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Heat Transport Limitations and Overall Heat Transfer Coefficient for a Heat Pipe

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***Abstract:** The objective of the present work is to investigate the heat transport limitations and overall heat transfer coefficient for a Copper - Acetone heat at different vapor temperatures. A dimensional analysis has been made to the overall heat transfer coefficient in the heat pipe, A new correlation for the overall heat transfer coefficient has been obtained . It has been found that latent heat vaporization , the pipe diameter and Reynolds number are the parameter affects the overall heat transfer coefficient. A computer program was used to calculate heat pipe limits theoretical and correlated overall heat transfer coefficients using the data of (6). The sonic, capillary, and entrainment limits are increased with increasing the vapor temperature but the boiling limit is decreased with the increasing of vapor temperature. The correlated function that relates overall heat transfer coefficient and vapor temperature is very close to the theoretical overall heat transfer coefficient.*

***Keywords:** objective, present, transport limitations, overall, correlation, coefficient, temperature, transfer*

I. INTRODUCTION

The maximum heat transport capability of the heat pipe is governed by several limiting factors which must be addressed when designing a heat pipe. There are five primary heat pipe heat transport limitations. These heat transport limits which are a function of the heat pipe operating temperature, include: viscous, sonic, capillary pumping, entrainment or flooding, and boiling, Abed Alr zaq S. Alshqirate and el. [2] obtained the experimental results for the convection heat transfer coefficient and pressure drop values during condensation and evaporation of CO_2 at different operating conditions for flow inside micro pipes. Reynolds number ranged between 2000 and 15000. The dimensional analysis technique was utilized to develop correlations for Nusselt numbers and pressure drops. A comparison between experimental and correlated results was carried out. The results showed that for the condensation process, the bias errors were 5.25% and 0.4% for pressure drops and Nusselt number respectively. Consequently, Average Standard Deviation (ASD) values reached 17.94% and 4.62% for both respectively. On the other hand, for the evaporation process, the Nussle number error was 3.8% with an ASD of 4.14%. The obtained correlations can be used in calculating pressure drops and heat transfer coefficients for phase change flows in mini and micro tubes. It helps to enhance design of heat exchangers, condensers and evaporators. Ground tests of axially grooved heat pipes [**3**] have specific features associated with influence of gravity on heat pipe performance and heat transfer, influence of attached accompanied elements as heaters, Condensers, sensors, insulation. These factors can influence thereby that resulting characteristics as heat transfer coefficients, thermal resistance, heat productivity will be not evident enough and reliable. The aim of the current paper is to investigate theoretically and by experiments the influence of affected factors. The typical modeling object is an ammonia aluminum grooved heat pipe by shell diameter 12 mm and 30 grooves.

A theoretical and experimental study [4] of a wire screen heat pipe, the evaporator section of which is subjected to forced convective heating and the condenser section to natural convective cooling in air. The theoretical study deals with the development of an analytical model based on thermal resistance network approach. The model computes thermal resistances at the external surface of the evaporator and condenser as well as inside the heat pipe. A test rig has been developed to evaluate the thermal performance of the heat pipe. The effects of operating parameters (i.e., tilt angle of the heat pipe and heating fluid inlet temperature at the evaporator) have been experimentally studied. Experimental results have been used to compare the analytical model. The heat transfer coefficients predicted by the model at the external surface of the evaporator and condenser are reasonably in agreement with experimental results

Experimental work [**5**], wickless heat pipe (thermosyphon) is designed and constructed from a copper tube simulating the actual applications in practice of this device. Pure water, pure hydrocarbon fluid (acetone) and mixtures of the two fluids at different ratios by weight were used as working fluid to investigate the effect of a working fluid type and mixture ratio on the performance of the device. Results show that using pure fluid is more effective than using mixture. The maximum heat transfer coefficient is obtained when water is used as a working fluid. and lower heat transfer coefficient is obtained when a mixture is used as a working fluid with a ratio of 50%. Comparison between results and a theoretical correlation shows a good agreement especially when using pure fluid. An experimental work [6] is to investigate the performance of a wrapped screen heat pipe for atmospheric air heating. It was shown that The vapour temperature of working fluid increases as the heat load increases at constant air velocity. It was also been found that the range of vapour temperature deceases as the filling ratio increases that means the increasing of the filling ratio results the decrease of the maximum vapour temperature and the variation in the vapour temperature. The best recorded filling ratio is 0.6 which has the lowest vapour temperature at highest heat load.

