Bypassing annular gas by means of jet device in oil wells with electric submersible pumping units

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Abstract. Nowadays the main equipment for oil production is the installation of electric centrifugal pumps. When operating oil wells with such installations, various complicating factors arise, in particular, the accumulation of free gas in the space between the outer surface of the tubing and the casing string. The experience of the ESP unit operation shows the negative impact of high gas pressure in the annular space on the efficiency of the unit. The technical solutions available today for the wells characterized by high GOR are the different types of valves, which have a number of operational shortcomings. To improve the efficiency of oil well operation, the authors suggest a jet device to bypass free gas above the dynamic level, thus reducing the gas pressure in annular space. The solution of the problem of reducing the negative effect of excess free gas in annular space is based on the study of experimental data from oilfields by using up-to-date information technology. The technology using a jet device in combination with a submersible electric centrifugal pump is proposed. The use of the jet apparatus enables reducing the gas pressure in the annular space of oil-producing wells even regardless of the discharge pressure and external ambient temperature, which increases the operating efficiency of the electric submersible pumping unit.

1. Introduction

Currently, many oil-producing companies use electric submersible pumps (ESPUs) as the main type of equipment for formation fluid production. These installations experience serious problems when pumping reservoir fluid containing an increased volume of free gas.

The degree of influence of the free gas determines the quality of operation of electric submersible pumps (ESPUs). This indicator is determined by the level of gas content at the ESPU reception.

The increase of free gas pressure in annular space facilitates pushing down the dynamic level of formation fluid to the bottomhole (to the level of submersible centrifugal pump's inlet level in extreme cases). This can trigger a failure of the submersible unit (pump starvation). That is why the development of devices and technologies for pressure reduction in the annular space of wells is relevant at this stage. The reduction of free gas pressure in annular space does not entail the reduction of bottomhole pressure, as this pressure is balanced by the increase of formation fluid's dynamic level. To prevent the process of formation fluid level fall to the level of ESP inlet and critical increase of gas pressure in annular space special valves can be installed at the wellhead. Experience analysis shows that stabilization of free gas pressure in annular space is not always possible by using wellhead valves (especially in case of freezing at low temperatures) and is not always effective.

The presence of free gas in the annular space between the pipes entails a reduction in the head capacity of a centrifugal pump. Presence of gas in the annulus increases the volume of formation fluid delivered to the first impellers and diffusers of the centrifugal pump and withdraws some portion of...
the energy that is supplied to the shaft of the ESP and is wasted on the compression of gas bubbles and their complete dissolution in the formation fluid. Then a certain amount of energy is returned to the fluid in the tubing. The released gas bubbles create a so-called “gas lift effect”. They facilitate the lifting of formation fluid to the ground surface and reduce the required pressure head for the operation of an oil well. As the gas content increases, cavities are formed in the channels of ESPs' working stages (impellers and diffusers), which are not involved in the movement of gas-liquid mixture (GLM) through the channels in the general flow. The emergence of gas-filled cavities in a submersible centrifugal pump provides a rapid degradation of flow across impeller blades, reduces the flow capacity of the working channels, disrupts the energy exchange process of the pump with the pumped medium. The presence of gas bubbles on the operating surfaces of ESPs facilitates cavitation processes. The operation of the pump in forced cavitation modes is characterized by delivery failure, especially when the gas content increases.

The large-scale introduction of the pressure-assisted oil production system contributed to the increase in pressure at the wellheads of producing wells, which eventually increased free gas pressure in annular space. The increase in gas pressure at the wellhead is influenced by many different factors, such as unevenness of terrain lines, high pressure in the discharge lines due to remote location of automatic group metering station, increased viscosity of the produced fluid, etc. (figure 1).

![Figure 1](chart.png)

**Figure 1.** Consequences of high GOR influence on pumping equipment’s operation in oil-producing wells

The excess amount of free gas in the space between the casing string and tubing facilitates heating of the submersible pump's housing components, the occurrence of gas-hydrate plugs, blocking of formation fluid flow, reduction of the effective volume of pumped fluid in ESP stages, lowering of dynamic level in a producing well. In case the dynamic level value reaches a critical point when the maximum gas content value at ESP inlet is exceeded, pump starvation and complete shutdown of the formation fluids production is expected.

