TRANSIENT BEHAVIOR OF A VERTICAL PLATE EVAPORATOR FOR AMMONIA

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1. Abstract

The paper analyses the transient behavior of a vertical plate evaporator for ammonia, this piece of equipment belonging to a refrigeration machine or heat pump.

The evaporator consists of vertical wavy metal plates, tighten together by welding points. The liquid ammonia is fed at the upper side of the plates and flows film-wise downwards under the force of gravity. The secondary heating fluid is a thermal oil and flows upwards (in counter-current to the refrigerant) at full section.

The mathematical model of this heat exchanger takes into account the fact that dry boiling may occur, so that the equations for normal elements, for the last wetted element and for the dry elements have particular forms.

For the last wetted element, the heat passing from the heating fluid to the refrigerant film is not computed by means of the thermal resistance between the oil and the upper surface of the film, but by means of the total vaporized liquid quantity coming from the previous element. The vapor mass flow rate leaving this element is equal to the liquid mass flow rate that leaves the previous element. A special procedure for computing the total wetted length of the evaporator is developed.

The program built for simulating the transient response of the evaporator allows to find out the values of the outlet parameters according to the values of the inlet parameters and their type of time variation.

The inlet parameters are:
- the mass flow rate density of the secondary heating fluid
- the mass flow rate density of the refrigerant at the upper side of the evaporator
- the refrigerant temperature at the upper side of the evaporator
- the temperature of the secondary heating fluid at the lower side of the evaporator
- the refrigerant mass flow rate absorbed in the absorber

The outlet parameters are:
- the mass flow rate density and the temperature of the refrigerant as function of time and space
- the mass flow rate and the temperature of the secondary heating fluid as function of time and space
- the pressure in the evaporator as function of time

A few graphical representations for some outlet parameters at different time and space steps for stepwise time variations of some inlet parameters are also provided. The start of the vaporizing process is analyzed too and the results are plotted.

Comments on the physical meaning of the results of the simulation are provided for each analyzed case.

2. Introduction

The analysed ammonia - water absorption refrigeration machine is presented in figure 1.

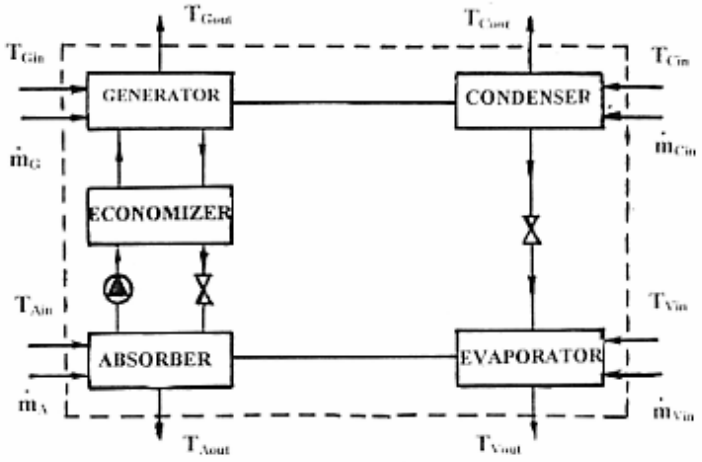

Figure 1. The ammonia - water absorption refrigeration machine provided with wavy - plate type heat- and mass exchangers

The vapor generator, the absorber, the condenser and the evaporator use as secondary heating agent a special type of thermal oil.

All the heat and mass exchangers within the above presented ammonia - water absorption refrigeration machine are of the wavy plate type. Some details of these wavy - plate type exchangers are presented in figure 2.

Figure 2. The construction of the wavy multi-plate type heat- and mass exchangers

For modeling purpose, the system will be divided into sub-systems. The variables occurring in this model can be separated in two categories:
- potential variables (the temperatures),
- flow variables (mass flow rates).

The generator's and evaporator's temperatures and mass flow rates represent independent variables since these ones do not always work with the same temperatures and mass flow rates.

The inlet variables represent the temperatures and mass flow rates of the four fluids that enter the main four components of the thermal absorption machine, namely: the absorber, the vapor generator, the condenser and the evaporator.

The outlet variables represent the outlet temperatures of the four fluid flows.

The heat flows and the system power performances can be computed from these twelve inlet and outlet variables.

The block schemes of the absorber and evaporator are presented in figure 3.

As for the evaporator it is thought that the concentration is a parameter with given value and therefor it is not comprised by the other inlet or outlet parameters.

The heat pump - or the refrigeration machine - has a high pressure zone and a low pressure zone. It can be thought that the pressure in those zones (subsystems) depends on the vapor mass flows that leave the film or are absorbed by the film as well as the vapor temperature. The influence of the solution variable flows upon the components volume can be neglected.

The vapor flows depend - among other things - on the balance temperatures and concentrations of the solution upper films.

One can notice the validity of the same equations for the model construction of the evaporator and condenser on the one hand, and for the absorber and generator on the other hand.

As for the subsystem from figure 4, the concentration, the temperature and the mass flow rate should be considered as independent inlet variables.

