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Heat Transfer Performance and Friction Loss of a Concentric Tube Heat Exchanger Using Dimple Tube, Wired Coil and Rings

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Abstract

This study focuses on the enhancement of heat transfer performance and friction loss in concentric tube heat exchangers. The flow in a circular tube annulus is disturbed by employing three techniques: dimple surface, wired coil and ring. The flow directions have been arranged in counter flow and the water flow rate of the annulus tube varies from 16.-4.8 L/min. Reynolds number of water flowing through the outer tube is varied from 900 to 3,000. Dimple arrangement on the tube surface are primarily investigated by using a numerical modeling to determine the most suitable patterns. The achieved dimple arrangements, wired coil and ring are employed in the concentric tube heat exchangers. Water flow rate, water temperature and pressure at the inlet and outlet of both hot and cold water circuits were measured. The heat transfer performance and friction factor of each techniques were investigated to compare with a smooth tube. The experimental results revealed that the dimple tube, wired coil and ring techniques provide better performances consequently comparing to the smooth tube. Nusselt number ratio of dimple tubes for both inline and staggered arrangement increase about 1.05-1.64 times the value on smooth tube, rings techniques shows the Nusselt number ratio increasing about 2.78-3.44 times, while the wired coil technique reveals the increasing ratio of about 3.72-4.82 times compare to the smooth tube. The friction factor of both dimple arrangements show a lower value than that of the smooth tube about 0.73-1.0 times. Considering rings technique, the friction factor increases about 3.78-4.76 times whereas the wired coil gives quite high number at 56.2-64.9 times. Regarding the effectiveness, ring technique yields a higher friction factor than other techniques at similar Reynolds number.

***Keywords**:* Concentric tube heat exchanger, dimpled tube, wired coil tube, periodic ring tube.

1. Introduction

Heat exchanger is a crucial element and used in many engineering applications. The heat exchange process occurs between two fluids with different temperature and separated by a solid wall. The concentric tube is a simple heat exchanger which the hot and cold fluids move in the same or opposite directions. There are many heat transfer enhancement techniques. The conventional methods such as fins, baffles, turbulizers and etc., increase either the heat exchange surface area or create turbulence flow or both. Although these techniques result in the heat transfer improvement, pressure loss is also an inevitable effect. Another approach to modify the heat transfer area, dimple surface is a notable technique to augment the heat transfer rate without the significant pressure drops.

Recently, many researchers reported the benefits of dimples or concave surfaces on heat transfer performance. Chudnovsky and Kozlov [1] and Afansayev et al. [2] stated that the dimples surface increased the heat transfer rate of around 30-40% without the significant pressure losses. Chyu et al. [3] and Mahmood et al. [4] revealed vortex flow above the dimpled flat surface which leading to the heat transfer augmentation. The dimple generates vortex flow within its hole and Katkhaw et al. [5] studied the effects of dimple arrangement surfaces on heat transfer characteristic. They showed that the highest heat transfer rate can be achieved on an appropriate staggered arrangement.

Concentric tube heat exchanger is used in a wide range of engineering applications. There are several techniques to augment the heat transfer such as internal corrugated tube, inserted strip, finned double pipe and etc. Han et al. [6] presented the novel shape of corrugated pipe that exhibited 8-18% overall heat transfer coefficient higher than the conventional smooth pipe. Iqbal et al. [7] and Cavazzuti et al. [8] investigated the optimal fin shape in finned double pipe. They reported that the optimal shape yields the higher Nusselt number up to 59-312%. Pholboorn [9] revealed the heat transfer performance enhancement in circular tube using wired coils, turbulators and ring. The results showed that the conical cut-out turbulators with internal fins provided the maximum heat transfer performance of 2.4 times of that without fins. Sripa and Thianpong [10] investigated the effect of heat transfer rates and friction loss of a counter flow concentric tube heat exchanger. They reported that the heat transfer rate can be increased by using internal dimpled tube. However, the dimples caused the increase in frictions loss. Wang et al. [11] examined the influence of the tube with novel ellipsoidal dimples on heat transfer enhancement. The results indicated that the Nusselt number and friction factor of dimpled tube increased around 38.6–175.1% and 26.9–75%, respectively.

