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Review of Heat Transfer Enhancement Techniques in Swirl Flow Using Active and Passive Methods

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Abstract

This survey suggests a broad review of the various heat transfer enhancement techniques caused due to swirl flow and broadly classified in two distinct ways viz. Active and passive. Swirl flow has various applications in the area related to engineering field such as chemical and mechanical mixing and separation devices, turbo machinery, chemical reactors, combustion chambers. To enhance the heat and mass transfer, there is a need of the better utilization of swirl flow. The swirl flow can be generated by various techniques either by active or passive. This paper contains literature survey which provides various enhancement techniques in heat transfer using swirl flow.

Keywords: Swirl flow, active methods, passive methods, Friction factor.

1. Introduction

As far as heat transfer enhancement in heat exchanger is concerned, the prime aim is to increase the heat transfer coefficient. For that purpose it is needed to increase the turbulence level. So more is the turbulence, more will be the heat diffusion causing augmentation in heat transfer rate. Heat transfer enhancement at heat exchangers may be achieved by numerous techniques, and these techniques can be classified into three groups: passive, active and compound techniques.

In the active techniques, heat transfer is improved by giving additional flow energy into the fluid. In the passive techniques, however, this improvement is acquired without giving any extra flow energy. In the compound techniques, two or more of the active or passive techniques may be utilized simultaneously to produce an enhancement that is much higher than the techniques operating separately

2. Literature Review

2.1 Passive methods

Ebru Kavak Akpinar, Yasar Bicer [1] has studied the effect of heat transfer rates, friction factor and exergy loss by applying the holes on the swirl generators. Various numbers of holes having different diameters were used. Hot air and cold water were passed through the inner pipe and annulus, respectively. Experiments were carried out for both parallel and counter flow models of the fluids at Reynolds numbers between 8500–17 500. Heat transfer, friction factor and exergy analyses were made by comparing with and without swirl generators conditions. By giving rotation to the air with the help of swirl elements Nusselt number was increased upto130% at a value of about 2.9 times increase in the friction factor. With Swirl generators exergy was found to be increased by 1.25 times as compared with that for inner pipe without swirl generators.

After performing the experiment for both counter and parallel flow mode, results were compared to those obtained from the empty tube and Dittus–Boelter correlation $Nu = 0.023Re^{0.8}Pr^{0.4}$ (describes non-swirling flow in the smooth-tube). Indeed, the empty tube has the tangential inlet, which generates the swirl flow. The swirl flow induced by the step-shape distribution of the vorticity has a set of axial velocity profiles under the same Reynolds and swirl numbers. This is the main distinction between flows with and without swirling. The highest Nusselt number was achieved with the heat exchanger operated in a counter-flow mode and equipped by a swirl generator having 20 circular holes with 3 mm diameter. While the increase in the Nusselt number was 113% at swirl generator having 20 circular holes with 6 mm diameter, the increase was 109% at 9 mm diameter. In all cases, the swirling flow gave higher values of Nusselt number than those for the empty tube and the Dittus–Boelter regime (non-swirling flow). However swirling flow is not only responsible to increase heat transfer, but also to decrease it. As are, two types of vortex structures in the swirl flows with the same integral characteristics i.e vortices with left-handed and right-handed helical symmetry. Left-handed helical vortexes generate wake-like swirl flows and increase heat transfer in comparison with the axial flow. For flow having same *Re* number, right-handed vortex structures generate jet-like swirl flows and can diminish heat transfer in comparison with the developing axial.

Betul Ayhan Sarac, Tulin Bali [2], had investigated heat transfer and pressure drop characteristics of a decaying swirl flow in a horizontal pipe. The decaying swirl flow was produced by the insertion of vortex generators with propeller-type geometry (fig 1). Three different positions of the vortex generator in the axial direction are examined: at the inlet x = 0, x = L/4 and x = L/2. The author for each position, effects of the vane angle about the core of the insert device and the number of the vanes attached circumferentially to the device on heat transfer and pressure drop were studied. Experiments were conducted at Reynolds numbers ranging from 5000 to

