2.1

90

Tropical Agricultural Research Vol. 3 1991

Reducing Friction Losses of Pipes used in the Food Industry by Enamel Coating

Y. Shaogong, S.G. Ilangantileke and V.M. Salokhe

Division of Agricultural and Food Engineering,
Asian Institute of Technology,
Bangkok, Thailand.

ABSTRACT. A series of preliminary studies were conducted to investigate both technical and economic feasibilities of using enamel as a coating material for pipes used for conveying liquid food materials in food industry. This was done by testing the effect of enamel coat during the transfer of selected fluids through enamel coated pipes and comparing their performances in relation to head loss with that of stainless steel pipe transferring the same fluids.

The results of this study indicated that the hydraulic gradient of ordinary mild steel pipe can be reduced by about 10 to 40% by enamel coating compared with the hydraulic gradient of the same size of stainless steel pipe. Enamel coating was found to be a very attractive characteristic for reducing the head loss while conveying both Newtonian and non-Newtonian fluids compared to conventionally used stainless steel pipes. Preliminary economic analysis also showed promising results for using enamel coating in equipment manufactured for the food industry.

INTRODUCTION

Generally, the sanitary requirements in the food industry are influenced by the specific characteristics of the food materials, such as acidity and alkalinity, oxidation, the propagation of microorganisms in food materials and the materials used in the processing equipment. The sanitary requirements can be well satisfied by equipment made of stainless steel. Therefore, stainless steel is commonly used to fabricate food processing equipment, especially in the areas where the surface of the equipment is in contact with food materials.

The main disadvantage of using stainless steel is that it results in a high initial capital costs in the layout of equipment. This is a big practical problem for developing countries, especially those that are venturing out into food processing to effect added value to agricultural produce. The availability of stainless steel and the necessary accessories to manufacture equipment made of stainless steel may also be a problem for some developing countries.

In order to find solutions for some of the problems of using materials such as stainless steel, the feasibility of the use of other material such as enamel coatings on ordinary steel should be perused with the aim of partially substituting the use of stainless steel in the food industry. With this view in mind this particular study was undertaken to investigate both the technical and economic feasibility of using porcelain enamel coatings in pipeline systems used in food industry. The performance of enamel coating in pipeline was evaluated in terms of reduction in hydraulic gradient and head loss.

