Modern methods of utilization and disposal of oil-containing waste for the elimination of the environmental pollution

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Abstract. This paper presents a comparative description of traditional methods of neutralization and disposal of oil-containing waste. The basic methods used for these purposes are effective, but have significant drawbacks. In this regard, it is necessary to find new environmentally friendly and cost-effective ways. Low-temperature pyrolysis at the TPU 1 installation, purification of oil-contaminated sludge using solar energy, as well as complex purification of oil sludge are proposed as such methods. Their main advantages are compliance with modern environmental standards and the formation of products that can be used in the future as a result of cleaning. It is concluded that it is appropriate to use each of the proposed methods depending on the amount of contamination.

1. Introduction

Russia is one of the first places in terms of oil production, transportation, and processing, so the problem of neutralization and disposal of oil-containing waste has a high degree of relevance. Every year, Russia produces about 400 million tons of oil, 1.5-10% of it (4.5% million tons per year) is lost during production and transportation, leading to catastrophic environmental pollution [1].

One of the significant sources of environmental pollution is oil sludge. Oil sludge refers to oil-containing waste generated during oil production and preparation, which are the most dangerous pollutants and belong to the II hazard class [2].

Oil sludge has a diverse composition, including petroleum products, water, sand, clay, and other mineral parts. Oil sludge compositions contain both organic components and heavy metals with a typical concentration range, as reported by the American Petroleum Institute (API) [3]. The ratio of all elements of the composition varies very widely. The composition of slurries depends on the depth and type of raw materials being processed, equipment, processing schemes, and other factors [4]. The improper disposal of petroleum sludge to the environment creates a major threat such as significant modifications in the chemical and physical properties of the surrounding soils, resulting in morphological change. Table 1 shows the classification of the composition of oil sludge depending on the source of formation [3]. Table 2 shows the chemical and mineral compositions of oil sludge [4].

As a result of aging of oil sludge, volatile hydrocarbons evaporate, which leads to an increase in the concentration of iron and sulphur. Moreover, due to the course of oxidation, polymerization, and polycondensation reactions over time, other compounds are formed, for example, asphaltenes can pass into carbides and carbenes, which are undesirable reaction products due to their toxicity [5-7].

As a rule, the accumulation of oil-containing waste is carried out on specially equipped sites or in bunkers, while their sorting and classification is not performed. However, this method of handling such
waste is not reliable, because the sludge can self-ignite due to the possibility of the development of microorganisms, the course of oxidation, etc. Thus, it is necessary to neutralize them [4].

Table 1. Classification of oil sludge [5].

| Composition, % | Oil contaminated soil | Bottom sludge | Tank cleaning products | Oil-water emulsion | Trap oil | Drill cuttings | Barn top layer |
|----------------|-----------------------|----------------|-----------------------|-------------------|---------|----------------|----------------|
| Mechanical admixture | 50-90 | 15-50 | 5-10 | 1.5-15 | 0.05-0.5 | 11-25 | 0.5-1.5 |
| Oil, petroleum products | < 10 | 10-30 | 50-70 | 30-80 | 70-90 | 7-14 | 90-95 |
| Asphaltenes | - | 6.5 | 42 | 5-10 | 4-15 | - | 9.5 |
| Resins | - | 18 | 20 | 10-20 | 10-45 | - | - |
| Paraffins | - | 2.5 | 5.6 | 3-9 | 2-10 | - | 3 |
| Water | < 20 | < 60 | 25-40 | < 70 | < 15 | 75-90 | 1.5-5 |

Table 2. Chemical and mineral composition of oil sludge.

| Organic components | Moisture | Sulphur | Mineral part |
|-------------------|----------|---------|--------------|
| 72                | 10.2     | 1.8     | 16           |
| Content of components, % | SiO₂ | CaO | Fe₂O₃ | Al₂O₃ | Mg | The rest |
| 4.55 | 3.14 | 1.65 | 2.36 | 1.0 | 3.3 |

2. Methods of neutralization and disposal of oil sludge

Various methods are used to neutralize and dispose of oil-containing waste: physical, chemical, physico-chemical, and biological. All these methods can be combined into two fundamentally different technological approaches: the first approach involves direct recycling or disposal of waste. The second one is based on suppressing the activity of the pollutant, for example, by neutralizing, decomposing, binding, localizing, etc. [8]. All methods used today have both advantages and disadvantages (Table 3).

