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Analysis of uncontrolled flares in the oil and gas industry

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ABSTRACT :*During the drilling carried out to explore or exploit oil and/or natural gas deposits, there were uncontrolled eruptions (technical accidents) that led to the damage of the well and significantly affected the ability of the productive layers to continue producing under the initial conditions provided by the initial exploitation projects. This article describes the main ways these accidents occur and analyzes the effects of changing the hydrostatic pressure of the drilling fluid during drill string handling.*
KEYWORDS *oil, gas, drilling, eruption, flare, accident.*

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I. INTRODUCTION

During the drilling carried out to explore or exploit oil and/or natural gas deposits, uncontrolled eruptions (technical accidents) damaged the well and especially affected the ability of the productive layers to continue producing under the initial conditions provided by the initial exploitation projects.

These (serious) technical accidents can occur [1]:

a. During the crossing of the productive layer, as a result of the penetration of the fluids that saturate this layer into the drilling fluid,
b. As a result of the pressure variation during the drill string extraction maneuver,
c. As a result of carrying out pistoning or sleeve operations of the productive layer and/or the tubing string,
d. Following the loss of drilling fluid during rock dislocation operations (as a result of its penetration into the productive layers) and its complete isolation,
e. As a result of using a blowout preventer that is not rated or is inappropriate for the pressure class in the well,
f. During drilling or well productivity enhancement operations,
g. As a result of erosion/corrosion of the drill tubing or tubing strings and thus the occurrence of unscheduled multiphase fluid leaks,

This is a result of the failure of the seals on the flanges of the columns or the eruption heads (the appearance of fluid leaks in the form of a jet).

It should be noted that the fluids that could erupt are made up of [2]:

a. Natural gas associated with productive deposits or under exploration,
b. Oil,
c. Water associated with the deposit penetrated by drilling,
d. Sand and traces of rocks dislodged by drilling,
e. Components of the drilling fluid (chemical products, biological products, components to increase the capacity of the productive layer, elements to reduce the permeability of the drilled layer, etc.),
f. Dislocated elements of equipment (metallic or otherwise) damaged by the uncontrolled flow of fluids from erupting wells.

An uncontrolled blowout occurs primarily because during drilling, during the passage of the layer saturated with pressurized fluids, a pressure imbalance usually occurs (between the hydrostatic pressure of the fluid column in the well and the pressure under which the fluids in the layer are found).

If the fluid column's hydrostatic pressure is lower than the formation's pressure, the formation fluids enter the wellbore fluid, resulting in a sharp drop in the fluid column's hydrostatic pressure at the formation level (due to the diffusion of gas particles in the drilling fluid).

It has been observed that fluids saturating the formation can penetrate the drilling fluid even if the hydrostatic pressure of the fluid column in the well (at the level of the formation) is higher than the pressure at which the fluids saturating the formation are found (due to the gasification of the drilling fluid by the adsorption of gases on the surface of colloidal clay particles in the drilling fluid).

In the case of saturation of the productive layer only with the liquid phase (there are no free gases or in solution), a decrease in the specific gravity of the drilling fluid is observed (which can be corrected), which is due to the diffusion of the liquid particles due to the density variation between the two fluids in contact.

Pathways of gas penetration into drilling fluids lead to gasification of the drilling fluid and are due to:

a. The dissolution of gases in the free water from the drilling fluid,
b. Diffusion in the form of bubbles,
c. Adsorption on the surface of colloidal particles,
d. Dislodgement of rocks by the drill bit and ingress of gases into the fluid,
e. Effusion processes.

II. DETERMINATION OF THE VOLUME OF GASES THAT ENTERS THE DRILLING FLUIDS

The volume of gases entering the solution is a function of pressure, temperature, nature of the gas, type of rocks, adsorption capacity of colloidal particles, etc.

The influence of pressure on the amount of dissolved gases (at a constant temperature) is determined by Henry's law:

$$V_g = \alpha p \tag{1}$$

In equation 1 α is the solubility coefficient of gases in liquid (Nm^3/m^3 atm), V_g represents the volume of gases dissolved in a m^3 of liquid (Nm^3/m^3), and p is the pressure of the analyzed system (bar).

However, considering that the temperature in a well cannot be constant (from the bottom of the well to the surface), the coefficient of solubility is variable (the solubility of gases is lower at the bottom of the well).

On the other hand, the volume of dissolved gases depends on the nature of the gas, with ethane and propane dissolving in a larger volume than methane.

In site practice, it was observed that as the digging fluid rises, the pressure at different levels decreases (toward the surface), leading to the exit of gases from the solution and, therefore, its gasification (reduction of specific gravity).

The penetration by diffusion of gases into the drilling fluids occurs near the layers saturated with hydrocarbons (especially when the circulation is interrupted for long periods).

The variation of the solubility coefficient of gases in liquid (depending on temperature) is given by the relation [1]:

$$\alpha_2 = \alpha_1 e^{\frac{\Delta H}{R}\frac{(T_2 - T_1)}{T_2 T_1}} \tag{2}$$

In equation 2 we have:

- α is Bunsen's constant (the coefficient describing the volume of gases expressed in standard conditions that dissolves in a unit volume of solvent at a given pressure and temperature),
- H is the differential heat of dissolution,
- T is the absolute temperature, ºK,
- R is the universal gas constant.

