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Research Article

Heat Transfer Enhancement in Shell and Tube Condenser

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Abstract

To increase the efficiency of the heat exchanger, the heat transfer enhancement techniques are utilized. This can be achieved once the heat transfer power of a given device is magnified or once the pressure losses generated by the device are reduced. Heat transfer enhancement is require to achieve a high heat transfer rate using minimum pumping power, to make the equipment compact, to minimize cost of energy and material, to get high heat transfer effectiveness, to increase efficiency etc. Condensers are primarily heat exchangers within which the refrigerant undergoes a phase transition which have various designs and come in many sizes. Shell and tube condenser is the most common type of condenser used in systems from 2 TR up to thousands of TR capacity. The Condensation of steam on single horizontal copper tube in a shell and tube condenser has been investigated using experimental and theoretical ways during this study. The outer surface of the tube was changed by brazing it with a copper wire lengthwise and helically to enhance the heat transfer constant. The result of varied the pitch of the helically brazed wire was studied with twenty five millimeter and thirty five millimeter pitch. Lengthwise Wire Brazed (LOWIB) and Helically Wire Brazed (HEWIB) Copper tubes with pitch twenty five millimeter and thirty five millimeter were found to extend the heat transfer constant by an element of about 1.5, 2 and 1.2 severally.

Keywords: *Condensation, Enhancement of heat transfer constant, wire wrapped tube.*

1. Introduction

There has always been a challenge for researchers for achieving significant improvement in heat transfer coefficient by means of less complex, easily manufacture able and economical solutions in the field of condensation.

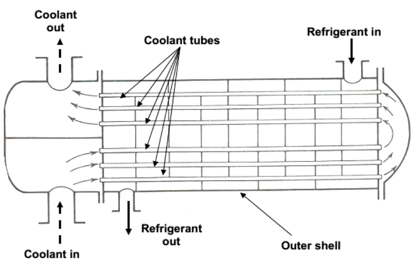

Fig. 1. Schematic Diagram of a two-pass, Shell and Tube type condenser.

Thus, continuous efforts are being made by many researchers to understand the variations in the condensation behavior in detail and reduce the resistances to the heat flow i.e. to improve the wall heat transfer coefficient of the condenser by making appropriate surface modifications according to wide variety of industrial applications such as automobiles, power plants, desalination plants and refrigerators.

Shell-and-tube type is the most typical form of condenser utilized in systems from two TR up to thousands of TR capacity. In these condensers the refrigerant flows through the shell whereas water flows through the tubes in single to four passes. During this paper heat transfer characteristics of horizontal wire wrapped tubes with diameter > 19mm, wire diameter of 3mm and pitch > 10mm were studied.

2. Literature review

Domingo studied the condensation of refrigerant R-11 on several fluted, spiraled, roped and corrugated external surfaces and also in some cases internal surfaces of vertical tubes in comparison with smooth tube and found that flutes on external surface of tube increases the heat transfer coefficient by 5.5 times for a given heat flux and flutes on either sides of the tube render an additional 17% increase in heat transfer coefficient for a given overall temperature difference and water rate.

G. D. Gosavi *et al.* they experimentally investigated that, as far as the review is concerned, fins are the method of enhancing heat transfer. The perforated fin may dissipate about 50 to 60 % more heat. Heat transfer becomes more uniform by applying the

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perforations. The fin efficiency of perforated fin is greater than the solid fin. The perforated materials can have better strength.

Ravi Kumar et al. investigated steam condensation over circular and spine integral fin tubes in comparison to plain tube and found that circular and spine integral fin tubes enhance heat transfer coefficient by 2.5 and 3.2 times respectively.

Takahiro Murase et al. studied the condensation of steam, R113 and ethylene glycol on a horizontal wire-wrapped tube and found that the enhancement ratios exceeding by 3 for R113 and 2 for steam and glycol.

Thomas et al. studied the impact of rectangular fins on external surface and detached promoter, twisted tape and fins within a vertical aluminum tube on heat transfer and witnessed a rise in heat transfer constant by 2.5 to 4 times in case of fins on external surface and twisted tape within the tube.

N. C. Kanojiya et al. [6] studied that, various ways of enhance the heat flow rate by passive method by using various types of inserts. In perforated twisted tape inserts, heat transfer rate increases. In a perforated twisted tape, the friction factor increases in the laminar region. They concluded that the twisted tape perform better in case of laminar flow than turbulent flow.

