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Review on Recent Progresses in Heat Transfer Enhancement through the Use of Passive Vortex Generators And Its Applications in Solar Parabolic Trough Systems

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Abstract —*Heat transfer surface enhancement is required for heat exchanger systems in order to obtain reduction in their operating costs. Heat transfer performance of a conventional heat exchanger can be improved by using heat transfer augmentation methods. Passive vortex methods are being used for increasing heat transfer rate in heat exchangers since long times. In this review of heat transfer enhancement through use of passive vortex generators, the theoretical basis for the method is discussed and its implementations in simple heat exchangers as well as solar parabolic rough receiver are reviewed. The aim of this survey is to critically review recent progress and to identify research needs in the area of vortex-induced heat exchanger enhancement.*

Keywords*: heat transfer enhancement, pressure drop, longitudinal vortices, delta winglets, heat exchangers, passive vortex generators, solar parabolic trough systems*

I. INTRODUCTION

Heat exchangers have found its place in wide range of industries including petrochemicals, transportation, food processing, air conditioning and refrigeration. Desire to improve energy performance with reduced volume and manufacturing costs has continuously motivated research in subject of heat transfer enhancement. The design procedure of heat exchanger systems is a bit complicated, as it requires precise analysis of heat transfer rate and pressure drop estimates apart from concerns regarding long-term performance and the financial aspect of the equipment. However in recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchanger equipment. Besides, occasionally there is a requirement for miniaturization of a heat exchanger in particular applications, such as space application, through an increase of heat transfer. In general for the given process, a turbulence promoter known as turbulator is employed in heat exchangers in form of swirl or vortex flow device such as rib, fin, baffle, propeller, winglet and many others to obtain better thermal performance although it comes at a cost of increasing pumping loss. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years and are discussed in the following sections.

II. NEED OF FLOW MANIPULATION FOR HEAT TRANSFER AUGMENTATION

The temperature distribution inside heat exchanger tubes is widely dependent on the velocity profile of the fluid and often forms thermal boundary layer. This temperature distribution is a function of heat transfer resistance which can be modified by flow manipulation. One of the most used method for flow manipulation is alteration of main flow using obstructions in the tube. The other method used involves introduction of the secondary flow into the system so as to originate turbulence which in turn is responsible for heat transfer enhancement of the system. In secondary flow enhancement local flow structures are deliberately introduced. In some cases it is difficult to distinguish between main flow enhancement and secondary flow enhancement. A review has been presented here on recent trends and developments that took place in the described field and its implementations on the recently developed solar parabolic trough receivers.

III. CLASSIFICATION OF TECHNIQUES USED FOR AUGMENTATION

Single - phase heat transfer enhancement methods are generally classified as active, passive, or compound. Active methods use external power input to obtain the necessary enhancement but does not show much potential due to complexity involved in designs, some of the common examples used for active methods are the use of a magnetic field to disturb the seeded light particles in a flowing stream, Electrohydrodynamics etc. On contrary to this passive methods uses modifications made in circular geometry of tubes to form the vortices which enhance the heat transfer at the cost of available power in the system. More turbulence results into more vortices resulting in an increase in entropy of the system. An efficiently designed heat exchanger should provide maximum heat transfer with minimum generation of entropy. Compound method uses active as well as passive methods simultaneously to obtain greater enhancement in heat transfer. As this method involves complex design it has very limited applications.

IV. SOLAR PARABOLIC TROUGH CONCENTRATOR RECEIVER

Solar power has been a source of renewable energy and has potential to supply humanity with the power for centuries to come. Presently continuous research is being carried out on increasing the heat transfer for solar parabolic trough concentrator receivers as it seems to be one of the promising ways to obtain the unused potential of the solar energy. Solar parabolic trough collectors are used commercially for generation of the thermal power. In this systems solar radiation incident on the parabolic trough is focused onto the receiver and transmitted into the working fluid. Image of the solar parabolic trough concentrator is as shown in the figure1. The receiver design influences overall efficiency of the solar parabolic trough collector system. The important factors deciding the efficiency of the system are thermo-physical properties, geometrical design of the receiver and concentration ratio. Presently intensive research is being carried out to increase the heat transfer in the receivers of the solar trough concentrator systems through use of developed passive vortex generation methods. At the later part of the review recent implementations carried out to enhance heat transfer particularly in the receiver of the solar parabolic trough concentrator system by using passive vortex methods have been discussed.

