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Experimental investigations of dynamic sorption of diesel from contaminated water

Dainius Paliulis

Vilnius Gediminas Technical University, Lithuania

*Corresponding author's e-mail: dainius.paliulis@vilniustech.lt

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Abstract: Surface wastewater pollution due to accidental runoff or release of oil or its products is a longstanding and common environmental problem. The aim of the study was to investigate the impact of concentrations of oil products (diesel) and suspended solids, the sorbent type, the water flow rate and the interfering factors (chlorides) on the dynamic sorption of diesel and to test regeneration of polypropylene after its use for sorption. The sorbents used for study included common wheat straw (*Triticum aestivum*), polypropylene and sorbents modified with hydrogen peroxide solution. Standard methods were used for the determination of the investigated parameters and an in-house procedure employing a gas chromatograph was used for the determination of diesel concentration. The following factors that impact the sorption of diesel were investigated during the study: diesel concentration, concentration of suspended solids; type of sorbent (common wheat straw (*Triticum aestivum*), wheat straw modified with hydrogen peroxide, and polypropylene), water flow rate; and influence of the interfering factors (chlorides). Filtration speed in the range of investigated speeds does not affect the efficiency of diesel removal. Removal efficiency does not depend on the concentration of diesel before the sorbent reaches its maximum sorption capacity. Filling containing 50% of polypropylene and 50% of wheat straw was used for the study. It was found that polypropylene and wheat straw do not remove chlorides and suspended solids from solution. The study found that the solution of hydrogen peroxide boosts the hydrophobic properties of common wheat straw, but does not affect the sorption of diesel. The recommended number of regenerations of polypropylene should be limited to two.

Introduction

Petrochemical products often cause deterioration of surface water and groundwater quality Hybská et al. (2018). Removal of hydrocarbons from the environment and safe extraction of oil are two major challenges for the oil industry (Varjani et al. 2015).

Many oil products end up in surface water bodies, causing surface runoff. Oil hydrocarbons are the prevailing pollutants of surface wastewater. Diesel fuels are complex mixtures that consist of a large number of hydrocarbons with C8 to C26 carbon molecules, as well as organic compounds of sulphur, nitrogen and oxygen (Vuruna et al. 2017). Dieseline contains from 2,000 to 4,000 hydrocarbons and is a complex mixture of linear, branched and cyclic alkanes and polyaromatic compounds obtained from the middle fraction of the distillate during oil separation process Mauricio-Gutiérrez et al. (2020). Oil spills and improper discharge of industrial wastes contribute to the rising contamination of the environment with petroleum hydrocarbons (Chandra et al. 2013). Many crude oil constituents are harmful and highly toxic due to the presence in them of toxic, carcinogenic and teratogenic components such as benzene, toluene, ethylbenzene, xylene and polycyclic aromatic hydrocarbons (Chandra et al. 2013). Inorganic compounds can contribute to the spread of oil pollution: suspended solids can carry hydrocarbons and various sediments and block the penetration of sunlight into water bodies. Oil hydrocarbons in the form of an immiscible liquid (fat, oil) accumulate on the surface of water bodies due to their lower density. Even a small amount of oil can contaminate a large area. For instance, a 1 μm-thick oil film significantly reduces the rate of oxygen transfer from atmosphere to water (Sari et al. 2018).

The Surface Wastewater Management Regulation lays down environmental requirements for the collection, treatment, and discharge of surface wastewater in order to protect the environment from pollution (The surface waste... 2019). The Regulation contains restrictions on concentrations of the pollutants discharged into general surface wastewater drains and into the natural environment. The Surface Wastewater Management Regulation of the Republic of Lithuania establishes the following concentrations of pollutants allowed for discharges of effluent directly into the natural environment: an average annual concentration of SS (suspended solids) stands at 30 mg/L (with a maximum instantaneous concentration of 50 mg/L), and an average annual concentration of OP (oil products) stands at 5 mg/L (with a maximum instantaneous concentration of 7 mg/L). A range of chemical and physical methods can be used for surface wastewater treatment

(Yalcinkaya et al. 2020, Lurchenko et al. 2019, Voronov et al. 2018, Kwasny et al. 2018). Sorption with a solid sorbent is one of the possible treatment methods. Sorbents can be used for the removal of oil products and organic pollutants from polluted water (Gushchin et al. 2018, Akpomie and Conradie 2021, Quím 2020, Rudkovsky et al. 2016, Paulauskiene 2018, Króla and Rożek 2020, Baiseitov et al. 2016).

Clay minerals and modified clay minerals are also widely used for removing oil products and organic pollutants from water and soil (Li et al. 2016, Moshe and Rytwo 2018, Bandura et al. 2017). Scientists have tested polypropylene and other types of plastic for the removal of hydrocarbons and other organic pollutants as well (Baig and Saleh 2019, Karyab et al. 2016, Thilagavathi and Das 2018, Mohammadi et al. 2020). The sorption efficiency of oil depends on the porosity of the sorbent: sorbents with higher porosity have higher sorption capacity. There are three stages of sorption: the first stage is the initial one, where sorption is most intensive during the first minute. This represents the most intensive process of oil products removal in the whole sorption process. The second stage is a transitional phase in which sorption is slowed down. The third stage is a constant phase in which sorption no longer occurs even with increasing contact time. The aim of the study was to investigate the influence of oil products (diesel) and suspended solids concentrations, sorbent type, water flow rate and interfering factors (chlorides) on the dynamic sorption of oil products (diesel).

Materials and methods

By using a mixture of tap water, cellulose and sodium chloride, contaminated water was artificially prepared to simulate the surface effluent and placed in a 100 l tank (Fig. 1). The flow rate was determined and the effluent level in the tank was kept constant by adding tap water, in order for the pressure not to affect the flow rate.

Water was supplied by a pump from the tank to a pipe where it was mixed with oil products. Dieseline was lifted from a smaller diesel tank by help of a rotary pump and mixed with the water stream. The mixture flowed through a pipe in which there were steps with 15 cm distance between them to cause stream turbulence and create better conditions for mixing water and diesel. Next, the mixture flowed out of the tube through a grid that distributes the water stream over the entire diameter of the column for more accurate estimation of sorption capacity. The test water, filtered through the layer of sorbent in the column, flowed through the valve at the bottom of the column.

