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A Comparison Between The Fractal And Swirl Injector Of Diesel Spray Characteristics In The Burner System

Ronny Yii Shi Chin[1,a], Amir Khalid[1,b], Abd Malek Abd Ghani[1], Mahad Mohamed Issak[1], Shahrin Hisham Amirnordin[1]
[1]Combustion Research Group (CRG), Centre for Energy and Industrial Environment Studies (CEIES), Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400 Johor, Malaysia
E-Mail: [a]ronny2ii@hotmail.com, [b]amirk@uthm.edu.my

ABSTRACT

Low energy use to produce high power technique is demanding by many industries in order to achieve the economical expenses. Cost and energy still a problematic area for the burner combustion for many industries in the world. Besides, combustion process is a main key point for the performance of burner. Well mixture formation for a spray could achieve the wonderful combustion during the burning process. The main purpose of this research is to investigate the performance of turbulence generators (swirler and fractal grids) to the spray characteristics while related to the prediction of combustion process. The studied parameters include equivalent ratio from lean, stoichiometric and rich, in diesel-air mixture formation and spray characteristics such as spray penetration length, spray angle and spray area. The spray images of different equivalence ratio are taken by the direct photography method with a digital camera. The real spray images with the time changes was analyzed by the image processing technique and the swirler and two types of fractal grids (fractal regular grid and fractal grid) are taken into account of comparison with the based diesel fuel. The result showed that the swirler can easily control the penetration length of the spray from preventing contact to the wall of combustor chamber and it is predicted that the combustion will be more complete due to its short primary spray breakup and reduce the emission produce. Nevertheless, fractal grids have been proven that generated high turbulence intensity with increased the spray penetration length and spray area in this experiment and it is predicted to produce high burning velocity than swirler during the combustion process. Application of fractal grid in burner system could produce high power of combustion with lower energy used. However, the emission produced predicted will be slightly higher.

Keywords: Turbulence generators • Swirler • Fractal grids • Diesel fuel • Burner system • Spray characteristics • Performance.

INTRODUCTION

Premixed combustion is currently one of the most crucial technologies in order to reduce pollutant emissions at high efficiencies in the power generation sector, e.g. [1, 2]. However, flame stability and flashback still are problematic areas for many researchers [2-4]. Flame stability is referred to the flame extinction which is the lean limit is approached, while flashback gives negative impact when it is at low heat release rates. Generally, higher turbulent velocities are preferred and for any given fuel, the turbulent flame speed is determined by the turbulent fluctuations of the flow [2, 5]. Therefore, local turbulence level adjusting is strongly desirable in a variety of situations. Combustion is a very complex phenomenon which involving atomization, evaporation and mixing processes and chemical kinetics [6]. Spray combustion models have been under research development for a period [7-9], but the suitable and realistic models have not yet been developed. The spray model development still on a considerable effort which is targeted at accurate prediction and also in detail the second order dependent quantities like particular emission pollutant species concentration [6]. Furthermore, Dent *et al.* [10] knowledge that the fuel spray field is prior essential to combustion as the input data in respects of analytical model and simulation.

Swirl Effects

A common technique used in the industries to stabilize the flame and to control its length to surround the fuel spray by a swirling co-flow [11-13] to generates a recirculation zone (RZ) which to confine the droplets. This configuration is convenient to avoid the flame from reaching the opposite combustor wall in the particular case of power plant combustion chambers. Besides, it also can prevent potential damage to the heat exchanger tubes. Apart from that, physical contact of the flame to the comparatively combustion chamber cold walls can produces a temperature reduction in the reaction zone that can contribute to flame extinction. These phenomena occur when temperatures are lower especially critical in rich or lean mixtures [14].

There are few researcher attempts to conduct experimental investigation about the effect of swirl on the flow and flame dynamics in combustion systems. Tangirala *et al.*[15] focused on the study about the influence of swirl and heat release on the flame properties and flow structures in a non-premixed swirl burner. They

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found that the increasing in swirl number to approximately unity can improve the mixing and flame stability. Furthermore, they also discovered that further increase in swirl actually reduced the turbulence level and flame stability. Stone and Menon [16, 17] studied about a swirl-stabilized combustor flow and they focused on the impact of varying swirl and equivalence ratio on flame dynamics was studied. Other than that, Wang *et al.* [18] conducted an examination about the vortical flow dynamics in a swirl injector with radial entry. Various flow instability mechanisms, such as the Kelvin–Helmholtz, helical, and centrifugal instabilities, as well as their mutual interactions, were investigated in detail.

