Stability of the liquid particles separation in the apparatus of oil and gas systems

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Abstract. The article considers the methods of associated gas purification from liquid particles**.** The sintering of liquid particles occurs during the separation process and the trapped droplets can be removed as a liquid stream, i.e. there is no need for unloading units. The droplet size depends on the energy input during their fragmentation. The efficiency of drops separation depends on the flow rate and the intensification of droplets coalescence, film formation and liquid flow to the receiver. The dispersion of the liquid particles is the main drawback of the existing purification methods, i.e. lack of sustainability of particle separation. The comparison of the separation system methods and the devices with flow control elements is carried out. The estimation of gas purification efficiency is conducted. It is concluded that the efficiency of associated gas purification gives the possibility to use it in turbine generators, heating furnaces, etc. It significantly reduces the proportion of gas being flared.

1. Introduction

The presence of moisture in gas after separation degrades the quality of gas for in-situ use and further transportation to gas processing plant due to the formation of crystalline hydrates. The same techniques which are used to purify gases from solid particles are applied to purify natural gas from liquid impurities. The separation of drops has advantage over the separation of solid particles. The advantage is that the liquid droplet agglomeration occurs during separation and the trapped droplets can be removed as a liquid stream, i.e. there is no need for unloading units. The droplet size depends on the energy generated during their fragmentation. If the liquid fragmentation is due to the energy of the gas flow then droplets form, with the average size being from the tens of micrometers, and sometimes hundreds of micrometers [1]. In the most cases, the various types of nozzles are used to separate droplets from the gases. They are installed at the gas outlet from devices [2]. High-speed filters are used as mist-liquid trap to protect the compressor from damage, with the first stage being agglomerator, where the particles of all sizes are precipitated but the liquid in the form of large droplets is removed by stream and precipitates in liquid trap [3]. The irregularity of the flow cross-section resistance, the deformation of filter, and the reduction in purification efficiency are the main disadvantages of such a gas-purifier.

In fields and oil treatment units, gas is commonly purified from the impurities (solids, oil droplets, and water) by means of louver separator [4]. The advantages of louver apparatus are as follows: the low hydraulic resistance and ease of layout in gas separators, scrubbers, absorbers, and gas dehydrators. The efficiency of drops separation depends on the flow rate within this separator, i.e. the

inertial effects of drops interaction with the apparatus surfaces increase with the flow rate rise up to the maximum value. This leads to the intensification of the droplet coalescence and film formation, as well as it causes liquid to flow to the receiver. The separation of drops is defined by further increase in flow rate, with liquid droplets being entrained with gas flow.

2. Louver separator speed modes

The optimal rate in the cross section of vertical louver separator is defined by formula [1] $\upsilon_G = 0{,}122\sqrt{\dfrac{\rho_L - \rho_G}{\rho_G}}$. The paper [1] provides information about residual moisture content in the

various separators provided by the Kutateladze criterion $K = \dfrac{\upsilon'_G \sqrt{\rho_G}}{\sqrt[4]{g\sigma(\rho_L - \rho_G)}}$. Here υ'_G is speed of the

flow incoming to the nozzle, m/sec; ρ_L, ρ_G are the liquid and gas density respectively, kg/m^3; σ is surface tension at the gas-liquid interface, N/m; g=9.81 m/sec^2. The sharp increase in droplet entrainment begins at K >0.42. At K<0.3 the efficiency decreases, and the required area of flow cross-sections decreases. The area of the nozzle cross-section (m^2) is determined by the formula [4] $F = \dfrac{Q_G T z p_{at}}{86400 T_0 p \upsilon'_G}$. Here Q_G is gas consumption, m^3/days; T_0 ,T − gas temperature under standard

conditions and current, respectively K; p_{at}, p are atmospheric pressure and current respectively; z is gas compressibility factor. The gas density increases with pressure rise, while the gas speed must decrease under the condition K <0.42. In order to endure the required high-speed modes of louver separator, it is necessary to apply the devices which allow regulating cross-section area of the nozzle or use several separators, which makes it possible to switch gas flow.

3. The proposed separator specifications

3.1. The proposed separator with adjustable gas flow

The separator (figure1) consists of a scroll 1 with enclosing surfaces 2, 3, curved channel 4 the input section 5 and the admixture discharge connection 6, purified gas discharge connection 7, regulating blade 8, springs 9, gap 10, liquid seal 11.

