Auxiliary equipment for downhole fittings of injection wells and water supply lines used to improve their performance in winter

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Abstract. The article deals with two methods for eliminating freezing of injection wellhead fittings. The first method involves removing injected water from the well fitting under long well operation stoppage at negative ambient temperatures. Water is removed and air is supplied through the system of valves (a spring loaded valve and a float valve). When pumping water into the injection well, the float valve closes the access to the environment, and the spring-loaded valve is open for injected water. When the injection process stops, the spring-loaded valve supplies remaining water into the well fittings and the surface part of the water supply line and closes; the float valve opens. Air into the free space of the well fittings is supplied through the float valve thereby preventing the wellhead and the surface part of the water supply line from freezing. The second method is used to prevent the mouth of the injection well from freezing. A device is installed inside the casing, which allows heat to be accumulated in summer and winter. Accumulated heat is used to heat up the mouth when the water injection process stops.

1. Introduction
The current stage of development of the oil industry in Russia is characterized by intensive development of small and medium-sized oil fields with hard-to-recover reserves. When using traditional methods, the final oil output is not more than 0.2 [1–4] which requires application of new innovative methods to increase the degree of development of reserves and increase profitability. One of these methods is non-stationary water-flooding [5]. However, in Russia, the use of this method is constrained by climatic conditions causing freezing of water lines and injection wellhead fittings.

2. Methods and materials
One of the simplest and most effective ways to prevent the mouth from freezing during prolonged shutdowns of the injection well at negative ambient temperatures is to remove the injected water from the well fitting. Other similar ways have several disadvantages:
- penetration of the device or its working units to a depth of > 3 m which makes it difficult to control their integrity and tightness of connection with the water supply line and casing;
- use of packers to divide the annular space limiting the scope of use;
corrosion of the casing when draining the fluid in the annulus and violation of its integrity;
- complexity and intensity of the structures [6, 7].

A more simple, economical and effective method is to prevent the injection well equipped with a tubing string from freezing. It involves connection of the tubing string for injecting fluid into the surface part of the water supply line through the shut-off valve and draining the fluid from the water supply line into the well when pumping is stopped. Water is injected through the spring-loaded valve along the surface part of the water supply line equipped with a spring-loaded valve on the side of the pipeline well. On the other side water is injected from the valve to the upper point by the float valve. The liquid is drained into the tubing from the underground part of the water supply line below the seasonal soil freezing level through the pipeline along the above-ground part of the water supply line after opening the float valve when exceeding the pressure drop between the water supply line and the external environment created by fluid moving to the reservoir when the well stops.

3. Results and discussion
The advantage of the proposed method is simplicity of the devices required for its implementation as well as the ability to reliably prevent the wellhead from freezing and reducing material and labor costs during its long-term shutdowns [8, 10].

The general scheme of the device and the mouth of the injection well is presented in Figure 1.

The mouth of the injection well 1 (Figure 1) equipped with tubing string 2 contains the ground part of water supply line 3 communicated with the tubing through spring-loaded valve 4 opening the flow of fluid in the water supply line and dividing the water supply line into two chambers (chamber 5 is formed by the ground part of water supply line 3 and the tubing cavity; chamber 6 is formed by ground part 3 and underground part 7 of the water supply line).

Method implementation includes the following stages.

Before injecting fluid into well 1 (Figure 1), chambers 5 and 6 of spring-loaded valve 4 are communicated by pipeline 8, whose inlet part 9 is located below the level of seasonal soil freezing. In this case, chamber 6 at its upper point communicates with the external environment by float valve 10 which closes chamber 6.

Figure 1. The mouth of the injection well: 1 - mouth of the injection well; 2 - tubing string; 3 - ground part of the water supply line; 4 - spring loaded valve; 5 - camera formed by the ground part of water supply line 3 and tubing cavity 2; 6 - chamber formed by the surface part of water supply line 3 and the underground part of water supply line 7; 8 - pipeline; 9 - entrance of the pipeline located below the level of seasonal freezing of the soil; 10 - float valve.

Element 11 is used as float valve 10 (Figure 2). It is made in the form of a ball and made of a material whose density is less than density of the injected fluid and opening 12 blocked in body 13.
Figure 2. The operating element of the float valve: 10 - float valve; 11 - working element (ball) of the float valve; 12 - hole with diameter \(d\) connecting chamber 6 with the external environment; 13 - body where the float valve is located.

Thus, when the fluid under pressure moves through the underground part of water supply line 7 (Figure 1), chamber 6 is filled and air is forced out through float valve 10. When the liquid level of valve 10 is reached, working element 11 (Figure 2) floats and closes hole 12 in body 13 due to smaller fluid density. Under different pressure in chambers 6 and 5 (Figure 1), valve 4 opens and fluid is injected into the formation through chamber 5 along the tubing (not shown in Figures). The well operates in the normal mode.

