A REGRESSION MODELS OF THE GAS DRILLING WELL ERUPTION

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ABSTRACT

During drilling operations carried out to explore or exploit oil and/or natural gas deposits, uncontrolled eruptions (technical accidents) have also occurred, which have led to damage to the well and, above all, have affected the capacity of the productive layers to continue producing under the initial conditions provided for in the exploitation projects. Also, the explosion of the Deepwater Horizon platform has brought the creation of numerical models (based on numerical regression or artificial intelligence) to avoid such accidents back into the discussion. We developed AI-based numerical regression models to prevent uncontrolled eruptions during Black Sea drilling.

Keywords: oil and gas drilling, risk assessment, numerical regression models, oil rig explosion, intelligence artificial model

INTRODUCTION

During drilling operations carried out to explore or exploit oil and/or natural gas deposits, uncontrolled eruptions (technical accidents) occurred, which damaged the well and, above all, affected the capacity of the productive layers to continue producing under the initial conditions provided for in the exploitation projects [1].

These technical and unpredictable (serious) accidents can occur during the passage of the productive layer (as a result of the penetration of fluids that saturate this layer into the drilling fluid), as a result of pressure variations during the drill string extraction maneuver and the performance of pistoning or sleeve operations on the productive layer and/or the casing string, as well as a result of the loss of drilling fluid during rock dislocation operations (as a result of its penetration into the productive layers) and its complete isolation [2].

Blowing manifestations may also occur when using a blowout preventer that is not classified or suitable for the well's pressure class and during drilling or well productivity enhancement operations [3].

Eruptive fluids consist of natural gas associated with productive or explored deposits, the existing crude oil in the deposit being explored/exploited, the water related to the deposit penetrated by drilling, sand, and traces of rocks dislocated by drilling, as well as components of the drilling fluid (chemicals, biological products, components to increase the capacity of the productive layer, elements to reduce the permeability of the drilled layer, etc.) [4].

An uncontrolled eruption occurs primarily because during drilling, while crossing the layer saturated with fluids under pressure, a pressure imbalance usually occurs (between the hydrostatic pressure of the liquid column in the well and the pressure under which the fluids in the layer are found) [5].

Suppose the hydrostatic pressure of the liquid column is lower than the pressure in the formation. In that case, the fluids in the formation penetrate the well fluid, leading to a sharp decrease in the hydrostatic pressure of the liquid column at the formation level (due to the diffusion of gas particles into the drilling fluid) [6].

Oil and gas exploration and exploitation are risky ventures. The risks associated with drilling a well are not negligible, and oil rigs are hazardous environments with heavy equipment, dangerous substances (flammable chemicals and gases), and remote locations from shore where weather and water conditions are unpredictable [7].

Safety standards in the US oil and gas industry have been developed primarily by the American Petroleum Institute (API), and in Romania, oil and gas industry safety standards have been created by national authority [8].

These safety standards are based on the European Union Strategy for Environment Safety and are based on extensive and long-standing technical expertise.

Indeed, from 2004 to 2024, fatalities in the offshore oil and gas industry were significantly higher (more than four times) per person-hour worked in US waters than in European waters, even though the companies operating in these waters are frequently the same [9].

In Romania, Offshore platform incidents are at a low level because the strategy of working with Romanian Offshore Platforms is approved by the Life and Safety Management Authority Standards [10].

This striking discrepancy reinforces the view that the problem is not so much about the business itself but rather is determined by the specific cultures and regulatory systems in which the industry's many members operate.

Past accidents in offshore oil and gas operations must be analysed to establish new work procedures, and this should be considered when estimating overall risk and in the risk-based decision-making process.

The entire risk management process and the ALARP (as low as reasonably practicable) principle are based on the prerequisite of discernment and the fact that most risks can be controlled, while only a tiny percentage of "remaining risk" needs to be tolerated – and should be managed cost-effectively [11].

