 ft(V/c)\cos\theta \qquad (2)$$

Where V is the velocity of the scatterers, and c is the acoustic velocity.

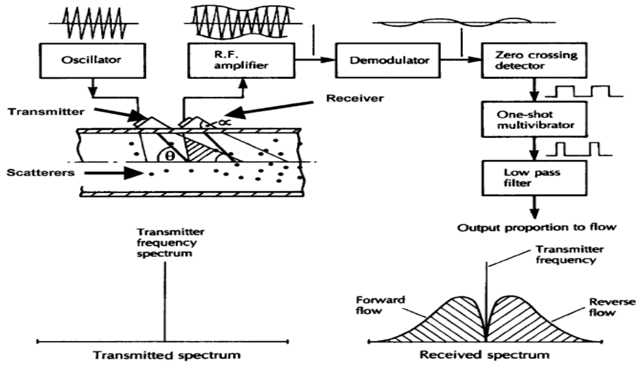

FIGURE 3, ULTRASONIC DOPPLER FLOWMETER, TAKEN FROM SANDERSON AND YEUNG, (2002)

However, The Doppler flow meters function is limited as a result of the nature, size, and spatial distribution of the scatterers which varies the attenuation of ultrasonic beam.

Since the sensed velocity is as a result of scatterers, slippage might not correspond to the actual fluid velocity.9 Normally, the wall section near the transducer is the only section that is monitored. The zone of reflection is in a region of variable velocity.[6]

3. *Ultrasonic Cross-Correlation Flowmeter*

In this method of measurement two diametral acoustic paths displaced on axial direction allow two ultrasound beams to be transmitted and received. When the ultrasonic signal is injected through an investigated material, it is disturbed by turbulence or second phase (bubbles or particles) in the flow. These disturbed signals are correlated, and the time lag in the downstream signal can be obtained as a measure of the time of the fluid velocity between the paths can be evaluated[7].

$$v = l/t \qquad (3)$$

Figure 4 shows ultrasonic cross-correlation flowmeter installation and signal processing method.

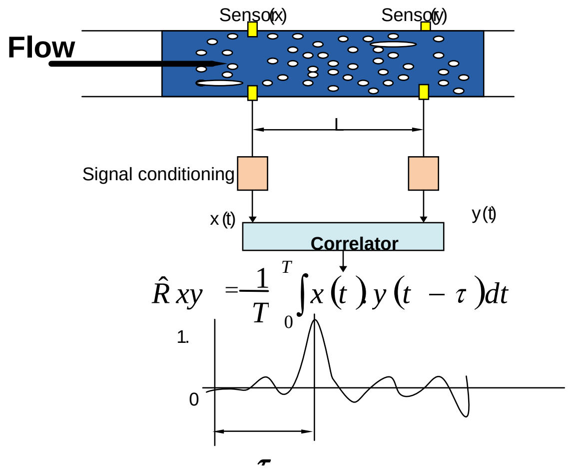

FIGURE 4, CROSS – CORRELATION FLOWMETER, TAKEN FROM SANDERSON AND YEUNG (2002)[8]

4. Conductivity Rings

The main objective of the conductivity rings is to determine the phase fraction. It is based on injecting a known electrical current into the flow, and then measure the voltage drop between two electrodes along an insulated cross section pipe.

As a result the resistance or conductance can be obtained using Ohm's law. This resistance is converted into a conductivity measurement.

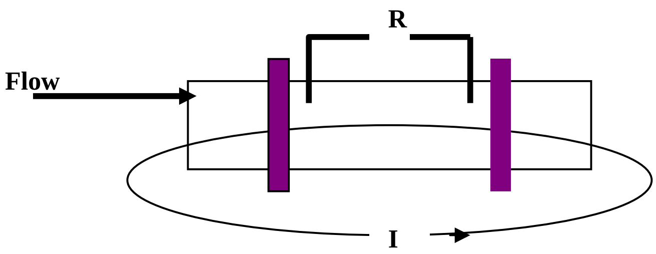

FIGURE 5, CONDUCTIVITY RING.