In order to evaluate sorption, sampling of the water mixed with oil products was performed before it entered the column and after it exited the column at the bottom. Two kinds of sorbent were used in the experiment, namely, common wheat straw as a natural sorbent, chosen due to its ability to remove water-immiscible organic matter; and polypropylene as a synthetic sorbent, chosen due to its ability to efficiently remove high concentrations of organic matter and solvents. Sorption of oil products was tested in three cases. In all the cases, the column height and filling height were 100 cm and 90 cm, respectively (Figure 2):

1. The column was filled with polypropylene.
2. The column was filled with common wheat straw.
3. The column was filled with a combination of polypropylene and common wheat straw (1:1 by height).

The experimental studies used two types of artificially contaminated aqueous solutions simulating road surface

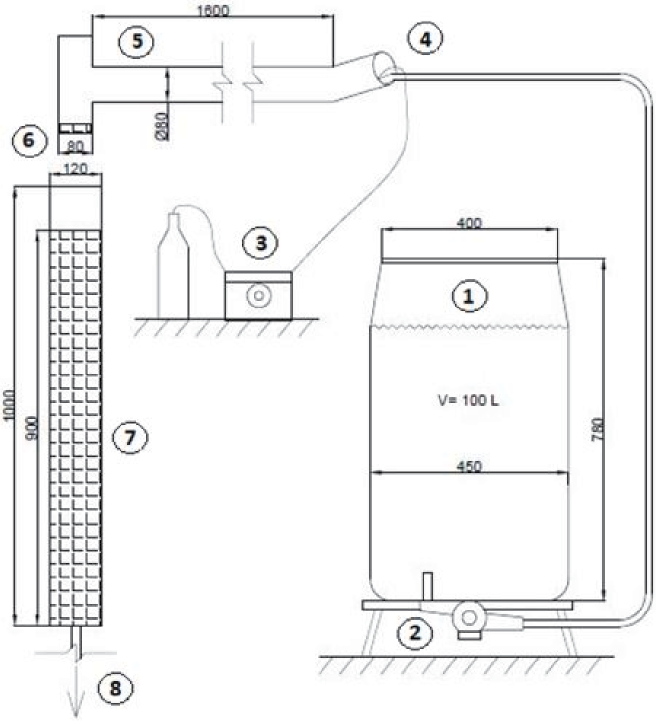

Fig. 1. Scheme of laboratory test bench: 1 – tank with water simulating surface wastewater; 2 – water pump; 3 – rotary pump for oil products; 4 – place of water and oil products supply; 5 – oil and water mixing pipe; 6 – water outlet; 7 – column with sorbent; 8 – treated water outlet

effluents, one containing only oil products and the other containing a mixture of suspended solids and oil products. The study investigated the following factors that impact the sorption of oil products: the concentration of oil products, the concentration of suspended solids, the type of sorbent, the water flow rate, and the influence of the interfering factors (chlorides) on sorption.

The impact of the concentration of oil products on the sorption efficiency was tested in all the three abovementioned cases; the impact of flow, suspended solids, and chlorides was tested using a combined sorbent consisting of polypropylene and common wheat straw. A SHIMADZU gas chromatograph *GC-2010* with a flame ionization detector (FID) was used for the determination of diesel concentration. An in-house procedure was used, as solvent n-hexane was selected for the study. The solvent used for the in-house procedure was n-hexane and this was selected for the research. N-hexane and diesel were mixed through using a range of ratios and a calibration curve was drawn.

The concentration of chlorides in the test solution was determined in accordance with the Lithuanian standard LST ISO 9297: 1998. The concentration of suspended solids in the test solution was determined in accordance with the Lithuanian standard LAND 46-2007. The adsorbed amount (Q) was calculated based on the formula as follows:

$$Q = \frac{(C_i - C_f) \cdot V}{m} \tag{1}$$

where:
C_i – initial concentration of diesel (mg/L),
C_f – concentration of diesel after sorption, (mg/L),
V – the volume of test solution used for sorption (L),
m – the mass of the sorbent (g).The sorption efficiency (E) was calculated based on the formula as follows:

$$E = \frac{(C_i - C_f)}{C_i} \cdot 100,\ \% \tag{2}$$

where:
C_i – initial concentration of diesel (mg/L),
C_f – concentration of diesel after sorption, (mg/L).

Sorbents can be reused after regeneration. According to the results of the experimental studies, up to 10% of organic matter may remain in the sorbent after regeneration (Mandal and Mayadevi 2009). The solvent used for sorbent desorption must be highly soluble in oil products (e.g. diesel), such as methyl ethyl ketone, acetone, light oil, or n-hexane. Based on the results of a study of other researchers, n-hexane (C_6H_{14}) was used for the experiments (Maceiras et al. 2018).

During regeneration, the sorbent was placed in a column and treated with n-hexane. After 24 h, n-hexane was discharged through a valve at the bottom of the column. The second stage of regeneration was desorption of the solvent. The sorbent was washed with a mixture of ethanol: deionized water 1:1 (v/v) to remove residual solvent. After washing, the sorbent was dried to constant weight at 60 ± 2°C, the sorption of oil products was determined and compared with the previously determined sorption of a new sorbent.

Quality control

All chemicals and reagents were of analytical grade or higher purity and were used in the experiments as received without further purification. All volumetric flasks used in the experiments were soaked for 24 h in 5M HNO_3 and then rinsed 3–4 times carefully with deionized water. All the volumetric flasks were only the highest accuracy class. High accuracy analytical balance AS 60/220.R2 was used for weighing. Calibration curves for oil product analysis were created by using a gas chromatograph GC 2010 with a flame ionizing detector.

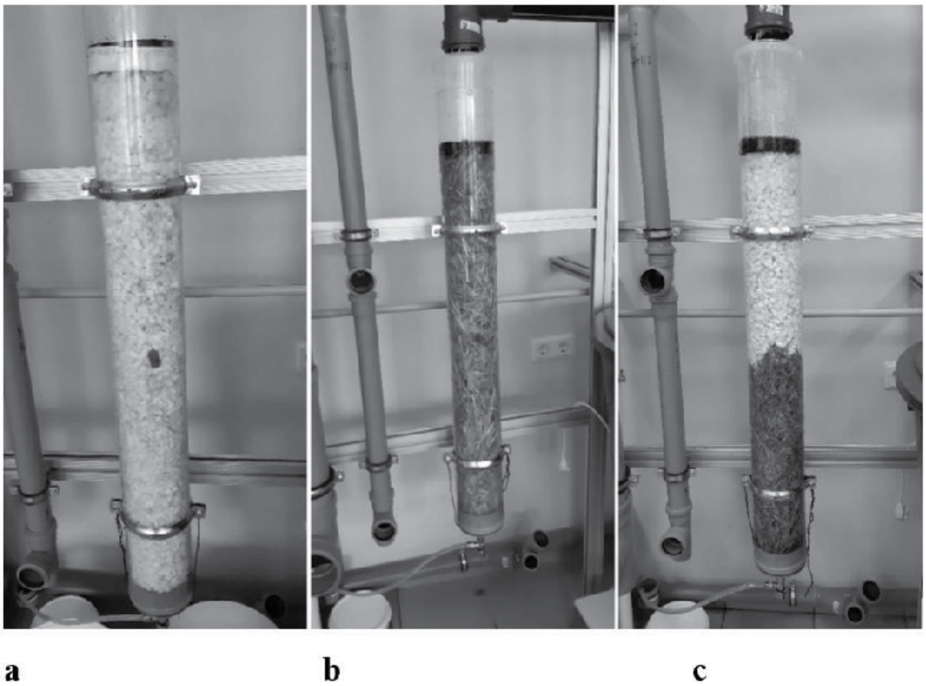

Fig. 2. Column packing options: a – polypropylene; b – common wheat straw; c – 50% polypropylene and 50% common wheat straw

