Journal of Engineering Research

Volume 7
Issue 6 *Issue 6*

Article 10

2023

Experimental Study on the Impact of Secondary Air Injection and different swirl van angles on Premixed Turbulent Flame Propagation and Emission Behaviors

Medhat Elkelawy Prof. Dr. Eng.
Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt, medhatelkelawy@f-eng.tanta.edu.eg

E. A. El Shenawy Prof. Dr.
Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt, el-shinawi.abdulhamid@f-eng.tanta.edu.eg

Hagar Alm-Eldin Bastawissi Prof. Dr. Eng.
Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt, hagaralmeldin@f-eng.tanta.edu.eg

Ibrahim Ali Mousa Eng.
Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt, ousa@f-eng.tanta.edu.eg

Mohamed M. Abdel-Raouf Ibrahim Dr. Eng.
Borg Al-Arab Higher Institute of Eng. & Technology, Mechanical Power Eng. Department, Alex, Egypt, engibraheemelshennawy@gmail.com

Recommended Citation
Elkelawy, Medhat Prof. Dr. Eng.; El Shenawy, E. A. Prof. Dr.; Bastawissi, Hagar Alm-Eldin Prof. Dr. Eng.; Mousa, Ibrahim Ali Eng.; and Ibrahim, Mohamed M. Abdel-Raouf Dr. Eng. (2023) "Experimental Study on the Impact of Secondary Air Injection and different swirl van angles on Premixed Turbulent Flame Propagation and Emission Behaviors," *Journal of Engineering Research*: Vol. 7: Iss. 6, Article 10.
Available at: https://digitalcommons.aaru.edu.jo/erjeng/vol7/iss6/10

Experimental Study on the Impact of Secondary Air Injection and different swirl van angles on Premixed Turbulent Flame Propagation and Emission Behaviors

Cover Page Footnote

The authors would like to thank the editor of Journal of Engineering Research for giving us the opportunity to revise the paper. We heartily appreciate the time and efforts dedicated by the reviewers for providing constructive feedback for our work which improved the paper quality significantly. We have addressed all these comments carefully and have made thorough corrections which we hope would meet the expectation of the journal. Those corrections are in red colour in the revised manuscript.

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

Experimental Study on the Impact of Secondary Air Injection and different swirl van angles on Premixed Turbulent Flame Propagation and Emission Behaviors

Medhat Elkelawy[1], E. A. El Shenawy[2], Hager Alm-EldinBastawissi[3], Ibrahim Ali Mousa[4], Mohamed M. Abdel-Raouf Ibrahim [5]

[1] Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt – email: medhatelkelawy@f-eng.tanta.edu.eg
[2] Mechanical Power Eng. Departments, Faculty of Engineering, Tanta University, Tanta, Egypt – email: el-shinawi.abdulhamid@f-eng.tanta.edu.eg
[3] Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt – email: hagaralmeldin@f-eng.tanta.edu.eg
[4] Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt
[5] Borg Al-Arab Higher Institute of Engineering and Technology, Mechanical Power Eng. Department, Alex, Egypt- email:MRAOUFSALAH@yahoo.com

Abstract: **The objective of the present paper is to investigate experimentally the flame characteristics utilizing different secondary air inlet direction for different primary air swirl numbers and equivalence fuel-air ratios. In this study, an experimental test rig was carried out to investigate the flame temperature and emission behavior with flame length at the equivalence fuel-air ratios taken0.96, 0.80, 0.70, and 0.60, and swirl vane angles were varied as 20, 30, 45, and 60° to generate different swirl numbers of 0.26, 0.416, 0.71 and 1.23, respectively. In addition to the introduction of secondary air in test combustor, whereas the primary air and fuel mass flow rates were kept constant at 12.5. Also, the secondary air flow rate was changed to give different secondary over primary air and fuel ratios of 0.19, 0.32, 0.41, and 0.48. The study showed that the flame temperature distribution with flame length at the equivalence fuel-air ratios is increased at 20.0 mm of radial flame distance and decreases gradually with radial flame distance. Also, the experimental investigation illustrated the emission characteristics at different equivalence fuel-air ratios accounting for nitrogen oxide and unburned hydrocarbon were decreased gradually with radial flame distance at different swirl vane angles. Moreover, the emission characteristics at different equivalence fuel-air ratios accounting for the concentration percent of carbon dioxide and carbon monoxide were decreased gradually with radial flame distance at different swirl vane angles**

Keywords: **Premixed Burner Flame; swirl vane angles; Flame temperature; Emissions characteristics; Secondary air ratio**

I. INTRODUCTION

Premixed combustion technologies are being pursued as effective means to decrease undesirable emissions in industrial burners. Elkelawy et al. [1, 2] elucidated that combustion and emissions behaviors could be improved to an acceptable level if alternative fuel such as biodiesel is used to fuel the conventional diesel engine[3-8]. However, the use of solid fuel as co-firing was considered a new method for solving the problem of industrial burner combustion [9-12]. Extensive studies have been performed regarding the solid particle fuel dilution in the horizontal fuel pip in order to enhance the fuel distribution in the furnace room [13, 14]. A porous burner has been tested to determine the effect of firing rate, equivalence ratio, and flame speed on the stability of the flame by S. A. Hashemi, and M. R. Faridzadeh[15]. Razvan Carlanescu1 et al.[16]introduced a method that considered a method can be used for contracting a CH4-H2 mixtures combustion chamber. Lanzhou Gao et al.[17]carried out an experiment to measure the flame oscillation. In addition, the author obtained the differences that occur in the flame area at different operating conditions. Xingyu Su et al. introduced an approach to studying the chemical kinetic reaction mechanism of the used fuel in achieving good progress to reduce the reaction mechanism from 290 to 32 equation reactions[18]. However, the ignition delay times have been tested and optimized by facilitating the polynomial fitting for constructing the response surface. Marco Osvaldo Vigueras-Zúñiga et al.[19]did a study on flame behavior and found that using a swirler with a high swirl number in a premixed flames burner can be used to promote the biogas fuel combustion in combustion chambers [20, 21]. The obtained results show that the pollutant emissions including NOx, CO2, and CO decreased dramatically because the swirler enhances the combustion process [22-24]. The swirler also prevents non-combustion zone creation. However, the tested mathematical code might be used to investigate successively how flames behave when the mixture of biogas contains various moles of CO2.

Elkelawy et al. [25, 26]determined experimentally the effect of different amounts of biogas components mixed with commercial diesel fuel at various supplied air on combustion and emissions behaviors[27-29]. The results obtained data elucidated that the NOx and CO emissions were enhanced, while the flame temperature significantly changed with using different biogas portions in the combustion process. Ziyu Wang [30] performed an experimental investigation to evaluate the combustion performance and flame behavior using fuels such as Syngas, Biogas, Liquefied Petroleum Gas (LPG), and Gas to Liquid (GTL) premixed flames. The author concluded that flame instability is affected by equivalence ratio, flame radius, temperature, pressure, diluent type, and diluent mole fraction. As the flame propagates, the flame

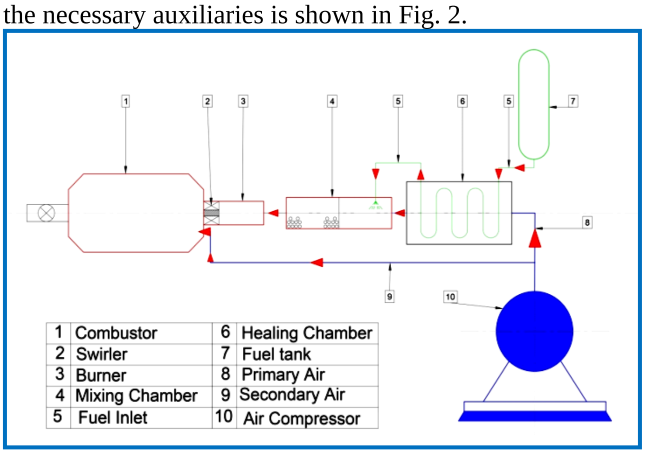
Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

becomes more unstable. As temperature increases, the flame becomes more stable. As pressure increases, the flame becomes more unstable[32 ,31] . The diluents such as him, EGR, and CO2 act as the inhibitors of flame instability. As the mole fraction of the diluent increases, the flame becomes more stable. Ahmed El-Said Azam et al.[33]the swirl and counter swirl were experimentally investigated and the obtained results elucidated that the performance of the counter swirl was better than the co-swirler. When compared to the co-swirler, the counter-swirl produces higher flame temperatures and lower emissions concentrations [34, 35]. Expanding the internal point of the twirling stream prompts the improvement of the burning system. Numerical and experimental research was conducted to figure out the impact of non-premixed swirl flow on flame NOx emission [36].As a result, the authors came to the conclusion that the swirler flame consists of a central toroidal recirculation zone, corner recirculation zone, and CTZ comprising the swirl-based flow region. Additionally, as the number of swirls increases, the combustor's inlet tends to receive the highest flame temperature. However, the experiment work has been achieved to study and test a conical stabilizer for flame steadiness to improve the swirl phenomena through combustion gases [37]. Also, the measurements have been performed on the new burner (slot) and the conventional one (coaxial) to investigate the axial temperature, the flame appearance, and the axial gas analysis [38]. In this regard, experimental and theoretical studies have been performed to investigate the effect of different secondary air directions, normal, forward, backward, and tangential directions on natural gas combustion characteristics[39]. The results show that the introduction of secondary air leads to a decrease in flame size, and the tangential direction gives the shortest flame length for most cases while the backward direction gives the longest one. Normal and forward directions produce higher O2 and lower CO and CO2 concentrations. In addition, a numerical investigation has been carried out to study the effect of the burner configuration and H2 as fuel content on the internal recirculation zone [40]. The study illustrated stoichiometric mixtures with pure ammonia, 25% H2, and 50% H2 blends whereas the flame for pure ammonia firing was longer, and the introduction of hydrogen in the fuel mixture increased the reactivity, as typified by the higher temperature and product formation rate[41 ,35] . Also, experiments were performed to depict the important features of the premixed chamber and the primary zone of practical gas turbine combustors[42]. The analysis illustrated the effects of premixing efficiency on flame stabilization, propagation, and pollutant formation under overall lean burning conditions. Fuel composition and the level of the swirl created by the burner have been investigated experimentally to evaluate the premixed flame combustion and emissions characteristics [43]. The obtained data elucidated that the swirl number on the reaction zone has a great impact on the combustion species and temperature distributions. The flow field characteristics of reacting flow in a swirler burner have been studied [44]. The different velocity components in axial, radial, and tangential directions have been measured experimentally to establish the impact of the swirler on the combustor's behaviors of the premixed burner. Vipul Patel and Rupesh Shah [45]carried out an experiment to investigate the impact of swirl number in inverse diffusion flame by applying 30° of swirler vane angle. The impact of changing the number of vanes on the configuration and color of inverse diffusion flames is investigated[46] . In addition, the investigation included the impact of premixed flow configuration and the charge equivalence ratio on flame temperature, length, shape, NOx, and CO emission. Numerical and theoretical investigation about combustion flame temperature has achieved. Results quantified the flame temperature at specific values of the fuel and air species. Analysis also shows that it is feasible to employ a measured quantity of air for combustion efficiency whereas; the combustion within the oxygen has a more remarkable positive impact than in the air

