Investigations of the Liquid-Jet Gas Pump’s Mixing Throat Lengths for Well Operations and Associated Petroleum Gas Utilization

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Abstract. One of the solutions of water-alternating gas injection technology and utilizing of associated petroleum gas enhancement is application of pump-ejector system technology, which uses a liquid-jet gas pump (LJGP) as a water and gas mixer. This paper is devoted to the test bench studies of the LJGP’s performance characteristics with change of the mixing throat’s length at excess pressures of the ejected gas. As a result of the bench studies, it was obtained that the excess pressures of the ejected gas $P_{in}$ require a different approach when choosing the optimum length of the LJGP’s mixing throat, as compared to atmospheric pressure. So, it was determined that at $P_{in}$ from 0.05 to 0.18 MPa, a long mixing chamber should be chosen, and $P_{in}$ from 0.18 to 0.6 MPa, the optimal length is medium. It was also obtained that with an increase in $P_{in}$, the optimum working range of the mixing throat lengths increases, which makes it possible to select the mixing throat in wider ranges, without losing the efficiency of the LJGP. With the optimal length of the mixing throat, the highest gas injection coefficients were in the range of $P_{in} = 0.2 – 0.5$ MPa.

1. Introduction

The water alternating gas injection technology (WAG) is an effective method of enhanced oil recovery, in which gas can be injected both as a finely dispersed water-gas mixture, and separately. As a gas phase can be used not only a gas cap in the oil field, but also associated petroleum gas, which in some fields for several reasons is flared. The associated petroleum gas of the second and subsequent separation stages has an overpressure of about 0.2 - 0.6 MPa, which is considered a low-pressure gas. A technological solution for the utilization of such gases is the use of pump-ejector systems, where LJPG is used as a mixing device. Also, LJGP can be used in purging the gas accumulated in annulus, which leads to enhancing oil production [1-8].

One of the main geometric parameters of the LJGP are the ratio of the mixing throat diameter to the nozzle diameter $D_{th}/D_{n}$ and the mixing chamber length to its diameter $L_{th}/D_{th}$. Several works are devoted to the study of the optimal values of these parameters [9-18]. However, one of the unsolved problems is the study of optimal geometric parameters at excess pressures of the ejected gas. The paper [12] is devoted to the study of the LJGP’s performance with excess pressures of ejected gas $P_{in}$ for the optimal ratio of $D_{th}/D_{n}$. Was noted that, at atmospheric pressure of ejected gas, the efficiency of LJGP increases with decreasing $D_{th}/D_{n}$ and at excess pressures of ejected gas the optimal ratio $D_{th}/D_{n}$ is in the range of
1.55 – 1.65. Thus, it was obtained that the selection of geometric parameters should be carried out depending on the pressure of the ejected gas $P_{in}$.

Current investigation is devoted to the bench studies of the LJGP performance in change of mixing throat length, where the pressure of the ejected gas is varied from 0.05 to 0.6 MPa.

2. Materials and methods

The investigations were carried out on a model of the pump-ejector system (PES), a detailed description of the test bench is given in [12]. Figure 1 shows a diagram of PES where an electric centrifugal pump CR1-25 (GRUNDFOS) with a single-phase motor (rated flow $Q = 1 \text{ m}^3/\text{h}$; 25 pump stages, power 1.5 kW) was used as a power pump 2. As jet apparatus 3, a liquid jet gas pump (LJGP) was used, with a cylindrical mixing chamber and diaphragm nozzles with rectangular edges (figure 2). Such nozzles were previously tested and recommended for LJGP by other studies [1,5,15]. The diffuser opening angle was 6°. Water was used as a working liquid, and atmospheric air was used as a gas.

The laboratory test methodology was as follows.

