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Effect of Flame on Various Swirler Angle in Combustion Performance

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ABSTRACT

The industrial revolution is the central cause for the increase of NOx emissions in the atmosphere. Based on the research by Bowman (1992), electricity generation, transportation, industrial activities and biomass burning are the major sources of NOx emissions. Among all NOx, NO is particularly important since about 90% of the NOx produced in the combustion process is in the form of NO. After that, NO2 is produced when NO is reacted with the oxygen gas, O2, in the atmosphere. Because of that, most of the efforts to reduce the emission of NOx in the atmosphere are concentrating on the reduction of the NO emission from the combustion process. A study was conducted to find a way to develop energy sources that are environmentally friendly. A liquid fuel burner with various radial swirl angles has been investigated. All tests were conducted using a diesel as fuel. A radial swirler with curved blades having 50 mm outlet diameter was inserted at the inlet plane of the combustor to produce swirling flow. Tests were carried out using six different radial swirlers with angle of 10°, 20°, 30°, 40°, 50° and 60° respectively.

Keywords: Liquid fuel burner, Radial swirler, Combustion

INTRODUCTION

In recent years, the outcomes of NOx formation in atmosphere have become the subject of many debates due to the increase in the awareness among people on the protection of their health. NOx emissions contribute to the acid rain, reduction of atmospheric visibility, production of tropospheric ozone and also depletion of stratospheric ozone, and all these consequences are detrimental to the environment and human's health [4]. Based on the study by Delfino [8], Kraft *et al*. [11] and Curtis *et al*. [7], NOx can cause serious respiratory and cardiovascular problems to human due to the formation of ground-level ozone and nitrate particles in the atmosphere. In addition to that, the emissions of NOx also result in the large scale environmental issue like global warming, since the gases can be moved with the help of winds. Because of the global warming, the agriculture activities will be negatively affected and as a result, the global food supply chain will be interrupted.

Nevertheless, the emission of NOx can still be reduced through the combustion modifications techniques and also the post combustion methods [6]. Through the combustion modifications techniques, the formation of NO from the burner will be prevented, hence reducing the emission of NOx. On the other hand, through the post combustion methods, the emission of NOx is reduced through the destroying of NO from the products of the combustion process. In this research, the reduction of NOx emission by incorporating swirling flow had been studied. This is one of the possible approaches in the combustion modifications techniques. By incorporating the swirling flow, the turbulence can be enhanced; hence the mixing of fuel and air prior to the ignition can be improved. As a result, the quality of combustion process can be potentially increased and finally the emission of NOx can be reduced.

According to Escott [9], Swirling flow is a result of the tangential velocity component or the swirl using swirl generator. Swirling method is widely used in industrial applications such as furnaces and gas

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turbine combustor, the flame must be short and high intensity to achieve maximum heat release quickly. Meanwhile, if the distance of flame is too long and usually yellow in color, it shows that the ratio of fuel and air mixing is less. This situation increases the emissions of carbon monoxide and unburned hydrocarbons. Besides, the yellow flame also forms regions with non-uniform temperature throughout the flame and this increases the formation of oxides of nitrogen, NOx.

The main role of the swirl flow is to reduce a distance of flame during combustion takes place with producing accompanying rate for high ambient fluid and fast mixing near the nozzle exit and at the boundary of the recirculation, furthermore it helps to improve flame stability due to the formation of recirculation regions in a strong swirling zone. Recirculation area is an area where heat and active chemical species distributed to the ignition source which in turn reduces the velocity required to stabilize the flame. The aerodynamic shaped blocker cause an effect of flame on the burner can be reduced to ensure a minimum maintenance and a long life combustor unit.

Methodology:

Swirler design:

Based on a study conducted by Al-Kabie [3], states swirling flow used for stabilization and control of a flame and to achive a high intensity of combustion. The common method of generating swirl is by using angled vanes in the passages of air.

