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Use of stripping tower and reverse osmosis in removal of petroleum hydrocarbons from water

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ABSTRACT

The universality of occurrence and usage of petroleum leads to higher water environment pollution by oil derivatives products. Taking into account their high toxicity on living organisms, effective methods of water treatment should be found in order to protect health of consumers and natural water resources. In the paper, the issue of petroleum hydrocarbons' removal from C_7 to C_{35} from model water, which means distilled water with addition of diesel fuel and petroleum, was analyzed. The experiments were conducted in order to assess the efficiency of their removing from water with the use of the following combination: stripping tower and reversed osmosis. Technological experiments were done on stripping tower in the conditions of different concentration, stable aeration intensity, and hydraulic load of 1 [$m^3/m^2 h$]. Reverse osmosis was done with pressure of 1.1 MPa and line speed over membrane of 1.1 m/s. Two series were done with the concentration of 252.96 and 192.62 $\mu g/dm^3$. Analyzed water was brought to stripping tower, and then, it was exposed to reverse osmosis process. The determination of petroleum hydrocarbons was done on gas chromatograph according to Polish Norm PN-C-04643 and classified as index of mineral oil. As a result of this process, 80% effect of petroleum hydrocarbons removal was obtained.

Keywords: Air stripping; Water; Petroleum hydrocarbons

1. Introduction

Hydrocarbons and their derivatives, which belong to the most numerous and common group of organic compounds, occur in surface and ground water. It is due to the scale of the use of synthetic and natural products containing these compounds, the possibility of their infiltration into hydrosphere caused by transport, and industrial failure as well as surface flows and other sources [1–3].

Since petroleum and its products show toxicity on alive organisms, it is necessary to monitor constantly the level of pollution of the environment and take all possible steps in order to minimalize the accident risks connected with petroleum and its derivatives [4,5].

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In the case of ground water pollution by petroleum compounds, the high toxicity of these substances together with the fact that such water is used as the source of tap water makes it necessary to take some firm action [2,3,6]. It requires some effective methods of water treatment in order to protect consumers' health and natural water resources. The choice of treatment method depends on the quantity and the quality of petroleum substances occurring in water, but it is necessary to choose the method which would enable to obtain the high level of treatment [7–10].

In this paper, the combination of stripping tower and reverse osmosis in order to remove petroleum compounds from water from C_7 to C_{35} was analyzed. The idea of integrated processes is the combination of two or more unit processes into separation of chosen ingredients, which assures higher effectiveness in comparison with unit processes [10–12]. The aspect, which demands experimental tests, is to obtain some data concerning the influence of working conditions of research system (technological parameters of water treatment process) and the values of petroleum substances' concentrations in water on effectiveness of the process.

2. Material and research methods

In conducted research, the process of petroleum hydrocarbons removal was done in the following combination: stripping tower and reverse osmosis (RO). Polluted water (distilled water with the addition of petroleum compounds) (Fig. 1) was from the top of the reservoir in desorption column, which was aerated while water was flowing. The desorption column included a spray nozzle on the top through which the polluted water was injected into the column, while ventilators caused the air movement opposing the direction of water flow. Afterward, the flowing water was gathered in a tank. Technological experiments were conducted in the condition of stable aeration intensity and hydraulic load of 1 [m^3/m^2 h]. Packing of tower was built by Raschig's rings [13–15]. The process of flowing through packing leads to breaking of water drops and ensures a sharp decrease in interfacial tension, which is the lowest in the period of reforming of drops.

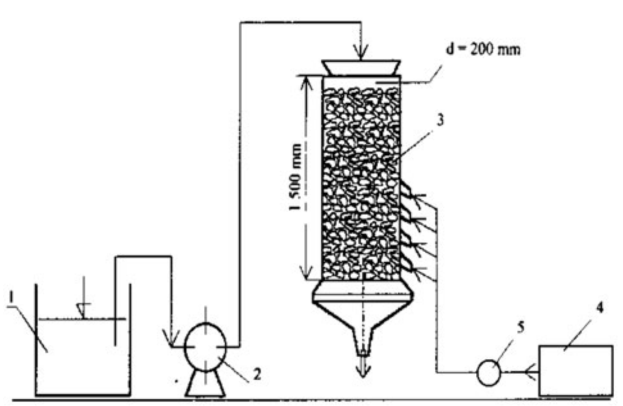

Fig. 1. Laboratory stripping tower: 1—the output solution tank, 2—metering pump water, 3—model of desorption column, 4—compressor, 5—rotameter.

After the stripping process, model water was brought into the reversed osmosis structure. RO process was conducted on the installation with a spiral membrane made of aromatic polyimide. RO configuration worked in a constant configuration with partial recirculation of concentrate. The membrane worked in the range of pH from 4 to 11. The research on membrane filtration was conducted at the temperature of 19°C with the pressure of 1.1 MPa and line speed over membrane of 1.1 m/s. Before appropriate measurement was done, deionized water had been made to flow through the membrane in order to assess the maximal permeate stream, and afterward, appropriate experiments were done. After proper research, the membrane was swilled out with the use of distilled water. In that way, the changes of membrane transport assets were determined. The effectiveness of a filtration process of infiltration water was assessed on the basis of the capacity of permeate stream (J_V) and its chemical analysis. The preparation of analysis considered the determination of index of mineral oil as hydrocarbons fraction in the range of C_7–C_{35}.

