



Prediction temperature field and wax deposition based on heat–fluid coupling method

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Abstract

Wax deposition can reduce flow channel, increase the resistance and decrease fluid producing intensity in oil pipelines, which bring a critical operational challenge for the oil development. The prediction of temperature field and wax deposition location is the basis in thermal washing and wax removal. In this paper, the wells of sucker rod pump in Da Qing oil field is selected as the research object, a new method is proposed to predict temperature field and wax deposition location based on heat–fluid coupling method. The regularities of temperature distribution and wax deposition location are simulated with different fluid producing intensities and moisture contents. With the migration of produced liquid, the temperature decreases from bottom to upward, while the decline rate becomes less and less. With the increase of fluid producing intensity and moisture content, the temperature is increasing and the wax deposit location becomes shallower. In contrast to the calculated and measured results, the coincidences rate distribution is in the range of 95.61–97.86%. The results have a significance to the thermal washing plan formulation.

Keywords Wax deposition location · Temperature field distribution · Heat–fluid coupling · Fluid producing intensity · Moisture content

Introduction

The problem of wax deposition is common in the oil production (Elsharkawy et al. 2000; Alcazar-Vara and Buenrostro-Gonzalez 2011). The wax may be precipitated and deposited in any place where the crude oil flows, such as rod, tubing, pump, extractor, oil tank and so on (Agrawal et al. 1990; Matzain et al. 2002; Li et al. 2014). Especially in the pipelines, the wax will reduce the flow channel, increase the flow resistance, decrease the rate of flow presenting many difficulties to the petroleum production and transportation (And and Weispfennig 2005; Arasu et al. 2013; Tian et al. 2014). In the last decades, a lot of work have been carried out on the wax deposition mechanism (Hamouda and Viken 1993; Hoffmann and Amundsen 2010; Xiao et al. 2012). The wax deposition is mainly caused by the decrease of temperature

and pressure, which is affected by the oil composition, moisture content, physical and chemical characters, fluid producing intensity, and other production operation conditions (Azevedo and Teixeira 2003; Weingarten and Euchner 1988; Banki et al. 2008; Kelechukwu et al. 2013). The wax deposition of tubing and sucker rod is shown in Fig. 1. Pipelines transporting waxy crude oil should be periodically pigged to remove the paraffin wax deposits (Andrea et al. 2007; Haitao et al. 2013).

In order to schedule the pigging operation properly, design engineering project effectively, and mitigate the wax deposition problem, it is necessary to predict the well temperature and wax deposit location (Wang et al. 2014; Haj-Shafiei et al. 2014; Duan et al. 2017). In this paper, the wells of sucker rod pump in Da Qing oil field are selected as the research object, a new numerical simulation method is proposed to predict temperature field and wax deposition location based on heat–fluid coupling.

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Fig. 1 Wax of tubing and sucker rod

Mathematical model of heat–fluid coupling

The heat exchange between formation, cement sheath, casing, oil tubing, produced liquid and sucker rod is a typical heat–fluid coupling process. The heat–fluid coupled equations include continuity equation, momentum equation and energy conservation equation, as shown in formulas (1)–(3).

$$\nabla \cdot (A\rho u) = 0, \quad (1)$$

$$0 = -\nabla p - f_D \frac{\rho}{2d_h} u|u| + F, \quad (2)$$

$$\rho AC_p u \cdot \nabla T = \nabla \cdot Ak \nabla T + f_D \frac{\rho}{2d_h} |u|^3 + Q_{\text{wall}}. \quad (3)$$

According to Churchill equation, the friction factor f_D is obtained in the region of laminar and turbulent flow, as shown in the formula (4)

$$f_D = 8 \left[\left(\frac{8}{\text{Re}} \right)^{12} + (A + B)^{-1.5} \right]^{1/12}, \quad (4)$$

$$A = \left[-2.457 \ln \left(\left(\frac{7}{\text{Re}} \right)^{0.9} + 0.27(e/d) \right) \right]^{16}, \quad (5)$$

$$B = \left(\frac{37530}{\text{Re}} \right)^{16}, \quad (6)$$

$$\text{Re} = \frac{\rho u d}{\mu}, \quad (7)$$

where A is the cross-sectional area of the tube, ρ is the liquid density, u is the flow velocity, p is the pressure, F is the

