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MATHEMATICAL MODEL OF MEMBRANE DISTILLATION PROCESS

Introduction

Due to changing lifestyles, increasing economic activity and pollution, complicating the use of fresh water may be a serious shortage of water. Desalination of salt water is becoming increasingly important not only to support the industry but also to sustain. To remove excess salts and minerals from sea water or salt water is widely used process of reverse osmosis. An alternative to existing technologies can be a membrane distillation, which is characterized by low operating costs [1–4].

Setting objectives

The mathematical model of the process contact membrane distillation, taking into account the effect of hydrodynamic flow solution and distillate, size and characteristics of membrane temperature conditions at specific mass flow of vapor through the membrane [5], thermal polarization on the performance of the process [6], nonlinear vapor diffusion through the membrane [7–10]. There was a need to create a mathematical model of the process of membrane distillation, designed for process control purposes.

The main material research

The mathematical model of the membrane distillation process.

During separation the main element is a hydrophobic polymer membrane, which is a selective barrier, which pass through a pair of solvent and does not pass salt solution (Fig. 1).

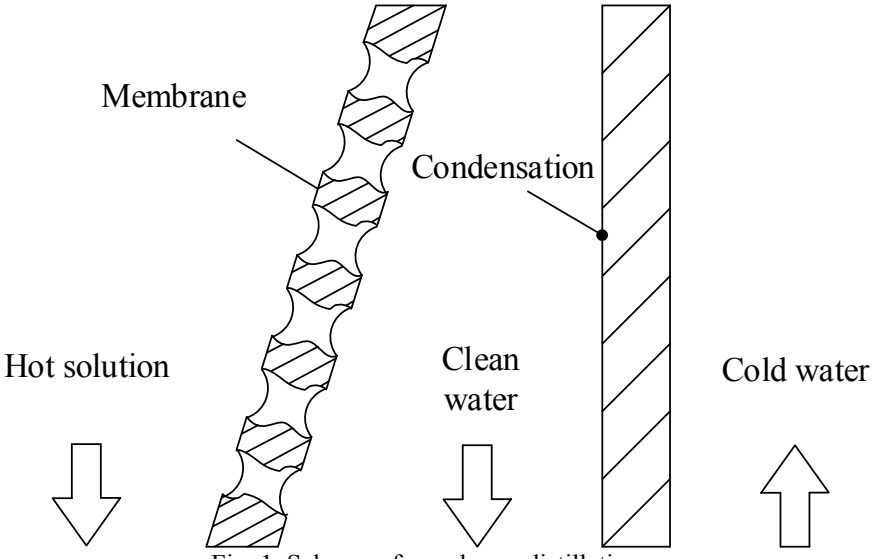

Fig. 1. Scheme of membrane distillation process

Membrane distillation takes place at atmospheric pressure and a temperature of 60–80 °C solution driving force of the process is the temperature difference between the solution and the cooling water. Water vapor passes through the membrane and condenses on the surface, which is cooled from

the outside. It allows you to clean water. Diffusion in the pores of the membrane differs from diffusion free environment. Diffusion transfer of water vapor in kapilyarnoporuvatomu environment characterized by three flow regimes: vilnomolekulyarnym, knudsenivskym and transitional. Flow regime determines the ratio of the mean free path of the molecule and pore diameter.

When creating a mathematical model, the following assumptions:

1. The ideal membrane that is hydrophobic pores with the same radius and intact selective layer;
2. Do not include the impact of temperature and concentration polarization;
3. Unaccounted changes in temperature and concentration along the canals of the membrane module;
4. The capacity of the membrane was not considered because of its thickness as compared with high feed solution and distillate.

