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Purification of Oil-Containing Waste Using Solar Energy

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Abstract **– Significant oil losses in oil-containing wastes and their adverse impact on the region environmental setting bring about the need to develop an oil-containing wastes treatment technology. To tackle this issue, the authors have set an aim of designing a helio device and creating an oil-containing wastes treatment method based on it to extract oil products. Considering a widespread in the composition and properties of potential oil sludge raw materials and their tendency for either formation of stable emulsions or phase separation, we have conducted in-depth modern physical and chemical studies and defined the need to develop a commercial oil-containing wastes purification method. We have designed the device, in which oil product hydrocarbons undergo thermal treatment using solar energy. Following oil-containing wastes purification using solar energy, the particulate load in soil does not exceed 6.65–6.79 % and the absolute molecular weight of hydrocarbons approaches that of bitumen. The developed oil-containing wastes purification method solves an important environmental issue of oil-containing wastes recycling, promotes recovery, and prevents degradation of natural complexes, and reduces soil and water pollution.**

Keywords **– Helio device; oil-containing wastes; oil-containing wastes purification; thermal treatment; treated soil**

1. INTRODUCTION

Although Kazakhstan is located at the latitude between 42 and 55 degrees northward, the solar radiation potential in the republic is quite high – 1300–1800 kWh/m^2 a year. Because of inland climate, there are 2200–3000 solar hours a year. This high potential of solar energy enables its economic use in Kazakhstan. The annual solar energy potential in oil-producing regions is $0.652 \cdot 10^{15}$ J. Thus, wide use of solar energy may be of high economic value here. Use of the solar energy potential in oil field regions for the processing of accumulated and current oil-containing wastes during oil production defines the technical feasibility of this work. Besides, solar technology development is an innovative focus area for Kazakhstan that does not have enough utility capacity to meet the entire power demand.

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Each year some 3 million tonnes of oil-containing wastes are generated on a global scale with over 100 thousand tonnes in Kazakhstan. Significant oil losses in oil sludge and other types of oil-containing wastes and their adverse impact on the region's environmental setting brings about the need to develop the oil-containing wastes treatment technology.

The issue of oil-containing wastes purification is a burning one everywhere. However, as of now, there is still no efficient industrial scheme of its processing, although attempts to design and improve treatment and recovery equipment have been made by nearly all leading chemical plant manufacturers. The world's first separator stations for oil sludge treatment were designed and installed in Russia. The separators were designed for cleaning oil sludge but proved to be uneconomical due to the fact that after each work shift it was necessary to disassemble and free the working surfaces from contamination [1], [2].

The improved oil sludge treatment plant was created by the Swedish company 'Alfa Laval'. In the process of cleaning, the oil sludge is distilled into a tank and left for several days to settle. The water that has come to the surface is discharged from the tank to the treatment facilities, and the oil phase is sent to the installation 'Alfa Laval'. According to the results, it is concluded that such an installation is suitable only for cleaning fresh oil sludge and, on the contrary, is not applicable for bottom sediments of sludge collector. In addition, the water obtained during the purification process is contaminated with persistent petroleum emulsions, and it is impossible to process the mechanical impurities (soil) discharged from the separators from time to time. The disadvantage is that to destroy persistent petroleum emulsions and achieve a high degree of purification are not used chemical reagents-demulsifies [3]–[6].

The plant for cleaning oil sludge of the German manufacturer 'KHD' is offered to several enterprises of the oil industry. The initial stage of cleaning at this plant is that the oil sludge is pumped into the tank. From this tank, the petroleum phase is distilled to a three-phase centrifuge, where the oil sludge is divided into components: petroleum, water, and mechanical impurities –under the influence of centrifugal forces. Before loading the petroleum sludge into the centrifuge, it is treated with a chemical reagent. This installation has the following disadvantages: in order for the petroleum content in the petroleum sludge supplied to the installation to be at least 70 %, it is necessary to ensure a high degree of separation in the tank, otherwise the purified petroleum will contain a high percentage of water. It can also clean only freshly formed petroleum sludge and is not suitable for cleaning deep sediments of sludge collectors [1].

Developed by the American company 'Bogart Environmental Services', the method of cleaning oil waste has been successfully operating in the fields in Kuwait for several years. This method allows you to clean the sandy soil from oil spills after accidents. To do this, the contaminated soil is removed and formed into high (up to 10 meters) burt. Under the ground's own weight, the petroleum is squeezed out. After that, it is sent to a centrifuge for cleaning. The soil is diluted with water to a humidity of 95 % and transported to containers where the process of biological destruction of hydrocarbons takes place. The use of Bogart equipment and methods for cleaning light soils is associated with certain difficulties. First, such soils to form into burts difficulty. This means that the soil is subjected to biological treatment with virtually no separation of free oil, but microbiological methods are effective only when the concentration of hydrocarbons is not more than 15 %. Microorganisms contain toxic elements and compounds. The more hydrocarbons are used for biodegradation, the greater the amount of excess biomass will be obtained as a result of the purification process. Cleaning of soils with a high content of hydrocarbons can lead to an increase in the number of harmful elements contained in the cells, which can lead to biological pollution of the environment [7], [8].

