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Modeling Gas Flow Through Blowout Preventers

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ABSTRACT: Eruptive manifestations in the oil and gas industry are often followed by environmental pollution and especially equipment destruction and human accidents. That is precisely why knowing the gas flow equations through the explosion preventers is absolutely necessary in dealing with the problems arising in the case of these industrial accidents. This material describes how natural gas behaves when it flows through vertical pipelines and through blowout preventers.

KEYWORDS: blowout preventers, drilling, gas, oil.

INTRODUCTION

The way an uncontrolled blowout occurs is primarily due to the fact that 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 hydrostatic pressure of the fluid column is lower than the pressure in the formation, the fluids in the formation penetrate into the fluid in the wellbore, resulting in a sharp drop in the hydrostatic pressure of the fluid column 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 into 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).

The installation of a device to prevent eruptions during their occurrence depends on ensuring a low level of temperature in the area of the eruptive well and also on the existence of a vacuum created at the contact between the closure head and the well column (to be able to ensure its welding).

Given that the velocity of the gases at the exit from a well in eruptive manifestation is greater than the speed of sound, the blowout preventer must ensure a reduction of the velocity of the gases to a value lower than the supersonic velocity

NUMERICAL MODELING OF GAS FLOW THROUGH BURST PREVENTERS

To simulate the flow through blowout preventers, we will start from Bernoulli's equation for gases[1,2,3]:

$$\frac{\chi}{\chi-1}\frac{p}{\rho}+\frac{v^2}{2}=const. \quad (1)$$

Where χ ($\chi=\frac{c_p}{c_V}$) is the adiabatic exponent, p represents the pressure, ρ represents the density, v is the gas velocity:

$$\rho=\frac{\gamma}{g} \quad (2)$$

In relation 2 we denoted by γ the specific weight of gases (kgf/m^3) and g is the gravitational acceleration (m/s^2).

The isotropic speed of sound has the expression[2,3,4,5]:

$$a=\sqrt{\chi\frac{p}{\rho}}=\sqrt{\chi gRT} \quad (3)$$

In equation 3 the pressure p is obtained from the natural gas equation of state[3]:

$$\frac{p}{\rho}=gRT \quad (2.4)$$

În the above equation R is the universal gas constant (for methane we take the value 52.89 kg/ºK), and T is the absolute gas temperature (ºK) [5].

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The gas velocity being negligible in the reservoir and taking into account equation 4, equation 1 can be rewritten in the form:

$$\frac{a^2}{\chi-1}+\frac{v^2}{2}=const. \quad (5)$$

Applying Bernoulli's equation at two points (before entering the blowout preventer and after it - where the velocity is zero v=0,a=a_0) we can rewrite equation 5 in the form:

$$\frac{a^2}{\chi-1}+\frac{v^2}{2}=\frac{a_0^2}{\chi-1} \quad (6)$$

$$a^2(\frac{1}{\chi-1}+\frac{1}{2}M^2)=\frac{a_0^2}{\chi-1} \quad (7)$$

Where a_0 este the isotropic speed of sound for v=0, and we can write the Mach number (M) in this case:

$$M=\frac{v}{a} \quad (8)$$

$$\frac{a^2-a_0^2}{\chi-1}+\frac{v^2}{2}=0 \quad (9)$$

Equation 9. can also be written in the form:

$$a^2=a_0^2(1+\frac{\chi-1}{2}M^2)^{-\frac{1}{2}} \quad (10)$$

And from equations 3 and 4 we can determine the value of the dependence of the speed of sound in gases on their temperature:

$$\frac{a_0^2}{a^2}=\frac{T_0}{T} \quad (11)$$

Where T_0 corresponds to the speed v_0.

Inserting equation 11 into 10 we get:

$$T=T_0(1+\frac{\chi-1}{2}M^2)^{-1} \quad (12)$$

By introducing the temperatures from this last relation and taking into account equation 2 we can determine the pressure variationp_0:

$$\frac{p}{\rho}=\frac{p_0}{\rho_0}(1+\frac{\chi-1}{2}M^2)^{-1} \quad (13)$$

But considering that the report $\frac{p}{\rho^x}=const$ where:

$$\frac{p}{\rho^x}=\frac{p_0}{\rho_0^x} \quad (14)$$

$$\frac{\rho}{\rho_0}=(\frac{p}{p_0})^{\frac{1}{\chi}} \quad (15)$$

$$\frac{\rho}{\rho_0}=(\frac{p}{p_0})^{\frac{1}{\chi}}(1+\frac{\chi-1}{2}M^2)^{-1} \quad (16)$$