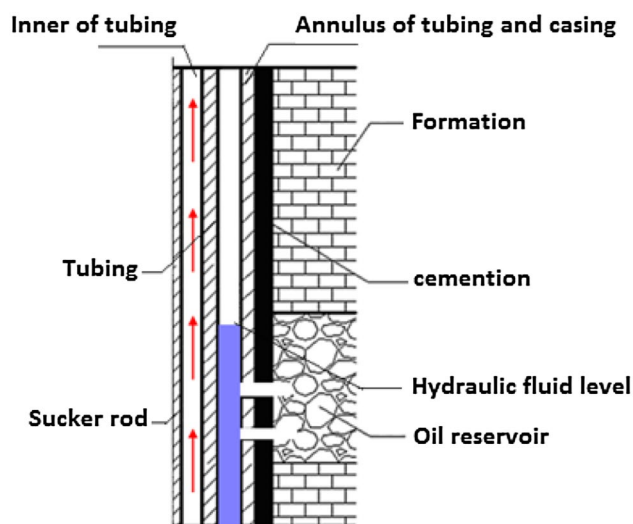


Fig. 2 Numerical physical model of producing well

volume force (gravity), C_p is the heat capacity at atmospheric pressure, T is the temperature, K is the thermal conductivity, Q_{wall} is the heat exchange between tubes and surroundings, μ is the dynamic viscosity of flushing fluid, f_D is the friction factor of the laminar and turbulent flow.

Temperature field distribution in the process of liquid production

Numerical physical model, basic material properties and boundary conditions

Based the structure of the well, the axisymmetric finite element model is established for rod–tubing–casing–cement–formation with the borehole axis as the center, as shown in Fig. 2.

In the numerical simulation, adopt the following assumptions: (1) the cementing status is well, and each interface between casing, cement and formation is neither disengaged nor sliding; (2) the heat transfer reduction due to wax layer formation is neglected. The depth of well is about 1000 m. The rod diameter is 22 mm. The inner and outside diameter of tubing are 62 and 73 mm, respectively. And the inner and outside diameter of casing are 124 and 139.7 mm, respectively. The diameter of borehole is 215.9 mm. The basic performance parameters of various materials are as follows: the heat absorption capacity of water and crude oil are 4200, 2200 J/(kg K), respectively. The coefficient of heat conductivity are 0.5 and 0.32 W/(m K), respectively. The heat absorption capacity and the coefficient of heat conductivity for casing and tubing are 460, 18.5 W/(m K), respectively. The coefficient of heat conductivity for cement and stratum

is 5 W/(m K). The entrance is set on the bottom of tubing, the velocity boundary is applied according to the liquid production rate, and the temperature boundary is set as 321.65 K which is the oil reservoir temperature. The exit is set on the wellhead of tubing, and the pressure is given as one bar pressure. The symmetry plane is a symmetrical boundary.

Simulation results and distribution of temperature field

The fluid producing intensity and moisture content are the most important influence factors in the temperature field. The temperature field is simulated and analyzed with different fluid producing intensities and moisture contents. When the water content is 90%, the fluid producing intensity is 110 t/d, the temperature field of whole well is shown in Fig. 3, and the temperature distribution of central axis for tubing and annulus of tubing and casing is shown in Fig. 4.

Seen from Figs. 3 and 4, the temperature field in the tubing decreases gradually from bottom to wellhead with the produced liquid migrating, while the temperature in the tubing is higher than the value in annulus of tubing and casing. When the moisture content is 90%, the temperature distribution in tubing with different fluid producing intensities is shown in Fig. 5.

Seen from Fig. 5a, the drop rate of temperature field in tubing is different with different depths, and 700 m is a key point, the temperature changes smoothly when the depth is

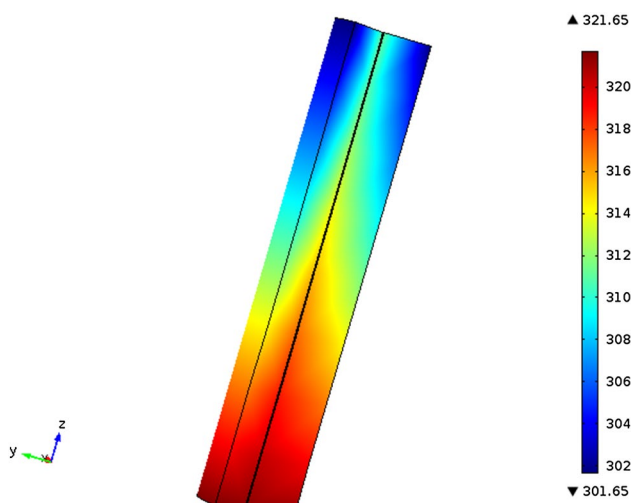


Fig. 3 Temperature field of whole well

more than 700 m, while the temperature changes intensely from 700 m to wellhead. Seen from Fig. 5b, the temperature of tubing is increasing with the increase of fluid producing intensity, and the temperature changes obviously when the fluid producing intensity is 0–100 t/d, while the temperature

