Polytechnic Journal
Polytechnic Journal

Volume 8 | Issue 2 Article 17

5-1-2018

Numerical Study of Heat Transfer Enhancement of Nanofluids Spry in Shell and Tube Heat Exchangers

Ranj Sirwan Abdullah
Erbil Technical Engineering College, Erbil Polytechnic University, ranj.abdullah@epu.edu.iq

How to Cite This Article
Abdullah, Ranj Sirwan (2018) "Numerical Study of Heat Transfer Enhancement of Nanofluids Spry in Shell and Tube Heat Exchangers," *Polytechnic Journal*: Vol. 8: Iss. 2, Article 17.
DOI: https://doi.org/10.25156/ptj.2018.8.2.206

Numerical Study of Heat Transfer Enhancement of Nanofluids Spry in Shell and Tube Heat Exchangers

Abstract

A variety of heat exchangers are available for the evaporator in absorption cooling system. In this work a comparison of spray film evaporator for different liquid sprays such as liquid NH3, Ag-NH3 and CuO-NH3 nanofluids on the stainless steel shell & tubes heat exchanger has been investigated theoretically. The effects of saturation temperatures and flow rate of ejected liquid spray have been studied. The results show that the nanofluids demonstrate enhancement of heat transfer rate comparing to the base working fluid, (NH3). Ag-NH3 nanofluids provides higher heat transfer performance than CuO-NH3 nanofluids for the same volume fraction and nanoparticles size. In addition, the results show that the increase of the flow rate will increase the heat transfer rate at different rates, depending on the working fluids. Furthermore, the results show that the shell side heat transfer performance improved as the saturation temperature decreased, for all tested working fluids. Finally, the enhancement of the heat transfer rate between the pipes and the shell side, yields a decrease of the overall temperature of the chilled water inside the pipes. This study provides base data for more investigation of the enhancement of evaporator heat exchange, inside the cooling systems.

Polytechnic Journal: Vol.8 No. 2 (May 2018): Pp: 324-346
http://epu.edu.krd/ojs/index.php/Journal

Numerical Study of Heat Transfer Enhancement of Nanofluids Spry in Shell and Tube Heat Exchangers

Ranj Sirwan Abdullah

Mechanical and Energy Engineering Department, Erbil Technical Engineering College, Erbil Polytechnic University

ABSTRACT

A variety of heat exchangers are available for the evaporator in absorption cooling system. In this work a comparison of spray film evaporator for different liquid sprays such as liquid NH_3, Ag-NH_3 and CuO-NH_3 nanofluids on the stainless steel shell & tubes heat exchanger has been investigated theoretically. The effects of saturation temperatures and flow rate of ejected liquid spray have been studied. The results show that the nanofluids demonstrate enhancement of heat transfer rate comparing to the base working fluid, (NH_3). Ag-NH_3 nanofluids provides higher heat transfer performance than CuO-NH_3 nanofluids for the same volume fraction and nanoparticles size. In addition, the results show that the increase of the flow rate will increase the heat transfer rate at different rates, depending on the working fluids. Furthermore, the results show that the shell side heat transfer performance improved as the saturation temperature decreased, for all tested working fluids. Finally, the enhancement of the heat transfer rate between the pipes and the shell side, yields a decrease of the overall temperature of the chilled water inside the pipes. This study provides base data for more investigation of the enhancement of evaporator heat exchange, inside the cooling systems.

Key words: *Heat exchanger, Impact spray cooling, Spray-film evaporation, Spray type heat exchanger, Shell and tube evaporator, Horizontal tubes evaporator, Nanofluids.*

Nomenclature

C_p	Specific heat capacity (J/ (kg.K))
T	Absolute temperature (K)
t	Time (s)
u	Velocity vector (m/s)
q	Heat flux by conduction, heat transfer rate (W/m^2)
P	Pressure (pa)
S	Strain rate tensor: $1/2(\nabla u + (\nabla u)^T)$ (1/s)
Q	Heat sources other than viscous heating (W/m^3)
F	Volume force vector [N/m^3]
K	Thermal conductivity (W/ (m.K))
C	Specific heat capacity (J/Kg.K)

Greek symbols

ρ	Density (kg/m$^{3)}$
τ	Viscous stress tensor (Pa)
μ	Viscosity (kg/m.s)
φ	Volume fraction
β	Phase index
ε	Heat exchanger effectiveness

Subscripts

f	Basefluid
nf	Nanofluid
p	Particle
max	maximum
min	minimum
hi	hot liquid in
ci	cold liquid in

INTRODUCTION

Since the heating, ventilation and air conditioning (HVAC) equipment consumes a large amount of energy in the residential and commercial buildings. The worldwide alert about the green house effects has led to an increasing interest in developing and improving much more environmental friendly HVAC systems. One of the utilized HVAC equipment is the absorption cooling system. The advantage of using the absorption system its environmental friendliness and zero depletion potential of the working fluids such as ammonia solution (Misra et al., 2006). Using renewable energy sources will reduce the amount of using conventional energy. Furthermore, saving energy leads to saving environment and therefore saving the world (Kilic, 2011). The evaporator heat exchanger is one of the major sub-components which produces the cooling effect in the absorption cooling cycle. Shell and tube heat exchanger type with spray falling film is used in evaporator sub-system of the absorption system. The spray evaporation "falling film evaporation" heat exchanger has two major benefits compared to the conventional pool (flooded evaporator). The first benefit is the reduction in the refrigerant mass inventory inside the evaporator by 20-90%. Secondly, the spray evaporation process can increase the heat-transfer performance and the energy efficiency (Tong-Bou, 2009). Moreover, the purpose of spray evaporation process is to maximize the heat-transfer duty while minimizing the heat-exchanger size (Ayub et al., 2006).

(Tong-Bou, 2009) investigated experimentally the effect of an interior spray method on enhancing the heat-transfer performance of a spray evaporator system using a triangular-pitch bundle. The results showed that the new technic increases the heat transfer rate. Furthermore, the heat-transfer flux improved as the saturation temperature decreased as, the density and the thermal conductivities of the spray liquid increased. In addition, the heat transfer coefficient increases with an increase in refrigerant mass flow rate for constant heat flux and saturation temperature.

