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Energy-Efficient Technology for Processing Oil Sludge into Commercial Oil Products

K. Shevchenko[1], A. Grigorov[1], V. Khrystych[2], S. Vavreniuk[2], L.Yurchenko[2]

[1] *National Technical University «Kharkov Polytechnic Institute», 61002, 2 Kirpichova str., Kharkov, Ukraine*
[2] *National University of Civil Defense of Ukraine, 61023, 94 Chernyshevskaya str., Kharkov, Ukraine*

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Abstract

The article considers the possibility of processing oil sludge, a waste product of oil refining, using an energy-efficient technology based on the thermal cracking process. This process takes place at a temperature of 460-470°C and a pressure of 0.11-0.14 MPa. The process produces 57-60 % fuel and 27-34 % oil fractions that can be used in the production of commercial oil products. The industrial implementation of this oil sludge processing technology allows to produce an additional amount of commercial oil products, as well as to solve the problem of accumulation of harmful waste from the oil refining industry, which has a negative impact on the environment.

Keywords: *Oil sludge; Energy-efficient processing; Thermal cracking; Fraction; Motor fuels; Lubricating oils; By-products.*

1. Introduction

Environmental safety and environmental protection is an important component of the sustainable development of modern Ukrainian society. Ukraine's European choice and its aspiration to join the European community as soon as possible requires strict compliance with global environmental safety standards.

The main sources of environmental pollution are chemical, metallurgical, oil and gas, coal and other industries. This pollution can occur due to emissions of industrial gases into the atmosphere and discharge of waste water containing toxic substances into natural reservoirs, as well as due to the accumulation of multi-tonnage waste, which represents a significant potential danger to natural ecosystems.

The widespread use of energy-efficient technologies in all industries can be a decisive factor in improving the environmental situation in the country. These technologies pay for themselves in a short period of time and can provide the highest output of the final product per unit of raw material per unit of labor input. However, the involvement of secondary material resources in the production process, despite its expediency, is currently constrained by the economic capabilities of society.

2. The objective of the research

The disposal of industrial waste is a serious economic and environmental problem, which is still waiting for its radical solution. One of the promising ways of such a solution is to use the industrial waste to create new effective materials [1]. It is estimated that only about 30 % of the large amount of recyclable industrial waste is currently used [2-3]. The other 70 % is not used and, as a result, is a source of environmental pollution and increased danger for the population of industrial regions. The processing of waste, which is in many cases a valuable raw material for the manufacture of commercial products, is economically feasible if the value of the obtained products exceeds the costs of disposal [4].

Oil sludge is a complex physical and chemical mixture containing hydrocarbons, water and mechanical impurities (clay, metal oxides, sand) [5-6]. Oil sludge is generated during production processes related to the storage, transportation and processing of oil. This type of waste poses a great danger to the environment and is subject to the first stage of recycling [7]. Therefore, the work associated with the introduction of new, energy-efficient technologies for its processing will, on the one hand, remove a source of significant environmental pollution and, on the other hand, produce additional valuable products (see Figure 1).

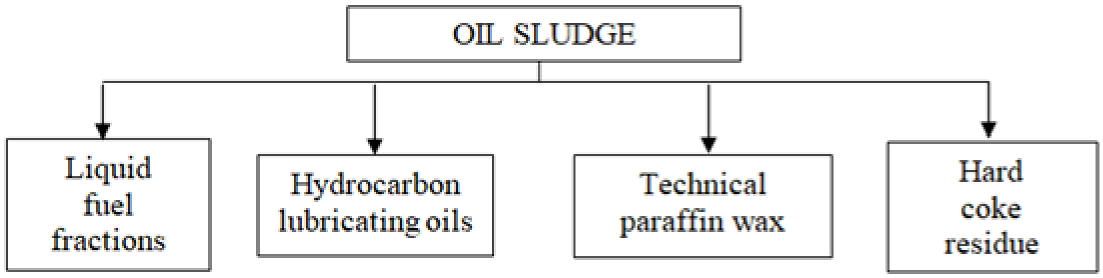

Figure 1. Oil sludge processing products.

