International Journal of Automation, Mechatronics & Robotics
Volume 3 : Issue 1 [ISSN 2374-1546]
Publication Date : 31 August, 2016

Design of Heat Pipe Heat Exchanger with Plate Fins by two Methods LMTD and ε-NTU

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Abstract*—*In this study, the effective factors on the heat transfer and pressure drop in heat pipe heat exchanger design based on the LMTD and effectiveness-NTU has been investigated. Increasing fuel cost and energy conservation, fuel consumption and also, pollution air are the most important consideration to be taken in new heat exchanger design, and modern compact heat exchangers. This paper describes a theoretical method to the design and performance of heat pipe heat Exchanger. Design of heat pipe heat exchanger for identifying of the principal parameters, which can optimize the performance of heat exchanger. Heat pipe heat exchanger efficiency with copper pipes is 10% higher than steel but steel pipe for strength and its ability to heat recovery of hot gases is preferred. Increasing the number of rows of tubes will increase efficiency. The largest diameter pipes and increasing the number of fins improved efficiency. Pressure drop of the heat pipe heat exchanger placed as heat recovery unit in hot gas duct of boilers and furnace depends on velocity and it is very important.

Keywords*— *Heat Pipe, Design of Heat Exchanger, LMTD and ε-NTU method, Pressure Drop

I. Introduction

At present, several methods exist for the transfer of heat between the hot and cold fluid. One of the ways that today's attention is heat pipe heat exchanger. Heat pipe heat exchanger is one of the most effective and efficient way for heat transfer. This heat exchanger made of heat pipe or thermosyphon. So that a heat pipe or thermosyphon heat exchanger such as components becomes part of the evaporator, condenser and working fluid is made. In HPHE heat pipe heat exchanger, heat from hot fluid to cold fluid by evaporation and condensation and heat the working fluid in individual tubes or thermosyphones be transferred. The main objective to design a heat exchanger is, first the heat exchanger to provide necessary heat transfer and second, the pressure drop over the heat exchanger and other connections in the flow direction of an economically constrained not exceed the limit. In general, the design and calculation of heat exchangers are divided into two categories. Categories in which issues first heat exchanger type and size are known, and the main issue was to determine the type of heat transfer and fluid outlet temperatures and intake temperatures is based on flow.

Categories in which issues first heat exchanger type and size are known, and the main issue was to determine the type of heat transfer and fluid outlet temperatures and intake temperatures is based on flow. These types of heat exchangers are known to performance issues.Categories in which issues second the flow rate and inlet and outlet temperatures of hot and cold fluid given. The design is to choose suitable exchangers, determine its size and calculate the surface needed to achieve the desired outlet temperature. After computing thermal energy there is the mechanical design. In this paper the exchangers design is performance and includes the following steps [1, 2]:

- Determine the type and size of the heat exchanger. At this stage surfaces are determined.
- Calculate thermal resistance and overall heat transfer coefficient.
- Calculate outlet temperatures and heat transmitted by two methods ε-NTU and LMTD.

II. Heat Pipe Heat Exchanger Design Steps

A. Choose Size and Surface of Heat Exchanger

At this stage exchanger surface characteristics with respect to the definition of the problem and accordingly determined in accordance with Table 1 [2-4].

TABLE I. THE PHYSICAL CHARACTERISTICS OF THE HEAT PIPE HEAT EXCHANGER

Physical dimensions of exchangers	Height (H), Length (L), Width (W)
Physical dimensions of the heat pipe, material and working fluid	In and Out Diameter (D_i , D_o), Length (L), Copper and Water
Types of fins	Plate, thickness (t_f), number (n_f), distance (S_f) , Length (l_f) Aluminum
Pipe arrangement	Staggered, Longitudinal pitch (S_L), Traverse pitch (S_T)
The number of rows and the total number pipe	$N=N_L*N_T$

B. Hot and Cold Fluid Properties

At this stage, the physical properties of the hot gases entering the evaporator and cold air entering the condenser at the average temperature determined. It is necessary to determine the properties as primary assumption, outlet temperatures guessed [5].