TSF0012

Nomenclature

A	heat transfer surface area, m^2
Cp	specific heat of the fluid, J/kg·K
D	diameter of outer tube, m
d	diameter of inner tube, m
eff	effectiveness
f	friction factor
h	heat transfer coefficient, W/m^2·K
k	thermal conductivity, W/m^2·K
L	length of concentric tube, m
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number
Pr	Prandtl number
Q	heat transfer rate, W
Re	Reynolds number
T	temperature, K
u	fluid mean velocity, m/s
U	overall heat transfer coefficient, W/m^2·K
ΔT_{LM}	logarithmic mean temperature difference, K
ΔP	pressure drop, Pa

Greek symbols

ν	kinematic viscosity, m^2/s
ρ	fluid density, kg/m^3

Subscripts

0	smoot tube
a	augmented technique
avg	average
c	cold water
Dh	hydraulic diameter
di	inside diameter
h	hot water
i	inside
o	outside

According to the literatures, the results indicated the superior performance of dimple surface and dimple tube. However, they only studied the enhanced heat transfer for internal flow of inner tube. The heat transfer enhancement techniques in the outer flow has not been reported yet. In some application such as waste heat recovery system and recuperator, the internal surface of the inner tube cannot be modified. Heat transfer enhancement on the external surface is an option. Therefore, the objective of this study is to find the heat transfer enhancement techniques for annulus flow tube by employing dimple tube, wired coil and rings.

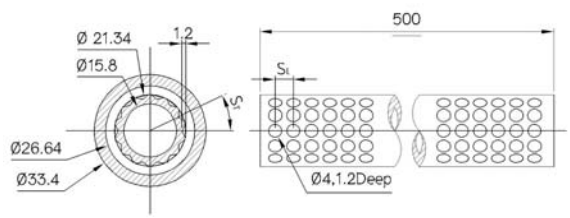
2. Experimental Preparation

2.1 Primary simulation

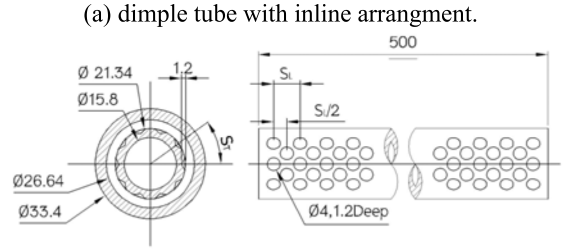
The dimple arrangement on the tube surface was initially study by numerical simulation. The stagger and inline patterns and dimple pitch are simulated to find the superior enhanced heat transfer. Fig. 1 shows the tube with dimple employed. The problem under consideration is the heat transfer of water flow in tube annulus. Conditions for the simulation are as following;

- Flow rate through the annulus is kept constant at 3 L/min.
- Water inlet temperature is 350 K and the outer surface of the inner tube is 300 K.
- The heat exchanger is fully insulated.
- The water flow rate is assumed to be steady in three-dimensional domain.

Dimples are employed in an inline and staggered array where the dimple depth is 1.2 mm and dimple pitch is varied as shown in table 1.



(a) dimple tube with inline arrangment.



(b) dimple tube with staggered arrangment.

Fig. 1 Details of dimple tube. All dimensions are in mm.

Table. 1 Geometric dimension of dimple arrangement

No	Arrangement	S_T (mm)	S_L (mm)
1	Staggered	36°	8
2	Staggered	36°	12
3	Staggered	36°	16
4	Inline	26°	5
5	Inline	26°	7
6	Inline	26°	9

The *k*-ε model is applied as the turbulence model for all numerical predictions. Fig. 2 shows sectional view of the computational domain. The smoot tube is firstly simulated to find the Nusselt number (Nu_0) of the annulus flow for validating the model. According to the numerical results, the deviation of the Nusselt number is about 13% compare with Kay and Perkins [12].

