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TREATMENT OF PHENOL WASTEWATER USING PERVAPORATION

The removal of phenol from aqueous solution was studied. In this case, the separation process consisting in the vacuum pervaporation and pervaporation with inert phase (gas, water) was applied. Standard pervaporation cell (Sulzer) with modified cooling zone was used. A hydrophobic membrane PDMS (Pervatech) was applied as a separating barrier.

An influence of the phenol concentration in feed on its permeate flux values and the water permeate flux values in vacuum pervaporation was studied. A linear relation between the phenol permeate flux and its concentration in the feed was observed. The fluxes of penetrants dependent on the feed temperature and the pressure applied or air flow in the permeate zone were determined. On the basis of these data the selectivity coefficients were calculaed. An increase in the temperature intensifies the separation process in each option of the pervaporation process. It was observed that the selectivity and the fluxes in the vacuum pervaporation are several times higher than in pervaporation with the inert phase.

Keywords: *vacuum pervaporation, sweep gas pervaporation, pertraction, phenol, PDMS membrane*

1. INTRODUCTION

Many branches of industry generate various kinds of wastes, one of them is wastewater. Depending on the source of their generation, they contain a wide spectrum of chemical contaminations. Their high toxicity causes that a special attention is paid to the aromatic hydrocarbons among which are phenol and its derivatives [1]. In order to prevent the environment from polluting, a systematic and effective wastewater treatment must be undertaken.

The specific properties of the pervaporation process allow its application to the treatment of wastewater of low concentrations. This work presents the experimental results of phenol removal from the model wastewater by the use of pervaporation process. The separation process was conducted on two kinds of permeate in the unit of

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a special design. The aim of the process analyzed was to remove an organic compound from wastewater and to obtain the permeate whose microbiological parameters are acceptable and harmless.

2. CHARACTERISTICS OF THE PERVAPORATION PROCESS

The separation effect in the pervaporation stems from the difference in diffusion intensity of compounds in a dense membrane. The concentration gradient in the membrane, which is the diffusion-driving force, arises due to the vacuum or inert phase flow (gas, water). The way of permeate collection determines the option of pervaporation process. The choice of the method of the process is connected with the way of the permeate utilization.

The mass transport mechanism in the pervaporation process can be described by the solution-diffusion model [2]. The concentration profile in the vaccum pervaporation and pervaporation with the inert phase is shown in figures 1 and 2.

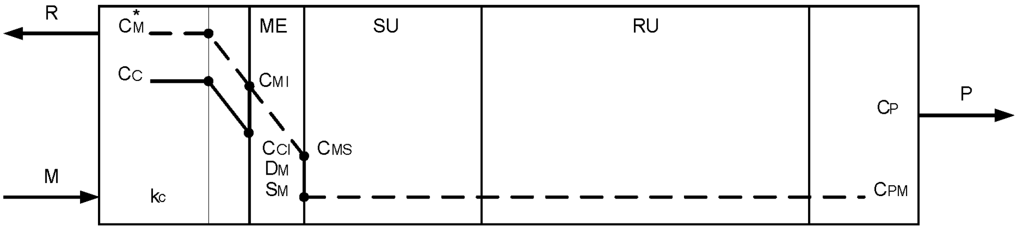

Fig. 1. The concentration profile in vacuum pervaporation

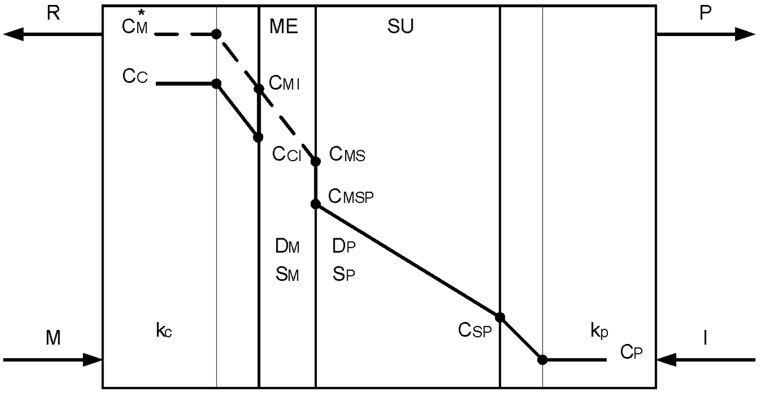

Fig. 2. The concentration profile in pervaporation with the inert phase (gas or water)

The concentration distribution of separated compound testifies to the process interpretation assumed. The identification of the mass transport in each stage of the pervaporation process enables their quantitative description by kinetic equations.