Figure 3. Block representations of the absorber and evaporator

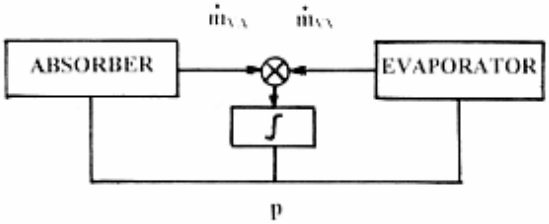

Figure 4. The low pressure zone of the ammonia-water absorption machine

3. The equations for the model

The model selection can be done based on the analyses of processes taking place on the plates. It can be noticed that the phenomena occur for two thin laminar flowing films- that's why the maximum - gradient model was chosen for simulation, according to which the phenomena of heat, mass and impulse transfer are described by equations with partial derivatives of hyperbolic type.

The models with distributed parameters have proven to be more suitable for the evaporator. By resort to the conservation equations, the evaporator is divided into several elements and each constituent element is to be treated as a group with concentrated parameters. This kind of representation leads to a set of ordinary differential equations connected at their turn.

Only heat transfer can be met between the thermal oil and the plate (on the one hand), and between the wall and the refrigerant film (on the other hand).

According to the Reynolds criterion for the working medium and oil it can be noticed that the flowing regime is laminar, while the velocity profile is parabolic. Due to their welding points, the upper surface of the plates is light wavy. The plate can be thought as a plan wall because the vertical deviation is small.

In the vapor generator and in the evaporator the same processes are met, but in opposite directions, and the heat and mass flows should be considered in counter sense.

The basic assumptions in constructing the equations for the evaporator are:

1. Each plate of the evaporator is formed from a series of elements distributed on the plate height. The plates are considered as plane plates. For different elements the parameters representing the evaporators' behavior, as well as the thermodynamic and physical properties can be different but inside each element they do not change.

2. The tangent heat conduction in the cooling fluid and wall is neglected. The thermal resistance of the metal wall is neglected too.

3. The ammonia is a Newtonian liquid with laminar flowing only under the action of the gravity forces and abrasion forces to the wall.

4. The mass transfer is achieved by diffusion perpendicularly to the flow direction, while the heat transfer by convection in the flow direction. The mass transfer by diffusion and the heat transfer by convection in the flow direction are neglected - assumptions of the maximum - gradient model.

5. The met temperatures and pressures allow the ideal gas assumption for the vapors.

6. As the interface, thermodynamic balance between liquid and vapors is met. The valid relation for this interface regarding the temperature, mass concentration and vapor pressure is linear.

7. For a liquid element film, in computing the heat transfer rates, a linear variation of the temperature is assumed between the liquid-vapor interface and the wall.

8. The released heat from the liquid film towards the vapor phase by free convection or radiation is neglected.

9. The parameters for the simulation model can be considered as having one-dimension geometry.

The concentration, temperature and velocities profiles in the evaporator are presented in figure 5.

In order to have an accurate representation of the dry boiling in the evaporator, two additional systems of equations are to be built: one for the last wetted element and one for the dry zone. That element that is still fed with liquid, and releases vapors only, was noted with the "nwet" index. For this element the following considerations are available:

- The heat passing from the oil towards the refrigerant film is not computed by means of the thermal resistance between the oil and the upper surface of the film, but by means of the vaporized liquid quantity coming from the previous element.
- The vapor mass flow rate leaving this element is equal to the liquid mass flow rate that leaves the previous element.

$$\frac{\partial T_w}{\partial t} = \frac{\alpha_c}{\rho_w \delta_w c_{p,w}}(T_c - T_w) - \frac{\alpha_m}{\rho_w \delta_w c_{p,w}}(T_w - T^*) \quad (1)$$

$$T_m - 0.625T^* - 0.375T_w = 0 \quad (2)$$

$$T^* = Ep + D \quad (3)$$

$$\frac{\partial M'}{\partial t} + 3v_m \frac{\partial M'}{\partial x} = -3v_m \frac{\alpha_m b(T_w - T^*)}{\Delta h} \quad (4)$$

$$\frac{\partial T_v}{\partial t} - \frac{M'_v}{\rho_v \delta_v b}\frac{\partial T_v}{\partial x} = 0 \quad (5)$$

$$\frac{\partial p}{\partial t} = \frac{RT_v \alpha_m (T_w - T^*)}{M\delta_v \Delta h} + \frac{RT_v \partial M'_v}{M\delta_v b \partial x} + \rho_v \frac{R}{M}\frac{\partial T_v}{\partial t} \quad (6)$$

$$\frac{\partial M'_v}{\partial t} - v_v \frac{\partial M'_v}{\partial x} = v_v \frac{\alpha_m b(T_w - T^*)}{\Delta h} \quad (7)$$

$$\frac{\partial T_c}{\partial t} - \frac{M'_c}{\rho_c \delta_c b}\frac{\partial T_c}{\partial x} = -\frac{\alpha_c}{\rho_c \delta_c c_{p,c}}(T_c - T_w) \quad (8)$$