To measure the characteristics at atmospheric pressure in the receiving chamber of the LJGP, valves 16, 17 and 19 are opened, and 18, 20, 21, 22, 23 are closed. Experiments at atmospheric pressure in the receiving chamber with an open valve 16 are carried out in order to avoid an increase in pressure in the system by the ejected air from the atmosphere. Next, the power pump 2 is turned on, which pumped liquid into the ejector’s nozzle 3. The valves 18 and 20 are opened, while the ejector 3 begins to pump out gas (atmospheric air). In this case, the flow rate of the liquid is measured by the flow meter 6 and the flow rate of the gas by the gas meter 4, as well as the temperatures of the working liquid, the incoming gas and the gas-liquid mixture (GLC) at the outlet from the ejector with thermometers 13, 14 and 15, respectively. The steady state working pressure $P_r$ is recorded with a pressure gauge 10, the pressure in the receiving chamber of the LJGP $P_{in}$ with a pressure gauge 11 and the pressure at the outlet of the ejector $P_o$ with a pressure gauge 12 are recorded. Then the valve 19 is closed, which leads to a certain increase in $P_o$. The measurements are carried out at various degrees of closing the valve 19, until the gas is almost completely pumped out of the atmosphere.

Figure 1. The scheme of the experimental test bench: 1 - a tank for liquid with gas; 2 - power pump; 3 - investigated jet apparatus; 4 - gas flow meter; 5 - liquid flow meter; 6 - rheometric stand; 7, 8, 9, 10, 12 - manometers; 11 - manovacuum meter; 13, 14, 15 - thermometers; 16, 17, 18, 19, 20, 21, 22, 23 - control valves and latches; 24 - compressor.
To measure the characteristics at excessive pressures in the receiving chamber of the LJGP, valves 16 and 20 are closed, and 21, 22 and 23 are opened. Further, the tank was filled with gas using a compressor 24 to the required excess values $P_i$ (0.1; 0.2; 0.3; 0.4; 0.5; 0.6 MPa). The measurement procedure was carried out similarly to the studies at atmospheric pressure in the receiving chamber, but with the difference in determining the gas flow rates - under these conditions, the measurement was carried out according to the calibration dependences for the rheometric stand 6.

Based on the measurement results, the pressure-energy characteristics of the ejector were constructed. The efficiency of the ejector during gas ejection $\eta$ was determined by the formula [1]:

$$\eta = \frac{u g P_{in} ln P_{in}}{(P_p - P_o)}$$

(1)

where $P_{in}$ - pressure in the suction chamber (intake chamber);

$P_o$ – outlet pressure of the ejector;

$P_p$ – power pressure in front of the nozzle;

$u g = Q_{e}/Q_{p}$ – volumetric injection coefficient in the suction chamber, where $Q_e$ and $Q_p$ are gas (air) and power fluid (water) volumetric rates.

Relative pressure drop is calculated by:

$$\frac{\Delta P_o}{\Delta P_p} = \frac{P_o - P_{in}}{P_p - P_{in}}$$

(2)

To carry out experiments from the available LJGP’s elements, three variants of the design of the flow path were mounted, which are presented in table. 1. In all cases, the pressure drop was assumed to be constant and amounted to $\Delta P_p = 1.32 - 1.34$ MPa.

| $D_{in}$ (mm) | $D_n$ (mm) | $L_{in}$ (mm) | $D_{in}/D_n$ | $L_{in}/D_{in}$ |
|---------------|------------|---------------|--------------|-----------------|
| 5.4           | 3.3        | 60            | 1.64         | 11.11           |
| 5.4           | 3.3        | 110           | 1.64         | 20.37           |
| 5.4           | 3.3        | 160           | 1.64         | 29.63           |

The distance from the edge of the nozzle to the entrance of mixing chamber 1 was selected according to the results obtained in [19], which was achieved by changing the thickness of the ring plate 12 (figure 2). The mixing chamber length $L_{in}$ was varied using modular sections 5 in figure 2.
3. Results and discussion

As a result of laboratory tests, the pressure-energy characteristics were built, the maximum values of which were reflected in figures 3, 4 and 5. Figure 3 shows the dependence of the LJGP’s efficiency at the inlet pressure $P_{in}$ when changing the length of the mixing throat. The results show that in the range $P_{in} = 0.05$ - $0.18$ MPa, the maximum efficiency is achieved with a long mixing throat. In the range $P_{in} = 0.18$ - $0.6$ MPa, the maximum efficiency is achieved with a medium length of the mixing throat. Figure 3 shows the dependence of $\eta$ on $P_{in}$ with a change in the mixing throat length $L_{th}$.