(Chang, 2006) investigated the effect of impact spray on cooling heat transfer in a heat exchanger; shell and tube evaporator system. This study discovered that the shell side heat transfer performance depends mainly on the nozzle diameter, heat flux and spray mass flow rate, but slightly on the height of the nozzles. Moreover, the function of the liquid catcher fitted to the underside of tubes in the bundle is to reduce the dry-out phenomenon that occurs when the surface heat flux increases. In addition, he observed that the heat-transfer performance for spray cooling with liquid catchers is superior to that of the pool boiling under both low and high heat flux. (Zeng et al., 2001a, Zeng et al., 2001b) conducted an experimental work on spray evaporation of ammonia using spray nozzles and horizontal 3-2-3 triangular-pitch bundles. The use of the triangular-pitch bundle has the advantage of size reduction. They concluded that the spray evaporation heat transfer coefficient increases with the increase in heat flux along the tubes. Also indicated that the square pitch bundle has a higher spray evaporation coefficient compared to the triangular-pitch bundle at low saturation temperature. They further stated that at a high saturation temperature, triangular-pitch tube is more likely to produce a much higher spray evaporation coefficient. Hence, the effect of the tube bundle is less considerable at a lower saturation temperature. The influence of the tube spacing (tube gaps) and the concentrations of water/salt mixtures on the boiling heat transfer has also been studied. The results showed that the small tube gaps can significantly increase boiling heat transfer in an enhanced compact tube bundle.

(Chyu et al., 2009) studied the effect of ammonia/lubricant mixture boiling on a horizontal tube bundle exposed to vapor at the inlet of a flooded evaporator and the effect of heat-transfer coefficients between the rows. The results showed that the heat-transfer coefficient increases as the saturation temperature and heat flux increase inside the tube bundles. Furthermore, they noted that the heat-transfer coefficient increased progressively from the bottom row towards the topmost one. The effect of the bundle tubes was more significant at a higher saturation temperature.

(Ayub et al., 2006) carried out a comparative analysis between a spray evaporator and conventional flooded type. The spray evaporator has been selected to be the best option due to its higher heat transfer coefficient. Low approach temperature produced in vapor phase; hence the suction temperature can be raised ensuing a good enhancement for compressor capacity. Moreover, the suction temperature maintained close to or higher than the freezing temperature. Furthermore, the benefit of the spray process appeared in the low refrigerant charge comparing with the same capacity of flooded one, which makes it very attractive for the environmental considerations.

(Zheng et al., 2008) studied the flooding evaporator in ammonia vapor compression system. The results showed that the boiling heat transfer coefficient increases with an increasing saturation temperature and heat flux. In addition, the heat transfer coefficient increases with the inlet vapor quality. However, this effect is not so much clear at high temperatures. The vapor quality effect is less considerable with higher lubricant concentrations, and an increase in the lubricant's concentrations will result in a reduced boiling heat transfer coefficient. Moreover, the coefficient of heat transfer does not necessarily decrease. They concluded that the lubricant's concentration has more effect on the heat transfer coefficient than vapor quality.

From the above literature survey, the evaporator heat exchanger design has been comprehensively studied by varying the design parameters such as spray process, tube layout and heat transfer coefficient, then it is compared with the other types of evaporator designs (flooded evaporators). The design parameters have already reached their optimum limit. Meanwhile, the working fluids still play a vital rule in the evaporator heat exchanger performance and need to be considered more, in the future studies. The nanofluid is a suspension of nanoparticle materials in the base fluid that are used to enhance the thermo physical properties of the working fluid (Hyder H. Balla, 2012). The addition of small amounts of nanoparticles of high thermal conductivity will increase the heat transfer rate, furthermore the nanoparticles will reduce the boundary layer thickness which enhances the heat transfer rate (Daungthongsuk and Wongwises, 2007, Trisaksri and Wongwises, 2007). In order to apply the nanotechnology and improve the heat transfer performance, different studies have been done to demonstrate the effect of adding nanoparticles to the ammonia-water refrigerant. (Yang et al., 2011b) added four different types of mixtures of nanoparticles and surfactant to the ammonia-water solution. An experiment was performed to investigate the dispersion stability of each kind of nanofluid with different mass fractions of surfactant. (Yang et al., 2011a) studied the stability of ammonia-water nanofluid by adding the mixture of carbon black nanoparticles with emulsifier op-10, and Al_2O_3 nanoparticles with sodium dodecyl benzene sulfonate (SDBS) in the ammonia-water solution at different mass fraction of nanoparticles. Another study by (Liu Yang, 2011) experimentally investigated the enhancement of ammonia-water absorption by adding nanoparticles. The results showed that the sorts and mass fraction of ammonia in the based fluid were considered as the key parameters in the absorption process. Moreover there is an optimum mass fraction for each kind of nanoparticle. While, (Kim et al., 2006) showed the effect of adding nanoparticles to the ammonia solution and its effect on the absorption rate and the heat transfer rate.

The aim of this study is to demonstrate and compare the effect of operating parameters such as, saturation temperature and flow rate (using different nanofluids ammonia solution as a refrigerant), on spray evaporation. Also to investigate the effect of these parameters on the heat flux performance between the water inside the tubes and liquid film on the shell side as well as to estimate of the average outlet temperature of the water from the tubes (chilled water), computational fluid dynamic (CFD) method will be used for the simulation analysis.

