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Theoretical basis for determining the practical loss of production in the barrel of oil and gas wells

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I. Introduction

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For the first time in oil and gas industry practice special issues on the loss of extracted products are considered, which is a mixture of two and multi component phase systems in the wellbore, during its ascent to the wellhead in a turbulent regime, due to the formation and impact of negative pressure and the gravitational force of the earth.

The technological process is described in terms of the frequency of its change, physicochemical and thermodynamic properties, the main technological parameters of the products produced in the wellbore, and theoretical methods for determining the loss.

On the basis of a long-term study of the practically assembled technological parameters in the board, bottomhole and wellhead, empirical formulas are given for determining the coefficient of resistance and mass of lost production in the barrel, flowing back to the bottomhole, and solutions are also given. This material will allow students, post-graduate students, scientists and engineers to obtain necessary and partially scientific and practical training for the work in the field of oil and gas production, preparation and transportation of production.

From the first day of development of oil and gas condensate fields, production (oil, gas, water, mechanical impurities) is carried out due to naturally occurring reservoir energy, and technological flow of wells takes place. As the field develops, the operating conditions of the wells are deteriorating: the physico-chemical state of the products often changes, the produced natural or associated petroleum gas, the watercut of the production is increased, the hydrostatic pressure of the column of the production increases, which leads to a decrease in the well production rate, the formation of a high viscosity oil emulsion, a significant increase in pressure loss, not friction when rising the wellbore and flow-line of the well, the formation of a sand corks in both the bottomhole shoe and the wellbore, the reduction of the effective gas factor, in the pressure decrease, and accordingly in the debit wells and so on.

Therefore, the reasoning behind this work is that the presence of high reservoir pressure and temperature, which in many respects determines the special conditions of turbulent movement of products in the process of exploitation of oil and gas wells to the mouth, creates complicating factors in the barrel -this is the negative pressure and influence of magnetic-gravitational force of gravity.

The technological process leading to loss of production in the barrel is practically impossible to be determined using the appropriate instruments, however, the commercial truth about loss is based on the practically measured parameters in the layer, bottomhole and at the wellhead. Laboratory analyzes of the products confirm that the change in technological parameters in the wellbore leads to a change in the physicochemical and thermodynamic potential of the product, and this, in turn, accelerates the effect of negative pressure and the magnetic-gravitational force of gravity. In this process, under the influence of negative pressure and magnetic gravitational force of gravity, a part of the production passes to the zone of the boundary in the wells near the inner wall of tubing, along which it flows back to the bottomhole. This process also contributes to reducing the technological parameters of the product rising to the mouth along the barrel, consisting of a multicomponent phase system.

Therefore, in the process of raising production from the bottomhole to the wellhead, inside the tubing, a natural phase transformation of the hydrocarbon components takes place, characterized by abrupt changes in temperature, pressure, density, volume of production, viscosity and speed. As it is shown by numerous field measurements of process, parameters measured in the layer, at the bottomhole and at the wellhead, the change occurs for many factors, but the main ones are pressure and temperature [1,8].

The authors studied the technological process of several wells exploitation in NGDU named after May 28 during 5 years and practical measurements of the main technological parameters were carried out. After processing, numerous data were summarized and listed in Table 1. These works were conducted for the first time in the process of oil and gas wells exploitation in conditions when there is a constant change of technological parameters in the layer, in the bottomhole and in the wellhead.

As it is seen from table 1, only two main technological parameters change increases the pressure drop and temperature in the barrel of lifting tubing and this contributes to the formation of the influence of the magnetic-gravitational force of the earth's gravity and the negative pressure in the wellbore. As a result, this rise in production occurs in an enhanced turbulent regime, resulting in its losses in the barrel.

Table 1

N	Measured parameters	On the central lifting tubing	On the annular lifting tubing	Central tubing temperature, ^0C
1	2	3	4	5
1	Debit, t/day	125	86,5	5
2	Bottomhole pressure, kgs/ cm^2, (P_1)	166	148	-
3	Wellhead pressure, kgs/ cm^2, (P_1)	66	61	-
4	Differential pressure on the tubing, (ΔP)	99	87	-
5	Bottomhole temperature (T_1), ^0C	-	-	48/61
6	Wellhead temperature, (T_2), ^0C	-	-	16/18
7	Differential pressure on the tubing, (ΔT)	-	-	32/43

Having studied numerous main measured technological parameters of the exploited wells, it can be concluded that, the loss of pressure in the barrel between the bottomhole and the wellhead is 30-40%, and the temperature loss in the barrel between the bottomhole and wellhead is 35-40%.