All experiments were conducted in triplicate and the mean of the three was calculated. A *Shimadzu* gas chromatograph *GC-2010* with ф flame ionization detector was used for the determination of diesel concentration. An in-house procedure devised in a chemical laboratory and using n-hexane as solvent was selected for research. N-hexane and diesel were mixed using a range of ratios and a calibration curve was drawn.

Statistical analysis

Mean, standard deviation, and confidence intervals were calculated. Microsoft Excel 2016 software was used for statistical estimation. Based on Council Directive 98/83/EC of 3 November 1998, the result is acceptable when trueness and precision of the method is less than 10%. Trueness is a measure of systematic error, i.e., the difference between the mean value of a large number (10 measurements) of repeated measurements and the true value. Precision is a measure of random error and is usually expressed as standard deviation (within and between batches) of the spread of results from the mean. Acceptable precision is twice the relative standard deviation. Trueness and precision of the method were tested and the results for diesel (5 mg/L) were presented.

The result obtained in the study is the arithmetical average of concentrations of three samples, when distribution does not exceed 6%. Tests resulting in distribution exceeding 6% were repeated. The calculated confidence interval stands at 95%.

Results and discussion

Setting the filtration rate

The optimal filtration rate was determined during the experimental study, where the concentration of diesel (50 mg/L) was a constant. The following filtration rates were tested: 0.5, 1.0, 2.0, 2.5, and 3.0 L/min. The option of 3.0 L/min filtration rate was chosen due to the maximum possible speed of the water flow possible for generation in the column. Fig. 3 shows that the efficiency of diesel removal varies slightly (65–70%) when the filtration rate is changed (0.5–3.0 L/min). It can therefore be assumed that the filtration rate does not affect the diesel removal efficiency in the range the of studied filtration rates and no statistically significant difference was found between the obtained diesel removal efficiency results. For the purposes of the experimental study, a flow rate of 2.0 L/min was chosen, which is the maximum speed in the laboratory bench at which the column does not cause flooding.

A similar filtration rate of 1.3 L/min was used in other research, but this method of sorption, namely the one that employs a column, has not been studied adequately (Mažeikienė, Švedienė 2015). Various synthetic sorbents were tested for removing diesel from contaminated water by using a filled column (Vilunas et al. 2014, Mazeikiene et al. 2014)). It was determined that diesel removal efficiency was in the range of 91–99%, when diesel concentration was 30–158 mg/L. Most commonly used commercial sorbents are synthetic sorbents made of polypropylene or polyurethane. They have good hydrophobic and oleophilic properties (Deschamps et al. 2003). In the study, two natural sorbents were tested for the removal of diesel from contaminated water under dynamic conditions. Experimental results revealed that the removal efficiency was 87% and 37% for *Schoenoplectus lacustris* and *Acorus calamus*, respectively (Chaouki et al. 2020).

Influence of oil product concentration

The experimental study investigated the impact of oil product concentration on the efficiency of oil product removal using polypropylene. The following concentrations were tested: 10 mg/L (twice the permissible limit of 5 mg/L based on the Surface Wastewater Management Regulation), 20, 30, 40, 50, 60, 70, 80, 90, and 100 mg/L. The results in terms of efficiency of oil product removal at different concentrations are presented in Fig. 4. Oil product removal efficiency has been found to range from 65% to 88%. The efficiency varies regardless of

Table 1. Trueness and precision of method

Parameter	Trueness of diesel	Precision of diesel
Average value, mg/L	4.9	5.1
Assigned value, mg/L	5.0	5.0
Standard deviation, mg/L	0.21	0.24
Relative standard deviation,%	4.2	4.8
Acceptable trueness,%	8.4	9.6

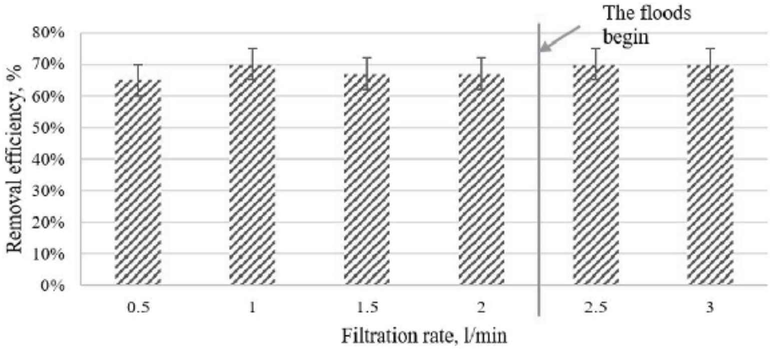

Fig. 3. Setting the optimal filtration rate for diesel removal

the concentration of oil product(s) in the filtered solution, so it can be assumed that the removal efficiency does not depend on the concentration of oil product(s) as long as the sorbent (polypropylene, in this case) reaches its maximum sorption capacity. The reason for the high (23%) difference in removal efficiency between the lowest and highest value may be error in the method selected for the determination of diesel concentration resulting from insufficient mixing of diesel with n-hexane.

A study by other researchers who used a column filled with polypropylene, but did not check for changes in the concentration of oil products, obtained removal efficiency of 85–87% by using a light fraction of oil product (diesel) (Bayat et al. 2005), Another study (Bayat et al. 2005) examined a range of sorbent grids that were made of straw, rice husks and polypropylene and were used for oil products collection at their spills. The study analyzed different types of oil products, including gasoline, volatile (crude oil) and non-volatile oil products (motor oil). The maximum sorption capacity was determined using a mesh made of polypropylene (7–9 g/g); the sorption capacity reached 5–6 g/g for straw, and 3–5 g/g for rice husk.