In the work [10], the pyrolysis process as an alternative technology for the treatment of oil sludge is studied. Bentonite with different Fe/Al ratios was used as a pyrolysis catalyst. It was determined that the Fe/Al ratio of 0.5 almost double the oil yield (from 29.23 % to 52.46 %) in comparison with the addition of catalyst. The use of bentonite with Fe/Al ratios as catalyst in catalytic pyrolysis promotes the formation of porous material with an increased surface area and an acidic center on the inner surface, which further promotes the destruction of the petroleum molecule in the oil sludge. In addition, the use of catalyst contributes to additional formation of CH_4 and CO, and improves the quality of the pyrolysis oil, which in turn can be used as a fuel.

In paper [10] thermal treatment of drilling waste from Poland shale gas exploration was studied. The result of study showed that thermal treatment allows to get rid of organic constituents of drilling waste, which are vaporized completely at temperature up to 500 °C. However, the main problem is inorganic product of the thermal process. High content of chloride, sulphate, sodium, potassium, magnesium in water leachate poses important risk for environment, therefore the product of thermal process needs further treatment in order to remove its high salinity. Mixing with fly-ash and gypsum may be one of solutions, as it can restrain the leaching of these elements, making possible to use thermal treatment product in road construction. Besides, due to the high content of barium, the drilling waste may be utilized in production of cement with high chemical and heat resistance and opaque to X-ray.

It is known that microorganisms are widely used to maintain a safe environment due to their ability to degrade wide range of organic toxicants. Bacteria are mostly applied in contaminants treatment while fungal strains are less studied despite their ability to degrade highly persistent organic contaminants and survive extreme conditions. Meanwhile they can be observed as promising organisms to maintain safe environment together with bacteria. Microplate screening method was applied to find new fungal candidates for biological treatment of organic toxicants such as toluene, hexadecane, or polychlorinated biphenyl 126. Not many microbial strains are known that degrade these three contaminants, while the PAH contamination acted as selective pressure for the soil microbiota. Fungal strains were isolated from twelve soil samples from polycyclic aromatic hydrocarbon (PAH) contaminated sites in Austria. After obtaining pure cultures, the fungal strains were further screened for their ability to survive in the presence of toluene, hexadecane, or polychlorinated biphenyl 126. 11 best performing strains were chosen from initially isolated 12 samples using ITS and 18S rDNA. These eleven strains have potential for technical application in treatment of wastes contaminated with organic toxicants including above listed three compounds. Microplate screening method was shown to be cost efficient and quick approach to identify fungal strains for pollutant degradation [11].

Study of biodegradability of organic constituents of the oil/water emulsion obtained from a metal-processing waste stream was carried out in paper [12]. The conducted study showed that oil/water emulsion is non-toxic to bacterial consortia, therefore it was colonized with indigenous microorganisms. Emulsion was treated using a threefold wastewater dilution and employing two variants of bio stimulated aerobic bacterial communities:

1. Bioremediation of uninoculated emulsion by the autochthonous bacteria alone;
2. The wastewater samples inoculated with a ZB-01 microbial consortium which is a source of specialized bacteria for process bioaugmentation.

Determination of biodegradation efficiency achieved in a 14-day test was carried out using two parameters: total load of organic content determined as a chemical oxygen demand (COD) and concentration of high-boiling organic compounds. Both approaches showed significant reduction of the emulsion organic fraction, however bioaugmented with inoculated

consortium demonstrated higher biodegradation efficiency. High degradation yields (58 % and 71 %, respectively) obtained for both cases in a 28-day test were confirmed by means of gas chromatography analyses coupled with mass spectrometric detection (GC-MS). The study demonstrated that oil-based metalworking emulsions can be efficiently treated by biological method under conditions enabling aerobic bacterial proliferation.

To tackle this issue, the authors have designed a helio device and created an oil-containing wastes treatment method based on it to obtain oil products. The method has passed laboratory and extended laboratory tests at al Farabi's Kazakh National University and Almaty University of Technology. This technology has been tried at oil-polluted soils and oil sludge of Kazakhstan oil producers. Research and development have been conducted to design the helio device and test it with various oil-containing wastes types. Positive results obtained confirm cost-effectiveness of oil-containing wastes processing that implies mitigation of damage to environment and economy from waste disposal and profit from obtaining additional oil volumes.

Scientific novelty of the work lies in the design of the helio device and method of oil products extraction during oil-containing wastes purification that enable maximum recovery of hydrocarbons from oil waste without prejudice to their chemical structure.

Almost no oil producer in Kazakhstan has an industrial oil-containing wastes purification scheme. Each year, only one oil-producing region generates some 50–100 thousand tonnes of oil-containing wastes that implies significant losses of oil produced. Besides, accumulation of this waste is a huge environmental threat to neighbouring regions. This work envisages oil-containing wastes processing using the helio device to obtain oil products and treated soils.

Organic fracture of oil waste is a quite complex mixture of hydrocarbons of varying structural-group composition and their hetero-derivatives with a broad range of physicochemical properties [13]. Most researchers use thermal methods to extract hydrocarbons.

Despite available methods [14]–[16], the effect of temperature on heat processing has not been properly studied yet. Despite high extraction of organic waste fracture, proposed heat methods have the following drawbacks: high cost of plants, complexity of process flow schemes and high smoke release due to burning-out of oil that has been recovered with difficulties from the subsoil in the burning area.

The developed efficient method of oil-polluted soil and oil sludge purification using solar energy prevents heat loss during heating over a light day and ensures required environmental temperature conditions and high recovery of productive oil.

2. Materials and Methods

The following has been used as the experimental research methodology:

- analysis of theoretical assumptions;
- review of the main characteristics of the object under study subject to various restrictions imposed by immediate experimental tasks;
- review of the application and operational characteristics of the oil-containing wastes treatment method developed.