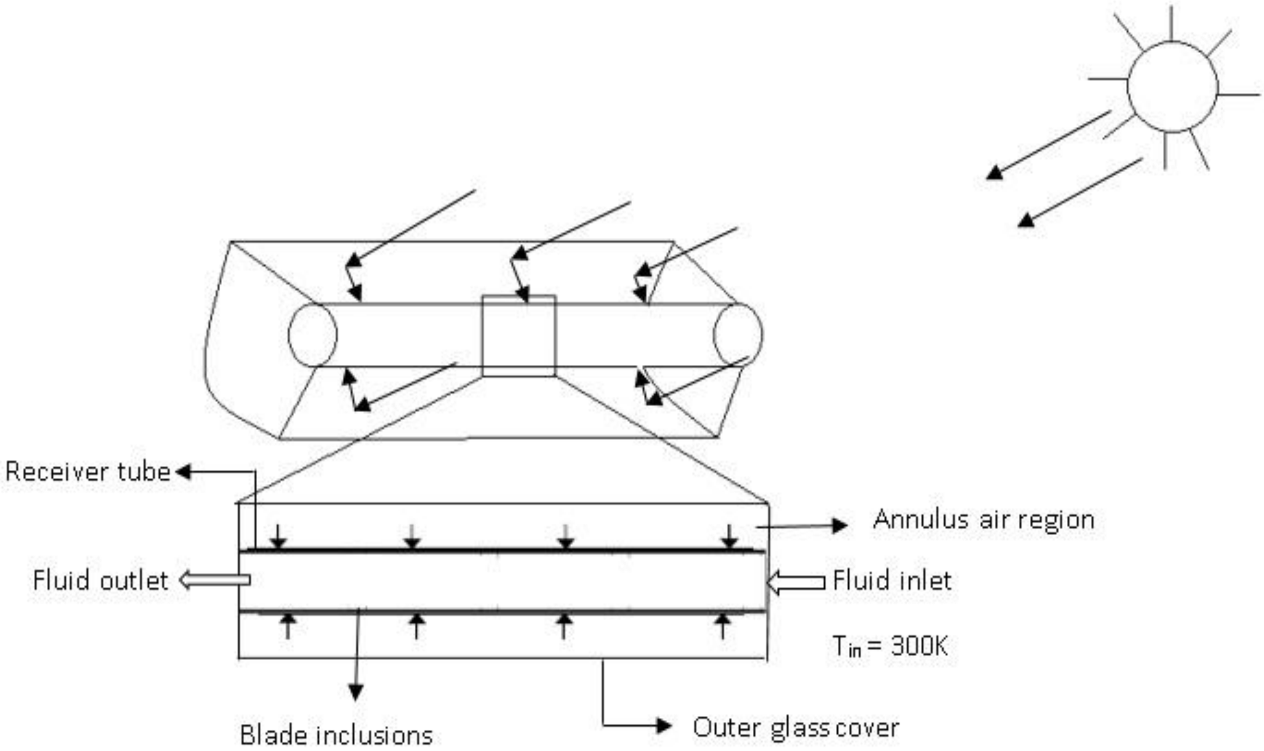

Figure 1. Solar Parabolic Trough Collector System

V. IMPORTANT DEFINITIONS RELATED TO HEAT TRANSFER AUGMENTATION

a. Nusselt Number

Nusselt number (Nu) is defined as the ratio of convective to conductive heat transfer across (normal to) the boundary of a fluid.

b. Prandtl Number

It is a dimensionless parameter used in calculations of heat transfer between a moving fluid and a solid body. Prandtl number equals c_p*v/k, where v its kinematic viscosity, c_p is the heat capacity per unit volume of the fluid and k its thermal conductivity.

c. Thermal Performance Factor

Thermal performance factors are being used by the researchers to evaluate the performance of different inserts such as delta winglets, wire coil, etc. under a particular fluid flow condition. It mostly depends upon heat transfer coefficient, Reynolds number and friction factor. If for a particular device inserted in the tube heat transfer coefficient shows a very high increase with a very less rise in the friction factor then it is considered to be having good thermal performance factor. Below are most commonly used factors to evaluate thermal performance of the system.

d. Overall Enhancement Ratio

The overall enhancement ratio is defined as the ratio of heat transfer enhancement ratio to friction factor ratio. This parameter can also be used to compare different passive techniques for same pressure drop. Here Nu, Nu_0, f, f_0 are Nusselt numbers and friction factors for configuration with and without inserts respectively.

