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Experimental Study of the Pressure Drop after Fractal-Shaped Orifices in a Turbulent Flow Pipe

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Abstract**—**The fractal-shaped orifices are assumed to have a significant effect on the pressure drop downstream pipe flow due to their edge self-similarity shape which enhances the mixing properties. Here, we investigate the pressure drop after these fractals using a digital micro-manometer at different stations downstream a turbulent flow pipe then a direct comparison has been made with the pressure drop measured from regular orifices with the same flow area. Our results showed that the fractal-shaped orifices have a significant effect on the pressure drop downstream the flow. Also the pressure drop measured across the fractal-shaped orifices is noticed to be lower that that from ordinary orifices of the same flow areas. This result could be important in designing piping systems from point of view of losses consideration with the same flow control area. This is promising to use the fractal-shaped orifices as flowmeters as they can sense the pressure drop across them accurately with minimum losses than the regular ones.

Keywords**—**Fractal-shaped orifice, pressure drop, turbulent flow.

I. Introduction

MEASURING the flow rate of liquids and gases in piping systems is an important issue in many industrial applications which depends on the accurate flow measurements. In orifice flowmeters, the pressure drop is measured across a flat plate metal orifice with a specific hole size relative to the pipe inner diameter and most of these orifices are of the concentric type, this hole has a certain finishing in its edge. The major advantage of using such that orifice flowmeters is that: they have no moving parts then no maintenance needed and their cost of manufacturing does not increase significantly with pipe size. The measuring accuracy of the orifice flowmeters depends on the installation conditions, the accurate orifice area ratio calculation and the physical properties of the fluid being measured. The effects of insertion of such that orifice flowmeters in piping systems, either the flow is laminar or turbulent, have been received a lot of attentions due to its importance as a flow measuring tool.

As an innovative thinking, we expect that the fractal-shaped orifices flowmeters have a significant effect on the pressure drop measured across them due to their edge self-similar shape which enhances the mixing flow properties. The turbulence has different scales, a progressive scaling from large scale to small scale, which are structured in a space-filling fractal behavior; this plateau is expected to have an impact on the scaling properties of the turbulence structures which may lead to improvement in the drag properties and the pressure losses in these turbulence generated systems. This was the motivation for some recent experimental and numerical investigations to use a fractal-shaped grid to generate turbulence. Most of the researches that have been dealt with the fractal theory, either numerically by using the fractal concept to calculate the topology of complicated geometry of an interface surface as in combustion premixed flames using one of the fractal dimension methods or experimentally to find this value. Because of their complexities in manufacturing, limited experimental studies of fractal-shaped objects have been established to study their effects in the turbulent flow. However, their applications in the recent years have been became a dominant in some industries: [1] explain the importance of the fractal-shaped objects in distributing the fluid in the molasses chromatography process for controlling exhaustion/ regeneration in thin juice ion exchange and for providing uniform air circulation in a sugar silo. Their increasing role is base on their rapid mixing, controlled formation of specified fluid geometry and due to their low energy fluid distribution. In [2] they introduced a shell-model to study the fractal-generated turbulent flow for different fractal dimension objects as in [3]. They found the power of the shell-model fractal forcing is an increasing function of the fractal dimension of the furcal object. Also, their results are sensitive to the modelling of the fractal forcing but supported the idea that the furcal forcing expected to change the turbulence scaling properties. In [4] investigated experimentally the effect of scaling properties of objects have a fractal-shaped, self-similar structure and limited to the 4th iteration, on the turbulence generated in a wind tunnel flow using 10 hot wires anemometry at different positions

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downstream the flow. They measured the energy spectrum and both the transverse and the longitudinal structure functions for different fractal objects and for different orientations and positions. They found that: the scaling properties of the turbulence, as the turbulence intensity, are depending on the orientation and the position of the fractal object relative to the velocity sensors. Also, it is difficult to relate between the dimension of the fractal-shaped objects and the scaling properties of the turbulence for this low Reynolds number, for more investigations it requires high Reynolds number and more fractal-shaped objects.

Here, we tried to manufacture a well-defined shape, Von Koch shape, in which a precise calculation has been done to produce the accurate generation of the basic shape. The pressure drops across these fractal-shaped orifices have been investigated using a digital micro-manometer at different stations for different fractal-shaped in a turbulent flow and a comparison with those results obtained from ordinary orifices with the same flow area has been made to illustrate their effect on the pressure drop.