The methodology is elaborated with a primary focus on the conditions that ensure consistent results. Data obtained is used to select prototype models, equipment, establish simulation parameters, calculate a number of individual experiment repetitions.

Both generally recognized traditional and non-traditional analysis methods were used during research. Various modern and classical physicochemical analysis methods were used

to determine morphology, structure and chemical composition of samples. Empirical data obtained was used with the application of induction and deduction methods to establish theoretical knowledge that was practically grounded, which will remove its speculative nature and turn it into direct knowledge.

Pilot studies were conducted directly on the object of study and (additionally) on artificial solutions to eliminate side effects on studied phenomena. Physical and chemical parameters of oil-containing wastes were assessed using standard methods. The source information derived from tests was analysed using computer programs based on elements of the theory of chances and mathematical statistics.

Oil-polluted soil and oil sludge of Atyrau region where large oil and gas fields of Kazakhstan are concentrated were used for research. Their composition is provided in Table 1.

TABLE 1. COMPOSITION OF OIL WASTE

Oil waste	Composition, w %		
	Organic fraction	Solids	water
Oil sludge	76.8	8.0	15.2
Oil-polluted soil	11.6	85.4	3.0

Physicochemical properties of polluting oil products are also important. Cluster analysis of oil sludge under study was conducted by gas chromatography with mass-spectrometer detection [17], [18].

Oil waste was treated to separate oil components from the bulk of the waste. The oil fraction of the waste was analysed to select conditions for its extraction.

Fractional makeup of an oil sample provided was determined by simulated distillation using a gas chromatograph with mass spectrometric detector [ASTMD2887] with the modifications set out in [19].

The oil sample for analysis was dissolved in chloroform in 3:1 ratio and 1.0 μL of the resulting solution was introduced using Combi-PAL autosampler (CTCAnalyticsAG, Switzerland) in 7890A gas chromatograph loader (Agilent, US) heated to 300 ºC with a split ratio of 30:1.

Separation was made by DB-35MS column (Agilent, US) 30 m long with an inner diameter of 0.25 mm and the film thickness of 0.25 μm. Chromatography temperature was set from 40 ºC (5 min exposure) with a heating rate of 10 ºC/min to 320 ºC (15 min exposure). Detection was made by 5973N mass-spectrometer (Agilent, US) with total ion current recording in the mass number range of 10–550. The mass-spectrometer interface temperature was 300 ºC. Chloroform was used as a reference sample. Ionization mode: electron impact 70 eV, signal-to-noise ratio of 70:1, dynamic linear interval of 6 orders of magnitude.

For the purposes of benchmarking effects of various sources of energy on thermal treatment of oil-containing wastes, experimental works were conducted in two ways:

1. Using solar energy;
2. Using electric energy.

The first method implies the use of solar energy to heat oil-containing wastes. The second method uses electric energy to heat oil-containing wastes. After the heating using different methods was performed, conditions were recorded with meters. Complex analysis using a well-known physicochemical study method was made after thermal treatment.

Studies using a differential thermal analysis of oil-containing wastes were also conducted before and after thermal treatment using different sources of energy. The differential thermal

analysis was conducted using Derivatograph Q – 1500 D with a heating rate of 10 °C per minute to 1000 °C.

3. Results and Discussion

Experimental studies were conducted in Almaty, Kazakhstan. Solar radiation in the region is $1343 \cdot 10^{15}$ J a year. If we consider the total insolation of solar energy by month in Almaty, Republic of Kazakhstan, then the maximum value of the amount of solar energy falls from May to August, i.e., is $632 \cdot 10^6$–$729 \cdot 10^6$ J/m^2 (kwh/m^2), and the minimum value is from November to February $136 \cdot 10^6$–$239 \cdot 10^6$ J/m^2 (kwh/m^2). Based on the results of calculated studies to determine the total insolation of solar energy by month, it can be concluded that from March to October, it is quite sufficient to use solar energy in the treatment of oil-containing waste.

Widespread in the composition and properties of potential oil sludge raw materials and their tendency for either formation of stable emulsions or phase separation requires a detailed study and defines the need to develop an innovative method based on non-conventional engineering solutions. We have offered a universal commercial oil-containing wastes purification method.

Hydrocarbon waste fraction analysis results are shown in Fig. 1, Fig. 2, Fig. 3, and Table 2. For higher analysis precision, blank sample chromatogram was deducted from the chromatogram obtained and data was processed. The chromatogram obtained after deduction is shown in Fig. 1.