In this investigation, the experimental work was conducted on an instrumented combustor that consists of a cylindrical combustor equipped with all necessary auxiliaries that facilitate its operation and control. All the tests were conducted using axial vane swirls with vane angles of 20, 30, 45, and 60◦. The premixed flame was prepared by applying two air systems, one for primary air and the other for secondary air. In the present experimental technique, the different burner designs and operating parameters that include the influence of equivalence fuel–air ratio (ϕ), swirl vane angle (S), secondary air ratio (SAR), and the magnitude of the secondary air injection angle have been tested. Therefore, these parameters have a significant impact on the measured temperature, velocity vectors, and species concentrations.

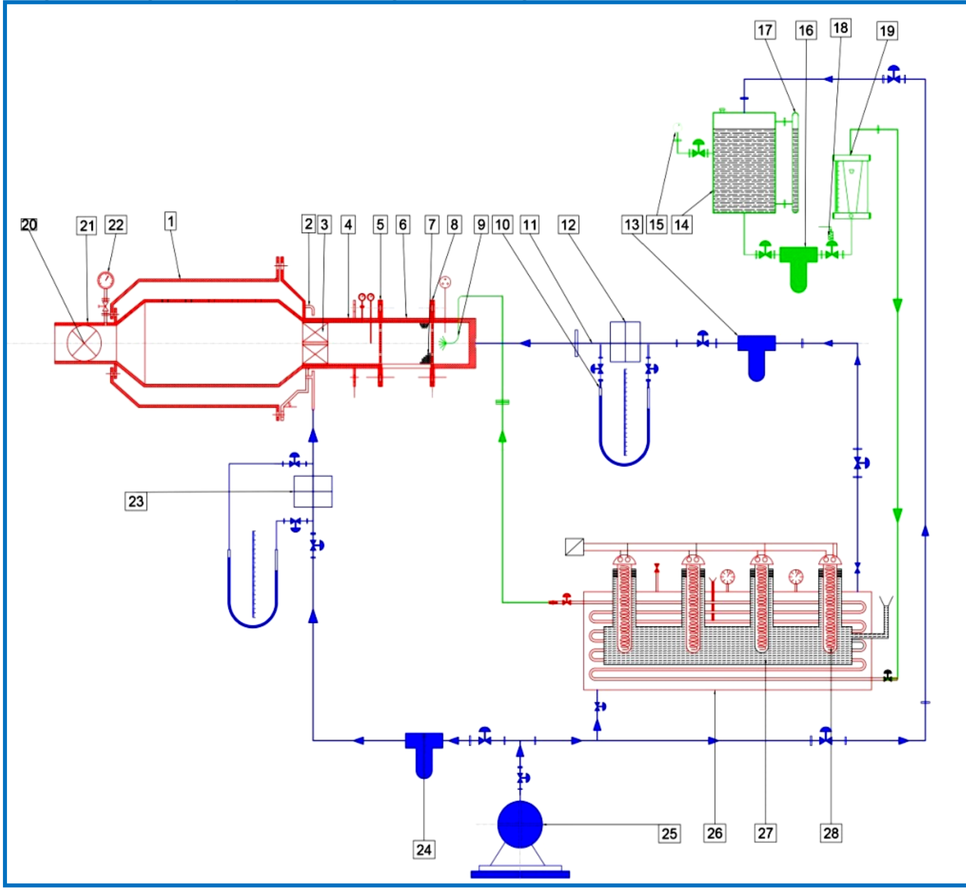
II.METHODOLOGY OF THE EXPERIMENTAL WORK

Commercial diesel fuel is tested in a constructed premixed flame burner. The burner was equipped with a set of R-type thermocouples to measure the flam temperature distribution. In addition, flame emissions such as CO, CO_2, HC, and NOx have been recorded at different burner designs and operating conditions. However, the general layout of the burner test rig (as a line diagram) is shown in Fig.1, whereas the detailed test rig equipped with the necessary auxiliaries is shown in Fig. 2.



Journal of Engineering Research (ERJ
ISSN: 2356-9441 | Vol. 7 – No. 6, 2023 | ©Tanta University, Faculty of Engineering | e ISSN: 2735-4873

Figure1. The general layout of the test rig (as a line diagram)



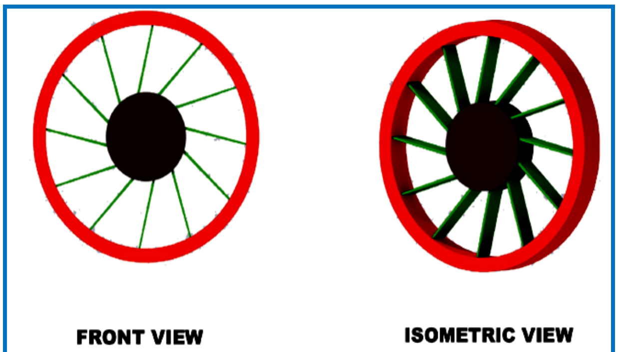
SER	DESCRITION
1	COMBUSTOR
2	SECONDARY AIR INLET
3	SWIRLER
4	BURNER
5	SECOND DRILLED PLATE
6	MIXING SECTION
7	STAINLESS SPHERE
8	FIRST DRILLED PLATE
9	FUEL NOZZLE
10	PRIMARY AIR - U - TUBE MANOMETER
11	PRIMARY AIR INLET
12	PRIMARY AIR OFFICE - METER
13	PRIMARY AIR FILTER
14	FUEL TANK
15	PRESSURE INDICATOR
16	FUEL FILTER
17	LEVEL INDICATOR
18	PRESSURE REGULATOR
19	FUEL - ROTA - METER
20	EXHAUST VALVE
21	EXHAUST LINE
22	PRESSURE INDICATOR
23	SECONDERY AIR ORIFICE METER
24	SECONDARY AIR FILLTER
25	AIR COMPRESSOR
26	HEATING CHAMBER
27	OIL
28	FOUR ELECTRIC HEATERS

Figure2: Test rig arrangement and measuring devices

Therefore, Fig. 2 illustrated the three stages of the burner test-rig sections; the first one is the preheating section, the second is the burner, and the last one is the combustor or combustion chamber.

The first stage of the burner test-rig is the heating system, which consists of a primary air receiver with two heaters, a primary air inlet, and an outlet. For user-friendly measuring parameters the constructed burner system is equipped with instrumentation and all necessary control. Swirler with vane angles of 20, 30, 45, and 60 degrees have been designed and constructed with the burner system. The geometry was chosen to produce the full defections of flow as possible with simple and symmetric vanes as shown in Fig.3. The swirler is simply axial cascaded guide vanes. Four different swirler of setting angles 20, 30, 45, and 60 degrees are used to generate rotations of swirl numbers 0.26, 0.416, 0.71, and 1.23, respectively, as calculated according to Mather and McCollum[47].

The second part that consisting of mixing, burner, and swirler as shown in Figure 4, which is known as burner three portions. The portions between two drillers (parts 4 and 7 in Figure 4) plate have been constructed for completing the mixing, homogenous, and vaporization of the fuel with primary air to get a premixed turbulent flame. The second portion of the burner has been filled with stainless balls (spheres) of small diameter to satisfy complete mixing and homogeneity of heated air and evaporated fuel. The third portion contains a swirler to measure the mixture temperature before exiting from the burner to control the evaporating of fuel droplets.



MAIN DIMENSIONS OF SWILLERS

SN	VANES SETTING ANGLES --- DEGREES	OUTER RACE DIAMETER -- mm	INNER HUBE DIAMETER -- mm	SWILLER DIAMETER COMB. DIAMETER
0.26	20°	76.1mm	15mm	0.3044
0.416	30°	76.1mm	15mm	0.3044
0.71	45°	76.1mm	15mm	0.3044
1.23	60°	76.1mm	15mm	0.3044

