Contemporary Engineering Sciences, Vol. 9, 2016, no. 22, 1067 - 1074
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2016.67122

Optimal Grooves Number for Reducing Pressure Drop

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Abstract

Optimal rectangular grooves number on internal wall surface of pipe for reducing pressure drop and drag has been investigated experimentally. The change of pressure drop and drag have been observed at numbers of grooves of 2, 4, 8, 12, 16, 20 and Reynolds number of 22146, 20637, 18155 and 15038. The optimum groove number that resulted in minimum pressure drop is 8 grooves, that is when the distance between grooves is 9.2 mm. This configuration is appropriate to produce smaller velocity gradient, inducing both lower wall shear stress and less pressure drop and drag.

Keywords: grooves, pipe flow, pressure drop, radial velocity

Introduction

Proper fluid flow control is very important in many engineering applications such as heat exchangers, the aero, shipping industries and the chemical industry. Some of the biggest challenges arise when designing heat exchangers for installation in limited spaces, on one hand, efficient heat transfer units require plenty of space, but on the other hand this a major problem where space is limited. One solution is to cut grooves into the internal walls of flow pipes, grooves increase heat exchanger surface areas which not only improves heat transfer but also reduces pressure drop. Over the years a lot of research has gone into lowering pressure drop, into fluid flow characteristics from grooves and their influence on heat transfer [1, 2, 3, 4]. [5, 6, 7, 8, 9] studied flow behavior, vortex interaction and their transformations. In addition [10, 11, 12] experiments with grooves conducted and riblets of varying forms to improve flow characteristics, such as helical grooves, and semi-circular riblets.

However, none of the above references mentions number of grooves for optimum reduction in both pressure drop and drag in order to maximize flow. Theoretically in the pressure drop mechanism, the lateral flow fluctuation influences the three dimensional vortices near pipe walls reported by [13]. And, in order to be able to observe fluid velocity in lateral/ radial flows, a new and simple approach is needed. Thus, this paper introduces a new and simple method of measuring radial fluid flows as well as a way to establish the optimum number of grooves to cut drag to a minimum. Radial flow speeds were measured through plastic threads attached to the centres of flow pipes and when fluid flowed, the forms/ movements of thread ends were recorded by a high speed CCD camera enabling the computation of flow velocity.

Materials and Methods

Figure 1 shows a sketch of the experiment equipment for computing pressure drop and drag in flow turbulence.The flow was driven by a centrifugal pump which was stabilized by an electric stabilizer. The flow rate was varied by a valve set some distance from the test sections as 0.41, 0.38, 0.33, and 0.28 l/s with Reynolds number (Re) of 22146, 20637, 18155 and 15038, respectively. The water temperature was 27°C (±1°). The test section was made of a 2.6 cm diameter PVC pipes with 100 cm groove lengths.

A conventional etching technique was employed to cut the grooves, there were 6 differing groove number replications, namely, 2, 4, 8, 12, 16, 20, measuring distance between grooves 39.8, 19.4, 9.2, 5.8, 4.1, and 3.1 mm respectively. Figure 2(b) shows details of the grooves in which the darker areas are groove valleys. A smooth wall (no groove) pipe was employed for comparison.

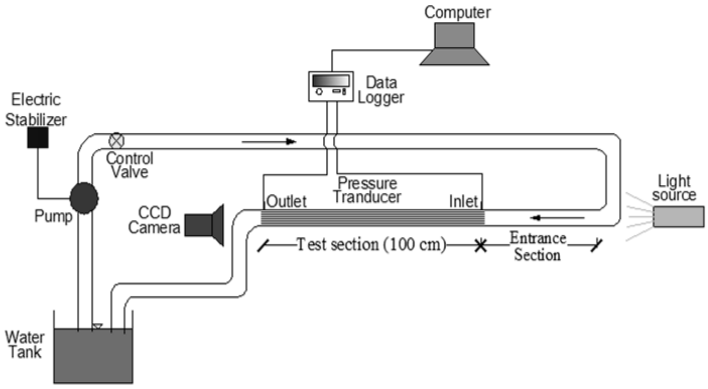

Fig.1 Experiment set-up

In this study, entrance length was found to be 60 cm. Therefore, the flows in the pipe test section were considered to be fully developed as the entrance lengths of the experiment apparatus (70 cm) were longer. The pressure drop measured using pressure tranducers.

