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Simulation of Ammonia-Water Two Phase Flow in Bubble Pump

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***Abstract*—**The diffusion-absorption refrigeration cycle consists of a generator bubble pump, an absorber, an evaporator and a condenser, and usually operates with ammonia/water/ hydrogen or helium as the working fluid. The aim of this paper is to study the stability problem a bubble pump. In fact instability can caused a reduction of bubble pump efficiency. To achieve this goal, we have simulated the behaviour of two-phase flow in a bubble pump by using a drift flow model. Equations of a drift flow model are formulated in the transitional regime, non-adiabatic condition and thermodynamic equilibrium between the liquid and vapour phases. Equations resolution allowed to define void fraction, and liquid and vapour velocities, as well as pressure and mixing enthalpy. Ammonia-water mixing is used as working fluid, where ammonia mass fraction in the inlet is 0.6. Present simulation is conducted out for a heating flux of 2 kW/m² to 5 kW/m² and bubble pump tube length of 1 m and 2.5 mm of inner diameter. Simulation results reveal oscillations of vapour and liquid velocities along time. Oscillations decrease with time and with heat flux. For sufficient time the steady state is established, it is characterised by constant liquid velocity and void fraction values. However, vapour velocity does not have the same behaviour, it increases for steady state too. On the other hand, pressure drop oscillations are studied.

***Keywords*—**Bubble pump, drift flow model, instability, simulation.

I. INTRODUCTION

THERE are two kinds instability of a system, static or dynamic. Dynamic type instability mode resulting from multiple feedback effects between the flow rate, the vapour generation rate and the pressure drops in the boiling channel constitutes an issue of special interest for the design of industrial systems and equipments involving vapour generation. If the steady state flow becomes unstable under certain conditions, flow is subject to a static stability. Studies on the static instability are presented in [1], [2].

For understanding fundamental of boiling phenomena and safety of boiling heat exchangers, previous studies on two-phase flow instabilities in single circular channels, both experimental and theoretical are published [3]. Most of the studies found in literature have been carried out in multiple parallel channels or single channel, but with non-uniform heat flux, as one of the channel walls is usually non-heated for visualization purposes.

In the absorption diffusion cycles, the bubble pump is one of the most critical components in cycle, since it is responsible for displacing the solution from the generator to the rectifier [4]. A bubble pump is basically a vertical cylindrical tube used to pump fluid. The fluid is heated at the bottom of the pipe in a generator, causing it to form gas bubbles as the onset of boiling occurs [5]. Two-phase flow is essentially the co-existence of both a liquid and a vapour phase in the flow through a pipe. A phenomenon of oscillation may exist due to the diphasic flow in this compound. Similarly, heating along the tube may be a factor inducing instability. However, few data are available reflecting the oscillation phenomenon in the bubble pump.

Previous studies were conducted and aimed at understanding the behaviour of two-phase flow in the bubble pump. Benhmidene et al. References [6]-[8] conducted a theoretical study where they defined the flow pattern and the influence of operating conditions on the efficiency of the bubble pump. On the other hand, authors are realised an experimental study [9] from which was identified the oscillation behaviour flow in the bubble pump. These experimental results showed an oscillation of pressure at the outlet of the bubble pump. Pressure oscillation is influenced by the submersion ration, it increases with the submersion ratio increase; in addition it is not periodic. Mazouz et al. [9] carried out an experimental and thermodynamic investigation of a 20W an ammonia/water diffusion absorption machine. They noted that a minimal heat power (roughly 20 W) has to be supplied to the generator to ensure the functioning and the stability of the refrigerator [10]. Oscillating temperatures of a generator and evaporator are observed when the machine is supplied with insufficient heat power (17.5 W) [9]. The same observation was detected by Ben Ezzine et al. [10] when they experimentally investigated an air-cooled diffusion absorption machine operating with a binary light hydrocarbon mixture (C_4H_{10}/C_9H_{20}) as working fluids and helium as pressure equalizing inert gas.