Model water was made as the mixture of distilled water and petroleum with diesel fuel in proportion of 1:3. This mixture depended on the quantity and the type of fuel sold on domestic market in the period of 2008–2010 [16]. Water in experiment was used in two concentrations of hydrocarbons: 192.62 and 252.96 $\mu g/dm^3$. The concentrations of hydrocarbons were simulated by adding the mixture of fuel and diesel fuel proportionally: 0.3 and 0.5 ml per 1 l of distilled water. The mixture of fuel with water was homogenized each time before being inserted on the structure with the use of a fan homogenizer in order to obtain a definite mixture.

Homogenized model water (distilled water with the addition of fuel) was brought into stripping tower. During the desorption process, some water sample was taken to analytic research every 30 min. In RO process, the research sample was taken every 10 min. The determination of monitored aliphatic petroleum hydrocarbons from C_7 to C_{35} was done on a gas-coupled chromatograph, according to Polish Norm PN-C-04643 with VARIAN spectrometer with the 4000 symbol. The apparatus was equipped in VF-5 MB stirrer with the dimension of 30 m × 0.25 mm × 0.25 m. Polydimethylsiloxane with 5% content of phenyl group was made in a stationary phase.

Helium was a carrier gas. Aliphatic hydrocarbons were extracted from water by the liquid–liquid method with the use of hexane. After separating water from an organic layer, eluate was brought to measurement flasks, and afterward, it was dried by anhydrous sodium sulfate (analytically pure Na_2SO_4). The following temperature program was used as follows: 40℃ (5 min)–130℃ (0 min) with temperature increase from 0℃/min to 300℃, transfer line temperature 230℃, and temperature of ions source −180℃.

3. Results and discussion

With the initial concentration of petroleum hydrocarbons 192.62 μg/dm^3 in I series (Table 1), the percentage rate of petroleum hydrocarbons' removal in the stripping process fluctuated in the range of 21–28%. The highest effect was obtained after 90 min and reached 28% and there was left 140.48 μg/dm^3 of analyzed hydrocarbons in water.

In the case of the second process series on stripping tower (Table 1), the initial concentration reached 252.96 μg/dm^3 and was higher of about 38% than in water in I series. After 90 min of process duration in stripping tower in II series, the concentration of analyzed compounds was reduced to 170.01 μg/dm^3 reaching 33% of removing effect. In the first 30 min, the concentration of analyzed compounds decreased by about 28%, during next 30 min—5% reaching 33%, which was maintained up to the end of the process. After 1.5 h of duration water treatment (Table 1) process in II series on stripping tower, some reduction in the content of petroleum hydrocarbons was observed reaching 5% higher of the removing effect rather than in I series during which the initial concentration was lower.

Table 1
Obtained concentrations of checked parameters in two series

	The time of collecting samples	Concentration of petroleum hydrocarbons (index of mineral oil) [μg/dm^3]	Removing increased [%]
I series	0	192.62	0
	30	152.74	21
	60	145.68	25
	90	140.48	28
II series	0	252.96	0
	30	182.54	28
	60	170.68	33
	90	170.01	33

References data [15,17] reveal that the barbotage hydrodynamics is influenced by physical properties of the liquid phase, especially those which decide about coalestention of gas bubbles. Modeling water (distilled water plus mixture of fuel) on the basis of which the research was done has high coalestensive properties, which could cause some slight increase in the removing effect. The removing effect on stripping tower in both series reached the level of 33%. Low efficiency of petroleum hydrocarbons' removal can be caused by: high concentration of analyzed hydrocarbons in water, too fast water speed, low air speed, and low temperature of analyzed water [18]. Some authors [9,14,18] prove the removing process of petroleum substances from water at the level of 83–90%. In order to increase the effectiveness of stirring tower work, the temperature of the flowing air is raised [9,15] or according to La Branche [17,19] the proposed proportion of water to air should be at the level of 1:6; however, Hwang claims [19] that level should be 1:9. However, the conducted research was in proportion of water to air like 1:5, which probably influences the effectiveness of the process.

In RO process in I series (Fig. 2), the experiments were started from the concentration of 140.48 μg/dm^3. The concentrations of hydrocarbons in permeate fluctuated from 100 to 5 μg/dm^3. During the whole process, retention coefficient level of petroleum compounds was determined. In the first series after 10 min, the concentration of analyzed compounds decreased by only 29% down to 100 μg/dm^3. In the following sampling in RO, the process result showed a higher impact fluctuating from 65% after 20 min, later 71% after 30 min, 94% after 40 min, 91% after 50, and at last 98% after 60 min.

