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CONVECTIVE HEAT TRANSFER ENHANCEMENTS IN TUBE USING INSERT – A REVIEW

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Abstract— **Enhancing heat transfer surface are used in many engineering applications such as heat exchanger, air conditioning, chemical reactor and refrigeration systems, hence many techniques have been investigated on enhancement of heat transfer rate and decrease the size and cost of the involving equipment especially in heat exchangers. One of the most important techniques used are passive heat transfer technique. These tchniques when adopted in Heat exchanger proved that the overall thermal performance improved significantly. This paper reviews experimental and numerical works taken by researchers on this technique since 2004 such as twisted tape, wire coil, swirl flow generator, etc. to enhance the thermal efficiency in heat exchangers and useful to designers implementing passive augmentation techniques in heat exchange. The authors found that variously developed twisted tape inserts are popular researched and used to strengthen the heat transfer efficiency for heat exchangers. The other techniques used for specific work environments are studied in this paper. Twisted tape inserts perform better in laminar flow than turbulent flow. However, the other several passive techniques such as ribs, conical nozzle, and conical ring, etc. are generally more efficient in the turbulent flow than in the laminar flow.**

***Index Terms*— passive heat transfer, twisted tape, wire coil, swirl flow**

I. INTRODUCTION

Heat exchangers are popular used in industrial and engineering applications. The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate, efficiency and pressure drop apart from issues such as long-term

performance and the economic aspect of the equipment. Whenever inserts technologies are used for the heat transfer enhancement, along with the improvement in the heat transfer rate, the pressure drop also increases, which induces the higher pumping cost. Therefore any augmentation device or methods utilized into the heat exchanger should be optimized between the benefits of heat transfer coefficient and the higher pumping cost owing to the increased frictional losses. In general, heat transfer

augmentation methods are classified into three broad categories:

A. Active method

This method involves some external power input for the enhancement of heat transfer. Some examples of active methods include induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, mechanicals aids, surface vibration, fluid vibration, electrostatic fields, suction or injection and jet impingement requires an external activator/power supply to bring about the enhancement.

B. Passive method

This method generally uses surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. For example, inserts extra component, swirl flow devices, treated surface, rough surfaces, extended surfaces, displaced enhancement devices, coiled tubes, surface tension devices and additives for fluids.

C. Compound method

Combination of the above two methods, such as rough surface with a twisted tape swirl flow device, or rough surface with fluid vibration, rough surface with twisted tapes. This paper focuses on reviewing the passive methods in pipe heat exchanger. The passive heat transfer augmentation methods as stated earlier do not need any external power input. For the convective heat transfer, one of the ways to enhance heat transfer rate is to increase the effective surface area and residence time of the heat transfer fluids. The passive methods are based on this principle, by employing several techniques to generate the swirl in the bulk of the fluids and disturb the actual boundary layer so as to increase effective surface area, residence time and consequently heat transfer coefficient in existing system. Although there are hundreds of passive methods to enhance the heat transfer performance, the following nine are most

popular used in different aspects:

- Treated Surfaces: They are heat transfer surfaces that have a fine-scale alteration to their finish or coating. The alteration could be continuous or discontinuous, where the roughness is much smaller than what affects single-phase heat transfer, and they are used primarily for boiling and condensing duties.
- Rough surfaces: They are generally surface modifications that promote turbulence in the flow field, primarily in single-phase flows, and do not increase the heat transfer surface area. Their geometric features range from random sand-grain roughness to discrete three-dimensional surface protuberances.
- Extended surfaces: They provide effective heat transfer enlargement. The newer developments have led to modified fin surfaces that also tend to improve the heat transfer coefficients by disturbing the flow field in addition to increasing the surface area.
- Displaced enhancement devices: These are the insert techniques that are used primarily in confined force convection. These devices improve the energy transfer indirectly at the heat

exchange surface by displacing the fluid from the heated or cooled surface of the duct/pipe with bulk fluid to the core flow.

