Circle grid fractal plate as a turbulent generator for premixed flame: an overview

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Abstract. This review paper focuses to ascertain a new approach in turbulence generation on the structure of premixed flames and external combustion using a fractal grid pattern. This review paper discusses the relationship between fractal pattern and turbulence flow. Many researchers have explored the fractal pattern as a new concept of turbulence generators, but researchers rarely study fractal turbulence generators on the structure premixed flame. The turbulent flow field characteristics have been studied to investigate in a premixed combustion application. In terms of turbulence intensity, most researchers used fractal grid that can be tailored so that they can design the characteristic needed in premixed flame. This approach makes it extremely difficult to determine the exact turbulent burning velocity on the velocity fluctuation of the flow. The decision to carry out additional research on the effect circle grid fractal plate as a turbulent generator for premixed flame should depend on the blockage ratio and fractal pattern of the grid.

1. Introduction

Turbulent flow is defined as formation of chaotic and eddies motions which do not contribute to the volume flow rate. It's also described as moving in irregular patterns, while the overall flow is in one direction. Turbulent flow is common in nonviscous fluids moving at high velocities. Turbulent flow considered as most exiting topic to explore, there are many researchers had been studied about it [8-13], over past decade or so. They purpose fractal grid/multiscale space-scale structure as a new type of turbulent flow generator. These new approach depend on correlation between fractal behaviour and turbulent flow. The turbulent flow field characteristics have been studied to investigate in a premixed combustion application. Turbulent flows were distinguished from laminar flow by Reynolds number [14] characterized qualitatively as irregularity in space and time (chaotic behaviour with coherent structures), continuous spectrum of time and length scales, higher Reynolds number, domination of vortical motion and enhance both, mass and heat transfer [15].

The idea of the fractal/multiscale as a turbulent generator establish from a fractal object obstructing a steady laminar stream that turbulence force by a 3-D fractal grid [16]. Fractal can create space-filling fractal devices for high efficient fluid mixing. The invention was changed in the fractal dimension of the grid alters the scaling of the structure function of the structure functions of turbulence generated by fractal grid. The fractals potential also identified by distinguishes between the scaling properties of turbulence stirred by fractal object [16, 17].
In the structure of premixed flame, fractal grid produced different characteristic compared to the regular grid. At the same burner, same mean and turbulent condition, the turbulent burning velocity fractal grid produced is higher than standard turbulent grid. Although with same turbulent intensity background, the turbulent burning velocity is different depends on the different decay law of turbulent. [18].

2. Relation between fractal pattern and turbulence

2.1 Blockage Ratio
Blockage ratio is defined as ratio of the area blocked by the grid to the whole area of the channel/tunnel square or circle section before it become turbulent or laminar flow. Experiment investigation on a turbulence generation system with high blockage ratio that compared two families of turbulent generator (multi circular jet plate and non circular jet plate) show the multi circular jet have high turbulent level at same blockage ratio, flow rate and preserving radial uniformity.[8].

Figure 1. Families multi-circular jet (MCJ) plate (top left) and non-circular jet (NCJ) plates (single-jet (top center); central-jet (top right); central wake (bottom left), multi-jet (bottom center), wake (bottom right))[8].

Non-circular geometry considered as a good candidate for turbulence generation in a system compared to the circular geometry. It is because, in the same percentage of blockage ratio, the maximum turbulence intensity of non-circular geometry is much higher than circular geometry. There have been several studies looking at the effect of blockage ratio [19]. Depending on blockage ratio Castro demonstrated experimentally that two well distinguishable flow regimes exist. As the blockage ratio decreases, more bleed air is allowed to pass resulting in the re-circulation region moving further downstream until at a certain blockage, it disappears all together. As the blockage ratio increased from 70% to 80% suggesting that at some point in this range, the bleed air is not allowing the flow to come around to create the re-circulating region. To increase the blockage ratio, some geometry altered such as decreasing the bar thickness ratio of the fractal grid, but when lower blockage close to the grid centre and therefore produce large velocities in the central region of the grid [20].
Even though same blockage ratio=0.507, the average normalised pressure drop between upstream and far downstream of the fractal grid is about half that of the regular grid. [12, 21, 22]. Figure 2 satisfied that pressure drop fractal grid higher compare to the regular grid. But in turbulent intensity graph, the fractal grid lower than regular grid [21].

