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Experimental Investigation the Effect of Fluidize Bed Concentration on Heat Pipe Performance

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Abstract: An experimental research was carried out to study the effect of flowing a solid particle with hot air on heat pipe performance, three heat pipes were manufactured with outer and inner diameter of 22.225, 19.8 mm, respectively and with 1000 mm long for both evaporator, condenser and adiabatic sections were (64.5, 34.5,1) cm long, respectively. The three heat pipes were fixed in a wooden box and the cement fly ash was used as a bed particle cross the evaporator part with the hot air, cement fly ash properties were measured experimentally. Tests were done with air velocity range of 3.5-5.5 m/sec and solid particle bed thickness of 2.5, 5 cm, the results show that the Nusselt number was enhanced by 61.5% for the case of 5 cm particle bed thickness and (5.5 m/sec) air velocity with respect to the case of flow of air without solid particle. An acceptable pressure drop will happened for this case which is not exceed (39%).

Key words: Heat pipe, fluidization, particle fluidize bed, thickness, air velocity, manufactured

INTRODUCTION

A heat pipe is a devise included a closed pipe and working fluids. The liquid mass is such that the tube can have simultaneously vapor and liquid phases over the predictable range for operating temperatures. Fluid is moved from the condenser part to evaporator part via. capillarity in a porous material call wick. For this aim, they research in isothermal conditions and have been established to be effective in spacecraft cooling and heat recovery system and many other application due to their light weight and its reliability (Reay *et al*., 2013).

In design ward heat pipe consists of container always pipe with different diameter according to amount of heat wanted to transfer, wick turn inside it to create capillary force required to return the liquid to evaporator part (represent as pumping force) also, number of layer and wick material chosen depend on amount of heat wanted to transfer during heat pipe and working fluid amount of that fluid also, depend on operation condition (Reay *et al*., 2013).

The working fluid inside pipe absorbs heat from one place caused increasing working fluid temperature that leads to evaporate it that happened in evaporator part and then vapor transmit during the hole in heat pipe to condenser part which applied to cooled fluid wanted to be heated it there the vapor loss its heat and transmit to liquid collected at condenser and bay capillary force return to evaporator part and so on (Bejan and Kraus, 2003).

Heat pipe as heat exchangers was used in heat recovery applications. Many researches discuss running enhancement for heat pipe in many types such as changing the wick layer number, type of container material, type of working fluid, changing falling ratio and inclination angle for heat pipe to cool the incoming fresh air in air conditioning application.

Lin *et al.* (2005) discuss the heat pipe design heat exchanger that confronts amount of challenges. The researcher gifts a design method by CFD simulation of the dehumidification procedure by heat pipe heat exchangers the simulation shown as that heat pipe have a good performance in dehumidification process, the researchers showed higher inlet temperature also, flow rate for the saturated moist air can lead to greater heat transfer taken place in the system (Lin *et al*., 2005).

Borundia and Tran (1995) discovers the usage of heat pipes when small heat loads (0.1, 5) W in accuracy engineering applications where the need of steady and close unchanging temperature is stringent. Researchers found that heat pipes reply quite well in transporting randomly variable low heat loads that happen either due to friction among mechanisms in motion or due to concentrated heat input in circumstance of the lithography procedure at steady temperature gradients (Borundia and Tran, 1995).

Guttierrez *et al.* (1998) mathematical analysis has been conducted, to model the flow in an axially revolving heat pipe. The researchers find the thermal physical properties

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for working fluid affected very hard on transport capacity, rotating speed have sever effect in vapor space but it doesn't affect so much in fluid flow inside wick structure (Guttierrez *et al*., 1998).

He *et al*. (2007) used nano fluid TiO_2 flow upward inside vertical pipe and studied it affect on thermal conductivity and also, studied rheological behavior for different (size and concentration) in laminar and turbulent flow. The result showed as addition of nanoparticle to base fluid increased thermal conductivity and that enhancement increased with increasing particle concentration and degrease particle diameter (He *et al*., 2007).

Mahjoub and Mahtabroshan (2008) study incompressible flow in cylindrical coordinates in both vapor region and wick structure for heat pipe numerically using governing equations, Navier-Stokes, energy equations. The results showed as thermal resistance for a conventional tubular heat pipe, raises when growing wick porosity and decreases when increasing thermal conductivity during the wall and the radius of heat pipe (Mahjoub and Mahtabroshan, 2008).

