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EXPERIMENTAL STUDY OF CIRCLE GRID FRACTAL PATTERN ON TURBULENT INTENSITY IN PIPE FLOW

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ABSTRACT

Fractal turbulence is deemed much more efficient than grid turbulence in terms of a turbulence generation. In this paper, the hotwire experimental results for the circle grids fractal pattern as a turbulent generator will be present. The self-similar edge characteristic of the circle grid fractal pattern is thought to play a vital role in the enhancement of turbulent intensity. Three different beta ratios of perforated plates based on circle grids fractal pattern were used in the experimental work and each paired with standard circle grids with similar porosity. The objectives were to study the fractal scaling influence on the flow and also to explore the potential of the circle grids fractal pattern in enhancing the turbulent intensity. The results provided an excellent insight of the fractal generated turbulence and the fractal flow physics. Across the circle grids fractal pattern, the pressure drop was lower but the turbulent intensity was higher than those across the paired standard circle grids.

Keywords**:** Turbulent intensity, fractal, pressure drop, hot wire anemometer

INTRODUCTION

Since turbulent flows were discriminated from laminar flows by Reynolds (Reynolds 1883) more than a century ago, they have been experimentally generated mostly using simple shapes. There have been attempts at understanding turbulence using fractal formalism (Meneveau and Sreenivasan 1990) but until today, most of the grids used to generate turbulence rely mostly on classical geometry. However, recently a new class of turbulent flows is attracting interest. These flows are based on geometrically complex, multiscale shapes, often following a fractal pattern. In parallel to these new experimental approaches there have been attempts at understanding how particular interactions would generate particular energy spectra but the researchers are still far from any complete theory relating fractal and spectral aspects of turbulence. The study here is related to this new trend of turbulent flows but the interest though still theoretical focuses more towards applications. The purpose of this study is to investigate the effect of a circle grids fractal pattern on the generation of turbulent flows in a pipe.

An orifice flowmeters is the most common form of differential pressure flowmeters used in industry (D.Johnson 2005). The orifice flowmeters have become the most popular form of flowmeter due to its simple construction, low maintenance costs, simplicity and ease of installation, and its wide range of applications to different fluids, from liquid to gas. In addition, there is a great weight of experience to confirm its operations and this method have been documented in more detail in BS 1042 (British Standard 1042 1992) and ISO 5167 (ISO 5167 1991). Though the orifice plate as a differential flowmeter has gained an overwhelming popularity because of its low maintenance cost (Miller 1989) compared to many other existing flowmeters, the inefficient mixing which it generates results in a larger than required pressure drop. To sustain the flow rate, the necessity to overcome the accumulating pressure drop caused by many orifice plates over the entire pipe network may become expensive. Ideally we would like the flow to recover as fast as possible in order to lower the energy cost associated to the pressure drop necessary for flow metering.

One way to speed up the flow recovery is to fill the pipe as fast as possible by improving the flow mixing, perhaps by a forced energy cascade. This is where practical interest meets the theoretical research on fractal-generated turbulence which can provide interesting alternatives for forcing turbulence. To tackle this problem from the engineering point of view, we developed fractal orifice plates, and studied their performance as turbulent generators.

EXPERIMENTAL WORK

Circle Grids Fractal

The work described here is based on a novel family of fractal space filling grids with circles. Figure 1 shows the generation of the fractal space filling circle grids from the initiator (first iteration) to higher order iterations up to the fourth level of fractal pattern.

