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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

IMPROVING THE EFFICIENCY OF SAFE OPERATION OF PISTON COMPRESSOR VALVES IN THE GASLIFT SYSTEM

Specialty: 3313.02 - Machines, equipment and processes

Field of science: Technical

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GENERAL DESCRIPTION OF WORK

The relevance of the work. The intensive development of the oil and gas production industry in Azerbaijan requires ensuring the efficiency of the technological processes of oil and gas production, improving the systems for their development and operation, as well as providing this industry with reliable and safe equipment.

At the present stage of oil development in the Azerbaijan sector of the Caspian Sea, especially the gas-lift operation of offshore oil and gas wells, occupies an important place and has a broad perspective.

The efficiency and safety of gas-lift operation is largely determined by the reliability of individual units and parts of compressor equipment. In particular, defects associated with the valve assembly lead to energy losses and complete equipment failure.

Fundamental researches in the area of increasing reliability and durability of compressors are described in the works of A.A. Dollezhal, A.A. Lomakin, S.E. Zakharenko, M.I. Frenkel, V.F. Ris, K.I. Strakhovich, T. F. Kondratyev, B. M. Repin, A. M. Lyulka, B. S. Fotin, I. B. Pirumov, I. K. Prilutsky, S. A. Anisimov, P.I. Plastinin, V.I. Aliyev and others.

Based on the results of these studies, generally accepted methods have been created for calculating and designing compressor units. However, the assessment of the performance of the compressor cylinders and their assemblies in the conditions of compression and transportation of associated and oil gas have not been studied.

The dissertation is dedicated to improve the efficiency of the safe operation of piston compressor valves, working in the gas lift system to compress low-pressure associated petroleum gas, and therefore it is relevant.

The goal of the dissertation work: to study the dynamics of the movement of the plate of a straight-flow valve in a stationary gas flow, development of the calculation method of the diagram of its movement, formation of the quantitative relationship between the tightness of the valve and the technical and economic parameters of

the compressor and the development of criteria for the effective operation of valves in the conditions of a cyclic dynamic loads, frequent changes in the pressure of associated petroleum gas.

The main objectives of the research. In the dissertation work, the following tasks have been set and solved to achieve the above goal:

-analysis of the use of technological conditions for the operation of gas-lift wells and the mode of gas-engine reciprocating compressors (GEC);

-study of the main causes of failure of valves of reciprocating compressors;

-development of an algorithm for calculating the motion dynamics of the plates of a straight-flow valve in a GEC with frequently changing pressure of associated petroleum gas, taking into account the pressure force of the gas flow, its velocity, the elastic force of the plate and its mass;

-determination of the plates vibration modes, identification of the breakdowns causes and development of recommendations on the effective and safe operation of straight-flow valves.

-study of the influence of the operation of various straight-flow valves designs on the efficiency indicators of the GEC under the variable operating modes.

-development of methods for checking, blowing and cleaning the valves;

-development of a gas purification separator installation scheme on the suction line of each GEC, after which the finally purified gas enters the suction cavity.

Methods for solving problems. To solve the set tasks, the methods of mathematical statistics and the theory of probability, the theory of reliability and mass maintenance of complex field systems in a gas-lift compressor station (GCS) are used with the widespread applying the possibilities of computer technologies, visual and experimental studies with the appropriate apparatus and devices with full-scale samples.

The reliability of the results obtained is ensured by the mathematical correctness of the set tasks posed by strict analytical methods using certain practical technological parameters, the results of numerical calculations, as well as the non-contradiction of the obtained results with the results of the known studies in the literature.

Scientific novelty:

-on the basis of the results of practical study of technological parameters of the gas-lift system for oil wells and GCS operation the method has been developed for blowing straight-flow valves with the determination of plate lift in conditions of frequent changes in the pressure of the associated petroleum gas flow;

-equations of the motion of the straight-flow valve plate have been derived, taking into account the frequent changes in the pressure of the compressed associated petroleum gas;

-it has been found that among existing valve plate designs, ПИК-АМ valves are more hermetic and their use is more efficient and safer.