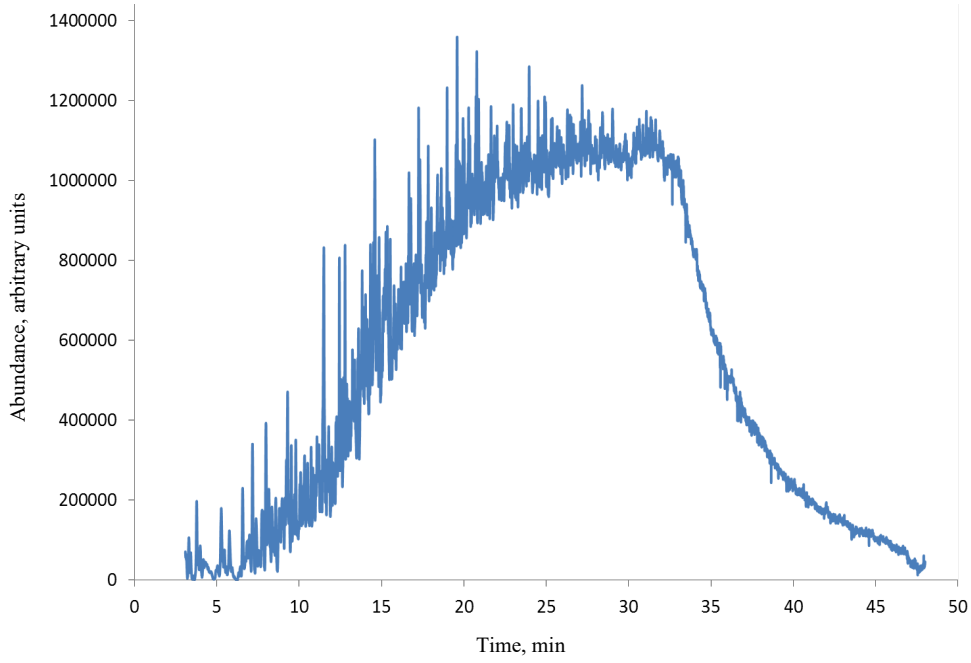


Fig. 1. Chromatogram obtained after deduction of blank sample chromatogram from oil chromatogram.

The oil distillation curve obtained is shown in Fig. 2. According to the method, mass fraction of distilled oil to 530–550 °C is accepted as 100 %.

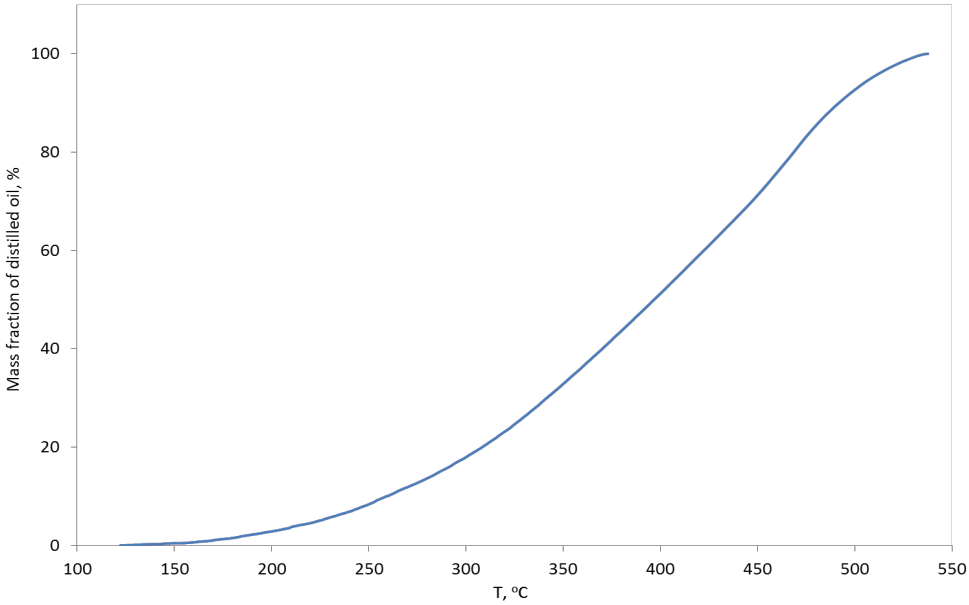


Fig. 2. Oil sample distillation curve.

Typical ion signals in the mass spectra recorded in each chromatogram point were used to identify individual compound classes (Table 2).

TABLE 2. RESULTS OF COMPONENT ANALYSIS OF VOLATILE RRACTION OF OIL SAMPLE PROVIDED

Compound class	W %
Paraffins	15.32
Uncondensed naphthenes	22.13
condensed naphthenes with 2 rings	19.45
condensed naphthenes + all naphthenes with 3 rings	14.11
Benzenes	6.63
Naphthene benzenes	3.09
Dinaphthene benzenes	3.26
Naphthalenes	3.91
Acenaphthenes	3.91
Fluorenes	4.88
Phenanthrenes	3.31

A distribution curve of saturated and aromatic hydrocarbons in the oil sample under study versus their boiling point (Fig. 3) was built using capabilities of the method in use.

