Experimental &Theoretical Investigation of Pressure Drop across Tube Bundle of a THPHE and Introducing a New Correlation

Zare aliabadi*, Hassan
Department of chemical engineering, Islamic Azad University of Shahrood, I.R.IRAN

Noie, Seyed Hussein
Department of chemical engineering, Ferdowsi University of Mashhad, Mashhad, I.R.IRAN

Khoshnoodi, Mohammad; Atashi, Hussein
Department of chemical engineering, University of Sistan and Baluchestan, Zahedan, I.R.IRAN

Abstract

Hydrodynamic and thermal performance of a heat pipe heat exchanger depends on a number of parameters such as heat pipe diameter, bundle geometry, orientation, fin spacing and size, etc. In this paper experimental and theoretical research has been carried out to investigate the pressure drop across tube bundle of an air to liquid thermosyphon heat pipe heat exchanger (THPHE). According to experimental data and the other methods, a new correlation for THPHE with individual finned tubes and in-line geometry has been introduced. The error of pressure drop for 40 experimental points in the new correlation is less than %15. It indicates that the new correlation possesses an acceptable accuracy in the prediction of pressure drop.

Key words: Pressure Drop, THPHE, Finned Tube Bundle

* Corresponding author: Tel: +98915 5056588, E-mail: h_a_zare@yahoo.com

Introduction

Heat pipe heat exchanger is one of the most effective devices for waste heat recovery. It has many advantages such as; large quantities of heat can be transported through a small cross-sectional area, simplicity of design and manufacturing, extremely wide temperature application range, ability to control and high heat transfer rates at various temperature levels, the capability to operate as thermal transformers, by altering the relative lengths of the evaporator and condenser sections **[1-2]**. Appropriate performance of a HPHE is function of many parameters, such as hot air mass flow rate, inlet air temperature, filling ratio and pressure drop across tube bank of heat pipes. Detailed pressure drop analysis of various tubes with fin geometries has been presented by Kays and London **[3]**, Rohsenow et.al **[4]** and Shah and Giovanelli **[5]**. In this research, by manufacturing a THPHE we have investigated pressure drop across tube bundle experimentally and theoretically.

Theory

Heat pipe heat exchanger design is a complex problem which involves both quantitative calculations and qualitative judgments .Heat transfer between the high and low temperature fluids and the pressure drop of the fluids as they flow across the THPHE core are two major design criteria. The amount of pressure drop is highly dependent on the geometry of the tubes and fins, mass flow rate across tube bundle, maximum velocity of flow through tube bundle and temperature of flow **[6].**

Kays and London Correlation

Kays and London correlation is one of the best method for calculating pressure drop across heat pipe heat exchanger with various tube and fin geometries.The fluid flow configuration in the core of a heat pipe heat exchanger is flow normal to either a bare or finned bank of tubes. The fractional pressure drop for flow normal to tube banks is given by:

$$\frac{\Delta P}{P_{in}} = \frac{G^2}{2P_{in} r_{in}}[(1+(\frac{A_c}{A_f})^2)(\frac{r_{in}}{r_{out}}-1)+f\frac{A_o}{A_c}\frac{r_{in}}{r_m}] \quad \text{Where } G=\frac{\dot{m}}{A_c} \tag{1}$$

Friction factor correlation is empirically based on the Reynolds number and geometric parameters. For a bank of individually finned tubes with various geometries, it is obtained by:

$$f=\left\{0.44+\frac{0.08\, {}^{S_L}\!/_{d}}{[{}^{(S_T-d)}\!/_{d^{0.43+1.13d/S_T}}]}\right\}\mathrm{Re}_{\max}^{-0.15} \quad , \quad f=\left\{0.25+\frac{0.118}{[{}^{(S_T-d)}\!/_{d}]^{1.08}}\right\}\mathrm{Re}_{\max}^{-0.16} \tag{2}$$

For in – line and triangular configuration of tube bank, respectively.

Shah and Giovanelli Correlation

For individual circular finned tubes Kay's & London equation can be written as:

$$\Delta P = 2nf'\frac{G^2}{r_{in}}+G^2(\frac{1}{r_{out}}+\frac{1}{r_{in}}) \tag{3}$$

Where, f′ is a modified friction factor per tube row, for flow normal to a circular finned bank of tubes the correlation of Robinson and Briggs can be used to obtain f′:

$$f' = 9.465\,\mathrm{Re}_d^{-0.316}(\frac{X_t}{d_o})^{-0.937} \tag{4}$$

Here, the Reynolds number is based on the outside tube diameter.

Experimental set-up and procedure [7]

In this research we have manufactured a pilot plant for the data acquisition purposes with below conditions:
Thermosyphon heat pipe heat exchanger (THPHE) module is composed of 6(rows)*15(columns) copper pipes with aluminum plate fins with dimensions of 130cm(height), 47cm(width), and 20cm(depth) which have been filled by water with filling ratio of 30%, 50%, and 70% .the density and thickness of fins are 300 fin/m and 0.4mm, respectively.

