An Experimental Design Study on CO_2 and CH_4 Adsorption Equilibria in MWCNT-OH and Optimal Conditions for Maximum CO_2 Adsorption against CH_4

M. Salmasi[1], M. Doroudin[1], Sh. Fatemi*, M. Cyrus[1], Z. Hajjar[1]

[1] *MSc students of Chemical Engineering, university of Tenhran*
Associate professor, Chemical engineering, University of Tehran, Englelab Ave.

shfatemi@ut.ac.ir

Abstract
Equilibrium adsorption property of multi-walled carbon nanotubes functionalized by hydroxyl group (MWCNT-OH) was studied using experimental design for adsorption of CH_4 and CO_2. The effect of temperature, pressure and their interaction on the adsorption capacity was examined by the central composite orthogonal design (CCOD) and the significant effects were determined by analysis of variance. The experiments were carried out at various temperatures (from 288.15 to 308.15 K) and pressures (4.5 to 39.8 bars) to find out the optimal conditions for the maximum adsorption of CO_2 versus CH_4 on the MWCNT-OH. The statistical analysis of the results showed the significance of linear, interaction and quadratic relation of temperature and pressure to CO_2 and CH_4 adsorbed capacity. After optimization, the maximum CO_2/CH_4 selectivity was determined at temperature of 288.15 K and pressure of 21.32 bar which was predicted as 6.35.

Keywords: Design of experiment (DOE), Central composite orthogonal design (CCOD), MWCNs, light gas adsorption

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Effect of a magnetic field on the Copper oxide/water nanofluid heat transfer enhancement in two-phase closed thermosyphon

H. Salehi[a, b], S. Zeinali Heris[a, b], S. H. Noie[a, b]

[a] *Department of Chemical Engineering, Engineering Faculty, Ferdowsi University of Mashhad, Mashhad, Iran*
[b] *Heat pipe and nano fluid research center, Engineering Faculty, Ferdowsi University of Mashhad, Mashhad,*

Abstract
The application of two-phase closed thermoyphon is increasing in heat recovery systems in many industrial practices because of their high effectiveness. The enhancement heat transfer of the heat transfer devices can be done by changing the fluid transport properties and flow features of working fluids. In the present study, therefore, the decrease of thermoyphon thermal resistance with nanofluid is presented. The distillated water is used as a base working fluid while the nanoparticles used in the present study are the copper oxide nanoparticles with diameter of 30-50nm. Effects of magnetic field and nanoparticles volume concentrations on the thermal resistance of thermoyphon are considered. The nanoparticles and magnetic field have a significant effect on the enhancement of thermal resistance of heat pipe.

Keywords: Nanofluid; two-phase closed thermosyphon; magnetic field

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H. Salehi [a, b], S. Zeinali Heris [*a, b] , S. H. Noie [a, b]

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1. Introduction

The application of a magnetic field in various research areas has significantly increased in recent years. A strong magnetic field can influence the behavior or movement of non-electro-conducting fluids, on which a weak magnetic field has limited effect. The effect of the magnetic buoyancy force on the convection of paramagnetic fluids was first reported by Braithwaite et al. [1], who described the suppression or enhancement of gravitational convection of paramagnetic fluid by a magnetic field. Ikezoe et al. [2] succeeded in droplet levitation not only diamagnetic but also for paramagnetic fluids, while the groups of Wakayama investigated the behavior of air as a paramagnetic fluid in a strong magnetic field. New magnetoaerodynamic phenomena such as airflow generation [3] and the promotion of combustion [4] were found.

