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Solving the prevention of the formation of traffic jams in pipelines in the transportation of gases by the autoejection process

Rozwiązanie problemu tworzenia się zatorów w rurociągach podczas transportu gazu poprzez proces automatycznego strumieniowania

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ABSTRACT: The article presents the application of autoejection process to ensure efficient operation of pipeline systems and gas separation installations when it is impossible to remove and utilize the condensate from the pipelines. Thus, in the suggested ejector, a single common stream is separated into two streams, i.e., an active and a passive stream, as opposed to two separate independent streams in existing ejection devices. As a result, we refer to such an ejection process as autoejection, or a self-ejection process. Such a procedure is run in the pipeline with the goal of blowing and dusting the liquid phase through the central high-velocity nozzle in circumstances of mass blocking and coating rather than expelling the liquid from the pipes. On the cross-sectional area of the belts, the velocity profiles of flows in laminar and turbulent regimes are known to differ greatly from one another. The adhesion forces acting from the tube's central axis outwards, towards its walls cause the flow rate to decrease. There is a cross-sectional interaction of flows in this mode, according to experimental studies of turbulent flows. As a result, compared to the laminar domain, the flow velocities in this regime are more equally distributed across the cross-section of the flow, and their values are roughly equal to the flow's average value. In this case, based on the dependences of the flow $\Delta p = f(W)$, it is known from the calculations and the table that at such velocity limits of the flows, the "braking" pressure (p_0) of the liquid coating on the pipe walls corresponds to the maximum velocity of the central gas flow. The autoejection process can occur due to the difference between the static pressures. Unsaturated absorbent coatings can be blasted off the tube absorber's walls using this technique and blended back into the main gas stream. Gas-liquid autoejectors installed along the pipe absorber's length make it possible to use this method. The purpose and principles of autoejectors' operation are considered and a perspective of their application in tube absorbers is noted.

Key words: pressure, temperature, flow, velocity, gas, liquid, pipeline, ejector.

STRESZCZENIE: Artykuł prezentuje zastosowanie procesu automatycznego strumieniowania w celu zapewnienia efektywnej pracy systemów rurociągowych i instalacji separacji gazu, gdy niemożliwe jest usunięcie i wykorzystanie kondensatu z rurociągów. W związku z tym w sugerowanej strumienicy automatycznej pojedynczy wspólny strumień jest rozdzielany na dwa strumienie, czyli aktywny i pasywny, w przeciwieństwie do dwóch oddzielnych, niezależnych strumieni w istniejących urządzeniach strumieniowych. Taki proces strumieniowania nazywany jest automatycznym strumieniowaniem lub procesem samostrumieniowania. Procedura ta uruchamiana jest w rurociągu w celu przedmuchiwania i odpylania fazy ciekłej przez centralną dyszę o wysokiej prędkości w warunkach masowego blokowania i usuwania, a nie wypierania cieczy z rur. Wiadomo, że profile prędkości przepływów w reżimach laminarnym i turbulentnym w przekroju poprzecznym stref znacznie się od siebie różnią. Siły adhezji działające od centralnej osi rury na zewnątrz w kierunku jej ścian powodują spadek prędkości przepływu. Zgodnie z wynikami badań eksperymentalnych przepływów turbulentnych w tym trybie występuje interakcja przepływów w przekroju poprzecznym. W rezultacie, w porównaniu do domeny laminarnej, prędkości przepływu w tym reżimie są bardziej równomiernie rozłożone w przekroju przepływu, a ich wartości są mniej więcej równe średniej wartości przepływu. W tym przypadku, na podstawie zależności przepływu $\Delta p = f(W)$, wiadomo z obliczeń i tabeli, że przy takich granicach prędkości przepływów, „hamujące" ciśnienie (p_0) powłoki cieczy na ścianach rurociągu odpowiada maksymalnej prędkości centralnego przepływu gazu. Proces automatycznego strumieniowania może zaistnieć dzięki różnicy między ciśnieniami statycznymi. Nienasycone powłoki absorbujące mogą być zdmuchiwane ze ścian absorbera rurociągu przy użyciu tej techniki i ponownie mieszane z głównym strumieniem gazu. Wykorzystanie tej metody jest możliwe dzięki zastosowaniu automatycznej strumienicy gazowo-cieczowej zainstalowanej wzdłuż absorbera rurociągu. Artykuł zawiera również rozważania dotyczące celu stosowania i zasad działania strumienic automatycznych, zwracając uwagę na ich zastosowania w absorberach rurociągowych.

