Indirect Method Measuring Oil Well Debit

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***Abstract*— Developed a new method determining oil well debit using measuring outlet flow temperature values. Proposed mathematical model allowing calculate temperature profile of the fluid along well-bore for determining oil well debit, taking into consideration geothermal gradient in the rock, surrounding the well-bore. It has been shown, that unlike the existing methods proposed the new method allowed very easily determined instantly oil well debit. Proposed new oil well debit measuring system allowed realize continuous monitoring and improve efficiency oil well work.**

***Key words*— thermodynamics; heat friction; heat capacity; heat transmission; energy; entropy; enthalpy**

I. INTRODUCTION

Calculation of the temperature profile of the fluid along well-bore (well-lifting tube) for determining well debit in the case non-stationary termic field in the rock, surrounding the well-bore (WB) is one of the topical problems on the oil field exploitation. A large number of investigations has been published on this effect [1-5]. As a result of integrated analysis it has been revealed that the changes of temperature in the WB are characterize hydro-and thermodynamic processes which taking place in the productive interval. In such case information of oil stratum (OS) thermal motion may be derived by using fluid flow temperature and pressure measuring in well-bore (WB). WB temperature characterized with changes summary thermal processes taking place both in the OS and WT. Well bottom whole temperature controlled by OS thermal phenomenon. In vertical (lifting) flow are accomplished series energetical transformation: growing or fall potential energy; kinetic and internal energy change; heat exchanges between fluid and rocks; mixture fluids and gazes in a productivity interval entering from the different horizons with different temperature, bringing to the calorimetrical temperature effect; adiabatical expansion effect in WB; OS Joul-Tomson drossel effect etc. In this connection it is establish [1, 3] that thermogram (temperature curve) measuring in WB may be using as debitogram.

II. PROBLEM FORMULATION

Problem determining oil mixture flow (OMF) temperature in the well throw out in general case is related to WB ascension flow (AF) investigation.

Heat conducting flow (HCF) in homogeneous horizontal bedding rock, surrounding of the well is very close to radial. HCF rate in element of height dz on the temperature drop $\Delta T(z)$ between rock and OMF may be specified by following formulas:

$$\frac{dQ(z,t)}{dz} = \lambda K(t)\Delta T(z) \quad (1)$$

$$K(t) = \frac{2\pi}{ln\left[1+\left(\frac{\pi a t}{r_0^2}\right)^{1/2}\right]} \quad (2)$$

$$a = \frac{H}{l}a_l + \frac{l-H}{l}a_g$$

where λ is the heat conductivity coefficient $\left(\frac{Kkal}{MS^0C}\right)$; $K(t)$ is the indimensioned coefficient of heat exchange between flow and surrounding rock; r_0 is radius WB (M); a is the sum total casing annulus temperature conductivity (m^2/s); a_l , a_g and H are the relative OM and gas temperature conductivity (m^2/s) and H is the liquid column in the casing annulus (M); l is well depth (M).

In the case variable temperature drop the equation (1) acquired following form:

$$\frac{dQ(z,t)}{dz} = \lambda\int_0^t K(t-\tau)\frac{\partial\Delta T(z,\tau)}{\partial\tau}d\tau \quad (3)$$

WB vertical flow energy balance described using following formulas:

$$G\frac{\partial}{\partial z}\left[I - A\left(z+\frac{v^2}{2g}\right)\right] + F\gamma\left(T\frac{\partial S}{\partial t} + A\frac{v}{g}\frac{\partial v}{\partial t}\right) = = \lambda\int_0^t K(t-\tau)\frac{\partial\Delta T(z,\tau)}{\partial\tau}d\tau \quad (4)$$

$$G = F\gamma v$$

where: G is the stream flow weight (kr/s); F is the cross-sectional flow area (m^2); γ is the specific weight (kr/m^3); A is the heat equivalent of work $\left(2{,}344\frac{Kkal}{K\Gamma\cdot M}\right)$; v is the flow rate (M/S); $T_n(z)$ is the rock temperature as function of depth z (^{0}C); $T(z,t)$ is the flow temperature (^{0}C);

S is thermodynamic function (entropy) of systems (Kkal/^{0}C);
I is the thermodynamic function (enthalpy) of system (Kkal).

