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Conceptual model of fluid recovery from the gas well bottom-hole

The gas wells operation can be accompanied by the liquid phase condensation in the bottom-hole formation zone and in the tubing. With increase in the condensate amount, the rate of gas flow into the wellbore from the bottom-hole formation zone decreases and, as a consequence, its ability to transfer fluid particles from the bottom-hole to the wellhead is lost. This leads to the accumulation of fluid in the wellbore and, accordingly, to the decrease in draw-down pressure, which, in turn, leads to a drop in the production potential of gas wells.

The aim of this paper is to make a conceptual study of the way to prevent the well self-kill (self-controlled well killing) process, which occurs as a result of condensation and accumulation of fluid in the wellbore and at the well bottom-hole. The method is based on the natural process - the manifestation of the effect of capillary rise of the fluid column in thin tubes.

In the course of the work, various methods of the gas wells operation are analyzed, preventing condensate separation, as well as technologies for recovery of already accumulated fluid at the well bottom-hole. The mechanism of water rise by surface tension forces in capillary tubes of various configurations has been investigated. The features of multiphase flow in a vertical pipe have been considered. A series of calculations were carried out to determine the gas flow rate through the wellbore with different ratio of tubing string diameters.

On the basis of the comprehensive consideration of the gas wells operation issues, the conceptual model of liquid removal from the bottom-hole using the capillary tubes located in concentric tubing is proposed.

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1.0 Introduction

The gas wells operation can be accompanied by the fluid phase condensation in the bottom-hole formation zone (BHZ) and in the tubing. The fluid phase elements can be vaporous water contained in the produced gas phase, hydrocarbon condensate (in the case of the operation of the gas condensate reservoirs) [1].

With increase in the specific concentration of condensate per volume of the bottom-hole formation zone and the wellbore, the rate of gas flow into the wellbore from the bottom-hole formation zone decreases and, as a consequence, its ability to transfer liquid particles from the bottom-hole to the wellhead is lost. This leads to the accumulation of fluid in the wellbore and, accordingly, to the decrease in draw-down pressure, which, in turn, leads to a drop in the production potential of gas wells [2]. Thus, the problem of recovery the fluid (condensate) accumulating at the bottom-hole or prevention its accumulation is relevant.

2.0 Materials and methods

The literature review [3] has shown that a fairly extensive list of methods has been developed currently to prevent condensate separation and recovery of already accumulated fluid at the well bottom-hole (Fig.1).

In general, the presented methods [4] can be divided into two groups in relation to the place of condensate occurrence - methods that reduce/prevent the flow of condensate from the bottom-hole formation zone, and methods that mitigate risk of condensate occurrence in the wellbore [5], [6]. Each method has its own advantages and disadvantages. But there is no universal technology nowadays [7].

Prevention of the condensate inflow into the well is possible by the wells operation optimization in such a way that the liquid phase carry over resulted from the rate of the gas phase flow at a given current reservoir pressure [8]. In addition, it is possible to isolate the most water-encroached sub-layers by performance of the isolation works with various