Yang *et al*. (2012) studied the way to reduce heat pipe weight used light weigh material reduce weight for more than 80%, reduce the wick structure can reduces that heat pipe weight but more thin wick layer mean less capillary force that effect on heat pipe efficiency.

Asirvatham *et al*. (2013) experimentally performed how to improve heat pipe heat transfer performance by using silver nano particle with DI-water that happened by increased thermal conductivity with power range (20-100 W), the researcher found 76.2% reduction in thermal resistance and 52.7 enhancement in heat transfer coefficient at used nano with 0.009% concentration.

Ahmad and Rajab (2013) experimentally studied heat pipe working and effected parameter on its performance such as power supply, falling ratio inclination angle, working fluid. The thermal conductivity bay use heat pipe with heptane (C_7H_{16}) as a working fluid be approximately thousand times greater than solid stainless steel bar.

Better heat pipe performance at F.R (50-75)% and inclination angle 500 and the worst at 25% and angle 250 because of dryness happened, since with increased power inter to evaporator part mean more probability to happen dryness (Ahmad and Rajab 2013).

Aldabbagh (2015) descripted the optimum design of heat pipe by using MATLAIP (7) heat pipe performance increased with increasing its diameter and wick cross section area and wick wire diameter and number of wick layer and specific heat for working fluid and also, increased with increasing heat pipe tilting angle.

Hameed and Rageb (2014) muhssan work to find numerical model to calculate the screen mesh effect and evaporator length on heat pipe with water as a working fluid increasing mesh number led to increasing in capillary pressure and decreasing the maximum heat transfer limited also, found the operation temperature increased with mesh number increased. And with increased evaporator part length led to increase the limit of maximum heat transfer and the operation temperature decreased (Hameed and Rageb, 2014).

Majeed and Skheel (2016) experimentally investigate the wick material and structure on heat pipe performance by used (Bronze 150*150, Copper 145*145 and Bronze 200*200) the inside pipe with 6 layers. The heat pipe material should be good for perfect heat pipe performance while wick material has no effect on heat pipe resistance because heat transfer inside heat pipe depends on convection (working fluid motion inside heat pipe) with increased porosity degreased heat resistance.

The copper wick performances better than bronze with low power range in evaporator part because of bronze have greater resistance. One of the most important method to modify heat pipe performance was using fluidization (add solid particle in the fluid path until solid will be behavior like liquid) that process increased heat transfer coefficient in fluidize bed that increased amount of power transfer (Majeed and Skheel, 2016).

Jasem *et al*. (2009) experimental researches were approved out in gas-solid CFBs to examine the steady state case for heat transfer among gas and solid and the surface immersed in the bed, heater power was (105 W), air velocity (4.97, 5.56, 6 m/sec) with different bed high (15, 25, 35) cm with different particle diameter (194, 295, 356 μm). The researcher found that less particle diameter lead to more heat transfer coefficient and also its effect on bed density and porosity (Jasem *et al*., 2009).

Blaszczuk *et al*. (2017) the result of bed particle diameter on local heat transfer coefficient among a fluidized bed and vertical rifled tubes OD (38 mm) with particle range of 0.219-0.4110 mm, furnace with cross section area 27.6×10.6 m and temperature range 1080-1164 k and superficial gas velocity changed from 2.99-5.11 m/sec. The result was total heat transfer coefficient severely dependent on particle diameter and density maximum value in heat transfer coefficient at smaller bed particles size (Blaszczuk *et al*., 2017).

MATERIALS AND METHODS

Experimental apparatus: An experimental rig was manufactured to test the effect of fluidize bed on heat pipe performance. The main rig body made from wood of 1 cm thickness used to make two boxes for (64.5*20*40) cm dimensions that contained evaporator part and other beside it with (34.5*20*40) cm dimensions that contained condenser part, the adiabatic study was (1 cm) thickness which separate evaporator from condenser part. The front face made from class to be easy to show the particle behavior inside evaporator part in front of this box and across the flow direction a flat plate with holes was fixed to get a good air distribution, the plate holes are covered by special textile to prevent particle goes in airline.

