Evaluating environmental hazards of the potential sources of accidental spills

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Abstract. This article deals with the problem of protecting the environment from pollution in case of accidental oil spills. To date, we have accumulated some practical experience in the elimination of emergency spills, which is characterized by the presence of various technical devices for the elimination of emergency spills – booms and oil collectors. However, more relevant is the direction of preventive protection against accidental oil spills, which is aimed at preventing their occurrence. Preventive protection is based on a set of measures that should be aimed at the most dangerous potential sources of emergency spills, which are different in design, and purpose technical devices are used to move oil. Such devices are characterized by their own value of the level of danger, which must be evaluated in the process of forming a set of protective measures. Therefore, the development of a methodology for assessing the level of environmental danger, being a necessary fragment of preventive protection, was the goal of the study, the results of which are presented in this paper. One of the strategies for such an assessment is based on data on accidental spills that have occurred at the study site in the past. In the absence of such information, the authors suggest using a different strategy based on the use of the expert assessment method. The main parameter of the assessment is the amount of oil that was released into the environment during emergency spills. At the same time, the authors suggest taking into account the number of both single spills, total and maximum possible spills. Such a systematic view of the objects and phenomena under study allows us to objectively assess the level of danger of individual devices and identify the most dangerous ones. As a result of the research, the authors proposed a set of parameters that allows for a comprehensive and objective assessment of potential sources of emergency oil spills.

1. Introduction

The movement of oil, which includes transportation in any way, temporary storage, technological pumping in the process of temporary storage or handling operations, as well as loading operations, is well-known to be characterized by the risk of emergencies, as a result of which an emergency oil spill may occur [1–3]. The scale of environmental damage in such cases can be significant [4–5]. This forced the world community to take certain measures both at the legislative level and in the organizational and engineering areas. At present, a wide variety of designs of technical means have been created that are used in the elimination of emergency oil spills – booms and oil collectors [6, 7]. In addition, researchers are engaged in modeling the movement of an oil slick in order to improve the efficiency of emergency spill response [8, 9].
The analysis of modern achievements in the field under study shows that these achievements are mainly aimed at eliminating accidental spills. However, the environmental safety of facilities that move oil is largely ensured by preventive measures, that is, aimed at preventing accidental spills.

In general, protection against accidental pollution should include three main groups of measures. The first group includes preventive measures, which are aimed at excluding the occurrence of accidental oil spills. The second group (active protection), is aimed at preventing an accidental oil spill. And the third group are the measures to eliminate the consequences of environmental pollution.

In terms of their content and goals, protective measures can be of a legal, organizational and engineering and technological nature.

Preventive protection is a set of organizational measures and technical means, the formation of which should take into account the level of environmental hazard of devices and structures that ensure the movement of oil, and also exclude the causes of accidental spills that lead to the most dangerous consequences. Preventive measures are based on determining the level of environmental hazard of these devices and structures – which are simultaneously the potential sources of emergency oil spills – and identifying the most dangerous of them. Hence, it becomes necessary to assess the level of environmental hazard.

2. Materials and Methods

On the basis of rightful assumption that environmental pollution be divided into operational and emergency ones, as well as the methods of system analysis of the considered problem of environmental protection from pollution in case of emergency oil spills, one can come to the conclusion that environmental protection can be ensured not only by the actions to eliminate the emergency spill, but also by the measures to prevent the occurrence of accidental oil spills [10, 11]. This approach gives a greater environmental and economic effect than planning and using only measures to eliminate accidental spills, since preventing the occurrence of accidental spills reduces the likelihood or prevents even insignificant ones.

A systematic approach to the formation of a set of parameters characterizing the level of environmental hazard shows that the main parameter is the volume of oil in an accidental spill.

3. Results

Every device that is used in the process of moving oil is a potential source of accidental spills. However, all the mentioned sources are characterized by different levels of environmental hazard. It is obvious that measures to prevent accidental spills should be targeted, i.e., aimed, first of all, at the most dangerous ones from the point of view of possible environmental damage.

The level of environmental hazard of potential sources of pollution can be fairly objectively characterized by the amount of oil that gets into the environment, most often, into oil-related water bodies [10]. This amount depends on the design features and operating conditions of potential sources of accidental spills, as well as on the characteristics of the occurrence and course of the accidental spill process. It should be understood that the specified amount of oil can be different in meaning.

A distinction should be made between:

- the amount of oil in the i-th single spill from each j-th potential source, \( W_{i,j} \);
- the total amount of oil spilled from each j-th source over the entire observation period, \( W_j \);
- the maximum amount of oil in one-time spills, \( W_{\text{max},j} \);
- the theoretical maximum possible amount of oil that can enter the environment from the j-th source, \( W_{\text{max}} \);
- the total amount of oil that entered the environment from all sources of the spill at the investigated object during the observation time \( t \), \( W_E \).

Each of the above parameters reflects the hazard level of potential sources of accidental spills from a certain side. An objective assessment requires taking into account the influence of all these parameters on the hazard level of the source device under investigation.