-taking into account the identified requirements to the gas lift system, it is recommended to purge the valves on a special installation available at the GCS to determine the tightness of the valves for the effective impact of the operating hours of valves with increased tightness of the valves with increased tightness of operation and prevention of a dangerous situation.

The practical value of the work. On the basis of practical studies of the nature of the gas lift system and work in this GCS system, a Patent of the Republic of Azerbaijan was obtained for a gas separator cleaning the associated petroleum gas before it enters the suction cavity of the compressor cylinder of the 1st stage, which allows to clean gas and decrease the tightness and valve performance.

Practical tests carried out on the operation of straight-flow valves and their effect on the tightness of the plate with purified associated petroleum gas in the gas separator installed on the suction line confirmed the increase in the efficiency of the valves and, in general, the GEC mounted in the GCS. After installing gas separators

on the suction line and checking the valves at the blowdown unit, the operational indicators increased, the efficiency and safety of the GEC valves in the gas lift system raised.

THE MAIN PROVISIONS ON DISSERTATION FOR THE DEFENSE

1. Results of detailed studies and analysis of existing operating modes of the gas-lift system and the main technological parameters of gas-lift and operation of the GCS in this system, including the GEC.

2. Methods for calculating the plate movement of straight-flow valves of the GEC taking into account the frequent changes in the pressure of the compressed associated petroleum gas.

3. Results of practical tests on the tightness of the valve plate on a special installation for determining the quality criteria.

4. The results of the study of the valve operation by blowing on a special stand, allowing widespread introduction of the ПИК-АМ type valve.

5. Developed recommendations on the tightness criteria of the design of the plate tongue and the operating hours for ПИК-АМ type valves.

Approbation of the work. The main provisions and results of the thesis have been presented and approved:

• at the XII Scientific and Practical Conference "Scientific Perspectives of the XXI Century"; “Achievements and Prospects of the New Century”, Novosibirsk (2015);

• at the X International Scientific and Practical Conference "Actual Issues of Science, Technology and Production", St. Petersburg (2015);

• at the Scientific and Practical Conference "Khazarneft-gazyatag-2016", Baku (2016);

• at the IX International Scientific and Practical Conference "Actual Problems of the XXI Century", Moscow (2016);

• at the XIII International Scientific and Practical Conference "European Research", Penza (2017);

• at the XXXII International Scientific and Practical Conference, Scientific journal Archivarius, "Science in the modern world", Kiev (2018);

• at the XXVI International Scientific and Practical Conference "Scientific journal" Chronos "; Problems of modern science, trends and prospects ", Moscow (2018),

• at the XLIX international scientific and practical conference "World science: problems and innovations" Penza (2020).

Publications. 24 publications on the thesis have been published, including 16 articles, 8 reports in the materials of various republican and international scientific-technical and scientific-practical conferences, 1 Patent of the Republic of Azerbaijan.

Place of dissertation. The work was performed at the Research Institute "Geotechnological Problems of Oil, Gas and Chemistry" at the Azerbaijan State Oil and Industry University.

Author's personal participation. The purpose and direction of the research, the implementation of experiments, and the analysis of the results were carried out with the participation of the author

Structure and scope of work. The dissertation work consists of an introduction, four chapters, conclusions and recommendations, a list of used references, including 159 titles and applications.

The work is presented on 170 pages of typewritten text, including 9 pages of applications. It contains 23 figures and 4 tables.

THE MAIN CONTENT OF THE WORK

In the introduction the relevance of the dissertation has been substantiated, the goal and objectives of the research have been formulated, practical value and implementation of the work in practice have been shown.

In the first chapter the features of the operation of oil and gas field reciprocating compressors in the gas-lift system operation of oil

wells are discussed in detail, where favorable operating conditions and technological modes of reciprocating compressors operating are set out, design features of the valves used, as well as the main reasons for their failures are outlined. The main results of this chapter were published [4, 15, 17, 18, 22, 23, 24] by the author.

At present, piston engines 10ГКНАМ2/5-55, 10ГКНАМ3/5-100 and 10ГКНАМ2/55-125 with a capacity of 259.2 thousand m^3/day, 192.2 thousand m^3/day and 400 thousand m^3/day and centrifugal with gas turbine drives (company "Solor" USA) compressors respectively, are used in gas-lift practice and in the transportation of associated petroleum gas from offshore fields to onshore facilities.

