N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 5, Number 443 (2020), 150 – 155 **https://doi.org/10.32014/2020.2518-170X.115**

UDC 622.276.72

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POSSIBILITY OF VORTEX SEPARATION EJECTOR APPLICATION IN THE COLLECTION AND SEPARATION OF GAS

Abstract. The article analyzes the experimental and pilot ejector installations and shows shortcomings in their work with two-phase flows. Association of high and low pressure gas flows with a conventional choke device leads to a significant loss of flow energy of high pressure gas. This union of gas flows of high and low pressures, also limits the selection of gas from wells with low wellhead pressure and the combined gas stream in this case becomes a low-pressure, so transporting it over long distances becomes impossible. Thus, new design of the vortex and separation ejector for the improvement of technological processes is proposed.

Its design and principle of operation are described. The proposed ejector consists of a feed chamber with a tangential inlet of the passive flow, and a tangential exit of the liquid phase, mixing chamber and diffuser.

The possibility of implementing it at the same time in the ejection and low-temperature gas separation processes were considered. The advantages of the ejector are shown. Due to the cold created by very low temperature in the proposed vortex ejector it is possible to carry out the process of static low-temperature gas separation simultaneously with the process of ejection. The use of this small-sized ejector instead of compressor installations on limited areas of offshore platforms, bushes and flyovers is especially expedient and advantageous.

The vortex ejector is simple in design and can be made out of the factory by forces of the manufacturers themselves from tube elements.

Key words: pressure, temperature, flow velocity, nozzle, adiabatic expansion, flow, energy, vortex flow.

Introduction. In the operation of gas condensate fields in the technological scheme of collection and preparation of gas to transport gas-liquid flows with different (high and low) pressures appear. In some cases, because of the inability to dispose of these low-pressure gas streams with a high content of gasoline fractions, they are useless burned in flares or released into the atmosphere. With the aim of increasing the pressure of low-pressure gases requires the construction of a compressor station, which is not always profitable with a techno-economic point of view.

Vortex tubes of small diameters ($D_t \leq 30$ mm), working with air flow at low pressures, have found their industrial application in the field of aviation, refrigeration, air conditioning, instrumentation, measuring equipment and others.

However, vortex tubes, like other jet devices (ejectors, turbo-expanders), have not found their wide industrial application and have remained at the experimental and pilot stage in the field of high pressure and gas processing practices. There are several reasons for this. Firstly, in the technical literature, vortex tubes have an opinion that they, as a transformer (converter) of energy, have a low performance index due to the need for a high initial gas pressure. Secondly, it is difficult to carry out laboratory and bench tests of large vortex tubes with high flow rates and initial gas pressures that simulate field and factory conditions. In addition, there is currently no reliable theoretical basis and universally accepted methods for technological and structural calculations of vortex tubes in the widely changing thermodynamic conditions of field and factory practice. Heating half of the total flow in a vortex tube is also considered a vulnerable factor when used in a low-temperature gas separation unit (LTS) installation.

At the same time, the presence of "free" natural high reservoir pressures in gas condensate fields and the need for rational use of the energy of these pressures cast aside the opinion of the low efficiency of vortex tubes. It should be noted that the "hot stream" in the vortex tube can form at low initial pressures at the inlet of the pipe, and at higher initial pressures at the inlet of the vortex pipe, the temperature of the hot stream is equal to the initial temperature of the total flow at the inlet of the vortex pipe. At higher initial gas pressures at the inlet of the pipe, the so-called "hot flow" of the vortex tube may have a negative temperature. In this case, a strongly cooled dry (central) stream and a moderately cooled and supersaturated vapor of heavy hydrocarbons and water (peripheral) stream will leave the vortex tube. The decrease in the temperature of the "hot stream" is explained by the fact that the total vortex temperature effect is the algebraic sum of the Rank effect and the usual throttling $[(\Delta T)_{Total} = (\Delta T)_{Rank} \pm \beta_{throttling}]$. When determining the total vortex effect by the "hot flow", the value of the integral throttling effect $(\beta_{throttling})$ gets a negative value.

