EXPERIMENTAL INVESTIGATION OF FRICTION COEFFICIENT IN RIBLETED PIPES AND THE EFFECT OF FINE PARTICLES

M. Rad

Department of Mechanical Engineering
Sharif University of Technology
Tehran, Iran

B. Firoozabadi

Water and Energy Research Center
Sharif University of Technology
Tehran, Iran

Abstract The effect of fine particles on turbulence damping and reduction of flow friction coefficient in ribleted pipes, have been investigated experimentally. Tests have been conducted in a ribleted pipe with hydraulic diameter of 18.6 mm, and 20 streamwise riblets of 1.8 mm depth, along the pipe. Flows of water tap with Reynolds number from 5000 to 30000 were compared with flows containing silt-clay particles and stone powder of less than 63 micron sizes. In the flows containing 1.6 kg/m^3 of stone powder, the pressure drop along the pipe reduced by 25 percent, and with flows containing silt-clay particles, the pressure drop reduction was about 15 percent. Reduction of friction, in flows containing fine particles, may be due to the interaction of particles and turbulence generated at pipe boundary, and damping of this turbulence.

Key Words Ribleted Pipes, Friction Coefficient

چکیده اثر ذرات در کاهش اغتشاش (Turbulence) جریان و به تبع آن کاهش ضریب اصطکاک لوله به صورت تجربی بررسی شده است. آزمایشات در یک لوله شیاردار با قطر هیدرولیکی ۱۸/۶mm که دارای ۲۰ شیار طولی به عمق ۱/۸mm می باشد، در دو حالت انجام شده است. در یک حالت آب شهر و در حالت دیگر آب حاوی ذرات رس و نیز ذرات پودر سنگ به قطر زیر ۶۳ میکرون از لوله عبور داده شده و در هر حالت افت فشار در طول لوله اندازه گیری شده است. آزمایش در محدوده اعداد رینولدز ۵۰۰۰-۳۰۰۰۰ انجام شده و نتایج نشان می دهد که در عدد رینولدز ۳۰۰۰۰، افت فشار (Head loss) در جریان آب حاوی ۱/۶ Kg/m³ خاک رس، ۱۵ درصد و برای جریان حاوی ذرات پودر سنگ با غلظت ۱/۶Kg/m³، ۲۵ درصد کاهش یافته است. کاهش اصطکاک در لوله را می توان مستقیماً به کاهش شدت اغتشاش ربط داده و در نحوه و چگونگی تغییر پدیده های موثر در تولید اغتشاش به صورت کیفی بحث کرد.

INTRODUCTION

More than a third of the world energy is used for residental and commercial space heating and air-conditioning, residental and commercial water heating and industrial petrochemical processing. In these applications, heat exchangers play a major role. A ten percent efficiency improvement in the cited applications would save over 3 million barrels of oil per day and reduce atmospheric CO_2 emissions [1].

Particles in the flow reduce the turbulent intensity of boundary layer. With small particles, most parts of the boundary are smooth and in turn the friction factor will decrease [2]. With the presence of particles, the heat transfer coefficient could significantly increase. Kianjah & Dhir reported that the relative enhancement was accentuated when mass flow ratio of solids to fluids was increased, but it diminished when flow Reynolds number was increased. The enhancements were caused by the interaction of the particles with the wall. From a mechanistic model of the transport in the turbulence dispersed flow, the increase of turbulence intensity showed that it would increase thermal diffusivity in the flow which could predict the enhancement of heat transfer coefficient [3]. While increase of heat transfer coefficient will increase the heat exchnage efficiency, it may increase the friction coefficient factor as well. It is most advantagous to increase heat exchange efficiency and decrease the head loss at the same time.

