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GAS CONGESTION INFLUENCE ON PIPELINE SYSTEM CURVE

ANNOTATION

Gas-air congestion is one of the typical operational mode deviations in pumping of oil and petroleum, which reduces the pipeline system capacity on an average 30…60%. The development of measures for pipeline capacity support on designed level is faced up a crucial problem of parametric diagnostic system for hilly terrain pipelines.

The qualitative and quantitative estimation methodology of possible capacity reduction for a pipeline section with gas congestion is suggested. Monitoring of pressure distribution along pipeline length allows revealing and observing their accumulation and migration in time.

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INTRODUCTION

The gas congestion influence on a pipeline capacity is a popular theme of operational modes investigations of trunk pipelines and oilfield manifolds. We could have seen a lot of famous works of Russian scientists, working in the Moscow Academy of Oil & Gas: V.K. Kasperovitch [1], K.G.Donetz [2], V.L.Goldberg [3]; Grozny Oil University – A.I.Gudgov and V.F.Medvedev [4]; Ufa Oil University – G.E. Korobkov [5], A.K.Galljamov [6], M.I.Merduch [7], A.M.Nechval [8], etc. The investigation of two-phases stratified flows is traditionally paid close attention over the world. There is conducted the program with the purpose of two-phase flows study “Fluid Flow Projects” (TUUFFP) from 1972 in Tulsa University, USA with annual budget 500…1000 thousand dollars. Every half-year the leading scientists of the world are invited to take part in the competition to check experimentally their investigations. The most competent and mentioned are N.Brauner [9], D.Barnea [10], Y.Teitel, A.E. Dukler [11] (Israel), H.Furukawa, M.Ihara, K.Kohda [12] (Japan), G.F.Hewitt [13] (UK) and others.

GAS-AIR CONGESTION SYMPTOM AND REMOVING TECHNOLOGY

Specialists dealing with pipelines system are well acquainted with distinctive features of phenomenon:

- reduction of pipeline capacity;
- pump shock stall at gas-congestion passing through its passages;
- fall of waterhammer amplitude;
- pressure and discharge pulsation due-to big bubbles migration;

and also in measures of gas congestion removing [2,8,14]:

- pigging and cleaning;
- pipeline discharge increasing up to removal velocity;
- long time pipe pressure increasing up to the congestion erosion;
- automatic gas escape devices for exhaust of congestion into a satellite line.

The first method is the most effective, and it’s noted as a priority one by all the authors, but it supposes to bear rather large and not always justified additionally operation expenses in the absence of operating diagnostics and well-founded model of gas congestion kinetics.

The second method is most reasoned from the scientific point of view. A lot of researchers of two-phase flow has contributed to rationale of removal velocity [1,2,3,4,5]. However it’s rather problematically to fulfill technologically their recommendations for unloaded pipelines, which have 60% deterioration.

The third method has the same drawbacks as the previous one.

The fourth one suggests large capital investments and is realized only at the oilfields with twin-lines gathering system, which may be seen very seldom.

Gas congestions are formed in the highest parts of a line from gas bubble agglomerates emerged in uphill pipeline sections. The volume of such congestion varies with time: due to rise of capacity or pipe pigging. It shrinks up with gas removing or partial solution if pressure increase or velocities reduce. Vice versa it grows with disparaged gases separation and gas-air mixture migration by bubbles and slugs at erosion of up-hill congestion. So, beside the oil motion there is noticed a gas-air bubbles migration in any low loaded pipeline section. These bubbles form streamless congestions at the highest parts of a line, which are drawn out by inter-phase friction forces along inclined pipeline sections. Gas congestion is limited by accumulating ability of the downhill section of a pipeline. Having passed the lowest point of the line, gas surplus can arise along the uphill section like big bubbles (“slugs”), replenishing downstream gas-air congestion. But such way is more typical for field manifolds. As for trunk pipelines the growth of an congestion alternates with the periods of partial removal and solution. Properly pressure and flow velocity pulsations are detected in trunk pipeline seldom.