It should also be noted that by cooling a hot pipe with an external source of cold (water or another cooling agent), it is possible to increase the proportion of cold flow

(μ = 0.8-0.9). This situation (the use of a non-adiabatic vortex tube) increases the cooling capacity and thereby increases the possibility of the use of vortex tubes in LTS installations (figure 1).

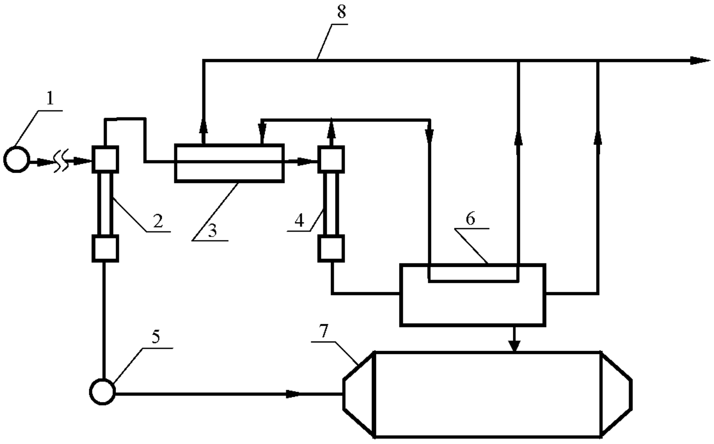

Figure 1 – Schematic diagram of the low-temperature separation of natural gas using vortex tubes
1 - well; 2 - the first vortex tube; 3 - heat exchanger; 4 - the second vortex tube; 5 - blockhouse;
6 - separator-heat exchanger; 7 - capacity for liquid; 8 - dry gas reservoir

Thus, the technological need to reduce wellhead pressure during the operation of gas condensate wells to the pressure of apron gas pipelines, the simultaneous cooling and separation of gas in small vortex tubes without rotating metal elements, makes it possible to rationally use the pressure energy of the gas flow during its expansion and significantly reduce the specific consumption of metal. The throughput of a vortex tube with a diameter of 60 mm at a critical expiration of a gas stream with an initial pressure of 100 kgf / sm^2 is approximately 350 thousand nm^3 / day. The mass of such a vortex tube is about 4550 kg. In the separation mode of operation (μ = 0.6), this jet apparatus can carry out gas separation in an amount of: $0.6 \cdot 350000 = 210000 nm^3 / day$. A comparison of the mass of the vortex tube and the amount of treated gas shows a very low specific metal consumption for separating gas in the vortex tubes.

This article proposes a model of a vortex separation ejector for collecting and separating produced gas.

Methodology. Association of high and low pressure gas flows with a conventional choke device leads to a significant loss of flow energy of high pressure gas. This union of gas flows of high and low pressures, also limits the selection of gas from wells with low wellhead pressure and the combined gas stream in this case becomes a low-pressure, so transporting it over long distances becomes impossible.

In the case of high-pressure gas stream in the field scheme of gas collection is much beneficial the use of ejector units in exchange for the construction of the compressor station. From oilfield practices there are known some results of experimental and experimental-industrial tests of straight ejector installations in technological scheme of the high and low pressure gas flows' collection [1]. However, these ejector installations is not found wide industrial application in field practice, and remained at the stage of experimental work for the following reasons:

- The lack of reliable calculation methods of the ejection for not-separated gas-liquid flows' process;
- Violation of the optimal operation mode of straight ejector installations in the presence of a liquid phase in active (high-pressure) and passive (low-pressure) gas flows;
- the need to implement the process of active and passive gas-liquid flows separation before entering them into the ejector unit;
- difficulty controls work of straight ejector installations, as in the case of change of initial parameters of active and passive flows, you often need to change all the transverse dimensions of the ejector units elements (i.e., dimensions of cross sections of the nozzles, chambers and displacement diffusers);
- presence of a liquid phase in the active and passive flow leads to a large hydraulic resistance, loss of energy pressure, the emergence of a "flooding" regime in existing ejector systems;
- Appearance of the liquid in the gas enter to those set, also dramatically affects the main indicators, including the coefficient of efficiency and coefficient of ejection.