Figure 3.Optimized swirler configuration

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

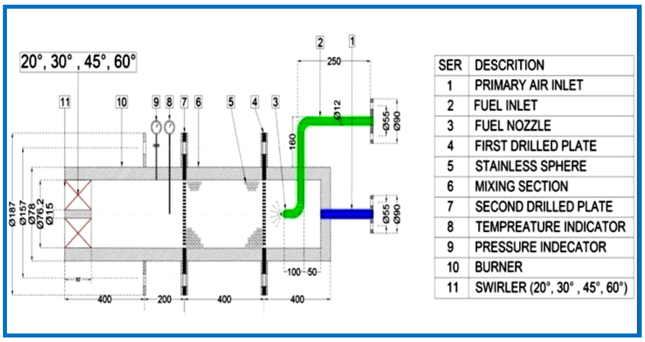
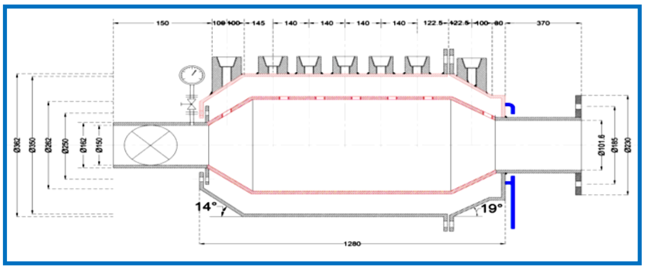
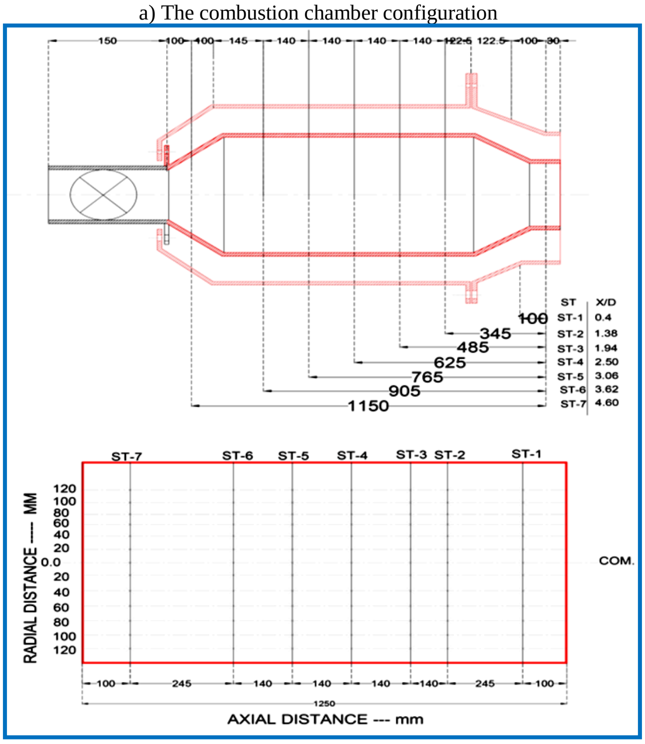


Figure 4: Dimension of the tested burner, mixing section, burner, and swirler



a) The combustion chamber configuration



b) The measuring mesh points along the flame length

Figure 5: Plan view for combustor configuration and temperature sampling probe stations

The last section of the tested burner in the test rig has known by the combustor or combustion chamber as showed in figure 2 and 5. The burner combustor in the present work is responsible for hosting the premixed flame. However, the mixing of fuel and primary air takes place before entering the combustion zone. The combustor has been designed with seven stations to fix the R-type thermocouple to measure the temperature distribution along the flame length as can be seen in figure 5.

III. MEASUREMENT TECHNIQUE

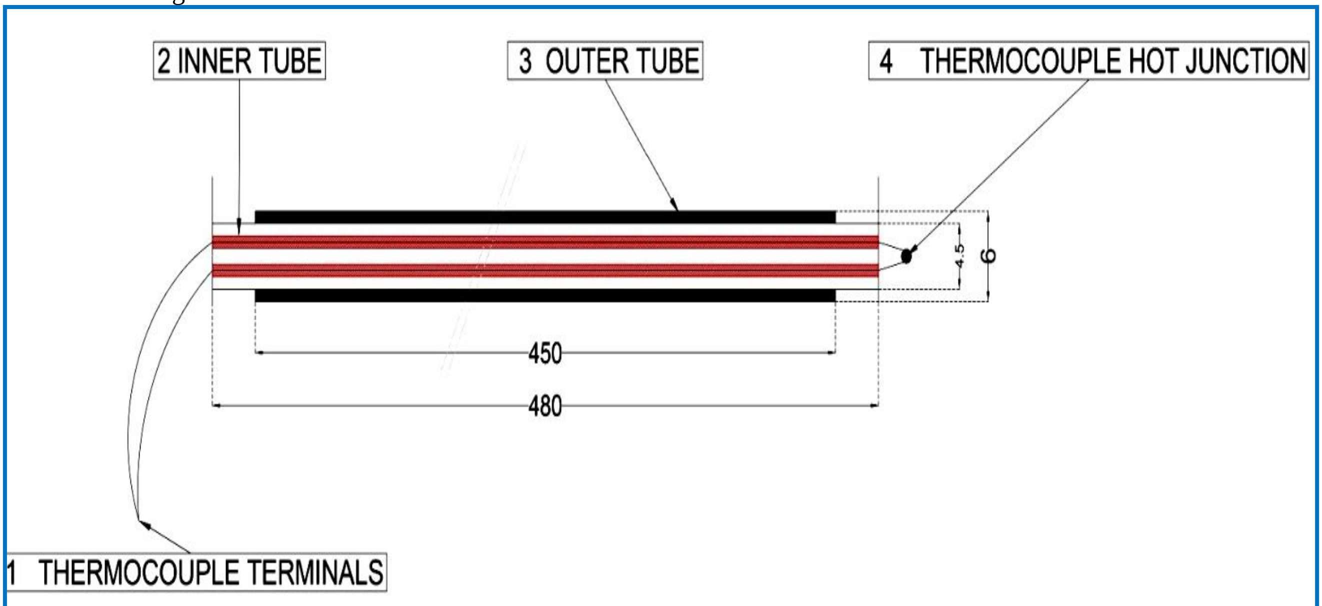
The measurement technique depends upon the flow pattern inside the combustor under operating conditions. The main measured parameters are the velocity and temperature in the experimental program that considered the fundamental quantities necessary to investigate the aerodynamic behavior of swirling premixed turbulent flames[48-50]. The system of instrumentation and control used in the present study consists of a velocity vector, gas sampling and temperature probes, fuel and air rate as well as gas analyzing equipment. Velocity vectors, gas sampling, and temperature measurements have been performed at different radial positions in the combustor using several probes at seven positions along the combustor.

The performing measurements give the temperature at different measurement stations, relative to the combustor inlet. Exhaust gas analysis has carried out continuously depending on the type of analyzer. Velocity measurement depends upon a three-hole water-cooled probe, which is a cylinder placed inside the combustor as an axis normal to a fluid[51-53]. Thus, to obtain both the magnitude and direction of the velocity, a cylindrical tube containing three holes, apart from the total head hole, two static holes have been arranged on either side at 40°to the total head established. If the tube is now positioned such that the middle hole is at stagnation conditions which are achieved when the two static holes give equal readings, the velocity head is obtained from the difference between the stagnation hole and one of the side holes.

The direction of the flow is determined by the angle rotated by the probe from a definite reference by means of a protractor. A velocity measurement is subjected to calibration[2, 54]. Temperature is one of the fundamental quantities using which a complete study of controlling flow behavior from the point of view of transfer and combustion in industrial furnaces can be obtained. It is there for important that measurements of temperature are made with a high degree of accuracy. The true measurements of the temperature of the gas can be determined from the thermocouple measurements by correcting the measured values by using the equation for errors resulting from various types of heat exchange between the thermocouple wires and the surroundings. The most direct method to determine the local temperature is to insert a thermocouple into the flame. Platinum – 13 % Rhodium as positive VS Platinum as negative wires were used for the thermocouple used in the experiments. The wire diameter is 150 μm, and the ends of the wires forming the thermocouple were fused to form the hot junction. The wires were insulated by fine tubes of ceramic each has two holes one for each wire. The type of

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

this thermocouple is R-type and the range of its measurement is from 0.0˚C to 2400.0˚C. Pyrometer is used to obtain directly the gas temperature by the suction pyrometer[55]. It is obvious that there is a certain minimum velocity required for suction in order to reach the correct gas temperature. The gas temperature has also been found to be affected by the position of the thermocouple junction in the shield. For this reason, the suction pyrometer is made such that the position of the junction can be easily changed. The suction pyrometer is constructed from three co-axial stainless steel tubes of outer diameters 6 mm, 9 mm, and 12 mm. They are connected to fulfill the probe requirements. The inner pipe is used as a casing for the ceramic tubes inside which the thermocouple wires are mounted. In addition, this inner pipe conforms to the passage of the sucked gases. The two outer tubes with the inner one form the water jacket required for cooling the probe. The three tubes are fitted at one end with three fittings for the inlet and exit of cooling water in addition to the gas extraction hole. A ceramic tube is arranged in the central pipe. This ceramic tube is supplied by two axial holes distant 1 mm through which the thermocouple wires are passed. These wires are Platinum- 13 % Rhodium as positive V. S. Platinum as negative wires of 0.2 mm. diameter was used for the thermocouple used in the suction Pyrometer as shown in figure6.



SER	DESCRITION	DIAMETER m.m.	MATERIAL
1	THERMOCOUPLE TERMINALS	150μm	PL-13%Rh AND PL
2	INNER TUBE	3.0	CERAMIC
3	OUTER TUBE	6	ST. STEEL
4	THERMOCOUPLE HOT JUNCTION	0.2	ST. STEEL

Figure 6.Thermocouple probe of flame temperature measurements

Measurements using gas analyzers and constant volume sample techniques to provide accurate species concentration measurements. The continuous analysis of gases is important for the control of chemical processes. Exhaust gas sampling measurements were performed at different radial positions in the combustor using several probes located at seven positions along the combustor. Table 1 gives the position of different sampling stations relative to the combustor inlet (as can be seen in Figure 5).

The accuracy of the gas analyzer instruments of about + 0.5 %. The combustion gases are sampled by an isokinetic water-cooled stainless steel tube probe, as shown in Figure 7.

