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CALCULATION OF DEGASSING NETWORKS TAKING INTO ACCOUNT THE ACCUMULATION OF THE LIQUID PHASE

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РОЗРАХУНОК ДЕГАЗАЦІЙНИХ МЕРЕЖ З УРАХУВАННЯМ АКУМУЛЯЦІЇ РІДКОЇ ФАЗИ

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РАСЧЕТ ДЕГАЗАЦИОННЫХ СЕТЕЙ С УЧЕТОМ АККУМУЛЯЦИИ ЖИДКОЙ ФАЗЫ

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Annotation. The article the issue of accounting for accumulations of liquid in the degassing network and humidity of the gas mixture during gas-dynamic calculations is considered. The estimated scheme of the degassing network of the mine is presented**.** The shape of the accumulation liquid in the cross section of a degassing pipeline is considered. Formulas are obtained for determining the perimeter of the passage section of the pipeline in the place of accumulation of the liquid phase, the area and hydraulic diameter of the passage section of the pipeline, the cross-sectional area of the segmental volume of the liquid accumulation, Reynolds numbers. Relations are presented for the coefficient of resistance to friction and the coefficient of resistance to interfacial friction for places of localization of the liquid phase. It is shown that the interaction of the gas mixture with the free surface of the liquid accumulation leads to the appearance of wave perturbations of the liquid. These disturbances are considered as an analogue of the roughness of the contaminated surface of the pipeline. In this case, the interaction of the gas mixture with the free surface of the liquid can be characterized by a coefficient of resistance to interfacial friction. Relations are presented for the absolute pressure, flow rate and density of the gas mixture in the degassing pipeline. Numerical methods for calculating gas pipelines are considered. An analysis of the methods used showed that the main errors in the calculation of gas-dynamic parameters are most characteristic for local resistances (including accumulations of liquids), as well as for joints of pipelines of various diameters. The results of calculating the friction and interfacial friction loses coefficients, the gas mixture consumption and the consumption characteristics of degassing pipelines are presented. The results showed that the values of the coefficient of loss interfacial friction at the place of accumulation of fluid can exceed the value of the Darcy coefficient. It was established that in places of accumulations of the liquid phase, additional losses of the absolute pressure of the gas mixture occur, which leads to a decrease in its flow rate. In this case, fluctuations in the consumption of gas mixture are observed, which are caused by the periodic formation of wave disturbances of the liquid.

Keywords: degassing network, accumulation of liquid, degassing pipeline, gas mixture.

The operation of the mine degassing of system is characterized by the interaction of its main elements with each other. The efficiency of degassing depends on the nature of the gas-dynamic processes in the degassing network.

The unsatisfactory condition of mine degassing pipelines is caused by a decrease in their tightness, damage to the walls, as well as their contamination by distributed and local sediments. This leads to an increase in the total aerodynamic resistance of degassing network [1-3], and growth in the cost of electricity for transporting the gas mixture and an increase in the concentration of methane in mining.

When designing degassing of systems, local resistances in the degassing network are taken into account by increasing the length for pipes by 10 % or more. At the same time influence of liquid phase accumulations formed as a result of condensation processes and liquid from degassing wells is not fully taken into account. These accumulations lead to noticeable fluctuations in vacuum, absolute pressure and flow of the gas mixture in the pipelines.

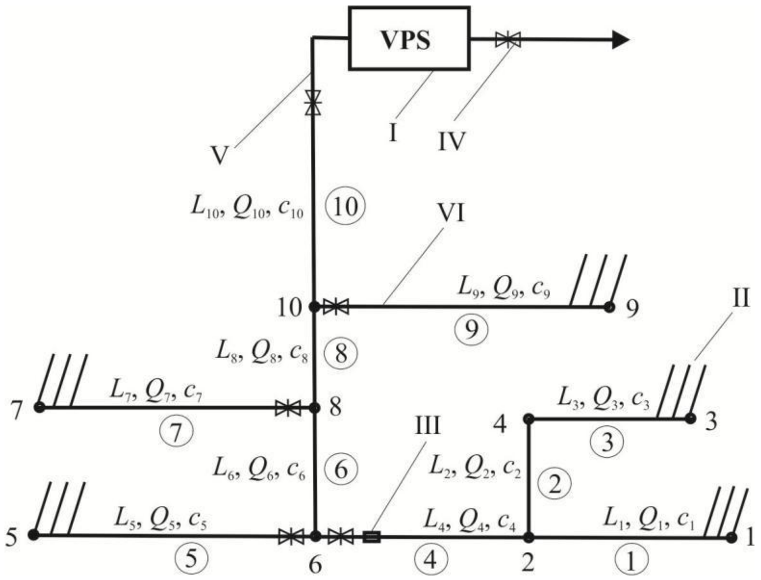
In the case of complete closure of the pipeline section, these fluctuations reach a maximum. This disrupts the process of transporting the gas mixture and increases the likelihood of accidents. In this regard, when carrying out gas dynamic calculations at the design and reconstruction stage of the degassing system, it is necessary to take into account the factor of moisture accumulation [1].

