*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 1 Ver. III (Jan. - Feb. 2018), PP 45-50*
*www.iosrjournals.org*

# Simulation of A Thin- Liquid smooth Falling- Film In An Absorption Cooling System

K.M. Odunfa[1], C.E. Onwuka[2] and L.O. Ajuka[3]
[1,2,3]*Mechanical Engineering Department, University of Ibadan, Ibadan, Oyo State, Nigeria.*
**Correspondence author: K.M. Odunfa1*

***Abstract:*** *Refrigeration hinges largely on efficient cooling system, energy conservation and environmental safety. In this work, a numerical model for the absorption process on a thin-liquid smooth falling-film in an absorption cooling system using Lithium Bromide (LiBr) and Lithium Chloride (LiCl) solutions was developed. The model considered a two-dimensional steady laminar flow within the film thickness to the absorber wall and utilized conservation of mass, energy and momentum equations for its development. The domain was discretised and the finite difference formulated equations were applied across each element including boundary conditions. Standard values of the absorber dimension and fluid properties were utilized in the MATLAB programming for the simulation. Data were validated using student t-test. With the bulk and interface of the film approaching an equilibrium concentration of 54.0% at a wall temperature Tw = 35$^oC$, the Concentration distributions within the film thickness in the bulk and interface between the liquid and vapour region ranged between 60.0 and 54.0% while that of the temperature was between 44.4 and 35.0 $^oC$ for LiBr – Water solution. While for the LiCl–Water solution, when the bulk and interface concentration approaches an equilibrium concentration of 35.8% at Tw = 30$^oC$, the concentration distribution within the film thickness in the bulk and interface between the liquid and vapour region were between 45.0 and 35.8% and temperature range was between 35 and 30$^oC$. The developed model in this work established that the interface and bulk concentrations reaches equilibrium faster for LiCl–Water solution than LiBr–Water solution.*

***Keywords:*** *Numerical modelling, refrigeration, lithium bromide, lithium chloride, Simulation temperature.*

---

Date of Submission: 26-01-2018 Date of acceptance: 12-02-2018

---

## I. Introduction

The importance of energy conservation and environmental prosperity in recent years have become a thing of worldwide recognition as a result of the extending imperative costs and the ensuing regular impact of our energy sources and uses. The present unevenness of energy demand and supply consolidated with the environmental debasement in many developing nations has furthermore extended the necessity for exceptionally powerful and sensible energy progress. Ajuka et al. (2017) noted that energy conserved is energy profited. The general enthusiasm for this phenomenon has incited the ascent of new advances in various domains of the overall economy, such as in the cooling system development sector.

Basically, the cooling structure may be segregated into two arrangements namely, vapor pressure and sorption systems. The vapor pressure system incorporates the use of a compressor for the pressure procedure. Sorption system can be subdivided into absorption and adsorption systems frameworks. An absorption system is basically the uniform distribution of gas or liquid solute throughout the liquid while adsorption system is a method that happens when a gas or liquid solute assembles on the surface of a solid or a liquid (adsorbent) shaping a sub-atomic or nuclear film (absorbate). In the ingestion strategy, warmth and mass exchange generally happen inside a thin-liquid falling-film. Warmth and mass move in thin-liquid falling film maintenance plan has received the thought of various examiners consistently, especially over the latest two decades. This is along the lines of its broader application in various forefront contraptions, for instance, retention air circulation and cooling frameworks, ingestion chillers, assimilation warm pumps etc., Odunfa*et al*. (2014)
This study has been approached by various researchers such as Armou (2016), Odunfa*et al(2014)* and Yang & Wood, 1992 using various modelling techniques which may be categorized either (I) numerical or (ii) experimental methods.

Several works carried out in numerical modelling includes:

In Armou*et al.* (2016) "Numerical study of simultaneous heat and mass transfer in absorption of vapor in laminar liquid film", they found that temperature is lowest at the wall and increases to the highest at the interface liquid-vapor due to heat liberated at the interface during the absorption process. Also the temperature gradient is high at the inlet and decreases towards the exit of the channel. Furthermore the concentration gradient is high at the inlet and decreases towards the exit of the channel, due to end of the absorption. For the variation of temperature and concentration along the liquid film, the interface temperature is varying rapidly near the inlet region but gradually as the length of the plate increase due to the heat absorption released at the interface, while the wall temperature varied linearly and the bulk temperature decreases slowly as y increases. Similar distributions were spotted for the interface, bulk and wall concentration, the interface concentration decreased due to absorbed mass of vapor, the bulk concentration decreased at a slower rate because the mass boundary layer propagates slowly into the film due to low mass diffusivity. From y=0.2 all concentrations decreased linearly along the plate.

