The effect of gap width between horizontal tube and twisted tape on the pressure drop in turbulent water flow

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This paper presents the effect of gap width between twisted tape and horizontal tube on the pressure drop in a turbulent flow. Tests were performed on nine different twisted tape inserts in a horizontal tube with water as a working medium. It was observed that the gap between the tape and the internal diameter of the tube resulted in an anomalous pressure drop behavior at a critical twist ratio. The pressure drop increased and decreased in the case of the tape with twist ratio $Y = 3.6$ with the optimum at a clearance of 0.89 mm.

Keywords: twisted tape; pressure drop; turbulent flow

Introduction

Twisted tape inserts have been investigated and used in the past for heat transfer augmentation. Several numerical and experimental studies have been reported. Date (1974) presented a numerical study, and Hong and Bergles (1976), Marner and Bergles (1978), and Sukhatme *et al.* (1987) showed experimentally the effect of twisted tapes on heat transfer and pressure drop under uniform heat flux conditions in laminar flow in the tubes.

Duplesis (1982) and Monheit (1987) conducted a numerical and experimental study, respectively, for the constant wall-temperature boundary condition under laminar flow. On the other hand, Lopina and Bergles (1969) developed correlations for turbulent flow conditions that are widely used in the heat-exchanger industry. More recently, Peterson *et al.* (1989) performed experiments in high-pressure turbulent swirl flow with water as a working fluid.

Most of these studies have been comprehensive and have resulted in valuable information. However, none of them has analyzed the effect of the gap between the twisted tape and the internal diameter of the tube on the pressure drop and heat transfer characteristics. In the most recent published work of Bandyopadhyay *et al.* (1991), the effect of free convection in a laminar flow in large-diameter pipes has been presented. Again, there is no mention of the effect of clearance between tape and pipe.

It is this lack of information in the open literature that led to the undertaking of this short but important experimental work. The study deals with the effect of gap width on the pressure drop for various twist ratios and flow conditions.

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Received 21 February 1992; accepted 17 May 1992

Test facility and procedure

A schematic diagram of the test facility is shown in Figure 1a. The rig included a horizontal test section of a single tube-in-tube heat exchanger. The test section consisted of a smooth copper tube with an outside diameter of 15.9 mm and a wall thickness of 1.05 mm. The test section had a nominal length of 100 cm, preceded by a calming length of 100 cm, used to eliminate the entrance effects. The system was insulated by wrapping insulation tape around the exposed portion of the tube and the shell. The other components included a flow meter, pressure taps, thermocouples, and a data acquisition system.

Saturated steam was introduced in the annulus and provided an isothermal heat source. Two pressure taps, one at each end of the test section, were provided to measure the pressure drop. The test section was equipped with two thermocouples to measure the inlet and outlet temperatures of water. A mixing chamber was brazed to the outlet, and the temperature was measured within the chamber. The readings from the thermocouple at the outlet and the one in mixing chamber were similar within acceptable limits, thereby confirming the validity of the thermocouple outputs. Three thermocouples were inserted in the annular region to monitor the steam saturation temperature. Also, four equally spaced thermocouples were located in punched dimples on the outside of the tube and then soldered flush in place to measure the wall temperatures. Since all four thermocouples showed close agreement for any run, the average of these four readings was used as the wall temperature. All thermocouples were 36-gauge copper-constantan.

Nine different tapes, as shown in Figure 1b were used in this study: three twist ratios, each with three different tape widths. The physical dimensions of the tapes are given in Table 1. For each test run, the tube was loaded with one of the nine tapes.

Measurements were recorded by a data acquisition system under steady-state conditions. It was observed that a