Due to the fact that the change in temperature of the solution along the length of the channel membrane module is several degrees, for controlling MM mathematical description is based on energy flow process. After recording all relevant volume equations were mathematical description of the dynamics of the object as a system of equations:

$$G_{So}C_{So}\theta_{So} - k_1F_V(\theta_{Sf} - \theta_{Vf}) - IFr - G_{Sf}\theta_{Sf} = = V_S\rho_S C_S\frac{d\theta_{Sf}}{dt}; \quad (1)$$

$$k_1F_V(\theta_{Sf} - \theta_{Vf}) + IFr - k_2F_2(\theta_{Vf} - \theta_{Cf}) = -V_V\rho_V C_V\frac{d\theta_V}{dt}; \quad (2)$$

$$G_{Co}(C_{Co}\theta_{Co} - C_{Cf}\theta_{Cf}) + k_2F_2(\theta_{Vf} - \theta_{Cf}) = = V_C\rho_C C_C\frac{d\theta_{Cf}}{dt}, \quad (3)$$

where G_{So} — consumption of salt solution inlet MM, kg/s; ρ_S — density of the solution at the outlet of MM, kg/m^3; C_{So}, C_{Sf} — heat capacity of the solution at the inlet and outlet of the MM, J/(kg·K); θ_{So} — temperature salt solution at the inlet of MM, K; θ_{Sf}, θ_{Cf} — the temperature of the solution and distillate output from MM, K; k_1 — coefficient of heat transfer solution to clean water, W/(m^2·K); k_2 — coefficient of heat transfer from the refrigerant to clean water, W/(m^2·K); F — membrane area, м^2; I — specific vapor mass flow, kg/(m^2·s); r — enthalpy of vaporization, J/kg; G_{Co} — flow refrigerant inlet MM, kg/s; ρ_C — distillate density, kg/m^3; C_{Co} — the temperature of the cooling water inlet MM, K.

Coefficients for equations of thermal balance of the dynamics of channel solution MM (1), the channel clean water (2) and feed cooling water (3), which takes into account the heat transmitted through the porous structure of the membrane, and also due to steam condensation on the cold surface of the wall which is removed from the membrane and thermal balance equation in cooling water.

Distribution of heat passed through the membrane by convection as the average heat transfer coefficient determined by the formula

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_M}{\lambda_M} + \frac{1}{\alpha_2}}, \quad (4)$$

where α_1, α_2 — espectively the heat transfer coefficient of the solution to the membrane and a pair of the wall W/(m^2·K); δ_M, λ_M — the thickness of the membrane (m) and its thermal conductivity W/(m·K).

The average rate of heat transfer from the solution to the membrane [5] was:

for turbulent flow solution

$$Nu = \frac{\alpha_1\lambda}{\bar{d}} = 0,23\,\mathrm{Pr}^{0,25}\,\mathrm{Re}^{0,8}\,\varepsilon, \quad (5)$$

for laminar flow solution

$$Nu = \frac{\alpha_1\lambda}{\bar{d}} = 1,62\left(\mathrm{Re}\,\mathrm{Pr}\frac{l}{\bar{d}}\right)^{1/3} w, \quad (6)$$

where

$$\mathrm{Pr} = \mu c_s/\lambda;\ \bar{d} = 2ld/(d+l);\ \varepsilon = 1 + 2\bar{d}/l.$$

Heat transfer through the membrane is a heat loss through the membrane and spent, primarily thermal conductivity porous polymer composite structure — gas

$$\lambda_M = \varepsilon\,\lambda_{VA} + (1+\varepsilon)\,\lambda_{PM}, \quad (7)$$

where λ_{VA}, λ_{PM} — respectively the thermal conductivity vapor-air mixture of polymer membrane W/(m·K).

Solvent evaporation is carried in the pores of the membrane, with the host membrane condenses on the surface that cooled. To calculate the mass flow ratio of steam used in the case of molecular diffusion

$$J_s = \frac{M\bar{D}_{MD}\ln\left[\frac{p_c - p_2(\Theta_2)}{p_h - p_1(\Theta_1)}\right]}{\delta_M R\Theta_{PK}};$$

$$\frac{p_c - p_2(\Theta_2)}{p_h - p_1(\Theta_1)} = \exp\frac{-D_{KD}(p_h - p_c)}{\bar{D}_{MD}\bar{p}},$$

або

$$J_s = \frac{MD_{KD}(p_h - p_c)}{\delta_M R\Theta_{SF}}, \quad (8)$$

where $\bar{D}_{MD} = \varepsilon D_{MD} / q$ — effective mutual diffusion coefficient of vapor in air, m^2/s; D_{MD} — coefficient of mutual diffusion of vapor in air, m^2/s; D_{KD} — Knudsen diffusion coefficient, m^2/s; p_h, p_c — pressure vapor-air mixture to heat and cool the membrane surface, *Pa*; p_1, p_2 — partial vapor pressure of the solvent in warm and cold surfaces of the membrane, *Pa*; Θ_1, Θ_2 — the temperature at the surface of the membrane channels solution and distillate, *K*. Calculated system of equations in static mode (1–3), static characteristics of the channel "costs of cooling water — temperature solution" shown in Fig. 2.

