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A review study on twisted tape inserts on turbulent flow heat exchangers: The overall enhancement ratio criteria ☆

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ABSTRACT

Enhancing heat transfer mechanisms are used in many industrial applications like heat exchanger, air conditioning, chemical reactors and refrigeration systems. Therefore several techniques have been promoted to enhance heat transfer rate and to decrease the size and cost of equipment especially the heat exchangers. One of the leading tools used in passive heat transfer methods mainly at turbulence flow is twisted tape inserts. The current paper acclaims that want to review experimental researches done on this technique in recent years at the turbulent zone and with respect to the overall enhancement ratio pick the most efficient type of twisted tape.

1. Introduction

Heat exchangers are so common and very useful in heating and cooling systems in various types of industries such as petrochemical and oil organizations, power plant stations and even residential areas. The design procedure of heat exchangers is complex because it needs the analysis of heat transfer rate, pressure drop and efficiency plus issues like long term endurance and easy maintenance. One of the main categories of increasing heat transfer methods is called as passive technique. It means that there is no need for any kind of extra power source and the heat transfer can increase just using modified surfaces or modified geometries. This method includes the techniques such as treated surface [1], rough surfaces [2], extended surfaces [3], coiled tubes [4], displaced enhancement devices [5], vortex generator devices [6] and additives to the fluids [7]. Also twisted tape (TT) is one of the main inserts which can improve heat transfer rate and it is studied completely through the current paper. At any time that twisted tape (TT) inserts are used, in conjunction with the augmentation in the heat transfer rate, the pressure drop increases. So that any augmentation devices used into the heat exchanger should be optimized among the benefits of heat transfer and the higher pumping cost rate. There are some other literature reviews [8–11] on using TT in heat exchangers but the clarification of their conclusion is not so high. It means that, a researcher maybe cannot decide which kind of TT has the better performance than the others and thus which type of TT can be chosen for the future works. But this problem can be solved by using a parameter which can be helpful to find the best layout of TTs. As mentioned earlier and it will be emphasized at the next pages of the current paper, all enhanced technique includes TT inserts should be optimized between improved heat transfer rate and increased pressure drop or pumping cost. So by giving attention to the definition of the overall heat transfer or enhancement ratio which means the portion of the heat transfer coefficient of an augmented surface to a smooth surface at a constant pumping power, it can be chosen as a decision maker parameter. Therefore a researcher can pick up a range of best twisted tapes with respect to their value of overall enhancement ratio or in other words their capability to be used in the heat exchangers. This is one of the main and notable differences of the current literature review in comparison to others.

2. TT insert devices

2.1. Preface

Among the swirl flow devices which are used to create swirl or secondary flow, twisted-tape inserts are very popular because of their good thermal performance in a medium like single and two phase flow, boiling and condensation, owning to design and application issues. Fig. 1 shows a typical configuration of TT which is used commonly [12]. TT inserts increase the heat transfer coefficients with an increase in the pressure drop. Because of the design and application convenience, they are widely used over decades to generate the swirl flow in the fluid. The size of the new heat exchanger can be reduced significantly by using TTs

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Nomenclature

D	Channel inner diameter
F	Friction factor
H	Half-pitch
Ne	Number of revolutions
Nu	Nusselt number
P	Pressure of flow in a tube
Re	Reynolds number
W	Twisted tape width
Y	Twist ratio
ΔP	Pressure drop
$\dot{m}$	Mass flow rate
$\dot{V}$	Volumetric flow rate

Greek symbols

η	Overall enhancement ratio

Subscripts

0	Base tube
a	Twisted one

Abbreviations

OER	Overall enhancement ratio
TT	Twisted tape

in the new heat exchanger for a specified heat load. Thus it provides an economic advantage over the fixed cost of the equipment. Another benefit of TTs is its easy manufacturing and implementation which are considerable compared to other swirl flow generators [13].

2.2. Application

From the 60s onwards, researchers and engineers have been looking for the use of instruments to enhance the mixing and turbulence intensity of the fluid flow to reach the higher value of heat transfer properties [8]. The TTs have a great capability to increase these parameters and therefore become so common in heat transfer devices like boilers, shell and tube heat exchangers and even simple car radiators (see Fig. 2).

2.3. Main parameters of TT

In order to understand and discuss the characteristics of TTs, it is important to define some important parameters used in this discussion, first. These parameters, which are used throughout this report, are the empty tube Reynolds number (Re), half-pitch (H), twist ratio (Y) and number of revolutions (Ne) [8].

Fig. 1. Typical configuration of TT [6].

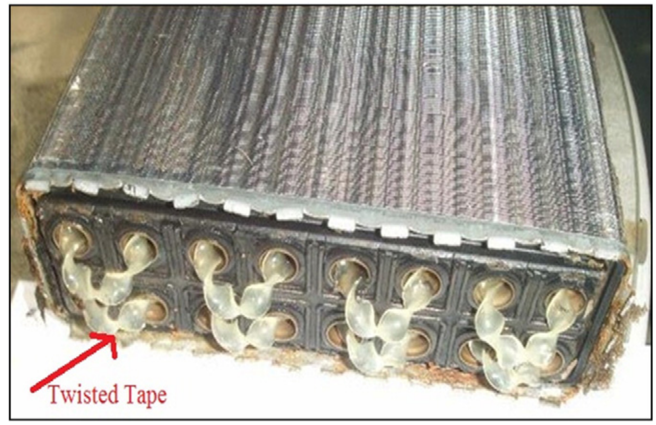

Fig. 2. TT insert into the industrial heat exchanger (car radiator).

- The Reynolds number:
  Re is defined with respect to the empty tube. The Reynolds number is given by: $\mathrm{Re} = 4\dot{m}/\pi D\mu$ where $\dot{m}$ is the water mass flow rate, μ is the viscosity, and D is the tube inside diameter.
- The half-pitch:
  H is defined as the distance between two points on the edge of a TT which lie down on the same plane or in other words the length of the tube in which a TT completes 180° of revolution (Fig. 3).
- The twist ratio:
  Y is defined as the ratio of the half-pitch to the inside diameter of the tube, $Y = W/D$.
- The number of revolutions:
  N is described as the number of 360° revolutions of a TT.

2.4. The heat transfer enhancing mechanism

TTs have been widely used as heat transfer enhancing devices in heat exchangers. In this part the main and effective mechanisms of heat transfer enhancement are discussed for better understanding of TT abilities. The important effects induced by the TT are the swirl flow which improves fluid mixing, helically twisting fluid motion which offers an effectively longer flow path and separating and blockage of the tube flow cross section which leads to a higher flow velocity [14]. All the effects mentioned above are responsible for the enhancement of heat transfer within the TT heat exchanger. In other words, the following reasons can be presented as the effective mechanisms and consequently motivation and results for using the TTs in heat exchangers:

- The effective stream lines of flow field and its velocity in the swirl flow induced by TT are more than the plain tube. This point affected the heat transfer coefficient by two aspects: increasing the turbulence of heat convection and more tangential velocity near the tube walls.
- The induced secondary flow by TTs increases the stream mixing because of the swirling flow. The induced centrifugal force which is into the direction of bulk flow generates the swirl flow at both sides of the tape. This secondary flow can be seen in Fig. 4 [15].

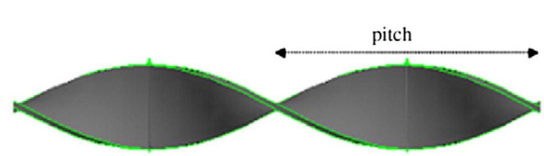

Fig. 3. Half pitch of a TT [8].