The two-phase closed thermoyphon is widely used because of their simple structure when compared with other types of heat pipes. Therefore, thermoyphon are being used in many applications such as: heat exchangers (air pre-heaters or systems that use economizers for waste heat recovery), cooling of electronic components, solar energy conversion systems, spacecraft thermal control, cooling of gas turbine rotor blades, etc. [5]. Li et al. [6] investigated experimentally the steady-state heat transfer characteristics of a vertical two-phase closed thermoyphon at low temperature differences with R11, R22, and water as working fluids. Park and Lee [7] made an experimental study on the performance of stationary two-phase closed thermoyphon with three working fluid mixtures (Water–glycerin, water ethanol, and water–ethylene glycol). Yoshiharu and coworker [8] investigated the influence of transverse magnetic field on heat transport characteristic of potassium heat pipe. B. Jeyadevan and coworker [9] evaluated the performance of heat pipe (HP) using citric ion-stabilized magnetic fluid (CMF) as working fluid (WF). El_zbieta Fornalik et.al [10] investigated effect of a magnetic field on the convection of paramagnetic fluid in unstable and stable thermoyphon-like configurations. There were seen some application of nano-fluid in heat pipe. Yu-Tang Chen

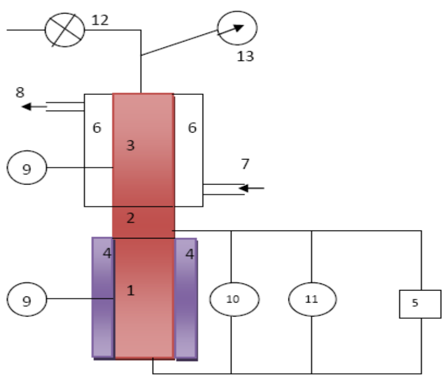
[*] Corresponding author email: zeinali@ferdowsi.um.ac.ir, Fax: (+98) (511) 8816840
Tel: (+98) (511) 8816840

et.al [11] investigated the effect of Nanofluid on Flat Heat Pipe Thermal Performance. Paisarn Naphon [12] investigated effect titanium nanofluid on the heat pipe thermal efficiency. Sameer Khandekar studied Thermal performance of closed two-phase thermoyphon using nanofluid. Noie et al. [13] prepared Nanofluids of aqueous Al2O3 nanoparticles suspensions in various volume concentration of 1% ~3% and used in a TPCT as working media. They showed that for different input powers, the efficiency of the TPCT increases up to 14.7% when Al2O3/water nanofluid was used instead of pure water.

In the present investigation, the effect of a permanent magnetic field on the convection of silver nano-fluid water as a paramagnetic fluid in two-phase closed thermoyphon is experimentally presented.

2. Experimental apparatus and procedures

Figure 1 shows Schematic of experimental set up. The test rig consists of a heater, a condenser for cooling the condensation section. Two parallel plates of permanent magnet, and also measuring instruments. The upper part of the thermoyphon was equipped with a vacuum seal valve for connection to a mechanical vacuum pump and to the working fluid charging line. Working fluid are pure water and copper oxide nano-fluid. Various concentrations have been used (1.5% vol, 2% vol, and 2.5% vol).



1. Evaporasation section
2. Adiabatic section
3. Condensation section
4. Permanent magnet
5. Power supply
6. Shell of condenser
7. Inlet running water
8. Outlet running water
9. Mini-thermometer
10. Ampere meter
11. Volt meter
12. Vacuum valve
13. Pressure gauge

figure 1: Schematic of experimental test rig.

A mechanical vacuum pump capable of up to -0.9 bar absolute and pumping capacity of 142 l/min was used for partial elimination of the non-condensable gases (NCG) from the thermoyphon. Figure 1 show the detail of experimental apparatus. The thermoyphon consisted of a 400 mm long copper tube having an inside diameter of 20 mm and outside diameter of 25 mm. The tube was sealed at one end and was provided with a vacuum valve at the other. The evaporator and adiabatic sections had a total length of 0.25m. The length of the evaporator section was varied by varying the length of the electrical resistance. The condenser section of the pipe consisted of a 0.15 m long (45 mm OD) concentric tube acting as running water jacket surrounding the pipe. An electrical resistance of a nominal power 250 W, which was wrapped around the evaporator section, heated the evaporator section. To prevent the heat loss, the electric elements were insulated by Rock Wool having a thickness of 20 mm and 10 mm in evaporasation, adiabatic sections and condensation section respectively. The power supplied to the evaporator section was determined by monitoring the applied voltage and ampere. Running water inlet and outlet temperatures were measured using digital mini-thermometer with an accuracy ± 0.1ºC. The nanofluid was charged into the tube under -0.9 bar absolute vacuum pressure. The mini-thermocouples were mechanically attached to the surface of the pipe. Permanent magnets (0.12T, 0.35T, and 1.2 T) are placed on the evaporasation section.