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The maximum heat transport limit for this pipe is 80 W and the maximum temperature difference for air is 5 °C. An experimental investigation of heat transfer performance of a heat pipe **[7]** for dry condition and with three different liquids as acetone, methanol, and water having four fill ratios, for each liquid has been conducted. The heat pipe was 5 mm in diameter and 150 mm long with a thermal capacity of 10 W. The evaporator and condenser's temperatures were measured with varying input power to estimate the heat transfer coefficient. This study reveals that the dominating parameters for the heat transfer coefficient are evaporator surface temperature, saturated boiling temperature of working fluid, latent heat of vaporization, and fill ratio. The investigation also showed that 85% fill ratio can be regarded as an optimum value for a heat pipe. A proofed correlation for the heat transfer coefficient has been proposed here which fairly agrees with the experimental results.

The objective of the present work is to investigate the heat transport limitations and overall heat transfer coefficient for a heat pipe using copper pipe material and acetone as working fluid at different vapor temperatures.

II. HEAT TRANSPORT LIMITS

Limits to heat transport [1] in heat pipes are classified to:

(i) Viscous limit. (ii) Sonic limit

(iii) Entrainment or flooding limit.

(iv) Capillary limit. (v) Boiling limit

Viscous limit

When the vapor pressure from the evaporator to the condenser cannot overcome the vapor pressure drop caused by the viscous forces, the heat pipe reaches a heat-transport limit, which is called the viscous limit. In particular, the viscous limit is reached when the vapor pressure in the condenser is equal to zero

Sonic limit

Sonic limit is given by (1):

$$Q = \rho_v L \sqrt{\frac{\gamma_v R_v T_v}{2(\gamma_v + 1)}} \qquad (1)$$

Entrainment limit

The entrainment limit is given by (2):

F_V: Frictional coefficient for vapor flow (s/m^4)

$$Q_{ent} = \pi r_v^2 L \sqrt{\frac{2\pi \rho_v \sigma_l \cos\theta}{\lambda}} \qquad (2)$$

Capillary limit

The maximum capillary limitation is given by (3):

$$Q_{c,max} = \frac{(QL)_{c,max}}{0.5L_c + L_a + 0.5L_e} \qquad (3)$$

Boiling limit

Boiling limit is encountered when the radial heat flux in the evaporator section is high enough to cause vapor nucleation within the wick. The Boiling heat transport limit can be obtained by (4):

$$Q_{b(\max)} = \frac{2\pi L_e k_e T_v}{L \rho_v L_n (r_i / r_v)} \left(\frac{2\sigma_L}{r_n} - P_c \right) \qquad (4)$$

A computer program was used to calculate heat pipe limits (ESS) using the data of (6).

III. THEORETICAL OVERALL HEAT TRANSFER COEFFICIENT

When operating below its heat transport limits, a heat pipe's performance be characterized by a coefficient of heat transfer. Theoretically, overall heat transfer coefficient based on the pipe's cross-sectional area $U_{hP,P}$ can be calculated from the equation (5):

$$\mathbf{Uhp,p} = \frac{\mathbf{1}}{\mathbf{R_{p,e} + R_{W,e} + R_v + R_{W,C} + R_{P,C}}} \qquad (5)$$

Where:

$R_{P,e}$:Thermal resistance of the heat pipe wall at the evaporator.

$R_{W,e}$:Thermal resistance of liquid saturated wick at the evaporator.

R_v : Thermal resistance of the vapor flow.

$R_{W,c}$:Thermal resistance of the liquid saturated wick at the condenser.

$R_{p,c}$:Thermal resistance of the heat pipe wall at the condenser.