The study of other researchers compared this efficiency with the removal of light fraction oil product, namely, gasoline (94.27%) and heavy fraction oil product, namely, grease (95.67%). Other researchers (Li et al. 2015) also investigated polyester, whose sorption capacity was equal to 6.89 g/g for diesel.

In the present experimental study, the influence of changes in the concentration of oil products on the efficiency of their removal using wheat straw was determined. The same concentrations of oil products with polypropylene (10–100 mg/L) were studied. The results are presented in Figure 5. The oil product removal efficiency has been found to range from 45% to 75%. The efficiency varies regardless of the concentration of oil products in the filtered solution, so it can be assumed that the removal efficiency does not depend on the concentration of oil products as long as the sorbent (wheat straw in this case) can fully sorb the contaminant. The large difference in efficiency (45–70%) may be due to the high sorption capacity of water on common straw and the leaching of oil products through contaminated water.

A single factor (*one-way*) *ANOVA* was used to test the null hypothesis that there is a difference in the efficiency of the removal of different concentrations of diesel using polypropylene and common wheat straw. The f-ratio value is 10.38672. The p-value is .005316. The result is significant at $p < .05$.

Studies by other researchers, *(*Adebajo et al. 2003) who used agricultural waste as filling for the column without checking the concentration of oil products, produced the following results: the efficiency of rice husk stood at 90–96% and the efficiency of barley straw was 78–80% using light fraction oil product. The study compared this efficiency with the efficiency of removal of light fraction oil product, i.e., gasoline (94.27%) and heavier fraction oil product, i.e, grease (95.67%). The content of polypropylene in the plastic waste stream reaches up to 20% (American Chemistry Council 2018) and requires investment in surface wastewater filtration. It was decided to test the column with both sorbents by placing 50% of polypropylene on top due to hydrophobicity and high oil sorption and 50% of common wheat straw at the bottom in order to remove residual oil products. The results in terms of the removal efficiencies in a range of concentrations of oil products (diesel) for both sorbents are presented in Fig. 6.

It was found that the efficiency of oil product (diesel) removal (65–80%) is similar to the use of sorbents alone and does not depend on the concentration of oil products, so it can be assumed that for economic reasons it is possible to

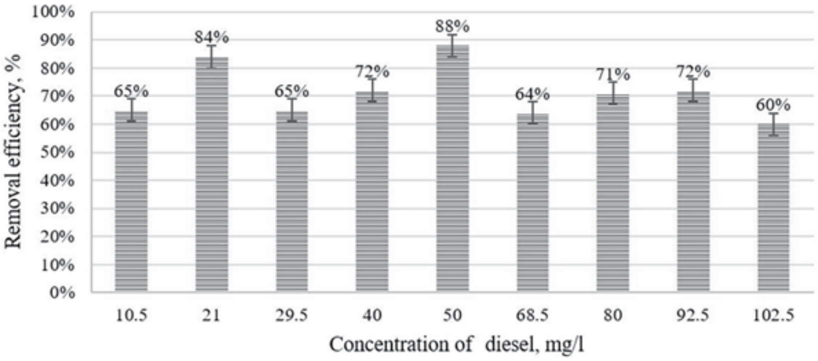

Fig. 4. Efficiency of removal of different concentrations of diesel using polypropylene

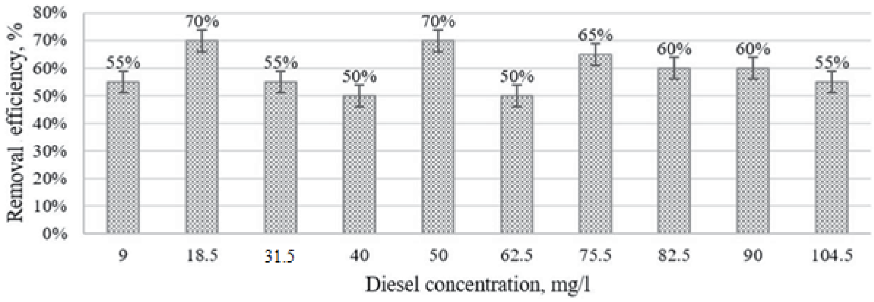

Fig. 5. Efficiency of removal of different concentrations of diesel using common wheat straw

use a filler consisting of 50% of polypropylene and 50% of common wheat straw.

It was found that the efficiency of oil product (diesel) removal (65–80%) is similar to the use of sorbents alone and does not depend on the concentration of oil products, so it can be assumed that, for economic reasons, it is possible to use filling containing 50% of polypropylene and 50% of common wheat straw.

A single factor (*one-way*) *ANOVA* was used to test the null hypothesis that there is a difference in the efficiency of the removal of various concentrations of diesel by using polypropylene, on the one hand, and a combination of polypropylene and common wheat straw, on the other (1:1, v/v). The f-ratio value is 1.4016. The p-value is .253746. The result is not significant at $p < .05$.

A single factor (*one-way*) *ANOVA* was used to test the null hypothesis that there is a difference in the efficiency of the removal of various concentrations of diesel by using common wheat straw, on the one hand, and a combination of polypropylene and common wheat straw, on the other (1:1, v/v). The f-ratio value is 34.36457. The p-value is .000015. The result is significant at $p < .05$.

Assessment of the influence of external factors on the disposal of oil products

As an additional study, the impact of important surface wastewater parameters, namely, the concentrations of chlorides and suspended solids, on the removal of oil products was studied by using filling made of polypropylene and common wheat straw (Fig. 7). A proven hypothesis has been made by other researchers (Kamble et al. 2007) that chlorides have very little effect on the sorption of oil products, but the effect may have a negative impact on sorption capacity as inorganic salt ions block active sites on the sorbent surface, thereby deactivating the sorbent. The study ensured the same concentration of oil product (diesel, 50 mg/L) and the concentration of chlorides (NaCl) from 10 mg/L to 2.000 mg/L (twice the permissible value). Polypropylene and common wheat straw were found not to sorb or otherwise retain chlorides, and the diesel removal efficiency did not depend on the chloride content and remained in the range from 71% to 83%.

Suspended solids and chlorides were added to water containing an oil product, for checking their impact on the sorption of an oil product (diesel) (Fig. 8). The study ensured a uniform concentration of oil products (50 mg/L) and suspended solids (microcrystalline cellulose) ranging from 50 mg/L to 1.000 mg/L. Polypropylene and common wheat straw do not retain suspended solids, so the removal efficiency was independent from the amount of suspended solids (SS) and ranged from 70% to 85%.

