Progress in Engineering Application and Technology Vol. 4 No. 1 (2023) 538-544
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PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Investigation on Flame Characteristics of a Flameless Combustor Ignition System Using Spiral Nozzle

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DOI: https://doi.org/10.30880/peat.2023.04.01.057
Received 15 January 2023; Accepted 12 February 2023; Available online 12 February 2023

Abstract: This study was conducted to identify and learn about the fire characteristics when a spiral nozzle is used. The purpose of this study was to discover and learn about the fire characteristics that occur when a spiral nozzle is utilized. Several issues were discovered throughout the ignition system's fabrication and testing phases. The challenge of initiating the fire in the combustor chamber was one of them. The research objectives are as follows: to establish the best operating method for igniting and firing up the combustor chamber. Determine the flame characteristics of the ignition system during combustor chamber firing. Experiments were carried out in the automobile lab of the Faculty of Mechanical and Manufacturing Engineering FKMP during the project's preliminary testing. To conduct out this investigation. This experiment was carried out using premixing (air pressure and Liquefied Petroleum Gas (LPG) and air pressure). For this experiment, the equipment was 1 LPG gas barrel, an air compressor, pipe tubing size 10, 2 flow meters for air and LPG gas, a spiral nozzle 12 inch, and a blow torch to light the fire. Five thermocouples were employed, with a 5 cm space between them. Researchers will be able to overcome the firing up problem during preheating as a result of this research. The use of flameless combustion will help to extend the life of the equipment by ensuring that there is no flame present in the combustion chamber.

Keywords: Temperature Profile, Length Of Flame, Ignition, Spiral Nozzle.

1. Introduction

Nowadays combustion is one of the methods used in the industry for the purpose of heating, drying, shrinking, and polymerizing. Combustion will produce hot air and then it will be channeled in designated places for its purpose of use. Now the world is evolving with the development of technology and expertise in flameless combustion is now developed after seeing some bad effects from

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conventional combustion on the environment and development in industries and daily life energy usage demands immediate action for solutions. It was created because of its primary benefit which is the capacity to produce nearly no CO and NOx emissions throughout the combustion process.[1] This is due to the process itself, in which complete combustion can be achieved without the use of a flame. When old technology which is conventional combustion used to generate hot air has been identified as a source of hazardous gas emissions and a contributor to global warming. There are several advantages of using flameless combustion to create energy over conventional combustion. One of the benefits of flameless combustion is that NOx, CO, and emissions have been reduced to a bare minimum, resulting in a more efficient combustion process that may be classified as green technology.[2] University Tun Hussein Onn Malaysia (UTHM) strives to promote research and development innovative combustion technologies. This project have been done several phases, which is, design, development and fabrication, testing, and finally commissioning to the industry.

1.1 Flameless combustion

Since its discovery, the Flameless Combustion (FC) regime has been regarded as a potentially useful alternative combustion method with the potential to lower the pollutant emissions produced by gas turbine engines [3]. Flame roots are not attached to the fuel nozzle or burner lip, allowing for dispersed combustion in a homogenous temperature field, which results in lower NOx emissions as a result [4]. The well-distributed response zones of this combustion mode can potentially reduce temperature gradients, acoustic oscillations, and NOx emissions. In some aspects, it varies from traditional combustion. One of them is the need to create a high-temperature environment in which to carry out the combustion process. At high furnace temperatures, well above the temperature at which the mixture would automatically ignite, an intriguing occurrence was observed: in the presence of recirculated exhaust gas, there was no visible sign of a flame [5] The recirculation of hot exhaust gas raises the temperature of the freshly injected reactant mixture, preserving the above-mentioned thermal NOX production temperature and lowering CO2 gas dissociation into CO under high temperature circumstances [6].

1.2 Issue arises

During project progress, there were several issues arise. One of the issues was the combustor had difficulty in firing up for pre-heating process. It is highly important to study fuel ignition system and the flame characteristics for a stable and save ignition process. The objectives of the research are to determine the best operating system to ignite and firing up the combustor chamber. Other than that, to determine the flame characteristics of the ignition system during firing up of the combustor chamber.

2. Materials and Methods

The work flow chart for the current investigation is explained at the start of this section This section describes testing facilities, including the spiral nozzle. The instrumentation and measurement technique are then shown, including measurements with a smartphone camera. Adobe Photoshop was utilised for image analysis in this study. The research investigation was conducted in stages or phases. The first step in the research process would be to do a literature review in order to discover and comprehend the combustion process, idea, and technology. The design and development of the flameless combustor are the next steps. Solid Work 2019 was used to make a detailed sketch of a combustor component for this step. Before proceeding, the analysis has been performed.