In a similar work done by Odunfa *et al.* (2014), the modal temperature distribution obtained within the film thickness both in the bulk and interface between the liquid and vapor regions were between 44.4 and 35.0°C while concentration was between 60.0 and 54.5% for LiBr-$H_20$. Similarly for LiCl-$H_2O$, the model temperature distribution was between 35.0 and 30.0°C while the concentration was between 45.0 and 35.8%. He also observed that lithium bromide has

higher concentration values than Lithium chloride thus suggesting a better working fluid combination especially in the absorption-air cooling system.

Furthermore Odunfa 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 the previous work done in literatures within 9% for interface temperature, but much better at approximately 5% for bulk temperature. He also stated that concentration results are much closer for both interface and bulk calculations, being generally less than 1% which confirmed with the assumptions he used in his work.

Also in another research "magnetic field enhancement in ammonia-water absorption refrigeration systems" by Odunfa*et al.* (2014), it was observed that the velocity distributions across the film thickness remains constant until a certain value of y is reached before it started to increase with increase in the magnetic induction. This was as a result of that at the inlet section, absorption has just begun 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 vapor-liquid interface as established. This indicates that the refrigerants vapor in the working fluid permeates towards the inner solution from the vapor-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.

Kyung *et al.* (2007) developed a model for the absorption of water vapor by the LiBr aqueous solution on a smooth horizontal tube using three different flow regimes. The calculation indicates the importance of droplet formation regime for predicting the absorber performance.

The previous works done on absorption cooling system using experimental data are as follows:

In a research work "Modelling and Experimental Validation of Water Vapor Absorption by Falling Films of LiBr Aqueous Solution Under Wave Regimes Conditions and Presence of Non-Absorbable Gases" Rivera, (2015) Experimentally, the mass of refrigerant absorbed was maximum at $Re \approx 100$, from this point the higher the Re, the less is the mass absorbed. Numerical results presents similar tendency. He further stated that the heat contribution due to mist flow ($\dot{Q}_{abs,l}$) in the absorber increased with Reynolds number.

He also observed that an optimal Reynolds number is reached where heat and mass transfer rates are maximum. Higher values of Reynolds number than the optimal, entails in a decrement in absorption performance. The driving potentials decreases as the Reynolds number increases. The trend changes when $Re \approx 90 \div 100$, when increasing the Reynolds number, it results also in an increase of the interface velocity of the film. Consequently, there is a reduction in the exposure time between liquid film and gas phase and a reduction of the absorption phenomena.

Suresh and Mani(2013) reported the heat and mass transfer studies on a compact bubble absorber operated with R134a-DMF mixture for an absorption refrigeration machine. In his experiment, the mass transfer and heat transfer phenomenon were separated: the working fluid vapor flowed through an inner tube with nozzles and the bubbles mixed with absorbent solution in an annular section, such as an adiabatic absorber. After that, the heat transfer was carried out in a plate heat exchanger with 22 effective plates and 0.6 $m^2$ for heat transfer.

Yoon *et al.* (2008) evaluated a horizontal tube falling-film absorber with different diameter tubes, using water/lithium bromide mixtures. The test tubes were bare copper tubes. Tubes of 400 mm length and three different tube outer diameters were tested: 15.88, 12.70 and 9.52 mm. These tubes were installed inside the absorber with the same heat transfer area and pitch to diameter ratio to compare their heat and mass transfer performances. For a constant inlet concentration mixture of 61% w/w, the heat transfer coefficients were 571–803 $Wm^{-2}K-1$ and the mass transfer coefficients were $2.19 \times 10-5–3.22 \times 10-5\ ms^{-1}$. The smallest tube (9.52 mm of external diameter) showed the highest heat and mass transfer performance. For the tube diameter of 12.70 mm, the heat and mass coefficients were, respectively, 3.6% and 4.2% higher than those at the tube diameter of 15.88 mm. For the tube diameter of 9.52 mm, the heat and mass coefficients were higher by 9.8% and 11.8%, respectively, than those at the tube diameter of 15.88 mm. The authors concluded that the small tube diameter can be used to create a smaller tube bank volume, therefore, an efficient and compact absorber can be achieved by using small diameter tubes.