$$c_p = 0.219 + 0.342\times10^{-4}T - 0.293\times10^{-8}T^2 \qquad (1)$$

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$$\mu = 2.27\times10^{-8}\left(\frac{T^{1.5}}{T+198.7}\right)\times32.2\times3600 \quad (2)$$

$$K = (c_p + 0.0857)\mu \quad (3)$$

$$\rho = \frac{MP}{RT} \quad (4)$$

C. Calculation of Reynolds number, Stanton – Colburn factor and Velocity in Evaporator and Condenser Section

Reynolds number flow of hot gases entering the evaporator and cold air entering the condenser is calculated as follows [6].

$$\mathrm{Re}_L = \frac{GS_L}{\mu} \quad (5)$$

$$G = \frac{\dot{m}}{A_c} \quad (6)$$

$$A_c = [(N_T - \tfrac{1}{2})(S_T - D_o)(1 - t_f n_f)L_e] \quad (7)$$

$$u = \frac{G}{\rho} \quad (8)$$

$$j = 0.195\,\mathrm{Re}_L^{-0.35} \quad (9)$$

$$j = St.\mathrm{Pr}^{2/3} \quad (10)$$

$$St = \frac{h}{\rho u c_p} \quad (11)$$

$$\mathrm{Pr} = \frac{\mu c_p}{k} \quad (12)$$

Calculation external convective heat transfer coefficient:

$$h = \frac{j\rho u c_p}{\mathrm{Pr}^{2/3}} = \frac{0.195\,\mathrm{Re}_L^{-0.35}\rho u c_p}{\left(\frac{\mu c_p}{k}\right)^{2/3}} = 0.195\,\mathrm{Re}_L^{-0.35}\rho u c_p^{1/3}\mu^{-2/3}k^{2/3} \quad (13)$$

Substituting physical properties, heat transfer coefficient in the evaporator and condenser section is determined.

D. Calculation of Fin Efficiency

Evaporator section with subtitles e (the condenser section relationships like this are part and only with subtitles c):

$$\eta_{e,o} = 1 - \frac{A_{fe}}{A_{eo}}(1 - \eta_{fe}) \quad (14)$$

$$A_{fe} = 2N\left[S_L S_T - \frac{\pi}{4}D_o^{\,2}\right]n_f L_e \quad (15)$$

$$A_{eo} = [2(S_L S_T - \frac{\pi}{4}D_o^2)n_f + (1 - t_f n_f)\pi D_o]NL_e \quad (16)$$

Where A_{fe} is the total surface of fin in evaporator section and A_{eo} is the total surface of heat transfer in the evaporator section.

$$\eta_{fe} = \frac{\tanh(ml_f)}{ml_f} \quad (17)$$

$$m = \sqrt{\frac{2h_{eo}}{K_f t_f}} \quad (18)$$

$$l_f = \frac{S_L}{2} \quad (19)$$

E. Calculation of Overall Heat Transfer Coefficient

Heat pipe heat exchanger can be considered as a thermal resistance network. For evaporator and condenser section as below calculated [7-9].

$$(UA)_e = \left[\frac{1}{\eta_{eo}h_{eo}A_{eo}} + \frac{1}{2\pi K_p L_e}\ln\left(\frac{D_o}{D_i}\right)\right]^{-1} \quad (20)$$

$$R_{eo} = \frac{1}{\eta_{eo}h_{eo}} \quad (21)$$

$$R_{ep} = \frac{A_{eo}}{2\pi K_p L_e}\ln\left(\frac{D_o}{D_i}\right) \quad (22)$$

$$(UA)_t = \left[\frac{1}{\eta_{eo}h_{eo}A_{eo}} + \frac{1}{2\pi K_p L_e}Ln\left(\frac{D_o}{D_i}\right) + \frac{1}{2\pi K_p L_c}Ln\left(\frac{D_o}{D_i}\right) + \frac{1}{\eta_{co}h_{co}A_{co}}\right]^{-1} \quad (23)$$

F. Calculation of Outlet Temperatures and Heat Transfer rate

- LMTD method

$$Q_t = U_t A_t \Delta T_m \quad (24)$$

$$Q_h = (\dot{m}c_p)_h(T_{h,in} - T_{h,out}) \quad (25)$$

$$Q_c = (\dot{m}c_p)_c(T_{c,out} - T_{c,in}) \quad (26)$$

If $\dot{m}_h$ and $\dot{m}_c$ are known with regard to the relationship $Q_h = Q_c = Q_t$, three unknowns $T_{c,out}, T_{h,out}, Q_t$ are calculated by solving simultaneous equations.

