A Review of Research in Thermal Engineering.Study of Various Factors and Parameters Involved in Usage of different types of turbulators in heat exchangers

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Abstract - Great efforts has been put forthfor developing efficient heat transfer enhancement devices with several designs in order to enhance the turbulence, enhance the friction factor, separation of boundary layer and thereby improving the heat transfer efficiency leading a way to improve the efficiency of heat exchanger without altering its size and simultaneously increasing the heat transfer surface area. Among various turbulator designs current paper emphasizes three specific designs viz. nozzle turbulator, conical wire coils, perforated conical ring and (non-perforated) conical rings and slight variations in the parameters that were considered when these were employed in different investigations.

Keywords - Heat transfer, conical wire coil, Nozzle, Perforated conical ring, turbulator, turbulent flow, pressure drop, Heat transfer enhancement, Heat exchanger, Friction factor, Thermal performance factor.

I. INTRODUCTION

Techniques for heat transfer enhancement in heat exchangers is a subject of great importance in fields such as automotive, refrigeration and process industries because of reduction of the heat transfer surface area for a given application. Such techniques generate a great scope for various analytical and experimental investigations in Heat Enhancement. These techniques can be categorized as Active, Passive and Compound. Whereas, the active techniques require external power viz. surface vibration, fluid vibration, injection, suction, and electric or acoustic fields, the passive techniques employ special surface geometries, partial obstructions, perforations etc. for heat transfer enhancement viz. extended surfaces, rough surfaces, twisted tapes, helical springs, perforated conical rings, conical spring, nozzle inserts etc., which also forms the category of turbulators. Typically, the turbulators increase fluid mixing, by increasing turbulence or by limiting the growth of fluid boundary layers close to the heat transfer surfaces.
Several enhancement techniques have been used till date to significantly enhance the performance of heat exchangers. These intriguing techniques are not germane to typical heatexchangers but also find there use from industrial boilers to space vehicles. Numerous amounts of research works has been performed regarding such techniques leaving no page unturned and no fact uncovered.
Yakut et al.[3] investigated the role of conical-ring turbulator on heat transfer enhancement and friction factor by judging fluid flow in tubes when a uniform heatflux was maintained varied pitch ratios were used.It was observed that the turbulator with the smallest pitch ratio offered highest heat transfer enhancement and thermal performance factor. Yakut and Sahin[4] showed that the conical-ring also producedthe vortices in the tubeflow.
Promvonge[5]investigated the effect ofthe conical ring turbulator arrangements (converging conical ring - CRarray, diverging conical-ring - DRarrayandconverging–diverging conical-ring - CDR array) on the heat transfer rate and frictionfactor. The results revealed that the conical-ring with the DR arrayprovided superior thermal performance compared to thosewith the CRand CDR arrays.

Durmus[1] employed conical turbulators with four variations in conical angles viz. 5°, 10°, 15°and 20° for heat transfer enhancement. Apparently, the heat transfer rates as well as friction coefficients increased with increasing turbulator angles.

V. Kongkaitpaiboon, K. Nanan and S. Eiamsa-ard[7] proposed perforated conical-rings (PCR) and sorted out the heat transfer enhancement in a circular tube as shown in fig.1. PCRs with different number of perforated holes,N=4, 6 and 8 and variable pitch ratios of 4, 6 and 12 were employed and their respective effect on the heat transfer enhancement wereinvestigatedunderuniformheatfluxconditions.

S. Eiamsa-ard, P. Somravysin, S. Sripattanapipat and S. Pethkool, P. Promvong[6]experimentally studied the enhancement of the heat transfer in the tube has been when fluid is flowed thoroughly the nozzle turbulator, as shown in fig.2. The experiments were conducted with the electrically heated tube at which air was used as the test fluid. The effects of the Reynolds number were studied parametrically.

D.G. Kumbhar, N.K. Sane[2]focused on the effects of the conically shaped coiled wire springswith differentpitches and conical shapes inserted in a tube, on heattransfer and friction characteristics of air flows intube, as shown in fig. 3(a) and 3(b)