Słowa kluczowe: ciśnienie, temperatura, przepływ, prędkość, gaz, ciecz, rurociąg, strumienica.

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Introduction

The output of oil and gas wells is combined and prepared for transportation in the mining process, and gas-liquid phases are transferred through a pipeline in gas transportation systems. When oil-margined gas-condensate deposits are in operation, gas, condensate, and oil are all carried in the same well plume. There are both technical and financial benefits to collecting the byproducts of the nearby gas-condensate wells in a collection system and transporting them to the facilities for preparing the gases for transportation. As a result, in this instance, the mine's product collection plan is made simpler, the metal needed for the pipelines is reduced, the transportation of very heavy hydrocarbon-containing oils is made simpler, and tar deposits are carried out in the pipelines. By using this method, gas-condensate fields' high formation pressure energy can be used effectively, indirect gas losses can be avoided, and the fields can be placed into service quickly (Guzhov, 1973; Grishchenko, 1978; Chugaev, 1982; Panakhov and Abdullaev, 1990; Aliyev et al., 2005; Aliyev and Sultanov, 2007; Gurbanov and Sardarova, 2022).

Materials and methods

In addition, due to the accumulation of liquid plugs following depressions that occur when gas and liquid phases are moving together in a convex turn-elbow part of a well plume, this system significantly impairs the operation of gas pipelines and gas preparation facilities (Guzhov, 1973; Grishchenko, 1978; Chugaev, 1982; Panakhov and Abdullaev, 1990). The vertical elbow configuration of the plumes in this swivel-elbow layout resembles the inlet pipes of separation units. As a result, these devices connect to the inlet pipes of the separation devices in the bend's direction.

Liquid phase plugs build up in these stationary zones in such bends along well plumes. The liquid phase that has accumulated in those areas acts as a structure (nozzle), narrowing the pipes and causing a pressure difference. As a result, liquid plugs are collected in turning sections of the pipes, and because of the pressure difference that is formed there, they are propelled in the shock-projectile motion mode into the separating devices. This circumstance not only hinders the work of separators but also lowers their useful work coefficient (WCF). Under specific thermodynamic conditions, the gas phase and free water phase in the turning-constriction areas of the pipes create hydrate-ice crystals, reducing the cross-sectional area of the flow. According to the Bernoulli's principle, in this situation, the flow velocity can fluctuate up to the velocity of the critical motion mode at specific pressure ratios both before and after the flow narrows.

This concept states that in the vast cross-sectional region of the flow, the pressure is high, and the velocity is small, while in the narrow cross-sectional area, the pressure is low, and the velocity is high.

The gas dynamics model of flow out of a high and constant pressure tank corresponds to the movement of the pipe from a large to a tight cross-sectional area. Based on the aerodynamic properties, pressure, and temperature ratios (Table 1) and their different formulas are provided for this model and correlate to the rise in velocity of flow in narrow zone (1):

$$T_0 = T + \frac{k-1}{2kgR}W^2$$
$$\frac{p_0}{P} = \left(\frac{T_0}{T}\right)^{\frac{k}{k-1}} \tag{1}$$

where:

p_0, T_0, p, T – the pressure and temperature in the cross-sectional areas narrowed to the flow, respectively,
W – flow velocity,
g – gravitational constant,
k – adiabatic index,
R – gas constant.

The values in the table were determined by calculating the functions of $W(P_0/P)$, $W(T_0/T)$, ΔP and ΔT in the narrowed

Table 1. Calculated values

Tabela 1. Obliczone wartości

p_0/p	$\Delta p = p_0 - p$ [MPa]	T_0/T	$\Delta T = T_0 - T$ [°K]	W [m/s]
Up to the critical mode of motion of the flow				
1.0083	0.004	1.0018	0.5	50
1.0335	0.200	1.0070	2.0	100
1.0770	0.400	1.0170	4.9	150
1.1430	0.600	1.0310	8.8	200
1.2340	0.900	1.0500	13.9	250
1.3580	1.300	1.0730	20.0	300
1.5030	1.700	1.1030	27.0	350
1.7520	2.200	1.1380	36.0	400
1.8300	2.300	1.1500	38.0	414
In the flow velocity movement above the critical regime				
2.2	27.3	1.20	49.0	470
2.4	29.0	1.22	53.0	488
2.6	31.0	1.25	59.0	515
3.8	32.0	1.27	63.0	533
3.0	33.0	1.27	66.0	545
3.2	34.4	1.30	67.0	552
3.4	35.3	1.33	72.7	572
3.6	36.0	1.34	74.0	577
3.8	36.8	1.36	78.0	593

zones of the pipes according to the gas-liquid flow velocity, pressure, and temperature (T_0 = 273°K). Calculations were performed for two motion modes: up to the critical motion mode and for high velocities. In the first case, the formation of pressure and temperature indicators in the narrowing zone of the flow is determined to obtain a certain velocity.