From the heat balance for the first element the following equations can be obtained:

$$\alpha_m (T_w - T^*) b dx = M'_{in} c_{p,m}(T_m - T_k) + dM'_\lambda \Delta h \quad (9)$$

$$dM'_\lambda = \frac{\alpha_m}{\Delta h}(T_w - T^*) b dx - \frac{M'_{in}}{\Delta h} c_{p,m}(T_m - T_k) \quad (10)$$

For the first element, the equations (4), (6) and (7) are modified into:

$$\frac{\partial M}{\partial t} + 3v_m \frac{\partial M}{\partial x} = -3v_m \left[\frac{\alpha_m b(T_w - T^*)}{\Delta h} - \frac{M'_{in}}{\Delta h dx} c_{p,m}(T_m - T_k) \right] \quad (11)$$

$$\frac{\partial p}{\partial t} = \frac{RT_v}{M\delta_v}\left[\frac{\alpha_m (T_w - T^*)}{\Delta h} - \frac{M'_{in}}{\Delta h b dx} c_{p,m}(T_m - T_k) \right] + \frac{RT_v}{M\delta_v b}\frac{\partial M'_v}{\partial x} + \rho_v \frac{R}{M}\frac{\partial T_v}{\partial t} \quad (12)$$

$$\frac{\partial M'_v}{\partial t} - v_v \frac{\partial M'_v}{\partial x} = v_v \left[\frac{\alpha_m b(T_w - T^*)}{\Delta h} - \frac{M'_{in}}{\Delta h dx} c_{p,m}(T_m - T_{cond}) \right] \quad (13)$$

For the last wet element (figure 6) it is presumed that the film from the former element is all evaporated within this element. Thus, the equation (1) changes to:

$$\frac{\partial T_w}{\partial t} = \frac{\alpha_c}{\rho_w \delta_w c_{p,w}}(T_c - T_w) - \frac{M' \Delta h}{\rho_w \delta_w c_{p,w} b dx} \quad (14)$$

One of the boundary conditions is: $M'_{x=0} = 0$ (15)

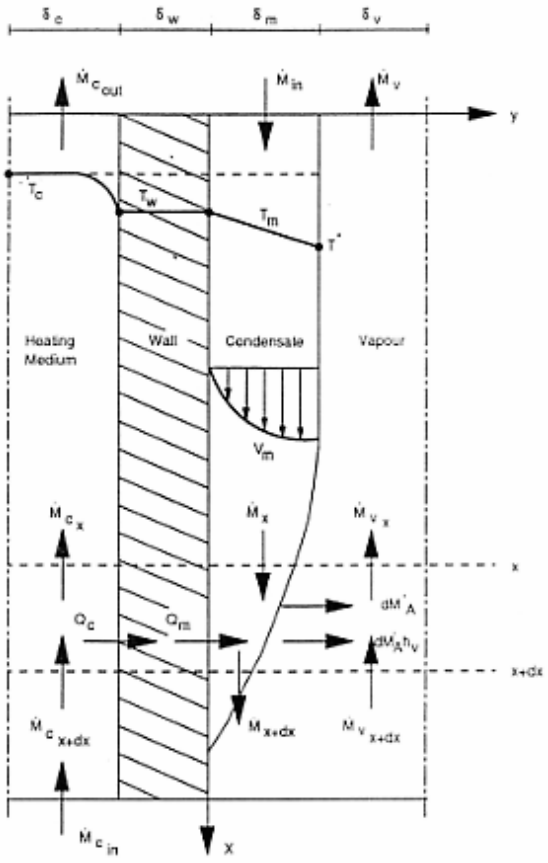

Figure 5. The concentration, temperature and velocity profiles in the evaporator

When the wetted length is chosen too long, the computed mass flow rate density is negative, which is impossible from physical point of view. When the wetted length is chosen too small, the mass flow rate density will be zero and the temperature differential T_w - T_{ml} will be so large that T_w will be under T*, which in vaporizing is impossible (it makes no sense). During the dynamic functioning the wetted length can change. This means that for each time step the real wetted length should be searched. According to this reason it was developed a special procedure implying that the mass flow rate density tends to zero.

Firstly, a calculation that uses the same wetted length as for the previous time step is done. By means of the value from the first and the second element behind the last wetted element the new wetted length can be estimated. The mass flow rate density can not be used to do this due to its supposition as being equal to zero.

During the dynamic functioning certain situations may occur when some of the model equations are not valid. Strong subcooling of the dry zone (when the wall has a temperature below the condensation one), represents a proper example. It is then when condensation takes place in that zone and therefor the last values of the mass flow rate density are not used because the wetted length stays the same. The way to solve this problem is to choose a domain of the wetted length by means of a correction factor greater than one. If "nwet" is taken too large, the mass flow rate density for the element behind the last wetted one becomes negative and thus the "nwet" decreases.