$$\text{Overall Enhancement Ratio} = (Nu/Nu_0) / (f/f_0)1/3$$

e. Performance Evaluation Criteria (PEC)

Another reliable option used by many authors is PEC, which is also defined as the ratio of the heat transfer enhancement ratio to friction factor ratio but with different power on the friction factor ratio.

$$\text{Performance Evaluation Criteria} = (Nu/Nu_0) / (f/f_0)^{0.293}$$

f. Corrugation Pitch

The distance between two same points on consecutive corrugations measured on a straight line joining them is known as corrugation pitch. Variation of corrugation pitch makes considerable effects on the thermal performance factor as it affects the degree of turbulence in the flow.

g. Corrugation Height

The height or depth of corrugation above or below the bore or base diameter is defined as the corrugation height.

h. Twist Ratio

Twist ratio is defined as the ratio of the corrugation height to inside diameter of the tube.

VI. HEAT TRANSFER AUGMENTATION BY PASSIVE METHODS: PHENOMENON

Heat transfer enhancement in a tube flow obtained by inserts such as twisted tapes, wire coils, ribs and dimples is mainly due to flow blockage, partitioning of the flow and secondary flow. Flow blockage increases the pressure drop and leads to increased viscous effects as the area available for free flow gets decreased. Blockage also increases the flow velocity and in some situations leads to a significant secondary flow. Additionally, secondary flow offers an improved thermal contact between the surface and the fluid because secondary flow generates swirl and the subsequent mixing of fluid improves the temperature gradient, which eventually leads to a high heat transfer coefficient.

VII. PASSIVE VORTEX METHODS: A DETAILED REVIEW ON RECENT GEOMETRICAL MODIFICATIONS

a. Brief History

According to our best knowledge the first archival article on the heat transfer impact of vortex generators gave its appearance in 1969 [4]. A right circular cylinder in cross flow with delta winglet vortex generators located at a fixed angular position on the cylinder was studied by the author Johnson T.R. Vortex generators increased the measured local Nusselt numbers as much as 200%, but overall heat transfer results were not encouraging because of decreases obtained elsewhere on the cylinder. Local enhancements were explained in terms of enhanced thermal mixing, and the areas of reduced heat transfer were explained through the diminished impact of recirculation eddies behind the cylinder. When this article got published it became a wide area of interest and many researchers got involved in this subject of research. An extensive literature review of all types of heat transfer augmentation technique with external inserts up to 1985 has been discussed by Bergles.[1]. U. Brockmeier [3] in 1992 carried out intensive work which provided the decrease in heat exchanger surface area that can be obtained using different geometries.

Another review which proved to be of supreme importance in those days was the one presented by Martin Fiebig [6]. In this review he described three enhancement mechanisms as follows: (1) developing boundary layers on the vortex generator surface; (2) swirl; and (3) flow destabilization. He also provided us with the conclusions that show (1) winglets are more effective than wings and (2) rectangular and delta winglets give similar performance. Although further detailed work was done by A.M Jacobi and R.K.Shah in 1995[2] regarding the performance given by delta winglets and rectangular geometries and came to a conclusion that, in general delta wing and winglet offered heat transfer and pressure drop superior to that of rectangular geometry, but rectangular winglet proved to be competitive in some cases. The pressure drop penalty incurred during application to turbulent channel flows made the method of using delta wing and winglet unattractive. According to them most successful method examined for the application was use of delta winglet downstream of a tube under laminar flow conditions. The results showed that for laminar flow with Re of 400 an approximate increase in Nu was 20% while drag coefficient increase was 40%for a fin tube exchanger with delta winglet.

In 2002, K. Torii [7] came with a unique heat transfer enhancement which not only brought heat transfer augmentation of 10%-30% but also reduced pressure loss of 34%-55% for staggered tube banks when Re as varied from 2100-350.

Recently A.Jordar and A.M.Jacobi conducted research on use of winglet vortex generators for heat transfer enhancements. The heat transfer and pressure drop performance were evaluated under dry-surface conditions over a Reynolds number range of $220 \leq Re \leq 960$ and it was found that the heat transfer coefficient on air side got increased from 16.5% to 44% for the single-row winglet arrangement with a rise in pressure drop of less than 12%. With time a large number of heat transfer enhancement techniques has been studied and different results are obtained. A Review has been made here to describe these techniques and arrive at a conclusion.

