Geometric parameters determination of the installation for oil-contaminated soils decontamination in Russia, the Siberian region and the Arctic zones climatic conditions with reagent encapsulating

L O Shtripling, E G Kholkin
Omsk State Technical University, 11, Mira ave., Omsk, 644050, Russia

e-mail: holkin555@mail.ru

Abstract. The article presents the procedure for determining the basic geometrical setting parameters for the oil-contaminated soils decontamination with reagent encapsulation method. An installation is considered for the operational elimination of the emergency consequences accompanied with oil spills, and the installation is adapted to winter conditions. In the installations exothermic process thermal energy of chemical neutralization of oil-contaminated soils released during the decontamination is used to thaw frozen subsequent portions of oil-contaminated soil. Installation for oil-contaminated soil decontamination as compared with other units has an important advantage, and it is, if necessary (e.g., in winter) in using the heat energy released at each decontamination process stage of oil-contaminated soil, in normal conditions the heat is dispersed into the environment. In addition, the short-term forced carbon dioxide delivery at the decontamination process final stage to a high concentration directly into the installation allows replacing the long process of microcapsule shells formation and hardening that occur in natural conditions in the open air.

Key words – Equipment for decontamination, oil spills, oil-contaminated soil, oil sludge, decontamination, reagent encapsulation.

1. Introduction
The problem of overcoming the consequences of accidental soils contamination with oil products does not lose its relevance. Potential sources of emergencies are operated machines, equipment for the extraction, storage and transportation of hydrocarbons [1, 2]. Various technologies for reducing pollution effects have been developed and are being applied, but practically all of them are effective only at positive temperatures [3, 4, 5]. Siberia and the Arctic zone of the Russian Federation occupy a significant territory of the country and differ from other regions with special natural and climatic conditions, in particular a long period of negative temperatures and relatively undeveloped infrastructure. The main problem of neutralizing soils contaminated with oil products in conditions of negative ambient temperature is that the contaminated soil is in a frozen state, and it prevents the normal course of the neutralization process, so additional energy is required for preparing the soil, but the problem is in its lack. Considering the short vegetation period and the extreme natural and climatic conditions, it is very important to develop and to use equipment and technologies adapted to arctic conditions.
For regions with winter time more than six months, the most promising technology for the operative elimination of emergency consequences involving oil spills is based on the pollutant encapsulation (reagent encapsulation technology) using an alkaline reagent based on calcium [6]. In this case, the end product of oil-contaminated soil decontamination is encapsulated material which looks like fine mixture similar to ordinary sand.

The authors conducted studies to clarify the formulation of soil decontamination, contaminated with petroleum products, using for neutralization the reagent encapsulation technology, including adapted to "winter conditions" [7]. Also a patent for utility model for decontamination of oil-contaminated soil, and oil sludge was obtained [8], which allows, if necessary (e.g., in winter conditions) to use the heat energy dissipated at each stage of decontamination process of oil-contaminated soil, which in normal conditions is dispersed into environment. In addition, a short-term forced carbon dioxide delivery at the final stage of the decontamination process to a high concentration directly into the installation allows replacing the long process of microcapsule shells formation and hardening that occur in natural conditions in the open air. An assessment of energy potential of an exothermic process chemical reaction of chemical decontamination of soils contaminated with petroleum products, indicates that the thermal energy dissipated with an exothermic process chemical reaction of chemical decontamination of soils contaminated with petroleum products, is guaranteed enough for successful implementation of the oil-contaminated soils decontamination process, which allowed to implement the oil-contaminated soil decontamination process in winter conditions [6].

2. The problem setting
The study object is to determine the main geometric parameters of the installation for decontamination of oil-contaminated soils with reactant encapsulation method when the thermal energy dissipated at each stage of decontamination process, is guaranteed enough for thawing frozen soil portions, contaminated with petroleum products.

3. Theory
All the energy released at each stage of the oil-contaminated soil decontamination process is used for thawing the frozen pieces of oil-contaminated soil, heating the coolant located in the inner cavity of the unit casing, and part of the energy is dissipated into the environment and is a loss. Then, in a first approximation, the heat balance equation looks as follows:

$$\Sigma Q_{CH.R} = Q_{HEATING} + Q_{COOLANT} + Q_{LOSSES}.$$  

where $Q_{CH.R}$ is energy released during a chemical reaction;

$Q_{HEATING}$ is energy required to thaw the frozen pieces of oil-contaminated soil;

$Q_{COOLANT}$ is energy transferred to the coolant located in the inner cavity of the unit casing;

$Q_{LOSSES}$ is energy dissipated into the environment (approximation $Q_{LOSSES} = 0.5 \cdot Q_{CH.R}$).

