Renewable and Sustainable Energy Reviews 49 (2015) 444–469

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Review of heat transfer enhancement methods: Focus on passive methods using swirl flow devices

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ARTICLE INFO

Article history:
Received 10 August 2014
Received in revised form
19 March 2015
Accepted 24 April 2015

Keywords:
Heat exchanger
Passive heat transfer
Swirl flow devices
Turbulators
Friction Factor
Nusselt number
Heat transfer performance

ABSTRACT

Economic reasons (material and energy saving) leads to make efforts for making more efficient heat exchange. The heat transfer enhancement techniques are widely used in many applications in the heating process to make possible reduction in weight and size or enhance the performance of heat exchangers. These techniques are classified as active and passive techniques. The active technique required external power while the passive technique does not need any external power. The passive techniques are valuable compared with the active techniques because the swirl inserts manufacturing process is simple and can be easily employed in an existing heat exchanger. Insertion of swirl flow devices enhance the convective heat transfer by making swirl into the bulk flow and disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. An effort has been made in this paper to carry out an extensive literature review of various turbulators (coiled tubes, extended surfaces (fin, louvered strip, winglet), rough surfaces (Corrugated tube, Rib) and swirl flow devices such as twisted tape, conical ring, snail entry turbulator, vortex rings, coiled wire) for enhancing heat transfer in heat exchangers. It can be concluded that wire coil gives better overall performance if the pressure drop penalty is considered. The use of coiled square wire turbulators leads to a considerable increase in heat transfer and friction loss over those of a smooth wall tube.

Contents

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http://dx.doi.org/10.1016/j.rser.2015.04.113
1364-0321/

1. Introduction

1.1. Importance of heat exchangers

Heat exchangers have different applications ranging from conversion, recovery of thermal energy in different industrial, domestic and commercial uses. Some public examples include cooling in thermal processing of chemical, condensation in power, agricultural products, pharmaceutical, steam generation, sensible heating, cogeneration plants, waste heat recovery and fluid heating in manufacturing. Enhance in heat exchanger's performance can make more economical design of heat exchanger which can aid to make energy, material and cost savings related to a heat exchange process.

The importance of increasing the thermal performance of heat exchangers has caused development and use of many techniques termed as heat transfer enhancement. These methods augment convective heat transfer by reducing the thermal resistance in a heat exchanger. Utilize of augmentation techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. To reach high heat transfer rate while taking care of the augment pumping power, various techniques have been presented in recent decade. Recently, swirl flow devices have widely been used for increasing the convective heat transfer in various industries. This application is because of their low cost and easy setting up. The main aim of this paper is to introduce the different ways to improve heat transfer performance. An extensive literature review of various turbulators (coiled tubes, extended surfaces (fin, louvered strip, winglet), rough surfaces (Corrugated tube, Rib) and swirl flow devices such as twisted tape, conical ring, snail entry turbulator, vortex rings, coiled wire) are investigated.

1.2. Important definitions

In this part a few significant terms usually used in heat transfer enhancement work are introduced. Thermal performance factor is commonly used to estimate the performance of different inserts such as wire coil, twisted tape, etc. It is a function of the heat transfer coefficient and the friction factor. The thermal performance factor of an insert device is good if this device can reach significant increase of heat transfer coefficient with minimum increase of friction factor. This parameter is expressed as

$$\eta = \frac{Nu/Nu_0}{(f/f_0)^{1/3}} \tag{1}$$

where Nu, f, Nu_0 and f_0 are the Nusselt numbers and friction factors for a tube configuration with and without inserts respectively.

The Nusselt number is a measure of the convective heat transfer occurring at the surface and is defined as hd/k, where h is the convective heat transfer coefficient, d is the diameter of the tube and k is the thermal conductivity.

The friction factor is a measurement of pumping power. The friction factor for the tube with tabulators can be calculated from

$$f = \frac{\Delta P}{(\rho u^2/2)(L/d_H)} \tag{2}$$

where ΔP is the pressure drop across the test section, ρ is the density of fluid, d_H is the Hydraulic diameter of the tube, u is the velocity of fluid and L is the length of the tube.

The Prandtl number is introduced as the ratio of the diffusivity of momentum to the diffusivity of heat, (υ/α). Pitch is defined as the distance between two points that are on the same plane, measured parallel to the axis of tape. The twist ratio is defined as the ratio of pitch to inside diameter of the tube.

2. Classification of enhancement techniques

Usually, heat transfer enhancement techniques are classified in three broad categories: active method, passive method and compound method. The compound method uses for complex design, so it has limited applications.

2.1. Active method

In these methods, some external power input needs in order to reach augment in the rate of heat transfer. Because of the need of equipment, this method has limit application in many practical applications. In comparison to the passive techniques, these techniques have not shown much potential as it is difficult to provide external power input in many cases. Various active techniques are as follows:

- ✓ **Mechanical Aids**: These devices stir the fluid by mechanical means or by rotating the surface. Examples of the mechanical aids include rotating tube exchangers and scrapped surface heat and mass exchangers.
- ✓ **Surface vibration**: They have been used primarily in single phase flows. A low or high frequency is applied to facilitate the surface vibrations which results in higher convective heat transfer coefficients.
- ✓ **Fluid vibration**: Instead of applying vibrations to the surface, pulsations are created in the fluid itself. This kind of vibration enhancement technique is employed for single phase flows.
- ✓ **Electrostatic fields**: Electrostatic field like electric or magnetic fields or a combination of the two from DC or AC sources is applied in heat exchanger systems which induces greater bulk mixing, force convection or electromagnetic pumping to enhance heat transfer. This technique is applicable in heat transfer process involving dielectric fluids.

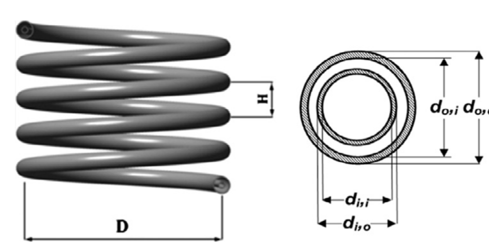

Fig. 1. Schematic diagram and cross section of coiled tube-in-tube heat exchanger [3].

Table 1
Comparison between the passive and active methods.

Method	Approach	Description
Passive	Surface interruptions	Slits or offset fins interrupt the boundary layer, restarting it, creating secondary flows, and/or generating flow unsteadiness.
	Surface roughness	Accelerates transition from laminar flow to turbulent; also increases turbulent flow heat transfer
	Surface protuberances	Ridges or three-dimensional shapes (cube, pyramid, etc.) generate secondary or unsteady flows
Active	Forced flow unsteadiness	Surface vibration or sound waves thins or restarts boundary layer and/or induces secondary flows.
	Boundary layer injection	Enhancement primarily for multiphase flows.
	Boundary layer suction	Removal of boundary layer restarts boundary layer downstream.