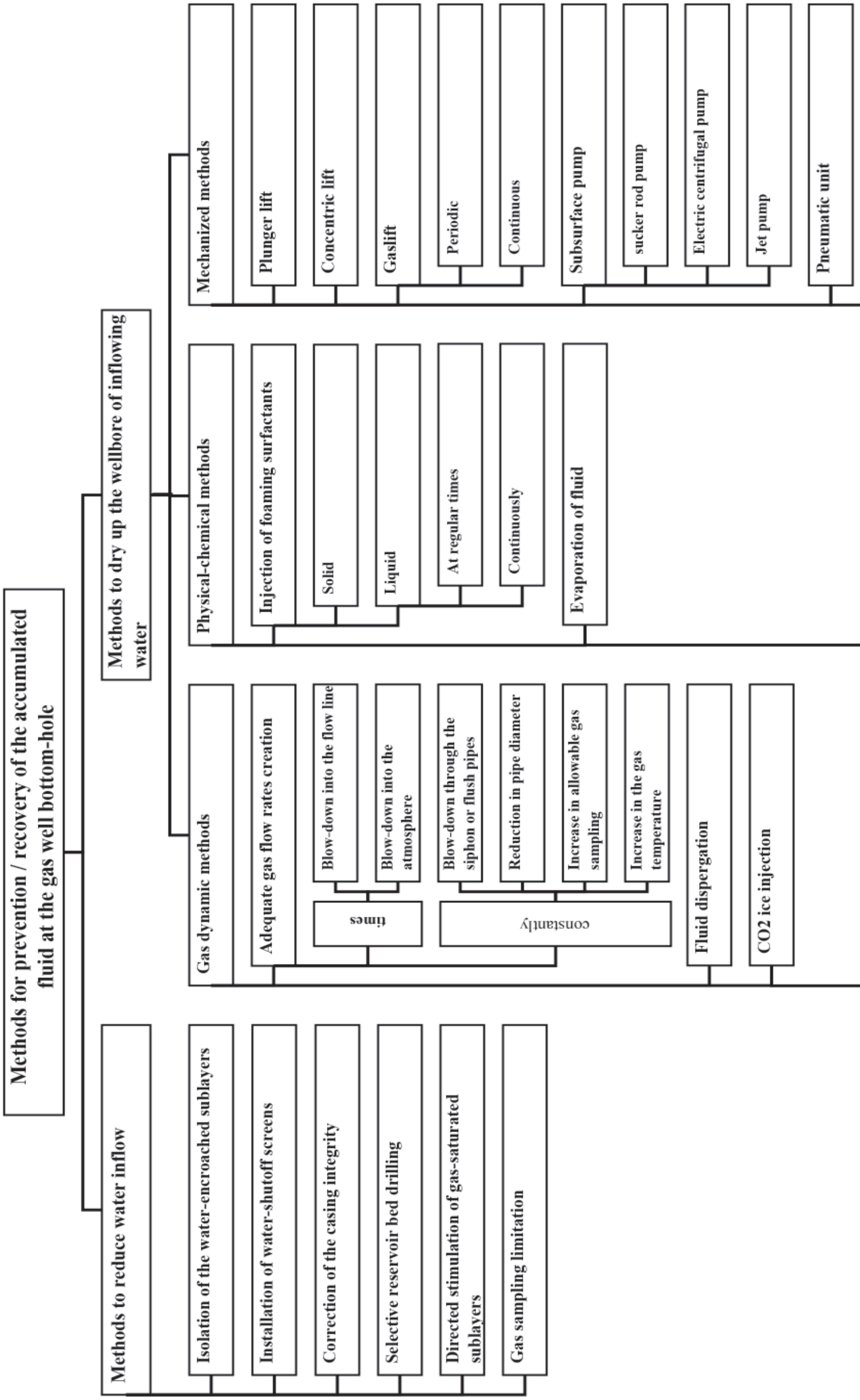


Fig.1 Methods for prevention/recovery of the accumulated fluid at the gas well bottom-hole

chemicals (polymers, micro-cement, curing resins, etc.) [9]. If a gas well is operated in the presence of bottom water, it is necessary to maintain the over balance modes that do not allow to form aqueous coning [10].

If the above methods do not work effectively for some reason, the process of condensate (fluid) accumulation begins at the bottom-hole formation zone of a gas well. Other principles and technologies are already applied for its recovery.

So, if continuous condensate removal from the well bottom-hole is necessary, then such rates of the ascending gas flow velocity (gas rates) are selected experimentally, at which the liquid phase is carried out from the bottom-hole to the surface [11]. For example, it is known that for a string with the diameter of 63-76 mm for deposits located at a depth of about 2500m, the minimum required gas velocity is more than 5m/s. The maximum possible ascending gas flow velocity (gas rates) is limited by geological and field conditions - current reservoir pressures, reservoir properties, tubing diameter. At the same time, it should be noted that the tubing diameter acts as a regulating parameter i.e. the problem of finding the optimum between maximizing the gas flow rate with a decrease in the tubing diameter and minimizing the hydraulic resistance, which increases with a decrease in the tubing diameter, is solved. The method is not suitable for the fields with low-permeability reservoirs, low current reservoir pressures [12].

Another common method for continuous fluid removal from the bottom-hole is gas-lift well operation of gas injection from the wellhead to the bottom-hole in order to increase the total gas flow rate to the minimum required values that allow the gas mixture to carry liquid from the bottom-hole [13]. The method is not suitable for fields with high viscosity of liquid fluids, depleted fields and fields with the water drive development mode.

