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Assessment of Aqueous Solutions Concentration Efficiency of Mineral Salts and Organic Media Applying Rotary-Film Evaporator for Natural and Waste Water Treatment

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ABSTRACT

The paper focus is the efficiency evaluation of aqueous solutions concentration of mineral salts and organic media by evaporation applying rotary-film evaporator with hinged blades. The volume flow rate of the initial solutions (irrigation density) and solutions viscosity were chosen as independent experimental parameters, which determine the hydrodynamic mode of the film movement in the rotary film evaporator. An experimental rotary-film evaporator with hinged blades was used for the research. According to the experimental results, the dependence of the concentration degree in the rotary film evaporator on the irrigation value and the viscosity of the initial solutions was defined. It shows that the concentration in the rotary-film evaporator is mostly effective at the irrigation density of 3.5 l/h, and for viscous solutions (≈ 2 MPa·s) at minimum irrigation values (≈ 1 l/h).

Key words: rotary-film evaporator, aqueous solutions of mineral salts and organic media, irrigation density, solutions viscosity, concentration degree.

1. INTRODUCTION

The method of evaporation is widely applied in the practice of water pretreatment and in natural and industrial wastewater treatment technologies. Commonly evaporation is used in order to increase the salt concentration in water, and thereby to accelerate their subsequent crystallization. Besides evaporation is used to neutralize small amounts of highly concentrated effluents, if other treatment methods are not only economically ineffective, but also practically difficult to implement. The main aqueous technological systems, which processing by evaporation is advisable, include highly mineralized industrial waste water of enterprises (eluates, saline effluents of galvanic industries), desalination reverse osmosis concentrate plants [1]-[3], heat power plants waste water, spent lubricants, etc.

The evaporators of different types and designs are used to evaporate solutions. The choice of evaporator design for a specific industrial area depends on many factors: rate of evaporated liquor, initial and final solution concentration, possible crystallization and sediments on the heating chamber surface, etc. The variety of evaporator design is stipulated by the variety of methods and process conditions, the variety of concentrated solutions properties, the variety of heat-transfer types. In this research, the rotary film evaporator **(RFE)** with hinged blades was used for experimental studies concerning concentration of mineral salts and organic media aqueous solutions.

This evaporator advantage is short-term contact of solutions with the heating surface and significant increase of heat transfer coefficient [4], [5]. Moreover, due to the ability of the rotor with hinged blades to clean heat exchange surface, such devices can be used for processing sticky and viscous liquid mixtures with high concentration degree [6]. However, taking into account the heterogeneity of hydrodynamic modes, observed in rotary film evaporators, nonlinear effects are possible in the process of aqueous solutions concentration. Therefore, one of the actual applied problems solved by the experiments was to assess the concentration efficiency of aqueous solutions of mineral salts and organic media in **RFE** depending on the irrigation density (volumetric flow rate) and aqueous solutions viscosity.

2. RESEARCH OBJECTS AND METHOD

An experimental rotary-film evaporator installed in the scientific educational center "Clean water" in the Vladimir State University was used to investigate the concentration efficiency of mineral salts and organic media aqueous solutions (Figure 1) of the following specifications:

- drive - power N = 0,1 kW, speed n = 200 min^{-1};

- housing - stainless pipe 50×3 mm; working height-0.8 m.

- rotor with hinged blades; material - stainless steel;

- separator for steam and liquid phase separation, material - stainless steel.

Figure 1: Experimental rotary film evaporator with hinged blades

Direct-flow type **RFE** with jacket for heat transfer supply. The evaporation is carried out in a continuous mode and at the atmospheric pressure.

The aqueous solutions concentrating in this experimental **RFE** is carried out both in the automated and manual mode with the output of all main technological process parameters into the computer. During evaporation the display shows complete current information of the process: inlet and outlet coolant temperature, secondary steam temperature, heat transfer consumption, coolant consumption, conductivity of feed solution, distillate and concentrate, feed solution flow rate, temperature from built-in sensors (temperature profile from the falling film).

Basic technologic diagram of **RFE** operation is presented in Figure 2.