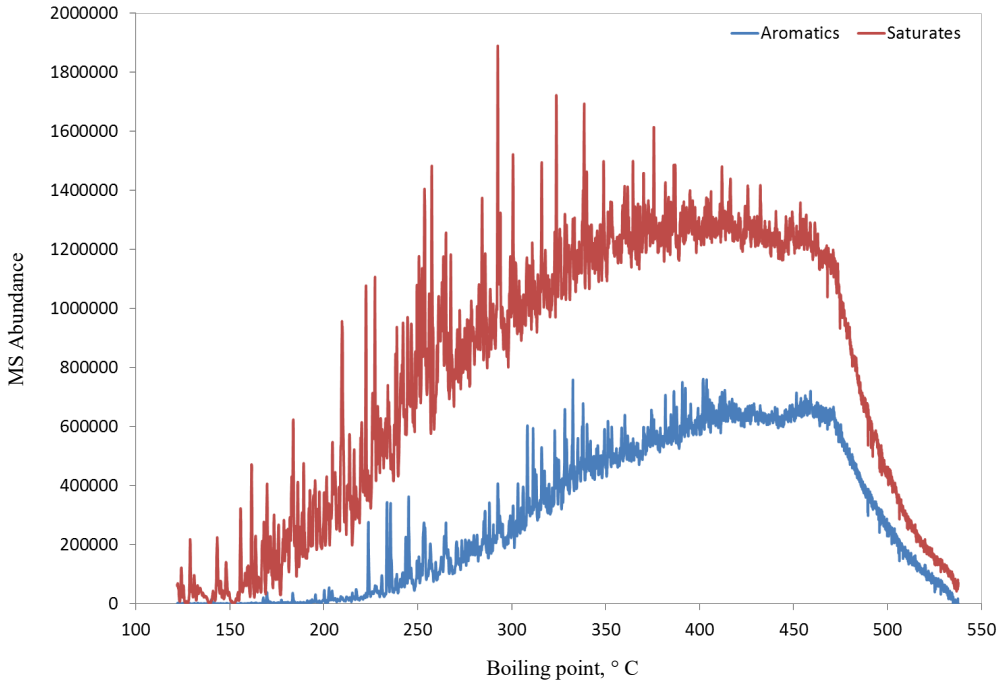


Fig. 3. Distribution curve of saturated and aromatic hydrocarbons in the oil sample under study versus their boiling point.

The studied oil sludge sample with a density of 942 kg/m^3 features typical predominant content of paraffins. Gasoline cut content is low – at a temperature of up to 200 °C, some 2 % of the sample burns out. Diesel oil cut up to 350 °C is 23 % on the average and gasoil cut amounts to 16 %. It follows from the figures that the product of oil-containing wastes purification is valuable hydrocarbon material that may be processed or recycled.

The helio device, in which oil product hydrocarbons undergo thermal treatment using solar energy, has been designed to extract oil products.

Helio device is a plant that transforms solar energy into heat energy. The optimal design of the plant must ensure maximum use of solar energy. The optimal design of the device must be created regarding natural and climatic peculiarities of the region.

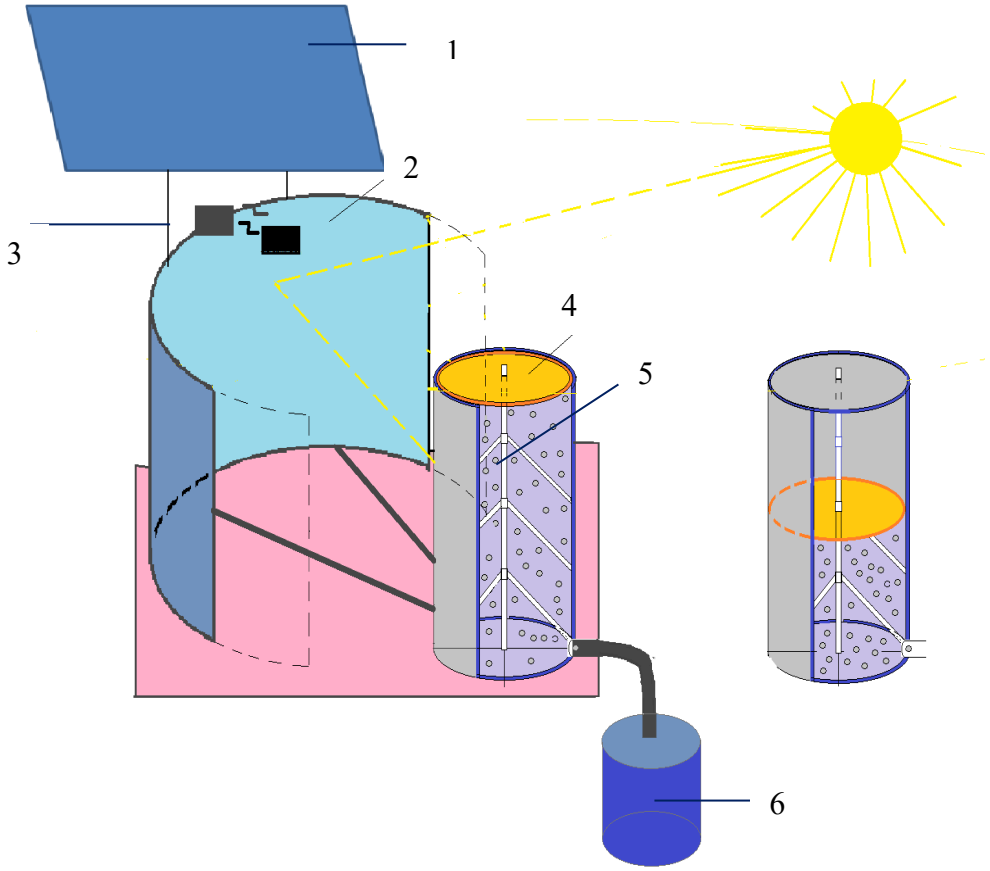
Review of the current state of use of the helio device has revealed efficiency of application of solar energy cylindrical parabolic concentrators (CPC) for various industries. Tracking and fixed parabolic concentrators are most commonly used in plants that transform solar energy into heat and electric energy. Unlike point focus concentrators, they are easier to manufacture and more convenient for modular scale-up. Solar radiation estimates defined usability of the cylindrical parabolic concentrator in Atyrau region. We have elaborated helio device design specifications to enable processing of 5 kg/h of oil waste in semi-continuous mode during daylight hours in spring, summer, and fall. Efficient operation of the entire system is guaranteed by the efficiency of all its functional parts. CPC parameters such as geometry, aperture angle, focal spot dimension, surface reflection power and accuracy of manufacturing must ensure the required level of solar energy concentration in the reflector's line focus.