In the Romanian oil platform simulation, we need to analyse the risks assumed and not assumed following the drilling operation on the platform, errors in the prevention and control mechanism, and the effects of the oil platform accident.

It is necessary to determine the effect on blowout level and amplitude if the sealer (BOP-Bops) is operated closed and to prevent accidents considering a blowout pipe diameter of 8%, 10%, 25%, 50%, 75%, and 100% of the drill rod diameter (5 ¾ inches).

MATERIALS AND METHODS

The installation and operation of the blowout preventer ensure the protection of the environment and oil and gas wells during well drilling operations.

Also, in the event of an eruptive manifestation, the implementation of possible intervention works on the drill string consists of ensuring a reduced temperature in the eruption zone and specially creating a vacuum at the contact between the closing head and the well string (ensuring a gas velocity below the supersonic speed).

Since the gas velocity at the exit of a well in eruptive manifestation is greater than the speed of sound, the blowout preventer must ensure that the gas velocity is reduced to a value lower than the supersonic speed [7].

To simulate the flow through blowout preventers, we developed the following system of equations [12]:

$$\frac{v_1}{v_2} = \frac{a_1 M_1}{a_2 M_2} \tag{1}$$

$$\frac{T_1}{T_2} = \frac{1+\frac{\chi-1}{2}M_2^2}{1+\frac{\chi-1}{2}M_1^2} \tag{2}$$

$$\frac{a_1}{a_2} = \left(\frac{T_1}{T_2}\right)^{\frac{1}{2}} \tag{3}$$

$$\frac{v_1}{v_2} = \frac{M_1}{M_2}\left(\frac{T_1}{T_2}\right)^{\frac{1}{2}} \tag{4}$$

$$\frac{p_1}{p_2} = \left(\frac{T_1}{T_2}\right)^{\frac{\chi}{\chi-1}} = \left(\frac{\rho_1}{\rho_2}\right)^{\chi} \tag{5}$$

$$\frac{\rho_1}{\rho_2} = \left(\frac{T_1}{T_2}\right)^{\frac{1}{\chi-1}} \tag{6}$$

$$\frac{A_2}{A_1} = \frac{\rho_1}{\rho_2}\frac{v_1}{v_2} = \frac{M_1}{M_2}\left(\frac{T_1}{T_2}\right)^{\frac{\chi+1}{2(\chi-1)}} \tag{7}$$

Equations 1-6 are written starting from the analysis of data before (with index 1 of the equations above) and after the eruption preventer (with index 2 of equations 1-6), v_1 represents the gas flow velocity at the moment of eruption (m/s), T_1 is their temperature (K), a_1 is the isotropic speed of sound (m/s), M_1 represents the Mach number, χ is the adiabatic exponent, p_1 is the pressure measured before the eruption preventer (Pa), ρ_1 is the gas density (kg/m^3) [13].

$$a = \sqrt{\chi\frac{p}{\rho}} = \sqrt{\chi g R T} \tag{8}$$

$$M = \frac{v}{a} \tag{9}$$

$$\chi = \frac{c_p}{c_V} \tag{10}$$

$$\rho = \frac{\gamma}{g} \tag{11}$$

Given that d is the inner diameter of the closure head, g is the gravitational acceleration (m/s^2) and γ is the specific gravity, we can write:

$$A = \frac{\pi d^2}{4} \tag{12}$$

$$\frac{p}{\rho} = gRT \tag{13}$$

The pressure p can be obtained from the gas equation of state where R is the universal gas constant (for methane we take the value 52.89 kg/K), and T is the absolute gas temperature (K) [14].