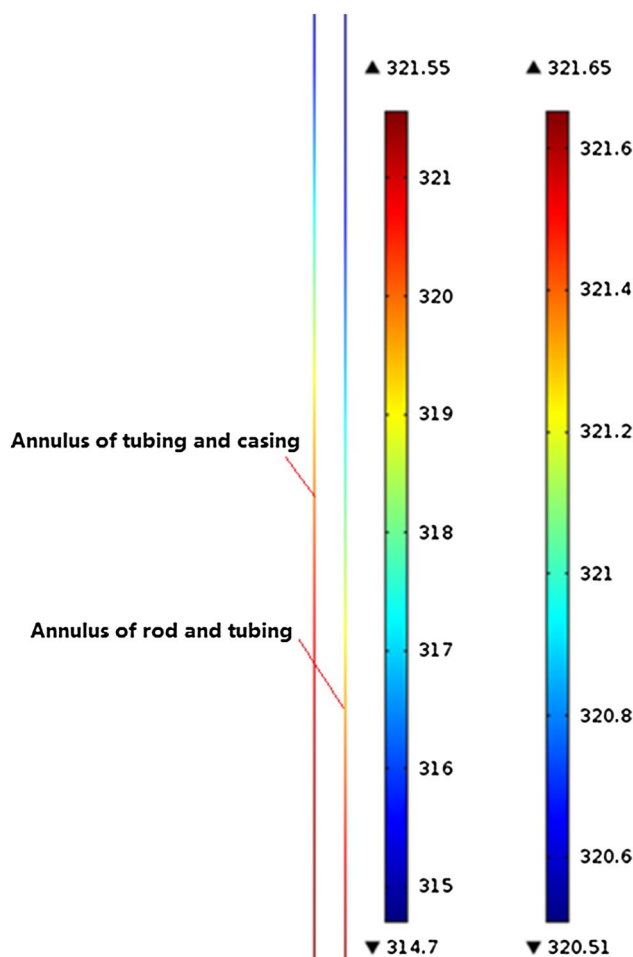


Fig. 4 Temperature field of center line of annulus of rod and tubing, tubing and casing

changes slowly and tends to be stable when the liquid production rate is more than 100 t/d. When the fluid producing intensity is 110 t/d, the temperature distribution of tubing with different moisture content is shown in Fig. 6.

Seen from Fig. 6a, b, the temperature increases gradually with the increase of moisture content, while the temperature rise rate is different in different depth positions.

Wax precipitation temperature

The crude oil composition is tested in Da Qing oilfield. The results show that the composition of crude oil is as follows: the saturated hydrocarbon is 52.31%; the aromatic hydrocarbon is 24.35%; gum is 18.71%; asphaltene is 10.66%; wax content is 11.21%. To determine the wax precipitation temperature, the viscosity–temperature curve is tested. The apparatus is shown in Fig. 7a, and the test results are shown in Fig. 7b.