\[ \text{Figure 2. Comparison between fractal grid and regular grid.} \]

From figure 2 it’s shown that, there are differences between grid turbulence generation is distributed in the streamwise direction causing the turbulence to be less and the pressure drop smaller very near the grid by compare to the regular grid. By using fractal grid of larger blockage ratio, particularly because the relation between blockage ratio and pressure drop is very nonlinear and a small increase in blockage ratio can thereby lead to a significant increase in turbulence intensity, which is proportional to the square root of the pressure drop [12, 13, 22]. Multiple perforated plates used to achieve high turbulence close to the grids. Their grids are shifted in space such that the blockage ratio of the plates increases the further downstream the grids are located. By measuring the blockage ratio, the maximum turbulence intensity that plays important role in premixed flames combustion could be determined.

2.2 Fractal pattern
Fractal pattern is variable that important to measure the turbulent burning velocity, pressure drop and turbulent intensity. Reference such as F. C.G.A. Nicolleau [3] used different pattern in their experiment, they found that pressure drop from a lower value to higher value by increasing the distance. The blockage ratio used in their experiment is 33.6%. The experiment that had done to compare pressure drop and velocity on the centerline normalized by inlet velocity by using different patterns such as circle, triangle and pentagon with same blockage ratio.
From figure 3, circle pattern shows the lower pressure drop compared to the others pattern. Meanwhile, velocity on the centerline normalized by inlet velocity for circle pattern is higher compared to the other pattern such as triangle and others fractal orifice plate. It’s shown in figure 4. In our research, we try to introduce combination of circle grid and perforated plate in a plate. The suitable blockage ratio is about 50% to 70% because of the some limitation during fabrication the plate.

2.3 Turbulence intensity in premixed flame.

Turbulent intensity also often referred to as turbulence level. For fractal generated turbulent case, the level classified as medium turbulent case (no complex device) usually in between 1% and 5% turbulent intensity. The location maximum turbulence intensity determined by the blockage ratio (the ratio between the area occupied by the grid and the duct area). By using similar blockage ratio, the fractal grids have higher turbulence intensity compare to the regular grids [12, 20, 22, and 23].

Figure 4 significantly shown the turbulence intensity for regular grid is lower compared to the fractal grid. By compare fractal grid plate and without fractal grid, R. E. Seoud decided that using the fractal grids as higher as three times turbulence intensities produced than classical non fractal grids [22]. They also concluded that their space filling fractal square grids generated a kind of homogeneous isotropic turbulence which decays and locked into a single length scale. But N. Mazellier [13] stated
that the grids are shifted in space such that the blockage ratio of the plates increases the further downstream the grids are located by using multi-scale injector (tested on a premixed v-shape flame) then they assume injectors double the turbulence intensity of normal grids. According to the need of combustion application, some researchers [12, 20] use the grid that can „tailor” so that they could design the position of the location maximum turbulence intensity. In term of position of fractal grid, the turbulence intensity depends on the position of the fractal grid located.

Griebel [24] studied the differences of turbulence intensity by used different position of the fractal grid. The result shown, the turbulence intensity for fractal grid located near to the chamber have more turbulence intensity compare to fractal grid located far away from the chamber.

3. Conclusion

In this present review paper, the aim is to introduce the circle fractal grid perforated as one of the option to generate the turbulence in order to stabilize on the structure of premixed flames. There are many researchers done their studied (experiment and simulation) about fractal grid as turbulence generator, but, a circle fractal grid perforated was introduce to stabilize on the structure of premixed flames.

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