As it is seen from fig. 1, in the initial period of the rise of production from the bottomhole to the welhead, boundaries 10 are formed at the inner surface of the tubing, and this is shown by reverse direction of pointers 8, whereby the product in this zone under the influence of negative pressure and the magnetic-gravitational force of gravity flows down to the bottomhole.

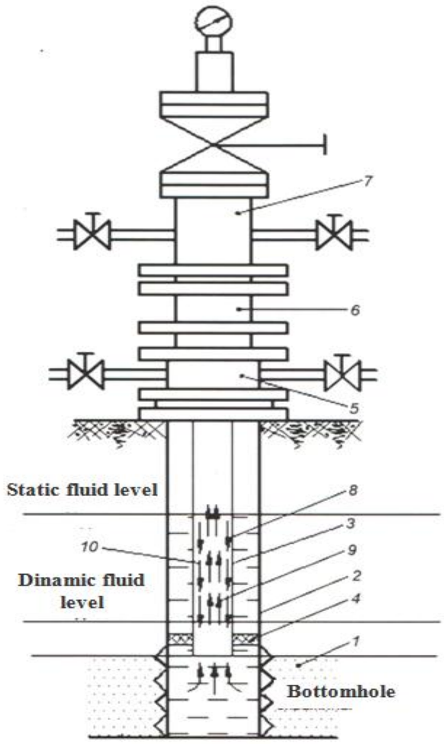

Fig. 1. Schematic diagram of gushing and compressor gas-lift production of wells.

In this diagram: 1 - is a bottomhole; 2 - is an exploitation annular column; 3 - is a fountain (gas lift) central lifting pipes (tubing); 4 - is a packer; 5 - is a preventer; 6 - is an adapter; 7 - is a Christmas tree; 8 - is direction flow of products along the inner wall of the fountain lifting tubing back to the bottomhole; 9 - is the direction of production lifting from the bottomhole to the wellhead; 10 - is a boundary layer on the inner walls of the lifting tubing.

The measured industrial data and laboratory analyzes of oil and gas being the basis of production have shown that the changes in the physical and chemical potential actually taking place are accompanied by the changes in the volume of production. At the same time, it was necessary to investigate the distribution of gas molecules with different pressures and velocities being one of the main operating forces of lifting products throughout the inner vertical and transverse contour of the tubing and contributing to a change in viscosity and specific gravity.

It means that the physicochemical properties of the extracted products during the rising along the barrel to the wellhead in the enhanced turbulence regime also affect the formation of negative pressure and create favorable conditions for the effect on the maximum level of the magnetic-gravitational force of the earth’s gravity. The problem of forming a rational version of the use of the equation of the energy state of real gases [2] for two and multiphase systems in the wellbore, of which the extracted production consists, is reduced to the choice of such a scientific and practical solution that will effectively manage the technological process with underestimated technological parameters, minimum impact of complicating factors leading to loss of production in the barrel for the entire life of the well.

In the literary sources, which we were able to get access, not any article or monography was found, whereby an attempt was made to study the effect of negative pressure and the magnetic gravitational force of the earth’s gravity, leading to loss of extracted products in the barrel of the tubing [3]. The main issues of interest to industry engineers in the exploitation of oil and gas condensate wells are the determination of pressure and temperature losses in the barrel, as well as the effects of negative pressure and the magnetic-gravitational force of the earth’s gravity, which cause loss of production.

From industrial practice it is known that, with time the energy of the layer decreases and the operational technological parameters are significantly reduced, and the volume (mass) of the extracted production is limited. To this end, in order to use the equation of the energy state of real gases and to determine the pressure loss, the temperature in the barrel of the tubing, taking into account the influence of the magnetic-gravitational force of the earth’s gravity, the negative pressure in the barrel, it is recommended to introduce a correction empirical parameter to the existing equation [4,5]. In this case, the positive part of the pressure drop and temperature is expended on friction, i.e. overcoming the resistance of the falling product along the barrel of the tubing [6,7] with a change in its physicochemical properties.