For current elements - excepting the first, the last wetted and the dry elements - the equations are as follows:

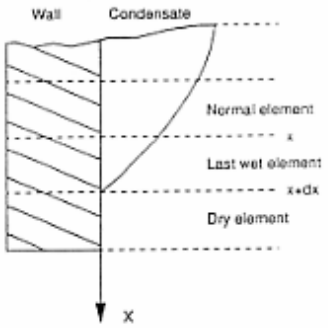

Figure 6. Scheme of the last wetted element in the evaporator

For the dry elements, the equations (2), (4) and (7) turn to:

$$T - T_w = 0 \tag{16}$$

$$M^{\cdot} = 0 \tag{17}$$

$$M_v^{\cdot} = 0 \tag{18}$$

4. The space and time boundary conditions

In order to solve the presented partial derivatives equations both space and time boundary conditions are necessary. The space and time boundary conditions should be available for the opened domain. As for T_m, ξ and Γ regarding the domain $[x=0,\ t=(t_0, t_1)]$ the following conditions are valid

$$\begin{aligned} T_1(0, t) &= T_{1,in}(t) \\ \xi(0, t) &= \xi_{in}(t) \\ \Gamma(0, t) &= \Gamma_{in}(t) \end{aligned} \tag{19}$$

As for T_c regarding the domain $[x = L,\ t = (t_0, t_1)]$ the following condition is valid

$$T_c(0, t) = T_{con}(t) \tag{20}$$

As for the initial space values in the domain $(x = (0, L),\ t = t_0)$, continuos functions can be chosen for T_m, T_w, T_c, ξ si Γ. The calculation starts from the related equations to the model's steady state working conditions. Beginning from this steady state, the calculation for the dynamic regime is then done. This approach is proven to be a realistic one due to the frequent practical situations when disturbances occur during the steady state working conditions.

The modeling required equations for the steady state regime are obtained by setting to zero the time depending terms from the differential equations.

In the evaporator simulation, the vapor phase has been divided into the same number of elements as the liquid film.

The matrix of the model is constructed as a band matrix. By changing rows or columns, a minimal band width is constructed

When the elements are coupled together in order to form a system, the output parameters of the mass flow, the heat flow and the vapor phase of one element will affect the similar parameters of another element. That is why the mass conservation must be accomplished not only for one element but for the whole system. As for the system simulation, the following assumption should be considered:

1. The entire condense leaving the condenser towards the evaporator should evaporate there. Otherwise a part of the condensate will remain in the evaporator, causing there the increase of the liquid level (this liquid which can reach the plates that form the heat transfer surface).

2. The evaporator and the absorber are coupled by the vapor phase. The vapor pressure is established by means of the evaporation temperature in the evaporator. The absorbed vapor mass flow rate should equal the vapor mass flow rate from the evaporator in order to reach the steady state working conditions.

3. The parameters of the system, which are computed and measured should be stable under steady state working conditions.

The vapor phase model used for the absorber and the evaporator is presented in figure 7.

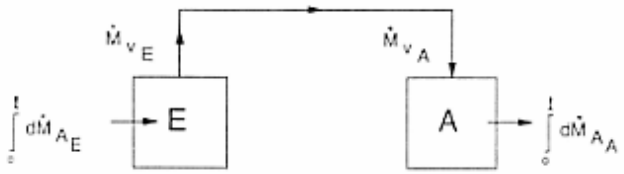

Figure 7. The vapor phase model for the absorber and the evaporator

The equations of the vapor phase model used for the absorber and the evaporator are:

$$\frac{\partial p}{\partial t} = \frac{RT_v}{MV}\left(\int_0^1 dM_{dE} - \int_{01}^1 dM_{dA}\right) + \frac{RM_v}{MV}\frac{\partial T_v}{\partial t} \tag{25}$$

$$\frac{\partial T_v}{\partial t} + \frac{\phi_p}{c_{p,v}}\frac{\partial p}{\partial t} = 0 \tag{26}$$

5. Numerical solution of the equations system for the model

The system of equations presented for modeling the evaporator will be solved numerically.

The dynamic behavior of the distributed system is described by means of certain quasi-linear differential equations with partial derivatives of hyperbolic type. Related to their solving there is a need of a space and time discretization. The spatial discretization is achieved based on a rectangular grid.

The method used for solving the system of equations is the implicit one. The implicit method computes the differential coefficients as function of the searched solution. Due to the fact that this one is still unknown, a non - linear system of equations should be solved. Therefor, the implicit method requires more computing time. Yet, there is a great advantage consisting in the fact that the method of computing is stable. As for the explicit method, there is always a limit of the step dimension depending on the variables.

Another reason for choosing the implicit method is that the film from generator/absorber and evaporator/condenser has a low time constant and therefor not only the previous values but even the time constant show a dependence varying with the dimension of the time step. The met time constants - after the input of the specific - seem to be about 0,3 s while the time step should be much lower as for the explicit method. In the case of implicit method a larger step of time can be used.

The equations presented above are discretized and written as matrix equations as follows:

$$\mathbf{z}^{n} = \mathbf{A}\mathbf{z}^{n+1} \tag{21}$$

By changing the rows and columns in an adequate way, the matrix for the model forms a band matrix. To start the simulation the boundary values are considered valid in every plate element in the static version. Thus initial values are given, although they are far from the equilibrium situation. The equations are solved, providing new values of state. This procedure is iteratively repeated until the values for the last element do not differ less than a small number ε between two steps. The iterating procedure implies the method of successive substitutions. Thus, the static solution for the evaporator is established, and the right initial values for dynamic simulation are provided. These values are written in a file which is red by the dynamic part of the program. Consequently, it is not necessary to compute initial values for different values of a step beginning from the initial standard conditions.

