Hydrocarbons pipeline transportation risk assessment

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Abstract. The pipeline transportation applying risks assessment issue in the arctic conditions is addressed in the paper. Pipeline quality characteristics in the given environment has been assessed. To achieve the stated objective, the pipelines mathematical model was designed and visualized by using the software product SOLIDWORKS. When developing the mathematical model the obtained results made possible to define the pipeline optimal characteristics for designing on the Arctic sea bottom. In the course of conducting the research the pipe avalanche collapse risks were examined, internal longitudinal and circular loads acting on the pipeline were analyzed, as well as the water impact hydrodynamic force was taken into consideration. The conducted calculation can contribute to the pipeline transport further development under the harsh climate conditions of the Russian Federation Arctic shelf territory.

Key-words: risks assessment, offshore pipeline, hydrodynamic load, mathematical model

1. Introduction
For the Russian Arctic shelf exploration the stationary offshore oil platforms with high ice loads resistance are mainly used. Risks assessment is one of the most important factors for the continental shelf deposits development. Offshore installations emergencies occurring in the process of extracted products drilling, production, treatment and processing, as well as when oil transporting may result in the vast human losses, apparatuses losses, serious environmental and economic consequences [16]. Offshore pipeline oil transportation from platforms is largely due to such characteristics as the distance from the coast, extreme weather events, seabed geological and hydro meteorological hazards, etc. High hazard when oil transporting from oil-rig platforms is confirmed by large-scale accidents that occurred during operation. Accidents with fires and explosions both on offshore oil platforms and during the pipelines operation can result in disastrous consequences, in which case human and material resources engagement at the level of one or several states may be required [4, 5].

The defined objectives are relevant and clear: firstly, the offshore pipeline laying risk is necessary to be understood and therefore calculations are required to be conducted, the optimal pipeline both with regard to materials and diameter to meet the harsh environmental conditions of the promising region where the work will be performed needs to be analized and defined [11].

2. Theory
With regard to the offshore pipelines, the conditions of the line construction from the oil production platform and to the major transport hub should be understood. Therefore, the Arctic shelf territory environmental conditions are worth studying and as the only developed field in this area is the Prirazlomnoye oil field, then all the initial data on the environmental conditions will be derived from the given territory [2, 6].
Transportation from this platform is inexpedient, as it is performed only by using the tankers. Pipeline transportation would be more profitable from the economic perspective as Arctic shelf reserves are very high and amount to 15 billion tons of oil, and pipeline transportation will allow to deliver oil to the nearest oil export terminal as fast as possible and to reduce both human labor in extreme conditions and quantity of the equipment used [13].

Before starting the given research, foreign and Russian scientific journals have been examined. The similar topic have been considered by Alireda Aljaroudi, Faisal Khan, Ayhan Akinturk, Mahmoud Haddara, Premkumar Thodi in the paper «Risk assessment of the offshore crude oil pipeline failure» of the scientific journal «Journal of Loss Prevention in the Process Industries» in which the authors provide methodologies when laying the pipeline on the seabed [12].

The authors of the mentioned papers did not take into account the projected conditions severe natural and climatic features. Based on findings and conclusions, the study taking into consideration the parameters required for achieving the objectives was possible to be carried out.

The offshore ice-resistant stationary platform is located on the south-eastern shallow marine shelf of the Barents Sea (Pechora Sea) in the exclusive economic zone, 55 km from the coastline within the plain with depths from 18.0 to 20.5 m. Sea depths are reduced to the lowest theoretical level. Onshore depths vary quite evenly, especially in 5 km from the coast in the locality of Varandey they reach 12-13 m [3, 7].

Hydro meteorological, ice, geological engineering conditions have been compiled from the geotechnic survey on the Barents Sea [8].

Based on the data obtained, it is possible to start the mathematical model calculations and development.