3. EXPERIMENTAL

Diluted water solutions of phenol were separated by hydrophobic pervaporation membranes (PDMS). The options of the pervaporation process mentioned above were realized in the following conditions: phenol concentration in the feed (c_r), 1.5–4 g dm^{-3}; feed temperature, 40–80 °C; permeate pressure (p), 6–200 hPa; air flow (V_{air}), 250–900 dm^3 h^{-1}; air temperature, 25–60 °C; water flow (V_w), 65 dm^3 h^{-1}; water temperature, 60 °C. Schemes of pervaporation units are shown in figures 3 and 4.

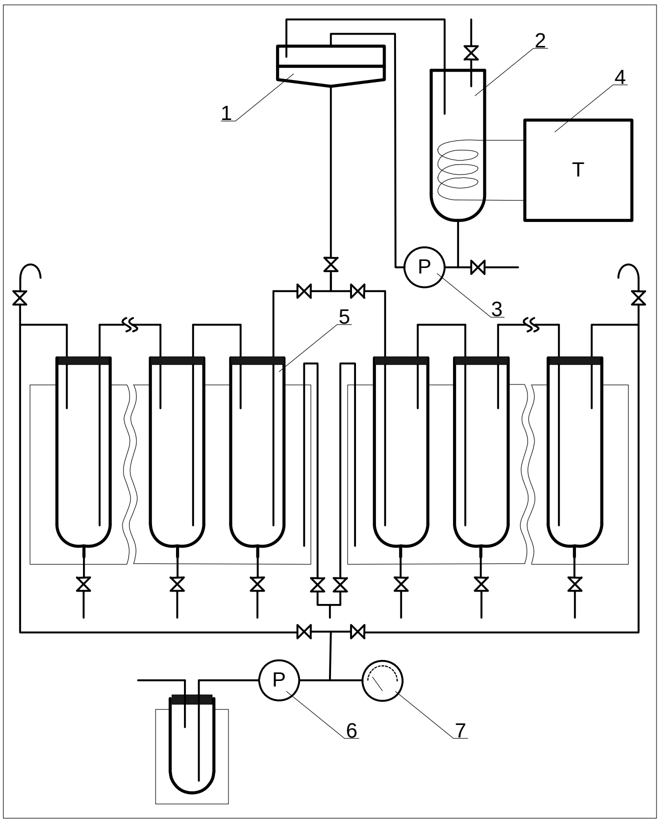

Fig. 3. The scheme of the test unit for vacuum pervaporation:
membrane cell (1), feed vessel (2), feed pump (3), thermostat (4), cold trap (5),
vacuum pump (6), vaccummetre (7)

