DESIGN AND ANALYSIS OF DOUBLE-PIPE HEAT EXCHANGER WITH NEW ARRANGEMENTS OF CORRUGATED TUBES USING HONEYCOMB ARRANGEMENTS

by

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Double-pipe heat exchangers are utilized as a part of mechanical procedure to recuperate heat between two process liquids. The main objective of this project to augment the heat transfer in a counter flow double-pipe heat exchanger filled with inner tube of honeycomb arrangements. To increase the efficiency of doub-le-pipe heat exchanger is made up of concave and convex corrugated type of outer and inner tubes. Hot water (inner tube) and cold water (outer tube) inlet temperatures were maintained at 40 °C and 8 °C, respectively. Investigation were performed for inward tube (high temperature water) and external tube (cool water) volume flow rate was kept at 15 L per minute and 20 L per minute. Different parameters such as overall heat transfer coefficient, Nusselt number, pressure drop, friction factor, convective heat transfer coefficient, and effectiveness were obtained and compared for new arrangements of corrugated tubes filled with and without honeycomb arrangements. The analysis was carried out for porosity range is 0.8 and pore density (greater than 9 parts per litre) to ensure high effectiveness. Maximum effectiveness was obtained for heat exchanger made of concave corrugated outer tube and convex corrugated inner tube with honeycomb structure.

Key words: *double-pipe heat exchanger, corrugated tubes, effectiveness, honeycomb arrangement*

Introduction

A heat exchanger is a gadget that is utilized to exchange heat vitality (enthalpy) between two or more liquids, between a strong surface and a liquid, or between strong particulates and a liquid, at various temperatures and in heat contact. In heat exchangers, there are normally no outer heat and work co-operations.

The device used to actualize the trading of heat between two liquids that are at various temperatures while keeping them from blending with one another is termed a heat exchanger. They are utilized as a part of an extra-ordinary measure of uses, for example, air conditioning system, chemical processing, power creation and aeronautical applications. The weight and size of heat exchangers utilized as a part of space or aeronautical applications are extremely huge parameters, furthermore, in these cases, expenses of heat exchanger generation are specified as an optional thought. In any case, heat exchangers are intended to get most

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extreme heat transfer, low weight drop, high adequacy, least volume, and weight. A few strategies have been utilized for these purposes. Coarsening surfaces can enhance the heat execution of heat exchanger by expanding liquid blending and turbulence level of the fluid-flow. Corrugated tubes can be presented as one of the coarsening surface routines and they can be grouped into two fundamental sorts: internal concave corrugated tubes and outward convex corrugated tubes. Two are contemplated in present paper.

Different literatures were contemplated for checking impact of corrugated tubes on heat enhancement and pressure drop. Dizaji *et al.* [1] performed experimental studies on heat transfer and pressure drop characteristics for new arrangements of corrugated tubes in double-pipe heat exchangers. Vicente *et al.* [2] performed an experimental about heat transfer and isothermal pressure drop in corrugated tubes for laminar and transition flow. Kumar *et al.* [3] investigated the effectiveness of the heat exchanger and Aavudaiappan *et al.* [4] formulated a mathematical model for measuring the flow properties of the fluid in heat exchanger. Han *et al.* [5] analyzed multi objectives shape optimization of double-pipe heat exchanger with inner corrugated tube using RSM method. Xu *et al.* [6] performed numerical investigation on self-coupling heat transfer in counter flow double-pipe heat exchanger filled with metallic foams. Sivaprakash *et al.* [7] calculated the effectiveness of heat exchanger and Sathivel *et al.* [8] developed a mathematical model for heat exchangers. Aroonrat *et al.* [9] carried out an experimental investigation on evaporation pressure drop and heat transfer of R-134 through a vertical corrugated tube. Lately, Darzi *et al.* [10] experimentally investigated the convective heat transfer and friction factor of Al_2O_3-water nanofluid in helically corrugated tube.