When calculating the degassing pipeline, the following gas dynamic parameters are determined:

1. Density and flow rate of gas mixture.
2. Speed of gas mixture and concentration of methane.
3. Absolute pressure and vacuum in the pipeline.
4. Aerodynamic resistance for pipeline.
5. Temperature of the gas mixture.

Initial data for the calculation of degassing system: gas flow; type of local resistance; degassing wells; fluid intensity from wells; length and diameter of the pipeline.

Fig. 1 a scheme of a degassing network is present.



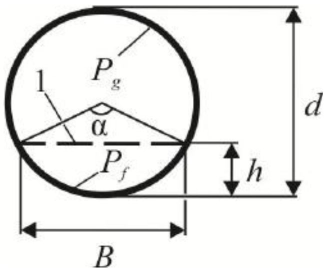
1, 2 - 10 – nodes; 1, 2 - 10 – branches; L_i – lengths of branches, m; c_i –methane concentration, %, Q_i – gas mixture flow rate, m^3/s; I – vacuum pumping station (VPS); II – degassing wells; III – device for draining water; IV – adjusting valve; V – main pipeline; VI – precinct pipeline

Figure 1 – Degassing network

During the calculations, the parameters of the gas mixture in the branches and nodes of the network are determined; efficiency of the vacuum pumps is checked. According to the results, adjustment of the design scheme is carried out.

Presence of the water in degassing network, as well as the flow of air through the flange connections of the pipeline lead to a change in values of resistance coefficients and density of gas mixture. In turn, this leads to corresponding changes in other gas-dynamic parameters.

Fig. 2 illustrates the form of fluid accumulation in the pipeline cross section.



1 – free surface of liquid; P_g, P_f – pipeline perimeters, respectively, for gas and liquid, m; h – liquid level, m; α – central angle, rad; B – fluid accumulation width, m; d – pipeline internal diameter, m

Figure 2 – Form of liquid accumulation in cross section pipeline

For the liquid accumulation segment (fig. 2), the following relations can be written:

$$P = P_g + B; \tag{1}$$

$$B = 2(hd - h^2)^{0.5}; \tag{2}$$

$$P_g = 0.5d(2\pi - \alpha) = 0.5d\,[2\pi - 2arccos(1 - 2d^{-1}h)]; \tag{3}$$

$$S_g = 0.25\,\pi d^2 - S_f; \tag{4}$$

$$d_g = \frac{4S_g}{P_g}; \tag{5}$$

$$d_z = \frac{4S_g}{P}; \tag{6}$$

$$Re_g = \frac{Qd_g\rho}{S_g\,\mu}; \tag{7}$$

$$Re_z = \frac{Qd_z\rho}{S_g\,\mu}, \tag{8}$$

where P is perimeter of the passage cross section of the pipeline, m; S_g is area of passage section of the pipeline, m^2; S_f is cross sectional area of liquid accumulation, m^2; d_g is hydraulic diameter of the pipeline, m; d_z is hydraulic diameter for the passage section, m; Re_g is Reynolds number for the gas perimeter; Re_z is Reynolds number for perimeter of the passage section of the pipeline; ρ is density of the gas mixture, kg/m^3; μ is dynamic viscosity of the gas mixture, kg/(m·s); Q is flow rate of the gas mixture; m^3/s.