Three wicked heat pipes were manufactured and fixed horizontally in the main body to create the evaporator and condenser part as shown in Fig. 1 and 2, after welding two flange at each end of heat pipe putting plate to cover the pipe end and O ring between flange and plate, then full the pipe with air under pressure (10 bar) for two days and watching the pressure drop, after checking heat pipes open all side and turn the stainless steele with (180 hole/inch) out of small diameter pipe which enough for (5 layer) inside heat pipe then but the small pipe inside heat pipe and remove the small one gradually leaving wick inside heat pipe, then reclosed the end bay tight 4 bolt for each one side then evacuated the pipe by 3 mm hole leave at condenser part until (-30 psi) and leave the pipe for one day then charging each one of heat pipe with distilled water which consider as working fluid with amount for each pipe was (65.56 CC) calculate from equation (Harley and Faghri, 1994):

$$(\varphi = Vl/Vw)$$

Where:

φ = Filling ratio and from experiment ideal amount was 255 %

V1 = Amount off working fluid inside heat pipe

Vw = Cross section area for wick

Then test the heat pipe by putting it at hot water and check the velocity at which heat reaches to another part and also, shake it if we hear water sound inside heat pipe that means water doesn't saturated with wick.

From (Harley and Faghri, 1994) equation working fluid was (65.56 mL) put it at buret and closed valve A and open each C and B valve and running the evacuated pump for half an hour and immersed the heat pipe in boiling water at that procedure all the air was exit from heat pipe and the pressure inside heat pipe was reach to

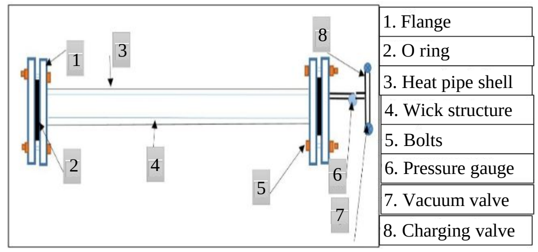

Fig. 1: Heat pipe and charging system

Fig. 2: Wick turn inside heat pipe

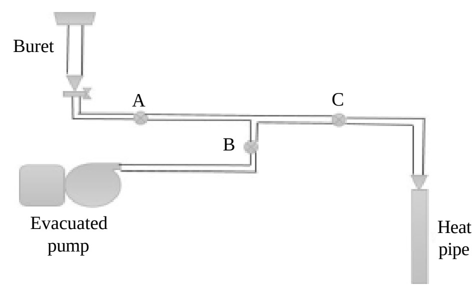

Fig. 3: Charging unit

Fig. 4: Gauge on heat pipe condenser

(-30 psi) then closed the valve B and open gradually the valve A and put the heat pipe in ice water the working fluid was inter to heat pipe and closed valve A when working fluid finished and valve C also closed, the valve C will be remain in heat pipe at the same way, we charged each one of three heat pipes (Fig. 3 and 4).