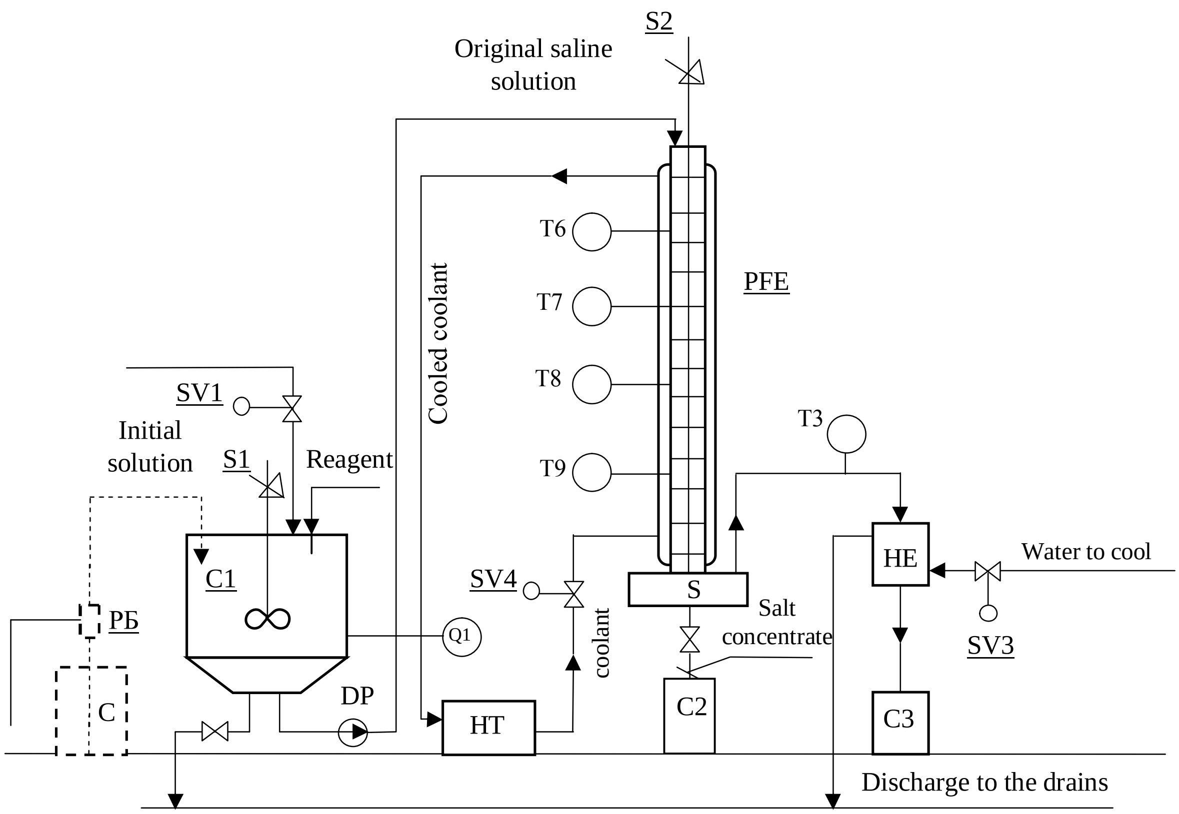

Figure 2: Basic technological diagram of the experimental RFE for aqueous solutions concentration of mineral salts and organic media by evaporation, where:
C - stock tank; C1 - tank for test solution preparation; C2 - tank for collecting salt concentrate; C3 - distillate collecting tank; P – pump; DP - dosing pump; HT - heating circulation thermostat; S1, S2 – stirrers; RFE - rotary-film evaporator; S – separator; HE - heat exchanger; T3, T6-T9 - temperature sensor; SV1 SV3 SV4 - solenoid valve; Q1- conductivity sensor

The research experiments applying **RFE** were conducted as follows:

The required amount of the test solution was fed into the tank C1 by the pump P. When the model solution was prepared, the estimated amount of water was fed into the tank C1 by opening the valve SV1, the stirrer S1 was manually turned on and the estimated amount of salts was added, the mixture was stirred until complete salts dissolving. The dosing pump DP was adjusted to the required test solution flow rate. The solution salinity was determined by its conductivity using conductivity sensor Q1. When the pump DP started, the stirrer S2 simultaneously started and the valves SV3 - feeding circulating water in the heat exchanger HE and SV4 - feeding preheated circulating water up to the coolant operating temperature into the **RFE** jacket, opened. The evaporated salt concentrate is continuously fed and collected in the tank T2, the secondary water vapor from the separator S along the still-head pipe is fed into HE for further condensing and cooling. Distillate (secondary water vapor condensate) flows to the tank C3.

During RFE operation the temperature was controlled vertically along the RFE housing at T6-T9 (100-150^{o}C) from the side of the solution falling film (temperature profile). For this purpose, temperature sensors are fixed vertically at equal intervals along the evaporation module. The data were transferred to the computer to calculate the evaporation kinetics in the film mode. During the process the secondary steam temperature T3 at the evaporator outlet, distillate temperature and salinity after the condenser-refrigerator HE, coolant flow rate and temperature at the evaporator inlet and outlet, the cooling water flow rate and temperature (prior and after the condenser) were monitored. Process control was executed from the control board, according to the software embedded in the controller and SCADA-system. The process data were displayed on the operator screen and collected by the server.

Sodium chloride (NaCl), 2% aqueous solution; magnesium sulfate ($MgSO_4$), 2% aqueous solution; glycerin ($C_3H_5(OH)_3$), 10% aqueous solution; sucrose ($C_{12}H_{22}O_{11}$), 20% aqueous solution were used as feeding solutions in the experiments. Polymethylsiloxane liquid PMS-20 (GOST 3032-77) was used as a coolant in HT.