IV. CORRELATED HEAT TRANSFER COEFFICIENT OF HEAT PIPE

In the present study a dimensional analysis has been made to the overall heat transfer coefficient in a heat pipe,

A correlated relation obtained to relate the overall heat transfer coefficient to the parameters that affect it

D: Pipe diameter (m) .

L: Pipe Length (m) . k: Thermal Conductivity (W/m.K)

ρ_V: Vapor density (kg/m^3) λ : Latent heat (kJ/kg) .

Q : Heat flow rate (W)

μ : Dynamic viscosity (kg/m.s)

$$U=f(D ,L ,K ,F_v ,\rho ,\lambda ,Q,\mu) \qquad (6)$$

m=n-q, n=9, q=4 m=n-q = 9-4 = 5 Groups

n=No. of variables in Problem. Q = No. of basic Variables. m =No. of (π)

For:(π_1)

$$M^0.L^0.T^0.\theta^0 = Q.D^a.K^b.\lambda^c.\mu^d \qquad (7)$$

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$$M^0.L^0.T^0.\theta^0 = \left(\frac{M.L^2}{T^3}\right).(L)^a.\left(\frac{M.L}{T^3.\theta}\right)^b.\left(\frac{L^2}{T^2}\right)^c.\left(\frac{M}{L.T}\right)^d$$
(8)

Using equation (8)

gives a= -1, b=0, c=-1, d=-1

Then: $\pi_1 = \frac{Q}{D.\lambda.\mu_v}$

For:(π_2)

$$M^0.L^0.T^0.\theta^0 = L.D^a.K^b.\lambda^c.\mu^d$$
(10)

$$M^0.L^0.T^0.\theta^0 = (L).(L)^a.\left(\frac{M.L}{T^3}\right)^b.\left(\frac{L^2}{T^2}\right)^c.\left(\frac{M}{L.T}\right)^d$$
(11)

Using equation (11)

gives a= -1, b=0, c=0, d=0

Then: $\pi_2 = \frac{L}{D}$
(12)

For:(π_3)

$$M^0.L^0.T^0.\theta^0 = F_V.D^a.K^b.\lambda^c.\mu^d$$
(13)

$$M^0.L^0.T^0.\theta^0 = \left(\frac{T}{L^4}\right).(L)^a.\left(\frac{M.L}{T^3.\theta}\right)^b.\left(\frac{L^2}{T^2}\right)^c.\left(\frac{M}{L.T}\right)^d$$
(14)

Using equation (14)

gives a= 3, b=0, c=0.5, d=0

Then: $\pi_3 = \sqrt{\lambda}.D^3.F_V$
(15)

For:(π_4)

$$M^0.L^0.T^0.\theta^0 = \rho_V.D^a.K^b.\lambda^c.\mu^d \qquad (16)$$

$$M^0.L^0.T^0.\theta^0 = \left(\frac{M}{L^3}\right).(L)^a.\left(\frac{M.L}{T^3.\theta}\right)^b.\left(\frac{L^2}{T^2}\right)^c.\left(\frac{M}{L.T}\right)^d$$
(17)

Using equation (17)

gives a= 1, b=0, c=0.5, d=-1

$$\pi_4 = \frac{\sqrt{\lambda}.\rho_V.D}{M}$$

Then:

For:(π_5)

$$M^0.L^0.T^0.\theta^0 = U.D^a.K^b.\lambda^c.\mu^d$$
(18)

$$M^0.L^0.T^0.\theta^0 = \left(\frac{M}{T^3.\theta}\right).(L)^a.\left(\frac{M.L}{T^3.\theta}\right)^b.\left(\frac{L^2}{T^2}\right)^c.\left(\frac{M}{L.T}\right)^d$$
(9) (19)

Using equation (19)

gives a= 1, b=-1, c=0, d=0

Then: $\pi_5 = \frac{U.D}{K}$
(20)

$$\frac{U.D}{K} = f\left(\left(\frac{Q}{D.\lambda.\mu}\right)^a, \left(\frac{L}{D}\right)^b, \left(\sqrt{\lambda}.D^3.F_v\right)^c, \left(\frac{\rho.D.\sqrt{\lambda}}{\mu}\right)^d\right)$$

Using (π_1 *to* π_5) yields to

Where : $N_u = \frac{UD}{K}$ $R_e = \frac{Q}{D\lambda\mu}$

Using the data in (6) and the computer program the constants a, b ,c ,and d were calculated. It was found that latent heat vaporization ,diameter and Reynolds number are the parameter affects the overall heat transfer coefficient.