In another experimental research by Kyung et al.,(2007),they evaluated an absorber that consist of a set of 19.1 mm OD smooth horizontal copper tubes arranged in a vertical row at 180°. They tested two different tube bundles, eight tubes of 0.46 m length and four tubes of 0.36 m length. They reported that the experimental result of the study showed a good mass diffusivity of vapour water/lithium bromide solutions, with its value calculated in $1 \times 10^{-9}\ m^2 \cdot s^{-1}$ for concentrations of about 50% to 63%.

## II. Methodology

***Assumptions***:

For the derivation of the balance equations, appropriate assumptions were utilized to simplify the model and these are highlighted here:

The fluid flow is a fully developed smooth laminar flow

The fluid properties are constant and not varying with temperature or concentration.

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.

Heat transfer in the vapour phase is negligible.

Vapour pressure equilibrium exists between the vapour and liquid at the vapour-liquid interface.

The Peclet numbers are high enough that the diffusion in the flow direction can be neglected.

Diffusion thermal effects (heat rise during diffusion process) are negligible.

The shear stress at the liquid-vapour interface is negligible.

The Governing Equations

The two-dimensional heat and mass transfer process requires the evaluation of the basic laws. The equations considered in the formulation of the differential equation of the model are:

$$V_x \frac{\delta C_A}{\delta x} - D_{AB} \frac{\delta^2 C_A}{\delta y^2} = 0 \quad (1)$$

$$V_x(y) = \frac{3}{2} V_o \left( \frac{2y}{h_o} - \left( \frac{y}{h_o} \right)^2 \right) \quad (2)$$

$$V_o = \frac{\rho g h_o^2}{3\mu} \quad (3)$$

$$V_x \frac{\delta T}{\delta x} - \alpha \frac{\delta^2 T}{\delta y^2} = 0 \quad (4)$$

Following the algorithm described in Figure 2, a computer program was written and run. The results presented include the concentration and temperature variations in the solution. Two points were investigated in this study:

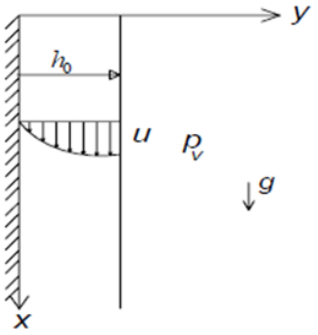



**Figure 1:** 2D representation of domain

**Bulk property:** this is the property of the film observed at the centre of the domain.
**Interface property:** this is the property of the film observed at the edge of the domain.
The computations were carried out with a Matlab program code written and run on a laptop computer. The specifications are detailed in Table 1 as shown below.

**Table 1:**

| | | |
|---|---|---|
| Matlab | Version | R2016a(9.0.0.341360) |
| | Type | 64 bit |
| | Date | February 11, 2016 |
| Computer | Processor | Intel Pentium CPU B980 @ 2.40Giga Hertz [Dual Core] |
| | RAM | 8.00Giga Byte |
| | System Type | 64 bit Operating System, x64 – based processor |

Lithium Bromide – Water Absorption System

**Computation details:**

Table 2 shows the initial conditions for a simulation of the absorption process in an absorber using water as the refrigerant and lithium bromide or lithium chloride as the solution. These were carefully chosen from literature, based on the operating conditions of a typical lithium bromide absorber. The calculations used a uniform or constant segment width, unlike the ones found in Odunfa et al., (2014) Table 3 are other general parameters that were set for the successful simulation of the process.