MATHEMATICS MODEL

The equations used for the heat transfer and fluid flow analyses are described below

The Energy Equation

The fundamental law, governing heat transfer is the first law of thermodynamics, which involves the principle of conservation of energy. The basic law is usually rewritten in terms of temperature. For the different fluids, the resulting energy equation is stated as below (Comsol Multiphysics, 2008):

$$\rho\,\mathrm{C_P}\left(\frac{\partial T}{\partial t}+(u.\nabla)T\right)=-(\nabla.q)+\tau:S-\frac{T}{\rho}\frac{\partial\rho}{\partial T}\left(\frac{\partial p}{\partial t}+(u.\nabla)p\right)+Q \qquad (1)$$

Where

By using Fourier's law of conduction, the conductive heat flux, *q*, is proportional to the temperature gradient:

$$q_i = -k\frac{\partial T}{\partial xi} \tag{2}$$

Inserting equation (2) into equation (1) and rearranging the terms, ignoring the viscous heat and pressure gradient, the energy equation can be written in this form:

$$\rho\, \mathrm{C_P}\frac{\partial T}{\partial t} + \rho\, \mathrm{C_P}\ \mathrm{u}.\nabla \mathrm{T} = \nabla.(\mathrm{k}\nabla \mathrm{T}) + \mathrm{Q} \tag{3}$$

The Continuity and Momentum Equations

Equation (4) represents continuity equation that refers to the conservation of mass, and Equation (5) represents the conservation of momentum.

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0 \tag{4}$$

$$\rho\frac{\partial \mathrm{u}}{\partial \mathrm{t}} + \rho(u.\nabla)u = \nabla.[-pI + \tau] + F \tag{5}$$

Where u is the fluid velocity, p is the fluid pressure, ρ is the fluid density, t is the time, τ is stress tensor, *F* is the external forces, ∇ is the divergence, and *I* is the identity matrix. The above three equations (energy, continuity, and the conservation of momentum) represent the Navier-Stokes equations which COMSOL Multiphysics uses to solve a single-phase fluid-flow with heat transfer (Comsol Multiphysics, 2008).

Properties of nanofluid

Two different types of nanofluids were obtained by suspension of silver (Ag) nanoparticles and CuO nanoparticles in the ammonia base fluid, respectively. The nanoparticles are assumed spherical and the purity is higher than 99.8%. The mass fraction of the added nanoparticles is 1% to the nanofluid ammonia solution. The thermophysical properties of the nanofluids are calculated at different operating temperatures by the following equations (D. A. Drew, 1999, W. Yu, 2003) which are shown in **Table1**.

Table 1

Thermophysical properties of nanofluids

emperature	ρ_{nf} *Kg/m³*	C_{pnf} *J/kg.K*	K_{nf} *W/ (m.K)*	$\propto_{nf}$ *Pa-s*
5 º C	691.67	4242.85	0.516656	0.0001723
0 º C	697.214	4222.46	0.5247	0.0001804
-5 º C	703.55	4197.87	0.5348	0.0001901
5 º C	731.77	4009.185	0.51705	0.0001723
0 º C	737.314	3991.657	0.5251	0.0001804
-5 º C	743.65	3970.3668	0.5359	0.0001901

$$\mu_{nf} = \frac{(1+2.5\ \varphi)\rho_f C_{pf}}{\rho_{nf}} \qquad (6)$$

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_f \qquad (7)$$

$$C_{Pnf} = \frac{\varphi\rho_p C_{Ps} + (1-\varphi)\rho_f C_{Pf}}{\rho_{nf}} \qquad (8)$$

$$K_{nf} = \left(\frac{K_p + 2K_f + 2(K_p - K_f)(1+\beta)^3\varphi}{K_p + 2K_f - (K_p - K_f)(1+\beta)^3\varphi}\right)K_f \qquad (9)$$

Where β is 0.1 for the spherical nanoparticles

Boundary Conditions

The boundary conditions were also considered. The saturation temperatures for the spray nanofluids ammonia solutions at the outlet of the holes are (5, 0, -5 ^oC). These were assumed to be at the same saturation temperature and corresponding saturation pressure inside the shell vessel. The velocities applied from the nozzles to the shell were changed from 0.01 to 0.55 m/s (0.25 to 1.4 kg/min). The inlet temperature for the water inside the tubes is 20 ^oC with average mean velocity of 0.4 m/s, according to the specific cooling load applied. The shell-side boundary condition is considered to be pressure at no viscous stress. While, the pressure value is different according to the saturation temperature and the pressure of the next component in the system, which is the absorber. The convective heat flux boundary condition is considered for both outlets of the tubes (pure water) and the outlet from the shell side (ammonia vapour). The heat transfers by convection and conduction across the boundary between the liquid inside the pipes and the liquid outside then the tubes' thickness is assumed, during the 1st trial. The temperature gradient in the vertical direction is zero and there is no radiation (Comsol Multiphysics, 2008). No-slip boundary condition is applied for the flow at the inner and outer walls of pipes and shell. The fluid is considered as Newtonian and incompressible. The physical properties of the fluids inside the pipes and shell vary from one, another, and they are temperature dependent, as well for the pipe material. The flow inside the pipes is laminar, and equally the flow in the shell is laminar. Incompressible Navier-Stokes equations with convection and conduction modules are used in the simulation. Holes with 1 mm diameter inside the shell are arranged above the tube bundles to describe the spray evaporation process. The inner diameters of the pipes are assumed to be 7 mm which gave optimum high flux coefficient (Ranj Sirwan, 2012), with 2 mm tube thicknesses and tubes length 0.8 m. The shell side dimensions are 13 cm inner diameter with 0.8 m length. The overall flow rate inside the pipe is 0.046 kg/s. Steel AISA 4340 was used for the pipes and shell material.

NUMERICAL METHOD

COMSOL Multiphysics 3.5a is employed for this study. COMSOL Multiphysics uses Finite Element Method (FEM) to solve the model which is defined as a numerical analysis technique for obtaining an approximate solution to a wide variety of engineering problems. The software runs the finite-element analysis together with adaptive meshing and error control, using different numerical solvers (Comsol Multiphysics, 2008). The direct PARDISO solver is also applied with relative tolerance parameter of 1.0E-6, and minimum damping factor of 1.0E-4. This solver uses a stationary analysis approach with the non-linear solver system.

