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Effect of Flame Angle Using Various Swirler Angle in Combustion Performance

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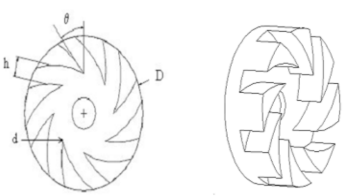
Graphical abstract



Abstract

The abbreviation NO_x is commonly used as a reference to all oxides of nitrogen and the examples of oxides of nitrogen are NO, NO_2 and N_2O. These emission gases mostly come from the combustions of fossil fuels and biofuels in industrial activities and also in road traffics globally. NO_x as a pollutant deserves special attention because of its various issues on human's health and environment. Some of these issues are global warming, acid rain, ozone layer depletion and photochemical smog. To address these issues, some studies are concentrating on the reduction of NO emission from the combustion process. This paper describes a study in the effects of swirling flow generated by using a radial swirler on flame characteristics that is related to the emission of NO. The radial swirlers used in this study have the angles of 40°, 50° and 60°. Diesel is used as a fuel in this study. The results show that all radial swirlers used have different effects on the flame characteristics. From all these radial swirlers, the one with an angle of 60° produces flame with high temperature, short flame length with blue colour and wide spread. The results also show a short time residence during combustion process that could reduce the formation of CO and NO_x.

Keywords: Pollutants; swirling flow; radial swirler; combustion

■1.0 INTRODUCTION

The purpose of developing an advanced combustion system is to reduce the formation of pollutants such as NO_x, CO and UHC in the atmosphere and at the same time to increase the efficiency of the combustion. Boilers, furnaces, industrial burners and the increasing number of cars used on the road are the major sources of these pollutants' formation. According to a study by Sperling and Gordon [1], the number of cars on the road will reach at least two billion units globally by year 2035 and this trend will continue afterwards. This suggests that without appropriate actions, the formation of NO_x, CO and UHC pollutants in the atmosphere will keep on increasing in the future. The formation of these pollutants causes environmental problems that lead to negative implications on the human's health and wildlife's ecology [2]. Awareness on these consequences leads to the development of NO_x reduction techniques, which can be categorized into three main techniques namely pre combustion fuel treatment, combustion modifications and post combustion exhaust gas treatment.

Previous research implies that the combustion intensity, flame size, shape and stability are influenced by the degree of swirl imposed on the flow. The purpose of swirling flow combustion is to accelerate the mixing of two flows that have different densities thus increasing the reaction rate in the combustion process. On the other side, a swirling flow can control and stabilize the combustion process which can improve the mixing of air and fuel in the flow [3].

The common method of generating swirl is by using angled vanes in the passages of air. The characteristics of swirling flow depend on the swirler vane angle. Air swirler is needed to deflect the course of the axial velocity, thus a radial velocity will be produced and this forms a swirling flow in the primary zone. Basically there are two types of swirler design; axial swirler and radial swirler. Most conventional combustors use axial flow type of swirler. The swirler vane is usually flat, but curved vane is sometimes performed for their better aerodynamic properties [4].

A research by Ahmad *et al* [5] encounters some problems in the achievement of combustion efficiency and stability with lean primary zones 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 mix with fuel and requires a larger diameter and length for a combustor. However by using of radial flow swirler can provide more air to be mixed at the desired pressure loss. These problems of combustion efficiency, according to Alkabie *et al.* [6], could be overcome by using a radial swirler.

This paper focuses on the combustion modifications techniques where the reduction of NO_x emission had been studied by incorporating a swirling flow technique to the liquid fuel burner system. By incorporating the swirling flow, the mixing of fuel and air prior to the ignition can be improved. As a result, turbulence can be enhanced, which leads to the potential improvements in the quality of combustion process and also the reduction of the emission of NO_x.

2.0 METHODOLOGY

2.1 Swirler Design

The flow with tangential direction in addition to axial and radial directions is in general regarded as a swirling flow. The swirling velocity component is imparted to the flow normally via the use of three methods. These methods are the axial plus tangential entry of the fluid stream or directly tangential to it, the turning vanes in axial tube and the rotation mechanical devices to impart swirling motion to the flow.