Table 1: Sampling probe locations along the combustor

Position (Station)	Distance From Burner Inlet (X) (mm)	X / D, D = 250 (mm)
1	100	0.40
2	345	1.38
3	485	1.94
4	625	2.50
5	765	3.06
6	905	3.62

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

7	1150	4.60

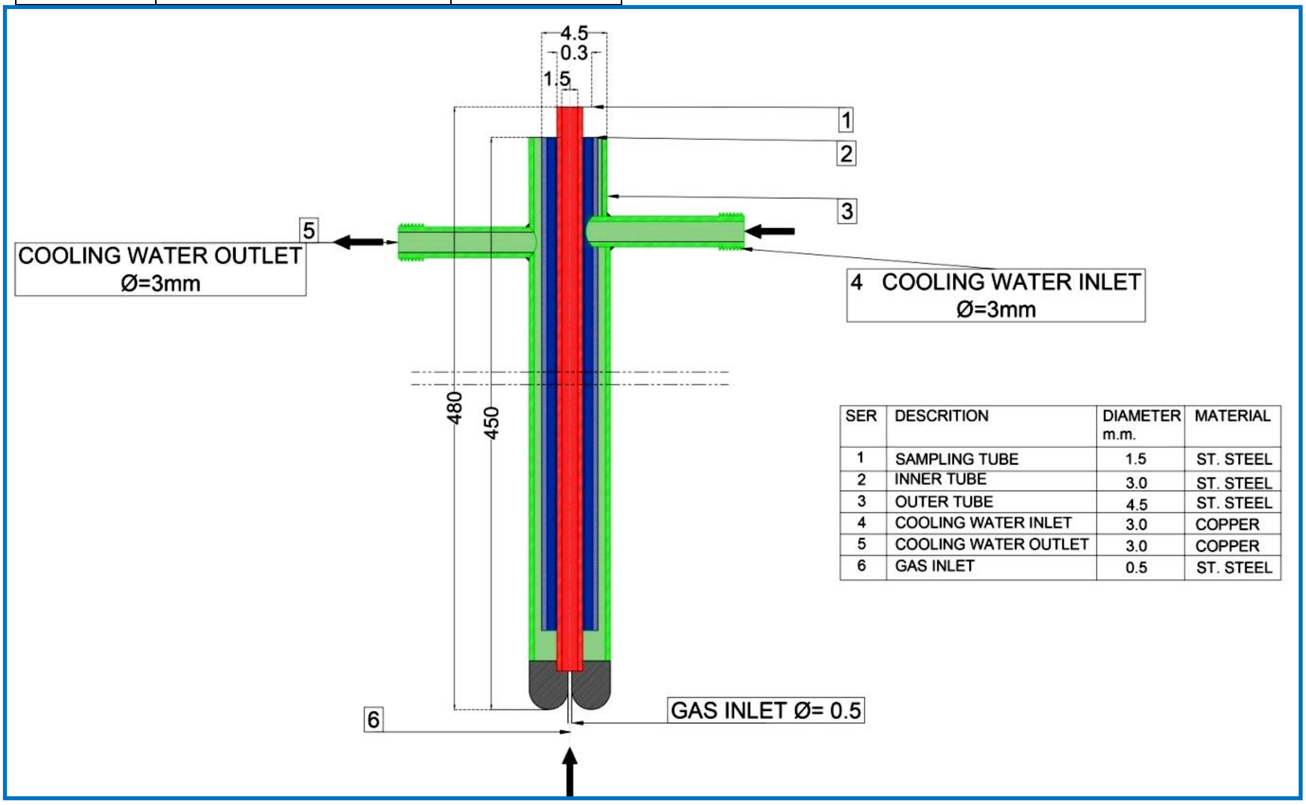


Figure 7.Isokinetic Sampling Probe

IV.UNCERTAINTY ANALYSIS OF THE EXPERIMENTAL

Uncertainty analysis is used to ensure an acceptable limit for the experimental setup accuracy accounting a technique of Robert J. Moffat [56]. Operating parameters such as flame temperature and the emission characteristics such as NO*x*, CO_2, CO, and HC were calculated. Equation (1) stated the uncertainty calculations for the measured output responses:

$$W_R = \sqrt{\left(\frac{\partial R}{\partial x_1} * w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} * w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} * w_n\right)^2} \quad ----- (Equ. 1)$$

W_R is the total uncertainty value in the experimental observation, where the uncertainties of the independent test rig operating parameters measured are denoted by w_1, w_2, ...,w_n, and R is the result function computed for the independent test rig. The type of this thermocouple is R-type and the range of its measurement is from 0.0° degree to 2400.0° as illustrated in table 2.

Table 2: Uncertainty values of measured and calculated parameters of the flame temperature.

S. No.	Range of Calculated Parameter, Temp. °C	Percentage uncertainties
1	0.0000 → 1000.0	0.143872
2	1000.0 → 1500.0	0.345302
3	1500.0 → 2000.0	0.468237

The overall uncertainty for measured and calculated parameters of flame temperature with secondary air is approximated at 0.32. According to this concept, the accuracy of a gas analyzer is ordinarily stated in terms of the reproducibility area of at least 8 repeated analyses of the same mixture containing the interest components than the arithmetic mean could be taken as the correct result with probability.

Uncertainty values (with secondary air) for NOx, HC, CO_2, and CO, were about ± 3.210 ppm, ± 0.152 mg/cm^3, ± 0.198 %, and ± 0.600 % respectively, Percentage of uncertainties of measured and calculated parameters are shown in tables 3.

Table 3: Uncertainty values of measured and calculated parameters of the emission characteristics.

Parameter	NO_x, (ppm)	UHC, (mg/cm^3)	CO_2, Vol. (%).	CO, Vol. (%).
$\sigma = \sqrt{\sum d_i^2 /(N-1}$	1.8535	0.08760	0.11436	0.34625
$w_T = \sqrt{\sum d_i^2}$	± 3.210 ppm	± 0.152 ppm	± 0.198 %	± 0.600 %
$P_e = 0.6745\sqrt{\sigma}$	0.91828	0.2000	0.2281	0.3970

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

	7			

V. EXPERIMENTAL RESULTS:

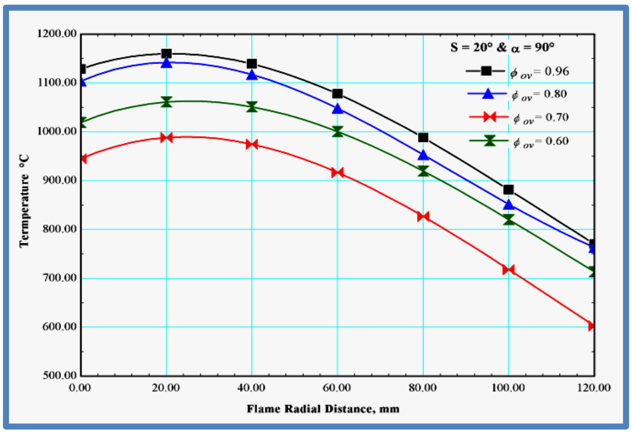
a. Flame Performance at Different Swirl Vane Angles and Air Fuel Ratio with Injection of Secondary Air (Perpendicular Mode (α = 90°)).

The premixed burner flame temperature measurement was performed via the thermocouple probe shown in figure 6. There are seven axial and seven redial stations configure 49-measurement mesh points, which were recorded at steady state operation for each case of air fuel ratios and swirl vane angles in the present work. The results of this research accounting the flame temperature distribution at different air-fuel ratios ϕ = 0.96, 0.80, 0.70 and 0.6 (Lean Fuel) accounting the injection of secondary air is perpendicular mode (α = 90°) at swirl vane angles 20°, 30°, 45°,and 60° as shown in figures 8a, 8b, 8c, and 8d. Also the results under this condition indicates the temperature distribution in three zones: 0.40≤ X/D ≤ 1.94, 1.94 ≤ X/D ≤ 3.06, and 3.06≤ X/D ≤ 4.60 for the primary zone, recirculation zone, and combustion zone of combustor respectively.

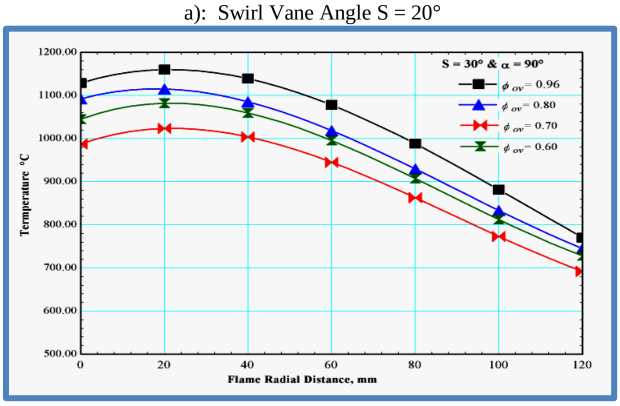
Figures 8a, 8b, 8c, and 8d illustrate the average maximum temperatures takes place at 1239, 1200, 1140, and 1046 °C along 20 and 34 mm accounting for the equivalent fuel-air ratio ϕ = 0.96, 0.80, 0.70, and 0.60 and swirl vane angles 20° , 30°, 45°, and 60° respectively.
Figure 8 indicates a maximum temperature was attained and prevails in a large area of the central zone as the equivalence fuel air ratio ϕ increase and observed temperature levels increase by 100 to 200 ° by increasing the equivalence fuel air ratio ϕ, whereas the secondary air ratio improves the velocity of turbulent reaction rate and decreases the combustion zone length.

b. Emission Characteristics at Different Swirl Vane Angles and Air Fuel Ratio with Injection of Secondary Air (Perpendicular Mode (α = 90 ∘)).

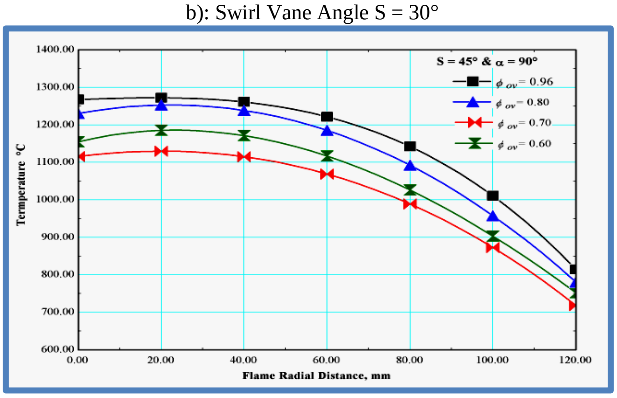
Figures 9a, 9b, 9c, and 9d reflected and illustrated the measured premixed flame NOx distribution with flame radial distance at equivalent fuel-air ratio ϕ = 0.96, 0.80, 0.70 and 0.60 (Lean Fuel) at swirl vane angles 20°, 30°, 45°, and 60°andthe injection of secondary air is perpendicular mode (α = 90°). Also figures 9a, 9b, 9c, and 9d indicate the overall average of NOx (ppm) distribution along the flame length ranged from 85 to 55 ppm under the conditions of equivalent air fuel ratios and swirl vane angles. There is fast reduction in NOx emissions when the swirl vane angle increased from 20°, 30°, 45°, and 60° swirl number from (SN from 0.26 to 1.23). This was apparent for the whole range of operating equivalence ratio due to maximum heat release occurs off the combustor center line.