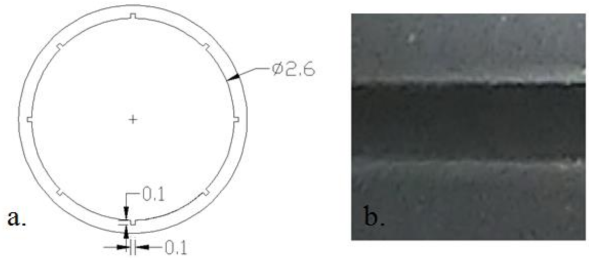

Fig.2 Groove geometry (a) parameters of groove (unit: cm); (b) grooves detailed images.

For ease of lighting and flow visualization, the elbows installed before and after the pipe test sections were made of transparent acrylic pipes. A high-speed camera was used to record plastic thread end movements at 240 fps over 1 minute.The video images were framed into sequential still photographs and thread movements were recorded employing image processing.

Results and Discussions

Preliminary experiments were done using the smooth pipe to determine the amount of the pressure drop from such pipes as well as radial velocity. This data was then used as a comparison. Pressure data from the various Re and groove numbers are laid out in fig. 3.

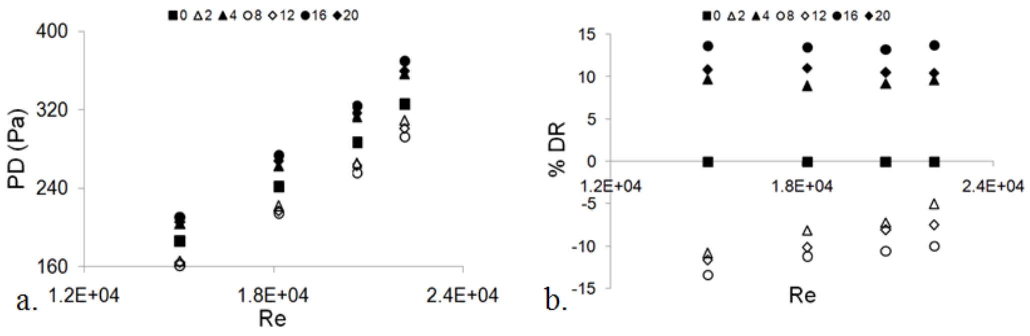

Fig.3 (a) Average pressure drop for various Re; (b) Drag reduction for various Re.

Figure 3a indicates linear pressure drop for each Re and groove number. Increased Re increases pressure drop and vice versa. However, when these figures were analyzed in more detail, it was clear that pressure drop percentages indicate an interesting trend (fig. 3b). Figure 3b demonstrates that for grooved pipes with 4, 16, and 20 grooves, drag reduction was worse than that for the smooth pipe, and also that the their DR percentages were relatively similar. Whereas, a different and interesting phenomenon was observed in the 2, 8, and 12 pipe groove number.It is clear that the higher the Re, the lower the DR percentage.This indicated that the more turbulence there was, the higher the convection of momentum. This caused the increased pressure drop and radial flow in various groove number and Re. The faster the streamwise velocity,the lower the ability of the grooves to reduce flow fluctuation.

Figure 4 shows the pattern of the relationship between groove numbers, pressure drop and also radial velocity at various Re. Figures 4a and 4b demonstrate a similar trend.This indicates that pressure drop is related to radial velocity. When there is a rise in pressure drop, there will also be a corresponding increase in radial velocity. This was proved when thread ends moved closer to pipe walls each time there was an increase drop in pressure (fig. 5 to 8).This also showed that there were higher velocity gradients at pipe walls which in turn increased momentum transfer and shear stress. Conversely, when pressure drop fell, the plastic threads ends remained nearly to the centre of the pipes and their movements where more confined, which demonstrated that in fluid radial plane, velocity fluctuation and momentum transport were smaller.

What attracted attention here was the fact that when percentage of drag reduction changed from negative to positive, or vice versa, or when gradients of pressure drop or radial velocity were zero. Namely, in groove numbers between 4 and 16, a pattern of valleys appeared indicating optimum conditions for reducing pressure drop (fig. 4a) and radial velocity (fig. 4b).The gray areas in fig. 4a are those of optimum pressure-drop reduction. Whereas, in fig. 4b, the gray portions are those of optimum radial velocity decreases. The optimum condition occurred in groove number of 8. The dash-dot curves represent average radial velocity for the various Re.