The use of swirling flow obtained with a swirl generator improves flame stability in a combustion chamber by forming a toroidal recirculation zone and the flame length also can be reduced [7]. A study conducted by L. Khezzar [8], states that swirlers are used in combustors to impart rotation to the internal air flow. Consequently, in a study conducted by Nazri, *et al* [9], it is also implied that swirler is used as a flame holder by imparting swirl to the incoming air. The strength of swirl of combustion air is very important for holding a flame in a combustor [10]. As a result by using swirlers, the swirling motion ensures flame stabilization and improves mixing between the fuel and air, thus increasing combustion efficiency. Swirl also plays an important role by preventing the direct impingement of the flame on the combustor walls, thus reducing the potential of damage to the walls [11].

According to Lefebvre [4], one of the most effective ways of inducing flow recirculation in the primary zone is to fit a swirler in the dome around the fuel injector. Vortex breakdown is a well-known phenomenon in swirling flows; it causes recirculation in the core region when the amount of rotation imparted to the flow is high. This type of recirculation provides better mixing than normally obtained by other means, such as bluff bodies, because swirl components produce strong shear regions, high turbulence and rapid mixing. Swirlers are widely use in both tubular and annular combustors. The swirlers include single swirler and double swirler which can be used to supply swirling airflow for combustor.

There are certain matters that have to be taken under consideration in the design of air swirler such as the shape of the air flow required, pressure determination and loss of pressure from the use of air swirler. Other design characteristics of air swirler are such as internal radius before entering the orifice and the thickness of the blade depending on its design and the blade angle. Figure 1 shows the various types of air swirler.

In this paper, the radial swirler is designed by using mild steel (Figure 2) with a same characteristics as Nazri and Shaiful [12]. All the information about the swirler is given in Table 1. Table 2 shows the previous design of the radial swirler. In this study swirler with the design from Nazri and Shaiful [12] is used.

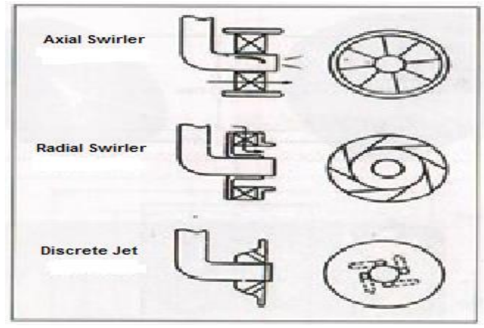


Figure 1 Various types of air swirler [3]

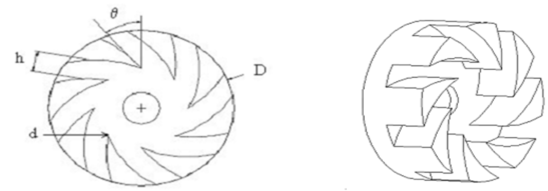


Figure 2 Schematic diagram of radial swirler design

Table 1 Technical data of the radial swirler

Swirler Angle / Parameter	40º	50º	60º
Passage width, *h* (mm)	12.3	11.2	9.6
Outlet diameter, d_o (mm)	98		
Inlet diameter, d_i (mm)	50		
Vane depth, L (mm)	25		

Table 2 Comparison between previous researchers

Radial Swirler Design	**Al-Kabie** [6]	**Escott** [6]	**Nazri & Shaiful** [12]
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

Experimental set-up for combustion test is shown in Figure 3. This set-up consists a low NO_x burner with a radial swirler, in which fuel and air will be mixed during the combustion process, a laboratory scale of combustion chamber with 500mm length, 335mm outside diameter and 5mm of thickness, thermocouple which can hold the temperature up to 2000°C, thermocouple reader, electronic gas analyzer, fuel tank, a camera, ring blower and quartz glass cylinder. The quartz glass cylinder is used as the primary combustion chamber when a flame formed in the zone is observed. In the combustion experiments, diesel as fuel to be tested is stored in the fuel tank and 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 fuel is supplied at the center of a burner. The combustion test has been done at an equivalent ratio equal to 1. The equivalent ratio equal to 1 means the air and the fuel mixed in a good condition.