In contrast to the previous practice, the study of oil and gas condensate wells exploitation in conditions of lowering technological parameters, the influence of magnetic-gravitational force of earth’s gravity and negative pressure in the barrel on parameters rising to the wellhead of the product is relevant. In addition, in the existing literature there are no papers describing the effect of pressure drop and temperature, magnetic-gravitational force of the earth’s gravity and negative pressure on the products rising along the wellbore, resulting in a loss of 6-7% of the produced products. The study of this phenomenon is even more urgent when the reservoir energy is not actively manifested. In this case, the delta pressure will increase, and hence the actions of gravitational force and negative pressure will also increase. As a result, there will be a decrease in the technological parameters of the well, a change in the physicochemical and thermodynamic potential of the extracted products, losses in the barrel will increase and the volume of production to be extracted at the wellhead will decrease [8].

Using the equation of the energetic state of real gases for determining the loss in the barrel of products consisting of two and multiphase systems, a corrective technological parameter is introduced: the mass of the product lost in the barrel (m) and the coefficient of resistance (λ), i.e. the friction between liquids rising to the wellhead and flowing back to the bottomhole. At the present time, there is no practical or theoretical work on a unique relationship with the internal technological parameters of products, negative pressure and magnetic-gravitational force of gravity in order to establish the exact causes and mechanism of loss of production in the wellbore.

Figure 2 describes the product loss curves in the barrel due to the action of negative pressure and the magnetic-gravitational force of gravity - this is the opposite direction of the gravitational force rising to the wellhead of the flow in the wellbore.

As it is seen from figure 2, a great opportunity opens up a way of flexible regulation of technological parameters at the wellhead to establish a stable turbulent regime for lifting products and, at the same time, to reduce the effect of negative pressure and magnetic-gravitational force of gravity, and consequently loss of production in the barrel.

The foregoing allows us to conclude that, without studying the parameters of the current state of exploitation of each well, it is practically impossible to make a decision on the flexible regulation of technological parameters in order to minimize the turbulence of lifting the product to the wellhead, the effect of negative pressure and the magnetic-gravitational force.