In a relative movement between a body and fluid, energy is consumed due to drag force. To reduce this energy consumption, it is necessary to recognize all the effective variables of drag force in order to reduce the drag. In most internal flows, considerable energy is needed to pump the working fluid. The technology yet is awaiting to find reliable and effective ways of reducing pumping cost. Most internal flows are turbulent and the shear force or friction is related to the condition of turbulence in the boundary layer. The theory of turbulence is not yet completely understood and experimental studies are still the most reliable ways in investigating turbulent flows, especially when dealing with additives of particles or bubbles in the flow. Previous studies show that it is possible to decrease the friction and skin resistance in pipes by addition of solid particles, polymer solution or bubbles in the flows [4]. One of the ways to increase the heat exchange efficiency and decrease the head loss is to use ribleted pipes. In this investigation, after a brief review of literature in the effects of particles in pipes, the experimental investigations of ribletted pipe flows with and without particles are described.

It was found that muddy rivers flow faster. This was the first inspiration to reduce friction by addition of fine solid particles. Vannoni [5] found that silt and clay particles of less that 20 μ, change the turbulence characteristics of boundary-layer and consequently the friction is reduced. Zandi [6], in his series of experiments with different size particles of sand, clay and coal powders, reported reduction of head loss in pipes due to addition of particles in flow of water. He also reported that the percentage of reduction was related to the size, shape, population density and nature of the particles. Madavan [7,8] found that when the particles diameter increased over 50 to 100 μ, the result may reverse and particles additive may increase the friction. Experimental studies of other investigators, Vukoslavcevic [9], Rad and et al. [10], confirm the previous results. Rad [11], also found that turbidity currents with suspended particles reduce turbulent level and run faster, in contrast with salt solution of density current.

However, while the additive increase the viscosity of the mixture, and referring to a Newtonian law of viscosity, $\tau = \mu \, du/dn$, one may ask how increase of viscosity may decrease the shear stress. Marie [12] showed that the gradient of velocity near the wall may decrease in flows containing particles, and this in tern, reduces the wall shear stress. In other words, particles can affect the turbulence structures near the wall, and may increase the sublayer effective thickness [11].

On a hydraulicly rough wall, the turbulence strucutre is a function of roughness size and shape. Walsh [13] experimented with various shape grooves along the pipe or perpendicular to the flow. He reported that with V shaped grooves, rounded of the edges, with 0.025 cm depth, 0.05 cm distance between each groove, along the pipe, the pipe coefficient of resistance reduced by 7 percent. In this work we do not attempt to study the best groove for lowest friction, but to find out, why different shape and size grooves produce different turbulence structures, and how this structure may change by introduction of particles. In other words, how the change of turbulence strucutres in rough pipes may change the velocity distribution in boundary layer and may reduce or increase the shear force at the wall.

DESCRIPTION OF EXPERIMENTS

Tests were conducted in a ribleted pipe of 18.6 mm hydraulic diameter (Figure 1). There are 20 streamwise riblets of 1.8 mmdepth along the pipe. The maximum diameter of the pipe at the roots of the riblets is 22.6 mm, and the minimum diameter at the upper edge of the groove is 19.0 mm.

The set-up consists of 2 m^3 tank at the 2.5 meter elevation. Water flows through a Venturi meter and control valves and enters the horizontal pipe at zero elevation. The test section is 1.0 meter long and the head loss in this length was measured using differential manometers located at the two ends of the pipe. Particles used in the flows were stone powder of less than 63 μ diameters or silt and clay of less than 40 μ diameters.

EXPERIMENTAL RESULTS

a) Tap water was first used to investigate the turbulence created by the riblets. The friction factor vs. Reynolds number, based on hydraulic diameter of the pipe, was drawn on a Moody Chart (Figure 2). It shows for Re<12000, near transition region, riblets increase the turbulence level of the pipe and the friction coefficients are increased in this region. However with higher Reynolds number, at fully developed turbulence, ribleted pipe friction factors are less than smooth pipes. This may be due to the trapping of fluid between riblets near the wall, and the valley parts acting like smooth pipe boundaries, and top of the riblet along the flow may damp the turbulence created near the wall. At the lower Reynolds numbers a secondary eddy flow at the lower part of the riblets would cause the higher friction coefficients. At the higher Reynolds numbers, the constant velocity contours follow nearly the boundary lines but the laminar sublayer is very thin at the tip of the riblets. At the valley parts of riblets, the flow is hydrodynamically smooth, while the flow is rough surface condition at the tip. Therefore, the friction factor compared with smooth pipes, for ribleted pipes are higher at lower Reynolds and lower at higher Reynolds numbers. Change of effective diameter of the pipe and use of Reynolds number based on this diameter may change the picture. However to be sure about the change in turbulent level, one should measure the components of the turbulence in different pipes.