In this case, it is necessary to take into account the following circumstances.
The total amount \((W_\Sigma)\) of accidental spills for a certain observation period for different \(j\)-th source devices may differ in magnitude (see Fig. 1)

\[
(W_\Sigma)_j = \Sigma(W_i) = W_1 + W_2 + \cdots + W_{i=m},
\]

where \(W_i\) is the total amount of oil in single \(i\)-th spills from the \(j\)-the source.

\[W_\Sigma = \Sigma[ (W_\Sigma)_{j=1} + (W_\Sigma)_{j=2} + \cdots + (W_\Sigma)_{j=n} ]\]

**Figure 1.** Number of single spills \(W_i\) (height of each bar on the graph) from \(j\)-th sources of accidental spills

The comparison of values \((W_\Sigma)\) allows identifying the sources, which will have the highest values of this parameter, and thereby perform a comparative assessment of the sources under consideration by the total amount of spilled oil in each considered source device during the observation period (see Fig. 2).

\[W_\Sigma = \Sigma[ (W_\Sigma)_{j=1} + (W_\Sigma)_{j=2} + \cdots + (W_\Sigma)_{j=n} ]\]

**Figure 2.** Comparison of cumulative spills from sources of accidental spills

From this point of view, the comparative hazard of all sources of accidental spills can be estimated using the parameter \(K_i\), which shows the proportion of the number \((W_\Sigma)\) of all spills at the \(j\)-th source, which it occupies in the total number \(W_\Sigma\) of spills that occurred at the object under study.

\[W_\Sigma = \Sigma[ (W_\Sigma)_{j=1} + (W_\Sigma)_{j=2} + \cdots + (W_\Sigma)_{j=n} ]\]
$K_1$ is calculated by the following equation:

$$K_1 = \frac{(W_j)}{W_{\Sigma}}.$$  

Among single spills from each $j$-th source, one can distinguish the spill, which was characterized by the maximum amount ($W_{i_{\text{max}}}^j$) of spilled oil (see Fig. 3). This circumstance cannot be ignored, since such a spill may not occur at the most dangerous source, but be characterized by severe consequences. The above can be taken into account using the parameter $K_2$, which characterizes the ratio of the value ($W_{i_{\text{max}}}^j$) of the maximum of single $i$-th spills at the $j$-th source relative to the total volume of spills $W_{\Sigma}$ and is calculated by the following equation

$$K_2 = \frac{(W_{i_{\text{max}}}^j)}{W_{\Sigma}}.$$

For each of the considered devices-sources of accidental spills, it is necessary to take into account the number of maximum ($W_{i_{\text{max}}}^j$) of the one-time $i$-th spills, as well as the amount of the theoretically possible maximum ($W_{\text{max}}^j$) of the spill (see Fig. 3).

The value of the theoretically possible maximum ($W_{\text{theor}}^j$) of the amount of oil allows assessing the potential hazard of the source of the spill, which in a certain way must be taken into account in the complex of protective measures.

The numerically indicated potential hazard of an accidental spill source can be taken into account using the $K_3$ parameter, which is the ratio of the theoretical maximum possible amount of a spill in the $j$-th source ($W_{\text{max}}^j$) to the total $W_{\Sigma}$ and is calculated by the following equation:

$$K_3 = \frac{(W_{\text{theor}}^j)}{W_{\Sigma}}.$$

A comprehensive assessment of the level of environmental hazard of each $j$-th investigated potential source of an accidental spill can be obtained using the parameter $K_j$, calculated by the following equation:

$$K_j = K_1 K_2 K_3.$$  

**Figure 3.** The maximum volume ($W_{i_{\text{max}}}^j$) of the observed spill and the maximum theoretical volume ($W_{\text{theor}}^j$) of single spills

The highest values of the parameter will correspond to the most environmentally hazardous devices that are the sources of possible oil spills. The data on the parameters $K_j$ should be taken into account in the extended algorithm for the formation of a complex of protective measures for the object under
study (Fig. 4). The first step of this algorithm is to identify the most environmentally hazardous source devices, for which the next steps will be taken in the process of developing a set of measures.

Figure 4. Extended algorithm for the formation of a set of preventive protective measures

The next step is to identify measures aimed at eliminating or reducing the likelihood of situations (causes) that led to the maximum amount of oil spills. The reason for this is the value of the parameter $K_2$ and the results of the analysis of the reasons that led to the indicated situations.

4. Discussion
The research in the field of environmental protection in case of accidental oil spills is mainly aimed at reducing the negative environmental consequences of these spills. At the same time, the risk parameter is often used to assess the possibility of accidental spills [12–14].

However, in the opinion of the authors of this work, prevention of accidental spills is more effective. This complies with the "precautionary principle" in environmental protection, which involves the implementation of some activities and the use of technical means to prevent the occurrence of accidental spills [15–17]. This principle is increasingly being recognized and applied in the field of environmental management.

The authors of this article proceeded, first of all, from the fact that the assessment of the level of environmental hazard is a component of some algorithm, which ultimately involves obtaining information necessary for the formation of a set of protective measures. Determining the level of environmental hazard when using data on accidental spills that took place in the previous period of operation of facilities used to move oil, makes it possible to more accurately form the main group of protective measures in a targeted manner by identifying the most potentially dangerous source devices. Such sources can be determined by comparing the $K_1$ parameters for these sources.

Information on the maximum theoretically possible amount of oil that can spilled into the environment is most relevant for sources in which the values of the maximum observed amounts of oil are close in value to the theoretically maximum. In such cases, it is advisable to take the theoretically possible value as the design value of the maximum spill, and for such a situation to provide for a set of additional protective measures.
5. Conclusions
The proposed algorithm for the comparative assessment of the level of environmental hazard of potential sources of accidental spills, which are devices or structures that transport oil or oil products, makes it possible to identify the most dangerous of them. The parameters that determine the level of environmental hazard and which underlie the assessment are the total volume of oil spilled into the environment from each of the potential sources under consideration for a certain period of time, the maximum volume of a spill that took place over the same period of time, as well as the theoretical maximum possible spill volume.

The algorithm objectively takes into account the danger of an accidental spill of the investigated potential sources of accidental oil spills. At the same time, the parameters of the comparative assessment of the level of environmental hazard make it possible to comprehensively take into account both the maximum possible spill volume and the maximum observed for a certain period of time, as well as the total for the same period.

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