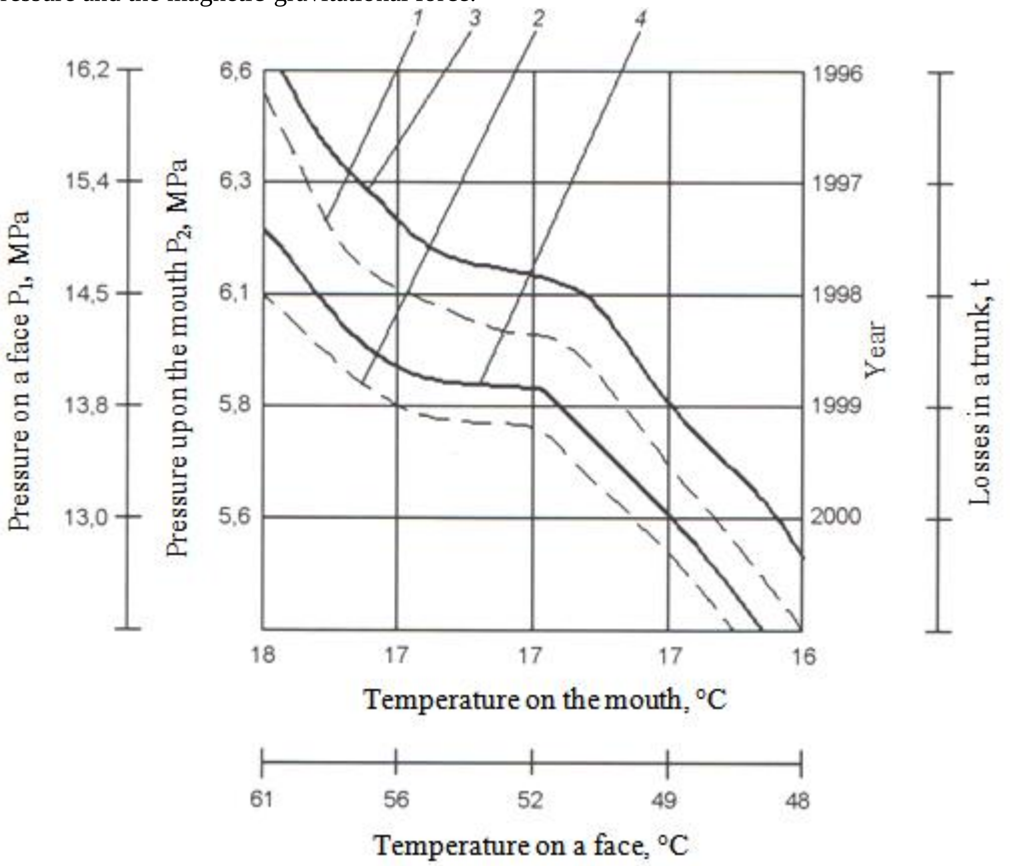

Fig. 2. Nomogram of pressure and temperature changes in the bottomhole, wellhead and production loss curves in the barrel.

1-is provided production according to the technological regulations of the industry on the central hoist; 2 -is the actually measured production in the wellhead by the central hoist; 3 -is the provided production according to the technological regulations of the industry along the annular hoist; 4 -is actually measured production at the wellhead.

It is required for each well in the fields to study the primary technological parameters at the wellhead and in the bottomhole, after which a decision on the regulation of technological parameters is made by the operating personnel. Industrial practice shows that, in order to optimize the operation of oil and gas wells by the operating personnel, it is necessary in advance to establish a mode of operation for production, according to the approved process schedule for each well. For several years, the study of the work of wells and measurement of technological parameters in the wellhead and the bottomhole showed a real difference of about 6-7% between the measured production at the wellhead and the technological regulations of the field. This process is clearly seen in fig.2., where the nomogram of the pressure and temperature change in the bottomhole, the wellhead and the production curves in the barrel are shown. As a result of this technological process, a part of the production falls into the zone of the turbulent boundary layer near the inner wall of the tubing and from there flows back to the bottomhole. Moreover, this process is irreversible, and under the conditions of frequent changes in technological parameters it is not able to resist before the rate of falling production to the bottomhole.

In this regard, the increased rate of falling production back to the bottomhole approximation is taken in the interval of thirty and twenty-five millionths of the speed of light, which is V= 10:12 m/sec.

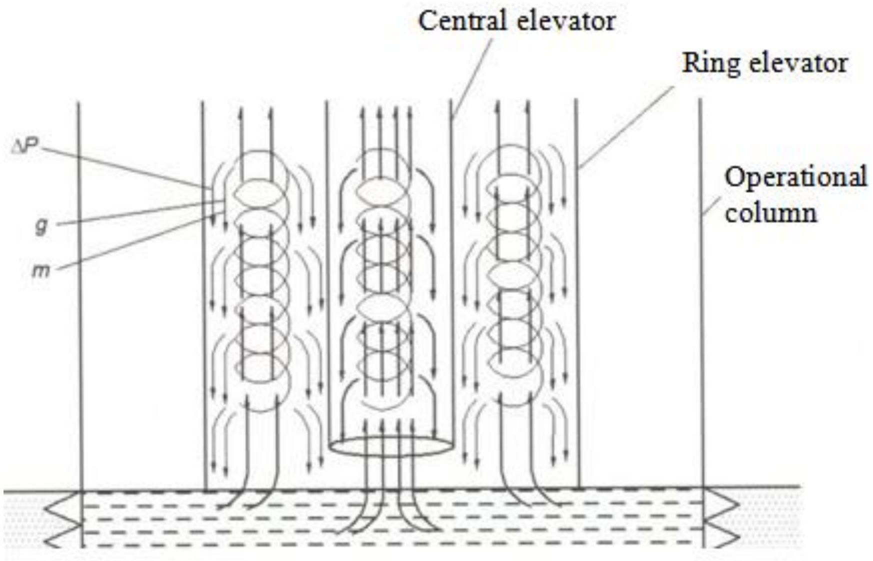

Fig.3. The scheme of the negative pressure effect of the magnetic- gravitational force of gravity and the turbulent boundary zone of the inner wall of the lifting pipes of the well.