The main constructive elements of the installation for oil-contaminated soils decontamination are shown on the diagram scheme (Fig.1). The inner cavity made in the wall of the unit housing is filled with coolant Dixis-65, as it has a sufficiently high specific heat capacity ($c=2.974 \text{ kJ/kg}^\circ\text{C}$) and a freezing point 65$^\circ\text{C}$ below zero. The main geometrical parameters of the installation, that affect its operability and performance are internal $d$ and the outer mixer diameter $D$, the hopper wall height $H$ for thawing frozen oil-contaminated soils, the installation length $L$ and cavity width $t$ in the housing wall filled with coolant Dixis-65.
The width of the cavity $t$ in the housing wall is defined starting from the necessary amount of the coolant that is required for the accumulating and transferring heat to thaw the frozen subsequent portions of oil-contaminated material into the tank. The thickness of the unit walls is assumed equal to 5 mm. To determine the geometric parameters of the remaining parameters one introduces the following ratios: $D=d+2\cdot t+10\text{mm}$; $H=0.6\cdot d$; $L=2.5\cdot d$.

In determining the geometric parameters, conditionally there were distinguished three types of installations: small, medium and large. Small installations allow loading the mixer up to 100 kg of oil-contaminated soil, medium – up to 1,000 kg, large – up to 20,000 kg. Experimental studies [7] show that for the guaranteed oil-contaminated soil decontamination process on average is necessary to use lime as a reagent, in an amount not exceeding 80% by weight of the oil-contaminated soil. Calculations [6] showed that due to exothermic process chemical reaction of chemical decontamination of soil contaminated with petroleum products, using 1 kg reagent is dissipated $Q_{\text{CH.R.}} = 2332.25 \text{ kJ}$, and for thawing 1 kg frozen pieces of oil-contaminated soil is necessary $Q_{\text{COOLANT.}} = 424.4 \text{ kJ}$. Using equation (1), the quantity of energy is determined ($Q_{\text{COOLANT.}}$), transferable to the coolant in the inner cavity of the installation housing. The mass of coolant is determined, using the formula for determining the heat amount during the unit heating:

$$Q_{\text{COOLANT.}} = c \cdot m \cdot (t_f - t_i),$$  \hspace{1cm} (2)

where $c$ is specific heat capacity of the coolant (for coolant Dixis-65 $c=2.974 \text{ kJ/kg} \cdot \text{°C}$); $m$ is the coolant mass, kg; $t_f$ and $t_i$ are final and initial temperatures of the unit, respectively, °C.

Then, knowing the coolant density ($\rho=1091 \text{ kg/m}^3$), the volume of coolant and a width of the inner cavity $t$ in the housing wall have been determined. Parameter setting calculations for oil-contaminated soil decontamination were conducted using software Microsoft Excel, and results of calculations are presented in Table 1.

| Oil-contaminated soil mass, kg | d  | D   | H   | L   | t   |
|------------------------------|----|-----|-----|-----|-----|
| 100                          | 450| 640 | 270 | 1125| 90  |
| 1000                         | 1000| 1350| 600 | 2500| 170 |
| 20000                        | 2500| 3700| 1500| 6250| 580 |
4. The calculation results
The main geometric parameters for three types of the installation for oil-contaminated soil decontamination with reagent encapsulation method (Table I), when thermal energy released at each stage neutralization process is guaranteed enough for thawing of frozen portions of soils contaminated with petroleum.

5. Results and discussions
Installation for oil-contaminated soil decontamination as compared with the other units has an important advantage, which is to use, if necessary (e.g., in winter) the heat energy released at each stage of oil-contaminated soil decontamination process, in normal conditions it is dissipated into the environment. In addition, a short-term forced carbon dioxide delivery at the final stage of the decontamination process to a high concentration directly into the plant allows replacing the long process of microcapsule shells formation and hardening that occur in natural conditions in the open air.

6. Conclusion
In the installation model the exothermic process heat energy of oil-contaminated soil decontamination is accumulated in a coolant which is in the inner cavity wall of the installation housing, and then, if necessary (e.g., in winter) it is used for the subsequent thawing of frozen portions of oil-contaminated soil placed in a tank, snow to obtain water needed for encapsulation reaction. The installation allows decontaminating not only the oil-contaminated soils, but saturated with oil ice or snow. The installation can be used both in stationary conditions and in the field at low (negative) ambient temperatures.

It is possible to design the considered installation model for almost any performance.

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