**Table 2**

| | Temperature | Concentration |
|---|---|---|
| $LiBr - H_2O$ | | |
| $x = 0;$ | $T_{in} = 44.44℃$ | $C_{in} = 60.0\ wt\%$ |
| $y = 0;$ | $T_w = 35℃$ | $\frac{\delta C_A}{\delta y} = 0$ |
| $y = h_o;$ | $-k\frac{\delta T}{\delta y} = \rho D_{AB} \frac{\delta C_A}{\delta y} . H_a$ | $C_{equ}(T, P_v) = 54.0\ wt\%$ |
| $LiCl - H_2O$ | | |
| $x = 0;$ | $T_{in} = 35℃$ | $C_{in} = 45.0\ wt\%$ |
| $y = 0;$ | $T_w = 30℃$ | $\frac{\delta C_A}{\delta y} = 0$ |
| $y = h_o;$ | $-k\frac{\delta T}{\delta y} = \rho D_{AB} \frac{\delta C_A}{\delta y} . H_a$ | $C_{equ}(T, P_v) = 35.8\ wt\%$ |

**Table 3**

| | |
|---|---|
| Mass flow rate | $\dot{m} = 0.001 kgm^{-1}s^{-1}$ |
| Mean Velocity | $V_o = 0.039601 ms^{-1}$ |
| Mean film thickness | $h_o = 7.289 \times 10^{-5} m$ |
| Number of nodes | $X - axis = 2000$ |
| | $Y - axis = 10$ |

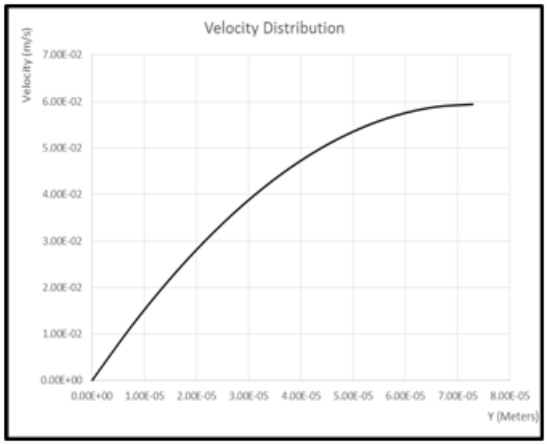



**Figure 2**: Velocity distribution along the y-direction of the domain

## III. Results And Discussion

***Velocity Distribution***

The velocity distribution (equation 2) is governed by equation (2). This study assumed a constant velocity across the x- direction (to avoid complexity). This is not usually the case, as the absorbed refrigerant vapour increases the velocity. However, without such assumption, the computation would be complicated. Hence, it is found that the velocity varies only in the y-direction. Figure 2 illustrates the velocity distribution in the y-direction of the domain.

Concentration Distribution

The concentration distribution of thesolution as it falls down the depth of the absorber is shown in both Figure 4(a) and Figure 6(a). All concentrations were represented as a percentage weight of lithium bromide in the solution. The bulk and interface values of the concentration were plotted in figure 4(a) and 6(a).for Libr-$H_20$ and LiCl-$H_20$ respectively. It can be observed that the interface has lower concentration values than the bulk of the fluid for both cases. This is because the point at which the interface values were selected is closer to the surface of the fluid, where the equilibrium concentration boundary condition is applied. The change in concentration is as a result of diffusion of the water vapour (refrigerant), through the surface of the fluid to the bulk of the fluid. Diffusion is maximum at the surface of the fluid in contact with the refrigerant and minimum at the wall of the absorber. Figure 4(b) and 6(b) are plots of the concentration distribution for LiBr-$H_20$ and LiCl-$H_20$ respectively as was obtained from literature (Odunfa et al, 2014). In the present study, however, the concentration at the interface is less than that of the bulk and there is a gradual decrease in the concentration of the lithium bromide across the absorber depth.

***Temperature Distribution***

The temperature distribution of the solution as it falls down the depth of the absorber is shown in Figure 5(a) and 7(a) for LiBr-$H_20$ and LiCl-$H_20$ respectively. The temperature varies from the wall of the absorber to the surface of the film. The solution enters the absorber at a temperature higher than the wall temperature of the absorber. In the absorber, heat is added at the surface of the film (solution) due to the absorption of the refrigerant. At the wall of the absorber, heat is lost to the wall. These two processes define the temperature variation in the absorber and can be observed in the temperature distribution. The value of the interface temperature is higher than that of the bulk temperature. The temperatures (interface and bulk) are also observed to tend towards the wall temperature as the depth of the absorber increases.

