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EXPERIMENTAL METHOD OF CONTACT MEMBRANE DISTILLATION PROCESS RESEARCH

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Abstract. A laboratory setup for the research of contact membrane distillations (CMD) process is described; a non-standard algorithm of defining dynamic characteristics of a channel, which are directly inaccessible for measurement, by its transitive characteristics that can be represented as a chain of consistently connected elements, as well as separate elements of this chain, is offered.

Keywords: contact membrane distillation, desalination, experimental researches, identification of dynamic characteristics.

1. Introduction

Experimental research method of the process of contact membrane distillations is investigated with the purpose of creating a mathematical dynamics model of this process.

Membrane distillation (MD) is of interest, *imprimis*, as a water purification and desalination as well as technological solutions concentration method. In comparison with baromembrane processes (reverse osmosis, ultra- and microfiltration) MD has advantages as it allows to concentrate the solutions of numerous non-volatile organic and inorganic substances close to their solubility limit. The driving force of the MD process is the solvent's vapors partial pressures difference at both sides of the membrane created due to the temperatures differences of the initial solution on the outlet side of the membrane and the permeate or distillate on its inlet side. The membrane is porous and hydrophobic and plays a role of a selective barrier which is permeable to vapor only.

The membrane distillation process is insufficiently investigated, and the reliable formulas for obtaining specific productivity and other characteristics of the membranes exist only for the limited number of elementary tasks at certain assumptions.

Using such dependences frequently causes substantial divergences with the real data. Moreover, membrane productivity decreases with the exploitation time due to the change of the hydrophobic-hydrophilic balance and salt formation on the membrane surface.

For the purpose of the process control a mathematic model of contact membrane distillations (CMD) dynamics, which takes into account channel-length and time change of the membrane permeability, was developed [1].

To check the conformity of the mathematical model to the process and adjust the indexes of the model experimental investigations of the dynamic modes of operation were conducted [2].

2. Experimental

Experimental investigations were carried out on the laboratory plant graphically represented in Fig. 1. The laboratory plant has the characteristic of the real processes running in the industrial machines. The device consists of two circuits: hot solution and cold distillate. The liquids are supplied into the membrane module *1* with the help of a peristaltic pump *2* from collecting vessels *3* and *4*, 100 ml each. A membrane module of flat-chamber type with the membrane area of 0.0063 m^2 and channel length of 0.5 m is used. The experiments were carried out using MFFK-5 membrane.

The necessary temperature of the solution was maintained with the help of a heater *5* from whose piped opening using a peristaltic pump the solution was supplied to the membrane module. From the membrane module the solution got to the collecting vessel *3*, from where it got to piped space of the heater *5*. Through the tube space *5* the heat carrier, heated with the help of thermostat *6*, was pumped. Such design allowed carrying out the experiment at the solution concentration close to crystallization, which could lead to the thermostat damage.

From the collecting vessel *4* distillate was supplied to the membrane module *1* and then to the piped space of trumpet space of the coiled refrigerator *7* and poured into