In the model, the static version has three further equations for energy and mass conservation checking.

The heat transferred from the liquid film towards the wall is:

$$Q_m = \int_0^1 dQ_m = \int_0^1 \alpha_m (T_m - T_w) b dx \tag{22}$$

The heat transferred from the wall towards the cooling medium is:

$$Q_c = \int_0^1 dQ_c = \int_0^1 \alpha_c (T_w - T_c) b dx \tag{23}$$

The total mass of absorbed vapors is:

$$M'_{out} - M'_{in} = \int_0^1 dM'_x = M'_{v,in} \tag{24}$$

In case of dynamic simulation these checks are not relevant because heat and mass storage during the transient behavior may occur.

6. Results of the simulation

In order to clarify the way the simulation program works, the main elements that should be taken into account for the evaporator are illustrated further on.

Data required by the construction of equations describing the evaporator should be entered from the keyboard. These equation can also be written in vectorial form:

$$\frac{d}{dt}\underline{X} = A\underline{X} + B\underline{U} \qquad (27)$$

$$\underline{Y} = C\underline{X} + D\underline{U} \qquad (28)$$

In the above mentioned relations, $\underline{X}$ represents the state vector, $\underline{U}$ the inlet vector and $\underline{Y}$ the outlet vector. A, B, C and D represent the matrixes revealing the connection between different vectors. According to this form, one can notice that the state vector is differentiated with respect to time.

The state parameters are:
- The mass flow rate density of the refrigerant Γ (Kg / m s)
- The temperature of the heating fluid T_h (K)
- The temperature of the heat exchanger wall T_w (K)
- The temperature of the refrigerant (K)
- The pressure within the evaporator and absorber p (N / m^2) or the vapors' enthalpy H_v (J / Kg)

The input parameters (including the boundary conditions, but excepting the initial conditions) are:
- The mass flow rate density of the heating fluid Γ_h (Kg / m s)
- The mass flow rate density for the refrigerant at the upper side of evaporator $\Gamma_m(0,t)$ (K)
- The temperature of the refrigerant at the upper side of evaporator $T_m(0,t)$ (K)
- The temperature of the heating fluid at the lower side of evaporator $T_h(L,t)$ (K)
- The temperature of the wall at the lower side of evaporator $T_w(L,t)$ (K)
- The mass flow rate of the refrigerant absorbed by the absorber m_{abs} (kg / s)
- The evaporator's heat loss due to the vapor transport to the absorber and the imperfect thermal isolation of the system.

The variation of an input parameter can be done according the following models:
- Step-wise function;
- Sinus function;
- Exponential function;
- 'Trend ' function

The output parameters are:
- The mass flow rate density and temperature of the refrigerant as function of time and space;
- The mass flow rate and temperature of the heading fluid as function of time and space;
- The pressure within the evaporator and absorber as function of time;
- The temperature of the vapors within the evaporator and absorber as function of time.

In order to obtain functions for each outlet parameter, a system of six independent equations has to be built according to those six parameters.

Besides the state, input and output parameters one needs some additional information for the computation, such as:

- physical properties of the substances ρ , η , c_p , λ
- rates of heat transfer α
- temperature of saturation T_{sat}
- latent heat of evaporation Δh_{lv}
- rate showing how large the wetted zone of an element is (for the dry zone ξ=0; for the first up to last but one wetted element ξ=1; for the last wetted element $0 < \xi < 1$)

The computing program consists of three main parts:

Part I	**Data input** regarding:	- construction elements and fluids
		- initial conditions in the process
		- boundary conditions (the input parameters)
Part II	**Effective computation**	
Part III	**Results' output into files**	

The initial conditions can be introduced in the system by two alternatives:

The first alternative starts from the steady state working regime. The values of the start parameters are calculated by means of the boundary conditions met in the respective steady state situation. In this case, the following data are be introduced:

- the refrigerant mass flow rate at the upper side of evaporator
- the temperature of the refrigerant at the upper side of evaporator
- the mass flow rate of the heating fluid
- the temperature of heating fluid at the upper side of evaporator
- the pressure within the evaporator

In the second alternative it is presumed that the evaporator starts for the first time. By means of the heating fluid, the evaporator is heated and afterwards the liquid refrigerant is pumped into the evaporator. As for this case the required data refer to:

- the mass flow rate of the heating fluid
- the temperature of the heating fluid at the lower side of evaporator
- the pressure within the evaporator

Then, it is presumed that the entire evaporator is brought up to the inlet temperature of the heating fluid.

Some of the simulation results are herein presented. Three cases of simulation are to be discussed:

1. Step-wise variation of refrigerant's mass flow rate.
2. Step-wise variation of heating fluid's inlet temperature.
3. Beginning of the evaporation process.