Figure 5(b) and 7(b) are plots of the temperature distribution obtained from literature (Odunfa et al, 2014) for LiBr-$H_20$ and LiCl-$H_20$ respectively. Here, it is found that the temperature at the interface is greater than the temperature at the bulk of the solution. Odunfa et al's result has a steep and constant slope. This is not as found in the present study.
Odunfa et al, 2014, utilized a variable grid size and this is one of the reasons for the difference in the curves in the both plot

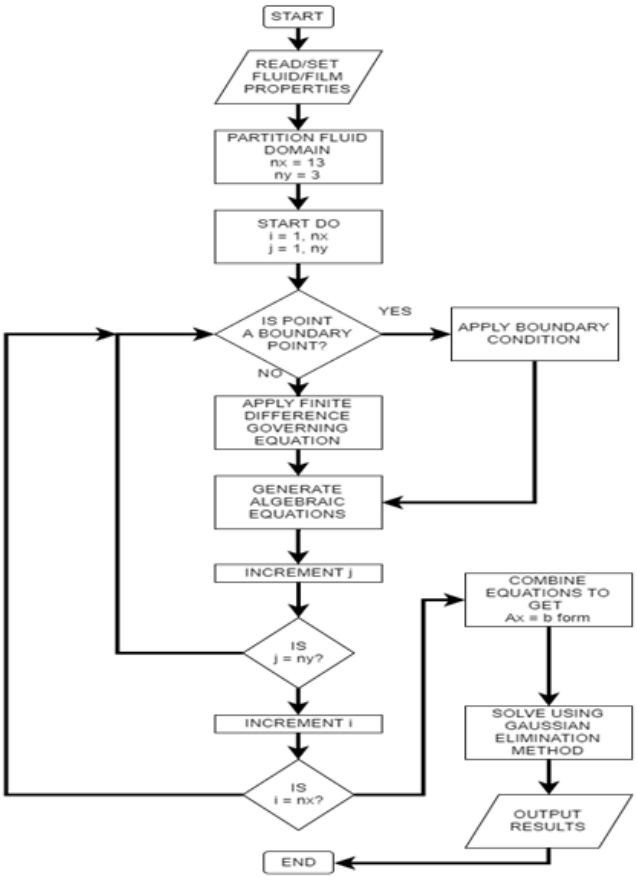



**Figure 3:** Program Algorithm

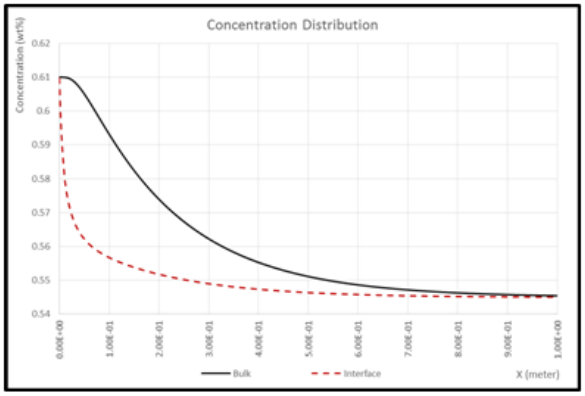



**Figure 4 (a)** present study

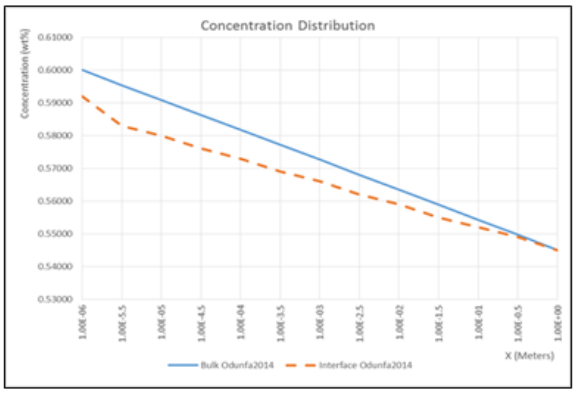