Got transients on channels, "the cost of cooling water — solution temperature at the outlet of MM," "costs of cooling water — temperature pure water at the outlet of MM" and "costs of cooling water — temperature of cooling water at the outlet of MM 'shown in Fig. 3–5.

The transition process is 20–40 sec.

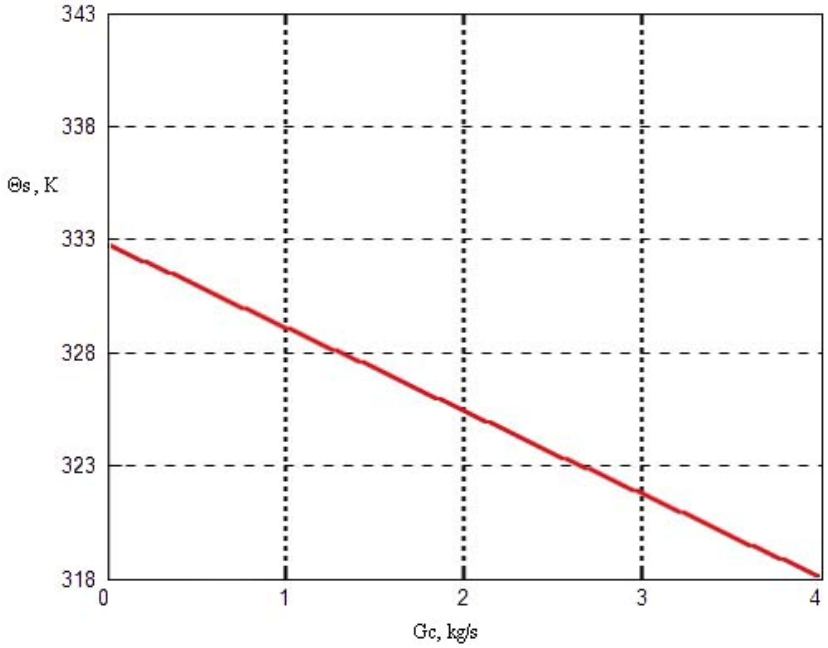

Fig. 2. Static characteristics of the channel «costs of cooling water — solution temperature at the outlet of MM»

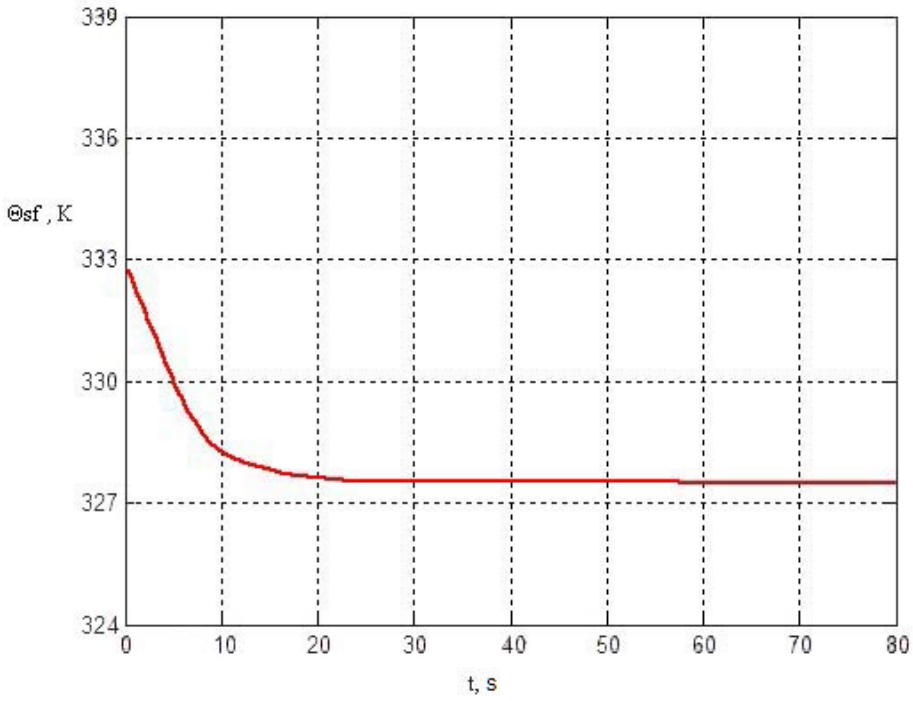

Fig. 3. Transfer characteristic for the channel «costs of cooling water — solution temperature at the outlet of MM»

