Analysis the Changes of the NGL Product Pipe Safety in the Process of Operation

V I Berg, V A Petryakov and A E Brand

Tyumen Industrial University
Volodarsky str. 38, Tyumen, Russian Federation, 625000

E-mail: Allbert-@mail.ru

Abstract. The paper presents to analyze the changes of the NGL product pipe safety in the process of operation. In the article the analysis and to mathematically calculated the margin of safety and durability according to change thickness of pipeline. The study of analysis the accident conditions risks during the pipeline operation have shown that such measure as the pipe wall thickness increase is appropriate. The proposed conditions on the application of the obtained results.

1. Introduction
The accidents in the process of hydrocarbon wide fractions transport are characterized by a high degree of danger in the parameters of their impact on the people and the environment. In the case of the hydrocarbon vapors ignition, the wave-front time and the hazardous exposure area may be of hundreds kilometers. Some specialists used to consider 1989 to be the starting date of the priority accident assessment risk, a year, when there was Ufa train disaster, the largest in the history of the Soviet Union and modern Russia. On the product pipeline "Western Siberia - Ural - Volga region" in the process of NGL transport, the 1.7 m slit has been formed, through which the hydrocarbons leak and the petroleum accumulation occurred. This product pipeline was located 900 meters to the Trans-Siberian Railway section. During the trains passing there was a spark, which caused the hydrocarbon vapors ignition. Then there was a large volume of hydrocarbons explosion with a capacity of about 250-300 tons of TNT. The fire covered the area of 250 hectares and the shock wave caused the substantial damage to the city of Ash, located 10 km from the explosion place. More than 1,000 people were injured as a result of this disaster.

The analysis of the causes and results of the disaster has changed the approach to the definition of the security and the accidents risk. The substantial changes were made to the SNIP 2.05.06-85* "Main pipelines", such as the increase of the minimal distance from the NGL transport subjects to the settlements and the 400 mm diameter NGL transport pipes ban. These changes provided the basis for the safety in the design and operation of the product pipelines. However, according to the technical and economic assessment, the given changes are extremely expensive and prevent the whole industry from the progress [1-3].

Currently, there is a necessity of petroleum industry intensive development due to the record level of hydrocarbon production and at the same time the active construction of additional product pipelines for petroleum derivatives transportation, including natural gas liquids. In view of the number of
economic difficulties and the necessity for the economic rationalization, it is important to analyze the accidents risk during the operation and to develop the optimal prescriptions and measures to increase the security level [4-6].

The aim of the article is to analyze the changes of the NGL product pipe safety in the process of operation.

2. Materials and methods
The analysis of the empirical and mathematical material: D = 700 mm with the pressure change from 4 MPa to 4.8 MPa, and cyclical voltage change Ng = 30 000 times should be produced to 11 mm. The technological linear section security level depends on the level and nature of the stress-strain state and the geometry of its components and the metal composition of the pipe. In the context of a large number of the short-term pressure changes in the pipeline, there is a tension increase in the pipe wall, which leads to the service life reduction.

During the transient regime, which is characterized by the pressure increase from P₁ to P₂, the hoop stresses occur, resulting in the strength and durability decrease. While reaching the significant strain indices in the pipe wall, the pipe bend appear which is accompanied by the pipeline and soil mass misalignment and the buckling failure. The result is the emergency situation of a breakthrough.

3. Results and Discussion
The differential equation of a curved surface should be applied:

\[ \frac{\partial^4 w}{\partial x^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{q}{D}, \]  

where \( q \) — load distributed over the inner surface of the pipeline; \( w \) — pipe wall bend; \( D \) — bending rigidity.

Rework the differential equation of bending wall and write the final form of the common bend.

\[ w = e^{\beta x} (C_1 \sin \beta x + C_2 \cos \beta x) + e^{-\beta x} (C_3 \sin \beta x + C_4 \cos \beta x) + f(x), \]  

where \( f(x) = \frac{\Delta PR^2}{\delta E} \)

Taking the second derivative we obtain the maximum bending moment:

\[ M_{max} = \frac{(P_2 - P_1)R^2}{2\beta^2 D}, \]  

The resulting bending stress:

\[ \sigma(x) = \frac{6M(x)}{\delta^2}, \]  

Considering the abovementioned formula, the maximum bending stress:

\[ \sigma_{max, eq} = \pm \frac{6(P_2 - P_1)R^2}{\delta \cdot E \cdot \delta^2} \left( \frac{3(1 - \nu^2)}{(R \delta)^2} \right)^{\frac{3}{2}}, \]  

The maximum equivalent stress \( \sigma_{eq, max} \) when \( \nu = 0.3 \):

\[ \sigma_{eq, max} = \sigma \left[ 1 + 4.90 \cdot \frac{P_2 - P_1}{P_1} \left( 1 + 1.73 \cdot \frac{P_2 - P_1}{P_1} \right) \right] = \sigma \cdot K, \]
The safety factor by the ultimate stress and the flow characteristics:

\[ n_b = \frac{\sigma_b}{\sigma_{\text{max}}} = \frac{\sigma_b \cdot \delta}{P_1 \cdot R \cdot K}, \quad (8) \]

\[ n_e = \frac{\sigma_e}{\sigma_{\text{max}}} = \frac{\sigma_e \cdot \delta}{P_1 \cdot R \cdot K}, \quad (9) \]

To determine the durability of \( N_{\text{dur}} \) when the pressure change is from \( P_1 \) to \( P_2 \), we use the deduced Manson experiments formula for the low cyclical failure, which connects the cycle total stress AM (elastic and plastic) with the number of cycles to fracture, and which is often used in practical calculations.

\[ \varepsilon_a = \frac{1}{2} \left( \ln \frac{1}{1-\psi} \right)^{0.6} \cdot N_{\text{dur}}^{-0.6} + 1.75 \frac{\sigma_b - \sigma_m}{E} \cdot N_{\text{dur}}^{-0.12}, \quad (10) \]

where \( \varepsilon_a \) - alternating stress; \( \psi \) - material necking; \( \sigma_b \) - material ultimate stress limit; \( \sigma_m \) - mean cycle stress; \( N_{\text{dur}} \) - number of cycles to fracture.