In the case of fluids containing gases from the productive strata (derived by diffusion from fluids existing in the productive horizons or containing gases in the composition), the extraction of the dislocated rocks takes place (through the circulation of the drilling fluid), the gas bubbles (present in the fluid) reaching the detritus treatment and separation unit.

In practice, it is desired that in the case of fluids containing associated gases, the digging speed should be chosen in such a way that the volume of gases entering the digging fluid is lower than that which would cause a decrease in the specific weight of the fluid between the column (wellbore) and the drilling casing and thus the migration of gases to the surface.

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In practice, it is desired that in the case of fluids containing associated gases, the digging speed should be chosen in such a way that the volume of gases entering the digging fluid is lower than that which would cause a decrease in the specific weight of the fluid between the column (wellbore) and the drilling casing and thus the migration of gases to the surface.

Adsorption of free gases on the surface of colloidal clay particles can lead to the manifestation of the productive layer (even if the hydrostatic pressure of the liquid column in the well at the level of this layer is higher).

Given that the trench fluids are colloidal solutions of clays and water, the radius of the particles being of the order of $r = 3 \cdot 10^{-6}$cm, the specific surface is of the order of $S = 105\ cm^2/dm^3$ of the fluid.

The value of the specific surface area of the rock particles brought to the surface by the drilling fluid is extremely high, at the boundary of the separation of the two phases (water/clay) the phenomenon of gas adsorption occurs (ie the agglomeration of gas molecules on the surface of the solid phase).

Thanks to this phenomenon, we can determine the fluid pressure in the layer (at equilibrium) as:

$$p_s = (\frac{1}{A\Psi} + C)\frac{h\gamma}{10} \qquad (3)$$

In equation 3 Ψ represents the content of gases embedded in the drilling fluid (expressed as a decimal fraction), *A* and *C* being experimentally determined coefficients.

Also in determining the pressure in the formation, it is important to determine the drilling depth *h* (m) and the specific gravity of the drilling fluid.

The analyzes performed on the data from the studied boreholes, demonstrate that the useful values for the coefficients *A* and *C* should be considered close to the values 1.08 and 0.074.

But analyzing equation 3 we can state that below the value $\Psi \leq 1$ (that is, below the saturation limit), the factor $\frac{1}{A\Psi} + C$ is greater than 1 and therefore there is the possibility of excavating a gas layer with a drilling fluid (dig) that has a hydrostatic pressure of the fluid column lower than the pressure in the layer.

The presence of gases in the drilling fluid makes the real pressure at the level of the productive layer to be[1]:

$$p_r = p_s - p_a = \frac{h\gamma}{10} \qquad (4)$$

Or the above equation can be written in the form:

$$p_r = \beta_a \frac{h\gamma}{10} \qquad (5)$$

Unde:

- $p_s$is the fluid pressure in the layer (bar),
- $p_a$is adsorption pressure (bar),
- $h$represents the height of the fluid column in the well (m),
- $\gamma$is the specific gravity of the drilling fluid(gr/cm^3),
- $\beta_a$represents a correction coefficient due to the phenomenon of adsorption.

This coefficient is a function of the gas content α in the drilling fluid (expressed as a decimal fraction) and two coefficients (*A* and *C*) determined experimentally.

$$\beta_a = \frac{1}{A^\alpha} + C \qquad (6)$$

Analyzing equation 6, it is observed that below the saturation limit $\alpha \leq 1$), we obtain $\beta_a \geq 1$ and therefore the pressure in the gas layer can be higher than the hydrostatic pressure of the drilling fluid used to penetrate this layer by drilling.

$$\beta_a \cong \frac{1}{1{,}08^\alpha} + 0{,}074 \qquad (7)$$

Upon reaching the gas adsorption limit in the drilling fluid, α>1, the gases penetrate through the drilling fluid cake (deposited on the wellbore walls) in the form of fine networks of bubbles (adhering to the solid particles in the drilling fluid).

The radius of these bubbles varies inversely proportional to the gas-fluid interfacial tension and the viscosity of the fluid, at high values of viscosity the bubbles have small radii and therefore can be more easily pulled from the walls of the wellbore by the drilling fluid in the movement in which they then penetrate it.

In order tomathematicalize the above mentioned, a correction factor was introduced which is a function of the viscosity of the digging fluid (μ expressed in s Marsch), namely:

$$\beta_V = 0{,}24\frac{1}{1+(\frac{\mu}{30})^2} + 0{,}88 \qquad (8)$$

In this case, the layer pressure of the fluids p_s can be written in the form:

$$p_s = (0{,}24\frac{1}{1+(\frac{\mu}{30})^2} + 0{,}88)(\frac{1}{A\Psi} + C)\frac{h\gamma}{10} \qquad (9)$$

Which has the condition fulfilled:

$$(0{,}24\frac{1}{1+(\frac{\mu}{30})^2}+0{,}88)(\frac{1}{A\Psi}+C)<1 \tag{10}$$

The influx of fluids from the layer into the well can occur although apparently the hydrostatic pressure of the drilling fluid column ($\frac{h\gamma}{10}$), at the level of the productive layer, has a higher value than the pressure of the fluids that saturate the p_s layer.

$$p_s = \beta_a\beta_V\frac{h\gamma}{10} \tag{11}$$

When the viscosity tends to infinity β_V from equation 11 becomes equal to 0.88.