A value of the total coefficient of friction resistance at the place of accumulation of liquid [4] is determined by the formula [1, 2]

$$\xi_{sum} = \xi_t + \xi_f\,, \tag{9}$$

where ξ_t is coefficient of friction resistance; ξ_f is coefficient of resistance to interfacial friction [4].

A coefficient of friction resistance for a clean pipeline is determined by the formula [2, 5]

$$\xi = \lambda d^{-1} L_t = 0.11(d_g^{-1}\Delta + 68Re^{-1})^{0.25}\, d^{-1} L_t, \tag{10}$$

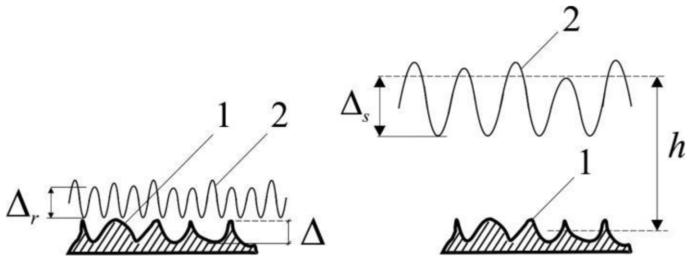
where λ is Darcy coefficient; Δ is absolute equivalent roughness for internal surface of the pipeline, m; Re is Reynolds number; L_t is pipeline length, m.

For fluid accumulation, the expression (10) takes the view

$$\xi_t = 0.11(d_g^{-1}\Delta + 68Re_g^{-1})^{0.25}\, L_s d_g^{-1}, \tag{11}$$

where L_s is length of accumulation, m.

Suppose that the wave surface of liquid (small waves) is similar to the roughness for inner surface of degassing pipeline (fig. 3)



1 – protrusions roughness; 2 – wave surface; Δ_r, Δ_s – wave heights on free surface of film water and fluid accumulation, m; h – liquid level, m

Figure 3 – Formation of waves on the free surface of the liquid in the pipeline

The maximum roughness of the inner surface of the pipeline $\Delta = \Delta_{max} \approx 2\text{-}2.5$ mm. This is typical for degassing pipes after long-term operation (effect of corrosion processes).

The total coefficient of friction resistance can be determined by the formula

$$\xi_{sum} \approx 0.11\left(\frac{\Delta}{d_z} + \frac{68}{Re_z}\right)^{0.25} \frac{L_s}{d_z}\,. \tag{12}$$

Using the expression (12) it is possible to obtain an approximate dependence of the coefficient of resistance to interfacial friction

$$\xi_f = \frac{\lambda_f L_s}{4S_g B^{-1}} = 0.11 L_s\left[\frac{1}{d_z}\left(\frac{\Delta}{d_z} + \frac{68}{Re_z}\right)^{0.25} - \frac{1}{d_g}\left(\frac{\Delta}{d_g} + \frac{68}{Re_g}\right)^{0.25}\right], \tag{13}$$

where λ_f is interfacial friction loss coefficient (analogue λ).

Based on the analysis of accumulation form [1, 5], the formula for cross-sectional area of the degassing pipeline is obtained

$$S_g = \frac{1}{8} d^2 \left\{ 2\pi - 2arccos \left(1 - \frac{2h}{d} \right) - sin \left[2\pi - 2arccos \left(1 - \frac{2h}{d} \right) \right] \right\}, \qquad (14)$$

where $h = aV^b$; V is volume of liquids, m^3; a, b are numeric coefficients.

The expression (14) allows connecting the cross-sectional area of the pipeline with the liquid level and its volume. A volume and level of liquid are determined experimentally. The degassing pipeline consists of links. It should be borne in mind that the air enters the pipeline through the flange connections of the links.