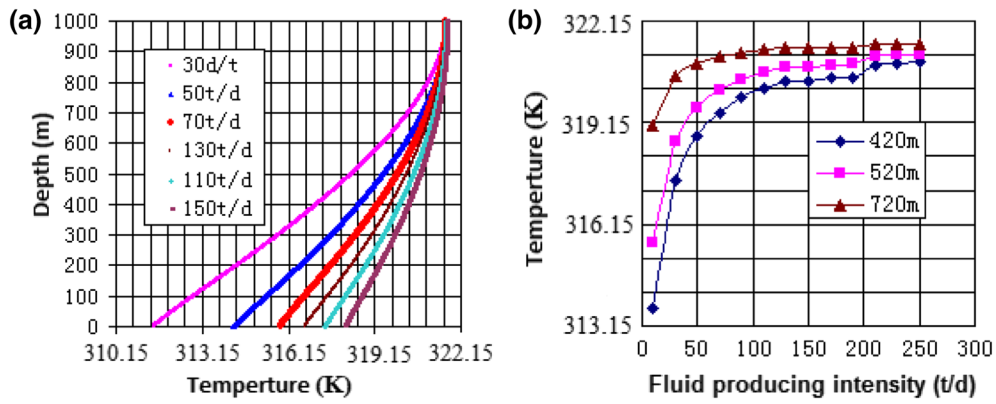


Fig. 5 Temperature of tubing for different fluid producing intensities

Fig. 6 Temperature of tubing for different moisture contents

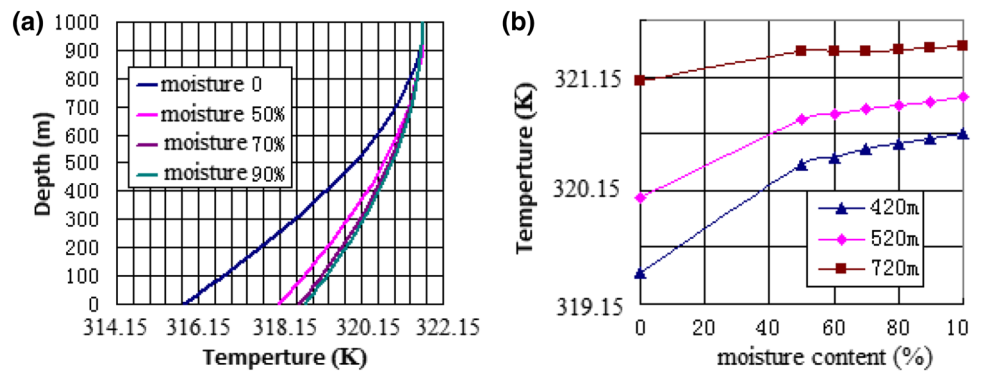


Fig. 7 Apparatus, relation of viscosity and temperature

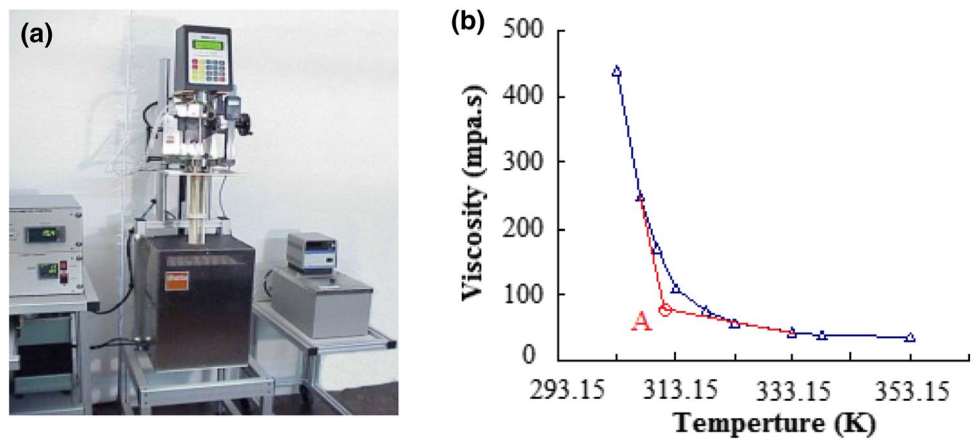


Table 1 Predictive and actual value of wax deposition location

No.	Well	Wax deposition predictive value (m)	Wax deposition actual value (m)	Coincidence rate (%)
1	L4-PS2317	327	342	95.61
2	L4-AS2223	254	265	95.85
3	L8-2232	572	560	97.86
4	L5-2001	172	167	97.01
5	L8-2135	464	480	96.67

The coincidence rate of predicted and actual results is in the range of 95.61–97.86%

Figure 7b shows that the viscosity increases sharply when temperature is lower than point “A”, and the wax crystal will be precipitated from crude oil, and the value is 311.89 K.

Prediction of wax deposition location

The wax is usually dissolved in the crude oil under the formation condition, while it may be precipitated and deposited with the temperature decrease. The wax deposition location can be predicted by comparing the well temperature field and wax precipitation temperature. The wax deposition locations of five wells are predicted with this method, and then the pump inspections are carried out, and the actual wax deposition locations are observed. The predicted results are compared with the measured results, as shown in Table 1.

Conclusions

1. Based on heat–fluid coupling method, the temperature field is simulated under different fluid producing intensities and moisture contents. With the increase of fluid producing intensity and moisture content, the temperature drop rate becomes slow from bottom to upward.
2. The viscosity–temperature curve is tested for the crude oil of Da Qing oilfield, the wax precipitation temperature is 311.89 K, the viscosity will increase sharply when temperature is lower than this value.
3. The method to predict wax deposition location is established by comparing the temperature field in the tubing and wax precipitation temperature. The coincidence rate of numerical simulated and tested values is in the range of 95.61–97.86%.

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