Prabhakar Ray et al.conclude that; wire coiled tube will increase the pressure drop as compare to an empty tube. Inside the transition region, if wire coils are fitted within a smooth tube heat exchanger, heat transfer rate is magnified up to 200% keeping pumping power constant. In turbulent flow, wire coils cause a high pressure drop increase that depends mainly on pitch to wire diameter ratio p/e. within the choice of the wire coil inserts, the form of the insert is very important.

3. Study of different methods of heat transfer enhancement

Different enhancements techniques have been broadly classified as passive, active and compound techniques.

3.1 Active method

This requires external power as input for heat transfer enhancement.

3.2 Passive Method

This technique doesn't want any external power as input. Within the convective heat transfer one among the ways in which to enhance heat transfer rate is to extend the effective surface area and residence time of the heat transfer.

3.2.1 Treated Surfaces

This technique involves using pits, cavities or scratches. They're primarily used for boiling and condensation duties. It consists of a range of structured surfaces (continuous or discontinuous) and coatings.

3.2.2 Inserts

Inserts needs further arrangements to create to fluid flow that enhance the heat transfer. The different types of inserts are: plates, wire coiled twisted tape, ribs, baffles, helical screw insert, mesh inserts, convergent – divergent conical rings, conical rings etc.

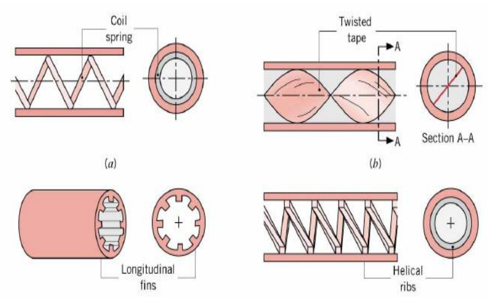

Fig.1. Tubes inserted with twisted tape and coiled tubes

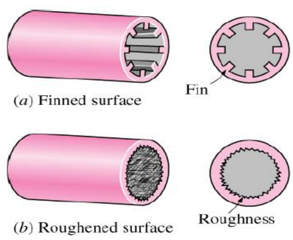

Fig.2. Tube with internal Fins and roughened surface

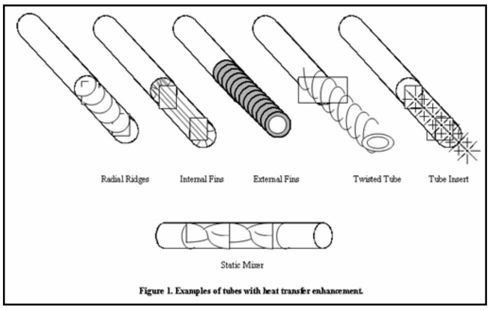

Fig.3. Example of tube with heat transfer enhancement

(a)Twisted Tape

Twisted tapes are the metallic strips twisted that are inserted within the flow. It will increase heat transfer rates with less friction factor. These varieties of tapes induce turbulence and swirl flow which supplies higher results of heat transfer coefficient and Nusselt number because of the changes in geometry of twisted tape inserts. At the same time, the pressure drop within the tube is going to be will increase once using twisted-tape as an insert. The heat transfer improvement of twisted tapes inserts depends on the Pitch and Twist ratio.

Fig.4. Twisted Tape

(b) Wire Coil

1) Simple installation and removal.
2) Easy producing method with low price.
3) Preservation of original plain tube from mechanical strength.
4) Chance of installation in associate existing smooth tube heat exchanger (retrofit).
5) Fouling mitigation (in refineries, chemical industries and marine applications).

3.2.3. Extended Surfaces

Whenever the offered surface is found in adequate to transfer the specified amount of heat with the available temperature drop, extended surfaces or fins are used to maintain the system in steady state conductivity. Heat transfer by convection will be increased by attaching to the surface thin strips of metals known as fins. The fins increase the effective space of the surface thereby increasing the heat transfer by convection.

The speed of heat transfer depends on the expanse of the fin. The heat flow through the fin is by conductivity. So the temperature distribution in a fin can depend on the properties of each the fin material and also the close fluid. Completely different form of cavity is employed to extend the expanse of the fin with the fluid flowing around it. Types of cavity provided on fin are (a) Rectangular Cavity, (b) Triangular Cavity (c) Trapezoidal Cavity, (d) Semicircular Cavity.

