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A New Method For Predicting the Depth of Karstic-fault Reservoir With Well Temperature log

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ABSTRACT

In the exploitation of oil and gas resources, when the development area is karstic-fault carbonate reservoir, large-scale borehole collapse is often encountered in the process of drilling. The borehole even cannot be kept drilling directly into the reservoir, so conventional logs can't be run. In this case, the reservoir is connected with the well through fracture or karst cave, and it is impossible to determine the reservoir depth through log evaluation. If the production depth of oil source is not known, it is difficult for long term and stable development of oil and gas.

The temperature becomes the only available log curve. In order to explore the method of predicting reservoir depth by using temperature log, the fluid flow field and temperature field in the well were coupled with the formation temperature field by numerical simulation.

In the case that the well is connected to the cave reservoir, the temperature log in the borehole in both transient and static modes during production time and shut-in time is simulated. When the cave reservoir is at the bottom-hole, the temperature measured at the bottom-hole is the same as the cave. When the cave reservoir and the well are connected by fractures or cave, the source depth of the fluid can be determined by the comparison of static and transient temperature logs.

1. INTRODUCTION

In Tahe Oilfield, Tarim Basin, NW China, the carbonate reservoir displays poor porosity and permeability in its matrix, while the karstic-fault system is distributed in a random, discreet and discontinuous way, which yields significant oil rates once the karstic-fault system is connected by production well (Ping Yue et al, 2018). The karstic-fault carbonate reservoirs are consisting of a group of large caves and inter-connected by high permeability fractures or caves. The reservoirs are highly heterogeneous and ultra-deep ranging from 5000 m to 7000 m (Li et al., 2016). Based on core, drilling, logging and seismic data, the karstic-fault reservoir was divided into four types by Li Yang et al(2016), namely cave, dissolved pore, fracture and Matrix block types. Cave reservoirs contribute more than95% of productivity in those blocks put into development in Tahe oilfield (Li Yang et al, 2011)

Well drilling reveals that large caves can generate "bright spots" in seismic images, which are produced by high reflection energy in a plane (Figure 1a). The "bright spot" seismic facies usually leak drilling mud, and these wells are characterized by high and stable oil production (Xinbian Lu et al,2017). The blue dotted line in Fig. 1a is the situation that karst cave is drilled in the development of oil reservoir, and this part is drawn as the schematic diagram in Figure.1b for the geometric model of simulation. The symbol h in the Figure.1b is the depth difference between the bottom-hole and the reservoir.

If mud leakage occurs after drilling to a certain depth, the drilling can be resumed smoothly after effective plugging, and the specific depth of well leakage can be directly obtained by drilling depth. If there are many lost layers within a certain range, and the sealing effect is unsatisfactory, that is, the mud lost layer is not completely blocked, or due to mud performance changes in subsequent drilling or repeated loss caused by the lifting and lowering of the drilling tool, the drilling cannot accurately determine the lost layer(Alexandre Lavrov,2016). The drilling fluid loss may affect log measurements, resulting in the leakage of open borehole logging data (Pan Baozhi et al 2014).

Temperature log is essentially transient process due to shut-in (cooling) and Production (heating) processes. During production, both the temperature of borehole and formation around the borehole increases, if production keep for a long time, the temperature of borehole will be stable called flow temperature. After shut-in, the formation and borehole temperature return to the original temperature, and the temperature log is measured in the shut-in state. At this period, the temperature log is related to the shut-in time (Mou Yang,2013).

Temperature data as geothermal heat can be considered as a natural tracer of groundwater or oil flow (Anderson, 2005; Saar, 2011). Temperature log appears to be a promising approach for characterizing connectivity patterns of the main flow paths (Maria V,2014).

The relationship between temperature and time are summarized from the numerical simulation results. The depth of oil reservoir can be determined by flow temperature curve.