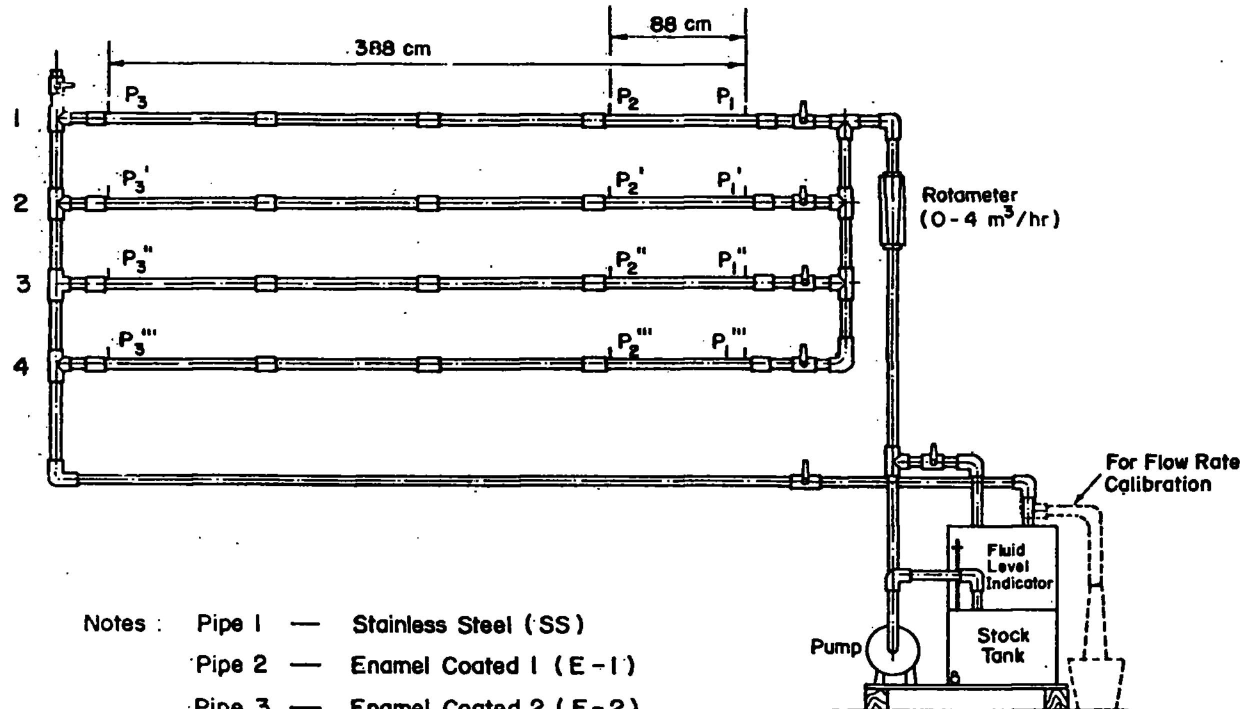
In a general case, the hydraulic drag consists of two components, namely the pressure drag and the drag due to friction force of wave and inductive drags are neglected. It is obvious that in cross flow over a plate and in sudden expansion of a pipe there is virtually no frictional drag, whereas in axial flow and in a flow in a cylindrical pipe it constitutes 100% of the total (Povkh, 1984). Under optimum conditions *i.e.* when the machine works at their highest efficiencies, the contribution of frictional forces to drag is particularly large and may reach 90% and more of the total hydrodynamic drag. Therefore reduction in frictional drag is one of the main avenues for potential savings in power consumption (Povkh, 1984). Pelt (1964) found that skin friction in pipelines could be reduced by as much as 35% by lining the pipe with a flexible tube. Klinzing *et. al.*, (1969) worked with water flow through damped flexible tubes and found friction reduction of 20% or higher. It was proved that addition of small quantities or high molecular-weight polymers to turbulent flow of water significantly reduces friction drag. This occurs in spite of the fact that the additives increase the viscosity of the solution, and consequently should increase the drag (Povkh, 1984). Experiments with rough pipes showed that polymers are less effective in this case and that drag reduction tends to zero as the roughness is increased. No theory has been offered to explain these observations (Spangler, 1969).

The porcelain enamel is a substantially vitreous or glassy inorganic coating bonded to metal by fusion at a temperature above 218 C. Usually the enamel consists of two specific coating compositions, a ground coat *i.e.* the first coat, applied to the metal and designed to adhere to it and a cover coat applied over the ground coat which often matures at a somewhat lower temperature than the ground coat and which provides all of the physical and optical characteristics required for the end use (Spencer-Strong, 1972). Strongly bonded to a steel backing, porcelain enamels are roughly comparable to organic coatings in resistance to mechanical damage. They bear good resistance to wear and abrasion. Porcelain enamels can be formulated for all degrees of acid resistance and only for mild alkalies at temperatures up to boiling (Stedfeld, 1958).

MATERIALS AND METHODS

For studying the effect of coating on the friction loss in pipes an experimental set up was fabricated as shown in Figure 1. It consisted of four pipes. The pipe 1 was made up of stainless steel while pipe 2 was electrical metallic tubing and pipe 3 was seamless steel pipe. Pipe 2 was enamel coated from inside in continuous processing furnace and was designated as E-1. While pipe 3 was enamel coated from inside by a manually controlled batch processing and was designated as E-3. Pipe 4 was made up from galvanized iron. The other components of experimental set up were manometers, centrifugal pump, a rotameter, a stock tank, a switch and several ball valves. All pipes were cut into four pieces of one meter each length and were connected by spigot joints. Three pressure taps were welded on each pipeline in such a way that the head losses could be tested within two different pipe lengths *i.e.* L = 88 cm and L = 388 cm. (Figure 1). The pressure taps were connected to the manometer taps by flexible tubes. The flow rate was measured by a rotameter and was controlled by two valves, namely, the by-pass valve through which the high flow rate could be adjusted and the valve in the circulating pipe, which was used to adjust the flow rate at a lower range. The stock tank functions as both a container and an energy releasing unit.