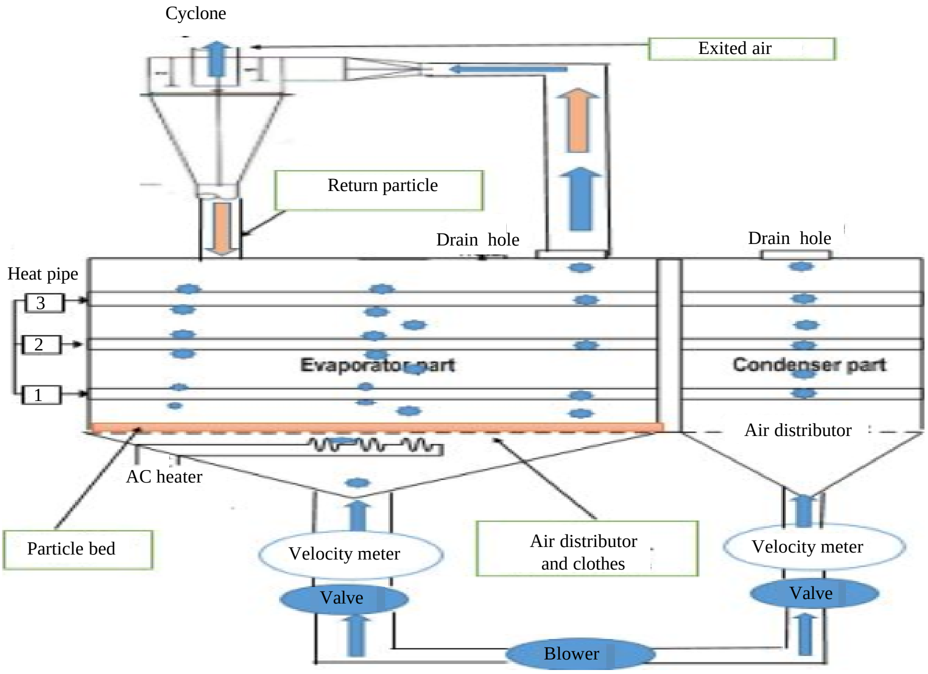

Fig. 5: Rig schematic diagram

Heat pipe have many limitation was calculated at operation temperature properties which calculated from equation:

$$T_V = \frac{T_{Se}L_e + T_{Sc}L_c}{L_e + L_c}$$

And after calculation it found equal to 60°C the water properties taking at that temperature to calculate heat pipe limitation which found (Table 1 and 2).

Used at present work cyclone to return the partial to box and heater with capacity of 2860 W to heat air before interring to evaporator box and use blower multispeed with Gunt HL710 type (1 kW) then calculate air flow rate used hot wire anemometer model (TES 1340) (Fig. 5 and 6).

Experimental procedure: Run the system to explain if there was air leak or no then start with taking reading procedure:

- Setup the evaporator line with velocity 3.5 m/sec and condenser 3 m/sec
- Run the heater and start taking reading from data logger for time step 2 min and for long time 30 min
- Measured pressure drop by water manometer
- Stop data logger recording and turn off heater and leave blower run to cool heat pipe until reach to start temperature

Table 1: Present work heat pipe limitation

Capillary limit	Viscous limit	Sonic limit	Entrainment limit
$3.1813*10^4$	$23.08*10^5$	$15.637*10^3$	$17.013*10^3$

Table 2: Heat pipe properties

Name	Symble	Values
Container outer diameter	(D_o)	22.225 (mm)
Container inner diameter	(D_i)	19.8 (mm)
Overall length	L	1000 (mm)
Evaporator length	L_e	645 (mm)
Condenser length	L_c	345 (mm)
Adiabatic length	L_a	10 (mm)
Working fluid	Distilled water	65.56 (cc)
Porosity	ε	0.773
Number of screen layer	No	5
Vapour radius	rv	9.35 (mm)
Wick zone thickness	t	0.55 (mm)

- Change the evaporator air speed to 4.5 m/sec and leave condenser 3 m/sec
- Repeat steps 2-4
- Change the evaporator air speed to 5.5 m/sec and leave condenser 3 m/sec
- Repeat steps 2-4
- Open the upper box cover and add cement fly ash with high 2.5 cm from box base and recovered it and put silicone to prevent fly ash leakage
- Repeat steps from 1-8
- Repeat step 9 for particle high (5) cm and getting all temperature reading and pressure drop under each velocity and each loading particle height

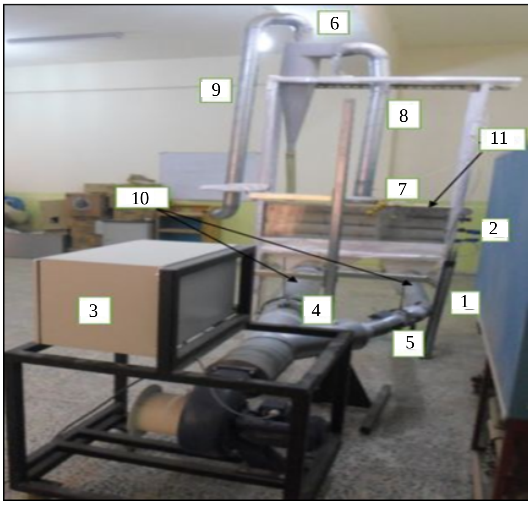

Fig. 6: Rig photo: 1) Water manometer; 2) Heat pipes; 3) Blower; 4) Evaporator valve; 5) Condenser valve; 6) Cyclone; 7) Thermocouples; 8) Rising pipe; 9) Exhaust pipe; 10) Velocity port and 11) Drain hole