In II series, where initial concentration was 18% higher than in the first series and amounted to 170.52 μg/dm^3, the results of petroleum hydrocarbons' removal from water were lower but still maintaining 70% on average. The lowest effect amounted to 77 μg/dm^3 in 10 min of this process in permeate which gave 55% of retention coefficient, while the highest amounted to 94% after 60 min reaching 10.14 μg/dm^3 of analyzed compounds in permeate.

In RO process, 86% of conversion degree of model water was reached. The capacity stream of permeate (Fig. 3) in both series was gradual, in the first series

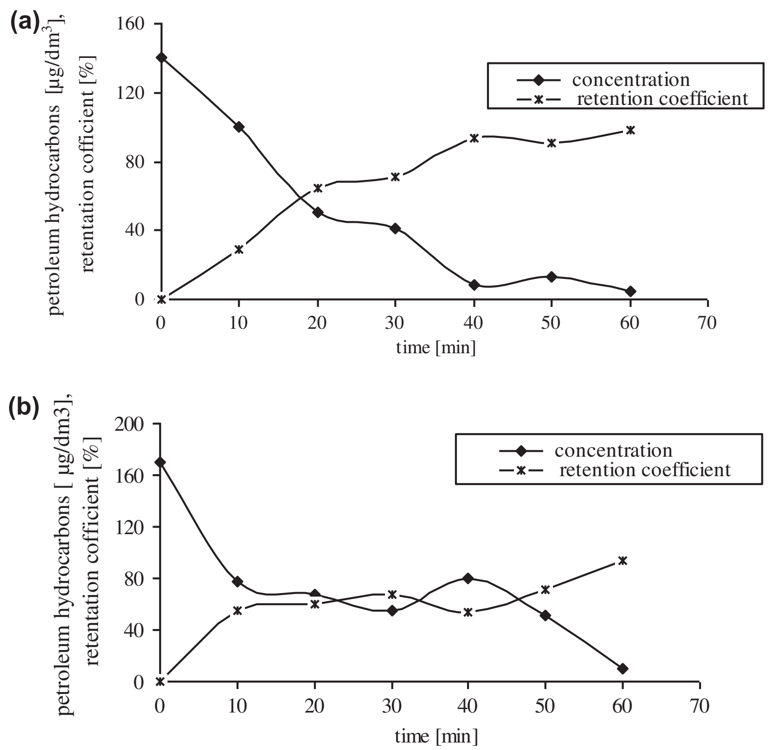

Fig. 2. Comparison of results obtained while studying the grade of removing petroleum hydrocarbons on the RO (a) I series and (b) II series.

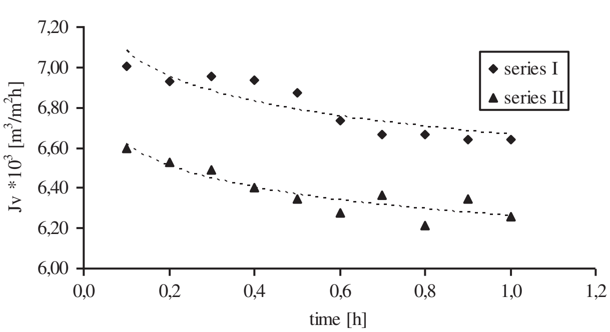

Fig. 3. The change of capacity stream of permeate in time.

reached the level of $6.3 \times 10^{-3}\,[m^3/m^2\,h]$ and in the second $6.7 \times 10^{-3}[m^3/m^2h]$. Deionized water stream before the process maintained on the level of $7.0 \times 10^{-3}[m^3/m^2\,h]$, and after it, $6.9 \times 10^{-3}\,[m^3/m^2\,h]$. It increased in comparison with the stream of analyzed water and due to that partial regeneration of membrane occurred. Slight differences between the capacity streams of permeate in I and II series and the initial and final ones prove that there was a slight decrease in membrane efficiency. The proportion of $J_V/J_W < 1$ shows the adsorption of the rest organic compounds left after stripping or the influence of formed fouling on the process duration [20].

4. Conclusions

The research proves that there exists a possibility of water treatment from petroleum hydrocarbons in combination: stripping–reverse osmosis. The experiment showed that water treatment by reverse osmosis method is possible and the efficiency of this method is high. Conducted stripping and removing of petroleum hydrocarbons on RO from water is the efficient method, which allows to decrease their content in water to the safe level [1–3].

On the basis of the conducted research, the following conclusions were made:

- Conducted stripping and petroleum hydrocarbons' removing from water on RO is the efficient method, which enables to decrease their content in water to safe level,
- water treatment by the method of reversed osmosis is possible, and the efficiency of this method is high,
- during membrane filtration high membrane efficiency was reached, the higher permeate concentration the lower membrane efficiency was observed, and
- there were obtained lower values of petroleum hydrocarbons' removal on RO process during

filtration of model water, in which the initial concentration was higher.

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