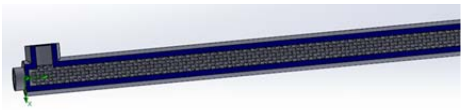


Fig. 2 Computational domain of a dimple

As the simulation completed, the hea coefficients of annulus flow are obtained. transfer coefficients ratio is accomplished as in table 2.

Table. 2 Heat transfer coefficient ratio of th flow for each test samples.

No	Arrangement	S_L (mm)	h_a/h_0
1	Staggered	8	1.94
2	Staggered	12	1.45
3	Staggered	16	1.21
4	Inline	5	2.05
5	Inline	7	1.74
6	Inline	9	1.23

From table 2, the heat transfer coefficients ratio decrease as the S_L increase. As the enhanced heat transfer of the staggered and inline arrangement is comparable, the dimples on inner tube are created according to both geometries.

2.2 Experimental setup

Schematic diagram of the experimental apparatus is presented in Fig. 3. The flow of fluid consists of two circuits, hot and cold, separately. Cold water flows through the annulus tube and drain to a reservoir. Hot water is pumped through the inner tube in a closed loop. A hot water bath is installed in the loop to heat water. Hot water temperature is maintained at 80ºC by means of electronic thermostat. The outer tube is insulated by closed cell insulation in order to minimize the heat loss.

The inlet and outlet temperature of the hot and cold water are measured by type T thermocouples. All of thermocouples have been calibrated to ±0.5ºC. Water flow rate of both stream are measured by rotameter with a precision of ±0.32 L/min. The U-type manometer with ±5 Pa accuracy is also used to measure pressure different between water inlet and outlet across the test section. The conditions for this experiment are as the followings;

- Hot water flow rate at the inner tube is kept constant at a constant flow rate of 3 L/min.
- Cold water flow rate in the annulus tube side rage from 1.6-4.8 L/min.
- Hot water inlet is kept constant at 80 ºC.

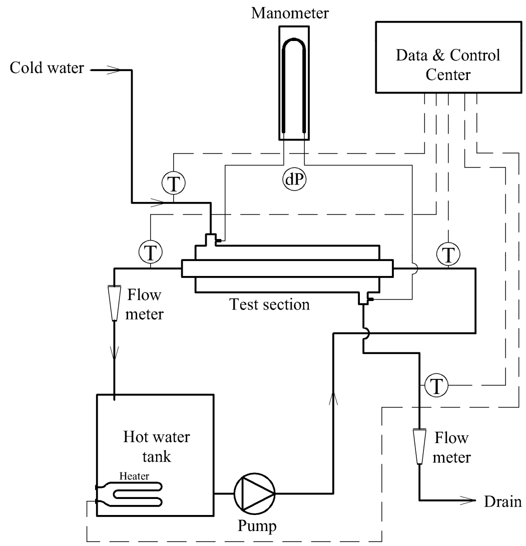
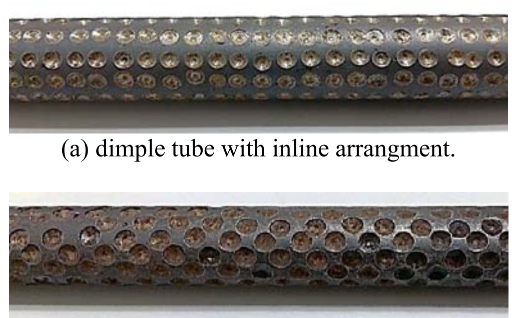


Fig. 3 Schematic diagram of the experimental setup.

2.3 Experimental tube

In the tested section, the flow in the annulus tube is disturbed by four configurations: staggered-dimple tube, inline-dimple tube, wired coil and rings. The concentric tube is made from steel pipe with nominal diameter of inner tube and outer tube at 1/2 inch and 1 inch, respectively. The inner tube thickness is 2.8 mm and the concentric tube length is 1000 mm.