As depicted previously, the greater part of the works were done utilizing corrugated tubes as only inner tube and outer tubes of a double-pipe heat exchanger. There is no study on using honeycomb arrangements in the inner tube of corrugated tubes. The main scope of the present study is using honeycomb arrangements as an inner tube of different arrangements of corrugated tubes. Tests were performed for volume flow rate of inward tube (high temp water) and external tube (cool water) volume flow rate was kept at 15 L per minute and 20 L per minute. The result of this study is provided as Nusselt number, friction factor, effectiveness, and NTU of the heat exchanger with and without honeycomb arrangements.

Equation

Heat capacity flow rate of cold water:

$$C_c = m_c C_{p,c}$$

Heat capacity flow rate of hot water:

$$C_h = m_h C_{p,h}$$

Minimum heat capacity flow rate:

$$C_{min} = \text{minimum value of } C_c \text{ and } C_h$$

Maximum heat capacity flow rate:

$$C_{max} = \text{maximum value of } C_c \text{ and } C_h$$

Maximum possible heat transfer:

$$Q_{max} = C_{min}(T_1 - t_1)$$

Effectiveness of the heat exchanger:

$$\varepsilon = \frac{Q_{\text{avg}}}{Q_{\text{max}}}$$

Cross sectional area of annulus through which cold water flows:

$$A_{\text{annulus}} = \frac{\pi}{4} D_h^{\ 2}$$

Cross sectional area of annulus through which hot water flows:

$$A = \frac{\pi}{4} D_i^2$$

Velocity of hot water:

$$V_{\text{h}} = \frac{m_{\text{h}}}{\rho_{\text{c}} A}$$

Velocity of cold water:

$$V_{\text{c}} = \frac{c}{\rho_{\text{c}} A_{\text{annulus}}}$$

Reynolds number for cold water flows:

$$\text{Re}_{\text{c}} = \frac{\rho_{\text{c}} V_{\text{c}} D_h}{\mu_{\text{c}}}$$

Nusselt number for cold water flows:

$$\text{Nu} = 1.3 \left[\frac{\text{Re}_D \, \text{Pr}}{\frac{x}{D}} \right]^{0.33}$$

when $\text{RePr}(D/x)$ is greater than 10 for smooth and rough tubes, friction factor for cold water flows $f = 64/\text{Re}_D$ for smooth and rough tubes when $\text{Re}_{Dh} < 2300$.

Pressure drop for cold flow:

$$\Delta p = f\, 0.5 \frac{l}{D} \rho v^2$$

Reynolds number for hot water flows:

$$\text{Re}_{\text{h}} = \frac{\rho_{\text{h}} V_{\text{h}} D_i}{\mu_{\text{h}}}$$

Nusselt number for hot water flows for both smooth and rough tubes, Dittus-Boelter equation states:

$$\text{Nu} = 0.023(\text{Re}_{Di})^{0.8} \, \text{Pr}^n \text{, when Re} > 2500 \ (n = 0.4)$$

Friction factor for hot water flows for smooth tubes and rough tubes:

$$f = 0.25(1.82\log_{10}\mathrm{Re}_{Di} - 1.64)^2$$

Pressure drop for hot water flow:

$$\Delta p = f\,0.5\frac{l}{D}\rho v^2$$

Simulation details and methods

In my task, the corrugated tubes is done through by simulation software packages. For planning purposes CATIA V5 software is utilized, For meshing purpose HYPERMESH software is used. For analysis purpose familiar software such as FLUENT 15 is utilized.

Tubes geometry and modeling

Both of the smooth and corrugated tubes are made up of aluminum material with a thickness of 1 mm. A geometric specification of the tubes are tabulate in tab. 1, where *e, S, b*, and *P* are the geometrical properties of the corrugation as illustrated in fig. 1, by using these specification designing of these tubes are done through CATIA V5 software [11, 12].

By using this geometry new arrangements of corrugated tubes are considered. The different arrangements are: both tubes are smooth; inner tube are convex, outer tube are smooth; inner tube are concave, outer tube are smooth; inner tube are convex, outer tube are concave; inner tube are concave, outer tube are convex; both tubes are concave, and both tubes are convex.