It has been noted that the causes of the failure of reciprocating compressors are: the assembly of the intake and discharge valves of the compressor cylinders (46-54%), spark plugs (30-50%), irregularities associated with the ignition system (10-11%), etc.

More than 250 units of different modifications of reciprocating compressors are operated in the SOCAR system, however, two of them are the main ones: operating with ring and direct-flow valves It has been found out the most progressive type of valves used in the design of reciprocating compressors are straight flow self-regulating valves.

The largest number of failures are associated with straight-flow valves installed on the compressor cylinders of the 1st stage.

Analysis of the results of observations of the operation of the intake and discharge valves operation in the compressor shops, at the 1st stage of the GEC showed that in 67 cases the failures refer to the suction valves and 148 – to discharge valves of the 1st stage, and 95 – to discharge and 43 – to the suction valves of the 2nd stage.

It has been shown that the main factor determining the insufficient operating of self-acting valves is the cyclic dynamic loads at the intake and discharge of a reciprocating compressor associated with a frequent change in the gas pressure in the gas lift, which is accompanied by vibrations of the valve plates.

Based on these, the main directions of research have been formulated.

The second chapter is devoted to the analysis of the theoretical prerequisites for ensuring the tightness of self-acting valves of reciprocating compressors and the derivation of the equation of the plates motion, as well as the features of their safe operation. The main results of this chapter were published [1, 3, 9, 13, 20] by the author.

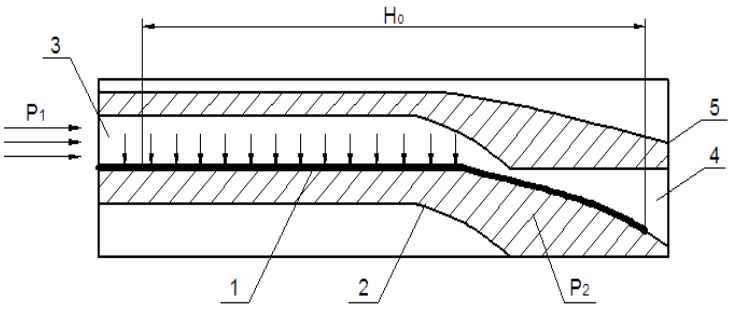
After studying the practical work of compressor units, the issues related to the technology of oil and gas production by the gas lift method have been considered and the following tasks have been set:

- to analyze the practical technological performance of the GMC and the GCS in general, as well as the field gas pipeline for the simultaneous transportation of compressed associated petroleum gas to the gas lift system and if necessary, partially to the consumer;
- to study and analyze the mode of operation of low and high pressure field gas transport systems, characterizing their work in conditions of frequently changing technological parameters of associated low pressure petroleum gas to be compressed;
- to show the real technical and technological state of the GMC during operation in gas lift and gas transport systems with frequently changing technological parameters;
- to analyze the features of the repair work of GMC (its nodes and parts) in the field conditions directly at the GCS.

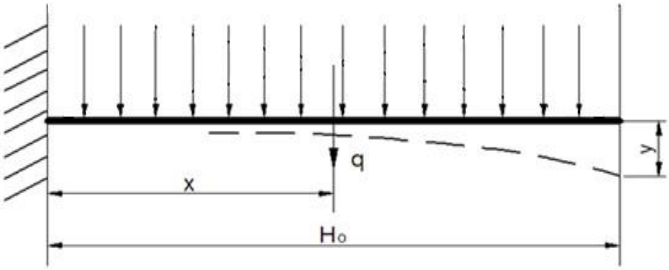
Fig.1 shows the elements and calculation scheme of the valve plate.

During valve operation (when the valve is partially open), the elastic force of the plates and the pressure of the gas flow are influenced by two opposite forces: the elasticity of the plate (for a direct-flow valve) closing the valve, and the pressure force of the gas flow tending to open it. In static equilibrium, both of these forces are equal. In a fully open valve, the pressure force of the gas flow is counteracted by the elastic force of the plate and the response of the lift limiter against which the plate is pressed (Fig. 1).