From the above equations we can determine the effect of the diameter variation as a function of the gas flow:

$$\frac{d_2}{d_1} = \sqrt{\frac{M_1}{M_2}\left(\frac{1+\frac{\chi-1}{2}M_2^2}{1+\frac{\chi-1}{2}M_1^2}\right)^{\frac{\chi+1}{2(\chi-1)}}} \tag{14}$$

Applying machine learning principles, we determined for the $\chi = 1{,}285$ (Figure 1):

a. Pressure ratio before and after the blowout preventer $(\frac{p_2}{p_1})$ function to the $\frac{T_2}{T_1}, \frac{d_2}{d_1}, \frac{v_2}{v_1}$.

$$y\left(\frac{p_2}{p_1}\right) = -3{,}67 + 0{,}66\ X1\left(\frac{d_2}{d_1}\right) + 3{,}88X2\ \left(\frac{T_2}{T_1}\right) + 0{,}15\ X3\left(\frac{v_2}{v_1}\right) - 0{,}062\ X4\ (M_1) \tag{15}$$

b. When we also introduce the M_2/M_1 ratio into the discussion, we will have an equation of the form:

$$y\left(\frac{p_2}{p_1}\right) = -4{,}34 + 0{,}46\ X1\left(\frac{M_2}{M_1}\right) + 0{,}67\ X2\left(\frac{T_2}{T_1}\right) + 4{,}42\ X3\left(\frac{d_2}{d_1}\right) - 0{,}22\ X4\left(\frac{v_2}{v_1}\right) - 0{,}03\ X5\ (M_1) \tag{16}$$

For the adiabatic coefficient (χ) of 1.18 we obtained the equation (Figure 2):

c. Pressure ratio before and after the blowout preventer $(\frac{p_2}{p_1})$ function to the $\frac{T_2}{T_1}, \frac{d_2}{d_1}, \frac{v_2}{v_1}$.

$$y\left(\frac{p_2}{p_1}\right) = -0{,}66 + 1{,}05\ X1\left(\frac{T_2}{T_1}\right) - 0{,}66\ X2\left(\frac{d_2}{d_1}\right) - 0{,}59\ X3\left(\frac{v_2}{v_1}\right) \tag{17}$$

d. When we also introduce the M_2/M_1 ratio into the discussion, we will have an equation of the form:

$$y\left(\frac{p_2}{p_1}\right) = 1{,}80 - 3{,}10\ X1\left(\frac{M_2}{M_1}\right) - 0{,}23\ X2\left(\frac{T_2}{T_1}\right) + 0{,}16\ X3\left(\frac{d_2}{d_1}\right) + 2{,}51\ X4\left(\frac{v_2}{v_1}\right) - 0{,}15\ X5\ (M_1) \tag{18}$$

In current practice, it is necessary to determine the gas outlet pressure, while the inlet (or bottom) pressure can be estimated.

Following the application of the above equations, we created a numerical model based on determining the ratio $\frac{p_2}{p_1}$ (y) as a function of the ratios $\frac{d_2}{d_1}$(x_1), $\frac{T_2}{T_1}$ (x_2) and the adiabatic coefficient χ.

The equation is of the type:

$$\frac{p_2}{p_1} = -1{,}36 - 0{,}11\frac{d_2}{d_1} + 1{,}21\frac{T_2}{T_1} + 0{,}76\,\chi \tag{19}$$

