Study of the processes of the purification of water from surface sources from petroleum products

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Abstract. Recently, the amount of natural waters contaminated with petroleum products, which enter surface sources together with wastewater, has increased. Therefore, the issues of natural water purification of petroleum products are given great importance. Purification of natural waters from petroleum products is possible by sorption and ultrafiltration methods. Kazan State University of Architecture and Engineering conducted research on the purification of natural waters from petroleum products in adsorption filters using various sorbents, as well as membrane separators with ultrafiltration modules from various manufacturers. As a loading of sorption filters, it is recommended to use activated charcoal as a sorbent that is optimal in terms of price and quality of water purification. The membrane modules manufactured in Europe and the United States, have a high cleaning effect from petroleum products and a sufficiently high productivity. However, they are extremely expensive.
Keywords: natural waters, petroleum products, purification of natural waters from petroleum products, adsorption filters, sorbents, membrane separators, ultrafiltration modules.

1 Introduction

Since petroleum products are often used in various sectors of the national economy, they, together with industrial wastewater, enter surface sources, polluting natural waters[1-3].

Oil and petroleum products can be in the water in an emulsified or dissolved state. According to the requirements of SanPiN 2.1.4.1074-01, the content of petroleum products in tap water cannot be more than 0.1 mg/l. Therefore, the purification of natural water from petroleum products is of great scientific importance.

Large drops of petroleum products that are suspended in natural water (emulsions of the «oil in water» type are well removed by mechanical methods. To separate the particles of petroleum products from water in the gravitational field, sedimentation tanks of various designs are used [2,4,5]. Filters with granular loading are also used to purify natural waters from petroleum products [2,6,7].

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Pollution with a density lower than that of water can be separated from it in hydro cyclones of various modifications [8-10].

Kazan State University of Architecture and Engineering (KSUAE) has created devices of the «hydro cyclone-sump block» type for the removal of petroleum products with a sufficiently high content from water. These installations consist of batteries, elementary hydro cyclones, and settling tanks with various devices [2, 3].

For chemical purification of natural water from petroleum products, their oxidation is used with the help of chlorine, ozone, potassium permanganate or hydrogen peroxide [11-13].

It is possible to purify natural waters from petroleum products using biosorbers and membrane bioreactors [14-17]. In these devices, biological oxidation of contaminants and membrane separation of oil emulsions occur simultaneously. The content of petroleum products in water in such devices is reduced from 20 mg / l to 0.5-1.2 mg/l [18].

Physical and chemical methods are widely used to remove petroleum products from natural waters. These include flotation, coagulation, electrochemical treatment, sorption, and ultrafiltration [18-20].

Pressure flotation is most often used to purify natural water from petroleum products [19, 21, 22].

Coagulation (addition of reagents to water) allows intensifying the processes of subsequent purification of natural waters from petroleum products [19].

When cleaning water from petroleum products by natural electrocoagulation, metal electrodes are used, which, when dissolved, form metal hydroxides that reduce the stability of «oil in water» type emulsions, which contributes to their stratification under the influence of various external forces [19, 23]. The disadvantage of the method of electrocoagulation water purification from petroleum products is the large consumption of electricity.

For the purification of natural waters from petroleum products, adsorption filters are also used with a load of activated natural charcoal or synthetic sorbents [24-27].

Methods of cleaning wastewater from small settlements from oil products are presented in the work [28].

Ultrafiltration purification of natural waters from petroleum products is carried out in membrane separators operating under excessive pressure [29, 30]. The membranes used, which are usually made of polymers, have pairs with dimensions of 10^{-9}–10^{-8} m. These membranes are shaped like hollow cylinders and assembled in special modules. The water moving inside the membranes penetrates through the vapors, and the pollution particles, which are much larger, are retained by the membranes i.e., two streams are formed: purified water and an «oil in water» type emulsion with a high content of petroleum products.

To study the processes of natural water purification from petroleum products using adsorption filters and membrane separators, these studies were conducted.

2 Materials and methods

A pilot plant was developed for the study of water purification from petroleum products using adsorption filters (Fig. 1). This unit includes a model of an adsorption pressure filter 1, a water tank 2, a P-1 pump, pipelines, fittings and control and measuring devices. Tap water is supplied to tank 2 via pipeline 3. Oil products are supplied to the suction line of pump P-1 via pipeline 4 by a metering pump. Pump P-1 supplies water for cleaning through pipeline 5. The water treated in the adsorption filter is returned to the reservoir 1 via line 6. This water can also be discharged into the sewer through pipeline 7. Pipeline 8 serves to divert excess water to the drainage system.