Fractal Grids

Basic research for the dependence of the turbulence characteristics is convenient to use grids generating turbulence such as perforated plates or meshes. Fractal are the geometric shapes with self-similar for certain similar structure which can be observed at different levels of magnification. The grids are usually located at upstream of the flame with a distances of several characteristic mesh sizes to ensure a well-developed velocity field. Turbulence will decays quickly with downstream distance although the grids can generate high levels of turbulence intensity [19, 20].

Fractal grids generate turbulence fields is differ from those formed by regular turbulence generators such as perforated plates or meshes. Fractal grids usually generate high turbulence intensities travelling an extended region at some distance downstream of the grid with relatively a small pressure drop. According to the Damköhler's theory of premixed flame propagation and Taylor's theory of turbulent diffusivity, adequately described the area of increase in turbulence intensity will cause an increase on the effective flame surface which is deduced from regular turbulence fields. Other than that, variation of the turbulent fluctuations, integral length scale and turbulent Reynolds number are allowed to be independent by using fractal grids [20]. Moreover, fractal grids can produced more than approximately 30% higher turbulence intensities than regular grids even both grids have the same blockage ratio [21].

Several previous researches have been done on fractal grids in various sectors to use the turbulence generating for multipurpose researches. A. Khalid and M. Bukhari [22] conducted a numerical investigation about the circle grids fractal flow conditioner for orifice plate flowmeters. They successfully discovered that the fractal grids could remove the flow distortions and produced the fully developed flow. Besides, M. Fahmi *et al.* [23] also studied numerically about the circle fractal grid perforated plate as a turbulent generator in combustion chamber. They investigated that the fractal grids showed good perceptivity in generating turbulence and the fractal flow physics. Other than that, they found also the turbulent intensity can be increased by a grid with higher blockage ratio. Moreover, M. Bukhari *et al.* [24] conducted an experimental investigation to study the effect of fractal baffles and impellers with double stage 4-blade rushton turbine to fluid flow behaviour in stirred tank. They observed the fractal impeller showed some vortex in the tank with high velocity vector on flow field compared to normal impeller. Meanwhile, they also discovered that the normal baffles gives high velocity vector depends on the configuration used. From their results, the fractal design can give impact on a certain level of mixing efficiency in stirred tank. Soulopoulos *et al.* [25] studied a comparison of flames in fractal and regular grid generated turbulence and they found that the same downstream position fractal grids produced flames with more wrinkling, higher flame surface density and turbulent burning velocities.

EXPERIMENTAL SETUP

The experimental setup basically based on the previous burner experimental setup [26, 27]. The Table 1 shows the properties of Euro 5 diesel fuel which is the only type of diesel fuel used through out whole experiment process.

Table 1: Properties of biodiesel fuels [28]

Specification	Unit	Limits	
		Min	Max
Density at 15 °C	Kg/m^3	820 800^5	845 845^5
Cetane number		51.0	-
Cetane index		46.0	-
Flash point	°C	>55	-
Sulfur content	mg/kg	-	10.0
Water content	mg/kg	-	200
Viscosity at 40 °C	mm^2 /s	2.00 1.50^5	4.50 4.00^5
Cloud point^5 : -class 0 -class 1	°C	 - -	 -10 -16

A schematic diagram drawn for presenting the experimental set up is shown in Fig. 1. The schematic diagram is roughly describes the operation of the burner premix injector which is first invented and designed by Y. Kidoguchi [29]. From the diagram, the injector is equipped in a close spray chamber with one air compressor and two electrical pumps. The input parameters used are the air flow rates and fuel flow rates which are controlled by the control valves and a voltage regulator respectively.