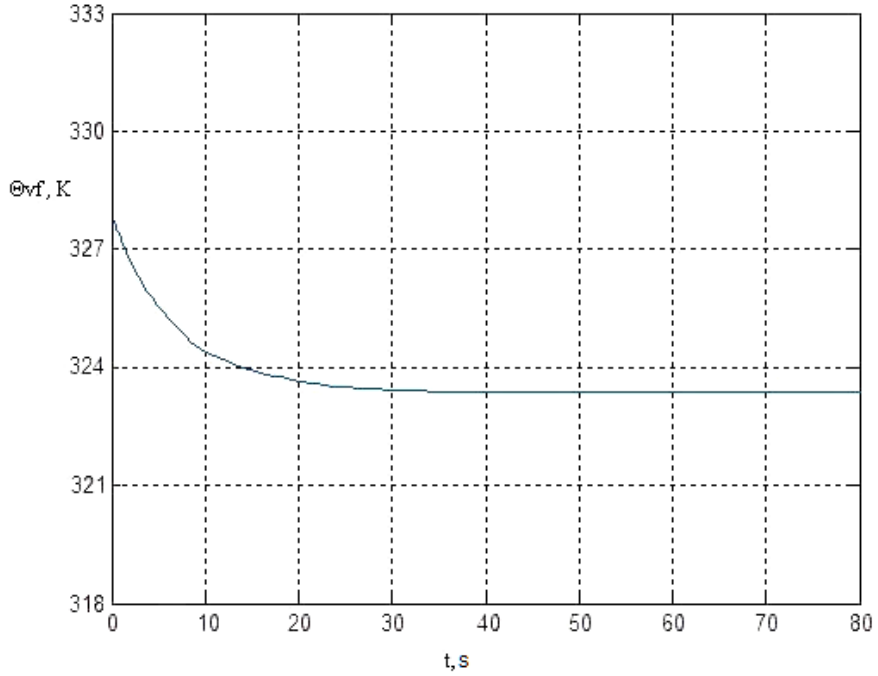

Fig. 4. Transfer characteristic for the channel «costs of cooling water — clean water temperature at the outlet of MM»