The operation principle of the separator is as follows: the gas-liquid mixture passes through the input section 5 in curved channel 4, liquid is discharged through the admixture discharge connection 6 and liquid seal 11. Then the gas-liquid flow passes into the vortex scroll 1, in which the drops are separated in the enclosing surfaces 2, 3 and removed by gas flow through the gap 10 in curved channel 4 in the form of a film. The position of the blade 8 determines the flow rate in the channel 4, i.e. flow rate is influenced by narrowing the area between blade 8 and channel outer wall 4. The magnitude of the stream momentum through the cross section defines the magnitude of the ejected stream from the scroll 1 to the channel 4. The springs 9 are configured so that pressure differential at the end of the blade 8 is enough to for separation carried out in a wide range of gas-liquid mixture flow rates. The stability of process is achieved by increasing the coefficient of the gas ejection, which comes from the scroll 1 to the channel 4, i.e. the area of the input section decreases with decrease in flow Q, constant speed, and increase in the amount of ejected gas q. The vortex scroll 1 serves as a lock for the particles larger than a set size.
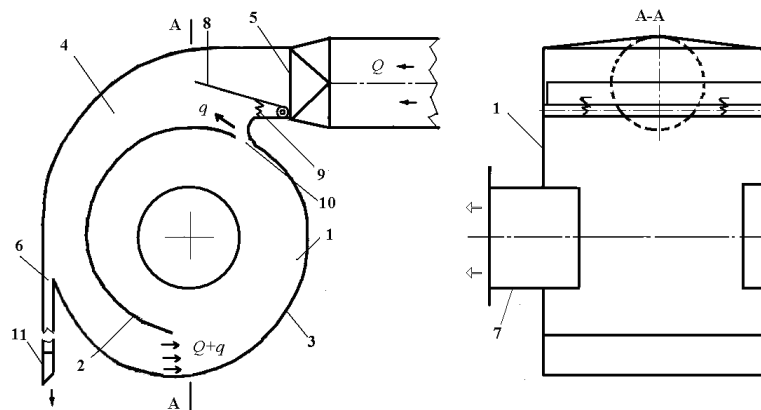
Figure 1. Separator scheme.

Thus, there are two stages of separation. The first stage takes place in the curved channel and the vortex scroll, where the separated liquid droplets pass through the curved channel and fully captured in the vortex scroll in the form of a film.

3.2 Efficiency of particle separation in curved channel
Figure 2 shows the design scheme of individual particles separation in the channel. Here, $X = R - R_{в}$, $H - h$ is the particle coordinate in the inlet, X_0 is the coordinate of gas discharge with separated particles flowing to the receiver Π.
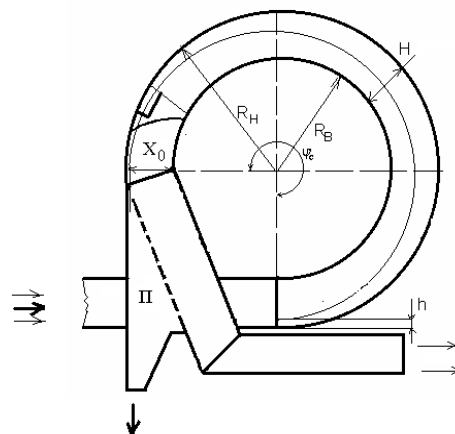

Figure 2. The scheme of particles separation in curved channel.

The speeds of the particles and gas are constant along the channel. $R_{\text{c}} = \dfrac{R_{\text{H}} + R_{\text{B}}}{2} \gg R_{\text{H}} - R_{\text{B}} = H$,

$\text{Stk} = \dfrac{\delta^2}{18\nu} \dfrac{\rho_{\text{L}}}{\rho_{\text{G}}} \dfrac{W_0}{R_{\text{c}}}$, here ρ_{L}, ρ_{G} are liquid and gas density, respectively, ν is a kinematic viscosity of gas, δ is a diameter of liquid particles, W_0 is gas speed in the channel. The calculation shows that the effectiveness of particle penetration into the gap, i.e. the particle passing through the coordinate X_0, is

determined by $\eta_1 = \text{Stk}\, \dfrac{R_c}{H}\, \varphi_c$. Here φ_c is flow deflection angle in radians. Moreover, if $\eta_1 > 1$, then η_1 will be equal to unity. There is a boundary size, and all particles which are larger than this size will penetrate into the gap of the receiver. This size can be determined by the equation $\delta_{\text{LIM}} = \sqrt{\dfrac{\rho_G}{\rho_L}\dfrac{18v}{W_0}\dfrac{H}{\varphi_c}}$, m. For example, the calculation shows that if $\rho_L/\rho_G = 20$; $v = 1.5 \cdot 10^{-5} \text{m}^2/\text{sec}$; $\varphi_c = 2$; $W_0 = 20$ m/sec; $H = 0.1$m, then $\delta_{\text{LIM}} = 3.35 \cdot 10^{-4}$m. It means that the larger particles are separated. Consequently, in case of large liquid formations (more than 0.5 mm), complete removal of these formations occurs in the channel.