V. RESULTS AND DISCUSSION

Figures . (1),(2),(3), and (4) indicate heat pipe limits variation with vapor temperature .

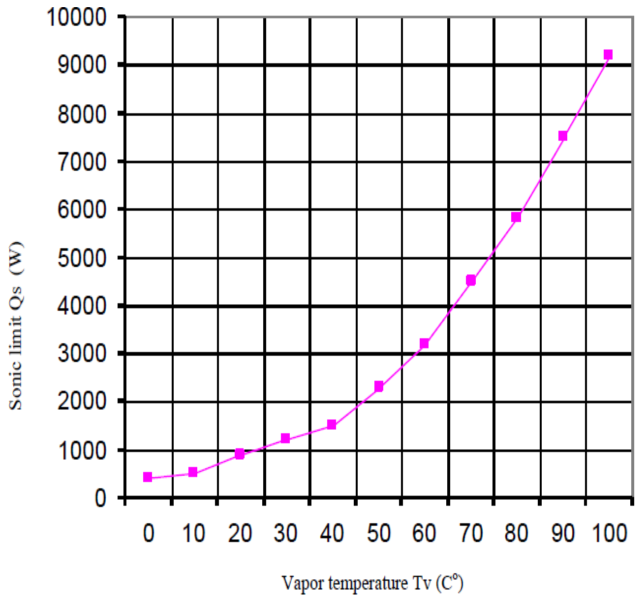

Fig . 1 Sonic limit (Q_s) variation with vapor temp. (T_v)

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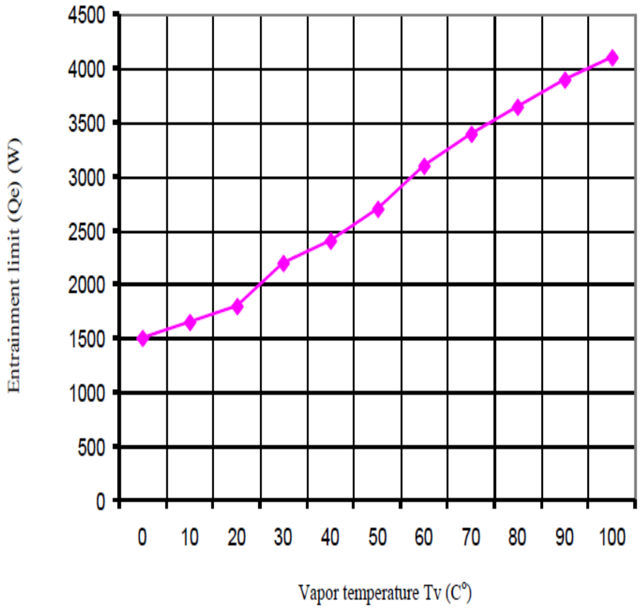

Fig.2 Entrainment Limit (Q_s) variation with vapor temp. (T_V)

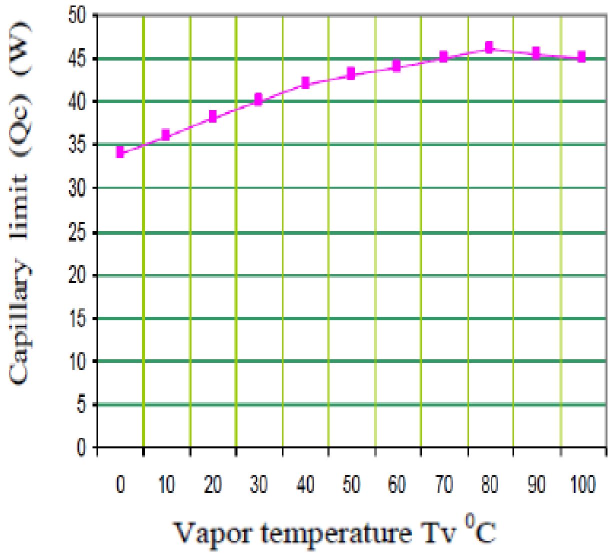

Fig.3 Capillary limit (Q_s) variation with vapor temp. (T_V)