Periodic removal of the liquid phase can be carried out by delivery and injection chemicals (surfactants, dryers (alcohols)) [14] to the well bottom-hole formation zone, as well as using special techniques - the well blow-down, the well shut-down aimed at imbibitions of fluid from tubing [15]. The disadvantages of these methods are as follows: low fluid removal rate, risks of sanding up [16].

If the application of all of the above methods is impossible, or their effectiveness is low, down-hole pumping units [17], [18] are used for fluid (condensate) removal. The disadvantage of this method is high operational and capital costs intensive. In the case of circulation behind the string, there may be risks of flush gas produced through the annulus to other formations.

It is also necessary to consider the features of multiphase flow in a vertical pipe [19], [20]. Classically, there are four modes of the multiphase mixture of fluid and gas flow (Fig.2), the prevalence of one or another flow mode depends on each of the phases (fluid, gas) velocity and the volumetric ratio of these phases. Moreover, several flow modes are possible within the same well at different gas-fluid mixture lifting depths.

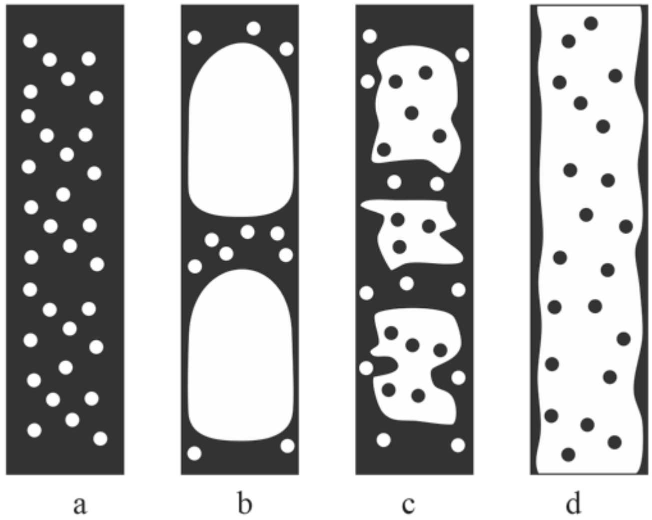


Fig.2 The multiphase fluid and gas mixture flow diagram

In the case when the tubing borehole is filled with a fluid column (for example, due to the condensate accumulation), the non-associated gas phase produced from the formation will move along the liquid column in the form of separate bubbles due to the difference in phase density and high filtration resistance (Fig.2a).

In the liquid phase density and pressure decrease, or in the gas inflow (filtration rate, gas volume) increase, the moving gas phase will coalesce into larger gas bubbles; the flow regime (gas rate) becomes unsteady in this case (Fig.2b).

There is a transit mode between the continuous flow of the liquid phase and the continuous flow of the gas phase (Fig.2c); and also the mode of continuous gas filtration (Fig.2d) – in this case, if the gas flow rate is sufficient, the fluid phase is freely carried to the surface in the form of separate drops. The latter is the best flow mode that provides self-ascending of the fluid produced with gas to the wellhead. And the minimum gas flow velocity that provides this self-ascent is called the “critical speed”.

As a rule, when gas wells are commissioned, the flow mode in the tubing corresponds to case “D” (Fig.2) - gas fills in free form the entire lift space, the produced fluid (as a rule, the condensate saturation of the bottom-hole formation zone is small at the initial stage) is freely removed from the bottom-hole gas well.

With the increase in condensate saturation, the decrease in the gas rate (due to the blocking of the pore space by condensate) and the gas flow rate decreases, the flow mode changes to transit - the well operation will be characterized by unstable fluid and gas rates and an increase in the gas production decline rate.

With a further increase in the condensate saturation of the bottom-hole formation zone, due to a decrease in the gas flow rate, the transit flow mode becomes stable, like the well operation mode, but with the inversion of the prevailing phases, the fluid becomes the main transportation phase. If measures are not taken to reduce the condensate saturation of the bottom-hole formation zone, then a complete loss of gas rate is possible.

Under the condition of constant bottom-hole pressure, a decrease in the diameter of the tube leads to an increase in the gas and fluid flow rate, while the gas phase velocity increases faster than the liquid phase velocity.

