Treatment of oil-containing wastewater of machine-building enterprises using pressure hydrocyclones

Andrey Busarev*[1][0000-0002-7063-2519], and *Aleksandr* Selyugin[1][0000-0003-2427-3698]

[1]Kazan State University of Architecture and Engineering, 420043 Kazan, Russia

Abstract. Wastewater treatment of machine-building enterprises contaminated with oils, petroleum products and mechanical impurities is an urgent task. A promising direction in the field of treatment of such wastewater is the use of pressure hydrocyclones and hydrocyclone installations. The article presents the results of research on the treatment of oil-containing wastewater of machine-building enterprises in pressure of hydrocyclones, conducted on an experimental hydrocyclone installation, which includes the pressure hydrocyclone under test, a sedative tank, and tanks for receiving water from the upper and lower drains of the hydrocyclone. The studies were carried out in two stages: the first stage was used to determine the diameter of the pressure of hydrocyclone suitable for the treatment of oily wastewater, and the second stage was used to study its geometric characteristics. At the first stage, seven modifications of pressure hydrocyclones with a diameter of 40 to 100 mm with different diameters of the upper and lower drain pipes were tested. A 75 mm diameter hydrocyclone is recommended for the treatment of oily wastewater. At the second stage, nine pressure hydrocyclones with a diameter of 75 mm with different diameters of the upper and lower drain pipes were tested. As a result of the experiments, the design parameters of the hydrocyclone that showed the best results were determined. The results of the research were used in the design of industrial hydrocyclone installations.
Keywords. Oily wastewater, treatment, hydrocyclone, experimental plant, research, industrial plant.

1 Introduction

Oil-containing waste water is formed in oil fields during the production and preparation of oil, during car washing, from the cooling of technological equipment at machine-building enterprises, in fuel oil storage tanks, etc.

For the treatment of wastewater from petroleum products and suspended solids, settling tanks of various designs are often used [1–4]. Hydrocyclones with different geometries are often used for the treatment of oily wastewater [5–9].

Kazan State University of Architecture and Engineering (KSUAE) has developed devices that combine the treatment of oil-containing wastewater in pressure hydrocyclones,

*Corresponding author: kgasu.viv@gmail.com

succeeded by purification from petroleum products and suspended substances by sedimentation. These installations are called the «hydrocyclone – sump block» (HSB) [10, 11]. Coalescing nozzles made of granular materials are used to intensify the deposition of oily wastewater [12].

Chemical purification of water from petroleum products is carried out by the method of oxidation [13–16]. Biological purification of water from petroleum products is carried out using membrane bioreactors [17–20].

Physical and chemical methods are also used for the treatment of oily wastewater: flotation [21], sorption [22], ultrafiltration [23], as well as electrocoagulation [24].

Deep purification of oil-containing wastewater from petroleum products and suspended substances is carried out in filters with granular loading [25–27].

The aim of the study was to define the geometric parameters of the pressure hydrocyclone for its use in industrial hydrocyclone facilities for the treatment of oil-containing waste water effluent.

2 Materials and methods

Studies of the oil-containing wastewater treatment processes at machine-building enterprises were carried out in two stages: at the first stage, the diameter of the pressure hydro cyclone was determined, and at the second stage, its geometric characteristics were determined. At the first stage, seven modifications of pressure hydrocyclones with a diameter of 40 to 100 mm with different diameters of the upper and lower drain pipes were tested.

To determine the geometric parameters of the hydrocyclone intended for operation as part of the installation of the «hydrocyclone – sump unit», studies of the oil-containing wastewater treatment processes were carried out on an experimental hydrocyclone installation (Fig. 1).

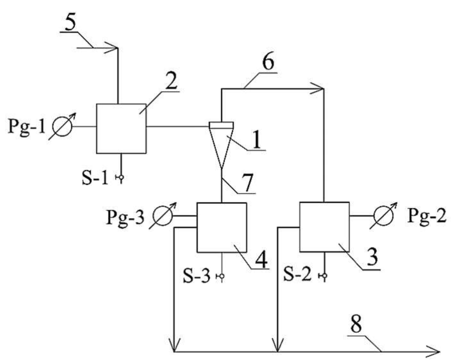

Fig. 1. The Scheme of the experimental installation: 1 – pressure hydrocyclone; 2 – sedative tank; 3 – tank for receiving water from the upper drain of the hydrocyclone; 4 – tank for receiving water from the lower drain of the hydrocyclone; 5 – waste water supply; 6 – pipeline of the upper drain of the hydrocyclone; 7 – pipeline of the lower drain of the hydrocyclone; 8 – pipeline for removing liquid to the sewer.