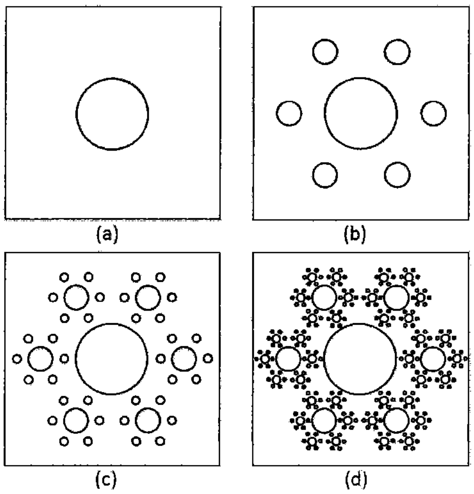

Figure 1. Fractal space filling circle grids

As this pattern will be used as turbulent generators in a pipe flow, a small modification was made to the design to fit with the size and shape of the pipe. Starting from third iteration, the circle grids fractal orifices used for this work is shown in Figure 2. The first orifice is equivalent to 14.45% porosity, followed by the second orifice with 25% porosity and the last is the orifice with 51.85% porosity.

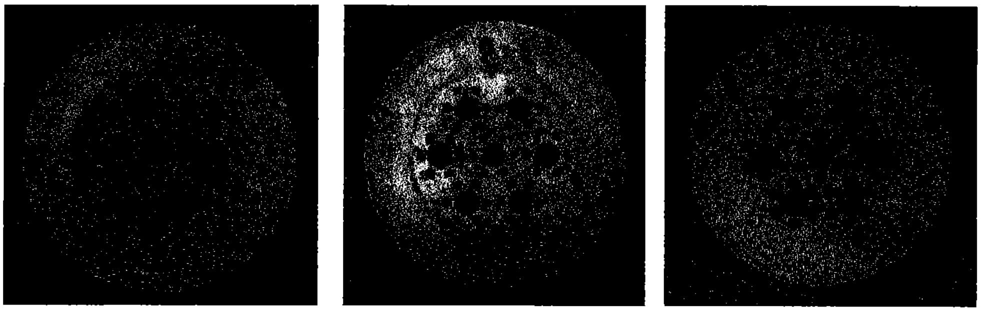

Figure 2. Circle grids fractal pattern

Hot-Wire Anemometer

Hot-wire anemometry is the most common method used to measure instantaneous fluid velocity. The technique depends on the convective heat loss to the surrounding fluid from an electrically heated sensing element or probe. A hot-wire anemometry measures fluid velocity by sensing changes in heat transfer from a small, electrically-heated sensor (hot-wire) exposed to the flow. Hot-wire anemometry is a well-established technique for fluid flow (Bruun 1995). It works based on convective heat transfer from a heated sensor to the surrounding fluid, the heat transfer being primarily related to the fluid velocity. By using very fine wire sensors placed in the fluid and electronics with servo-loop technique, it is possible to measure velocity fluctuations of fine scale and of high frequencies.

When the wire is placed close to a solid wall, heat will be conducted through the flowing medium to the wall. If not corrected for this will cause the velocity to be measured too high. The wall influence starts at:

$$y+\leq \frac{yU_\tau}{\nu} = 3.5 \qquad (1)$$

Where, y is distance to the wall, $U\tau$ is friction velocity and $\boldsymbol{\nu}$ is kinematic viscosity. The critical wall distance is typically 0.1 to 0.2mm depending on free streaming velocity [6]. The advantages of the CTA over other flow measuring principles are ease-of-use, the output is an analogue voltage, which means that no information is lost, and very high temporal resolution, which makes the CTA ideal for measuring spectra.

Experiment Set-up

An experimental setup was established to measure the pressure drop after the circle grids fractal orifices as a function of the distance apart from the orifice position. The airflow in the test section was supplied through a open circuit tunnel with a cross section area of 0.00196 m^2 and a total length of 2.75 m. The inlet velocity was measured by a pitot tube located 15D downstream of the pipe entrance. The measurements were taken every 25 mm starting from 1.5D to 5D downstream of the circle grids fractal orifices, then in 50 mm increments to 8D and finally at the last location at 9.5D to give total of 12 measurement positions. A schematic drawing of the experimental set-up is shown in Figure 3.