The aim of this paper is to make a conceptual study of the way to prevent the well self-kill (self-controlled well killing) process, which occurs as a result of condensation and accumulation of fluid in the wellbore and at the well bottom-hole. The method is based on the natural process - the manifestation of the effect of capillary rise of the fluid column in thin tubes.

So, the main idea is to transfer a part of the fluid from the bottom-hole up through the wellbore to the area of higher gas velocities using capillary tubes of a certain design for the subsequent removal of the fluid phase by the incoming gas flow to the wellhead.

To assess the fundamental possibility of the above idea, let us consider a capillary tube with an uneven cross-sectional radius [21]. Let us study this issue using the method of mathematical calculation.

The lower radius is designated as r_1, the upper radius is designated as r_2. The total height of the fluid rise in two sections is equal to H, and the height of the capillary of radius r_1 protruding above the fluid surface is equal to h.

Let us find the height of the fluid rise in the capillary of radius r_1:

$$x = \frac{2\sigma * cos\alpha}{r_2 * \rho * g} - h * \left(\frac{r_1^2}{r_2^2}\right) = h_2 - h * \left(\frac{r_1^2}{r_2^2}\right)$$

Suppose in n capillaries with radius r_2 are located in tubing with radius r_1 at some height h from the bottom-hole; let us find the total height of the water lift H in the system and the height of the water lift in n capillaries.

The height of the fluid lift in n capillaries will be:

$$x = h_2 - \frac{1}{n} * h * \left(\frac{r_1^2}{r_2^2}\right)$$

The total lift height will be described by the formula:

$$H = h + x = h_2 + h * \left\{1 - \frac{1}{n} * \left(\frac{r_1^2}{r_2^2}\right)\right\}$$

Hence it follows that the height of the fluid lift in the capillary system depends on the number of capillaries and the ratio of the tubing and capillary radii. The height of the fluid lift is directly proportional to the number of capillaries and inversely proportional to the ratio of the tubing and capillary radii.

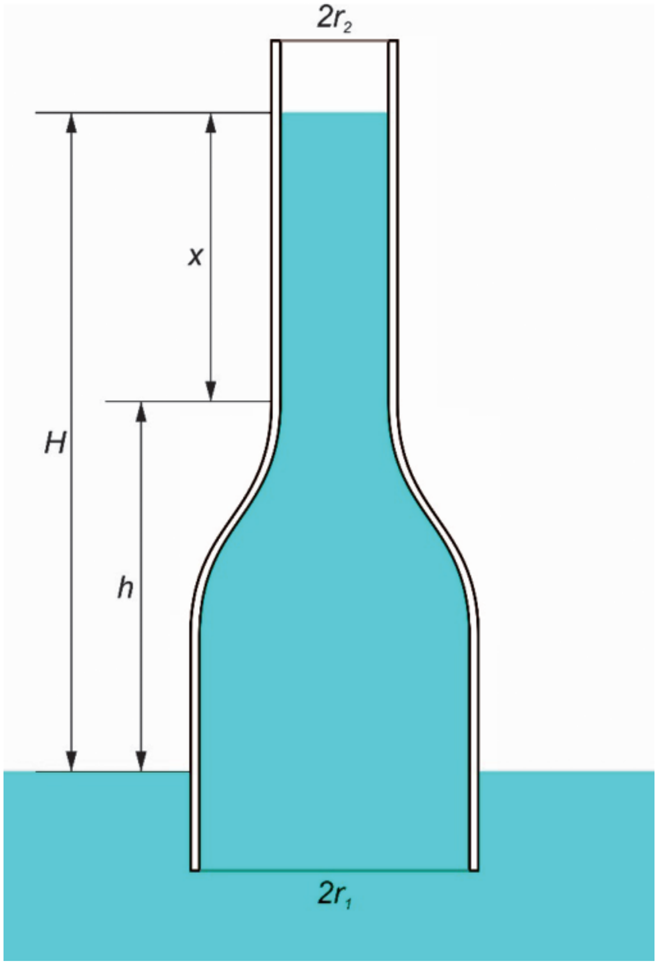


Fig.3 The capillary tube with an uneven cross-sectional radius

Let us consider the fluid lift in a capillary of radius r_1 with transverse baffles (holes) of radius r_2.