The two flow parameters, *p* and *T*, are local (static) quantities that cannot be directly measured by instruments at the pipe's exit. Since it is not feasible to measure *p* and *T*, these parameters must be calculated.

The study of the Table 1 reveals that the parameters *p* and *T* deviate slightly from the flow indicators for low values of the velocities at the outlet of the restricted segment of the flow. These variations do, however, become more pronounced as the flow narrows and velocity is up. In this scenario, the flow rate may exceed the velocity of sound. Indicators of such critical flow mode are the values of the last horizontal line in the first section of the table. In this situation, the critical flow rate is determined using the formula (2):

$$W_{kr} = [2\ \mathrm{kg}\ RT_0 /(k+1)]^{0.5} =$$
$$=[2.0\cdot 1.3\cdot 9.81\cdot 52.9\cdot 273.0/(1.3+1)]^{0.5} = 414\ \mathrm{m/s} \qquad (2)$$

In this case, the static temperature of the flow at the outlet of the narrowing part of the pipe drops to T_{st} = 254°K. There is currently a risk of mishaps in the plumes because the gas phase and free water phase that have accumulated in the pipe's constrained area can, at a certain pressure, create frozen hydrate crystals. These situations can happen in the separators' inlet pipelines at the wellhead and in other parts of the gas transportation system. Placing liquid separators of various constructions (such as scruples, expansion chambers, pulsation quenchers, and pipe separators, which are thought to be the most practical in the field) in the liquid collection zones of the pipes could be an efficient way to eliminate the collection of liquid phase in pipelines and the difficulties caused by it in gas pipelines. In situations where there are no requirements for the disposal of the condensate to be separated from gas pipelines on land and the middle of well plumes in the sea, however, it is difficult to install and utilize such liquid separators. We offer a new auto-ejection procedure and an auto-ejector structure for use with this process in such situations if it is not possible to remove the liquid phase from the pipelines, in order to prevent and remove liquid jams in the stagnation zones of those pipelines. A high-velocity flow nozzle flowing in the direction of the pipelines' central axis completes the role of active working flow in this operation. Small, swift liquids that adhere to pipe walls and liquid plugs gathered in spinning stagnation zones perform the function of passive flow (Aliyev and Sultanov, 2007). Thus, in the suggested ejector, a single common stream is separated into two streams, i.e., an active and a passive stream, as opposed to two separate independent streams in existing ejection devices. As a result, we refer to such an ejection process as autoejection, or a self-ejection process. Such a procedure is run in the pipeline with the goal of blowing and dusting the liquid phase through the central high-velocity nozzle in circumstances of mass blocking and coating rather than expelling the liquid from the pipes. The diffuser used in flow compressors is not needed, because of the autoejector's design. These ejectors' generalized reception and mixing chambers, slit tubes on their walls, and a confusor that quickens the flow of the gas-liquid mixture make up their design (Figure 1).

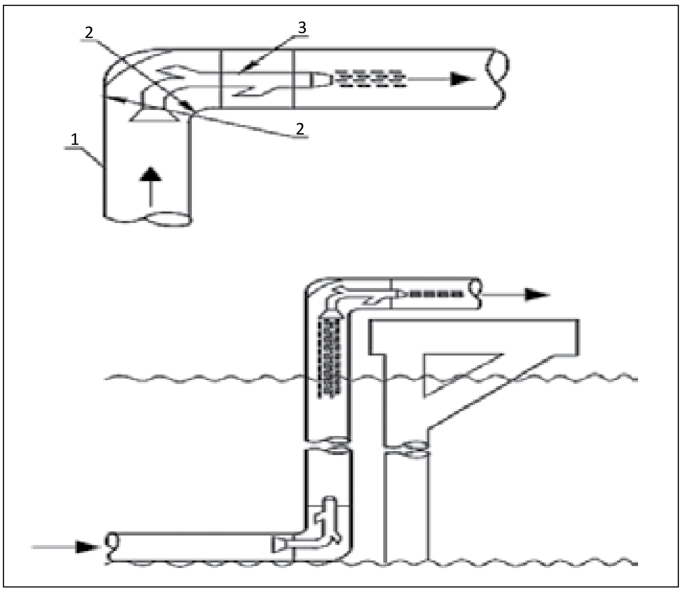

Figure 1. Supplying liquid to the liquid plugs through the autoejector: 1 – turning tube part, 2 – liquid collection parts, 3 – autoejector

