EXPERIMENTAL INVESTIGATION OF FLOWS GENERATED BY FRACTAL ORIFICES

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Abstract Fractal shapes are considered as an alternative to the classical circular orifice used for flowmetering. Fractal orifices have been shown to decrease pressure drops across the plate by about 10% when compared to classical circular orifice [1]. They also provide formidable test-cases for numerical validations [2]. In this contribution, We study the mixing properties of flow generated after fractal plates in a circular wind tunnel. In particular, we examine the effects of using non-axi-symmetric orifices on the flows and investigate the effect of the Reynolds number.

We consider two sets of plates: one orifice-like and one perforated-like. The mean velocity profiles are presented at different distances from the plate and we study the convergence of a flow rate based on these profiles. The return to axi-symmetry depends on how far was the original plate from an axi-symmetric design. It also depends on the level of iteration of the fractal pattern. In line with results for other flow properties [1], it seems that there is not much to be gained by manufacturing fractal plates with more than three iteration levels.

INTRODUCTION

We propose to study the effect of a complex shape on the generation of turbulent flows in a pipe. The purpose is to use such shapes as optimal flowmeters or flow mixers.

Classical orifice flowmeters consist in an orifice plate which is placed in the pipe or duct to create a pressure drop. The flow rate is then deduced from this pressure drop. Behind the orifice plate a substantial pressure deficit occurs weakening the turbulence cascade process and slowing down the mixing which results in delaying the flow recovery. 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 flowmetering.

Though the orifice plate as a differential flowmeter has gained an overwhelming popularity because of its low maintenance cost (no moving part) 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.

One way to speed up the flow recovery is to improve the flow mixing, perhaps by a forced energy cascade and fractal-generated turbulence which can provide interesting alternatives for forcing turbulence.

EXPERIMENT

A perspex tube is used for the experiment. The fractal orifice is inserted in the middle of the pipe and measurements are recorded at different stations after the plate. The 5 mm thick polycarbonate tunnel has a length of 4400 mm and an inner diameter of 140.8 mm. The Reynolds number based on the pipe diameter is $Re_D = 40\,000$. (More cases will be available by the date of the conference.)

Pressure drops are recorded at different stations, that is, different distances x from the orifice plates. The results are given in pipe diameter, $x^* = x/D$, where x is the distance from the plate and D the pipe diameter. The 12 stations are located respectively at $x^* = 0.25$, 0.5, 0.75, 1, 1.25, 1.50, 1.75, 2, 2.25, 2.50, 2.75 and 3.

Fractal orifices and plates

The fractal orifice plates we use are shown in Fig. 1 [1]. They are meant as a variation of the classical (smooth) circular orifice plate. We modified the perimeter of the circular orifice plate to add sharpness and irregularity to this smooth circle. For our ‘fractal’ orifices, we consider different iterations of the pattern corresponding to different achievement of the fractal geometry.

For each set a total of four fractal orifice plates $(N = 0-3)$ were considered for the present study. All plates except those in Set 4 have the same porosity. All the plates in Set 4 have the same porosity but this for practical reason is different from that in the other sets. This is because by construction when the fractal iteration increases in Set 4 in order to maintain the porosity the scales have to increase. Whereas for the other sets it is the other way round when the iteration increases to maintain the porosity the object needs to be scaled down. Set 2 is not based on a fractal pattern but just a set of polygons.

RESULTS AND DISCUSSION

Figure 1 shows the normalised pressure drop ($\Delta P/\frac{1}{2}\rho U^2$) across the fractal orifice for different iterations of the fractal pattern for four sets of plates. The first thing to notice is that for the fractal sets (a,c,d) the larger pressure drop (in absolute value) is always that of the circular orifice. That is the circular orifice will need more pipe length to recover. So the use of the different fractal shapes leads to a net decrease in pressure drop. This is a crucial point for flow metering where the aim is to create a pressure drop large enough to be measured while perturbing the flow as little as possible allowing it to recover as fast as possible and as much as possible. The higher the fractal iteration the lower the pressure drop but this may be Reynolds number dependent. However polygonal shapes (b) do not necessarily lead to optimised pressure drops.