Table 3. Comparative characteristics of oil sludge disposal and disinfection methods [9].

| Method | Type of method | Advantages | Disadvantages |
|--------|----------------|------------|---------------|
| Thermal | Combustion in furnaces of various designs | High decontamination efficiency, applicable for many types of waste | High costs for flue gas cleaning and neutralization |
| | Pyrolysis | A high degree of decomposition, the possibility of using the degradation products | High material and energy costs |
| | Electric fire incineration | Created almost ideal conditions of the combustion flame from the burning waste, a high degree of purification of flue gases | High material and energy costs |
| Method                          | Characteristics                                                                 |
|--------------------------------|---------------------------------------------------------------------------------|
| Physical                       |                                                                                 |
| Gravity settling               | Does not require large capital and operating costs                               |
| Separation in a centrifugal field | The possibility of intensification of the process                                 |
| Separation by filtering         | Relatively low costs, high degree of reliability, high quality of target products, less demanding on the quality of raw materials |
| Cavitation dehydration         | Cost-effective: reducing water content twice                                      |
| Vibro-cavitation grinding       | Low energy consumption, high degree of efficiency, possibility of utilization of various oil sludge compositions, including bottom sludge |
| Chemical                        |                                                                                 |
| Chemical encapsulation of pollutants with hydrophobic reagents based on calcium oxide | Simplicity of technology, speed of disposal, high efficiency of the process, the possibility of using recycling products as secondary material resources |
| Application of specially selected surfactants, demulsifiers, and dispersants | The possibility of intensifying processes with the introduction of small amounts of additives |
| Vibro-cavitation extraction, washing with ultrasound | The yield of marketable oil, the possibility of disposing of the soil |
| Biodegradation using special bacterial strains | The ability to intensify the process, requires little capital and energy costs |
| Biological                      |                                                                                 |
| Bioremediation                 | Restoration of soil cover                                                        |
| Seeding with plants             | Restoration of soil cover                                                        |

Among all these methods, the base are thermal and chemical ones, but they are environmentally unfriendly due to the formation of the combustion and heat-stable toxic (polyaromatic hydrocarbons, dioxins, and furans) in waste gases and emissions of significant quantities of heavy metals (lead, cadmium, mercury, vanadium, etc.).
3. The modern methods

Oil production companies and refiners are looking for the technologies, which are aimed to extract the hydrocarbons from the sludge to the maximum extent and thus to minimize the final treated sludge quantity, which can be disposed of more economically, quickly, and eco-friendly [10].

3.1. Low-temperature pyrolysis at the T-PU1 installation

One of these methods is low-temperature pyrolysis at the T-PU1 installation (Fig. 1) [11].

The technological process of the installation can be reduced to the following stages:

- loading the retort with waste through the loading hatch;
- installing the loaded retort in the oven;
- connection of the retort steam and gas pipeline to the refrigerator pipeline;
- turning on the cooling water supply to the refrigerator;
- loading on grates and ignition of solid fuel (firewood, coal, briquettes made of carbon black);
- improving and maintaining the temperature in the furnace before occurrence of the pyrolysis gas with solid fuel.

The main advantages of the installation are:

1) low cost, compact size, easy operation and maintenance (compared to other pyrolysis plants);
2) the installation does not affect surface and underground water, since the water supplied for cooling circulates in a closed system;
3) when the installation is operating, the maximum surface concentrations of all dispersed substances at the border of the approximate sanitary protection zone do not exceed the MPC;
4) it is approved in the state environmental expertise for the equipment of a sanitary protection zone of only 100 metres;
5) the result of the semi-coking process is the formation of an ash residue, which has a wide range of applications: it is used as a filler in the production of rubbers, conveyor belts, technical plates, and much more, it is a pigment for the production of paints. Ash residue of lower quality is used in construction (paving slabs, concrete products, and bricks are made from it), as a solid fuel, for the preparation of modified liquid fuel, and as a sorbent, a substitute for activated carbon.

