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A REVIEW ON HEAT TRANSFER AND PRESSURE DROP CORRELATIONS IN SOLID CIRCULAR FINNED TUBE BUNDLES POSITIONED AT INLINE AND STAGGERED ARRANGEMENT IN CROSS FLOW

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Abstract

The present review is organized in different arrangement of finned tube bundles placed on inline arrangement and staggered arrangement in cross flow. A large number of experimental and numerical works had been performed for enhancement of air-side heat transfer. A brief discussion is done on the effect of local heat transfer behaviour of circular finned tube and analysis of geometric and flow parameters included in this paper. Different parameters like fin height, fin spacing, fin thickness, tube diameter, tube spacing, effects of row and arrangement of tube bundles affect directly on the performance of solid circular finned tube. All these parameters are briefly discussed in this paper. Discussions on some important points which affect the performance of tube bundles (i.e. inline and staggered arrangement) from various authors and their problem and related issues are presented in this paper. The flow profiles and the related heat transfer characteristics in the complex geometries are still needed to be verified.

Keywords: Heat Transfer Augmentation, inline arrangement, staggered arrangement, cross flow.

1. Introduction

Finned-tube heat exchangers have been used to exchange heat between gases and liquids, which are single- or two-phase, for many years. The performance of the finned-tube heat exchanger is limited by the air side heat transfer resistance because the air side heat transfer coefficient is significantly lower than the refrigerant side heat transfer coefficient. Finned-tube heat exchangers having discrete plate fins with large fin pitches have been widely used to enhance the heat transfer performance of evaporators in refrigerators and freezers under dry and frosting conditions. Adding the fins in a heat exchanger is a very common procedure to enhance the overall heat transfer coefficient. One of the important processes in engineering is the heat exchange between flowing fluids, and many types of heat exchangers are employed in various types of installations, as power plants, petro chemical plants, building heating, ventilating, air conditioning and refrigeration (HVAC/R) systems. As far as construction design is concerned, the tubular or shell and tube type and the extended surface or finned tube type heat exchangers are widely in use. Finned-tube heat exchangers are used for the processes in which a liquid or gas is required to be either cooled or heated. Generally, a liquid flows within the tubes while gas is directed across the finned-tubes. Because of the poor thermal conductivity and thus the heat transfer coefficient of the gases, it is necessary to apply the extended surfaces on the gas side to enhance the heat transfer without losing its compactness. In addition, the problems concerned with pressure loss in flow medium must not be overlooked. A large number of experimental works has been performed for enhancement of the overall heat transfer coefficient and for enhancement of air side heat transfer; however, the flow profiles and the related heat transfer characteristics in the complex geometries are still needed to be verified. The circular finned-tube bundles are commonly used in the industries. Investigations are carried out mainly for the staggered arrangement under the cross flow conditions and numerous correlations have developed. The heat-transferring surface can be enlarged by an arrangement of annular fins or other elements. This increase of total tube surface allows transfer of a greater amount of heat from hot gas, but the demand for smaller installation sizes requires smaller fin pitch with larger fin height. On the other hand, finned tubes with segmented fins show somewhat higher turbulence than those with smooth fins since the boundary layer has to be established at each individual segment [1].An excellent overview of plate fin and circular finned tube studies is presented. Factors such as fin spacing, fin efficiency and fin configuration yield enhanced heat transfer. Yet one finned tube heat exchanger study claims to maximize the heat transfer rate while simultaneously minimizing pumping power [2].The heat transfer in a finned-tube heat exchanger is a conjugate problem**.** Conjugate heat transfer means computing more than one mode of the heat transfer simultaneously and it can be established efficiently by the way of numerical means. For a finned-tube heat exchanger, when the convection effect is intended to calculate for the fluid through the bundle, the conduction in the fins has to be considered as well [3].The fin efficiency of serrated fins is calculated using an analytical model, with the assumption of a heat transfer coefficient uniformly distributed over the fin surface and the segmented section, as well as a second equation for theoretical fin efficiency [4]. Investigation on seven different segmented finned tube bundle arrangements in cross flow. They ascertained that, compared to solid fins, the fin height of segmented fins can be greater than the maximum fin height because such fins are easier to laser-weld. This would increase the total outside surface area and as a result the efficiency of the heat exchanger [5]. Investigated experimentally local heat transfer behaviour in staggered and in-line arrangements with the help of optical adaptation of the naphthalene sublimation technique in order to evaluate the analytical fin efficiency and also gave the expression for the pressure drop of in-line and staggered arrangement [6].Experimentally studied the influence of rows in cross-flow heat exchangers. They compared their results with theoretical correlations. All measurements were performed in the Reynolds range between 10000 and 30000.They also present evaluation of heat transfer and pressure drop predictive method for tube bundles with stud fins [7].

2. LITERATURE SURVEY

Brauer [8] had done his investigation on the total surface area of the finned-tube bundle and the heat transfer coefficient *h* were closely linked and governed by the layout and the form of fins and tubes. Therefore, it is important to ensure that an enlargement of the fin surface area must be implemented without causing the decrease in heat transfer coefficient. It concluded that the fin surface area can be augmented by increasing the fin height and the number of fins per meter.