According to Lefebvre [12], basically most of the conventional burner using axial flow swirler. The swirl vanes are usually flat for ease of manufacture, but curved vanes sometimes performed better aerodynamically. Meanwhile, Ahmad, *et al* [1] also found problems in the achievement of an adequate combustion efficiency and stability with lean primary zone using large air flow axial swirler with central fuel injection. At high air flow, axial swirler has a weakness in terms of air used to mixed with fuel and requires a combustor larger diameter and length. Meanwhile the use of radial flow swirler can provide more air to be mixed at the desired pressure loss. By the study conducted by Alkabie, *et al* [2] showed that these problems could be overcomed by the use of radial swirlers, according to him based on the study on the radial swirler angle of 30°, 45° and 60°. He found 30° swirler provides high combustion efficiency and emissions of CO and UHC are low but high NOx value. Meanwhile, 45° and 60° swirler give otherwise.

In this research radial swirler had been designed using mild steel (figure 1) with a same characteristics as Nazri and Shaiful [13] and the information about the swirler in the table 1.

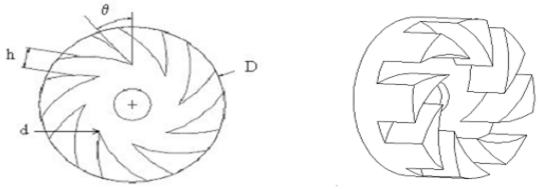

Fig. 1: Schematic diagram of radial swirler design.

Table 1: Dimensions of various radial swirler.

Swirler Angle Parameter	10º	20º	30º	40º	50º	60º
Passage width, *h* (mm)	16	15	13.6	12.3	11.2	9.6
Outlet diameter, *do* (mm)	98					
Inlet diameter, *di* (mm)	50					
Vane depth, L (mm)	25					

Table 2: Comparison between previous researchers.

Radial Swirler Design	Al-Kabie (1989)	Escott (1993)	Nazri and Shaiful (2012)
D(mm)	127	76	98
d(mm)	76	40	50
L(mm)	30.5-11.5	32-8	25
d/D	0.598	0.526	0.51

2.2 Experimental Set-up:

Figure 2 shows the schematic of experimental set-up for combustion test. The set-up includes a low NOx burner, thermocouple, thermocouple reader, electronic gas analyzer, afuel tank, a camera, ring blower, quartz glass and combustion chamber. By using a diesel as fuel to be tested was stored at the fuel tank and was then delivered to a liquid fuel burner which initiated the combustion using excess fuel and air passed from the ring blower until reached stable condition (30 minutes). The combustion test has been done at equivalent ratio 1. The equivalent

ratio 1 means the air and the fuel mixed in a good condition.

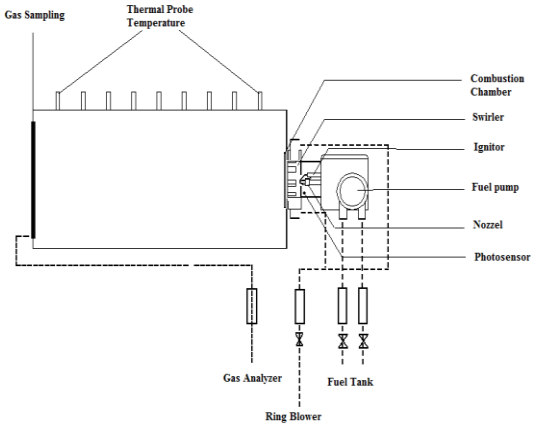

Fig. 2: Schematic of experimental set-up for combustion test.

Procedures:

The liquid fuel burner was switched on and the equivalent ratio set equal to 1. The camera was mounted on a tripod to capture the flame length with high consistency and to avoid vibration, quartz glass that can hold the temperature up to 1500°C located in front of swirler outlet area. For gas emission measurement, electronic gas analyzer will record the rate of emission at a stable condition (30 minutes) and at the same time thermocouple reader will give the result of temperature along the combustion chamber. The whole experiment was repeated by replacing radial swirler with angle of 10°, 20°, 30°, 40°, 50° and 60° respectively.

Results And Discussion

The experimental results for combustion test will include temperature profile and flame length.

Flame Length:

The study of flame length used six different of radial swirler with angle of 10°, 20°, 30°, 40°, 50° and 60°respectively. Basically the flame length has strong correlation to the temperature profile in the combustion tests. A factor involves in a flame length only the properties of the fuel such as fuel type, burning rate and the diameter of the pool, however, the extension of the flame length is not dependent on fluid dynamics.

