Investigation and Calculation of Pump-Ejector System Parameters at SWAG in Conditions of Megion Oil Field

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Abstract. The average oil recovery rate (ORR) in Russia is 0.3, which means that the achieved amount of extracted oil is 30% of the geological (lying in the formation). Due to the irrational selection of the enhanced oil recovery method this problem is quite common. There is the trend of growing demand for petroleum products each year, it is necessary to increase the volume and pace of production. Due to the low ORR in Russia, it is necessary to search for new methods that can significantly increase the amount of extracted oil, as well as the productivity of wells and oilfields. The use of pump-ejector systems and injection of water-gas mixture into the reservoir is an excellent solution of this problem. The optimal pump-ejector parameters equipment providing SWAG injection on the formation in conditions of the Megion oil field were calculated in this work.

1. Introduction
Russia occupies one of the first places in the world ranking in terms of the amount of associated petroleum gas (APG) burned, which means that the APG obtained during oil production is not fully used. Also, the oil recovery rate of most oil fields in Russia is quite low and does not exceed 30%. Due to the wrong approach to choosing the method of enhanced oil recovery, often using the most common artificial flooding. That is why it is necessary to further research and study SWAG technology, which can be implemented at any stage of field development, providing both solutions to the problem of oil extraction, APG and the problem of increasing oil recovery. This method combines the positive aspects of the interaction of oil and its displacement by water and gas, without disadvantages that are inherent in the injection of water or gas separately [5].

The main purposes of this work are:
1. Selection of effective working pump-ejector system that is superior to artificial flooding;
2. Calculation of the pump-ejector system for the Megion oil field.

1.1. Experience with the use of WAG and SWAG injection in oil fields
The first use of water-alternated-gas injection (WAG) was in 1957, Canada. Simultaneous water-alternated-gas injection (SWAG) was implemented later in 1962 at the Seeligson field.

Experience with the use SWAG shows that the greatest increase in oil recovery occurs when the gas content is in the range of 25-75% [9].

SWAG as a method of enhanced oil recovery is mainly used in the United States, Canada and Norway. Usually, hydrocarbon gases, dry or enriched, as well as carbon dioxide are injected. Most
often, an increase in oil recovery with WAG is reported by about 5%, but, as noted in some fields, oil recovery can increase by 20% [7].

The number of fields where WAG was applied has exceeded 100 nowadays, and there is a tendency to increase demand, including for pump-ejector equipment. Experience shows that nearly always the use of a system for pumping water and gas into the reservoir gives a positive effect, and the results are shown in 8-12 months after implementation [6].

2. Materials and methods

This technology of SWAG with pump-ejector system involves obtaining a fine water-gas mixture (MVGS) on the surface and then pumping it into the reservoir. Gas from low pressures is compressed to the pressures necessary for pumping the mixture into the reservoir (up to 15.0-20.0 MPa). The use of surface active agents in the system reduces the harmful effect of gas on the operation of a centrifugal booster pump, creates a stable fine water-gas mixture that can be transported from the surface to the reservoir without splitting into components, thereby increasing the degree of oil displacement by the mixture. The schematic diagram of this technology is shown in figure 1.

![Figure 1. Schematic diagram of the pump-ejector system at SWAG.](image)

1 – ejector, 2 – injection wells, 3 and 4 – pumps, 5 – surfactant tank, 6, 7 and 8 - adjustable valves, 9 – water injection line, 10 – gas line, 11 – surfactant supply line, 12 – water-gas mixture injection line.

Gas bubbles in the mixture in the presence of stabilizing surfactants have a spherical shape. The shape of the bubbles encased in the surfactant armor shell is preserved under the influence of external forces: pressure, collisions with the walls of pipes, with the formation surface, and with other similar bubbles. Gas bubbles behave like solid particles [2,4].

2.1. Multi-stage pump-ejector system

A multi-stage pump-ejector system (MSPE) provides the creation of a fine water-gas mixture on the surface. The equipment involved in the formation of the mixture is not multicomponent, it does not require any special resources or highly qualified staff [10].