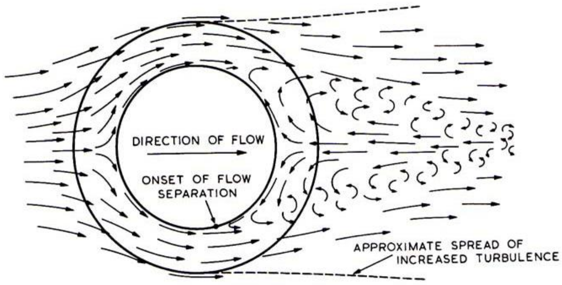
Zozulya et al. [9] had done his work on Effect of Flow Turbulization on Heat Transfer in a Finned Tube Bundle and concluded that the flow mode should be treated as a temperature dependent problem because the flow variables directly depend on the temperature of air. Furthermore, the heat transfer from a bundle (especially in the first row) depends on the conditions of turbulence intensity occurred at the bundle inlet.

Sparrow and Chastain [10] investigated on a single circular fin by mass transfer method. They measured the variations of the angle of attack by a thin film of a naphthalene sensor. The authors concluded that the overall heat transfer performance of a circular fin was not significantly affected by small angles of attack. However, the measurement of the heat transfer coefficient at only one side may yield erroneous results.

Neal and Hitchcock [11] carried out a comprehensive study on the local heat transfer and airflow occurring within a circular finned-tube bank in staggered tube arrangement. Three different tube spacing were examined and instrumented tubes were installed in row two and six. They found and concluded that the heat transfer upstream in the fin is considerably higher, and the heat transfer coefficient decreases at the base of the tube as the boundary layer increases.

Hu and Jacobi [12] investigated that the use of thermocouples and few sensors might be inadequate for resolving details of the flow and the heat transfer interaction and suggested that the point heating method could lead to serious errors. The author concluded that the total heating method, the thermal boundary layer will not be developed at the fin tips where both (velocity and thermal) boundary layers should have to develop. Instead, thermal boundary layer only will develop when the airflow reach to the heated area and According to this dependency on the heating models, the heat transfer distribution patterns over the fin will be dissimilar.

Watel et al. [13] had done his work on the influence of the fin spacing on the convective heat transfer from a rotating circular finned-tube in transverse airflow. The fin cooling was monitored by aid of the infrared thermography and the flow field in the mid-plane between two fins was obtained by Particle Image Velocimetry (PIV) device. Their results were compared and validated with various authors' experimental works and concluded that the heat transfer coefficients over the circumference were more uniformly distributed on a tube in the bundle rather than on a single tube.



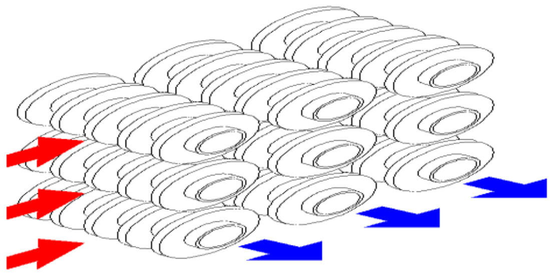


Fig -1 Schematic view of general flow pattern over a row of staggered arrangement tube bundle

Fig -2 Cross-flow circular finned-tube heat exchanger

Yudin et al. [14] had done his investigation on experimental correlation data on convective heat transfer in cross flow over finned bundles with different fins and these fins are transverse, spiral and circumferential fins and observed and concluded that an increase of the fin height of the staggered tube arrangement provides the decrease of heat transfer coefficient and the increase of pressure drop.

Zukauskas et al. [15] investigated that the highest value of the average heat transfer coefficients along the fin height, are found to be narrowest near the flow passage in the bundle exists. It can be explained that due to the construction in the flow passage, the flow velocity reaches maximum and causes a high local heat transfer. At ($\theta = 0°$) and ($\theta = 180°$) the relative heat transfer coefficient, i.e. the ratio of local heat transfer coefficient to the averaged heat transfer coefficient over a fin height, attained its maximum at the fin tip. At ($\theta = 90°$), the relative maximum heat transfer occurred in the middle of the fin height. Author concluded in his work is that the nature of the local heat transfer distribution over the fin height was changed according to the angle of fin surface.

Rabas et al. [16] had investigated that the fin density has much stronger impact on the performance for the larger diameter of tube (d = 31.75 mm). They examined for the low fins, which is less than 6.35 mm at the range of $1000 \leq Re \leq 25000$. He also gave his results for the longitudinal pitch effect to the heat transfer performance. Authors concluded that the thermal performance is almost independent of the Reynolds number for the larger fin density (0.98 fins / mm).

Mirkovic [17] investigated the heat transfer and pressure drop in an eight-row deep staggered tube bundle for the two tube diameters 38.1mm and 50.8 mm with constant transverse and longitudinal tube pitches. The tube diameter only was changed while other parameters such as the fin height and fin spacing were kept constant in his investigation. Author concluded that when the tube diameter increases, the wake region behind the tube will increase and the air-side pressure drop will rise.