Three kinds of fluid were used for testing *viz.* water, sugar solution and tomato juice, four concentration of sugar solution *i.e.* 20, 30, 40 and 50% were selected for testing. There was no variation in the



Notes : Pipe 1 — Stainless Steel (SS)
Pipe 2 — Enamel Coated 1 (E - 1)
Pipe 3 — Enamel Coated 2 (E - 2)
Pipe 4 — Galvanized Iron (GI)

Fig. 1 Experimental Set - up for Testing Head Loss of the Pipes concentration of tomato juice. Eight volumetric flow rates were selected. The flow rates were 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 m^3/h. The water from the water supply was used for testing. The sugar solutions were prepared by mixing commercially purchased sugar with the water. About 37.6 liters of freshly processed tomato juice was diluted using 18 liters of water to satisfy the minimum quantity required for circulation. The properties of fluid used in the test are given in Table 1. The flow rates were calibrated before experimenting. The pressure difference within two different pipe lengths *i.e.* 88 cm and 388 cm were measured by inverted manometers under different flow rates. The experimental results were analyzed in term of friction factor, f, and hydraulic gradient, h_f, which were calculated by using equations given by Streeter and Wylie (1975). These equations are:

$$f = \frac{h_f \, 2 \, D \, g}{L} \quad V^2$$

Where,

f = friction factor
h_f = hydraulic gradient, m
D = pipe diameter, m
g = gravitational acceleration, m/s^2
L = length of pipe, m
V = average fluid velocity, m/s

RESULTS AND DISCUSSION

The experimental relationship between friction factor and Reynolds number for three kinds of fluids, *i.e.* water, sugar solutions and tomato juice, and different pipes were evaluated. This explained the flow characteristics of both Newtonian (water and sugar solution) and non-Newtonian (tomato juice) fluids flowing in the pipes. It was observed that under similar range of flow rates for different fluids (0.5 to 4.0 m^3/h), the test covered a range of Reynolds number from about 4,000 to 77,000 for Newtonian fluids, and 270 to about 4,000 for the non-Newtonian fluid. Correspondingly the friction factor ranged from 0.017 to 0.106 for the former and from 0.0141 to 0.1441 for the latter. According to Moody chart (Moody, 1944) these two ranges of Reynolds numbers are located in the transition zone and laminar to critical zone, respectively.

Table 1. Some of the properties of fluids used in testing.

1) Sugar solution

Concentration %	20	30	40	50
Densities (kg/m^3)	1078	1126	1178	1225
Viscosities (PaS)	8.28×10^{-4}	9.4×10^{-4}	1.12×10^{-3}	1.73×10^{-3}

2) Tomato juice

	Diluted	Undiluted
Total Solids %	4.1	5.9
Total Soluble solids %	4.0	5.7
Density (kg/m^3)	1431	1438

Figure 2 illustrates the friction factor and Reynolds number relationship for different pipes. There was a gradual decrease in friction factors along with an increase in the Reynolds numbers. The stainless steel pipe showed higher friction factor at any value of Reynolds number compared to other pipes. The inner surface of G1 pipe was not as smooth as pipe E-1 and E-2, but was smoother than that of stainless steel pipe.

Although, theoretically, under the same Reynolds numbers, the friction factor should be the same for a given pipe, it was observed that the friction factors computed for the length L = 388 cm was higher than the friction factor computed for the L = 88 cm for the same pipe. This can be attributed to losses due to the pipe fittings within the 388 cm length.

The generalized Reynolds number for tomato juice ranged from 275 to about 4,000, which falls between both laminar and critical zones in the Moody chart. A series of straight lines as shown in Figure 3 were obtained for the tomato juice representing the relationship between the friction factor and Reynolds number. This might be due to some