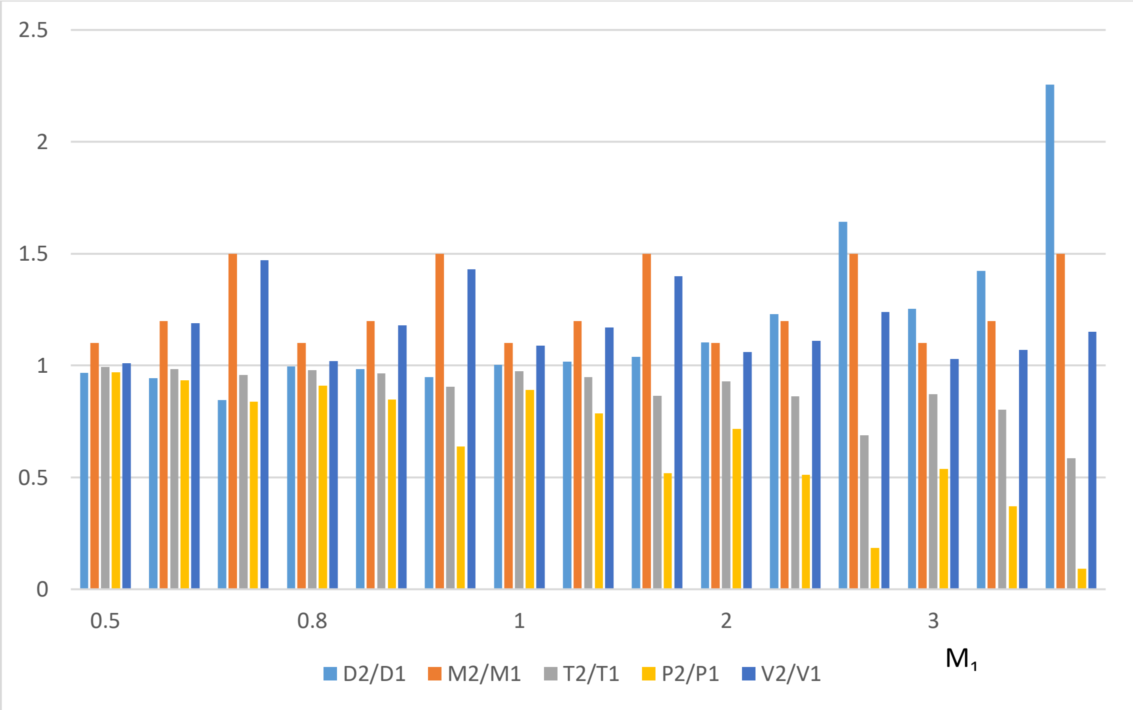

Figure 1. *Parametric variation* $\frac{T_2}{T_1}, \frac{d_2}{d_1}, \frac{p_2}{p_1}, \frac{v_2}{v_1}$ *function to* $\chi = 1{,}285$ *function Mach* M_1 *number*