3. RESEARCH RESULTS AND DISCUSSION

The applied RFE has a number of peculiarities to be taken into account when planning the experiments:

– single-pass RFE operation mode at minimum evaporation time determines the compliance with the time interval from **RFE** start (change settings) up to measuring parameters, as stationary operation ramp-up takes over 30 min.;

- possibility to avoid sedimentation effect on the heat-emitting (heating) surface in the analysis, which practically does not happen at the medium evaporation temperature up to 150 °C;

– in **RFE** large temperature difference between the heating and evaporating media can be effectively used, so all experimental studies are carried out at a constant temperature of 150 °C, which is close to the possible maximum.

The independent experimental parameters determining hydrodynamic mode of the film movement in **RFE** were as follows:

1) volumetric flow rate of the initial solution (irrigation density), the values are set regularly on logarithmic scale (up to 12 l/h),

2) viscosity set through the salt composition of aqueous solutions
(NaCl, MgSO4, glycerin, sucrose).

In the experiments the following volume flow rates of the initial solution were chosen: 1.0 l/h; 1.9 l/h; 3.5 l/h; 6.4l/h; 12 l/h.

Salts and their initial concentration in the feeding solution were selected basing on the solutions viscosity at the ambient temperature of 20 °C and at the average evaporation operating temperature, estimated approximately at about 80 °C. The salts total concentration in the feeding aqueous solution and concentrate should not exceed 1 mole/l, since at higher concentrations the linear relation between conductivity and concentration is violated, and, therefore, the concentration degree cannot be reliably determined by the conductivity method. It was set: volumetric flow rate of the feeding solution: 8 % /0.97 l/h; 16 % /1.92 l/h; 29 % /3.49 l/h; 53 % /6.37 l/h; 100 % /12 l/h;

coolant temperature **-** 150 °C;

rotor velocity **-** 200 min^{-1};

RFE total operation time ≈ 2.5 hours.

For each variant of volumetric flow the following parameters were measured:

- electric conductivity of the initial solution and concentrate;

- temperature of the initial solution and concentrate;

- temperature profile from the side of the falling film.

During the experiments the solutions concentration coefficients in **RFE** were determined, basing on the measured electrical conductivity of the initial and concentrated solutions (Figure 3).

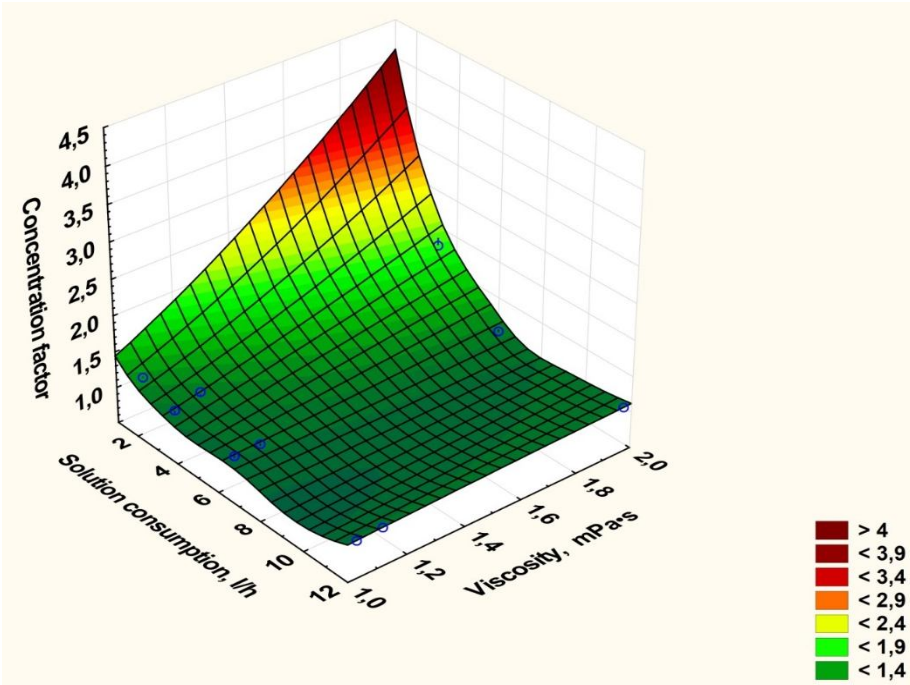

Figure 3: The solutions concentration coefficients depending on irrigation and viscosity of the initial solutions.

As Figure 3 demonstrates, the solutions concentration degree in RFE increases nonlinearly (exponentially) alongside the irrigation decrease and solutions viscosity increase. When irrigation exceeds 3.5 l/h, the concentration degree of the solutions tends to minimum values, and the concentration process in RFE becomes inefficient.

4. CONCLUSION

The most optimal concentration areas for aqueous solutions of mineral salts and organic media in RFE are detected at irrigation values not exceeding the limit values, above which the solutions concentration degree tends to unity in compliance with the exponential law, and the concentration process in RFE becomes inefficient. The irrigation value of 3.5 l/h is considered as a kind of limit value, estimated empirically at the RFE plant. Concentrating in RFE is mostly effective for viscous solutions (≈ 2 MPa·s) at minimum irrigation values (≈ 1 l/h).

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