Для збільшення ефективності видобутку нафти і газу газліфтним способом необхідне поліпшення роботи компресорних станцій, а саме підвищення надійності встановлених в них газомоторних поршневих компресорних агрегатів. Встановлено, що одними з уразливих вузлів, що впливають на надійність та ефективність газомоторного поршневого компресора, є прямоточні самодіючі клапани.

У процесі підготовки газу до транспортування, а також для забезпечення надійності та ефективності всього виробничого процесу, потрібно виключити усі можливі витоки газу, не допустити потрапляння рідких вуглеводневих компонентів і твердих механічних домішок на пластини клапанів.

Для вирішення цієї задачі необхідно очистити попутний нафтовий газ від твердих механічних домішок, важких вуглеводневих компонентів і вологи. З цією метою рекомендується встановити на всмоктувальній лінії газомоторних поршневих компресорів додатковий горизонтальний газовий сепаратор нової конструкції.

Корисність і важливість газового сепаратора нової конструкції полягає в тому, що він ефективніше очищує попутний нафтовий газ, що надходить на всмоктування компресорних циліндрів 1-го ступеня, що призводить до поліпшення техніко-економічних показників роботи компресора, максимально знижуючи порушення герметичності пластин клапанів.

Сепаратор нової конструкції служить для очищення газу від крупної та дрібнозернистої крапельної рідини, частково рідини, що знаходиться у парофазному стані і твердих механічних частинок. Сепаратор нової конструкції також може знайти застосування в різних галузях нафтогазовидобувної промисловості.

Мета установки газового сепаратора нової конструкції – підвищення ефективності очищення газу від рідких і твердих домішок

Ключові слова: сепаратор, пластини клапана, герметичність, нафта, газ, газліфт, газомоторний поршневий компресор

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EVALUATION OF GAS SEPARATOR EFFECT ON OPERABILITY OF GAS-MOTOR PISTON COMPRESSOR VALVES

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1. Introduction

Efficiency and safety of gas-lift operation of oil and gas producing wells are largely determined by the reliability of individual components and parts of compressor equipment. In particular, defects arising in the valve units of these units lead to energy losses and complete equipment failure.

The majority of studies on the strength of self-acting valves note that valve plate failures are mainly caused by high-frequency dynamic stresses occurring from the impact of the plates on the seat and the guard [1, 2].

The efficiency of compressor units working in the system of gas-lift operation of oil and gas producing wells depends on performance indicators, safety and tightness of their individual units.

Thus, technical defects and energy losses in valves make up almost 10–12 % of compressor power consumption. The number of failures due to valves is 40–50 % of the total number of failures of the compressor unit [3, 4].

In this regard, the problem of increasing the reliability, tightness and safety of the direct-flow compressor valves during gas-lift operation of oil and gas producing wells is of great technical and economic importance.

2. Literature review and problem statement

In [5], a separator for cleaning gas from impurities is considered, having inlet and outlet pipes, a cloth arranged in the case with centrifugal elements fixed on it including separating chambers. The separator case is made horizontal. The cavity formed by the inner surface of the case, the cloth and the separating chambers is divided into sections by partitions mounted on the cloth and installed between the rows of centrifugal elements. The length of each section exceeds the length of the separating chamber of the centrifugal element. The partition is inclined to the horizontal plane of the separator.

The disadvantage of the above separator for cleaning gas from impurities is the complexity of the interior structure. In field conditions, in the system of gas production, collection, preparation and transportation to the consumer, the main process parameters of gas are frequently changed. The abundant content of liquid hydrocarbon components and solids therefore significantly reduces the efficiency of such separators.

In [6], the most similar device for gas cleaning from liquid and solid impurities is developed. The device has a horizontal body, inlet pipe and coaxial gas outlet pipe with openings on the side surface. The end face of the outlet pipe is plugged by vertical sheet steel. It is fixed to the body with rigid ribs, and the other end is connected to the body with the possibility of axial movement.

The disadvantage of this gas cleaning device is the inability to create turbulence (vortex motion) of the gas stream. In this case, there is no impact of dropping liquids and solids, which results in incomplete gas cleaning. Thus, the efficiency of the devices is reduced.