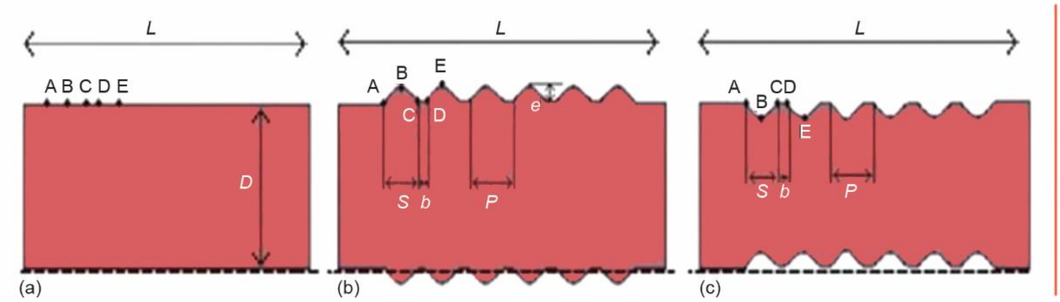

Figure 1. Schematic illustration of tubes; (a) smooth tube, (b) convex corrugated tube, (c) concave corrugated tube

Table 1. Geometry of tubes

Tubes	S [mm]	P [mm]	e [mm]	L [mm]	D_{ave} [mm]
Inner tube: smooth	–	–	–	346	85
Outer tube: smooth	–	–	–	346	106
Inner tube: convex	13.52	16.52	4	346	89
Outer tube: convex	13.52	16.52	4	346	110
Inner tube: concave	13.52	16.52	4	346	81
Outer tube: concave	13.52	16.52	4	346	102

Following figures show some of the design of the different arrangements of corrugated tubes with and without honeycomb arrangement modeled by using CATIA V5 software.

Figure 2. Both tubes are smooth

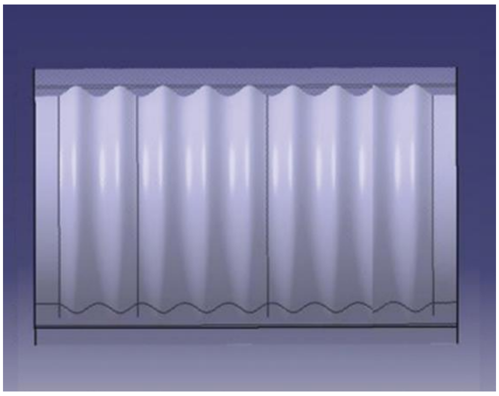

Figure 3. Inner tube is convex, outer tube is smooth

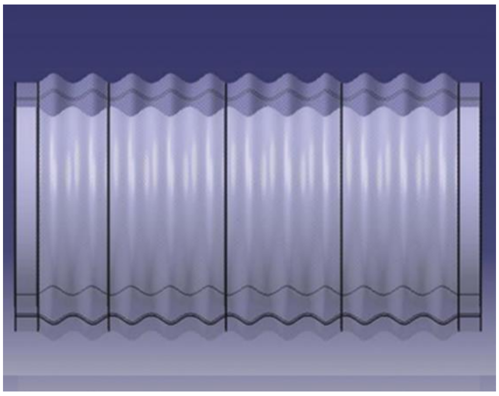

Figure 4. Outer tube is convex, inner tube is concave

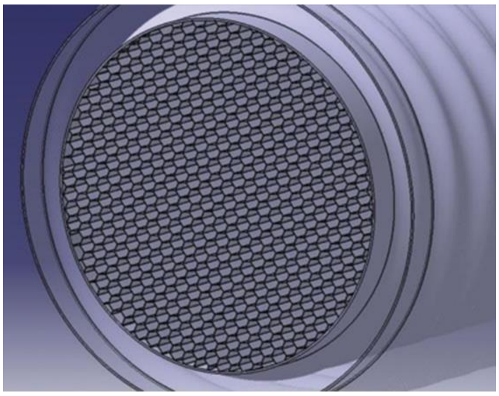

Figure 5. Inner tube filled with honeycomb arrangement

Analysis detail and method

For analysis method the FLUENT software was used. In my tasks the boundary condition are hot water (inner tube) and cold water (outer tube) inlet temperatures were maintained at 40 °C and 8 °C, respectively. The volume flow rate of inward tube (high temperature water) and external tube (cool water) volume flow rate was kept at 15 L per minute and 20 L per minute. The material used is aluminum of both tubes with a thickness of 1 mm. The honeycomb material is taken as a stainless steel and analyzed by using the option named porous zone with a porosity of 0.8 in these software. The outlet temperature of hot and cold water of the tubes are calculated by using FLUENT software. Figure 6 shows that the temperature variation of the tubes by FLUENT software.