5. THE EXPERIMENTAL SET-UP

1. Two-Phase Facility Test Rig Overview

The test rig consists of a closed loop of two different internal pipe diameters. The first pipe geometry of 50mm internal diameter and 20 metre length whereas the other pipe is 1.5 meter length of T-junction system from 50mm to 152.4mm diameter and then the separated flows is combined back to 50mm. The loop is about 1 metre high from the ground to allow ergonomically access, better visualization of the fluid and easy to access and control the liquid and gas valves and it is also required for the return mixture pipe to the water tank to be entered from the inlet above the water level which is 90cm. Figure 6 illustrates the two-phase rig facility. Electromagnetic and turbine flow meters are used to as reference points to measure the introduced liquid and gas flowrate, respectively.

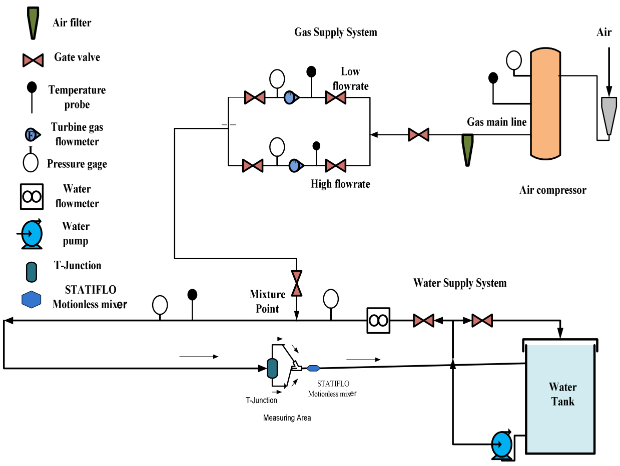

FIGURE 6, SCHEMATIC OF TWO-PHASE RIG TEST

2. T-Junction and Mixing Area's Design

Two-phase air/water primary separation facility was designed and constructed to perform the test measurement. The proposed T-junction was made of 152.4mm plastic pipe with two liquid and gas outlets of that has 50mm inner pipe diameter. The aim of using the T-junction was to achieve a partially separation of air/water slug flow. However, the two-phase partially separated gas and liquid were combined to mix again at the outlet of the separator. At the gas/water mixture section ultrasonic Doppler was clamped on to measure the mixture velocity.

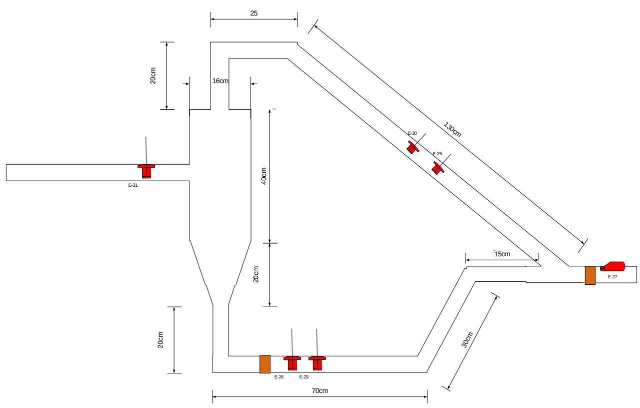

Figure 7, SCHEMATIC OF T-JUNCTION AND MIXER DESIGN.

Figure 7 shows also some ultrasonic transducers have been used such as one set ultrasonic cross correlation clamp-on the upstream pipe to identify the flow regime, two sets of ultrasonic cross correlation clamped-on the separated liquid line, Doppler within the homogeneous, and the transit time will be installed in the separated gas side.

Figure 8 shows T-junction as a two-phase partially separation and the homogeneous section of fluid combining installed in the process and systems engineering department laboratory.

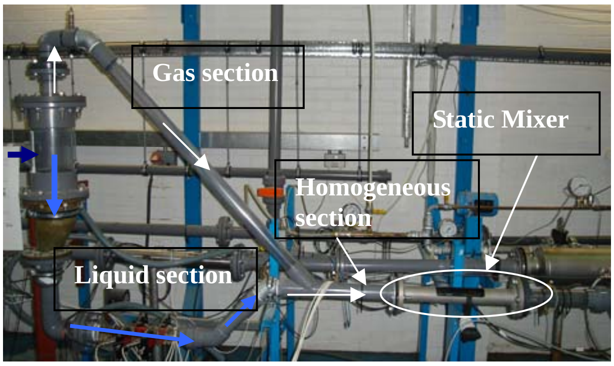

Figure 8, T-JUNCTION INSTALLED IN THE TEST RIG.