$$(\frac{p}{p_0})^{1-\frac{1}{\chi}}=(1+\frac{\chi-1}{2}M^2)^{-1} \quad (17)$$

Inserting the values obtained from equation 17 into equation 1 and successively eliminating p and ρ we will obtain:

$$p_0=p(1+\frac{\chi-1}{2}M^2)^{\frac{\chi}{\chi+1}} \quad (18)$$

$$\rho_0=\rho(1+\frac{\chi-1}{2}M^2)^{\frac{\chi}{\chi+1}} \quad (19)$$

Equations 18 and 19 can be written if the borehole (flow) area is constant, then:

$$\rho vA=ct. \quad (20)$$

The movement being one-dimensional, we can consider the device as a tube with constant speed (current tube) and therefore the speed is constant:

Considering the input section to the device (which we denote by 1), v_1, p_1, ρ_1, T_1 , and $M_1=\frac{v_1}{a_1}$, and considering the current section (v,p,ρ,T,M) get:

$$T_1=T_0\left(1+\frac{\chi-1}{2}M_1^2\right)^{-1} \quad (21)$$

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$$T = T_0\left(1 + \frac{\chi - 1}{2}M^2\right)^{-1} \quad (22)$$

$$T = T_1 \frac{1 + \frac{\chi-1}{2}M_1^2}{1 + \frac{\chi-1}{2}M^2} \quad (23)$$

$$p = p_1\left(\frac{1 + \frac{\chi-1}{2}M_1^2}{1 + \frac{\chi-1}{2}M^2}\right)^{\frac{\chi}{\chi+1}} \quad (24)$$

By applying equation 24 in both sections we get:

$$\rho = \rho_1\left(\frac{1 + \frac{\chi-1}{2}M_1^2}{1 + \frac{\chi-1}{2}M^2}\right)^{\frac{1}{\chi-1}} \quad (25)$$

$$\rho v A = \rho_1 v_1 A_1 \quad (26)$$

$$\frac{A}{A_1} = \frac{\rho_1 v_1}{\rho v} \quad (27)$$

$$\frac{\rho_1}{\rho} = \left(\frac{1 + \frac{\chi-1}{2}M^2}{1 + \frac{\chi-1}{2}M_1^2}\right)^{\frac{1}{\chi-1}} \quad (28)$$

We can also write:

$$\frac{v_1}{v} = \frac{v_1}{a_1}\frac{a}{v}\frac{a_1}{a} = \frac{M_1}{M}\frac{a_1}{a} \quad (29)$$

From equation 3 we can write:

$$a = a_0\left(1 + \frac{\chi-1}{2}M^2\right)^{-\frac{1}{2}} \quad (30)$$

$$a_1 = a_0\left(1 + \frac{\chi-1}{2}M_1^2\right)^{-\frac{1}{2}} \quad (31)$$

$$\frac{a_1}{a} = \left(\frac{1 + \frac{\chi-1}{2}M^2}{1 + \frac{\chi-1}{2}M_1^2}\right)^{\frac{1}{2}} \quad (32)$$

And equation 29 is rewritten in the form:

$$\frac{v_1}{v} = \frac{M_1}{M}\left(\frac{1 + \frac{\chi-1}{2}M^2}{1 + \frac{\chi-1}{2}M_1^2}\right)^{\frac{1}{2}} \quad (33)$$

Finally we get the relation:

$$A = A_1 \frac{M_1}{M}\left(\frac{1 + \frac{\chi-1}{2}M^2}{1 + \frac{\chi-1}{2}M_1^2}\right)^{\frac{\chi+1}{2(\chi-1)}} \quad (34)$$

In practice it is found that A_1 and M_1 and are known, as well as v_1, p_1, ρ_1, we know the variation of the cross section along the axis Ox from equation 34 we calculate *M(x)*.

Since we know the size of the adiabatic exponent χ from equation 33, we calculate *T(x)*, the values of *p(x)* and the densities *ρ(x)*.

When we do not know the area of the section, the calculation is carried out on a number of sections and then the variation curves of the quantities *M(x)*, *p(x)*, *T(x)* and *ρ(x)* are drawn through the obtained points.

The initial data are the diameter d_1 of the inlet section of the device, the pressure p_1 and the temperature T_1. The flow rate Q_0 defined at pressure p_0 and temperature T_0 is also known.