HYDRODYNAMIC MODEL OF HILLY TERRAIN PIPELINE

Gas congestions change the operation pipeline system curve differently. On the one hand gas congestions erect additional hydraulic resistances in the wide range of the pipe filling. But in diapason [0,87…0,97] the reducing of cross-sectional area is less than wetted perimeter. The pipeline operation at such pipe filling levels is possible only under conditions of congestion fixation in a pipeline (for example, increase of upstream inclination). In the opposite, any disturbance leads to the congestion removing from the section. Let’s choose the downhill sections on the line profile from “top elevation” point – $П_j$ to “saddle” – C_j (figure 1).

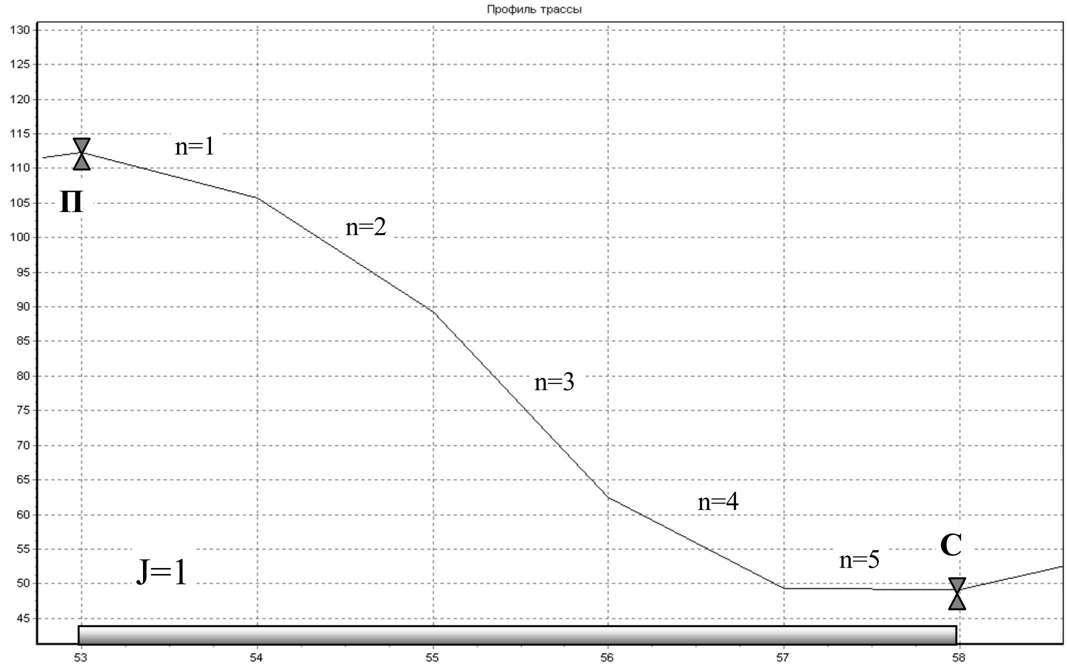


Figure 1 – Profile of a pipeline section.

The real profile is approximated by a polygonal line, which has links of the axis constant inclination to horizon. Having calculated the most possible gravitational discharge for every such pipeline section, we’ll choose the satisfactory one to prerequisite $Q < Q_{max}$. We’ll begin the analysis of gas congestion possibility from the last parts of polyline. Nothing prevents gas migration along these sections, so we can use the recommendations [4,5,6,8,15,16] from laboratory experiments.