During the research, oil-containing waste water was supplied to the installation by a pump through pipeline 5. Water from the upper drain of the hydrocyclones was diverted through pipeline 6, and from the lower drain of these devices – through pipeline 7. From tanks 3 and 4, the liquid was diverted through pipeline 8 to the industrial sewage system. The pressure at the inlet to the hydrocyclones was set according to the readings of the pressure gauge Pg-1 installed on the tank 2.

In the course of the research, after the flows at the inlet to the hydrocyclone and at its drains became steady, samples of the initial waste water from the S-1 sampler and liquid from the upper and lower drains of the hydrocyclone from the Pg-2 and Pg-3 samplers were simultaneously taken. In the samples, the concentration of mechanical impurities was determined by the weight method, and the concentration of petroleum products was determined by the photo colorimetric method [1, 28].

Table 1 shows the geometric characteristics of the hydrocyclones tested in the course of experimental studies.

Table 1. Geometric characteristics of hydrocyclones with a diameter of 40-100 mm.

Type of the hydro-cyclone	Diameter, mm				Immersion dept of the upper drain pipe, mm	Height of the cylindrical part, mm	Total height of the hydro-cyclone, mm
	hydro-cyclone	Inlet pipe	upper-drain pipe	Lower drain pipe			
HC-40-V	40	15	15	10	48	15	525
HC-40-III	40	15	8	5	20	15	470
HC-75-II	75	15	20	18	48	15	730
HC-75-III	75	15	20	10	48	15	730
HC-80-I	80	20	20	10	50	20	745
HC-100-I	100	20	20	15	48	20	1100
HC-100-II	100	20	20	10	48	20	1155

At the second stage, the research of a 75 mm diameter hydrocyclone was carried out. In the course of the studies, the diameters of the upper and lower drain pipes were changed. The geometrical characteristics of the tested hydrocyclones are given in Table 2.

Table 2. Geometric characteristics of 75 mm diameter hydrocyclones.

Type of the hydro-cyclone	Diameter, mm				Immersion dept of the upper drain pipe, mm	Height of the cylindri-cal part, mm	Total height of the hydro-cyclone, mm
	hydro-cyclone	Inlet pipe	upper-drain pipe	Lower drain pipe			
HC-75-I	75	15	20	26	48	15	730
HC-75-II	75	15	20	18	48	15	730
HC-75-III	75	15	20	10	48	15	730
HC-75-IV	75	15	15	18	48	15	730
HC-75-V	75	15	15	26	48	15	730
HC-75-VI	75	15	15	10	48	15	730
HC-75-VII	75	15	10	18	48	15	730
HC-75-VIII	75	15	10	10	48	15	730
HC-75-IX	75	15	10	26	48	15	730

The effect of oil-containing wastewater treatment from petroleum products, E_p, %, is determined by the formula [28]:

$$E_{p.p.} = \frac{C^{sw.}_{p.p.} - C^{ld}_{p.p.}}{C^{sw.}_{p.p.}} \cdot 100, \% \quad (1)$$

where $C^{sw}_{p.p.}$ – is the concentration of petroleum products in the source water, *mg/l*; $C^{ld}_{p.p.}$ – is the concentration of petroleum products in the water from the lower drain

of the hydrocyclone, *mg/l*.

The effect of purification by mechanical impurities $E_{m.i.}$,%, was determined by the formula [23, 28]:

$$E_{m.i.} = \frac{C^{sw.}_{m.i} - C^{ld}_{m.i.}}{C^{sw.}_{m.i.}} \cdot 100, \% \quad (2)$$

where $C^{sw}_{m.i.}$ is – the concentration of mechanical impurities in the source water, *mg/l*; $C^{ld}_{m.i.}$ – is the concentration of mechanical impurities in the purified water, *mg/l*.

3 Results and discussion

Tables 3a-b show the results of studies on the treatment of oily wastewater in pressure hydrocyclones of various diameters.

Table 3a. Results of experimental studies.