$$T_{h,out} = T_{h,in} - \frac{Q_t}{(\dot{m}c_p)_h} \quad (27)$$

$$T_{c,out} = T_{c,in} + \frac{Q_t}{(\dot{m}c_p)_c} \quad (28)$$

$$Q_t = U_t A_t \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln\dfrac{T_{h,in} - T_{c,out}}{T_{h,out} - T_{c,in}}} \quad (29)$$

Substituting the equation (27) and (28) in (29) we have:

$$Q_t = \frac{(T_{h,in} - T_{c,in})(1 - \exp[U_t A_t(\frac{1}{(\dot{m}c_p)_h} - \frac{1}{(\dot{m}c_p)_c})])}{\frac{1}{(\dot{m}c_p)_c} - \frac{1}{(\dot{m}c_p)_h}\exp[U_t A_t(\frac{1}{(\dot{m}c_p)_h} - \frac{1}{(\dot{m}c_p)_c})]} \quad (30)$$

Outlet temperatures can be corrected by guessed temperatures in the physical properties.

- ε-NTU method [7-9]

$$NTU_h = \frac{(UA)_h}{C_h} \qquad (31)$$

$$C_h = (\dot{m}c_p)_h \qquad (32)$$

$$NTU_c = \frac{(UA)_c}{C_c} \qquad (33)$$

$$C_c = (\dot{m}c_p)_c \qquad (34)$$

$$\varepsilon_h = 1 - \exp(-NTU_h) \qquad (35)$$

$$\varepsilon_c = 1 - \exp(-NTU_c) \qquad (36)$$

$$\varepsilon_p = \left(\frac{1}{\varepsilon_{\min}} + \frac{C}{\varepsilon_{\max}}\right)^{-1} \qquad (37)$$

$$\varepsilon = \frac{\left(\frac{1-C\varepsilon_p}{1-\varepsilon_p}\right)^n - 1}{\left(\frac{1-C\varepsilon_p}{1-\varepsilon_p}\right)^n - C} \qquad (38)$$

$$\varepsilon = \frac{(\dot{m}c_p)_h (T_{h,in} - T_{h,out})}{(\dot{m}c_p)_{\min} (T_{h,in} - T_{c,in})} = \frac{(\dot{m}c_p)_c (T_{c,out} - T_{c,in})}{(\dot{m}c_p)_{\min} (T_{h,in} - T_{c,in})} \qquad (39)$$

$$T_{h,out} = T_{h,in} - \varepsilon_p \frac{(\dot{m}c_p)_{\min}}{(\dot{m}c_p)_h} (T_{h,in} - T_{c,in}) \qquad (40)$$

$$T_{c,out} = T_{c,in} - \varepsilon_p \frac{(\dot{m}c_p)_{\min}}{(\dot{m}c_p)_c} (T_{h,in} - T_{c,in}) \qquad (41)$$

These temperatures can be corrected by guessed temperatures in the physical properties. The difference between the amount of heat transfer calculated by the two methods LMTD and ε-NTU and the desired value (defining the problem), by reducing or increasing the number of tubes and fins and overall geometry Exchangers is minimal.

III. Calculation of Pressure Drop

$$\Delta P = \Delta P_{non-fin} + \Delta P_{fin} \qquad (42)$$

Where $\Delta P_{non-fin}$ is the pressure drop of tube bundle without fins and ΔP_{fin} is the pressure drop caused by fins.

