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# Risk Assessment of Oil Pipeline Accidents in Special Climatic Conditions

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**Abstract**. The present study identifies the main accidents' factors and causes for oil pipeline located in Siberia and operated in special climatic conditions. Various types of pipeline accident scenarios were modeled. It is showed that the most dangerous scenarios are oil spills fire and oil vapor explosion due to the loss of piping integrity (rupture) of the pipeline's section, laying on marshlands and oil spill on the water surface due to the loss of piping integrity (puncture). The most probable scenario is oil spills fire due to the loss of piping integrity (puncture) of the pipeline's section, laying on dry lands and marshlands. To estimate the scenarios «event tree analysis» is used. Also such risk indexes as individual, societal, public and potential risks were determined.

## 1. Introduction

The first paragraph Pipeline system is a source of increased danger due to a large amount of welded and flanged joints, shut-off and control valves, harsh environment and significant amounts of substances transported by them. Fluid transmission risks are associated with constant dynamic loads on the system and instability of the process. Pressure drops, dynamic and static loads create good conditions for the deformation aging of metal. From this point of view, the oil transportation by pipeline is the greatest danger, since this substance is characterized by the formation of two-phase flow, the existing of pulsation flow, the formation of shock waves and discharge zones. Non-stationary processes can lead to vibration of communications and equipment, leakage of pipelines up to their complete catastrophic destruction. A large number of connecting fittings creates an additional danger of piping integrity's loss.

Nowadays, the oil industry gives great attention to providing the reliability and safety during the construction and operation of main pipelines. Despite this fact, the emergency situations associated with oil transportation by pipelines occur very often [1-4]. In general, such accidents include high material costs for the oil pipeline’s operating companies and significant damage to the environment, people, and property in the vicinity of the failure pipelines. Therefore, the decreasing of the probability of emergency situations on the main oil pipelines is one of the immediate issues in this field. The problem is especially important for pipelines, which are located and operated in special climatic conditions. The main factors, which contribute to the emergency occurrence, are the following: the usage of significant amounts of flammable and explosive substances in operating procedure; the existence of mechanical impurities in oil, causing abrasion of equipment and pipelines; operating procedure under pressure; harsh climatic conditions and others.

Preaccident analysis is an important aspect of emergency oil spills problem. The main causes of oil pipelines accidents are pipeline corrosion (including internal and external), construction defects, mechanical damage (including excavation work), diversions, unauthorized junctions, third party activity, oil pipelines' operational imperfection, manufacturing defects of pipes and equipment, natural disasters [1, 3].

During the oil transportation, the loss of piping integrity may occur, which would lead to release of hazardous substances into environment. The main result of such accident is the transported oil leakage, which creates toxic pollution of the environment (water, air and soil). Moreover, as a result of spilled oil evaporation the cloud of fuel-air mixture is formed. The presence of ignition source within the cloud may lead to its inflammation. The highest risk of accidents on pipelines is connected with longitudinal damages. They can occur during the formation of corrosive gas pocket or guillotine ruptures both on the base part of pipe and in the zone of welding joints. Therefore, the loss of piping integrity is considered as the most frequent initiating event, which causes the hazardous substance's release into environment [1, 5-8]. The loss of piping integrity mode influences the types of leakage. If discharge area is small, relatively longtime liquid outflow through a hole is observed. On the other hand, if pipeline integrity damage is significant, considerable volumes of hazardous substance reach environment immediately.

The most probable oil pipeline accidents are characterized by considerable volumes of oil blowout from different parts of the pipeline. If the considerable volumes of oil are released, the most hazardous accidents occur, since it is volumes of hazardous substances that cause the largest damage to the environment, human, infrastructure facilities. Therefore, the possible pipeline accident analysis includes the amount of substance assessment, which could be involved in the accident. Also the accident consequences and probability of their occurrence should be determined.

To analyze the accident the different scenarios of its development are prepared. They include the sequence of logically connected individual events, which are caused by a specific initial event. Some aspects should be taken into account as part of possible pipeline accidents determination of scenarios. For example, the characteristics of the transported oil, known oil pipeline accidents analysis, descriptions of technical security solutions, preaccident analysis, and others.