The rate of heat transfer to the evaporator section was calculated from the following relation:

$$Q_{in} = VI \tag{1}$$

The rate of heat removal from the condenser section was obtained from the following relation:

$$Q_{out} = \dot{m} Cp(T_o - T_i) \tag{2}$$

Therefore heat of loss was obtained from the following relation:

$$Q_{loss} = Q_{in} - Q_{out} \tag{3}$$

Where

$$Q_{out} = Q_{net,conv} = \dot{m} Cp(T_o - T_i) \tag{4}$$

And

$$Q_{net,conv} = \frac{\pi}{4} d^2 k \dot{m} \frac{\Delta\theta}{l} \tag{5}$$

Test procedure began by charging distilled water as working fluid. Experiments were carried out with increasing input heat in the range of $12 < Q < 60W$ to the evaporator section. After 30-40 min, when the system reached the steady state, Data was recorded when the system reached steady-state condition. The hot and cold wall temperatures were measured by thermocouples to provide the thermal resistance. Also inlet and outlet temperatures of running water were measured to provide the rate of heat removal from condenser section.

Afterwards the magnetic field was applied to the system. The permanent magnetic was changed from 0 up to 1.2 T. After 15-20 min, when the system reached the steady state, before procurers were repeated.

In this research effect of magnetic field is investigated on thermal resistance that was obtained from the following relation:

$$R_{th} = \frac{\Delta\theta}{Q_{in}} \tag{6}$$

There were seen magnetic field have no effect on the distillated water. Therefore we don’t consider results in relation of distillated water.

3. Experimental results and discussion

Figure 2 shows the thermal resistance distribution according to magnetic field for various concentrations of nano-fluid. By using the magnetic field, it was seen that the thermal resistance of thermosyphon was increased about 9.3% compared to thermosyphon without magnetic field.

As it was seen, the increase of nanofluid concentration from 1.5% vol up to 2.5% vol and the magnetic field from zero to 1.2 T resulted in the reduction of thermal resistance of thermoyphon about 9.31%.

The causes of these changes are magnetic field and nanofluid. Because of the presence of nano particles in the fluid the thermal conductivity increases which results in the improvement of total heat transfer coefficient, and therefore thermal resistance reduces. Magnetic field affects on thermosyphon performance in following ways:

1. release the bubbles which accumulated on the inner wall of evaporator;
2. reduce temperature fluctuation in the evaporation section;
3. reduction of temperature difference between the fluid and wall; consequently, occurring critical heat flux a shorter time;
4. Increase of vapor movement due to Lorentz force.
5. Increase of liquid turbulency in evaporator dump.

