SENRA Academic Publishers, British Columbia
Vol. 8, No. 2, pp. 2933-2942, June 2014
Online ISSN: 1920-3853; Print ISSN: 1715-9997

Canadian Journal of pure&applied sciences

MODELING OF THINLIQUID FALLINGFILM IN H_2O-LiBr AND H_2O-LiCl ABSORPTION REFRIGERATION SYSTEMS

*KM Odunfa[1], RO Fagbenle[2], O O Oluwole[1] and OS Ohunakin[3]
[1]Mechanical Engineering Department, University of Ibadan, Ibadan, Oyo State
[2]Mechanical Engineering Department, Obafemi Awolowo University, Ile-Ife, Osun State
[3]Mechanical Engineering Department, Covenant University, Ota, Ogun State, Nigeria

ABSTRACT

Experimental modeling has over the past three decades been used in analyzing simultaneous heat and mass transfer in thin-liquid falling-film absorption processes. However, numerical modeling applications in this area have been minimal due to complications arising from the presence of waves. An approach in numerical modeling is to consider waves as a second order effect, thereby making it a smooth falling-film. The objective of this paper was to develop a numerical model for the absorption process on a thin-liquid smooth falling-film using lithium bromide (LiBr) and lithium chloride (LiCl) solutions. The absorption process of a thin-liquid smooth falling-film was considered as a two-dimensional steady laminar flow within the film thickness to the absorber wall. The conservation equations were used to determine temperature and concentration distribution within the film-thickness using the finite difference technique. Existing data on LiBr and LiCl solutions in the literature were used to validate the developed model. Standard values of absorber wall length, film thickness, solution mass flow-rate, absorbent inlet concentration, inlet temperature, absorber wall temperature, conventional film Reynolds number and absorption design effectiveness were used for both LiBr and LiCl solutions. Data were analyzed using descriptive statistics and student's t-test ($p<0.05$). The physical properties distribution for both LiBr and LiClsolutions were not significantly different from published results available in the literature($p<0.05$). The nodal temperature distribution obtained within the film thickness both in the bulk and interface between the liquid and vapour regions were between 44.4 and 35.0^oC while concentration was between 60.0 and 54.5% for LiBr-H_2O. Similarly for LiCl-H_2O, the model temperature distribution was between 35.0 and 30.0^oC while the concentration was between 45.0 and 35.8%.A numerical model on a thin-liquid smooth falling film using LiBr and LiCl solutions was developed. Lithium bromide was also observed to have higher concentration values than lithium chloride thus suggesting a better working fluid combination especially in the absorption air-conditioning system.

Keywords: Absorption refrigeration, lithium bromide, lithium chloride, air-conditioning.

INTRODUCTION

Energy conservation and environmental safety in recent years, have become a thing of global concern due to the increasing energy prices and the consequent environmental impact. The current imbalance of energy demand and supply coupled with the environmental degradation in many developing countries has further increased the urgent need for highly efficient and sustainable energy technologies. The worldwide demand for this phenomenon has prompted the emergence of new technologies in many areas of the global economy, such as in the cooling system development sector. Basically, cooling system may be divided into two categories:vapour compression and sorption systems. The vapour compression system involves the use of a compressor for the compression process. Sorption system can be sub-divided into absorption and adsorption systems; an absorption system is simply the replacement of the traditional compression with a thermo-chemical fluid lifting process. In other words, it is the mixture of a gas in a liquid, the two fluids present 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 (adsorbate). However, in the manufacturing of the cooling machine/system, the 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 systems driven by electrical energy. 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 (Yang and Wood, 1992).

*Corresponding author email: m.odunfa@mail.ui.edu.ng

Many researchers such as Andberg (1983), Grossman (1983) and Andberg and Vliet (1983) have approached the study of this area using various modeling techniques which may be categorized either into (i) numerical or (ii) experimental.Numerical methods (including finite element, finite difference, boundary element, Monte Carlo technique and vortex methods etc.) have been developed over many decades and are still being developed to effectively tackle many engineering problems. These methods may be categorized into two: deterministic approach and probabilistic approach. Probabilistic methods such as Monte Carlo and vortex element techniques make constant recourse to random numbers while finite element, finite difference and boundary element techniques are deterministic in nature.

Several works have been carried out on modeling with experimental data of heat and mass transfer in thin-liquid falling film absorption while there are relatively few studies on numerical modeling of the problem. For instance, the technical feasibility of driving a lithium chloride-water solution absorption-cooling unit by a low-temperature heat source (such as solar energy using a simple flat-plate collector) for air-conditioning applications was thoroughly investigated by Ali and El-Ghalban, 2002. The operating characteristics of the unit were extensively investigated and the Coefficient of Performance (COP) of the unit was found to be 19% as against the expected designed value of 21%. Safarik *et al.* (2004), also carried out an experimental modeling on a solar power absorption chiller with low capacity using lithium bromide-water solution as the working fluid. The field test carried out at three sites in the summer of 2003 after the prototype test in this experimental modeling showed that the absorption chiller works reliably and flexibly over a wide range of external conditions. Abdelmessih *et al.* (2004) experimentally investigated the use of non-traditional absorbent/refrigerant pairs such as ethylene glycol-water in an absorption refrigeration cycle. The investigation was successful in replacing the traditional hazardous absorbent/refrigerant pairs with a safe working fluid (ethylene glycol-water pair). Yaxiu *et al*. (2008) also experimented a compact solar pump-free lithium bromide absorption refrigeration system equipped with a second generator, a falling-film absorber, a falling-film evaporator and an efficient luminate thermosiphon elevation tube. The experiment confirmed a 48.5% increase in the COP.The numerical modeling is complicated by the presence of the waves in the falling liquid-film; an approach in numerical modeling is therefore to consider waves as a second order effect, thereby, making it a smooth falling-film. This smooth falling film absorption approximation has been more popularly investigated,the earliest of such being the work of Grossman (1983). The work was even considered complicated in formulation due to the restriction of the model to the case with the inlet absorbent temperature being equal to that of the wall. Andberg and Vliet (1983) also investigated the smooth falling-film absorption under laminar flow using a different model from the work of Grossman (1983), it was also considered most sophisticated and somewhat too complicated in formulation.