A mesh is a partition of the geometry model into small units of simple shapes. In this study, 3D geometry is used with a free mesh and a fine meshing within the number of degree of freedom 1634637, and the number of mesh points created is 55521. The free mesh automatically creates an unstructured mesh, which is selected by the domains. The free mesh contains tetrahedral elements. The mesh statistics for this case are:

a) Number of mesh points: 52587

b) Number of elements: 302425

c) Tetrahedral cells: 302425

d) Number of boundary elements: 62435

e) Triangular cells: 62435

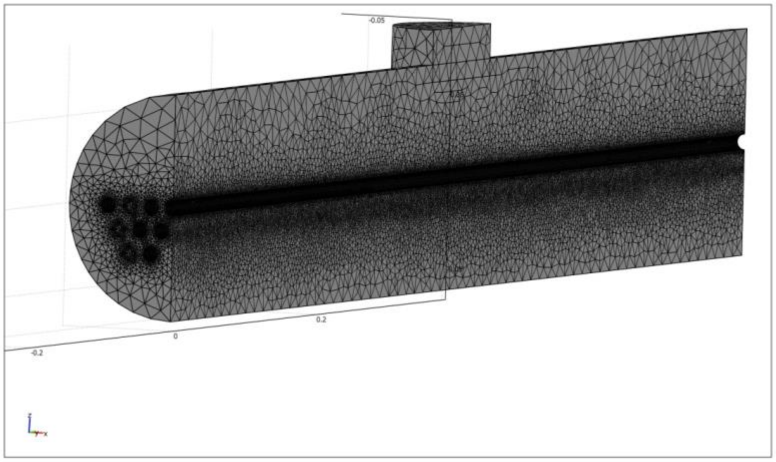
f) Number of edge elements: 9434

g) Number of vertex elements: 260

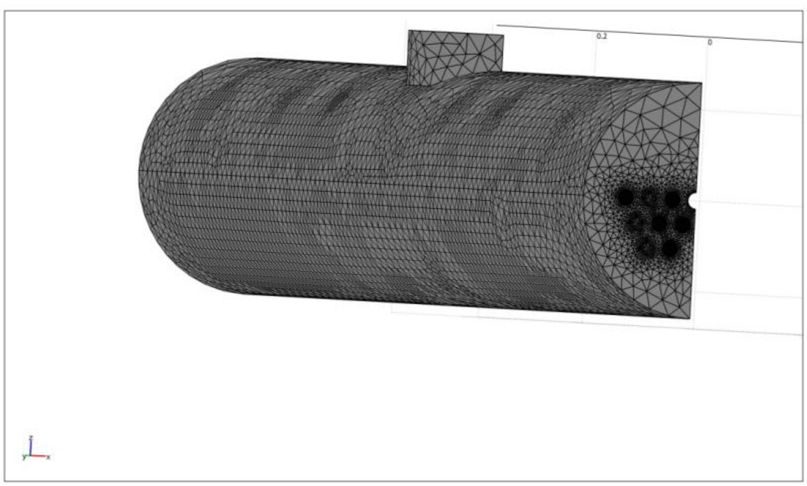
h) Minimum element quality: 0.1108

i) Element volume ratio: 4.76E-5

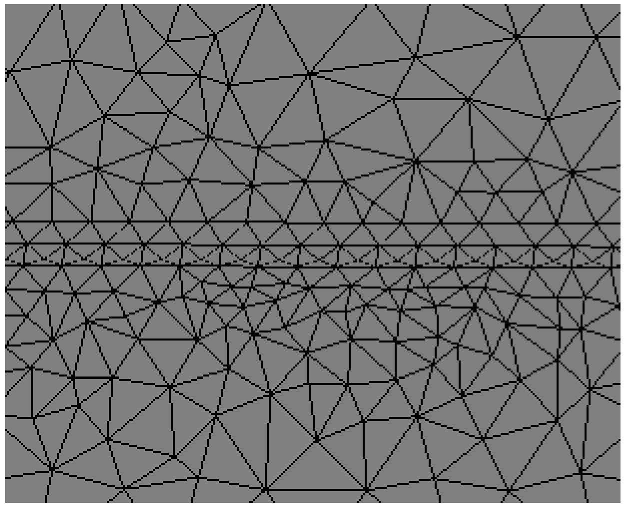
Figure 1 (a), (b), and (c) show the mesh statistics at different views. And **figure 2** shows the temperature profile of the fluid inside 3D axisymmetric shell side heat exchanger for triangular and rectangular tube bundle.



(a)



(b)



(c)

Figure 1 (a, b, and c) The mesh statistics at different views

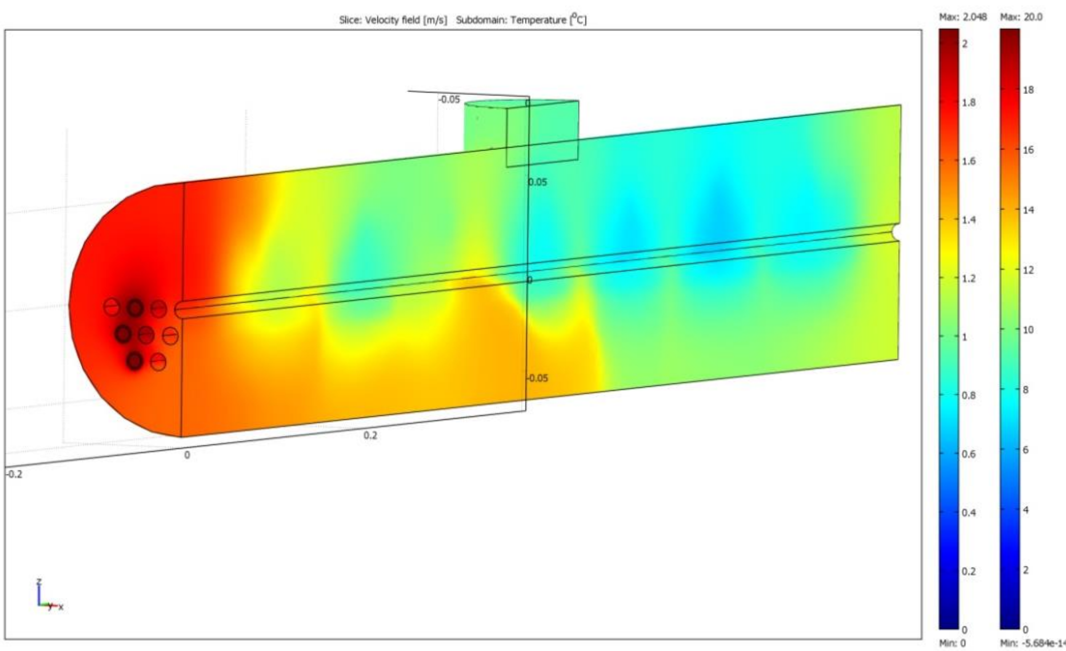


Figure 2 Temperature profile distribution in the shell of the heat exchanger.