Rysunek 1. Dostarczanie cieczy do zatyczek cieczowych za pomocą strumienicy automatycznej: 1 – obracająca się część rury, 2 – części zbierające ciecz, 3 – strumienica automatyczna

When a gas-liquid mixture is transported through a pipeline using the autoejection process, the gas and liquid phases are thoroughly mixed in cases of clogging and coating. This is true of both laminar and turbulent motion modes. At this point, the capacity of pipelines to release liquid increases, hydraulic resistance decreases, the impact-projectile regime of gas-liquid flows is eliminated, and the useful work coefficient of gas transport preparation devices increases. Additionally, the accumulation of liquid plugs and covers in various pipeline parts is prevented.

The advantages of executing the gas absorption process in pipes as opposed to the column-type vertical absorber are underlined as a result of the studies (Grishchenko, 1978). In this scenario, gas processing and transportation procedures are carried out simultaneously in pipes, negating the need for the metal-intensive separation and absorption devices currently in use.

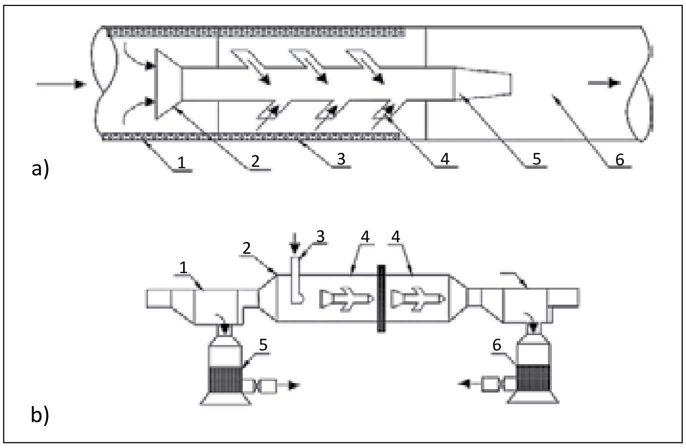

Figure 2. The principal schemes of using the in-pipe auto ejection process in pipelines; a) the use of auto-ejectors in liquid-coated gas streams: 1 – pipeline, 2 – autoejector, 3 – liquid cover, 4 – test tubes, 5 – confusor, 6 – liquid/powder/gas flow; b) the use of autoejectors in the process of absorption of gases in horizontal tubes: 1 – pipe separators, 2 – pipe absorber, 3 – absorbent efficiency, 4 – autoejectors, 5 – initial liquid capacity, 6 – saturated absorbent capacity

Rysunek 2. Podstawowe schematy wykorzystania procesu automatycznego strumieniowania wewnątrz rury w rurociągach; a) wykorzystanie strumienic automatycznych w gazowych strumieniach pokrytych cieczą: 1 – rurociąg, 2 – strumienica automatyczna, 3 – pokrywa cieczowa, 4 – probówki, 5 – konfuzor, 6 – przepływ cieczy/proszku/gazu; b) wykorzystanie strumienic automatycznych w procesie adsorpcji gazów w poziomych rurach: 1 – separatory rurowe, 2 – absorber rurowy, 3 – sprawność absorbentu, 4 – strumienice automatyczne, 5 – początkowa pojemność cieczy, 6 – pojemność wysyconego absorbentu

Figure 2 depicts the general layout of autoejector-based gas flow separation and absorption operations in pipelines. It is suggested not to inject the absorbent into the pipes at various places in the current absorption process design to achieve a complete solubility balance between the gas and the absorbent. The plan becomes more difficult in this situation, and the absorbent, which is not yet entirely saturated – quickly transforms into a coating on the pipe walls before being extracted from the pipe.