VIII. WIRE COIL INSERTS

The important investigations of wire coil include experiments carried out by Ravigururajan and Bergles [7] who developed correlations for friction factor and heat transfer coefficient that are widely applied. By incorporating the roughness type and Prandtl number their heat transfer data from correlation were in good agreement with the correlation of Petukov and Popov [8]. Rahai and Wong [9] predicted that wire coil with a large pitch spacing increases the mixing, turbulent kinetic energy and half-width but decreases the maximum mean velocity. Kim et. al. [10] observed that the slug rise velocity and void fraction in a vertical round tube is higher for a wire coil insert than a smooth tube and studied flow pattern. The noteworthy investigations by Inaba and Ozaki [11] showed that the turbulent flow was induced by a wire coil that enhances heat transfer even downstream of the insert. They also established empirical relations for the Nusselt number as a function of the Prandtl number. They also found that pressure drop and the friction factor rise are proportional to the length of the wire coil. They observed a high heat transfer coefficient and a small pressure loss owing to the leading edge effect near the tube inlet and turbulent flow downstream of the wire coil. Ujhidy et. al. [12] in his investigation further concluded that the helical static element was responsible for producing the secondary flow. Wang and Suden [13] in their series of experiments observed that a wire coil insert performs effectively in enhancing the heat transfer in the turbulent flow region, whereas tape has a poor overall efficiency. Inaba and Huraki [14] further investigated heat transfer enhancement of flowing water in a tube with flow drag reduction additives by inserting wire coils. They found that a reduction in the flow resistance resulted in a reduced heat transfer coefficient in the tube. Oliver and Shoji [15] performed experiments in a tube using a non-Newtonian fluid and found that heat transfer is enhanced by a factor of 4 and the relative pressure drop caused by the wire coil was by a factor of 5.

IX. TWISTED TAPE INSERTS

As twisted tapes are easy to manufacture and design they have been widely used in heat exchangers since a long time. Various researchers have studied different configurations of the twisted tapes such as full length twisted tape, short length twisted tape, tape with varying pitch, regularly spaced twisted tape and many more. Whitham [16] back in the 19th century studied the effects of the twisted tapes which results in enhancement of the twisted tape inserts in fire tubes of steam boiler. The important effects induced by twisted tapes which results in enhancement of heat transfer in flow as given by Bergles [17] are a) swirl flow which improves fluid mixing, b) helical motion of the fluid flow which results in effectively longer flow path and c) blockage of the tube flow cross section which results into a higher flow velocity. Thus considering this rationale following points can be considered as responsible for the heat transfer enhancement. 1) The effective stream lines of flow field and its velocity in the swirl flow induced by twisted tapes are more than plain tube. This affected the heat transfer coefficient by two aspects. Firstly, it increases the turbulence resulting into better heat convection in the fluid. Apart from that, it provides fluid with more tangential velocity near the tube walls ultimately resulting into higher heat transfer across the pipe surface and the fluid. 2) The induced secondary flow by twisted tapes 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 in both sides of the tape. 3) As described by H. Yuxiang and D. Xianhe [18]; the fin effect of twisted tube could be able to change the heat transfer area because of heat conduction of flow to the tape's body. This heat transfer is a function of the contact area of tape and tube, the material of the tape, flow characteristics and dimensions of tape as well as tube. But by the attention to the very low contact area between tape and tube, this effect can be assumed negligible.

There have been many researches carried out describing the relations between friction factor and Nusselt number, following section gives the information regarding various observations described by different researchers after carrying out a series of experiments with different geometries used for vortex generation. A twisted tape insert mixes the bulk flow well and therefore performs better in a laminar flow.

X. OBSERVATIONS

a. Twisted tape in laminar flow

A twisted tape seemed to mix the bulk flow well and thus performed better in laminar flow than any other insert. Apart from this as in a laminar flow thermal resistance is not limited to a thin region, better mixing of the flow generates better results. Still, performance of twisted tape also relies on the properties of fluid such as the Prandtl number. If its value is high, say $Pr>30$, the twisted tape will not provide good thermohydraulic performance compared with other inserts such as wire coil. On the basis of a constant pumping power, short length twisted tapes are better than full length twisted tape. In design of a compact heat exchanger for laminar flow, twisted tapes can be used effectively to enhance the heat transfer.