If the product $\beta_a\beta_V < 1$ then the influx of fluids from the layer into the well takes place even if the numerical value of the hydrostatic pressure (($\frac{h\gamma}{10}$) of the drilling fluid at the level of the trench has a value greater than the pressure of the saturated layer p_s.

At low values of the drilling fluid viscosity, the bubbles are large and adhere strongly to the wellbore walls (requiring more mechanical energy to remove them).

II. ANALYSIS OF THE HYDROSTATIC PRESSURE CHANGE OF THE DRILLING FLUID DURING THE DRILLING RIG MANEUVER

The change in the hydrostatic pressure of the fluid column in the well, during the operation of the drill string, was highlighted by W.T Cardwell [2].

W.T Cardwell defined the viscosity of drilling fluid in linear flow, starting from the relationship of axially symmetric flow:

$$\frac{\partial}{\partial x}(p+\rho gh) = \frac{\mu}{r}\frac{\partial}{\partial r}(r\frac{\partial v}{\partial r}) \tag{12}$$

Where:

- *x* is the viscosity and velocity measurement distance along the flow axis,
- *p* is the drilling fluid pressure,
- *ρ* is the density of the drilling fluid,
- *g* is the gravitational acceleration,
- *v* is the velocity of the drilling fluid,
- *r* is the radius of the probe.
- *h* is the depth of the well.

Given that the x-axis corresponds to the vertical of the borehole, equation 12 can be written in the form:

$$\frac{\partial p}{\partial x} - \rho g = \frac{\mu}{r}\frac{\partial}{\partial r}(r\frac{\partial v}{\partial r}) \tag{13}$$

In the axial flow of the drilling fluid, none of the variables in equation 13 varies in the x-direction, except for pressure and pressure drop, and equation 13 can be simplified to:

$$\frac{\Delta p}{l} - \rho g = \frac{\mu}{r}\frac{\partial}{\partial r}(r\frac{\partial v}{\partial r}) \tag{14}$$

In equation 14, Δp is the pressure drop over length l (which is taken to be the length of a cylinder of surface *S* immersed in a cylinder of radius *R*.

An approximation is implicitly introduced in equation 14, namely that considering the flow at depth, its effects on the borehole radius can be neglected, the deviation of the pressure from the hydrostatic pressure being equal to:

$$P = \Delta p - \rho g l \tag{15}$$

In this case equation 15 becomes:

$$\frac{P}{l} = \frac{\mu}{r}\frac{\partial}{\partial r}(r\frac{\partial v}{\partial r}) \tag{16}$$

Equation 16 allows us to define the fluid flow (drilling fluid) inside the drill string (with radius *S*) and in the area between the drill string and the wellbore with radius *S*.

The equation for the flow rate of the drilling fluid through the inside of the drill string is given by the relation:

$$Q_p = -\frac{\pi P S^4}{8\mu l} + \pi S^2 u \tag{17}$$

And integrating the fluid flow through the area between the well and the drill string, we get:

$$Q_a = -\frac{\pi P S^4}{8\mu l}(R^2-S^2)\left(R^2+S^2-\frac{R^2-S^2}{ln\frac{R}{S}}\right)+\frac{\pi u}{2}(\frac{R^2-S^2}{ln\frac{R}{S}}-2S^2) \tag{18}$$

If the borehole of radius R is closed at the bottom, the two fluxes must cancel each other out:

$$Q_p + Q_a = 0 \tag{19}$$

$$P = \frac{4l\mu u}{R^2}\frac{1}{(\frac{z^2}{z^2-1})lnz-(\frac{z^2}{z^2-1})} \quad (20)$$

$$P = \frac{4l\mu u}{R^2}F(z) \quad (21)$$

Where$z = \frac{R}{S}$and$u$is the velocity of the fluid.

The function *F(z)* is given by the relation *F(z)*=$\frac{1}{(\frac{z^2}{z^2-1})lnz-(\frac{z^2}{z^2-1})}$, in the specialized literature being determined by numerical calculation.

Analyzing the data from the wells in Romania We managed to calculate the value of the function *F(z)* as a function of *z*, namely (figure 1):

$$\boldsymbol{F(z) = -0{,}0057z^6 + 0{,}1767z^5 - 2{,}1847/\ /z^4 + 13{,}686z^3 - 45{,}007z^2 + 70{,}913z - 35{,}963} \quad \textbf{(22)}$$

