Improvement of Pump-Ejector Systems in order to Increase the Gas Discharge Pressure and System Efficiency

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Abstract. Rational use of associated petroleum gas (APG) is the most important task of the oil industry. One of the options for its solution can be the use of pump-ejector systems for injecting APG together with water into the reservoir when implementing simultaneous water and gas injection (SWAG) in order to increase oil sweeping. However, the problem of increasing the pressure developed by the pump-ejector system is currently insufficiently studied issue. This paper presents an improved layout of the pump-ejector system, recommendations for the optimal composition of the working fluid, as well as the calculation of the system for the conditions of one of the fields in the Ural-Volga region.

1. Literary review of the problem under study

The issue of increasing oil recovery by injecting a water-gas mixture into the reservoir is very relevant to this day. An analysis of the results of the implementation of injection of a water-gas mixture is presented in [1]. According to these data, the increase in oil production was 5-10%. A comprehensive overview of SWAG technology is presented in [2,3]. In these sources, the influence of various factors of the field on oil recovery is considered, as well as calculations of the ratio of produced gas and water are given. In [4] the technology of foam WAG using surfactants is considered. The description of the object and the results of WAG using CO2 at the field are given in [5]. A comprehensive overview of enhanced oil recovery by injection WAG is presented in [6, 10 - 12]. The works [7 - 8] provide an analysis of the world and domestic experience in the implementation of technology, as well as a proposal for improving the technology. The study of flow characteristics and their influence on equipment operation is presented in [9].

2. Introduction

In the development of oil fields, associated petroleum gas is released from oil. The issue of the rational use of APG is topical. Every year around 150 billion cubic meters of APG are burned in flares in the world. At the same time in Russia in 1814 torches burn 12.9 billion cubic meters, or 13.1 percent of its total production. Construction of compressor stations for APG utilization is in many cases unprofitable.

At the same time, work [13] shows that APG can be utilized using simple and reliable pump-ejector systems that don’t require high capital investments.
3. Purpose
The objective of the study is to develop a schematic diagram of an improved pump-ejector system of increased pressure for SWAG of the reservoir and recommendations for the optimal composition of the operation liquid.

4. Scheme of the improved pump-ejector system
Figure 1 shows the scheme of APG utilization according to [13]. Water from the separator enters the pump inlet. The pump injects water into the ejector nozzle, which pumps out associated petroleum gas from the separation unit. After the ejector, the mixture with increased pressure is sent to the separator, where the gas is separated from the water.

However, the pressure developed by such a pump-ejector system is not enough for the implementation of WAG during injection into injection wells of oil fields.

Work [14] presents a diagram of a pump-ejector system (figure 2) of increased pressure. It includes not only a booster, but also an additional booster pump. From the separator, the liquid enters the booster pump, and from the pump to the ejector nozzle. Gas flows through the channel to the ejector. The ejector provides compression of the gas-liquid mixture, and then the mixture is supplied to the booster pump. Then the mixture is fed to the separator.

**Figure 1.** Utilization of associated petroleum gas using a system containing a pump and an ejector [13]:
1 - ejector, 2 - pump, 3 - separator, 4 - pump suction line, 5 - pump discharge line, 6 - low-pressure gas pumping line, 7 - water-gas mixture discharge line, 8 - separated gas discharge line, 9 - water supply line, 10 - water outlet line.

**Figure 2.** Scheme of the pump-ejector unit [14] equipped with an additional booster pump to increase the mixture pressure:
1 - booster pump, 2 - inlet valve, 3 - outlet valve, 4 - ejector with mixing chamber, 5 - nozzle, 6 - inlet gas channel, 7 - separator, 8 - separator inlet channel, 9 - gas separator outlet channel, 10 - liquid separator outlet channel, 11 - remotely controlled valve, 12 - booster pump, 13 - liquid injection line, 14 - common engine.
The disadvantage of this installation is that both pumps are driven by the same motor. Since the booster pump runs on liquid, and the booster pump runs on a gas-liquid mixture, the operation of the proposed system is ineffective. In addition, the scheme presented in [14] is circulating, and the water consumption is not useful, which significantly reduces the efficiency of the installation according to [7–9]. Also, the known solution does not offer the optimal composition of the liquid for ejection and operation of the booster pump. At the same time, recent experiments [18–21] have shown that for the most efficient operation of ejectors and pumps, it is necessary to take into account the composition of the operation liquid.

To increase the discharge pressure, a schematic flow diagram of the pump-ejector system for water-gas action, shown in figure 3.