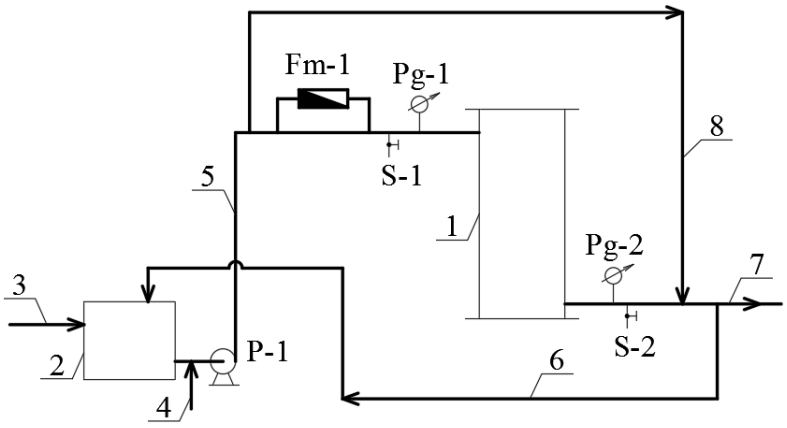

Fig. 1. Technological scheme of the sorption pilot plant.

The pressure gauge Pg-1 is installed on the pipeline 5, which determines the pressure at the inlet to the adsorption filter 1, and the pressure gauge Pg-2 is installed on the pipeline 7, which measures the pressure at the outlet of this device. The flow rate of water entering the treatment is determined using the F-1 flow meter.

The S-1 sampler located on the pipeline 5 is intended for the selection of source water, and the S-2 sampler located on the pipeline 7 is intended for the selection of purified water.

The instrumentation system includes a pressure gauge Pg-1 and Pg-2, as well as a flow meter Fm-1.

The filter model 1 can operate at a filtration speed of no more than 8 m/h. The contact of water with the sorbent in the filter 1 reaches 15-20 minutes.

During the studies, the pressure at the inlet to filter 1 reached 6 kgf /cm^2.

The temperature of the water entering the treatment was determined using a thermometer with a division price of 0.1 ^{o}C.

The content of petroleum products in water was determined by the photo collorimetric method [31].

The effect of water purification from petroleum products is [24]:

$$E_{p.p.} = \frac{C_o^{p.p.} - C_c^{p.p.}}{C_0^{p.p.}} \cdot 100, \ \% \qquad (1)$$

where $C_0^{p.p.}$ is the content of petroleum products in the source water mg/l;
$C_c^{p.p.}$the concentration of petroleum products in the water at the outlet of the treatment plant is mg/l.

Activated charcoal AG-3, sorbent SGN-30, and Karelian shungite were used as a sorbent.

The processes of water purification from petroleum products using membrane separators were studied using an experimental setup (Fig. 2). This installation consists of a membrane module 1, a water tank 2, a filter tank 3, a pump P-1, connecting pipelines, shut-off and control valves and an instrumentation system.

Tap water enters the tank 2 through line 4. The oil products are fed into the suction pipeline of the pump P-1 by the metering pump through the pipeline 5. The water contaminated by them is fed by the pump P-1 for cleaning to the membrane module 1 through the pipeline 6. The purified water through the line 7 enters the container 3, from which it can be discharged into the drainage system through the pipeline 8. The «oil in water» type emulsion with a high content of petroleum products is returned to tank 2 via line 9. The concentrate is pumped through pipeline 10 by pump P-1 for disposal.

On the pipeline 6, a pressure gauge Pg-1 is installed, which determines the pressure at the inlet to the membrane separator 1, as well as a sampler S-1, which allows you to obtain

samples of water entering for treatment. On the pipeline 7 there is a pressure gauge Pg-2, showing the pressure at the outlet of the membrane module 1 and the sampler S-2 for obtaining samples of purified water.