We’ll define the minimum inclination of downhill section of the line when gas congestion existence in a pipeline is possible. There is known dependence by I.A. Charny [17] flow velocity for gas removing from a pipeline on inclination:

$$\vartheta = k_{\Gamma} \cdot \sqrt{\frac{2g \cdot D \cdot \sin\alpha}{\lambda}}. \qquad (1)$$

According to A.K.Galljamov’s [6] recommendations one can express with the factor through the ratio of oil and gas-air mixture viscosity:

$$k_{\Gamma} = 0.225 \cdot \sin^{-0.36}\alpha \cdot \left(\frac{\nu_f}{\nu_g}\right)^{0.39}, \qquad (2)$$

since ν_f – oil viscosity;

ν_g – gas-air mixture viscosity.

Having substituted (1, 2) experimentally registered the maximum pipe filling level of steady stratified flow $\frac{\varpi}{\varpi_0}$ = 0,82, when dimensionless hydraulic radius $\frac{4R_{\text{г}}}{D}$ has value 1,21 and having solved it according to angle α, we can get the minimum line inclination, when gas-air congestion is fixed in a pipeline:

$$\sin\alpha_{\min} = 12 \cdot \left(\lambda \frac{Q^2}{D^5}\right)^{3.57} \left(\frac{\nu_g}{\nu_f}\right)^{2.79} . \qquad (3)$$

The finite link of polyline shoul be checked for possible gas fixation:

$$\alpha > \alpha_{\min}. \qquad (4)$$

For estimation of the most possible gas volume, jammed in a polyline, we calculate pipe filling coefficient for each its link satisfying the term ($Q < Q_{max}$):

$$\frac{\varpi}{\varpi_0} = \frac{\dfrac{Q}{Q_f}}{\sqrt{\dfrac{\lambda_f}{\lambda} \dfrac{4R_{\text{г}}}{D}}} \qquad (5)$$

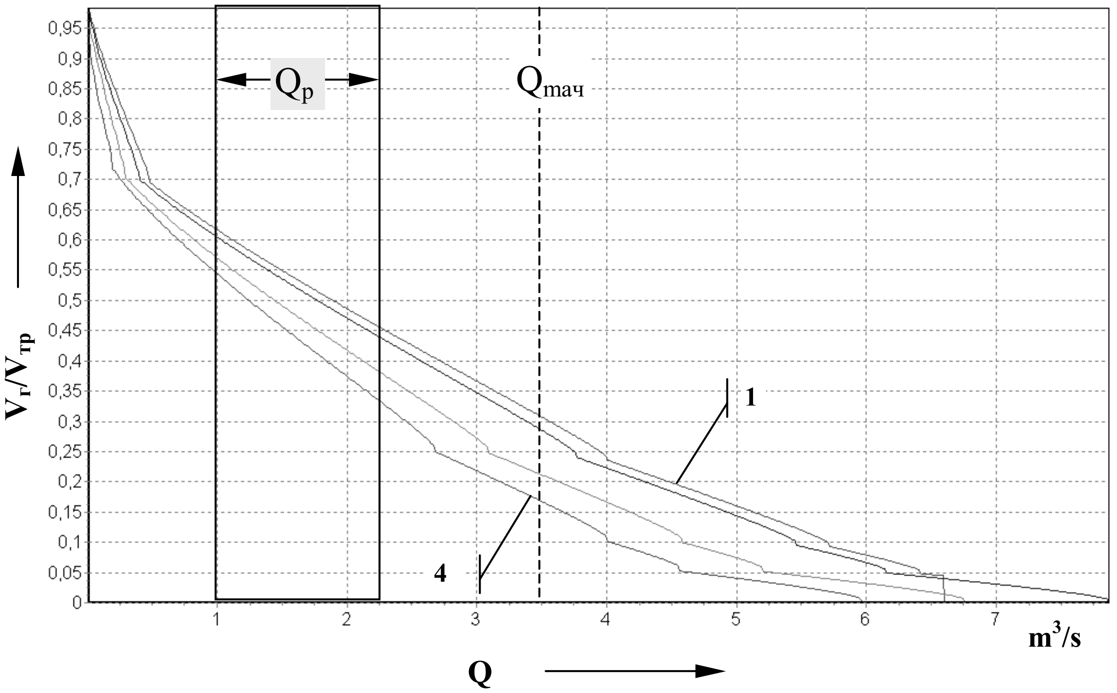
Summing up the gas volumes along the polyline length, we'll get the estimation of the most possible gas volume, jammed in the polyline:

$$V_{Г} = \frac{\pi D^2}{4}\sum_{n}\left(1-\frac{\varpi_n}{\varpi_0}\right)\cdot l_n, \qquad (6)$$

where n – link index in downhill polyline;

l_n – link length.

The change of most possible gas volume, jammed in trunk pipeline "Kuibyshev-Lisichansk" between piquets PK53…PK58 depending on capacity, is shown on the figure 2.



1 - ν = 1 cSt; 2 - ν = 10 cSt; 3 - ν = 100 cSt; 4 - ν = 300 cSt.

Figure 2. The most possible gas volume between piquets PK53…PK58 of trunk pipeline "Kuibyshev-Lisichansk" .

There are well seen points of fracture, corresponding to the removing gas-air congestions from the next downhill polyline link on the curves.

Hydraulic loses within gravitational flow are calculated by formula [18]:

$$h = 0.0826\cdot\lambda\frac{Q^2}{D^5}\left(l_{экв}-\sum_{n} l_n\right)+\sum_{n} l_n \sin\alpha_n, \qquad (7)$$

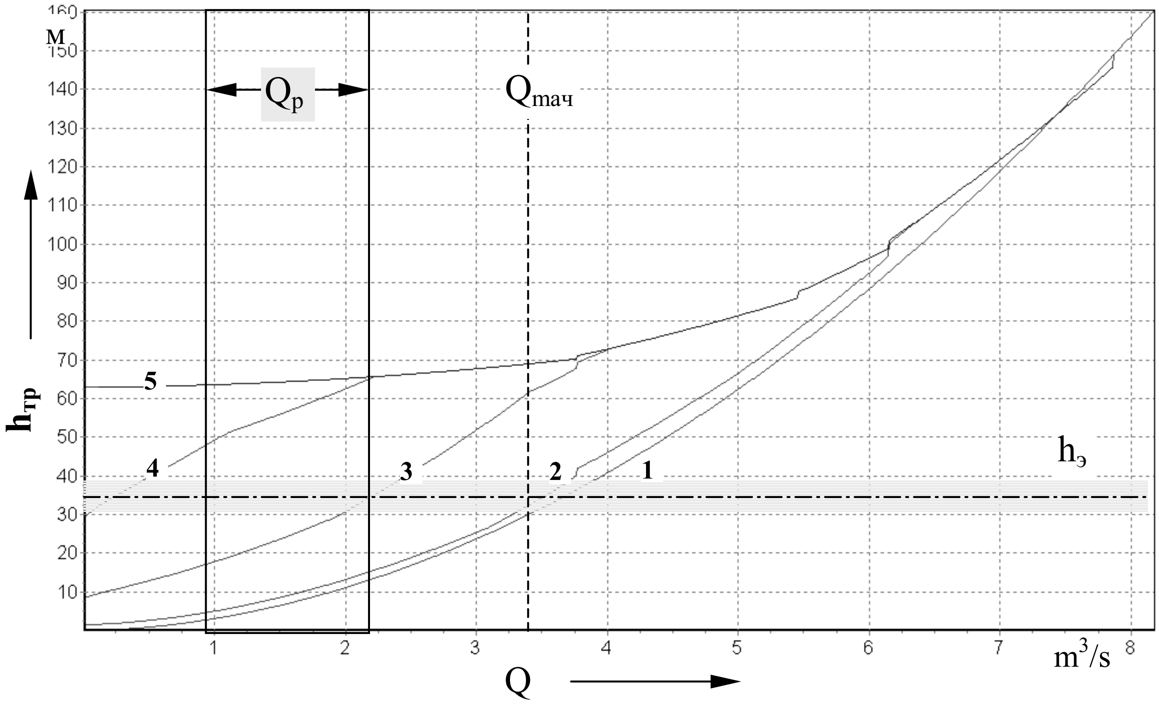
where l_n, α_n – length and inclination of n-link within gravitational flow in downhill polyline;