A valuable component of oil sludge to be processed into motor fuel components is its hydrocarbon part, which is either mixed with oil and fed to primary processing plants [8] or subjected to thermal cracking, which is carried out at temperatures of 420-480°C and pressures from 0.1 MPa to 3.0 MPa [9]. The main liquid product of thermal cracking is used as a component of various fuels. For example, fractions with boiling points of 30-210°C and 200-350°C are used to produce compound motor fuel (petrol or diesel), and fractions with boiling points above 300°C are used to produce boiler fuel. At the same time, there is no proposal to use the obtained high-boiling liquid fractions formed during the cracking of the hydrocarbon part as components of lubricating oils: process, motor, etc. Therefore, the purpose of this article is to develop an energy-efficient oil sludge processing technology that will allow obtaining, along with fuel fractions, fractions that can be used in the production of lubricating oils - oil products that are in great demand on the world oil market.

3. Materials and methods of the research

The raw material for the study was two samples of oil sludge taken from storage ponds at two different oil refineries in Kharkiv (Sample 1) and Kremenchuk (Sample 2) regions of Ukraine. This sludge was formed during the technological operations of primary processing of oil raw materials into fuels and lubricants.

The oil sludge was prepared by settling at 80°C for 3 hours, followed by centrifugation of the settled part in a laboratory centrifuge type 800-1E Medica (China), at a rotor speed of 3500 rpm, for 30 minutes. After preparation, the residual water content in the hydrocarbon mixture was 0.2 % by weight, and mechanical impurities - 0.05 % by weight.

The concentration of the prepared hydrocarbon part of the oil sludge (separation of hydrocarbons with a boiling point of up to 360°C) was carried out according to the ASTM D86 method. Thermal cracking was carried out at a temperature of 460-470 °C and a pressure of 0.11-0.14 MPa and a feedstock heating rate of 5-7 °C/min at the equipment described in [10].

The study of the quality indicators of the obtained products was carried out according to the standardized methods of ASTM D1298, ASTM D445, ASTM D92, ASTM D97.

4. Results and discussion

As a result of cracking the hydrocarbon part of the oil sludge, a product was obtained that represents a broad fuel and oil fraction (see Table 1) and by-products - hydrocarbon decomposition gases and a product of polymerisation and polycondensation of hydrocarbons - solid coke residue. The total yield of by-products, together with losses, was 10.0-14.0 % (vol.) of the feedstock volume, depending on the sample under study.

Table 1. Characteristics of a wide fuel and oil fraction

Parameter	Sample №1	Sample №2
Yield, %, (vol.)	86.0	90.0
Density at 20°C, kg/m^3	878	864
End of boiling point,°C	398	405

The resulting broad fuel and oil fraction was divided into narrower fractions to isolate individual fuels and base oils, for which the main physical and chemical parameters characterizing the possibility of their use for the production of motor oils were subsequently determined (see Table 2).

Table 2. Characteristics of the obtained products.

Parameter	Sample №1	Sample №2
Fuel fractions (components of motor fuels)		
Boiling point, °C	85	86
Fraction b.p.-180°C, %, (vol.)	10,0	12,0
Fraction 180-240°C, %, (vol.)	9,5	10,0
Fraction 240-360°C, %, (vol.)	35,5	38,0
Oil fraction (component of lubricating oils)		
Fraction >360°C, %, (vol.)	27,0	34,0
Density at 20°C, kg/m^3	886	877
Kinematic viscosity at 100°C, mm^2/s	6,42	5,59
Flash point, °C	220	218
Pour point, °C	11	6

According to the given physico-chemical indicators, the obtained oil fractions contain a large amount of paraffins in their composition, and in order to obtain commercial lubricating oils, it is necessary to deparaffinize them, the by-product of which will be technical paraffin [11].

Any oil fraction (as well as oil) is a complex mixture of hydrocarbons that boil in a certain temperature range [12]. However, many calculation formulas include a certain temperature that characterizes the boiling of an oil product. Therefore, in practice, the concept of average boiling point is used to characterize distillate fractions. There are several modifications of it, but the most widely used is the average molar t_{av}, which can also be roughly defined as the temperature of 50 % of the distillation of the fraction according to the true boiling point curve (ITK) or as the arithmetic average of the initial and final boiling points [13].