In Yang and Wood (1992), the finite difference approach was adopted to develop a simple, smooth-film absorption model using LiCl-H_2O and LiBr-H_2O systems with Reynolds number of 2.7, 27 and 100. The model handles various initial/boundary conditions and gives solutions similar to the earlier work of Grossman (1983) and also with experimental data. Ghaddar *et al*. (1996) modeled solar lithium bromide absorption system performance in Beirut using a simulated computer program; the result shows that for each ton of refrigeration, it is required to have a minimum collector area of $23.3m^2$ with an optimal water storage tank capacity ranging from 1000 to 1500 liters for the system to operate solely on solar energy for about seven hours a day. The energy use in cooling was also found to be of function of solar collector area and storage tank capacity. Based on the economic assessment performed on the current cost of the conventional cooling system, it was also found that the solar cooling system is marginally competitive only when combined with domestic water heating Ghaddar *et al*. (1996). An overview of the performance assessment of a developed prototype low capacity (10kw) solar assisted lithium bromide absorption heat pump (AHP) coupled with a sub-floor system with the use of a commercial simulator known as TRNSYS was carried out by Argiriou *et al*. (2005). The assessment was done for two building types (high and low thermal mass) in three climatic conditions with different types of solar collectors, hot water storage tank sizes and different control systems for the operation of the installation. The results indicated that the estimated energy savings against a conventional cooling system using a compression type heat pump was in the range of 20-27%. In Bruno *et al*. (2004), Ammonia-water-sodium hydroxide mixtures absorption refrigeration plant was modeled using a commercial process simulator "Aspen Plus 2003". It was found that the system performance is notably increased (lower driving temperature and higher COP).

However, Fernandez *et al*. (2005) solved the simultaneous heat and mass transfer equations in Ammonia-water absorption system using finite difference approach. The results established the expected typical range of values $x_{vb} < z < \infty$or $-\infty < z < x_{Lb}$ and $x_{Lb} < z < x_{vi}$ for mass transfer against temperature variations in different components of the plant such as absorber and evaporator; where x, z, b, L, i and v are defined as ammonia molar concentration, ammonia to net molar flux transferred ratio, bulk conditions, liquid, liquid-vapour interface and vapour respectively. In Staicovici and Isvoranu (2005) water-lithium bromide absorption/generation processes in a Marangoni Convection Cell (applied practical method by the thermal absorption technology in the past decades to significantly improve the absorption process) using the Two-Point Theory (TPT) of mass and heat transfer was modelled. The model established the capability of TPT approach in the Marangoni convection assisted water-lithium bromide absorption process following the successful modeling of the ammonia-water absorption process. It also confirms Marangoni convection basic mechanism explanation in the case of the water-lithium bromide medium. Zohar *et al*. (2007) investigated the influence of diffusion in the ammonia-water Diffusion Absorption Refrigeration (DAR) cycle configuration on the system performance using a computer simulator known as Engineering Equation Solver (EES). The result reveals that DAR cycle without condensate sub-cooling shows higher COP of 14-20% compared with the DAR cycle with the condensate sub-cooling, but it occurs at a higher evaporator temperature of about 15^oC.