For an arbitrary link of the pipeline, we write down the relations for the following gas-dynamic parameters:

$$p_k = \sqrt{{p_n}^2 - p_n \rho_n \frac{{Q_n}^2}{S_g^2} \xi_{sum}}\,; \qquad (15)$$

$$Q_k = \left(Q_n + \Delta Q\right) \frac{p_k T_0}{p_a T_k}; \qquad (16)$$

$$\rho_k = \rho_v(1 - c_k) + \rho_m c_k, \qquad (17)$$

where p_n is absolute pressure of the gas mixture in the initial cross section of the pipeline link, kg/(m·s^2); p_k is absolute pressure of the gas mixture in the final cross section of the pipeline link, kg/(m·s^2); Q_n is gas mixture flow rate in the initial cross sectional of the pipeline link, m^3/s; Q_k is gas mixture flow rate in the final cross sectional of the pipeline link, m^3/s; p_a is air pressure under normal conditions, kg/(m·s^2); T_0 is air temperature under normal conditions, K; T_k is temperature of the gas mixture in the final cross section of the pipeline link, K; ΔQ is inflow of air for the link of pipeline, m^3/s; ρ_n is density of the gas mixture in the initial cross section of the pipeline link, kg/m^3; ρ_k is density of the gas mixture in the final cross section of the pipeline link, kg/m^3; ρ_v, ρ_m are air and methane density, kg/m^3; c_k is concentration of methane at the end of the pipeline link, %.

When calculating degassing pipelines, it is necessary to take into account the presence of fluid accumulations and changes in the parameters of the gas mixture due to air inflows. To improve the accuracy, a sequential calculation of each pipeline link is carried out (Fig. 4).

Flow rate coefficient method takes into account the change in the capacity of the gas pipeline in comparison with the reference pipeline. Nodal pressure method allows determining the gas pressure in the network nodes. Contouring method is used to consider a network graph indicating the direction of gas flow. Global gradient method allows calculating networks with different configurations. In this case, the gas flow and pressure values are set at the network nodes.

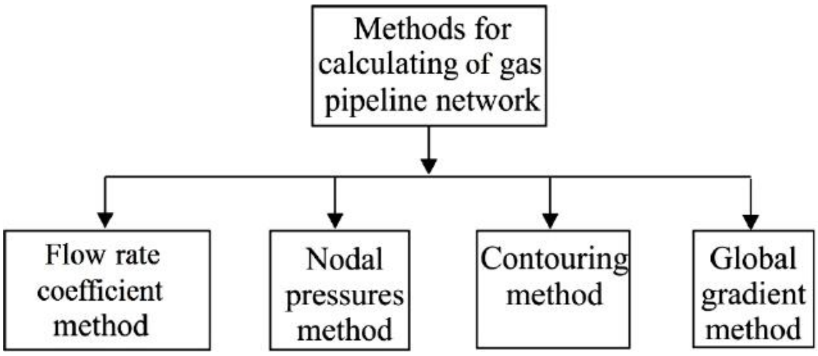


Figure 4 – Classification of calculation methods gas pipelines

The considered methods use assumptions about stationary and isothermal gas flow. The disadvantages of the methods are the occurrence of errors in the calculation of gas-dynamic parameters for local resistances (including fluid accumulations), as well as for the connections of pipelines of different diameters.

During the calculations, a degassing pipeline with an internal diameter of 0.257 and 0.309 m was considered. The velocity of the gas mixture is U = 10-15 m/s. The liquid level in the place of its accumulation is $h = 0.5d$.

Table 1 the results calculation of Darcy coefficient and the coefficient of loss for interfacial friction is presents

Table 1 – Resistance coefficients for degassing pipeline

d, m	U, m/s	Δ, m	$Re \cdot 10^5$	λ	λ_f
0.257	10-15	0.00005	1.36-2.0	0.018-0.017	–
		0.001	1.35-1.99	0.0283-0.028	–
		0.002	1.35-1.98	0.033	0.056
0.309		0.00005	1.63-2.41	0.02-0.015	–
		0.001	1.63-2.40	0.027	–
		0.002	1.63-2.39	0.032-0.031	0.053-0.054