3. Conductivity Ring Stratified Calibration

FIGURE 9, CONDUCTIVITY RING STATIC CALIBRATION

The main objective of the conductivity rings calibration was to set the corresponding Volts according to the liquid hold-up in 50 mm pipe diameter. The conductivity ring was sampled out of the rig and the both 50mm pipe ends were blocked with special calibration purpose ends.

This calibration was performed by implementing well known liquid volume to a horizontal 50mm pipe diameter. Basically, water was gradually injected into the horizontal pipe with extra care to maintain flat surface of water inside the pipe. The measurements of the conductivity ring was taken to cover a liquid fraction range from 0 to 1.

As it can be seen from figure 9, the weight of water excluding the weight of conductivity ring was measured as well as the corresponding value in volts was obtained. The calibration curve was obtained as it can be seen from the diagram 10. The curve was normalized using 5th order polynomial.

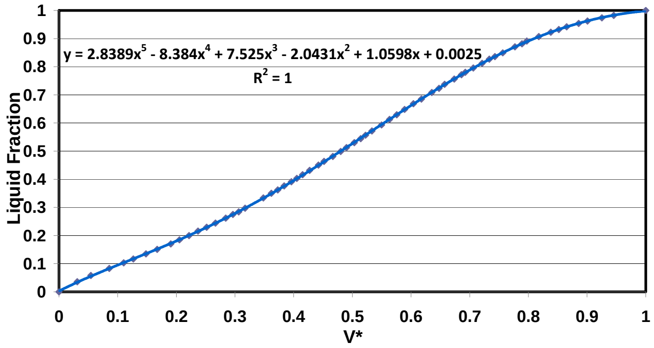

FIGURE 10, CONDUCTIVITY RING CALIBRATION CURVE.

4. Conductivity Ring Homogeneous Calibration

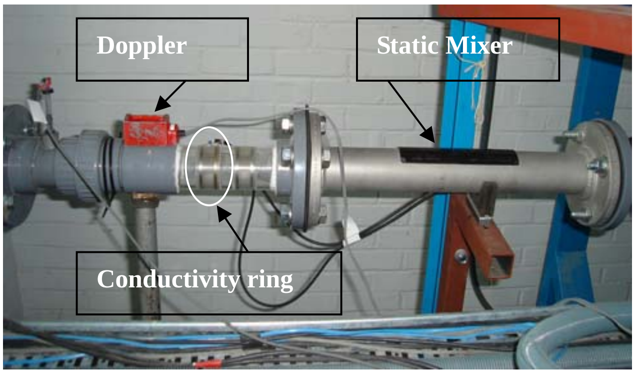

FIGURE 11, CONDUCTIVITY RING CALIBRATION.

Figure 11 illustrates homogeneous calibration for the conductivity ring. The static mixer and the conductivity ring were installed front of the test rig liquid and gas reference devices. The conductivity ring calibration was performed with the GVF correlated as a result of electromagnetic flow and turbine gas flow-meters. The signal produced from the conductivity ring was normalized to correspond to the correlated gas viod fraction by the reference measurements intalled on 50mm pipe diameter with 1 presents an empty pipe whereas number 0presents the pipe is full of liquid.

From figure 12 illustrates linear relationship between the correlated Gas Void Fraction and normalized conductivity ring's signal. The performed homogeneous calibration has been undertaken in the laboratory.

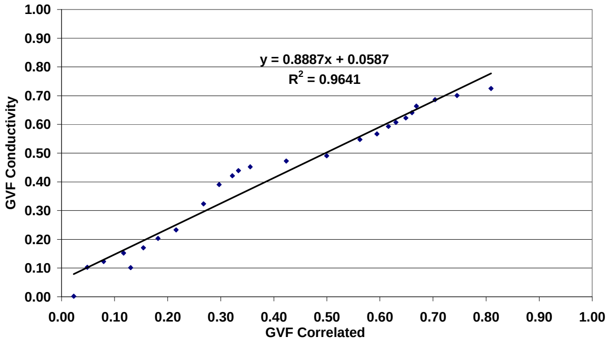

Figure 12, CONDUCTIVITY HOMOGENEOUS CALIBRATION

5. RESULTS AND DISCUSSIONS

In fact, this approach of metering system is mainly focused on the slug flow regime flowing in horizontal 2 inch pipe under atmospheric pressure, however, there are some more experiments are undertaken to implement this system on wider flow regimes and higher mixture pressure. Moreover, higher viscosity liquid is going to be introduced to the test rig in order to simulate the real world of oil and has measurement where this approach is going to be eventually implemented.

