HYDROCARBONS TRANSPORTATION SAFETY

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Trunk pipelines, both in Russia and abroad, were mostly built during the period of 60's – 80's, and the age of the pipelines that are currently operated is exceeding 30 years. It is the reason of the great importance attached to determining the safe operation life for pipelines and optimizing capital investments and maintenance schedules.

In order to ensure safe operation of a pipeline, the maximum allowable working pressure (hereinafter referred to as MAWP) downstream the pumping stations (hereinafter referred to as PS) must be designed and set, which pressure will not cause damage to each spool piece.

Determining the technical condition of pipelines through diagnostic examination, particularly with the use of inline inspection tools, and timely rectification of dangerous faults will ensure the industrial and environmental safety of hydrocarbons transportation by trunk pipelines. The allowable pressure of faulty spool pieces is also designed in foreign practice [1], [2].

The approaches adopted in Russia's oil/products pipeline transportation are discussed in this study.

The allowable working pressure (hereinafter referred to as AWP) in spool pieces designed in accordance with the Russian standards [3] is determined using the classic Mariotte formula (boiler formula), with a specific safety factor:

$$P_{ДРД} = \frac{2\delta_{факт} \cdot \sigma_{вр}}{D_{вн}} \cdot \frac{m}{n \cdot k_1 \cdot k_н}, \qquad (1)$$

where $\delta_{факт}$ is the wall thickness according to smart pigging data; $\sigma_{вр}$ is the design strength; $D_{вн}$ is the internal diameter; m, n, k_1, $k_н$ are the design safety factors.

MAWP for a pipeline according to the US standards [4] is also designed using the boiler formula, nevertheless, the pipe metal yield point is used instead of the break point to limit the maximum pressure:

$$P_{ДРД\ ASME} = \frac{2 \cdot \delta \cdot S_v \cdot F \cdot E}{D_н} \qquad (2)$$

where δ is the pipeline's wall thickness; S_v is the specific minimum yield strength; $D_н$ is the outside diameter, mm; F is the estimated factor based on the nominal wall thickness (F = 0.72); E is the welded connection factor (E = 1 for all welding types, other than furnace pressure welding and deposit welding).

The standards used in Canada [5] are similar, on the whole, to those used in the US.

Figure 1 is demonstrating the comparative results of AWP calculation based on the example of D1220x14-K56 and D720x9-K52 pipes, with the use of the standard safety factors.

As is clear from Figure 1, the design wall thickness values at the higher importance sections (water courses, motor road/railroad crossing points, etc.) are higher under SNiP 2.05.06-85* than those stipulated by the US and Canadian standards. As regards the sections located outside the points of crossing natural and artificial barriers, the US standards offer a more conservative solution with a higher wall thickness, as compared with the RF standards, while the Canadian standards offer a solution close to the RF standards. The importance of a pipeline section is determined by its category under the design standards.

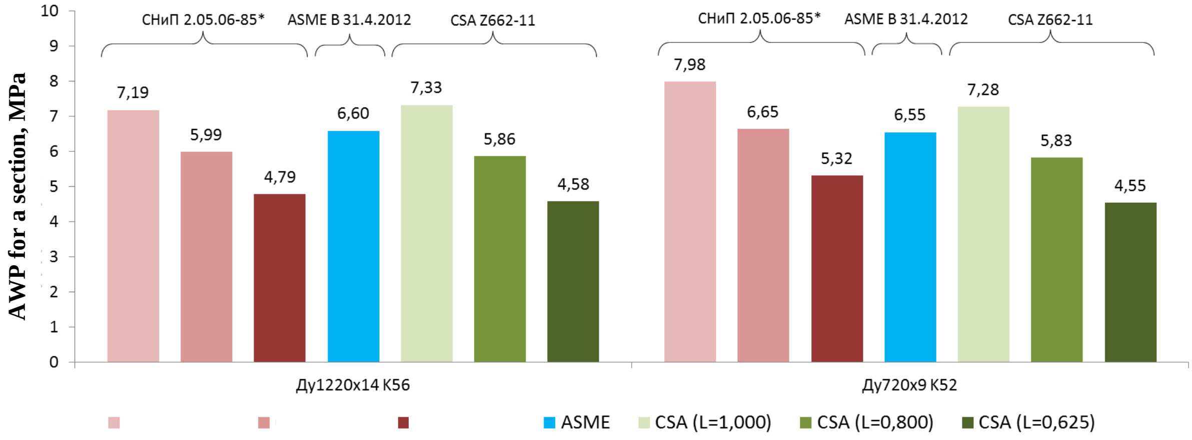

Figure 1 Comparative results of spool piece AWP design under the methods prescribed by SNiP 2.05.06-85*, ASME B 31.4.2012, CSA Z662-11

A specific of designing MAWP for pipelines in the long-term operation conditions is that safety factors for such pipes are not regulated separately.

The safety factors system adopted in the RF to design AWP for a spool piece was remaining unchanged, as a matter of principle, since 1975. The higher quality of pipe products, the development of technologies used in construction, diagnosis, industrial automation, development of the design software allow and require a revision of safety factors.

A study of safety margins

The authors have analyzed the results of testing 217 spool pieces made by 14 manufacturers using 33 various specifications from 29 unique steel grades.

Table 1 Deviation of the actual safety margin from the standard and certified values

Deviation of ultimate strength according to test results							
with respect to TU data (min. requirements)				with respect to pipe certification data*			
Average upward deviation		Average downward deviation		Average upward deviation		Average downward deviation	
%	pcs.	%	pcs.	%	pcs.	%	pcs.
8.93	**230**	**-2.66**	**4**	**7.72**	**206**	**-5.32**	**14**

* warranted by the manufacturer (usually higher than under TU; particularly confirmed by foreign studies [6])

The reliability factor for k_1 material is providing for cumulative probability of the standard strength characteristics of a pipe metal at the level of at least 0.95 [7], as confirmed by tests.