Niu *et al*. (2007) performed a numerical analysis of falling film ammonia-water absorption in a magnetic field using a computer program referred to as TDMA due to the tri-diagonal matrix formation of the equations after discretization. It was found that when the magnetic induction intensity at the solution's inlet was 3Tesla, the increment in concentration of ammonia-water solution at outlet was 1.3%, the absorbability increased by 5.9%, COP of the absorption refrigeration system increased by 4.7% and the decrement in circulation ratio was 8.3%. This establishes a positive effect on the ammonia-water falling film absorption to some degree. Kyung *et al*. (2007) further developed a water-lithium bromide absorption process model over a horizontal tube using finite difference approach. The model predicted a significant absorption in the drop formation regime with a considerable variation of temperature and mass fraction. Simulation of aqueous lithium bromide (H_2O-LiBr) advanced energy storage system using finite difference method was carried out by Xu *et al*. (2007a, b). The result predicted the dynamic characteristics and performance of the system, including the temperature and concentration of the working fluid, the mass and energy in the storage tanks, the compressor intake mass or volume flow rate, discharge pressure, compression ratio, power and consumption work, the heat loads of heat exchanger devices in the system and so on. The result also indicated that the Integrated Coefficient of Performance (COP_{int}) of the system was as high as 3.26 as against the expected value of 3.0 under the two storage strategies, while the isentropic efficiency of water vapour compressor was set as 60%. These results were found to be very helpful in understanding and evaluating the system as well as for system design, operation and control. Gustavo *et al*. (2008), studied a two-stage water-LiBr absorption chiller driven at two temperature levels using thermodynamic modeling technique. The study established that the machine can operate in summer as a double-stage chiller driven by heat at 170^oC from natural gas, as a single-stage chiller driven by heat at 90^oC from solar energy, or simultaneously in combined mode at both temperatures. It also established the capability of operating in winter in "double-lift" mode for heating with a driving heat at 170^oC from natural gas. In Balghouthi *et al*. (2008), model work on both experimental and numerical modeling of solar water-lithium bromide absorption air conditioning in Tunisian climatic conditions (36^o latitude and 10^o longitude, 400cal/cm^{2}day average solar irradiation, and 3700h/year of the total insolation period) were conducted using the TRNSYS and EES programs. The model established that the absorption solar air-conditioning system was suitable for Tunisia. Although, the system has a high initial cost, but with its advantage of near zero maintenance cost, the system could help to minimize fossil fuel-based energy use, reduce electricity demand on the national grid (especially at peak demand periods in summer), and eliminate the use of CFCs.

The finite difference method has been applied much more than any other methods in the analysis of absorption/adsorption systems. Probabilistic or deterministic methods could also be used depending on the degree of accuracy required of the solution in comparison with the solutions obtained experimentally or analytically. This paper thus employs the finite difference method for establishing temperature and concentration distributions during the absorption process on a thin-liquid falling-film in a cooling system using (H_2O-LiBr) and (H_2O-LiCl) refrigerants/absorbents combinations. Such an investigation would reveal sections of the absorber that need to be redesigned for optimal efficiency of refrigerant absorption by the absorbent.

MATHEMATICAL MODEL

Assumptions

In formulating the model equations, the following assumptions are made.

1. The flow is a fully developed smooth laminar flow in a steady state as shown in figure1.
2. The fluid properties are constant and not varying with temperature and concentration.
3. 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.
4. Heat transfer in the vapor phase is negligible.
5. Vapor pressure equilibrium exists between the vapour and liquid at the interface.
6. The Peclet numbers are large enough such that the diffusion in the flow direction can be neglected.
7. Diffusion thermal effects are negligible.

Table 1. Data for LiBr-H_2O and LiCl-H_2O solutions as obtained in literatures.

Working fluid parameters	symbols	LiBr-H_2O	LiCl-H_2O
film dynamic viscosity	μ	4 x 10^{-4}kgm^{-1}s^{-1}	4 x 10^{-4}kgm^{-1}s^{-1}
mean velocity	ν_o	3.15 x 10^{-4}ms^{-1}	3.15 x 10^{-4}ms^{-1}
Thermal diffusivity	α	0.155m^{2}s^{-1}	0.155m^{2}s^{-1}
Liquid density	ρ	127kgm^{-3}	1000kgm^{-3}
Thermal conductivity	K	176Wm^{-1}k^{-1}	176Wm^{-1}k^{-1}
Species diffusivity	D	1 x 10^{-10} m^{2}s^{-1}	2.0 x 10^{-9} m^{2}s^{-1}
Wall Temperature	T_w	35^{o}C	30^{o}C
Inlet Temperature	T_{in}	44.44^{o}C	35^{o}C
Initial absorbent Conc.	C_{in}	60%	45%
Equilibrium absorb. Con	C_{eq}	60%	35.8%
Gravity	g	9.8ms^{-2}	9.8ms^{-2}
Mean film thickness	h_o	1.74 x 10^{-3}m	1.74 x 10^{-3}m
Heat of absorption	H_a	3466kj/kg	3466kj/kg
Absorbent Vapour Pressure	Pv	7.02mmHg	9.2mmHg
Film Reynolds number	R_{ef}	100	100
Film mass flowrate	I	0.01kgm^{-1}s^{-1}	0.01kgm^{-1}s^{-1}

Data source: Yang and Wood (1992)

8. The shear stress at the liquid – vapor interface is negligible.

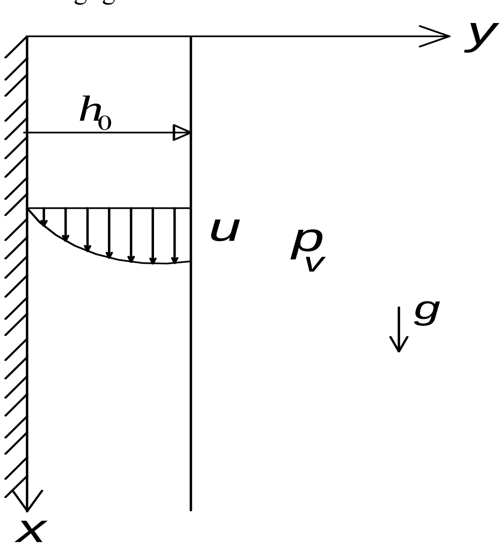

Fig. 1. 2-D representation of a thin-liquid falling-film.