Saha and Dutta [22] investigated the effects of using twisted tape in laminar flow with water as heat transfer fluid. Variations in the tapes were carried out by varying length and pitch of the insert. These experiments were carried out in a circular tube and results obtained showed that friction and Nusselt number remained low for short length tapes and it required less pumping power. It was also concluded from the experiments that multiple twists and single twist does not make a drastic difference in overall augmentation of heat transfer. Apart from this one major conclusion deduced from this study showed that uniform pitch performs far better than gradually decreasing pitch. Bergles and Hong [23] carried out similar type of experiments using full length twisted tapes with water as fluid in a circular tube and found that Nusselt number was a function of twist ratio, Reynolds number and Prandtl number. Bergels and Manglik [24] further performed experiments with water and ethylene glycol as fluid using tapes with three different twist ratios of 3, 4.5 and 6 in isothermal tubes and proposed correlation for friction factor and Nusselt number. Ray and Date [25] stated investigating flow in square duct with full length twisted tape inserts whose width is equal to side of the duct and were able to propose staunch relations for friction factor and Nusselt number. It was concluded from these studies that higher rates of heat transfer were obtained in case of square duct than circular pipes. They found that higher values of Nusselt number were obtained where tapes were aligned with diagonal of the duct. Lokanath and Misal [26] then carried out similar experiments using water and lube oil as the fluids in plate, and shell-tube heat exchangers to find out viability of utilizing these tapes in real life applications. It was observed that fluid with low value of heat transfer coefficient showed more increase in heat transfer rates than fluid with higher values of heat transfer coefficient. Kiran Mruti Patil [37] carried out experiments with twisted tape inserts in laminar flow with water as fluid and established that for low Reynolds number heat transfer rate is higher with lower twist ratios. K. Sivakumar [38] carried out similar experiments and observed that when applied with uniform heat flux with twisted tape inserts in circular tube correlation can be established between Reynolds number and outlet temperature of the pipe. Prashant Tikhe [39] carried out experiments in circular tubes with uniform heat flux and water as heat transfer fluid and observed that with increasing the ratio of width to diameter in range of 0.35 to 0.71 at constant twist ratio of 2.5 thermal efficiency gets increased.

b. Twisted tape in turbulent flow

Twisted tape, when considered for turbulent flow is effective up to lower values of Reynolds Number in turbulent regime, but is not suited for higher Reynolds number. The increase in heat transfer in case of twisted tape is not efficient compared with wire coil in turbulent flow. Therefore, it may be concluded that, for compact heat exchanger design, wire coil is a good choice in turbulent flow. Though, a short length twisted tape provides better and efficient heat transfer augmentation when compared with full length twisted tape in turbulent flow.

Royds [27] used full length twisted tapes to carry out experiments in circular tube with water as fluid at higher Reynolds number. He concluded that when twist ratio is very high, values of heat transfer rate and friction factor obtained are higher. Smith and Landis [28] further carried out analytical investigation for full length twisted tape and proposed analytical model for tape generated swirl mechanism. Cresswell [29] further carried out experiments in circular tube with twisted tapes and found that ratio of maximum velocity to mean velocity is smaller in swirl flow when compared with straight flow. Colburn and King [30] further investigated turbulent flow with baffle and short length twisted tape inserts into circular tube and found that short length twisted tapes are more effective than full length in heat transfer augmentation. Gupte and Date [31] further carried out similar experiments with air as the heat transfer fluid and after conducting numerical studies concluded that semi-empirically evaluated friction and heat transfer data for tape-generated swirl flow in annulus. R.M. Manglik and A.E.Bergles [24] studied heat transfer and pressure drop correlations with twisted tape inserts for isothermal flow in circular tube and provided important contribution to this field. S. Eiamsa [40] carried out heat transfer enhancement in counter flow in a tube fitted with twin twisted tapes and provided empirical co-relations for Nusselt number, friction factor, and thermal enhancement index. S. Eiamsa-ard et. al. [41] also carried out heat transfer enhancement in a tube using oblique and straight delta-winglet twisted tape inserts and obtained correlations for friction factor and Nusselt number enhancement. CFD analysis of twisted tape inserts was carried out by Masoud Rahmini et. al. [42] and concluded that most of the heat transfer enhancement took place because of the higher amount of turbulence generated in fluid close to the tube walls.

c. Wire coil in laminar flow

Wire coil, augments the heat transfer rate significantly in laminar flows. Still the performance, depends on Prandtl number. If the Prandtl number is high, the performance would be good, because for a high Prandtl number the thickness of the thermal boundary layer is small compared with the hydrodynamic boundary layer and wire coil can break this boundary layer easily. Therefore, both the heat transfer and pressure drop are large.