Fig. 4 illustrates dimples on the inner tube. The arrangement of the inline and staggered dimples has been made according to the previous simulation. The dimples are created by drilling with 1.2 mm deep and 4 mm diameter.

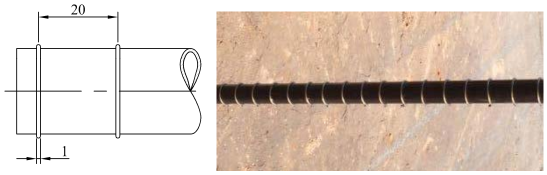


(a) dimple tube with inline arrangment.

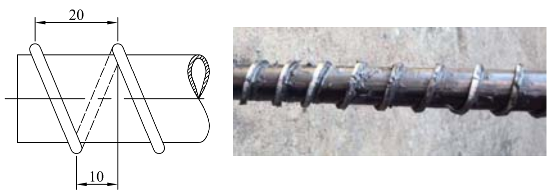
(b) dimple tube with stagger arrangment.

Fig. 4 Photograph of the dimple tubes.

Regarding Pholboorn's study [9], the superior enhanced results of heat transfer performance by using rings and wired coil for flow inside tube was reported. The results show that 1 mm-pitch of wired coil provided the best heat transfer performance. For initially experiment, those techniques were employed in the annulus tube to study the enhanced heat transfer performance. Fig. 5 presents the rings and wired coil winding around the inner tube. Wire diameter in Fig. 5(a) is 1 mm and the ring pitch is 20 mm. The ring height is about one-third of the channel height. In Fig. 5(b), the diameter of wire is 2.6 mm and the coil pitch is 20 mm. The wire height is equal to the channel height.



(a) inner tube with rings.



(b) inner tube with wired coil.
Fig. 5 Details of experimental tube with rings and wired coil. All dimensions are in mm.

3. Data reduction

During the experiment, water temperature, water flow rate and pressure drop are measured after the system reaches a stable condition. At all operating conditions, the difference of the heat transfer rate between the hot and cold water stream are within 10%.

$$\frac{|Q_h - Q_c|}{Q_h} \leq 10\% \qquad (1)$$

where Q_h and Q_c are heat transfer rates of the hot and cold water side, respectively. The heat transfer rate can be calculated by

$$Q_h = \dot{m}_h Cp_h (T_{h,out} - T_{h,in}) \qquad (2)$$

$$Q_c = \dot{m}_c Cp_c (T_{c,out} - T_{c,in}) \qquad (3)$$

The average heat transfer rate is the mathematical average of the hot and cold water side which expressed as

$$Q_{avg} = \frac{(Q_h + Q_c)}{2} \qquad (4)$$

The average heat transfer coefficient for the inside of inner tube are achieved by

$$h_i = \frac{Nu_{di} k}{d_i} \qquad (5)$$

In the investigation, the hot water flow rate is kept constant at 3.0 L/min while the cold water flow rate is varied from 1.6- 4.8 L/min. The Reynolds number of fluid can be calculated by

$$Re_{di} = \frac{u_i d_i}{\nu} \qquad (6)$$

$$Re_{Dh,c} = \frac{u_o (D_i - d_o)}{\nu} \qquad (7)$$

where Re_{di} and $Re_{Dh,o}$ are the Reynolds number of hot and cold water side respectively. Parameter d_i is inside diameter of the inner tube, D_i is inside diameter of the outer tube, and d_o is outside diameter of the inner tube.