The experiment equipment consists of an premix injector which having 8 orifice holes at nozzle angle of 45° degree with 1mm diameter. The air and fuel inlet of injector are fixed with one-way valve to prevent the flow back. The air flow rate was supplied with the values of 45 cc/min from the bottom inlet of the injector while the side inlet is for fuel injection. Fuel was pumped from the tank by continuous recirculation through washer pump. The values of air and fuel flow rate is based on the calculation. Measurements were made in an optical-accessible burner

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in order to observe the spray pattern in the chamber with the light source is provided. Fully black surface used on the wall of spray chamber in order to produce a better spray image when captured by Digital Single-Lens Reflex (DSLR) camera of EOS 550D. The camera aperture was set to f5.6, the shutter speed is at 1/80 Sec for the spray image. The spray characteristic such as spray penetration length, spray angle and spray area are analyzed through image processing technique. Moreover, only a spray pattern injected from a nozzle taken for analysis.

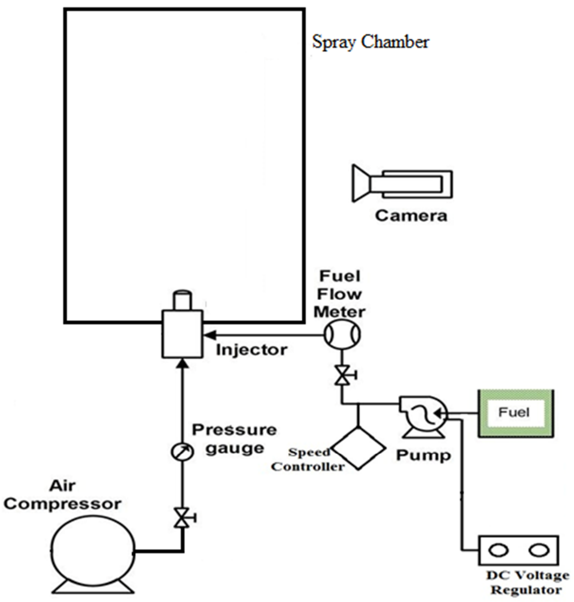

Figure 1: Schematic diagram of experimental setup

Two types of turbulence generator used in this experiment, swirler and fractal grid. Besides, fractal grids model included regular grid and fractal grid. Therefore, total turbulence generators are one swirler and two fractal grids. Few sets of spray image from different equivalent ratio and turbulence generators are taken and compared. In this study, the injection air pressure and ambient density are kept constant at 1 bar and 300K respectively. Fig. 2 indicates the picture of turbulence generators (swirler and fractal grids) used in the experiment.

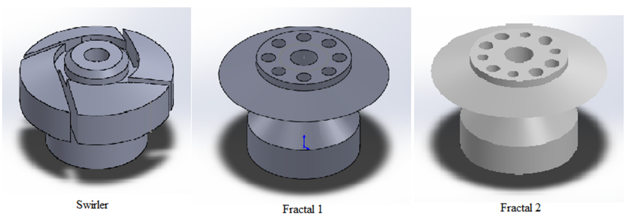

Figure 2: Design of swirler, fractal regular grid and fractal grid

RESULT AND DISCUSSION

The effects to the spray characteristics between the swirler and fractal grid turbulence generator are investigated in this section. An experimental photo captured was conducted with real photography picture captured to observe the behavior of spray atomization in the respect of spray characteristics such as spray penetration, spray angle and spray area. Figure 3 indicates the time duration from 0 to 0.12 seconds of the burner spray with different equivalent ratio such as 0.6 to 1.4 where equivalent ratio of 0.6 identified as the lean air-fuel ratio, 1.0 is the stoichiometric air-fuel ratio and 1.4 is the rich air-fuel ratio. The spray become clearer once the equivalent ratio increase from lean to rich (equivalent ratio from 0.6 to 1.4) due to the fuel loaded into the premix injector increase. Moreover, the Figure 3 shows the burner spray produced by different types of turbulence generator like swirler and fractals. From the Figure 3 showed obviously that the spray produced by the swirler has short spray penetration and small spray area compared to the spray produced by fractal grid. Nevertheless, the fuel and air mass flow rate supplied to the swirler and fractals are the same throughout the experiment, while Fractal 2 design showed the most powerful among the swirler and fractals due to its spray penetration length is the longest compared to swirler and Fractal 1.