Studies using natural zeolite for the removal of phenols from a mixture of organic matter and water were carried out by other researchers Kamble et al. (2007). It was found that the efficiency of NaCl removal was reduced by 45% to 10%, and the effect of suspended solids was not studied.

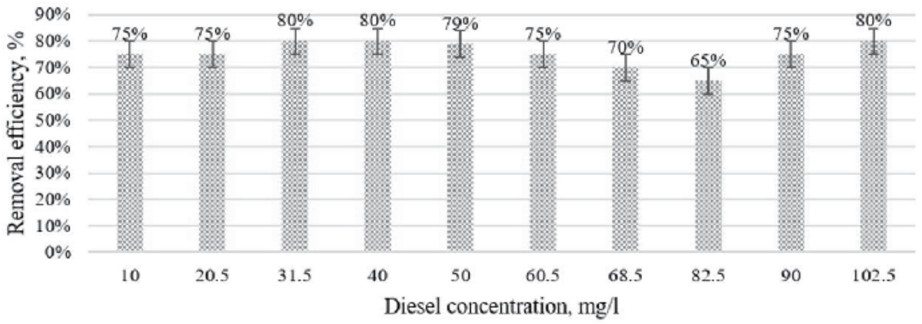

Fig. 6. Efficiency of removal of different concentrations of diesel using a combination of polypropylene and common wheat straw (1:1, v/v)

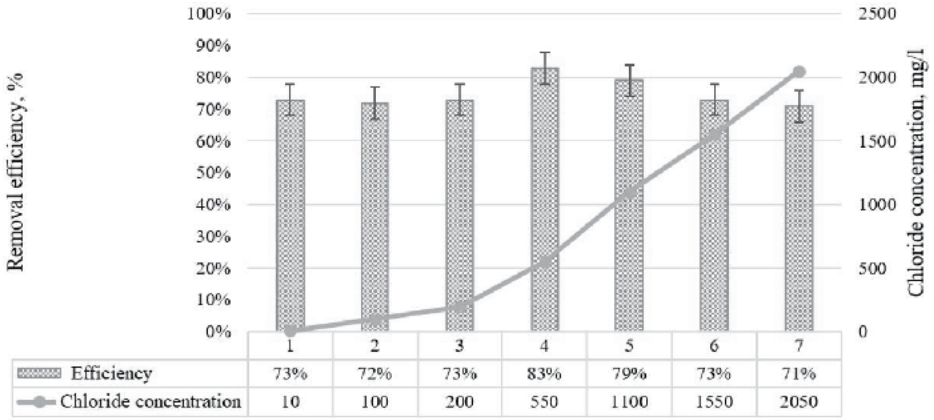

Fig. 7. Dependence of diesel removal efficiency on chloride concentration using a combination of polypropylene and common wheat straw (1:1, v/v)

Evaluation of sorbent modification possibility

The change in water and diesel sorption in polypropylene and wheat straw modified with 30% hydrogen peroxide (H_2O_2) solution was tested in the experimental study. The H_2O_2 solution was selected based on previous experimental studies with biochar modification using oxidants for increasing the hydrophobicity of the sorbent (Xiao Jun et al. 2016).

The sorption results of water and diesel on modified polypropylene and their comparison with the sorption values of unmodified polypropylene are presented in Fig. 9–10.

In an experimental study, the maximum water sorption on polypropylene (0.60 g/g) was reduced 1.3-fold (to 0.46 g/g). This level was reached in half an hour and no longer changed. The change in diesel sorption was not significant (Fig. 10). The obtained results show that the modified polypropylene bed has a shorter water insertion time. Therefore, the modified PP reached its maximum adsorption faster.

Based on the obtained modification result for polypropylene, common wheat straw was modified in the same way to increase its hydrophobicity. The results of water and diesel sorption for modified common wheat straw and their comparison are presented in Fig. 11–12. In the experimental study, the maximum water sorption of modified common wheat straw (6.0 g/g) was reduced 1.6-fold (to 3.84 g/g) and reached the maximum value in 5 hours (Fig. 11). It was assumed that hydrogen peroxide increased the hydrophobic properties of the sorbent due to the oxidizing properties of wheat straw.

It was found that the sorption of an oil product (diesel) on modified common wheat straw did not increase, but the character of sorption changed as diesel sorption was slower during the first 4 hours (3.42 g/g for wheat straw, 3.04 g/g for modified common wheat straw), but the sorption maximum (3.73 g/g) was reached in 5 hours.

It can be assumed that the oxidizing properties of hydrogen peroxide enhance the hydrophobic properties of wheat straw but do not enhance its diesel sorption properties.

Evaluation of polypropylene recovery potential

Due to the hydrophobic nature of oil products (i.e. diesel), aqueous solutions are not suitable for sorbent regeneration. The possibility of thermal regeneration has also been ruled out, as diesel decomposes when heated, carbon dioxide and carbon monoxide are formed during decomposition, and the concentration of these gases in an enclosed space or room can reach a limit deemed dangerous by Orlen (Lithuania) under the Diesel Data Safety Sheet. Based on the results of our experiments, desorption of the sorbed oil product (diesel) is required. (Folleto et al. 2002).

This can be achieved by using organic solvents such as methyl ethyl ketone, acetone, oil ether or n-hexane. N-hexane was used in this study. Polypropylene was regenerated after the sorption of diesel (when the maximum level of sorption of diesel was reached). Fig. 13 shows that, after the regeneration of polypropylene, the sorption of diesel (4.60 g/g) decreases by 1.2 times (up to 3.73 g/g) or by ≈19% during the first regeneration. It is assumed that polypropylene can be regenerated a limited number of times.

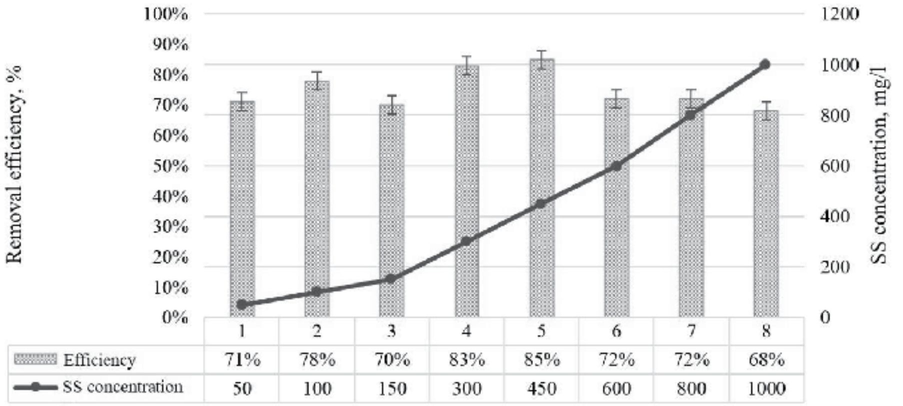

Fig. 8. Dependence of diesel removal efficiency on the amount of suspended solids using a combination of polypropylene and common wheat straw (1:1, v/v) (SS – suspended solids)