In [7], the method for diagnosing compressor piston valve failures using acoustic emission signal in combination with simulated valve motion is considered. The actual operating condition of the valve can be obtained by analyzing the acoustic emission signal in the crank angle region, and valve motion can be predicted by simulation. The exact opening and closing points of a normal valve provided by simulated valve motion can be used as reference for diagnosing valve malfunctions.

In [8], the numerical study of the effect of natural gas compositions on piston compressor performance is considered. The numerical model is built on the basis of the first law of thermodynamics. The model can predict compressor parameters (pressure, temperature, mass flow rate, mass and movement of valves) at different crank angles and cylinder volumes. For verification, the numerical results are compared with previous experimental values to assess their consistency, and good agreement is achieved. The effect of basic parameters, such as clearance, angular velocity and molecular weight of natural gas, on compressor performance is investigated. The results show that for higher molecular weight natural gas, the opening time of the suction valve is shorter than for lower molecular weight natural gas.

In [9], various layouts of compressors and compressor stations are considered, as well as a detailed description of various analyses that can be performed to design new systems of compressor stations and assessment of existing problems are given. The description of each analysis includes a reference to the relevant standard or directive, which specifies the parameters determining the suitability of the project for operation.

It is studied in [10, 11] that piston compressors are critical components in the oil and gas sector, although their operating costs are known to be rather high. Compressor valves are the weakest components, being the most frequent type of failure, and they account for nearly half of maintenance costs. One of the major challenges in the industry is minimizing downtime and costs while maximizing availability. The safety of piston compressors, as well as their maintenance, is considered a key aspect in achieving this goal. The concept of maintenance and forecasting based on diagnostic principles is a step in this direction.

In [12], fluid motion in an oil and gas separator is studied by numerical simulation. To solve the model, the RSM turbulence model and the finite volume method are used. The iterative velocity field solution uses a simple algorithm. An analysis of the internal velocity field, pressure field, and flow line in the oil and gas separator reveals the separator flow mechanism, providing a theoretical basis for the optimization and design of new separators in the future.

Thus, it is determined that the failure-free operation of compressor units largely depends on the operability and reliability of valve units. Piston compressor valves are found to be the most vulnerable and frequently failing units, whose failures lead to compressor shutdown.

Therefore, one of the main directions of increasing the compressor efficiency is to minimize compressor equipment downtime and, accordingly, maintenance costs. It should be borne in mind that under field conditions, the process parameters of oil gas in the oil production system are frequently changed. Changes in the content of various solid and liquid impurities in oil gas significantly affect the efficiency of separators and degree of gas purification. Insufficient oil gas cleaning from impurities significantly affects the operability of valve units and, accordingly, the entire compressor unit.

It follows that special attention should be paid to the quality of oil gas supplied to compressors, for which it is necessary to ensure a high degree of purification using an advanced separation system.

3. The aim and objectives of the study

The aim of the study is to increase the efficiency of piston compressor valves operating in the gas-lift system for pressurizing low-pressure associated petroleum gas.

To achieve the aim, the following objectives were set:

– to study the main causes of piston compressor valve failures;

– to develop a new design of gas cleaning separator.

4. Study of the main causes of piston compressor valve failures

As the operating experience of compressors shows, the gas flow at the inlet and outlet of piston compressors differs not only in volume, pressure and temperature due to compression of the injected gas, but also in mass. The latter is explained by:

a) incomplete cleaning and drying of pressurized associated petroleum gas;

b) fall-out of various liquids and solids from the 1st stage compressor cylinder entering the suction cavity;

c) leakage of the valves of the 1st stage compressor cylinder.

To investigate the causes of failures of gas-motor piston compressors, an analysis was made of failures of some parts and units of gas-motor piston compressors installed at the gas-lift compressor station of the Narimanov oil and gas production department in Baku, Republic of Azerbaijan (Table 1).