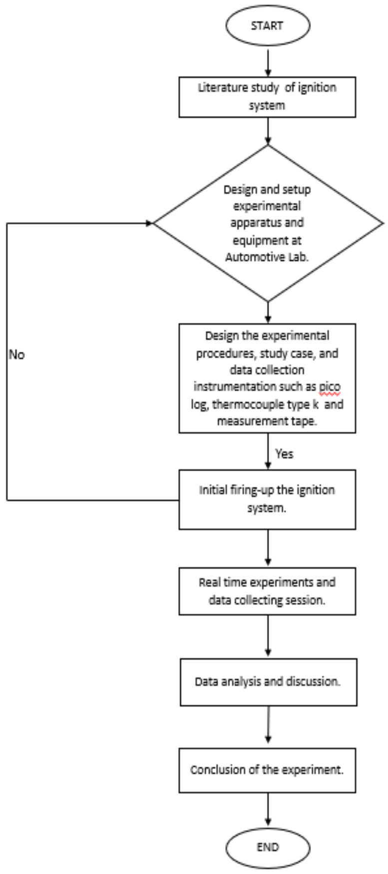

Figure 1 Flowchart

2.1 Materials

The following below was the experimental setup

I. • Air compressor to supply air pressure
II. LPG barrel to supply gas.
III. Two flowmeters for air and pressure.
IV. Pressure gauge to monitor pressure.
V. Spiral nozzle used and located horizontal
VI. Five thermocouples were set and each gap 5cm between it.

2.2 Methods

The process must be followed for this experimental investigation to guarantee that there are no problems while firing up the flame during pre-heat to providing. To begin, turn on the compressor and the LPG tank to feed air and fuel to the direct injection inlet. In the premix experiment, 1 liter per minute of fuel and 5 liters per minute of air have been injected into the direct injection intake as controlled and adjusted by a flow meter. The air will then be set at 5 l/min, 10 l/min, 15 l/min, 20 l/min, 25 l/min, and 30 l/min while the fuel remains constant at 1 l/min to examine the flame characteristics and temperature as the air increases. The air and fuel mixture was then ignited with a blowtorch.

2.3 Stoicometric equation

Stoichiometric condition in a combustion process is when the amount of oxidizer is at the exact amount needed to burn a specific amount of fuel completely.

$$CxHy + a(O2 + 3.76N2) \rightarrow xCO2 + (y\ 2)H2O + 3.76(a)N2 \qquad Eq.1$$

$$a = x + \frac{y}{4} \qquad Eq2$$

The ratio of mass between the oxidizer (normally air) to the mass of the fuel is widely used as a basic tool to describe a combustion process. The stoichiometric air fuel ratio (A /F) stoic can be calculated as;

$$(A/F)stoic = (mi\ mf\ )\ stoic = 4.76a\ MWair\ MWfuel \text{ Eq3}$$

where,

MW_{air} = molecular weight of air

MW_{fuel}= molecular weight of fuel Another term used in describing any combustion

3. Results and Discussion

3.1 Results

This experiment required air and fuel as working fluid. The air and gas fuel were supply to mixing chamber before it reaches to nozzle. The study on the flame is necessary to determine the best equivalence ratio for temperature and flame distance. Data will be determined by plotting x-y graphs.

3.2 Discussions

Figure 1 above show the graph average temperature vs distance from nozzle at Φ 1.33. At equivalence ratio 1.33 the average temperature is between 60.77 degree Celsius until 61.53 degree Celsius. As the temperature increase, the distance from nozzle increase. The distance was setup at tip nozzle starting at 5 cm. At 5 cm the average temperature value was 60.77-degree Celsius. The value continues increase at 10 cm which is the value of average temperature was 70.66 degree Celsius. After that the value sudden decrease to 60.82 degree Celsius before the average temperature continues increase from 15 cm until 25 cm. At 10 cm distance from nozzle, the graph shows the highest temperature 70.66 degree Celsius. It means that the maximum combustion reaction occurs at 10 cm from nozzle. Figure 1 shows the relationship average temperature is directly proportional to distance from nozzle. Figure 1 gives information about the best equivalence at 1.33. This is because, there were no significant different average temperature from at 5 cm and 25 cm distance from nozzle. The average temperature slightly increases from 15 cm to 25 cm. As mentioned earlier, one of the main characteristics that are unique to flameless combustion is the temperature uniformity inside the furnace.(Chanphavong et al., 2018)