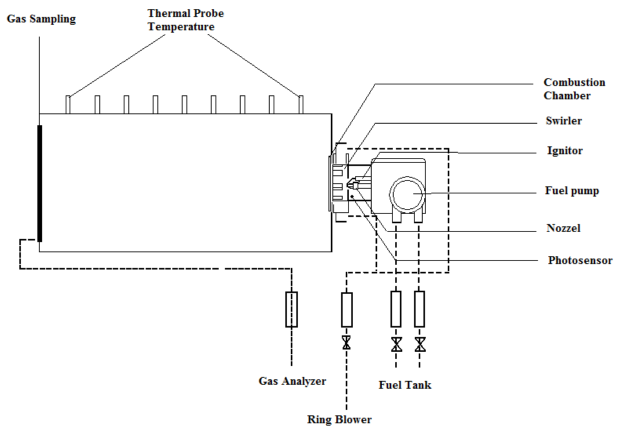


Figure 3 Schematic of experimental set-up for combustion test

2.3 Procedures

The liquid fuel burner is switched on and the equivalent ratio is set equal to 1. The camera is mounted on a tripod to capture the flame with high consistency and to avoid vibration, quartz glass that can hold the temperature up to 1500°C is positioned in front of burner exit area as primary combustion chamber. For gas emission measurement, electronic gas analyzer is used to record the rate of emission at a stable condition (30 minutes). The thermocouple reader is used to measure the temperature along the combustion chamber. The whole experiment is performed by using radial swirler with an angle of 40°, 50° and 60°.

3.0 RESULTS AND DISCUSSION

The experimental results for combustion test include temperature profile and effect on flame angle using different radial swirler angle.

3.1 Temperature Profile

Temperatures along the combustion chamber are recorded during the combustion test. Thermocouple probe are located at six points along the combustion chamber. The temperatures are recorded at the wall and the center of the combustion chamber. The temperature at the center represents the internal flame structure during combustion process. The center temperatures give a higher value than the wall temperature. Graph in Figure 4 shows the temperature profile at the center of the combustion chamber.

Basically the pattern between the center temperature and the wall temperature of the combustion chamber are the same, but both are different in term of value. Figure 5 shows the wall temperature distribution along the combustion chamber.

