Investigation of Booster Multi-Stage Centrifugal Pump’s Characteristics When Pumping-Out of Water-Gas Mixtures

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Abstract. The investigation of multistage centrifugal booster pump performance when delivering water-gas mixtures in configuration water jet gas pump at excess pressure intake chamber. As a dispersing device for a water-gas mixture used WJGP of various designs flow path with diaphragm nozzles having rectangular edges were used. When gas supplies at excess pressures from 0.2 to 0.37 MPa into intake chamber of water jet gas pump, it promotes the formation of a finely dispersed water-gas mixture, which leads to reduce the effect of free gas on the performance of the booster pump’s. When intake pressure of pump rises, the stability of the water-gas mixture also increases. When an increase in pressure at the inlet of the booster pump, the curves of the shaft rotation frequency - the input gas content acquire a flatter form.

1. Introduction

The pump-ejector system (PES) of simultaneous water alternating gas injection (SWAG) technology on increases the oil recovery enhancement by simultaneously injection of associated gas and water. This system allows to prepare a water-gas mixture on the surface and pump it through injection wells into oil reservoirs [1-10]. The pump-ejector system is simple, reliable and much cheaper unlike with traditional technologies of water-alternating gas injection (WAG) [11-16]. In figure 1 presents the diagram of the pump-ejector system at the Samodurovskoye field is presented.

![Diagram of the pump-ejector system at Samodurovskoye field.](image)

Figure 1. Scheme of the pump-ejector system at Samodurovskoye field.

During the operation, the power pump injection water into the nozzle of water-jet gas pump (WJGP), which pumps out gas from the gas line. The water-gas mixture, which created by the WJGP,
enters at the inlet of a multi-stage centrifugal pump and compresses to the pressures required for injection into the formation.

In [18] conducted investigation of operation an electric centrifugal pump’s (ESP) when pumping out gas-liquid mixtures at pressures pump intake $P_{in}$ from 0.6 to 2.1 MPa. The results of the experiments showed the influence of various parameters and designs of the WJGP on the pump performance. When increases the pressure pump intake, the effect of gas in the pumped-out mixture decreases, and with an increase in the inlet gas content and the average size of the gas bubble diameter above a certain value, it increases. An increase of average gas bubbles diameter more than 0.9-1.2 mm, the pressure developed by the pump $P_b$ decreases. Gas supplied through the gas line from the compressor to the inlet chamber of WJGP.

In works [17, 19], conducted investigation of operation the booster pump operation, when pumping out water-gas mixtures on the experimental bench-model of a pump-ejector system. When conducting experiments on a water-gas mixture with fresh water and unsuppressed coalescence of gas bubbles, the pressure developed by the pump decreased, when the gas content increased. It was also revealed that, when the salt adds in the range of rational concentrations, it suppresses the coalescence of gas bubbles in the pumped-out mixture, which leads to reduce the effect of free gas on the operation booster pump’s on water-gas mixtures. Gas supply at the inlet chamber of WJGP observed at atmospheric pressure. At the moment, the first steps have been taken in this direction in relation to the technology of SWAG [20, 21]. In this way the aim of this work is investigation of booster multi-stage centrifugal pump’s characteristics when pumping-out of water-gas mixtures at the intake pressures from 0.2 to 0.6 MPa, at excess pressures in the intake chamber of WJGP from 0.2 to 0.37 MPa.

2. Materials and methods

The research was carried out on an experimental bench-layout of the pump-ejector system, which is shown in Figure 2. This test bench provides for a closed hydraulic system for both liquid and gas, therefore, gas injection by a compressor is required only when the expansion tank is filled under the required pressure for research. In this case, the tank was filled at a pressure of 0.2 to 0.37 MPa. In consequence of modernization the stand, it became possible to minimize energy consumption and there is no need to constantly maintain pressure in the system. At the initial stage, expansion tank 1 filled with water and the power pump 2 starts with WJGP 3, the gas injects with compressor 5 to the required pressure in the system. Bypass line opens with valves 22 and 25. As soon as, the bypass line is fully open, the booster pump 4 starts and close again the valves 22 and 25. To set the required pressure at the pump intake, close the valve 28. The parameters of the booster pump are taken according to the readings of manometers 17 and 18, where the pressure are at the inlet and outlet, respectively. Water flow rate determines by the liquid flow meter 7. The temperature is recorded by thermometers: working fluid 8, supplies gas 9 and water-gas mixture 10. After install of regime at the pump intake the valves 23, 24 open to supply gas to the WJGP. The volumetric flow rate of the incoming gas to inlet chamber of ejector, determined by the differential pressure gauge 6. As the valve 24 opens, the $P_{in}$ increases. Then the valve 28 opens to reduce the pressure to the previous values. According to the above methodology experiments are repeated until the limiting values of gas contents. Also necessary to take readings of the pump shaft speed. To do this, remove the cover at the pump head and at a distance 30-50 mm and record speed readings. In this case, used the laser digital tachometer «Megeon 18001» . The investigation object is multi-stage centrifugal pump «Grundfos» CR1S-30 with 30 stages ($Q_{nom}=0.8$ m$^3$/h, maximum efficiency 35 %, power 1.1 kW) with single-phase electric motor. The parameters of the pump impellers are similar to those of the low-speed ESP stages. The main task of the experiments is to obtain the pressure-flow characteristics of the booster pump.