$l_{экв}$ – equivalent pipeline length: $l_{экв} = \frac{D \cdot \sum_{m} \zeta}{\lambda} + L$;

L – pipeline length;

$\Sigma\zeta$ – the sum of friction coefficients.

The dependence of system curve of trunk pipeline “Kuibyshev-Lisichansk” between piquets PK53…PK58 on the gas volume jammed in it, is shown at the figure 3.



1 – $V_г = 0$; **2** – $V_г = 250$ m^3; **3** – $V_г = 1250$ m^3 ; **4** – $V_г = 2500$ m^3; **5** – $V_г = V_{max}$.

Figure 3. System curves with gas congestions.

In gas absence ($V_г = 0$, line 1) the pipeline system curve is described by Darcy’s equation and proceeds from origin of coordinates. Line 5 describes the pipeline system curve at the most gas volume. Intermediate meanings of gas volume give the system curve within these limits. As the expense increasing the pipe filling coefficient grows as well, and gas surplus is removing with fluid flow. They cross axis Y on the points of level marks overfall of the origin and the end of gravitational flow lines. There are seen the migration lines of gas bubble through downhill polyline links with its further removing at large discharge on them.

A regulation of pipeline “Kuibyshev-Lisichansk” supposes the operational discharge range Q_p = 3600…8000 m^3/hour, or 1…2.2 m^3/sec. There is possible gas jamming 3500…2600 m^3 at light oil pumping over ($V_г/V_{тр}$ = 0.46…0.62 on fig.2) in this discharge range for section PK53…58. But monitoring pressure data along this line shows the value of energy loses $h_э \cong 35 \pm 5$ m, what gives the estimation of gas congestion volume 1000…1250 m^3 (fig. 3). The registered value of pressure in the described section is 1,5…3 times more than the designed hydraulic loses. On the uphill sections of the polyline this difference is meaningfully less – 10…70%. This leads to the pipeline capacity reduction till 60% in whole. Taking into account the other possible operational complications (water congestions, wax and paraffin deposits, gaufres, hollows and so on), one can value the differential influence of gas congestions to the pipeline capacity reduction as 30…60%.

Provided by pumps HM 10000-210 maximum discharge Q_{max} is 12500 m^3/hour ≈ 3,5 m^3/sec. The trunk pipeline “Kuibyshev-Lisichansk” is equipped by these pumps. Figure 2 shows that it is impossible to reach the removal velocity. At these regime gas congestion ≈ 0,3 $V_{тр}$ is possible. The whole gas volume of the considered section can be removed at discharge 7.8 m^3/sec or 28000 m^3/hour. Neither installed on the pipeline pumping equipment nor solidity system curve of the pipe can provide it.

The very rough estimation of the gas congestion influence on the pipeline system curve one can get summing the hydraulic loses at uphill (horizontal) sections, calculated by Darcy’s formula, and the sum of top elevation marks on downhill sections:

$$\mathbf{O}(h_\Sigma) = \mathbf{h}_{Дарси} + \mathbf{\Sigma\Delta z_j} \tag{8}$$

If the loses exceeds the designed value that means the gas-air congestions to be not the only factor reducing capacity of the pipeline section.

There are shown the lines of pressure distribution along trunk pipeline “Kuibyshev-Lisichansk” at different volumes of gas congestion between piquets PK48…PK65 on the fig. 4.