All cited works above aim to improve bubble pump efficiency. However they did not explain the oscillation phenomenon and did not define the type of instability. For this, a theoretical and experimental study of the oscillatory phenomenon in the bubble pump finds its importance.

Because of the undesirable instabilities found in boiling two-phase flow systems, present in many fields and scales, ranging from large heat exchangers and boilers in industrial applications to micro-scale heat exchangers for high density power electronics, mathematical modelling is needed to assist in the determination of safe operating regions. In the literature we find three common models used in the modelling of two-phase flows: the homogeneous equilibrium model, the drift flux model and the general two-fluid model. However, the

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drift model is the most common model using in this area, because it is adopted to characterize the two-phase flow in the up flow and boiling flow systems. In addition drift-flux formulation, which has gained much acclaim in the last decade, takes the relative velocity between the phases into account, while assuming thermodynamic equilibrium [11].

In the present work, the transitional regime of two-phase ammonia water flow in a bubble pump of diffusion absorption diffusion machines was investigated using numerical simulation. The basis of the method involves the one-dimensional transitional solution of the governing equations using the drift flow model. Numerical results show an oscillation of hydrodynamic parameter such as pressure, mass flux rate and vapour and liquid velocities.

II. Mathematical Formulation

A. Mathematical Equations

The drift flow model was used for the two-phase flow region in the bubble pump. Their conservation equations of mass, momentum and energy are formulated for transient regime; with negligible kinetic and potential energy are the following:

Mixture continuity

$$\frac{\partial \rho_m}{\partial t} = -\frac{\partial}{\partial z}(\rho_m . v_m) \tag{1}$$

Gas continuity

$$\frac{\partial(\alpha.\rho_G)}{\partial t} = -\frac{\partial}{\partial z}(\alpha.\rho_G.V_m) - \frac{\partial}{\partial z}\left(\frac{\alpha\rho_G.\rho_L}{\rho_m}\bar{V}_{gj}\right) + \Gamma_g \tag{2}$$

Mixture momentum

$$\frac{\partial(\rho_m . V_m)}{\partial t} = -\frac{\partial}{\partial z}(\rho_m . V_m^2) - \frac{\partial P}{\partial z} - \rho_m g - \frac{f_m}{D_h}\rho_m V_m^2 - \frac{\partial}{\partial z}\left[\frac{\alpha\rho_G\rho_L}{(1-\alpha)\rho_m}\bar{V}_{gj}^2\right] \tag{3}$$

Mixture energy

$$\frac{\partial}{\partial t}(\rho_m h_m) = -\frac{\partial}{\partial z}(\rho_m h_m V_m) - \frac{\partial}{\partial z}\frac{\alpha\rho_G\rho_L}{\rho_m}(h_g - h_l)\bar{V}_{gj} + \frac{q£_h}{A_c} + \left(V_m + \frac{\alpha(\rho_L - \rho_G)}{\rho_m}\bar{V}_{gj}\right)\frac{\partial P}{\partial z} \tag{4}$$

B. Drift Velocity and Distribution Coefficient

All The diffusion effects in the present formulation are expressed in terms of the mean drift velocity of the dispersed phase $\overline{V_{gj}}$ according to the DFM and can be expressed in the functional form described below:

$$\overline{V_{gj}} = \frac{\rho_m(v_{gj} + (C_0 - 1)V_m)}{\rho_m - (C_0 - 1)\alpha(\rho_L - \rho_G)} \tag{5}$$

In (5), v_{gj}, C_0 are drift velocity and distribution coefficients of the model, respectively, and are functions of the flow regime and are the same as those suggested by [12]. Also the phase velocities can be calculated by a drift-flow model [12]

$$\begin{cases} v_g = v_m + \frac{\rho_l}{\rho_m}\bar{V}_{gj} \\ v_l = v_m - \frac{\alpha\rho_g}{(1-\alpha)\rho_m}\bar{V}_{gj} \end{cases} \tag{6}$$