The density of can be calculated from the relationship:

$$\frac{p}{\rho} = gZRT \quad (35)$$

Applied to the input section 1 we get:

$$\rho_1 = \frac{p_1}{gZRT_1} \quad (36)$$

Sound velocity is a_1:

$$a_1 = \sqrt{\chi\frac{p_1}{\rho_1}} \quad (37)$$

The flow in section 1 is determined from the relationship:

$$Q_1 = Q_0\frac{p_0}{p_1}\frac{T_1 Z_1}{T_0} \quad (38)$$

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Because Z_0=1, velocity v_1 are forma:

$$v_1 = \frac{4Q_1}{\pi d_1^2} = 4\frac{p_0}{\pi d_1^2 p_1}\frac{T_1 Z_1}{T_0}Q_0 \quad (39)$$

Finally we determine the Mach number:

$$M_1 = \frac{v_1}{a_1} \quad (40)$$

Then we can determine the type of subsonic flow M_1<1, or supersonic M_1>1.
When p_1 is close to the atmospheric one, then Z≅1.

Usually the flow of gases in an uncontrolled eruption cannot be determined, and that is why a lot of assumptions are needed.

That is precisely why in the present work we will analyze the possibility of its calculation, as well as the velocities in the flow sections of the eruption preventers.

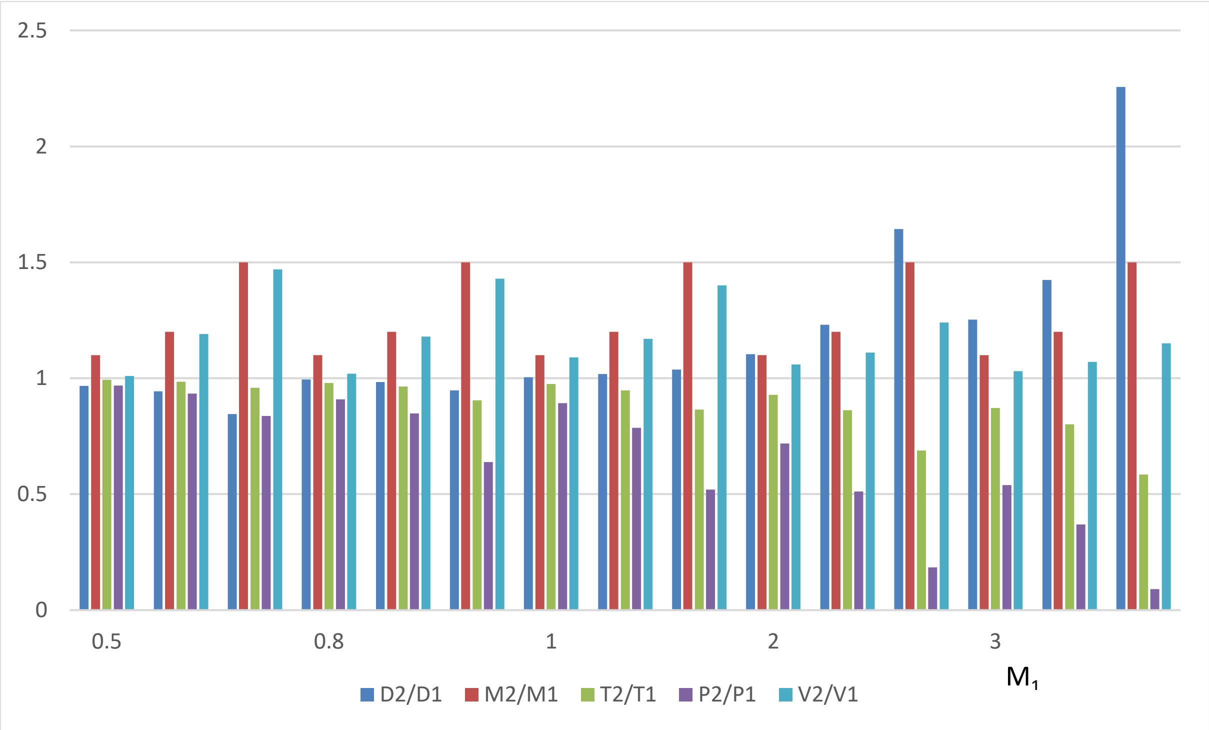

Fig. 1. Variation of parameters $\frac{T_2}{T_1}, \frac{d_2}{d_1}, \frac{p_2}{p_1}, \frac{v_2}{v_1}$ calculate for $\chi = 1,285$ depending on the Mach number M_1

It is very important to determine the pressure variation before and after the blowout preventer: $(\frac{p_2}{p_1})$,depending by $\frac{d_2}{d_1}, \frac{v_2}{v_1}$.