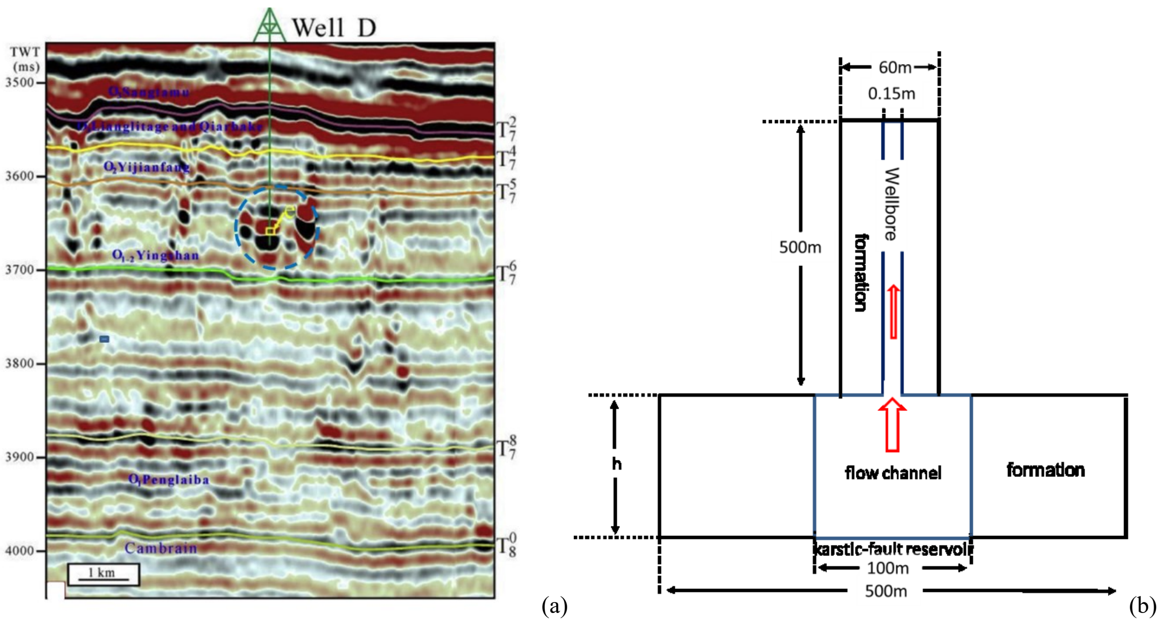

Figure 1: (a) Seismic image of karstic-fault reservoir (Xinbian Lu,2017); (b) Schematic of production well, h is the depth difference between the bottom-hole and the reservoir.

2. WORKFLOW

2.1 Physical conceptual model

In this paper, the analysis of heat transfer involved during the oil production and shut in is carried out for karstic-fault reservoirs. The physical model is divided into three sections: (i) borehole, (ii) surrounding formation, (iii) cave of flow channel (Figure.1b). For the 3D heat transport simulation, the commercial software Fluent was utilized (Evgeniy Burlutskiy,2015).

Figure. 1b shows the simulated geometric diagram and reservoir production process. At the bottom-hole is the part of the karstic cave that can't be measured by logging because of the collapse, and the oil goes into the well through this flow channel.

2.2 Governing equations

In the numerical simulation of the production process at karstic-fault reservoir, the mass conservation, momentum conservation and energy conservation control the flow and heat transfer(Pijush K,2016), and the control equations are as follows:

fluid flow

momentum conservation

$$\rho(u\cdot\nabla)u=\nabla\cdot\left[-p+\mu\left(\nabla u+(\nabla u)^{\tau}\right)\right]+F \tag{1}$$

mass conservation

$$\rho\nabla\cdot(u)=0 \tag{2}$$

heat transfer

energy conservation

$$\rho C_{\rho}u\cdot\nabla T+\nabla q=Q \tag{3}$$

$$q=-\lambda\nabla\mathrm{T} \tag{4}$$

where: ρ is fluid density, kg/cm3; u is flow velocity, m/s; μ is fluid viscosity, Pa·s; p is pressure, pa; C_{ρ} is constant pressure heat capacity, J/(kg·); q is heat flux, W/m²; λ is thermal conductivity, W/(m·k); T is temperature, k; F represents the influence of volume force, and the gravity is not considered in this paper. Q represents the influence of the heat source that has been ignored in this paper, so Q is equal to 0.