On the basis of theoretical studies, the equation of motion of the plate end of a self-acting straight-flow valve has been obtained.



a)



b)

Fig. 1. Elements (a) and design scheme (b) of the valve plate: 1- plate; 2-lift limiter; 3-holes at the entrance; 4-holes at gas outlet; 5-seat.

$$h = \frac{A\cos 2\omega(t+t_p)}{0{,}76m(4\omega^2-\upsilon^2)} - \frac{A\omega\sin 2\omega t_p}{0{,}38m(4\omega^2-\upsilon^2)\upsilon}\sin\upsilon t - \frac{A\cos 2\omega t_p}{0{,}76m(4\omega^2-\upsilon^2)}\cos\upsilon t$$

This equation allows to build continuous curves of opening and closing the valve, to calculate the main parameters of the valve and the diagram of movement that characterize its operation.

To protect the equipment from premature wear and the formation of a technical defect, the associated petroleum gas sucked into the compressor cylinder of the 1st stage of the GEC must be cleaned of solid inclusions (dust, sand, scale, corrosion products) and dried from liquid hydrocarbon components.

The technical condition of the GMC must meet the requirements of the rules for the design and their safety during operation, approved by the Ministry of Emergency Situations of the Republic of Azerbaijan. All failures are accompanied by a step-by-step decrease in all intermediate pressures and an increase in the discharge temperature, followed by the occurrence of fire hazardous situations.

For this purpose, the installing an additional horizontal gas separator of a new design on the suction line is recommended (Fig. 2).

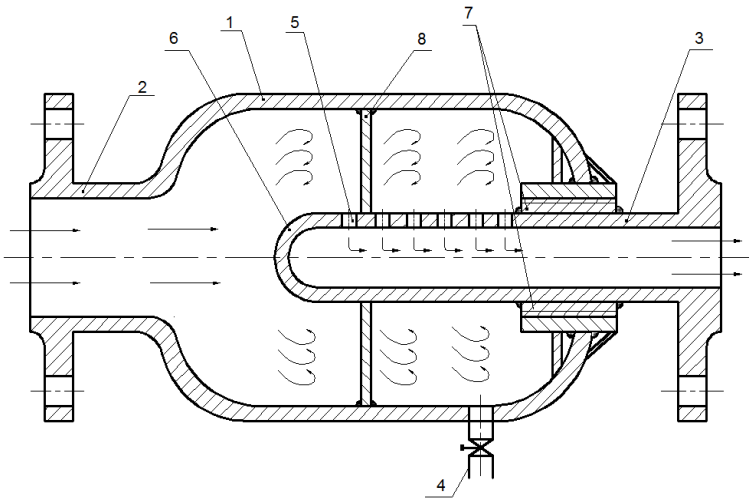


Fig. 2. Device for gas cleaning from liquid and solid impurities: 1-case; 2-inlet pipe; 3- outlet pipe; 4-drain pipe; 5 holes; 6-spherical end; 7-threaded connection; 8-wall.

In the separator, additional cleaning from solid inclusions takes place, and the partially entraining gas flow is dried from medium and fine-grained droplet hydrocarbon liquid.

The patent of the Republic of Azerbaijan was obtained for this design of the separator.

The principle of operation of the separator is as follows. The gas flow enters the body of the separator 1 through the inlet pipe 2 and strikes into the muffled hemispherical end 6 of the outlet pipe 3, thereby creating increased turbulence with the formation of a strong vortex motion of the gas flow near the wall inside the body 1, accompanied by the emergence of centrifugal force conducive to impacts of medium and fine-grained liquid droplets and partly liquid in a vapor-phase state, as well as solid mechanical impurities, on the inner wall of the housing 1 and falling out to the bottom, from where they are periodically discharged through the drain pipe 4 to the outside. After that, a significantly purified gas flow enters through hole 5 into outlet pipe 3, and from there is directed to the suction cavity of the compressor cylinder of the first stage for further compression. Practice shows that during long-term operation there is a decrease in pressure and other technological parameters of gas. Therefore, at all stages of the technological process, the maintenance of the normal operation of the separator is carried out by changing the distance between the inlet pipe 2 and the hemispherical end 6 of the outlet pipe 3, by rotating with the threaded connection 7 installed on the outlet pipe 3. The gas outlet pipe 3 is always installed so that the holes 5 are oriented upwards. The process flow diagram of the piping of the GEC at the gas lift compressor station is shown in Fig. 3.