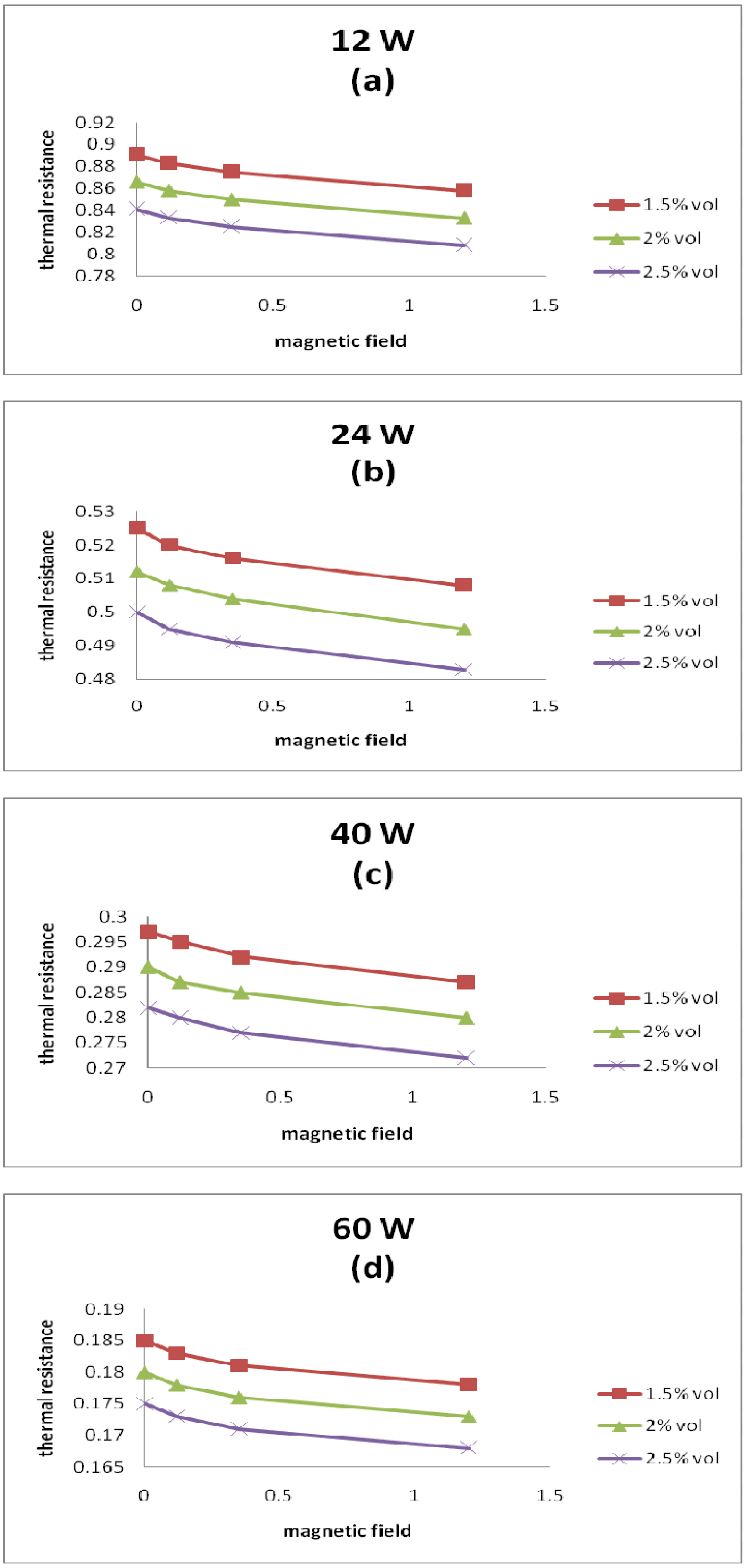


Figure 2: effect of magnetic field on the thermal resistance for (a) 12W, (b) 24W, (c) 40W and (d) 60W.

4. Conclusions

This preliminary study investigated the effect of thermoyphon thermal resistance and Nusselt number using CuO/water nanofluid as a working fluid under magnetic field. The thermal resistance of the thermoyphon with the Copper oxide nanoparticles suspension under magnetic field was lower than that of without magnetic field effect. Also the application of magnetic field increases the Nusselt number in the thermoyphon.

Notations

Q_{in} :	Input power	W
Q_{out} :	Output power	W
Q_{loss} :	Power of loss	W
$Q_{ner,conv}$:	Net convection heat transfer	W
$Q_{net,cond}$:	Net conduction heat transfer	W
V :	voltage	V
I :	ampere	A
T_o :	Outlet temperature	$^\circ C$
T_i :	Inlet temperature	$^\circ C$
C_p :	Heat capacity of water @ 25 $^\circ C$	$j/Kg.^\circ C$
$\dot{m}$:	Mass flow rate of running water	$Kg/.s$
$\Delta\theta$:	Temperature difference between vaporization and condensation sections	$^\circ C$
R_{th} :	Thermal resistance	$W/.^\circ C$

References

1. Braithwaite, D., Beaugnon, E., Tournier, R., "Magnetically controlled convection in a paramagnetic fluid", Nature, 354, 134 (1991).

2. Ikezoe, Y., Hirota, N., Nakagawa, J., Kitazawa, K., "Making water levitate", Nature, 393, 749 (1998).

3. Wakayama, M., Wakayama, N.I., "Magnetic acceleration of inhaled and exhaled flows in breathing", Jpn. J. Appl. Phys., 39, 262 (2000).