Governing equations

The general governing heat and mass transfer equations for the falling film medium areas follows:

$$U\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} \quad (1)$$

$$U\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_{ab}\frac{\partial^2 C}{\partial y^2} \quad (2)$$

From the preceeding assumptions (mathematical model), the heat and mass transfer equations in thin-liquid falling-film (corresponding to the coordinate system) shown in figure 1 and expressed in Equations 1 and 2 will become Equations 3 and 4:

$$U\frac{\partial T}{\partial x} - \alpha\frac{\partial^2 T}{\partial y^2} = 0 \quad (3)$$

$$U\frac{\partial C}{\partial x} - D\frac{\partial^2 C}{\partial y^2} = 0 \quad (4)$$

$$U = \frac{3}{2}V_0\left[2\frac{y}{h_0} - \left(\frac{y}{h_0}\right)^2\right] \quad (5)$$

where, T is temperature, C is concentration (absorbent), α is thermal diffusivity and D or D_{ab} is species diffusivity

$$V_0 = \frac{\rho g h_0^2}{3\mu}, \qquad h_0 = \left(\frac{3\mu V_0}{\rho g}\right)^{\frac{1}{2}}$$

Boundary conditions

At x = 0; T = T_{in} and $C = C_{in}$ (6)

At y = 0 (non-permeable wall); $T = T_w,\ \frac{\partial C}{\partial y} 0$ (7)

At $y = h_0$;

$$-K\frac{\partial T}{\partial y} = \rho D\frac{\partial C}{\partial y}H_a, C = C_{equil}(T, P_v) \quad (8)$$

Table 2. LiBr-H_2O solution.

X (m)	a) Temperature Distribution					
	Bulk			Interface		
	Literature result	Present result	Percentage deviation	Literature result	Present result	Percentage deviation
0 or 10^{-6}	44.44	44.44	0.00	44.44	44.44	0.00
$10^{-5.5}$	44.40	43.65	-1.69	44.44	44.35	-0.20
10^{-5}	43.50	42.87	-1.45	44.44	43.50	-2.18
$10^{-4.5}$	43.20	42.08	-2.59	44.44	42.65	-4.03
10^{-4}	43.00	41.29	-3.98	44.44	41.80	-5.94
$10^{-3.5}$	41.50	40.51	-2.39	44.44	40.95	-7.85
10^{-3}	39.50	39.72	+0.56	44.00	40.10	-8.86
$10^{-2.5}$	38.00	38.93	+2.45	42.00	39.25	-6.55
10^{-2}	36.60	38.15	+4.23	39.50	38.40	-2.78
$10^{-1.5}$	36.40	37.36	+2.64	38.00	37.55	-1.18
10^{-1}	36.00	36.57	+1.58	37.00	36.70	-0.81
$10^{-0.5}$	35.50	35.79	+0.82	36.00	35.85	-0.42
10^{0}	35.00	35.00	0.00	35.00	35.00	0.00

X (m)	b) Concentration Distribution					
	Bulk			Interface		
	Literature result	Present result	Percentage deviation	Literature result	Present result	Percentage deviation
0 or 10^{-6}	0.600	0.600	0.00	0.599	0.592	-1.17
$10^{-5.5}$	0.600	0.59545	-0.76	0.599	0.583	-2.67
10^{-5}	0.600	0.59090	-1.52	0.599	0.580	-3.17
$10^{-4.5}$	0.600	0.58635	-2.28	0.599	0.576	-3.84
10^{-4}	0.600	0.58180	-3.03	0.599	0.573	-4.34
$10^{-3.5}$	0.600	0.57724	-3.79	0.599	0.569	-5.01
10^{-3}	0.600	0.57267	-4.56	0.591	0.566	-4.23
$10^{-2.5}$	0.599	0.56810	-5.16	0.580	0.562	-3.10
10^{-2}	0.590	0.56352	-4.49	0.570	0.559	-1.93
$10^{-1.5}$	0.575	0.55892	-2.80	0.560	0.555	-0.89
10^{-1}	0.567	0.55432	-0.01	0.550	0.552	+0.36
$10^{-0.5}$	0.559	0.54970	0.07	0.548	0.549	+0.18
10^{0}	0.545	0.54500	0.00	0.545	0.545	0.00

where H_a = heat of absorption, T_w = wall temperature, P_v = vapour pressure and $C_{equil}(T, P_v)$ = equilibrium concentration at the interface temperature and ambient vapour pressure.

At the boundary, usually the parameters such as temperature and concentration are known (Dirichlet conditions) or the boundary is considered to be perfectly insulated (Newmann or Adiabatic conditions). Insulated boundaries are handled by developing boundary element/nodal equations. Hence, Newmann or Adiabatic boundary condition was used along the absorber wall in this model.

Solution of the model equations

The Gaussian elimination method is adopted in this work towards the development of a computer program written in FORTRAN 90 language. The main program with the flow chart shown in figure 2 solves equations (3) and (4) using modified Gaussian elimination scheme. This program utilizes two different subroutines (1 and 2) having their flowchart shown in figure 3. These subroutines are developed to execute various steps involved in applying the finite difference scheme and function after the implementation of the boundary conditions in the global domain. Solution1 generates the temperature profile of the domain, while solution 2 produces a concentration profile within the domain. The problem data are introduced into the program in the “data

Table 3. LiCl-H_2O solution.