ΔP - is the direction of negative pressure action;
q - is the magnetic-gravitational force of gravity, i.e., constant;
m - is the mass of the product, merging back to the bottomhole.

Figure 3 indicates the technological process of directing the action of negative pressure (ΔP) and the magnetic-gravitational force (d), as well as the direction of the rate of production flowing back to the bottomhole at a speed.

For the aforementioned reasons, the mass of the product (t) lost in the barrel is directly proportional to the negative pressure and the magnetic-gravitational force of gravity and the direction of action of these forces coincides with the direction of the rate of mass drop (t). Therefore, the larger the production mass, measured in the wellhead, the greater the mass of lost products in the barrel. This is clearly seen from the nomogram of falling production back to the bottomhole (Fig. 3), which is compiled on the basis of practical measured data in 1996-2000.

Against the background of annual decrease in production from oil and gas wells and the effect of negative pressure and magnetic-gravitational force in the form of a gravitational constant, as well as the drop rate, the authors propose an empirical formula for determining the mass of products (t) that flows back to the bottomhole:

$$m = \frac{2V^2(R_1 + R_2) \cdot \Delta P \cdot l \cdot \lambda}{g \cdot \Delta h \cdot 1000}, \qquad (1)$$

where V is the drop rate to the bottomhole of the detached part of the production in the wellbore, its approximate value is assumed $M = 10 \div 12 m/sec.$; R_1 is the radius of the tubing of the central lift, according to the approved technological regulations of the field, it is taken as $R_1 = 76mm$; R_2 is annular hoist according to the approved technological regulations of the field, $R_2 = 101mm$; ΔP is current pressure drop in the wellbore. For the central lift, taking into account the data in Table 1, we take $\Delta P_{C.E.} = P_1 - P_2 - 166 - 66 = 100\ kq/sm^2$, for the annular hoist we take $\Delta P_{A.E.} = P_1 - P_2 - 148 - 61 = 87\ kq/sm^2$; l is the average depth of tubing, where the approximate loss of production. From the operational experience we take $l = 1800 \div 2000m$; coefficient of hydraulic resistance, takes into account the resistance or internal friction, moving towards each other products during the rise and fall in the wellbore. There are many different empirical formulas for determining the value of hydraulic resistance.

With constant changes in the technological parameters of oil and gas wells, as well as the effects of negative pressure and magnetic-gravitational force, in order to determine the coefficient of hydraulic resistance (λ), the authors propose an empirical formula for introducing it into equation (1):

$$\lambda = 0{,}227\left(\frac{P_1 + P_2}{\Delta P} + \frac{T_1 + T_2}{\Delta T}\right), \tag{2}$$

where 0.2227 is the empirical correction factor [3];
P_1 is measured bottomhole pressure;
P_2 is the measured pressure at the wellhead;
ΔP is pressure drop in the wellbore of the well;
T_1 is the measured temperature at the bottomhole of the well;
T_2 is the measured temperature at the wellhead;
ΔT is the temperature drop in the wellbore.
Taking into account table 1, the authors propose the solution of equation (2) and the following data are taken as a sample:
1) On the central elevator (hoist):
$P_1 = 166\,kqs/sm^2$; $P_2 = 66\,kqs/sm^2$; $\Delta P = 100\,kqs/sm^2$; $T_1 = 48^\circ C$; $T_2 = 16^\circ C$; $\Delta T = 32^\circ C$.
Substituting these data into formula (2), we obtain:

$$\lambda = 0{,}2227\left(\frac{166 + 66}{100} + \frac{48 + 16}{32}\right) = 0{,}96\ .$$

2) On the annular elevator (hoist):
$P_1 = 148\,kqs/sm^2$; $P_2 = 61\,kqs/sm^2$; $\Delta P = 87\,kqs/sm^2$; $T_1 = 61^\circ C$; $T_2 = 18^\circ C$; $\Delta T = 43^\circ C$.