Result and discussion

By using the FLUENT software, the outlet temperature of inner tube and outer tube are obtained. By having that temperature all other parameters are easily found.

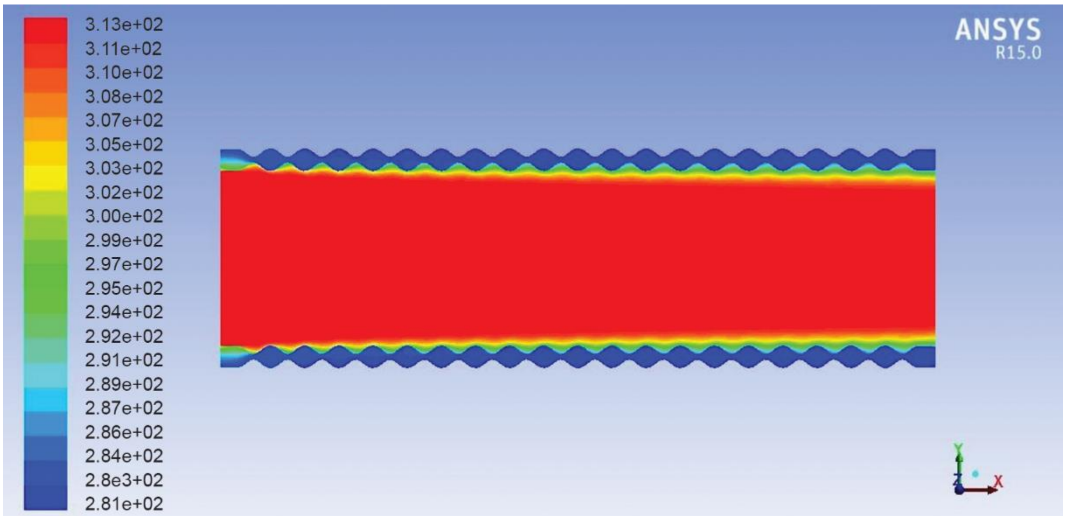

Figure 6. Temperature variation of tubes (*for color image see journal web site*)

Heat transfer rate

Figure 7 shows heat transfer rate with and without honeycomb arrangement at new arrangements of corrugated tubes. It is concluded that the Q can be increased using honeycomb arrangement. The arrangements such as inner tube convex, outer tube concave can have high heat transfer rate. Figure 8 shows NTU with and without honeycomb arrangement at new arrangements of corrugated tubes. It is concluded that the NTU can be increased using honeycomb arrangement. The arrangements such as inner tube convex, outer tube concave can have high number of transfer units. Figure 9 shows effectiveness with and without honeycomb arrangement at new arrangements of corrugated tubes. It is concluded that the effectiveness can be increased using honeycomb arrangement. The arrangements such as inner tube convex, outer tube concave can have high effectiveness.

Figure 10 shows velocity with and without honeycomb arrangement at new arrangements of corrugated tubes. It is concluded that the velocity can be decreased using honeycomb arrangements but it can be give a better efficiency and Reynolds number also decreeased and its became a laminar flow. Figure 11 shows velocity with and without honeycomb arrangements at new arrangements of corrugated tubes. It is concluded that the velocity is