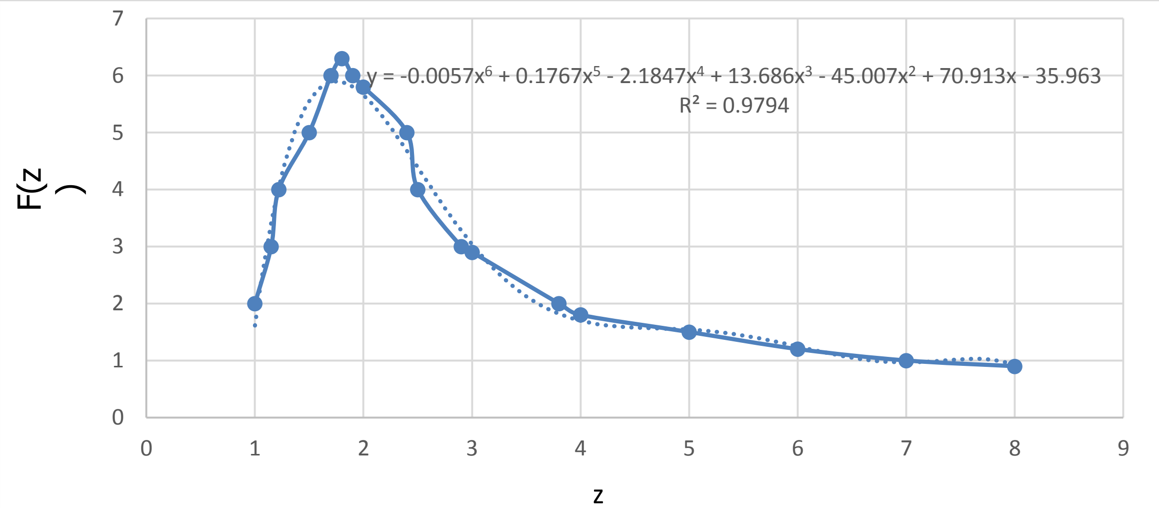

Fig. 1.Evolution of the function *F(z)* as a function of *z*,(*F(z)*=$\frac{1}{(\frac{z^2}{z^2-1})lnz-(\frac{z^2}{z^2-1})}$**)**

With a margin of error (the proportion of variation in the dependent variable that is predictable from the independent variable) $R^2 = 0.9794$.

So when pulling a cylindrical tube (the drill string) into another fluid-filled tube (the wellbore), the fluid in the immediate vicinity of the rising tube is entrained in the same direction, while the fluid further away from the tube tends to descend.

Since the fluid in the tube (annular space) has an appreciable viscosity (of the drilling fluid) a shear phenomenon occurs between the two streams, the rising fluid tends to decrease the hydrostatic pressure of the fluid column.

These pressure variations occur along the drill string and decrease along the fluid column from the bottom of the well to the surface.

So the pressure drop also depends on the extraction speed, increasing with the packing lift speed.

These pressure variations occur along the entire drill string and decrease linearly from the bottom of the well to the surface.The pressure drop that occurs along the fluid column depends on the extraction speed, i.e. it increases with the casing lifting speed and also increases with the size of the annular space between the rod casing and the wellbore and directly proportional to the viscosity of the drilling fluid.

In the case of loading the hoe or the heavy drill with materials resulting from the dislocation of the rocks, the space between them and the borehole shrinks even more so that this pressure variation, in reality, leads to a decrease in the hydrostatic pressure of the liquid column (so at a value of this the layer starts to produce).

During the period when the gasket is stopped to unscrew a step, the balance is restored, but the pressure variation will occur when the next step is extracted.So fluids saturating the formation penetrate from the formation into the borehole as plugs at approximately equal time intervals. As the number of plugs increases, they are transshipped to the surface, causing small eruptions.Finally, the hydrostatic pressure of the liquid column in the well drops below the value of the pressure in the productive layer, at which point the layer will ensure the violent eruption of the drilling fluid-petroleum fluid mixture.

In the case of plugging the hole holes, the pressure variation is accentuated at all levels in the well.

As the drill string (rod) is lowered into the wellbore, the same phenomenon occurs, except that the additional pressure this time acts downward, resulting in an increase in the hydrostatic pressure of the fluid column exerted on the lower stratum.The increase in the value of the hydrostatic pressure leads to the reaching of the cracking pressure of the productive layers and therefore the decrease of the liquid level in the well (due to its penetration into the cracks).When the seal is turned off, the balance is restored, but the liquid level in the well being low and therefore the value of the hydrostatic pressure having a lower value than the pressure of the petroleum fluids, it may lead to the appearance of some eruptive manifestations, due to the influx of fluids from the layer into the well.

Crossing an area with loss of circulation (area under oil, gas or aquifer formations) causes the level of liquid in the well to decrease and therefore the hydrostatic pressure of the column of liquid in the well (at the level of these formations) will become lower than the pressure under which the fluids that saturate the respective formations are found and therefore the fluids in the layer will begin to erupt.

Unlike the pistoning or sleeve effect, the pressure variation effect can occur at the rod packing without any external (ie perfectly clean) deposits or plugging of the hoe holes.

The pistoning or sleeve effect occurs when the bit, heavy rod or turbine is covered with rock material, and as the liner moves up, there is a decrease in the hydrostatic pressure of the fluid column below the sleeve, which causes fluids from the formation to flow into the wellbore.

When the maneuver is stopped, the pressure is restored, but the gases and crude oil no longer enter the layer, by repeating the phenomenon reaching a moment when the hydrostatic pressure of the liquid column at the level of the layer is lower than the pressure in the layer, so the sudden eruptive manifestation of the layer can be triggered.