2.3 Thermal boundary conditions

The boundary of formation maintains the original temperature

$$T_\Omega = T_0 + g_T \cdot z \tag{5}$$

The flow inlet is at the bottom-hole

$$T_{in} = T_0 + g_T \cdot z \tag{6}$$

$$u_{in} = \upsilon \tag{7}$$

The flow outlet is at the top of the borehole

$$p_{out} = 0 \tag{8}$$

Where, T_Ω is temperature of formation boundary, k; T_0 is surface temperature, k; g_T is geothermal gradient, k/m; z is formation depth, m; T_{in} is inlet fluid temperature, k; u_{in} is fluid velocity at the inlet, m/s; υ is fluid inflow velocity, m/s; p_{out} is outlet pressure, pa.

2.4 Parameters

The simulation parameters as shown in table 1 are adopted in this paper, where the changes of density and viscosity with temperature and pressure are not considered.

Table 1 simulation parameters

Name	Symbol	Unit	Value
Fluid density	ρ	Kg/m	796
Fluid constant pressure heat capacity	C_ρ	J/(kg·k)	2200
Fluid viscosity	μ	Pa·s	0.002
Fluid thermal conductivity	λ	W/(m·k)	1
Formation density	ρ_f	Kg/m	2715
Formation constant pressure heat capacity	C_f	J/(kg·k)	700
Formation thermal conductivity	λ_f	W/(m·k)	3.1
Geothermal gradient	g_T	k /m	0.018
Surface temperature	T_0	k	20
Fluid inflow velocity	υ	kg/s	1.39

2.5 Mesh generation

Because the wellbore radius is 0.075m and the karst cave radius is 50m, the size difference is huge. When the two parts are meshing together, the quality of the grid is very poor, so the two parts are simulated separately. The results of karst cave simulation can be used as the input of wellbore simulation. Figure 2 is mesh of borehole and cave. Borehole, cave, and formation are meshed in different sizes.

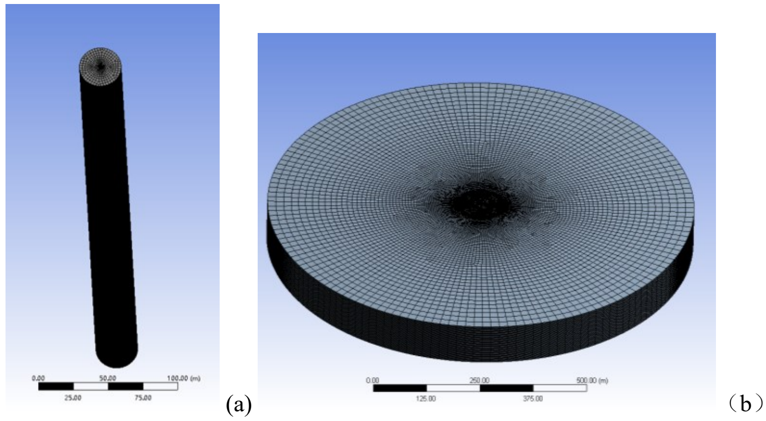

Figure 2: (a) Mesh generation of borehole. (b) Mesh generation of cave (h=100).

3. DISCUSSION

3.1 Well temperature and production time and shut-in time

In the simulation, the borehole length and formation thickness are 500m, and the formation is homogeneous and isotropic. The borehole radius is 0.075m, and the formation radius is 30m. The bottom-hole depth is 7400m, and the h is 0m. Figure 3a is the static temperature before production, and Figure 4a is the temperature distribution after the heat exchange reaches steady state during production.

Figure 3 is a cross-sectional view of the borehole and formation temperature after the well began production. In production, high-temperature fluid flows through the borehole, then fluid is cooled and the formation temperature is risen. Figure 4 is a cross-section of the temperature recovery process after shut-in. After shut-in, the borehole and formation temperature will gradually return to the original formation temperature.