The emergence of gas hydrates is facilitated by such processes during the operation of ESP units as the shutdown of production wells and the presence of a free gas phase at those sections of wells that are located above the level corresponding to the oil's bubble point pressure. When the well is shut down, the formation fluid starts cooling down and moisture is generated therein. Statistical analysis of field data on gas hydrate deposits indicates that such incidents are most frequently encountered in areas at the top of the tubing and annular space above the dynamic level. The formation of gas hydrates may lead to blocking of a wellbore's annular space between the tubes and to the reduction of formation fluid's flow characteristics, down to complete outage of the ESP unit.

Due to potential drop in the dynamic level in a producing well, it might be required to increase the location depth of a submersible unit. This entails additional material costs (submersible electric cable, tubing) and increased load on the tubing string.

Jet devices can be used to remove gas from the annulus of a producing well.
Jet devices came into use in various industries, as they can be used as standalone units or in combination with other pumping units [1, 2].

Gas injection is performed in jet devices. This process is featured by the transfer of kinetic energy from one stream to another during direct contact (through mixing method). Flows, in this case, may be in the same or different phases. The phase of the flowing streams may behave differently when they are mixed: either change or remain unchanged. A stream that starts the mixing process at a higher speed is called a working stream and another one at a lower speed is called an injected stream.

The following advantages are the reason for the wide popularity of the jet devices: small overall dimensions, no wear surfaces and moving parts, possibility of using even in hard-to-reach areas, high degree of reliability, no need for regular maintenance, possibility of pumping the fluids, which may have different phases, simple design, and high self-priming capacity.

Owing to their distinctive design features and operating principle, the jet devices have been adopted in many petroleum industry sectors, such as drilling and operation of oil and gas wells, formation fluid recovery, enhanced oil recovery from pay zones, bottom-hole zone treatment of production and injection wells [3 - 5].

2. Problem statement

Nowadays the technologies that involve the joint use of jet devices and submersible centrifugal units are effective. The joint use of jet devices and ESP units is reasonable in cases where there are complicated conditions: high content of free gas in formation fluid, aggressive pumped media, high temperature changes. Currently, the technology of jet devices implementation is widely used on oil-producing fields of Western Siberia in Russia, the USA, in Ukraine [6 - 9].

Certain requirements are imposed on the submersible unit as a whole when operating jet devices in oil wells. These requirements include the ability to provide three streams when the jet device and submersible unit are operated in conjunction: incoming injected and main flows, outgoing total flow. Then the following requirements should be considered: overall dimensions of individual submersible unit parts, located directly in the oil well, should match the internal diameter of the production string. The use of jet devices for recovery of downhole fluids contributed to the implementation of such principal types of equipment as a downhole power drive and surface power drive.

In the case of the surface power drive application, two independent flows are required – incoming main flow and the output total flow. If a submersible power drive is used, the axial lines of all three flows will coincide [10, 11].

To ensure the performance of oil wells, submersible power drive is the most suitable option, given the overall dimensions of the unit.

There is an application experience [6] of the submersible jet pump as a part of an ESP installation ("ESP installation - jet device" tandem technology).

Combined application of a jet device and a submersible centrifugal pump constitutes the tandem technology.

Application of tandem installations makes it possible [6], to effectively apply free gas at the inlet of a submersible centrifugal pump by bypassing it through a jet device into the tubing string from the annular space providing the creation of the optimal structure of the gas-liquid stream when recovering the formation fluid to the ground surface.

The jet device used in combination with an ESP makes it easier to maintain the required pressure in the annular space of an oil-producing well, which is close to the pressure created in the reservoir. This prevents the process of dynamic level lowering, reduces the consumption of tubing and submersible electric cable [12].

The method used to reduce the free gas pressure in the annular space is determined depending on various conditions of the formation fluid recovery process, such as oil well's flow rate profile, value of water cut in the formation fluid, gas-oil ratio and the amount of gas at the inlet of a submersible pump, the method of operating the producing well.
3. Research results
To implement the tandem technology, the authors propose a layout providing for the combined application of an electric submersible pump and a jet pump. The jet device is positioned above the dynamic level. The jet pump removes free gas from the annular space of a producing well. The jet pump shall have an automatic valve assembly as the main unit to reduce the pressure of annular gas in wells equipped with ESP installations. The automatic valve assembly bypasses the free gas into the inner space of the tubing string regardless of the value of free gas pressure in annular space and thermal conditions [13 - 15].