This modified distribution parameter suggests that the dominant factor to determine the distribution parameter in boiling flow would be the void fraction. Thus, a key to develop the constitutive equation of the distribution parameter is to find a dominant factor to determine the distribution parameter. Ishii [12] also developed the constitutive equation of the distribution parameter for boiling flow based on the effect of nucleate bubbles on a void distribution as:

$$C_0 = 1.2 - 0.2\sqrt{\left(\rho_g/\rho_l\right)}\{1 - \exp(-18\langle\alpha\rangle\} \tag{7}$$

Ishii [12] also studied the kinematic constitutive equation for the drift velocity in various two-phase flow regimes. The constitutive equation that specifies the relative motion between phases in the drift–flux model has been derived by taking into account the interfacial geometry, the body–force field, the shear stresses, and the interfacial momentum transfer, since these macroscopic effects govern the relative velocity between phases. The different correlations of local drift-velocity in various two-phase-flow regimes are grouped and presented in Table I:

TABLE I
Drift Flow Velocity Versus Flow Regime

Flow regime	Drift flow velocity
Bubbly	$v_{gj} = \sqrt{2}\left(\frac{g\sigma\Delta\rho}{\rho_f^2}\right)^{1/4}(1 - \langle\alpha\rangle)^{1.75}$ for $\mu_f \gg \mu_g$
Slug	$v_{gj} = 0.35\left(\frac{gD\Delta\rho}{\rho_f}\right)^{1/2}$
Churn	$v_{gj} = \sqrt{2}\left(\frac{g\sigma\Delta\rho}{\rho_f^2}\right)^{1/4}$
Annular	$\overline{V_{gj}} = \frac{1-\langle\alpha\rangle}{\langle\alpha\rangle + \left\{\frac{1+75(1-\langle\alpha\rangle)}{\sqrt{\langle\alpha\rangle}}\frac{\rho_g}{\rho_f}\right\}}\left\{\langle j\rangle + \sqrt{\frac{gD\Delta\rho\,(1-\langle\alpha\rangle)}{0.015\,\rho_f}}\right\}$

The constitutive equations proposed by Ishii [12] give excellent predictions for vertical upward two-phase flow for small diameter pipes (25-50mm). where g, σ, Δρ, μ_f andμ_g are the gravitational acceleration, the surface tension, the density difference between phases, the liquid viscosity and the gas viscosity, respectively.

C. Resolution Method

In this section mass, momentum and energy balance equations have been resolved according the following assumption:

- One-dimensional flow
- Heat input is supplied along tube
- Same pressure for liquid and vapour phase

To better highlight interesting features of the model, we rewrite (1)–(4) using the following transformation to obtain a new set of variables:

$$u_1 = \rho_m \tag{8}$$

$$u_2 = \alpha\rho_g \quad (9)$$

$$u_3 = \rho_m V_m \quad (10)$$

$$u_4 = \rho_m h_m \quad (11)$$

$$\frac{\partial U}{\partial t} = Q(U) + \frac{\Delta F(U)}{L} U = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{bmatrix} \quad (12)$$

$$Q = \begin{bmatrix} 0 \\ \Gamma_g \\ \rho_m\, g + \frac{f_m}{D_h}\rho_m V_m^2 \\ \frac{q\xi_h}{A_c} \end{bmatrix}, F = \begin{bmatrix} -(\rho_m . V_m) \\ -\left(\alpha\rho_g V_m + \frac{\alpha\,\rho_G\rho_L}{(1-\alpha)\rho_m}\bar{V}_{gj}^2\right) \\ -\left(\rho_m . V_m^2 + \frac{\alpha\,\rho_G\rho_L}{(1-\alpha)\rho_m}\bar{V}_{gj}^2\right) \\ -(\rho_m h_m V_m) \end{bmatrix} \quad (13)$$

III. Simulation Results

A. Simulation Conditions

The main components of an absorption-diffusion refrigeration cycle and flow configurations in the bubble pump are showing in Fig. 1.