Based on the data collected in the specialized literature, in the following we created a numerical model regarding the evolution of the pressure drop when pulling or handling the drill string for three pipe diameters (2 7/8 inches, 3 ½ inches and 4 ½ inches) in several time periods (90 seconds, 30 seconds, 10 seconds).

Thus we determined the pressure drop reported in psi/1000 feet (0.0689 bar/304 m or 0.000227 bar/m).

The equations are given Figures 2,3,4 and table 1.

In the above equations y represents the pressure drop reported in psi/1000 feet (0.0689 bar/304 m or 0.000227 bar/m) and x is the borehole diameter (inches).

Table 1.Pressure drop reported in psi/1000 feet (0.0689 bar/304 m or 0.000227 bar/m).

Times to operate, s	Diameter of drilling pipe	Equation
90	2 7/8	$y = 203,41e^{-0,428x}$
90	3 ½	$y = 60,61e^{-0,25x}$
90	4 ½	$y = 70,39e^{-0,244x}$
30	2 7/8	$y = 317,39e^{-0,363x}$
30	3 ½	$y = 437,01e^{-0,374x}$
30	4 ½	$y = 490,27e^{-0,362x}$
10	2 7/8	$y = 1228,3e^{-0,413x}$
10	3 ½	$y = 1479,8e^{-0,362x}$
10	4 ½	$y = 1150,5e^{-0,371x}$

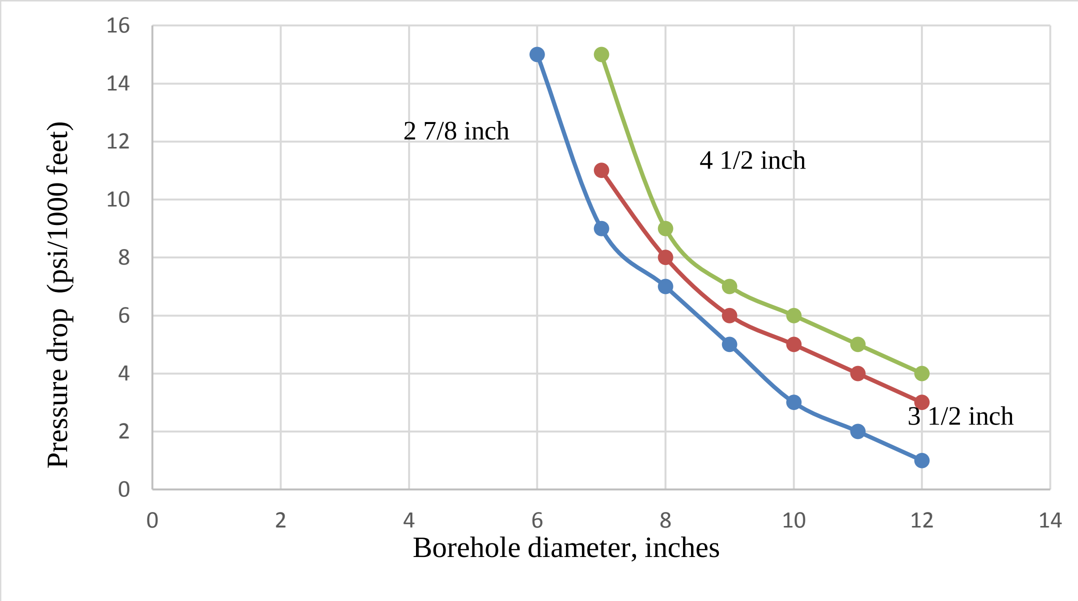

Fig.2. Evolution of pressure drop (psi/1000 feet) as a function of borehole diameter and drill string diameter at a 90 s handling time