The test rig has two sections, top and bottom sections. The top section is condensation part of HPHE in which cooled water is drowned into it by a pump with constant flow rate (7lit/min) at about 17°C; the bottom section is evaporation part of HPHE. The bottom duct is straight and forms a closed looped. A centrifugal blower and 90 electrical heaters were installed in the duct to circular hot air through the evaporator section. In the bottom duct mass flow rate varies by changing the input frequency to blower in the range of (20-70HZ), therefore the mass flow rate varies in the range of (0.15-0.55kg/s). Pressure drop between inlet and outlet of THPHE was measured by inclined manometer. The inlet hot air temperature was controlled at five quantities as100, 125, 150, 175, 200°c.

Results and Discussion

In this paper, pressure drop across a THPHE has been investigated experimentally and theoretically. The experiments were done in the hot temperature range of 125-200°C.Since the measured pressure drop of hot air has been alike in various temperature, we have used experimental data for inlet hot air at 125,200°C **(Table. 1)**. Geometrical dimensions of heat pipe heat exchanger which has been used are:

$$A_C = (W - N_b d)(L_e - t_f n_f L_e), \quad A_f = 2N(Wb - \tfrac{p}{4} d_o^2) n_f L_e \tag{5}$$

$$A_o = 2N(Wb - \tfrac{p}{4} d_o^2) n_f L_e + (L_e - n_f t_f) p d_o N \tag{6}$$

$$A_c = 0.099 m^2, A_f = 22.278 m^2, A_o = 23.84 m^2$$

Table1. Experimental data for pressure drop

(Inlet hot air at 125°C)

$n\,(HZ)$	$T_{h,out}\,(°c)$	$\Delta P_{exp.}\,(mmH_2O)$
20	58	6
30	68	14
40	74	23
50	78	34
60	81	48
70	84	60

(Inlet hot air at 200°C)

$n\,(HZ)$	$T_{h,out}\,(°c)$	$P_{exp.}\,(mmH_2O)$
20	74	6
30	90	14
40	100	24
50	107	34
60	114	46
70	120	62

We have obtained the parameters of fluid flow in bottom duct of test rig as follows:

$$\dot{m} = C\sqrt{r_m \Delta P} \quad (7)$$

Where C is calibration factor of orifice meter in pilot plant that the amount of it is 0.067 and ΔP is pressure drop of fluid flow through the orifice meter.

$$U_\infty = \frac{\dot{m}}{r_m A}, \qquad U_{\max} = U_\infty \frac{S_L}{S_L - d} = 2U_\infty \quad (8)$$

Where A is cross sectional area of duct. The amount of it equals 0.3 m2 for test rig of this research.

The configuration of tubes is in-line with 30mm pitch. Pressure drop across THPHE has been obtained by using experimental data and equations 1 -10. The results of various correlations have been showed in **Tables2, 3**.

Table2. Pressure drop obtained from **various Correlations**
(Inlet hot air at 125°C)

$\dot{m}_h (\frac{kg}{s})$	$\Delta P_{cal.}(mmH_2O)$ **new correlation**	$\Delta P_{cal.}(mmH_2O)$ **kays & London**	$\Delta P_{cal.}(mmH_2O)$ **Shah & Giovanelli**
0.175	8	8	6
0.245	14	15	11
0.319	24	25	17
0.396	36	37	25
0.473	50	52	34
0.543	64	68	43

Table3. Pressure drop obtained from **various Correlations**
(Inlet hot air at 200°C)

$\dot{m}_h (\frac{kg}{s})$	$\Delta P_{cal.}(mmH_2O)$ **new correlation**	$\Delta P_{cal.}(mmH_2O)$ **kays & London**	$\Delta P_{cal.}(mmH_2O)$ **Shah & Giovanelli**
0.165	8	7	7
0.231	15	14	12
0.294	24	25	18
0.366	35	37	27
0.43	48	51	35
0.493	62	66	44

New correlation

The authors of this paper present a new correlation to predict pressure drop in the THPHE with continuous fins and in-line configuration according to experimental data obtained in the pilot plant and advising from the other correlations.

$$\Delta P = 0.345 f \frac{A_f}{A_c} \frac{G^2}{r_m} \qquad (9)$$

We can calculate fanning friction factor for various configurations of tube banks by using below correlations.

$$f = [0.176 + \frac{0.32b}{(a-1)^{0.43+1.13/b}}]\mathrm{Re}_{\max}^{-0.15} \;,\; f = [1 + \frac{0.47}{(a-1)^{1.08}}]\mathrm{Re}_{\max}^{-0.16} \qquad (10)$$

Where $a = \frac{S_L}{d}, b = \frac{S_T}{d}$

For in- line and rectangular configuration of tube bank, respectively.
The results show that the new correlation has a high degree of accuracy to predict pressure drop in heat pipe heat exchanger with continuous fins and in - line configuration of tubes. **(Figs.1, 2)**