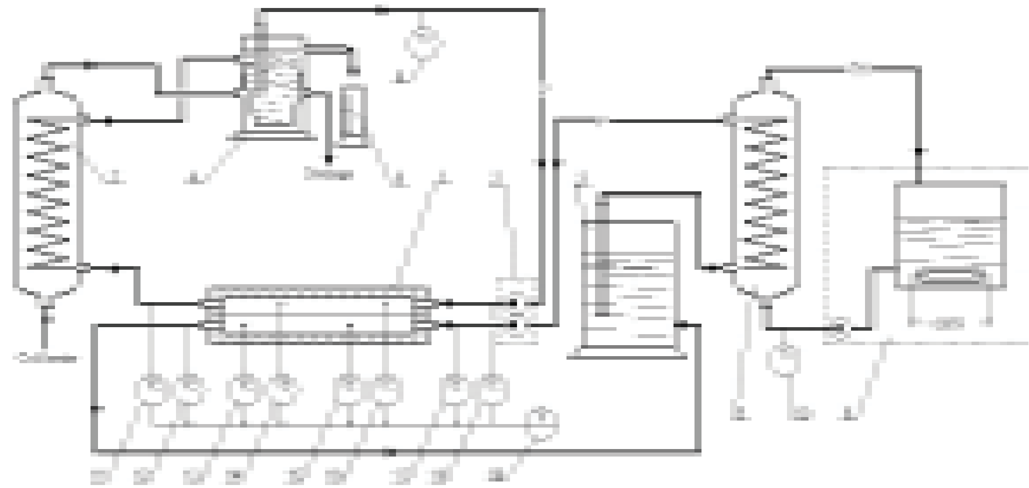

Fig. 1. The scheme of the laboratory setup for CMD process research 1 – membrane module; 2 – peristaltic pump; 3 – collecting vessel for solution; 4 – collecting vessel for distillate; 5 – heater; 6 – thermostat; 7 – refrigerator; 8 – measuring vessel; 9, 10 – mercury thermometer; 11-18 – thermocouples; 19 – thermo converter

the collecting vessel *4*. Such solution enabled maintaining constant temperature of water in a cold circuit. Vessel *4* was also equipped with an overflow pipe. The surplus of water which appeared in the cold circuit due to its penetration through the membrane from the solution of the hot circuit, overflowed through this pipe into the measuring vessel *8*.

The temperature mode of the membrane module was defined with the help of system chromium-copal thermocouples *11-12* which were mounted on the inlet and outlet pipes of solution and distillate and two thermocouples per the membrane module and channels of a solution and distillate channels. As a secondary device digital multichannel thermal converter TSP-100 19 was applied.

The productivity of the device by the speed of solution and distillate streams was established with the help of the peristaltic pump which allowed changing speeds in the range of: 1.25–5 ml/s.

The productivity of the membrane module by permeate was established by fixing the time during which the volume of water which got to the measuring vessel reached the value of 100 ml.

It is necessary to note that it is impossible to read the transitive characteristic for the channel "temperature of the solution at the inlet point of the membrane module – temperature of the solution in a control point on the membrane module length axis" since prior to being supplied to the membrane module the solution is heated in the coiled heater.

To obtain the transitive characteristics of the membrane module for the channel "temperature of the solution at the inlet point of the membrane module – temperature of the solution in a control point on the membrane module length axis" transitive characteristics for the channels: «heater capacity in the thermostat – temperature of the solution at the inlet point of the membrane module» and «heater capacity – temperature of the solution in a control point on the membrane module length axis» were taken (Figs. 4, 5).

To establish the transfer function of the channel "temperature of the solution at the inlet point of the membrane module – temperature of the solution in a control point on the membrane module length axis" a non-standard approximating structure shaped as a closed contour presented in Fig. 2 is used. Such a structure allows to unite both the smoothing and the identification processes within one algorithm.

For experimental data smoothing a closed system like below was used:

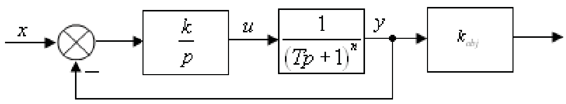

Fig. 2. Approximating structure scheme

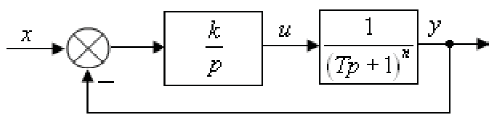

Fig. 3. Normed approximating structure

As the object transfer factor k_{obj} in the presence of the transitive characteristic is determined as the height of the transitive characteristic, the normed (reduced to the transfer factor) approximating structure was determined.