Type of hydro-cyclone	Waste water temperature, ^{0}C	Pressure at the inlet to the hydrocyc-lone, MPa	Back pressure at the jet-cyclone drains, MPa	Concentration of petroleum products in water, *mg/l*			The effect of cleaning oil products, $E_{p.p.}$,%
				In the sourcewater, $C_{p.p.}^{sw}$	From the upper drain, $C_{p.p.}^{ud}$	From the lower drain, $C_{p.p.}^{ld}$	
1	2	3	4	5	6	7	8
HC-40-III	18.80	0.3	0.05	521	799	162	69
			0.10	483	827	140	71
			0.15	492	783	157	68
			0.20	509	815	173	66
HC-40-V	19.2	0.3	0.05	484	784	111	77
			0.10	497	749	119	76
			0.15	511	785	133	74
			0.20	490	691	137	72
HC-75-II	18.9	0.3	0.05	504	737	141	72
			0.10	490	743	147	70
			0.15	488	635	156	68
			0.20	493	680	167	66
HC-75- III	19.0	0.3	0.05	501	764	159	68
			0.10	498	787	174	65
			0.15	486	699	190	61
			0.20	492	702	207	58
HC-80-I	19.1	0.3	0.05	507	699	177	65
			0.10	489	673	196	60
			0.15	495	698	213	57
			0.20	488	701	224	54
HC-100-I	19.1	0.3	0.05	499	689	190	62
			0.10	482	671	188	61
			0.15	522	695	214	59
			0.20	491	683	211	57
HC-100-II	18.90	0.3	0.05	485	662	175	64
			0.10	496	650	173	65
			0.15	508	637	188	63
			0.20	513	649	307	62

During the second stage of the research, the concentration of petroleum products in the wastewater entering the hydrocyclone for treatment was in the range of 442-2937 *mg/l*, and mechanical impurities – 82-111 *mg/l*. The results of studies of wastewater treatment in hydrocyclones are shown in Figures 2 and 3.

Table 3b. Results of experimental studies.

Type of hydro-cyclone	Concentration of mechanical impurities, *mg/l*		The effect of cleaning by mechanical impurities, $E_{mi.}$%	Consumption, *l/s*		Capacity of the hydrocyclone, *l/s*
	in the source water, $C_{m.i.}^{sw.}$	in purified water, $C_{m.i.}^{ld.}$		From the upper drain	From the lower drain	
1	9	10	11	12	13	14
HC-40-III	198	77	61	0.292	0.118	0.410
	185	81	56	0.288	0.106	0.394
	202	93	54	0.275	0.101	0.376
	197	97	51	0.259	0.090	0.349
HC-40-V	206	80	61	0.342	0.220	0.562
	204	84	59	0.337	0.201	0,538
	195	84	57	0.318	0.192	0.510
	191	90	53	0.281	0.183	0.464
HC-75-II	193	71	63	0.550	0.841	1.391
	201	80	60	0.543	0.819	1.362
	189	85	55	0.527	0.756	1.283
	196	93	53	0.515	0.672	1.187
HC-75- III	194	66	66	0.931	0.248	1.179
	202	73	64	0.916	0.237	1.164
	199	86	57	0.872	0.212	1.084
	187	69	63	0.865	0.189	1.054
HC-80-I	192	67	65	0.985	0.269	1.254
	203	67	67	0.958	0.251	1.204
	197	81	59	0.937	0.244	1.181
	195	86	56	0.922	0.226	1.137
HC-100-I	182	67	63	2.427	0.395	2.822
	200	78	61	2.393	0.387	2.780
	198	87	56	1.978	0.381	2.359
	185	91	51	1.869	0.374	2.243
HC-100-II	207	85	59	1.529	1.053	2.582
	189	83	56	1.503	1.045	2.548
	187	90	52	1.490	1.036	2.526
	190	97	49	1.462	1.020	2.482

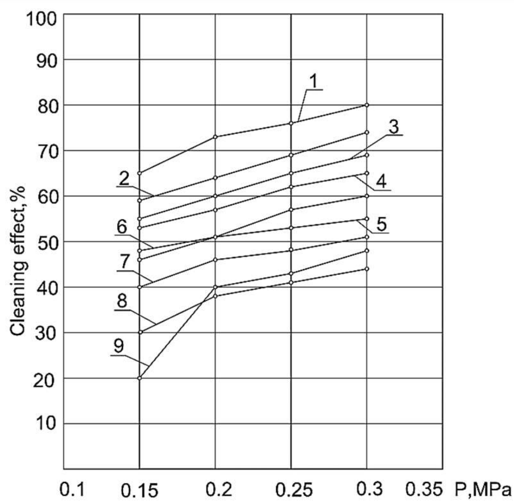

Fig. 2. Dependence of the efficiency of oily wastewater treatment for petroleum products on the pressure at the inlet to the hydrocyclone: 1 – HC-75-II; 2 – HC-75-I; 3 – HC-75-III; 4 – HC-75-VI; 5 – HC-75-VII; 6 – HC-75-VI; 7 – HC-75-VIII; 8 – HC-75-IX; 9 – HC-75-V.