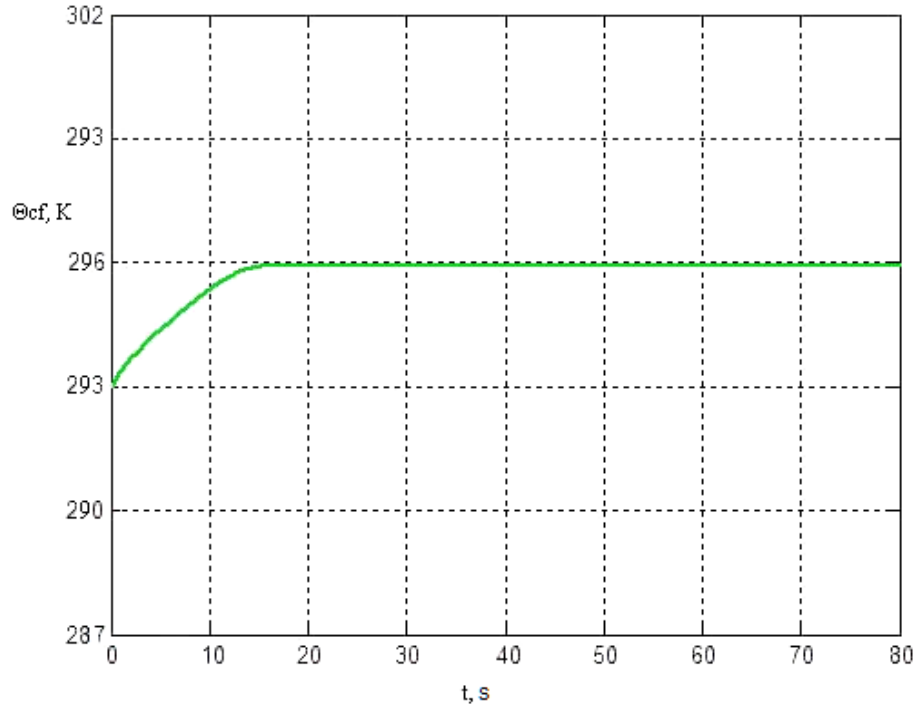

Fig. 5. Transfer characteristic for the channel
«costs of cooling water — temperature of cooling water at the outlet of MM»

Conclusion

The mathematical model of KMD, which allows for heat transfer through the membrane with the flow of steam and due to heat transfer through the structure of the polymer membrane. The resulting static and dynamic characteristics of the membrane. As a control action is selected coolant costs. As the adjustable parameter is selected temperature drop of solution and distillate, which drives the process.

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МАТЕМАТИЧНА МОДЕЛЬ ПРОЦЕСУ МЕМБРАННОЇ ДИСТИЛЯЦІЇ

Представлена математична модель процесу мембранної дистиляції, е якому водяна пара проходить крізь мембрану і конденсується на поверхні, яка ззовні охолоджується. Це дозволяє отримати чисту воду. Мембранний модуль розглянуто як об'єкт із зосередженими параметрами, який складається з теплових ємностей: канал розчину, канал чистої води і канал охолоджуючої води. Розглянуто математичну модель технологічної контактної мембранної дистиляції з урахуванням впливу гідродинамічного потоку розчину і дистиляту, розмірів і характеристик температурних умов мембрани за питомого масового потоку пари крізь мембрану, термічній поляризації на продуктивність процесу, нелінійної дифузії парів через мембрану. Отримано статичні і перехідні характеристики. Як контроль обрано витрати на охолоджуючу рідину. Як регульований параметр обрано падіння температури розчину і дистиляту, що приводить в рух процес.

Ключові слова: очистка води, мембранна дистиляція, математична модель динаміки.

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МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ПРОЦЕССА МЕМБРАННОЙ ДИСТИЛЛЯЦИИ

Представлена математическая модель процесса мембранной дистилляции, в которой водяной пар проходит через мембрану и конденсируется на поверхности, снаружи охлаждается. Это позволяет получить чистую воду. Мембранный модуль рассматривается как объект с сосредоточенными параметрами, который состоит из тепловых емкостей: канал раствора, канал чистой воды и канал охлаждающей воды. Рассматривается математическая модель технологической контактной мембранной дистилляции с учетом влияния гидродинамического потока раствора и дистиллята, размеров и характеристик температурных условий мембраны при удельном массовом потоке пара через мембрану, термической поляризации на производительность процесса, нелинейной диффузии паров через мембрану. Получены статические и переходные характеристики. В качестве контроля выбираются затраты на охлаждающую жидкость. В качестве регулируемого параметра выбрано падение температуры раствора и дистиллята, которое приводит в движение процесс.

Ключевые слова: очистка воды.мембраннаядистилляция,математическая модель динамики.

Lesya Ladieva, **Sergiy Dovbnya**, **Roman Dubik**

MATHEMATICAL MODEL OF MEMBRANE DISTILLATION PROCESS

The presented mathematical model of the process of membrane distillation, in which water vaporpasses throughthemem brane and condenses on the surface, is cooled from the outside. Thisallowsyouto getclean water. The membrane moduleis consider edasan object with lumped parameters, which consists of heatreser voirs: a solution channel, a clean water channel, and a cooling water channel. A mathematical model of technological contactmem branedis tillationis considered, takingin to account the in fluence of the hydrodynamic flow of solution and distillate, the dimension sand characteristic sof the membrane temperature conditions, with a specific mass flowof vaport hrough the membr ane, the rmalpolarizationon the productivity of the process, and nonlinear diffusion of vaporsthrough the membrane. Staticandtr an sient character is ticsareobtained. As a control, the costsfor the coolingliquida reselected. As a controlled parameter, the dropin temperature of the solutionand the distillate is selected, which drives the process.

Keywords: water treatment; membrane distillation; mathematical model of dynamics.

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