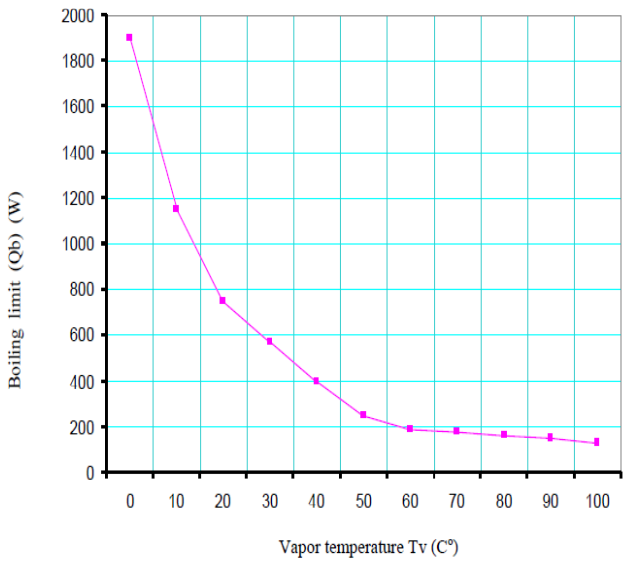

Fig.4 Boiling limit (Q_b) variation with vapor temp. (T_v)

It is shown from Figures.1,2,3 that the sonic limit, entrainment and limit capillary limit, are increased with increasing the vapor temperature .The boiling limit is decreased with the increasing of vapor temperature.

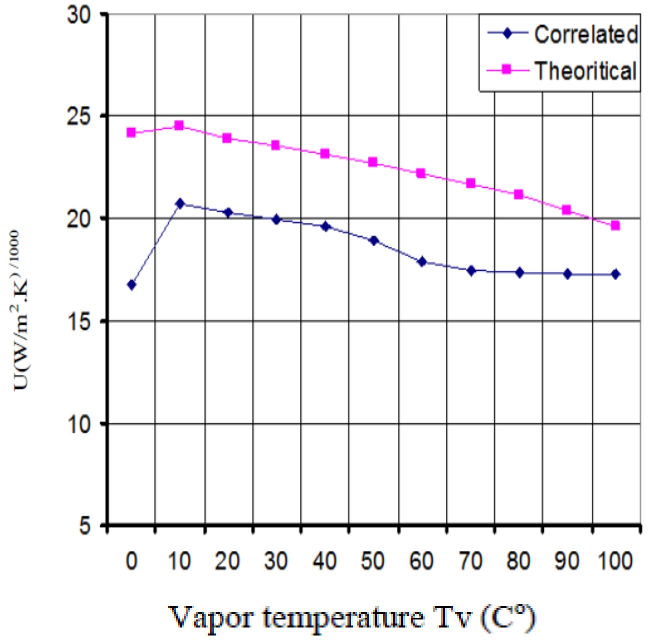

Fig. 5 Comparison between the theoretical and correlated overall transfer coefficient &Vapor temp.

It is indicates from Fig.5 that a little difference between the correlated and theoretical relations for overall heat transfer coefficient of heat pipe at different vapor temperatures.

VI. CONCLUSIONS

1- The following conclusions resulted from this work
2- The sonic limit, entrainment limit and capillary limit increase with increasing the vapor temperature while the boiling limit is decreases with the increasing vapor temperature.
3- 3-Anew correlation for overall heat transfer coefficient has been obtained.
4- It can be seen that the correlated function that relates overall heat transfer coefficient and vapor temperature is very close to the theoretical calculated overall heat transfer coefficient.

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