For turbulence flow of the inner tube with $10^4 < Re_d < 10^6$, the Nusselt number is defined as

$$Nu_{di} = 0.23\, Re_{di}^{0.8}\, Pr^{0.3} \qquad (8)$$

The average heat transfer coefficient of the annulus flow is calculated from the heat transfer resistance analysis as follow:

$$U = \frac{1}{h_i} + A_i \frac{\ln(d_o / d_i)}{2\pi k L} + \frac{A_i}{A_o}\frac{1}{h_o} \qquad (9)$$

where U is an overall heat transfer coefficient which is obtained by Newton's law of cooling as shown below

$$U = \frac{Q_{avg}}{A \Delta T_{LM}} \qquad (10)$$

The Nusselt number of the annulus flow can be obtained as

$$Nu_{Dh,c} = \frac{h_o (D_i - d_o)}{k} \qquad (11)$$

Once the pressure drop between the inlet and outlet of the cold water circuit is obtained, friction factor is calculated by

$$f = \frac{\Delta P}{\dfrac{L}{(D_i\text{-}d_o)}\dfrac{\rho u_o^2}{2}} \qquad (12)$$

In order to compare the integrated performance of each techniques, the effectiveness is defined by

$$eff = \left(\frac{Nu_a}{Nu_0}\right)\left(\frac{f_a}{f_0}\right)^{-1/3} \qquad (13)$$

4. Results and discussions

4.1 Heat transfer

In this section, heat transfer performance of the smooth tube and the modified tube with dimples, ring and wired coil are presented. Reynolds number of the annulus flow varies from 900 to 3,000. The heat transfer performance is represented in term of Nusselt number ratio ($Nu_{Dh,c}/Nu_0$). According to the experimental results, the value of $Nu_{Dh,c}/Nu_0$ for all cases as shown in Fig. 5 are higher than 1.0. This can be interpreted that the heat transfer performance on the modified tubes is significantly higher than those of the smoot tube.

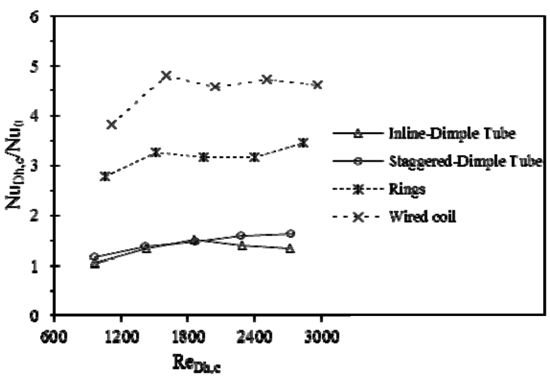


Fig. 5 Nusselt number of enhance $Nu_{Dh,c}/Nu_0$ vs. Reynolds number

The $Nu_{Dh,c}/Nu_0$ for both arrangments of the dimple tubes are obviously closed to each other with the variation between 1.05-1.64. The$Nu_{Dh,c}/Nu_0$ value of the staggered-dimple tube increases with the increase of $Re_{Dh,c}$. However, $Nu_{Dh,c}/Nu_0$ of the inline-dimple tube shows the increasing trend until reaching the $Re_{Dh,c}$ value of around 1400, then the slightly drop of $Nu_{Dh,c}/Nu_0$ occures for the higher $Re_{Dh,c}$. The reason for this phenomenon can be described as a result of vortex flow generated by the inline dimple arrangement. Normally the vortex will also spread out to the downstream and lateral area of the dimple which can augment the heat transfer on these area. However, at the higher Reynolds number, the vortex flow will be accelerated to appear only on downstream of the dimple. Hence, the average the heat transfer rate of the inline arrangement decreases as increase the Reynolds number.

According to Fig. 5, $Nu_{Dh,c}/Nu_0$ for the tube with wired coil and rings exhibits the higher value comparing to the tube with dimples. It can be clearly seen that $Nu_{Dh,c}/Nu_0$ value gradually increases until reaching the value of $Re_{Dh,c}$ around 1400, then the curves seem to remain constant. Generally, the tube with wired coil and ring provide the $Nu_{Dh,c}/Nu_0$ value of about 3.72-4.82 and 2.78-3.44 respectively.

