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CFD BUBBLE PUMP'S NUMERICAL SIMULATIONS FOR LiBr–H2O ABSORPTION REFRIGERATION'S CYCLE MOVED BY SOLAR ENERGY

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Abstract. *The growing use of renewable energies has the need for research in the refrigeration cycles by vapor absorption. These systems are being proposed as an alternative for the climatization of hot environments in regions favored by solar irradiation such as Brazil. Therefore, this work uses the absorption refrigeration cycle with the use of solar energy in the system generator, so through the use of finite volumes, the objective of the work was to simulate the flow of the fluid that occurs inside the solar collector, main component of the cycle. The finite volume model was approached with the Ansys Fluent software (2012) and it was necessary to add a interfacial mass transfer of interface in the governing equations. The geometry used is two-dimensional and the study was implemented with different heat flow conditions. According to the analysis, it can be seen that the three data flows tested favorable values of steam formation along the proposed geometry. The results obtained in the computer simulations were validated with the available literature and criteria that this methodology can be used when it is desired to design a solar collector with the mixture* $H_2O/LiBr$

Keywords: *Absorption Refrigerant, Bubble Pump, Solar Energy, Finite Volume, Multiphase.*

1. INTRODUCTION

Brazil has a high incidence of solar energy throughout the year, being among one of the highest in the world (ANEEL, 2008). The Northeast region is in a prominent position in Brazil, having a solar irradiation capacity that can reach 6100 $Wh/m^2/day$ (ANEEL, 2008). However, the use of this irradiation source still has a lesser influence on the Brazilian energy matrix when compared to other traditional energy sources (Tiba and Fraidenraich, 2000).

It can be mentioned that in addition to the use of solar energy to produce energy through photovoltaic panels, solar energy can also be used as a direct energy source, an example would be for heating water in homes, whose use of solar collectors is accentuated in Brazil (Oliveira, 2014). Solar collectors can also be used in absorption refrigeration systems (Hammad, 1995). Such a system has a simple operation, where it due to environmental appeal is becoming important again (Adewusi and Zubair, 2004).

The absorption systems are composed of two fluids, an absorbent in the liquid phase is responsible for absorbing the refrigerant fluid in the form of vapor. This is only possible due to the chemical affinity of some refrigerants with absorbents, with which they form a homogeneous mixture with different vaporization temperatures for each substance.

Recently, Krepper and Rzehak (2014) said that absorption systems are becoming more attractive because their driving forces can be low-cost energies such as solar thermal energy or waste heat discharged from industrial processes. These systems also feature low maintenance cost and long service life.

The absorption refrigeration cycle is similar to the vapor compression refrigeration cycle, because both have evaporator, condenser and expansion device. However, the compression is replaced by another form of vapor pressure increase, which in this case is through a very low energy cost pump located before the fluid entry from the (generator), as seen in Fig. 1. The two-phase flow that occurs in the collector (generator) of the absorption cooling system is caused by the formation of bubbles and is called in the literature as bubble pump, which can be represented simply as a vertical tube that receives a heat source.

According the work of Jo (2012), the generation of the gas phase is provided by the generation of bubbles that originates from the application of heat to the tube from a source of thermal energy. This phase change from liquid to steam and the influence of the gravitational force intensifies the buoyancy of the fluid, which allows it to rise along the pipe.

According to Kaniowski and Poniewski (2013), the heat transfer between the phases and between the wall and the fluid in contact is not uniform, it depends on the title of the vapor and the physical-chemical properties of the mixture . Thus, for the generator to work correctly, a flow dynamics of the bubble pump must be known, since the system only works if the refrigerant phase changes along the system generator. Benhmidene and Chaouachi (2019) investigated the modeling of a bubble pump with simplified tube geometry. The ammonia and water pairs were used as working fluids, a simulation consisted of a heat source ranging from 5000 to 25000 W/m^2 as a parameter, in order to verify how this influences the biphasic flow. He determined the maximum velocity of the liquid over a range of heat flow for known diameters and mass flow and pumping rates.