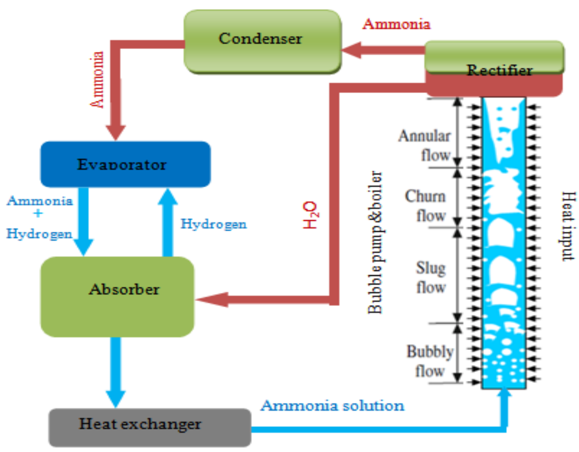

Fig. 1 Absorption diffusion machine and their compounds

Solving the system of equations of the mathematical model, allowed to determine void fraction, liquid and vapour velocities and enthalpy according to operating conditions illustrated in Table II.

B. Two-Phase Flow Simulation

According of the operating condition illustrated in Table II, void fraction, pressure and vapour and liquid velocities are plotted versus time. As can be seen in Fig. 2, void fraction increases along time and when heat flux rises. It is obvious that the amount of vapour generated increases with received heat flux in time. However, when we review Fig. 2, it is clear there is an absence of oscillation of void fractions along time and for different heat flux studies. That can be explained by the amount of generated vapour which is function of heat supplied to the flow. In fact, void fraction evolution is separate from the hydrodynamic condition which can be caused by oscillation flow. On the other hand, void fraction is not influenced by the transition flow regime, because it increases without perturbation. In regard to the time when void fraction achieved its maximum, it is clear that the considerate time increase with heat flux is about 25 s. According to Fig. 2, for times below 25 s, the void fraction increases slowly. We can considerate it as the steady-state time.

TABLE II
Operating Conditions

Parameters	Values
Heat flux (kW /m^2)	2-5
Tube diameter (mm)	25
Tube length (m)	1.000
Ammonia concentration at the inlet	0.6
Inlet pressure pump (bar)	13

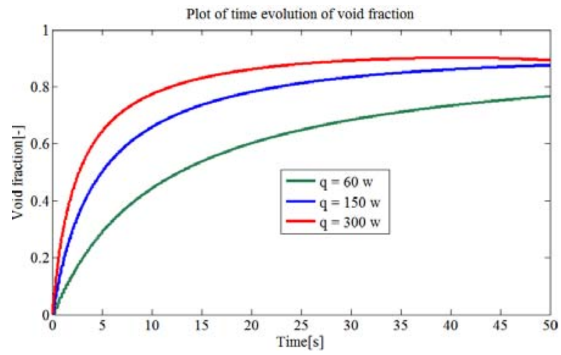

Fig. 2 Variation of void fraction versus time

However in Fig. 3, where it shows the variation of liquid velocity along time, its behaviour is different from void fraction. Liquid velocity starts its variation by oscillations. The time and amplitude of oscillations increase with heat flux decrease. Indeed, as shown by the void fraction behaviour, the amount of generated vapour can be able to hold up solution in the bubble pump. However in the beginning, the heat flux supplied is not sufficient to generate vapour able to overcome the inertia and the friction effect, which causes instability along time.

Fig. 3 shows for heat input of 300 w, liquid velocity finish its oscillation below time of 5 s, this is explained by the dominant of bubbly regime (α<0.3) on the flow regime configuration in this time (see Fig. 2).

For the study vapour velocity, we plotted its behaviour along time, as seen in Fig. 3. Vapour velocity has the same behaviour at the start i.e. an oscillation until 5 s. In addition, it oscillates in the same way as that of liquid velocity; however, the vapour velocity values are greater than liquid velocity. This difference is due to difference between liquid and vapour density. However, when state steady state is established (t = 25 s), vapour velocity is not constant along time; this can explained by the dependence of liquid velocity by the vapour generated, where it is a function of heat supplied.