At the gas lift compressor station, associated petroleum gas from the common station suction header (with a pressure of 0.38 ÷ 0.45 MPa) enters the gas separator 5. After additional cleaning and drying, the associated petroleum gas enters the suction cavity of the compressor cylinder of the first stage 3, for further squeeze.

It has been found that the sizes of mechanical impurities at the outlet of the head separator vary in the range of 40 μm, and at the outlet

of the proposed design of the separator - in the range of 15–18 μm. The content of coarse-grained droplet liquids in the new separator does not exceed 1.0%, while in the composition of the gas taken at the outlet of the head separator it is 1.5-1.88%.

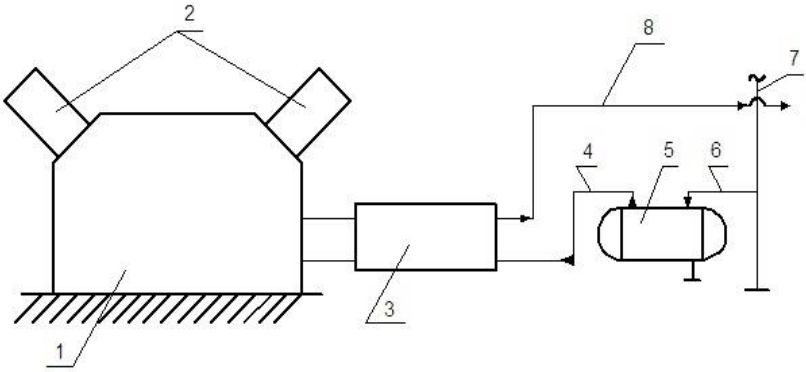


Fig.3 Technological diagram of the piping of the GEC at the gas-lift compressor station:
1-frame of GEC; 2-power cylinders; 3-compressor cylinder of the 1st stage; 4-suction pipe; 5-separator; 6-pipe for supplying associated petroleum gas to the separator for final gas purification; 7-common station suction manifold; 8-discharge line of the 1st stage compressor cylinder.

Experimental evaluation of the efficiency and tightness of the valves of reciprocating compressors is one of the mandatory stages in the process of checking, preparing and improving the tightness, hence the efficiency and safety of operation of the valves of the compressor unit.

The third chapter is devoted to the discussion of the results of experimental researches on the study of valve tightness and increasing their efficiency during operation. The main results of this chapter were published [2, 7, 10, 11, 12, 21] by the author.

The study of the valves directly on the gas compressor station has been carried out in a purge chamber connected to the compressed air pipeline diagram in order to determine their static characteristics.

A schematic of the stand for static blowing of valves is shown in Fig. 4.