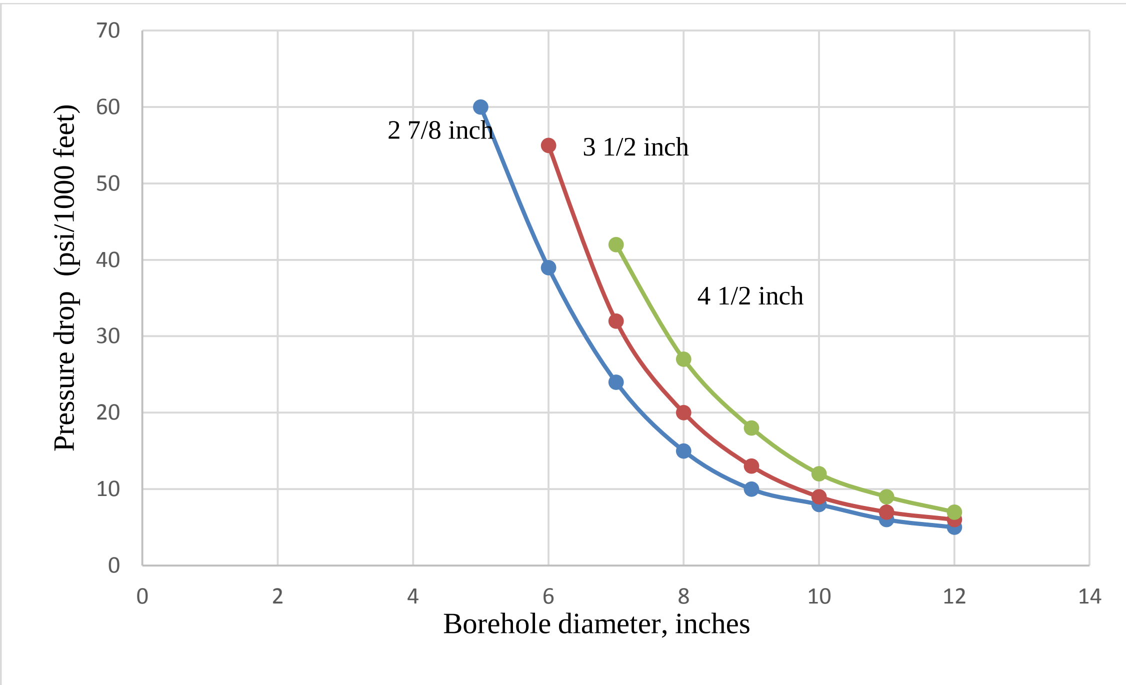

Fig.3 Evolution of pressure drop (psi/1000 feet) as a function of borehole diameter and drill string diameter at a 30 s handling time

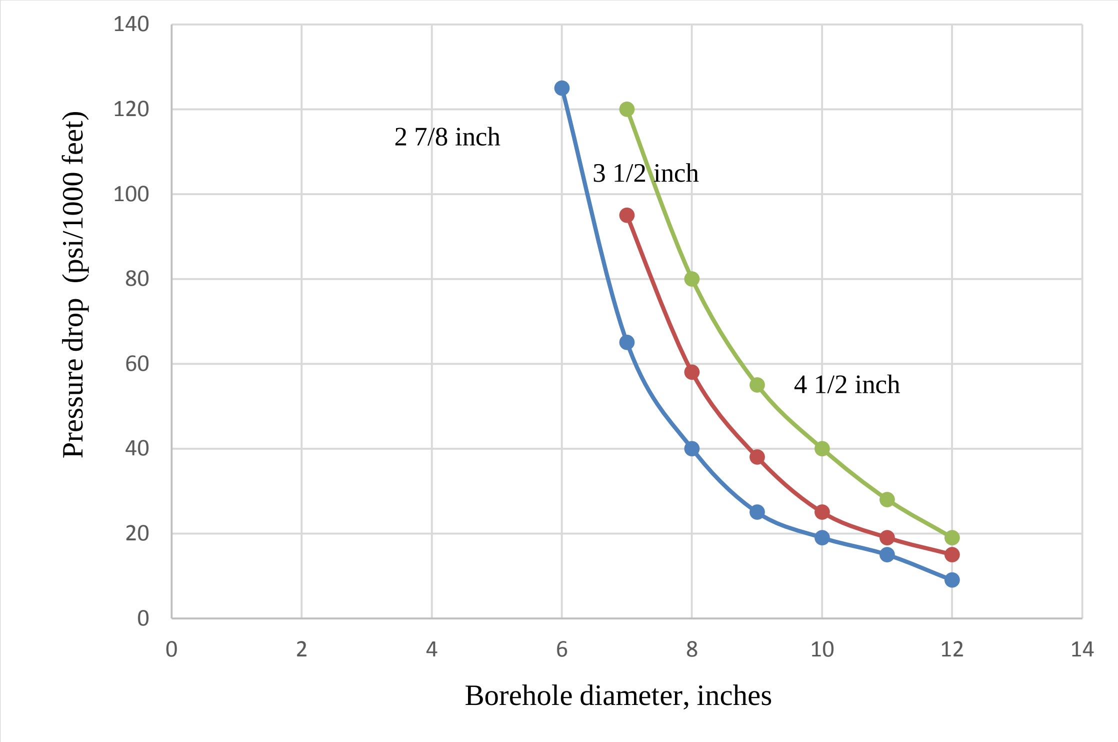

Fig.4. Evolution of pressure drop (psi/1000 feet) as a function of borehole diameter and drill string diameter at a 10 s handling time

III. The variation of the pressure in the head of the column according to the bottom pressure at the wells in the borehole

Writing the energy balance equation between the corresponding section of the lower part of the column (at the level of the productive layer) and the exit section from the well, we will obtain:

$$\int_{p_f}^{p_c} V dp + L + \Delta\frac{v^2}{2g} + F + \tau = 0 \qquad (23)$$

In equation 23 p_c and p_f are the pressures in the column (from the surface) and at the level of the productive layer (kgf/m^2), V is the specific volume of the gases (m^3/kg), L is the length of the analyzed column (m), v is the gas flow velocity (m/s), g represents the gravitational acceleration (m/s^2), F is the total energy loss between the two ends of the column (resulting from friction), and τ is the work external mechanical force performed by the fluid (during flow between the two sections).

$\int_{p_f}^{p_c} V dp$represents the mechanical work resulting from the expansion of a mass unit of the mixture and $\Delta\frac{v^2}{2g}$ is the variation of the kinetic energy of the mass unit, between the two measurement points.