The obtained equation is of the form:

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

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

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

Following the calculations performed on I was able to determine the values $\frac{T_2}{T_1}, \frac{d_2}{d_1}, \frac{p_2}{p_1}, \frac{v_2}{v_1}$ calculated for the adiabatic coefficient $\chi = 1,285$.

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We also calculated for the adiabatic coefficient (χ) by value 18 an equation that assimilates all the data calculated according to the numerical model.

In this case the pressure variation before and after the preventer $(\frac{p_2}{p_1})$ function by $\frac{T_2}{T_1}, \frac{d_2}{d_1}, \frac{v_2}{v_1}$ is given by the equation:

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

When we introduce the report into the discussion M_2/M_1 we will have an equation of the form:

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

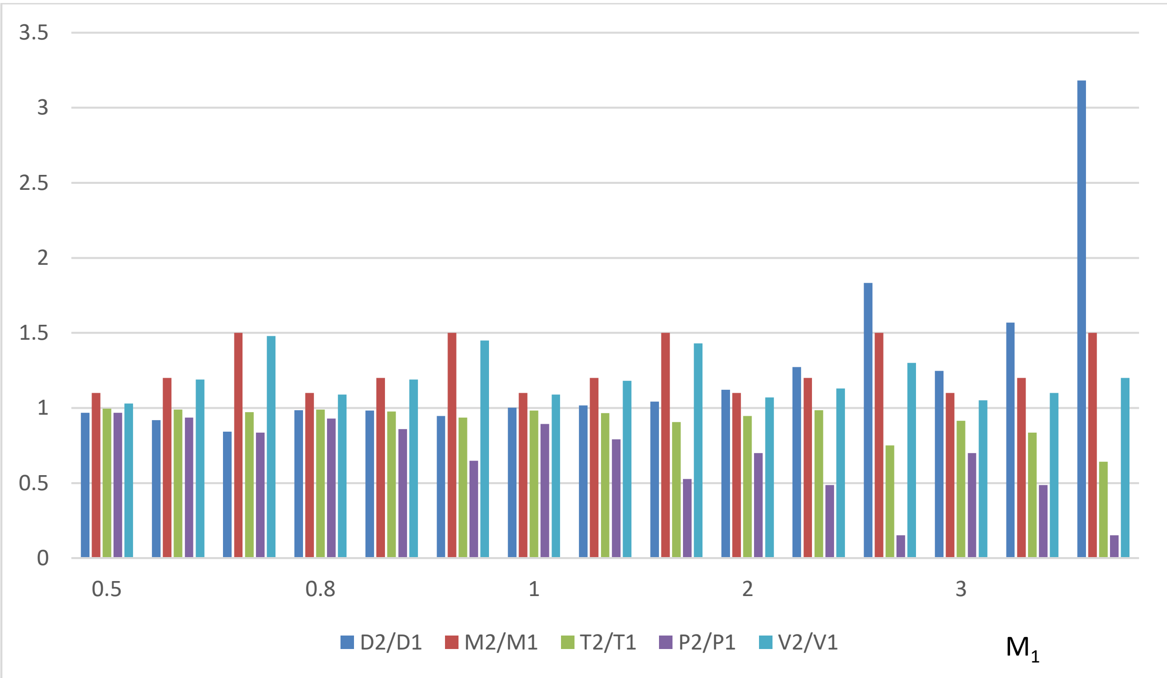

Fig. 2. Variation of parameters $\frac{T_2}{T_1}, \frac{d_2}{d_1}, \frac{p_2}{p_1}, \frac{v_2}{v_1}$ calculate for $\chi = 1,18$ depending on the Mach number M_1 *(for the number of Mach M we took the value of 340 m/s - as the speed of sound in fluid)*

CONCLUSION

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 CO2 foam jets,
e. Setting off explosions and then, after extinguishing the fire, installing suitable installations to stop the leakage of petroleum fluids.

In this paper I studies the modeling of gas flow through blowout preventers, managing to determine:

a. The flow equations,
b. The variation of gas properties when passing through the blowout preventer.

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And we determined for the first time in the literature the pressure variation equation before and after the blowout preventer

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