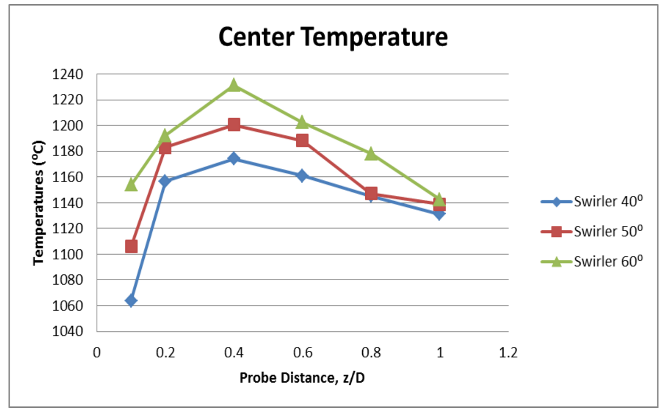


Figure 4 Center temperatures at equivalent ratio equal to 1

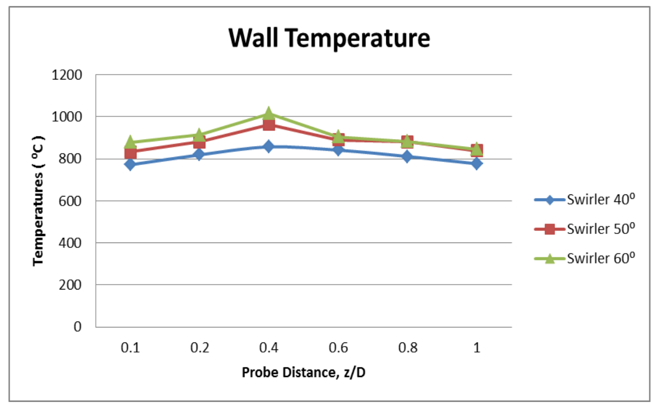


Figure 5 Wall temperatures at equivalent ratio equal to 1

These two graphs show the highest temperature values are produced at z/D = 0.4 from the swirler exit. According to these two graphs, the temperatures for the center and the wall of the combustion chamber at a distance of z/D = 0.4 are 1231.2°C and 964.2°C respectively. Both of these temperatures are produced by a radial swirler with the angle of 60°.

3.2 Effect on Flame Angle

Figure 6, 7 and 8 show the different flame angle produced using 3 different of radial swirlers with the angle of 40°, 50° and 60° at equavalent ratio equal to 1. From this observation, the side view of flame are taken by using the quartz glass cylinder as the primary combustion chamber. It can be seen that the V-shape or cone flame angle from the side view increases as the radial swirler angle is increased. From the combustion test, the radial swirler with angle 40° shows the smallest cone flame angle of 70°. For the radial swirler with angle 50°, the cone flame angle is 93°. The widest cone flame angle is 100° which is recorded in the radial swirler with angle 60°. The widening of cone flame angle by using 60^0 radial swirler indicates that the combustion process is stabilized immediately as compared to both of 40^0 and 50^0 radial swirlers.

Furthermore, the widening of cone flame angle also has influence on the flame length and the formation of CO and NO_x emissions. Based on the studies conducted by previous researchers, the combination of short distance formation of flame, short time residence during combustion and high flame temperature could reduce the formation of CO and NO_x [12,13]. However, the yellow-colored flames with a long distance contributes to the pollutants' formation because the flame is not mixed perfectly, while the blue-colored flame indicates a good and complete mixing [14].

