Regeneration of a fibrous sorbent based on a centrifugal process for environmental geology of oil and groundwater degradation

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Data were obtained in the experimental study of the process of regeneration of the fibrous sorbent centrifugally. This data characterised the dependence of the sorption rate of fibre loss in the regeneration of fibrous sorbent quality. We found that the increase of sorbent samples regeneration cycles based on polyethyleneterephthalate (PET) fibre of 1 to 50 leads to sorption reduction ratio of 20 ... 60 % and a weight loss of sorbent is 25-47 %. If the shelf life is increased up to three years, the sorbent does not reduce the rate of sorption and leads to increased sorbent losses due to its mechanical destruction during regeneration in a custom installation centrifugal experimental stand. It was established experimentally that the rate of oil sorption and oil, defined as the ratio of the mass of oil sorbed to the weight of the sorbent used, depends on the mean diameter of the fibres, the sorbent structure and viscosity petroleum products and varies between 5-20. It is also believed that all of the capillaries are filled uniformly and completely with a liquid. Another result of this research is the increase in the process productivity by increasing the average diameter of fibres, reducing the transverse dimension of the fibrous sorbent and increasing the radius and angular speed of the centrifuge perforated drum. A new experimental stand for centrifugal plant separating oil products from fibrous sorbent material has been proposed, which could be used to fight the oil pollution. This is the method used in environmental geology in the degradation of oil. Such a method can be extended to lower the groundwater or geological drilling.

Key words*: fibrous sorbent, polyethyleneterephthalate fibre, ecotechnology, adsorption coefficient, regeneration centrifugally, centrifugal installation, regeneration process, cycles, environment*

Introduction

To cope with the consequences of oil spills, for example, oil on the water surface (Blistan and Pačaiová, 2011), accidents of oil drilling equipment or accidents of ships transporting oil (Ibrahim, Wang, 2010; Lin et al., 2012) and (Husseien et al., 2009), the importance of testing new experimental centrifugal unit stands for oil product separation from fibrous sorbent units increases. Designed and manufactured by centrifugal test, a bench installation for the regeneration of fibrous sorbents products is one of the most important machines required for solving the problem mentioned above.

As shown earlier by studies made by the authors (Sviatskii et al., 2010), the sorption process of oil from water surface for these purposes should be used as a sorbent staple polyethyleneterephthalate (PET) fibres. Such a fibre blowing process is performed by streams of molten feedstock - primary or secondary airflow of PET blow head using the original design.

It was established experimentally that the rate of oil sorption and oil, defined as the ratio of the mass of oil sorbed to the weight of the sorbent used, depends on the mean diameter of the fibres, the sorbent structure and viscosity petroleum products and varies between 5-20. The proposed sorbent, unlike, for example, from coal thermal cracking sorbent STRG, can repeatedly be used (Han et al., 2015; Flegner et al., 2015).

Methods and materials research

Water contaminated by oil represents a big environmental concern. Oil is a very important commodity as a global source of energy any oil spillage is therefore not only an environmental issue, but also poses as an economic loss (Akhzat et al., 2006; Tijani et al., 2016). Various technologies have been proposed to deal with the given issue of wastewater treatment, such as absorption, filtration, membrane technology and physical,

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mechanical, biological and photochemical method (Yim et al., 2012; Han et al., 2015). The most common is the absorption, or filtration, by porous sorbents (Zhang et al., 2014), such as polypropylene, polyester, polyurethane and other synthetic polymers or acrylic resin (Sabir, 2015; Haoyi et al., 2014).

The number of crude petroleum spillages of various scales has increased in the past as a result of the extensive use and transport of crude petroleum and petroleum products. The mentioned spills may contaminate large areas of the sea, as well as its shores, which can lead to major problems for the environment due to many compounds contained in petroleum, which are toxic to aquatic organisms, birds and humans (Lin et al., 2012; Wu et al., 2014). Moreover, atmospheric pollution can be caused by the evaporation process of the toxic volatile constituents of petroleum spills. Thus, different methods have been proposed for the removal of petroleum from the water surface, such as thermal, biological, mechanical and physiochemical (using coagulants and adsorbent materials) techniques (Sayed, 2006; Gammound et al., 2007). The mot effective and safe method for the given tasks so far seems to be the removal of petroleum spills by adsorbent materials (Ray et al., 2008) and (Flegner et al., 2015).