Benhmidene *et al.* (2017), simulates a heating flow from 2000 W/m^2 to 5000 W/m^2 with a bubble pump tube with a length of 1 meter and an internal diameter of 2.5 mm. The results of the simulation reveal oscillations in the variations of vapor and liquid over time and satisfactory steam generation, a simulation with ammonia and water with one-dimensional geometry.

It can also be mentioned that for the climatization of environments, the criterion of low toxicity must be fully met by the absorbent-refrigerant pair. The lithium bromide and water pair is used in this work to reject the ammonia and water pair, as according to Dossat (2001) the two fluids are stable, safe and non-corrosive.

In addition to this research, most of the theoretical studies of bubble pumps were also done with 1D models and only with ammonia and water pairs. One-dimensional simulations do not allow an analysis of important generator parameters such as: volumetric fraction, temperature and speed, varying them along the radius of the geometry. This was observed in the article by Jo (2012), but only with the pair of ammonia and water, the use of which is suitable for industrial refrigeration applications and not for air conditioning (Jo, 2012).

The results of a two-dimensional simulation on the absorption system tend to be more realistic and accurate than a one-dimensional model (Jo, 2012).

In this sense, the focus of the present work is a simulation of the two-dimensional flow with the pair of lithium bromide and water along a cylindrical tube of an absorption cooling system, with the investigation of important parameters of the flow in nucleated boiling, such as as the temporal evolution of the void fraction and the velocity distribution along the flow, the program used is Ansys Fluent, which uses the finite volume method.

2. METHODOLOGY

2.1 Absorption cycle

The absorption refrigeration cycle can be exemplified by Fig. 1, where the model proposed here addresses the flow that occurs in the generator of the system that receives solar radiation.

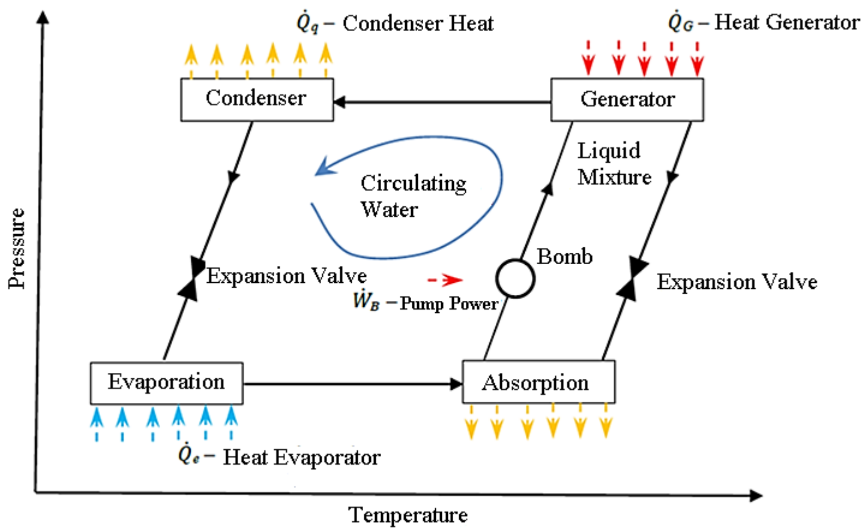

Figure 1. Absorption cycle

2.2 Geometry

The collector is formed by internal vertical tubes in which the amount of heat received by the collector is directly proportional to the size of its area. Based on that context, the vertical tube can be seen in Fig. 2, which receives a heat flow from the cylindrical walls and the system's entrance is a mixture of lithium bromide and water in the liquid phase.