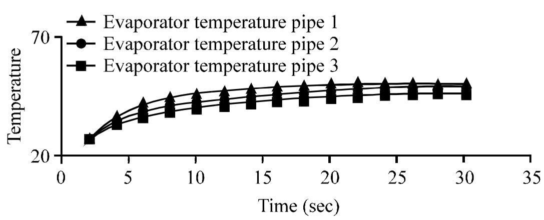

Fig. 7: Increased temperature in heat pipes at evaporator part at particle thickness 2.5 cm and velocity = 3.5 m/sec

RESULTS AND DISCUSSION

Evaporator temperature: Figure 7 represents the temperature variation for evaporator part of three heat pipes with time which is show that the steady state case will reached at 30 min from starting point.

Heat pipe location: Figure 8 shown that the heat pipe number (1) have maximum amount of heat gain because of its location which is closed to heat source and also big amount of particles impact it.

Particle bed thickness: Figure 9a-c taking in consideration the effect of particle bed thickness at different velocities (3.5-5.5 m/sec) for each pipe shown that biggest amount of heat gain could found at maximum velocity 5.5 m/sec and highest particle bed 5 cm, that's because amount of particle impact the pipe increased and each particle carried amount of heat to pipe that lead to more heat gain at highest velocity and highest bed thickness.

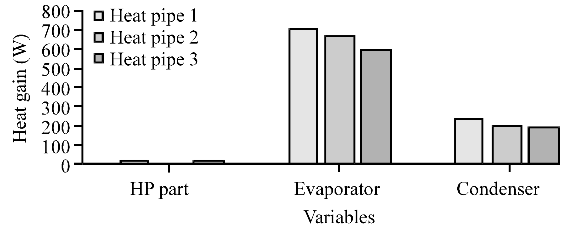

Fig. 8: Heat pipe place effect on heat gain

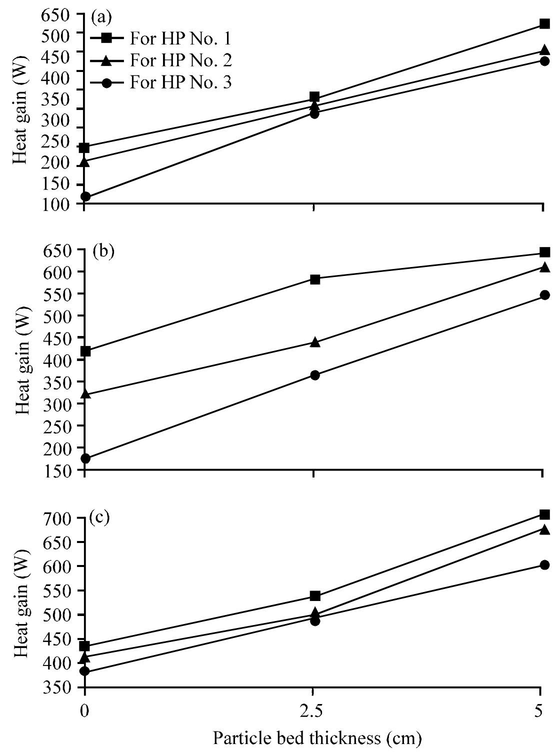

Fig. 9: The particle bed effect on heat gain for all heat pipes at different velocities: a) v = 3.5 m/sec; b) v = 4.5 m/sec and c) v = 5.5 m/sec

Porosity variation effect: Figure 10 represent that porosity increased when degreased particle bed high and that because of decreased amount of practical in region and also noted that at increased velocity porosity was degreased because at high velocity there was more amount of pressure drop.

Velocity variation effect: Figure 11 shown that maximum heat gain at highest velocity and at highest particle bed thickness and that because of number of particle impact the pipe at unit time was increased.