30,000. Depending on the Reynolds number, the position of the vortex generator, the angle and the number of the vanes, the Nusselt numbers were found to increase, which ranges from 18.1% to 163%. . From the experimental results, it can be concluded as follows:

1. For the decaying swirl flow, the heat transfer and pressure drop decreased with the axial distance.
2. The inserts with six vanes resulted in more heat transfer values than those with four vanes.
3. The position of the insert in the axial direction had a considerable effect both on heat transfer and pressure drop. In general, Case B (x = L/4) presented the higher heat transfer rates and friction factors.
4. Increasing the vane angle resulted in lower heat transfer and pressure drop results. This was attributed to the fact that an increase in the vane angle would increase the swirl period

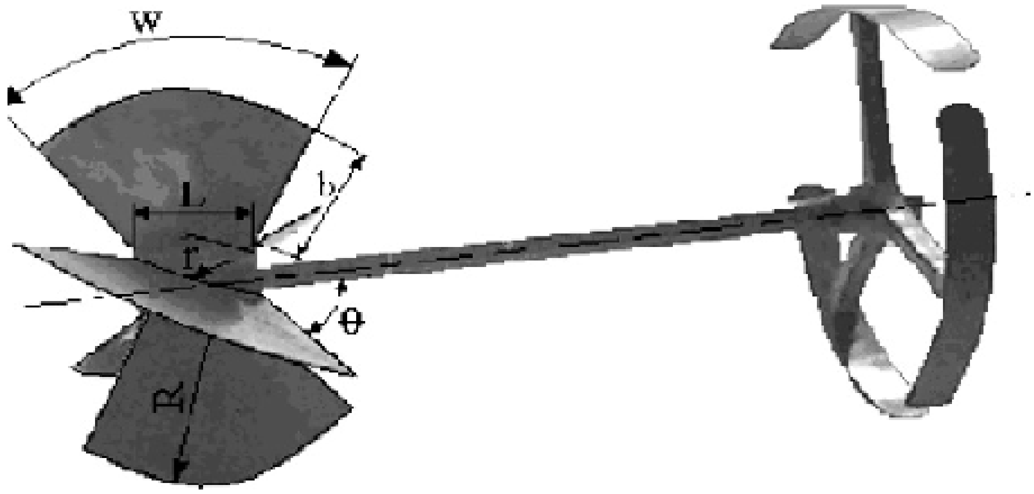

Fig. 1 The geometry of the propeller-type swirl generator.

Gülşah Çakmak , Cengiz Yıldız [3], imposed the swirling motion on the hot air by placing injectors with various diameters and numbers in triangle line rows on the entrance section of the inner pipe of the concentric heat exchanger. The experiment was carried out by preparing various injectors.. The experiments were carried out for counter current flow models of the fluids at different Reynolds numbers. The heat transfer rates increased with decreasing diameter and with increasing number of the injectors. With this kind of swirl generators, heat transfer was enhanced by 93%..

The maximum enhancement occurred by using swirl elements having 6-mm diameter, 20 injectors with injector angle 60°. Further, these improvements may be achieved with increase Reynolds numbers. Thus heat transfer was found to be enhanced by having a swirl flow caused due to these injectors