**Figure 4 (b)** Odunfa et al., 2014

**Figure 4 (a & b):** Concentration distribution in the absorber (LiBr-Water).

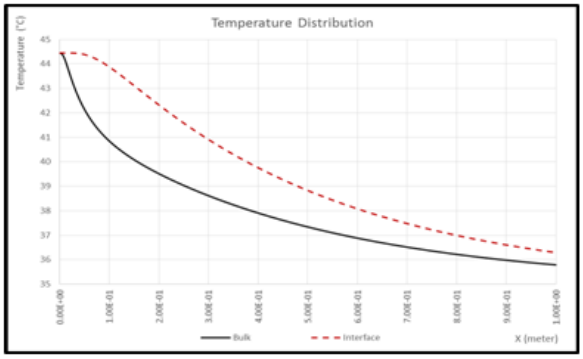



**Figure 5: (a)** present study

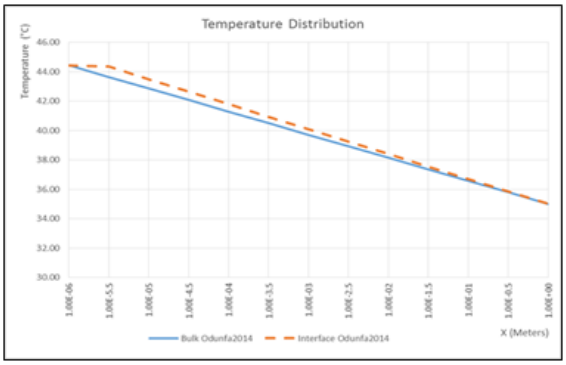
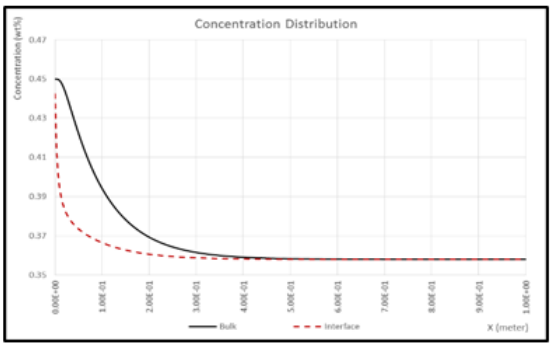



**Figure 5 (b)** Odunfa et al., 2014

**Figure 5:** Temperature Distribution in the absorber (LiBr-Water).



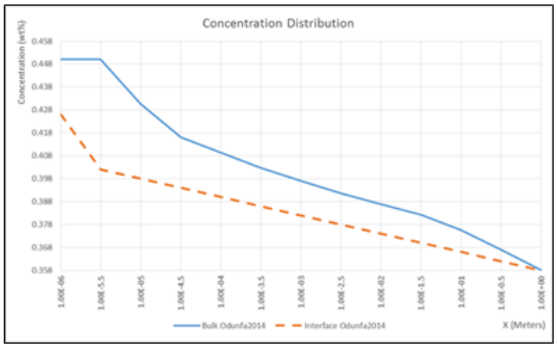
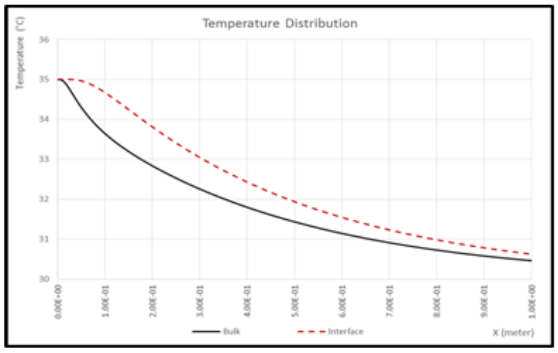




**Figure 6: (a)** present study **Figure 6 (b)** Odunfa et al., 2014

Figure 6: Concentration Distribution in the Absorber (LiCl-Water).



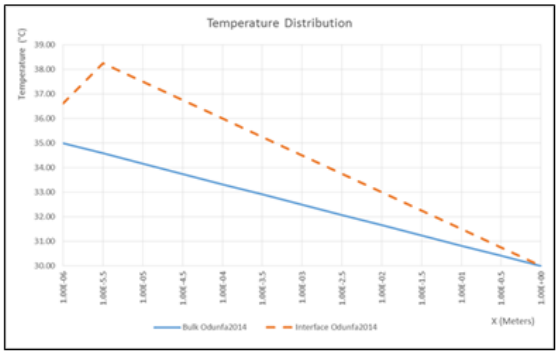




**Figure 7: (a)** present study **Figure 7 (b)** Odunfa et al., 2014

Figure 7: Temperature Distribution in the absorber (LiCl-Water).