Ujhidy [12] carried out various experiments by placing wire coil inserts into circular pipe, with water as fluid and explained the flow structure taking place. Wang and Sunden [13] carried out similar experiments and concluded that wire coil proved to be efficient means of heat transfer augmentation technique than twisted tape. Inaba and Ozaki [11] also performed similar experiments with wire coil in laminar flow of water and brought into light the importance of leading edge effect near the inlet in enhancing heat transfer rates. Oliver and Shoji [15] used Non-Newtonian fluid in circular tube with wire coil inserts and delineated its effect on heat transfer enhancement for different Prandtl number. Inaba and Haruki [14] also explained the effects on heat transfer by varying flow velocity, wire coil diameter, pitch and length. S.B.Uttarwar [43] also studied augmentation of laminar flow heat transfer in tubes by means of wire coil inserts by varying diameter and pitch of wire coil. Results provided about four fold increase in the heat transfer enhancement. Pongjet Promvonge [44] also carried out thermal augmentation in circular tube with twisted tape and wire coil turbulators.

d. Wire coil in turbulent flow

Wire coil augments the heat transfer efficiently, in case of turbulent flow. It performs better in turbulent flow than in laminar flow. The thermohydraulic performance of wire coil is good in turbulent flow compared to twisted tape in turbulent flow.

Arici and Asn [19] carried out experiments with wire coil in turbulent flow and deciphered that an increase in pitch of the wire coil resulted into increase of the heat transfer rate. Rahai [20] carried out similar experiments with air as the working fluid ad explained the effect of various coil spacing on the mixing process. Kumar and Judd [21] further proposed correlations of Nusselt number and friction factor for turbulent0 flow with wire coil inserts. Rahai and Wong [9] carried out experiments with air as heat transfer fluid and fund that coil with larger pitch spacing increase mixing, turbulent kinetic energy and half width but reduces maximum mean velocity. Ravigururajan and Bergles [7] also developed similar correlations by carrying out various experimental studies using water as the working fluid.

e. Other passive techniques

There are numerous passive methods available apart from twisted tape and wire coil to boost the heat transfer in the flow, such as corrugations, ribs, fins, dimples, etc. These techniques are normally found to be more effective in turbulent flow than in laminar flow.

Vatsal and Arch [67] carried out CFD analysis of corrugated tubes and found that secondary vortex generation in the flow due to presence of corrugations in the pipe resulted into higher heat transfer rates. Thermal enhancement factor of about 2.1 was achieved with water as the heat transfer fluid. These study showed variations carried out in dimensions of the corrugations which ultimately led to optimum size of corrugations, both for laminar as well as turbulent flow regimes. Variations in thermal enhancement factor obtained for different p/d and h/d ratios by changing Reynolds number of the flow is as shown in the figure 2.Here p, h, and d stands for pitch, height and diameter of corrugations respectively. Arch and Vatsal [68] also calculated the radiative effects on natural convection heat transfer enhancement in asymmetrically heated vertical channel using horizontal rectangular fin. Chang [32] used ribs in a reciprocating duct and observed that heat transfer got enhanced by 260-300%. He also calculated effects of pulsating force and convective inertia on local heat transfer. Mahmood and Ligrani [33] carried out heat transfer enhancement in channels with air as the flowing medium using dimples as vortex generators. They found out that vortices periodically shed off as H/D ratio decreases. Kumar [34] used steam as the heat transfer fluid and enhanced heat transfer using horizontal fins placed in the tubes. It was observed that spines found to be more useful when placed in bottom side of the tube. Afanasyev [35] used spherical cavities as the vortex generator and got heat transfer enhancement of 30-40% with air as the working fluid. Mahmood [36] also tried to use dimpled channel to enhance the heat transfer but obtained a very less increase in heat transfer and pressure drop as no form drag was produced by the protruding objects.

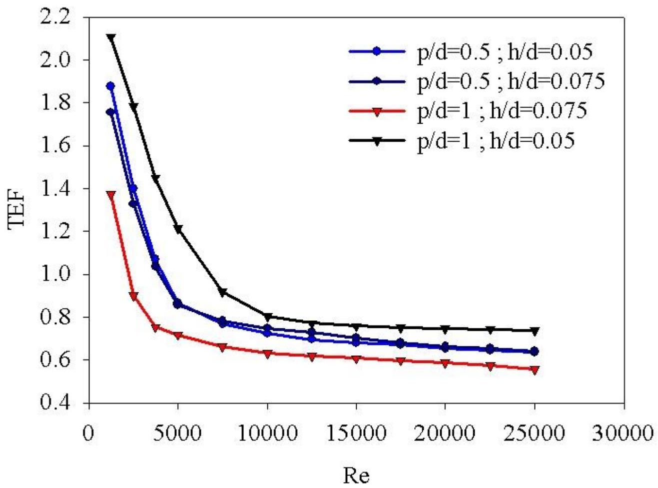

Figure 2: Variation of Thermal enhancement factor obtained by Vatsal and Arch [67] by varying Reynolds number for different p/d and h/d ratio