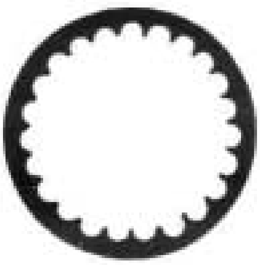

Figure 1. Cross section of ribleted pipe.

To be sure about the correct use of diameter for calculation of Reynolds number, we compared f-Re diagrams of ribleted pipe using hydraulic diameter of 18.6 mm, minimum inside diameter of 19 mm, and an equivalent diameter of circle having the same cross section of the ribleted pipe (Figure 3). Except with so the called equivalent pipe (which has no physical meaning), use of other two diameters show similar results which confirm our conclusion.

b) In the second set of tests we used mixture of water with stone powder. Powder was passed through mesh 230 and powder sizes less than 63μ. Four mixtures of 200, 500, 1000, 1600 gr per m^3 of water were used. Since the viscosity of mixture may change and hence the Reynolds number, we used the head loss vs. discharge (Δh-Q) curve, (Figure 4). The Δh-Q curve (Figure 4), shows that the use of stone

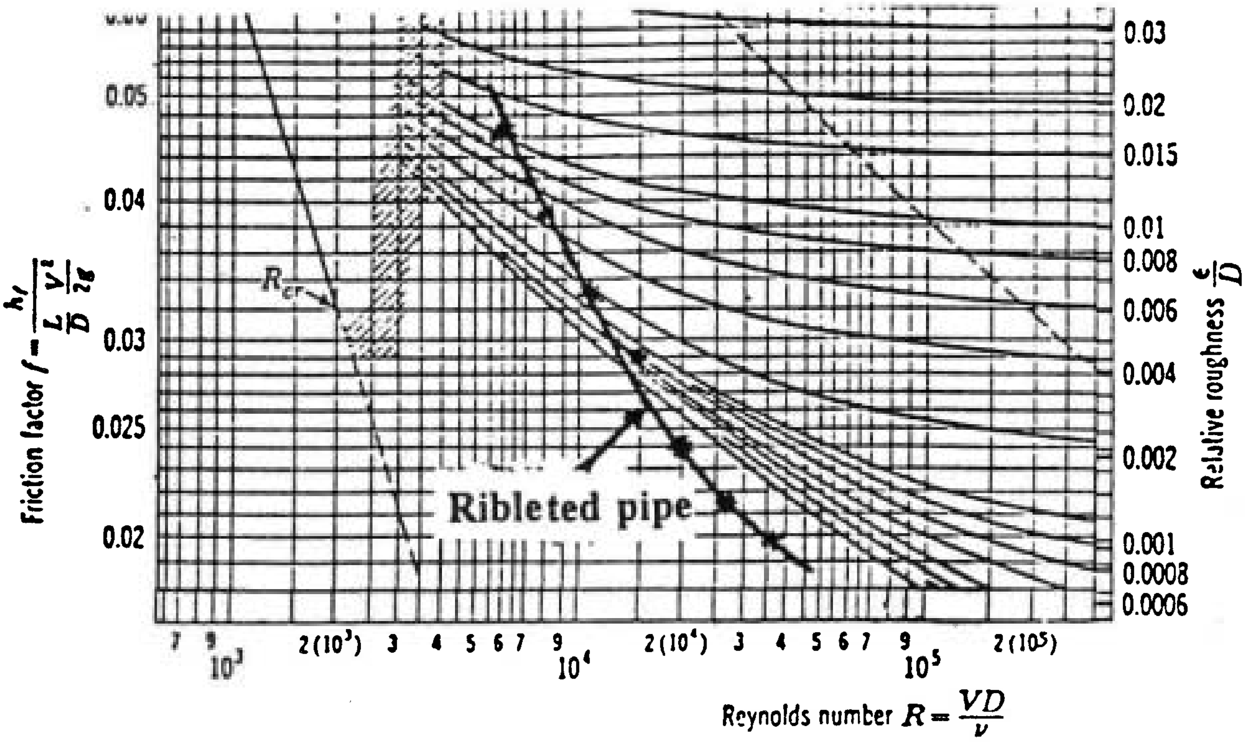

Figure 2. Friction factors of ribleted pipe on a moody chart.