It was necessary to solve three problems in the process of testing an experimental stand of centrifugal installation.

The first task - to verify the possibility of reusable PET fibres of different qualities as a sorbent for the collection of oily liquids to determine the dependence of sorption rate on some fibre samples using regeneration cycles designed and manufactured experimental stand the centrifugal unit.

The second task - to verify the use of PET fibre with a long shelf life for the sorption of oily liquids to determine the dependence of fibre loss in the process of regeneration of the number of regeneration cycles.

The third problem - the dependence of experimentally determine performance regeneration process centrifugally fibrous sorbents of the mean diameter of the filaments and check so according to the analytical value obtained previously.

When performing tests of experimental stand of centrifugal installation, the following prototypes of fibrous sorbent samples sorbed oil and measuring tools were used (Božek, 2014).

As the fibrous sorbent material (Sviatskii et al., 2015) and (Bobkova et al., 2015), subjected to forced initially saturate the petroleum product to a maximum sorption rate, and then - the regeneration in the test sample, two test bench PET fibers of different qualities, obtained at different times, were used. The first sample, shown in Figure 1 - a polymer fibre is white, diameter monofilament d = 0.08-0.1 mm, produced by the method of blowing a jet of molten recycled white PET stream of compressed air two weeks before the tests conducted. The second sample, shown in Figure 2 - the polymeric fibre red diameter monofilament d = 0.04-0.06 mm, obtained in the same manner from recycled red PET. This sample was made three years ago and stored at the temperature changes from minus 10 °C to plus 25 °C and a constant humidity of more than 60 % for the entire period (Oti Moto, 2006; Oti Moto, 2007; Oti Moto, 2014).

Fig. 1. A sample of white PET fibre.

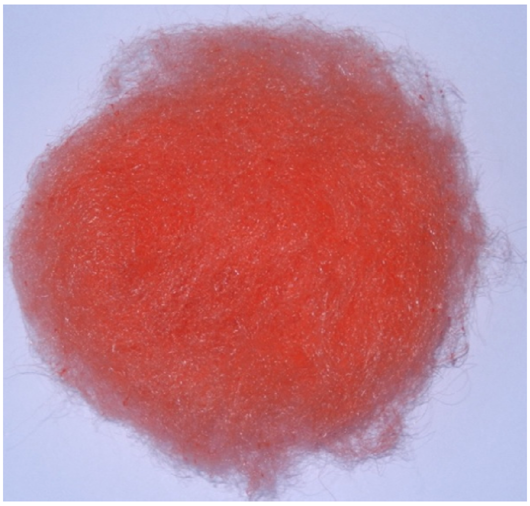

Fig. 2. A sample of red PET fibre.

As an oily liquid, which is saturated with sorbent samples of fibrous products as defined above, in the pilot study in the test stand of centrifugal installation, an industrial oil I-20A was used, with the characteristics: kinematic viscosity - 29.8 mm^2/s; density at 200°C - 867 kg/m^3. Note that we distinguish the dynamic viscosity (unit of measurement in the International System of Units (SI) - Pa·s, in the GHS system - Poise; 1 Pa·s = 10 poise) and kinematic viscosity (SI units - m^2/s, in the GHS - Stokes, off-system unit - Engler degrees). The kinematic viscosity is determined as a ratio to the fluid dynamic viscosity and density owes its origin to the classical methods of viscosity measurements, such as measuring a predetermined volume of flow time through the orifice under gravity. Further, the tests used in industrial oil I-20A will be called simply the liquid (Angelova, 2011).

The main parameters of the test process - the mass of the test specimens of fibre products to the saturation of oily liquid after saturation and after regeneration in the experimental stand of centrifugal installation and duration of the centrifugation process was measured using an electronic scale with a scale division of 0,01 g and an electronic timer with scale division 0,1 s.

Fig. 3. An example of the experimental stand of centrifugal installation.

The base unit in the manufacture of experimental stand of centrifugal separation plant for oily products from fibrous sorbent material used household juicer centrifugal type. An example of the experimental stand and his scheme are presented in Figures 3, 4.