In the assumption of a stationary flow $\tau = 0$, because the mass of fluid entering from the bed into the column is the same as that leaving the column, and so in this case equation 23 is simplified.

$$\int_{p_f}^{p_c} V dp + L + F = 0 \qquad (24)$$

Starting from the natural gas equation of state:

$$V = \frac{ZRT_m}{Mp} \qquad (25)$$

And considering energy losses due to friction:

$$F_1 = \frac{2\bar{v}^2}{g}\frac{L}{D}f \qquad (26)$$

Where R is the universal gas constant, T_m is the average temperature of the gases in the column (ºK), M is their molecular weight, Z is the deviation factor from the perfect gas law, D is the diameter of the drill string, f represents the admissible friction factor and v is the average velocity of the mixture between the two analysis points.

Equation 24 becomes:

$$\frac{gRT_m}{M}\int_{p_f}^{p_c}\frac{Zdp}{p}+gL+\frac{2\bar{v}^2L}{D}f=0 \quad (27)$$

The average speed of the mixture can also be written in the form:

$$\bar{v}=\frac{gQ_m\ddot{V}}{\pi\frac{D^2}{4}} \quad (28)$$

And using pseudoreduced pressures:

$$I_f=\int_{0,2}^{p_{fr}}\frac{Zdp_r}{p_r}$$

$$I_c=\int_{0,2}^{p_{cr}}\frac{Zdp_r}{p_r}$$

We get the relation:

$$L\left(1+\frac{32fgQ_m^2R^2T_m^2}{\pi^2D^5M^2}\left(\frac{I_f-I_c}{p_f-p_c}\right)^2\right)=\frac{RT_m}{M}(I_f-I_c) \quad (29)$$

The value of the friction factor f is determined based on Poettman's relationship [3]:

$$f=k\frac{\mu^{0,065}}{Q^{0,065}D^{0,058}\Delta^{0,065}} \quad (30)$$

Also, in the above relationships, we noted with Q the volume flow rate, μ the viscosity of the gas, Δ the relative weight of the gas in relation to air, k is a dimensionless quantity and has the value determined by Naville as equal to $0{,}76\cdot10^{-14}$ [4].

And so the pressure variation in a well during drilling is:

$$(p_f-p_c)^2=\frac{100\,k\mu^{0,065}(Q\Delta)^{1,935}x^2}{D^{5,058}(x-100L)} \quad (31)$$

In the above equation $x=2{,}9227\cdot\frac{T}{\Delta}(I_f-I_c)$, Q being the gas flow rate in Nm³/24 h, L is the length of the column (wellbore depth) m, D is the inner diameter of the drill string, cm, μ is the gas viscosity cP, T_m is the average temperature °K, p_f and p_c are the pressures kgf/cm².

The values of the integrals I_f and I_c are tabulated, solving equation 31 by repeated attempts.

Another method for determining the pressure variation in the well starts from the analysis of the energy balance based on Bernoulli's equation applied to real fluids [5,6].

$$\frac{dp}{\rho g}+dh\cos\theta+d\left(\frac{v^2}{2g}\right)+dF=0 \quad (32)$$

In relation 32, ρ is the specific mass of gases, in a section that is found at a distance h from the level of the productive layer, and the uncle that the column makes with the vertical (where cosθ is almost equal to 1).

The energy value of frictional losses is obtained from the classic relationship:

$$F=\lambda\frac{v^2}{2g}\frac{h}{D} \quad (33)$$

In the hypothesis of a small velocity gradient, the following assumptions are allowed:

$$dv^2=0 \quad (34)$$

$$dF=\lambda\frac{v^2}{2g}\frac{h}{D} \quad (35)$$

Where the dimensionless friction coefficient λ and the column diameter D are identified.

From the continuity equation (32) we obtain by replacing equation 35:

$$g\rho V\Omega=Q_m=ct. \quad (36)$$

Given that the area of the flow section:

$$\Omega=\frac{\pi D^2}{4} \quad (37)$$

We get:

$$\rho=\frac{p}{gZRT_m} \quad (38)$$

And so:

$$v=\frac{Q}{\frac{\pi D^2}{4}g}\frac{1}{\rho}=\frac{4ZRT_m}{\pi\rho D^2} \quad (39)$$

Where Q is the volumetric flow rate and Q_m is the mass flow rate.

After substituting 39 and38 into 32 and separating the variables we obtain the relation:

$$dh=-\frac{ZRT_m\rho dP}{\frac{8Z^2R^2T_m^2Q^2\lambda}{\pi^2gD^5}+p^2}=\frac{4ZRT_m}{\pi D^2\rho} \quad (40)$$

I noted:

$$\alpha = \frac{8R^2T_m^2Q^2\lambda}{\pi^2 gD^5} \quad (41)$$

For the natural gas deviation factor, a constant value Z_m can be assumed as the arithmetic mean of the corresponding pressure value at the lower end of the well and at the top of the column.

The friction coefficient can be determined as a function of the Reynolds number and the relative roughness coefficient ε.

$$Re = \frac{\rho v D}{\mu} \quad (42)$$

Because in the flow of petroleum fluids and drilling fluids in drill pipes (drill strings) $\rho v = const.$, and the variations of viscosity with pressure are small, at a value of temperature that varies little and a value of constant pipe roughness, it makes that the corresponding value of the friction coefficient λ is also constant.