Torikoshi et al. [18] investigated numerically the tube diameter effect on heat transfer and flow behaviour for a two-row staggered arrangement of plate finned-tubes. In contrast to the circular finned-tubes, the plate fin surface is decreased when the tube diameter increases. He observed no significant variation of the average heat transfer coefficient. Author concluded that the tube diameter effect may be largely ignored for the cases where the diameter is changed only slightly.

Rabas and Taborek [19] studied on the rows effect of low finned-tube bundles and presented a shallow bundle correction factor. It means that the factor increased with the number of rows for low fin density (0.393 fins/ mm) but decreased for high fin density (0.984 fins/ mm). For a high fin density tube bank in a staggered array, some performance characteristics similar to those of the in-line bank are noted. In his study he concluded that the heat transfer performances of shallow in-line tube banks always decreased with row number regardless of the fin density.

F.Halici and I. Taymaz [20] they provide experimental data for the study of air side performance of tube row spacing in finned tube. They also provided an extensive reference database for heat transfer and pressure drop of finned-tube bundles in cross flow. Their work covers 21 different seven-row finned-tube bundles. The heat transfer correlations were obtained from their own data and the experimental data for the bundles scatter over the range of ± 14 %. They concluded that the effect of bundle configuration and the fin parameters are affect directly on performance of finned tube bundle.

Sparrow and Samie [21] observed that the pressure drop increases with the longitudinal pitch. It is possible that the tubes will act as a single tube if the longitudinal pitch is too wide. They showed that the longitudinal pitch effect depends on the fin density of the low finned-tube bundle. They concluded that the heat transfer performance is identical for Sl = 37.12 mm and 50.80 mm with 0.4 fins per mm. However, for the fin density of 0.98 fins per mm, the heat transfer performance lowered for a larger Sl applied.

Jacobi and Shah [22] discussed that the air flow was likely to exhibit all of possible flow features (e.g. steady or unsteady, laminar or turbulent) in a single heat exchanger. They suggested that there were still limitations to the air-side heat transfer performance and a clear understanding of airflow in the complex passages of heat exchangers was needed so that surface design can be optimized efficiently.

Rene Hofmann et al. [23] had done his work on heat transfer and pressure drop at different transverse serrated and solid finned-tubes and investigated in cross-flow with aim of optimizing heat exchanger performance. Three different finned-tube shapes were investigated. The I-shaped and U-shaped fin geometries under consideration have varying geometrical constants, i.e. fin height, fin pitch, fin thickness, and fin width. The heat exchanger consists of eight consecutive finned-tube rows and eleven tubes on top of each other. The finned tubes are arranged in a staggered formation at equal transverse and longitudinal pitch. The experimental setup, measurement technique and measurement uncertainties are presented. The design of an optimum heat exchanger must take into account the advantages and disadvantages of geometrical factors which influence heat transfer and pressure drop. After measurement validation, the derived correlations for the Nusselt number and the pressure drop coefficient were compared with experimental results and equations from literature. Authors concluded that serrated finned tubes, three ranges could be identified: Re < 10000, 10000 < Re < 20000 and Re > 20000. Despite varying fin height and fin pitch in the two different geometries, no substantially differing tendencies could be observed when applying these equations.

3. CONCLUSION

All studies verified that the heat transfer coefficient around the fin, and from row-to-row vary in accordance with the bundle depth. It is useful to note that only limited results with a single tube and very few rows are found, and further studies applying four and more tube row bundles should follow. On the other hand, some studies have done to resolve this situation by developing the row correction factors. A considerable amount of related data on the local and average heat transfer and the pressure drop were established and qualitative judgements on circular finned tube configurations are rendered. Despite of these earlier developments, this review indicated that further concentration on the existing problems in designing of optimum fin geometry and tube arrangements are still necessary. Some conclusion points are,

• Considerably more information on numerical simulation has been published for plate fins than circular fin tubes.

• The heat transfer coefficient and flow distribution over a tube in the bundle is different to a single tube.

• Temperature distributions over the fin surface and the flow structures between fins are of complex pattern. When the need arises to measure such effects accurately, it is an experimentally difficult task to do without disturbing the heat transfer behaviour on a fin surface. Therefore, more precise data on the local behaviour are necessary.

• Different results came out of the relevant information regarding the tube spacing adjustments and number of rows.

• Since most correlations were based on their own data, authors gave different formula for the heat transfer and pressure drop correlations. In addition, the characteristic dimension to define Reynolds number was dissimilar. Thus, it is fairly anticipated that to compare directly to experimental correlations is found to be difficult.

• Finally, all related works for the circular finned-tubes have been correlated experimental ones and respective correlations have not been verified yet under numerical simulations. Therefore, additional numerical data are needed in order to establish improved correlations.

4. FUTURE SCOPE

More work on the existing problems in designing of optimum fin geometry and fin spacing and tube arrangement are still necessary. A lot of works are still to do on these parameters and this area.

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