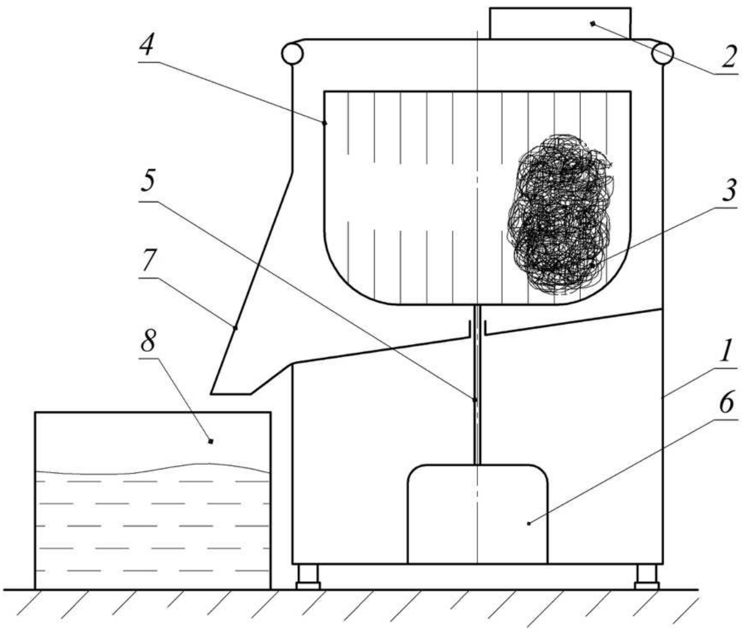

Fig. 4. Scheme of the experimental stand of centrifugal installation.

Experimental stand for the installation of centrifugal separation of the liquid from the fibrous sorbent consists of a housing made out of plastic (marked as 1 in Figure 4) with a quick cover (marked as 2). The housing is placed on a shaft (5), which is connected to an electric motor (6). The shaft rigidly fixes a perforated drum (4). A quick release cover 2 is fixed to the guard member 7 with a tray drain liquid. The kit also includes a stand for collecting liquid container 8, which is not shown in general form.

The perforated drum 4 is made of lightweight aluminium alloy and has an outer diameter of 150 mm and height 65 mm. The cylindrical surface drum has 5887 holes of 1 mm diameter with a pitch of 2 mm. The internal cavity of the drum was 1000 cm^3. The perforated drum was balanced to reduce vibration during its rotation.

The tests were carried out as follows (Sentyakov et al., 2016; Wahi et al., 2013). Just note that each of the two discussed above fibrous sorbent samples in the form of PET fibre was tested using an experimental stand of centrifugal installation 51 times. Each time before each experiment, the samples were placed for a few seconds in a vessel with the liquid and saturated to the maximum possible liquid volume so that it occurred not more 5 times a minute after removal from the vessel draining from them of liquid droplets (Mokrejs et al., 2016) and (Yang et al., 2016; Pang et al., 2016). At the same time, with the use of electronic scales, we determined the mass m_1 of the sample to liquid saturation and weight m_2 sample after fluid saturation, as well as the calculated mass of sorbed liquid sample. The sorption coefficient is then determined by the formula:

$$K_s = m_2 / m_1 \tag{1}$$

Tab. 1. Results of the study of the regeneration process.

Number of regeneration cycles	**Red PET fibre**			
	Mass of fibres with oil, [g]	**Mass separated oil,** [g]	**Weight fibre**, [g]	**Sorption coefficient K_s**
1	118,80	105,23	8,60	16,11
2	128,61	104,34	8,53	12,13
3	130.32	120,06	8,56	14,07
4	129,12	109,10	8,51	12,74
5	119,25	110,78	8,59	13,02
6	121,02	111,09	8,45	12,93
10	118,84	104,26	7,82	12,33
11	115,39	103,49	7,93	13,23
15	116,04	107,06	7,90	13,50
16	114,08	100,26	6,82	12,7
20	89,19	80,81	6,68	11,85
21	92,01	85,87	6,72	12,85
25	83,93	70,81	6,50	10,53
26	88,31	80,70	6,42	12,41
30	87,22	84,81	6,50	13,21
31	86,70	80,97	5,63	12,45
40	75,22	69,81	5,67	12,40
41	69,96	61,70	4,49	10,88
50	53,89	49,04	3,90	10,92
51	38,11	43,04	3,07	11,04
Number of regeneration cycles	**White PET fibre**			
1	124,79	112,91	11,37	10,33
2	127,82	117,39	11,22	10,32
3	128,79	116,32	11,65	10,36
4	129,06	118,21	11,57	10,14
5	128,83	117,80	10,98	10,18
6	126,76	115,96	11,08	10,56
10	121,39	112,0	11,01	10,11
11	118,52	110,87	10,72	10,07
15	120,09	111,43	10,87	10,39
16	120,31	109,07	10,83	10,03
20	123,01	111,57	10,81	10,30
21	119,51	108,15	10,93	10,0
25	98,01	87,57	10,11	8,02
26	84,51	78,15	9,97	7,73
30	77,01	74,54	9,70	7,47
31	79,51	74,15	9,73	7,64
40	75,63	69,92	9,59	7,19
41	76,25	66,99	9,52	6,98
50	79,43	66,85	8,28	7,02
51	74,65	60,98	8,29	7,36