As a dispersing device for a water-gas mixture used WJGP of various designs flow path with diaphragm nozzles having rectangular edges were used. Such this nozzles have been tested in previously and recommended for pumping gas [22]. The diameters of nozzles $d_z$: 2.9, 3.3, 3.6, 3.9, 4.3 mm and diameters through $d_{th}$: 4.4, 4.7, 5.4, 6.4 mm are used. The lengths of through $L_{th}$ varied from
110 mm to 159 mm. The ratio of the length through to the diameter through varied from 23.4 to 25 and the ratio of $d_l/d_n$ =1.38, 1.42, 1.5.

The gas content at the pump intake $\beta_{in}$ was determined as:

$$\beta_{in} = \frac{Q_{g,in}}{Q_{g,in} + Q_L}$$  \hspace{1cm} (1)

where, $Q_{g,in}$-the volume of free gas flow rate at the pump’s intake under thermodynamic conditions; $Q_L$- the liquid capacity in the same conditions.

3. Results and discussion

After processing obtained results, then constructed the head and rate characteristics of the booster pump’s, when pumping out water-gas mixtures at $P_{in}$= 0.2-0.6 MPa.

In figure 3, showed the diagram of dependence of the pressure developed by the pump on the supply of liquid flow rate $Q_w$ at $P_{in}$ = 0.2 MPa. On the left side of the booster pump’s characteristics up to $\beta_{in} = 2\%$, the $P_p$ practically does not change. At $\beta_{in}=8 \%$ the $P_p-Q_l$ curves is bent down at $Q_l= 0.79$ m$^3$/h. On the right side, the pump performance is improved.

In figure 4, it is seen an improvement in the pressure-flow characteristics of the pump at $P_{in}$ = 0.6 MPa. Curves $P_p-Q_l$ linear up to $\beta_{in} = 12\%$. With an increase $\beta_{in}$, the pressure developed by the pump does not decrease even with a low rate liquid supply, therefore, the formation of gas cavities is difficult.
Figure 3. The diagram of the head-rate characteristics CR1S-30 booster pump’s on water-gas mixtures at $P_{in} = 0.2$ MPa.

This is due to the fact that, when the gas is supplied with excess pressure into the intake chamber WJGP, it contributes to the formation of a finely dispersed water-gas mixture (DWGM) and with increasing pressure $P_{in}$, the stability of the water-gas mixture is increases.

This is confirmed in the work [23], where during the investigations of the WJGP’s performance at elevated pressures intake chamber it revealed that: at $d_{th}/d_{th} = 1.38$, the value WJGP’s efficiency is equal to 24% at pressures of intake chamber from 0.2 to 0.4 MPa, and at atmospheric pressure the value of efficiency at intake chamber WJGP’s is equal to 22.8%. At $d_{th}/d_{th}=1.5$ the value of efficiency is equal to 31 % in pressures range from 0.2 to 0.4 MPa at intake chamber WJGP and 22.5% at atmospheric conditions, respectively.

Figure 4. The diagram of the head-rate characteristics CR1S-30 booster pump’s on water-gas mixtures at $P_{in} = 0.6$ MPa.

Also, recorded the shaft rotation frequency of booster pump. In figure 5 shows the diagrams: a) the dependences of $P_p$ on $\beta_{in}$ at different $P_{in} = 0.2, 0.4, 0.6$ MPa. In this case, the design of WJGP’s are $d_{th}=3.6$ and $d_{th}=5.4$, with a $L_{th}=135$ mm. Liquid flow rate is $Q_l=1.16$ m$^3$/h. Pressure at receiving chamber WJGP’s is 0.2 MPa. Fig. 5 b, it can be seen that with an increase in pressure at the inlet of the
booster pump, the curves of the shaft rotation frequency - the input gas content acquire a flatter form. In figure 5 b) it is seen, that an increase $P_{in}$ the curves of the shaft rotation frequency – $\beta_{in}$ acquire a flatter form.

![Figure 5 a. Dependencies of $P_p$ on $\beta_{in}$ at different $P_{in} = 0.2, 0.4, 0.6$ MPa.](image1)

![Figure 5 b. Dependencies of shaft rotation frequency booster pump’s on gas content at $P_{in} = 0.2, 0.4, 0.6$ MPa.](image2)

4. Conclusion

1. In response to, modernization of bench pump-ejector system, it was possible to create a closed hydraulic system for gas and liquid, which does not require energy costs to maintain pressure in the system. By using this system, it was possible to realize the supply of gas to the intake chamber of WJGP’s an excess pressure of 0.2–0.37 MPa.

2. When gas supplies at excess pressures into intake chamber of WJGP, it promotes the formation of a finely dispersed water-gas mixture, which leads to reduce the effect of free gas on the performance of the booster pump’s. When intake pressure of pump rises, the stability of the water-gas mixture also increases.

5. References

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