The pump-ejector system contains (see figure 3) power pump 1, ejector 2, booster pump 3, as well as line 4 for water supply to power pump 1, water injection line 5, gas pumping line 6, and water-gas mixture injection line 7 into the reservoir. The inlet chamber of the ejector 2 is in communication with the gas pumping line 6, and the water injection line 5 is directed to the ejector nozzle 2. The outlet line 8 of the ejector 2 is connected to the inlet of the booster pump 3. An adjustable gate valve 9 is installed on line 5.

![Figure 3. Principal technological scheme of the pump-ejector system for SWAG.](image_url)

The system can also accommodate a dosing pump 10 with a surfactant supply line 11 from the tank 12 and an adjustable gate valve 13 at the outlet.

Power pump 1 and booster pump 3 are equipped with variable frequency drives 14 and 15. Dosing pump 10 is also equipped with variable frequency drive 16.

Independent drives of the booster and booster pumps of the system from different motors with variable frequency drives provide wider functionality in comparison with the known solution [14].

In system versions, an adjustable gate valve 17 and a low pressure compressor 18 can be installed on the gas pumping line 6.

As a booster pump 3, a multistage vane pump or a screw positive displacement pump can be installed.

SWAG on the formation in accordance with the proposed scheme is carried out as follows. Water is injected by the power pump 1 from the water supply line 4 along the water injection line 5 into the ejector nozzle 2, which is used to pump out gas from the gas line 6. The ejector 2 is created, dispersed and the pressure of the water-gas mixture is increased. It is directed through line 8 to receive the booster pump 3. Next, the booster pump 3 is injected with the water-gas mixture along the line for pumping the water-gas mixture 7 into the reservoir. At the same time, the content of free gas in the mixture at the intake of the booster pump 3 is maintained not higher than the value of the critical gas.
content of the cavitation-free operation of the booster pump 3 on the water-gas mixture. The content of free gas in the mixture at the intake of the booster pump 3 is regulated by changing the gas supply by the ejector 2. Regulation of the critical gas content is carried out by changing the pressure at the intake of the booster pump 3 by changing the pressure of the water injected into the ejector 2 and / or by changing the foaming properties water-gas mixture. In the latter case, from the tank 12, foam-forming surfactants are pumped out through the line 11 with a dosing pump 10 and the surfactants are supplied to them in the water injection line 5. The change in the foaming properties is achieved by changing the surfactant flow rate when regulating the feed of the metering pump by a frequency-controlled drive 10 and an adjustable valve 13. The flow rate of gas, water, pressure and the content of free gas in the mixture at the intake of the booster pump 3 is controlled by changing the dimensions of the flow path of the ejector 2 and / or changes in the gas pressure in the inlet chamber of the ejector 2.

The change in the measurements of the flow path of the ejector 2 is carried out by installing nozzles and mixing chambers of various diameters in the ejector 2. By increasing the diameter of the installed nozzle, the water flow rate can be increased, and by reducing the nozzle diameter, this flow rate can be reduced. By inserting a mixing chamber with a larger diameter into the ejector 2, it is possible to increase the gas flow rate, and vice versa. An increase in the gas pressure in the receiving chamber of the ejector 2 leads to an increase in the gas flow rate, and a decrease in this pressure leads to a decrease in the gas flow rate. A change in the flow rates of water and gas leads to a corresponding change in the pressure and content of free gas in the mixture at the intake of the booster pump 3.

The regulation of the flow rates of gas, water, pressure and content of free gas in the mixture at the intake of the booster pump 3 is carried out by changing the rotational speed of the shaft of the power 1 and / or booster pump 3 using variable frequency drives 14 and 15.

The change in the gas pressure in the receiving chamber of the ejector 2 is carried out either by an adjustable valve 17 (in the direction of decreasing the pressure behind it compared to the pressure in front of it), or by a low pressure compressor 18. In the latter case, an increase in the gas pressure in the receiving chamber of the ejector 2 due to gas compression compressor 18.

5. Calculation of the area of rational concentrations of salts dissolved in the operation liquid

In addition to improving the technological scheme of the system, it is proposed to increase efficiency by ensuring work in the field of rational concentrations and composition of salts, in which the intensification of energy exchange between the operation liquid and the ejected gas is achieved.

In this case, the values of the concentration and composition of salts in the operation liquid must be maintained within the range of rational concentrations and composition of salts, in which increased values of the efficiency of the ejector and pump are achieved. For this purpose, salts are added to low-mineralized aqueous solutions, and highly mineralized aqueous solutions are diluted with fresh water. As a operation liquid, reservoir and / or associated water of oil fields, which are aqueous solutions of salts, are used, if the composition and concentration of salts are within the range of rational concentrations and composition, in which the coalescence of gas bubbles is suppressed and the stability of the mixture is increased. The boundaries of the area of rational concentrations and composition of salts are preliminarily determined by laboratory bench studies.