After that, the sample liquid saturated fibrous sorbent was placed through a hole in the top cover in the centrifugal drum test bench setup, which was rotated (Janacova et al., 2015; Janacova et al., 2013). The drum acceleration time was 4 seconds to the speed of 0 to 800 rpm. The total time of centrifuging samples in each experiment was constant at 7 seconds. During this time, almost all the liquid from the sample of the fibrous sorbent passed beyond the perforated drum in a receptacle by centrifugal forces (Stojadinovic et al., 2014). Then, the sample was weighed again, saturated with liquid and centrifugation took place in the experimental drum stand. Thus, it was performed on 51 of each regeneration cycle of the two above described fibrous sorbent samples based on the PET fibre. Note that after each regeneration cycle, the sample mass decreases. The coefficient of fibre loss in each subsequent cycle of regeneration Kl is determined according to the formula (Sviatskii et al., 2014):

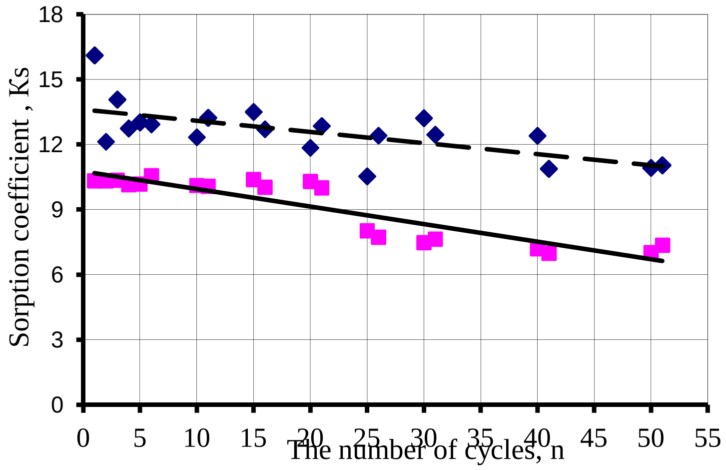

Fig. 5. Dependence of the sorption coefficient Ks on the number of regeneration cycles n (dashed line - red fibre, solid line - white fibre).

Tab. 2. Results of mass loss study of samples of fibrous sorbent during regeneration.

Number of regeneration cycles	**Red PET fibre**		**White PET fibre**	
	Weight fibre, [g]	**Coefficient of fibre loss K_l**	**Weight fibre**, [g]	**Coefficient of fibre loss K_l**
1	8,60		11,37	
2	8,53	0,99	11,22	0,98
3	8,56	0,99	11,65	1,02
4	8,51	0,98	11,57	1,02
5	8,59	0,99	10,98	0,96
6	8,45	0,98	11,08	0,97
10	7,82	0,91	11,01	0,97
11	7,93	0,92	10,72	0,94
15	7,90	0,92	10,87	0,95
16	6,82	0,79	10,83	0,95
20	6,68	0,77	10,81	0,95
21	6,72	0,78	10,93	0,96
25	6,50	0,75	10,11	0,88
26	6,42	0,74	9,97	0,87
30	6,50	0,75	9,70	0,85
31	5,63	0,65	9,73	0,85
40	5,67	0,66	9,59	0,84
41	4,49	0,52	9,52	0,83
50	3,90	0,45	8,28	0,72
51	3,07	0,36	8,29	0,72

$$K_l = m_{fn} / m_{f1} \qquad (2)$$

Where:
m_{fn} - fibre sample weight after each cycle of regeneration, [g];
m_{f1} - fibre sample weight after the first regeneration cycle, [g].

