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Convective Heat Transfer Performance of Tube-Fin Heat Exchanger

Krishna Purnavasi, Pratap Bhanu Shekhawat and Nitesh Mishra
Department of Mechanical Engineering,
Shri Dadaji Institute of Technology & Science, Khandwa, (MP)

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ABSTRACT: The numerical analysis on convective heat transfer behavior and pressure drop characteristics of staggered circular tube bank fin heat exchanger with smooth fin and with interrupted half annular groove fin is carried out under the conditions of different tube rows (1, 2, 3, 4, 5), different fin spans (1.5mm, 2mm, 2.5mm) and different annular angles of interrupted half annular groove (30°, 50°, 70°), in addition, the velocity fields and the temperature fields of the structures are obtained. The results show that the ability of heat transfer could be enhanced by increasing tube rows, fin spans and annular angle of interrupted half annular groove in certain range, and the number increases with the increase of Re number, whereas the resistance coefficient decreases with the increase of Re number in the heat exchangers both for the smooth fins and the interrupted half annular groove fins. The features of flow and heat transfer for heat exchanger with interrupted half annular groove fin are obtained by analysis of the formation, development and influence area of the vortices generated by interrupted half annular grooves.

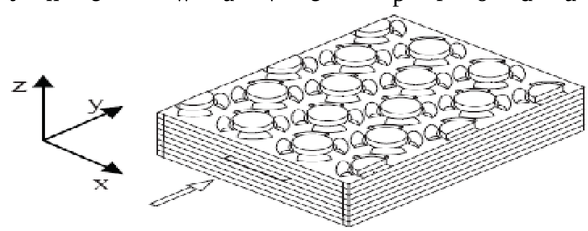
Key words: Interrupted Annular Groove Fin; Heat Transfer Enhancement; Tube-Fin Heat Exchanger

I. INTRODUCTION

An effective way to enhance heat transfer of tube-fin heat exchanger is to revise the structure of the fin, there are already many different fins used in tube-fin heat exchangers, such as wave fin, slit fin, louvered fin, rhombus punched fin and delta winglet fin[1-3]. Different fins have different ways of enhancing heat transfer ability. It is known from heat transfer theory that convective heat transfer depends on fluid temperature gradient near wall. To achieve large temperature gradient, the fluid heated or cooled by wall should be taken away and substituted by fluid far from wall. For tube–fin heat exchanger, tube surface is the main heat transfer surface, smooth fin is extended surface and belongs to secondary heat transfer surface, the structure added to smooth fin belongs to third heat transfer surface[4-5]. The third surfaces are indispensable to enhance heat transfer, they either can cut the boundary layer development to make the boundary layer develop periodically or produce swirls to mix fluid each other in order to transfer moment and mass. The fins mentioned above, some have only one way of enhancing heat transfer, some are the combination of different ways of enhancing h swirls on the down stream side of the wave, the swirls disturb the stability of fluid flow, the turbulence flow state appears earlier than smooth fin for the same inlet fluid velocity, the swirls can also mix adjacent fluid. For slit fin and louvered fin, their heat transfer enhancement mechanism mainly relies on periodic boundary layer development. Winglet fin is another kind of fins, the winglet can be rectangular or triangular. Wing or winglet can be used in plate heat exchanger and tube-fin heat exchanger, the early studies of their heat transfer performance and applications in compact heat exchangers are reported by Fiebig, *et al.* [2-3] Many investigations have been down on heat transfer performance for heat exchangers with wave fin, slit fin, louvered fin and delta winglet fin experimentally or numerically [1-12]. Wang, *et al.* [1] studied flow structures of annular and delta winglet vortex generators in fin-and-tube heat exchanger application using dye injection technique. There are four sections of annular around each tube, this is much like the case being investigated in this paper, but the annular in their study is humped up with two ends closed. Tube-fin heat exchanger with interrupted annular groove fin is used in intercooler of some diesel locomotives, but literatures about their heat transfer performance are not sufficient. The present study aims reveal some heat transfer performances of interrupted annular groove fin by numerical analysis.