3. Results

For designing the offshore pipeline among other steels K2, K52, 09G2S, 12H18N10T, steel 17G1S was chosen on account of its increased resistance to hydrodynamic loads and in respect of the ultimate strength. Further, $D_i$ pipelines five different diameters: 600 mm, 720 mm, 820 mm, 1020 mm, 1220 mm are considered. The pipeline class corresponds to G3. According to the project, the internal working pressure $p_i$ is 5 MPa, however, it is necessary to obtain the pipeline calculated pressure $p_0$ by the formula [15, 17]:

$$p_0 = (p_i - p_{g\min}) + \Delta p$$

The minimum external hydrodynamic pressure on the pipeline $p_{g\min}$, MPa is calculated according to the formula:

$$p_{g\min} = \rho_w g \left( d_{\min} - \frac{h_w}{2} \right) \cdot 10^{-6}$$

where $\rho_w$ is the sea water density considered equal to 1080 kg/m$^3$;

$d_{\min}$ is the still water minimum level along the pipeline route which is assumed equal to 9.1 m taking into account tidal variations and surges with reliability of $10^{-2}\times1$/year;

$\Delta p$ is the calculated wave height of the projected pipeline section which is considered equal to 10.1 m with reliability of $10^{-2}\times1$/year [1].

The additional imposed pressure value $\Delta p$, MPa considering the hydraulic impact phenomenon should be not less than the value determined by the formula:

$$\Delta p = V_{int} \sqrt{\frac{\rho_{int} \cdot E \cdot t_c \cdot K}{E \cdot t_c + D_{int} \cdot K}} \cdot 10^{-3}$$

where $V_{int}$ is the pipeline transported medium motion speed taken to be 1.0 m/s [18];

$E$ is the pipes material elasticity modulus which is assumed to be 2.06 MPa;

$K$ is the transported medium bulk modulus which is based on 1.1 MPa.

The steel pipeline wall thickness $t_c$, mm based on the local strength conditions is determined by the formula:
\[ l_c = \frac{P_0 D_a}{2\sigma} + c_1 + c_2, \]  

where \( \sigma \) is the pipe material permissible voltage MPa; 
\( \phi \) is the strength coefficient calculated depending on the pipes manufacturing method and is taken equal to \( 0.9 \cdot 10^{-3} \); 
\( c_1 \) is the corrosion allowance assumed to be 3 mm; 
\( c_2 \) is the allowance compensating the pipes manufacturing tolerance which is based on 2 mm. 

The permissible voltage \( \sigma \), MPa is assumed to be equal to the lowest value 
\[ \sigma = \min \left( \frac{R_e}{n_e}, \frac{R_m}{n_m} \right), \]  

where \( R_e \) is the yield tensile strength minimum value assumed to be equal to 510 MPa; 
\( R_m \) is the pipes metal tensile strength minimum value which is based on 335 MPa; 
\( n_e \) is the safety factor for the yield strength which is taken to be 1.25; 
\( n_m \) is the safety factor for the tensile strength assumed to be 2.0. 

The calculated pressure on the pipeline having been defined and \( l_c \) calculated for the loads acting on the pipe determining, the pipeline section (figure 1) of 10 m in size with the support spacing of 8 m on which the maximum hydrodynamic pressure \( p_{gmax} \), vertical load per unit length \( F_{w,v} \) as well as horizontal load \( F_{w,h} \) are acting, is considered. 

In the paper «An optimum design of on-bottom stability of offshore pipelines on soft clay» of the international journal «Architecture and Ocean Engineering», Su Young Yu, Han Suk Choi, Seung Keon Lee, Chang Ho Do, Do Kyun Kim constructed the projected pipeline on the clay. Based on their methods, the examined pipeline laying was projected, however, the conditions under which the calculations are performed in this study differ from ones described in the paper [10].