MSPE presented in figure 2 includes: 1 – ejector of the first gas compression stage, 2, 4, 5, 7 – multi – stage vane pumps, 3-gravity separator, 6 – ejector of the second gas compression stage.

The pump 4 provides liquid supply to the separator 3, where the liquid begins to circulate in a closed circle, which includes the pump 2 (provides an increase in pressure at the entrance to the next ejector) and the ejector 1 (pumps out low-pressure gas). Next, the liquid enters the separator 3, under a certain increased pressure, and the circle closes. While gravity separator 3 works gas-liquid mixture is separated, the water returns to a vicious circle with the pump 2, and enters the subsequent stage of ejection which is provided with the pump 5, which creates feed pressure at the nozzle of ejector 6.
Pressurized gas is fed straight to the reception to the mixing chamber of the second stage compression ejector 6 from the separator 3.

In addition, water is also supplied under pressure to the pump 5, which provides liquid supply at a higher pressure to the ejector nozzle 6. In front of the pump 5, there is a chamber with special surfactant, the surfactant supply is provided by a plunger pump comparable with pump-ejector system, enriching the liquid with special substances.

The mixture pressure decreases at the outlet of the ejector 6, due to mixing with the gas stream, which pressure is lower than the supplied liquid. It is necessary to provide the water-gas mixture with a suitable pressure for subsequent injection into the reservoir. With the supply of a fine water-gas mixture, the pump 7 increases the pressure of the mixture to the required values [5,9].

2.2. Monoblock multi-stage pump and ejector system

A special scheme was developed that allows saving mechanical seals and expensive magnetic couplings, but also to increase the reliability and maintenance period of the system. Monoblock two-stage pump-ejector system located on a single shaft [16].

The system shown in figure 3 is located on a single shaft and operates by only one ground engine, while all the pumps and the separator have a common axis of rotation, the last pump has a left-hand rotation, thereby the axis is unloaded and vibration is prevented. A centrifugal separator allows to save space. The number of seals is minimal, which provides additional design reliability.
Monoblock MSPE presented in figure 3 includes: 1 – motor, 2 – frequency converter, 3 – line water flow, 4, 8, 11, 16, 20, 21, 25, 29, 31, 34 – adjustable gate valves, 5 – mechanical seal, 6 – input module with axial fifth, 7 – the pump is not used because sufficient pressure of fluid supplied, 9, 10, 13, 18 – gas line 10 and 24 – supply line of water-gas mixture, 12 – centrifugal separator group 8, 14 – pump ESP8-1600, 15 and 22 – the discharge line from the water pump 14, 17 – first stage gas compression ejector, 18 – input gas line 23, the ejector of the second stage gas compression, 26 – seal, 26 - pump ESPP8-1000 with left rotation and radial guide devices, 28 – a line for feeding water-gas mixture to the injection well, 30 – a container SAA, 32 – a dosing pump, 33-a nozzle [9].

2.3. *Megion oil field characteristics*

Megion Field parameters required for calculating the pump-ejector system are presented in table 1.

| Name of parameter                             | Value                  |
|-----------------------------------------------|------------------------|
| Reservoir type                                | Terrigenous            |
| Formational pressure                          | 15,8-21,8 MPa          |
| Average depth of formation top                | 2186 m                 |
| Injection capacity of well                    | 50 m³/day              |
| Pressure of injected water at the wellhead    | 12,4 MPa               |
| Density of injected water                     | 1015 kg/m³             |
| Gas density at standard conditions            | 0,973 kg/m³            |
| Exist gas pressure                            | 0,45 MPa               |
| Gas flow-rate at standard conditions          | 50000 m³/day           |
| Water flow-rate at water injection station (WIS) | 6500 m³/day           |
| Water pressure at WIS                         | 14,3 MPa               |

The method used for calculating of the pump-ejector system parameters was developed by N A Drozdov in his science research [9].

3. *Results*

Calculations will be carried out only for one installation of the pump-ejector system, while the pump supply to the MSPE is 1000 m³/day, and the liquid flow rate for the entire field is 6500 m³/day, therefore the gas flow rate for this installation will be proportionally less, equal to 7692 m³/day.