Considering mentioned above drawbacks in operation and design of the existing straight ejector units upon their work with two-phase flow, the authors have developed a new design of vortex separation ejector (figure 2) that performs simultaneously two functions in the collection and preparation of gas for transport:

- Ejecting and increase of the passive flow pressure;
- Implementation of the active and passive flow separation together in the vortex ejector [2].

The proposed ejector consists of a feed chamber with a tangential inlet of the passive flow, and a tangential exit of the liquid phase, mixing chamber with a tangential nozzle for active flow input, the diaphragm installed between the receiving and mixing chambers to enter the passive flow in the chamber of the displacement, diffuser with a rectifier of common flow and tank for collecting liquid.

The principle of operation of the proposed ejector is as follows. Passive two-phase flow, coming through the tangential inlet to the receiving chamber, makes in it a rotational movement. The free liquid phase of the flow due to centrifugal force is forced out to the walls of the inlet chamber and through a tangential exit pipe is drained into a tank for collecting liquid. After separation, the rotating passive gas flow through the central hole of the diaphragm and enters into the mixing chamber, where through the tangential inlet nozzle the active two-phase flow enters too. Here the flow is also subjected to rotational movement. In this case, in the mixing chamber is a joint rotational movement of active and passive flows in the form of a "vortex inside another vortex", that is, in this camera continues the rotary motion of the passive flow inside rotating active flow. There is a separation of combined flows, and selected liquid phase through a tangential outlet of the mixing chamber is drained into a tubular container for collecting liquid. Then mixed combined separated flow in the diffuser straightening and raising its pressure, shell out of the vortex ejector.

Note that the active flow passing through tangential nozzle is subjected to adiabatic expansion in which the flow becomes very low static (local) temperature.

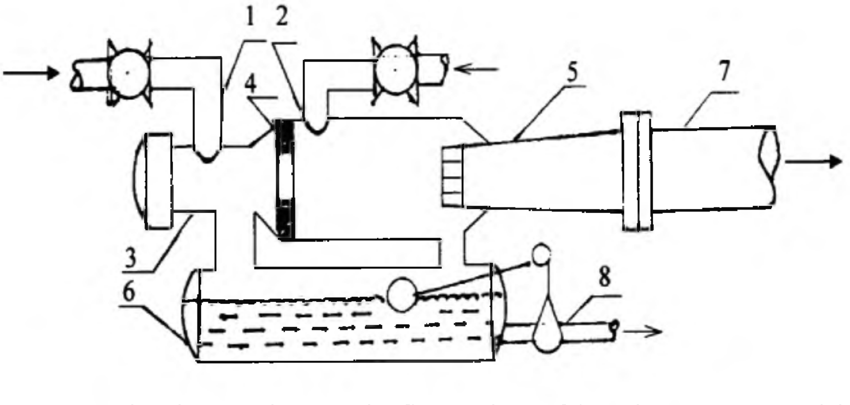

Figure 2 – Vortex separation ejector 1 - input passive flow; 2 - input of the active stream; 3 - receiving chamber; 4 - mixing chamber with a diaphragm; 5 - diffuser with a rectifier; 6 - tube fluid container; 7- gas line; 8 - fluid line

However, measurement of this low static temperature with a thermometer is almost impossible, since in this case the movement of the thermometer with the same speed at which the moving stream of gas is necessary. But, despite that this temperature is not subject to direct measurement, however, due to the cold created by this very low temperature in the proposed vortex ejector it is possible to carry out the process of static low-temperature gas separation simultaneously with the process of ejection.

The static temperature of a moving gas stream can be determined using the dependences of the adiabatic expansion of the gas. In the critical mode of the gas stream outflow through the nozzle (i.e., at the maximum flow rate of the active stream), the temperature ratio in front of the nozzle (T_0) and in the mixing chamber (T_{cr}) is equal to: $\frac{T_0}{T_{cr}} = \frac{k+1}{2}$, here k is the adiabatic index (for natural gases, $k = 1.3$). In this mode, the pressure ratio in front of the nozzle (P_0) and in the mixing chamber (P_{cr}) is equal to:

$$\frac{P_0}{P_{cr}} = \left[\frac{k+1}{2}\right]^{\frac{k}{k-1}}$$

For natural gases, these ratios are equal:

$$\frac{T_0}{T_{cr}} = \frac{1.3+1}{2} = 1.15$$

$$\frac{P_0}{P_{cr}} = \left[\frac{1.15+1}{2}\right]^{\frac{1.3}{1.3-1}} = 1.83$$