The total fluid lift height will be:

$$H = h + h_2 * \frac{r_1}{r_2} - h * \frac{r_1^2}{r_2^2} = h_2 * \frac{r_1}{r_2} + h * (1 - \frac{r_1^2}{r_2^2})$$

The lifting height of the liquid will double in comparison with the capillary shown in Fig.4

Thus, to increase the height of fluid lift from the well bottom-hole, it is necessary to have perforations in the capillary tube system [22], [23].

3.0 Results

Schematically, the concept of fluid recovery from the well bottom-hole, proposed by the authors of this article, is shown in the Fig.5, where 1 is a surface string, 2 is a production string installed concentrically in it. The main tubing string 3 is

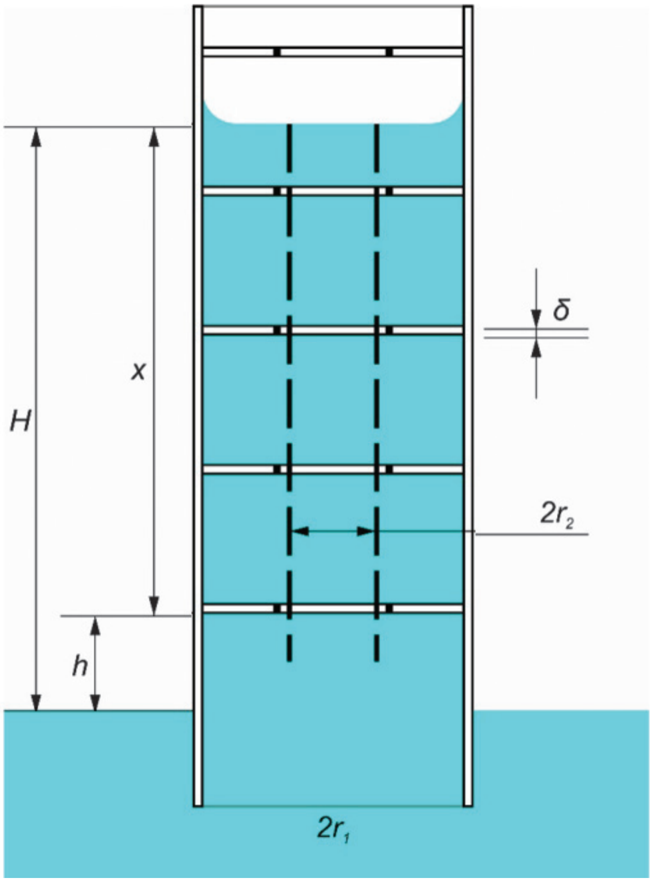
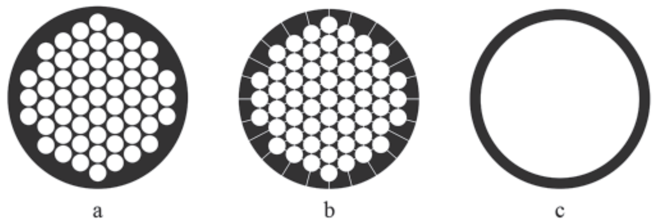


Fig.4 The capillary with perforation holes

located inside the production string 2. Inside the main tubing string 3, there is a centre tubing string 4. An annulus 5 is formed between the production string 2 and the main tubing string 3. An annulus 6 is formed between the main 3 and the centre tubing string 4.

The central tubing string design feature is that in the interval from its lower end to mark 7, the inner volume is filled with capillary tubes 8. The centre tubing string and capillary tubes in the area of mark 7 have holes 9, which ensures the connection of the tubes with each other and with the annulus 6, and also contributes to an increase in the height of the fluid lift through the capillaries (as shown above in the mathematical computations).