II. Experimental Set-up

An experimental setup was established to measure the pressure drop after the fractal-shaped orifices as a function of the distance apart from the orifice position; the airflow in the test section was supplied through a horizontal Perspex pipe with length 236 cm before the test section and 182 cm after the test section and with a cross section of diameter, D =140.8 mm. The flow is driven by a fan powered by a motor power of 0.5 HP and drive volt and ampere of 220/240 V and 3.6 A respectively at a constant speed 2850 rpm, as shown in Fig. 1.

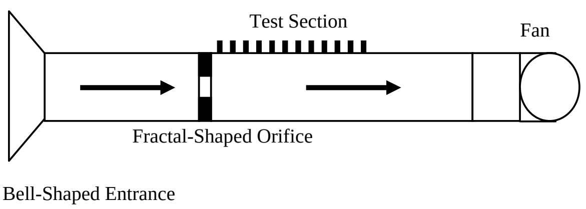

Fig. 1 Schematic drawing of the experiment

The flow is controlled in the pipe through an outlet rotating valve placed at the exit of the Perspex pipe near the fan. Enough length has been allocated before the test section from the pipe entrance to ensure the flow is being fully developed turbulent flow. The test section was taped with 12 holes to introduce the measuring stations of the pressure drop downstream the pipe. To avoid the influence of the fluctuating the flow through the measuring test section, more than 20 reading have been recorded per measuring station then the averaged has been calculated.

III. Test Section

The pressure holes were taped at fixed locations of order 1/4 of the diameter starting from the orifice position and downstream the flow in x-direction. The pressure taps were connected to a digital micro-manometer (Furness FC0510) using plastic tubes of 4.5 mm in diameter. The digital micro-manometer is a microprocessor-based precision measuring instrument for low range differential pressures. It contains a highly sensitive differential pressure transducer capable of resolution down to 0.001 Pascal and it displays the measured pressure in 12 different measuring units selected from the menu. A data logging facility allows storage of measurements in the memory and the results can be downloaded to a computer or printer, using the RS232C output. Its working temperature range is from 0°C to 45°C and the measured gas pressure must be dry.

IV. Fractal Concept

The world around us is not naturally smooth-edged but has been allocated with rough edges in which the nature deals with non-uniform shapes rough edges, Mandelbrot [5] assigned the name “Fractal” to describe the shapes or objects too irregular to include in traditional geometry and of which are detailed at all scales. The fractal geometry concept is used to the geometry of irregular shapes where an identical pattern repeats itself, self-similar, on an ever-diminishing scale. They are found in nature and characterized by infinite length and the absence of smoothness or derivative. The curve of Von Koch, shown in Fig. 2, is still one of the most important fractal curves because their significant characteristics. In its creation, it begins with a straight line of length 1, called the initiator then the middle third of the line is removed and replaced with two lines that each has the same length (1/3) as the remaining lines on each side. This new form is called the generator, because it specifies a rule that is used to generate a new form. By repeating this procedure, the complicated construction of the Koch Curve will appear.

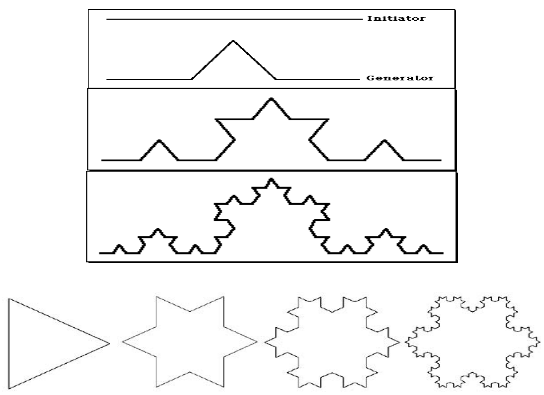

Fig. 2 The construction of the Von Koch curve

So, the used fractal-shaped orifices are similar to the Koch curve and have been constructed up to the forth generation as shown in Fig. 3.

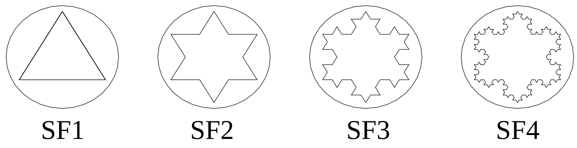

Fig. 3 Self-similar fractal–shaped orifices

These orifices are characterized by their fractal dimension of 1.26 and from the fractal concept the more the fractal dimension the more the space-filling of these objects. This set of fractal-shaped orifices is namely SF and characterized by increasing the flow area.