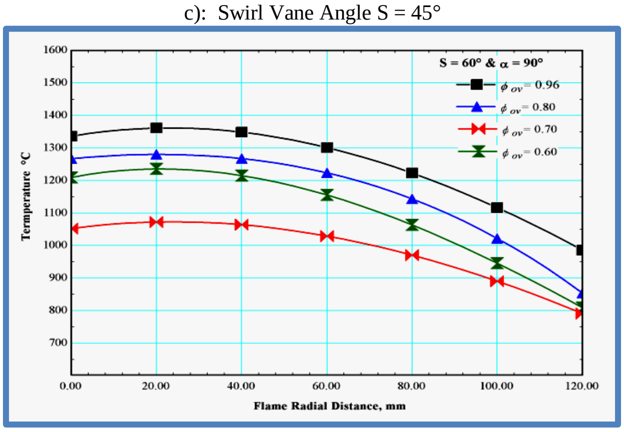
a): Swirl Vane Angle S = 20°



b): Swirl Vane Angle S = 30°



c): Swirl Vane Angle S = 45°



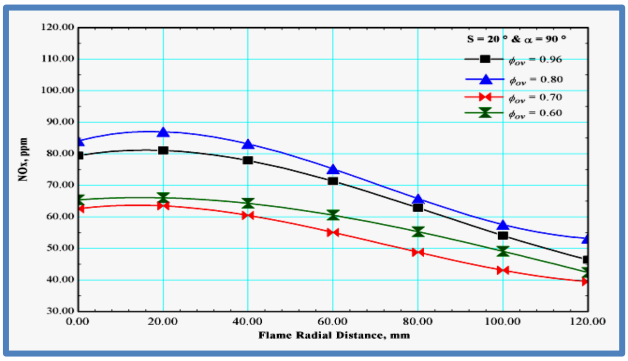
Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

d): Swirl Vane Angle S = 60°

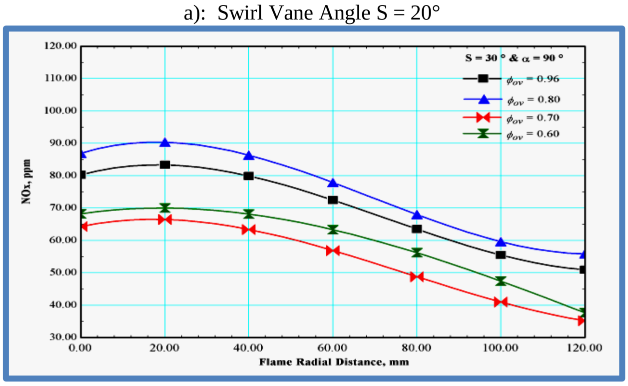
Figure 8: Premixed flame temperature data for different Swirl Vane Angle at different Equivalence Fuel – Air Ratio

d): Swirl Vane Angle S = 60°

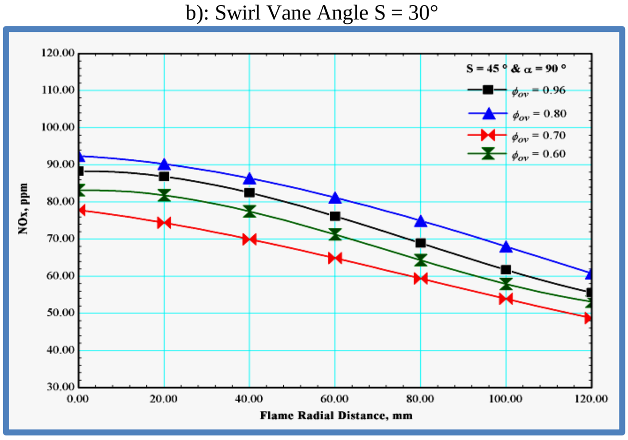
Figure 9: Premixed flame NOx emissions data for different Swirl Vane Angle at different Equivalence Fuel – Air Ratio



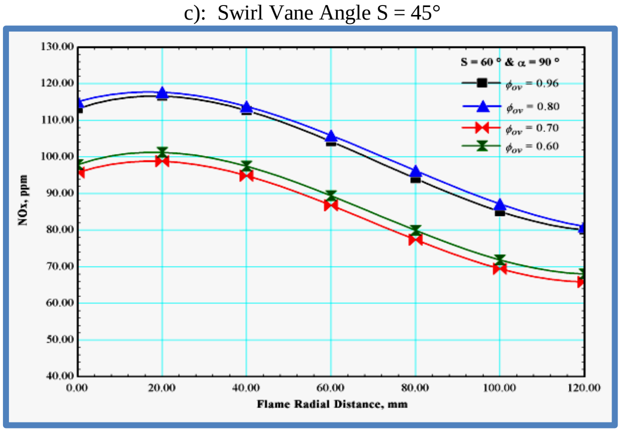
a): Swirl Vane Angle S = 20°



b): Swirl Vane Angle S = 30°



c): Swirl Vane Angle S = 45°



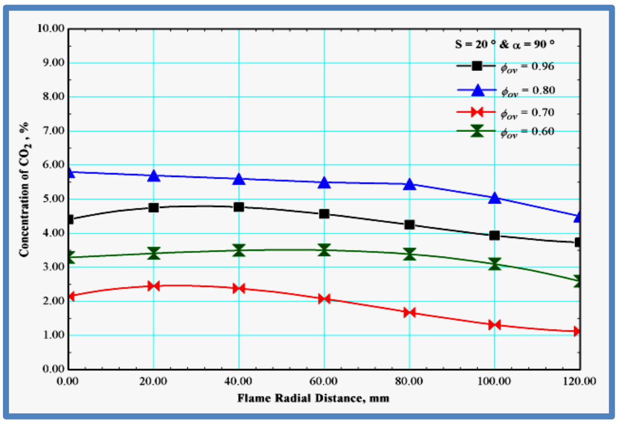
Figures 10a, 10b, 10c, and 10d indicate the carbon dioxide CO_2 has a stable distribution of emission for the whole range of equivalence ratios, whereas by increasing the equivalence fuel-air ratio CO_2 is increasing. However CO_2percent increases with higher swirl vane angle swirlers were used. Figures 10a, 10b, 10c, and 10d under the conditions of equivalent fuel-air ratio ϕ = 0.96, 0.80, 0.70 and 0.80 (Lean Fuel) at swirl vane angles 20°, 30°, 45°, and 60° accounting the injection of secondary air is perpendicular mode (α = 90°) CO_2volume concentration of about 5.0 percent, 6.3 percent and 7.3 percent decrease for swirl number of o.416, 0.71 and 1.23 respectively compared to swirl number of 0.26 this at equivalence ratio of 0.8.

There was a slight decrease in CO_2percent when increasing the swirl number. This was seen throughout the whole range of operating equivalence ratios. By increasing the injection of secondary air theCO_2 percent is decreased and that observation suggests that swirl significantly increase the rate of oxidation of carbon monoxide to carbon dioxide due to completely mixed flow resulting from recirculation of the flow gases.

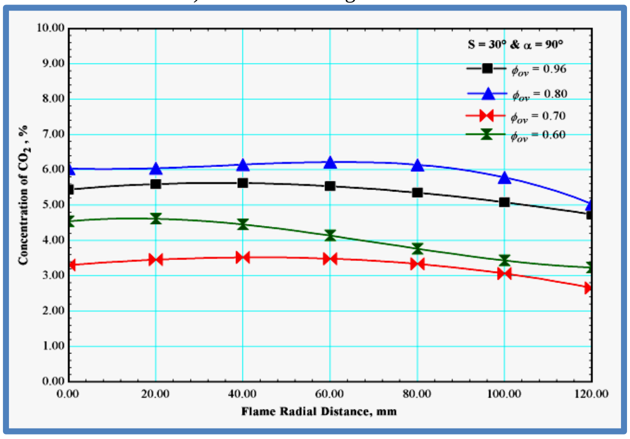
Figures 11a, 11b, 11c, and 11d shows the premixed flame carbon dioxide volume concentration percent (CO %) distribution with flame radial distance at equivalent fuel-air ratio ϕ = 0.96, 0.80, 0.70 and 0.80 (Lean Fuel) at swirl vane angle 20°, 30°, 45°, and 60° accounting the injection of secondary air is perpendicular mode (α = 90°).

Figures 11a, 11b, 11c, and 11d illustrate the overall mean volume concentration of carbon dioxide CO (%) distribution ranged from 1.56 to 0.78% and maximum volume concentration CO 1.675 % ; CO (%) distribution ranged from 1.125 to 0.55 % and maximum volume concentration CO 1.275 % ;CO (%) distribution ranged from 1.06 to 0.425 % and maximum volume concentration CO 1.0875 % CO (%) distribution ranged from 0.65 to 0.35 % and maximum volume concentration CO 0.7425 % at swirl vane angles20∘, 30∘, 45∘, and 60∘ respectively. It is observed that the increasing in the secondary air ratio decreases the carbon monoxide and concentrations.