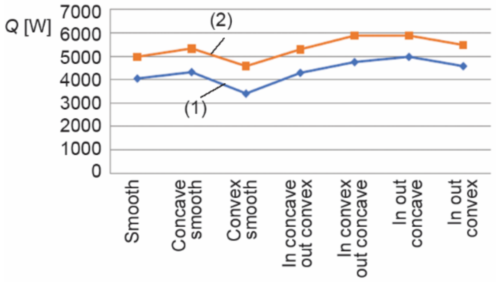

Figure 7. The *Q* [W]) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

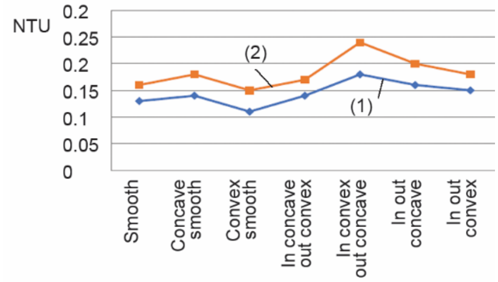

Figure 8. The NTU *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

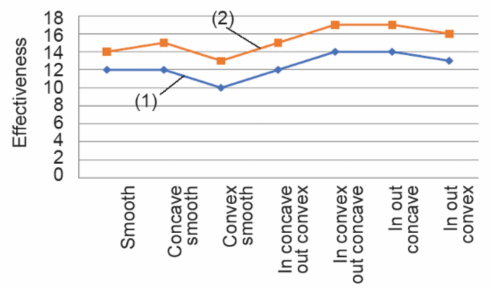

Figure 9. Effectiveness *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

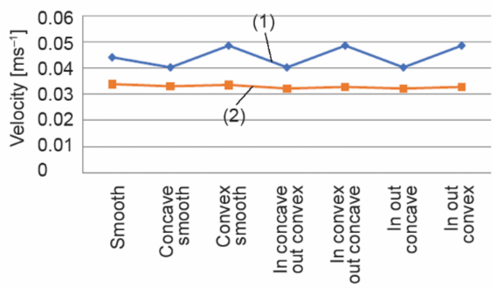

Figure 10. Velocity (hot side) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

constant using honeycomb arrangements or without honeycomb arrangements because honeycomb arrangements are placed only inside the inner tube of all cases. So, outer tube flow is not disturbed and its remains constant. Figure 12 shows Reynolds number with and without honeycomb arrangements at new arrangements of corrugated tubes. It is concluded that the Reynolds number is decreased using honeycomb arrangements because velocity is decreased so the Reynolds number is also decreased.

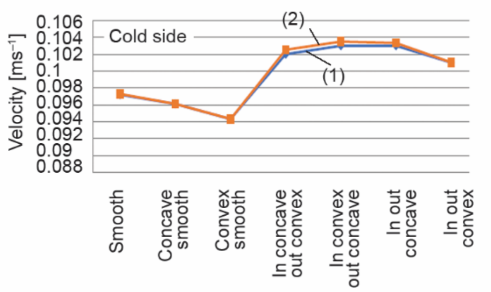

Figure 11. Velocity (cold side) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

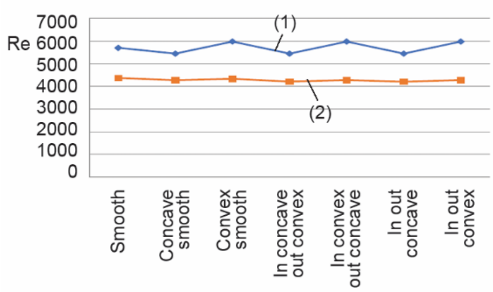

Figure 12. Reynolds number (hot side) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

Figure 13 shows Reynolds number with and without honeycomb arrangement at new arrangements of corrugated tubes. It is concluded that the velocity is constant using honeycomb arrangements or without honeycomb arrangements because honeycomb arrangements are placed only inside the inner tube of all cases. So, outer tube flow is not disturbed and its remains constant. Figure 14 shows Nusselt number with and without honeycomb arrangement at new arrangements of corrugated tubes. It is concluded that Nusselt number is decreased in hot side using honeycomb arrangement. In cold side Nusselt number is constant because honeycomb arrangements are placed only inside the inner tube of all cases. So, outer tube flow is not disturbed and its remains constant.