Typical scenarios of pipeline destruction may include:

- the formation of a persistent environment pollution due to oil blowout from the damaged pipeline;
- oil pool fire, causing the thermal impact on the environment, material objects and people;
- the explosion of fuel-air mixture;
- the distribution of explosive fuel-air mixture clouds with the wind, and possible explosion.

This work is devoted to compiling the possible scenarios of accidents during oil pipeline operation in special climatic conditions with the subsequent risk assessment.

## 2. Object of research

This paper presents the examination of the oil pipeline system located in the Siberian region. As the object of research we selected a pipeline section that passes through territory characterized by different conditions. Part of the pipeline is lined through dry land and 42% of the pipeline route includes marshes. The pipeline has 30 intersections with water bodies, the largest of which is a navigable river. Therefore, the analysis of scenarios of these pipeline accidents should take into account some factors of natural hazards, which could influence the loss of piping integrity or enlarge the level of it. For example, these factors are average annual air temperature gradients, high level of snow cover in the winter, the pipeline's passing through water bodies.

## 3. Methods of research

Nowadays there are several approaches to risk assessment: phenomenological, deterministic, expert and probabilistic.

Phenomenological approach is based on emergencies possibility determination using the analysis results that represent conditions connected with the nature laws. This approach is the easiest one to use and gives reliable results, if operating processes have sufficient margin to limiting levels. However, it is unreliable, when abrupt change of substances or systems occurs. This approach is preferable to compare the safety margins of different potentially dangerous objects and is useless in analysis of emergencies, which depends on reliability of different parts of the object or its safety facilities.

Deterministic approach provides an analysis of the sequence of the accident development from the initial event through a series of suggested failures. Emergency process is studied and predicted with the help of mathematical modeling, construction of simulation models and complex calculations. Disadvantages of this approach include the gaps in some important events in accident development; difficulty in adequate mathematical models construction; complexity and high cost of experimental studies to validate computer models.

Expert approach is based on obtaining quantitative risk assessments by processing of experts' opinions. The main disadvantage of this approach is the necessity to analyze the objectivity and reliability of experts' opinions.

The probabilistic approach involves the probability assessment of the accident. This approach allows analyzing the chain of events and equipment failures and estimating the total probability of accident. Main disadvantage of this approach is related to the lack of statistics on equipment failure. In addition the usage of simplified design schemes reduces the reliability of the risk assessment for serious accidents. However, this approach currently is considered as one of the most perspective ones.

In this paper probabilistic approach was used. Its application can be explained by capacity to model all possible pipeline accident scenarios. Different techniques (statistical data, event tree analysis, fault tree analysis, etc.) allows to identify and quantify all scenarios, as well as to determine the protective actions if emergency occurs.

To estimate the risk of oil pipeline failure, different risk assessment methods are used, for example event tree analysis [1,5,7], fault tree analysis [5,9,10], bowtie [11] and others [3,5,8,12]. For emergency modeling the methods of direct analysis of the events are applied. All events that may occur after the accident are connected with cause-effect relationships, depending on the operation or failure of the protection system components. In this paper, to identify cause-and-effect relationships of emergency the method of "tree of events" is used, which allows to provide qualitative and (or) quantitative risk assessment. The advantage of this method is the possibility to analyze the initiating events that can lead to various effects (thermal radiation, overpressure, emissions, toxic effects, and others). Each branch of event tree includes a separate effect, which is the result of specific functional relationships. The method helps identify accident scenarios with different effects from various initiating events; to determine the relationship of systems' failure with the consequences of accidents; to determine the accident sequences, which contribute most to the risk due to their high probability.

## 4. Results and discussion

Accident consequences depend on the sizes of the emergency port. To evaluate the risk of oil pipeline accidents two types of scenarios, connected with oil spill due to loss of piping integrity, are chosen.

For analyzed sections of the research object the following scenarios were identified:

- Type 1. The oil spill due to rupture of the pipeline - guillotine rupture (the typical size of the hole (the ratio of the hole's length to the nominal diameter (D) of pipeline) is 1.5D).
- Type 2. The oil spill due to puncture of the pipeline - gas pocket (the typical size of the hole is 0.3D).