V. Experimental Sequence

All the runs have been done at the same flow rate, in practice at same control valve position, all fractal-shaped orifices are placed at the same position and several measured pressure drops, dp, 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 Perspex pipe by operating the fan then left to an appreciated time, transient filling time, to ensure that the pipe is filled completely by the fluid then starting to take the measuring reading using the digital micro-manometer and adjusted to ensure the flow rate is constant for all the different fractal-shaped orifices.

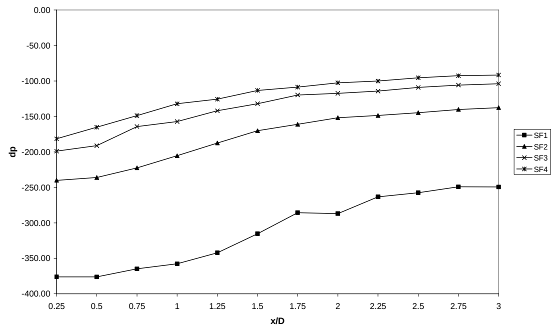

Fig. 4 The measured pressure drop across different fractal-shaped orifices as a function of the position downstream the flow

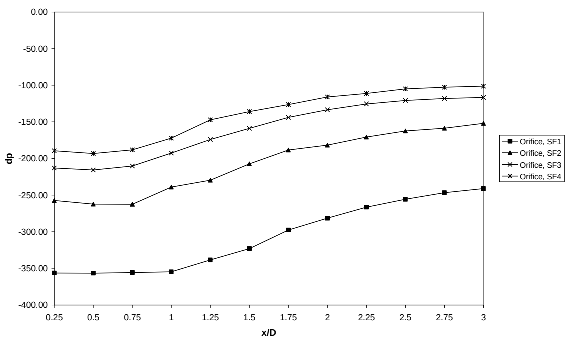

Fig. 5 The measured pressure drop across different ordinary orifices with the same flow area equal to the fractal-shaped orifices area as a function of the position downstream the flow

As in Figs. 4 and 5, with the increase of the position downstream the flow the pressure drop is reduced and from Fig. 6, the pressure drop resulting from the fractal-shaped orifices is lower that that from the ordinary orifices with the same flow area. This may be explained as the fractal-shaped orifices have significant effect on the flow downstream the flow and enhance the mixing properties leading to this pressure drop reduction.

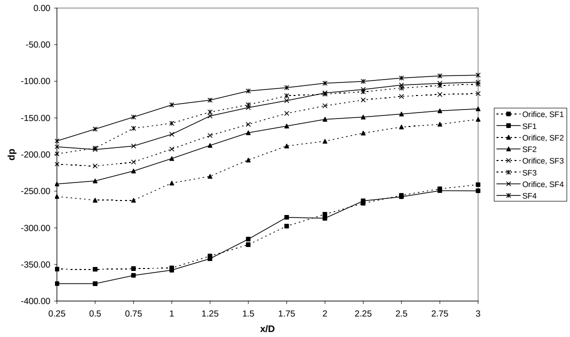

Fig. 6 The measured pressure drop across both the fractal-shaped orifices and the ordinary orifices with the same flow area as a function of the position downstream the flow

Also the results showed that with the increase of the fractal-shaped orifices generation, the differences between the pressure drop from the fractal-shaped orifices and that from the regular orifices increased until reach the forth generation the pressure drop reduces again which indicates that with the increase of producing more fine fractal-shaped orifice edges, it will approximately reach the characteristics of the ordinary orifices.

VI. Conclusion

In this paper, the pressure drop after fractal-shaped orifices in a turbulent flow pipe has been measured experimentally. A direct comparison has been made between these measures and that from ordinary orifices with the same flow areas. Our results showed that the fractal-shaped orifices have a significant effect on the pressure drop downstream the flow. The results also showed that the pressure drop across the fractal-shaped orifices is lower that that from ordinary orifices of the same flow areas. This result may be considered important in using them in designing of the piping systems from point of view of the losses consideration. These results indicate that the fractal-shaped orifices could be used as flowmeters as they can sense the pressure drop after these orifices more accurately than the regular ones. However, this is faced complexability in manufacturing such that self-similar orifices edge.

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