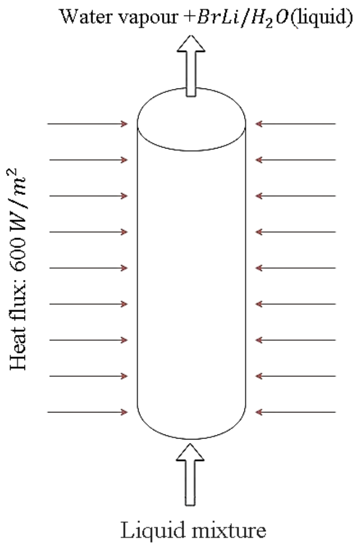

Figure 2. Representation of the vertical tube.

The 2D modeling of the generator of the absorption cooling system was used according to the Fig. 3. The use of a two-dimensional model instead of a three-dimensional model does not affect the results of the numerical simulation, as according to Jo (2012) the model is designed to globally calculate the distribution of the steam fraction in the system generator and not in a macroscopic way.

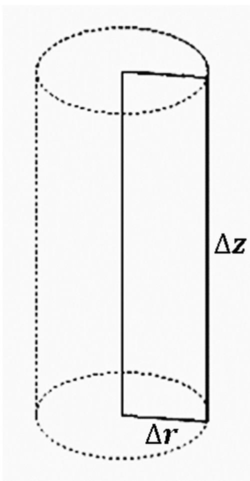

Figure 3. Representation of the slice used for two-dimensional simulation.

As seen in Fig. 2, the heat flow is considered uniform throughout the entire external surface of the tube, thus the flow that occurs in the internal region was also admitted as symmetry around the central axis, that is, the condition of axisymmetric was adopted for any plane that starts from the axis of symmetry, such a condition illustrated in Fig. 3.

The software used for the simulation was Ansys Fluent 18.1, with a geometry of 1 meter by 0.1 meter in width as can be seen in Fig. 4. The inlet temperature is 328 K, since the fluid must be preheated before entering the system generator. The mixture to be used consists of the pair of lithium bromide and water with a concentration of 55 percent. The mass flow of 0.005 kg/s used is compatible in order to have the air conditioning capacity of a conventional air conditioner of 9000 Btu.

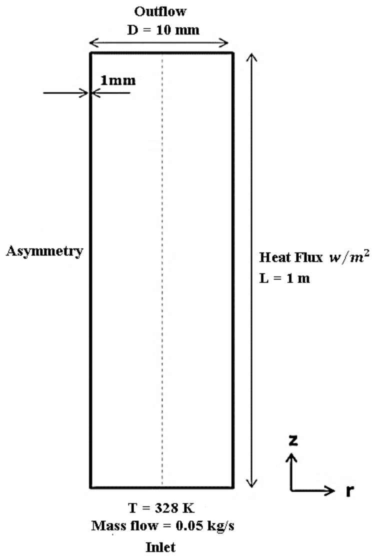

Figure 4. Simulation geometry and parameters.

2.3 Mesh

The mesh was made using the Workbench 18.1 software with rectangular elements, according to Oliveski *et al.* (2015), the region close to the heat flow at the ends of the geometry, requires a mesh refinement as shown Fig. 5, as it presents the largest thermal and dynamic gradients in the system. With the refinement of the mesh in this region, the functions of the region close to the wall in the k-epsilon model of turbulence were used.

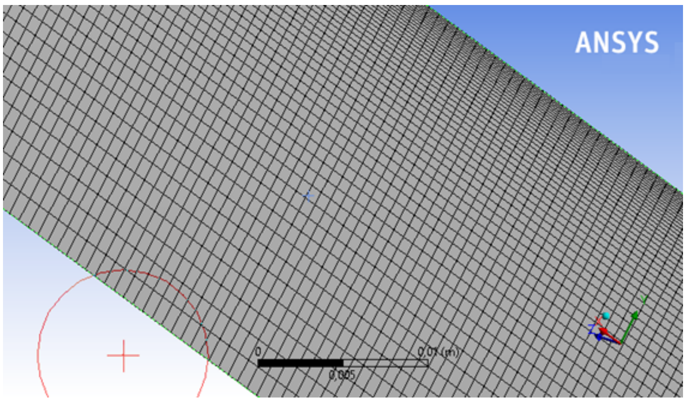

Figure 5. Representation of the mesh with refinement in the region on the wall.

