

FALLING-FILM ABSORPTION AMMONIA-WATER MAGNETIC FIELD

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ABSTRACT

Absorption refrigeration systems, despite having numerous advantages, are generally characterized by low Coefficient of Performance (COP). Absorption enhancement has been considered an effective way of improving the COP of the refrigeration systems, and magnetic enhancement is one of these. The literature is sparse on the use of magnetic field for the enhancement of absorption refrigeration systems. A numerical model of magnetic field enhancement in ammonia-water absorption systems is presented in this paper.

The flow within the film thickness to the absorber wall was considered as two-dimensional steady laminar flow. A finite difference model was developed based on the conservation of mass, momentum, energy equations and mass transport relationship. Macroscopic magnetic field force was introduced in the model equations. The model was validated using data obtained from the literature on ammonia solution. Changes in the physical properties of ammonia solution while absorbing, both in the direction of falling film and across its thickness, were investigated.

The distribution of the physical properties of ammonia solution within the film-thickness was not significantly different ($p < 0.05$) from results in the literature. The magnetic field was found to have positive effect on the ammonia-water falling film absorption to some degree. When magnetic induction intensity at the solution's inlet was 1.4 and 3 Tesla (T), the increments in concentration of ammonia solution at outlet was 0.004 and 0.01, respectively. Relative to 0.0 Tesla, the COP of simple ammonia solution absorption refrigeration system increased by 1.9% and 3.6% for magnetic induction of 1.4 and 3.0 Tesla respectively.

A numerical model for the magnetic field enhancement of the ammonia absorption system was developed. Absorption performance enhancement increased with magnetic intensity in ammonia solution.

INTRODUCTION

Modern energy for industrial development is largely based on fossil fuels which, along with other human (i.e. anthropogenic) activities, have been unequivocally shown to be responsible for the warming of the climate system. Further, global increases in CO₂ concentrations are, according to the UNFCCC, due primarily to fossil fuel use, with land-use change (LUC) providing another significant but smaller contribution. Thus, with this global awareness, there is the annual climate change talks among the United Nations member States where actions to stem the rising levels of GHGs through mitigation and adaptation activities, among others, engage the members. On the mitigation side, activities include reduction in the use of fossil fuels through energy efficiency measures, both on the supply as well as the demand side; uptake of renewable energy technologies as well as other clean energy technologies.

The drive for both renewable and clean energy technologies has similarly impacted on developments within the cooling technology sector. Cooling system basically may be divided into two categories; Vapour compression system and sorption system. Sorption system is further sub-divided into absorption and adsorption systems. Vapour compression system involves the use of a mechanical work such as that of a compressor for the compression process; An absorption system is simply the replacement of the mechanical compression with a thermo chemical fluid lifting process. In other words it is the mixture of a gas in a liquid, the two fluids presenting a strong affinity to form a solution, while adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or, more rarely, a liquid (adsorbent), forming a molecular or atomic film (the adsorbate).

In the manufacturing of cooling machine/system, this global demand for efficient use of energy at minimum environmental cost has necessitated the increased demand for absorption refrigeration systems driven by waste heat or solar thermal energy instead of conventional mechanical compression systems driven by electrical energy. The current

imbalance of energy demand and supply coupled with the environmental degradation and climate change impact in many developing countries has further increased the urgent need for highly efficient and sustainable energy technologies.

In the absorption process, heat and mass transfer usually take place within a thin-liquid falling-film. Heat and mass transfer in thin-liquid falling film absorption process has received the attention of many researchers over the years especially in the last two decades. This is as a result of its wider application in many modern devices such as absorption air-conditioners, absorption chillers, absorption heat pumps etc [7]. Absorption enhancement is an aspect of absorption refrigeration that has also attracted the attention of the researchers. Absorption enhancement is an effective way to improve the performance of absorption refrigeration systems. Generally, there are three kinds of methods in absorption enhancement [9]. The first kind falls under the category of mechanical methods, which improve the performance by modifying the shape, surface and structure of the heat transfer tubes [10]. The second kind comprise chemical methods which involve the addition of surfactant in the absorbent while the third kind is the addition of nano-particles in the absorbing solution e.g Cu, CuO and Al₂O₃ nano-particles added into ammonia-water solution [9], Fe and Carbon nano-tubes (CNT) in lithium bromide-water solution [8]. Research on nano-fluids / nano-particles in absorbent are categorized into five groups (i) stability analysis and experiments; (ii) property measurement such as thermal conductivity and viscosity; (iii) convective and boiling heat transfer; (iv) mass transfer in binary nanofluids; and (v) theoretical analysis and model development.

However, the effect of magnetic field on absorption refrigeration system is seldom mentioned in the literature apart for its established influence on the absorption process in ammonia vapour into ammonia-water solution absorption refrigeration system [5]. The magnetic field may therefore also have certain influence on the absorption process in other absorption refrigeration systems such as water vapour into lithium bromide-water solution absorption system. In enhanced absorption process study, [12] investigated experimentally the effect of additive on falling film absorption of water vapour in aqueous LiBr. The experimental results showed that small amounts of additive can enhance the heat transfer of absorption process significantly, and the enhancement degree is influenced by additive concentration and Reynolds number. Based on a dimensionless analysis of the Navier-Stokes equations applied to the falling film absorption process, a new dimensionless parameter, surface renewal number R_n was introduced, and a semi-empirical equation of enhancement factor of additive was obtained, which shows that the enhancement effect of additive on Nusselt number of absorption process is determined by the absorption Marangoni number Ma , the surface Marangoni number Ma_A , the surface renewal number R_n , the adsorption number η , and the Reynolds number Re . It was proved that the semi-empirical equation can agree with the experimental results well by introduction of the parameters related to surface tension into the equation. The study concluded as follows: i. There is an optimum additive concentration in which the enhancement effect of additive is strongest, ii. The Marangoni number Ma ,