Regarding the experimental results as shown in Fig. 5, the wired coil that attached on the external surface of the inner tube protrude into flow stream and makes the turbulence of fluid flow. The turbulence causing by the wired coil is stronger than that by the dimples on the tube surface. As a results, the enhancement of $Nu_{Dh,c}/Nu_0$ on the wired coil tube is noticebly higher than that on the dimple tube. Considering the heat transfer performance on the tube with rings on circumference of the inner tube, the strength of turbulence due to the disturbance from the rings is higher than that from the dimples but lower than that from the wired coil. Thus, $Nu_{Dh,c}/Nu_0$ value for the tube with rings is situated between the $Nu_{Dh,c}/Nu_0$ values of wired coil tube and dimple tube.

4.2 Pressure drop

Fig.6 shows the relationship between friction factor ratio ($f_{Dh,c}/f_0$) and Reynolds number. The friction factor ratio of the inline- dimple tube and staggered-dimple tube is generally about 0.73-0.84 and 0.83-1.1, respectively. It is very interesting that the friction factor on the dimple tubes of both arrangements is considerably lower than that on the smooth tube. It is possibly that the the dimples do not protrude into the flow which also decrease the skin friction drag on the tube surface.

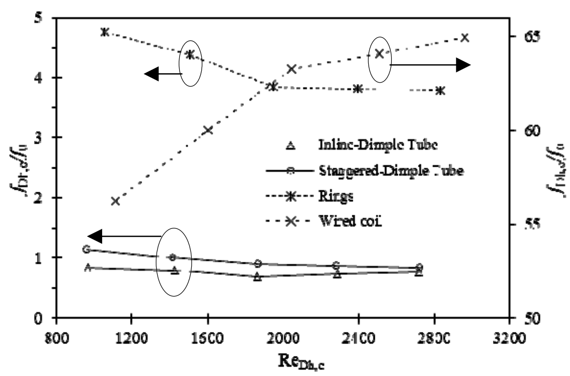


Fig. 6 Friction factor increase $f_{Dh,c}/f_0$ vs. Reynolds number

In case of the tubes with rings and wired coil, since these structures definitely disturb the flow of fluid , the friction factors extremely higher than that of the smooth tube about 3.78-4.76 and 56.2-64.9, respectively.

4.3 Effectiveness

In this section the integrated performances which represented in term of effectiveness for each technique is revealed in Fig. 7. From the results, all techniques provide better performance comparing to smooth tube which indicated by the value of effectiveness higher than 1.0 in all range of tested Reynolds number. The effectiveness of the staggered-dimple tube and rings significantly increase as the Reynolds number increase. For the inline-dimple tube and wired coil, the effectiveness significantly increase with the Reynolds number for the Reynolds number of less than 1800 and gradually decrease for the higher Reynold number. It is clearly seen that the tube with rings provides the best performance with the effectiveness ranges from 1.61 to 2.21.

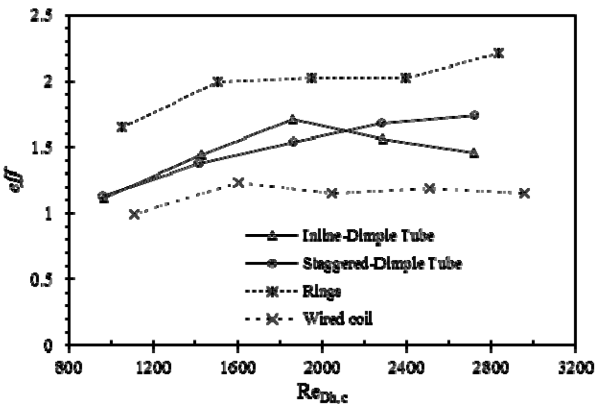


Fig. 7 Effectiveness (*eff*) vs. Reynolds number

5. Conclusions

This experimental study reports the heat transfer performance by using dimple tube, wired coil and rings in a circular tube annulus of concentric tube heat exchanger. The conclusions are given as following;

(1) Dimple tube, wired coil and rings show the better performances. Nusselt number of both dimple tubes were achieved at about 1.05-1.64 times of the smooth tube while rings technique shows the values to increase about 2.78-3.44 times, and wired coil technique shows the values to increase about 3.72-4.82 times compare to smoot tube.