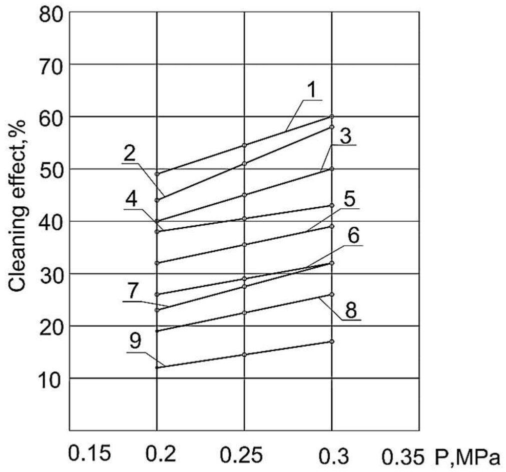

Fig. 3. Dependence of the efficiency of oily wastewater treatment by mechanical impurities on the pressure at the inlet to the hydrocyclone: 1 – HC-75-III; 2 – HC-75-II; 3 – HC-75-I; 4 – HC-75-VI; 5 – HC-75-IV; 6 – HC-75-III; 7 – HC-75-V; 8 – HC-75-VII; 9 – HC-75-IX.

4 Conclusion

The conclusions drawn from this study can be summarized in the following statements. Results of the first stage of research.

It is established that hydrocyclones with a diameter of 40 mm have a high efficiency of cleaning of oily wastewater, but a small capacity, and hydrocyclones with a diameter of 100 mm have a large capacity, but for their effective operation, a greater pressure at the inlet to the hydrocyclone is required. The pressure hydrocyclone HC-80-I has shown a high efficiency of wastewater treatment from mechanical impurities, but has a low efficiency of wastewater treatment from petroleum products. According to the research results, the pressure hydrocyclone HC-75-II is recommended for the treatment of oily wastewater.

The results of the second stage of research:

a) the efficiency of wastewater treatment for petroleum products was 20-80%, and for mechanical admixtures 12-60%;

b) as the pressure increases, the performance and efficiency of the hydrocyclones increases;

c) for the treatment of oily wastewater, it is recommended to use a hydrocyclone of the HC-75-II type.

According to the results of experimental studies, the possibility of sufficiently effective treatment of oily wastewater from machine-building enterprises in pressure hydrocyclones has been established. The geometric parameters of the pressure hydrocyclone for the treatment of oily wastewater are determined. The experimental data obtained were used in the calculation and design of industrial plants HSB-300 with a capacity of 300 m^3/day and the hydrocyclone installation-sump HIS-150 with a capacity of 150 m^3/day. These installations consist of pressure hydrocyclones HC-75-II and sedimentation tanks of the lower and upper drains, equipped with distribution, collection systems and oil collecting devices.

References

1. M.I. Farakhov, A.G. Laptev, M.M. Basharov. Theor. Found. Chem. Eng. **49**, 815 (2015). DOI: 10.1134/S0040579515060032.