This unfavorable element is taken out of our proposed plan. In this case, autoejectors take the place of the plates (trays) employed in column-type absorbers, allowing for considerably faster absorption of the gas flow through pipes. In this instance, it is sufficient to provide the absorbent to the pipe completely in one go. This plan can be applied to both the drying and degasification of gas streams. This method involves first passing the gas-liquid flow through a pipe separator to separate it from the free liquid phase. The moist gas stream next enters the tubular absorber, and only at this moment is a new absorbent injected into the gas stream in a predetermined amount. When the absorbed absorbent is not saturated, it transforms into a liquid coating that flows slowly by being drawn to the pipe absorber's walls. The absorbent coverings are flung back towards the center of the flow by auto-ejectors positioned at specific distances from the absorber. The unsaturated absorbent is again ground up and thoroughly saturated when it comes into touch with a fast-moving central gas stream. In this arrangement, a pipe separator is positioned after the pipe absorbent. The saturated absorbent is caught and collected in a pipe-shaped container in that pipe separator. The desorber receives the saturated absorbent from this capacity under controlled production settings. When using a light condensate as an absorbent, the saturated absorbent can once more be divided into various hydrocarbon fractions by being sent through a fractionation unit under controlled factory conditions. Modern gas processing plants can lower capital costs and significantly simplify the overall gas processing scheme by using the suggested scheme in numerous forms.

The considered autoejection process is based on the principle of distribution of flow at different velocities across the cross-section of pipelines.

On the cross-sectional area of the belts, the velocity profiles of flows flowing in laminar and turbulent regimes are known to differ greatly from one another. The adhesion forces (viscosity indicator) acting from the tube's central axis outward toward its walls cause the flow rate to decrease. Controlled experimental tests demonstrate that the velocities in the pipe's cross-sectional area are spread along a parabolic curve in the laminar flow regime. Thus, the flow velocity is equal to zero at the pipe wall ($W = 0$) and smoothly increases towards the central axis of the flow, reaching the maximum value in the center ($W – W_{\text{medium}}$). To determine the condition of the flow, the average velocity considered constant for each point on the cross-section of the pipe is determined, and this velocity is assumed to be half of the maximum flow velocity in laminar flow (3):

$$W_{\text{medium}} = 1/2\, W_{\max} \tag{3}$$

It is determined by the following dependence of the distribution of velocities at each point on the flow cross-section (4).

$$W_1 = W_{\max}\left(1 - \frac{r^2}{R^2}\right) \tag{4}$$

where:
R, r – the radius of the cross-section of the pipe and any point of it.

The velocity profile in the pipe cross-sections is very unpredictable in the turbulent regime of the flow. The cross-sectional velocity values on the pipe are near the average flow velocity in this regime, and the flow velocity drops to zero in a thin layer close to the pipeline wall. The velocity profile graph in this instance resembles a trapezoid.

There is a cross-sectional interaction of flows in this mode, according to experimental studies of turbulent flows. As a result, compared to the laminar domain, the flow velocities in this regime are more equally distributed across the cross-section of the flow, and their values are equal to the flow's average value. The following function can approximate the cross-sectional distribution of velocities for the turbulent regime (5):

$$W_r = W_{\max}\left(1-\frac{r}{R}\right)^{\frac{1}{m}} \qquad (5)$$

where:

m – is the denominator of the rate indicator and depending on the Reynolds number (R_e), it can be determined from the graph $m = f(R_e)$.

$W_{\text{medium}} = 0.5\ W_{\max}$ in laminar mode of flow. If this dependence is W_{medium} = 30 m/s in the turbulent regime, then the maximum velocity in the central part of this flow can reach $W_{\max}$ = 33.3–42.8 m/s. In this case, based on the dependences of the flow $\Delta p = f(W)$, it is known from the calculations and the table that at such velocity limits of the flows, the "braking" pressure (p_0) of the liquid coating on the pipe walls corresponds to the maximum velocity of the central gas flow. The autoejection process can occur due to the difference between the static pressure. Unsaturated absorbent coatings can be blasted off the tube absorber's walls using this technique and blended back into the main gas stream. Gas-liquid auto-ejectors installed along the pipe absorber's length make it possible to use this method.

Conclusions

The proposed autoejection process, as shown above, can be utilized for two distinct purposes in the gas industry:

- to remove the condensate from the pipelines using liquid separators of various designs in the installation of gas and liquid phases, when other methods are impractical;
- to replace the plates in existing column-type horizontal tube absorbers dealing with wet gas flow and a potent absorbent phase.

In both cases, autoejector structures can transform the flow into a mixed-emulsion structural form by facilitating the integration of gas and liquid phases.

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