(a) At the lower end of the capillary tube bundle (at the lower end of the centre tubing)

(b) At the upper end of the capillary tubes bundle

(c) In an area not equipped with the capillary tubes bundle

Fig.6 The cross-section of the centre tubing equipped with capillary tubes

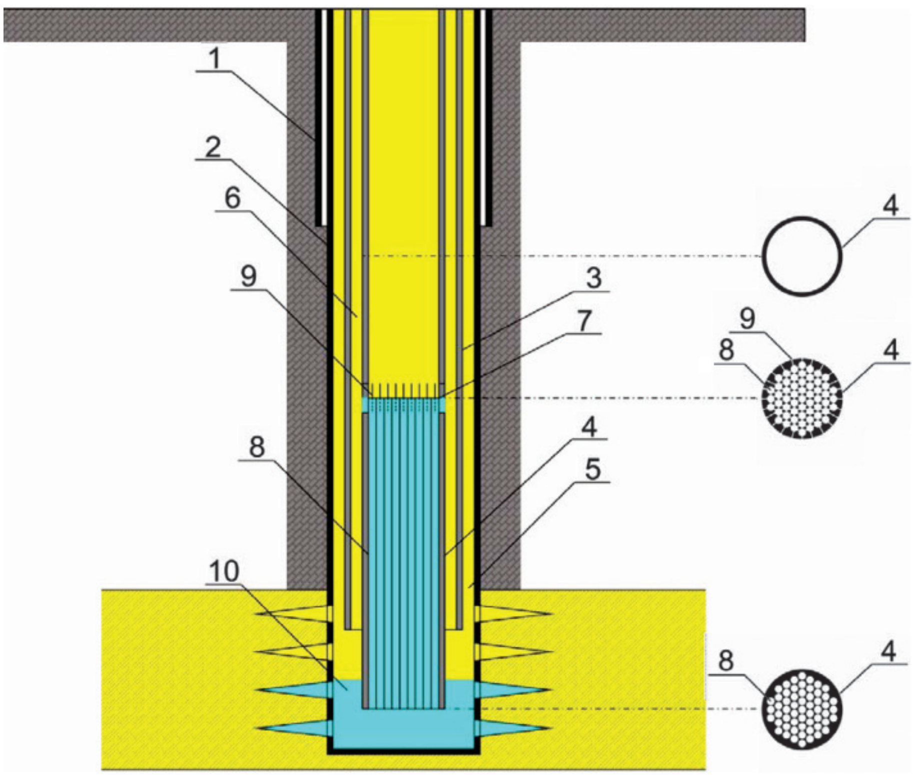


Fig.5 The conceptual model of fluid recovery from the bottom-hole

The layout plan of the main and central tubing strings described above goes down to the bottom-hole. The fluid 10 accumulated at the bottom-hole, under the action of the forces of capillary imbibitions, lifts through the capillary tubes 8 to mark 7, and penetrates into the holes 9. The gas stream moving through the annulus 6 blows the holes 9, evaporates the accumulated liquid from them and transfers it to the wellhead. It is worth noting that the gas velocity in the annulus 6 at the level of the upper end of the capillary tubes bundle (mark 7) will be higher than the initial gas velocity at the well bottom-hole. Accordingly, due to the higher gas flow rate, the fluid will be carried more intensively to the surface.

In more detail, the cross-section of the centre tubing string is shown in Fig.6 and represents a system of capillary tubes united by cross-