Figure 15 shows heat transfer coefficient with and without honeycomb arrangement at new arrangements of corrugated tubes. It is concluded that the heat transfer coefficient can be decreased using honeycomb arrangements because Reynolds number also decreased therefore Nusselt number is also decreased. Figure 16 shows friction factor with and without hon-

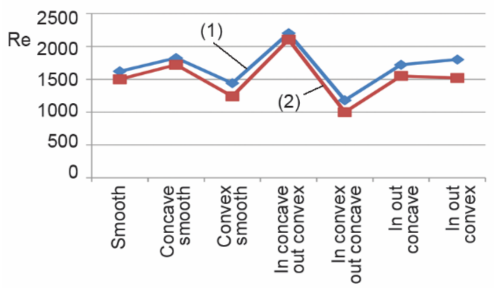

Figure 13. Reynolds number (cold side) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

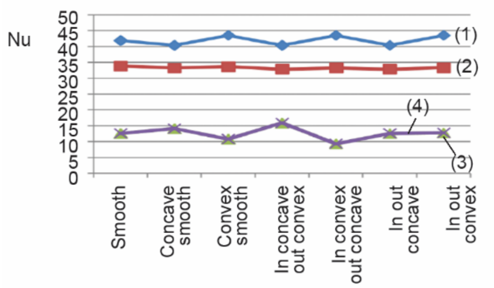

Figure 14. Nusselt number (hot and cold sides) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement (hot side), 2 – with honeycomb arrangement (hot side), 3 – without honeycomb arrangement (cold side), 4 – with honeycomb arrangement (cold side)*

eycomb arrangement at new arrangements of corrugated tubes. It is concluded that the friction factor can be increased using honeycomb arrangement in hot side. Because inner side of the tube is filled with honeycomb arrangement so that velocity can be decreased and pressure increases. Figure 17 shows pressure drop with and without honeycomb arrangement at new arrangements of corrugated tubes. It is concluded that the pressure drop can be increased using honeycomb arrangement in hot side. Because inner side of the tube is filled with honeycomb arrangement so that velocity can be decreased and pressure increases.

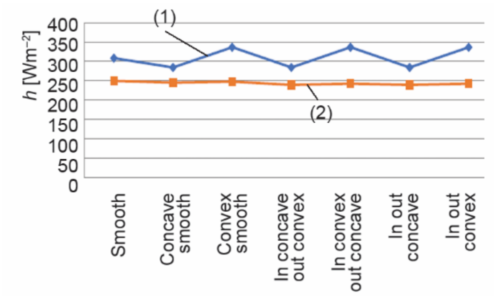

Figure 15. Heat transfer coefficient (hot side) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

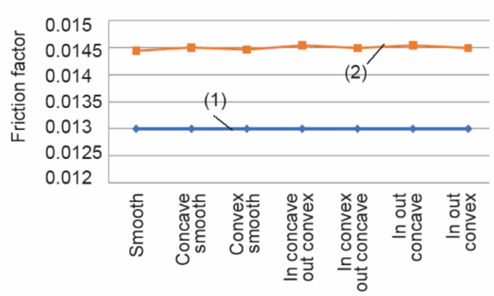

Figure 16. Friction factor (hot side) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

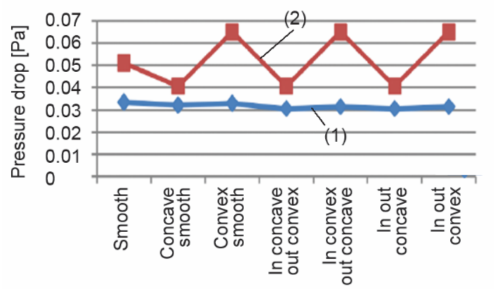

Figure 17. Pressure drop (hot side) *vs.* new arrangement of corrugated tubes; *1 – without honeycomb arrangement, 2 – with honeycomb arrangement*

Conclusions

Heat transfer enhancement in a double-pipe heat exchanger made of corrugated outer and inner tube was reported in this paper. The fundamental extent of the present study was to compare a double-pipe heat exchanger of a new arrangement of corrugated tubes with and without honeycomb arrangements. The result of these study were performed as Nusselt number, Reynolds number, effectiveness and friction factor. It is evident that the velocity has increased in the hot side of the heat exchanger when honeycomb arrangement was installed. A decrease in Reynolds number of about 1000 times was seen in the heat exchanger with honeycomb arrangement when compared to the other set-up without honeycomb arrangement, making the flow laminar. The effectiveness of the heat exchanger can be increased for about 3% to 4%. It is concluded that the proposed arrangements can be more efficient than the later.

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