X (m)	a) Temperature Distribution					
	Bulk			Interface		
	Literature result	Present result	Percentage deviation	Literature result	Present result	Percentage deviation
0 or 10^{-6}	35.00	35.00	0.00	36.00	36.62	+1.72
$10^{-5.5}$	35.00	34.58	-1.20	36.25	38.25	+5.52
10^{-5}	35.00	34.17	-2.37	37.00	37.50	+1.35
$10^{-4.5}$	35.00	33.75	-3.57	37.60	36.75	-2.26
10^{-4}	35.00	33.33	-4.86	38.00	36.00	-5.26
$10^{-3.5}$	35.00	32.92	-6.00	38.20	35.25	-7.72
10^{-3}	35.00	32.50	-7.14	38.20	34.50	-9.68
$10^{-2.5}$	34.80	32.08	-7.82	37.00	33.75	-8.78
10^{-2}	33.90	31.67	-6.52	36.00	33.00	-8.33
$10^{-1.5}$	32.10	31.25	-2.65	34.50	32.25	-6.52
10^{-1}	32.00	30.83	-3.66	33.00	31.50	-4.55
$10^{-0.5}$	31.50	30.42	-3.43	31.90	30.75	-3.61
10^{0}	30.00	30.00	0.00	30.00	30.0	0.00

X (m)	b) Concentration Distribution					
	Bulk			Interface		
	Literature result	Present result	Percentage deviation	Literature result	Present result	Percentage deviation
0 or 10^{-6}	0.450	0.450	0.00	0.400	0.426	+6.50
$10^{-5.5}$	0.450	0.450	0.00	0.402	0.402	0.00
10^{-5}	0.450	0.4406	-2.08	0.405	0.398	-1.73
$10^{-4.5}$	0.450	0.4360	-3.12	0.410	0.394	-4.00
10^{-4}	0.450	0.4313	-4.15	0.414	0.390	-5.80
$10^{-3.5}$	0.450	0.4267	-5.18	0.414	0.386	-6.76
10^{-3}	0.448	0.4221	-5.79	0.414	0.382	-7.73
$10^{-2.5}$	0.440	0.4174	-5.13	0.400	0.378	-5.50
10^{-2}	0.440	0.4128	-6.18	0.390	0.374	-4.10
$10^{-1.5}$	0.430	0.4082	-5.07	0.380	0.370	-2.63
10^{-1}	0.420	0.4036	-3.91	0.370	0.366	-1.08
$10^{-0.5}$	0.390	0.3990	2.30	0.365	0.362	-0.82
10^{0}	0.358	0.3580	0.00	0.358	0.358	0.00

block", where the input parameters can easily be modified to suit any case study. The input data utilized were obtained from literature in the work of Andberg (1983) and Yang and Wood (1992), as used for the available experimental and numerical modelingin order to obtain high quality output of temperature and concentration profiles in the domain. The data utilized from the literature are as shown in table 1 (LiBr–H_2O and LiCl–H_2O).

RESULTS AND DISCUSSION

Results in the direction of falling film (X)

The model run has been executed using the two working fluid pairs (lithium bromide-water and lithium chloride-water). The respective temperature and concentration distributions obtained from the models as compared with that found in literatures (previous work by Andberg (1983) and Yang and Wood (1992) are presented in table 2 for lithium bromide-water and table 3 for lithium chloride-water.Temperature and concentration profiles of smooth film absorption were further plotted as shown in figures 4 (a, b) and 5 (a, b) respectively to compare previous work with the developed model for thelithium bromide-water solution and lithium chloride-water solution. It was observed that downstream the wall, the absorbent solution approaches the equilibrium condition corresponding to the given wall temperature and the absorber pressure. The results agree quite well with previous work in literatures within 9% for interface temperature, but much better at approximately 5% for bulk temperature. Concentration results are much closer for both interface and bulk calculations, being generally less than 1% and also confirm the stated assumptions (3) and (7) of the mathematical model.

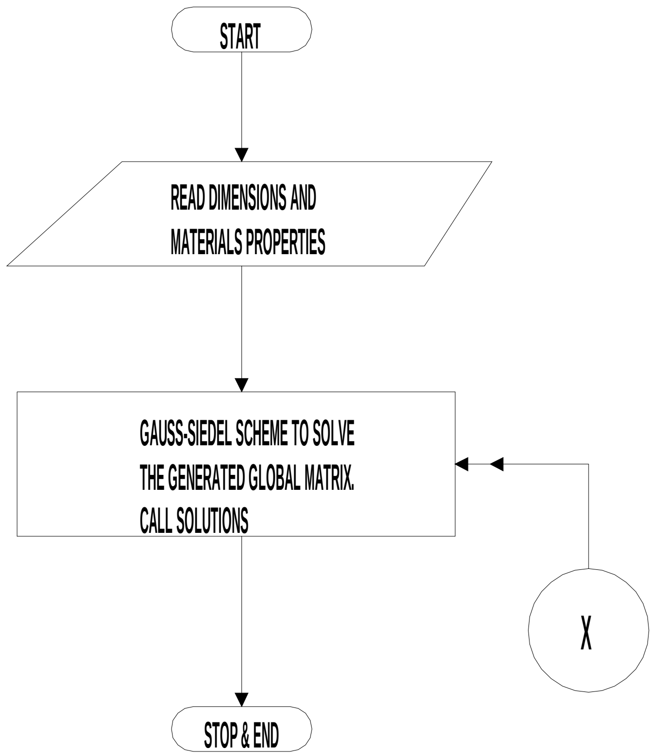

Fig. 2. Main program flow chart.