3.3. Efficiency of separation in the vortex scroll
When evaluating the effectiveness of particle separation from the flow by the method of trajectories in the vortex scroll, it is assumed that the circumferential speeds of gas and particles are remain constant and the minimum size of entrained particle is determined by the relationship

$$W_{\varphi 1}^2 \tau / R_1 = W_{r1}, \ \tau = (\rho_L/\rho_G)(\delta^2/18v), \tag{1}$$

where $W_{\varphi 1}$ is a tangential velocity of gas at the radius R_1, W_{r1} is a radial velocity of gas, R_1 is a radius of the discharge connection 7(figure.1), τ is a relaxation time, ρ_L, ρ_G are liquid and gas density repsectively, δ is a diameter of liquid particles, v is a kinematic viscosity of gas. In formula (1) it can determined the size, and the particles which are the smaller size will be submitted. Based on formula (1), it is possible to find $\quad \delta_{\text{LIM}2} = \sqrt{\dfrac{W_{r1} R_1}{W_{\varphi 1}^2}\dfrac{\rho_G}{\rho_L}18v}\,. \tag{2}$

For example, when $\rho_L/\rho_G = 20$; $v = 1{,}5 \cdot 10^{-5} \text{m}^2/\text{sec}$; $W_{\varphi 1} = 30$ m/ sec; $W_{r1} = 0{,}1$m; $R_1 = 0{,}05$ m, $\delta_{\text{LIM}2} = 8{,}7 \cdot 10^{-6}$ m is obtained.

Let us calculate the efficiency of the separation process on the assumption that particle sizes are described by the integral function with the lognormal distribution of particle diameters. In this case, the amount of moisture entrainment is determined by the value of integral function in terms of particle diameters calculated according to the equation (2).

The composition of the aerosol is determined by the mass content of the particles which are smaller than a given size determined in the flow sample. The particle integral function characterized by logarithmically normal distribution has the following values (table 1):

Table 1. The integral function of size distribution X [3].

X	−2.5	−2	−1.5	−1	−0.5	0	0.5	1	1,5	2	2.5
$F(X)$%	0.62	2.28	6.68	15.87	30.85	50	69.15	84.13	93.32	97.72	99.38

Here $X = lg(\delta/\delta_m)/lg\sigma$, $\sigma = \delta_m/\delta_{16}$, δ_m is a median size. The weight of particles which is less than this size is 50% of the sample weight. Physically, the integral function is related to flow areas when sizing the sample from gas suspension particles: greater part of dispersed material of relative weight passes through a sieve with large cell size. This means that δ_m is a cell size through which 50% of the sample material passes; δ_{16} is a cell size through which 16% of the sample material passes; δ_2 is a cell size through which 2% of the sample material passes. The magnitude $d_m/\delta_2 = \sigma^2$ is an indicator of particle size in small portion, i.e. the difference of cell size corresponding to the two-percent sample and the size of the cell corresponding to median value. Such an evaluation in terms of liquid particles can be performed as a part of disperse analysis using impactors [3].

Let δ_m=50 mkm, $\sigma_ч=\delta_m/\delta_{16}$=2, then the calculation of the efficiency without turbulence in cyclic trajectory is as follows $\eta_2 = 1 - F(X_y)$, where $X_y = \dfrac{\lg \delta/\delta_m}{\lg \sigma_ч} = \dfrac{\lg 8{,}7/50}{\lg 2} = -2{,}52$, $F(X_y) = F(-2.52) = 0.0062$, i.e. $\eta_2 = 1 - F(Xy) = 1 - 0.0062 = 0.9938$.

Thus, the separation process of droplets in the proposed separator is less dependent on fluctuations of gas and liquid volumes in gas-liquid mixture entering the separator.

The study of the similar method to control flow with solids is carried out in [5, 6].

The number of vortex separators and their sizes are determined by the condition that the flow rate at separator inlet should be less than 30 m/sec, and the minimum size of the entrained drops should be within the range of 2–5 mkm. However, the density of the purified gas in high-pressure devices is 2 times higher than the density at atmospheric pressure, therefore, the actual size of entrained droplets is bigger. Furthermore, taking into account the flow turbulence, the estimated droplet entrainment is 2–3 times higher than the provided calculations [5]. The vortex devices can be arranged as a battery and placed in high-capacity separators [7].

4. Conclusion

The equipment to purify gas from impurities does not operate effectively under the condition of varying impurity concentrations and gas flow rates. The vortex seperator with adjustable flow allows engineers to purify gas effectively. Usually, the qualitative dehydration of associated gas requires the large capital and operating costs, since it is required to build additional individual separation units. However, today it is possible to increase separation efficiency by upgrading equipment, precisely by using modern internal devices. One of these devices is the vortex separator. It is installed in the body of the vessel without welding, and does not change the separator technological scheme, which significantly reduces the expenses.

5. References

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