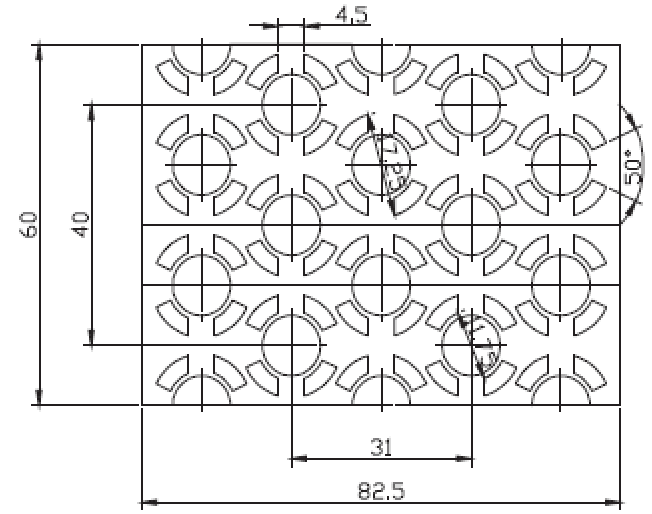
II. GEOMETRIC DESCRIPTION OF HEAT TRANSFER UNIT

Interrupted half annular groove fin has unique characteristic both in geometry and in heat transfer augmentation, the heat transfer unit of interrupted half annular groove fin is shown in fig. 1(a) to fig. 1(c).eat transfer. When fluid flows over wave fin, the wave produces



(a) Sketch of heat exchanger with interrupted half annular groove fin.

The fin is characterised by each hole surrounded by four half annular grooves. In this study, totally 32 different heat transfer units are considered, they are divided into two groups, one of the groups has smooth fins, the other group has interrupted annular groove fin. Each group has 5 kinds of tube rows of 1, 2, 3, 4, 5



(b) Top view of interrupted half annular groove fin.

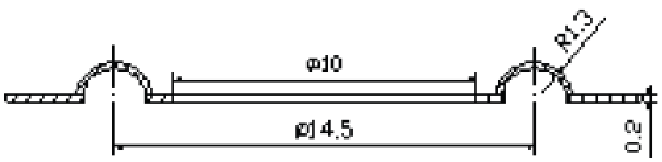


Fig. 1. Geometric model of heat exchanger with interrupted half annular groove fin.

and 3 kinds of fin spacings of 1.5mm, 2mm and 2.5mm. For interrupted annular groove fin, the attack angle of 50c is used in models with all kinds of tube rows and fin spacings, while the attack angles of 30c and 70c are only used in models with fin spacing of 1.5mm and tube rows of 5. Reynolds number in calculation ranges from 5000 to 20000. For each geometric model, the calculation is performed under 5 to 6 Reynolds number.

III. REGIONS OF CALCULATION AND MESHING

A. Regions of Calculation

For practical application, a complete heat transfer unit usually contains three to seven rows in flow direction and several columns in traverse direction. It can be inferred from fluid flow and fin structure that there exist symmetry faces through vertical central lines of round hole. The isolated calculation area of 5 rows model is shown in Fig. 2, the height of the passage equals to net fin spacing.

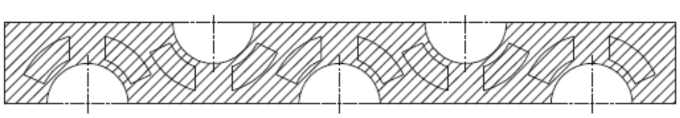
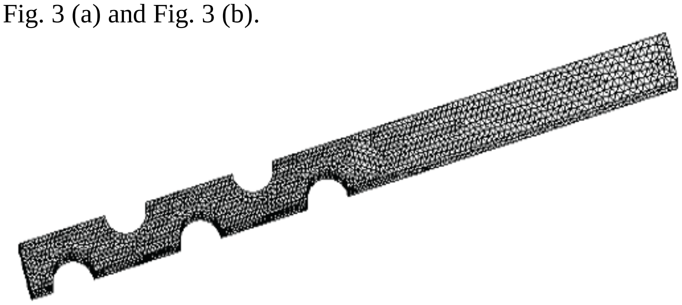
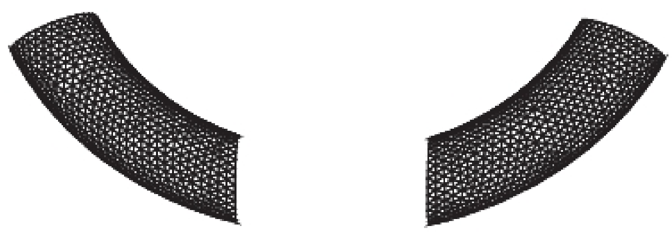


Fig. 2. Typical calculation area.