The consequences of the oil spill will be different. It depends on the failure mode (rupture, puncture), season (summer, winter), local conditions (dry land, marsh, water objects). To estimate the maximum risk there is a good reason to consider the occurrence of accident in summer, since during this time air temperature is the highest and the occurrence of adverse factors is more possible. The accident analysis in winter is not discussed in this work due to less considerable consequences. However, the pipeline maintenance in winter is the essential factor, which increases the possibility of accident occurrence.

There are several adverse factors, which influence environment, people and property. In case of rupture of the pipeline they are the thermal radiation intensity of oil spill fire and blast overpressure of oil vapors and toxic action of oil. If there is puncture of the pipeline, the main adverse factors consist of the thermal radiation intensity of oil spill fire and toxic action of oil.

To estimate the risk indexes, the following data should be determined: hazardous substance spill area and the amount of the hazardous substance involved in the scenario. In the calculation some certain assumptions were made: calculations are performed for routine maintenance conditions; the most unfavorable conditions of the accident with a maximum quantity of dangerous substances are considered; the combustion occurs over all oil spill area and others.

The research object is divided into 5 sections. For all sections of the pipeline (dry land, marsh, water bodies) volume, mass and the oil spill area after rupture or puncture of pipeline have been calculated. To evaluate the maximum risk of oil pipeline accident areas with maximum emissions of hazardous substances (oil) were considered. The section No1 includes the part of pipeline, which is laid on dry land and marsh. As a result of rupture of pipeline oil spill area is equal to 5259 $m^3$, mass of oil blowout - 4313 tons. The section No2 is laid on dry land and marsh with crossing a small river and stream. The puncture of pipeline led to formation of oil spill area, which size is 198 $m^3$, and mass of oil blowout - 162 tons. The maximum volume of oil spill from the puncture is predicted to be the same for sections, which are laid on dry land, marsh and water objects. Further calculations will be made for the section No2 as the most dangerous because of the maximal length (13473 m). The unsensed emergency for a long period (1 day or more) is more possible to occur on this section. In addition to the mentioned above sections, the sections No3, 4, 5 are the most dangerous. There is the maximal number of intersections with water bodies (two rivers and five streams) on the section No3. It is expected the maximum oil spill area on the water surface would be up to 1599207 $m^2$ in the case of oil rupture. The sections No4 and No5 cross the navigable river (the largest watercourse). In this case, oil spills will cause the maximum environmental damage.

Statistical data and results of expert method were used to determine the probability of certain events for each scenario. The prediction of accidental leakages frequency is conducted in the simplified way by using average accidents data.

Any scenario begins with the initiating event (the loss of piping integrity) that can occur with some frequency. The frequencies of basic events leading to the pipeline accident are listed in Table 1.

**Table 1.** The frequencies of basic events.

| Failure mode | The probability of failure, 1/year |
|---|---|
| Rupture (section No 1) | $1.03\ 10^{-4}$ |
| Puncture (section No 2) | $2.70\ 10^{-3}$ |

Two types of scenarios can be represented in the form of «event trees» (Figure 1 and Figure 2).

The frequency of the accident scenario is product of the probability of equipment failure and scenario probability. As a result of the accident scenarios assessment, risk indexes were obtained and the zones of the adverse factors’ action were defined. According to the calculations, the most dangerous are the following scenarios:

Scenario 1. This scenario describes oil spills fire due to the loss of piping integrity (rupture) of the section No1, laying on marshlands. The largest oil spill area (99454 $m^2$) and maximum property loss would be expected if the accident is developed by this scenario. The probability of output event is equal to $1.54\ 10^{-5}$ 1/year. The exposure probability of human by thermal radiation of 17 $kW/m^2$ at the distance of 135 m from the center of the oil spill is 99%. Lethal injuries of employees are not predicted, the expected number of victims is 3 people.

Scenario 2. This scenario describes oil vapor explosion due to the loss of piping integrity (rupture) of the section No1, laying on marshlands. The probability of output event is equal to 4.11 $10^{-6}$ 1/year. The largest area of the adverse factors (bursting radius is up to 1763 m) and the highest number of victims would be expected if the accident is developed by this scenario. The exposure probability of human by blast overpressure of 100 kPa at the distance of 157 m from the center of explosive cloud is equal to 99 %. The expected number of lethal injured is 2 people.