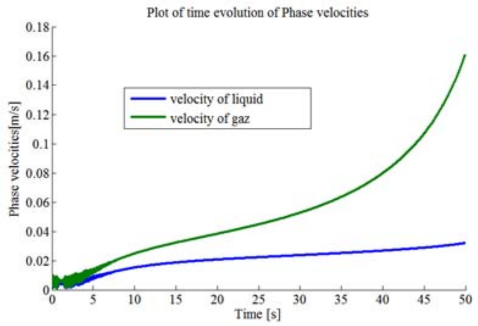

Fig. 3 Liquid and vapour velocities versus time

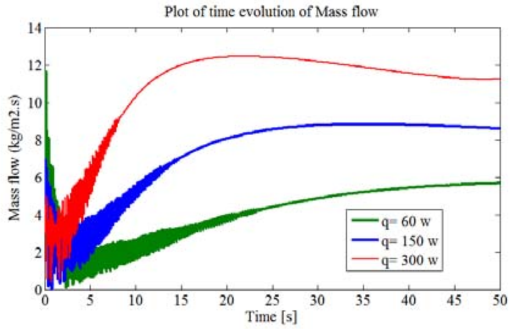

Fig. 4 Variation of mass flux rate versus time

The mass flow rate, as plotted in Fig. 4, shows the same instability like these for liquid and vapour velocities. Its time oscillation decreases with heat flux; however, for the steady state regime, the mass flow rate has different behaviour. It is constant for the lower heat flux used. Were increasing heat flux, mass flux rate achieves a maximum and then decreases.

Pressure drop with an oscillation, as seen in Fig. 5, shows three different zones, first where pressure oscillates for a little time (about 1 s) then pressure drops without oscillation, and for the third zone, pressure oscillation is in the vicinity value. We can distinguish that pressure drop and height of oscillation increase with heat flux.

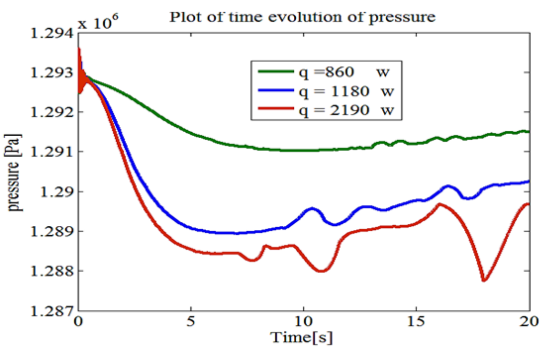

Fig. 5 Variation of pressure fraction versus time

IV. Conclusion

This paper reports the study of instability in the bubble pump of diffusion absorption machines. Drift flow models are adopted in the transitional regime and non-equilibrium between phases. Equations models are resolved to define void fraction, pressure, enthalpy and liquid and vapour velocities. Results simulation shows the oscillations of hydrodynamic parameters such us pressure mass flux rates, and liquid and vapour velocity; however, void fraction does not oscillate. Two regimes were distinguished, the first, caused by hydrodynamic effect, its time of oscillation is about 10 s and it decreases with heat flux increasing. In addition, the length of oscillation decreases with heat flux too. For the second regime, it is the steady state regime where liquid velocities and pressure become constant; however, vapour velocities increase in steady regime too. For void fraction behaviour, it is related to the generated vapour. Pressure drop oscillation increases with time and heat flux supplied.

TABLE III
Nomenclature

C_0	distribution coefficient
g	gravity vector, m.s^{-2}
h	enthalpy, J.kg^{-1}
P	pressure, Pa
q	heat flux, W.m^{-2}
t	time, s
V	velocity vector, m.s^{-1}
V_{gj}	drift velocity, m.s^{-1}
z	axial direction, m
Greek letters	
α	void fraction
ρ	density, kg.m^{-3}
μ	viscosity, Pa.s vapour or liquid generation rate per unit mixture volume, kg.m^{-3}.s^{-1}
Subscript	
g	gas phase
l	liquid phase
m	mixture

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