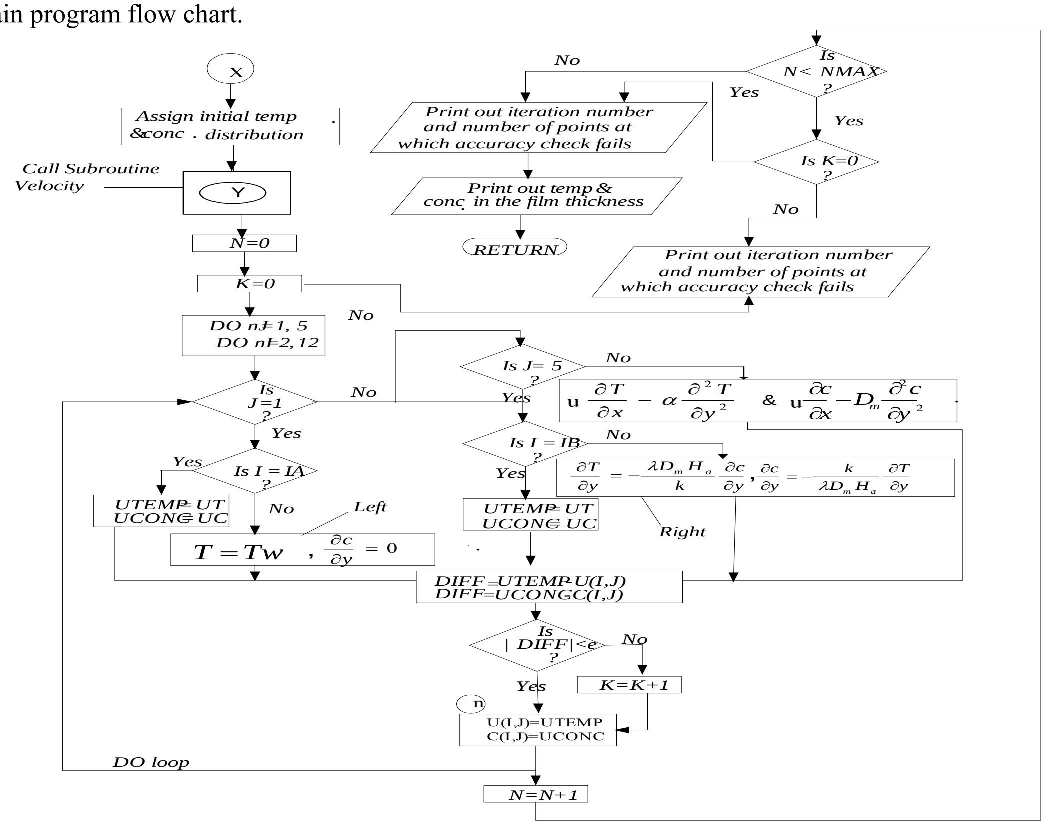

Fig. 3. Model subroutine solution flow chart.

