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STEAM BLOWOUT FROM AN OVER PRESSURE GEOTHERMAL RESERVOIR IN HUNGARY

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ABSTRACT

The existence of a high temperature and highly over-pressured geothermal reservoir was proven during a steam blowout in Fabiansebestyen, South-eastern Hungary.

The pressure balance of the drilling mud broke down during an incorrect drilling operation. An intensive inflow took place from a fractured dolomite reservoir at 3880m depth. The pressure of the reservoir was 73.1 MPa, its temperature was 199.6 ^{o}C. The damaged wellhead equipment released a powerful steam jet to the atmosphere. There was a unique feature of the blowout. The pressure permanently exceeded the value of 36 MPa in the immediate vicinity of the damaged wellhead. This was only possible if the liquid phase was sprayed through a narrow opening as with the case of the fuel injection nozzles of Diesel engine. The distortion of the continuous fluid flow into individual droplets reduced the 36 MPa pressure. The phase transition from liquid to steam phase took place in the droplets. The correlation of the calculated and measured data makes this assumption most probable.

INTRODUCTION

A set of deep petroleum prospecting boreholes were drilled in South-eastern Hungary in the 80's. The deepest of them attained a depth of 4239 m, during a drill bit change, the pressure balance broke down. Pulling out of the bottomhole assembly, large-amplitude pressure waves were generated, while substantial influx occurred at a depth of 3880 m. The abrupt pressure increase pushed the drill collar to the blowout preventer, seriously damaging the safety valve. The blowout displaced the mud from the borehole an in a very short time it developed into a steam blowout. The blowout held constant for 46 days until staff succeeded in sealing the well.

The most important discovery gained from this dramatic event, was the existence of a deep, over-pressured, high-temperature geothermal reservoir. The conditions of the blowout can be reconstructed by investigation of an appropriate mathematical model based on reliable measured data. This is an effective tool, to understand and predict the behaviour of the reservoir. The mathematical model of the blowout is presented herein.

THE KNOWN RELIABLE DATA

The schematic drawings of the well are shown in Fig.1. The wellhead equipment and the damaged blowout preventer with the outlet opening are shown in Fig.2. The last test measurement was made at a depth of 3684.5 m just above the blowout. The measured temperature was 190.5 ^{o}C and the pressure was 712.26 bar at this point so, the geothermal gradient is calculated to be 0.04885 ^{o}C/m.

The assumed depth of the influx can be a middle triassic dolomite breccia at the depth of 3880.0 m. The temperature at this depth is obtained to 199.6 ^{o}C. The extrapolated pressure of the over pressured region at this depth is 731 bar.

The wellhead pressure was measured consistently at 360 bar by a manometer built in the choke line (Fig.2.).

Fiure. 1. Schematic drawing of the well

Figure 2. The damaged blowout preventer

There were attempts to stop the blowout by filling the wellhead with cork and hardwood balls in the early stages of the blowout. It was successful temporarily, for only a few minutes. When the flow was been stopped, the wellhead pressure increased to 410 bar.

It is known that when abruptly stopping an incompressible fluid flow a sudden pressure rise occurs which is the so-called, waterhammer effect. This pressure rise is:

$\Delta p = \rho ac$

Where: ρ is the density of the hot water (920 kg/s) a is the speed of sound in the water-filled casing (1012 m/s)

c is the cross-sectional average velocity of the fluid flow

The flow rate during the blowout was estimated to be 8000 m^3/d by E. Buda (1996). The velocity of the water flowing away in an open channel from the site is calculated at 0.3 m/s. In accordance to this, the average velocity in the 8 5/8” casing was 3.1 m/s.

The amplitude of the pressure wave is calculated at 28.86 bar. The static pressure of the wellhead is known to be the difference between the maximum pressure and the amplitude. It is calculated at 381 bar.

We assume that as the flow stopped in the well, a hydrostatic pressure distribution developed. The temperature distribution gives the depth of the influx to 3880 m.

The pressure of this depth is

$$p_H = p_{wh} + \quad gH = 3{,}81 \quad 10^5 + 920 \quad 9{,}81 \quad 3880 = 731 \quad 10^5 \frac{N}{m^2}$$

These data form the main points for the following flow and heat transfer analysis of the blowout.

FLOW IN THE RESERVOIR AND IN THE WELL

There wasn’t a suitable flow rate measurement during the blowout. The roughly estimated flow rate was obtained as 8000 m^3/d in an open channel draining of the blowout area, while the wellhead pressure was permanently fixed at 360 bar.

The pressure of the flow decreased between the reservoir and the wellhead from 731 bar to 360 bar. The temperature of the inflowing water was 199.6 ºC. It decreased at the wellhead to 191.5 ºC, These data show, that water is in a liquid phase in the well. Since the pressure of the saturated steam at 191.5 ºC is 13.3 bar, the presence of a steam phase was impossible.

The well is an effective tool to determine the behaviour of the reservoir. The upflow in the well is obviously turbulent. The flowing bottomhole pressure can be calculated from a Bernoulli equation as:

$$p_{wf} = p_{wh} + \quad gH + \quad p'$$

where p_{wf} is the pressure of the water at the inlet of the well, p_{wh} is the wellhead pressure, p' is the friction loss of the upflowing water of the well and is represented as:

$$p' = \frac{8}{\quad ^2} \quad {}_1 \frac{L_1}{D_1^5} + {}_2 \frac{L_2}{D_2^5} \dot{m}^2$$

where λ_1 is the friction factor, L_1 is the length and D_1 is the diameter of the lower section of the well, without casing. The λ_2, L_2, D_2 values is referring to the 8 5/8” casing, $\dot{m}$ is the mass flow rate.