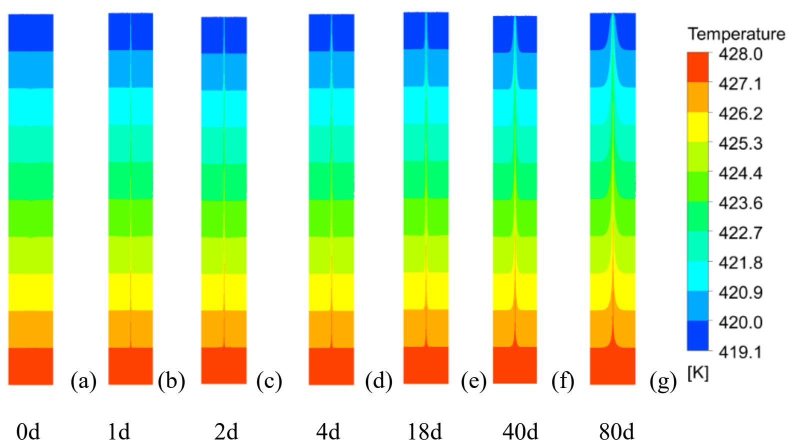

Figure 3: Temperature distribution at different times during production

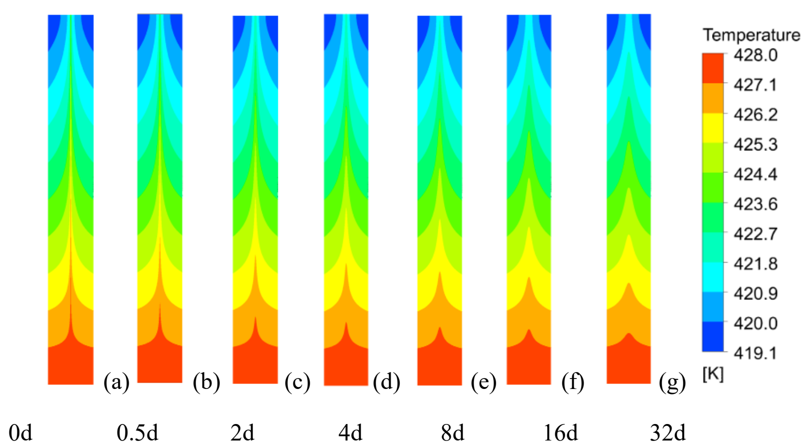

Figure 4: Temperature distribution at different times after shut-in

Figure 5 shows the borehole temperature at different times during production or shut-in. The dotted line is the original formation temperature and continuous lines are the borehole temperature in different times counted by days. After production started, the borehole temperature begins to rise and reaches a plateau before long. Figure 5b shows the borehole temperature at different times after shut-in. After shut-in, the temperature in the borehole begin to drop. The temperature drops fastest in the first 3 days and then slows down. In the early stages of shut-in, the temperature of the borehole fluid drops rapidly because the fluid is no longer flowing and heat isn't transferred vertically through the borehole.

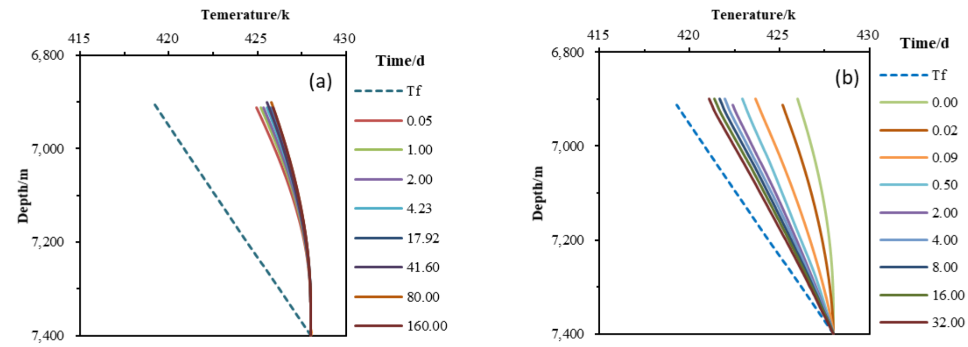

Figure 5: Borehole temperature distribution at different times, (a) during production (b) after shut-in, Tf is original formation temperature

The efficiency of vertical convection by oil is higher than radial heat conduction in well heat transfer, so formation temperature changes slowly and borehole temperature changes quickly.