the surface Marangoni number Ma_A , and the surface renewal number R_n enlarge the enhancement of the heat transfer during absorption, iii. The adsorption number η reduces the heat transfer of absorption, and iv. The enhancement factor decreases as the Reynolds number increases. An experimental study [8] also obtained the following results: (i). The vapour absorption rate increases with increasing solution mass flow rate and the concentration of Fe nanoparticles and CNT. The effect of coolant mass flow rate on the vapour absorption rate is not significant under the experimental conditions, (ii). The heat transfer rate increases with increasing the solution mass flow rate while it is not much affected by the concentration of nanoparticles, (iii). The mass transfer enhancement is much more significant than the heat transfer enhancement in the binary nanofluids with Fe nanoparticles and CNT, and (iv). The mass transfer enhancement from the CNT (average 2.16 for 0.01 wt % and average 2.48 for 0.1 wt %) becomes higher than that from the Fe nanoparticles (average 1.71 for 0.01 wt % and average 1.90 for 0.1 wt %). Therefore, the CNT is a better candidate than Fe nanoparticles for performance enhancement in H₂O/LiBr absorption system.

An experimental investigation into the effect of external magnetic field on falling film absorption in an ammonia-water system [13] was conducted by Xiao Feng Niu et al in 2010. The study established the following findings: (i) External magnetic field with the same direction as falling film has enhancing effect on absorption of ammonia-water, and the absorption enhancement is more obvious in stronger magnetic field, (ii) Not all magnetic fields can enhance the ammonia-water absorption process. While the external magnetic field against the direction of falling film is exerted, the absorption variables in magnetic field are all smaller than those in conventional absorption without magnetic field exerted. The magnetic field with direction against falling film weakens the absorption of ammonia-water (iii) The absorption can be more intense if the external magnetic field is combined with optimal operating conditions. Experimental results show that the changes in the outlet cooling water temperature, absorption heat and absorption mass with and without external magnetic field exerted, are larger when the inlet solution concentration is lower.

In the area of numerical modeling of enhanced absorption system, [13] established the mathematical model for magnetic field enhanced absorption process for ammonia-water solution on a falling-film. The changes in physical properties of ammonia-water solution in absorption, the variation of falling film and the convection in the direction of thickness of liquid film were considered in the model. The effect of the magnetic field on the distribution of some parameters in falling-film absorption, such as velocity, temperature and concentration etc., was obtained. The numerical results obtained showed that magnetic field can improve the performance of ammonia-water falling-film absorption, and that the absorption strengthening effect increases with the enhancement increasing magnetic induction intensity. The strengthening effect was limited within the magnetic field intensity range of 0-3 T, however the strengthening effect was observed to be stronger in stronger magnetic fields. For both un-enhanced and enhanced absorption

cooling systems, several working fluids have been investigated, among which are Lithium bromide-water (LiBr-H₂O), Lithium-Chloride Water (LiCl-H₂O) and Ammonia-water (NH₃-H₂O) all of which are popularly used in single-stage and advanced absorption air-conditioning/heat pump technology.

In engineering problems, either probabilistic or deterministic methods could be used depending on the degree of accuracy required of the solution while validation could be carried out using experimental data or exact analytic solutions where such exist. Absorption process enhancement under a magnetic field has been established as having an effect on falling-film Ammonia-Water absorption [13], but not on a smooth thin-liquid falling-film. This present paper therefore employs the finite difference method for establishing velocity, temperature and concentration distributions in magnetic field enhanced absorption process on a smooth thin-liquid falling-film using ammonia-water refrigerant/absorbent combination. The results have been compared with those obtained by [13] in the falling-film. Such an investigation would reveal sections of the absorber that might need to be redesigned and its material re-specified, e.g for optimal efficiency of refrigerant absorption by the absorbent. The smooth thin-liquid falling-film is quite different from non-smooth in the sense that the film-thickness in the smooth is defined and non wavy like non-smooth which is usually complex to analyse to obtain complete and reliable result.

NOMENCLATURE

| | | |
|----------|----------------------|-------------------------------------|
| μ | [kg/m/s] | film dynamic viscosity |
| v_0 | [m/s] | Mean velocity |
| α | [m ² /s] | thermal diffusivity |
| k | [W/mK] | Thermal conductivity of the fluid |
| ρ | [kg/m ³] | liquid density |
| D | [m ² /s] | species diffusivity |
| β | [K ⁻¹] | cubic expansivity of fluid |
| T_w | [°C] | dimensional wall temperature |
| T_{in} | [K] | inlet refrigerant temperature |
| C_{in} | [%] | initial absorbent concentration |
| C_{eq} | [%] | equilibrium absorbent concentration |
| g | [m/s ²] | Gravity |
| h_0 | [m] | Mean film thickness |
| ν | [m ² /s] | kinematic viscosity of fluid |
| Ha | [kJ/kg] | heat of absorption |
| P_v | [mm. Hg] | absorbent vapour pressure |

Mathematical Model

Assumptions

In developing the governing equations for this flow modeling of the absorption process in a smooth thin-liquid film, the following assumptions are made.