The **input data** for the simulation are:

a. Equipment dimensions for the low pressure zone:

Evaporator	Length	1.167 m	Absorber	Length	1.167 m
	Width	0.290 m		Width	0.290 m
	Height	0.992 m		Height	0.992 m
	Working height	0.800 m		Working height	0.800 m

Connection pipe between evaporator and absorber	Length	1.5 m
	Diameter	0.1615 m
Number of identical heat exchangers within the evaporator		3
Refrigerant		File NH3
Thermal agent		File OIL
Heat exchanger's material		File MATSC

b. The initial conditions will be mentioned for each analyzed case.

The results of the simulation for the three above mentioned dynamic situations will be presented in the next paragraphs.

6.1. Step-wise variation of refrigerant's mass flow rate

The values of the input parameters are:

- ammonia mass flow rate $m_{NH3} = 0.5$ kg / s
- thermal oil mass flow rate $m_{OIL} = 0.1$ kg / s
- ammonia's temperature at evaporator's inlet $T_{NH3} = 266.8$ K
- thermal oil's temperature at evaporator's inlet $T_{OIL} = 278$ K
- evaporation pressure $p_0 = 350\,400$ Pa

At $\tau = 0$, the ammonia mass flow rate increases suddenly by 10 %, up to 0.55 kg/s.

The other boundary conditions remain identical, and so does the vapor flow rate to the absorber too.

The time intervals for the simulation are of 1 second each. The total time for the simulation is 20 seconds, and it is longer than the time requested by the refrigerant flow to pass through the whole evaporator, so that after 20 seconds the disturbance will be experienced along the whole height of the evaporator. The evaporator is divided into 20 elements.

The time variation of the mass flow density for the refrigerant along the entire height of the evaporator and at different moments is presented in figure 8. The describing curve for this variation can be divided into 3 zones. The mass flow rate density for the first zone, that involves the first element, increases because the liquid enters the evaporator at a sub-cooled state (T=267.1 K), and the vapors condense at the liquid's film surface until the temperature becomes equal to the saturation one. When the exchanged heat towards a liquid film element overpasses the necessary of sensitive heating, the extra-heat is provided as latent heat to the refrigerant and therefor the mass flow rate density decreases. The second zone of the curve decreases from element 2 down to element 5. Element 4 is the last wetted element.

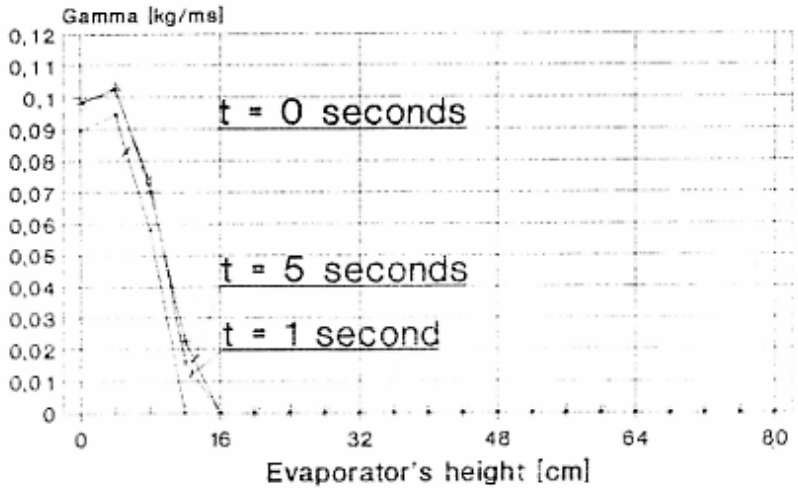

Figure 8. Time variation of the refrigerants' mass flow rate density within the evaporator. Case 1. Step-wise increase of ammonia mass flow rate by 10 %

According to figure 8, more refrigerant vaporizes at the lower side of the evaporator than at the upper side. This can be explained by the greater temperature difference between the refrigerant and the heating fluid. The temperature of the refrigerant is constant, while the temperature of the heating fluid increases from the upper to the lower side. The variation of the heat transfer coefficient on the refrigerant film side can not be emphasized because an average heat transfer coefficient was considered for this model.

The third zone refers to the dry zone of the evaporator because the mass flow rate density of the refrigerant is zero - due to its total evaporation.

The corresponding curves for the time moments of 0, 1 and 5 seconds have the same looks. After the disturbance has occurred and the time increases, the wetted length and the mass flow rate density will increase along the entire height of the evaporator.

Figure 9 presents the time variation of the heating fluid's temperature along the evaporator's height, as a result of a step-wise variation of the ammonia mass flow rate. The describing curves can be divided into two zones. Starting from the first element, the heat transfer between the heating fluid and the refrigerant is large due to the fact that the refrigerant enters the evaporator at a sub-cooled state and the temperature difference between these fluids is large. For an increasing ammonia mass flow rate, the temperature of the secondary fluid has the tendency to decrease along the first four elements of the evaporator, where the ammonia phase transfer takes place. The mass flow rate of the thermal oil is constant. At a given moment τ, the representation of the heating fluid's temperature shows its variation up to the 4th element, afterwards it remains stable - this forms the 2nd zone. The 4th element represents the last wetted element within the evaporator.