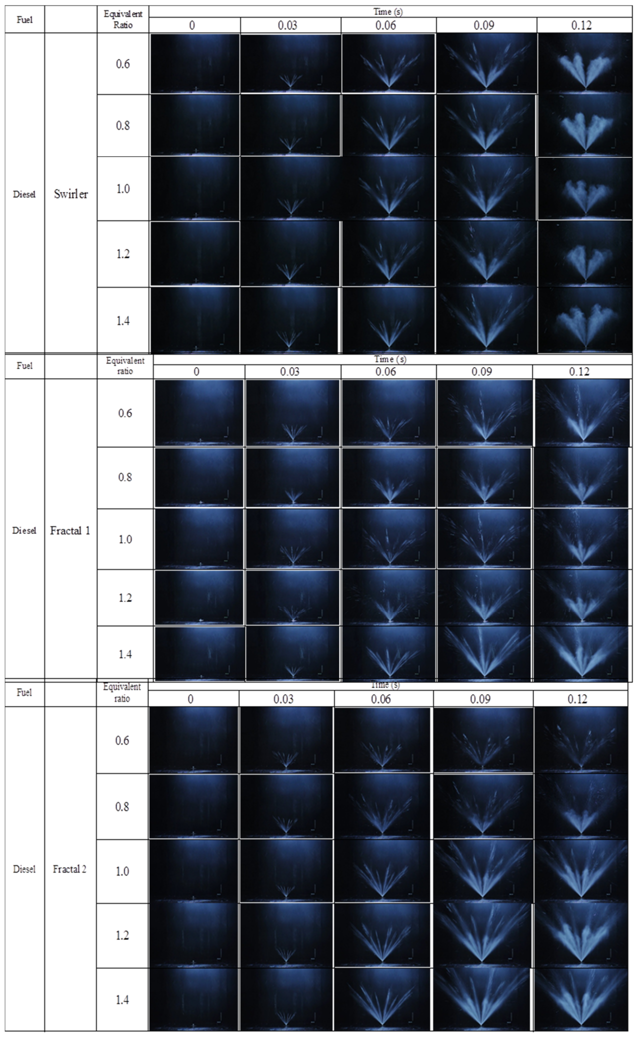

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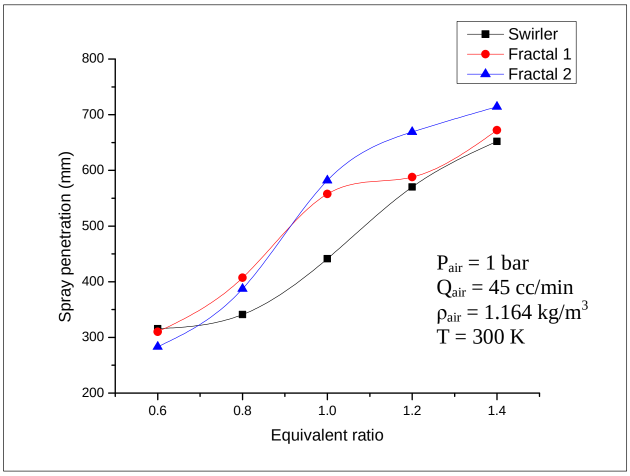
Figure 3: Spray formation of diesel-air using burner premix injector

Spray Characteristics

This section focuses on the graphs plotted from the experimental data obtained. The data simulated from the technique of image processing. There are few graphs plotted like the graph of spray penetration, spray area and spray angle against the equivalent ratio. Those spray characteristics obtained for the purpose of comparing the influences of turbulent generators.

Spray Penetration of Diesel Spray

The spray penetration length is referred to the spray from the nozzle of injector until the maximum tip of spray. Furthermore, it is a parameter which used to judge fuel spray performance. Figure 4 shows the graph of spray penetration length against the equivalent ratio for variant types of turbulence generator such as Swirler, Fractal 1 and Fractal 2.



ratio**Figure 4**: Spray penetration against equivalent

As seen in Figure 4, the spray penetration length produced by the Swirler is the shortest compared to the Fractal 1 and 2 from the equivalent ratio lean to rich. The Figure 4 shows the turbulence generator of fractal grid generated the higher penetration length than the swirler. However, the prediction of turbulent flame speed for any given fuel is determined by the turbulent fluctuations of the flow [2, 5]. Therefore, investigating the local turbulence level is highly desirable in a variety of situations.