The transfer factor of the normed structure is equal to one; the resulting transfer function looks like:

$$W(p) = \frac{\dfrac{k}{(Tp+1)^n p}}{1 + \dfrac{k}{(Tp+1)^n p}} = \frac{k}{(Tp+1)^n p + k}. \qquad (1)$$

Structure (1), having only three factors (k, T, n) that are subject to definition, can have any exponent $(n+1)$ under the condition that $n \geq 1$; by selecting k structure (1) can be made both oscillating and aperiodic.

By means of elementary transformations structure (1) can be transformed to:

$$W(p) = \frac{1}{1 + \sum_{s=1}^{n+1} a_s p^s}. \tag{2}$$

First let us consider k, T, n definition algorithm. For this purpose Symoju identification method will be used. Let us develop (1) as Maclaurin series in *p*. For this purpose we will present (1) as:

$$W(p) = \frac{k}{k + p + nTp^2 + \frac{n(n-1)}{2} T^2 p^3 + \ldots} \tag{3}$$

After division of numerator by denominator we will obtain:

$$W(p) = 1 - \frac{1}{k} p + \frac{1}{k}\left(\frac{1}{k} - nT\right) p^2 + \\ + \frac{1}{k}\left[2\frac{nT}{k} - \frac{n(n-1)}{2} T^2 - \frac{1}{k^2}\right] p^3 + \ldots \tag{4}$$

Here *p* factor was somewhat simplified.

The factors of the Maclaurin series the transfer factor is developed can be determined from the corresponding transitive characteristic using the formulas below

$$\begin{gathered} e_s = (-1)^s F_s, \quad 1 \leq s \leq Ne, \\ \partial e \quad F_s = \int_0^t (F_s - F_{s-1}) dt, \\ F_s = \lim_{t \to \infty} F_s(t), \quad F_0(t) = h_n(t). \end{gathered} \tag{5}$$

$$\begin{cases} -\frac{1}{k} = e_1, & (6) \\ \frac{1}{k}\left(\frac{1}{k} - nT\right) = e_2, & (7) \\ \frac{1}{k}\left[2\frac{nT}{k} - \frac{n(n-1)}{2} T^2 - \frac{1}{k^2}\right] = e_3. & (8) \end{cases}$$

Having determined $h_n(t)$ of the necessary amount of $(Ne = 3)$ factors e_s, comparing the factors of series (4) with the corresponding we will obtain:

As the result we have the system of three equations (6) - (8) with three unknowns: *k, T, n* . From (6) we will determine *k:*

$$k = -\frac{1}{e_1}. \tag{9}$$

Let us put (9) in (7):

$$-e_1(-e_1 - nT) = e_2 \Rightarrow nT = \frac{e_2 - e_1^2}{e_1}. \tag{10}$$

Since

$$v = e_2 - e_1^2; \quad R = \frac{v}{e_1}; \quad w = \frac{2(e_3 - e_1^3 - 2e_1 v)}{v}.$$

then from (8) we will obtain:

$$n = round\left(\frac{R}{R - w}\right). \tag{11}$$

As (10) is *R* we can determine:

$$T = \frac{R}{n}. \tag{12}$$

Formulas (9), (11), (12) solve the problem. Certainly, due to rounding in (11) equation (8) is satisfied approximately. If *n* is specified due to some additional reasons then the problem of inaccurate satisfaction of the condition (8) is eliminated.

Obtaining Maclaurin series for the channel "heater capacity in the thermostat – temperature of the solution at the inlet point of the membrane module":

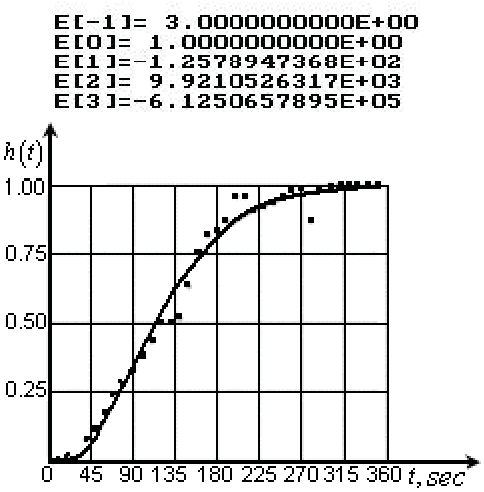

Fig. 4. The transitive characteristic and visualization of experimental data for the channel "heater capacity in the thermostat – temperature of the solution at the inlet point of the membrane module"