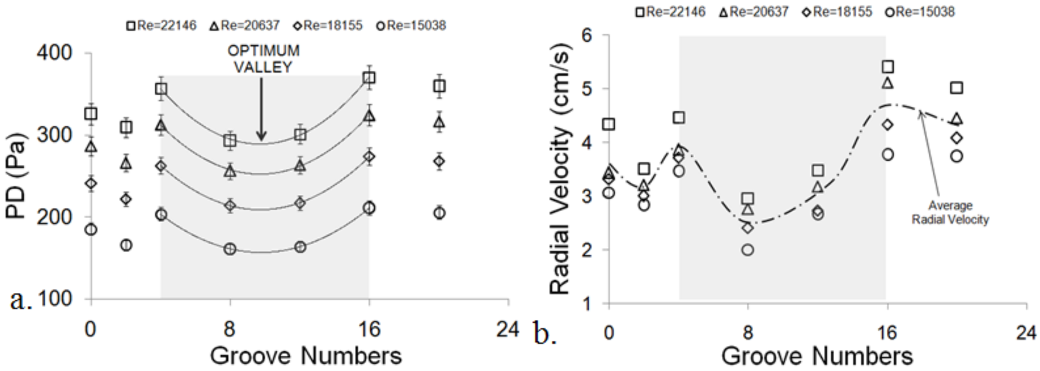

Fig. 4 Optimum pressure drop for various Re and groove number subjects (a) pressure drop and (b) radial velocities

Spaces between grooves helped to prevent high shear stress getting close to pipe walls [14]. However, theoretically, increasing spaces between grooves decrease the possibility of drag reduction. The spaces between groove for groove numbers of 2, 4, 8, 12, 16, and 20 were 39.8, 19.4, 9.2, 5.8, 4.1, and 3.1 mm respectively. The valley in figure 4 formed when the spacing between grooves was between 19.4 to 4.1 mm and optimum condition for drag reduction was observed in the space between grooves of 9.2 mm.In this case groove geometry and spacing created a flow pattern that held back any increase in gradient velocity so that shear stress could not get close to pipe walls.

To further understand what happened with groove number of 4 to 16 (thevalleys in fig.4), the threads was employed to visualize more clearly these flow phenomena arising from the grooves. Figures 5 to 8 indicate the visual results from groove number of 4 to 16, recorded from thread movements to calculate radial velocity in the downstream section of the test pipes. The small black dots show the initial positions of the plastic threads and the lines indicate the path lines of the thread ends.

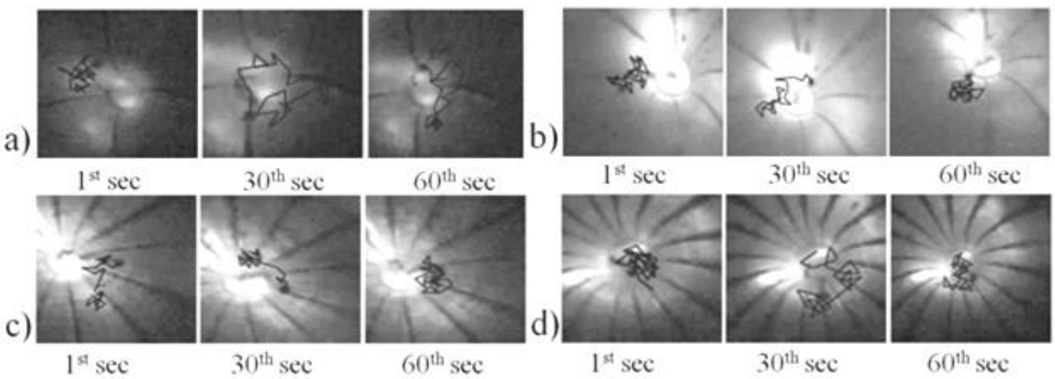

Fig. 5 Thread movement patterns inside pipes for Re 22146 (a) 4 grooves; (b) 8 grooves; (c) 12 grooves and (d) 16 grooves.