![Figure 1. The calculation scheme of the loads acting on the pipeline.](image)

The calculation of the maximum external water pressure on the pipeline \( p_{gmax} \), MPa under the temperature coefficient impact \( \gamma \) is defined by the following formula: 
\[ p_{gmax} = \gamma \rho_w g \left( d_{max} + \frac{h_w}{2} \right) \cdot 10^{-6}, \]  

The hydrodynamic pressure critical value \( p_t \), MPa, at which the avalanche collapse extent is possible to occur is determined by the formula:
The avalanche collapse absence condition is the following inequality requirements fulfilment:

\[ p_p = 24 \cdot R_e \cdot \left( \frac{t_c}{D_o} \right)^{2.4} \]  \hspace{1cm} (7) 

The avalanche collapse absence condition is the following inequality requirements fulfilment:

\[ p_{g_{\text{max}}} < 1.2 \cdot p_p \]  \hspace{1cm} (8) 

The hydrodynamic pressure maximum values \( p_{g_{\text{max}}} \) for the different pipeline diameters are shown in figure 2. Depending on the pipeline outer diameter \( D_o \), \( p_{g_{\text{max}}} \) decreases, simultaneously the condition according to the formula (8) should be met. The hydrodynamic pressure critical values \( p_p \) for each diameter are illustrated in dotted lines. If the dotted line is above the maximum hydrodynamic pressure, then the pipe loses its stability with a further destruction.

**Figure 2.** The action of hydrodynamic loads on pipelines.

The analysis of the dependencies presented in figure 2 showed the pipelines with the diameter of 600 mm, 720 mm, and 820 mm not to fulfill the condition according to formula (8). Consequently, further calculations will be carried out with the diameters of 1020 mm and 1220 mm. Hence, the linear loads on the pipelines are calculated. The total horizontal wave load \( F_{w,h} \) N/m is determined taking into account the wave action coefficient \( \gamma_1 \) by the formula:

\[ F_{w,h} = \gamma_1 \sqrt{F_{w,s}^2 + F_{w,i}^2} \]  \hspace{1cm} (9) 

The vertical linear wave load \( F_{w,v} \) N/m, is calculated considering the flow influence coefficient by using the formula:

\[ F_{w,v} = \gamma_2 c_v \cdot \frac{\rho_w \cdot V_w^2}{D_o} \]  \hspace{1cm} (10) 

Based on the calculations, the mathematical model development data taking into consideration the hydrodynamic loads having showed that not all diameters for the constructed offshore pipeline are suitable for the study further stages were obtained.
4. Discussion
The software product SOLIDWORKS application taking into account the calculations results made possible to develop the pipelines models having been applied hydrodynamic, linear, vertical and horizontal loads, which visualization is represented in figure 3. Hydrodynamic loads are wave loads, water column pressure is linear vertical load and seawater flow is horizontal loads. When developing the mathematical model the pipe weight, connections with fixed supports and liquid internal pressure variations along the pipeline length are taken into account.
Light shade indicates the places where the pipelines are under the maximum pressure, thus, based on the models it can be stated that pipelines with external diameters of 1020 mm and 1220 mm withstand all calculated loads.

![Figure 3. The pipelines models with diameters of 1220 mm and 1020 mm.](image)

Based on the data obtained, it can be concluded that the pipelines with the given diameters are equally ready for operation, however, it is necessary to take into consideration both the risk assessment and economic component.
Despite the fact that the pipeline 1220 mm in the nominal diameter has greater performance than the pipeline with diameter of 1020 mm, the first pipe operation risk is higher due to the increased pressures in it. It is also necessary to consider a great amount of passable raw materials increasing the internal circular as well as longitudinal loads. Consequently, at the wave hydrodynamic and internal loads resonance, the pipeline can achieve its maximum acceptable condition, which will result in the pipe breakage [14].
Moreover, it is economically feasible to use the smaller amount of consumed materials during the given pipeline construction work. Even with a lower flow capacity of the pipeline system with diameter of 1020 mm, this cannot be compared with the materials costs taking into account the projected pipeline length of 50 km [9].

5. Conclusion
In the course of conducting the research the pipe avalanche collapse risks were examined, internal longitudinal and circular loads acting on the pipeline were analyzed, as well as the water impact hydrodynamic force was taken into consideration. Thus, based on the calculations the oil pipeline transportation risk assessment from the Arctic shelf was conducted. The sampling for the pipe material and diameter was carried out until the results whereby it is recommended to use the material for the pipeline - steel 17G1S, the outer diameter of the pipeline - 1020 mm, were obtained.
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