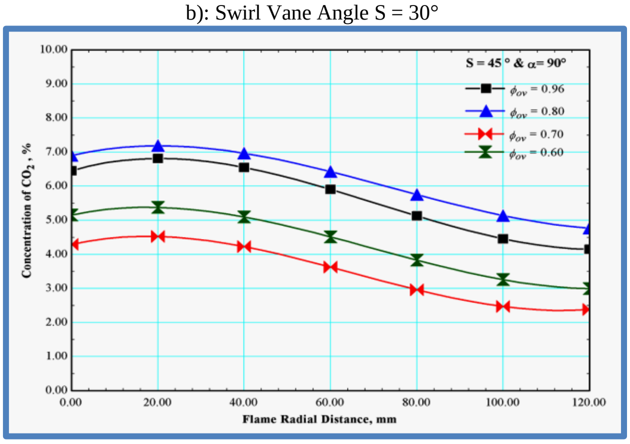
Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873



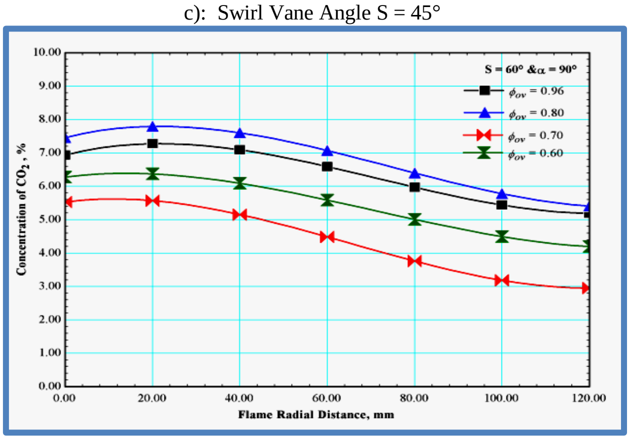
a): Swirl Vane Angle S = 20°



b): Swirl Vane Angle S = 30°



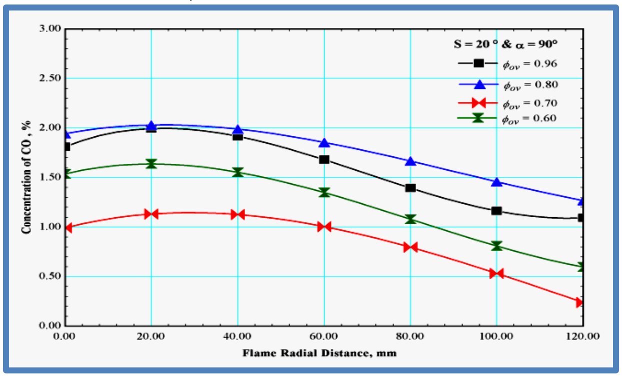
c): Swirl Vane Angle S = 45°



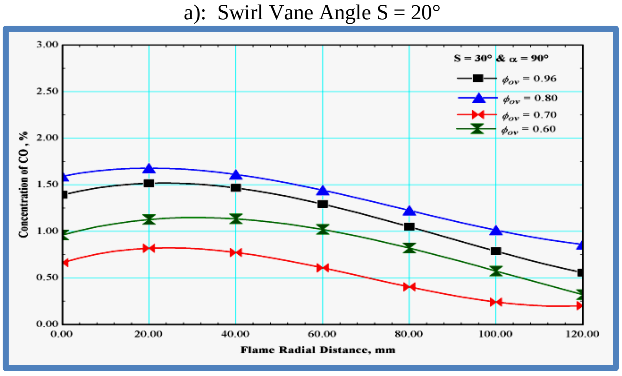
d): Swirl Vane Angle S = 60°

Figure 10: Premixed flame CO2 emissions data for different Swirl Vane Angle at different Equivalence Fuel – Air Ratio

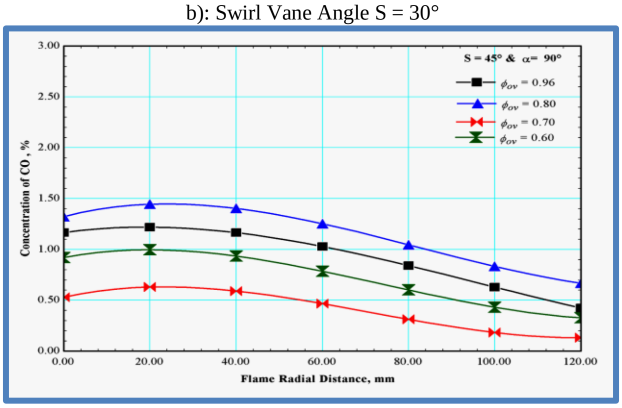
Figures 12a, 12b, 12c, and 12d reflected and illustrated the premixed flame unburned hydrocarbon, UHC (mg/cm^3) distribution with flame radial distance at equivalent fuel-air ratio ϕ = 0.96, 0.80, 0.70 and 0.80 (Lean Fuel) at swirl vane angle 20°, 30°, 45°, and 60° accounting the injection of secondary air is perpendicular mode (α = 90°). Under this condition figures shown the UHC (mg/cm^3) distribution found in the primary zone, recirculation zone, and combustion zone of combustor.



a): Swirl Vane Angle S = 20°

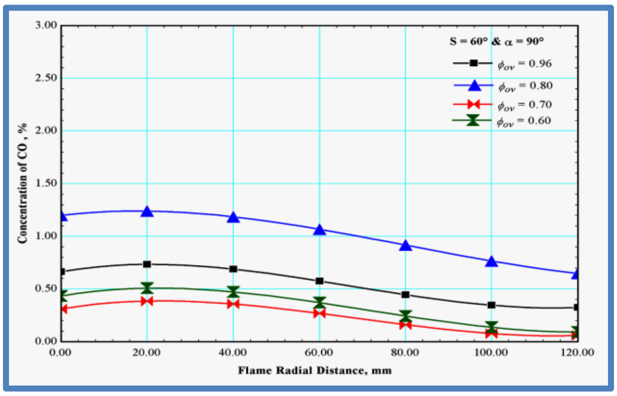


b): Swirl Vane Angle S = 30°



c): Swirl Vane Angle S = 45°

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

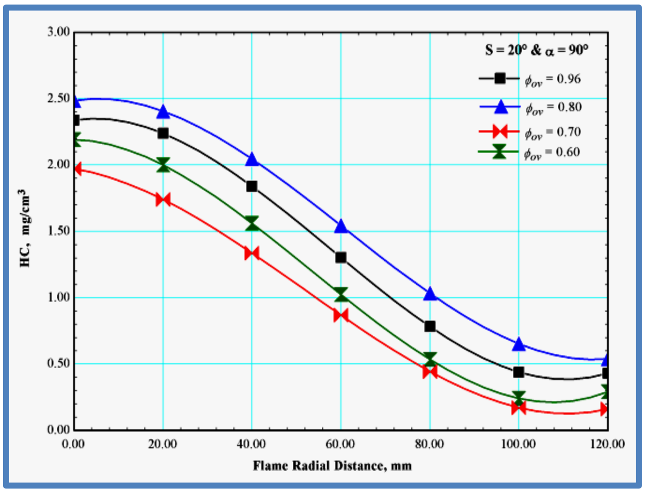


d): Swirl Vane Angle S = 60°

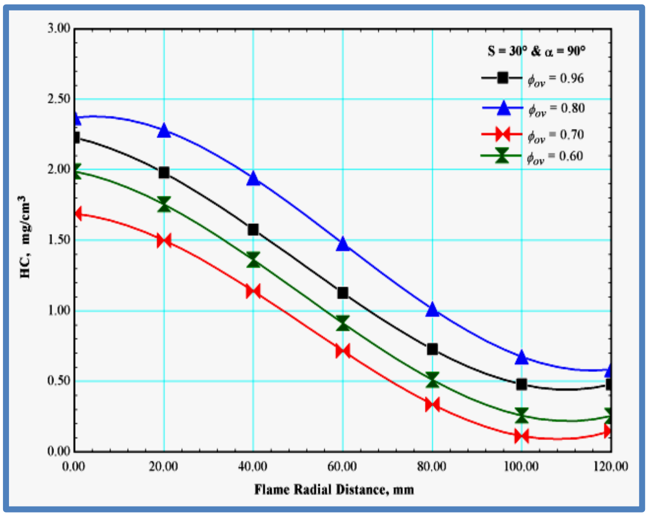
Figure 11: Premixed flame CO emissions data for different Swirl Vane Angle at different Equivalence Fuel – Air Ratio

Figures 12a, 12b, 12c, and 12d illustrate the overall mean unburned hydrocarbon UHC (mg/cm^3) distribution ranged from 2.24 to 0.40 mg/cm^3 and maximum UHC 2.28 mg/cm^3; UHC distribution ranged from 2.10 to 0.40 and maximum UHC2.2; UHC distribution ranged from 1.86 to 0.325 and maximum UHC 1.94; UHC distribution ranged from 1.60 to 0.325 and maximum UHC 1.65 at swirl vane angles 20°, 30°, 45°, and 60° respectively. It is observed that the increasing in the secondary air ratio decreases the UHC.

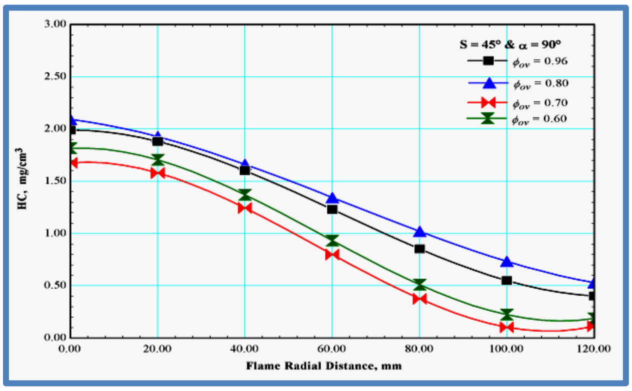
The figures depict the flow is characterized by maximum heat release occurs off the combustor center line. As the swirl vane angle increases, time dilution and temperature increased and consequently UHC emissions levels increase. When swirl vane angle increased from 20◦ to 60◦, fast reduction in UHC emissions. This was apparent for the whole range of operating equivalence ratios.The UHC emissions decrease with increasing swirl vane angle.