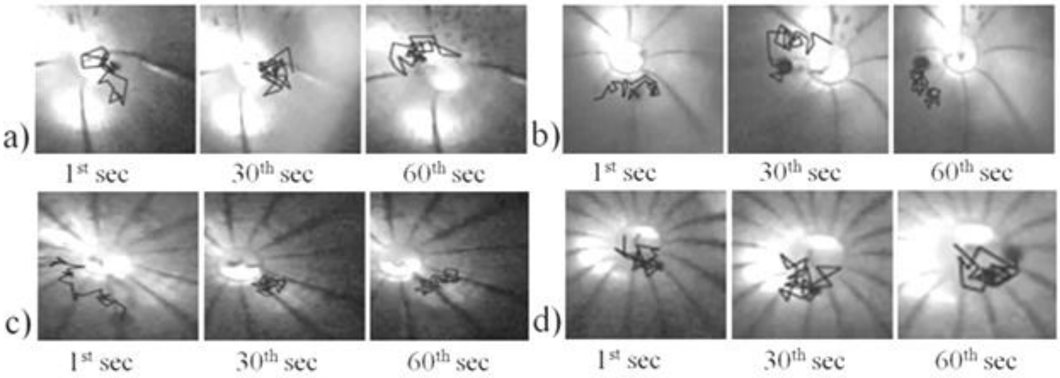

Fig. 6 Thread movement patterns inside pipes for Re 20637 (a) 4 grooves; (b) 8 grooves; (c) 12 grooves and (d) 16 grooves.

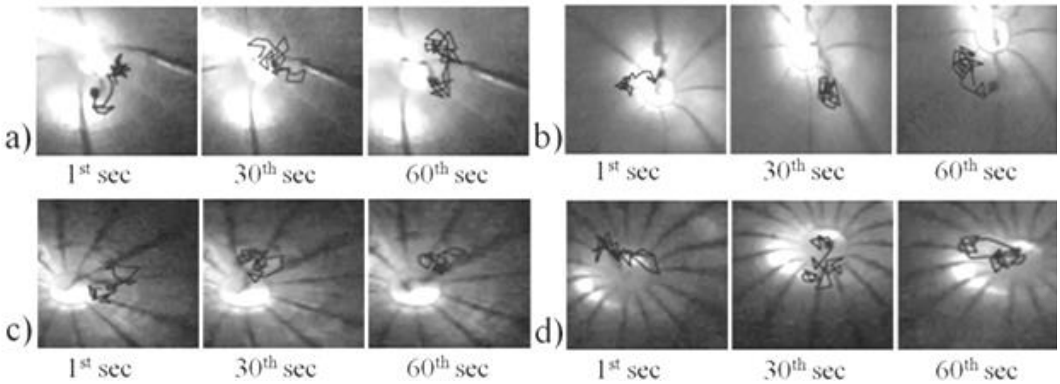

Fig. 7 Thread movement patterns inside pipes for Re 18155 (a) 4 grooves; (b) 8 grooves; (c) 12 grooves and (d) 16 grooves.

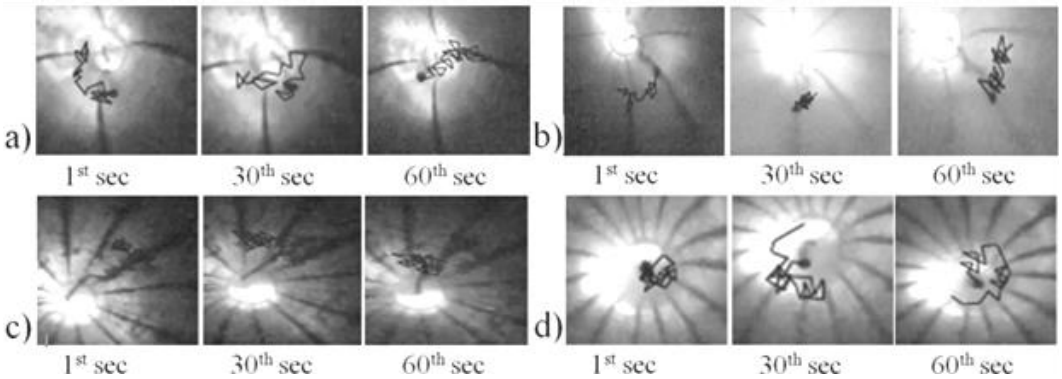

Fig. 8 Thread movement patterns inside pipes for Re 15038 (a) 4 grooves; (b) 8 grooves; (c) 12 grooves and (d) 16 grooves.

It can be clearly observed that with the 19.4 and 4.1 mm spacing between grooves that the thread ends are close to pipe walls with longer path, which demonstrates a high velocity gradient between central areas and pipe wall that increases wall shear stress. A different phenomenon revealed when spacing between grooves 9.2 and 5.8 mm. The thread end shows shorter path line and nearly to the centre of pipe.This proves that there was a smaller velocity gradient than that for the 19.4 and 4.1 mm spacing between groove, inducing both lower wall shear stress and less pressure drop.