(2) The friction factor of both dimple tube is lower than that the smoot tube about 0.73-1.0 times. Rings technique shows the friction factor to increase by 3.78-4.76 times and and 56.2-64.9 times for wired coil technique when compare to smoot tube.

(3) Although dimple tubes show the trend of decreasing pressure drop, the enhancement of heat transfer presents greatly lower than ring technique, so the ring technique yields a higher heat transfer performance than that of the dimple tubes at identical Reynolds number.

In addition, although wired coil technique has the extremely pressure drop, its enhanced heat transfer is greatly higher than other techniques. It can be used on some applications which require more heat transfer while disregard the pressure penalty.

6. Recommendation

From this study, the ring and wired coil techniques yield the superior heat transfer, but the ring and wired coil pattern has not study. The rings height, rings pitch and wired coiled pitch may have the influents with heat transfer performance, it should be the issues for further studied.

References

[1] Chudnovsky, Y. and Kozlov, A. (2006). Development and field trial of dimpled-tube technology for chemical Industry process heaters, Final report, Industrial Technology Program, U.S. Department of Energy.

[2] Afanasyev, Y.N., Chudnovsky, Y.P., Leontiev, A.I. and Roganov, P.S. (1993). Turbulent flow friction and heat transfer characteristics for spherical cavities on a flat plate, *Experimental Thermal and Fluid Science*, vol.7(1), July 1993, pp. 1 - 8.

[3] Chyu, M.K., Yu, Y., Ding, H., Downs, J.P. and Soechting, F.O. (1997). Concavity enhanced heat transfer in an internal cooling passage, paper presented in the *ASME 1997 International Gas Turbine and Aeroengine Congress and Exhibition*, Orlando, Florida, USA.

[4] Mahmood, G.I., Hill, M.L., Nelson, D.L., Ligrani, P.M., Moon, H.K. and Glezer, B. (2000). Local heat transfer and flow structure on and above a dimpled surface in a channel, *Journal of Turbomachinery*, vol.123(1), February 2000, pp. 115 - 123.

[5] Katkhaw, N., Vorayos, N., Kiatsiriroat, T., Khunatorn, Y., Bunturat, D. and Nuntaphan, A. (2014). Heat transfer behavior of flat plate having 45° ellipsoidal dimpled surfaces, *Case Studies in Thermal Engineering*, Vol.2, March 2014, pp 67 – 74.

[6] Han. H., Li, B., Yu, B., He, Y. and Li, F. (2012). Numerical study of flow and heat transfer characteristics in outward convex corrugated tubes, *International Journal of Heat and Mass Transfer*, vol.55, September 2012, pp. 7782 – 7802.

[7] Iqbal, Z., Syed, K.S. and Ishaq, M. (2013). Optimal fin shape in finned double pipe with fully developed laminar flow, *Applied Thermal Engineering*, vol.51, November 2012, pp. 1202 - 1223.

[8] Cavazzuti, M., Agnani, E. and Corticelli, M.A. (2015). Optimization of a finned concentric pipes heat exchanger for industrial recuperative burners, *Applied Thermal Engineering*, vol.84, April 2015, pp. 110 – 117.

[9] Pholboorn, S. (2015). A Review Study on Heat Transfer Performance Enhancement in a Circular Tube Using Wire Coils and Rings, *The Journal of Industrial Technology*, vol. 11(1), April 2015, pp. 88 – 102.

[10] Sripa, Y. and Thainpong, C. (2008). Experimental inveatigation of heat transfer and friction loss in a concentric double pipe heat exchanger with dimpled inner tubes. paper presented in *The 9th TSAE National Conference*, Thailand.

[11] Wang, Y., He, Y.L., Lei, Y.G. and Zhang, J. (2010) .Heat transfer and hydrodynamics analysis of a novel dimpled tube, *Experimental Thermal and Fluid Science*, vol.34(8), May 2010, pp. 1273 - 1281.

[12] Kays, W.M. and Perkins, H.C. (1972). Handbook of heat transfer, McGraw-Hill, New York.