So far as values of coefficient $K(t)$ has time dependence, vertical flow in WB it never cannot come to the strict stationary. But thanks to damping character of function (2), the coefficient $K(t)$ changes very slow. In such case one can decide $K(t) = const$ and one can using Nyuton's known heat transmission formula:

$$\frac{dQ(z,t)}{dF(z)} = \alpha \Delta T(z,t) \qquad (5)$$

where $F(z)$ is the heat transmission area (m^2); α - the heat transmission coefficient $\left(\frac{Kkal}{MS^0C}\right)$

When WB pressure distribution and heat exchange between flow and surrounding rock is known, the energy equation (2), (4) and (5) are to allowed determine WB temperature distribution. In this connection convenient thermodynamic functions dS and dI are replaced by

$$dS = \frac{Cp}{T}dT - A\left(\frac{\partial V}{\partial T}\right)_p dP$$

$$dI = CpdT + AV\left[1 - \frac{T}{V}\left(\frac{\partial V}{\partial T}\right)_p\right]dp$$

and equation (4) lead to following form:

$$GCp\left[\frac{\partial T}{\partial z} + \varepsilon_1\frac{\partial P}{\partial z} + \frac{A}{Cp}\left(1 + \frac{vdv}{gdz}\right)\right] + F\gamma Cp \times$$

$$\times\left[\frac{\partial T}{\partial t} - m_s\frac{\partial P}{\partial t} + \frac{Av}{Cpg}\cdot\frac{\partial v}{\partial t}\right] = \qquad (6)$$

$$= \lambda\int_0^t K(t-\tau)\frac{\partial \Delta T(z,\tau)}{\partial \tau}d\tau$$

$$\mu_S = \frac{AV}{C_p}\cdot\alpha T$$

$$\varepsilon_1 = \frac{AV}{C_p} - \mu_S$$

$$C_p = \left(\frac{\partial I}{\partial T}\right)_p$$

where V is the volume of substance of the unite mass (m^3/kr); m_s is the differential adiabatic coefficient (^{0}C/MПa); Cp - the specific isobar heat capacity (Kkal/^{0}C).

Equation (6) is basis for analytical investigation WB vertical flow temperature.

III. Problem Solution

In the case constant value of the stream flow weight G_0 and the WB cross sectional area F_0 we have $\frac{\partial v}{\partial z} = 0$; $\frac{\partial P}{\partial t} = 0$ and on laminar flow:

$$\frac{\partial P}{\partial z} = \frac{P_h - P_b}{l}$$

$$\frac{\partial T}{\partial z} + \frac{1}{v}\frac{\partial T}{\partial t} - M = \frac{\lambda}{G_0Cp}\int_0^t K(t-\tau)d\Delta T(z,t) \qquad (7)$$

$$v = \frac{G_0}{F\gamma}$$

$$M = \frac{A}{Cp}\left[\frac{P_h - P_b}{l} - 1\right]$$

where P_h and P_b – the relative well-head and bottom hole pressures (MПa) and equation (6) get simplified.

In the case $z = 0$ geothermic temperature distribution may be described using formulas

$$T_\Gamma(z) = T_0 - \Gamma z = T_0 - \frac{\partial T}{\partial z}z$$

where T_0 – the bottom hole temperature (^{0}C); Γ - the geothermic gradient (^{0}C/M).

As a result of solution of equation with condition $z > vt$ (when well vertical flow temperature is spreaded as flow rate) we have

$$T(z,t) = T_0 - \Gamma z + (M + \Gamma)\frac{CpG_0}{2\pi r_0\alpha}\times$$

$$\times\left[1 - \exp\left(-\frac{2\alpha}{r_0\gamma Cp}t\right)\right] \qquad (8)$$

$$\alpha = \frac{H}{l}\alpha_1 + \frac{l-H}{l}\alpha_2 \qquad (9)$$

where

$$\alpha_1 = f_1(\rho_l);\ \alpha_2 = f_2(\rho_2);\ \rho_l = \beta\rho_0 + (1-\beta)\rho_w.$$

ρ_l is the liquid density (г/m^3); ρ_g, ρ_0 and ρ_w are the relative gas, oil and water density (г/m^3).