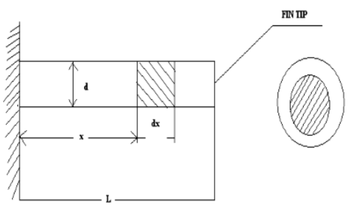

Fig.5. Schematic diagram of pin fin

3.3 Compound Method

When any two or additional techniques i.e. passive and active could also be used at the same time to rein-force the heat transfer of any device, that is larger than that of created by any of these techniques on an individual basis, the term called Compound enhancement technique.

4. Study of heat transfer Enhancement in different conditions

This study explains the different method of heat transfer enhancement in different heat exchangers.

4.1. In a Concentric Double Pipe Heat Exchanger with Different Axial Pitch Ratio of Perforated Twisted Tape Inserts

The experiments were performed using Pt tape inserts with tape-twist ratio of 3.97 and therefore the 3 axial pitch ratio (Sx/W= zero.56, 0.87 and 1.19) and constant the perforation hole diameter quantitative relation (d/W= zero.16). The experiments were performed for counter current flow mode of the fluids during a turbulent flow regime with Reynolds range starting from 5400 to 17,500.The experimental results disclosed that each heat transfer rate and friction issue of the heat exchanger equipped with pt tape inserts were considerably above those of the plain tube and with TT tape insert. an average friction consider the inner pipe generated by pt tape inserts with axial pitch ratios of 0.56, 0.87 and 1.19 is found to be around 47%, 38% and 29% more than that induced by TT tape insert, severally .

Based on the obtained results, conclusion of this study are as follows:

(a).The pt tape inserts supply a better heat transfer rate, friction factor and thermal performance factor compared to that of the plain tube and TT tape insert.
(b).At the given Reynolds number, heat transfer rate, friction factor and thermal performance factor will increase with decreasing axial pitch ratio (Sx/W).
(c).In the present range of condition, the utmost thermal performance factor of 1.39 is found wherever heat transfer rate and friction factor increase to 1.79 and 4.23 times of these within the plain tube, severally.

4.2. Helical coil Heat exchanger with fins

Helical coil heat exchangers offer high heat transfer constant in small expanse. This study concentrate on a rise within the heat transfer of a device by brazing the fins on its external surface therefore on increase the heat transfer rate by increasing its effective space. The thermal analysis is applied considering the varied parameters like flow of cold water, flow of hot water, temperature, effectiveness and overall heat transfer constant. the overall heat transfer constant and heat transfer rate will increase with increase within the effective space of the coil with brazing fins and further increases with increasing number of fins or increasing the outer diameter of the fins. Helical Coil Heat Exchanger is most effective for low flow rates, as flow rate increases heat transfer rate decreases.

5. Experimental Setup

N.Thangavelu and N.Mohandoss Gandhi, A detailed diagram of the experimental set-up is shown in Fig. 8 and Fig. 9.

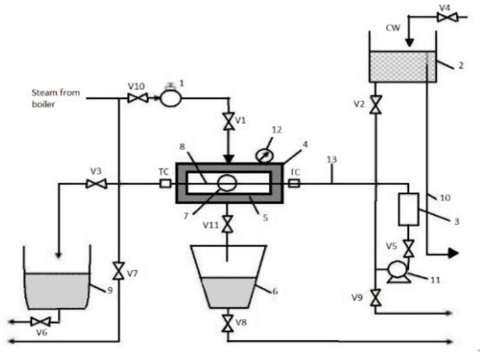

Fig. 6. Schematic of Experimental Set-up

The set-up comprised of a shell and tube condenser (4) having 5 mm thickness, 325 mm shell diameter and 500 mm length. The shell is provided with a glass opening (7) to observe the condensation phenomenon. (1) Pressure regulator, (2) Constant level cooling water tank, (3) Rota meter, (4) Shell and Tube condenser, (5) Thermal insulation, (6) Condensate vessel, (7) Viewing window, (8) Test section, (9) Hot water tank, (10) Overflow pipe, (11) Centrifugal Pump, (12) Pressure gauge, (13) Coolant flow tube TC – Thermocouple, CW – Cooling Water.