The pipeline operation durability (in years) is as follows:

\[ N_{\text{dur}} = \left[ 3.5 \left( \frac{n_b - 0.5\left(1 + \frac{1}{K}\right)}{1 - \frac{1}{K}} \right) \right]^{0.33}, \quad (11) \]

The probability of an accident due to the resource exhaustion (conventional) with low cyclicality is inversely proportional to the operation durability:

\[ P_a = \frac{1}{N_{\text{dur}}}, \quad (12) \]

According to the abovementioned formula the most important indicators with the initial conditions: \( P_1 = 4 \) MPa, \( D = 700 \) mm, \( \sigma_b = 520 \) MPa, \( N_g = 30 \ 000 \), Steel – 17GIC, should be calculated.

Displayed in Table 1, \( P_2 \) more detailed pressure changes (and consequently \( \frac{P_2 - P_1}{P_1} \) ratio) ranging from 0.3 to 0.4, which is equivalent to \( P_2 \) range from 5.2 MPa to 5.6 MPa at a constant wall thickness \( \delta \).

**Table 1. Detailed pressure changes**

| \( \frac{P_2 - P_1}{P_1} \) | \( \delta \) | \( R \) | \( K \) | \( n_b \) | \( N_{\text{dur}} \) | \( P_a \) |
|-----------------|-----|-----|-----|-----|--------|-----|
| 0.30            | 1.798 | 3.46 | 1.1E+11 | 2.7E-07 |
| 0.31            | 1.826 | 3.41 | 8.1E+10 | 3.7E-07 |
| 0.32            | 1.854 | 3.36 | 6.0E+10 | 5.0E-07 |
| 0.33            | 1.882 | 3.31 | 4.5E+10 | 6.7E-07 |
| 0.34            | 1.909 | 3.26 | 3.4E+10 | 8.9E-07 |
| 0.35            | 1.937 | 3.21 | 2.6E+10 | 1.2E-06 |
| 0.36            | 1.965 | 3.17 | 2.0E+10 | 1.5E-06 |
| 0.37            | 1.993 | 3.12 | 1.5E+10 | 2.0E-06 |
| 0.38            | 2.021 | 3.08 | 1.2E+10 | 2.6E-06 |
| 0.39            | 2.049 | 3.04 | 9.1E+09 | 3.3E-06 |
| 0.40            | 2.078 | 2.99 | 7.1E+09 | 4.2E-06 |
In Table 1, the ultimate indicator for counting is the failure probability calculation due to the resource end-of-life, and as a consequence, risk of mortality. Guided by the Federal Law № 123 amended on 10.07.2012, as well as "STR for the project documentation development for the object "The pipeline "AT GNS - THX ", point 2.1.1.1, where the established social risk is not more than 10 - 7 year - 1, the risks within these frames should be highlighted in red [10-14].

The safety factor percent growth with the wall thickness increase for different values pressure is displayed in Table 2. Step two and four mm are taken for more clarity.

### Table 2. The safety factor percent growth with the wall thickness increase for different values pressure

| $\frac{P_2 - P_1}{P_1}$ | Increasing the safety factor | 10-12 mm | 12-14 mm | 10-14 mm |
|--------------------------|-----------------------------|---------|---------|---------|
| 0.1                      | 17.180                      | 14.800  | 29.440  |
| 0.2                      | 17.160                      | 14.790  | 29.410  |
| 0.3                      | 17.140                      | 14.800  | 29.410  |
| 0.4                      | 17.150                      | 14.740  | 29.360  |
| 0.5                      | 17.130                      | 14.810  | 29.410  |
| **The average value:**   | **17.152**                  | **14.788** | **29.406** |

The data of the Table 2 are depicted graphically in the Figure 1.

[Figure 1 – Strength margin percent increase.]

The graph illustrates that with the $P_2$ pressure boost at transient regime, the pipeline operation durability is reduced. Thus, the emergency possibility increases. In order to diminish this risk, the measures to enhance security should be used, especially the wall thickness increase within the established norms of social risk by STR and the Federal Law №123. The calculations imply that the thickness increase of the pipe wall diameter $D = 700$ mm with the pressure change from 4 MPa to 4.8
MPa, and cyclical voltage change \( Ng = 30\,000 \) times should be produced to 11 mm.

### 4. Conclusion

The analysis of the accident conditions risks during the pipeline operation has shown that such measure as the pipe wall thickness increase is appropriate. It is calculated that the pipeline wall thickness increase by 1 mm improves the safety factor from 6 to 18\%, by 2 mm - for 14\%-17\%, and improves the durability from 3 to 10 times. The given data parameters decrease in the process of \( P_2 \) boosting and the initial wall thickness increase. The application of the abovementioned formulae and risk data can contribute to the technological objects security enhance during the dangerous substances transportation and preservation of human health and the environment.

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