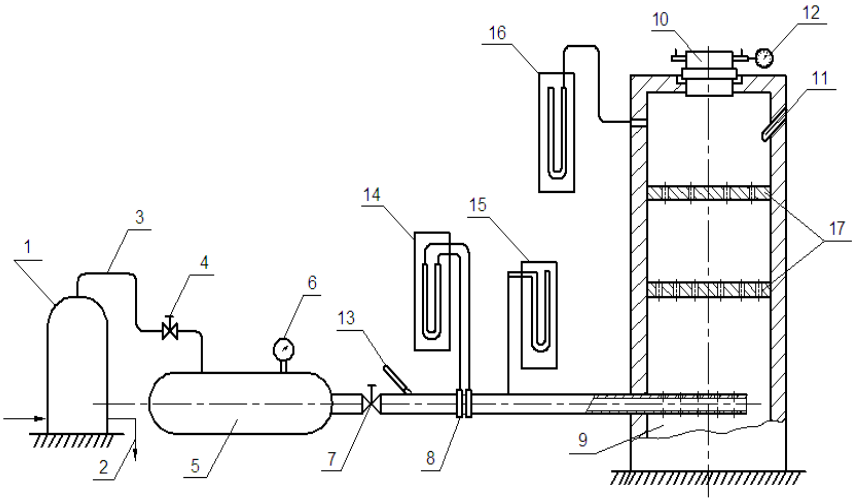


Fig. 4 Schematic of the stand for static blowdown of valves

A schematic of the stand for static blowing of valves is shown in Fig. 4. As it can be seen from figure 4 air from the high-pressure air line enters the separator 1 and from there through the air line 3 and the valves 4 it enters the damping tank 5, where the exemplary pressure gauge 6 is installed and then enters the purge chamber 9 through the control valve 7, flow diaphragm 8. This chamber is a cylinder having two baffles 17 with holes. In the upper part of the chamber there is a socket for installing a valve 10, which is attached to the chamber with a clamping flange. When air is supplied to the purge chamber, the air pressure in the damping tank is measured with a sample manometer 6, the temperature in front of the diaphragm is measured with a mercury thermometer 13 and the pressure drop - by

V- shaped manometer 14, the pressure behind the diaphragm and in front of the valve, have also been measured by V- shaped manometers 15 and 16.

The air temperature in front of the valve is measured using a mercury thermometer 11. In the upper part of the valve, a hole with a 2 mm diameter has been drilled, into which a needle connected to the indicator of the clock mechanism 12, fixing the height of the valve plate lift with an accuracy of 0.01 mm has been inserted.

The parameter that determines the tightness and efficiency of the valve is the time of the pressure drop in the tank from 0.4 to 0.2 MPa. The maximum value of the valve tightness criterion was established at 35 s, at which gas leaks do not exceed 0.6%.

Fig.5 shows the experimental and theoretical curves of the plate motion.

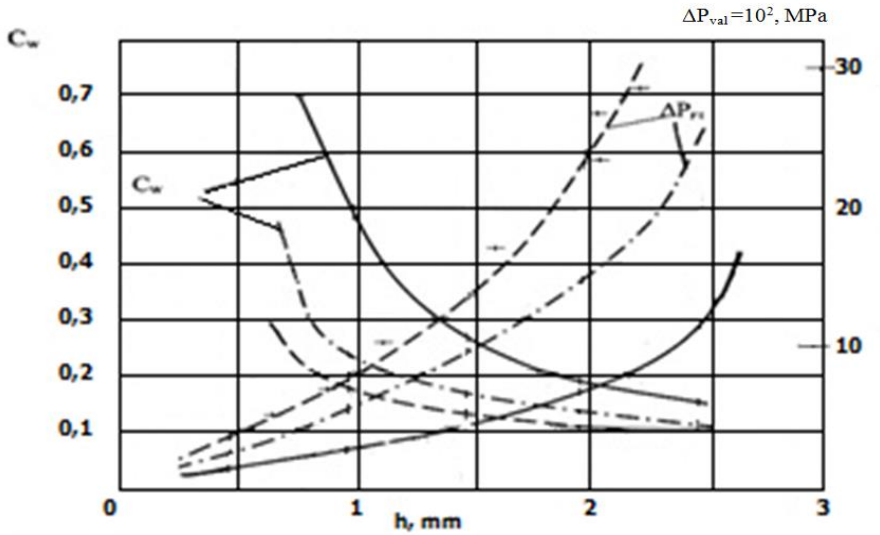


Fig. 5. Dependences of the gas flow pressure coefficient C_w and the pressure difference ΔP_{val} on the plate stroke h: with grooves __ 0 mm; _._ 1 mm; --- 2 mm.

In order to practically study the efficiency of the valves in the compressor cylinders, the dynamics of the movement of the straight-flow valve plates have been studied. As a result of a gas-dynamic study of the operation of the valves in a stationary gas flow, it has been found out that the preliminary bending of the plate (groove) significantly affects the operability of the valves: if the groove is zero, then the straight flow valve opens completely when the pressure difference across the valve $\Delta P_{по}$ is about 0.1 MPa. In the presence of a preliminary bending of the plate, the full opening of the valve occurs at a larger value $\Delta P_{по}$.