Table 1. Wall refinement data by Fluent software

Refinement on the wall	**Number of division**	**Behavior**	**Bias type**
Edge sizing	400	Hard	not aplicate

(1)

Table 2. Mesh data by Fluent software.

Mesh	**Mesh 1**	**Mesh 2**
Node Uniform	25x1000	25x2000
Maximum y^+	264	295

2.4 Mixture

The mixture used in the $H_2O/LiBr$ simulation is not composed in the Ansys Fluent 18.1 software, so the material was created in the program using the thermodynamic data according to Table 3 below, the data are according to Ferreira (2018).

Table 3. Thermodynamic data for the mixture

Properties	**BrLi**
Density$^{(1)}$, kg/m^3	1536
Specific Heat Capacity$^{(1)}$, $(J/kg \cdot K)$	2170
Thermal Conductivity,$(W/m \cdot K)$	0.4765
Dynamic Viscosity, $(kg/m \cdot s)$	1.931
Saturation Temperature, K	348.93
Mass Molecular, $(kg/kmol)$	104.86
Standard Enthalpy, (kJ/mol)	34.26

$^{(1)}$ Measured at 55 ^{o}C.

2.5 Equation model

According to Ishii (2006), it follows respectively as equations of mass Eq (1), transport Eq (2) and energy Eq (3) .

$$\frac{\partial(\alpha\rho)}{\partial t} + \nabla(\alpha_g\rho_g u_g) = \sum_{g=1}^{n} m_g \tag{1}$$

$$\frac{\partial(\alpha_g\rho_g u_g)}{\partial t} + \bigtriangledown(\alpha_g\rho_g u_l u_l) = -\bigtriangledown p + \bigtriangledown(u_g(\bigtriangledown\vec{u}_l + \bigtriangledown\vec{u}_g)) + \alpha_g\rho_g\vec{g} \tag{2}$$

$$\frac{\partial\rho h_l}{\partial t} + \bigtriangledown(\alpha_l u_l h_l) = \bigtriangledown(\alpha_l(\zeta_L + \zeta_L^t)) + \frac{\alpha_l}{\rho_l}\frac{\partial\rho}{\partial t} + \frac{\alpha_l}{\rho_l}u_l \bigtriangledown p - \frac{\Gamma_e h_l}{\rho_l} + \frac{q_w A_w}{\rho_l} \tag{3}$$

where $\vec{u}_g$, $\vec{u}_l$, are the velocity components, ρ_g the specific mass of the gas phase, h_l the enthalpy of the mixture, α_g the volumetric fraction of the gas phase, α_l the volumetric fraction of the liquid phase, $\bigtriangledown p$ the pressure gradient, $\vec{g}$ gravitational acceleration term, μ_g the dynamic viscosity, A_w the cross-sectional area, Γ_e vapor generation rates, q_w heat flux. The terms δ_L + δ_L^t corresponding to the sum of the molecular and turbulent heat fluxes of each phase.

2.6 Methods used

The algorithm Simple was originally put forward by Patankar and Spalding (1983) and is essentially a guess-and-correct procedure for the calculation of pressure on the staggered grid arrangement.

The Simple method was used in program to solve the pressure-velocity coupling and the upwind method for calculations of momentum, energy and volume fraction.

2.7 Turbulence model

The turbulence model used in the simulation was the k epsilon model, which is used for turbulent flows, as is the case of the nucleated boiling flow of the absorption system generator.

The K-epsilon turbulence model is the most common model used in computational fluid dynamics to simulate medium flow characteristics for flow regimes. It is a model of two equations that provides a general description of the turbulence, the first variable carried is the turbulent kinetic energy (k) and the second variable carried is the dissipation rate of the turbulent kinetic energy (ϵ) (Versteeg and Malalasekera, 2007) .