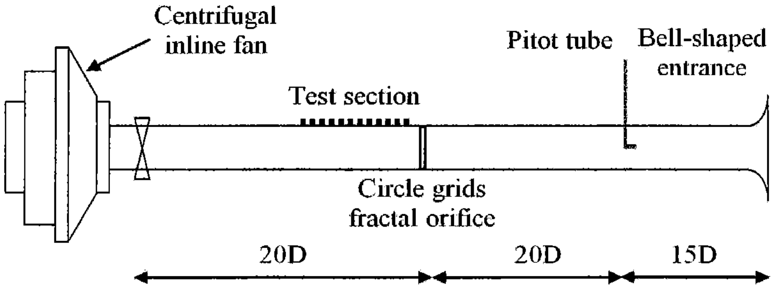

Figure 3. Schematic drawing of the experiment

The flow was driven by a centrifugal inline fan with a speed controller. A bell mouth was used at the inlet of the pipe to ensure that the flow was fully developed in a short distance. Enough length has been allocated before the test section from the pipe entrance to ensure the flow is fully developed turbulent flow. To avoid the influence of the fluctuating flow through the measuring test section, more than 20 reading have been recorded per measuring station, and then the averaged was recorded.

The pressure holes were taped at fixed locations in the order 1/4 of the diameter starting from the orifice position and downstream of the flow in x-direction. The pressure taps were connected to a digital differential pressure manometer using plastic tubes of 4.5 mm in diameter. The digital differential pressure manometer is a microprocessor-based precision measuring instrument for low range differential pressures. It contains a highly sensitive differential pressure transducer and it displays the measured pressure in 11 different measuring units selected from the menu.

All the runs have been done at the same flow rate, in practice at the same control valve position. All circle grids fractal orifices are placed at the same position and several measured pressure drops, Δp, at each tape have been recorded. For each measured orifice, the orifice and the tap-hoses connection have been investigated in order to reduce any leakage. The flow is initiated in the pipe by operating the fan and then left to an appreciated time, transient filling time, to ensure that the pipe is filled completely by the fluid. Next, the measurement is taking using the digital micro-manometer and adjusted to ensure the flow rate is constant for all the different circle grids fractal orifices.

RESULTS AND DISCUSSION

The test was divided in two sections and the first is measuring turbulent intensity while using the same porosity of plate but different Reynolds number. The second is measuring turbulent intensity while using the same Reynolds number but different porosity of plate.

Turbulent Intensity with Different Reynolds Number

As in Figs. 4 to 6, with the increase of the position downstream the flow the turbulent intensity is reduced for all range of the Reynolds number. This may be explained as the circle grids fractal orifices have significant effect on the flow downstream the flow and enhance the mixing properties leading to this turbulent intensity reduction. From the nearest location downstream of the circle grids fractal pattern, the turbulence intensity decreases dramatically and then decreases slowly until it achieved constant value. The highest turbulence intensity generated is 0.95 by plate with β = 0.38 at the lowest Reynolds number, while the lowest turbulence intensity was generated is 0.52 by plate with β = 0.7 at the highest Reynolds number