2. Y. Zhang, A. Chen, P. Zhang, Y. Zhou, T. Zhang. WaterScience Technol. **77** (8), 77 (2018). DOI: 10.2166/wst.2018.121.
3. E. Torfs, M.C. Martí, F. Locatelli, S. Balemans, R. Bürger, S. Diehl, I. Nopens. Water Science And Technology **75** (3), 39 (2017). DOI: 10.2166/wst.2016.485.
4. H. Gao, M.K. Stenstrom. Water Res. **143**, 445 (2018). DOI: 10.1016/j.watres.2018.06.067.
5. J. Yu, J. Fu. Sep. Sci. Technol. **55**, 313 (2020). DOI: 10.1080/01496395.2019.1565772.
6. T. Han, H. Liu, H. Xiao, A. Chen, Q. Huang. Chem. Eng. Res. Des. **145**, 12 (2019). DOI: 10.1002/cite.2019.00064.
7. X. Yang, M.J.H. Simmons, P. Liu, Y. Zhang, L. Jiang. Sep. Sci. Technol. **54**, 2959 (2019). DOI: 10.1080/01496395.2018.1548486.
8. Sriyono, R. Kusmastuti, S.L. Butarbutar, D.H. Salimy, Febrianto, I.D. Irianto, M. Pancoko, G.R. Sunaryo. J. Phys. Conf. Ser., (2019). DOI: 10.1088/1742- 6596/1198/2/ 022040.
9. M. Ghodrat, S.B. Kuang, L. Ji, A.B. Yu. Miner. Eng. **90**, 55 (2016). DOI: 10.1016/j. mineng. 2016.03.017.
10. A.V. Busarev, A.S. Selyugin, N.S. Urmitova, F.F. Kayumov. Izv. KGASU **2** (36), 15 (2016).
11. A. Busarev, A. Selyugin, R. Abitov. Int. Conference «Scientific Res. SCO Countries» Sunergy And Integr. **166**, (2019).
12. N. Urmitova, R. Abitov, A. Nizamova. *IOP Conf. Ser. Mater. Sci. Eng.* (2020). DOI: 10.1088/1757-899X/890/1/012151.
13. X. Wei, M. Kazemi, S. Zhang, F.A. Wolfe. Water Environ. Res. **92**, 1695 (2020). DOI: 10.1002/wer.1424.
14. M. Coha, G. Farinelli, A. Tiraferri, M. Minella, D. Vione. Chem. Eng. J. **414**, (2021). DOI: 10.1016/j.cej.2021.128668.
15. A.D.F. Ferreira, D.R.B. Coelho, R.V.G. dos Santos, K.S. Nascimento, F.A. Presciliano, F.P. da Silva, J.C. Campos, F.V. da Fonseca, C.P. Borges, S.E. Weschenfelder. Environ. Sci. Pollut. Res. **28**, 12803 (2021). DOI: 10.1007/s11356-020-11265-2.
16. P.N. Egbuikwem, J.C. Mierzwa, D.P. Saroj. Bioresour. Technol. **318**, (2020). DOI: 10.1016/j.biortech.2020.124200.
17. N. Makisha. IOP Conf. Ser. Earth Environ. Sci. (2020). DOI: 10.1088/1755-1315/459/4/042015.
18. O. Khalifa, F. Banat, C. Srinivasakannan, F. AlMarzooqi, S.W. Hasan. J. Clean. Prod. **289**, (2021). DOI: 10.1016/j.jclepro.2020.125764.
19. E. Abdollahzadeh Sharghi, A. Shourgashti, B. Bonakdarpour. Bioprocess Biosyst. Eng. **43**, 981 (2020). DOI: 10.1007/S00449-020-02294-9.
20. T. Kedrova, L. Khisameeva, R. Abitov. IOP Conf. Ser. Mater. Sci. Eng. (2020). DOI: 10.1088/1757-899X/890/1/012152.
21. V.V. Khaustov, V.V. Bredikhin, T.V. Khaustova, IOP Conf. Ser. Mater. Sci. Eng. (2019). DOI: 10.1088/1757– 899/687/066063.
22. L.A. Nikolaeva. Therm. Eng. **67**, 751 (2020). DOI: 10.1134/s0040601520100080.
23. A.B. Adelshin, A.V. Busarev, A.S. Selyugin, L.R. Khisameeva. Izv. KGASU **2** (12), 57 (2009).
24. S. Oladzad, N. Fallah, B. Nasernejad. Water Sci. Technol. **76**, 57 (2017). DOI: 10.2166/wst.2017.185.
25. T. Krahnstöver, A. Zenker, M. Baggenstos, B. Kobler, K. Leikam, G. Koch, T. Wintgens. Environ. Sci. Water Res. Technol. **5**, 2172 (2019). DOI: 10.1039/c9ew00658c.
26. J. Lee, M. Lee. Water Sci. Technol. **79**, 771 (2019). DOI: 10.2166/wst.2019.097.
27. S. Verma, A. Daverey, A. Sharma. Environ. Sci. Pollut. Res. **26**, 34148 (2019). DOI: 10.1007/s11356-018-3551-4.
28. B.M. Gareev, A.V. Busarev, A.S. Selyugin, F.F. Kayumov. Collect. Sci. Pap. X Int. Sci. Conf. Eurasian Sci. Assoc., 48 (2015).