Figure 6 is the relationship between the temperature difference of static and borehole temperature and time at various depth points. Various depth points mean various initial temperature differences. The relationship is shown in equation 9, and the coefficients a and b in the equation 9 are all related to the temperature difference of static and flow temperature in 0d. Normally, the temperature log is measured in the shut-in state, and the simulation shows that the shut-in time has a great impact on the measurement. The flow temperature curve during production can be inferred through the equation set (9-11), and it can predict the reservoir depth

$$\nabla T = -a \ln \tau + b \tag{9}$$

$$\nabla T0 = 13.574\,a - 0.0485 \tag{10}$$

$$\nabla T0 = 1.9105\,b - 0.0089 \tag{11}$$

Where: ∇T is the temperature difference of static and borehole temperature, k; τ is the time, day. a and b are coefficient. ▽T0 is temperature difference of static and flow temperature in 0d, k.

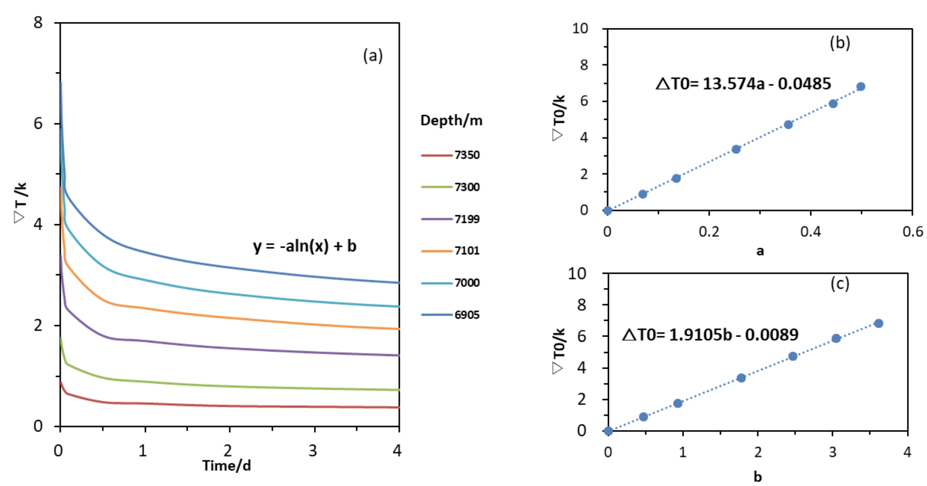

Figure 6: (a) ▽T with time at different depth points. (b) the relationship between the coefficients a and ▽T0, (c) the relationship between the coefficients b and ▽T0.

3.2 Well temperature and h

The radius of karst cave as the flow channel is 50m and a formation radius of 500m, and the depth of bottom-hole is 7400m.The temperature change of oil production in the karst cave and borehole is simulated, when the h is changing. The results are shown in Figure 7.

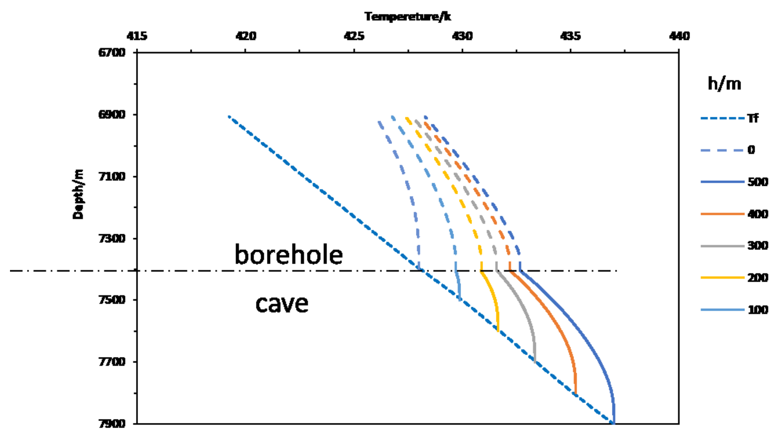

Figure 7: The temperature in the karst cave and borehole

The temperature difference of bottom-hole is used to determine h, and then the depth of reservoir is determined. Figure 8 is the temperature distribution in karst cave and the relationship between h and ∇Tb. ∇Tb is the temperature difference of flow temperature and static temperature at bottom-hole.