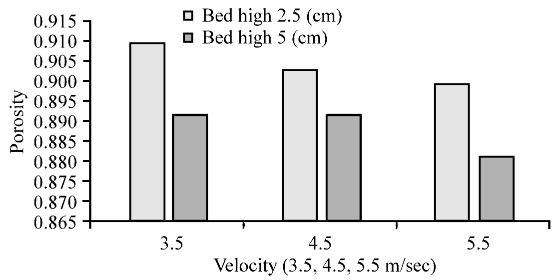

Fig. 10: The effect of particle bed thickness on the porosity for different velocities

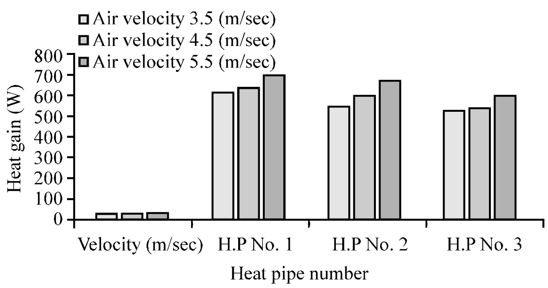

Fig. 11: Velocity effect on heat gain; Q for each pipe at 5 cm partical high

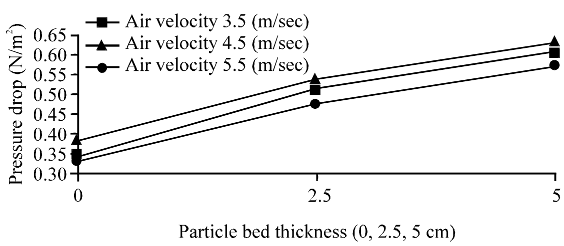

Fig. 12: Pressure drop with bed and velocity

Pressure drop: Figure 12 represents pressure drop at different particle bed and different velocity and clearly could note that pressure drop increased with increased velocity because of more energy losses at high speed because of particle impact together and impact between particle and wall also increased with increasing particle bed height since increased flow resistance.

Compound heat transfer coefficient and heat gain related for different particle bed thickness: Figure 13 appear the relation between heat transfer coefficient and heat gain with respect to particle bed thickness and velocities and showed clearly that maximum amount of H and Q found at higher velocity 5.5 m/sec and at higher bed thickness 5 cm and that because of maximum amount of fluidization appears at that values.

Nusselt number variation with renoldes number: Figure 14a-c represent relation between Nusselt and

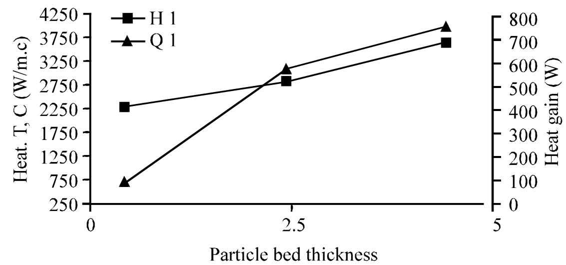

Fig. 13: Heat transfer coefficient and heat gain with particle bed thickness

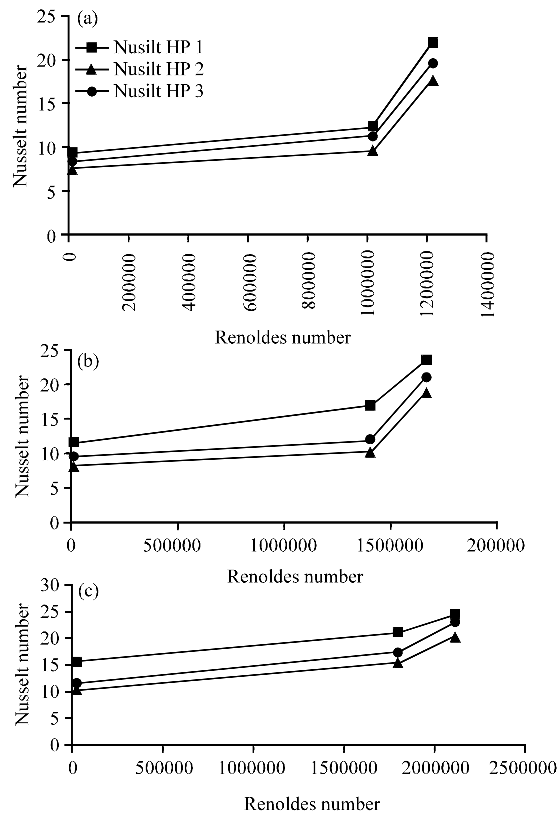

Fig. 14: The relation between Nusselt and Renoldes numbers for all heat pipe at different particle bed thickness and velocities: a) v = 3.5 m/sec; b) v = 4.5; c) v = 5.5 m/sec

Renoldes numbers for different velocities, Fig. 14 shows that maximum Nusselt number (24) occur at maximum Renoldes number ($21*10^5$) to heat pipe number (1) and at higher particle bed thickness (5 cm).