So in this case equation 41 can be rewritten in the form:

$$\int_0^L dh = -ZRT_m \int_{p_f}^{p_c} \frac{pdp}{\alpha Z^2 + p^2} \quad (43)$$

And from equation 43 we obtain the bottom pressure variation (from the level of the productive layer) during drilling and operation of the drill string:

$$p_f^2 = p_c^2 e^{\frac{2L}{ZRT_m}} + \frac{8\lambda Z^2R^2T^2Q^2}{\pi^2 gD^5}\left(e^{\frac{2L}{ZRT_m}} - 1\right) \quad (44)$$

They were written in usual calculus units (according to equation 1.31), we get:

$$p_f^2 = p_c^2 e^{\frac{0{,}06833\gamma L}{ZT_m}} + \frac{1{,}583\,\lambda\, Z^2T^2Q^2}{D^5}\left(e^{\frac{0{,}06833\gamma L}{Z\,T_m}} - 1\right) \quad (45)$$

Where Adanov's relation [7] should be used to calculate the friction coefficient λ:

$$\lambda = \frac{1}{4\left(\lg\left(\frac{5{,}62}{Re^{0{,}69}} + \frac{\varepsilon}{7{,}41}\right)\right)^2} \quad (46)$$

Calculations performed on a number of 100 wells and compared with field data, demonstrate that the 1.45 relationship is closer to reality than the 1.31 relationship.

IV. Determining the fluid flow of a well in eruptive manifestation

Determining the flow of petroleum fluids and drilling fluids, of a well in an uncontrolled (or controlled) eruptive manifestation, is difficult to determine precisely, due to the impossibility of measuring the parameters of the layers that discharge the fluids in the eruptive flow, and that is why an approximate flow is used, given by the relationship [8]:

$$Q = \sqrt[n]{\frac{H}{a}} \quad (47)$$

Where:
- Q is the gas flow rate expressed in 10^6 $Nm^3/24$ h,
- H is the height of the flame, m,
- a is experimental constant,
- n is the index showing the burning intensity (n=2/5).

In the event of an uncontrolled eruption at an oil and gas well, there is the possibility of having an eruptive manifestation at a well where we do not know the characterization data of the productive layer and the fluids contained therein (reservoir pressure, quality of petroleum fluids that feed the eruptive manifestation, the quantity of these products, etc.) or at a well where we know all the parameters of the eruptive manifestation.

The first case is typical of the majority of uncontrolled eruptions, due primarily to the eruption of the well when passing some productive layers that have not been very well analyzed. The second case of eruptive manifestation can occur when carrying out some maintenance work and especially replacing some components of the productive well.

It can also occur in the case of productive operations to increase the flow rate of the productive well following the performance of acidizing, hydraulic fracturing and/or shooting operations.

During an eruptive manifestation, the speed of gas flow through the productive layer has high values, the law of gas flow through porous media can no longer be linear, the most useful being the relationship:

$$\Delta p^2 = aQ + bQ^2 \quad (48)$$

Where a and b are constants resulting from the exploration of the well and Q is the gas flow produced by the layer and which is equal to the flow leaving the exploitation column $Nm^3/24$ h.

$$\Delta p^2 = p_s^2 - p_f^2 \quad (49)$$

p_s and p_f respectively are the layer and bottom pressures (kgf/cm^2).

So it can be seen that the eruption flow is a function of the pressure difference between the area of eruptive manifestation and the pressure of the respective layer, it being necessary to determine the bottom pressure (the one in the layer being constant and easy to determine).

In an uncontrolled eruptive well, the minimum condition for it to erupt is that the outlet pressure in the production column is greater than atmospheric pressure.

CONCLUSION

In the event of an eruptive manifestation at the level of an oil and gas well, releases of oil and natural gas may occur, embedded in the drilling fluid or containing components of the drilling fluid and ensuring the evacuation of well detritus dislodged by the drilling hole.

In the event of an eruptive manifestation, they can also lead to the occurrence of fires.

The analysis of several types of eruptions led to the conclusion that these accidents may be due to:

a.Leakage of the surface equipment, in this case removing this equipment and then inserting a pipe with a packer or sealing device at one end and a valve system at the other end and taking over the flow of petroleum fluids and reducing the pressure in the well by classical methods,

b. Damage to the pipe string and channeling of petroleum fluids through the soil or through the destroyed string. The remedy for the accident consists in the introduction of columns provided with packers at one end and with the isolating valve at the other end.

c. Damage to the tubing string in multiple locations downhole, remediation by drilling another well to contact the damaged area and injecting heavy drilling fluid (to kill the well).

In the case of eruptive manifestations that led to the start of fires and especially their maintenance, the technologies for reducing the environmental impact of these accidents, reducing the supply of fires with flammable substances and especially their elimination, start from the use of the following special techniques necessary in these cases, such as:

a. The use of special equipment,
b. Digging new probes directed to intercept the probe and then sink it,
c. Digging mining tunnels, directing petroleum fluids and sinking the well,
d. The use of concentrated CO_2 foam jets.

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