MATHEMATICAL MODELLING OF ABSORPTION PROCESS IN NON-STATIONARY STATE

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Rezumat. Lucrarea prezintă modelul matematic pentru procesul de absorbție în regim nestaționar. Modelul cuprinde ecuații diferențiale de legătură a variabilelor: concentrație, temperatură, presiune, masă de soluție, căldura transferată apei de răcire, temperatura finală a apei de răcire, în funcție de variabila independentă „timp".

1. INTRODUCTION

The absorber is a heat and mass exchanger in which, concentration of rich solution is reestablished. From a functional point of view the absorbers can be made with film distribution of the weak solution or with barbotage.

For the elaboration of the model concerning the absorption process of the ammonia vapors considering absorber with barbotage cooled with water (figure 1), [1].

Vapc .s of ammonia with the concentration x'' enter through the distributor mounted at the bottom of the device and barbotate through the mass of the solution with the concentration x_s and so the solution concentration increases to x_b. The absorption process is deployed in some stages [2]:

a) Vapors cooling: the ammonia saturation temperature (t_0) corresponding the pressure p_0 is little than solution temperature (t_l) because the ammonia vapors are overheat. To bring them back to the saturation temperature t_0 they have to give a certain quantity of heat. The heat given during cooling process by 1 kilogram of vapors is:

$$q_1 = c_p'' \cdot (t_l - t_0) \quad (1)$$

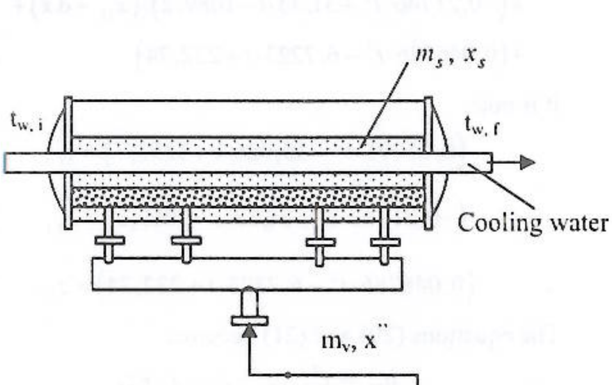

Fig. 1. Absorber with barbotage.

in which c_p'' is the specific heat of the vapors at constant pressure.

b) Vapors condensation: heat extracted for absorption of a kilogram of vapors is:

$$q_2 = l_c \quad (2)$$

in which l_c is the latent heat of condensation at pressure from absorber (p_0).

c) The heating of ammonia liquid from the temperature t_0 to the temperature t_l, for had an isothermal process. In this case the heat received by one kilogram of ammonia is:

$$q_3 = c_l \cdot (t_l - t_0) \quad (3)$$

in which c_l is the specific heat of ammonia liquid.

In case of one kilogram of vapors being absorbed by an infinite volume of solution the differential heat of mixture is taken in consideration:

$$q_4 = q_d \quad (4)$$

In the total process of absorption, the heat that must extract is:

$$q_{ab} = q_1 + q_2 - q_3 + q_4 \quad (5)$$

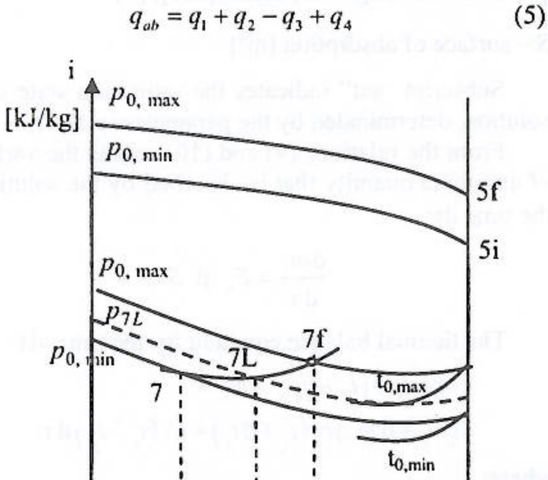

Fig. 2. Representation in the i-x diagram of the absorption process.