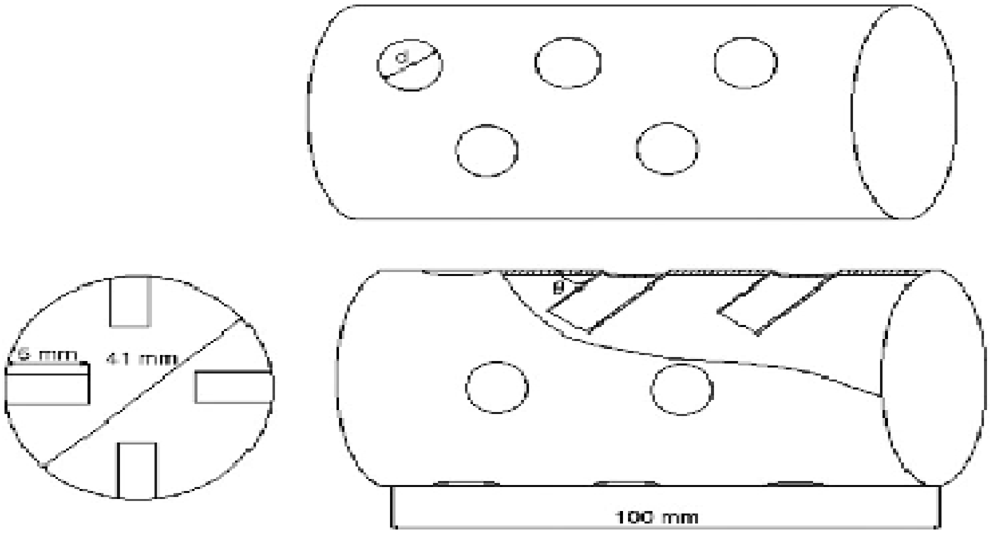

Fig 2 The swirl element with triangle arranged and 60° angle.

M. Ahmadvand et al. [4] had investigated the effects of axial vane swirler on heat transfer augmentation and fluid flow. Decaying swirling pipe flow was obtained by swirl generator which was installed at the inlet of the annular duct . Three different blade angels of 30°, 45° and 60° were examined (fig. 2). Flow rate was adjusted at Reynolds numbers ranging from 10000 to 30000. Study has been done under uniform heat flux condition and air was used as working fluid. Higher results were obtained by using vane swirler than the plane tube.., Nusselt was found to be increase from 50% to 110% depending upon the blade angle simultaneously friction factor increased by the range of 90–500%. Thermal Performance was evaluated for test section and test section together with swirler. In both cases, dependency of thermal performance on vane angle and Re number was observed and it was seen that thermal performance was increased as vane angle is increased and decreased by growth of *Re* number. When increasing the blade angle, higher decay rate has been observed for local Nusselt number.

As compare to axial pipe flow, heat transfer coefficients were improved by using this swirler. It was found that heat transfer enhancement was dependent on blade angle (or inlet swirl intensity) and *Re* has no significant influence. For overall heat transfer was enhancement between 50–110% depending on vane angle, while friction factor enhancement was between 90–500 By rising the vane angle, heat transfer performance was increased for a particular Re number.. Evaluated performances for test section, based on blade angle, have been obtained to be between 1.26–1.34, whereas for swirler in conjunction with test section it ranges from 0.95 to 1.02 at *Re* = 10000. Results show enhanced local *Nu* decays along the pipe in such a way that higher decay rate is specified to larger blade angles.