Temperature ($\Delta T_{cr} = T_0 - T_{cr}$) and pressure ($\Delta P_{cr} = P_0 - P_{cr}$) differences for this mode for natural gases will be:

$$\Delta T_{cr} = T_0 - \frac{T_0}{1.15} = T_0\left(\frac{0.15}{1.15}\right) = 0{,}13T_0 \qquad \Delta T_{cr} = 0.13T_0$$

$$\Delta P_{cr} = P_0 - \frac{P_0}{1.83} = T_0\left(\frac{0.83}{1.83}\right) = 0{,}454P_0 \qquad \Delta P_{cr} = 0.454P_0$$

In the proposed vortex ejector, the critical static temperature (T_{cr}) corresponds to the separation temperature (T_{sep}) of the total mixed flow in the mixing chamber ($T_{cr} = T_{sep}$) and can be determined in the critical mode of the flow of the active stream depending on the initial temperature (stagnation temperature) of the active stream ($T_{cr} = \frac{T_0}{1.15}$).

Results. The table shows the calculation results for the determination of critical temperatures (T_{cr}).

Temperature differences ($\Delta T_{cr} = T_0 - T_{cr}$) and coefficients $\alpha_s = \frac{\Delta T_{cr}}{\Delta P_{cr}}$ in the critical flow of the active stream at initial pressures and temperatures equal to $P_0 = 6.0 \div 10.0MPa$ and $T_0 = 273 \div 313K$.

Table 1- Calculation results for gas flow cooling during adiabatic gas expansion under critical outflow conditions for various initial pressures and temperatures

T_o, K	T_{cr}, K	$\Delta T_{cr} = T_o - T_{cr}$, K	P_o / P_{cr}, (MPa / MPa)				
			6.0/3.28	7.0/3.23	8.04/4.37	9.0/4.92	10.0/5.46
			$\Delta P_{cr} = P_o - P_{cr}$				
			2.72	3.17	3.63	4.08	4.54
			$\alpha_s = \Delta T_{cr} / \Delta P_{cr}$ (K / MPa)				
273	237	36	13.2	11.3	9.9	8.8	7.9
283	246	37	13.6	11.7	10.2	9.1	8.1
293	255	38	13.9	12.0	10.5	9.3	8.4
303	263	39	14.3	12.3	10.7	9.6	8.6
313	272	40.7	14.9	12.8	11.2	9.9	8.9

Analysis of table data shows that in the adiabatic expansion of the gas committed at the critical gas outflow with increasing initial temperature (T_0) increases the difference in critical temperature $\Delta T_{cr} = T_0 - T_{cr}$and the coefficient $\alpha_s = \frac{\Delta T_{cr}}{\Delta P_{cr}}$. This ratio also increases at lower values of ΔP_{cr} in case when $\Delta T = const.$

In the considered coefficient α_s [as an indicator of the degree of cooling efficiency during iso-entropic ($s = const$) expansion of the gas flow] equal to:

α_s = 7.9-14.9°C/MPa, whereas under these conditions, the corresponding ratio of the throttling process (i.e. constant enthalpy $i = const$) equal $\alpha_i = 3 - 4.5°C/MPa$ This means that under these conditions the process of iso-entropic gas expansion from the point of view of obtaining a cold at a lower temperature, significantly effective (2.5-2.7 times) than the gas throttling process, applicable in existing low-temperature gas separation units.

It should be noted that the mode of operation of the vortex ejector can be likened to the mode of operation of the turbine expander only with the difference of absence of rotating parts (wheels, bearings) in vortex ejector. In this ejector the rotation of the high circumferential and angular velocities is exposed to the gas stream. Therefore, in this case, unlike the wheel of the turbine expander, the gas vortex rotates with a significantly higher number of revolutions, which allows the low-temperature separation process more effectively, so this process can co-administer at lower static temperatures of the gas streams. Despite the fact that this static low temperature cannot be directly measured, it really exists and can be successfully used in the proposed vortex ejector for low-temperature gas separation. Its value, as has already been said, can be determined by calculation and confirmed by measuring the temperature of the dew point of the gas at the outlet of this ejector using a moisture meter.