Generally, the graph showed both turbulence generator swirler and fractal experienced an incline from lean to rich spray. These phenomena could be explained by the increasing of fuel quantities, which cause the air-fuel ratio become rich and heavier. Therefore the spray primary breakup become longer and thus penetration length increase. The penetration length generated by the swirler showed steadily increase, meanwhile both fractals showed slightly increase fluctuated which had shorter penetration length than swirler when it is lean, then higher around 120mm (Fractal 1) and 150mm (Fractal 2) than swirler at stoichiometric point. However, the penetration length produced by both fractals showed closer to the penetration length of the swirler when it is at rich point (equivalent ratio = 1.4) with longer length around 20mm (Fractal 1) and 70mm (Fractal 2).

The turbulence generator of Fractal 2 design produced higher penetration length compared to Fractal 1. It could be explained by the difference design of the fractal grids which means the structure of meshes or perforated plates affects to the spray performance [20]. Apart from that, the experimental data also agreed that the fractal grids (Fractal 2) can produced higher turbulence intensities than regular grids (Fractal 1) even they have same blockage ratio [20, 21]. Therefore, it can be assumed that the fractal grid (Fractal 2) has the potential to produced bigger burning surface area when it is in combustion process [20]. The advantage of using fractal grid is generating the turbulence fluctuation to enhance the air-fuel mixing and produced an effective turbulent premix flame [2] compared to the swirler even though given the same amount of fuel and air supply. On the contrary, short spray penetration length produced by the swirler is predicted that the spray has short primary breakup and thus the combustion will behaves more completion and less unburnt fuel.

Spray Angle of Diesel Spray

Spray angle is the total angle produce by a single spray. Generally, the spray angle is inversely proportional to the spray penetration [26]. In this experiment, the spray angle is determined to knowledge the total width of the spray produce in order to prevent misfire occurs during the combustion process. Furthermore, investigating the spray angle also could estimate the finer of spray droplets produce. The wider the spray angle, the shorter is the spray breakup, while the finer droplets produce. The complete combustion obtain when the spray droplets are finer. However, a very wider spray could lead to misfire, and it is dangerous and out of the industrial demand. Therefore, an experiment is conducted to investigate the range of spray angle produced by two types of turbulence generator, swirler and fractal from lean to rich mixture. Figure 5 indicates the graph of spray angle produced by one swirler and two types of fractal grid which against the equivalent ratio.

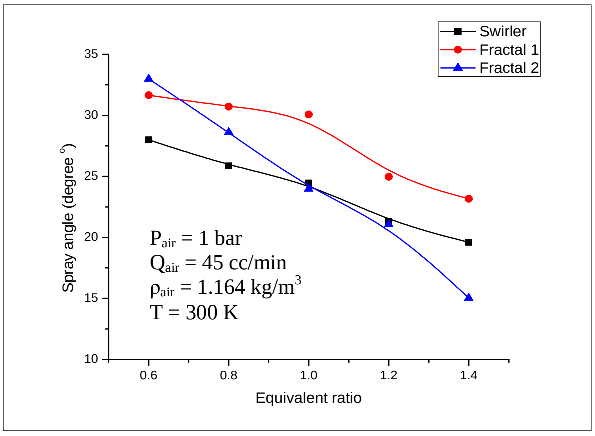


Figure 5: Spray angle against equivalent

The spray angle performed a declined generally for all types of turbulence generator. The swirler performed steadily decreased from equivalent ratio of 0.6 to 1.4 which exactly inversely proportional to its penetration length. The range of spray angle that produced by the Swirler within around 27° degree to 20° degree which is from lean to rich mixture. Meanwhile, the Fractal 1 perfomed unsteady drop from lean to rich mixture with steadily drop from equivalent ratio of 0.6 to 1.0 which is from 32° degree to 31° degree, while suddenly at equivalent ratio of 1.2 and 1.4 which is from 31° to 24° degree. Nevertheless, Fractal 2 showed an extreme drop from around 33° degree to 15° degree when the equivalent ratio from lean to rich mixture. The performance of Fractal 2 could be explained by its spray penetration length. High turbulence velocity brings the spray droplets travel far away while its spray breakup will be longer and thus causing the spray angle decrease.