In order to track the system that would define source data to install the solar energy cylindrical parabolic concentrator in the required geographical location and, even more so, to

ensure efficient solar azimuth and elevation tracking, it is required to determine the constant original values that will be used as the basis of calculations for actuators as part of the solar tracking system.

This installation has the following characteristics: power up to 250±3% W; focus temperature up to 120 °C. Oil-containing wastes is treated in a cylinder-shaped reactor secured on top with a disk and rotor with blades. The integrated parabolic concentrator collects solar energy into a focus where the rotor with blades made of copper and with solar pointing is located. Heat that lacks on cloudy days and in the cold season is provided by a solar panel of 250±3% W and an electric heater assembled under the tank.

The device operates as follows: to promote conditions for oil displacement from soil, oil-polluted soil or oil sludge is mixed with water and, once soil is saturated with water, cavities are formed, via which oil fractions begin to escape during heating by solar energy. Another benefit of this helio device is its automated operation; the solar collector automatically moves along the solar path, which ensures maximum concentration of solar radiation. Fig. 4 shows the principal scheme of the helio device fitted with concentrating elements.



1 – solar panel; 2 – cylindrical parabolic concentrator; 3 – solar energy tracking system; 4 – disk for oil displacement with pressing; 5 – rotor with blades for heated waste mixing; 6 – displaced oil discharge tank.

Fig. 4. Device for oil and oil products extraction during oil-containing wastes purification.

During the experiment with oil waste heating, the device temperature was 75–82 °C with an ambient temperature of 33–35 °C; heating was conducted during daylight hours. Changes of oil-containing wastes temperature in the helio device fitted with concentrating elements are shown in Fig. 5.

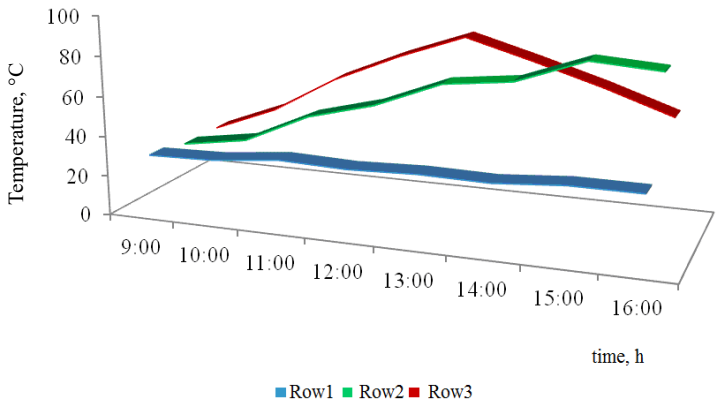
To promote conditions for oil displacement from soil, oil-polluted soil or oil sludge is mixed with water. To this end, the device is filled with water and oil-polluted soil or oil sludge is introduced on top. The focus part of the body is fitted with a parabolic concentrator with the solar tracking system on a metal frame. This concentrator focuses direct and disperse solar radiations, collects solar energy and forwards it to the focus part of the tank. Any material with reflection power may be used as a solar energy concentrator.

The helio device is fitted with solar panels made of concentrating solar modules mounted on the mechanical system that provides heat lacking on cloudy days and in the cold season. The tank bottom is fitted with an electric heater activated by the additional energy accumulated by the solar panel.

On top of the tank, there is a rotor with blades mounted on the disk; these blades mix the mixture being heated and oil fraction starts to escape through the cavities formed with the help of blades during heating with solar energy. To separate escaping oil from soil, the disk presses the mixture and resulting productive oil is drained into an oil tank through the pipe connected to the body.

During oil-polluted soil heating, the device temperature was 85 °C with an ambient temperature of 28 °C. Heating lasted 4 hours and when additional energy accumulated by the solar panel was used, the heating time reduced by 2–2.5 times. Oil-polluted and treated soil and oil sludge are loaded and discharged manually or mechanically, although this process may be automated.

In order to establish thermal effect of different sources of energy (solar and electric) on hydrocarbon properties, characteristics of waste thermal extracted organic fraction were studied. The hydrocarbon phase resulting from heat processing with solar energy is very different in its physicochemical properties compared to the hydrocarbon phase extracted electrically [20], [21].



Row 1 – Ambient temperature; Row 2 – Temperature of waste and water mixture during heat processing using solar energy; Row 3 – Temperature of waste and water mixture during heat processing using electric energy.

Fig. 5. Oil-containing wastes temperature changes with various sources of energy.

The results of the analysis of oil extracted from oil-containing wastes are shown in Table 3. It follows from Table 3 that the content of chloride salts, water cut and sulphur content with electrical heating are much above allowances and result in changes in physicochemical properties of oil.

When solar energy is used, the conditions required to extract oil from soil are established. As it follows from the figures provided, the product of oil-containing wastes purification is valuable hydrocarbon material that may be processed or recycled [22]–[27].

TABLE 3. PHYSICOCHEMICAL PROPERTIES OF OIL EXTRACTED FROM OIL-CONTAINING WASTES

Properties and methods	**Density at 20 °C, kg/m^3**	**Density of oil recovered, kg/m^3**	**Content of chloride salts, mg/L**	**Water cut, %**	**Content of solids**	**Sulphur content**
Normative meaning	830.0	833.7	100	0.50	0.0500	0.600
1st method (heating using solar energy)	948.0	942.7	127.480	18.0	0.0349	0.168
2nd method (heating using electric energy)	852.1	942.7	407.9	35.0	0.0394	0.265

Next, oil-containing wastes purification activation energy is calculated. For activation of oil sludge during thermal treatment requires 695.67 kJ/mol of energy, which is 300 times higher than oil-polluted soil activation energy (2.17 kJ/mol). However, in both cases, activation energy decreases with temperature increase. This is explained by the fact that temperature increase results in breaking of intermolecular bonds between asphaltene-tarry-paraffin substances in oil-containing wastes.