The simplified experimental design of the stand will perform the verification of the mathematical modelling results in the process of oil liquid separation from the fibrous sorbent material. This approach will have minimal costs and will not compromise the reliability of the results (Straka, 2014). The results are shown in Tables 1, 2 and the graphs in Figures 4, 5.

Note that in Tables 1 and 2, not all the 50 results of regeneration cycles of fibrous sorbents samples are shown; regeneration cycles during the experiments that were not fixed are not shown in some of the tables, but these cycles were carried out in the same manner as all the others. The increase in the loss ratio in the regeneration of 3 and 4 is greater than one cycle; it is not a sign that the sample weight has increased, it is due to an error of the experiment - probably, that these experiments could not fully recover the sample and the increase in weight due to the persistence in it a certain number of no remote oil. This explains the error and an increase in mass of the sample regeneration in cycles 6 and 21 compared with previous cycles 5 and 20.

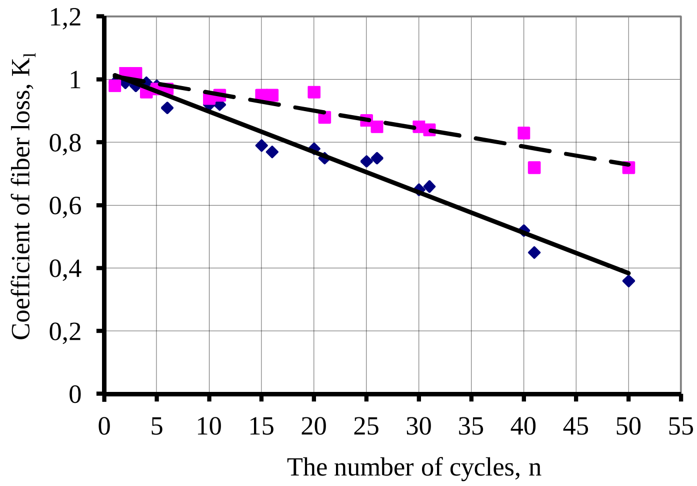

Fig. 6. Dependence of coefficient of fibre loss K_l of the number of regeneration cycles n (dashed line - red fibre, solid line - white fibre).

When the number of regeneration cycles of 1 to 51 ratio there is a decrease of sorption coefficient: red PET fibre sorbent - from 9,77 to 16,7, white PET fibre sorbent - from 11,4 to 9,02. The results are shown in graphs in Fig. 6.

This results in weight loss of regenerable sorbent samples: red sorbent weight decreased from 6,53 to 3,07 g and white sorbent weight decreased from 10,93 to 8,29 g.

It is the method used in environmental geology in the degradation of oil. Such a method can be extended to lower the groundwater or geological drilling.

Results and discussion

The experimental study described in this paper has confirmed the results of the theoretical calculations and showed that the increase of the regeneration cycles, from 1 to 50, for the PET fibre sorbent, decreased its sorption rate by 20 – 60 % and generated a weight loss of 25 – 47 %.

The process of the experimental centrifugal stand is described as follows:

A saturated liquid petroleum product and a fibrous sorbent are placed through a hole in the top cover of the stand into the inner cavity of the perforated drum, which is driven by rotation. The centrifugal forces force the product and fibrous sorbent on the peripheral surface of the drum, where the movement into the inner cavity through holes takes place.

The described process was used to build an experimental centrifugal separation stand for oil products from fibrous sorbent to verify the results of the above simulation (Stojadinovic et al., 2014). Because the experimental study of the separation of oil liquids from fibrous sorbent material is made in the laboratory at room temperature using a small sample of sorbent articles, the experimental stand construction was simplified. The perforated drum experimental stand is cylindrical - shaped without cells to accommodate large items in the form of cylindrical booms and without nozzle arrangements for the supply of steam or hot air. This simplified experimental design of the stand will perform an experimental verification of the results of mathematical modelling of the process of separation of oil liquids from fibrous sorbent material with minimal cost and without compromising the reliability of the results.