It is useful and can be declared as the simplest turbulence model for which only the initial or boundary conditions need to be provided (Versteeg and Malalasekera, 2007).

2.8 Interfacial Mass Transfer

An existing heat and mass transfer interface between liquid and vapor is modeled in Fluent (2015) with the use of energy conservation according to the equation below.

$$m_{lg} = \frac{q_l + q_g}{H_g - H_l} \tag{4}$$

where m_{lg} is the mass transfer rate that crosses the liquid-vapor interface, H_g enthalpy at the gas phase interface, H_l enthalpy at the liquid phase interface, q_g heat at the gas phase interface and q_l heat at the liquid phase interface.

3. RESULTS AND DISCUSSION

3.1 Validation

Figure 6 presents the results of validation of the Ansys Fluent model when compared with the experimental results of Bartolomei and Chanturiya (1967), where a single tube was simulated with a heat flow in the walls of 570 kW/m^2 with a mass flow of 900 kg/m^2s . It appears that the results of the present work are very close to the experimental results of Bartolomei and Chanturiya (1967).

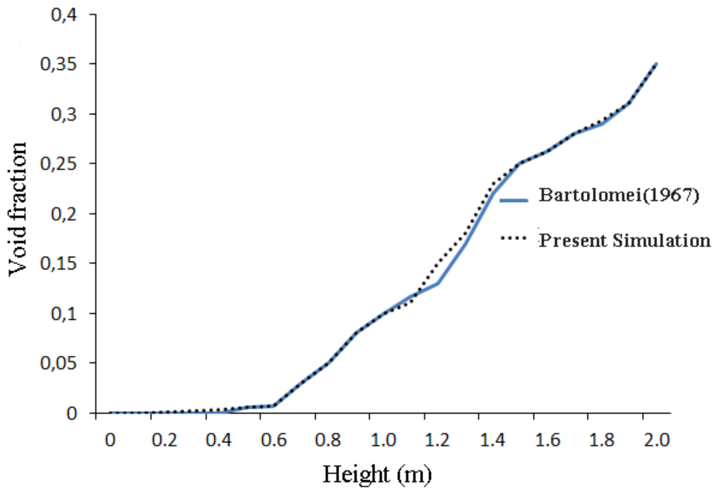

Figure 6. Ansys Fluent model validation results when compared to Bartolomei and Chanturiya (1967) experimental results.

3.2 Generator tube with lithium bromide and water

With the addition of a heat flow of 600 W/m^2 , the water and lithium bromide solution raises its temperature, as the saturation temperature for water phase change is lower than lithium bromide in pressures below atmospheric, it changes state along the tube and the lithium bromide remains in a liquid state, this can be seen in Fig. 7.

This fraction refers to the fraction of the volume occupied by the vapor phase, meaning how much of the binary solution initially in the liquid state has been transformed into the vapor phase along the vertical length of the tube by adding heat to the wall (Jo, 2012).

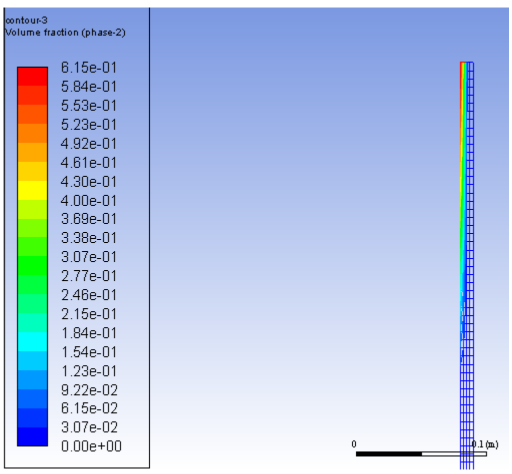

Figure 7. Representation of the formation of vapor close to the wall with the addition of the heat flow of 600 W/m^2 .