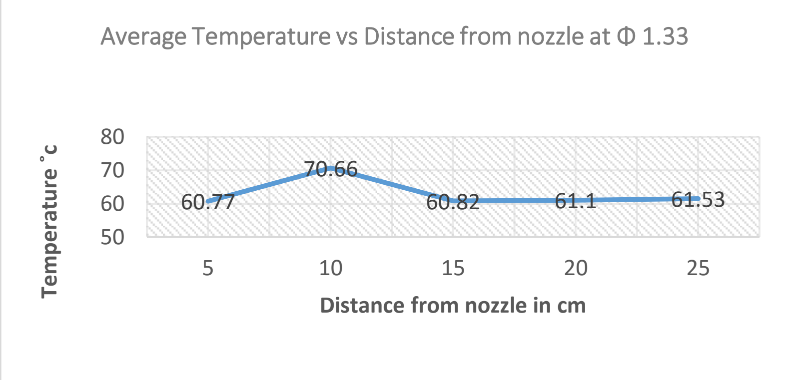

Figure 1 Average Temperature vs Distance from nozzle at Φ 1.33

Figure 2 show the value of maximum temperature and distance from nozzle. At equivalence ratio Φ 1.33 the maximum temperature is between 61.03 degree Celsius until 61.83 degree Celsius. At 5 cm, the value of maximum temperature was 61.03 degree Celsius. It was the lowest value for this graph. The value increase from 5 cm to 10 cm which is maximum temperature also increase from 61.03 degree Celsius to 71.01 degree Celsius. At this point, it was the highest value of maximum temperature which is 71.01 degree Celsius. The value decrease at 15 cm which is the values 60.95 degree Celsius. The value of maximum temperature slightly increases from 15 cm up to 25 cm. At 25 cm the value for maximum temperature is 61.68 degree Celsius. As the data obtain. The value from 5 cm to 25 cm does not show significant different of temperature compare to another graph. Maximum temperature graph provides supportive data about why we choose at equivalence ratio 1.33 was the best sociometric equation for this investigation. As the fuel flow rate increases, spray mists become finer, simultaneously improving the atomization and evaporation of liquid fuel. This resulted into better combustion rate(Puhan et al., 2009)

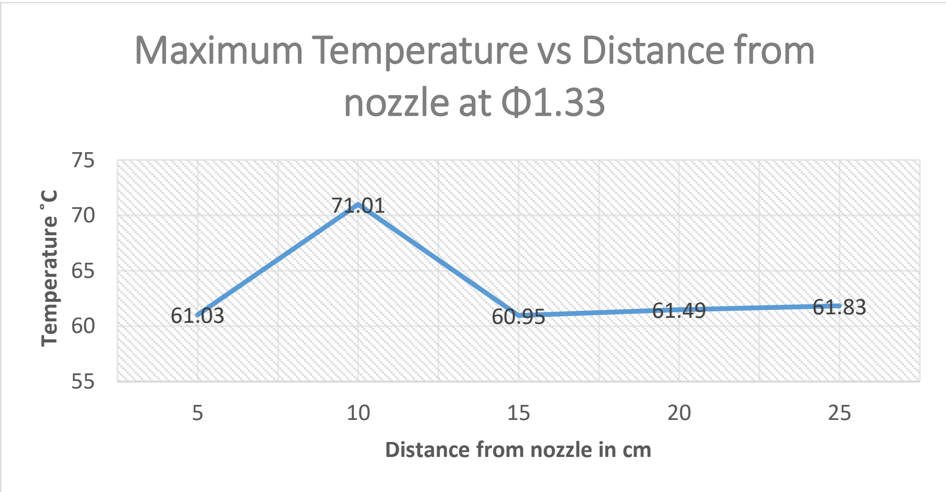

Figure 2 Maximum temperature vs distance from nozzle at equivalence ratio 1.33

Graph above show the average length and equivalence ratio. Air fuel ratio on combustion give a significant effect of flame length. The graph shows decrease pattern start at equivalence ratio 0.33, the length of flame at 35.31 cm. The highest flame length was at equivalence ratio 0.67 which was the 36.21 cm. This condition happens because supply gas was greater than supply air. The flame become bigger and longer than other. The length of flame show decreasing of length. At 31.38 cm the equivalence ratio

1 was recorded. The lowest length was observed at equivalence ratio 2 with the flame length 5.33 cm. This condition call lean mixture because air pressure air exceeds the gas supply. Flame length was one of the crucial characteristics as it need to determine the critical distance for fire from nozzle to ideal distance(Lönnermark & Ingason, 2006).