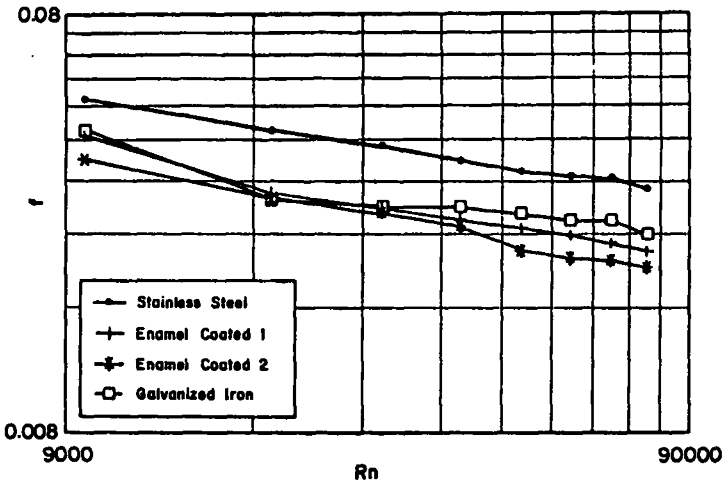


Fig. 2 Log (f) vs Log (Rn) [Water, L=388 cm]

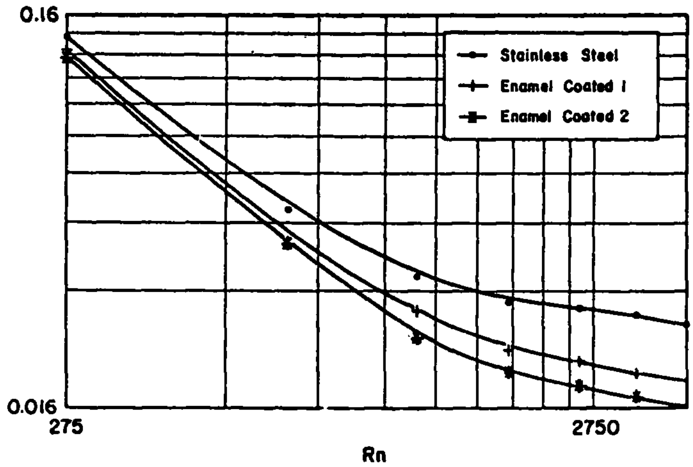


Fig. 3 Log (f) vs Log (Rn) [Tomato Juice, L = 388 cm]

errors in computing the consistency coefficient or in computing the head loss.

Hydraulic gradient is the head loss in a unit length of pipe length, which is influenced by the surface roughness, the physical properties of the fluids, and the flow rate. For Newtonian fluid, the higher the flow rate, the more viscous the fluid, and the rougher the surface of the pipes, the bigger the hydraulic gradient. Figure 4 shows the relationship between hydraulic gradient and flow rates of water for different pipes. It was observed that the hydraulic gradient increased with an increase in flow rates of water for all the pipes. The highest hydraulic gradient was observed for the stainless steel pipe and the lowest gradient was observed for E-2 pipe. Thus enamel coating gave more smoother surface than stainless steel and galvanized pipes. The performance of E-1 pipe was also better than the stainless steel pipe and galvanized iron pipe. In general, it was observed that the hydraulic gradient of ordinary mild steel pipe can be reduced by about 10 to 40% by enamel coating compared to hydraulic gradient of the same size of stainless pipe.

As the concentration of sugar solution increased, both density and viscosity also increased. This resulted in an increase in the hydraulic gradient. The influence of physical properties of the fluids on hydraulic gradient is shown in Figure 5 in which the hydraulic gradient of three different pipes were compared under a flow rate of 3 m^3/h for all the test materials.

The results of statistical analysis indicated that the difference in friction factor and hydraulic gradient for different pipes was significant at 95% level of significance. The effects of different flow rates on head loss were also highly significant.

The economic analysis of enamel coating showed that the cost of enamel coating plus the cost of pipe itself will amount to only 30 to 40% of the initial cost of stainless steel. About 60 to 70% initial cost can be saved based on the cost of stainless steel. The calculations also revealed that the total cost saved annually will be about US$ 460 to US$ 510 on a 500 m pipe installation compared with stainless steel pipes. The analysis was limited to flow rates up to 3 m^3/h, however, if improvements in the food industry will help to have increased flow rates, then the benefits derived by enamel coating could be improved further.