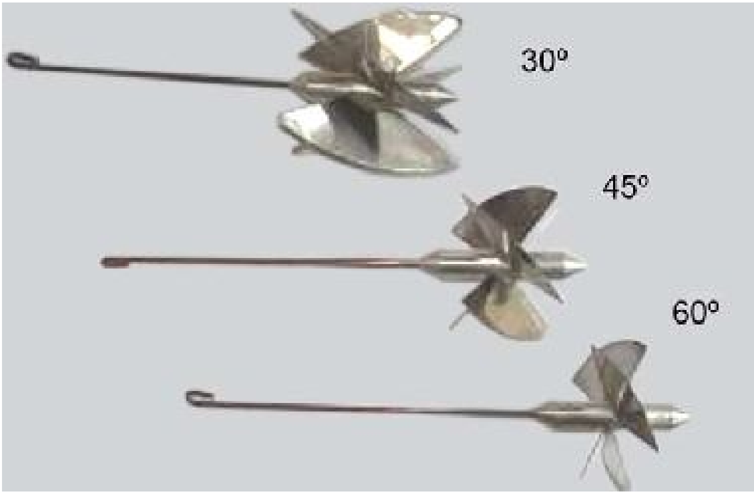

Fig.3 Axial guide vane swirler

2.2 Active Methods

A.E.Zohir et al. [5], aimed at studying the heat transfer characteristics and pressure drop for turbulent airflow in a sudden expansion pipe equipped with propeller type swirl generator or spiral spring with several pitch ratios (fig. 3). Reynolds number was kept ranging from 7500 to 18,500 under a uniform heat flux condition in the experiment. The experiments are also undertaken for three locations for the propeller fan (N = 15 blades and blade angle of 65_) and three pitch ratios for the spiral spring (P/D = 10, 15 and 20). The influences of using the propeller rotating freely and inserted spiral spring on heat transfer enhancement and pressure drop are reported. In the experiments, the swirl generator and spiral spring are used to create a swirl in the tube flow. Mean and relative mean Nusselt numbers are determined and compared with those obtained from other similar cases. The experimental results indicate that the tube with the propeller inserts provides considerable improvement of the heat transfer rate over the plain tube around 1.69 times for X/H = 5. While for the tube with the spiral spring inserts, an improvement of the heat transfer rate over the plain tube around 1.37 times for P/d = 20. Thus, because of strong swirl or rotating flow, the propeller location and the spiral spring pitch become influential on the heat transfer enhancement. The increase in pressure drop using the propeller is found to be three times and for spiral spring 1.5 times over the plain tube. Correlations for mean Nusselt number, fan location and
spiral spring pitch are provided.

Fig.4 Spiral spring with different pitches and propeller photos

Clayton and Morsi [6] studied turbulent swirling flows along the annulus formed between two concentric stationary cylinders. Hot wire anemometry was used to measure the time-mean parameters and turbulence components of the velocity components. In the swirling flow rig, Perspex bell-mouth was used to transport the vortex flow into a settling chamber with as little disturbance as possible.

Algifri et al. [7] investigated the heat transfer in turbulent decaying swirl flow generated by a radial blade cascade, and they used a bell-mouth in their radial swirl generator.

Kitoh [8] had investigated to obtain data about swirling flow through a pipe. A bell-shaped cone at the centre of the swirler and radial swirl generator to deflect smoothly the radial flow into the axial direction.

Yilmaz et al. [9] investigated the enhancement of heat transfer by turbulent decaying swirl flow generated by a radial guide vane swirler with conical deflecting element. The investigations in which radial swirl generators are used have been scant and have usually dealt with the flow characteristics, such as velocity, turbulence, shear stress, etc., and generally, a conical inserted centre body (deflecting element) has been used to deflect smoothly the radial flow into the axial direction in these investigations. An experimental setup was designed accordingly to investigate the effects of the geometry of the deflecting element in radial guide vane swirl generators on the heat transfer and friction characteristics in decaying swirl pipe flow. The swirl generator with conical deflecting element, with spherical deflecting element and with no deflecting element are three type of swirl generators that was used in the system

Conclusion

From this review, various ways of enhancing the heat transfer rate by generating the swirl flow either by active or passive method can be observed. It is seen that in most of the cases, enhancement in active method is more pronounced than passive method but simultaneously friction factor is also increased. A basic comparative study is provided below which gives an idea about the relation between the various governing parameters and heat transfer rate, friction factor and nusselt number.

Table 1: Comparative study of various results found in heat transfer enhancement techniques using active and passive method

Ref. No.	***Nu. No./ Q̇***	***Reynolds No. (R_e)***	***Friction factor***	***Concluded remarks***
1	Nu. No. : Up to 130% Q̇ : 130%	8500 – 17500	2.9 times Increased	As diameter of holes decreases and No. of holes increases , heat transfer rate increases
2	Nu. No. : Increases by 18.1 - 163%	5000 - 30,000	Decreases as vane angle increases and increases at x = L/4	As vane angle decreases and No. of vane increases, heat transfer increases. Heat transfer rate is found to be highest at x = L/4
3	Q̇ increases up to 93%	10,000 - 21,000		As diameter of holes decreases and No. of holes increases, heat transfer rate increases. Heat transfer rate is found to be maximum at 6mm diameter hole, 20 injectors at 60^o angle
4	Nu. No : increases from 50% to 110%	10,000 – 30,000	Increases to 90 to 500%	As angle increases, swirl intensity increases and thermal performance increases
5	Nu No. increases by (0.83-1.65), (1.35-1.69), (1.0-1.37)	7500 – 18500	Increases by 3 times	Strong swirl flow, the propeller location, and spiral spring pitch becomes influential on the heat transfer rate. Heat transfer rate increases by 1.37 times P/D= 20.

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