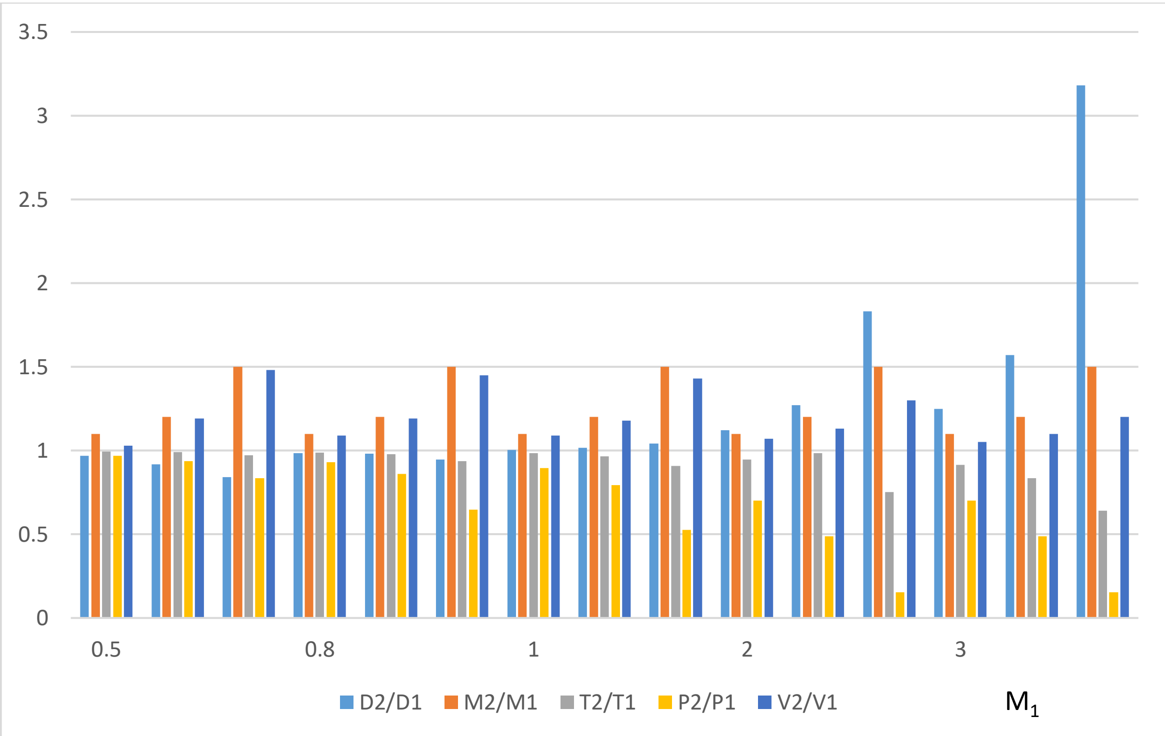

Figure 2. *Parametric variation* $\frac{T_2}{T_1}, \frac{d_2}{d_1}, \frac{p_2}{p_1}, \frac{v_2}{v_1}$ *function to* $\chi = 1{,}18$ *function Mach* M_1 *number*

RESULTS

When an explosion occurs, a transient pressure of the explosive cloud (develops) that is higher than the atmospheric pressure around the area of the blast (overpressure of well drilling fluids eruption) [15].

During such a phenomenon, the gas rapidly expands due to the released energy, and the surrounding atmospheric gas mixture is forced back, initiating a pressure wave that rushes from the source of the explosion to the outside of the production area.

Most of the damage they cause is caused by the propagation of a pressure wave in the air or blast wave.

The blast is composed of the pressure wave, and the overpressure changes during the blast period depending on the speed of air currents, air temperature, and weather conditions (precipitation level, etc.).

The dispersion of the gas cloud and the explosion of the explosive mixture are complex multiphase transport phenomena.

To obtain the effect of the blast on the facilities and employees, we used dynamic computational models.

We proposed dropping a pipe at the well, which was positioned obliquely in the blowout preventer.

This, coupled with the haste to cement the drill pipe (drill string) with nitrogen and cement, led to the eruption.

For the calculation of pressure losses on the pipe, we took into account the following aspects [16] of well drilling Black Sea area:

- well depth 5486 m,
- great depth (depth to the bottom of the sea) 1522 m,
- deposit temperature 167ºC (470 ºK),
- pressure in the well at the time of the accident 551 bar,
- BOP resistance pressure 1000 bar,
- normal reservoir pressure (designed and expected to be possible in operation) 466 bar.

The column on which the eruption occurred is 5 ¾ inches, and the isotropic speed of sound whose value enters the expression [17]:

$$a = \sqrt{\frac{\chi\, p}{\rho}} \tag{20}$$

Where R is the universal gas constant (52.89 kg/degree K), T is the reservoir temperature K) and pressure p is obtained from the relation [18]:

$$\frac{p}{\rho} = gRT \tag{21}$$

$$a = \sqrt{\chi g R T} \tag{22}$$

$$a = \sqrt{1{,}285 \cdot 9{,}81 \cdot 52{,}9 \cdot 470} = 263 \text{ m/s}$$

Because *M* is the Mach number, we determine the gas velocity [19]:

$$M = \frac{v}{a} \tag{23}$$

$$v = M\, a \tag{24}$$

$$v = 526 \text{ m/s}$$

For the column of 5 ¾ inch, d_1 is 148 mm and A_1=0.0125 m^2 and quantity of gas flow will be:

$$Q_1 = A_1 v_1 = 0{,}0125 \cdot 526 \cdot 86400 = 545356 \frac{Nmc}{24} h$$

Because $\frac{d_2}{d_1} = 1{,}104$ şi $\frac{T_2}{T_1} = 0{,}929$ and $\frac{p_2}{p_1} = 0{,}718$ we obtained $T_2 = 9^{\circ}C$.

So, a gas temperature of 9ºC was achieved through its expansion.