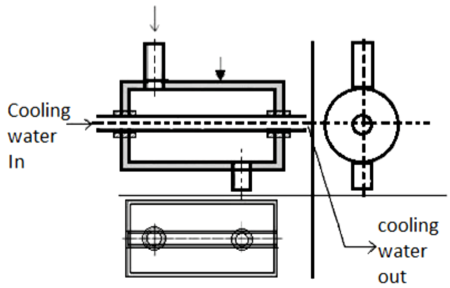

Fig.7. Schematic of Experimental Set-up

Outer diameter of the coolant flow tube used was 22 mm with 1 mm wall thickness. A copper wire of diameter 3 mm was brazed on the external surface of the tube. The system is experimented with steam and without cooling water supply to estimate the heat loss. In order to measure the test section tube wall temperature, 3 cromel alumel thermocouples of 36 gauge and nominal diameter 1mm were mounted on the tube wall at the top, side and bottom positions. Two thermocouples (TC) were used to measure the cooling water inlet and outlet temperature. The steam temperature was measured at two points, one higher than test section and other below the condenser. At the saturation pressure of steam, the temperature of each the thermocouples became equal once the air within the test condenser was replaced by steam.

6. Experimental Procedure: N.Thangavelu and N.Mohandoss Gandhi

1. Steam: Steam was generated using a 280 liters capacity cylindrical boiler at a rate of 70 kg per hour. The steam was routed into a condenser from the top and its flow rate was controlled with the help of control valve (V1).Steam temperature was maintained at 100°C during all the conditions with help of a centrifugal pump (11).
2. Cooling water: The cooling water at atmospheric temperature was circulated inside the tube. During the test, the cooling water was passed through the tube at different predetermined flow rates ranging from 8 to 28 liters per minute (lpm) in steps of 4 lpm.
3. Coolant: Coolant inlet temperature, outlet temperature and outside tube wall temperature were recorded during each flow rate. Experiments were conducted with different coolant tube configurations as mentioned below in fig (10) and Table (1) shows the test section dimensions.

Table 1 Test section dimensions

Parameters	Dimensions (mm)
Outer Diameter of the copper tube	22
Inner Diameter of the copper tube	20
Length of the tube	500
Thickness	1
Length of the shell	500
Diameter of the shell	345
Thickness of the shell	5
Diameter of copper wire	3
Pitches of helical rib	25,35

4. Copper Tube

- Plain copper tube with 20mm and 22mm inner and outer diameter. Fig. 7(a)
- LOWIB tube with copper wire brazed longitudinally on the plain tube. Fig. 7(b).
- HEWIB tube with copper wire brazed helically with 35 mm pitch on the plain tube. Fig. 7(c).
- HEWIB tube with copper wire brazed helically with 25 mm pitch on the plain tube .Fig. 7(d).

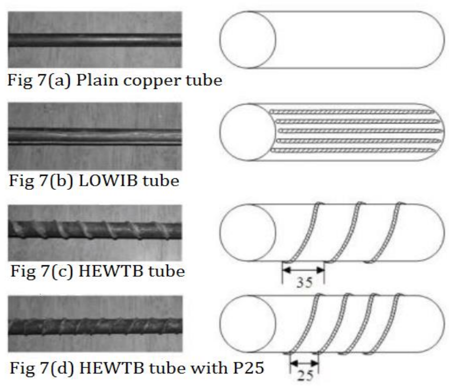

Fig.8. Different coolant tube configurations

The maximum uncertainty within the determination of heat transfer constant was found to be within the range of 8 to 12 %.

7. Result and Discussion

Calculations for finding heat transfer coefficient ho from

1. Experimental data

Initially the experiments were conducted using Plain tube and the tube wall outside heat transfer coefficient (ho) was calculated using following Equations (1) and (2) using the experimentally measured coolant inlet (Tci),outlet (Tco) and Tube wall outside (Two) temperatures.

$$Q = m_c C_p (Tc_o - Tc_i) \tag{1}$$

$$h_o = \frac{Q}{A_o (T_{sat} - T_{wo})} \tag{2}$$

2. Nusselt's Condensation theory

The heat transfer coefficient was predicted by applying Nusselt's condensation theory using the relation (3).

$$h_o = 0.725 \left[\frac{k_f^3 g \rho_f (\rho_f - \rho_v) h_{fg}}{\mu_f D_o (T_{sat} - T_{wo})} \right]^{0.25} \tag{3}$$

In Fig.11, It can be observed that the Nusselt's theory also under-predicted the heat transfer coefficient by 5% to 15% which is in accordance with the other investigations.