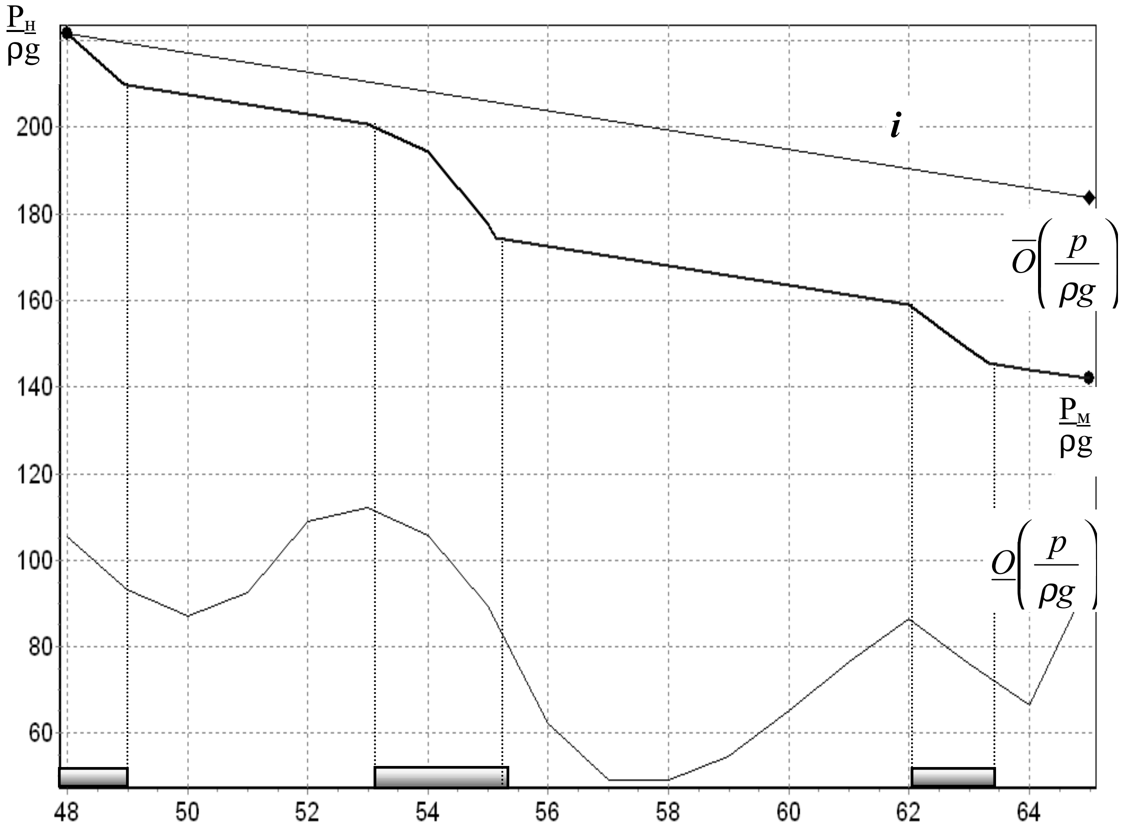


Figure 4. Pressure distribution between piquets PK48…PK65 of trunk pipeline “Kuibyshev-Lisichansk”.

Gas congestions location is shown by symbol ▭

Major and minor pressure estimations at the end of the pipeline section with gas congestions are marked with symbols $\overline{O}\left(\frac{p}{\rho g}\right), \underline{O}\left(\frac{p}{\rho g}\right)$ respectively.

CONCLUSIONS

1. Gas-air congestion is one of the typical technological complications of oil and petroleum pipeline transportation reducing the pipeline systems capacity average on 30…60%.

2. It is shown that there exist all the conditions for gas congestions formation in modern pipelines. Technological parameters of gas congestion removal regime pipelines considerably exceed the system possibilities. It’s necessary to provide the special measures and the means of their removal in regulations.
3. The monitoring of pressure distribution along the pipeline length allows exposing gas congestions for their timely removal from the pipe efficiently.

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