The mesh of whole calculation area is refined as finer as possible except for the extended section behind last tube. The extended section is to ensure that there is no back flow at outlet, the length of extended section is 10 times the size of tube diameter, and the length is same for different rows of tube. The mesh of calculation area of 5 rows of tube model is shown in Fig. 3 (a) and Fig. 3 (b).



(a) Mesh of typical calculation area.



(b) Mesh of Annular groove Fig. 3 Calculation region and mesh. The proper number of mesh cells is verified with the criteria of cell number independence to Nu number and pressure drop coefficient.

B. Boundary Condition Inlet Condition

From Reynolds number used in this paper, it can be inferred that the flow is in turbulence state. Although there many models of turbulence, Symmetry condition: According to the symmetry of geometry and heat transfer character, assume that there exists symmetry section on which there is no dissipation of momentum and heat flux. In numerical calculation, the constant wall temperature boundary condition of tube and fin is adopted. This implies that the fin efficiency is equal to 1. The wall temperature is set to 67 c, the temperature of air at inlet is set to 140c, the air is cooled by tube walls and fins.

IV. OBSERVATIONS CHECK IT)

A. The Effects of Tube Rows on Heat Transfer and

Pressure Drop The case where fluid flows across a round cylinder is a typical example to show the separation of boundary from the wall of cylinder and formation of swirl at the rear of cylinder, though the flow structure of fluid across passages of parallel fins with tubes inserted in them is different from the case of fluid across single or a bundle of tubes in in-line or staggered layout, the separation of boundary and formation of swirl are same for both cases.

The swirls behind the tube deteriorate heat transfer and increase momentum loss if fluid in the swirl region is not dissipated instantly by new coming fluid. From Fig. 4-Fig. 6, it can be seen that with the increase of tube row, heat transfer and pressure drop increase for both fin structures. Generally, tube itself has the ability to increase disturbance of flow, the successive tubes are submerged in the more disordered flow, the heat transfer is enhanced one tube row after another. For smooth fin unit, the increase amplitude of heat transfer is retarded, while it still has a tendency of increasing heat transfer for more tube rows in interrupted annular groove. Though pressure drop also increases with the increase of tube rows, the characteristics of interrupted annular groove fin unit with more tube rows allow it to be used in the case of high thermal load. For interrupted annular groove fin, the groove serves as bent guidance tubes leading fluid through rear region of round tube. Developing boundary layer is produced continuously not only on the surface of base fin, but also on the surface of bent groove. Like vortex generators, interrupted annular groove can also produce secondary flow superimposed on main flow which has great effect on augmentation of heat transfer.

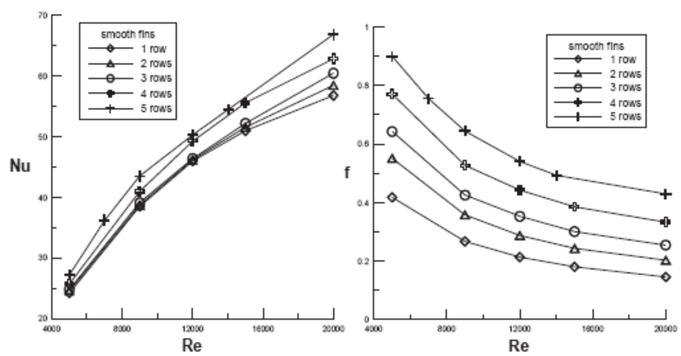


Fig. 4. Heat Transfer and Pressure Drop Curves of Smooth Fin unit with One to Five Rows.

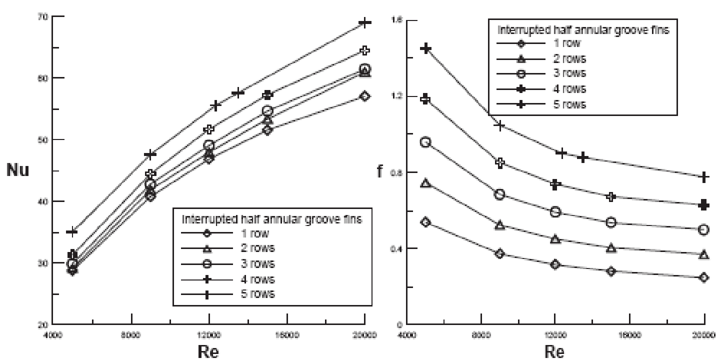


Fig. 5. Heat Transfer and Pressure Drop Curves of Interrupted Annular Groove Fin Unit with One to Five Rows.