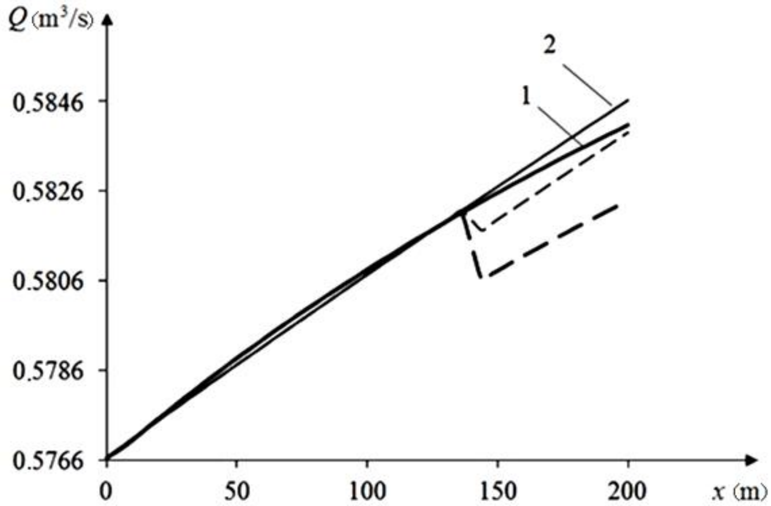
From the presented results it follows that the value of the coefficient of losses for interfacial friction exceeds the value of the Darcy coefficient by 1.7 times.

Fig. 5 the results of the calculation of the volume flow of the gas mixture on area of degassing pipeline with the accumulation of liquid is presents/

Analysis of fig. 5 shows that the decrease in the flow rate of gas mixture in the place of liquid accumulation is due to pressure losses. At the same time influence of the gas flow leads to the generation of wave disturbances in the liquid. This results in periodic overlap of pipeline.

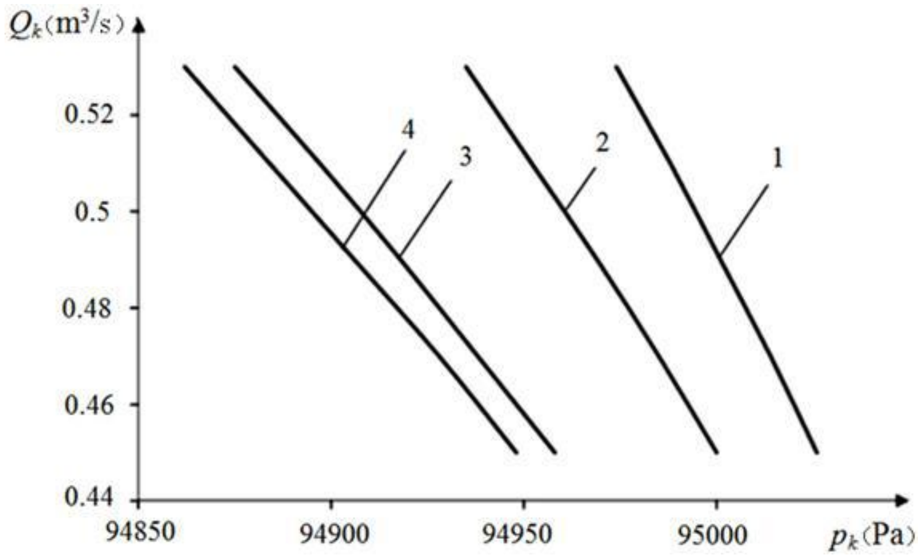
Fig. 6 the flow characteristics of the pipeline at different values of absolute equivalent roughness of its inner surface is presented.

Analysis of fig. 6 shows that the flow rate of gas mixture is inversely proportional to the absolute pressure at the end of the pipeline. With an increase internal roughness of the pipeline, its flow characteristic is shifted to the area of lower pressures.



---- – flow rate of behind an accumulation; 1 – *d* = 0.257 m; 2 – *d* = 0.309 m

Figure 5 – Changes in the flow rate of the gas mixture along the length of the degassing pipeline section with fluid accumulation



1 – Δ = 0.00005 m; 2 – Δ = 0.0003 m; 3 – Δ = 0.001 m; 4 – Δ = 0.001 m and fluid accumulation

Figure 6 – Flow characteristics for pipeline at various values of roughness of its inner surface

On the basis of research, the following conclusions can be made:

1. When determining the coefficients of friction resistance in degassing pipelines it is necessary to take into account the interaction of the gas mixture flow with the free surface of the liquid. In this case low-intensity wave perturbations of liquid are approximately considered as analogues of the roughness for solid surface.

2. At the given values of the conditional roughness for free surface of liquid in the degassing pipeline the value of the loss coefficient for interfacial friction exceeds the value of Darcy coefficient on average by 1.7 times.

3. A sharp drop in the flow rate of gas mixture is associated with the generation of wave perturbations liquid which periodically overlap the cross section of degassing pipeline.