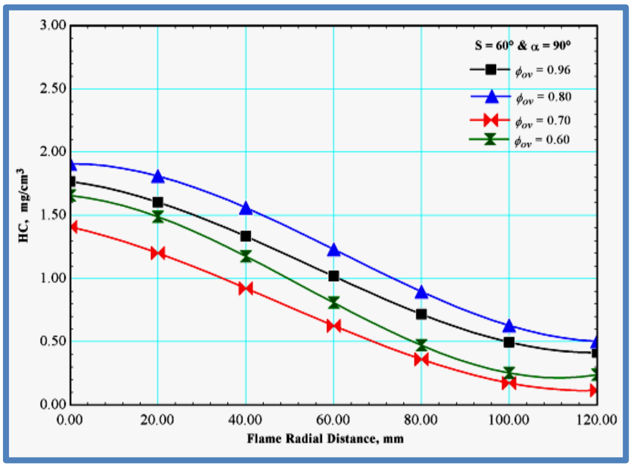
a): Swirl Vane Angle S = 20°



b): Swirl Vane Angle S = 30°



c): Swirl Vane Angle S = 45°



d): Swirl Vane Angle S = 60°

Figure 12: Premixed flame UHC emissions data for different Swirl Vane Angle at different Equivalence Fuel – Air Ratio

VI. Conclusion:

The impact of different swirl vane angles on premixed turbulent flame propagation and emission

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

characteristics is reflected in the different experimental runs, therefore the discussion and conclusions of the results are as follows:

1. The measuring technique of the temperature ranged from0 to2400 °C at different fuel air-fuel ratios of 0.96, 0.80, 0.70, and 0.60 (Lean Fuel) and swirl vane angles of 20°to 60° incorporated in a liquid fuel burner fired by conventional diesel. In addition, measurements were made for burners with the flow of secondary air were evaluated.
2. The results showed the radial temperature distribution with flame length, whereas the maximum temperature distribution ranged from 1380 °C to 1080 °C at 20 mm flame length accounting for the equivalent fuel-air ratio ϕ = 0.96, 0.80, 0.70, and 0.60 (Lean Fuel) respectively in the case of primary air and secondary air at swirl vane angle 20°, 30°, 45°, and 60°. A maximum temperature was attained and prevails in a large area of the central zone as the equivalence fuel-air ratio ϕ decreases.
3. The amount of swirling motion, there is an optimum value of the degree of swirl angles, which gives the required central recirculation zone dimensions corresponding to the confinement ratio and combustion intensity.
4. The nitrogen oxide concentrations at the exit from the combustor increase with increasing swirl vane angle. The decreases of swirl vane angles will increases carbon monoxide and unburned hydrocarbon concentrations. The carbon dioxide concentration steadily proportions with the swirl vane angle, whereas the increase in secondary air ratio increases the carbon monoxide concentrations and unburned hydrocarbon. The carbon dioxide concentrations decrease with increasing secondary air ratio.
5. Results indicated that swirl significantly increases the rate of oxidation of carbon monoxide to carbon dioxide due to completely mixed flow resulting from recirculation of the flow gases. The nitric oxide concentration at the exit from the combustor decreases with increasing the secondary air ratio.

VII. FUNDS

Research Fund Administration at Tanta University under the number of: tu: 02-19-01.

VIII. REFERENCES:

[1] M. Elkelawy, H. Alm ElDin Mohamad, A. K. Abdel-Rahman, A. Abou Elyazied, and S. Mostafa El malla, "Biodiesel as an Alternative Fuel in Terms of Production, Emission, Combustion Characteristics for Industrial Burners: a Review," *Journal of Engineering Research,* vol. 6, pp. 45-52, 2022.

[2] M. ElKelawy, H. A.-E. Bastawissi, E.-S. A. El-Shenawy, H. Panchal, K. Sadashivuni, D. Ponnamma*, et al.*, "Experimental investigations on spray flames and emissions analysis of diesel and diesel/biodiesel blends for combustion in oxy-fuel burner," *Asia-Pacific Journal of Chemical Engineering,* vol. 14, p. e2375, 2019.

[3] A. Singh, S. Sinha, A. K. Choudhary, H. Panchal, M. Elkelawy, and K. K. Sadasivuni, "Optimization of performance and emission characteristics of CI engine fueled with Jatropha biodiesel produced using a heterogeneous catalyst (CaO)," *Fuel,* vol. 280, p. 118611, 2020/11/15/ 2020.

[4] S. Chandra Sekhar, K. Karuppasamy, N. Vedaraman, A. E. Kabeel, R. Sathyamurthy, M. Elkelawy*, et al.*, "Biodiesel production process optimization from Pithecellobium dulce seed oil: Performance, combustion, and emission analysis on compression ignition engine fuelled with diesel/biodiesel blends," *Energy Conversion and Management,* vol. 161, pp. 141-154, 2018/04/01/ 2018.

[5] M. Elkelawy, H. A.-E. Bastawissi, K. K. Esmaeil, A. M. Radwan, H. Panchal, K. K. Sadasivuni*, et al.*, "Maximization of biodiesel production from sunflower and soybean oils and prediction of diesel engine performance and emission characteristics through response surface methodology," *Fuel,* vol. 266, p. 117072, 2020/04/15/ 2020.

[6] M. Elkelawy, H. Alm-Eldin Bastawissi, K. K. Esmaeil, A. M. Radwan, H. Panchal, K. K. Sadasivuni*, et al.*, "Experimental studies on the biodiesel production parameters optimization of sunflower and soybean oil mixture and DI engine combustion, performance, and emission analysis fueled with diesel/biodiesel blends," *Fuel,* vol. 255, p. 115791, 2019/11/01/ 2019.

[7] J.-z. Yu, Z. Yu-Sheng, M. Elkelawy, and Q. Kui, "Spray and combustion characteristics of HCCI engine using DME/diesel blended fuel by port-injection," SAE Technical Paper 0148-7191, 2010.

[8] H. A. El-Din, M. Elkelawy, and Z. Yu-Sheng, "HCCI engines combustion of CNG fuel with DME and H 2 additives," SAE Technical Paper 0148-7191, 2010.

[9] M. Elkelawy, Z. Yu-Sheng, A. E.-D. Hagar, and J.-z. Yu, "Challenging and Future of Homogeneous Charge Compression Ignition Engines; an Advanced and Novel Concepts Review," *Journal of Power and Energy Systems,* vol. 2, pp. 1108-1119, 2008.

[10] M. Elkelawy, E. A. El Shenawy, S. A. Mohamed, M. M. Elarabi, and H. A.-E. Bastawissi, "Impacts of using EGR and different DI-fuels on RCCI engine emissions, performance, and combustion characteristics," *Energy Conversion and Management: X,* vol. 15, p. 100236, 2022/08/01/ 2022.

[11] M. Elkelawy, Z. Yu-Sheng, H. A. El-Din, and Y. Jing-zhou, "A comprehensive modeling study of natural gas (HCCI) engine combustion enhancement by using hydrogen addition," SAE Technical Paper 0148-7191, 2008.

[12] M. M. El-Sheekh, M. Y. Bedaiwy, A. A. El-Nagar, M. ElKelawy, and H. Alm-Eldin Bastawissi, "Ethanol biofuel production and characteristics optimization from wheat straw hydrolysate: Performance and emission study of DI-diesel engine fueled with diesel/biodiesel/ethanol blends," *Renewable Energy,* vol. 191, pp. 591-607, 2022/05/01/ 2022.

[13] A. E. Kabeel, M. Elkelawy, H. A. E. Bastawissi, and A. M. Elbanna, "An experimental and theoretical study on particles-in-air behavior characterization at different particles loading and turbulence modulation," *Alexandria Engineering Journal,* vol. 58, pp. 451-465, 2019/06/01/ 2019.

[14] A. E. Kabeel, M. Elkelawy, H. A. El-Din, A. M. El-Banna, R. Sathyamurthy, and N. Prakash, "COMPUTATIONAL STUDY OF DIFFERENT TURBULENCE MODELS FOR AIR IMPINGEMENT JET INTO MAIN AIR CROSS STREAM," vol. 46, pp. 459-475, 2019-10-16 2019.

[15] S. a. Hashemi and M. R. Faridzadeh, "An Experimental Study on Submerged Flame in a Two-Layer Porous Burner," *AUT Journal of Mechanical Engineering,* vol. 4, pp. 79-88, 2020.

[16] R. Carlanescu, M. Enache, R. Maier, A. Alcea, R. Condruz, C. Stoica*, et al.*, "Calculation of the main parameters involved in the combustion process of CH4-H2 mixtures at different proportions," *E3S Web Conf.,* vol. 180, p. 01013, 2020.

[17] L. Gao, S. Peng, X. Huang, Y. Kang, S. Su, M. Sun*, et al.*, "A novel method for the identification of flame front's position on thermoacoustic coupling combustion oscillations," *Energy Science & Engineering,* vol. 9, pp. 1872-1886, 2021.

[18] M. Elkelawy, E. A. El Shenawy, S. A. Mohamed, M. M. Elarabi, and H. Alm-Eldin Bastawissi, "Impacts of EGR on RCCI engines management: A comprehensive review," *Energy Conversion and Management: X,* vol. 14, p. 100216, 2022/05/01/ 2022.

[19] M. O. Vigueras-Zúñiga, C. A. Ramírez-Ruíz, A. L. Herrera-May, and M. E. Tejeda-del-Cueto, "Numerical and Experimental Analysis of the Effect

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

of a Swirler with a High Swirl Number in a Biogas Combustor," *Energies,* vol. 14, p. 2768, 2021.

[20] E. A. El Shenawy, M. Elkelawy, H. A.-E. Bastawissi, M. Taha, H. Panchal, K. k. Sadasivuni*, et al.*, "Effect of cultivation parameters and heat management on the algae species growth conditions and biomass production in a continuous feedstock photobioreactor," *Renewable Energy,* vol. 148, pp. 807-815, 2020/04/01/ 2020.

[21] M. Elkelawy, E. A. El Shenawy, S. k. A. Almonem, M. H. Nasef, H. Panchal, H. A.-E. Bastawissi*, et al.*, "Experimental study on combustion, performance, and emission behaviours of diesel /WCO biodiesel/Cyclohexane blends in DI-CI engine," *Process Safety and Environmental Protection,* vol. 149, pp. 684-697, 2021/05/01/ 2021.

[22] M. Elkelawy, S. E.-d. H. Etaiw, H. A.-E. Bastawissi, H. Marie, A. M. Radwan, M. M. Dawood*, et al.*, "WCO biodiesel production by heterogeneous catalyst and using cadmium (II)-based supramolecular coordination polymer additives to improve diesel/biodiesel fueled engine performance and emissions," *Journal of Thermal Analysis and Calorimetry,* vol. 147, pp. 6375-6391, 2022/06/01 2022.

[23] M. Elkelawy, H. Bastawissi, S. C. Sekar, K. Karuppasamy, N. Vedaraman, K. Sathiyamoorthy*, et al.*, "Numerical and experimental investigation of ethyl alcohol as oxygenator on the combustion, performance, and emission characteristics of diesel/cotton seed oil blends in homogenous charge compression ignition engine," SAE Technical Paper 0148-7191, 2018.

[24] A. M. Elzahaby, M. Elkelawy, H. A.-E. Bastawissi, S. M. El_Malla, and A. M. M. Naceb, "Kinetic modeling and experimental study on the combustion, performance and emission characteristics of a PCCI engine fueled with ethanol-diesel blends," *Egyptian Journal of Petroleum,* vol. 27, pp. 927-937, 2018/12/01/ 2018.