The experimental dependences of the gas flow pressure coefficient C_w and the pressure difference ΔP_{val} on the plate travel h are shown in figure 5. Due to them, it is possible to calculate the lift of the plates in the phase of opening or closing the valve.

The study of the movement diagram of the valve plates allows not only to determine the characteristic points of opening and closing of the valve, but also to analyze the dynamic processes in one complete phase of the valve operation at various degrees of pressure increase. (fig. 6).

The diagrams of movement of the valve plates indicate the initial elastic impact of the plate against the lift limiter, at which the plate changes the sign of the velocity and the upper edge of the plate vibrates. The processing of the motion diagram showed that the value of the plate velocity when it impacts the lift limiter increases with a raise in the compression ratio and reaches 2 m/c, and when landing on the seat – 0,5 m/c. The speed of the plate during its vibration in the phase of full opening of the valve does not exceed 0,3 m/c.

Experiments have shown quite good agreement with the calculated dependence of the change in the travel of the plate in the rotation angle of the compressor crankshaft. Vibrations of the valve plates are reflected in the pressure in the cylinder and in the suction and discharge pipes of the compressor in the form of high-frequency

oscillations superimposed on the main pressure change in the cavities and pipes of the compressor cylinder of the 1st stage

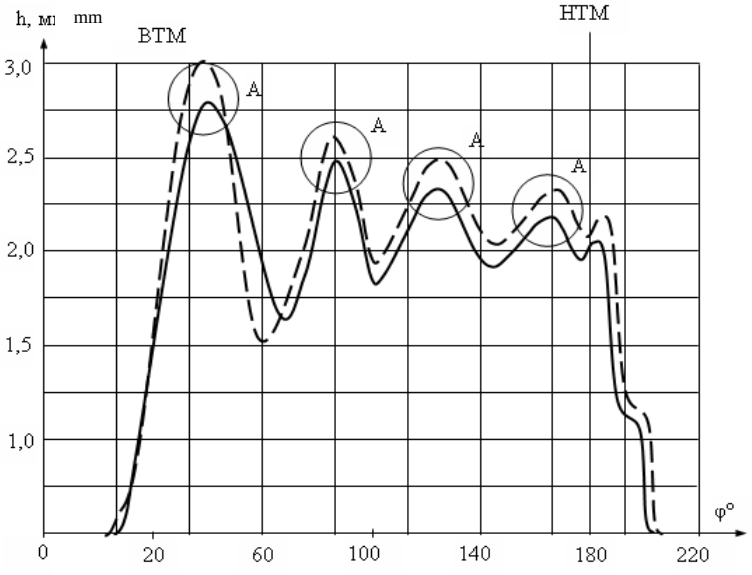


Fig. 6. Diagrams of movement of the plate of the suction straight-flow valve of the compressor cylinder of the 1st stage -- calculated; ___experimental

Based on the results of comparing the experimental and theoretical curves, the following conclusion can be drawn: a good coincidence of the theoretical dependences with experimental data has been achieved, which confirms the correctness of the derived equation of the straight-flow valve plate motion.

The fourth chapter contains the results of field tests, as well as comparative data on the technical and economic efficiency of using the valves of piston compressors. The main results of this chapter were published [5, 6, 8, 14, 16] by the author.

Periodic monitoring of the technical condition of the valves made it possible to determine the causes of valve failures of all types.

Comparative performance characteristics of the investigated valves and specific data obtained as a result of long-term field tests during the operation of the GEC in the gas lift system are shown in Table 1.

Table 1

Comparative performance characteristics of the investigated valves

№ n/n	**Indicator name**	Valve type		
		ПИК	ПИК-А	ПИК-АМ
1	Average operating time of the valve per year, hours	700	3120	6980
2	Downtime for a shift due to leakage of valve plates, per year, hours	678	317	246
3	Compressor unit operation factor	0,842	0,891	0,918
4	Compressor capacity, thousand m^3 per day	164,8	170,7	177,6
5	Operating temperature of compressor cylinders, ºC for discharge: I stage II stage III stage	 195 163 112	 180 147 107	 136 115 95
6	Measured fuel gas consumption per one GEC; m^3/day	9879	9854	9783

As a result of the analysis, two types of exploitation failures of the ПИК-type valve plates have been determined: this is the destruction of the free end of the plate tongue at the lift stop and the failure along the line of contact with the seat.