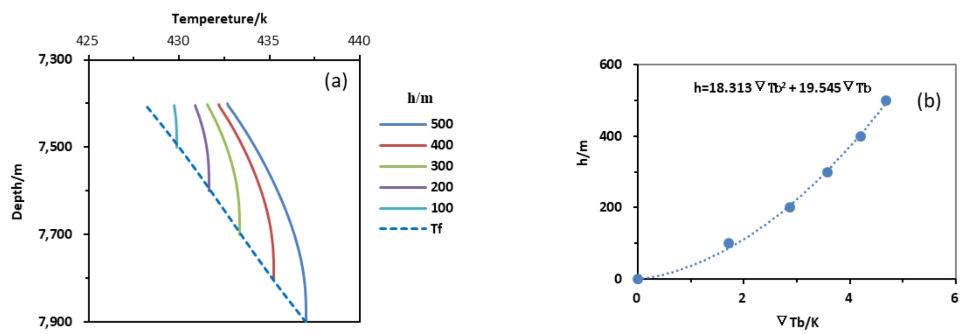

Figure 8: (a) Temperature distribution in karst cave, (b) the relationship between h and ∇Tb

When the bottom-hole flow temperature is known, the reservoir temperature can be obtained by using equation 12, and then the h and reservoir depth can be obtained.

$$h = 18.313\nabla Tb^2 + 19.545\nabla Tb \tag{12}$$

4.A CASE

Through the numerical simulation mentioned above, the method of predicting the flow temperature during production by the temperature log during shut-in and the method of prediction for the reservoir depth by the temperature difference of the bottom-hole between static and flow are obtained. The temperature log of well A in the study area are used to predict the depth of the reservoir. As shown in Figure.7, the temperature log was measured at 4 days during shut-in after the production was stabilized for a long time. The bottom-hole depth of well A is 6950m, and the prediction curve of flow temperature is obtained by the equation set 9-11. The bottom-hole flow temperature is 424.9k, and the difference with static flow temperature is 6k. The h is 800m by equation 12, so the depth of reservoir is 7750m.The temperature distribution in the cave is obtained by numerical simulation.

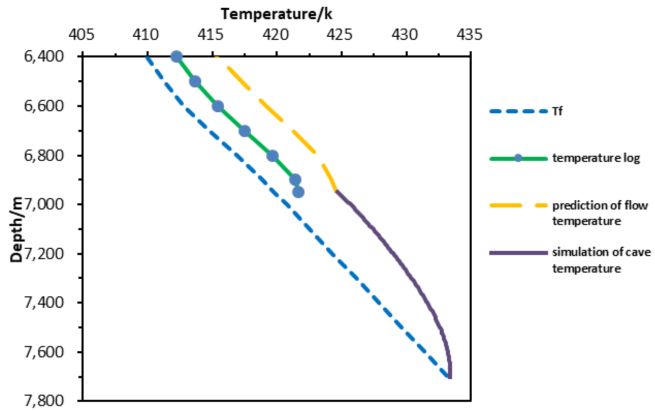

Figure.7 Temperature log and prediction temperature of well A

5. CONCLUSION

Through numerical simulation, it is found that the temperature measurement in the well is related to the shut-in time. During the first 3 days of shut-in, the temperature of the fluid in the borehole decreased rapidly. In this paper, the recovery rule of well temperature after shut-in in the study area is obtained, and the flow temperature curve during production can be predicted by equation 9-11. The karst cave is flow channel, and the depth of reservoir is predicted according to the temperature difference between static and flow temperature at the bottom-hole.

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