Conclusions

Mathematical modelling of the centrifugal method for separation of oil from fibrous sorbent articles was used, for instance, to determine the dependence of liquid separation process from the fibrous sorbent, as well as operating radius of the perforated centrifuge drum, or the viscosity of the sorbed liquid. The experiments, described in this paper, have resulted in the approval of the theory stating, that the productivity of the sorption process significantly increases with the increase of the average diameter of the filaments forming the fibrous sorbent article, as well as with the increase of frequency and radius of rotation of centrifuge and with reduction of the transverse dimension of the fibrous sorbent products. The application of this method will be in environmental geology in the degradation of oil. Such a method can be extended to lower the groundwater or geological drilling (mining industry).

This result should not be considered as a disadvantage of the fibre sorbent based on PET fibre, so the need to use a sorbent 50 times is unlikely - oil spills and oil products in the same region do not occur so often. Even if we have to use the sorbent 10 times during the liquidation of the consequences of the oil spill - the sorption coefficient decreases by only 3 - 5 %, which does not affect the overall efficiency of the process. Increased shelf life of up to three years sorbent does not reduce the rate of sorption and leads to increased losses in the adsorbent regeneration process in the manufactured test bench centrifugal installation 10 – 20 %.

References

Angelova D., Uzunov I., Uzunova S., Gigova A., Minchev L.: Kinetics of oil and oil products adsorption by carbonized rice husks, *Chem. Eng. J. 172 (1), pp. 306 – 311, 2011*.

Bediako K., Wei W., Yun S.: Conversion of waste textile cellulose fibers into heavy metal adsorbents. In *Journal of Industrial and Engineering Chemistry. Volume 43, 25 November 2016, Pages 61-68, 2016.*

Blistan, P., Pačaiová, H.: Modelling environmental influence on the pipeline integrity. In: SGEM 2011, 11th International Multidisciplinary Scientific GeoConference, Conference Proceedings Volume 2, 20-25 June, 2011, *Bulgaria. Sofia, 2011 P. 645-652. ISSN 1314-2704*

Bobkova L., Skvortsova N., Naumova, B., Kashkan, G.: Ion-exchange separation and concentration of ions of rare-earth elements on fibrous sorbents. In International Scientific Conference on Multifunctional Chemical Materials and Technologies, MCMT 2015; Tomsk; Russian Federation; 21 May 2015 through 22 May 2015, *Key Engineering Materials, Volume 670, Pages 270-275, 2015*.

Božek P., Turygin, Y.: Measurement of the operating parameters and numerical analysis of the mechanical subsystem. In *Measurement Science Review. Vol. 14, No. 4 (2014), pp. 198-203. 2014*.

Flegner, P., Kačur, J., Durdán, M., Laciak, M.: Application of adaptive filters in rock separation by rotary drilling process identification. *Acta Montanistica Slovaca, Volume 20, number 1, pp. 38-48, ISSN 1335-1788, 2015*.

Han, G., de Wit, J.S., Chung, T.S.: Water reclamation from emulsified oily wastewater via effective forward osmosis hollow fiber membranes under the PRO mode. *Water Res., 81, pp. 54–63, 2015*.

Husseien, M., Amer, A.A., El-Maghraby, A., Taha, N.A.: Availability of barley straw application on oil spill cleanup, Int. *J. Environ. Sci. Tech. 6 (1), pp.123-130, 2009.*

Ibrahim, S., Wang, S.: Ang, H.M.: Removal of emulsified oil from oily wastewater using agricultural waste barley straw, *Biochem. Eng. J., 49 (1), pp. 78–83, 2010*.

Janacova D., Mokrejs P., Vasek V., Drga R., Liska O., Krenek J.: Mathematic model of heat transport in materials during cutting process. In 26th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2015; *University of Zadar; Croatia*; 21 October 2015 through 24 October 2015

Janacova D., Mokrejs P., Vasek V., Drga R., Liska O., Piteľ J., Zálešák M.: Verification of diffusion mathematical model for long-term materials drying. In *International Journal of Mathematical Models and Methods in Applied Sciences. Volume 7, Issue 11, Pages 907-914, 2013*.

Lin, J., Shang, Y., Ding, B., Yang, J., Yu, J., Al-Deyab, S.S.: Nanoporous polystyrene fibers for oil spill cleanup, *Mar. Pollut. Bull., 64, pp. 347–352, 2012*.