Due to the fact that q_1 and q_3 have little effect over the thermal effect by comparison with other terms they can be neglected.

$$q_{ab} = q_2 + q_d \tag{6}$$

2. THE ELABORATION OF THE MATHEMATICAL MODEL

The heat exchange between solution and water in the $d\tau$ interval of time, at the moment τ, is [J] [3]:

$$\delta Q = k \cdot S \cdot (t_s - t_w) \cdot d\tau \tag{7}$$

k – overall heat transfer coefficient, taken as a constant for the entire heat exchange surface [W/m² K]

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_{OL}}{\lambda_{OL}} + \frac{1}{\alpha_2}} \tag{8}$$

in which:

α_1, α_2 – convective heat transfer coefficient between the tube and cooling water and between solution and tube [W/m² K],

δ_{OL} – tube thickness [m],

λ_{OL} – thermal conductivity of the steel [W/m K],

S – heat transfer absorber surface area [m²],

t_s – the solution temperature at the moment τ [°C],

t_w – the water temperature at the moment τ [°C].

The mass balance equation for the time $d\tau$ at the vapors absorption is:

$$d m_v = F_m \cdot \beta \cdot S \cdot d\tau \tag{9}$$

where, [4]:

$$F_m = \rho_{sat} x_{sat} - \rho x \text{ [kg/m}^3\text{]} \tag{10}$$

β – mass exchange coefficient [m/s], [4]

S – surface of absorption [m²]

Subscript "sat" indicates the saturation state of the solution, determinated by the parameters p and t_s.

From the relations (9) and (10) results the variation of ammonia quantity that is absorbed by the solution in the time $d\tau$:

$$\frac{d m_v}{d\tau} = F_m \cdot \beta \cdot S \tag{11}$$

The thermal balance equation for the time $d\tau$:

$$m_s c_s t_s + (l_c + q_d) \cdot d m_v = (m_s + d m_v) c_s (t_s + d t_s) + kS(t_s - t_w) d\tau \tag{12}$$

where:

l_c – latent heat of condensation for the vapors at p_{7L} pressure [J/kg],

q_d – differential heat of mixture [J/kg], [4]

$$q_d = 4186 \cdot (4000 \cdot x^3 - 4150 \cdot x^2 + 945 \cdot x + 115) \tag{13}$$

$d m_v$ – the vapors quantity absorbed by solution.

From the relations (12) results the variation of the solution temperature in the time $d\tau$:

$$\frac{d t_s}{d\tau} = \frac{l_c + q_d - c_s t_s}{m_s c_s} \cdot \frac{d m_v}{d\tau} - kS(t_s - t_w) \tag{14}$$

It is written the balance equation of materials in NH_3 in the absorber (is assumed $x'' = 1$), [4]:

$$m_s \cdot x_{7L} + d m_v \cdot x'' = (m + d m_v) \cdot (x_{7L} + d x) \tag{15}$$

and results the variation of solution concentration after the $d\tau$ interval of time:

$$\frac{d x}{d\tau} = \frac{d m_v}{d\tau} \cdot \frac{x'' - x_{7L}}{m_s} \tag{16}$$

Based on the enthalpy-concentration diagram the following relation was established for ammonia solution pressure in liquid state:

$$p_{sol} = (0,25793 \cdot t^2 - 35,926 \cdot t + 1257,7) \cdot x^2 + (-0,21746 \cdot t^2 + 31,33 \cdot t - 1089,2) \cdot x + (0,046786 \cdot t^2 - 6,7223 \cdot t + 232,74) \tag{17}$$

The solution pressure in the τ moment is p_{7L}. It is written p the solution pressure after the $d\tau$ interval of time.

$$p = p_{7L} + d p \rightarrow d p = p - p_{7L} \tag{18}$$

where:

$$p_{7L} = (0,25793 \cdot t^2 - 35,926 \cdot t + 1257,7) \cdot x_{7L}^2 + (-0,21746 \cdot t^2 + 31,33 \cdot t - 1089,2) \cdot x_{7L} + (0,046786 \cdot t^2 - 6,7223 \cdot t + 232,74) \tag{19}$$

$$p = (0,25793 \cdot t^2 - 35,926 \cdot t + 1257,7) \cdot (x_{7L} - d x)^2 + (-0,21746 \cdot t^2 + 31,33 \cdot t - 1089,2) \cdot (x_{7L} - d x) + (0,046786 \cdot t^2 - 6,7223 \cdot t + 232,74) \tag{20}$$

it is note:

$$(0,25793 \cdot t^2 - 35,926 \cdot t + 1257,7) = z_1, \tag{21}$$

$$(-0,21746 \cdot t^2 + 31,33 \cdot t - 1089,2) = z_2, \tag{22}$$

$$(0,046786 \cdot t^2 - 6,7223 \cdot t + 232,74) = z_3. \tag{23}$$

The equations (20) and (21) become:

$$p_{7L} = x_{7L}^2 \cdot z_1 + x_{7L} \cdot z_2 + z_3 \tag{24}$$

$$p = (x_{7L} + d x)^2 \cdot z_1 + (x_{7L} + d x) \cdot z_2 + z_3 \tag{25}$$

$$d p = p - p_{7L} = (x_{7L} + d x)^2 \cdot z_1 + (x_{7L} + d x) \cdot z_2 - x_{7L}{}^2 \cdot z_1 - x_{7L} \cdot z_2 \tag{26}$$