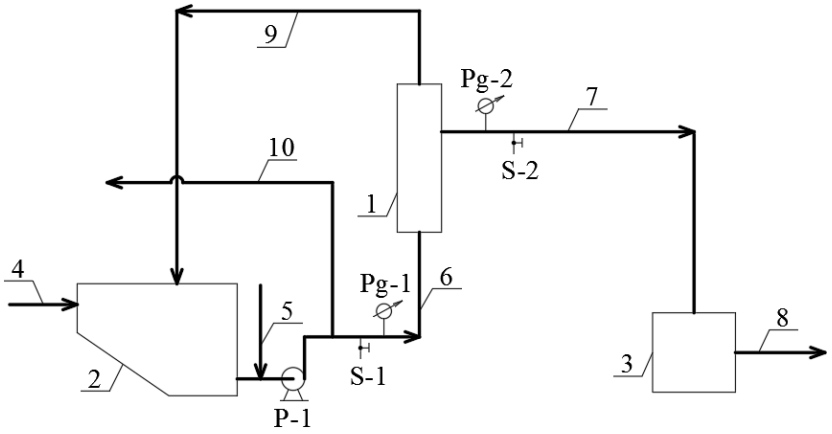

Fig. 2. Flow diagram of the experimental membrane separation unit.

The flow rate of treated water is measured by the volumetric method using a measuring cylinder and a stopwatch.

The content of suspended substances in water was determined by the weight method [30]. The temperature of the source water and the concentration of petroleum products in the source and treated water were also measured.

Three types of membrane modules were tested: the AR-2.0N made in the Russian Federation, the X-FLOW Aquaflex20 made in the United States, and the dizer Puozi-1.8 made in the Federal Republic of Germany.

The pressure at the entrance to the membrane modules did not exceed the recommended pressure by the manufacturers of these devices.

3 Results and discussion

The results of experiments on water purification from petroleum products by sorption are presented in Tables 1, 2.

The results of experiments on water purification from petroleum products by ultrafiltration are given in Tables 3, 4.

The results obtained allow us to state the following:

– the content of petroleum products in the source water reached 0.88-4.1 mg/l;

– the concentration of suspended substances in the water entering the treatment did not exceed 1.21-1.53 mg/l;

– the pressure loss in the adsorption filters during the operation of these devices did not exceed 3-5 m;

– the pressure during the operation of the membrane separation modules is reduced by 5-8 m;

– the temperature of the source water was +19.8 ... +20.2 ^{o}C;

– the efficiency of water purification from petroleum products for shungite was 87-90 %, for activated charcoal – 90-91 %, and for sorbent of the SGN-30 brand – 93-95 %;

– the effect of water purification from petroleum products in the membrane separators of the AR-2.0N type did not exceed 70-73 %, in the X-FLOW Aquaflex-20 modules – 89-92 %, and in the dizer separators – 80-83 %;

– an increase in the pressure at the inlet to the adsorption filters does not lead to an increase in the effect of water purification from petroleum products;

– the increase in the contact time of water with the sorbent increases the effect of its purification from petroleum products;

– the increase in pressure at the inlet to the membrane separators does not increase the effect of its purification from petroleum products, but increases the filtrate consumption for these devices;

– an increase in the content of petroleum products in the water does not affect the efficiency of the membrane separators.

Table 1. Results of experiments on water purification from petroleum products by sorption method.

Loading type	Pressure, kgf / cm^2		Water temperature, °C	Filtration rate, m/h
	at the entrance to the adsorption filter	at the outlet of the adsorption filter		
1	2	3	4	5
Shungite Karelian (d = 1-3 мм)	2	1.7	20.1	8
	3	2.7	20.0	8
	4	3.6	20.2	8
	5	4.5	19.9	8
Activated carbon (d = 0.5-1.5 мм)	2	1.7	20.1	8
	3	2.7	19.9	8
	4	3.6	20.0	8
	5	4.6	20.2	8
Sorbent SGN-30 (d = 0.5-1.5 мм)	2	1.7	19.8	8
	3	2.7	19.9	8
	4	3.6	20.1	8
	5	5.6	20.0	8
	2	1.7	20.1	8
	2	1.6	20.2	8
	2	1.7	19.9	8
	2	1.6	20.0	8
	2	1.5	20.1	8
	2	1.6	19.8	8

Table 2. Results of experiments on water purification from petroleum products by sorption method

Loading type	Duration of filtration, min	Concentration of petroleum products, mg/l		The effect of cleaning from petroleum products, $E_{p.p.}$, %
		in source water, $C_0^{p.p.}$	in purified water, $C_c^{p.p.}$	
1	6	7	8	9
Shungite Karelian (d = 1-3 мм)	15	1.86	0.22	88
	15	1.94	0.21	89
	15	2.10	0.27	87
	15	1.78	0.18	90
Activated carbon (d = 0.5-1.5 мм)	15	2.05	0.18	91
	15	2.11	0.19	91
	15	1.94	0.19	90
	15	1.87	0.16	91
Sorbent SGN-30 (d = 0.5-1.5 мм)	15	1.68	0.10	94
	15	1.60	0.09	94
	15	1.83	0.12	93
	15	1.61	0.09	94
	15	1.75	0.10	94
	15	1.93	0.09	95
	15	1.10	0.08	93
	15	1.79	0.10	94
	15	2.87	0.19	93
	15	4.10	0.32	92

Table 3. The results of a study on the purification of water from petroleum products by ultrafiltration.