RESULTS AND OBSERVATIONS

Different nanofluids of ammonia-solution for liquid spray in shell and tube heat exchanger have been investigated. The effects of saturation temperature and flow rates of ejected spray liquid on the heat flux performance between pipes and shell have been studied. The data were analysed for three tubes at different rows because they were symmetrical in shape and design parameters, in triangular pitch tube bundles. The results demonstrate the difference in heat flux performance, average outlet temperatures from the tubes and heat exchanger effectiveness at different operating conditions among different ammonia solution nanofluids.

Comparison of different ammonia solution nanofluids on the average heat flux at different flow rates and saturation temperatures.

The average heat flux results for different sprayed liquid flow rates are presented in **Figure 3 (a, b, and c)**. Results show that the heat flux between the tubes and the shell-side increases as the mass flow rate increases since more spray flow rate obtained higher heat transfer coefficient due to stronger, faster, and smaller droplet impingement effect of liquid on the tube bundle. In addition, these droplets increase the amount of turbulence inside the shell resulting high Reynolds number, thus, an increase in heat transfer flux between the tubes and shell-side occurs. The results also show that at low T_s (saturation temperatures), a greater heat flux results due to the higher temperature differences between the pipe walls and liquid ammonia and a decrease in the film thickness of liquid ammonia around the tubes as a result of the decrease in the viscosity. This result is in agreement with (Ribatski and Jacobi, 2005, Tong-Bou, 2009). Greater pressure drop across the nozzles implies, the injection of smaller droplets and higher velocity marks. Furthermore, the nanofluids showed an enhancement of the heat transfer performance compared to the base fluid (NH_3), due to the effect of higher thermal conductivity of the nano-solid particles, suspended in the base fluid (NH_3). The highest heat transfer appears with the Ag-NH_3 nanofluid. The maximum percentages of enhancement on the heat flux are 24% and 11.11% for Ag-NH_3 and CuO-NH_3 nanofluids, respectively, compared to the NH_3 base fluid.

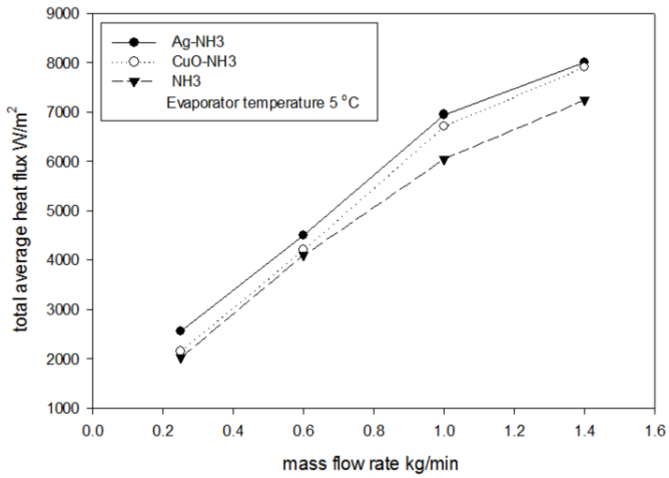


Figure 3 (a) Avarege heat flux at saturation temperature 5 ° C

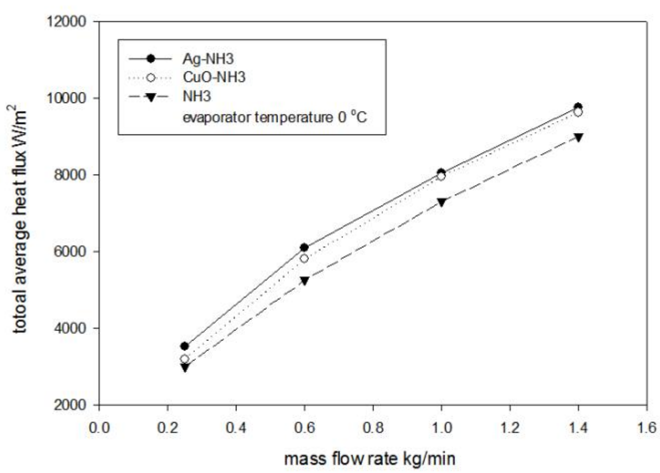


Figure 3 (b) Avarege heat flux at saturation temperature 0 ° C

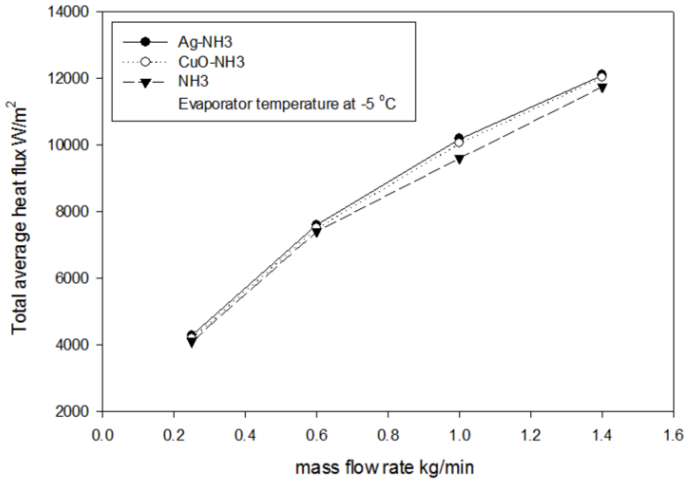


Figure 3 (c) Avarege heat flux at saturation temperature -5 º C

Effect of different mass flow rates and saturation temperatures on the average outlet temperature from the tubes (chilled water) for the nanofluids and ammonia refrigerant.