- i. The flow is a fully developed steady laminar flow as shown in fig. 1.1a hence velocity (v) in Y-direction is zero
- ii. The fluid properties are constant and not varying with temperature and concentration.
- iii. The mass rate of vapour absorbed is very small compared to the solution flow rate such that the film thickness and flow velocities can be treated as constant.
- iv. Heat transfer in the vapor phase is negligible.
- v. Vapor pressure equilibrium exists between the vapour and liquid at the interface.
- vi. The Peclet numbers are large enough such that the diffusion in the flow direction can be neglected.
- vii. Diffusion thermal effects are negligible.
- viii. The magnetic induction intensity decreases linearly along the flow of falling-film.
- ix. The shear stress at the liquid–vapor interface is negligible

Some factors which can not be neglected in building and solving mathematical model are listed as follows:

- i. the properties of ammonia-water solution are changeable in the absorption process
- ii. the convection along the thickness direction of film is not ignored

Then, corresponding to the coordinate system shown in Figure 1 the X-axis is along the falling direction, and the Y-axis is along the thickness direction of the falling-film. The velocity component in X and Y axis are u and v respectively. Heat transfer is described as the following energy equation:

$$\rho C_p u \frac{\partial T}{\partial x} + \rho C_p v \frac{\partial T}{\partial y} = \frac{\partial}{\partial y} \left(\lambda \frac{\partial T}{\partial y} \right) \quad (1a)$$

In a similar way, the continuity equation, transport equation [2] and mass equation can be described as follows:

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0 \quad (1b)$$

$$\frac{\partial^2 u}{\partial y^2} + 3 \frac{v_0}{h_0^2} + \rho g + \int_{mag} = 0 \quad (1c)$$

$$\rho u \frac{\partial \xi}{\partial x} + \rho v \frac{\partial \xi}{\partial y} = \frac{\partial}{\partial y} \left(\rho D_m \frac{\partial \xi}{\partial y} \right) \quad (1d)$$

Where \int_{mag} [4] in the above equation is the magnetic force which the falling-film solution experienced per unit volume. It is in the direction of downward vertically.

$$\int_{mag} = \frac{\rho\chi B^2}{l\mu_0} \quad (1e) \quad \text{where } \chi \text{ is the magnetic}$$

mass susceptibility of either Lithium bromide and or Lithium chloride water solution, B is the magnetic induction intensity, l is the length of falling-film flows, and μ_0 is the vacuum's permeability, u is the velocity in the film in X-direction and

$$V_0 = \frac{\rho g h_0^2}{3\mu} \quad \text{or} \quad h_0 = \left(\frac{3\mu V_0}{\rho g} \right)^{\frac{1}{2}}$$

From the above-mentioned assumptions, the final model set of magnetic enhanced transport, heat and mass transfer equations on a smooth thin-liquid falling-film corresponding to the coordinate system shown in figure 1 will now be:

$$u \frac{\partial T}{\partial x} - \alpha \frac{\partial^2 T}{\partial y^2} = 0 \quad (1e)$$

$$\partial \left(\frac{\rho u}{\partial x} \right) = 0 \quad (1f)$$

$$\frac{\partial^2 u}{\partial y^2} + 3 \frac{v_0}{h_0^2} + \rho g + \frac{\rho\chi B^2}{l\mu_0} = 0 \quad (1g)$$

$$u \frac{\partial \xi}{\partial x} - D_m \frac{\partial^2 \xi}{\partial y^2} = 0 \quad (1h)$$

The final model magnetic enhanced velocity field, heat and mass transfer equations on a smooth thin-liquid falling-film in a cooling system are:

$$\frac{\partial^2 u}{\partial y^2} + 3 \frac{v_0}{h_0^2} + \rho g + \frac{\rho\chi B^2}{l\mu_0} = 0 \quad (1i)$$

$$u \frac{\partial T}{\partial x} - \alpha \frac{\partial^2 T}{\partial y^2} = 0 \quad (1j)$$

$$u \frac{\partial \xi}{\partial x} - D_m \frac{\partial^2 \xi}{\partial y^2} = 0 \quad (1k)$$

where χ is the magnetic mass susceptibility, B is the

magnetic induction intensity, l is the length of falling-film flows, μ_0 is the vacuum permeability, T is temperature, ξ is concentration (absorbent), α is thermal diffusivity, D or D_m is species diffusivity, V_0 is the average velocity within the film thickness and h_0 is the film thickness

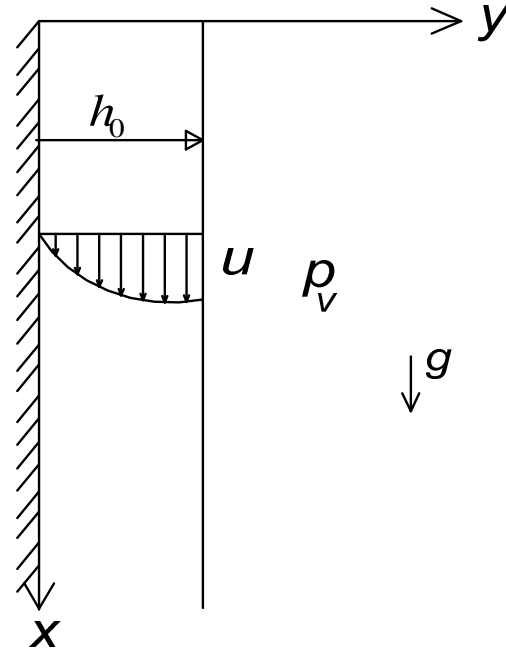


Figure 1: 2-d representation of a thin-liquid falling-film

BOUNDARY CONDITIONS

$$\text{At } x = 0; \quad u = u_{in}, T = T_{in} \text{ and } \xi = \xi_{equil} \quad (1l)$$

At $y = 0$; (non permeable wall);

$$u = 0, T = T_w, \frac{\partial \xi}{\partial y} = 0 \quad (1m)$$

$$\text{At } y = h_0; \quad -K \frac{\partial T}{\partial y} = \rho D_m \frac{\partial \xi}{\partial y} H_a \quad \xi = \xi_{equil}(T, P_v) \quad (1n)$$

At the vapour-liquid interface, $y = h_0$;

$$\left(\frac{\partial u}{\partial y} \right)_{y=0} = 0, P_v = (T_s, \xi_s) = const.$$

Where H_a = Heat of absorption, T_w = Wall temperature P_v = Vapour pressure and

$\xi_{equil}(T, P_v)$ = equilibrium concentration at the interface temperature and ambient vapour pressure.