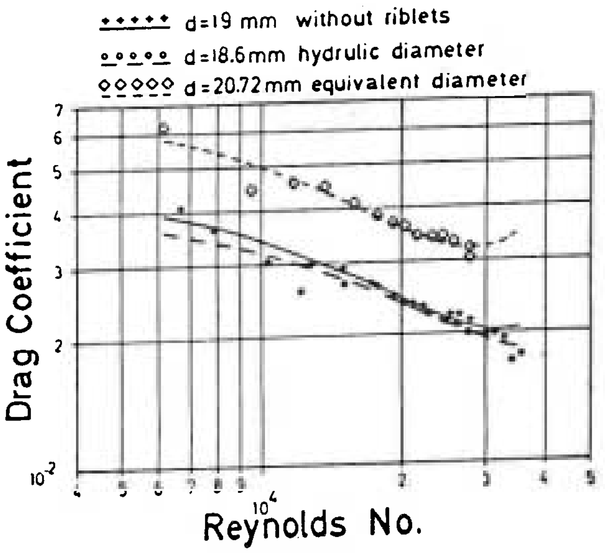

Figure 3. f vs. Re, using different diameters.

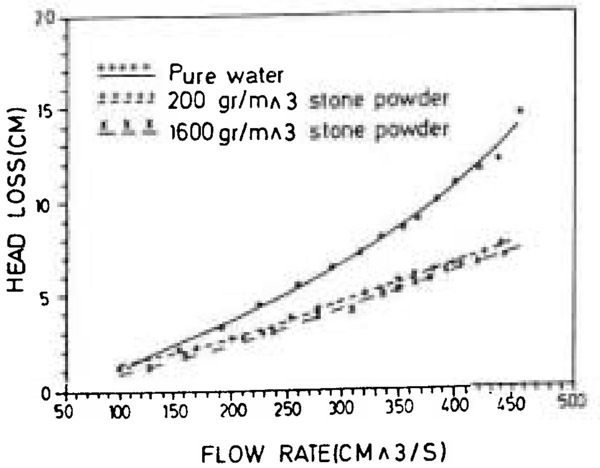

Figure 4. Decrease of head loss due to stone powder mixture.

powder in flow of ribleted pipe considerably decreases the head loss. The rate of decrease is increased with the increase of powder density. However, the effect of density or, population of particles, is small and even, may reverse the trend at higher particles population. This figure also shows that the effect is

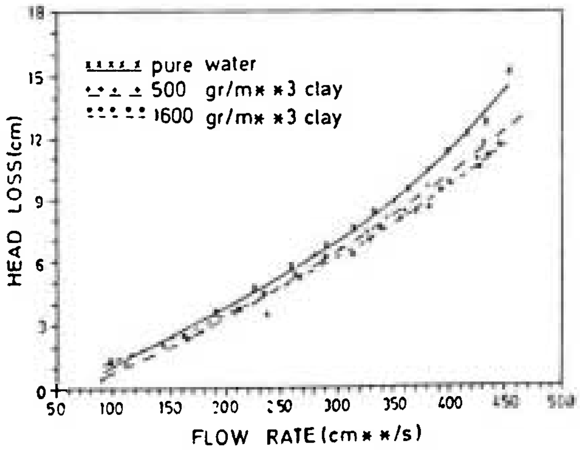

Figure 5. Decrease of head loss due to silt and clay.