We also simulated the explosion on the oil platform function to the equation of well explosion (Table 1) and equation 1-19.

Table 1. *Equations of variation of the effects of the oil platforms accident as a function of the position (opening) of the blowout preventer (BOP)*

Accident effects	Equation	Remarks
Area of fatal injury, m (10 kw/m^2)	y = 2E-07x^5 - 5E-05x^4 + 0,0039x^3 - 0,0995x^2 + 1,9046 x + 7,5117	y is the fatality distance (m) , x is the BOP opening (% of exhaust pipe)
Area of injury with hospitalization, m (5 kw/m^2)	y = 2E-07x^5 - 4E-05x^4 + 0,0034x^3 - 0,0959x^2 + 1,5139 x + 6,4249	y is the fatality distance (m) , x is the BOP opening (% of exhaust pipe)
Area of injury with minor burns, m (2 kw/m^2)	y = 1E-07x^5 - 2E-05x^4 + 0,0018x^3 - 0,0448x^2 + 0,7946 x + 4,9328	y is the fatality distance (m) , x is the BOP opening (% of exhaust pipe)
The length of the flame	y = -4E-08x^5 + 1E-05x^4 - 0,001x^3 + 0,0376x^2 - 0,4133 x + 2,2408	y is Flame Length (m), x is BOP opening (% of exhaust pipe)
Evacuation rate of methane gas through BOP, kg/min	y = 0,0003x^4 - 0,1214x^3 + 19,62x^2 - 237,84x + 1243,8	y is the Evacuation Rate of methane gas through BOP, kg/min, x is BOP opening (% of outlet pipe)

In this case the area of fatal injury was 91 m, of injury with hospitalization 126 m, and of minor burns 196 m.

The length of the open flame was 14 m, and the amount of gases burned was 71000 kg/minute, i.e. 234401 kilograms.

To observe how the BOP (blowout preventer) acted on the effects of the accident (based to the effects of this equipment on the Romanian oil platforms platform), we analyzed its closure.

The beneficial effect on the level and amplitude of the explosion, if operated with the sealing device closed (the blowout preventer tanks-BOP), is noted.

In Table 2, we analyzed the effect of preventer closure on the blowout on the oil platforms, considering a vent pipe diameter of 8%, 10%, 25%, 50%, 75%, and 100% of the drill rod diameter (5 ¾ inches).

In Table 3 we presented the variation equations of the effects of the accident on the oil platform according to the position (opening) of the blowout preventer (BOP).

Tables 2. *Effect of Preventer Shutdown on Romanian oil platforms Explosive Blowout*

Eruptive tube diameter, %	Eruptive tube diameter, mm	Open flame length, m	Exhaust rate, kg/min
100	146	14	86300
75	109	12	53300
50	73	8	25400
25	36	4	5700
10	14	1	863
8	10	1	440

Tables 3. *Effect of Preventer Shutdown on area of people activity*

Diameter of the eruptive pipe, %	Area of fatal injury, m (10 kw/m^2)	Area of injury with hospitalization, m (5 kw/m^2)	Area of injury with minor burns, m (2 kw/m^2)
100	91	126	196
75	67	94	146
50	43	59	92
25	17	23	36
10	10	10	10
8	10	10	10

We also analyzed a new relationship whose objective is to provide data on the opening value of the BOP (blowout preventer) according to the level of employee injury.

The multifactorial regression equation is of the form:

$$y=6{,}952-0{,}010\,x_1-3{,}434\,x_2+2{,}684\,x_3 \tag{25}$$

Where y is the opening of the BOP (% of exhaust pipe), x_1, x_2 and x_3 are the distances of fatal injury, hospitalization or minor burns (m).