Analysis of the characteristics of the plate tightness allows us to assert that the ПИК-АМ valves are characterized by greater tightness during operation in comparison with the ПИК-А valves.

Practical calculations have shown that the mean time between failures T_{ave}, of ПИК-АМ valves is 6980 hours, ПИК-А valves - 3120 hours.

The time of failure-free operation with good tightness of the plates with a probability of 0,9 is 2200 hours for ПИК-АМ valves, and only 1000 hours for ПИК-А valves, i.e. tightness, and therefore efficiency, increased 2.2 times.

CONCLUSIONS AND RECOMMENDATIONS

1. A method has been developed for calculating the movement of the straight-flow valve plate, taking into account the magnitude of the gas flow pressure force and the elastic force of the plate, as well as the number of double strokes of the piston of the 1st stage compressor cylinder, which makes it possible to determine the effect of various design and operational parameters on the dynamics of the valve plate motion.

2. Studies of the tightness of straight-flow valves revealed that gas leakage through the plates of the discharge valve, depending on the operating mode, is 1.5-2 times higher than through the suction valve. The maximum value of the valve tightness criterion is 35 c, at which gas leakage does not exceed 0.6%.

3. The criterion of valve tightness is significantly increased in the process of gas purification on the suction line by installing a new design of separators and running-in the plates of the straight flow valves. ПИК-АМ valves run in 5-7 times faster than ПИК. By about

40 hours of their operation, the efficiency of the compressor unit in comparison with ring valves increases by 10%. ПИК-АМ straight-flow valves allow to use them in compressors with high pressure ratios, making safe their operation and increase the efficiency.

4. The use of ПИК-АМ valves allows to increase the compressor capacity by an average of 7% and reduce the power consumption for compression by 4%. Due to the use of ПИК-АМ straight-flow valves and gas separators for gas purification on the suction line, an increase in the tightness of the plates occurs, while the productivity of the GCS with the 10th GEC increases by 8 ÷ 10%.

5. Safe and efficient operation of the ПИК-АМ type valves of the 1st stage compressor cylinders allows to increase their operating hours up to 7000 hours, which is 2.0 - 2.5 times higher than that of the ПИК-А type valves.

6. In the future, during the design process of the GCS, it is proposed to provide installation of gas separators of a new design on the suction line for each GEC, which will improve the gas quality and the efficiency of the compressor cylinders of the 1st stage and GEC in general.

7. Tests and blowdowns of the ПИК-АМ type valve plates installed on the suction line of a new separator, which make it possible to clean low-pressure associated petroleum gas from heavy liquid hydrocarbon components, solid mechanical impurities and to determine the tightness of the valve plates at the blowdown unit, - directly at each gas compressor station, made it possible to increase their efficiency and safety of work and the productivity of by 1.5 ÷ 2 times.

MAIN CONTENT OF DISSERTATION PUBLISHED IN WORKS:

1. Сеидахмедов Н.С. "Особенности безопасности эксплуатации клапанов влияющие на технико-технологические

показатели работы поршневых компрессоров", XII Международная научно-практическая конференция, Научные перспективы XXI века. Достижения и перспективы нового столетия, Новосибирск.- 2015. № 5(12).стр.107-109.

2. Сеидахмедов Н.С. "Газодинамическое исследование работы клапанов поршневых компрессоров в стационарном газовом потоке". X Международная научно-практическая конференция, Актуальные вопросы науки, технологии и производства, Санкт-Петербург. – 2015. стр. 61-64.

3. Габибов И.А., Сеидахмедов Н.С. "Управления движения пластин прямоточных клапанов поршневых компрессоров, работающих в системе газлифтной эксплуатации нефтяных скважин", Восточно-Европейский журнал передовых технологий, Харьков. - 2015. № 4/7 (76). стр. 34-38.

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