The result of the differential thermal analysis (DTA) is given in Fig. 6.

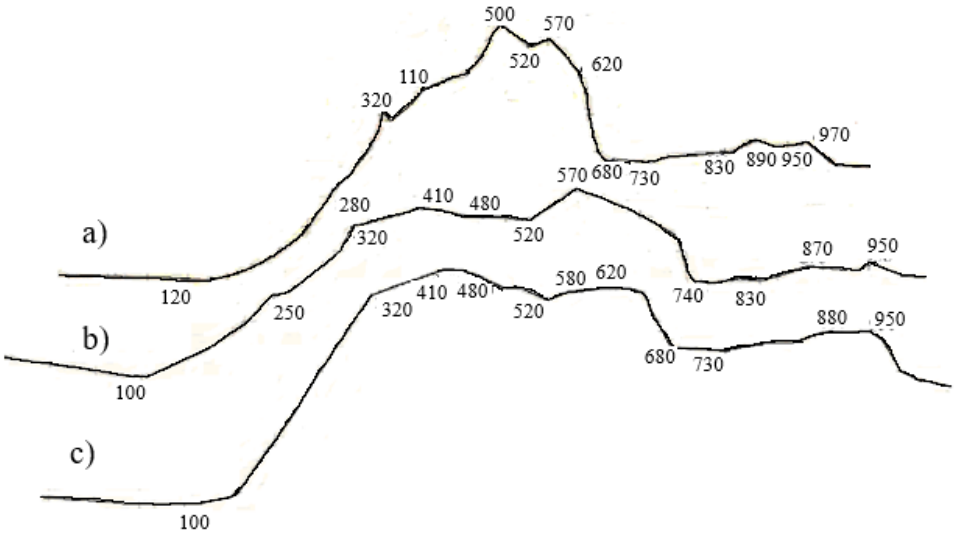


Fig. 6. Thermograms of oil-containing wastes in °C: a) before treatment; b) after electrical thermal treatment; and c) after heating using solar energy.

The DTA curve of oil-containing wastes heating before processing shows an intense extended exothermic effect with maxima in the temperature range of 200 °C to 680 °C accompanied by weight loss of 12.7 %. Weight loss is indicative of burning-out of oil components present: hydrocarbons. Exo-effect at (+) 260 °C is caused by thermal decomposition of methane hydrocarbons. Exo-effect at (+) 320 °C implies paraffin fraction decomposition. Exo-effects at (+) 410 °C and (+) 480 °C imply decomposition of naphthene's. Exo-effect at (−) 570 °C is caused by crystallization of high-molecular hydrocarbons of paraffinic oil (mineral wax) (Fig. 6(a)).

The thermogram underwent changes after solar treatment of oil-containing wastes. Exo-effects with maxima (+) of 480 °C and (+) 570 °C became less intense, which is indicative of decomposition of high-temperature fraction hydrocarbons with weight loss of 4.6 %. Endo-effect (−) at 100 °C is caused by adsorbed water decomposition (Figs. 6a and 6b).

Benchmarking of treatment methods (using solar and electric energy) yields the following conclusions:

1. Oil-containing wastes thermal treatment using solar and electric energy reduces the intensity of exo-effects: (+) 410 °C, (+) 480 °C and (+) 570 °C, (+) 620 °C relating to the effects of high-molecular paraffin oil hydrocarbons result in decomposition of hydrocarbons;
2. Thermal treatment using solar energy has more effect on high-temperature hydrocarbon component of oil residue. Exo-effect (+) 570 °C below (+) 480 °C;
3. Thermal treatment using electric energy, on the contrary, affects low-temperature hydrocarbon component of oil residue. Exo-effect (+) 480 °C < (+) 570 °C.

Fractional analysis of oil-polluted soils and oil sludge and their solid residue after treatment using solar energy in the designed device was conducted to study the efficiency of heat effect of solar energy on hydrocarbon properties.

After oil sludge thermal treatment using the plant 3 end products are obtained (Fig. 7):

- oil sludge derivative (organic fraction);
- water containing oil products;
- sludge (cake) containing oil products (Table 4, Table 5).

TABLE 4. MATERIAL BALANCE BEFORE THERMAL TREATMENT

Product	**%**	**kg/h**	**t/h**	**t/day**	**t/year**
Oil sludge, including:	100.00	50.0	0.05	0.25	325
Solids	8.0	4.0	0.004	0.02	26
Oil products	76.8	38.4	0.0384	0.192	249.6
Water	15.2	7.6	0.0076	0.038	49.4
Total		50.0	0.05	0.25	325

TABLE 5. MATERIAL BALANCE AFTER THERMAL TREATMENT

Product	**%**	**kg/h**	**t/h**	**t/day**	**t/year**
Oil sludge, including:	100	49.08	0.04908	0.2454	319.02
Solids	83.21	40.84	0.04084	0.204	265.2
Oil products	8.79	4.31	0.00431	0.022	28.6
Water	8.0	3.93	0.00393	0.0196	25.48
Total		49.08	0.04908	0.2454	319.02