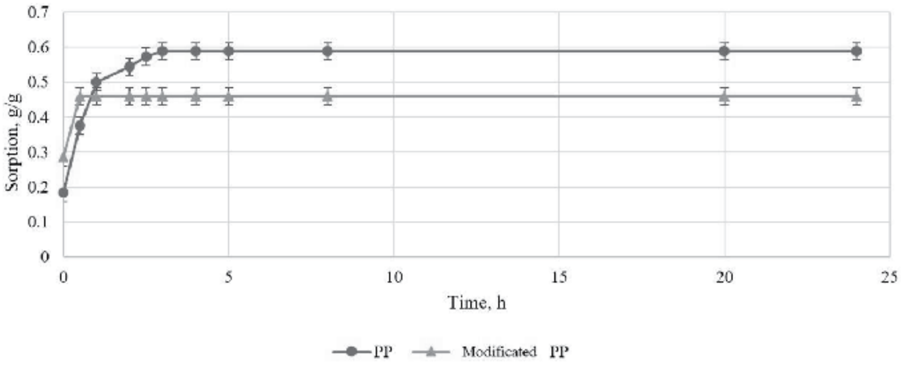

Fig. 9. Comparison of polypropylene and modified polypropylene water sorption (PP – polypropylene)

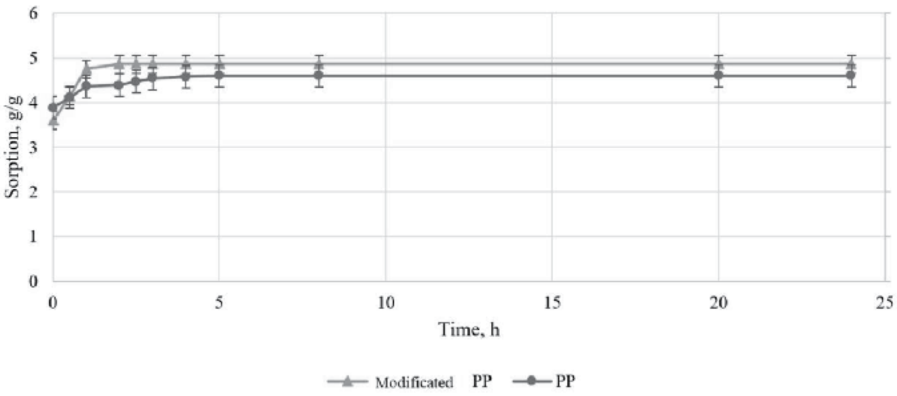

Fig. 10. Comparison of polypropylene and modified polypropylene diesel sorption (PP –polypropylene)

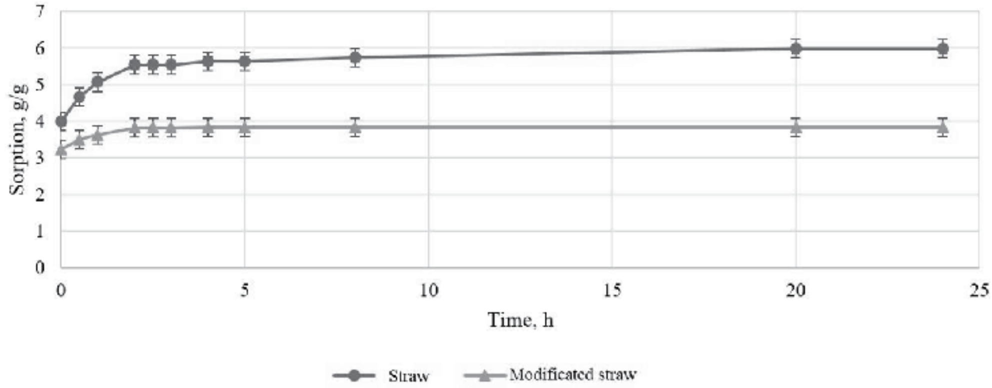

Fig. 11. Comparison of water sorption of common wheat straw and modified common wheat straw

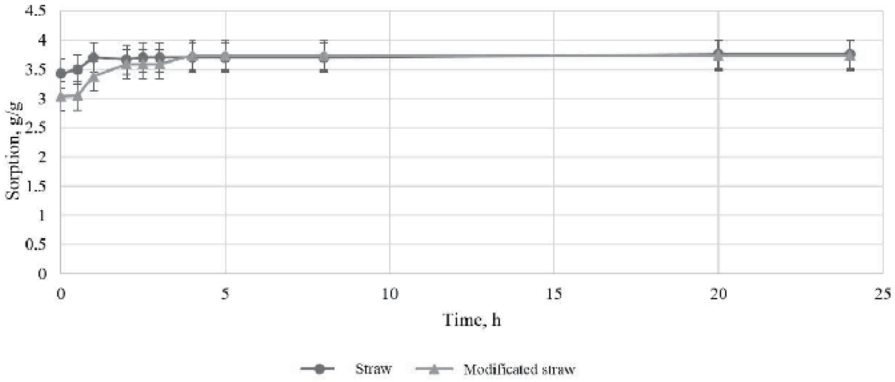

Fig. 12. Comparison of diesel sorption with common wheat straw and modified common wheat straw

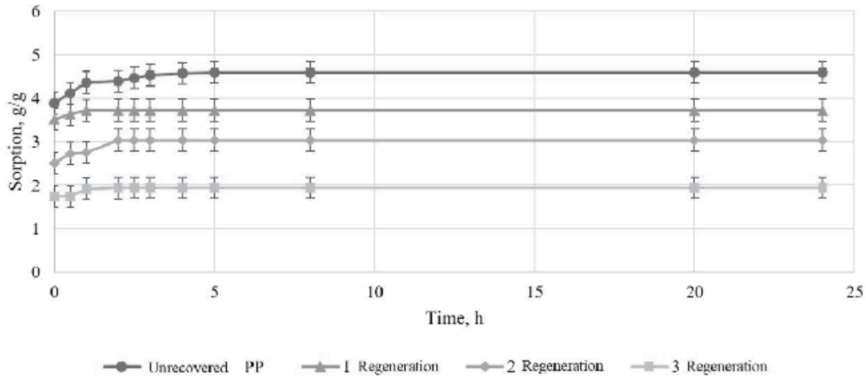

Fig. 13. Comparison of diesel sorption using polypropylene and regenerated polypropylene

Polypropylene was regenerated for the second time by employing the same procedure. After the second regeneration, the sorption of diesel through using polypropylene (3.73 g/g) decreased 1.2-fold (3.04 g/g), i.e., by ≈19%, which is a 1.5-fold decrease, i.e., ≈34% lower than the sorption of new polypropylene. Polypropylene was regenerated for the third time by employing the same procedure. After the third regeneration, the sorption of diesel by using polypropylene (3.04 g/g) decreased by an additional 1.5-fold (1.94 g/g), i.e., by ≈36%, which is a 2.37-fold decrease, i.e., ≈58% lower than the sorption of new polypropylene. It may be concluded that the recommended use of the same polypropylene for the sorption of diesel from water or wastewater should not exceed two times.