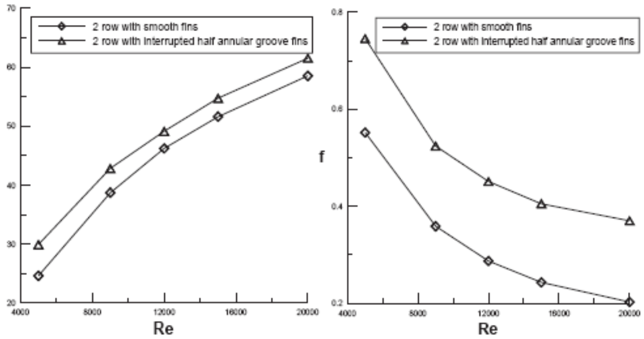


Fig. 6. Comparison of Heat Transfer and Pressure Drop between Smooth Fin Unit and Interrupted Annular Groove Fin Unit of Two Rows.

For the same tube row, the heat transfer performance of interrupted annular groove fin unit is better than smooth fin unit, the average Nusselt number is increased by 10% to 30% compared with smooth fin unit for corresponding structure and at given Reynolds number.

B. The Effect of Fin Spacing on Heat Transfer and Pressure

Drop Fin spacing of calculation models has three values; they are 2.5mm, 2.0mm, 2.5mm. The calculation is carried out both for smooth fin unit and interrupted annular groove fin unit with tube row of 5; some of the results are depicted in Fig. 7 to Fig. 10. For three kinds of fin spacing, the variation trends of heat transfer performance and pressure drop are similar accordingly both for smooth fin unit and interrupted annular groove fin unit. For small fin spacing, fluid flow is confined in a limited space, the disturbance and mixture of fluid caused by round tube or humped annular groove can not develop freely, the exchange of momentum and heat flux is insufficient. With the increase of fin spacing, the flow space is broadened; the strength of disturbance of flow is enforced. From velocity field of smooth fin unit, it is observed that the region size of back flow behind tube is almost the same for small and large fin spacing for same Reynolds number, but the strength of vortex in rear area of tube for large fin spacing is much stronger than that of small fin spacing, stronger swirl of fluid 2mm, 2.5mm can take more fluid away

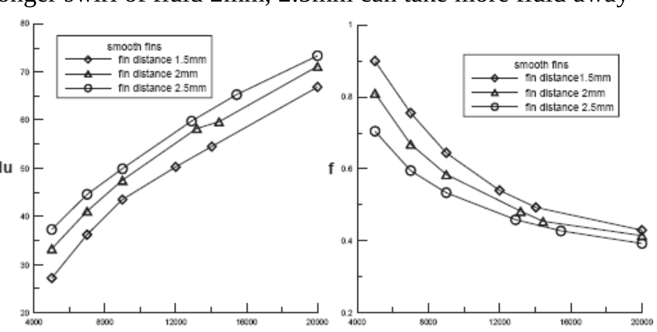


Fig. 7. Heat Transfer and Pressure Drop Factor Curves for Smooth Fin Unit with Fin Spacing = 1.5mm, 2mm, 2.5mm.

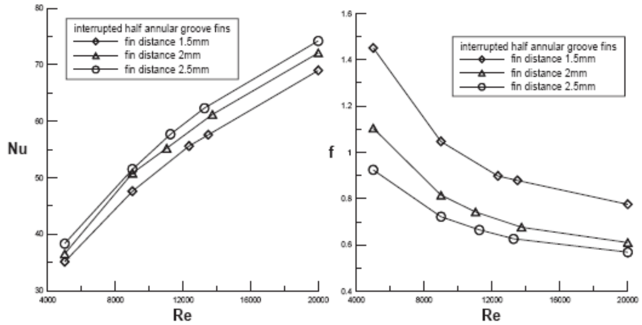


Fig. 8. Heat Transfer and Pressure Drop Factor Curves for Interrupted Annular Groove Fin Unit with Fin Spacing = 1.5mm.

from back zone than weaker swirl of fluid. It is also observed that the tube only produce transverse vortex with its rotating axes perpendicular to main stream, this situation also happens to interrupted annular fin unit, the difference is that the region of back flow is small and with the guidance of bent groove, vortex induced at rear region of tube consists mainly longitudinal vortex which can carry fluid both from near wall and at core region of flow to downstream.