4. Wakayama, N.I., "Magnetic promotion of combustion in diffusion flames", Combust. Flame, 93, 207 (1993).

5. Dunn, P.D., Reay, D.A., Heat pipes, third ed. Pergamon press, p.144, (1994).

6. Li, H., Akbarzadeh, A. Johnson, P., "The thermal characteristics of a closed two-phase thermoyphon at low temperature difference", Heat Recovery Systems & CHP, 11 (6), 533 (1991).

7. Park, R., Lee, Y., "Two-phase closed thermoyphon with two fluid mixtures", in: Proceedings of 8th International Heat Pipe Conference, Beijing, China, Vol. 2, pp. 220–225, (1992).

8. Fuzakawa, Y. and Fujii-E, Y., "Influence of Transverse Magnetic Field on Heat Transport Characteristics of Potassium Heat Pipe", Journal of NUCLEAR SCIENCE and TECHNOLOGY, 15 (10), 719 (1978).

9. Jeyadevan, B., Koganezawa, H., Nakatsuka, K., "Performance evaluation of citric ion-stabilized magnetic fluid heat pipe", Journal of Magnetism and Magnetic Materials, 289, 253 (2005).

10. Fornalik, E., Filar, P., Tagawa, T. H., Ozoe, Szmyd, J. S., "Effect of a magnetic field on the convection of paramagnetic fluid in unstable and stable thermoyphon-like configurations", International Journal of Heat and Mass Transfer, 49, 2642 (2006).

11. Shung-Wen K. , Wei-Chiang W. , Sheng-Hong T. , Shih-Yu Y., "Experimental investigation of silver nano-fluid on heat pipe thermal performance", Applied Thermal Engineering, 26, 2377 (2006).

12. Naphon, P., Assadamongkol, P., Borirak, T., "Experimental investigation of titanium nanofluid on the heat pipe thermal efficiency", International Communications in Heat and Mass Transfer, 35, 1316 (2008).

13. Noie, S.H., Zeinali Heris, S., Kahani, M., Nowee, S.M., "Heat transfer enhancement using Al2O3/Water nanofluid in a two-phase closed thermosyphon, Int. J. Heat Fluid Flow, 30, 700 (2009).

تاثیر میدان مغناطیسی روی انتقال حرارت نانوسیال آب/ نانوذرات اکسید مس در یک ترموسیفون دوفازی بسته

هادی صالحی ، سعید زینالی هریس* ، سید حسین نوعی باغبان

دانشگاه فردوسی مشهد- دانشکده مهندسی –گروه مهندسی شیمی – آزمایشگاه نانوسیال و لوله حرارتی

چکیده

امروزه لوله حرارتی به منظور افزایش و بهره وری انتقال حرارت در بسیاری از فرآیندها و کار های تحقیقاتی مورد استفاده قرار می گیرد. در این مطالعه تاثیر همزمان 3 پارامتر مهم که به منظور افزایش راندمان انتقال حرارت مورد مطالعه قرار می گیرد تحت بررسی قرار گرفته است. یعنی بطور همزمان استفاده از نانوسیال در یک ترموسیفون دوفازی بسته که میدان های مغناطیسی متفاوتی بر آن اعمال می گردد با غلظتهای مختلف نانوسیال و بارهای حرارتی متفاوت مورد مطالعه قرار گرفته و به صورت نمودارهایی تاثیر غلظت ذرات و اندازه میدان اعمال شده روی کاهش مقاومت حرارتی نانوسیال نسبت به آب خالص و نیز زمانی که هیچ میدان مغناطیسی اعمال نمي شود ارائه گردیده است و کاهش حدود 9/31 % مقاوت حرارتی ترموسیفون گزارش شده است.

کلمات کلیدی: نانوسیال، میدان مغناطیسی، ترموسیفون دوفازی بسته

* Corresponding author email: zeinali@ferdowsi.um.ac.ir, Fax: (+98) (511) 8816840
Tel: (+98) (511) 8816840