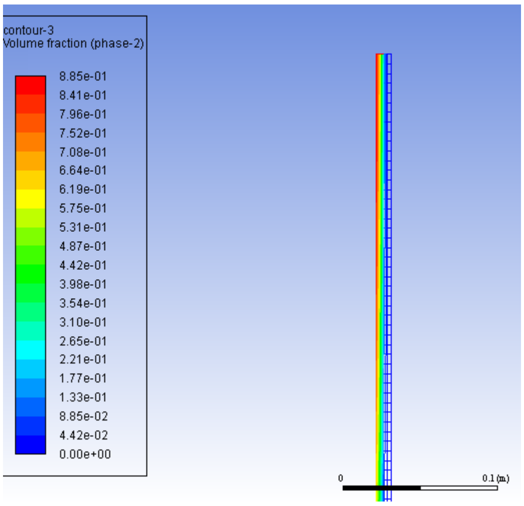

Figure 8. Representation of the formation of vapor close to the wall with the addition of the heat flow of 800 W/m^2

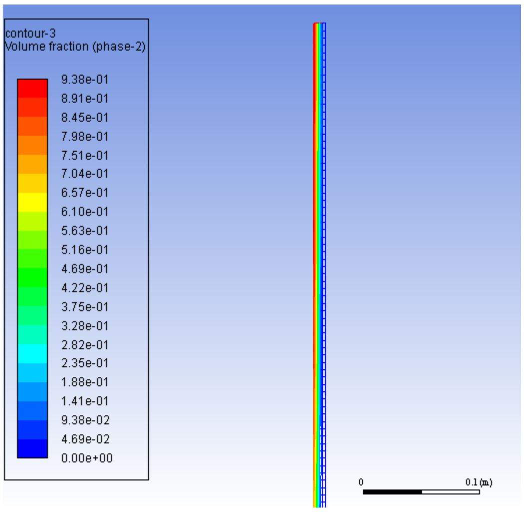

Figure 9. Representation of the formation of vapor close to the wall with the addition of the heat flow of 1000 W/m^2 .

3.3 Discussion

It can be seen from Figs. 7, 8, 9 and 10 that the greater the flow of energy received through the wall, the greater the formation of steam in the mixture.

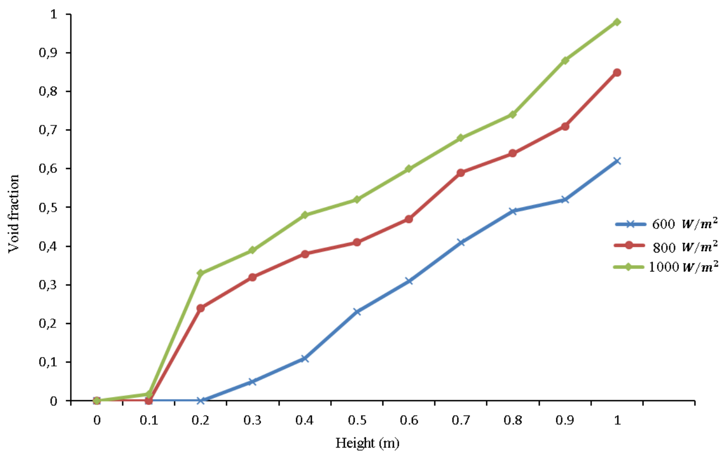

Figure 10. Comparison of vapor formation close to the wall with the addition of distinct heat fluxes.

From the graph above, it can be seen that the three heat flows presented.

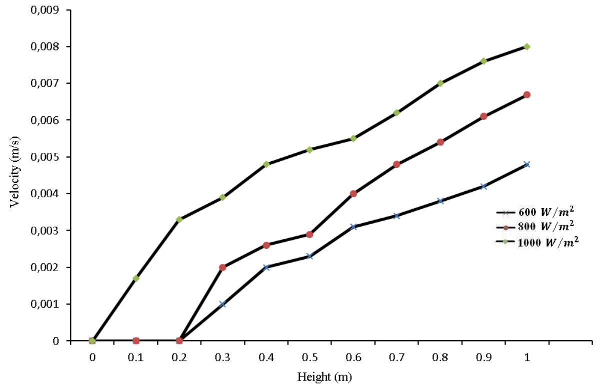

Figure 11. Generation of the gas phase velocity vector with the addition of distinct heat fluxes.