Spray Area of Diesel Spray

Spray area is determining to predict the flame area when it is in combustion process. According to A. Khalid *et al*. [26] who found that the spray penetration strongly effects to the spray area. They also emphasized that the rise of penetration length could lead to increase of spray area, while the flame area also increase [26]. Furthermore, Taylor's theory of turbulent diffusivity and Damköhler's theory of premixed flame propagation had adequately described the rise of effective flame surface area due to the influences of increasing in turbulence intensity [20]. According to the theories stated, the fractal grid is predicted to have the capability to increase the effective flame surface area due to its turbulence intensity is higher than swirler. Therefore, the data of spray area were obtained through image processing skill from the real photography picture. Figure 6 shows the graph of spray area against the equivalent ratio for two types of turbulence generator, swirler and fractals (Fractal 1 and 2).

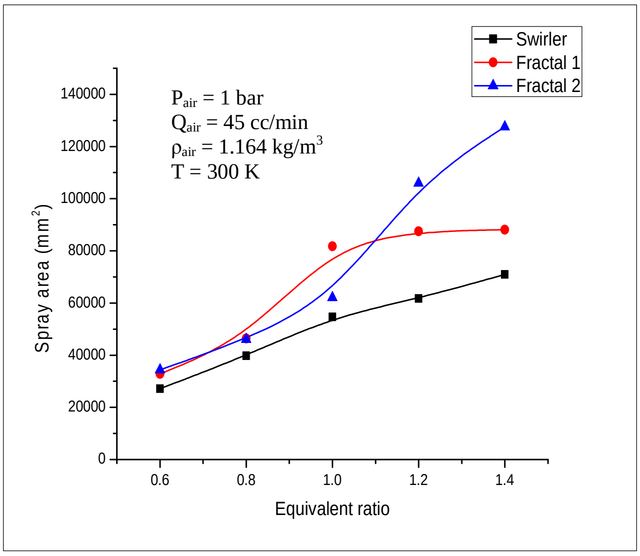


Figure 6: Spray area against equivalent ratio

The spray area of swirler increased gradually as similar with its penetration length which is around 25000 mm^2 until 65000 mm^2 when the equivalent ratio increased from 0.6 to 1.4. Meanwhile, the fractal grid showed slightly fluctuation when their equivalent ratio rise from lean to rich. Fractal 1 experienced a sudden increased from 30000 mm^2 at equivalent ratio of 0.6 to around 80000 mm^2 when it achieved stoichiometry point (equivalent ratio = 1), then increased slowly to around 85000 mm^2 when the mixture turned to rich (equivalent ratio = 1.4). Other than that, Fractal 2 performed an extremely inclined from equivalent ratio 0.6 to 1.4 which is increased from around 35000 mm^2 to 130000 mm^2. This situation could be related to the expression of A.Khalid *et al.* [26] which is penetration length directly proportional to the spray area. Apart from that, the fractal grid design also gives impact to the spray area. The fractal gird design of Fractal 2 successfully generated high turbulence intensity and brought out longer penetration length and bigger spray area. According the T Sponfeldner *et al.*[2], high turbulence intensity capable increase the effective flame area, thus the Fractal 2 is predicted to have high effective flame area than others.

CONCLUSION

At the end of this experimental investigation, a fundamental study on characteristics of the turbulence generator with fractal grids and swirler was carried out using a preliminary spray combustion burner system by changing equivalent ratio. Discussions were made on relation between the swirler and fractal grid into mixture formation and prediction of flame development during burning process. Results are summarized as follows;

1. Swirler can easily control the penetration length of the spray from preventing contact to the wall of combustor chamber. It produced shorter penetration length and wider spray angle. However, it is predicted that the combustion will

be more complete due to its short primary spray breakup and reduce the emission produce. Besides, it is also predicted that the swirler will cause the combustion only a slight change when the equivalent ratio from lean to rich.

2. Fractal grids have been proven that generated high turbulence intensity with increased the spray penetration length and spray area in the experiment. Moreover, fractal grids is also predicted to produce high burning velocity than swirler during the combustion process. It is proven that the fractal grid could generate higher turbulence than regular grid. From the experiment, Fractal 2 produced higher penetration length, spray area and smaller spray angle than Fractal 1.
3. The benefit of using fractal grid in burner system is produce high power of combustion with lower energy used. However, the emission produce by fractal grid might higher than swirler since its penetration length and spray area is higher. Meanwhile, the advantage of using swirler is it produced shorter penetration and it is assumed to have better mixture formation since the atomization breakup length is short. On the contrary, it produced lower combustion energy than fractal grids.

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