Table 1

Analysis of failures of parts and units of gas-motor piston compressors

Name of parts and units	Number of failures within six months at the gas-lift compressor station 4 of the Narimanov oil and gas production department			
	GMC–1	GMC–2	GMC–3	GMC–4
Compressor cylinder valves	75	71	79	82
GMC plug	51	64	70	72
Tristor ignition system	17	18	16	17
GMC flowline check valve	3	2	4	1
GMC gas outlet valve	5	6	4	7
Flowline safety valves	1	0	0	2
Other failures associated with GMC shutdown	10	7	4	5

Out of 10 gas-motor piston compressors at one gas-lift compressor station, the table lists the failures of parts and units of 4 gas-motor piston compressors. It should also be noted that Table 1 shows those elements whose failures lead to large compressor downtime. Within six months, each gas-motor piston compressor was found to be on average 3,665 hours in operation, 550 hours in downtime, 795 hours in repair (or in reserve).

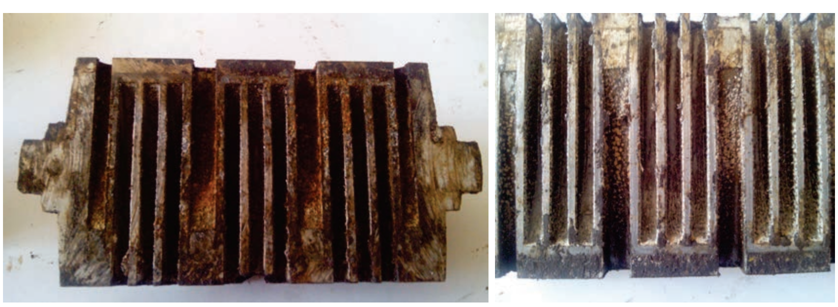
Thus, it is found that the main causes of piston compressor failures are the intake and pressure valve unit of compressor cylinders (46–54 %), plugs (30–50 %), violations related to the ignition system (10–11 %), etc.

The above data indicate the need to increase the failure-free operation of gas-motor piston compressors, where the main cause of failures are problems with valves (direct-flow).

An analysis was also made of the condition of failed parts that worked under different conditions at the intake and discharge. The analysis of the results showed that in 67 cases, failures relate to suction valves, 148 to the 1st stage pressure valves. In 95 cases, failures relate to pressure valves and 43 to the 2nd stage suction valves.

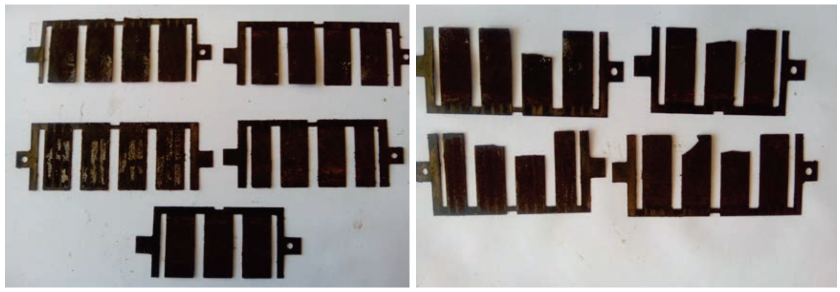
As can be seen, the largest number of failures falls on the valves of the 1st stage compressor cylinders, where the temperature of the injected gas is much higher in comparison with others. Consequently, temperature has a significant effect on the number of failures of direct-flow valves, which are mainly resulted from the destruction of their plates. After the failure of one or more plates, the valve begins to heat up, as well as the suction and pressure pipes. In this operating mode, the temperature of the valve and cylinder in the valve zone quickly reaches 180–200 °C. This temperature leads to valve seat warping, leakage, temperature rise, failure of other compressor cylinder, especially 1st stage, parts.

At the same time, it is found that, in addition to the cyclic dynamic load at the intake and discharge of the piston compressor, valve operability is significantly affected by the quality of associated petroleum gas containing both solids and vapors of heavy hydrocarbon components and moisture. The amount of the latter reaches 20...40 %, sometimes 60...80 % [13]. The aforementioned leads to additional local bending stresses, adhesion of the plates to the seat, breakdown, and on the seats – various damages to gas-motor piston compressors (Fig. 1). In most cases, the plates break along the line of their pinching in the valve or at the seat edge (Fig. 2).



a *b*

Fig. 1. Direct-flow valve seat:
a — subjected to corrosion; *b* — subjected to deposition of various minerals



a *b*

Fig. 2. Direct-flow valve plates:
a — subjected to corrosion; *b* — subjected to breakage and wear

Thus, to protect the equipment from premature wear and technical defects, associated petroleum gas sucked into the 1st stage compressor cylinder must be cleaned from solid inclusions and dried from liquid hydrocarbon components. It follows that for the safe operation of gas-motor piston compressors, the supply of associated petroleum gas to the 1st stage compressor cylinders without cleaning and drying is not recommended, which plays a decisive role in maintaining performance [14].