Based on the studies that have been conducted, combustion with highly temperature influences the formation of CO and NOx. At high combustion temperatures the formation of CO emission is reduced while NOx emission is increase. However, the increasing of CO and NOx emissions can be reduced with high temperatures, shorten time of combustion and short distance formation of flame [13].

Figure (3) shows a different flame length from different swirler angle 10°, 20°, 30°, 40°, 50° and 60°, at equivalent ratio equal to 1. From the Figure (3), shows the highest flame length during the combustion test is 19 cm from the swirler throat to the downstream, by using a radial swirler with angle 10° and the lowest flame length is 9 cm using a radial swirler with angle 60°, the flame is widely spread with a large diameter for a short length. Others flame length are 18 cm for radial swirler with angle 20°, 16 cm for radial swirler with angle 30°, 15 cm for radial swirler with angle 40° and 13 cm for radial swirler with angle 50°.

Moreover, there is buoyancy flame during the combustion tests, using radial swirler with angle 10° and 20°. A swirler with angle 10° has a large gap where the flame float 2.5 cm from swirler throat, while swirler with angle 20° has a small gap compare to the swirler with angle 10° which is 2 cm from a swirler throat.

For the flame profile, yellow flame shows that the temperature is lower than a blue flame but it's produce high CO emissions while the blue flame has a higher temperature but it is produce high NOx emissions, so to reduce NOx it's need a shorten time of combustion. From the figure (3) also shows that there is a yellow flame produce by swirler with angle 10° up to 40°, from the observation during combustion test the swirler with angle 10° shows the highly yellow flame produce, while the swirler with angle 40° shows the lowest yellow flame produce. While other two swirler with angle 50° and 60° shows a highly blue flame produce. From a study of the flame profile, the yellow colours with a long distance of flame shows an incomplete combustion where the flame is not mixed perfectly and contribute a pollution formation, while the blue flame indicates a good and complete mixing.

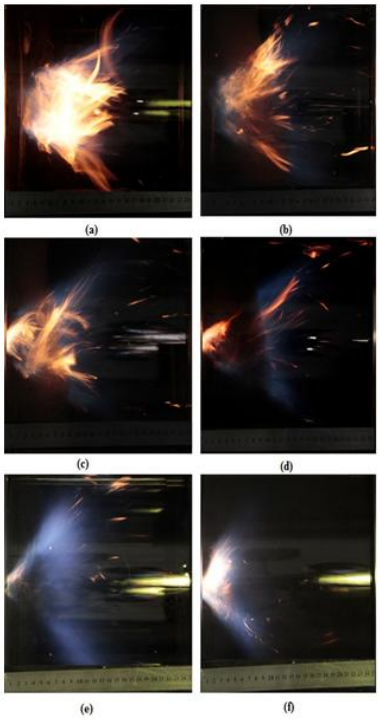

Fig. 3: Flame length at equivalent ratio 1. (a) 10°, (b) 20°, (c) 30°, (d) 40°, (e) 50° and (f) 60°.

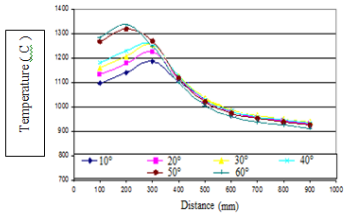

Fig. 4: Wall temperatures at equivalent ratio 1.

Temperature Profile:

During the combustion test, temperature along the combustion chamber has been recorded. There are nine points along the combustion chamber where the temperature has been recorded for wall temperature. Figure 4 shows the wall temperature distribution along the combustion chamber for various angle of swirler. It shown that the lowest temperature is 1100°C produced by radial swirler with angle 10° and the highest temperature is 1350°C produced by radial swirler with angle 60°. The graph also shown that the highest temperature was produce at 200mm from the swirler outlet.

Conclusion:

From the results of this study, the following conclusions could be drawn:

(1) The increasing of swirl angle can produce a high temperature and at the same time can reduce a formation of CO and NOx.

(2) In term of flame profile, blue flame shows a good mixing between fuel and air, while a long with yellow flame shows incomplete combustion.

(3) Overall, swirler with angle 60° produce a high temperature, shorten flame length with blue colour and wide spread.

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