- Swirl flow devices: They produce and superimpose swirl flow or secondary recirculation on the axial flow in a channel. These devices include helical strip or cored screw type tube inserts, twisted tapes. They can be used for single phase or two-phase flows heat exchanger.
- Coiled tubes: These techniques are suitable for relatively more compact heat exchangers. Coiled tubes produce secondary flows and vortices which promote higher heat transfer coefficient in single phase flow as well as in most boiling regions.
- Surface tension devices: These consist of wicking or grooved surfaces, which directly improve the boiling and condensing surface. These devices are most used for heat exchanger occurring phase transformation.
- Additives for liquids: These include the addition of solid particles, soluble trace additives and gas bubbles into single phase flows and trace additives which usually depress the surface tension of the liquid for boiling systems.
- Additives for gases: These include liquid droplets or solid particles, which are introduced in single-phase gas flows either as dilute phase (gas–solid suspensions) or as dense phase (fluidized beds).

II. Important definitions terms commonly used in heat transfer augmentation

A. . Thermal performance factor

Thermal performance factor is generally used to evaluate the performance of different inserts such as twisted tape, wire coil, etc., under a particular fluid flow condition. It is a function of the heat transfer coefficient, the friction factor and Reynolds number. For a particular Reynolds number, if an insert device can achieve significant increase of heat transfer coefficient with minimum raise of friction factor, the thermal performance factor of this device is good.

The overall enhancement ratio is defined as the ratio of the heat transfer enhancement ratio to the friction factor ratio. This parameter is also used to compare different passive techniques for the same pressure drop. The overall enhancement ratio is expressed as:

Overall Enhancement Ratio =

where Nu, f, Nu0 and f0 are the Nusselt numbers and friction factors for a duct configuration with and without inserts respectively. The friction factor is a measurement of head loss or pumping power.

III. Types of insert (swirl flow device)

A. Twisted tape

Twisted tapes are the metallic strips twisted with some suitable techniques at desired shape and dimension, inserted in the flow. The twisted tape inserts are popular and widely used in heat exchangers for heat transfer augmentation besides twisted tape inserts promote heat transfer rates with less friction factor penalty on pumping power.

Insertion of twisted tapes in a tube provides a simple passive technique for enhancing the convective heat transfer by introducing swirl into the bulk flow and disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. That is to say such tapes induce turbulence and superimposed vortex motion (swirl flow) which induces a thinner boundary layer and consequently results in a better heat transfer coefficient and higher Nusselt number due to the changes in the twisted tape

geometry. However, the pressure drop inside the tube will be increased by introducing the twisted-tape to insert. Hence a lot of researches have been carried out experimentally and numerically to investigate the optimal design and achieve the best thermal performance with less frication loss. The enhancement of heat transfer using twisted tapes depends on the Pitch and Twist ratio. The twist ratio is defined as the ratio of pitch to inside diameter of the tube y=H/d, where H is the twist pitch length

and d is the inside diameter of the tube. Pitch is defined as the distance between two points that are on

the same plane, measured parallel to the axis of a twisted tape.

B. Wire coil

The helical inserts are new addition to the family of inserts for enhancement of heat transfer. For the helical taps, the swirl moves in one direction along the helical and induce swirl in the flow, which increase the retention time of the flow and consequently provide better heat transfer performance over twisted tape insets. The high heat transfer with helical inserts is also accompanied by a higher pressure drop across the flow, but at low Reynolds number, helical tapes are used in solar water heating applications to drive heat transfer benefit. However inserts of different configuration are being used to meet the needs of higher heat dissipation rates. Wire coil inserts are currently used in the applications such as oil cooling devices, pre heaters or fire boilers. They show several advantages in relation to other enhancement techniques:

- Simple manufacturing process with low cost.
- Easy installation and removal.
- Preservation of original plain tube mechanical strength.
- Possibility of installation in an existing smooth tube heat exchanger.
- Fouling mitigation (in refineries, chemical industries and marine application).

IV. Application

All these methods of heat transfer enhancement techniques had been developed and widely applied to several industrial and engineering applications in double pipe heat exchanger such as

- Power plant
- Air-conditioning
- Petrochemical industry
- Refrigeration
- Process industry
- Solar water heater
- Chemical reactors
- Shell and tube heat exchangers
- Nuclear reactor

5 Effect of insert (swirl flow device)

Insert is a device placed along the axis of tube use to create swirling motion of working fluid that provides periodic redevelopment of the boundry layer, increase the effective heat transfer area and turbulence intensity. The swirl induced tangential flow velocity component causes improved fluid mixing between the tube core and the wall region nearby. Thus enhancing the heat transfer by rapid fluid mixing. On the other hand, the swirl induced heat transfer enhancement brings along inevitable shear stress and pressure loss in coiled wire or twisted tape inserted tube.