SOLUTION OF THE MODEL EQUATIONS

The solution technique used is Gaussian elimination scheme as modified by Paynes and Iron on the digital computer. The computer program is written in FORTRAN 90 language.

Computer Code

The computer code solves equations (1i, 1j) & (1k) using modified Gaussian elimination scheme.

DATA EMPLOYED

The data utilized from the literature are as shown in Table 1

Table 1 NH₃-H₂O Data [13]

| | | |
|----------------------------------|---|---|
| μ film dynamic viscosity | = | $4 \times 10^{-4} \text{kgm}^{-1} \text{s}^{-1}$ |
| μ_0 vacuum Permeability | = | $1.257 \times 10^{-6} \text{kgmA}^{-2} \text{s}^{-2}$ |
| u_{in} Initial velocity | = | 0.362 |
| ρ Liquid density | = | 127kgm^{-3} |
| K Thermal conductivity | = | $176 \text{Wm}^{-1} \text{K}^{-1}$ |
| T_w Wall Temperature | = | 35°C |
| T_{in} Inlet Temperature | = | 35°C |
| C_{in} Initial absorbent Conc. | = | 20% |
| C_{eq} Equilibrium absorb. Con | = | 20% |
| h_0 Mean film thickness | = | $1.00 \times 10^{-3} \text{m}$ |
| P_v Absorbent Vapour Pressure | = | 7.02mm.Hg |
| I Film mass flowrate | = | $0.01 \text{kgm}^{-1} \text{s}^{-1}$ |

PROCESSING OF RESULTS

The continuity, momentum, energy and species mass transport equations presented earlier were coded in a computer algorithm using FORTRAN programming coding language. The code was run on a personal computer with sufficient memory facilities to carry out the simulation exercise. The parameters utilized [1] in the literature, [7] and [13] as shown in Tables 1 have also been used. The domain area was divided into 13 x 5 mesh evenly spaced in both the direction of falling 1m (x) and in the direction of film thickness 10^{-3} m (y) in this paper. The results are presented graphically in the next section. The results cover the velocity, heat and mass analysis in both the direction of falling film and across its thickness.

RESULTS IN THE DIRECTION OF FALLING-FILM

The distribution of the significant parameters obtained in the direction of the falling film for Ammonia-water (NH₃-H₂O) solution agrees quite well with the existing literature results. For example Tables 2, 3, and 4 and Figs 2 to 10 and Figs 11 and 12 represent the distribution of average velocity,

Temperature and concentration of the falling-film within the bulk in X-axis or direction of the falling film at various magnetic induction intensities in NH₃-H₂O solution. Both the table and figures established that the velocity at stronger magnetic field is larger than that of the weaker one. The T-Test analysis results established that the velocity, Temperature and concentration distributions for ammonia-water was not significantly different ($p > 0.05$) from published results in literature as shown in the Tables 2, 3, 4 Figures 2 to 10 and 11 to 12

Table 2 NH₃-H₂O Velocity T- test analysis

| | Independent Samples Test | | | | | | | | | |
|----------------------|---|------|------------------------------|-------|------|------------|-----------------|-----------------------|--------|-------|
| | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | | |
| | F | Sig. | t | df | p | (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| Velocity @ 0.0 Tesla | .023 | .881 | .234 | 24 | .817 | .021292 | .05526 | .10114 | 1.2698 | |
| | | | .234 | 3.992 | .817 | .021292 | .05526 | .10114 | 1.2698 | |
| Velocity @ 1.4 Tesla | .084 | .775 | .382 | 24 | .706 | .02192 | .05745 | .09665 | 1.4050 | |
| | | | .382 | 3.942 | .706 | .02192 | .05745 | .09667 | 1.4051 | |
| Velocity @ 3.0 Tesla | .018 | .893 | .507 | 24 | .617 | .02908 | .05740 | .08939 | 1.4754 | |
| | | | .507 | 3.961 | .617 | .02908 | .05740 | .08940 | 1.4755 | |

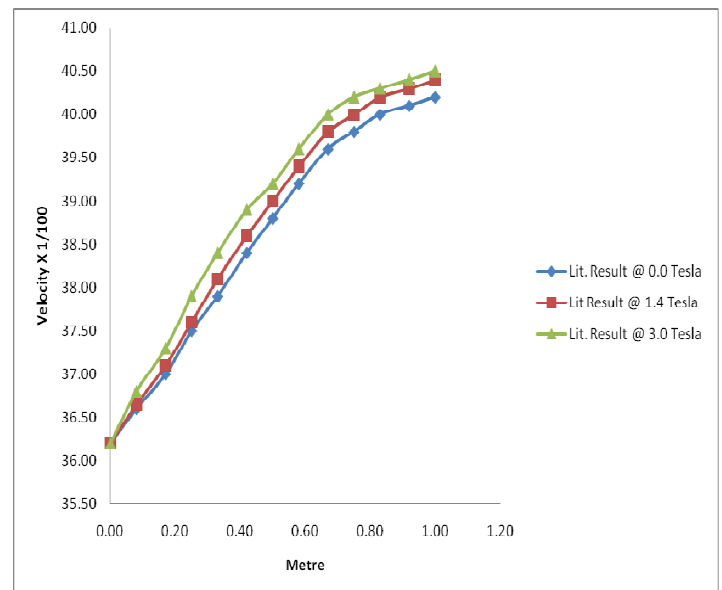


Figure 2 NH₃-H₂O Velocity Distribution in the film comparison @ 0.0, 1.4 and 3.0 Tesla