An axisymmetric radial flow develops in the reservoir toward the well. It is known the pressure loss is:

$$p \quad p_{wf} = \frac{\dot{m}}{2 \quad Kh} \ln \frac{R}{R_1},$$

where p_∞ is the pressure in the undisturbed reservoir, R_∞ is the radius of the drained area, h is the thickness of the reservoir, K is its permeability, ν is the kinematic viscosity.

The pressure difference p_∞-p_{wh} maintains the potential energy increase of the upflowing fluid and the pressure losses in the reservoir and the well:

$$p \quad p_{wh} = \quad gH + \frac{\dot{m}}{2 \quad hK} \ln \frac{R}{R_1} + \frac{8}{\quad ^2} \quad {}_1 \frac{L_1}{D_1^5} + {}_2 \frac{L_2}{D_2^5} \quad \dot{m}^2$$

It is a quadratic equation for the mass flow rate:

The necessary parameters for solution are the following:

p_∞ = 731 bar = $731 \cdot 10^5$ N/m^2

p_{wh} = 360 bar = $360 \cdot 10^5$ N/m^2

ρ= 920 kg/m^3, ν = $1{,}3 \cdot 10^{-7}$ m^2/s

H = 3880 m

$$\frac{D}{k}_{1} = 200,\ L_1 = 197\,\mathrm{m}, D_1 = 0{,}194\,\mathrm{m},\ \ _1 = 0{,}0303$$

$$\frac{D}{k}_{2} = 1000,\ L_2 = 3684\,\mathrm{m}, D_2 = 0{,}20\,\mathrm{m},\ \ _2 = 0{,}0197$$

h = 24 m, K = 1 Darcy = 10^{-12} m^2 R_∞ = 500 m

Solving the equation the obtained mass flow rate is 89.45 kg/s = 7728 t/d. The volume flow rate is 8400 m^3/d, which is surprisingly close to the roughly estimated value of 8000 m^3/d.

HEAT TRANSFER IN THE WELL DURING BLOWOUT

The temperature distribution of the upflowing water can be determined by solving the energy equation. TÓTH A. (2004) presented an analytic solution, obtaining the formula

$$T = T_s + \ \ (z + A)\ \ \ Ae^{\frac{z\ \ H}{A}}$$

Where:

T_s is the annual mean temperature at the surface

γ is the geothermal gradient

z is the vertical coordinate axis in downward direction

H is the depth of the influx

A is the so called performance coefficient

$$A = \frac{\dot{m}c\ \ k_r + \frac{D}{2}U_D\ \ f}{D\ \ U_D k_r}$$

in which c is the specific heat of the water

k_r is the heat conductivity of the rock

U_D is the overall heat transfer coefficient referring to the casing inner diameter

f is the so-called transient heat conductivity function

Thus the outflowing fluid temperature at the wellhead is:

$$T_{wh} = T_s + \ \ A\ \ \ \ Ae^{\frac{H}{A}}$$

This equation obtain a wellhead temperature of 191.5 ºC.

Knowing the wellhead temperature and the performance coefficient the depth of the influx can be determined as:

$$H = A\ln\frac{1}{1 + \frac{T_s\ \ T_{wh}}{A}}$$

Applying the known data of the blowout:

$$\dot{m} = 89{,}45\ \mathrm{kg/s},\ \mathrm{k_T} = 3{,}5W/mK,\ U_D = 42\ \mathrm{W/m^2}c\ \ \mathrm{f} = 1,$$

A = 44870 m

The wellhead temperature was measured as 150 ºC on the outer surface of the wellhead equipment. The heat flux through it is

$$Q = D_0 h_0 (T_0\ \ \ T_L) + D_0\ \ \ \ (T_0^4\ \ \ T_L^4)$$

where D_0 is the diameter of the outer surface 0.25 m

h_0 is the heat transfer coefficient there 1.518 W/m^2K

T_0 is the measured temperature of this surface

ε is the emissirtiy of steeal = 0.25

φ is the Stefan-Boltzmann constant $5.67\cdot10^{-8}$ W/m^2K^4

The heat flux is obtained as 707 W/m. In the other hand, calculated an overall heat transfer coefficient D_0 = 29 W/m^2C we obtain

$$Q = D\ \ U_D\left(T\ \ \ T_0\right)$$

from which

$$T_{wh} = T_0 + \frac{Q}{D\ \ \ U_D} = 150 + \frac{707}{0{,}2\ \ \ \ 29} = 188{,}8^{o}\,C$$

The agreement between the two wellhead temperatures seems to be acceptable.

The very high measured wellhead pressure of 360 bar seems to be in discrepancy with the other data of the blowout. During an isentropic expansion the outflowing fluid is continuous. The explanation is another mechanism of the outflow.

The possibility of a continuous fluid jet can be excluded because the 360 bar wellhead pressure. The enormous pressure energy of the continuous liquid flow is converted first into kinetic energy of a jet, which subsequently becomes subject to break-up phenomenon. This phenomenon is analogous to the injection of the fuel into the cylinder of a diesel engine. In some up-to-date system injection pressure can be as high as 2000 bar. It is assumed that the high pressure hot water was atomized first as going through the opening, next the small liquid particles turned into steam in the atmosphere. This can be an acceptable explanation of the dissipation of the very high wellhead pressure. The unusual shape of the steam jet is shown in Fig. 3. is an indirect argument of this assumption.

Figure. 3. The unusual shape of the steam jet at the end of the chokeline.

Consequently the measured parameters of the blowout can be fitted to a consistent conceptual and

SUMMARY

The dramatic event of the heavy steam blowout, resulted the discovery of Hungary's largest over-pressured (high pressure) high-temperature geothermal reservoir. The possible conditions of the blowout are reconstructed in this work. This work contribute to the knowledge and understanding of the behaviour of this type of reservoir.

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