An adjusted value of load carrying capacity P_f for actual ultimate stress is proposed to be determined using the following formula:

$$P_f = \frac{\sigma_f}{\sigma_H} \cdot P_H \, , \tag{3}$$

where σ_f is the actual ultimate stress of the pipe metal; σ_H is the standard ultimate stress of the pipe metal; P_H is the standard load carrying capacity.

In case of a reduction of impact strength with respect to standard value $\sigma_{vf} < \sigma_{vH}$, actual ultimate stress of the pipe metal σ'_f is proposed to be determined using the following formula:

$$\sigma'_f = \sigma_f \cdot \left(\frac{\sigma_{vf}}{\sigma_{vH}} \right)^{0,5}, \quad (4)$$

where σ_{vf} is the actual Charpy toughness; σ_{vH} is the standard Charpy toughness.

Studying standard safety factors

The safety factors can be adjusted with the uncertainty factors taken into account when determining such factors excluded. So, if the design pressure values are available for a steady pumping mode and maximum pressure values for transient processes (in case of an emergency stop of a PS, closing shut-off valves, etc.), the safety margin for load reliability factor (n) may be decreased.

One more possible method for an adjustment of safety factors is to analyze the wall thickness measured by smart pigging [8]. See Table 2 [9] for the results of studying wall thickness on an oil pipeline example.

Table 2 Distribution of wall thickness within a section*

Number of sections investigated, pcs.	Negative allowance, mm	Measuring area, % of section area				
		less than negative allowance	within negative allowance	Actual thickness measured by smart pigging	within positive allowance	more than positive allowance
25055	0.8	0.2	22.1	27.3	48.1	2.3

* measuring using an inline inspection tool (IIT)

As is clear from Figure 2, 0.2% of pipe area are faults, and safety factor is not exhausted by 77.7% (AWP in a spool piece can be increased by 1 to 5%).

An increase of MAWP in operated pipes is demonstrated in Figure 2.

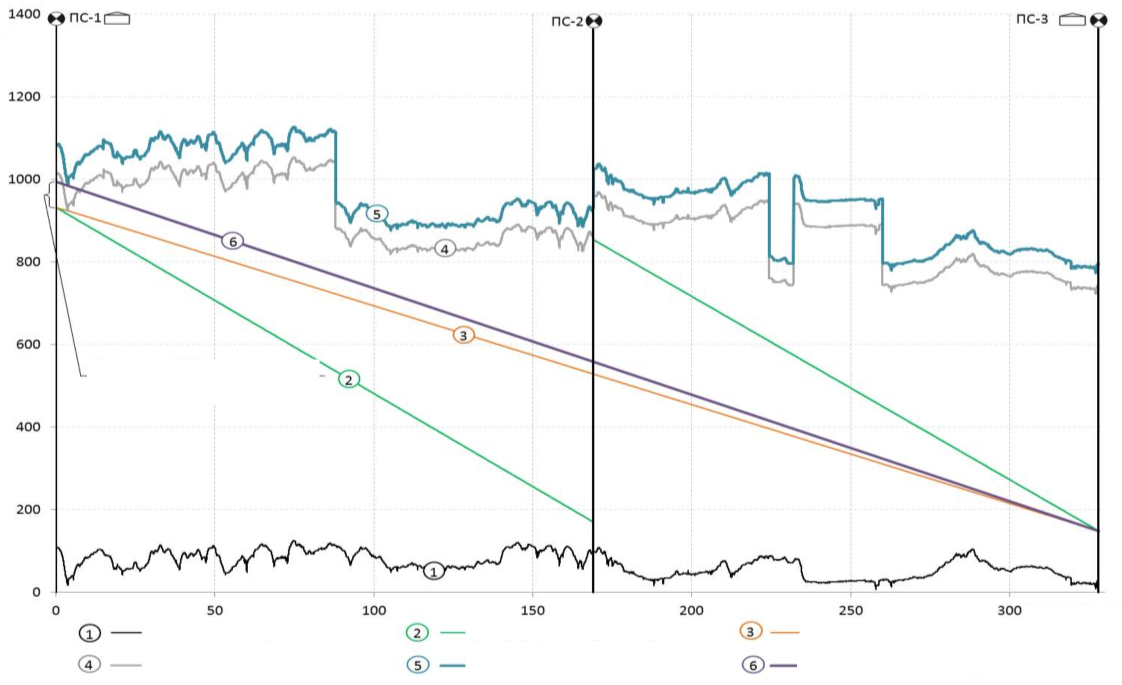

Figure 2 Hydraulic slopes and maximum working pressure curves

The maximum load carrying capacity of a spool piece at Figure 2 means the maximum allowable excessive pressure in the pipeline section calculated for the nominal wall thickness.

Conclusions. The authors have developed proposals for improvement of safety factors system through a more accurate determining the wall thickness, strength characteristics and possible overload relating to the working pressure, which proposals will allow, if implemented:

• a reduction of metal consumption for new pipelines;

• an increase in MAWP and throughput for operated facilities;

• an increase in operational safety of trunk pipelines' linear section.

Application of the study results will allow:

• an increase in MAWP for operated pipelines by up to 10%;

• a reduction of metal consumption for new pipelines by up to 6%.

The study results may also be applied to pipelines built in accordance with the foreign standards. An interpretation of safety factor (F) for calculation of the adjusted values of its components will be required in such case.

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