For HVAC applications, the shell and tube evaporator heat exchangers have to give the best heat flux performance and as a result, they cause the desired reduction in fluid temperature at the evaporator tubes' outlets. In case of this study, neither the heat flux nor the temperature along the tube is constant. Therefore, the effect of improving the heat flux performance has played a crucial role. In **figure 4 (a, b and c)** the results show that, with a decrease in the T_s and an increase in the spray flow rate, the average outlet water temperature decreases, and this is due to the increase in the average heat flux between the tubes and liquid spray. The temperature effect is related to the decrease in the viscosity and the resulting decrease in the film thickness (Ribatski and Jacobi, 2005, W. H. Parken, 1990, M. C. Chyu, 1987). The enhancement of adding nanoparticles to the liquid ammonia are implemented by reducing the temperature out of the secondary refrigerant (chilled water). The nanofluids contain higher thermal conductivity particles which, affect the heat transfer performance. F**igure 5 (a, b and c)** shows the heat exchanger effectiveness for different nanofluid solutions, at different evaporator temperatures.

Effectiveness is defined as a measure of the thermal performance of the heat exchanger (P.Sekulic, 2003). And it is equal to the actual heat transfer to the maximum heat transfer possible in the heat exchangers.

$$\varepsilon = \frac{q}{q_{max}} \tag{11}$$

$$q_{max} = C_{min}(T_{hi} - T_{ci}) \tag{12}$$

Where C_{min} is the minimum heat capacity among the both fluids.

From **figure 5 (a, b and c)**, it can be observed that the heat exchanger effectiveness, using Ag-NH_3 nanofluid has the highest values, followed by CuO-NH_3, and finally NH_3.

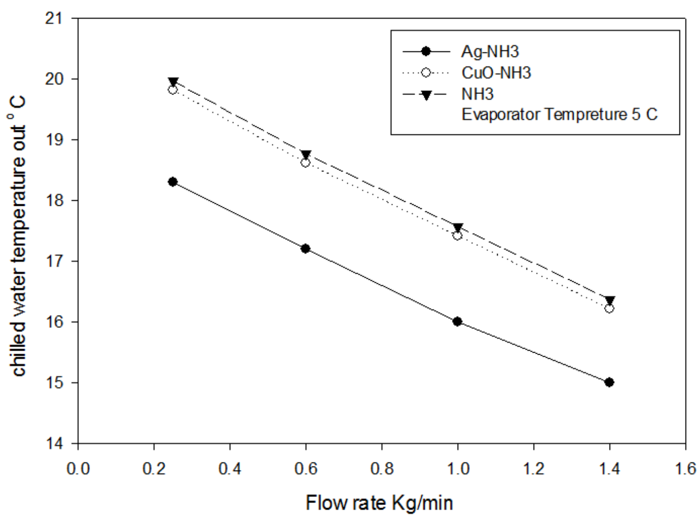
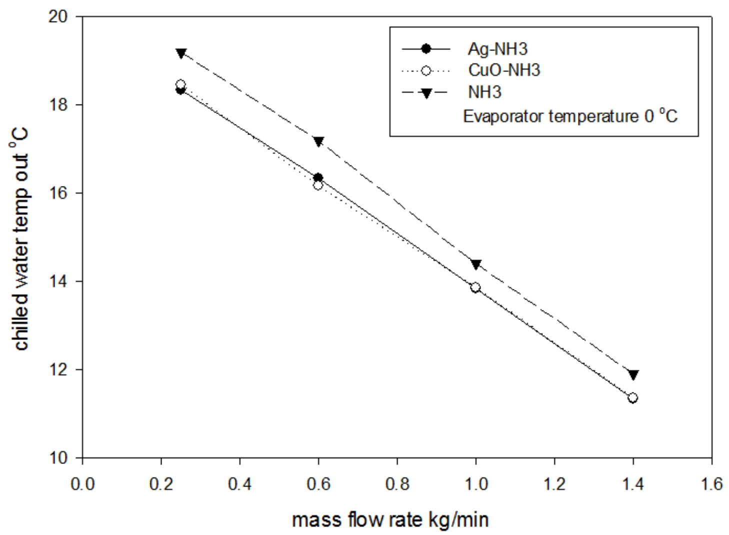


Figure 4 (a) Average outlet water temperatures at evaporator temperature 5^o C



(c)

Figure 4 (b) Average outlet water temperatures at evaporator temperature 0° C

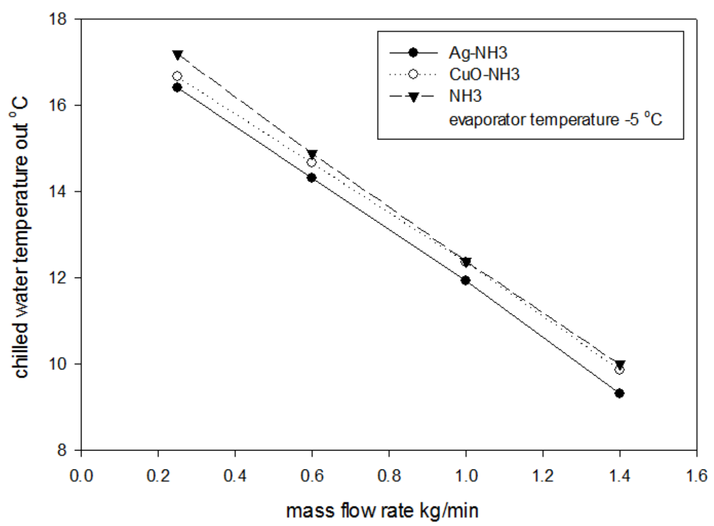


Figure 4 (c) Average outlet water temperatures at evaporator temperature -5°

C

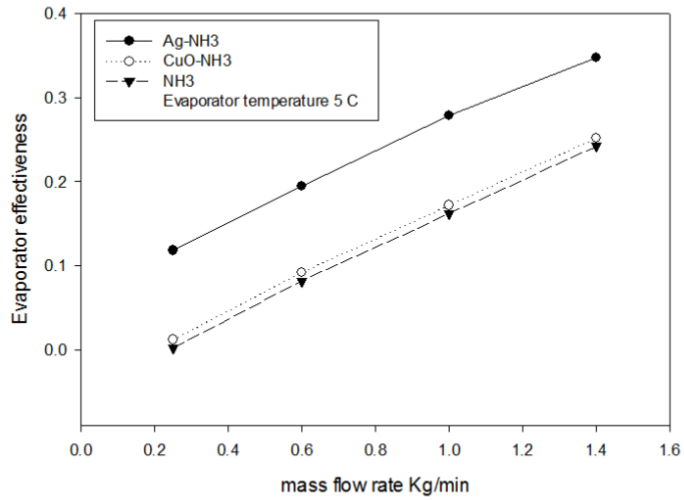


Figure 5 (a) Effectiveness of various nanofluids at different flow rates and evaporator temperature of 5^o C