In case of emergency or under cyclic injection of fluid, spring-loaded valve 4 closes. In this case, the liquid column remaining in tubing 2 creates repression on the formation \(\Delta P = \rho_f g H - P_{\text{form}}\) (where \(\rho_f\) is density of the fluid injected into the formation, \(H\) is depth of the well, \(P_{\text{form}}\) is formation pressure) which causes partial outflow of fluid from the tubing into the reservoir and reduction of pressure in chambers 5 and 6 by \(\Delta p\). When pressure \(\Delta p\) decreases by an amount exceeding the differential pressure supported by float valve 10, it opens. Air enters chamber 6, and the liquid from this chamber (due to differential pressure \(\Delta p\)) flows through pipeline 8 into chamber 5. When the liquid in chamber 6 reaches inlet part 9 of pipeline 8, the air flows from chamber 6 to chamber 5, accompanied by a decrease in the level of liquid in tubing string 2. The process continues until pressure of the liquid column in the tubing is equalized with reservoir pressure \(P_{\text{form}}\).

Figure 2 shows a float valve consisting of ball 11 (made of a material with density \(\rho_k\), which is less than the density of the fluid injected into the reservoir \(\rho_f\), with radius \(R\), volume \(V\)) and hole 12 with diameter \(d\) and cross-sectional area \(s\) in body 13. The operation condition is a proper material of the valve ball \(\rho_k\) and valve parameters, namely the ratio of ball radius \(R\) and hole diameter \(d\) at which pressure difference \(\Delta P\) generated by the formation is higher than differential pressure \(\Delta p\) maintained by the valve.

To determine the valve parameters, let us consider the equation of balance of forces acting on the ball (Figure 2):

\[ mg + \Delta P_S > F_A, \]  

where \(mg\) is gravity; \(m\) is ball mass, \(m = \rho_k V\); \(V\) is ball volume, \(V = \frac{4\pi R^3}{3}\); \(\Delta P_S\) is force created by differential pressure \(\Delta P\) on the ball surface with area \(s = \pi d^2/4\) under the decreasing liquid level by \(\Delta H\), \(\Delta P - \rho_f g \Delta H\); \(F_A\) is Archimedean force acting on the liquid side, \(F_A = \rho_f g V\).

Let us transform formula (1)

\[ \Delta P_S > F_A - mg, \]

\[ \rho_f g \Delta H > \rho_f g V - \rho_f V g. \]

Having solved the equation for \(d\), we have

\[ d > \sqrt{\frac{16R^3(\rho_f - \rho_k)}{s\Delta H\rho_f}}. \]
When $R = 0.03 \text{ m}$, $\rho_k = 300 \text{ kg/m}^3$, $\rho_f = 1000 \text{ kg/m}^3$, $\Delta H = 1 \text{ m}$ (it reaches 300 m), the valve opens at hole radius of 0.01 m.

Thus, by reducing fluid pressure in the surface part of the water supply line, the float valve opens and the wellhead, including the land part of the water supply line, is filled with air instead of fluid flowing into the well, which prevents the injection wellhead from freezing. Wellhead filling does not affect fluid injection into the formation.

The advantage of the method is simplicity of the devices required for its implementation; prevention of the wellhead from freezing under long-term shutdowns of the well; reduction of implementation material and labor costs [11, 12].

Another method used for preventing the injection well mouth from freezing is heating. It involves installation of the device made produced from standard equipment inside the casing, which allows the device to keep heat in the ground when pumping water in the summer or winter period or to heat the mouth when the water injection stops.

Figure 3 shows the design of the injection wellhead.

![Figure 3. The mouth of the injection well.](image)

In the period of normal operation of the well, water flows into inner pipe 3 along the surface part of water supply line 8 through inclined pipe 9, opens check valve 6 and is injected into the reservoir. The installation depth of check valve 6 is 58 m. A smaller part of water through the annular cavity between outer pipe 2 and inner pipe 3 is mixed with the main stream in bypass ports 5. The heat brought by the injected water is transferred to the soil through the walls of metal pipes, contributing to heat accumulation in the soil and raising its temperature above natural one, i.e. the device works as a normal heat exchanger. When the emergency situation is prevented, water is not injected into well check valve 6. The device works as a convective heat exchanger. Water heated from the ground heat, located in the annular cavity between inner pipe 3 and outer pipe 2, goes upwards, enters the ground part of water supply line 8 through inclined nozzle 7 and heats the wellhead equipment and the ground part of water supply line 8. Outer pipe 2 passing through the soil freezing zone (1.6 m) is covered with polyethylene
to reduce heat losses for useless heating of the frozen soil. Thus, thermal insulation of the upper part of pipe 2 is designed to prevent premature cooling of water and equalizing temperatures in the annular cavity and in the cavity of inner pipe 3. Water temperature and density equalizing decrease the driving force of convective heat exchange density difference between cold water and heated water in the bottom of the device. Cooled and denser water from the surface part of water supply line 8 flows into the internal cavity of this pipe through inclined pipe 9 along inner pipe 3, displaces warm water from the annular cavity through bypass windows 5. This is a closed circulation of water.

This device made from standard equipment heats the mouth with water due to the use of previously accumulated heat in the soil, i.e. the device is used to prevent the injection well mouth from freezing and does not require extraneous energy sources and special heat transfer fluids [13].

4. Conclusions
When using the first method, when the pressure of injected water in the surface part of the outlet decreases, the float valve opens and the wellhead, including the movable part of the water supply line, is filled with air instead of water leaving the well which prevents the wellhead from freezing. When the injection continues, the float valve closes, the spring-loaded valve opens and does not affect the injection process.

When using the second method, the proposed device is located in the casing and heats the mouth of water by using heat previously accumulated in the soil.

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