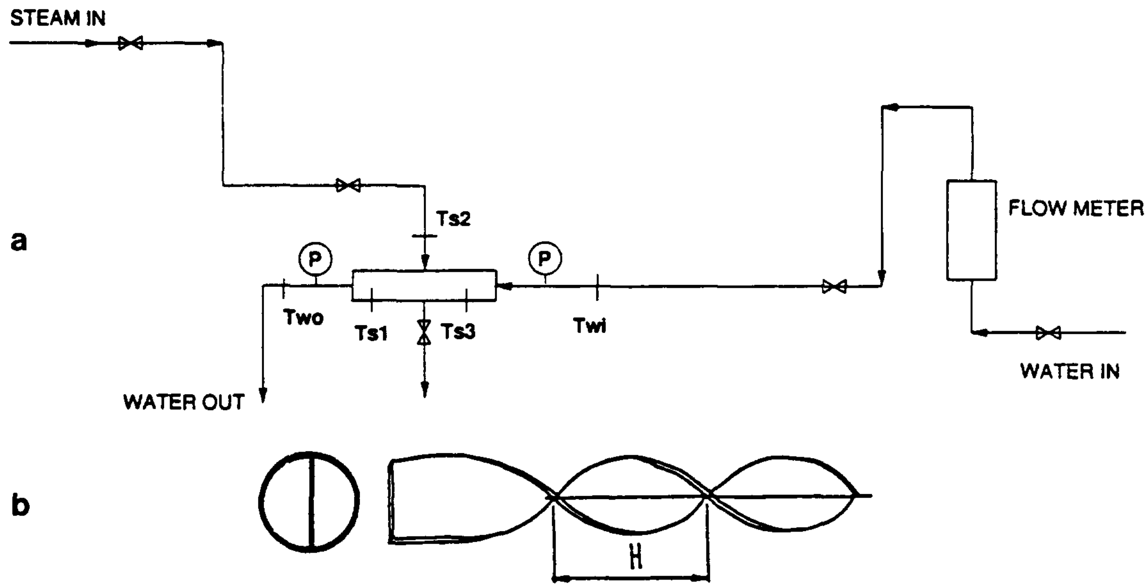

Figure 1 (a) Test loop; (b) twisted tape insert

steady-state condition was achieved within 10 minutes of a change in the mass flow rate. Hence, data were recorded after 10 minutes of each step change. Before taking the data, the signals received from the thermocouples were checked against a calibrated thermometer. The average uncertainty was observed to be less than ±0.10 K.

The tests started with low water-mass flow rates. The flow rate was increased stepwise for each new recording until a maximum flow rate of 0.37 kg/s was reached. The data were then repeated in the reverse order. The average uncertainty in Reynolds number and friction factor at each measured data point was observed to be less than ±1 percent.

Results and discussion

It was noticed that at Reynolds numbers less than 8000 the data for different tapes contained a scatter. Hence, it was decided to consider only those data at Reynolds numbers greater than 8000. The following analysis is based on data between 8000 < Re < 35000.

The results are shown in Figures 2 to 4. From the fluid-dynamics point of view, a restricted flow would result in a higher pressure drop. Hence, in the case of a twisted tape,

Table 1 Twisted tape specifications

	Tape width (mm)		
$Y = H/D$	10.80	12.00	13.55
3.6	A	B	C
5.5	D	E	F
7.3	G	H	I

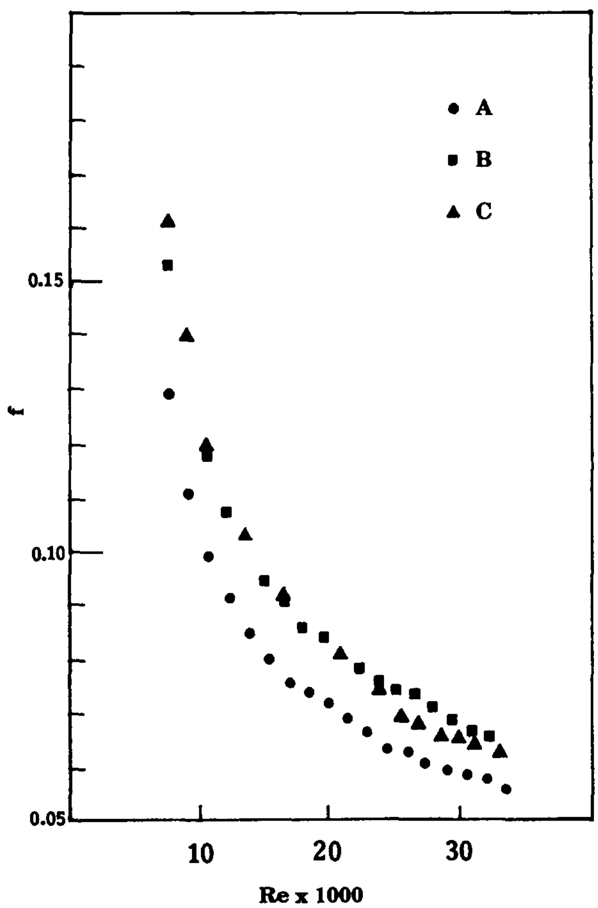

Figure 2 Friction factor for $Y = 3.6$

Notation

D	Inside diameter
f	Darcy friction factor
H	Pitch (based on 180°)
Re	Reynolds number
Y	Twist ratio (H/D)