Geometrical interpretation physical meaning results in coordinates [h, T] are plotted in Fig.1.

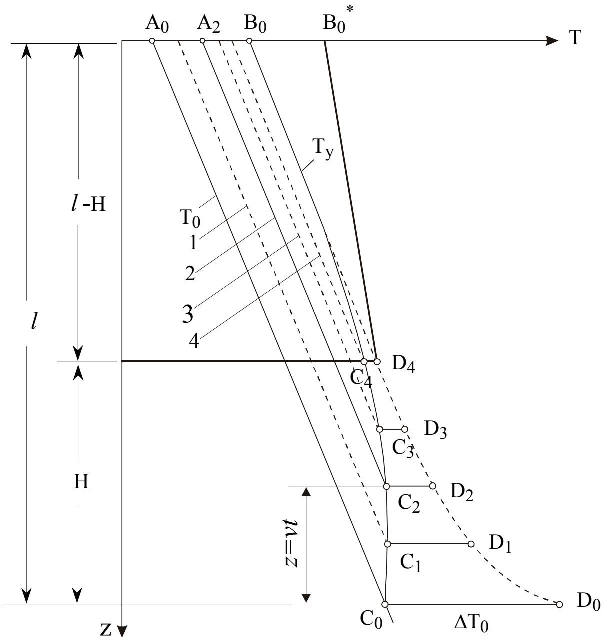

Figure 1. Temperature curves on the oil WB constructed using Nyutons heat exchange low. l is the well depth; H , l, H are the relative liquid (oil, water) and gaseus columns in the casing annulus.

After well starting temperature change in the WB from the bottom hole to the well-head in the case immediate well contacting with surrounding rocks characterized by straight lines 1, 2, 3, 4 which are parallels to the geothermic gradient A_0C_0. Consequently temperature increasing in the WB will same in all the depths from the well-head to the crossing points C_n in which moving up (C_1, C_2, C_3, C_4) on the flow rates *v*. For instance at the moment t_2 temperature epure in the WB interpretated with curve $C_0C_2A_2$.

Bottom hole temperature jump as a result of the Joul-Tomson drosseling effect. In such case well-head or well-outlet OM flow temperature depend more of bottom hole temperature [1]. Thought in the paper do not taking into consideration great casing annulus areas influence to the well outlet flow temperature. As shown from the table the relative values of the thermal conductivity of the liquid column and gas column present in the casing annulus order less than WB Wall thermal conductivity. Consequently well outlet OM flow temperature will depends not only of the volume of stream flow, also of the bottom hole temperature and of the gas column and the liquid column. As shown from the Figure 1 the line D_4B_0 is not parallel to the geothermic gradient and consequently well outlet flow temperature will more $\left(B_0B_0^*\right)$ than noted [1].

Straight A_0C_0 represents geothermal, that is WB temperature distribution before well action $t \le 0$.

Curve B_0C_0 corresponding temperature establishing in WB after well start action $\Delta T(0,t) = 0$. Maximum increasing flow temperature value over geothermic line following of formulas (8) on $t \to \infty$ has

$$\Delta T_{AB}\, max = \left(M + \Gamma\right)\frac{CpG_0}{2\pi\Gamma\alpha} \qquad (10)$$

where C – the experimental constant, value in which for different gazes changes at interval from 94 to 396.

As it is shown from formules (8)-(10) main influence to the well outlet OM flow temperature and heat transmission coefficient rendered liquid column H and column $l - H$ in the casing annulus.

As shown from above mentioned that values thermal conductivity of fluid and gaze order less than value WB Wall thermal conductivity. This confirmed with data bringing in [4] (see Table)

TABLE I. MATERIAL PROPERTIES

Property	Gaz	Water	Sand (rock)	Steel
Heat capacity	3,055	4,214	0,856	0,502
Thermal conductivity	0,08	0,72	2,25	16,27
Molecular weight	16	18		

IV. CONCLUSION

This paper presents a proposed new indirect method determining instantly oil well debit using developed mathematical models. As a result of integrated analysis using the models it has been revealed correlation between oil well debit and well throw out flow temperature. Therefore putting purpose was obtained.

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