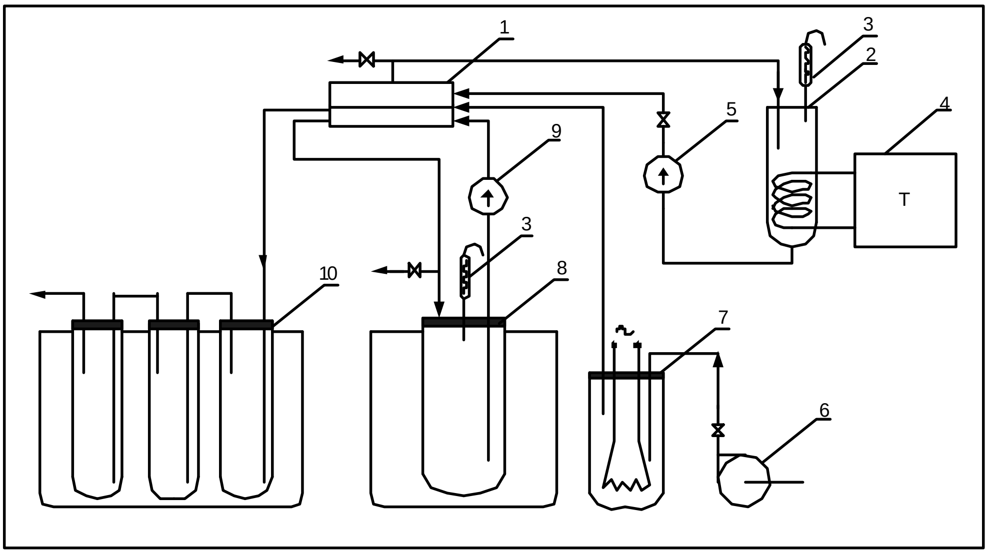

Fig. 4. The scheme of the test unit for pervaporation with the inert phase:
membrane cell (1), feed vessel (2), reflux condenser (3), thermostat (4), vacuum pump (5),
air blower (6), air heater (7), water vessel with thermostat (8), pump (9), cold trap (10)

Pervaporation set-up consists of membrane module, feed pump, feed vessel, and permeate vessel. In the option of pervaporation with the inert phase in the permeate zone under the composite membrane, the air flow or water flow is circulated. These streams are generated by gas blower or pump, respectively. The vacuum pump and cold traps in the case of gas permeate are additional elements.

The feed pump forces the solution circulation between the thermostated feed vessel and the membrane module where the selective transport takes place. In compliance with the option of pervaporation process, the permeate is condensed in the cold traps or is absorbed into the circulating water. The phenol concentration was measured with UV-VIS spectrometer ($\lambda = 270$ nm).

4. RESULTS

The characteristic quantitative indicators of the pervaporation efficiency such as permeate fluxes (phenol and water) and separation coefficient were determined. Examples of these relationships are shown in a graphic form.

In the case of vacuum pervaporation process, the constant water flux versus phenol concentration in the feed and its clear dependence on the temperature were found (figure 6). The temperature as well as the feed concentration (c_r) influence the magnitude of phenol permeate flux (figure 5).

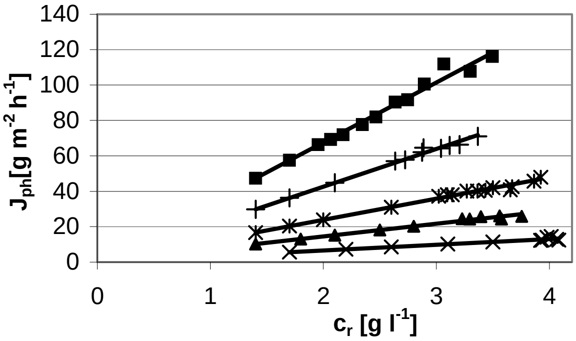

Fig. 5. Phenol flux as a function of its concentration in a feed (vacuum p = 12 hPa, feed temperature: ■ 80 °C, + 70 °C, ✱ 60 °C, ▲ 50 °C, × 40 °C)

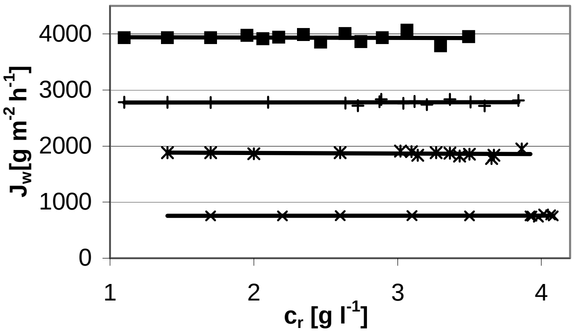

Fig. 6. Water flux as a function of phenol concentration in feed (vacuum p = 12 hPa, feed temperature: ■ 80 °C, + 70 °C, ✱ 60 °C, × 40 °C)

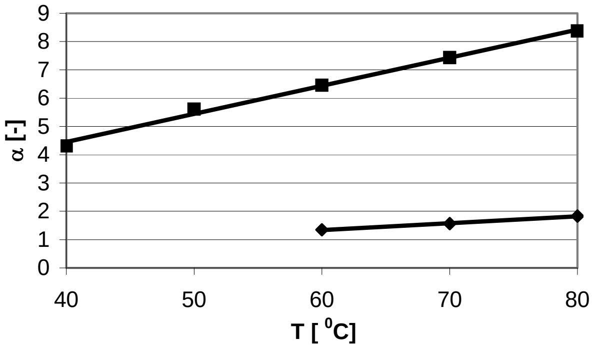

Fig. 7. Separation coefficient as a function of the feed temperature (c_r = 4 g dm^{-3}, ■ vacuum pervaporation: vacuum p = 12 hPa, ◆ sweep gas pervaporation: air flow V_{air} = 500 dm^3 h^{-1})

The behaviour of the water and phenol fluxes arises from the disproportion of their concentration in the solution. A rise in a feed temperature intensifies the process efficiency as well as its selectivity (figure 7).