Conclusion

The effect of various parameters on pressure drop of a THPHE was investigated. The following conclusions were obtained from the present study:
1) Shah and Giovanelli correlation is used for heat pipe heat exchanger with individual circular fins but we can use it for HPHE with continuous fins when Reynolds number is less than 2000.
2) Kays and London correlation is one of the best method to calculating pressure drop in heat pipe heat exchanger with various tube and fin geometries, but this correlation is very complicated with a lots variables.
3) The results show that the new correlation has a high degree of accuracy to predict pressure drop in heat pipe heat exchanger with continuous fins and in-line configuration of tubes.
As a result, the number of experimental tests that needed to be carried out on a large scale plant is quite limited. The authors believe that it is needed to study the accuracy of new correlation for a HPHE with various fins when Reynolds number of flow is higher than 5000.

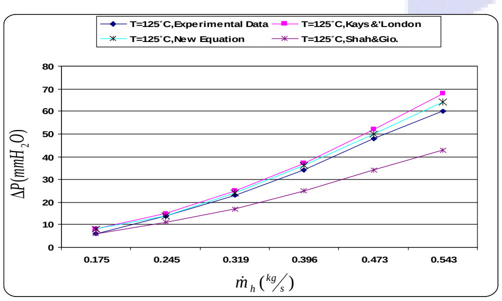

Figure1. Pressure drop vs. mass flow rate of inlet hot air to THPHE ($T_{h,in} = 125°C$)

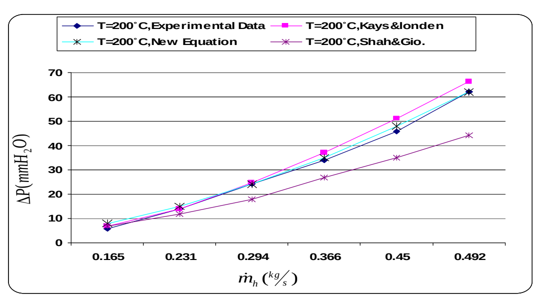

Figure2. Pressure drop vs. mass flow rate of inlet hot air to THPHE ($T_{h,in} = 200°C$)

Nomenclatures

A_c Minimum free-flow area in the core,(m2)
A_f Surface area of fins,(m2)
A_o Total frontal area of heat pipe heat exchanger,(m2)
D_i Inside Diameter of heat pipe, (m)
D_i Outside Diameter of heat pipe, (m)
f Fanning friction factor
f′ Modified fanning friction factor
G Maximum mass velocity in the core, (kg/m2.s)
L_c Length of condensing section,(m)
L_e Length of evaporator section,(m)
$\dot{m}$ Mass flow rate of fluid in duct,(kg/m3)
N Number of rows of tubes
$\Delta P_{exp.}$ Experimental pressure drop, (mmH_2O)
$\Delta P_{cal.}$ Theoretical pressure drop, (mmH_2O)
ΔP_f Pressure drop in fins,(Kpa)
ΔP_t Pressure drop in tubes bank (without fin) ,(Kpa)
S_L Longitudinal tube pitch, (mm)
S_T Transverse tube pitch, (mm)
$T_{h,in}$ Temperature of flow, inlet of HPHE, (°C)
$T_{h,out}$ Temperature of flow, outlet of HPHE, (°C)
$U_{\max}$ Maximum flow velocity in tube bank, (m/s)
W Width of a heat exchanger, (m)

Subscribes

c Condenser
e Evaporator
f Fin, Fouling
i Inside
o Outside, Overall
p Pipe

Dimensionless groups

$\mathrm{Re}_{\max}$, $\mathrm{Re}_{\max} = \frac{r_m U_{\max} d_o}{m}$ Reynolds number

Greek letters

μ Dynamic viscosity of fluid, N.s/m
ν Frequency of current, HZ
ρ Density of fluid, kg/m3

References

1. Faghri, A., Heat Pipe Science and Technology, Taylor & Francis, USA, 1995.
2. Peterson, G.P., an Introduction to Heat Pipes, John Wiley and Sons Ltd.., New York, 1994.
3. Kays, W.M.,and London, A.L., Compact heat exchangers, 3rd ed. McGraw-Hill, New York, 1984.
4. Rohsenow, W.M., Hartnett, J.P., and Ganic, E.N., Handbook of heat transfer applications, McGraw-Hill, New York, 1985.
5. Shah, R.K., and Giovannelli, A.D., Heat Pipe Heat Exchanger Design Theory, Heat Transfer Equipment Design, Hemisphere, Washington D.C., 1987.
6. Perez, R., and Bendescu, J., "the Influence of the Heat Pipe Heat Exchanger's Geometry on its Heat Transfer Effectiveness", Heat Recovery Sys. & CHP, 3(1), 9(1983).

7. Noie, S.H., "Investigation of Thermal Performance of Air-to-Air Thermosyphon Heat Exchanger using ε-NTU Method", Applied Thermal Engineering, 26, 1073(2005)