Membrane modules type	Pressure, kgf / cm^2		Water temperature, ºC	Suspension concentration, mg/l	Leakage rate, m^3/h
	at the entrance to the membrane module	at the inlet from the membrane module in the filter outlet line			
1	2	3	4	5	6
Dizzer Puozi-1.8 (FRG, Inge Gmbh)	1	0.5	19.8	1.44	0.10
	1	0.5		1.25	0.09
	1	0.4		1.53	0.10
	1.5	0.8	20.0	1.50	0.12
	1.5	0.7		1.47	0.12
	1.5	0.8		1.39	0.11
	2	1.3	20.1	1.24	0.17
	2	1.2		1.46	0.17
	2	1.2		1.38	0.16
AR-2.0N (Russia)	1	0.6	19.9	1.21	0.13
	1	0.5		1.30	0.14
	1	0.5		1.33	0.13
	1.5	1	20.1	1.41	0.20
	1.5	1		1.38	0.19
	1.5	0.9		1.34	0.18
	2	1.5	20.0	1.38	0.26
	2	1.4		1.40	0.26
	2	1.4		1.35	0.25
X-FLOW Aquaflex-20 (USA, Pentair)	2	1.6	20.2	1.47	12.74
	2	1.6		1.32	12.81
	2	1.5		1.28	12.63
	2.5	1.8	20.1	1.52	15.32
	2.5	1.8		1.36	15.25
	2.5	1.7		1.43	15.40
	3	2.4	19.9	1.41	17.83
	3	2.3		1.32	17.72
	3	2.3		1.48	17.70

Table 4. The results of a study on the purification of water from petroleum products by ultrafiltration.

Membrane modules type	Concentration of petroleum products, mg/l		The effect of cleaning from petroleum products, $E_{p.p.}$, %	Filtration surface, m^2
	in source water, $C_0^{p.p.}$	in purified water, $C_c^{p.p.}$		
1	7	8	9	10
Dizzer Puozi-1.8 (FRG, Inge Gmbh)	1.10	0.20	82	1.8
	1.99	0.39	80	
	3.24	0.61	81	
	0.91	0.17	81	
	2.06	0.37	82	
	3.10	0.63	80	
	1.13	0.20	82	
	2.14	0.36	83	
	2.92	0.53	82	
AR-2.0N (Russia)	1.11	0.32	71	2
	2.05	0.61	70	
	2.93	0.89	70	
	0.88	0.25	72	
	1.82	0.54	70	
	3.10	0.90	71	
	0.94	0.26	72	
	2.16	0.58	73	
	2.87	0.77	73	
X-FLOW Aquaflex-20 (USA, Pentair)	1.06	0.11	90	20
	1.92	0.21	89	
	3.21	0.29	91	
	0.96	0.10	90	
	1.85	0.17	91	
	2.79	0.28	90	
	1.17	0.09	92	
	2.20	0.18	92	
	3.05	0.27	91	

4 Conclusion

The efficiency of the adsorption filters and membrane separators in general is approximately comparable. However, the operation of adsorption filters is much easier. In addition, these devices can operate at a higher content of suspended solids in the water, the presence of which negatively affects the operation of ultrafiltration units.

The sorbent of the SGN-30 brand showed a higher efficiency of water purification from petroleum products, but this sorbent has the highest cost, and its regeneration is extremely time-consuming and expensive. Therefore, wood activated carbons can be recommended as a loading for adsorption filters. They have a sufficiently high efficiency of water purification from petroleum products and after their sorption capacity is exhausted, they cannot be regenerated, but disposed of by incineration.

Membrane modules manufactured in Europe and the United States have a high effect of water purification from petroleum products and a sufficiently large capacity for filtrate. However, their cost is very high. It is necessary to continue research on the processes of water purification from petroleum products on membrane modules that are mass-produced in Russia. When the concentration of petroleum products in natural water is up to 2 mg, it is recommended to use pressure adsorption filters with the direction of water movement from top to bottom.

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