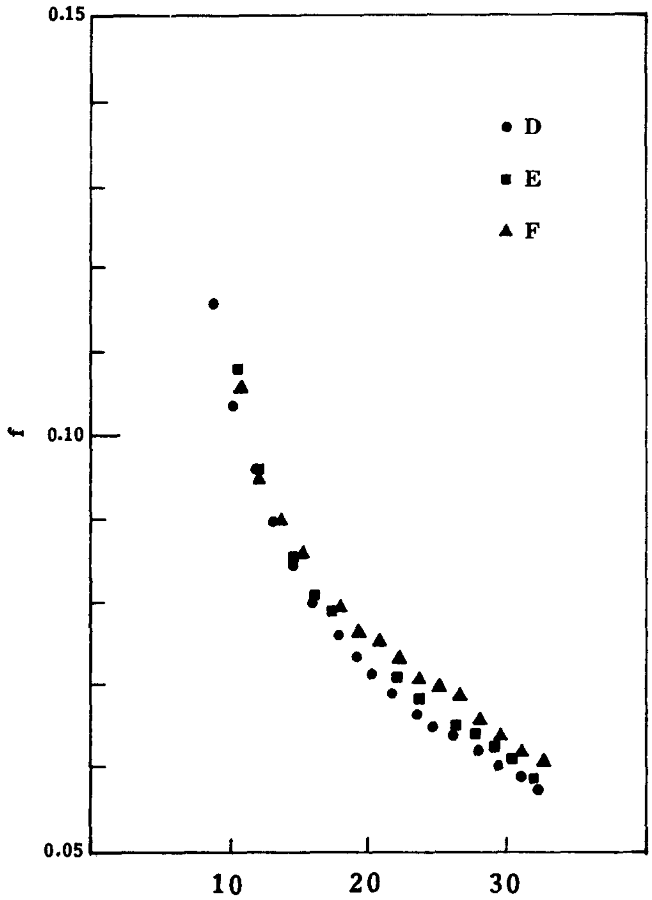

Figure 3 Friction factor for $Y = 5.5$

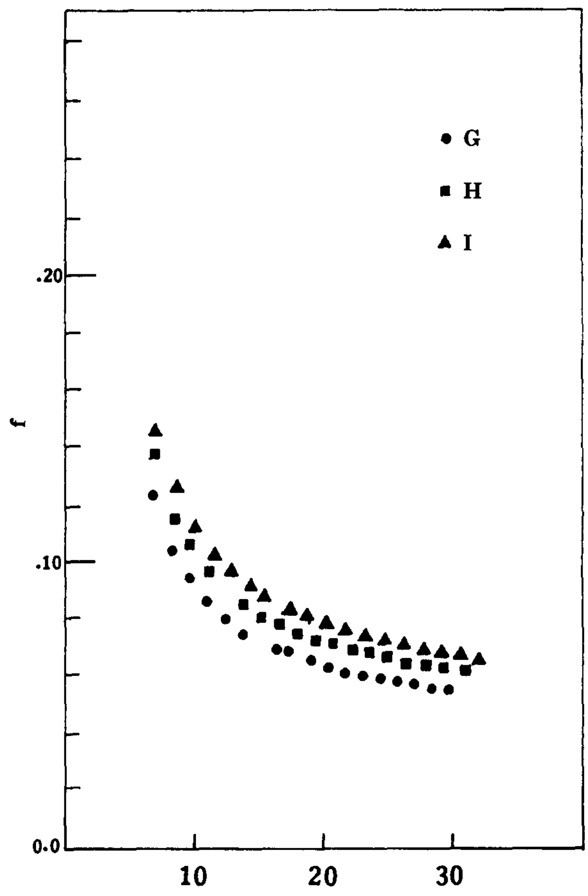

Figure 4 Friction factor for $Y = 7.3$

one would expect a higher pressure drop with increasing width for the same twist ratio, length, and flow conditions. In contrast, the results here show a different behavior. An increasing and decreasing trend in pressure drop was observed for increasing tape width, i.e., Tapes A, B, and C ($Y = 3.6$). A peak in friction factor was observed with Tape B (width = 12 mm) beyond Reynolds numbers of 20,000, as shown in Figure 2.

This phenomenon was not observed with Tapes D through I, as shown in Figures 3 and 4. As expected, the pressure drop increased with an increase in tape width. One plausible explanation could be that secondary flows are generated due to a pressure differential between the gap and the centerline of the tube that results in a flow reversal. At smaller gaps the quantity of fluid within the gap is not sufficient and at larger gaps the velocity in the gap is not enough to create drastic change in the flow behavior. It is only at a critical gap, a critical twist ratio, and a threshold Reynolds number that this phenomenon will occur. It is also possible that the critical gap width, twist ratio, and threshold Reynolds number combination could be different for different fluids, since the density factor would result in a different pressure drop across the gap and the central core of the tube.

For Tapes D, E, F with $Y = 5.5$ and for Tapes G, H, I with $Y = 7.3$, the results are different. The pressure drop increases with the decrease in a gap width. This shows that appreciable flow reversal would only occur when the twist ratio, the gap width, and the Reynolds number are at critical conditions. However, the probability increases at lower twist ratios. It is believed that the interplay of the above features serves an important role in enabling this phenomenon to occur.

Conclusions

An experimental study was performed on nine different twisted tape inserts in a horizontal tube using water as the test fluid. It was observed that the gap between the tape and the internal diameter of the tube was responsible for anomalous pressure-drop behavior at a critical twist ratio. The pressure drop increased and decreased in the case of the tapes with $Y = 3.6$, and the peak occurred at a clearance of 0.89 mm.

It is recommended that a detailed investigation on this fundamental aspect of twisted tape inserts be undertaken. Specifically, a continuation of present study is in progress to understand the heat transfer characteristics under similar conditions. Based on the analogy between heat and momentum transfer, it is believed that the heat transfer results will also show similar trends.

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