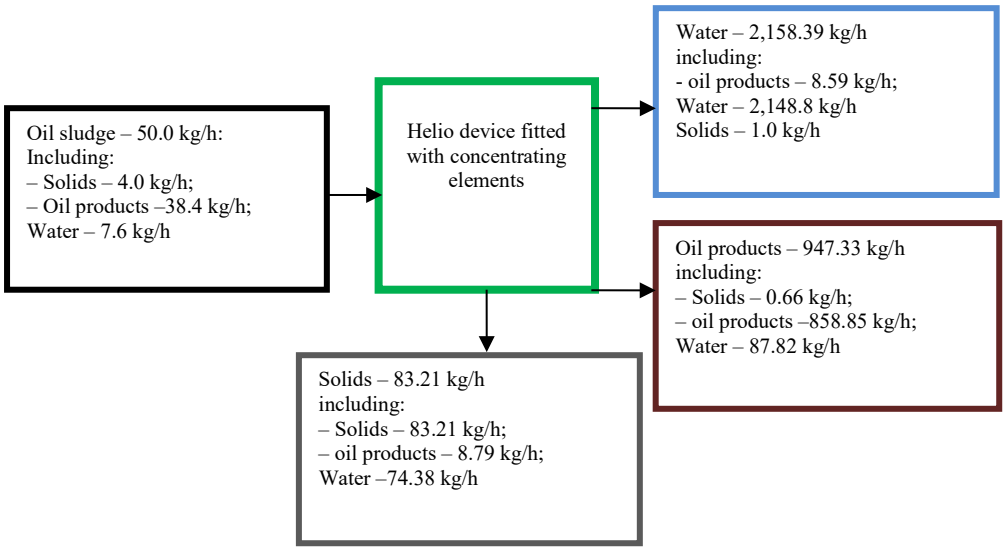


Fig. 7. Diagram of oil sludge passage through the helio device.

Thus, after oil-containing wastes purification using solar energy, the particulate load in soil does not exceed 8.65–8.79 %. After treatment, the absolute molecular weight of hydrocarbons approaches that of bitumen and carbon/hydrogen ratio changes as follows: bitumens (6.29–10.7) > oil-polluted soils or oil sludge (8.56–8.79). The benefits of this oil-containing wastes purification method in terms of oil and mineral fraction separation are simple design of the device, its high performance and relatively low price.

The above estimates and experimental data are provided in tabular form. Table 6 includes data of the solar radiation coming to the horizontal face by hours, estimated oil-containing wastes activation energy with various thermal treatment conditions and helio device efficiency.

TABLE 7. HELIO DEVICE PERFORMANCE WITH THERMAL TREATMENT OF OIL-POLLUTED SOIL AND OIL SLUDGE

Device	**Total solar radiation coming to horizontal face**		**Oil-containing wastes activation energy**			**Efficiency**
	Time, h	*S*, kJ·h/m^2	Temperature, K	*E*, kJ/mol		η
				oil-polluted soil	oil sludge	
Helio device	9.00	1 091.1	309.5	2.17	695.67	0.27
	10.00	1 143.5	315	10.29	10.11	0.30
	11.00	1 172.4	328	4.72	5.00	0.35
	12.00	1 181.6	336	5.72	3.54	0.40

4. CONCLUSIONS

Thus, after oil-containing wastes purification using solar energy, the particulate load in soil does not exceed 6.65–6.79 %. After treatment, the absolute molecular weight of hydrocarbons approaches that of bitumen. The raw materials disposed of using the helio device – treated soil – may find application in road construction. Thus, a sought-after 'waste – initial stock – product' technology cycle may be created.

According to the developed technology, pre-neutralized oil waste may be used in the production of building materials – bricks, claydite, small building products, etc. Construction of cheap dirt roads reinforced with cement, lime, and other binding agents, the so-called 'economy class' roads, may also be considered. These days, a method of soil reinforcement using processed oil wastes has gained the widest recognition among oil industry waste disposal methods for economic reasons. The practice of waste reutilization instead of storage or disposal allows to save place for storage, minimize the volume of waste, and reduce the environmental load due to the absence of material transportation and on-site waste use. In terms of use of the product obtained, such methods may be targeted at production of building, reclamation, and recultivating materials. Solar energy may be used as a source of energy required for disposal.

The helio device designed offers the following benefits:

- Eco-friendly generation of heat energy;
- Full absence of greenhouse gas emissions;
- Utilization flexibility, simple and lightweight design, mobility for operation, modular ramp-up principle and high reliability;
- Crude oil recovery from oil sludge back into circulation;
- Minimum amount of oil impurities in the solid residue, which enables the use of the solid phase to obtain modern composite building material;

Oil content of 1.5–2.5 % in the water phase, which enables photochemical purification using ozone. Helio device operation meets requirements of international environmental standard ISO 14000 as the helio device that separates waste into useful fractions has no environmental release.

The oil-containing wastes purification method developed solves an important environmental issue of oil-containing wastes disposal, promotes recovery and prevents degradation of natural complexes, and reduces soil and water pollution. Thus, this technology of oil-containing wastes disposal will significantly mitigate the adverse environmental impact of pollutants.

Setting of new tasks and determination of new approaches to the arrangement of oil-containing wastes complex treatment are intended to change priorities in ongoing and scheduled operations for the purposes of environmental protection. The oil-containing wastes purification method under study is an important element of the overall process of environmental safety assurance.

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