Table 3 NH₃-H₂O Temperature T- test analysis

| | | Independent Samples Test | | | | | | | | | | |
|---------------------------------------|-----------------------------|--|------|------------------------------|------|------------|-----------------|-------|-------|------|---|--|
| | | Levene's Test of Homogeneity of Variance | | t-test for Equality of Means | | | | | | | % Confidence Interval of the Difference | |
| | | F | Sig. | t | df | (2-tailed) | Mean Difference | Lower | Upper | | | |
| Temperature at assumed equal velocity | Equal variances assumed | .029 | .865 | .031 | 24 | .975 | .077 | 2.479 | .039 | .193 | | |
| | Equal variances not assumed | | | .031 | .980 | .975 | .077 | 2.479 | .039 | .193 | | |
| Temperature at assumed equal velocity | Equal variances assumed | .029 | .865 | .031 | 24 | .975 | .077 | 2.479 | .039 | .193 | | |
| | Equal variances not assumed | | | .031 | .980 | .975 | .077 | 2.479 | .039 | .193 | | |
| Temperature at assumed equal velocity | Equal variances assumed | .029 | .865 | .031 | 24 | .975 | .077 | 2.479 | .039 | .193 | | |
| | Equal variances not assumed | | | .031 | .980 | .975 | .077 | 2.479 | .039 | .193 | | |

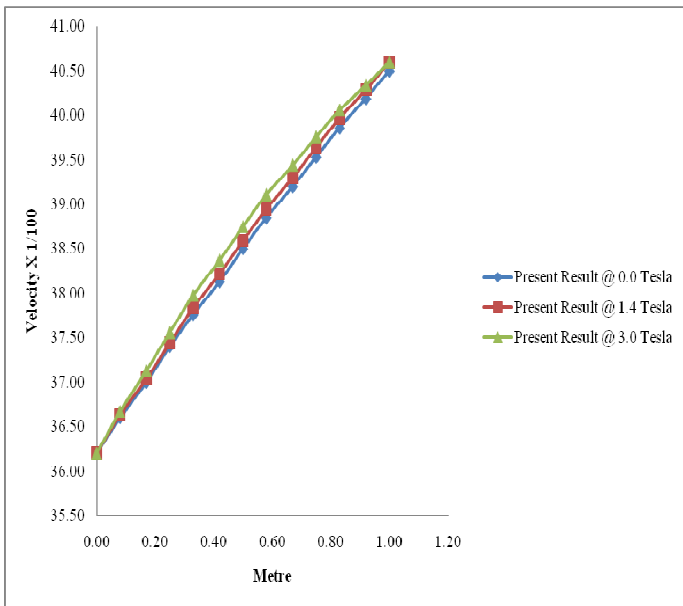


Figure 3 NH₃-H₂O Velocity Distribution in the film comparison @ 0.0, 1.4 and 3.0 Tesla