Fig. 1 Perforated Conical Rings

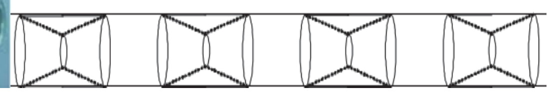

Fig.2 Nozzle Turbulators

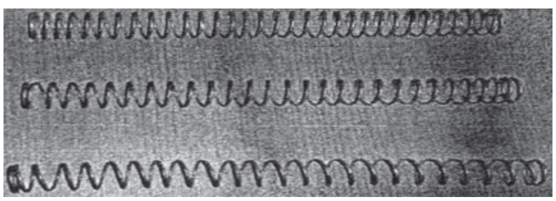

Fig.3(a) Wire coils with different pitches

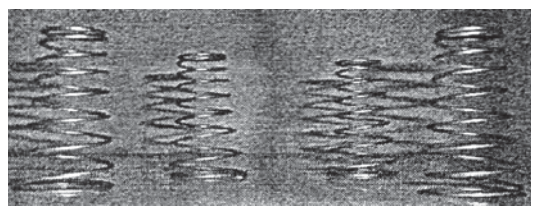

Fig. 3(b) Conical Wire Coils with different pitches

II. DATA REDUCTION

Heat exchangers with working fluid air was taken in all of the experiments mentioned in previous section, with parametric study of effects of Reynolds number varying from 2000 to 20000. Aspiration behind the variation of pitch ratios, number of holes, conical angles etc. was basically to enhance the friction factor which varies in an inverse proportion with all these parameters. But, increasing friction factor i.e. decrease in pitch ratio or an increase in the number of turbulators employed, puts a direct impact on pressure drop and hence on the required pumping power. But, to maintain higher levels of Reynolds number or high LPMs, a high and constant pumping power is desired. Hence, it is required to maintain optimum conditions such that a balance can be created between pitch ratio, friction factor, pressure loss and hence pumping power. Equations which form the basis of such experimental investigation can be summed as follows:

The steady state of the heat transfer rate is assumed to be equal to the heat loss from the test section which can be expressed as:

$$Q_{air} = Q_{conv} \quad (1)$$

Where,

$$Q_{air} = \dot{m} C_{p,a} (T_o - T_i) \quad (2)$$

$$Q_{conv} = hA(\overline{T}_w - T_b) \quad (3)$$

Where,

$$T_b = (T_o + T_i)/2 \quad (4)$$

$$\overline{T}_w = \sum T_w / N \quad (5)$$

Where,N – Total number of thermocouples or resistance temperature detectors between inlet and exit of the testsection and evaluation is done at the outer wall surface of the inner tube.
Theaverageheat flux fromthe tube wallto thefluidisdefinedin terms ofsurface area:

$$Q = hA(T_w - T_b) + \sigma A \epsilon (T^4_w - T^4_b) \quad (6)$$

The convective heat flux is assumed to be uniformly distributed over the heated wall tube and can be evaluated as:

$$Q_{conv} = hA\,(T_w - T_b) \quad (7)$$

Where,

$$T_b = (T_o + T_i)/2 \quad (8)$$

The averaged heat transfer coefficient, *h* and the mean Nusselts number, *Nu* are estimated as follows:

$$h = m.\, C_{p,a}(T_o - T_i) / A(\overline{T}_w - T_b) \quad (9)$$

$$Nu = \frac{hD}{k} \quad (10)$$

The Reynolds number is given by,

$$Re = \frac{UD}{\nu} \quad (11)$$

Friction factor, f can be written as:

$$\lambda = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho U^2}{2}\right)} \quad (12)$$

Where, U is mean velocity in the tube:

$$U = \dot{m} / \rho A$$

(13)

The thermal performance factor (η) at constant pumping power is the ratio of the convective heat transfer coefficient of the tube with heat transfer enhancement device to the plain tube that can be represented as:

$$\eta = (Nu_t / Nu_p) / (\lambda_t / \lambda_p)^{1/3} \quad (14)$$

or,

$$\eta = h_t / h_p \quad (15)$$

III. THEORETICAL/COMPARATIVE ANALYSIS

1. Heat Transfer Results –

1.1 Perforated Conical Rings (PCR)[7]:

A.Effect of Pitch Ratio(PR)-

PCR with N=4 holes at various pitch ratios i.e. PR=4, 6 and 12, were used and their respective effects on heat transfer rate (Nu) was studied. The heat transfer rates for the tube having PCRs are higher vis-a-vis plain tube for a given Reynolds number. Reynolds number was varied in range of 4000 to 20,000. Quantitative results showed that the mean heat transfer rate of tube with PCR installed, having smallest pitch ratio of PR=4 is 18.8%, 53.9% and 137% higher vis-a-vis the tube having PCRs at pitch ratio, PR=6, 12 and plain tube, respectively.

B.Effect of Number of Holes (N) in PCR -

Effect of the number of the perforated holes i.e. N=4, 6 and 8 on heat transfer rate is shown in fig.3.1. The PCR with larger number of N provides a lower heat transfer rate due to the decrease in turbulence in the tube. The Nusselts numbers of tube inserted with the PCRs with N=4, 6 and 8, are found to be 90–239%, 69–220% and 65–172% respectively higher than those found when plain tube was used.The Nusselts numbers of tube with PCRs having N=4, 6 and 8 are respectively, 2–11.6%, 9.5–21.3% and 20.7– 30.8% lower vis-à-vis tube equipped with Conical Rings.