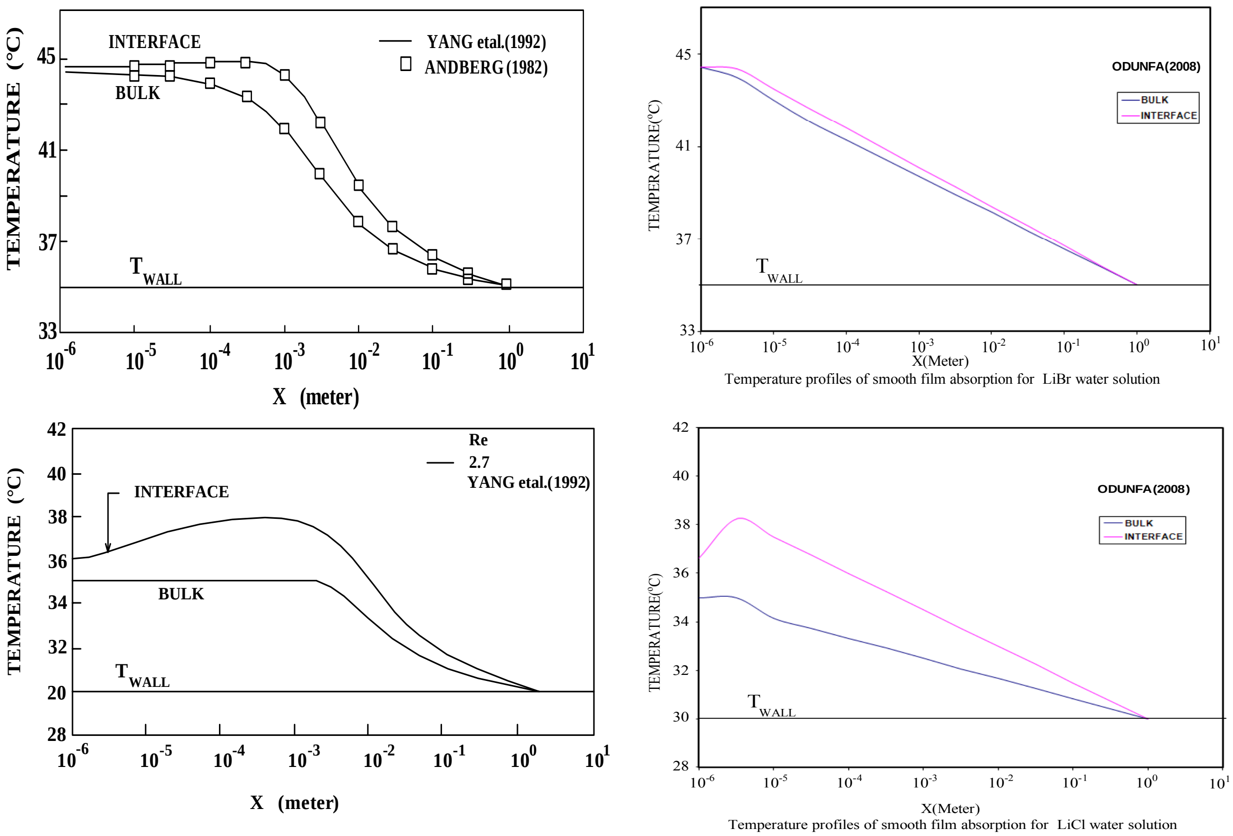

Fig. 4. Temperature profiles of smooth film absorption for (a) LiBr-Water Solution and (b) LiCl-water solution.

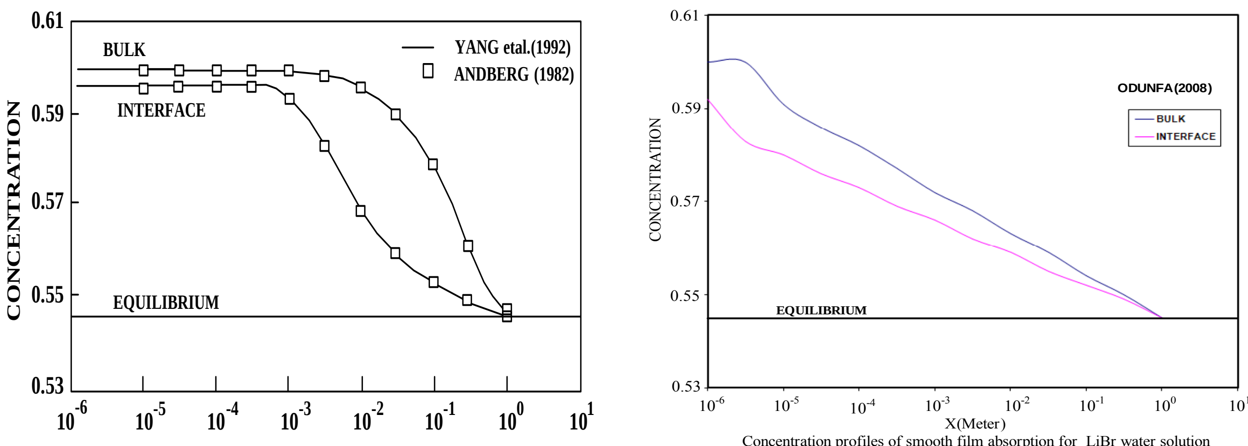

Fig. 5. Concentration profiles of smooth film absorption for (a) LiBr-Water Solution.

CONCLUSION

The use of finite difference method for simulation of an absorption process of a liquid falling-film in a cooling system using lithium bromide-water and lithium chloride-water working fluids was investigated in this work.

- It was observed that the simple finite difference solution method is quite adequate for first order analysis of the smooth falling-film absorption problem, especially where accuracy of less than 10% in interface temperature is acceptable.
- Bulk temperatures and concentration profiles are however very well predicted by the method,

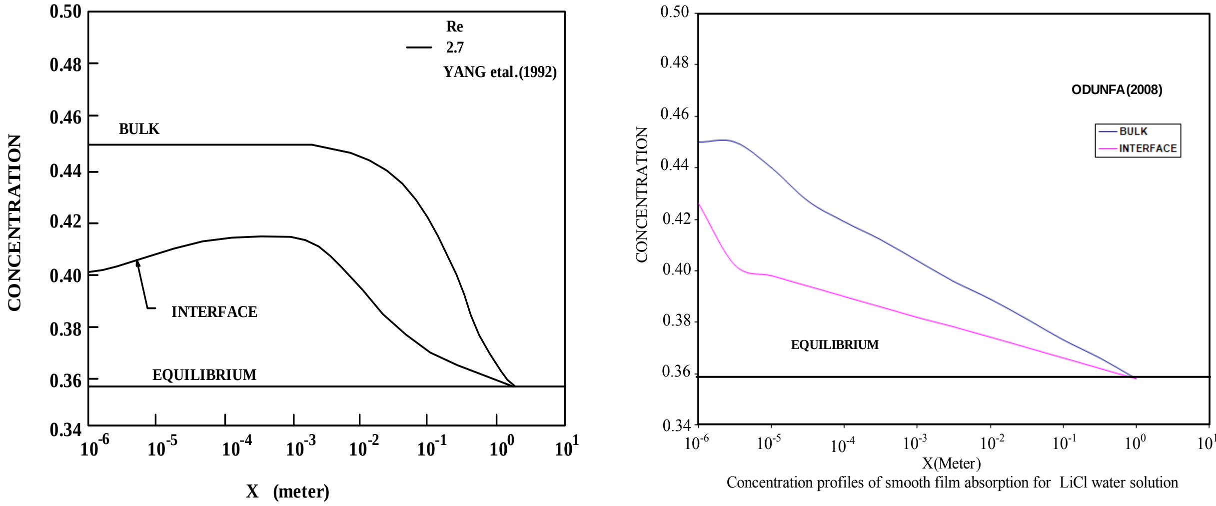

Fig. 5. Concentration profiles of smooth film absorption for (b) LiCl-water solution.