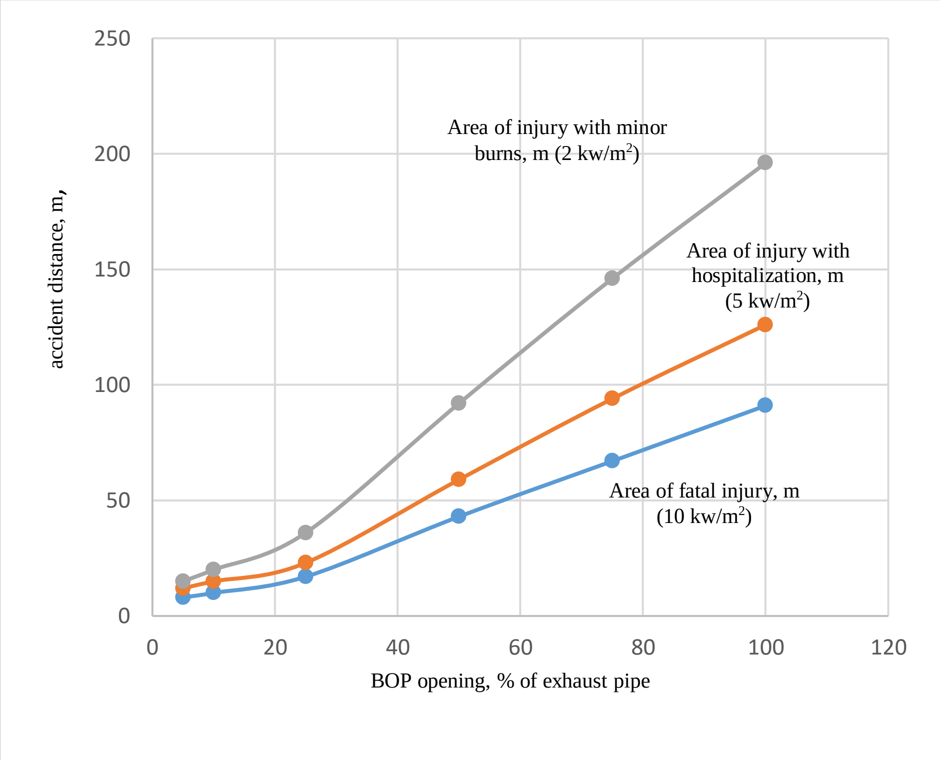

Figure 3. *The effect of the oil explosion*

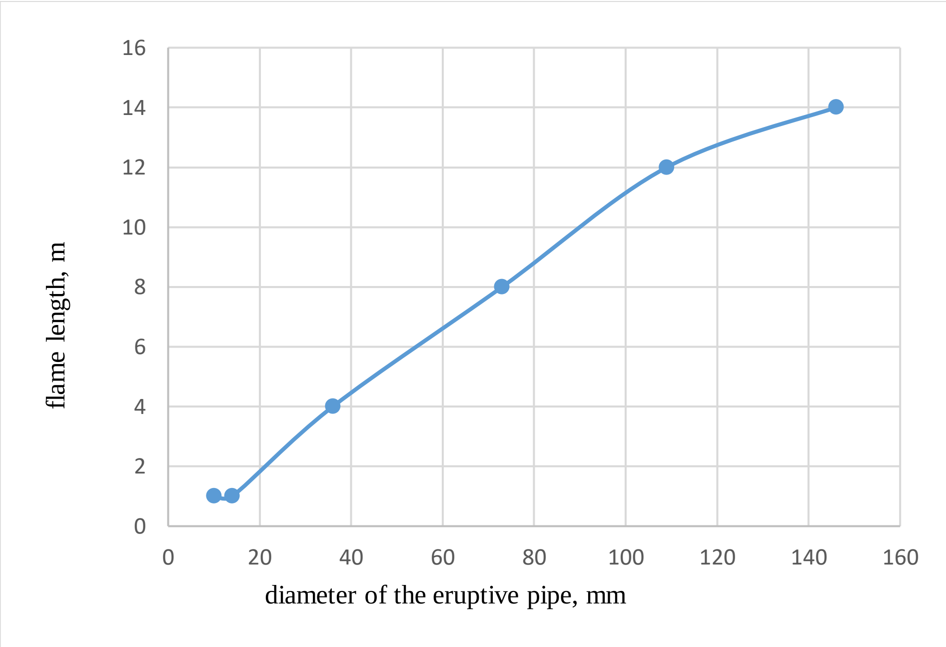

Figure 4. *The length of the oil rig flame (explosion)*

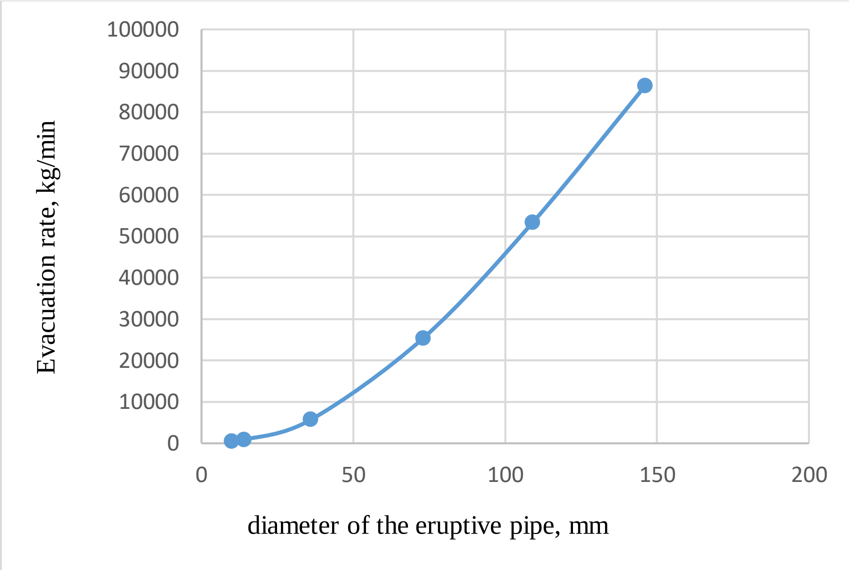

Figure 5. *Gas escape rate from the oil platforms modeling*

CONCLUSIONS

In the event of an eruptive manifestation at the level of an oil and gas well, oil and natural gas releases may occur, incorporated into the drilling fluid or containing components of the drilling fluid and ensuring the evacuation of the well debris dislodged by the drilling bit. In an eruptive manifestation, they can also lead to fires.

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

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

b. Damage to the casing string and channeling petroleum fluids through the soil or the destroyed string. Remedying the accident involves inserting strings equipped with packers at one end and a shut-off valve at the other.

c. Damage to the casing string in several locations placed deep in the well. The remediation is carried out by digging another well until it reaches the damaged area and introducing heavy drilling fluid (to kill the well).

In the following paper, we analyse the compressor explosion on the offshore platform based on the phenomenon of natural gas dispersion in its ventilation system.

This is the cause of more oil accidents. The extent of damage caused by releasing flammable gases is partly a function of cloud dispersion. If there is no immediate ignition, flammable vapours are dispersed through the structure's geometry (metal construction) and ventilation systems, and ignition may be delayed.

If the gas's flammability limits are met (based on gas composition) and an ignition source of sufficient energy is present, the resulting vapor cloud (VCE) will ignite and explode.

Several factors, namely influence an explosion of a gas cloud:

a. the probability of ignition increases with the size of the vapor cloud,

b. the effectiveness of the explosion and its impact is affected by the turbulent mixture of vapor and air,

c. the efficiency of the explosion depends on the location of the ignition sources,

d. the size of the explosion depends on the concentration of the explosive medium (gas cloud).

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

a. Use of special equipment,

b. Digging new wells directed to intercept the well and then drown it,

c. Digging of mining galleries, directing petroleum fluids and drowning the well,

d. Use of concentrated jets of CO_2 foam,

e. Triggering explosions and then, after extinguishing the fire, installing appropriate installations to stop the leakage of petroleum fluids.

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