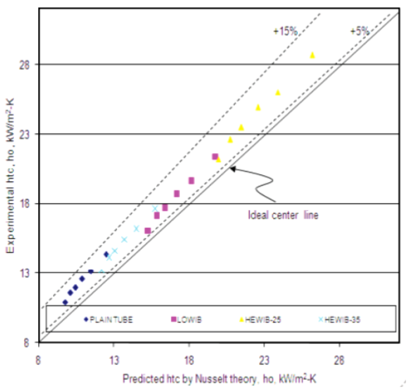

Fig.11 Comparison between the experimental heat transfer coefficient and predicted using Nusselt's Condensation theory"

3. Modified Wilson plot method (MWP)

In Fig12 it can be observed that the MWP method under-predicted the heat transfer coefficient by 12% to 17% which is in accordance with the other investigations.

$$h_{i/longtube} = C_i \frac{k_i}{D_i} \mathrm{Re}_i^{0.8} \mathrm{Pr}_i^{0.333} \left[\frac{\mu_i}{\mu_{wi}} \right]^{0.14} \tag{4}$$

With the help of Fig. 11 and Fig. 12, it concluded that the results are in-line with the one observed by other investigators in literature and the deviations are within the acceptable limits.

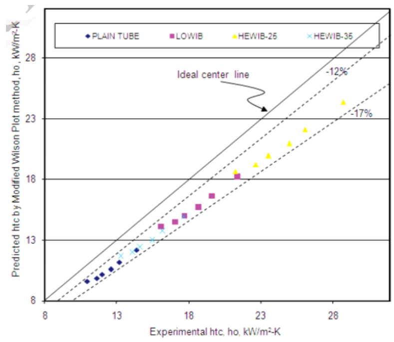

Fig.12. Comparison between the experimental heat transfer coefficient and predicted using Modified Wilson Plot (MWP) method

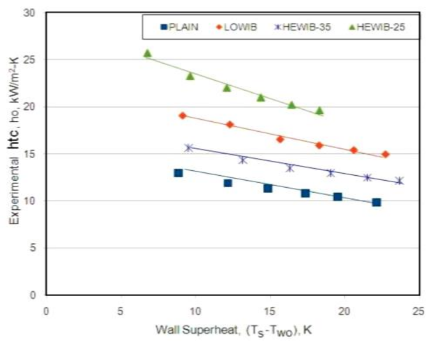

Fig.13. Change in Heat Transfer Coefficient with Temperature difference

Fig.13.shows the improvement in heat transfer coefficient with LOWIB, HEWIB-25 (Pitch = 25 mm) and HEWIB-35 (Pitch = 35 mm) is found to be 1.5, 2 and 1.2 times respectively higher than that of Plain tube.

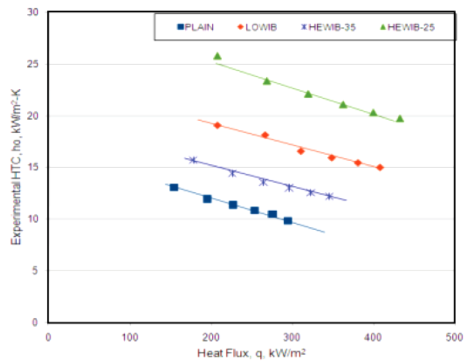

Fig .14 Graph between variations of Heat Transfer Coefficient with Heat Flux

Conclusions

The surface modifications using wire brazed helped to improve the heat transfer coefficient. The improvement in the wall heat transfer coefficient using HEWIB- 25 tube is found to be highest (2 times as compared to Plain tube) among the various modifications considered.

A simple surface modification of brazing a copper wire yielding significant amount of improvement in the heat transfer performance. The heat transfer coefficient is found to be increasing with decrease in helical pitch of the copper wire braze. This behavior observed in case of HEWIB-25 tube can be attributed the following two facts:

- The availability of higher heat transfer surface area enabling higher heat transfer rate.
- Increased surface discontinuities effecting onset of drop-wise condensation.

10. Nomenclature

Ao - Tube outside surface area, m2
Di - Inside and outside diameter of the tube,
htc- Heat Transfer Coefficient HEWIB Helically Wire Brazed.
hfg - Latent heat of evaporation of water, kJ/kg.
hi and ho- Tube inside and outside heat transfer coefficient, kW/m2-K.
mc - Cooling water flow rate, kg/s
Q - Total heat transfer rate, kW, q - Heat Flux, kW/m2
SF - Correction factor TC – Thermocouple
Tci - Inlet temperature of cooling water, K
Tco - Outlet temperature of cooling water, K
Tsat - Vapor condensation temperature, K
Two - Tube wall outside temperature, K
μw - Dynamic viscosity at wall temperature, kN-s/m2.
ρv - Density of the steam, kg/m3

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