The average velocity of the gas phase showed considerable changes according to the greater heat flow through the walls, which influences the heat transfer along the flow.

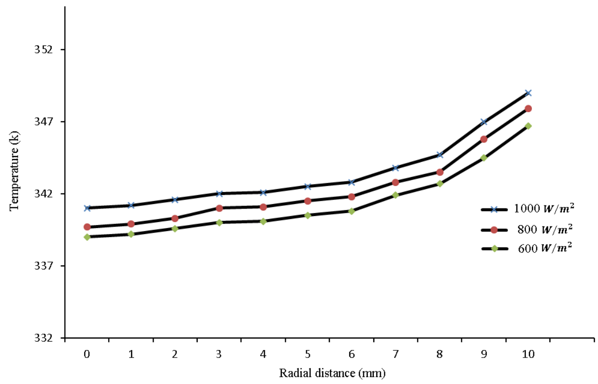

Figure 12. Temperature distribution in the radial direction with distinct heat flow.

Fig. 12 shows that the temperatures are higher near the wall due to the heat flow and that according to the distance in the radial direction there is a decrease in this temperature, so that it reaches saturation only in regions closer to the wall. Therefore, it can be seen in Fig. 13 that the volumetric fraction (steam generation) is high at the end, since there we have the largest gradient of heat flow that intensifies the mass transfer between the phases because it depends on the greater enthalpy of the mixture.

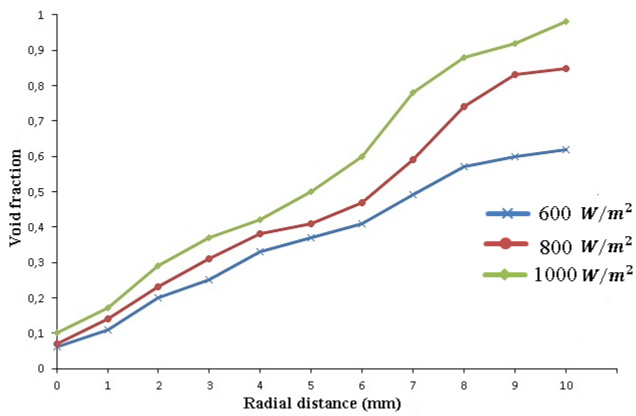

Figure 13. Distribution of the volumetric fraction in the radial direction with distinct heat flow.

3.4 CONCLUSION

The nucleated boiling process was simulated numerically by Ansys Fluent. The numerical model used is two-dimensional and the study was carried out under different heat flow conditions. It is important to emphasize that the simulation model provided values very close to the result of the experimental author (Bartolomei and Chanturiya, 1967).

With a heat flux smaller than 600 W/m^2, there is a greater difficulty in obtaining the volume fraction closer to one, which is the objective of the absorption generating systems, but the formation of vapor was still favorable. For heat fluxes with 800 W/m^2 and 1000 W/m^2, the formation of vapor was well intensified, which can be seen in the Fig. 13

According to Figs. 7, 8 and 9 it can be seen that the peaks of maximum steam generation occur at the ends of the wall, which shows the heat transfer make simulated solar irradiation flux. The mean velocity of the gas phase changed considerably with the addition of different heat fluxes, as can be seen in Fig. 11.

It is important to mention that, with the increase in temperature due to solar irradiation, there is an increase in the convective transfer coefficient, therefore, a greater transfer of liquid mass to a vapor interface in the flow.

Finally, it is possible to infer that the Ansys Fluent model for the study of the bubble pump is viable for a simulation of applications in which the phase change is used, and it can be used in several applications in the refrigeration area.

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