1.2 Nozzle Turbulators[6]

A.Effect of Pitch Ratio–

Nozzle turbulators when installed in heat exchanger tubes leads to the maximum heat transfer of 300% for a constant pitch ratio of, PR=1.0, in comparison with the plain tube. Reynolds number in range of 8000 to 18,000 was taken.
B.Effect of Reynolds number –

It was shown that nozzle turbulators provided a less effective heat transfer rate for lower values of Reynolds number. The turbulence speedof flow and hence theseparation of boundary layer especially in a shorter time is directly related to above effect. An increase in mean Nusselts number of 212 to 300% was observed when compared toDittus-Boelter correlation.

1.3Conically shaped coiled wire springs [2]

A.Effect of Pitch Ratio –

The Nusselts number of tubes when inserted with conical wire coils increases with decrease in pitches, when compared with those for the plain tube. The coiled wires of spring pitches 15 and20 mm were inserted into the tubeby wall attached position.Reynolds number in range of 2000 to 10,000 was taken.

B.Effect of Number of Coils -

Increase in number of coils of coiled wire turbulators further interrupt the of the boundary layer development ofthe fluid flow and increasethe degree of flowturbulence. Coiled spring with higher number of coils provides higher heat transfer than the plane pipefor higher Reynolds numbervalues.

C. Effect of Velocity of Flow:

This investigation revealed that heat transfer coefficient showed agradual increase with the increase in the airflow velocity. Plain pipe showed lowest heat transfer coefficient and increaseswith a decrease in coil spring pitch.

2. Friction Factor Results –

2.1 Perforated Conical Rings (PCR)[7] –

A.Effect of Pitch Ratio –

Effect of the PCR with pitch ratio, PR = 4, 6 and 12 onfriction factor is shown in fig 3.2. Friction factor noticeably increases with decreasing pitch ratio. Smaller is the distance between each pair of the PCRs, the more are the numbers of PCRs that can be inserted in the tube and hence more is theresistance against the flowing stream. It was deducted that the friction factors in the tube with PCRs are considerably lower vis-a-vis tube having typical CR, which are around 72.2% for PR=4, 68.1% for PR=6, and 72.5% for PR=12. It was concluded that the presence of perforated holes in the conical ring possesses reduces friction factor in the tube.

B. Effect of number of holes -

Friction factor decreases with an increase in the number of perforated holes due to reduction of turbulent fluctuation or eddy motion and appearance of reverse flow between consecutive turbulators can be noticed. The friction factors of PCRs with N=4, 6 and 8 holes, were found to be 57.2%, 73.6% and 82%, respectively lower than the friction factor obtained by typical CR.

2.2 Nozzle Turbulators [6]

Effect of friction factor was not taken into account to draw the results/conclusions for this investigation.

2.3 Conically shaped coiled wire springs[2]

(A) Effect of Pitch -With the increase of pitch the friction factor decreases.

(B) Effect of Reynolds number -This investigation revealed that the friction factor decreases with the increase of the Reynolds number. The friction factor is highest around at a Reynolds number 2200 - 3000.

3.Thermal performance factor results for Perforated Conical Rings (PCR) [7] –

The PCRs offers augmentation in heat transfer rate simultaneously giving an increase in friction factor which further leads to rise in pumping energy requirements.Performance evaluation criteria are used to determine the increase in heat transfer and friction factor which provides the actual effectiveness of turbulator. Such an evaluation is made using the data of the plain tube as reference and usually keeping a constant pumping power, keeping operation cost in consideration.
For constant pumping power:

$$(\dot{V}\Delta P)_p = (\dot{V}\Delta P)_t \quad (16)$$

Relationship between friction and Reynolds number:

$$(\lambda Re^3)_p = (\lambda Re^3)_t \quad (17)$$

The thermal performance factor (η) at constant pumping power is the ratio of the convective heat transfer coefficient of the tube with heat transfer enhancement device (PCR) to the plain tube given as:

$$\eta = (Nu_t/Nu_p) / (\lambda_t/ \lambda_p)^{1/3} \quad (18)$$

A.Effect of Pitch Ratio on thermal performance factor of PCR -

It is also observed that the turbulator with the smallest pitch ratio (PR) provide the highest thermal performance factor for both of the PCR and CR turbulators. Themaximum thermal performance factors of tube fitted with PCRs at PR=4, 6, and 12, are found to be 0.92, 0.87, and 0.79, respectively.The performance factors of the tube fitted with the CRs are lower than those of the tube with PCRs around 19.8–25.5% i.e. for same pumping power the PCRs can augment heat transfer rather efficientlyvis-a-vis CRs and hence it was proved that PCRs are better energy efficient devices than CRs.

B. Effect of Reynolds Number on thermal performance factor of PCR–

It was found that the thermal performance factor decreases with increasing Reynolds number.