A temperature similarly influences the process efficiency (figures 8 and 9) in the pervaporation with an inert phase. It is seen that the permeate fluxes are definitely smaller than these obtained in the vacuum pervaporation. In figure 7, the temperature influence on the separation coefficient is presented. The selectivity in the vacuum pervaporation is several times better than selectivity in the sweep gas pervaporation. The reasons for a poorer efficiency of the sweep gas pervaporation and pertraction are connected with its additional and strong resistance to mass transport in the permeate zone. In the vacuum pervaporation, this resistance has not been observed.

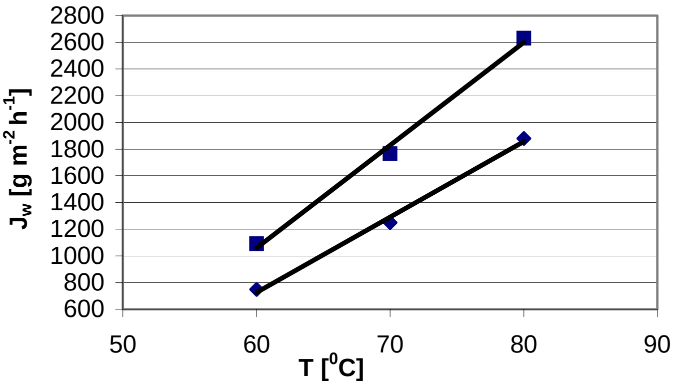

Fig. 8. Water flux as a function of the feed temperature in the sweep gas pervaporation (air flow: ■ 900 dm^3 h^{-1}, ◆ 500 dm^3 h^{-1})

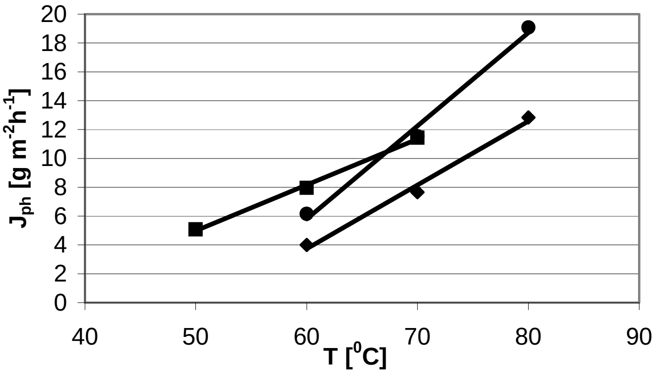

Fig. 9. Phenol flux as a function of feed temperature (c_r = 4 g dm^{-3}, sweep gas pervaporation – air flow: ● 900 dm^3·h^{-1}, ◆ 500 dm^3·h^{-1}, pertraction – water flow: ■ 65 dm^3·h^{-1})

An increase in the the permeate pressure is responsible for a decrease in the process efficiency and in the separation selectivity (figure 10).

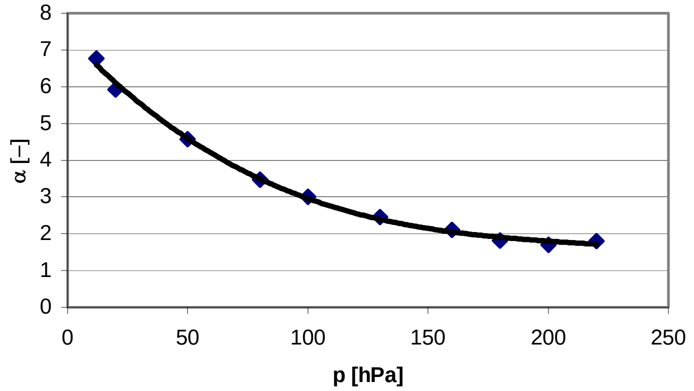

Fig. 10. Separation coefficient as a function of permeate pressure
(c_r = 4 g dm^{-3}, feed temperature, 60 °C)

A higher pressure in the permeate zone is responsible for a higher partial pressure of permeates and the corresponding higher concentration on the surface of the outlet side of the dense membrane [3]. The permeate flux versus the air flow is the increasing function in a limited range (figures 11 and 12). In spite of the further air flow increase the amount of permeate flux remains constant.