5. Development of a new design of gas cleaning separator

In existing gas-lift compressor stations, associated petroleum gas with a pressure of 0.38÷0.45 MPa passes through head separators installed at gas-lift compressor stations before being admitted to the 1st stage compressor cylinder.

Based on the practical studies on the nature of the gas-lift system and operation of gas-lift compressor stations in this system, a new design of gas separator for cleaning associated petroleum gas was developed, for which the Patent of the Republic of Azerbaijan was obtained [15]. The novelty of this model is that the end face of the outlet pipe is hemispherical.

It is proposed to install a new design gas compressor on the intake line of the gas-motor piston compressor, which is a novelty for the development of the installation diagram of gas-motor piston compressors at the gas-lift compressor station.

The device operates as follows (Fig. 3).

Gas flow enters the case 1 through the inlet pipe 2 and hits the plugged hemispherical end 6. This creates increased turbulence with the formation of strong vortex motion of the gas flow at the wall inside the case 1. This is accompanied by the occurrence of centrifugal force contributing to the impact of coarse and fine-grained liquid drops and partially liquid in the vapor-phase state, as well as solids, on the inner wall of the case 1. The impurities fall to the bottom and from there are periodically discharged through the outlet pipe 9.

After that, the substantially purified gas stream enters through the hole 5 to the gas outlet pipe 3 and from there it is sent for pressurizing. Practice shows that during the long-term process of production, collection, preparation and transportation of natural or associated petroleum gas, pressure and other parameters of the gas decrease. Therefore, at all process stages, the normal operation of the separator is maintained by changing the distance between the inlet and hemispherical end 6 by rotation using the threaded connection 7 and 8. The gas outlet pipe 3 is installed so that the holes 5 are always directed upwards.

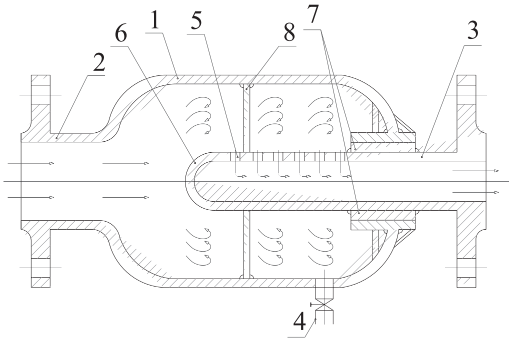


Fig. 3. Device for gas cleaning from liquid and solid impurities

6. Comparative experimental results

Studies were carried out to assess the gas quality (the content of solids, vapors of heavy hydrocarbon components and moisture in the associated petroleum gas) both on the head separator and after leaving the proposed device.

The experiments were carried out according to the RD 153-34.1-11.320-00 requirements. For associated petroleum gas samples, metal samplers were used in accordance with the requirements of GOST 31370.

The research results are given in Table 2.

Table 2

Solids and moisture content in the gas

Experiment No.	Solids content, g/m^3		Moisture content, %	
	At the outlet of the head separator	At the outlet of the proposed separator	At the outlet of the head separator	At the outlet of the proposed separator
1	0.0020	0.0011	1.56	0.98
2	0.0018	0.0009	1.88	0.97
3	0.0019	0.0014	1.71	0.99
4	0.0021	0.0015	1.65	0.97
5	0.0020	0.0012	1.55	0.95

It was found that the dimensions of solids at the outlet of the head separator vary within 20–40 μm, and at the outlet of the proposed separator are within 8–12 μm. The content of coarse-grained dropping liquids on the new separator does not exceed 1.0 %, whereas in the gas taken at the outlet of the head separator – 1.5–1.88 %.