1. The gas flow rate at the intake of the first stage compression ejector 17 is 1709 m³/day;
2. Supply of working fluid to the ejector nozzle 11 is 600 m³/day;
3. Injection coefficient at intake of the first compression stage ejector 17 of is 2.85;
4. The pressure of the mixture at the first compression stage ejector 17 outlet RS.1 = 12.4 MPa;
5. Working fluid pressure in front of the nozzle PP = 11.05 MPa;
6. pressure at the reception of RPR = 0.45 MPa;
7. the pressure of the mixture at the outlet of the jet apparatus RS = 4.03 MPa;
8. Efficiency of the first stage ejector $\eta = 0.4$;
9. The efficiency of the second stage compression ejector is 0.45;
10. Pressure developed by the pump 14 PH.1 = 7.02 MPa;
    Choose from the catalog of JSC "Novomet-Perm", the most comparable 48-stage pump ECNP8-1600 with a length of 4 m, in which the pressure developed on the reservoir water is 11.3 MPa, and the power consumption is 195.5 kW [17].
11. Pressure at the intake of the ejector 23 is 4.03 MPa;
12. Gas consumption at intake of the ejector 19 is 190.9 m$^3$/day;
13. Injection coefficient at intake of the second compression stage ejector 23 is 0.19;
14. The pressure of the mixture at outlet of the ejector 23 of the second compression stage is 7.03 MPa;
15. The pressure at the inlet of the pump 26 is 7.03 MPa;
16. The gas flow in terms of the inlet of the pump 26 is 109.5 m$^3$/day;
17. Gas content of the mixture at the pump inlet 26 is 0.1;
18. The value of the working pressure in front of the second compression stage ejector nozzle 23 is 8.08 MPa;
19. Average Integral gas supply is 57.9 m$^3$/day;
20. Average Integral supply of the pump 26 on a water-gas mixture is 1057.9 m$^3$/day;
21. Mass flow of the mixture is 1022484 kg/day;
22. Mass flow rate of liquid is 1015000 kg/day;
23. Mass flow of the gas is 7484 kg/day;
24. The average density of the mixture is 966.5 kg/m$^3$;
25. The average Integral head pressure of the pump 26 on a gas-liquid mixture is 1316 m.
    Choose a 92-stage 5-meter pump ESP8-1000, developing a pressure of 1515 m when feeding 1000 m$^3$/day. The water power consumed by the pump in nominal value will be 275.2 kW.
26. With a gas-liquid mixture, the power consumption is 267 kW;
27. The values of power consumed by pumps 14, 26 are shown in table 2.

| Pump  | N14  | N26  |
|-------|------|------|
| Typical size | ESP8-1600 | ESPPP8-1000 |
| Density of bail out mixture (kg/m$^3$) | 1015 | 852,9 |
| Power, kW | 200,4 | 267 |
| Length, m | 4 | 5 |

28. The GSA8 Centrifugal separator also consumes about 10 kW of power [17].
29. Total power consumed by all pumps and gas separator is 477.4 kW;
30. Useful power of the system for pumping liquid (water) is 95.28 kW;
31. Useful power of the system for gas injection is 4,61 kW;
32. The total effective power of the system is 99.89 kW;
33. The value of the pump-ejector system efficiency is 20.9%.

4. Discussions
Thus, with the pump-ejector system it is possible to fix the water-gas mixture with the following parameters: water consumption 1,000 m$^3$/day, gas consumption 7692 m$^3$/day, gas-water ratio 7.69 m$^3$/m$^3$, outlet pressure pout 20.8 MPa, with an average for pumping gas-liquid mixture the efficiency of the entire system of 20.9%. The useful power is 99.89 kW, the consumed power is 477.4 kW. The total length of the installation will be 15 m.

5. Conclusion
The SWAG demonstrates excellent performance in different oil fields, which proves its relevance. Pump-ejector system simplify implementation, as well as the affordable cost of equipment and reliability of the construction. The calculation carried out for the Mezgin Field reflects the compactness, low energy consumption and good efficiency, which indicates that the funds required for the maintenance of this system are small. However, you can get a significant increase both in the production rate and in the amount of oil produced.

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