The pressure drop local minimum near the orifice corresponds to the vena contracta effect, it is also observed on the velocity profile. This minimum disappears on the curves for the fractal orifices, indicating that these orifices are working by interacting with the boundary layer behind the orifice and helping the turbulence mixing leading to a faster recovery of the pressure.

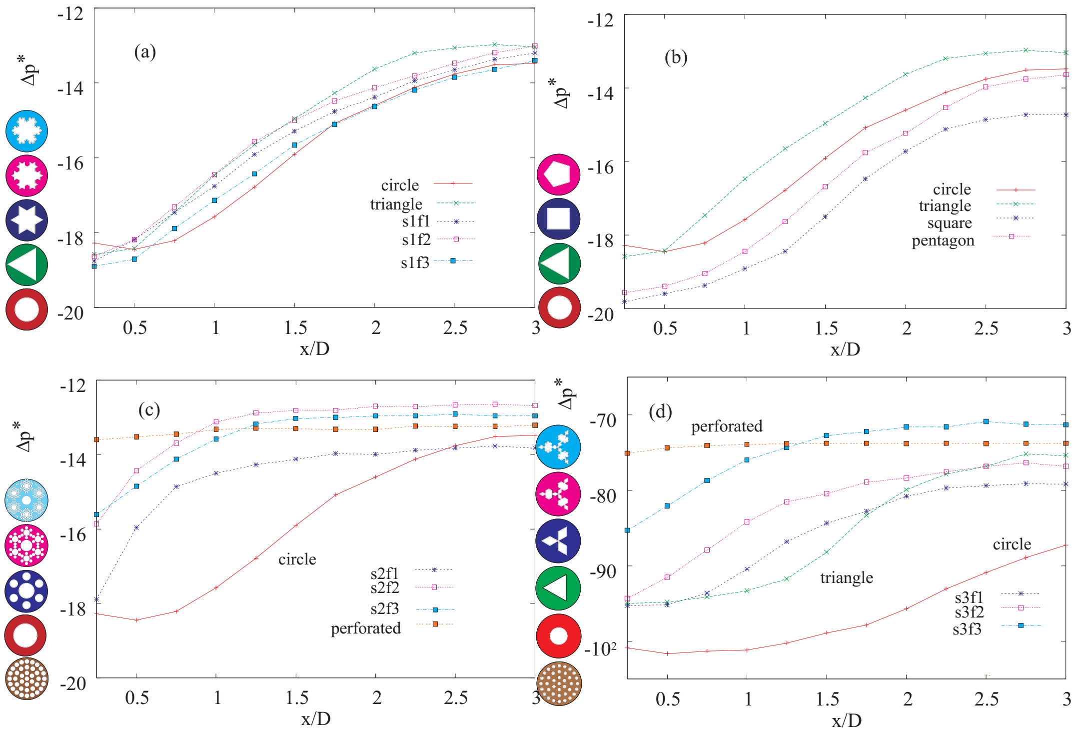

Figure 1. Evolution of normalized pressure drop as function of downstream location (a) set 1, (b) set 2, (c) set 3, (d) set 4.

CONCLUSION

We conducted experiments to measure pressure drops behind orifice plates in a circular wind tunnel. We discussed mainly applications as potential flowmeters there are of course many other applications one can think of in particular for mixing. Fractal-based orifices could be used as pre-conditioners for orifice flowmeters but also for other devises (e.g. hydrocyclones). Further to their theoretical and practical interests the flows presented here are quite challenging to modelling and provide good test-cases for validation in particular for advanced CFD method [2].

This abstract was to give a flavour of the work carried on fractal orifices. More results will be presented at the conference. In particular comparisons with non-fractal polygonal shapes will be made. More Reynolds numbers will also be available. Hot wire anemometry and LDA results will also be presented.

References

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