The heat transfer between the heating fluid and the ammonia film is proportional to the temperature gradient $\frac{\partial T}{\partial x}$. On the other hand, the heat transfer coefficients between the metal plate and the ammonia liquid film are much bigger that those between the metal plate and the vapor phase. Thus, the heat transferred to the refrigerant is much bigger during the first four elements, and the temperature of the refrigerant decreases in time at the upper side of evaporator.

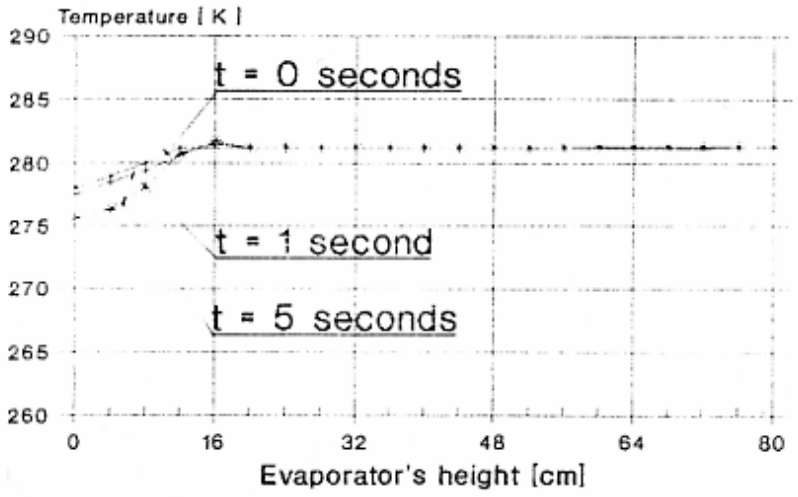

Figure 9. Time variation of the heating fluids' temperature within the evaporator. Case 1. Step-wise increase of ammonia mass flow rate by 10 %

Figure 10 presents the time variation of the evaporation pressure, as a result of the step-wise increase of the ammonia mass flow rate and under the assumption that the ammonia flow rate leaving to the absorber is zero. The pressure is computed by means of the ideal gas law. Since the ammonia enters the evaporator at a sub-cooled state, during the first second vapors' condensation takes place and the pressure decreases simultaneously. Starting from second 2, the mass flow rate increase leads to the pressure increase, as a result of the ammonia increased mass flow rate evaporating from the evaporator.

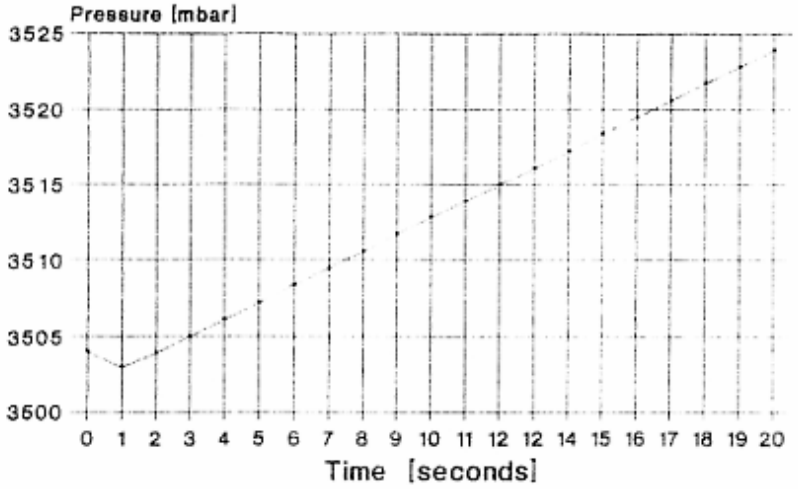

Figure 10. Time variation of the evaporation pressure
Case 1. Step-wise increase of ammonia mass flow rate by 10 %

6.2. Step-wise variation of the heating fluid's temperature

This simulation uses the same initial input parameters as those for the paragraph 6.1. The inlet temperature of the heating fluid has a sudden decrease by 5 K. The entire time for the simulation is of 20 seconds and the steady state situation is the same.

Figure 11 presents the variation of the refrigerant's mass flow rate density as function of time, along the evaporator's height. The 5 K decrease of the heating fluid's temperature has an insignificant impact upon the evaporator's wetted length, so that the number of the wetted elements is the same.

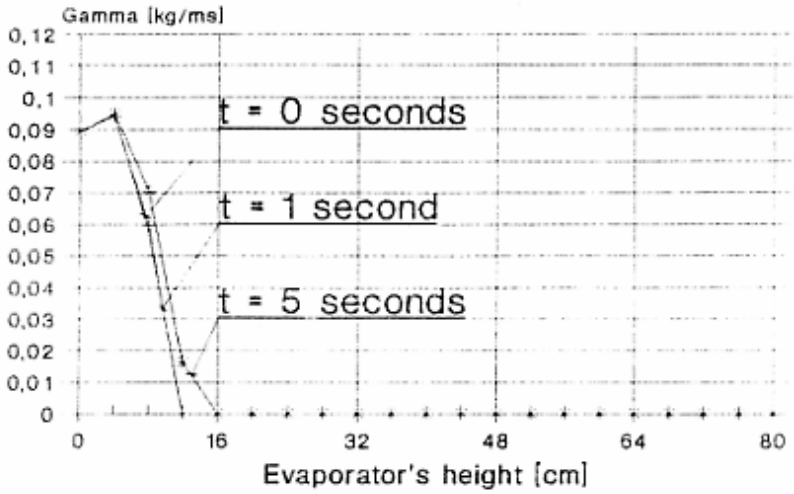

Figure 11. Time variation of the refrigerants' mass flow rate density within the evaporator. Case 2. Step-wise decrease of the heating fluid's temperature by 5 K