CONCLUSION

Heat pipe number (1) gain heat greater than heat pipe number (3) with 57% at air velocity 4.5 m/sec and no particle and maximum heat transfer to condenser part equal to 32.8% from inlet heat in evaporator at particle bed thickness 5 cm and air velocity 5.5 m/sec. Increased particle bed thickness by 5 cm increased heat transfer to heat pipe by 38%. Increased Renoldes number from 12144-2108822 increased heat gain by 57%. Maximum Nusselt number (24) occur at maximum renoldes number 2108822 at particle bed thickness 5 cm at heat pipe number (1).

REFERENCES

Ahmad, H.H. and R.H. Rajab, 2013. A heat pipe performance with heptane as a working fluid. Eng. Technol. J., 31: 646-660.

Aldabbagh, M.S., 2015. Optimum design of a heat pipe. AL Rafdain Eng. J., 23: 133-146.

Asirvatham, L.G., R. Nimmagadda and S. Wongwises, 2013. Heat transfer performance of screen mesh wick heat pipes using silver-water nanofluid. Intl. J. Heat Mass Trans., 60: 201-209.

Bejan, A. and A.D. Kraus, 2003. Heat Transfer Handbook. John Wiley and Sons, New York.

Blaszczuk, A., W. Nowak and J. Krzywanski, 2017. Effect of bed particle size on heat transfer between fluidized bed of group b particles and vertical rifled tubes. Powder Technol., 316: 111-122.

Borundia, A. and H.D. Tran, 1995. An experimental investigation of heat pipes at low power inputs. University of New Mexico, Albuquerque, New Mexico.

Guttierrez, F., G. Ke, C. Er and S. Sj, 1998. Preliminary estimate of coriolis force of vapor flow in rotating heat pipes based on analytical solution. Intl. J. Photoenergy, 116: 1116-1117.

Hameed, H.G. and A.M.A. Rageb, 2014. Numerical investigation of the effect of wire screen mesh specification and evaporator length on thermal performance of cylindrical heat pipe. Basrah J. Eng. Sci., 14: 240-254.

Harley, C. and A. Faghri, 1994. Complete transient two-dimensional analysis of two-phase closed thermosyphons including the falling condensate film. ASME J. Heat Transfer, 116: 418-426.

He, Y., Y. Jin, H. Chen, Y. Ding and D. Cang *et al*., 2007. Heat transfer and flow behaviour of aqueous suspensions of TiO_2 nanoparticles (nanofluids) flowing upward through a vertical pipe. Intl. J. Heat Mass Trans., 50: 2272-2281.

Jasem, N.M., G.M.H. Fadhil and H.H. Mohammed, 2009. Experimental study of the effect bed density on heat transfer coefficents in towers with gas-solid circulating fluidized bed. Al Qadisiya J. Eng. Sci., 2: 608-619.

Lin, S., J. Broadbent and R. McGlen, 2005. Numerical study of heat pipe application in heat recovery systems. Appl. Therm. Eng., 25: 127-133.

Mahjoub, S. and A. Mahtabroshan, 2008. Numerical simulation of a conventional heat pipe. World Acad. Sci. Eng. Technol., 39: 117-122.

Majeed, M.H. and O.R. Skheel, 2016. Experimental study of wick structure material and screen mesh on heat pipe performance. Iraqi J. Mech. Mater. Eng., 16: 339-349.

Reay, D.A., R.J. McGlen and P.A. Kew, 2013. Heat Pipes: Theory, Design and Applications. 6th Edn., Butterworth-Heinemann, Oxford, UK., ISBN:978-0-08-098266-3, Pages: 250.

Yang, X., Y.Y. Yan and D. Mullen, 2012. Recent developments of lightweight, high performance heat pipes. Appl. Therm. Eng., 33: 1-14.