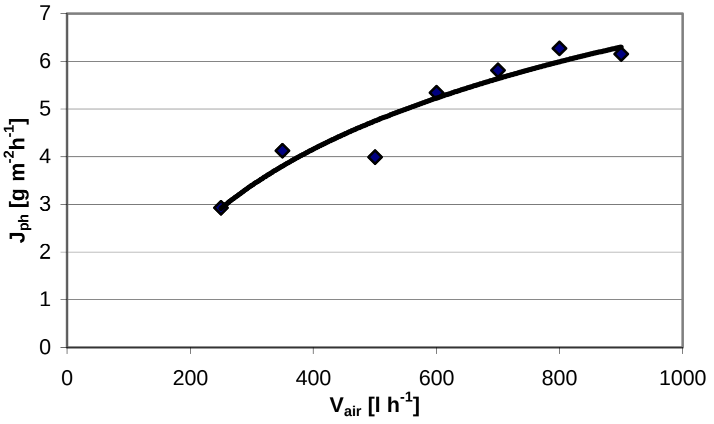

Fig. 11. Phenol flux as a function of air flow
(c_r = 4 g dm^{-3}; feed temperature, 60 °C; air temperature, 25 °C)

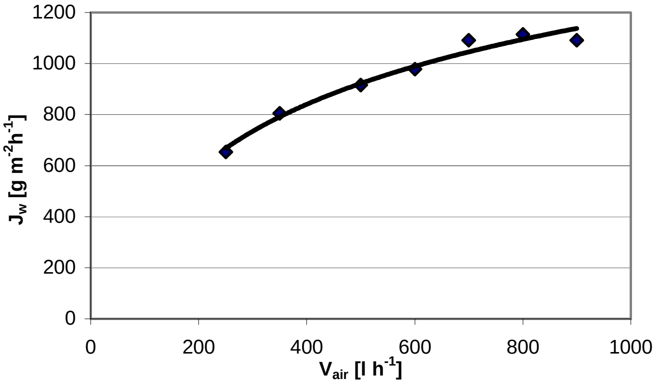

Fig. 12. Water flux as a function of air flow
($c_r = 4$ g dm^{-3}; feed temperature, 60 °C; air temperature, 25 °C)

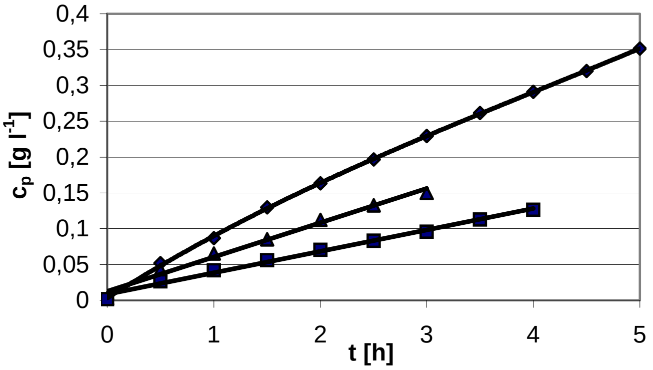

Fig. 13. Phenol concentration in the stripping phase during pertraction
(temperature: ■ 50 °C, ▲ 60 °C, ◆ 70 °C)

Phenol concentration in the stripping phase obtained during pertraction does not hinder its mass transport (figure 13). The process efficiency is better at higher temperature.

5. CONCLUSIONS

Specific properties of pervaporation and different options of this process allow its widespread application. In the technology of wastewater treatment, this method of separation can be used to reduce the aromatic compound concentration to an adequate standard level. The permeate flux obtained can be reused or rendered harmless in the biodegradation process. The quantitative rates of pervaporation efficiency are the highest in the vacuum pervaporation, but this option of the separation process is the most complicated technically. In all variants, a temperature affects the process selectivity and efficiency. In order to intensify the membrane permeability at the temperature of the process, the operating parameters (permeate pressure, air and water fluxes) must be appropriately selected.

The observation of the process allows us to modify the separation unit in order to lengthen the working time of the membrane and to improve the mass transport efficiency.

ACKNOWLEDGEMENTS

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