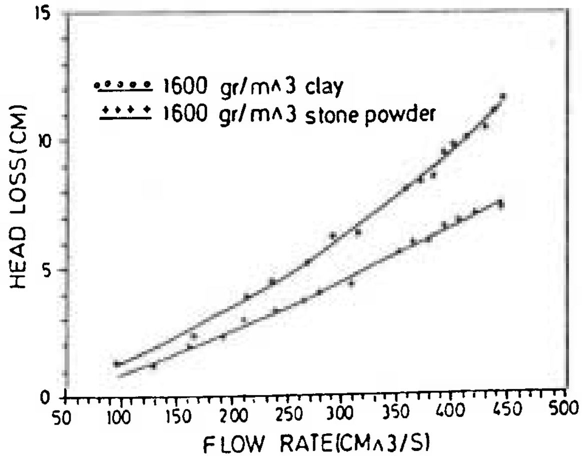

Figure 6. Comparison of stone powder and silt-clay.

more apparent at higher flows which may lead to the conclusion that at higher Reynolds number the particles effect is more significant.

c) In the third set of tests, silt and clay particles of less than 40μ size, with similar concentration of the previous test were used. The tests also show the

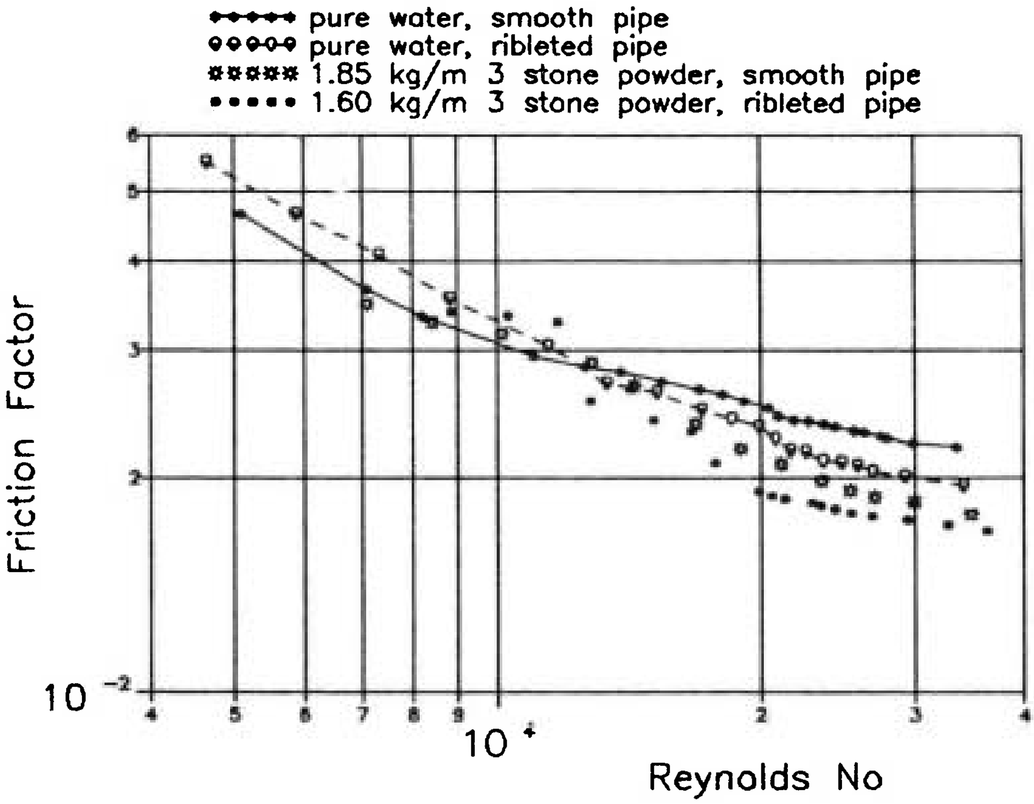

Figure 7. Comparison of flow with and without particles and riblets.

decrease of head loss with addition of powder and, increase of the particle effect with higher density of mixture. Figure 5 shows the effects of silt and caly particles.