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Анотація. У статті розглядається питання урахування скупчень рідини в дегазаційної мережі та вологості газової суміші при проведенні газодинамічних розрахунків. Наведено розрахункова схема дегазаційній мережі шахти. Розглянуто форма скупчення рідини в поперечному перетині дегазаційного трубопроводу. Отримано формули для визначення периметра прохідного перетину трубопроводу в місці скупчення рідкої фази, площі і гідравлічного діаметра прохідного перетину трубопроводу, площі поперечного перерізу сегментарного обсягу скупчення рідини, числа Рейнольдса. Наведено співвідношення для коефіцієнту опору тертя і коефіцієнту опору міжфазного тертя для місць локалізації рідкої фази. Показано, що взаємодія газової суміші з вільною поверхнею скупчення рідини призводить до виникнення хвильових збурень рідини. Зазначені обурення розглядаються як аналог шорсткості забрудненої поверхні трубопроводу. У цьому випадку взаємодія газової суміші з вільною поверхнею рідини може характеризуватися коефіцієнтом опору міжфазного тертя. Представлені співвідношення для абсолютного тиску, витрати і щільності газової суміші в дегазаційному трубопроводі. Розглянуто численні методи розрахунку газопроводів. Аналіз використовуваних методів показав, що основні похибки розрахунку газодинамічних параметрів найбільш характерні для місцевих опорів (включаючи скупчення рідини), а також для місць з'єднань трубопроводів різного діаметру. Представлені результати розрахунку коефіцієнтів втрат на тертя і міжфазного тертя, витрати газової суміші та витратних характеристик дегазаційних трубопроводів. Отримані результати показали, що значення коефіцієнтів втрат на міжфазне тертя в місці скупчення рідини можуть перевищувати значення коефіцієнта Дарсі. Встановлено, що в місцях акумуляції рідкої фази виникають додаткові втрати абсолютного тиску газової суміші, що призводить до зниження її витрати. При цьому спостерігаються коливання витрати газової суміші, які обумовлені періодичним утворенням хвильових збурень рідини.

Ключові слова: дегазаційна мережа, скупчення рідини, дегазаційний трубопровід, газова суміш.

Аннотация. В статье рассматривается вопрос учета скоплений жидкости в дегазационной сети и влажности газовой смеси при проведении газодинамических расчетов. Приведена расчетная схема дегазационной сети шахты. Рассмотрена форма скопления жидкости в поперечном сечении дегазационного трубопровода. Получены формулы для определения периметра проходного сечения трубопровода в месте скопления жидкой фазы, площади и гидравлического диаметра проходного сечения трубопровода, площади поперечного сечения сегментарного объема скопления жидкости, числа Рейнольдса. Представлены соотношения для коэффициента сопротивления трению и коэффициента сопротивления межфазному трению для мест локализации жидкой фазы. Показано, что взаимодействие газовой смеси со свободной поверхностью скопления жидкости приводит к возникновению волновых возмущений жидкости. Указанные возмущения рассматриваются как аналог шероховатости загрязненной поверхности трубопровода. В этом случае взаимодействие газовой смеси со свободной поверхностью жидкости может характеризоваться коэффициентом сопротивления межфазному трению. Представлены соотношения для абсолютного давления, расхода и плотности газовой смеси в дегазационном трубопроводе. Рассмотрены численные методы расчета газопроводов. Анализ используемых методов показал, что основные погрешности расчета газодинамических параметров наиболее характерны для местных сопротивлений (включая скопления жидкости), а также для мест соединений трубопроводов различного диаметра. Представлены результаты расчета коэффициентов потерь на трение и межфазное трение, расхода газовой смеси и расходных характеристик дегазационных трубопроводов. Полученные результаты показали, что значения коэффициентов потерь на межфазное трение в месте скопления жидкости могут превышать значения коэффициента Дарси. Установлено, что в местах аккумуляции жидкой фазы возникают дополнительные потери абсолютного давления газовой смеси, что приводит к снижению ее расхода. При этом наблюдаются колебания расхода газовой смеси, которые обусловлены периодическим образованием волновых возмущений жидкости.

Ключевые слова: дегазационная сеть, скопления жидкости, дегазационный трубопровод, газовая смесь.

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