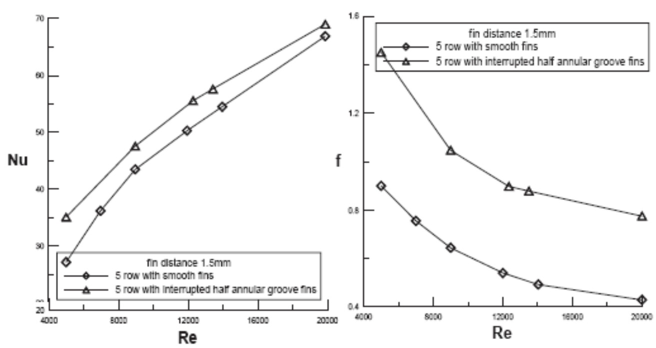


Fig. 9. Comparison of Heat Transfer and Pressure Drop between Smooth Fin Unit and Interrupted Annular Groove Fin Unit (Fin Spacing = 1.5mm).

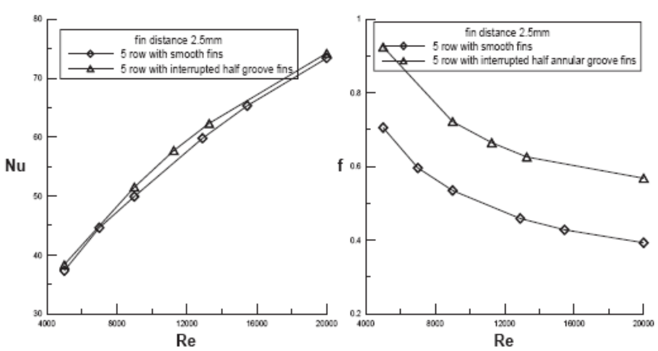


Fig. 10. Comparison of Heat Transfer and Pressure Drop between Smooth Fin Unit and Interrupted Annular Groove Fin Unit (Fin Spacing = 2.5mm).

For the same fin spacing, Nu increases with the increase of Re, pressure drop factor has inverse relation with Re. For the same Reynolds number, the Nusselt number and pressure drop factor increase with the increase of fin spacing both for smooth fin unit and interrupted annular groove fin unit. For tube-fin heat exchanger, tube wall is the main heat exchange surface, fin is auxiliary surface. With the increase of fin spacing, more tube wall surface is exposed to air, combined with increasing disturbance of air at high Reynolds number, the heat transfer is increased. But the rate of heat transfer increase for larger fin spacing is less than smaller fin spacing, since for larger fin spacing the heat transfer is mainly dominated by tube bundles, tubes themselves already produce sufficient disturbance and swirl in fluid flow. Owing to the existence of interrupted annular groove, the Nu number of interrupted annular groove fin unit is greater than smooth fin unit for the same fin spacing and same Reynolds number. In addition, the effect of heat transfer of rugged fin is more apparent at smaller Reynolds number than at larger Reynolds number.

C. The Effect of Attack Angle of Annular Groove on Heat Transfer and Pressure Drop

The attack angle of annular grooves is defined as the angle between two opposite surfaces in front and back of tube. The annular grooves are punched out from base fin, there are four half annular grooves around each tube with tube axis as symmetry axis. There are three kinds of attack angles used in the calculation, they are 30c, 50c, 70c. In case of attack angle of 30c, fluid flow is compelled to move along nearly exact circular track with very small back flow at the rear of tube. Though the back flow region is small for attack angle of 30c, it is worth noticing that the heat transfer and pressure drop are not favorable with one eye on Fig. 11, this may be due to the over correction of flow track for attack angle of 30c. With the increase of attack angle, the guidance function of annular groove is weakened and the back flow zone is increased correspondingly. In case of attack angles of 30c and 70c, the flow deviates from entrance flow direction too much, the former is due to the over correction of flow track, the latter is due to the lack control of fluid flow, so both cases do not receive effective heat transfer increase. In case of attack angles of 50c, the flow is almost consistent with main flow stream, so it has better heat transfer performance. It is worthwhile to notice that the pressure drop factor curve for attack angle of 50c ies in between the curves of attack nangle of 30c and 70c, while Nusselt number curve for attack angle of 50c at Re>9000 is located above the curves of attack angle of 30c and 70cshown in Fig. 11. This shed the evidence that the optimal geometry parameters exist in design of interrupted annular groove fin heat exchanger. Hear the structure with attack angle of 50c gets better heat transfer performance and moderate pressure drop.