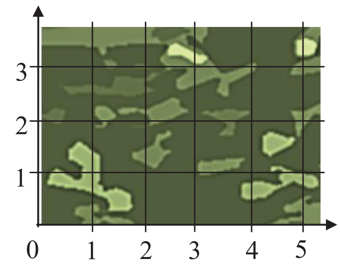
Fig. 4 shows the solids content in the gas when sampled on the head separator and after leaving the proposed new separator. A comparative analysis of the results of a 500-fold increase in the solids content in the associated petroleum gas showed that their quantity and dimensions correspond to the proposed design of the new separator.

Tests to determine the process parameters of the new separator directly at 4 gas-lift compressor stations operating in the system of gas-lift operation of oil wells included the following practically measured values:

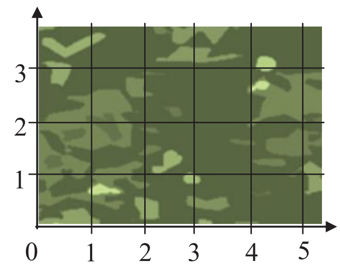
– thermodynamic parameters of associated petroleum gas pressurized in gas-motor piston compressors;

– gas flow rate at the 1st stage of the compressor cylinder of the gas-motor piston compressor;

– power characteristics of the gas-motor piston compressor.



a



b

Fig. 4. Solids content in the gas (×500): *a* — gas sampled from the head separator; *b* — gas sampled after leaving the proposed separator

Practical works carried out in field conditions directly at the operating gas-lift compressor stations allowed studying certain properties of compressor cylinder valves. The effect of the physicochemical properties of associated petroleum gas on the safety and efficiency of the 1st stage compressor cylinder was revealed.

After a comprehensive approach to the problem of tightness of piston compressor valves and installing a new separator on the suction line of the gas-motor piston compressor, the annual compressor overhaul life increased by more than 360 hours. Compressor output increased by 5.9 thousand m^3/day, which, taking into account the decrease in fuel gas consumption, increases the productivity of the gas-lift compressor station equipped with 10 compressors by 8÷10 %.

7. Discussion of the results of increasing the efficiency of oil and gas piston compressor valves

The analysis of compressor failures showed that the main cause is problems with the valve units. Most failures fall on plate pressure valves. Failures are mainly caused by the supply of poorly cleaned petroleum gas, containing large amounts of rock particles and other impurities, heavy hydrocarbon vapors and moisture in the first compressor cylinder. This leads to adhesion of the valve plates to the seat, bending, and ultimately plate breakage and valve failure.

To prevent failures of valve units, the oil gas entering the compressor should be more thoroughly cleaned from solids and other impurities.

A number of works have been devoted to solving the problem of associated petroleum gas purification and patents for new separator designs have been issued [1, 4–6, 13, 14].

Unlike the existing and patented [5, 6] designs, the developed separator has a perforated outlet pipe with a hemispherical end face, upon impact with which the gas entering the separator receives vortex motion (turbulence), which leads to intense gas cleaning from solid inclusions and other impurities.

The proposed design provides for changing the distance from the inlet to the spherical end of the outlet pipe, which allows expanding the scope of the separator depending on the operating conditions of oil and gas producing wells.

Separator designs that are similar to the patented design do not possess such qualities.

As a result, compressors are supplied with poorly cleaned petroleum gas, resulting in premature failure of the oilfield piston compressor valves.

It is necessary to conduct additional full-scale studies of operability of the proposed separator under different operating conditions to objectively determine its efficiency and identify possible design flaws.

8. Conclusions

1. One of the effective and rational methods for increasing the performance of piston compressors is to improve the tightness of the valve plate of the 1st stage compressor cylinders. To ensure the economic efficiency of continuous and safe operation, it is necessary to eliminate gas leakage in the valve plates. Liquid hydrocarbon components and solids must not be allowed to enter the valve plate. Only in this way, it is practically possible to maintain the GMC operating parameters at the level recorded in the manufacturer's data sheet and thereby fulfill its main purpose.

2. Installing a new gas separator, increasing the pressure of the cleaned associated petroleum gas coming to the suction of the 1st stage compressor cylinders improve the performance of the piston compressor. In particular, valve plate leakage is minimized. The original technical solutions used in the proposed separator, leading to the creation of turbulence in the incoming gas flow, provide a more complete gas cleaning from impurities in comparison with similar designs. This makes it more advanced and efficient when operating at oilfield compressor stations.

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