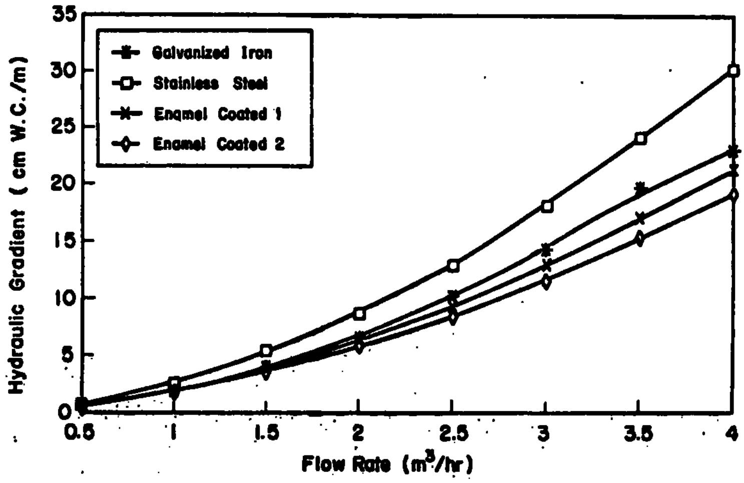


Fig. 4 Hydraulic Gradient Under Various Flow Rates [Water, L = 388 cm]

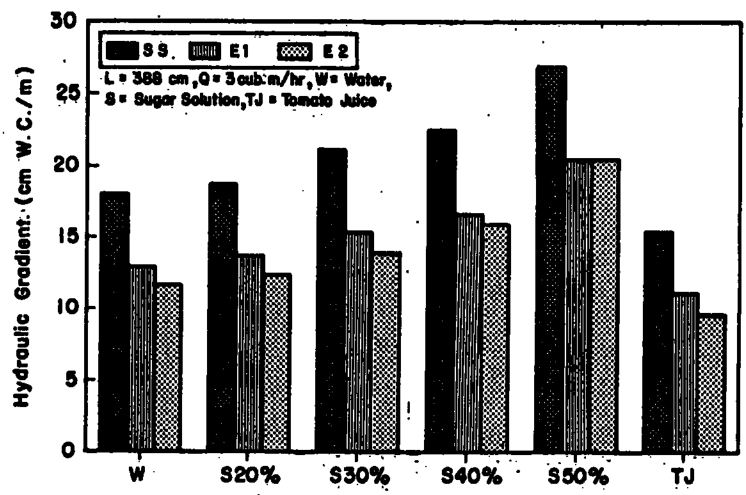


Fig. 5 Comparison on Hydraulic Gradient

CONCLUSIONS

The results of comparison of the performance of stainless steel and enamel coated pipes in transferring fluid form food materials showed that the hydraulic gradient can be reduced effectively by applying enamel coating on the inner surface of ordinary steel pipes. The hydraulic gradient reduction rate depends on the physical properties of the fluid transferred, flow rates and the coating quality. The cost analysis revealed that the enamel coating on steel pipe would reduce the total annual cost component to the use of stainless steel pipes.

REFERENCES

Klinzing, G.E.; Kuboucik, R.J. and Marmo, J.F. (1969). Frictional losses in form damped tubes. Ind. Eng. Chem. Process Design Development.

Moody, L.F. (1944). Friction factors for pipe flow. Transactions of ASAE, November.

Pelt, R. (1964). A preliminary investigation of surface damping effects on fluid flow through flexible tubes. Ph.D. Dissertation, Dept. of Chem. Eng., University of Pittsburgh.

Povkh, I.L. (1984). Reduction of skin friction – that's where energy savings are. Fluid Mechanics – Soviet Research, 13(4): 1 – 13.

Spangler, J.G. (1969). Studies on viscous drag reduction with polymers including turbulence measurement and roughness effects. *In*: Viscous Drag Reduction, (Ed). Wells, C.S. Plenum Press.

Spencer – Strong, G.H. (1972). Porcelain Enamels – A concept in transition. Materials Research and Standards, April, 20 – 23.

Stedfeld, R.L. (1958). Vitreous coatings. *In*: Engineering Materials Handbook, (Ed). Mantell, C.L. McGraw Hill Book Company, Inc.

Streeter, V.L. and E.B. Wylie (1975). Fluid Mechanics, 6th Edn., McGraw Hill Book Company Inc.