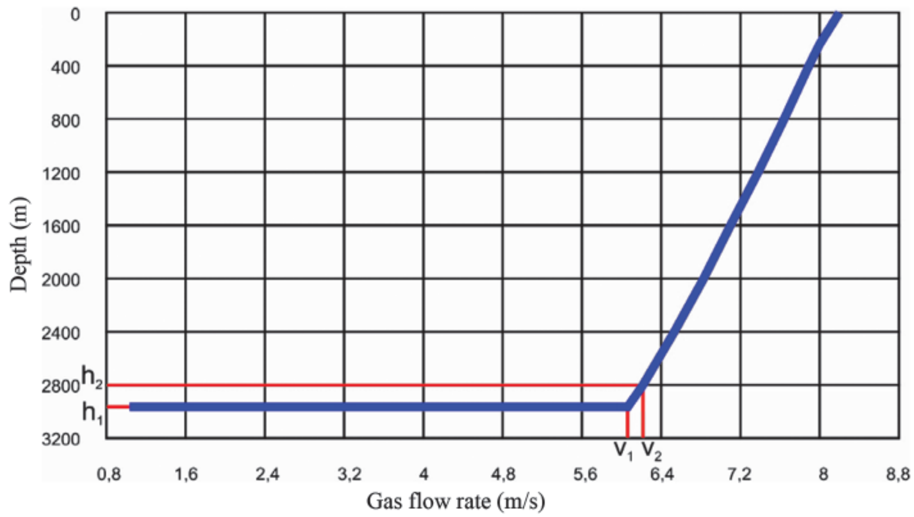
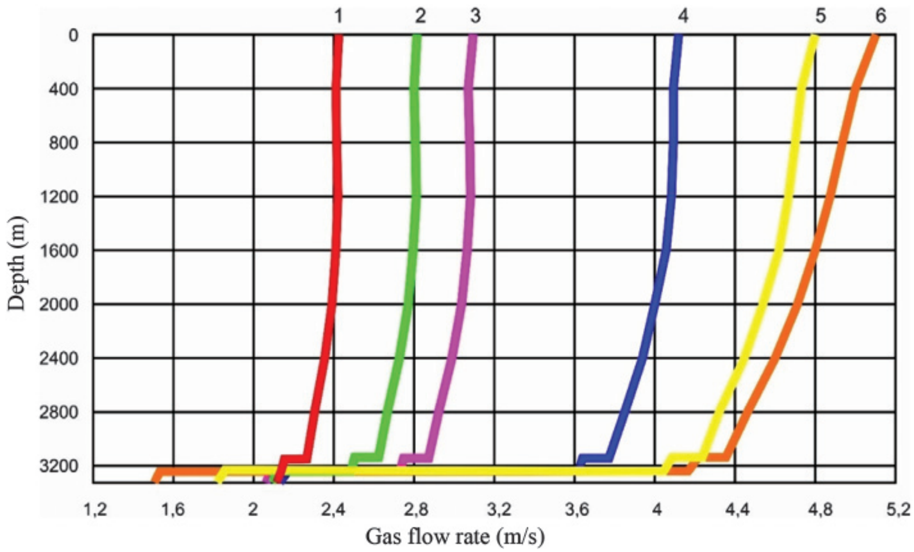


Fig7 Diagram of the gas velocity through the wellbore



1. In a pipe with a diameter of 114 mm;
2. In the annulus between pipes 114 and 38 mm;
3. In the annulus between pipes 114 and 48 mm;
4. In a pipe with a diameter of 89 mm;
5. In the annulus between pipes 89 and 38 mm;
6. In the annular space between pipes 89 and 48 mm.

Fig.8 The results of the gas flow rate modeling at different ratio of the tubing string diameters

links. This design will reduce the risks of shutting down the capillary during clogging due to an increase in the degree of fluid run freedom (Fig.6).

4.0 Discussion

In the concept presented here, the capillary radii are selected on the basis of the gas velocity diagrams through the wellbore. With a known critical gas velocity, the height of the required fluid lift (h_2) is selected, at which the gas velocity (v_2) will be higher than the critical gas velocity (Fig.7); required capillary diameter is calculated to lift the fluid to a given height [24].

It should be noted that the gas flow rate increases in the «pipe-in-pipe» (PIP) system in comparison with the single pipe variant (Fig.8). Thus, in the annulus between the outer wall of the centre tubing string, equipped with a capillary system, and the inner wall of the main tubing string, the gas flow rate will increase additionally due to the decrease in the diameter of the annulus [25].

5.0 Conclusions

The concept presented here is only a theoretical study of the very possibility of such approaches in application. A full-fledged implementation of this method will be possible when solving many accompanying problems: production of super-thin capillaries (selection of heat-wear-resistant materials for the manufacture of the capillaries capable of withstanding reservoir pressures without significant deformations); methods of super-thin perforation of capillaries; development of methods for capillaries cleaning during the critical clogging with solid suspended particles contained in the produced fluid.

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$5 TRILLION GDP BY 2024 – SIGNIFICANCE OF RESOURCES SECTOR IN INDIAN GDP: AN OPPORTUNITY FOR AUSTRALIA’S RESOURCES SECTOR?

(Continued from page 324)

Australia can continue to position itself as a strong, reliable supplier of resource commodities and METS services to India. It can also offer its skills to help India modernise mining, improve the quality of its products and to develop its trained human capital.

There are also opportunities for Australia and India to forge a mineral research, exploration and development alliance that can improve India’s relatively inefficient mining practices, as well as its mine safety and rehabilitation.

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