C. Effect of number of holes (N) on thermal performance factor of PCR–

The PCRs with larger number of perforated holes (N) offer higher thermal performance factor as these generate lower pressure drop.

4. Pressure Drop Results forNozzle Turbulators [6] -

It was shown that pressure drop due to nozzle turbulators was higher than that obtained from the plain tube. It's because, the introduction of these turbulators caused turbulent and re-circulation effects leading to viscosity loss near tube wall and hence the dissipation of fluid dynamic pressure.

5.Enhancement efficiency Results forConically shaped coiled wire springs [2] -

A.Effect of Reynolds Number –

Increase in Reynolds number leads to increase in enhancement efficiency.For different configurations of conical wire coils, enhancement efficiency was shown to vary between 0.78 and 0.98.
B.Effect of Pitch ratio –

The enhancement efficiency and Nusselts number increases with decrease in pitch of wire coil and also for conical wire inserts.

C. Effect of Pumping Power –

Forconstant pumping power when wire coils were compared with smooth tube, an increase in heat transfer was observed, especially at low Reynolds number.

IV. CONCLUSIONS

1) Friction Factor v/s Reynolds Number –

It is observed that in all these three types of turbulators friction factor tends to decrease with an increase in Reynolds number. For perforated conical rings - number of holes and the pitch ratio, for nozzle turbulators - pitch ratio, for wire coil turbulators – number of coils and pitch ratio are considered constant as demonstrated in in fig 4 for comparison. It can be concluded from the trend followed by the graph that friction factor changes drastically for lower values of Reynolds number but as Reynolds number approaches towards its upper limits a gradual stability in friction factor can be observed.

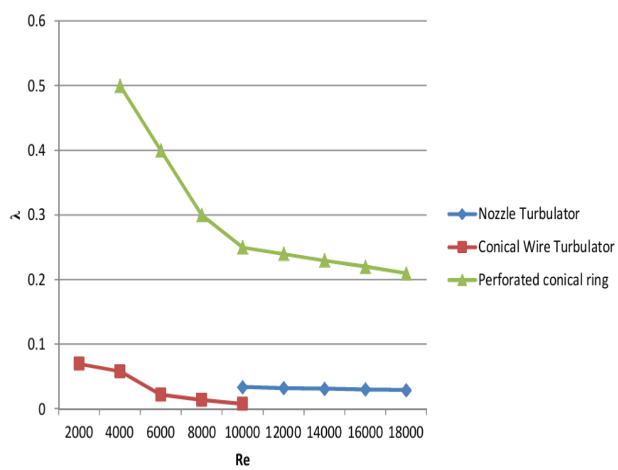

Fig.4 λ v/s Re

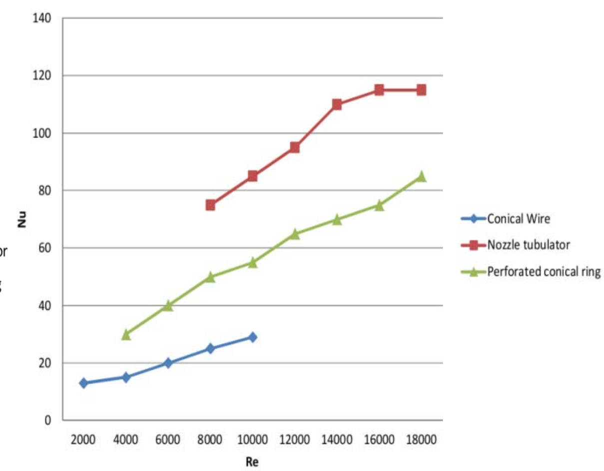

Fig.5 Nu v/s Re

2) Nusselts Number v/s Reynolds Number -

Fromthe graph shown in fig.5 it is observed that the increase of Reynolds number, an increase in convective heat transfer is obtained which further leads to an increase in Nusselts number. All three types of turbulators follow almost a similar trend. Effect of nozzle turbulators on heat transfer rate is less for low Reynolds number.For wire coil inserts increase in Nusselts number tends to decrease with increasein Reynolds number.

3) Swirl flow created by introduction of turbulator helps in decreasing the boundary layer thickness of hot air flow and increases the residence time of hot air in the inner tube.

4) In case of PCRs heat transfer rate and friction factor increases with decreasing pitch ratio and decreasing number of holes. Whereas, thermal performance factor increases with increasing number of holes and decreasing pitch ratio.

5) Enhancement efficiency and Nusselts number increases with decrease in pitch of wire coil and conical wire insert.

6) Maximum values of friction factor and heat transfer rate were achieved by Nozzle turbulators followed by PCRs and then wire coil springs. It’s worth noting that pumping power isn’t taken into consideration while concluding this point.

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