Substituting these data into formula (2), we obtain:

$$\lambda = 0{,}2227\left(\frac{148 + 61}{87} + \frac{61 + 18}{43}\right) = 0{,}984\ .$$

In order to determine the loss of production from the central lift, it is taken as: $\lambda = 0{,}96$; $g = 981\,sm/sec^2$; Δh is the average distance between the dynamic and static levels of the well, it is practically taken as $\Delta h = 300m$; 1000 – non-dimensional reduction coefficient for transmitting to a single measurement system and substituting the data into formula (1), the mass of production lost in the barrel of the central hoist is determined as follows:

$$m = \frac{2V^2(R_1 + R_2)\cdot \Delta P \cdot l \cdot \lambda}{g \cdot \Delta h \cdot 10000} = \frac{2 \cdot 1440000 \cdot 17{,}7 \cdot 200000 \cdot 96}{981 \cdot 30000 \cdot 10000} = 3300\,kq \approx 3{,}3\,ton\,.$$

After that, a comparison was made using the static method of practically measured parameters of the calculated data at the wellhead and the data was described in the geological and technological regulations of the field, and it was discovered that these data differ from each other.
Using the practically measured data (Table 1), the solution of equation (1) shows that there is a loss of product in the tubing, about 6-7% of the total production.
Using the empirical formula (1), and introducing it into the equation of the energy state of real gases consisting of two and multicomponent phase systems located in the lifting tubing, a unified equation for the state of real natural and associated petroleum gases is obtained in the following form [9]:

$$PV\Delta_{R.D.} = Z_{Q.P.} \cdot RT\frac{2}{3}W_\Delta \cdot \Delta_{r.v.p.w.} \cdot m, \tag{3}$$

For the practical solution of formula [3], the value of the discovered *t* is taken, and the remaining data are presented in [3,4,9], namely:
$P = 66\,kq/sm^2$ -pressure on the central hoist at the wellhead;

$\Delta = 0{,}62$ is relative density (specific gravity) of gas by air:

$m = 3300kq$ is the mass of the product lost in the barrel, flowing back to the bottomhole of the well;

$Z_{Q.P.} = 0{,}89$ is the gas compressibility factor in the flow of the produced products;

$R = 47{,}3m/deg$ is a universal gas constant;

$T = 289^{\circ} K$ is the temperature at the central hoist at the wellhead;

$\Delta_{r.v.p.w.} = 0{,}857$ is relative viscosity of the product at the wellhead, after leaving the 1st stage of the oil and gas separator.

Comparing all the data in formula (3), the volume of the production in the wellhead is determined after the nipple at the discharge of the first stage of the horizontal oil and gas separator:

$$V = \frac{Zqp \cdot RT\frac{2}{3}W_{\Delta} \cdot \Delta_{r.v.p.w.} \cdot m}{p \cdot \Delta \cdot \lambda} = \frac{0.89 \cdot 47.3 \cdot 283\frac{2}{3}0.43 \cdot 0.857 \cdot 3300}{66 \cdot 0.62} = 240.5t \approx 283m3$$

Thus, the determined volume of the produced oil 283 m3 calculated by formula (3) is insignificantly different from that measured at the wellhead with corresponding devices by the operating personnel in the volume of 279 m3 and registered in the field logbook. In this case, the deviation of production loss in the wellbore is no more than 7% or 3.3 tons.

II. Conclusions

1. The empirical formulas (1) and (2) mean that it is a question of a practical hypothesis that does not pretend to be absolutely correct, obligatory and final, but it stimulates further research.
2. The production extracted from the well constituting a mixture of two and multi-component phase systems, often changes its physico-chemical properties and technological parameters, where, together with the influence of negative pressure and the magnetic-gravitational force of the earth's gravity, leads to loss of product in the barrel.
3. The changes in technological parameters in the form of pressure drop and temperature, taking into account the influence of negative pressure and magnetic- gravitational force of the earth's gravity in aggregate, in any section of the barrel of lifting tubing, leads to an increase in resistance to rising production, which contributes to its loss of about 6- 7%.
4. Comparison of the calculated indications of the volume (mass) of oil with the practically measured at the wellhead differ with an error of about 7%. This corresponds to the mass of the product lost in the wellbore and therefore, the use of formula (3) in the field conditions is quite acceptable.
5. The operational personnel on the fields is suggested to apply special conditions of operation of oil and gas wells with flexible regulation of technological parameters in the barrel in order to keep the production output in the required volume (weight) and to reduce as much as possible the turbulence of the rise in production and the effect of complicating factors.

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