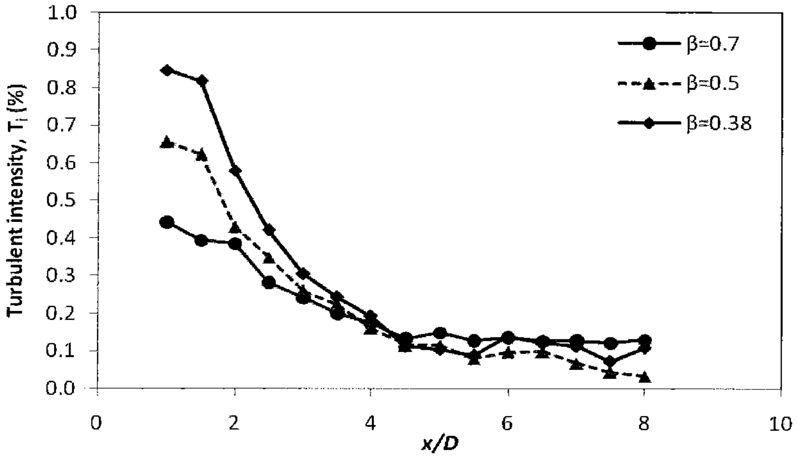

Figure 4. Turbulent intensity for Reynolds number 11528

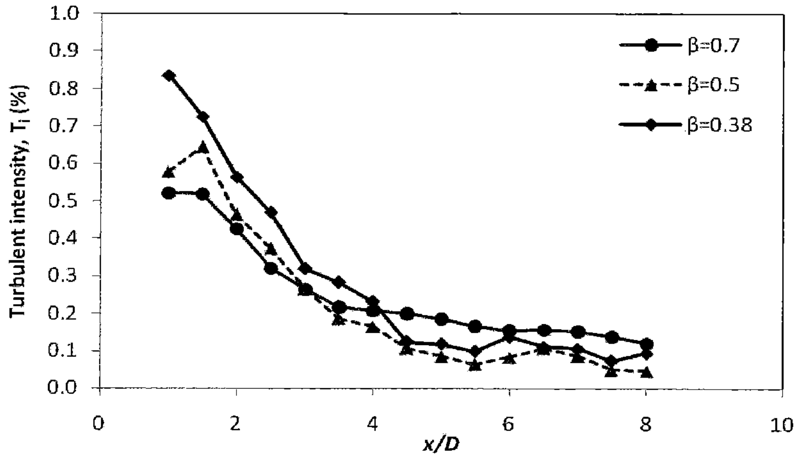

Figure 5. Turbulent intensity for Reynolds number 9722

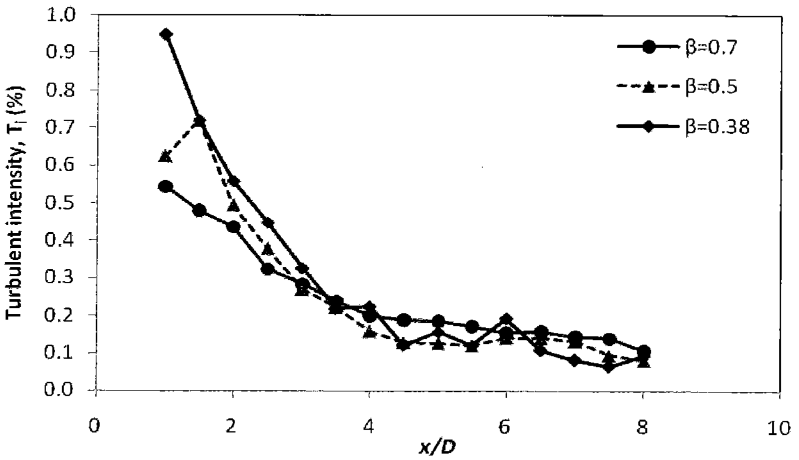

Figure 6. Turbulent intensity for Reynolds number 7917

Turbulent Intensity with Different Plate Porosity

Another interesting result to discuss here are the relation between the turbulent intensity and the plate porosity. From the Figs.7 to 9, the results show that with the increase of the porosity of the fractal plate, the turbulent intensity also increases. From 1D to 4D downstream of the plate, the turbulence intensity decreases dramatically and after the 4D downstream the decreasing of turbulent intensity starts to become constant.