generally within 1% for both bulk and interface concentration values;these results are normally expected even from the more sophisticated methods available with proprietary software. The developed model was also found to be promising, precise and can provide results that are in good agreement with those of complicated formulation found in the literature as well as with experimental data.

- The viability of the finite difference method, on a thin-liquid smooth falling-film in a cooling system was established. The Lithium-bromide solution was also confirmed to be of excellent performing working fluid pairs when it comes to an absorption air conditioning system.

REFERENCES

Abdelmessih, AN., Mohammad, A., Abdulwahab, A. and Jay, M. 2005. An Experimental Absorption Refrigeration Cycle. 4th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics (HEFAT), Egypt.

Ali, R. and El-Ghalban, D. 2002. Operational results of an intermittent absorption cooling unit. International Journal of Energy Research. 26:825-835.

Andberg, GW. 1983. Non-Isothermal absorption of gases into falling liquid film. M.Sc Thesis. University of Texas at Austin, Austin TX, USA.

Andberg, JW., Vliet, GC. 1983. Design guildlines for water Libr absorbers.ASHRAE Transactions.89:220.

Argiriou, AA., Balaras, CA., Kontoyiannidis, S. and Michel, E. 2005. Numerical Simulation and performance assessment of a low capacity solar assisted absorption heat pump coupled with a sub-floor system. Solar Energy. 79: 290-301.

Balghouthi, M., Chahbani, MH. and Guizani, A. 2008. Feasibility of Solar absorption air-conditioning in Tunisia. International Journal of Building and Environment. 43: 1459-1470.

Bruno, JC., Vidal, A., San-Roman, MF., Ortiz, I. and Coronas, A. 2004. Modeling of absorption refrigeration plants using ammonia-water-sodium hydroxide mixtures. 3rd International Conference on Heat and Powered Cycles (HPC), Cyprus.

Fernandez-Seara, J., Siere, J., Uhia, FJ. and Vazquez, M. 2005. Solution of the Simultaneous heat and mass transfer Equations in Ammonia-water absorption system processes. 4th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics (HEFAT), Egypt.

Ghaddar, NK., Shihab, M. and Bdeir, F. 1996. Modeling and Simulation of Solar Absorption System Performance in Beirut. Renewable Energy.10(4):539-558.

Grossman, G. 1983. Simultaneous heat and mass transfer in film absorption under laminar flow. International Journal of Heat and Mass Transfer. 26:357.

Gustavo, RF., Mahmoud, B. and Alberto, C 2008. Thermodynamic modeling of a two-stage absorption chiller driven at two-temperature levels.Applied Thermal Engineering. 28 (2/3):211-217.

Kyung, I., Keith, EH. and Tae-Kang, Y. 2007. Model for absorption of water vapor into aqueous LiBr flowing over a horizontal smooth tube. International Journal of Refrigeration.30:591-600.

Niu, X., Du, K. and Du, S. 2007. Numerical analysis of falling film absorption with ammonia–water in magnetic field.Applied Thermal Engineering. 27:2059-2065.

Safarik, M., Richter, L. and Otto, M. 2004. Solar Powered H_2O/LiBr-Absorption chiller with low capacity. 3rd International Conference on Heat and powered Cycles (HPC), Cyprus.

Staicovici, MD. and Isvoranu, D. 2005. Model of the water/Lithium Bromide Absorption/Generation Processes in a Marangoni Convection Cell, Using the Two-Point Theory (TPT) of Mass and Heat Transfer. 4th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics (HEFAT), Egypt.

Xu, SM., Zhang, L., Xu, CH., Liang, J. and Du, R. 2007[a]. Numerical simulation of an advanced energy storage system using H_2O-LiBr as working fluid, Part 1: System design and modeling. International Journal of Refrigeration. 30:364-376.

Xu, SM., Zhang, L., Xu, CH., Liang, J. and Du, R. 2007[b]. Numerical simulation of an advanced energy storage system using H2O-LiBr as working fluid, Part 2: System simulation and analysis. International Journal of Refrigeration. 30:354-363.

Yang, R. and Wood, BD. 1992. A numerical modeling of an absorption process on a liquid falling film. Solar Energy. 48 (3):195-198.

Yaxiu, G., Yuyuan, W. and Xin, K. 2008. Experimental research on a new solar pump-free lithium bromide absorption refrigeration system with a second generator.Solar Energy. 82:33-42.

Zohar, A., Jelinek, M., Levy, A. and Borde, I. 2007. The influence of diffusion absorption refrigeration cycle configuration on the performance.Applied Thermal Engineering. 27:2213-2219.

Received: Dec 2, 2013; Accepted: Jan 25, 2014