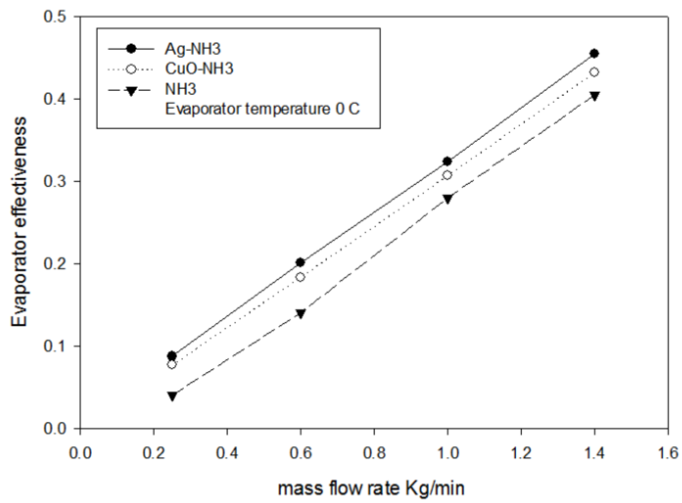


Figure 5 (b) Effectiveness of various nanofluids at different flow rates and evaporator temperature of 0^o C.

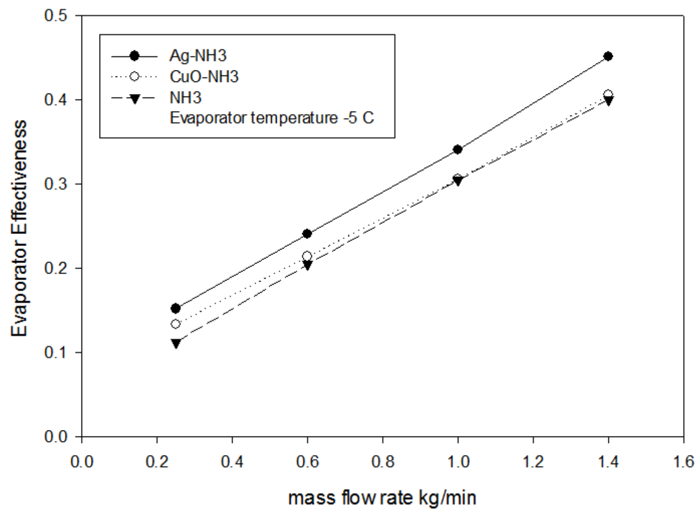


Figure 5 (c) Effectiveness of various nanofluids at different flow rates and evaporator temperature of -5^o C

CONCLUSIONS

The study of the spraying for different ammonia solution nanofluids onto horizontal triangular tube bundle, inside shell and tube heat exchanger has been presented. The effects of varying saturation temperatures and flow rates were also investigated analytically. The results show that:

1. The heat flux between the tubes and shell-side increases with the increase of the ejected flow rate from the liquid spray holes and decreases with the ejected liquid saturation temperatures.
2. The average outlet temperatures from the tubes are affected by varying the average heat flux which is largely due to the constant flow rate inside the tubes.
3. The ammonia solution nanofluids gives better heat transfer rate compared to the base fluid (NH_3).
4. The heat exchanger effectiveness is increased by adding the nanofluids solutions to the system. The improvement of the heat exchanger effectiveness will increase the

performance of the absorption cooling system and this leads to a reduction in the required energy consumption (Hasanuzzaman M, 2011).

REFERENCES

COMSOL MULTIPHYSICS. 2008. *COMSOL MULTIPHYSICS USER'S GUIDE,* STOCKHOLM, COMSOL AB.

AYUB, Z. H., CHYU, M. C. & AYUB, A. H. 2006. CASE STUDY: LIMITED CHARGE SHELL AND TUBE AMMONIA SPRAY EVAPORATOR WITH ENHANCED TUBES. *APPLIED THERMAL ENGINEERING*, 26, 1334-1338.

CHANG, T.-B. 2006. EFFECTS OF NOZZLE CONFIGURATION ON A SHELL-AND-TUBE SPRAY EVAPORATOR WITH LIQUID CATCHER. *APPLIED THERMAL ENGINEERING*, 26, 814-823.

CHYU, M. C., ZHENG, J. & AYUB, Z. 2009. BUNDLE EFFECT OF AMMONIA/LUBRICANT MIXTURE BOILING ON A HORIZONTAL BUNDLE WITH ENHANCED TUBING AND INLET QUALITY. *INTERNATIONAL JOURNAL OF REFRIGERATION*, 32, 1876-1885.

D. A. DREW, S. L. P. 1999. *THEORY OF MULTICOMPONENT FLUIDS* BERLIN, SPRINGER.

DAUNGTHONGSUK, W. & WONGWISES, S. 2007. A CRITICAL REVIEW OF CONVECTIVE HEAT TRANSFER OF NANOFLUIDS. *RENEWABLE AND SUSTAINABLE ENERGY REVIEWS*, 11, 797-817.

HASANUZZAMAN M, S. R., MASJUKI HH. 2011. EFFECT OF DIFFERENT VARIABLE ON MOISTURE TRANSFER OF HOUSEHOLD REFRIGERATOR-FREEZER. *ENERGY EDUCATION SCIENCE TECHNOL PART A*, 27, 401-418.