The jet pump is installed in the tubing string during set-up and running and pulling operations. The layout of the jet pump in the production well is shown in Figure 2.

![Diagram](image_url)

**Figure 2.** "Electric Submersible Pump – Jet Pump» tandem installation: 1 - submersible centrifugal pump; 2 - tubing string pipes; 3 - production string; 4 - submersible electric motor; 5 - seal section; 6 - check valve; 7 - fluid level; 8 - piston with magnetic components; 9 - jet pump; 10 - discharge pipe line; 11 - electric transformer; 12 - control station; 13 - surface part of the cable line; 14 - pressure control gauge.

The analysis of the theoretical and experimental research results [16] proves that in case the requirements to the technological process are fulfilled, there is an actual possibility to remove free gas from the wellbore annulus. To remove free gas from the annular space of the producing well and to further transfer this gas into the internal space of the tubing in accordance with the regulatory documentation, a jet pump is proposed (Russian Federation invention patent No. 2517287) [13, 16].

The proposed design provides for the jet pump which can be used to bypass free gas into the inner space of the tubing string. The jet pump is connected via a check valve to the inner space of the tubing string and the annular space. The jet pump is structurally designed as two symmetrical halves. The longitudinal section of the jet pump shows the following: one half is placed stationary in conjunction with the check valve, while the other half can move longitudinally inside the tubing string. The movable part of the device is connected by permanent magnets to a piston, which is spring-loaded from below. The piston is located in the cylinder parallel to the axis of the tubing string. In the lower part the cylinder is communicating with the annular space of the producing well, and in the upper part - with the inner space of the tubing [3, 13, 16].
The layout of the jet pump designed to remove free gas from the annular space is shown in Figure 3.

![Diagram of jet pump](image)

**Figure 3.** Jet pump designed to remove free gas from the annular space 1 - tubing string; 2 - cavity under the piston; 3 - stationary unit; 4 - check valve; 5 - movable unit; 6 - magnets; 7 - spring; 8 - piston; 9 - steel cylinder; 10 - hole; 11 - annular space; 12 - casing string; 14 - submersible centrifugal pump; H - tapering hole: (a) Inactive position; (b) Active position

The principle of a jet pump's operation is as follows. When operating the submersible installation, the degassing of the formation fluid is activated at the ESP's inlet level. A certain portion of the gas mixture enters the electric submersible pump and is further pumped through the tubing to the primary oil treatment station. The remaining portion of the gas mixture is collected in annular space, accumulates therein and may rise above the dynamic level over time, thereby increasing the pressure at the wellhead of the producing well. If gas pressure rises in the annular space of the well, it will apply pressure to the bottom of the piston through the hole. The piston moves upwards subject to the force of the spring and the pressure of free gas, which is higher than the pressure of formation fluid. The piston then displaces the movable symmetrical part of the jet pump designed to remove free gas, using permanent magnets. When the movable symmetrical part of the jet pump reaches the uppermost level, the pressure drop in the tapering section H begins (see Fig. 3, b). When pressure begins to drop, the check valve is opened and the gas mixture from the annulus flows into the inner space of the tubing string. Thus, the process of free gas pressure reduction is initiated in the annular space of the producing well. Further, the movable part of the jet pump begins moving downward under its weight. This increases the cross-sectional area between the stationary and movable parts, and also reduces hydraulic resistance of the formation fluid that moves along the tubing string.

4. **Conclusion**

1. Application of jet pump in combination with electric submersible pumping unit makes it possible to reduce the pressure of gas mixture in the annular space of producing wells. This makes it possible to increase the level of formation fluid in the well, which improves the operating conditions of the electric submersible centrifugal pump, namely, it increases the daily average output characteristics of the well. By reducing the gas mixture's pressure creation of gas hydrate plugs in the annular space of the well can be avoided.

2. Application of a jet pump designed to remove free gas from the annular space shall improve the performance of the submersible unit, namely: increase the efficiency of the submersible pump, reduce the submersible unit's installation depth by raising the formation fluid level in the annular space, i.e.
decrease the consumption of tubing pipes and increase the time between maintenance of electric submersible centrifugal units.

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