As an example of a possible implementation of the proposed technology, the selection and calculation of the parameters of the pump-ejector system for specific operating conditions for the conditions of the N oil field in the Ural-Volga region were carried out.

6. Using nitrogen as a component of the gas phase to create a water-gas mixture of the required volume

In the sections of the N field, there is an injection well A. In the immediate vicinity, three producers were drilled - B, C and D. These wells are operated by sucker rod pumps. Well D operates two reservoirs. To avoid disruption of the flow of borehole pumps associated with an increase in the annular pressure to the value of the buffer (from 1.3 to 1.7 MPa, depending on the ambient
temperature), the wells are periodically stopped in accumulation. In this case, associated gas is discharged from the annular spaces into the atmosphere.

Production well data are shown in Table 1.

Table 1 shows that the gas-oil ratio is low, the associated gas is not enough to create the required gas content of the water-gas mixture in reservoir conditions, therefore it is necessary to add to the associated gas nitrogen obtained from the nitrogen compressor.

| Parameter name                        | Values by well number |
|--------------------------------------|-----------------------|
| Collector type                       | B   C   D            |
| Reservoir pressure, MPa              | 16.4 15.3 7.84 11.83 |
| Gas density at standard conditions, kg / m³ | 1.079 1.079 1.24 1.274 |
| Current gas consumption from the annulus under standard conditions, m³ / day | 53.27 89.86 9.69 2.98 |
| Gas factor of oil, m³ / t            | 38.6 38.6 2.6 11.78 |
| Reservoir temperature, ° C           | 37.4 35.9 23 25      |

The proposed solution is the selection, mixing of associated gas and nitrogen with water, and their injection by the pump-ejector system shown in figure 3, in the form of a water-gas mixture into an injection well. At the same time, APG utilization is ensured, and oil recovery enhancement, and an increase in the operating factor of producing wells.

The calculation of the pressure at the mouth of the injection well A was carried out according to the following initial data:
- water injectivity of the injection well $Q_{well_w} = 70$ m³ / day;
- density of the injected water $\rho_w = 1122$ kg / m³;
- the vertical depth of the well to the top of the formation $H_{well} = 1745.96$ m;
- nominal tubing diameter $d = 60$ mm;
- inner diameter of tubing $d_{in} = 50.3$ mm;
- pressure at the wellhead during water injection $P_{m,w} = 14.6$ MPa;
- reservoir pressure $P_r = 17$ MPa;
- gas mixture consumption under standard conditions $Q_{g,st} = 3761.8$ m³ / day;
- the density of the gas mixture under standard conditions $\rho_{mix, st} = 1.1621$ kg / m³;
- value of gas-water factor in standard conditions $R = 53.74$ m³ / m³.

This ensures the value of the gas content of the mixture in reservoir conditions, which is 24%. To inject the required flow rate, a unit is required that generates 140 normal m³ / h of nitrogen with a purity of 95% and a discharge pressure of 1 MPa (for example, an adsorption nitrogen station of the "PROVITA-N" type).

Since the injected water at the field is saline, its composition with the addition of surfactants, as shown by studies by the method [18], will prevent the merging of negatively charged gas bubbles due to their repulsion in an aqueous solution of salts - electrolytes. The composition and concentration of salts in the injected water are within the range of rational concentrations and composition, in which the coalescence of gas bubbles is suppressed and the stability of the mixture is increased.

The calculations of the required pressure values, as well as the parameters of the pump-ejector system were carried out according to the method described in [17, 19], and the calculation of the ejector - according to the method [13]. The design wellhead pressure in the injection well during the injection of the water-gas mixture was 20 MPa, and at the outlet of the pump-ejector system - 20.1 MPa. A multi-stage centrifugal vortex pump VNN5A-124-3000 was selected as a booster pump.
according to the methods [17, 19]. With an average integral flow rate of 115 m³/day, the pump develops a head of about 2500 m, a pressure of 17.7 MPa with an efficiency of 59% and a power consumption for a water-gas mixture of 58.69 kW.

Consequently, the proposed technology for the use of a pump-ejector system for water-gas stimulation of the reservoir allows achieving high injection pressure values - more than 20 MPa.

The proposed solution can be used for oil production and enhanced oil recovery, as well as for drilling exploration and production wells with flushing with aerated fluids and foams.

7. Conclusion
The scientific novelty of this work is the justification of the feasibility of an independent drive of the booster and additional booster pumps of the system from different engines with variable frequency drives and the use of aqueous solutions of electrolytes as the operation liquid in areas of rational concentrations to suppress the coalescence of gas bubbles in the liquid. This makes it possible to operate in practice the pumps and the ejector in a wide range of changes in operating parameters, providing an improvement in the characteristics of the booster pump and ejector with an increase in the gas discharge pressure and the efficiency of the system as a whole.

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