HYDER H. BALLA, S. A., ROZLI ZULKIFLI, WAN MOHD FAIZAL AND KAMARUZAMAN SOPIAN 2012. EFFECT OF OXIDES NANOPARTICLE MATERIALS ON THE PRESSURE LOSS AND HEAT TRANSFER OF NANOFLUIDS IN CIRCULAR PIPES. *JOURNAL OF APPLIED SCIENCES* 12, 1396-1401.

KILIC, F. C. 2011. RECENT RENEWABLE ENERGY DEVELOPMENTS, STUDIES, INCENTIVES IN TURKEY. *ENERGY EDUCATION SCIENCE TECHNOL PART A,* 1, 37-54.

KIM, J.-K., JUNG, J. Y., KIM, J. H., KIM, M.-G., KASHIWAGI, T. & KANG, Y. T. 2006. THE EFFECT OF CHEMICAL SURFACTANTS ON THE ABSORPTION PERFORMANCE DURING NH3/H2O BUBBLE ABSORPTION PROCESS. *INTERNATIONAL JOURNAL OF REFRIGERATION*, 29, 170-177.

LIU YANG, K. D., XIAO FENG NIU, BO CHENG, YUN FENG JIANG 2011. EXPERIMENTAL STUDY ON ENHANCEMENT OF AMMONIA-WATER FALLING FILM ABSORPTION BY ADDING NANO-PARTICLES. *INTERNATIONAL JOURNAL OF REFRIGERATION*, 34, 640-647.

M. C. CHYU, A. E. B. 1987. AN ANALYTICAL AND EXPERIMENTAL STUDY OF FALLING-FILM EVAPORATION ON A HORIZONTAL TUBE. *JOURNAL OF HEAT TRANSFER*, 109, 983-990.

MISRA, R. D., SAHOO, P. K. & GUPTA, A. 2006. THERMOECONOMIC EVALUATION AND OPTIMIZATION OF AN AQUA-AMMONIA VAPOUR-ABSORPTION

REFRIGERATION SYSTEM. *INTERNATIONAL JOURNAL OF REFRIGERATION*, 29, 47-59.

P.SEKULIC, R. K. S. A. D. 2003. *FUNDAMENTAL OF HEAT EXCHANGER DESIGN* NEW JERSEY, JOHN WILEY & SONS

RANJ SIRWAN, Y. A., LIM CHIN HAW, SOHIF MAT, A. ZAHARIM AND K. SOPIAN. MODELLING AND OPTIMIZATION OF HEAT TRANSFER IN SMOOTH CIRCULAR TUBE USED IN THE SHELL AND TUBE EVAPORATOR. 9TH WSEAS INTERNATIONAL CONFRERENCE ON HEAT AND MASS TRANSFER JANUARY 25-27 2012 HARVARD USA. 133-137.

RIBATSKI, G. & JACOBI, A. M. 2005. FALLING-FILM EVAPORATION ON HORIZONTAL TUBES--A CRITICAL REVIEW. *INTERNATIONAL JOURNAL OF REFRIGERATION*, 28, 635-653.

TONG-BOU, C., CHUNG-CHENG LU, JUN-CHENG LI 2009. ENHANCING THE HEAT TRANFSER PERFORMANCE OF TRAINGULAR-PITCH SHELL-AND-TUBE EVAPORATORS USING AN INTERIOR SPRAY YECHNIQUE. *APPLIED THERMAL ENGINEERING* 29, 2527-2533.

TRISAKSRI, V. & WONGWISES, S. 2007. CRITICAL REVIEW OF HEAT TRANSFER CHARACTERISTICS OF NANOFLUIDS. *RENEWABLE AND SUSTAINABLE ENERGY REVIEWS*, 11, 512-523.

W. H. PARKEN, L. S. F., V. SERNAS, J. C. HAN 1990. HEAT TRANSFER THROUGH FALLING FILM EVAPORATION AND BOILING ON HORIZONTAL TUBES. *JOURNAL OF HEAT TRANSFER* 112, 744-750.

W. YU, U. S. C. 2003. THE ROLE OF INTERNATIONAL LAYERS IN THE ENHANCED THERMAL CONDUCTIVITY OF NANOFLUIDS: A RENOVATED MAXWELL MODEL. *JOURNAL OF NANOPARTICLE RESERACH* 5, 167-171.

YANG, L., DU, K., NIU, X., LI, Y. & ZHANG, Y. 2011A. AN EXPERIMENTAL AND THEORETICAL STUDY OF THE INFLUENCE OF SURFACTANT ON THE PREPARATION AND STABILITY OF AMMONIA-WATER NANOFLUIDS. *INTERNATIONAL JOURNAL OF REFRIGERATION*, 34, 1741-1748.

YANG, L., DU, K., ZHANG, X. S. & CHENG, B. 2011B. PREPARATION AND STABILITY OF AL2O3 NANO-PARTICLE SUSPENSION OF AMMONIA–WATER SOLUTION. *APPLIED THERMAL ENGINEERING*, 31, 3643-3647.

ZENG, X., CHYU, M. C. & AYUB, Z. H. 2001A. EXPERIMENTAL INVESTIGATION ON AMMONIA SPRAY EVAPORATOR WITH TRIANGULAR-PITCH PLAIN-TUBE BUNDLE, PART I: TUBE BUNDLE EFFECT. *INTERNATIONAL JOURNAL OF HEAT AND MASS TRANSFER*, 44, 2299-2310.

ZENG, X., CHYU, M. C. & AYUB, Z. H. 2001B. EXPERIMENTAL INVESTIGATION ON AMMONIA SPRAY EVAPORATOR WITH TRIANGULAR-PITCH PLAIN-TUBE BUNDLE, PART II: EVAPORATOR PERFORMANCE. *INTERNATIONAL JOURNAL OF HEAT AND MASS TRANSFER*, 44, 2081-2092.

ZHENG, J., CHYU, M. C. & AYUB, Z. 2008. BOILING OF AMMONIA/LUBRICANT MIXTURE ON A HORIZONTAL ENHANCED TUBE IN A FLOODED EVAPORATOR WITH INLET VAPOR QUALITY. *INTERNATIONAL JOURNAL OF REFRIGERATION*, 31, 564-572.