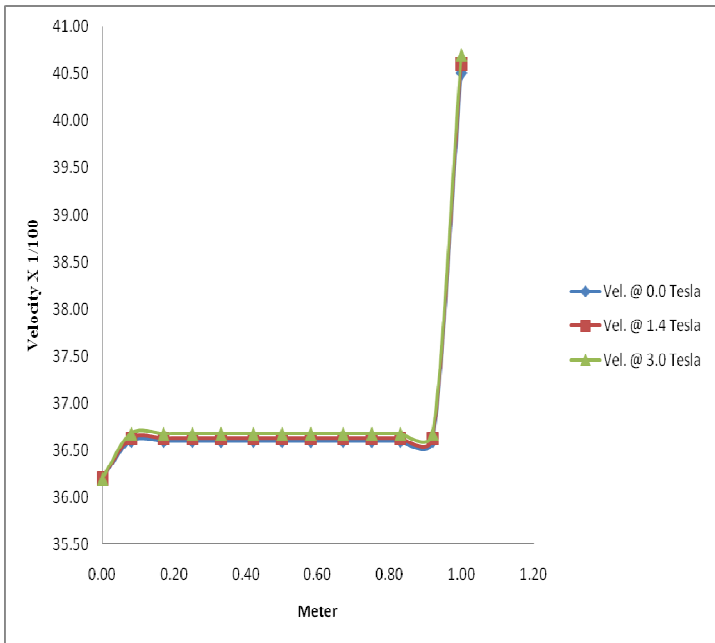


Figure 4 NH₃-H₂O Velocity Distribution at the film interface Comparison

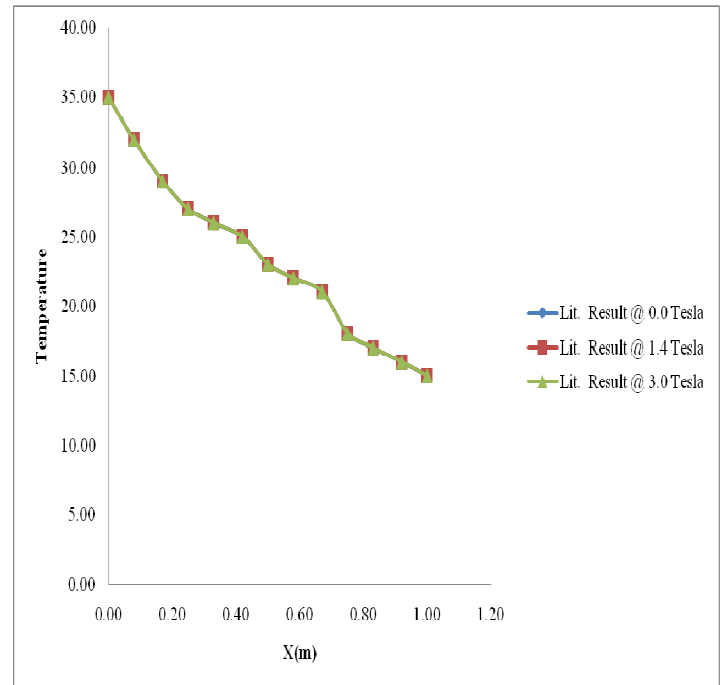


Figure 5 NH₃-H₂O Temperature Distribution in the film comparison @ Lit. Results

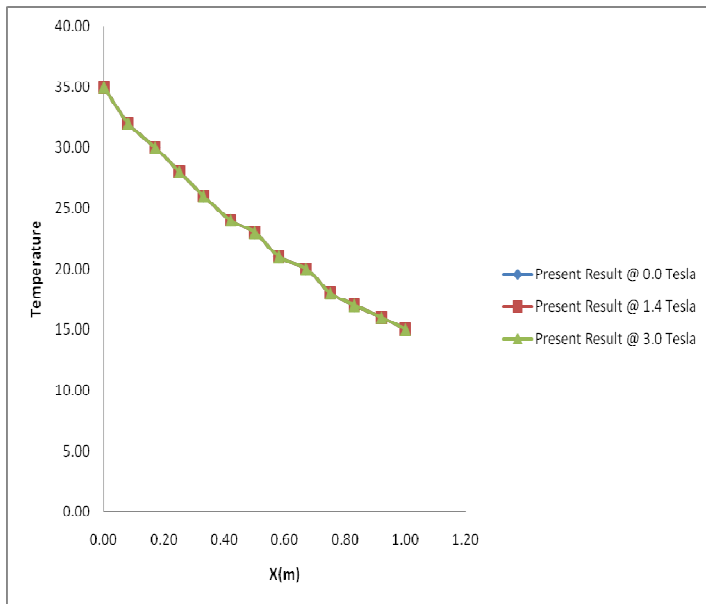


Figure 6 NH₃-H₂O Temperature Distribution in the film comparison @ Present Results

Table 4 NH₃-H₂O Concentration T- test analysis

| Independent Samples Test | | | | | | | | | | |
|---------------------------|---|------|------------------------------|-------|-----------------|-----------------|-----------------------|--|--------|-------|
| | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | | |
| | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 5% Confidence Interval of the Difference | Lower | Upper |
| Concentration @ 0.0 Tesla | Equal variances assumed | .015 | .904 | .857 | 24 | .400 | .0183 | .0213 | -.0257 | .0623 |
| | Equal variances not assumed | | | .857 | 3.993 | .400 | .0183 | .0213 | -.0257 | .0623 |
| Concentration @ 1.4 Tesla | Equal variances assumed | .013 | .911 | .888 | 24 | .383 | .0195 | .0219 | -.0258 | .0647 |
| | Equal variances not assumed | | | .888 | 3.993 | .383 | .0195 | .0219 | -.0258 | .0647 |
| Concentration @ 3.0 Tesla | Equal variances assumed | .009 | .924 | 1.113 | 24 | .277 | .0250 | .0225 | -.0214 | .0713 |
| | Equal variances not assumed | | | 1.113 | 3.994 | .277 | .0250 | .0225 | -.0214 | .0713 |