Mokrejs P., Janacova D., Benicek L., Plachy T., Svoboda P.: Optimising conditions for preparing collagen-type hydrolysates. In *Journal of the Society of Leather Technologists and Chemists, Volume 100, Issue 3, May-June 2016, Pages 114-121, 2016*.

Oti Moto P.M.: Analysis existing methods of drying and removing moisture from the timber, Proceedings of the St. Petersburg Forestry Academy. Collection of reports of young scientists at the annual scientific conference of the St. *Petersburg Forestry Academy: Vol. 11. St. Petersburg; SPbGLTA, pp. 98-102, 2006.*

Oti Moto P.M.: Study of quality of dehydrated timber during storage, Proceedings of the St. Petersburg Forestry Academy. Articles of young scientists, selected on the basis of annual scientific conference of the St. Petersburg Forestry *Academy number 13: Vol. 181 - St. Petersburg; SPbGLTA, pp. 145-150, 2007*.

Oti Moto P.M.: The economic efficiency of the centrifugal method of timber dehydration, Proceedings of the St. Petersburg Forestry Academy. *St. Petersburg; SPbGLTA, 2008*.

Pang L., Li R., Gao H., Hu T., Xing Z., Zhang X., Wang H., Wu Z.: Functionalized and reusable polyethylene fibres for Au(III) extraction from aqueous solution with high adsorption capacity and selectivity. In *RSC Advances. Volume 6, Issue 90, 2016, Pages 87221-87229, 2016.*

Stojadinovic S., Pantovic R., Zikic M., Stojanovic G.: FEM Comparison of crack response to blasting ground vibrations and environmental changes. In *Acta Montanistica Slovaca Vol. 19(2014), No. 4, pp.175-181*

Straka, M., Bindzár, P., Kaduková, A.: Utilization of the multicriteria decision-making methods for the needs of mining industry. *Acta Montanistica Slovaca, Volume 19 (2014), number 4, pp. 199-206, ISSN 1335-1788.*

Sviatskii V., Sentyakov B.A.: The fibrous sorbent for collecting oil on the basis of polyethylene terephthalate. Prevention of accidents of buildings and structures: Proceedings, *Issue 9 - Moscow, 2010. - pp. 631-634, 2010*.

Sviatskii V., Sentyakov B.A., Sviatskii M., Sentyakov K., Garayev S.: Simulation of the process of fabrication canvas with fibrous materials, *Vestnik ISTU, No. 2., Izhevsk 2015, pp.17-20*.

Sviatskii V., Sentyakov B.A., Sviatskii M., Shirobokov K., Fonareva K.: The process of obtaining and practical use of polyethylene terephthalate fiber from recycled materials (monograph). - *Stary Oskol: Publishing house "TNT", 2014. – pp. 162, 2014.*

The patent for invention №2476272 of Russian Federation.: Centrifugal apparatus for separating liquid from fibrous material. K.A.Fonareva, B.A.Sentyakov, V.M.Svyatsky. *Publ. February 2013*.

Sentyakov B., Repko A., Sviatskii V., Soldan M., Nikitin Y.: Simulation of oil products separation from fibrous sorbent material centrifugally. *Acta Montanistica Slovaca, Vol.21(2016), No 3, pp. 238-246. ISSN 1335-1788 http://actamont.tuke.sk/ams2016.html*

Tijani M., Aqsha A., Mahinpey N.: Development of oil-spill sorbent from straw biomass waste: Experiments and modeling studies. In *Journal of Environmental Management. Volume 171, April 15, 2016, Pages 166-176.*

Wang X., Yu J., Sun G., Ding B.: Electrospun nanofibrous materials: a versatile medium for effective oil/water separation. In *Materials Today. Volume 19, Issue 7, 1 September 2016, Pages 403-414*

Wahi R., Chuah L., Choong T., Shean Y.: Oil removal from aqueous state by natural fibrous sorbent. In *Separation iand purification technology. Volume: 113 Pages: 51-63 Published: 7/ 2013*.

Yang L., Wang Z., Li X.: Hydrophobic Modification of Platanus Fruit Fibers as Natural Hollow Fibrous Sorbents for Oil Spill Cleanup. *Water air and soil pollution. Volume: 227, Issue: 9, Number: 346, 2016.*