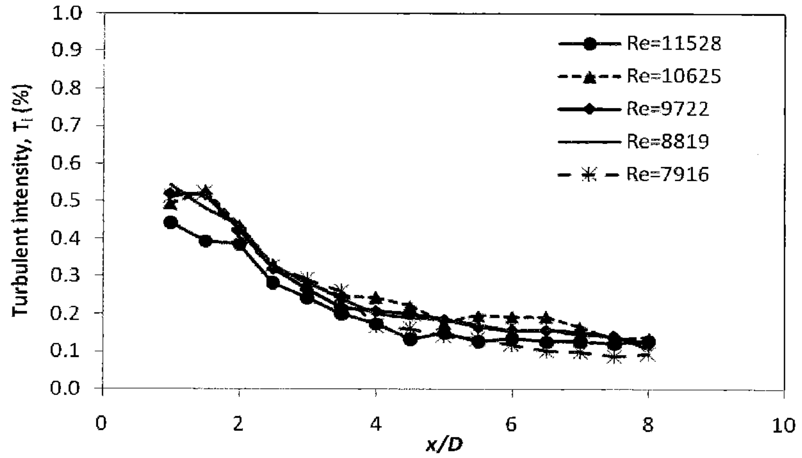

Figure 7. Turbulent intensity for plate porosity 14.15%

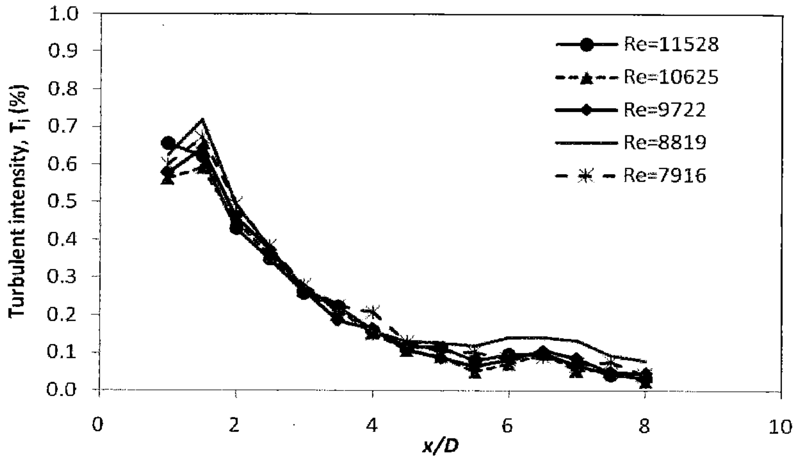

Figure 8. Turbulent intensity for plate porosity 25%

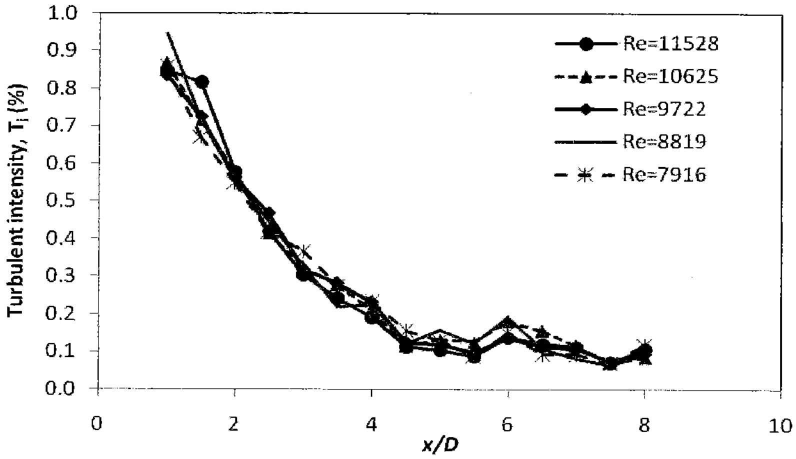

Figure 9. Turbulent intensity for plate porosity 51.85%

CONCLUSION

For conclusion, all of the fractal patterns used in this research was found to be effective to generate turbulence flow. The turbulence flow can be measured by measuring the velocity of the air flow after through the fractal plate at multiple-point. But, the value of turbulence flow is different following the porosity of plate. Three of the plates were compared and it was obtained that the plate with higher porosity (51.85%) generated low turbulence intensity at nearly downstream. Otherwise, in range 1D to 4.5D the plate with low porosity (14.45%) generated higher turbulence intensity than other plate. But, the turbulence intensity was decreased dramatically at that range. In contrast with the plate with higher porosity, although it generated low turbulence in short distances downstream it decreases slowly until a long distance downstream.

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