Scenario 3. This scenario describes oil spill on the water surface due to the loss of piping integrity (puncture) of the section No2. Oil spill area is predicted to be up to 66000 м$^2$ on water surface, which cause the maximal ecological damage. The probability of output event is equal to 5.25*$10^{-4}$ 1/year.

Scenario 4. This scenario describes oil spills fire due to the loss of piping integrity (puncture) of the section No2, laying on dry lands and marshlands. The probability of output event is equal to 2.42 $10^{-4}$ 1/year. In the case of pipeline laying on dry land, the exposure probability of human by thermal radiation of 17 kW/m$^2$ at the distance of 28 m from the center of the oil spill is 97%. In the case of pipeline laying on marshlands, the exposure probability of human by thermal radiation of 17 kW/m$^2$ at the distance of 30 m from the center of the oil spill is 97%. The expected number of lethal injured is 1 person; the expected number of victims is 3 people.

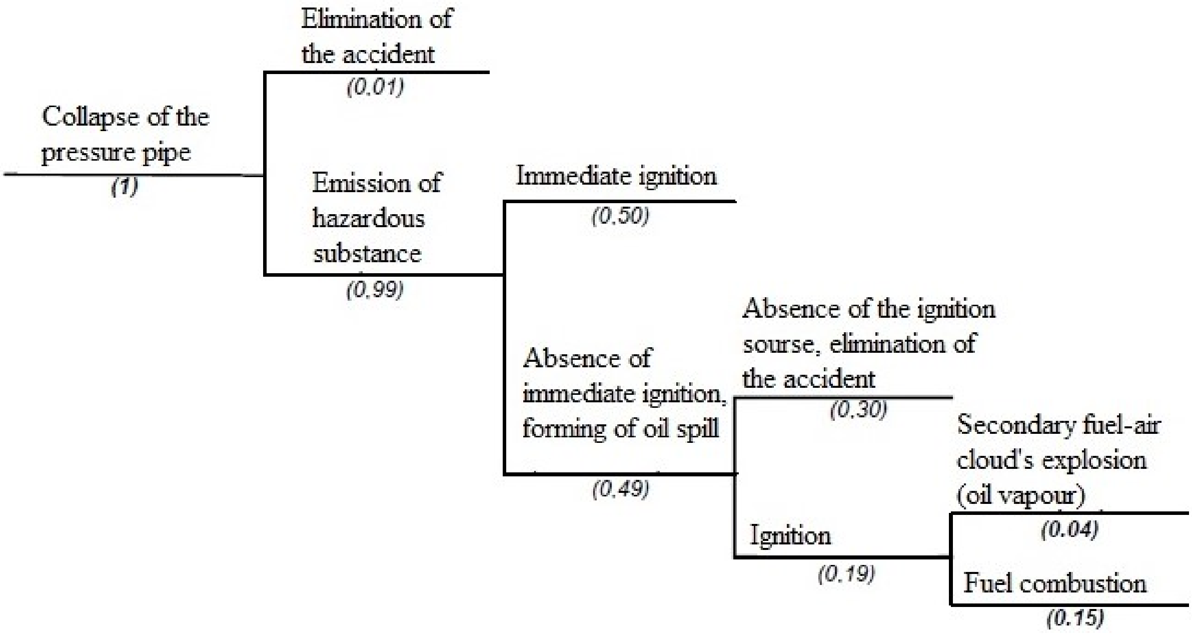


**Figure 1** – The first type of scenario

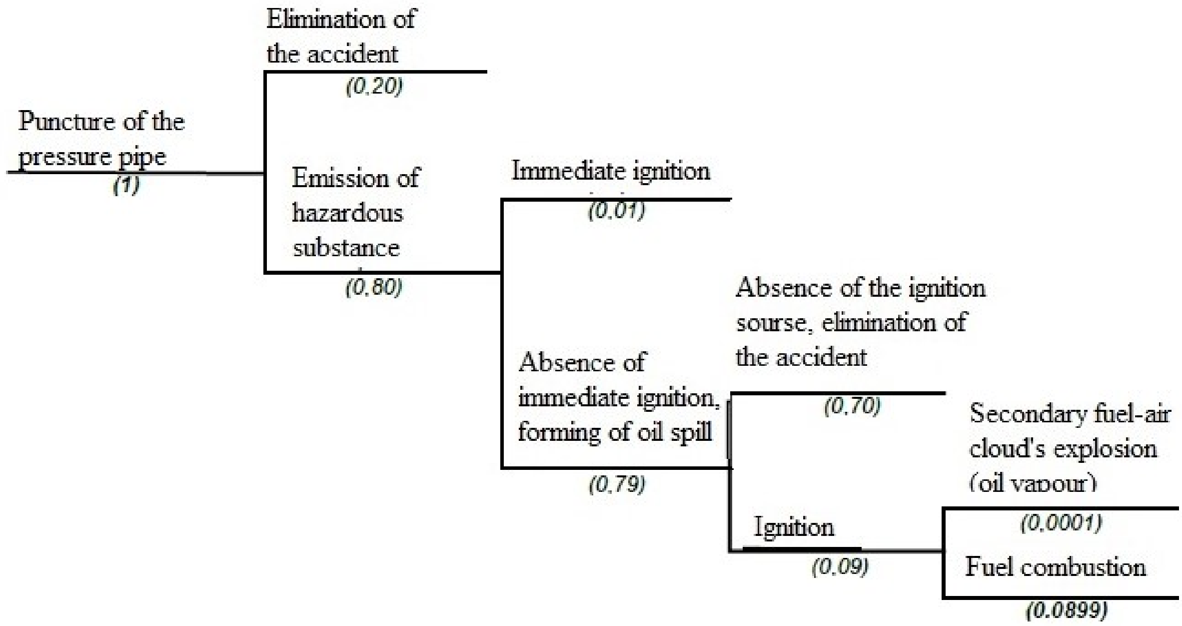


**Figure 2** – The second type of scenario

The main quantitative risk indexes are the individual risk, the potential risk of the territory, public risk and societal risk. Individual risk, which is estimated as the frequency of person's injuring under the influence of adverse factors of accident, is calculated for all pipeline's sections at the distance of 500 m and is equal to 3.95 $10^{-7}$ 1/year. The frequency of accident's adverse factors on the analyzed pipeline is independent from the fact of the people's presence in this area. It is assumed that conditional probability of a person's presence is 1, in other words a person stays at a territory point during the considered period of time). The results of potential risk evaluation for analyzed scenarios for oil pipeline are presented in Table 2.

**Table 2.** The results of potential risk evaluation.

| Section of pipeline | Failure mode | Potential risk, 1/year at the distance from possible accident, m | | |
|---|---|---|---|---|
| | | 600 | 700 | 800 |
| Section No 1 | Loss of piping integrity | 1.3 $10^{-6}$ | 6.2 $10^{-7}$ | 2.9 $10^{-7}$ |