Conclusions

1. It was found that the filtration speed in the range of investigated speeds does not affect the diesel removal efficiency. Therefore, the flow rate of 2.0 L/min was chosen for experimental studies, which is the maximum speed in the laboratory bench at which the column does not cause flooding.
2. It has been found that the removal efficiency varies regardless of the concentration of diesel in the filtered solution. Therefore, it is assumed that the removal efficiency does not depend on the concentration of diesel, because the sorbent does not reach its maximum sorption capacity.
3. Regardless of the diesel concentration, the removal efficiency in the column filled with both sorbents (65–80%) was found to be similar for both polypropylene (60–88%) and common wheat straw filling (50–70%). Therefore, it was decided for economic reasons to use a filling containing 50% of polypropylene and 50% of wheat straw.
4. Polypropylene and wheat straw do not sorb or retain chlorides and suspended solids from solution; the removal efficiency of diesel is independent of the concentration of these pollutants in the water and remains in the range from 70 to 83%.
5. Modification of polypropylene and wheat straw with hydrogen peroxide solution showed that the maximum water sorption of polypropylene (0.60 g/g) decreased 1.3-fold (to 0.46 g/g) and the maximum water sorption of modified wheat straw (6.0 g/g) decreased 1.6-fold (to 3.84 g/g). The solution of hydrogen peroxide increased the hydrophobic properties of common wheat straw, but did not affect the sorption of diesel.
6. The number of regenerations of polypropylene for the removal of oil products (diesel) from water or wastewater should be limited to two. After the first regeneration, the sorption of diesel (4.60 g/g) on polypropylene decreases 1.2-fold (to 3.73 g/g), i.e., by ≈19%. After the second regeneration, the sorption of diesel (3.73 g/g) decreases 1.2-fold (3.04 g/g), i.e., by ≈19%, which is 1.5 times or ≈34% lower compared to the sorption achieved by using new polypropylene.

References

Adebajo, M.O., Frost, R.I., Kloprogge, J.T., Carmody, O. & Kokot, S. (2003). Porous materials for oil spill cleanup: A review of synthesis and absorbing properties, *Journal of Porous Material*, 3, pp. 159–170. DOI: 10.1023/A:1027484117065

Akpomie, K.G. & Conradie, J. (2021). Ultrasonic aided sorption of oil from oil-in-water emulsion onto oleophilic natural organic-silver nanocomposite, *Chemical Engineering Research and Design*, 165, pp. 12–24. DOI: 10.1016/j.cherd.2020.10.019

American Chemistry Council. (2018). (https://plastics.americanchemistry.com/Reports-and-Publications/National-Post-Consumer-Plastics-Bottle-Recycling-Report.pdf).

Baig, N. & Saleh, T.A. (2019). Novel hydrophobic macroporous polypropylene monoliths for efficient separation of hydrocarbons, *Composites Part B: Engineering*, 173, pp. 106805. DOI: 10.1016/j.compositesb.2019.05.016

Baiseitov, D.A., Tulepov, M.I., Sassykova, L.R., Gabdrashova, S.E., Essen, G.A., Kudaibergenov, K.K. & Mansurov, Z.A. (2016). Sorption capacity of oil sorbent for the removal of thin films of oil, *Bulgarian Chemical Communications,* 3, pp. 446–450.

Bayat, A., Aghamiri, S. F., Moheb, A. & Vakili-Nezhaad, G. (2005). Oil spill cleanup from sea water by sorbent materials, *Journal of Chemical Engineering Technology*, 12, pp. 1525–1528. DOI: 10.1002/ceat.200407083

Chandra, S., Sharma, R., Singh, K. & Sharma, A. (2013). Application of bioremediation technology in the environment contaminated with oil hydrocarbon, *Annals of Microbiology*, 63, pp. 417–431. DOI: 10.1007/s13213-012-0543-3

Chaouki, Z., Zaitan, H., Nawdali M., Vasarevičius S. & Mažeikienė, A. (2020). Oil removal from refinery wastewater through adsorption on low cost natural biosorbents, *Environmental engineering and management journal*, 1, pp. 105–112. DOI: 10.30638/eemj.2020.011

Deschamps, G., Caruel, H., Borredon, M.E., Albasi, C., Riba, J.P., Bonnin, C. & Vignoles, C. (2003). Oil removal from water by sorption on hydrophobic cotton fibers. 2. Study of sorption properties in dynamic mode, *Environmental science & technology*, 21, pp. 5034–5039. DOI: 10.1021/es020249b

Gushchin, A.A., Grinevich, V.I., Gusev, G.I., Kvitkova, E.Y. & Rybkin, V.V. (2018). Removal of oil products from water using a combined process of sorption and plasma exposure to DBD, *Plasma Chemistry and Plasma Processing*, 5, pp. 1021–1033. DOI: 10.1007/s11090-018-9912-4

Hybská, H., Mitterpach, J., Samešová, D., Schwarz, M., Fialová, J. & Veverková, D. (2018). Assessment of ecotoxicological properties of oils in water, *Archives of Environmental Protection*, 4, pp. 31–37. DOI: 10.24425/aep.2018.122300

Kamble, S.P., Mangrulkar, P.A., Bansiwal, A.K. & Rayalu, S.S. (2007). Adsorption of phenol and o-chlorophenol on surface altered fly ash based molecular sieves, *Chemical Engineering Journal*, 138, pp. 73–83. DOI: 10.1016/j.cej.2007.05.030

Karyab, H., Mirhosseini, M. Moradi, S. & Karimi, F.F. (2016). Removal of light petroleum hydrocarbons from water sources using polypropylene and titanium dioxide nano-composite, *Journal of Inflammatory Disease*, 3, pp. 32–26.