Figure 6 shows the compariosn between stone and silt-clay powder at 1600 gr/m^3. Stone powder is more effective than silt-clay powder in reducing the head loss. This trend is also true for different comparable concentrations. Since the shape of the stone powder particle is more rounded and its size, is larger than silt-clay particle, the effect of particles in flow may be dependent on the size and shape of the particles, or even the size and shape distribution of the particles, which affects the damping different size and structure of turbulence eddies.

Finally Figure 7 shows the effects of riblets and particles in flow. However in a simple round pipe, the effect of particles are similar over all the boundary and with lower turbulent level. Due to particles, a rough boundary flow may change to a smooth pipe flow. Therefore, the friction factor reduction is more for simple pipes in comparison to ribleted pipes.

CONCLUSIONS

From the experimental results we can conclude that for current size ribleted of certain size pipes and shape of riblet, the friction factors decrease at higher Reynolds numbers, (Say Re>15000). This may be due to the change of condition of rough pipe to smooth pipe or the reduction of turbulence caused by wall roughness. Then, to use streamwise riblets is not advisable to increase the turbulence and heat transfer coefficients of heat exchanger pipes. Small size particles (Say $d<60\mu$) can decrease head loss in ribleted pipe flows. In other words, particles change the turbulent structure of boundary layer and may damp the turbulence level. Different size, shape, size distribution, and density of particles in the flow, affect the head loss reduction. For a better understanding of the effect of different parameters of particles and riblets on turbulent structure and head loss, further experiments specially measurements of turbulence factors are necessary.

REFERENCES

1. X. Hu, A. M. Jacobi, "Local Heat Transfer Behavior and Its Impact on a Single-Row Annulary Finned Tube Heat Exchanger", *J. of Heat Transfer, Trans. ASME*, Vol. 115, (1993).
2. H. Kianjah and V. K. Dhir, "Experimental and Analytical Investigation of Dispersed Flow Heat Transfer", *Experimental Thermal and Fluid Science (Int. J. of Experimental heat Transfer, Thermodynamics and Fluid Mech.)*, Vol. 2, No. 4, (1989).
3. H. Kato, et al., "Friction Drag Reduction by Injecting High-Viscosity Fluid into Turbulent Boundary Layer", *J. of Fluids Engineering, Trans. ASME*, Vol. 115, (1993).
4. M. Rad, B. Firoozabadi and M. Hakim-Javadi, "Methods of Skin Friction Reduction in Water Tunnel Models", Sharif University Research Reports, (1990).
5. V. A. Vannoni, et al. "Sediment Transport Mechanics: Density Current", *J. of the Hydraulics Division, ASCE*, Vol. 89, No. HY5, Proc. Paper 3636, (1963).
6. I. Zandi, "Decreased Head Losses in Raw-Water Conduits", *J. of American Water Work Association*, Vol. 59, (1967).
7. N. K. Madavan, E. L. Merkel and S. Deutsch, "Numerical Investigation into the Mechanism of Microbubble Drag Reduction", *ASME, J. of Fluid Eng.*, Vol. 107, (1985).
8. N. K. Madavan, S. Deutsch and C. L. Merkle, "Reduction of Turbulent Skin Friction by Microbulbbles", *Physics of Fluids*, Vol. 27, No. 2, (1984).
9. P. Vukoslavcevic, J. M. Wallace and J. L. Balint, "Viscous Drag Reduction Using Streamwise-Aligned Riblets", *AIAA. J.*, Vol. 30, No. 4, (1992).
10. M. Rad, B. Firoozabadi and M. Hakim-Javadi,

"Study of Particles Effects on Flow of Pipes and Open Channels" Sharif University Research Report, (1991).

11. M. Rad, "Silt Particle-Load Density Current and Deposition" *Iranian Journal of Science and Technology*, Vol. 12, No. 11, (1986).

12. J. L. Marie, "A Simple Analytical Formulation for Microbubble Drag Reduction", *Pch Physico Chemical Hydrodynamics*, Vol. 8, No. 2, (1987).

13. M. J. Walsh, "Drag characteristics of V-groove and Transverse Curvature Riblets", Symposium on Viscous Drag Reduction, Dallas, Texas, (Nov. 1979).