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Review Article

The heat transfer enhancement techniques and their Thermal Performance Factor

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ABSTRACT

Heat transfer devices have been used for conversion and recovery of heat in many industrial and domestic applications. Over five decades, there has been concerted effort to develop design of heat exchanger that can result in reduction in energy requirement as well as material and other cost saving. Heat transfer enhancement techniques generally reduce the thermal resistance either by increasing the effective heat transfer surface area or by generating turbulence. Sometimes these changes are accompanied by an increase in the required pumping power which results in higher cost. The effectiveness of a heat transfer enhancement technique is evaluated by the Thermal Performance Factor which is a ratio of the change in the heat transfer rate to change in friction factor. Various types of inserts are used in many heat transfer enhancement devices. Geometrical parameters of the insert namely the width, length, twist ratio, twist direction, etc. affect the heat transfer. For example counter double twisted tape insert has TPF of more than 2 and combined twisted tape insert with wire coil can give a better performance in both laminar and turbulent flow compared to twisted tape and wire coil alone. In many cases, roughness gives better performance than the twisted tape as seen in case of flow with large Prandtl Number. The artificial roughness can be developed by employing a corrugated surface which improves the heat transfer characteristics by breaking and destabilizing the thermal boundary layer. This paper provides a comprehensive review of passive heat transfer devices and their relative merits for wide variety of industrial applications.

Contents

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Nu	Nusselt Number	ρ	density of the fluid
Re	Reynolds Number	u	mean velocity of the fluid
TPF	Thermal Performance Factor	D_h	hydraulic diameter of the test section
TT	Twisted Tape	y/w	Twist ratio of the twisted tape
Pr	Prandtl Number	θ	Twist angle
Nu	Nusselt number with enhancement technique	LR	Tape length ratio
Nu_0	Nusselt number without enhancement technique	s/w	Spaced-pitch ratio
f	Friction factor with enhancement technique	d/w	Perforation hole diameter ratio
f_0	Friction factor without enhancement technique	p/D	Pitch ratio
h	heat transfer co-efficient	R_B	Winglet to duct height ratio
l	characteristic length	R_P	Winglet pitch to tape width ratio
k	thermal conductivity		
ΔP	pressure drop along the test section		

1. Introduction

Heat transfer devices have been used for the conversion and recovery of heat in many industrial and domestic applications. Some examples are boiling of liquid and condensation of steam in power plants, thermal processes involved in pharmaceutical and chemical industries, sensible heating and cooling of milk in dairy industries, heating of fluid in concentrated solar collector and cooling of electrical machines and electronic devices among others. Enhancing the performance of a heat transfer device is therefore of great interest since it can result in energy, material and cost saving.

Heat transfer enhancement techniques generally reduce the thermal resistance either by increasing the effective heat transfer surface area or by generating turbulence in the fluid flowing inside the device. Rough surfaces or extended surfaces are used for the purpose of increasing the effective surface area whereas inserts, winglets, turbulatorsetc. are used for generating the turbulence. These changes are usually accompanied by an increase in pumping power which can results in higher cost (Manglik, 2003). The effectiveness of a heat transfer enhancement technique can be evaluated by the Thermal Performance Factor (TPF) which represents the ratio of the relative effect of change in heat transfer rate to change in friction factor. It is defined by following equation

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

where Nusselt number $Nu = \frac{hl}{k}$ and friction factor $f = \frac{(\Delta P)}{(\rho u^2/2)(l/D_h)}$

In this paper, an effort has been made to review the analysis carried out by various researchers for passive heat transfer enhancement techniques provided with their Thermal Performance Factor.

2. Effect of enhancement techniques

Various heat transfer enhancement techniques have different advantages and limitations. They vary in geometrical configuration and construction complexity while operating under different flow and thermal conditions. On the basis of these parameters this review is classified as follows.

2.1. Effect of swirl producing devices on heat transfer

The twisted tape inserts have been used as a heat transfer enhancement device in last few decades and particular most widely used in heat exchangers to reduce their size and cost. Depending upon the application, twisted tapes are used with different twist ratio, with varying twist direction, fit and loose tape insert, full and short tape insert, perforated insert, insert with peripheral cuts, etc.

2.1.1. Effect of twisted tape dimensions

Instead of full length twisted tape, Saha et al. (2001) used regularly spaced twisted tape. They investigated experimentally the effect of twist ratio, space ratio, tape width, phase angle on heat transfer and concluded that reduction in tape width gives poor heat transfer and higher than zero phase angle creates complexity in tape manufacturing rather than improving the heat transfer. Eiamsa-ard et al. (2006) conducted experiments with a twisted tape with twist ratio of 6–8 for a full length tape and free space ratio of 1, 2 and 3 for a regularly spaced twisted tape insert. They concluded that the heat transfer coefficient increases with decrease in twist ratio and space ratio. Eiamsa-ard et al. (2009) also investigated the effect of short length twisted tape insert. They used twisted tape with fix twist ratio and different length ratio. Short length inserts generated strong swirl at the tube entrance while the full length tape produced strong swirl flow over the entire length. Outcome of their research revealed that the maximum Thermal Performance Factor obtained for full length tape is 1.04 at Re = 4000 and decreases as the length ratio decreases. They proposed following correlation of TPF in term of length ratio and Re: $\eta = 1.82Re^{-0.068}(LR)^{0.067}$.

Sarada et al. (2011) observed that the width of the twisted tape significantly affects the heat transfer rate. It was found that the heat transfer enhances as the width of insert increases. Piriyarungrod et al. (2015) presented the effect of taper in the twisted tape to enhance the heat transfer performance. Their experiments for different taper angles revealed that the taper twisted tape does not achieve the Thermal Performance Factor more than 1.05 but increases the heat transfer rate. Thus, taper tape is not a feasible method for heat transfer enhancement. Esmaeilzadeh et al. (2014) also analyzed the effect of thickness of twisted tape with nanofluid and showed that the increase in