| Section No 2 | | 0 | 0 | 0 |

Public risk is the expected number of affected people due to possible accidents within a certain period of time. This risk index depends on the hazards of production, the number of employees and other factors. It was estimated that the public risk for analyzed pipeline is 2.59 $10^{-4}$ person/year. Societal risk shows the number of victims and lethal injured, which depends on the frequency of accident. In this paper societal risk is estimated as probability of lethal injured due to fire, explosion of gas vapour mixture and is equal to more than 10 people in year. Consequently, the obtained results of individual, societal, public and potential risks can be compared with acceptable values, which mean that there is no need to risk reduction.

## 5. Conclusion

Risk assessment of oil pipeline accident involves the study of various types of scenarios, which are caused by natural and technogenic reasons. However, some factors may contribute to the accident occurrence namely the loss of piping integrity or increase the damage. These factors are average annual air temperature gradients, high level of snow cover in the winter, the pipeline's passing through water bodies. It is considered that the initiating event is the loss of piping integrity due to rupture or puncture of pipeline's section. The output event forms such adverse factors as thermal radiation (for oil spill fire) or blast overpressure (for oil vapor explosion). The results of this research include the following:

- The main reason of oil pipeline accident is depreciation and metal corrosion, which are caused as well as by local climate conditions.
- The most dangerous are the pipeline's sections, which have intersections with water bodies. The ecological damage is the main adverse affect for such accidents.
- The lethal injury for pipeline's servicers is possible during pipeline inspection or construction and assembling operations, if the time of their presence and accident occurrence will match.
- The obtained individual, societal, public and potential risks can be compared with acceptable values.

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