It should also bepointed out that Nusselt number curve for attack angle of 70c is intersected with Nusselt number curves for attack angle of30c and 50c.

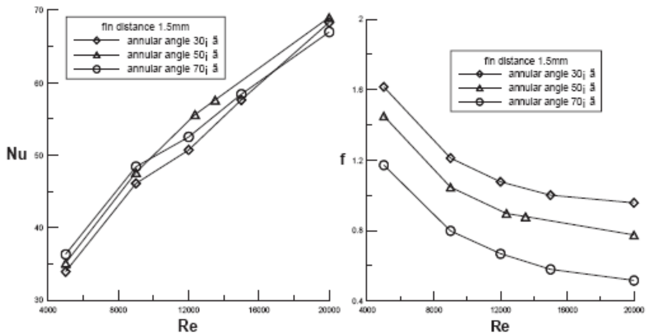


Fig. 11. Eat Transfer Performance and Pressure Drop Factor Curves for Interrupted Annular Groove Fin Unit with Attack Angle = 30,50,70.

The Nusselt number increase rate for attack angle of 70cis behind the increase rate for attack angle of 50c. For small Re number for instance Re<9000, the annular groove of attack angle of 70vcan lead fluid flow passing around tubes smoothly, it results in better heat transfer and lower pressure drop, with the increase of Re number for instance Re>9000, the flow structure is changed unfavorable to heat transfer, the relatively large back flow region at the rear of tube is formed which deters the effective heat transfer at that area.

V. CONCLUSIONS

The structure of interrupted half annular groove tube-fin heat exchanger is different from commonly used tube-fin heat exchanger, with the guidance of bent annular grooves, part of fluid in flow passage flows in a circular track around tube, which compress the back flow region behind tube. The humped annular groove with a certain attack of angle produces longitudinal vortices at entrance and exit of groove, the longitudinal vortices mix and wrap fluid around them to flow downstream. The enforced exchange of momentum and heat flux increases heat transfer. The protrusion of annular groove into flow field produces developing boundary layer on base fin and groove surface, the successive developing boundary also contribute to enhance heat transfer. For the particular features of interrupted half annular groove fin, the series of numerical calculations is carried out with respect to different rows of tube, different fin spacing and different attack angles of annular grooves at Reynolds number ranging from 5000 to 20000. As for the configuration studied in this paper, the results reveal that: 1) The interrupted half annular groove fin has the effect of guiding fluid around tube, reducing back flow area at the rear of tube; as the annular groove is punched out from base fin, the heat transfer area is increased about 5%. The punched annular groove cuts off the heat conduction route and boundary layer development on base fin, it also produce longitudinal vortices. These measures are helpful to enhance heat transfer. 2) With the increase of tube row number, the heat transfer coefficient and pressure drop factors both increase. For a certain number of tube rows, the heat transfer is decreased at back rows in flow passage, the number of tube rows should not exceed a critical number. 3) With the increase of fin spacing, the heat transfer coefficient and pressure drop factors both increase too. This is only part of the solution of heat transfer, as with the increase of fin spacing, the total heat transfer area is decreased, for heavy thermal load, the small fin spacing is an alternative design. 4) For three kinds of attack angles studied here, the annular groove with attack angle of 50c is superior to the annular grooves with attack angles of 30cand 70cin considering to heat transfer and pressure drop. 5) Compared with smooth fin model, the heat transfer coefficient of interrupted annular groove fin model is larger than that of smooth fin model, for fin spacing of 2 mm, attack angle of 50 c, the average Nusselt number of interrupted annular groove fin model is greater than that of smooth fin model by 10%-30% for tube rows from one to five.

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