[25] M. Elkelawy, A. Kamel, A. Abou-elyazied, and S. M. El-malla, "Experimental investigation of the effects of using biofuel blends with conventional diesel on the performance, combustion, and emission characteristics of an industrial burner," *Egyptian Sugar Journal,* vol. 19, pp. 44-59, 2022.

[26] M. Elkelawy, A. K. Abdel-Rahman, A. Abou-elyazied, and S. M. El-malla, "Experimental investigation on emission and combustion characteristics of an industrial burner using biogas co-fired with diesel and biodiesel," *Egyptian Sugar Journal,* vol. 19, pp. 29-43, 2022.

[27] S. C. Sekhar, K. Karuppasamy, R. Sathyamurthy, M. Elkelawy, H. A. E. D. Bastawissi, P. Paramasivan*, et al.*, "Emission analysis on compression ignition engine fueled with lower concentrations of Pithecellobium dulce biodiesel-diesel blends," *Heat Transfer—Asian Research,* vol. 48, pp. 254-269, 2019.

[28] M. Elkelawy, S. E.-d. H. Etaiw, H. Alm-Eldin Bastawissi, M. I. Ayad, A. M. Radwan, and M. M. Dawood, "Diesel/ biodiesel /silver thiocyanate nanoparticles/hydrogen peroxide blends as new fuel for enhancement of performance, combustion, and Emission characteristics of a diesel engine," *Energy,* vol. 216, p. 119284, 2021/02/01/ 2021.

[29] M. Elkelawy, S. E.-d. H. Etaiw, M. I. Ayad, H. Marie, M. Dawood, H. Panchal*, et al.*, "An enhancement in the diesel engine performance, combustion, and emission attributes fueled by diesel-biodiesel and 3D silver thiocyanate nanoparticles additive fuel blends," *Journal of the Taiwan Institute of Chemical Engineers,* vol. 124, pp. 369-380, 2021/07/01/ 2021.

[30] Z. Wang, "Experimental and Theoretical Studies of Laminar Burning Speed and Flame Instability of Alternative Fuels and Refrigerants," 27837061 Ph.D., Northeastern University, Ann Arbor, 2020.

[31] M. Elkelawy, H. A.-E. Bastawissi, E. A. El Shenawy, M. M. Shams, H. Panchal, K. K. Sadasivuni*, et al.*, "Influence of lean premixed ratio of PCCI-DI engine fueled by diesel/biodiesel blends on combustion, performance, and emission attributes; a comparison study," *Energy Conversion and Management: X,* vol. 10, p. 100066, 2021/06/01/ 2021.

[32] H. A. E. Bastawissi, M. Elkelawy, H. Panchal, and K. Kumar Sadasivuni, "Optimization of the multi-carburant dose as an energy source for the application of the HCCI engine," *Fuel,* vol. 253, pp. 15-24, 2019/10/01/ 2019.

[33] E. Azam, M. M. Kamal, and H. A. Abotaleb, "Combustion performance of triple flames issuing from elliptical Swirlers," *IOSR Journal of Engineering,* vol. 6, pp. 34-47, 2016.

[34] M. Elkelawy, E. A. El Shenawy, H. Alm-Eldin Bastawissi, M. M. Shams, and H. Panchal, "A comprehensive review on the effects of diesel/biofuel blends with nanofluid additives on compression ignition engine by response surface methodology," *Energy Conversion and Management: X,* vol. 14, p. 100177, 2022/05/01/ 2022.

[35] M. Elkelawy, A. E. Kabeel, E. A. El Shenawy, H. Panchal, A. Elbanna, H. A.-E. Bastawissi*, et al.*, "Experimental investigation on the influences of acetone organic compound additives into the diesel/biodiesel mixture in CI engine," *Sustainable Energy Technologies and Assessments,* vol. 37, p. 100614, 2020/02/01/ 2020.

[36] M. A. Abdel-Al, M. A. Yehia, M. R. Taha, and T. W. Abou-Arab, "The Effect of Tangential Swirl Angle on NOX Formation in a Non-Premixed LPG/Air Flame," *International Conference on Aerospace Sciences and Aviation Technology,* vol. 15, pp. 1-11, 2013.

[37] K. H. El-Nagar, "EXPERIMENTAL STUDY ON THE STABILITY OF PREMIXED FLAME USING CONICAL STABILIZER," *ERJ. Engineering Research Journal,* vol. 36, pp. 41-48, 2013.

[38] M. M. Abdelaal, S. M. Ali, A. M. Radwan, and A. A. Ismail, "INVESTIGATION OF A NEW DESIGN OF INVERSE DIFFUSION FLAME BURNER," *Journal of Al-Azhar University Engineering Sector,* vol. 11, pp. 1299-1309, 2016.

[39] M. Farag, "EXPERIMENTAL AND THEORETICAL STUDY OF THE EFFECT OF SECONDARY AIR DIRECTION ON NATURAL GAS DIFFUSION FLAME," *Port-Said Engineering Research Journal,* vol. 16, pp. 12-23, 2012.

[40] M. Yehia, F. Abdel-Aziz, and H. Haridy, "NUMERICAL ANALYIS OF AMMONIA/HYDROGEN FLAMES IN A SWIRL AND BLUFF-BODY STABILIZED BURNER," *The Egyptian International Journal of Engineering Sciences and Technology,* vol. 29, pp. 28-42, 2020.

[41] E. A. El Shenawy, M. Elkelawy, H. A.-E. Bastawissi, M. M. Shams, H. Panchal, K. Sadasivuni*, et al.*, "Investigation and performance analysis of water-diesel emulsion for improvement of performance and emission characteristics of partially premixed charge compression ignition (PPCCI) diesel engines," *Sustainable Energy Technologies and Assessments,* vol. 36, p. 100546, 2019/12/01/ 2019.

[42] L. I. d. C. Silva and A. Caldeira-Pires, "ANALYSIS OF THE IMPACT OF FLOW BOUNDARY CONDITIONS ON THE PERFORMANCE OF A LEAN-PREMIXING COMBUSTOR MODEL," in *Proceedings of the COBEM 2005: 18 th International Congress of Mechanical Engineering*, 2005.

[43] H. Yılmaz, Ö. Çam, and İ. Yılmaz, "An Experimental Study on Effect of Swirl Number and Gas Composition on Combustion and Emission Behavior of Premixed H2/CO/CNG Blending Synthetic Gas Flames in a Novel Combustor," 2018.

[44] B. K. Shah, A. K. Dhakiya, and A. S. Mohite, "Experimental study on the effect of various parameters of recirculating flows induced by vane swirler," *International Journal of Educational Research and Technology,* vol. 3, pp. 24-31, 2012.

[45] V. Patel and R. Shah, "Effect of swirl and number of swirler vanes on combustion characteristics of methane inverse diffusion flame," *Journal of Mechanical Science and Technology,* vol. 33, pp. 1947-1958, 2019/04/01 2019.

[46] M. Elkelawy, H. Alm-Eldin Bastawissi, E. A. El Shenawy, M. Taha, H. Panchal, and K. K. Sadasivuni, "Study of performance, combustion, and emissions parameters of DI-diesel engine fueled with algae biodiesel/diesel/n-pentane blends," *Energy Conversion and Management: X,* vol. 10, p. 100058, 2021/06/01/ 2021.

[47] M. Mathur and M. NR, "Swirling air jets issuing from vane swirlers. 1. Free jets," *Journal of the Institute of Fuel,* vol. 40, pp. 214-&, 1967.

[48] H. A. El-Din, Y.-S. Zhang, and M. Elkelawy, "A computational study of cavitation model validity using a new quantitative criterion," *Chinese Physics Letters,* vol. 29, p. 064703, 2012.

[49] M. Elkelawy, H. A.-E. Bastawissi, A. M. Radwan, M. T. Ismail, and M. El-Sheekh, "Chapter 15 - Biojet fuels production from algae: conversion technologies, characteristics, performance, and process simulation," in *Handbook of Algal Biofuels*, M. El-Sheekh and A. E.-F. Abomohra, Eds., ed: Elsevier, 2022, pp. 331-361.

[50] H. A. E.-D. Bastawissi and M. Elkelawy, "Computational Evaluation of Nozzle Flow and Cavitation Characteristics in a Diesel Injector," *SAE International Journal of Engines,* vol. 5, pp. 1605-1616, 2012.

[51] A. M. Elbanna, C. Xiaobei, Y. Can, M. Elkelawy, and H. A.-E. Bastawissi, "A comparative study for the effect of different premixed charge ratios

Journal of Engineering Research (ERJ
ISSN: 2356-9441 Vol. 7 – No. 6, 2023 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

with conventional diesel engines on the performance, emissions, and vibrations of the engine block," *Environmental Science and Pollution Research,* vol. 30, pp. 106774-106789, 2023/10/01 2023.

[52] H. A.-E. Bastawissi and M. Elkelawy, "Investigation of the Flow Pattern inside a Diesel Engine Injection Nozzle to Determine the Relationship between Various Flow Parameters and the Occurrence of Cavitation," *Engineering,* vol. Vol.06No.13, p. 13, 2014.

[53] M. Elkelawy, E. A. El Shenawy, H. A. E. Bastawissi, and I. A. El Shennawy, "The effect of using the WCO biodiesel as an alternative fuel in compression ignition diesel engine on performance and emissions characteristics," *Journal of Physics: Conference Series,* vol. 2299, p. 012023, 2022/07/01 2022.

[54] J. G. Vaghasia, J. K. Ratnadhariya, H. Panchal, K. K. Sadasivuni, D. Ponnamma, M. Elkelawy*, et al.*, "Experimental performance investigations on various orientations of evacuated double absorber tube for solar parabolic trough concentrator," *International Journal of Ambient Energy,* vol. 43, pp. 492-499, 2022/12/31 2022.

[55] M. Elkelawy, "Experimental Investigation of Intake Diesel Aerosol Fuel Homogeneous Charge Compression Ignition (HCCI) Engine Combustion and Emissions," *Energy and Power Engineering,* vol. Vol.06No.14, p. 14, 2014.

[56] R. Moffat, "Contributions to the theory of single-sample uncertainty analysis," 1982.