Conclusion

The flow behaviour in pipe with grooved internal wall was investigated using measuring and visualization techniques giving conclusion as: [1] The optimum number of grooves was 8 with 9.2 mm spacing between them, and [2] the more laminar the fluid flow, the more effective the grooves.

References

[1] K. Aroonrat, C. Jumpholkul, R. Leelaprachakul, A.S. Dalkilic, O. Mahian and S. Wongwises, Heat transfer and single-phase flow in internally grooved tubes, *International Communication in Heat and Mass Transfer*, **42** (2013), 62-68. http://dx.doi.org/10.1016/j.icheatmasstransfer.2012.12.001

[2] B. Frohnapfel, J. Jovanović and A. Delgado, Experimental investigations of turbulent drag reduction by surface-embedded grooves, *J. Fluid Mech.*, **590** (2007), 107-116. http://dx.doi.org/10.1017/s0022112007008221

[3] B. Frohnapfel, P. Lammers and J. Jovanović, The Role of Turbulent Dissipation for Flow Control of Near-Wall Turbulence, Chapter in *New Results in Numerical and Experimental Fluid Mechanics VI*, NNFM Vol. 96, 2007, 268-275. http://dx.doi.org/10.1007/978-3-540-74460-3_33

[4] P. W. Sunu, D. S. Anakottapary and W. G. Santika, Temperature approach optimization in the double pipe heat exchanger with groove, *MATEC Web of Conferences*, **58** (2016), 04006. http://dx.doi.org/10.1051/matecconf/20165804006

[5] M.A. Hongwei, Qiao Tian and Hui Wu, Experimental study of turbulent boundary layers on groove/smooth flat surfaces, *J. of Thermal Science*, **14** no. 3, (2005), 93-97. http://dx.doi.org/10.1007/s11630-005-0001-7

[6] Y.A. Litvinenko, V.G. Chernoray, V.V. Kozlov, L. Loefdahl, G.R. Grek and H.H. Chun, The influence of riblets on the development of a structure and its transformation into a turbulent spot, *Doklady Physics*, **51** (2006), no. 3, 144-147. http://dx.doi.org/10.1134/s1028335806030128

[7] P.W. Sunu, The characteristics of increased pressure drop in pipes with grooves, *Adv. Studies Theor. Phys*., **9** (2015), no. 2, 57–61. http://dx.doi.org/10.12988/astp.2015.412152

[8] P.W. Sunu I.N.G. Wardana and A.A. Sonief, Nurkholis Hamidi, Flow Behavior and Friction Factor in Internally Grooved Pipe Wall, *Adv. Studies Theor. Phys*., **8** (2014), no. 14, 643-647. http://dx.doi.org/10.12988/astp.2014.4573

[9] P.W. Sunu, I.N.G. Wardana, A.A. Sonief, Nurkholis Hamidi, The effect of wall groove numbers on pressure drop in pipe flows, *Int. J. Fluid Mech. Resch.*, **42** (2015), no. 2, 119-130. http://dx.doi.org/10.1615/interjfluidmechres.v42.i2.30

[10] S.J. Lee and S.H. Lee, Flow field analysis of a turbulent boundary layer over a riblet surface, *Experiments in Fluids*, **30** (2001), 153-166. http://dx.doi.org/10.1007/s003480000150

[11] S.J. Lee and Y.G. Jang, Control of flow around a NACA 0012 airfoil with a micro-riblet film, *Journal of Fluid and Structure*, **20** (2005), 659-672. http://dx.doi.org/10.1016/j.jfluidstructs.2005.03.003

[12] Shan Huang, VIV suppression of a two degree of freedom circular cylinder and drag reduction of a fix circular cylinder by the use of helical grooves, *Journal of Fluids and Structures*, **27** (2011), 1124-1133. http://dx.doi.org/10.1016/j.jfluidstructs.2011.07.005

[13] R. Grüneberger and W. Hage, Drag characteristics of longitudinal and transverse riblets at low dimensionless spacings, *Exp. Fluids*, **50** (2011), 363-373. http://dx.doi.org/10.1007/s00348-010-0936-7

[14] H. Choi, P. Moin and J. Kim, Direct numerical simulation of turbulent flow over riblets, *J. Fluid Mech.*, **255** (1993), 503–539. http://dx.doi.org/10.1017/s0022112093002575

Received: July 25, 2016; Published: August 31, 2016