Neglecting infinitely small of 2 order results the variation of solution pressure after the $d\tau$ interval of time:

$$\frac{dp}{d\tau}=\frac{dx}{d\tau}\cdot\left(2\cdot x_{7L}\cdot z_1+z_2\right) \tag{27}$$

The equations (11), (14), (16), (27) form a system of four differential equations, presented in a form that allows the using of a numerical method for solving:

$$\begin{cases}\dfrac{dm_v}{d\tau}=F_m\cdot\beta\cdot S\\ \dfrac{dt_s}{d\tau}=\dfrac{l_c+q_d-c_s t_s}{m_s\cdot c_s}\cdot\dfrac{dm_v}{d\tau}-k\cdot S\cdot\left(t_s-t_w\right)\\ \dfrac{dx}{d\tau}=\dfrac{Fm_v}{d\tau}\cdot\dfrac{x''-x_{7L}}{m_s}\\ \dfrac{dp}{d\tau}=\dfrac{dx}{d\tau}\cdot\left(2\cdot x_{7L}\cdot z_1+z_2\right)\end{cases} \tag{28}$$

It is written the thermal balance for water

$$\dot{m}_w\cdot c_w\cdot\left(t_{wf}-t_{wi}\right)=k\cdot S\cdot\left(t_s-t_w\right) \tag{29}$$

We can determine the temperature:

$$t_{wf}=t_{wi}-\frac{k\cdot S\cdot\left(t_s-t_w\right)}{\dot{m}_w c_w} \tag{30}$$

where:

$$t_w=\frac{t_{wi}+t_{wf}}{2} \tag{31}$$

3. CONCLUSIONS

The mathematical model elaborated describes the absorption process of the ammonia vapors by the weak solution, in non-stationary state.

Using the presented model through the numerical integration is can emphasized the variation in time of some parameters as: pressure, concentration, temperature, outlet cooling water temperature, the solution quantity resulted from the absorber.

By means of the suggested model the numerical calculation algorithm will be made up.

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[2] Radcenco V., Porneală S., Dobrovicescu A., *Procese în instalaţii frigorifice* (Processes in the refrigeration system), EDP, Bucureşti, 1983.

[3] Leca A., Cerna Mladin E., Stan M., *Transfer de căldură şi masă – O abordare inginerească* (Heat and mass transfer – an engineering approach), Editura Tehnică, Bucureşti, 1998.

[4] Porneală S., *Contribuţii la studiul proceselor de transfer de căldură şi masă în absorbitoarele maşinilor frigorifice cu absorbţie* (Contributions to the study of the heat and mass transfer processes in absorbers of frigorific machines with absorption) – teză de doctorat, Institutul Politehnic Bucureşti, 1981.

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Marţi 4 aprilie 2006 orele 14.00

Prof. Alexandru Chisacof (Catedra de Termotehnică, Facultatea de Inginerie Mecanică, Universitatea POLITEHNICA din Bucureşti)

Aspecte de mediu în cursurile cu profil termic

Marţi 16 mai 2006 orele 14.00

Drd Viorel Berbece (Catedra de Echipament Termo-Mecanic, Clasic şi Nuclear, Universitatea POLITEHNICA din Bucureşti)

Caracteristici ale reţelelor de profile de palete de turbine

Marţi 13 iunie 2006 orele 14.00

Prof. Niculae Antonescu (Catedra de Termotehnică, Universitatea Tehnică de Construcţii din Bucureşti)

Arderea lemnului şi a deşeurilor lemnoase

Marţi 31 octombrie 2006 orele 14.00

Prof. Gheorghe Popescu (Catedra de Termotehnică, Facultatea de Inginerie Mecanică, Universitatea POLITEHNICA din Bucureşti)

Studiu teoretic şi experimental al unui nou agent frigorific ecologic

Marţi 21 noiembrie 2006 orele 14.00

Dr. Ioan Ganea (Editura AGIR, Bucureşti)

Căldurile specifice ale gazelor reale

Marţi 12 decembrie 2006 orele 14.00

Prof. Viorel Bădescu (Catedra de Termotehnică, Facultatea de Inginerie Mecanică, Universitatea POLITEHNICA din Bucureşti)

Iniţiere în termodinamica ne-extensivă