Król, M. & Rożek, P. (2020). Sorption of oil products on the synthetic zeolite granules, *Mineralogia*, 51, pp. 1–7. DOI: 10.2478/mipo-2020-0001

Kwaśny, J. A., Kryłów, M. & Balcerzak, W. (2018). Oily wastewater treatment using a zirconia ceramic membrane–a literature review, *Archives of Environmental Protection*, 3, pp. 3–10. DOI: 10.24425/aep.2018.122293

Li, G., Guo, S. & Hu, J. (2016). The influence of clay minerals and surfactants on hydrocarbon removal during the washing of petroleum-contaminated soil, *Chemical Engineering Journal*, 286, pp. 191–197. DOI: 10.1016/j.cej.2015.10.006

Li, S., Wu, X., Cui, L., Zhang, Y., Luo, X., Zhang, Y. & Dai, Z. (2015). Utilization of modification polyester non-woven as an affordable sorbent for oil removal, *Desalination and Water Treatment*, 11, pp. 3054–3061. DOI: 10.1080/19443994.2014.913264

Lurchenko, V., Melnikova, O., Mikhalevich, N. & Borzenko, O. (2019). Surface wastewater treatment from various fractions of petroleum products from the territory of highway infrastructure facilities, *Environmental problems*, 2, pp. 74–81. DOI: 10.23939/ep2019.02.074

Maceiras, R., Alfonsin, V., Martinez, J. & de Rey, C.M.V. (2018). Remediation of diesel-contaminated soil by ultrasonic solvent extraction, *International Journal of Environmental Research*, 5, pp. 651–659. DOI: 10.1007/s41742-018-0121-z

Mandal, S. & Mayadevi, S. (2009). Defluoridation of water using as-synthesized Zn/Al/Cl anionic clay adsorbent: euilibrium and regeneration studies, *Journal of Hazardous Materials*, 167, pp. 873–978. DOI: 10.1016/j.jhazmat.2009.01.069

Mauricio-Gutiérrez, A., Machorro-Velázquez, R., Jiménez-Salgado, T., Vázquez-Crúz, C., Sánchez-Alonso, M.P. & Tapia-Hernández, A. (2020). Bacillus pumilus and Paenibacillus lautus effectivity in the process of biodegradation of diesel isolated from hydrocarbons contaminated agricultural soils, *Archives of Environmental Protection*, 4, pp. 56–69. DOI: 10.24425/aep.2020.135765

Mažeikiene, A. & Švediene, S. (2015). The suitability of natural and synthetic filter material for the removal of oil products from the aqueous media, *Desalination and Water Treatment*, 27, pp. 12487–12495. DOI: 10.1080/19443994.2015.1053993

Mažeikienė, A., Rimeika, M. & Švedienė, S. (2014). Oil removal from water by filtration, *Journal of Environmental Engineering and Landscape Management*, 1, pp. 64–70. DOI: 10.3846/16486897.2014.885906

Mohammadi, L., Rahdar, A., Bazrafshan, E., Dahmardeh, H., Susan, M., Hasan, A.B. & Kyzas, G.Z. (2020). Petroleum Hydrocarbon Removal from Wastewaters: A Review, *Processes*, 4, pp. 447. DOI: 10. 3390/pr8040447

Moshe, S.B. & Rytwo, G. (2018). Thiamine-based organoclay for phenol removal from water, *Applied Clay Science*, 155, pp. 50–56. DOI: 10.1016/j.clay.2018.01.003

Paulauskiene, T. (2018). Ecologically friendly ways to clean up oil spills in harbor water areas: crude oil and diesel sorption behavior of natural sorbents, *Environmental Science and Pollution Research*, 10, pp. 9981–9991. DOI: 10.1007/s11356-018-1316-8

Quím, R.C. (2020). Highly porous polymeric composite with γ-Fe_2O_3 nanoparticles for oil products sorption, *Revista Cubana de Química*, 1, pp. 104–116.

Rudkovsky, A.V., Fetisova, O.Y. & Chesnokov, N.V. (2016). Sorption of oil products by carbon sorbents from Siberian larch bark, *Chemistry,* 1, pp. 109. DOI: 10.17516/1998-2836-2016-9-1-109-118

Sari, G. L., Trihadiningrum, Y. & Ni'matuzahroh, N. (2018). Petroleum hydrocarbon pollution in soil and surface water by public oil fields in Wonocolo sub-district, Indonesia, *Journal of Ecological Engineering*, 2, pp. 184–193. DOI: 10.12911/22998993/82800

The surface waste water management regulation (2019). (https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.295779/asr) (in Lithuanian)

Thilagavathi, G. & Das, D. (2018). Oil sorption and retention capacities of thermally-bonded hybrid nonwovens prepared from cotton, kapok, milkweed and polypropylene fibers, *Journal of environmental management*, 219, pp. 340–349. DOI: 10.1016/j.jenvman.2018.04.107

Varjani, S.J. Rana, D.P. Jain, A.K. Bateja, S. & Upasani, V.N. (2015). Synergistic ex-situ biodegradation of crude oil by halotolerant bacterial consortium of indigenous strains isolated from on shore sites of Gujarat, India, *International Biodeterioration & Biodegradation*, 103, pp. 116–124. DOI: 10.12911/22998993/82800

Vilūnas, A., Švedienė, S. & Mažeikienė, A. (2014). The research of sorbent usage for oil products removal from storm water runoff. (https://iicbe.org/upload/1891C0214017.pdf).

Voronov, A.A, Malyshkina, E.S., Vialkova, E.I. & Maksimova, S.V. (2018). Development of the rational urban engineering systems for the surface wastewater treatment, *Urban construction and architecture*, 3, pp. 43–50. DOI: 0.17673/Vestnik.2018.03.10

Vuruna, M., Veličković, Z., Perić, S., Bogdanov, J., Ivanković, N. & Bučko, M. (2017). The influence of atmospheric conditions on the migration of diesel fuel spilled in soil, *Archives of Environmental Protection*, 1, pp. 73–79. DOI: 10.1515/aep-2017-0004

Xiao Jun, Z., Zhengang, L. & Min Dong, C. (2016). Effect of H_2O_2 concentrations on copper removal using the modified hydrothermal biochar, *Journal of Bioresourse Technology*, 1, pp. 262–267. DOI: 10.1016/j.biortech.2016.02.032

Yalcinkaya, F., Boyraz, E., Maryska, J. & Kucerova, K. (2020). A review on membrane technology and chemical surface modification for the oily wastewater treatment, *Materials*, 13, pp. 1–14. DOI: 10.3390/ma13020493