$$\Delta P_{non-fin} = N_L \chi f \left(\frac{\rho\, u_{\max}^2}{2}\right) \qquad (43)$$

$$\mathrm{Re}_{\max} = \frac{\rho\, u_{\max} D_o}{\mu} \qquad (44)$$

$$f = \left[1 + \frac{0.47}{\left(\frac{S_T}{D_o} - 1\right)^{1.08}}\right] \mathrm{Re}_{\max}^{-0.16} \qquad (45)$$

$$\Delta P_{fin} = f_f \left(\frac{A_f}{A_c}\right) \frac{G^2}{2\rho} \qquad (46)$$

$$f_f = 1.7\, \mathrm{Re}_L^{-0.5} \qquad (47)$$

IV. Result

Heat pipe heat exchanger design to determine the main parameters that can optimize the performance of this exchanger. Based on the design done in this paper it is studied the effects of various factors on exchanger efficiency. The plot of the efficiency of the evaporator and condenser velocity in two parts for copper and steel tubes in Fig 1, Variation of efficiency on heat pipe and the number of rows in Fig 2, Variation of efficiency of the heat pipe diameter and number of fins in Fig 3 and Variation of pressure drop and fluid velocity of the hot and cold sides of the evaporator and condenser in Fig 4 is displayed.

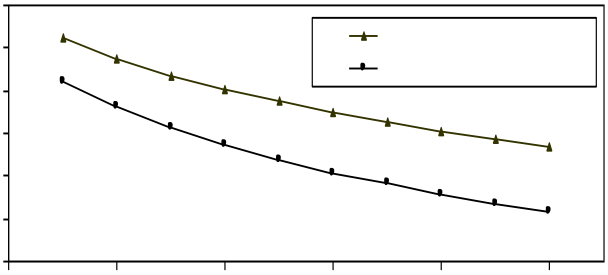

Figure 1. Variation efficiency than velocity in copper and steel heat pipe

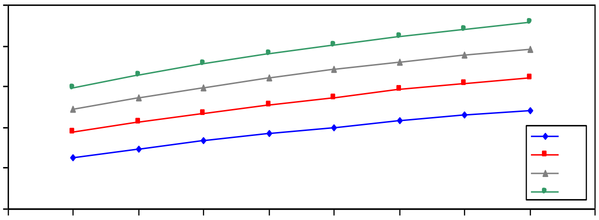

Figure 2. Variation of efficiency on heat pipe and the number of rows

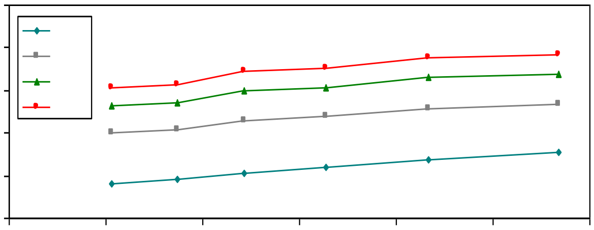

Figure 3. Variation of efficiency of the heat pipe diameter and number of fins

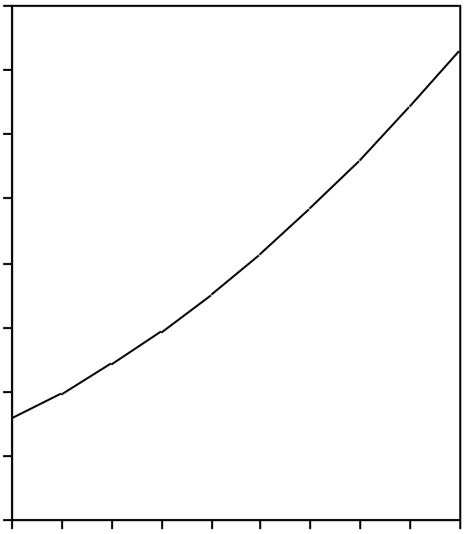

Figure 4. Variation of pressure drop and fluid velocity of the hot and cold sides of the evaporator and condenser

V. Conclusion

The base design and diagrams shown, the effect of the main factors in optimizing heat pipe heat exchanger performance includes:

- Heat pipe heat exchanger efficiency with copper pipes from 33.4 to 46.1 %, which is about 10 percent higher than steel. The heat transfer rate is higher in copper pipes. Although the efficiency of copper pipes is higher, but are limited in temperatures above 200 °C. Therefore, taking into account the working pressure safety and limit, type of steel pipe for strength and its ability to heat recovery of hot gases is preferred.
- In a mass flow rate specified maximum length and increasing the number of rows of tubes will increase efficiency.
- The largest possible diameter pipes and increasing the number of fins for improved performance and efficiency during Pipe length.
- The pressure drop of the heat pipe heat exchanger in the flow direction with increasing velocity directly related to the hot gas in boilers and furnace flue is important.

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