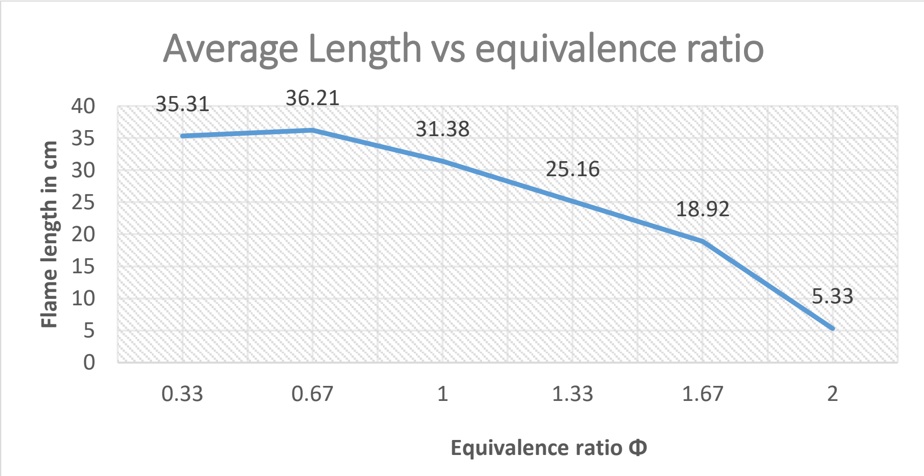

Figure 3 Average Length vs equivalence ratio

Air fuel ratio on combustion give a significant effect of flame length. Figure 4 show the maximum length for every equivalence ratio. To support data above, at equivalence ratio Φ 0.33 the length of flame 36.3 cm. This length was created because exceeds LPG and less air pressure was observed base on the colour of flame. At equivalence ratio Φ 0.67 the flame length 43.8cm. It was the longest length of flame. This length is not suitable for this investigation because the flame length too long for combustor chamber. It will touch the sight glass of combustor. The most ideal length base on graph below was at equivalence Φ1.33. This is because the length ate suitable with the design of combustor chamber and the mixing for flame air was the best operating system to ignite fire. At equivalence ratio Φ 2, the flame of length is not suitable for combustor because the flame length too short and cannot hold the fire too long to mixing with air at combustor chamber. The graph of maximum length also provides the information about the best equivalence ratio to determined flame length of this combustion reaction. Knowing the maximum length of flame provides a priori predict the radiative heat flux hazard from turbulent-jet flames originating from a ruptured, high-pressure hydrogen gas storage source or delivery pipeline(Schefer et al., 2006).

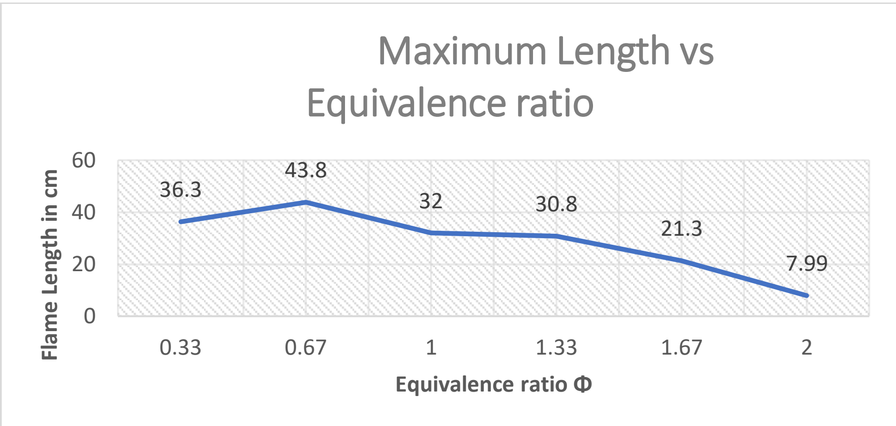

Figure 4 Maximum length vs equivalence ratio

4. Conclusion

The current investigation of flame characteristics of a flameless combustor ignition system utilizing a spiral nozzle effectively analyses flame temperature and length. When the equivalency of the ratio is 1.33, the flame average temperature that is suitable for combustion is determined by data analysis. The flame's average temperature ranges between 60.77°C and 61.53°C. The highest temperature for the equivalency ratio 1.33 is also constant and does not fluctuate significantly from the average temperature. On the other hand, the equivalence ratio 1.33 flame average length is 25.16 cm from the tip of the spiral nozzle. As a result, the flame's equivalence ratio does not differ significantly. Overall, due of the flame at rich mixture, the usage of spiral nozzle for flameless case study is recommended. The presence of a spiral nozzle allows the flame to be maintained. Meanwhile, if the flame is too lean, it will be extinguished due to the air velocity that is supplied disrupting the flame conditions.

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia

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