In view of this, the relationship (t_{av}, °C) with density (ρ^{20}, kg/m^3), kinematic viscosity (v^{20}, mm^2/s) and sulphur content (X_s, %) in fractions is of some practical interest (see Figures 2-4).

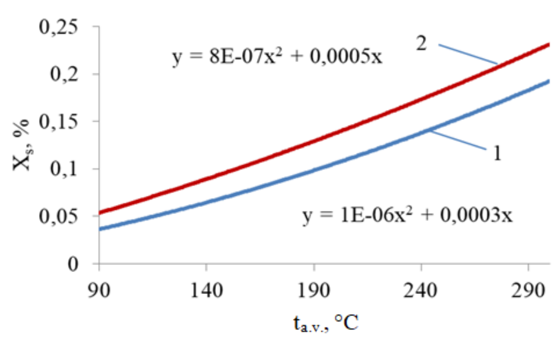

Figure 2. Dependence of X_s on $t_{av.}$: 1 – sample № 1; 2 – sample № 2

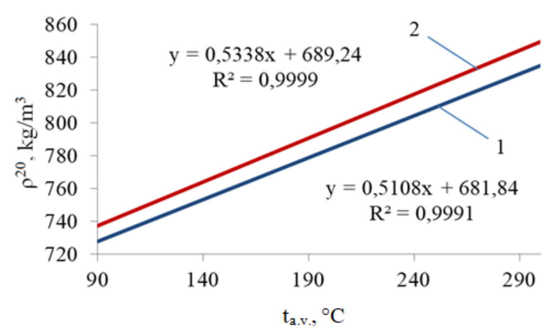

Figure 3. Dependence of ρ^{20} on $t_{av.}$: 1 – sample № 1; 2 – sample № 2

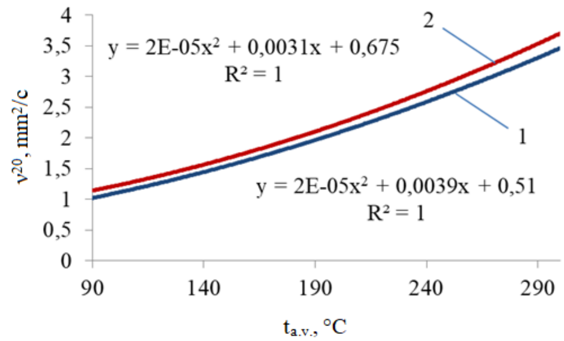

Figure 4. Dependence of v^{20} on $t_{av.}$: 1 – sample № 1; 2 – sample № 2

The obtained dependences indicate that sample № 2 has a heavier fractional composition and, therefore, a higher sulphur content, higher density, and kinematic viscosity than sample №1. In terms of sulphur content, without additional purification, the resulting distillate fractions can be used in the compounding of motor fuels that meet the environmental safety standard of no higher than Euro 3 [14]. Moreover, their final content in the fuel composition will be limited by the total sulphur concentration in the obtained commercial motor fuel compositions.

Thus, based on the experimental studies, we propose an energy-efficient technology for processing oil sludge into marketable oil products, which can be represented by the scheme shown in Fig. 5.

The implementation of this scheme (see Figure 5) takes place only after preliminary cleaning from water and mechanical impurities. After that, the resulting hydrocarbon mixture is concentrated, that is, light hydrocarbon fractions with boiling points of up to 350 (360) °C are removed from it. These light fractions are ballast during thermal cracking and only complicate the process. However, they can be used in the implementation of the technological process (they can be used as process fuels) or in further technological processes, in particular, in the compounding of commercial fuels.