XI. APPLICATION OF PASSIVE TECHNIQUES IN SOLAR TROUGH COLLECTORS

. In the recent centuries, after the advent of industrial revolution in 1700's in Britain, energy generation has become inevitable for mankind development. Also with increase in world population the energy requirement has increased many folds over the past few years. Thus maintaining a steady increase in rate of generation of energy with declining use of fossil fuels which are a threat to environment has become a topic of prime concern. Since fossil fuels presently are the prime source of energy generation and are declining day by day, it has become mandatory for us to come out with a better replacement which will not only fulfil our energy requirements but also prove itself to be environment friendly. Out of all the renewable energy resources available to mankind as alternative, amount of solar energy intercepted by earth in a day itself is much greater than the worldwide demand for energy today or in expected future [45]. These facts has generated a great need to conduct R&D in this field to convert this massive energy available to us into useful form.

Intensive research in this field has provided us with solar thermal systems which have contributed immensely in yielding us with non-polluting energy for domestic as well as industrial applications. Amongst all the solar thermal systems developed the ones which have gained popularity are the Solar Parabolic Trough Collector systems. Its use has been increased drastically due to its low installation cost and dispatchability.[46,47]. Heat transfer analysis and modelling of solar parabolic trough receiver system has been carried out by Foristall et al. [48]. Solar parabolic Trough collector consists of a parabolic reflector which in most cases is aligned in North-South axis to track the movement of the sun from east to west. The tracking system used tracks the sun to reflect the incident solar radiation onto the receiver/absorber tube placed at its foci. The additional heat gained by the receiver due to installation of this parabolic collector depends on the concentration ratio of the system and hence on the design of the receiver collector system. This energy is then supplied to fluid by passing it through receiver tube.

As the total energy available to us depends upon the losses incurred in parabolic trough's linear receiver, its design is considered to be of prime importance in overall system. The losses incurred in receiver generally consist of radiative and convective losses [49]. Generally receiver of the system consists of an evacuated glass envelope to minimize the heat losses incurred in convection and a selectively coated absorber tube to minimize radiation heat loss. Behaviour of solar parabolic trough receiver used for standard steam generation was studied by Almanza et al. [50] under different experimental conditions for direct steam generation. Clark et. al. [51] recognized different factors like reflectivity of mirror, end loss factor, absorptivity, and tube intercept factor which affects the performance of solar parabolic trough receiver system. Barra et. al.[52] determined performance of solar parabolic trough receivers using black body receiver. Riffelmann et. al. [56] analysed variation of optical efficiency of parabolic trough system with slope error, alignment of receiver and collector assembly. Omer et al. [54] analysed 2 stage concentration of collector onto the receiver. Construction of 2 axis tracking system for solar parabolic trough collector was carried out by Bakos et. al. [55].Entropy generation for turbulent flow inside the tube by baffle inserts was investigated by Tandiroglu[53] The thermal heat losses were studied and various relations were found out to calculate the net heat loss incurred in the system. Odeh et al. [57] calculated the heat losses from the receiver in terms of emissivity, wind speed, receiver wall temperature and radiation whereas Thomas et al.[58] developed curve fitting equations based on the parameters of heat such as temperature of absorber and receiver, size of the tube etc. , to determine overall heat loss from the receiver. Cermet coating (a specialized coating to be applied on the wall of the receiver tube to increase its absorptivity) for solar thermal applications with absorptivity as high as 0.95 and emissivity of 0.05 at room temperature was developed by Zhang et al. [59]. The heating profile in the absorber tube resulting from the concentrating parabolic mirror optics has been analysed and measured and the variation in heat flux along the circumferential surface is provided by Pfänder and Lüpfert et al. [60].