V. LITERATURE REVIEW

Large number of experimental work are carried out by researchers to investigate the thermohydraulic performance of various twisted tapes including the traditional simple twisted tapes, regularly spaced twisted tapes, varying length twisted tapes, tapes with different cut shapes, tapes with baffles and tapes with different surface modifications. The followings content will detail these reaches and display the finds from different researchers.

Kumar and Prasad [1] started to investigate the impact of the twist ratio on the enhancement efficiency for a solar water heater. When changed the twist ratios from 3.0 to 12.0 the heat transfer rate inside the solar collectors have been found increased by 18–70%, whereas the pressure drop increased by 87–132%. Synthetically consider the increase of heat transfer and pressure drop it is concluded that the twisted tape enhanced collectors would be preferable for higher grade energy collection to balance the pressure drop rather than for the solar collectors.

Murugesan et al.[2] carried out a study of the heat transfer and pressure drop characteristics of turbulent flow in a tube fitted with a full length twisted tape coupled with trapezoidal-cut. The results. show that for the twist ratio of 6.0, the mean Nusselt number and fanning friction factor for the trapezoidal-cut twisted tape are 1.37 and 1.97 times over the plain tube, respectively. When the twist ratio reduces to 4.4, the corresponding Nusselt number and fanning friction factor will increased to 1.72 to2.85

times. This indicate that trapezoidal –cut induces significant enhancement of heat transfer coefficient and friction factor ,in addition the impact will be heavier for a lower twist ratio.

Sivashanmugam and Suresh [3] studied circular tube fitted with full-length helical screw element of different twist ratio there is no much change of the heat transfer coefficient enhancement by increasing or decreasing the twist ratio, as the magnitude of swirl generated at the inlet or at the outlet is the same in the both of two cases.

Yakut and Sahin [4]. The vortex characteristics of tabulators, heat transfer rate and friction characteristics were considered as the criterions to evaluate the enhancement performance of coiled wire. Garcıa et al. experimentally studied the helical-wire-coils fitted inside a round tube in order to characterize their thermohydraulic behaviour in laminar, transition and turbulent flows. Results have shown that

- In laminar flow, wire coils behave as a smooth tube but accelerate transition to critical Reynolds numbers down to 700.
- At the low Reynolds numbers about Re $\approx$ 700, transition from laminar to turbulent flow occurs in a gradual way.
- Within the transition region, heat transfer rate can be increased up to 200% when keep the pumping power constant.
- Wire coils have a predictable behaviour within the transition region since they show continuous curves of friction factor and
- Nusselt number, which involves a considerable advantage over other enhancement techniques.
- In turbulent flow, wire coils cause a high pressure drop which depends mainly on the pitch to wire-diameter ratio (p/e).
- In turbulent flow, the pressure drop and heat transfer are both increased by e up to nine times and four times respectively, compared to the empty smooth tube.

Gunes et al.[5] also investigated the thermohydraulic behaviour of coiled wires in tube and pipe heat exchangers in 2010. Also experimentally investigated the coiled wire inserted in a tube for a turbulent flow regime. The coiled wire has equilateral triangular cross section and was inserted separately from the tube wall. They discovered that the Nusselt number rises with the increase of Reynolds number and wire thickness, and the decrease of pitch ratio; the best operating regime of all coiled wire inserts is detected at low Reynolds number, which leads to more compact heat exchanger; the pitch increases, the vortex shedding frequencies decrease and the maximum amplitudes of pressure fluctuation of vortices produced by coiled wire turbulators occur with small pitches.

VI. RESULT

[1] Full length twisted tape increases the pressure drop comparing to an empty tube. The pressure drop depends on the tape geometry and is always larger than185% for any geometry.

[2] Most of the researches need to reduce the extra pressure drop by using short length twisted tape located at the inlet of channel or multiple short length twisted tapes inserted into a long channel and spaced by an empty length.

[3] Twisted tape inserts perform better in laminar flow.

[4] Twisted tape in turbulent flow is not very effective.

[5] If the pressure drop is not concerned, twisted tape inserts are preferred in both laminar and turbulent regions.

[6] Wire coil gives better overall performance if the pressure drop penalty is considered.

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