The main advantages of this system are the approach is associated with low pressure flow loss in pipe since the flow is partially separated and the ultrasonic measurement techniques that have been used are clamped-on.

The tests were confined to low-pressure air-water mixtures measured by gas turbine flowmeter and electromagnetic flowmeter, respectively, with the ultrasonic Doppler meter and conductivity ring situated downstream of T-junction where the separated gas and liquid flow were combined. The following variables used in the analysis are defined as follows:

Q_M , Q_l and Q_g are the volumetric flow rates of the mixture, liquid and gas respectively.

A_l and A_g are the effective flow cross sectional areas of the liquid and gas as computed from the conductivity rings in the homogenized flow region. $V(Doppler)$ is the Velocity of the homogenized flow measured by the Doppler meter.

The experimental test conditions ranges were as follows:

- Superficial liquid velocity 1 m/sec.
- Superficial gas velocity range 0.2 to 5.2 m/sec.
- Mixture velocity range 1.2 to 6.2 m/sec.
- Gas volume fraction range 13% to 83.7 %.
- Pressure range 1.4 bar abs.
- Temperature room temperature 23oC.

1. *Separated Liquid Flowrate Measurement*

The separated liquid flowrate is measured using ultrasonic cross correlation transducers which are mounted in the axial distance 0.046 m, and a conductivity ring to measure the fraction. The following figures are illustrating the flowrate measurement and its deviation comparing with the reference.

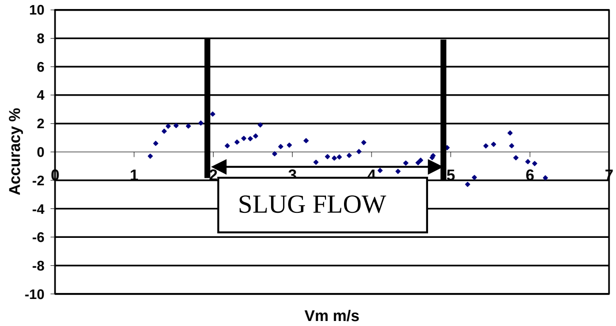

FIGURE 13, LIQUID FLOWRATE MEASUREMENT USING CROSS CORRELATION.

2. *Mixture Flowrate Measurement*

The flowrate of mixture with in the homogeneous area was obtained using ultrasonic Doppler flowmeter installed downstream of a static mixer. The measured mixture flowrate is compared with the references and the result is as the following diagram.

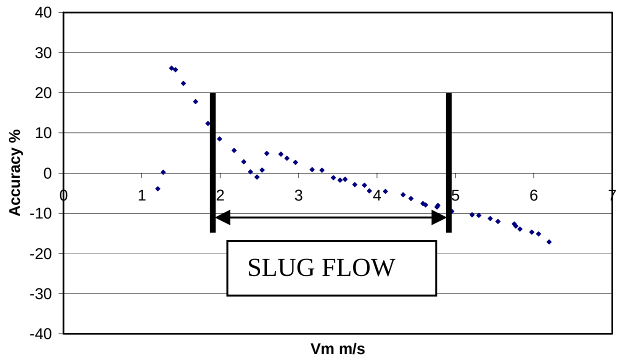

FIGURE 14, MIXTURE FLOWRATE MEASURED BY ULTRASONIC DOPPLER.

3. *Liquid Flowrate Measurement Within The Homogeneous Section*

In homogeneous flow area the liquid flowrate was measured using the clamped-on ultrasonic Doppler as a velocity measurement technique and the flush-mounted conductivity ring to measure the fraction. Figure 13 shows the results of the liquid flowrate measurement accuracy within the homogeneous section comparing with the reference measurement which is done by using electromagnetic flowmeter.