The normal length of these tubes is among 100's of meters. Due to very long length of these tubes the temperature attained on the surface of the receiver tube is relatively higher which ultimately results in bending of the tube which may break the upper glass coating. The annulus space in the glass coating is vacuumed so that the overall losses can be minimized. The bending of the tube can be significantly reduced or avoided if the heat transfer rate between the fluid and the receiver surface is increased. The temperature distribution inside receiver tube is dependent on the velocity profile of the fluid and often forms thermal boundary layer. This temperature distribution is a function of heat transfer resistance which can be modified by flow manipulation. One of the most used method for flow manipulation is alteration of main flow using obstructions in the tube. According to our best knowledge the first archival article on the heat transfer impact of vortex generators gave its appearance in 1969 [4] by author Johnson T.R. Whereas an extensive literature review of all types of heat transfer augmentation technique with external inserts up to 1985 has been discussed by Bergles.[1] . Whitham [16] back in the 19th century studied the effects of the twisted tape inserts in fire tubes of steam boiler. The important effects induced by twisted tapes which results in enhancement of heat transfer in flow as given by Bergles [17] are a)swirl flow which improves fluid mixing, b)helical motion of the fluid flow which results in effectively longer flow path and (c)blockage of the tube flow cross section which results into a higher flow velocity. The heat transfer rate inside the receiver can be enhanced by increasing contact surface between the receiver and the working fluid, and creating turbulence in the receiver. Reddy et al. [61] developed the energy efficient receiver for solar parabolic trough collector to increase the heat transfer rate from the receiver surface to heat transfer fluid by inserting solid and porous continuous as well as staggered (discontinuous) longitudinal fins with different aspect ratios and fin thickness. Muñoz and Abánades [62] analysed an absorber tube with helical fins on its internal surface with a view of improving thermal performance and minimizing the temperature gradients in the absorber tube. Heat transfer enhancement in the receiver tube was obtained by O.A. Jaramillo and Monica Borunda [63] by using twisted tape inserts into the receiver tube whereas Sh. Ghadirijafarbeigloo and A. H. Zamzamianb [64] obtained heat transfer enhancement through louvered twisted tape inserts into the receiver tube. Heat transfer enhancement by using perforated plates and porous discs inside the tube of the receiver was obtained by Aggrey Mwesigye, Tunde Bello-Ochende [65] whereas K. Ravi Kumar, K.S. Reddy[66] used porous discs for the same respectively.

XII. CONCLUSION

Flow through heat exchanger passages is complex, and there are many important length scales and geometric features available with us which does not involve the complications caused by vortex generators. Further research is needed to provide definite indications of how and when vortex induced air-side heat transfer enhancement should be pursued in these complex channels. The current uncertainty is largely due to a lack of fundamental research. While the extant work has augmented our understanding, the emphasis has been on vorticity in turbulent flat plate boundary layer, and most compact heat exchangers operate with laminar developing flows. There has been numerical studies of laminar flow for simplified vortex generator geometries, but there has been very little analytical work to help generalize the numerical predictions. A deeper understanding of the flow and heat transfer interactions could identify the desirable features of vortex flows for heat exchanger geometries and point toward schemes for exploiting their full potential. Thus, further basic research should be directed at narrowing a complex design parameter space to the promising regions and generalizing the results for application to heat exchanger designs.

The extant experimental and numerical work directed at applying vortex-induced enhancements shows that the technique holds promise. Further experimental work in representative heat exchanger geometries may be helpful; However, it should be carefully limited to extending the geometrical and flow conditions that have been studied, to filling gaps in currently available data, or to providing comparisons of model predictions. Careful experiments at low Reynolds numbers would be of particular value, as there has been few such studies published. . Furthermore, scaling experimental comparisons of vortex generator surfaces to current-generation competing surfaces in s compact heat exchanger, would prove to be very helpful. The viability of the vortex induced air side enhancement must stand the test of systematic studies in an actual heat exchanger with and without vortex enhancement for flat fins (as in tube and fin exchanger) or corrugated fins (as in plate fin exchanger). Such a heat exchanger will have more than three delta winglet pairs in flow direction and more than three passages in transverse direction, thus overcoming the end effects of all reported studies in the literature. The to-scale performance of vortex generators must be compared too alternative enhancements such as louvers and straight fins using an appropriate performance evaluation criteria. Finally, the effects of longitudinal vortices on heat exchanger fouling, water retention, or frost growth may need to be examined for some applications. The use of longitudinal vortices as a secondary flow heat transfer enhancement method for heat exchanger applications shows promise, but its potential remains unclear more than a decade after its first application to a finned tube geometry. A deeper understanding of flow and heat transfer interactions is needed to identify promising implementations for specific applications. Full-scale experiments with heat exchangers and careful low Reynolds number experiments are needed to provide a level playing field comparison of vortex methods to competing enhancement techniques.

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