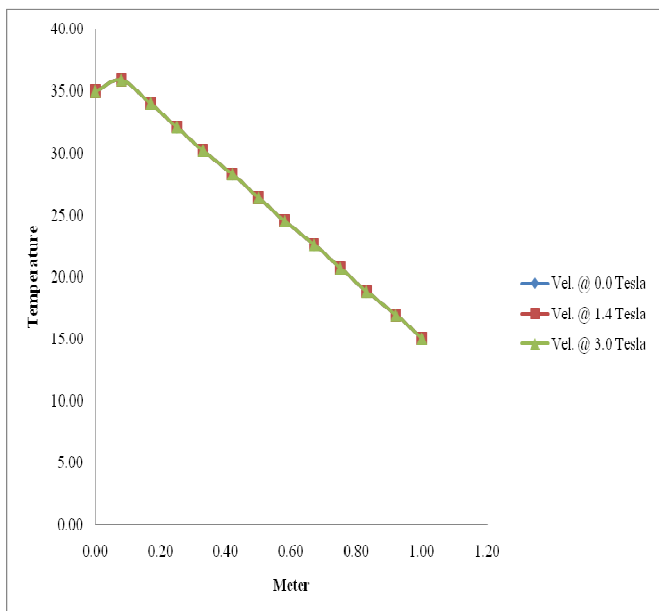


Figure 7 NH₃-H₂O Temperature Distribution at the film Interface Comparison

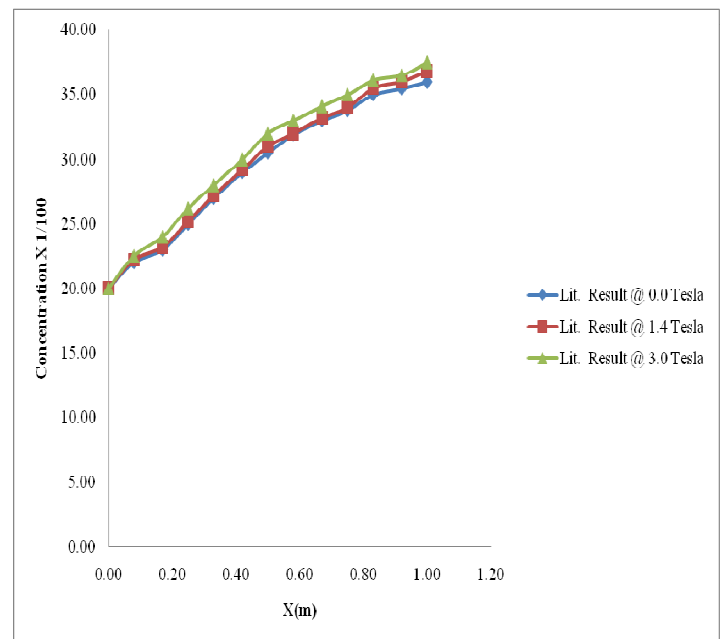


Figure 8 NH₃-H₂O Concentration Distribution in the film comparison @ Lit. Result

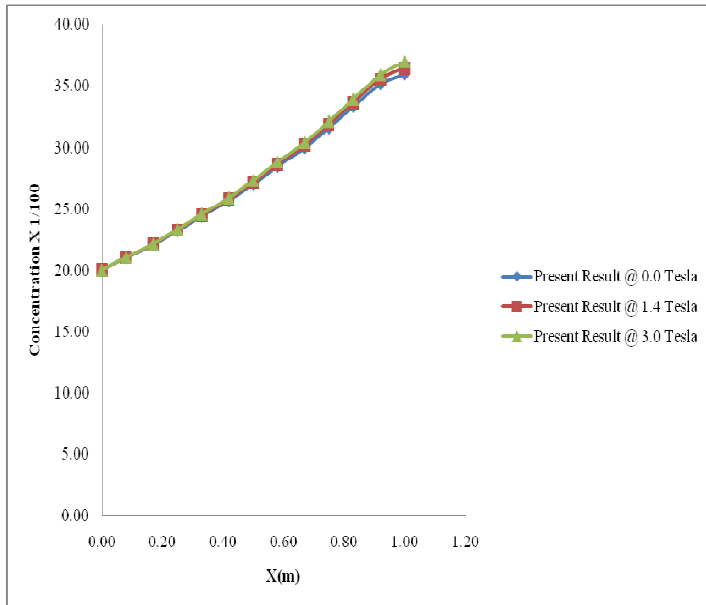


Figure 9 NH₃-H₂O Concentration Distribution in the film comparison @ Present Result

4.2: Coefficient of Performance (COP) for NH₃-water absorption Refrigeration

Coefficient of performance (COP) of an absorption refrigeration system is obtained from;

$$\text{COP} = \frac{\text{cooling capacity obtained at evaporator}}{\text{heat input for the generator + work input for the pump}} \times 100$$

or

$$\text{COP} = \frac{\text{Concentration at the outlet}}{\text{Concentration at the inlet}} \times 100$$

The work input for the pump is negligible relative to the heat input at the generator; therefore, the pump work is often neglected for the purposes of analysis.

From the result

At 0.0 Tesla, COP = 0.3518/0.2 x 100% = 175.9%

At 1.4 Tesla, COP = 0.3555/0.2 x 100% = 177.75%

At 3.0 Tesla, COP = 0.3590/0.2 x 100% = 179.5%

Increment at 1.4Tesla relative to 0.0Tesla 179%-177.75 = 1.9%

Increment = 179.5% - 175.9% = 3.6%

RESULTS IN THE DIRECTION OF THE FILM THICKNESS (δ)

The velocity distribution across the film thickness direction at sections X=0.25m in three different magnetic induction intensities are shown in Figures 11 to 12. A dimensionless parameter of y/δ is used as the abscissa. It is seen from Figures 11 and 12 that with the increase of the magnetic induction (β), the velocity increases at X= 0.25m, for NH₃-water solution. This could be explained as follows; At the inlet section, absorption just began in an intense way and the film thickness is very thin, the absorption enhancement effect by magnetic field is obvious, turbulence in direction of thickness therefore are more intense due to the above mentioned reasons. Velocity variations along the thickness direction at the selected section have the tendency of increasing from absorber wall to the vapour-liquid interface as established. This indicates that the refrigerants vapour in the working fluid permeates towards the inner solution from the vapour-liquid interface. When the liquid film drops, the increase in velocity is slowed down. Thus the result establishes positive influence of the magnetic field enhancement on the working fluid.