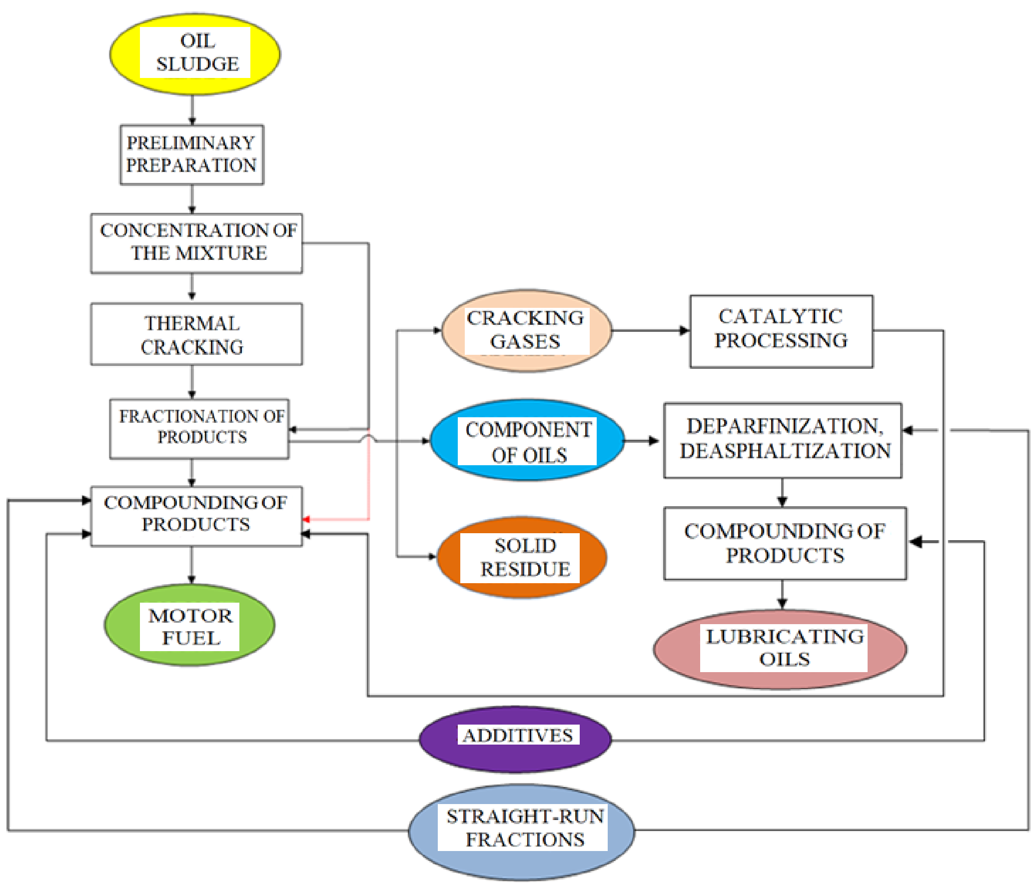

Figure 5. Scheme of energy-efficient processing technology of oil sludge into oil products

The by-products of this oil sludge processing scheme are hydrocarbon gases, industrial paraffin and solid coke residues, which are widely used in the petrochemical industry as raw materials for organic synthesis. In addition, cracker gases containing olefin hydrocarbons can be used for catalytic processing to produce hydrocarbons with high detonation resistance, which are components of motor gasoline.

5. Conclusions

Based on theoretical and experimental studies, it has been determined that the most promising method of oil sludge processing is thermal cracking, which takes place at a temperature of 460-470 °C and a pressure of 0.11-0.14 MPa. This produces 57-60 % fuel and 27-34 % oil fractions.

Based on the thermal cracking process, an energy-efficient technology for processing oil sludge aimed at obtaining light fuel fractions, lubricating oils for a wide range of applications and technical paraffin is proposed. The waste generated in the process of implementing the proposed technology (water and mechanical impurities), after treatment, can also be used for industrial purposes, for example, in construction or in the closed water cycle of heat exchange equipment.

By-products of the technology (hydrocarbon gases, light fractions, paraffin and solid residue) are used as fuel, raw materials for organic synthesis and components of commercial oil products. Rational use of by-products together with production waste is one of the most important industrial factors that determine the economic feasibility of a particular technological scheme, the cost of the final product and its competitiveness in the global oil market.

Using the proposed oil sludge processing technology, it is possible, on the one hand, to obtain a source of valuable raw materials for the production of commercial oil products, and, on the other hand, to solve the problem of accumulation of hazardous waste from the oil refining industry.

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To whom correspondence should be addressed: prof. Andrey Grigorov, National Technical University «Kharkov Polytechnic Institute», 61002, 2 Kirpichova str., Kharkov 61000, Ukraine, E-mail: grigorovandrey@ukr.net