The plant capacity is up to 8 m$^3$ per day.

Figure 1. Pyrolysis plant TPU 1. 1 – retort oven; 2 – retort; 3 – refrigerator; 4 – collector; 5 – separator; 6 – boost system.
3.2. Use of solar energy

Another innovative method is the treatment of oil-contaminated sludge using solar energy [12, 13]. The device (Fig. 2) has a heat-insulated body (1), painted black inside, on top of which a removable light-permeable shell of a cylindrical shape made of plastic lenses (3) is installed on a metal frame (2), filled half with oil (4), which maximally focuses direct and scattered solar radiation, even of low density, which plays the role of a heater in the device. The light-permeable shell is additionally covered with a polyethylene film (5) to prevent heat loss. After heating, the resulting productive oil is drained into the oil collection tank (6) through a pipe (7) connected to the device body.

![Diagram](image)

**Figure 2.** Device for cleaning oil-containing waste. 1 – heat-insulated housing; 2 – oil-contaminated soil or oil sludge; 3 – metal frame; 4 – removable light-permeable shell in the form of a cylindrical shape made of plastic lenses; 5 – oil; 6 – polyethylene film; 7 – oil collection tank; 8 – pipe connected to the device body.

The device has several advantages:

- the product of oil-containing waste treatment is a valuable hydrocarbon raw material that can be processed or used for other purposes;
- the simple design of the device;
- high device performance;
- its relative cheapness;
- use of such a device significantly reduces the level of negative impact of pollutants on the environment;
- use of absorbed and reflected solar radiation, which eliminates the need for traditional energy sources.

3.3. A complex technological installation for oil sludge utilization

The third possible option is a complex technological installation for oil sludge utilization [13]. It includes various components:

- Tools for removing waste from the tank. As a rule, these are submersible pumps, the design of which includes a heating system for a small area. An alternative is excavator with bucket.
- Tank cleaning tool. This is a special tractor that dilutes the sludge. The resulting waste is removed using a pump.

Primary processing involves heating, followed by mixing and clarification. Large impurities (for example, stones) are removed from the mixture. Heating is used to increase filtration efficiency. Then the waste is mixed with reagents to separate them into various components: water, oil, and solid elements. The final stage is the removal of filtered waste to a special landfill or its reuse in production.

A schematic representation of the integrated oil sludge treatment process is shown in Figure 3.
The oil sludge is fed into a container, where it is mixed and heated from 40 to 80°C. Then the oil sludge is fed into a decanting centrifuge. Under the action of centrifugal force, the decanting centrifuge is divided into three phases: water, oil, and solid. Water is diverted to the tank and then sent to the treatment facilities. The oil phase enters an intermediate heated tank and is then pumped to the plant. The solid phase is transported to the landfill, where biological post-treatment is performed [10].

The benefits of integrated cleaning:

- The material obtained as a result of cleaning has minimal impurities, which allows it to be used in the future (for example, when laying asphalt concrete).
- According to the results of cleaning, the minimum amount of oil impurity remains in the water: no more than 1.5-2 %, which facilitates biological cleaning in the future.
- The oil sludge treatment plant is highly efficient (capacity is up to 15,000 tons of destroyed waste per year).
- The cleaning results comply with modern environmental standards.
- Formation of hydrocarbons that can be reused in the creation of oil-containing products [14].

4. Conclusion
The purpose of the work was to search for modern methods of oil sludge disposal and compare the proposed methods to determine in which cases it would be appropriate to use each of them. All the methods discussed above are eco-friendly, but none of them is universal: each of them can be used depending on how much oil sludge needs to be cleaned and what results are expected from this cleaning.

The method of low-temperature pyrolysis at the T-PU1 installation and the treatment of oil sludge using solar energy will be appropriate if a small amount of oil sludge needs to be cleaned. For large amount of oil-containing waste, as well as waste stored in tanks for a long time, it is rational to use complex cleaning, which allows cleaning tanks with a volume of up to 5000 m³.

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