6.3. Beginning of the evaporation process

By pumping the heating agent into the evaporator, this one is heated up to 278 K. A refrigerant flow at 266.8 K is then introduced into the evaporator. Figure 12 presents the variation of the refrigerant's mass flow rate density, as function of time. The entire time for the simulation is 20 seconds.

It is presumed that the evaporator is already filled with vapors even before the liquid ammonia is introduced. Thus, the vapor's condensation takes place on the liquid surface and the mass flow rate density increases. It can also be noticed that as time passes, the wetted length increases, as a result of the flowing process that takes place along the entire evaporator's height.

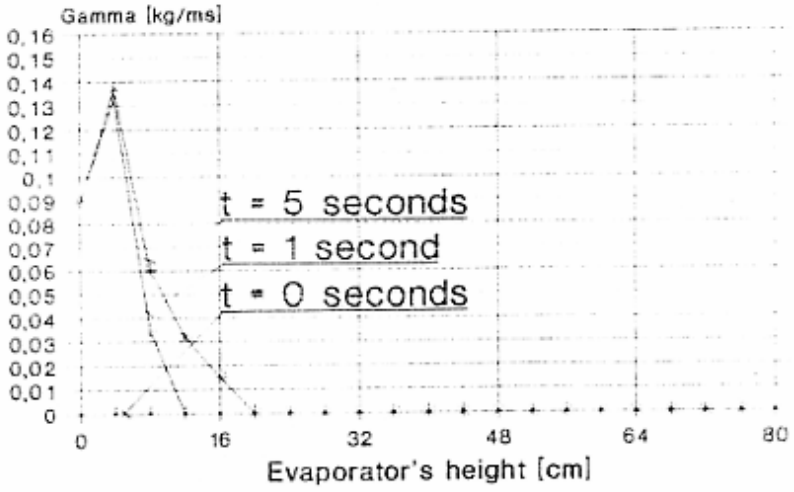

Figure 12. Time variation of the refrigerants' mass flow rate density within the evaporator. Case 3. Beginning of the evaporation process

7. Conclusions regarding the results of the simulation

Speaking from a qualitative point of view, the presented model leads to physical coherent results for the dynamic variation of the mass flow rate density, temperature and pressure.

The validation of the dynamic model for this type of ammonia evaporator will be studied by one of the Ph.D. students of our department, who will carry on the research regarding an ammonia-water absorption heat pump.

8. Aknowledgement

The authors express their gratitude for the support received from behalf of Professor C.H.M.Machielsen (T.U. Delft).

9. Nomenclature

Latin letters

b	Width of the plate	m
C	Specific molar heat	KJ / Kmol K
c	Specific heat	KJ/Kg K
D	Constant in the formula for the saturation temperature	
dM	Mass of the differential element	Kg
E	Constant in the formula for the saturation temperature	
H	Molar enthalpy	KJ / Kmol
h	Specific enthalpy	KJ / Kg
L	Height of the plate	m
M	Molar vapor mass	Kg / Kmol
M'	Mass flow rate	Kg / s
p	Pressure	bar
Q	Heat flow	W
q	Specific heat flow	KJ / Kg
R	Universal gas constant	KJ / Kmol K
r	Enthalpy of evaporation	KJ / Kg
T	Absolute temperature	K
t	Temperature on the Celsius scale	$^{\circ}$ C
t	Time	s
u	Velocity along the x axis	m/ s
V	Volume	m^3
v	Velocity along the y axis	m / s
x	Coordinate along the height of the plate	m
y	Coordinate perpendicular on the plate	m

Greek letters

α	Convective heat transfer coefficient	KW / m^2 K
Γ	Wetting density	Kg / m s
δ	Film thickness	m
Δ	Diference	
η	Efficiency	
Φ	Reflux ratio	

λ	Thermal conductivity	W / m K
μ	Dynamic viscosity	Pa s
ν	Kinematic viscosity	m^2 / s
ρ	Density	Kg / m^3
ξ	Ammonia mass concentration	Kg / Kg
ζ	Coefficient showing how large the wetted zone of an element is	

Subscripts

cond	Condensation	oil	Characteristic for the heating oil
c	Cooled medium	o	Evaporation
h	Heating fluid	out	Outlet
in	Inlet	p	At constant pressure
k	Sub-cooled temperature at the entrance in the first element	s	Saturation
		v	Vapors
m	Refrigerant fluid medium	w	Wall

Superscripts

*	Interface
*	Equilibrium

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