Figure 4 shows the dependence of the efficiency on $L_{ch}/D_{th}$ at various pressures in the receiving mixing throat $P_{in}$. The efficiency at $P_{in} = 0.05$-0.1 MPa increases proportionally with an increase in the length of the mixing throat. With $P_{in} = 0.2$-0.6 MPa, the optimal mixing throat length is in the range $L_{ch}/D_{th} = 20$-24. It is also observed that with an increase in $P_{in}$, the efficiency dropping decreases with a change in the length of the mixing throat. So, at $P_{in} = 0.05$ MPa, the difference between the maximum and minimum efficiency is 6%, which is 28.5% of the maximum efficiency. At $P_{in} = 0.6$ MPa, this ratio is 6.25%, which indicates an increase in the efficiency of the LJGP in a wider range of mixing chamber lengths with an increase in $P_{in}$. This is also confirmed by the fact that the maximum efficiency in the entire range $L_{ch}/D_{th} = 11.11$ - 29.63 corresponds to $P_{in} = 0.6$ MPa.
Figure 5 shows the dependence of the dimensionless pressure drop $\Delta P_o / \Delta P_p$ on the pressure at the receiving chamber $P_{in}$ at different lengths of the mixing throat. According to it, with an increase in the length of the mixing throat, a decrease in $\Delta P_o / \Delta P_p$ occurs, this phenomenon can be explained by an increase in resistance in the throat area. It is also a sharper decrease in $\Delta P_o / \Delta P_p$ is observed after $L_{th}/D_{th} = 20.37$. Another distinctive phenomenon is that at $P_{in} \geq 0.4$ MPa the values of $\Delta P_o / \Delta P_p$ begin to increase, which is especially noticeable with a short mixing chamber ($L_{th}/D_{th} = 11.11$).

![Figure 5](image.png)

Figure 5. Dependence of $\Delta P_o / \Delta P_p$ on $P_{in}$ at different lengths of the mixing throat $L_{th}$.

Figure 6 shows the dependences of the gas injection coefficient $u_g$ on the inlet pressure $P_{in}$ for different values of the mixing throat length. This figure shows that at $L_{th}/D_{th} = 11.11$ and 20.37, the greatest relative values of $u_g$ are achieved at $P_{in} = 0.3$-0.4 MPa and further is characterized by a decrease. At $L_{th}/D_{th} = 29.63$, the $u_g$ value is characterized by a stable decrease with an increase in $P_{in}$ from 0.05 to 0.6 MPa. It is also noted that with the optimal value $L_{th}/D_{th} = 20.37$, the maximum values of $u_g$ are achieved in the range $P_{in} = 0.2$ - 0.5 MPa.

![Figure 6](image.png)

Figure 6. Dependence of $u_g$ on $P_{in}$ at different lengths of the mixing throat $L_{th}$.

4. Conclusions

As a result of the carried-out test bench studies on the effect of the LIGP’s mixing throat lengths at excessive pressures near the receiving chamber $P_{in}$ in the range of 0.05 - 0.6 MPa, it was revealed:

1. The optimal length of the mixing chamber at $P_{in} = 0.05$ - 0.18 MPa is achieved at $L_{th}/D_{th} \geq 29.63$, and at $P_{in} = 0.18$ - 0.6 MPa in the range $L_{th}/D_{th} = 20$ - 22;
2. An increase in the pressure of the injected gas $P_{in}$ promotes the expansion of the region of optimal $L_{th}/D_{th}$ values.
3. The highest values of the gas injection coefficient $u_g$ at optimal values of $L_{th}/D_{th}$ are achieved in the pressure range of $P_{in} = 0.2$ - 0.5 MPa.
The results of the laboratory studies can be used in the selection of the optimal parameters of LJGPs for the utilization of associated gas, simultaneous water alternating gas injection and other operation with oil and gas wells.

5. References

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