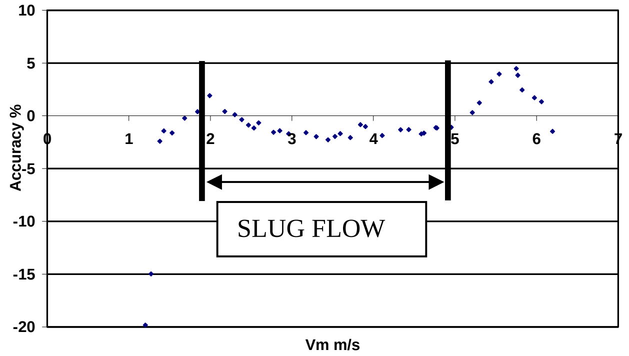

FIGURE 15, LIQUID FLOWRATE MEASURED BY ULTRASONIC DOPPLER.

4. *Gas Flowrate Calculation*

The gas flowrate is obtained by knowing the mixture (Total) flowrate measured by the ultrasonic Doppler and liquid flowrate (cross correlation or within the Doppler region).

$$Q_M = Q_l + Q_g \tag{4}$$

$$Q_g = Q_m - Q_l \tag{5}$$

$$Q_g = V(Doppler) * A_g \tag{6}$$

Where, Q_M denotes the total flowrate measured by the Doppler.

Q_g denotes the gas flowrate.

Q_l denotes the liquid flowrate measured by cross correlation or Doppler flowmeter.

$V(Doppler)$ denotes the velocity of the mixture measured by the Doppler flowmeter.

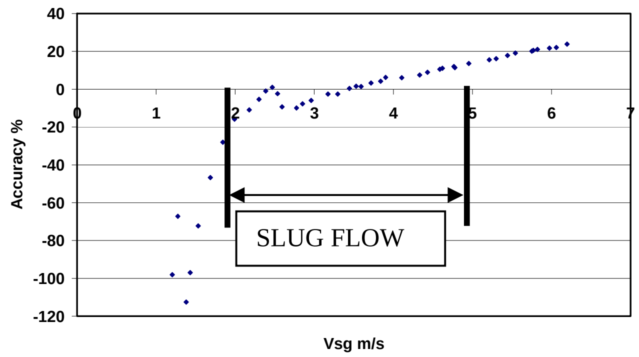

FIGURE 16, GAS FLOWRATE MEASURENET USING DOPPLER AND CROSS CORRELATION.

6. CONCLUSION

To sum up, the experimental test conditions ranges were performed as follows:

- ➢ Superficial liquid velocity 1 m/sec.
- ➢ Superficial gas velocity range 0.2 to 5.2 m/sec.
- ➢ Mixture velocity range 1.2 to 6.2 m/sec.
- ➢ Gas volume fraction range 13% to 83.7 %.
- ➢ Static pressure range 1.4 bar abs.
- ➢ Room temperature 23 Co.

The flowrate measurements' results were as the follow:

1. *Separated Liquid Flowrate*

The average measurement results for the separated liquid flowrate using ultrasonic cross-correlation were within $\pm 2\%$ from the reference liquid flowrate measurement.

2. *Homogenized Mixture Flowrate Measurement*

The mixture flowrate measurement made using the ultrasonic Doppler flowmeter and corrected for working pressure, were within $\pm 10\%$ from the reference mixture of gas and liquid flowrate.

3. *Homogenized Liquid Flowrate Measurement*

The liquid flowrate measurement within the homogeneous flow was performed using ultrasonic Doppler and a conductivity ring; the results were within $\pm 2\%$ from the reference liquid flowrate.

4. *Gas Flowrate Calculation*

Gas flowrate was obtained from the mixture flowrate measurement and the liquid flowrate whether it is measured within the homogeneous flow or within separation. 99% of the calculated gas flowrate results were within $\pm 10\%$ from the reference, however, some further investigation need to be made since this reference is out of calibration when it is being used for low flowrate of gas measurement. As it can be seen from the above conclusion that the laboratory performance tests of the T-junction have been showing successful results as the slug flow is eliminated and it was partially separated, when the proposed metering techniques have been compared to the reference points and they have provided us an anticipated overall accuracy of measuring the separated liquid, homogenized liquid, and calculated gas.

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