Obtaining approximation parameters and transfer function factors:

```
Kob=7.600

k=0.008
n=4
T=11.730

A[0]= 1.0000000000E+00
A[1]= 1.2578947368E+02
A[2]= 5.9019390582E+03
A[3]= 1.0384280465E+05
A[4]= 8.1203655430E+05
A[5]= 2.3812556191E+06
```

Obtaining Maclaurin series for the channel "temperature of the solution at the inlet point of the membrane module – temperature of the solution in a control point on the membrane module length axis":

```
E[-1]= 3.0000000000E+00
E[0]= 1.0000000000E+00
E[1]=-1.2925000000E+02
E[2]= 9.6175000000E+03
E[3]=-5.2805625000E+05
```

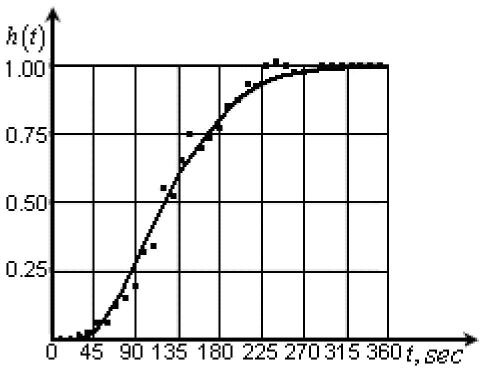

Fig. 5. The transitive characteristic and visualization of experimental data on the channel "temperature of the solution at the inlet point of the membrane module – temperature of the solution in a control point on the membrane module length axis"

Obtaining approximation parameters and transfer function fac

```
Kob=8.000

k=0.008
n=7
T=7.834

A[0]= 1.0000000000E+00
A[1]= 1.2925000000E+02
A[2]= 7.0880625000E+03
A[3]= 1.6658954409E+05
A[4]= 2.1751811741E+06
A[5]= 1.7040972767E+07
A[6]= 8.0102224945E+07
A[7]= 2.0918101752E+08
A[8]= 2.3411173189E+08
```

Let us divide transfer function $W_2(p)$ by $W_1(p)$, and in the resulting transfer function reduce close zeros and poles, and bring it to normed. The final result is:

$$W(p) = \frac{0{,}00135}{p^4 + 0{,}6923p^3 + 0{,}1872p^2 + +0{,}0236p + 0{,}001328}$$

Transitive characteristic of approximated structure is presented in Fig. 6.

4. Conclusions

The transitive characteristic obtained by this algorithm (Fig. 6) coincides with the information on the transitive characteristics for this channel and can be used for the development of the mathematical model of the CMD process.

Fig. 6. Transitive characteristic of approximated structure

References

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ЕКСПЕРИМЕНТАЛЬНИЙ МЕТОД ДОСЛІДЖЕННЯ ПРОЦЕСУ КОНТАКТНОЇ МЕМБРАННОЇ ДИСТИЛЯЦІЇ

Анотація. *Описується лабораторний стенд для дослідження процесу контактної мембранної дистиляції (КМД); пропонується нестандартний алгоритм визначення динамічних характеристик каналу, безпосередньо недоступного для вимірювання за перехідними характеристиками каналів, які представляють ланцюжок послідовно з'єднаних елементів та окремих елементів цього ланцюжка.*

Ключові слова: *контактна мембранна дистиляція, знесолення, експериментальні дослідження, ідентифікація динамічних характеристик.*