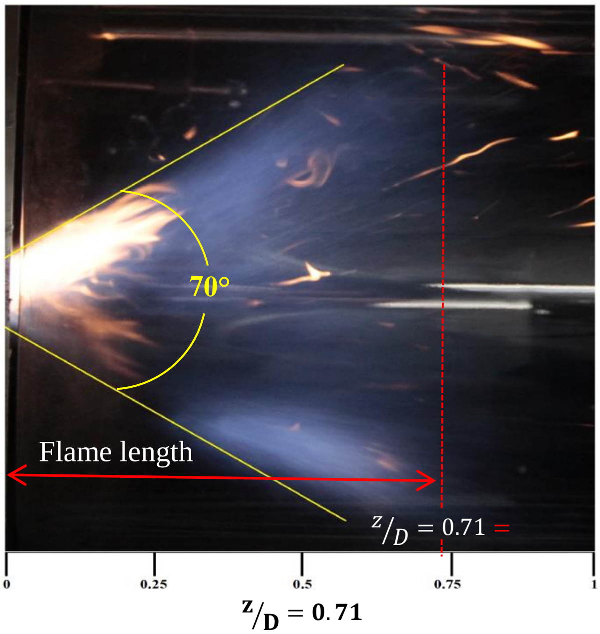


Figure 6 Angle of flame using 40° radial swirler

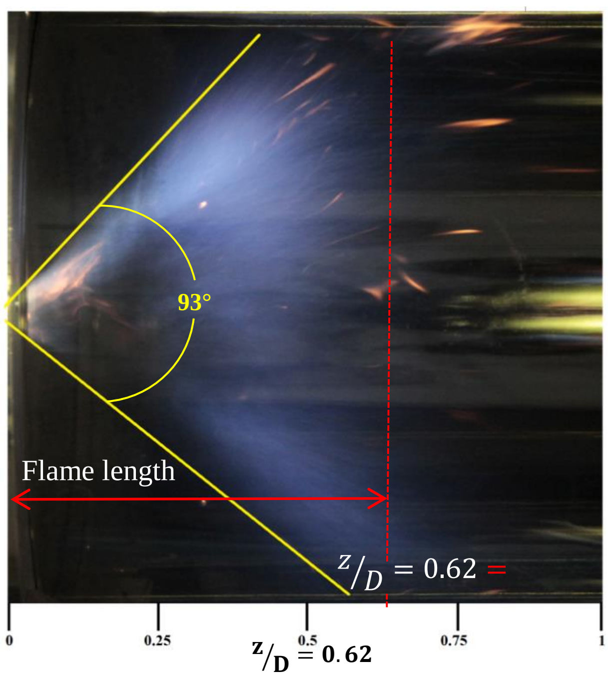


Figure 7 Angle of flame using 50° radial swirler

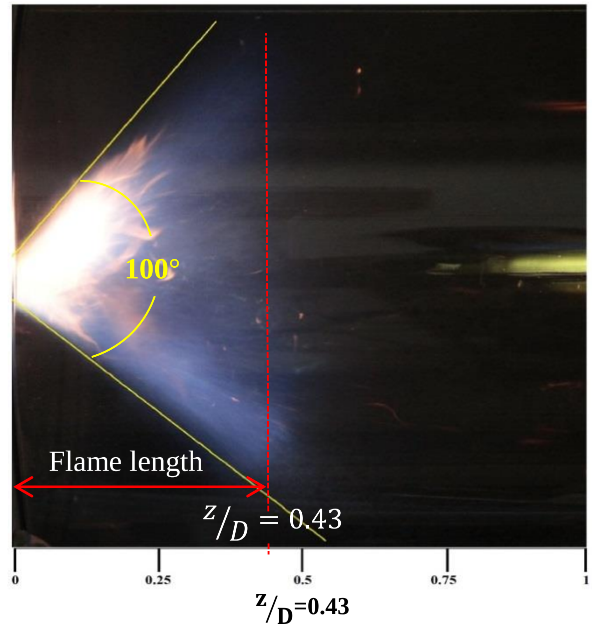


Figure 8 Angle of flame using 60° radial swirler

Figures 6, 7 and 8 also show different flame lengths produced by the three different radial swirlers. Figure 6 shows the flame length produced by 40° radial swirler is z/D = 0.71, followed by the flame length produced by 50° radial swirler which is z/D = 0.62 (Figure 7) and lastly the shortest flame length produced by 60° radial swirler which is z/D = 0.43 (Figure 8) and this flame is widely spread with a large diameter. These three different lengths of flame show that the increasing of swirler vane angles leads to a shorter and wider flame. The reduction of flame length which is necessary to complete the combustion process and at the same time generates a larger recirculation zone, which widen the flame diameter. The work by Nazri *et al*. [9] shows that larger vane angle imparts greater swirling flow and larger recirculation zone produced. As mentioned, the increasing of swirler vane angle could decrease the corner of circulation zone size as the tangential to axial momentum ratio increase [15].

4.0 CONCLUSION

The combustion experiment using radial swirler with three different angles, which is 40°, 50° and 60°, at equivalent ratio equal to 1, is summarized as follow:

(1) In term of reducing CO and NO_x emissions, there are three elements that need to be considered namely short distances of flame length, short time residence during combustion process and high temperature produced.

(2) The temperatures at the center and the wall of the combustion chamber have the same pattern but different temperature values. The wall has lower temperatures than the center of the combustion chamber. At the same time, the increasing of swirl angle produces high temperature and reduced a formation of CO and NO_x.

(3) In term of flame profile, a short-blue-colored flame indicates short time to produce high temperature during a combustion process. This shows a good mixing between fuel and air. On the contrary, a long-yellow-colored flame indicates incomplete combustion and a

long time residence is required to reach highly temperature and allowed formation of pollutant.

(4) From the combustion test, it shows that swirl flow plays an important role in mixing the air and fuel, thereby reducing the flame length.

(5) The increasing of swirler vane angles produces a shorten flame length and a greater swirling flow with larger recirculation zone that leads to widen flame diameter.

(6) Overall, 60° radial swirler angle produces high temperature, shorten flame length with blue colour and wide spread.

Acknowledgement

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