Thus, in the proposed vortex ejector, it is possible to combine the processes of ejection and gas separation. The use of this small-sized ejector instead of compressor units on limited areas of offshore platforms and overpasses is especially expedient and advantageous.

The vortex ejector is simple in design and can be made out of the factory by forces of the manufacturers themselves from tube elements. Its work is easily regulated by changing the initial parameters of the initial gas flows. In this case, it is enough to replace the dimensions of the nozzle cross sections and the diameter of the diaphragm for the passive flow to enter the mixing chamber.

Conclusions. 1. The reasons that delay the widespread use of existing rectilinear ejector installations in technological schemes for gas collection are indicated;

2. The presence of a free liquid phase in the composition of the active and passive flows impairs the reliability of the results of technological and mechanical calculations for the design of existing rectilinear ejector installations;

3. The presence of fluid in rectilinear ejector installations increases the hydraulic resistance in them, leads to a loss of pressure energy and violates their optimal mode of operation;

4. In the proposed vortex separation ejector, the above-mentioned disadvantages of existing ejector installations are eliminated and pressure energy is rationally used.

5. In the vortex ejector, the processes of ejection and gas separation occur simultaneously;

6. Low-temperature gas separation in a vortex ejector occurs at low static temperatures obtained due to high gas flow rates during adiabatic expansion of gases;

7. The advantages of vortex separation ejector using in the technological scheme of collecting and preparing gas for transport are indicated.

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ГАЗДЫ ЖИНАУ ЖӘНЕ АЖЫРАТУ ҮДЕРІСІНДЕ ҚҰЙЫНДЫ ЭЖЕКТОРДЫ ҚОЛДАНУ МҮМКІНДІГІ

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ВОЗМОЖНОСТЬ ПРИМЕНЕНИЯ ВИХРЕВОГО ЭЖЕКТОРА В ПРОЦЕССАХ СБОРА И СЕПАРАЦИИ ГАЗА

Аннотация. В статье проанализирована работа опытно и опытно-промышленных эжекторных установок, указаны недостатки в их работе с двухфазными потоками. Объединение газовых потоков высокого и низкого давлений посредством стандартного штуцера приводит к значительным потерям энергии газа высокого давления. Также такое объединение потоков газа низкого и высокого давлений ограничивает отбор газа из скважин с низким устьевым давлением и совмещенный поток в этом случае имеет низкое значение давления, что делает невозможным его транспорт на большие расстояния. В связи с этим, для усовершенствования технологических процессов предлагается вихревой и сепарационный эжектор.

Описаны его конструкция и принцип работы. Предлагаемый эжектор состоит из приемной камеры, камеры смешения с тангенциальным соплом для входа активного потока, диафрагмы, установленной между приемной и смесительной камерами для входа пассивного потока в камеры смещения, диффузора.

Были показаны возможности одновременного применения предложенного эжектора в процессах низкотемпературной сепарации газа и эжекции. Отмечены преимущества этого эжектора. Ввиду холода, создаваемого очень низкой температурой, в разработанной схеме предложена одновременная реализация вышеуказанных технологических процессов. Использование этого малогабаритного эжектора, вместо компрессорных установок на ограниченных участках морских платформ, кустов и эстакад является особенно целесообразным и выгодным.

Следует учесть также то, что в вихревых трубах сепарационная скорость газа значительно (в сотни раз) больше, чем в современных сепарационных аппаратах, что позволяет осуществить обработку большого количества газа в весьма малогабаритных вихревых трубах.

Учитывая ограниченность рабочих площадей эстакад и индивидуальных морских оснований, авторами предложена технологическая схема обработки газа с применением совместно трубного сепаратора и новой конструкции вихревой трубы, расположенных на дне моря.

Вихревой эжектор прост по конструкции и может быть изготовлен на заводе силами самих производителей из трубчатых элементов.

Ключевые слова: давление, температура, скорость потока, сопло, адиабатическое расширение, поток, энергия, вихревое течение.

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