## IV. Conclusions

In this study, a numerical model utilizing the finite difference method was developed to investigate the absorption process in a falling film absorber. From this we can conclude that:

The model has been successfully used to simulate the absorption process in the absorbers of two of the Vapour absorption systems encountered in literature (Lithium bromide – Water and Lithium chloride – Water systems). The project entailed an understanding of the Vapour absorption systems, as well as the functions of each component in the system, with a focus on the absorber.

The methodology and result of the work can be used for an understanding of the absorption process and design of the absorber. The results obtained in this study were compared to that found in literature and upon statistical analysis, it was discovered that the results have no statistically significant difference.

It was also observed that a constant grid size and Gaussian elimination method, although it requires more computer memory for computation, provide accurate results.

Lithium chloride – Water absorber requires physical dimensions less than that of Lithium bromide – Water system, since it attains the equilibrium concentration before the end of the absorber is reached.

MATLAB is adequate for the simulation of the absorption process.

## References

[1]. Ajuka, L.O., Odunfa, K.M., Ohunakin, O.S., Oyewola, M.O., (2017). Energy and exergy Analysis of vapour compression refrigeration system using selected eco-friendly hydrocarbon refrigerants enhanced with $tio_2$ nanoparticle. International Journal of Engineering & Technology, vol.6, 4, pp. 91-97.

[2]. Armou, S., Mir, R., El hammami, Y., El hamdani, S. Kaoutar Z. (2016). Numerical study of simultaneous heat and mass transfer in absorption of vapor in laminar liquid film. International Journal of Enhanced Research in Science, Technology & Engineering ISSN: 2319-7463, vol. 5, 4, Pp. 6-7.

[3]. Kyung, I.; Herold, K.E.; Kang, Y.T., (2007). Experimental verification of H2O/LiBr absorber bundle performance with smooth horizontal tubes. Int. J. Refrig., vol. 30, pp. 582–590.

[4]. Kyung I., Keith E. H., Yong T. K., (2007). Model for absorption of water vapor into aqueous LiBr flowing over a horizontal smooth tube, International Journal of Refrigeration, vol. 30, pp. 591-600. 48

[5]. Odunfa, M.K, Fagbenle, R.O. Oyewola,O.M and Ohunakin, O.S., (2014). Magnetic field enhancement in Ammonia-water absorption refrigeration system. Energy and Power Engineering, vol. 6, pp. 54-68.

[6]. Odunfa, K., Fagbenle, R., Oluwole, O., &Ohunakin, O. 2014.Modelling of Thin-liquid Falling film in H2o-Libr and H2o-Licl Absorption Refrigeration Systems. Canadian Journal of Pure and Applied Sciences,8:2933-2942.

[7]. Rivera, E. G., (2015). Modelling and experimental validation of Water Vapor Absorption by falling films of LiBr aqueous solution under wave Regimes Conditions and presence of non-absorbable gases" Ph. d thesis, Universidad politecadecatalunya, pp162-164.

[8]. Suresh, M.; Mani, A.(2013). Heat and mass transfer studies on a compact bubble absorber in R134a-DMF solution based vapour absorption refrigeration system. Int. Journal. Refrig. Vol.36, pp.1004–1014

[9]. Yang,R.andWood,BD.(1992). A numerical modeling of an absorption processon a liquid falling film.Solar Energy.48(3).pp.195-198

[10]. Yoon, J.I., Phan, T.T., Moon, C.G., Lee, H.S., Jeong, S.K., (2008). Heat and mass transfer characteristics of a horizontal tube falling film absorber with small diameter tubes. Heat Mass Transf., vol. 44, pp. 437–444.

K.M. Odunfa1. "Simulation of A Thin- Liquidsmooth Falling- Film In An Absorption Cooling System." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), vol. 15, no. 1, 2018, pp. 45-50