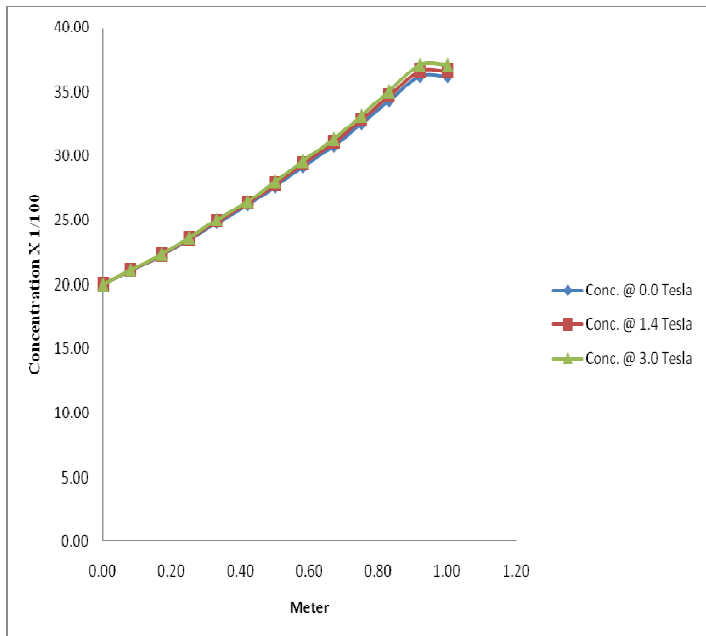


Figure 10 NH₃-H₂O Concentration Distribution at the film Interface Comparison

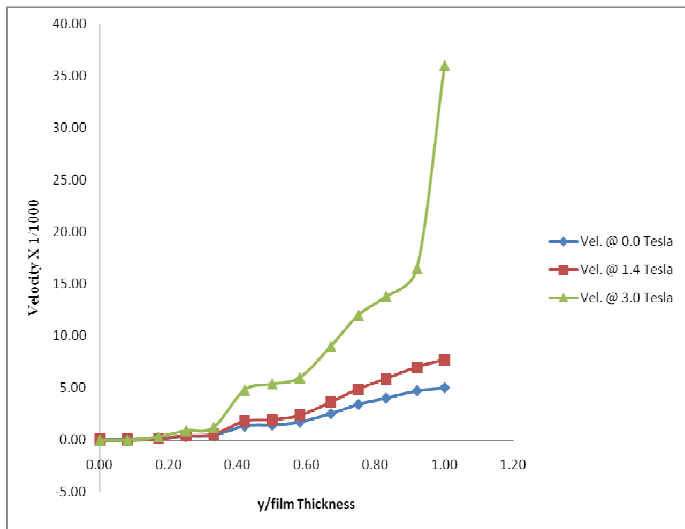


Figure 11 NH₃-H₂O Velocity Distribution in the Direction of Film Thickness @ X=0.25m (**Literature Result**)

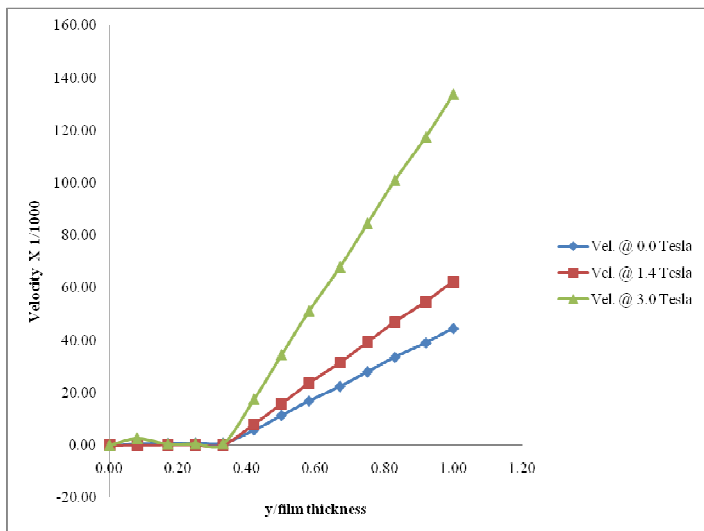


Figure 12 NH₃-H₂O Velocity Distribution in the Direction of Film Thickness @ X=0.25m (**Present Result**)

CONCLUSION

The absorption process modeling of a smooth thin-liquid falling-film in Lithium bromide-water absorption system in magnetic field enhancement medium has been undertaken. The developed mathematical model for the magnetic field enhancement of lithium bromide water absorption system was established. The model equations were developed from the continuity, momentum, energy, concentration or species and mass transport equations. The changes in physical properties of the working fluid in absorption system within the smooth thin-liquid film thickness along falling and across the film in the direction of its thickness were considered in the modeling. Distributions of parameters in falling-film absorption, such as velocity, temperature and concentration in the application of

magnetic field were obtained. The distributions of the parameters were obtained in both the direction of falling-film and across the film thickness.

The numerical results obtained show that magnetic field improved the performance of lithium bromide-water falling film absorption, and the absorption strengthening effect increases with the enhancement of magnetic intensity. In this work the strengthening effect is limited within the magnetic field intensity of 0-3Tesla, but there are trends of absorption strengthening effect increasing more in stronger magnetic fields. Macroscopic magnetic field force was introduced in the mathematical model to reflect the influence of magnetic field on lithium bromide water and lithium chloride water absorption, while the microcosmic impact of magnetic field was not considered in this work.

RECOMMENDATIONS

This work has limited its scope of study to only one working fluid-pair i.e lithium bromide solution out of numerous available absorption working fluids pairs. A few of such additional working fluid pairs are Ammonia-water solution, HFC-dimethylethylenurea [DMEU], NH₃-SrCl₂, ethylene glycol solution and Ammonia-water sodium hydroxide mixtures, although the literature survey indicated that of all these absorption working-fluid pairs, the working fluid pair used in this paper was rated the best for air-conditioning system. It has also limited its scope of solution method to finite difference method out of all the available numerical methods such as finite element method, finite volume, boundary element method, Monte Carlo technique, vortex method etc; due to its reliability from the literature and its adequacy in the flow under consideration.

The followings have therefore been established and recommended from this paper

- ❖ The developed model for the magnetic field enhancement of the lithium bromide-water absorption system has been established and therefore recommended for usage in investigating the magnetic field effect on any other available working fluids in absorption refrigeration.
- ❖ Improvement in the performance of lithium bromide-water falling film absorption, and absorption strengthening increasing with the enhancement of magnetic induction intensity has also been established.
- ❖ Positive effect of macroscopic magnetic field force on the working fluid used was also established.
- ❖ The Coefficient of Performance (COP) of NH₃ solution absorption refrigeration system was established to have increased by 3.6%, when magnetic induction was 3.0 Tesla.

The following areas are therefore worthy of further research work:

- ❖ Investigation of microcosmic impact of magnetic field on lithium bromide-water absorption refrigeration.

- ❖ Development of magnetic field enhancement absorption process model using any other absorption refrigeration working fluids apart from lithium bromide and ammonia-water solutions.
- ❖ Adoption of any other numerical solution method such as finite element method, finite volume, boundary element method, Monte Carlo technique, vortex method etc on absorption enhancement modeling study.

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