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Research article

Prediction of pressure between packers of staged fracturing pipe strings in high-pressure deep wells and its application

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Abstract

Addressing to the deteriorated load conditions of working string and packers caused by annular pressure drop between packers during the staged stimulation of high-pressure deep well, one 2D temperature field transient prediction model for borehole under injecting conditions which considers such influences as friction heat, convection heat exchange was set up, based on energy conservation principle and borehole heat transfer theory. By means of analyzing the influences of borehole temperature and pressure changes on the annular volume between packers, and in combination with borehole temperature transient prediction model, annular fluid PVT equations of state, radial deformation model of tubing and formation transient seepage equation, a typical high-pressure deep well inter-packer annular pressure prediction model was established. Taking a high-pressure gas well in Tarim Oilfield for example, the inter-packer annular pressure prediction was conducted, on which, the mechanical analysis on packers and working strings was carried out. The analysis results show that although the pipe string is safe in the viewpoint of conventional design methods, it is still susceptible to failure after the annular pressure drop between packers was taken into consideration. Such factor should be fully considered in the design of staged stimulation pipe strings, and this prediction model provides new thoughts for the optimal design of high-pressure deep well staged stimulation pipe strings.

Keywords: High pressure; Deep well; Staged stimulation; Annular pressure; Prediction model; Tarim Oilfield

In the early stage of test and production of an HPHT well, due to the drastic increase of wellbore temperature, temperature of the fluid sealed in all layers of casing annular will increase, which would lead to casing failure and wellhead lifting. A lot of researches in this aspect have been done both at home and abroad [1−7]. Sharp decline in wellbore temperature during staged fracturing of high-pressure deep wells would bring about fluid shrinkage in annular between packers, and the pressure during stimulation would cause tubing string expansion, which together would give rise to the drop of annular pressure between packers. This pressure drop would then result in a great pressure difference inside and outside the tubing packer and above and below the packer, deteriorated loading condition of both operation tubing string and packers, and ultimately would lead to packer and stimulation pipe string failure. There is little research at home and abroad on annular pressure between packers during simulation, in which the annular pressure between packers was hypothesized to be equal to the formation pressure [8]. In view of the defects in traditional tubing string design method, a 2D temperature field transient prediction model for wellbores was established based on the energy conservation equation, and an annular pressure prediction model between packers was established based on the relation of annular volume between packers and wellbore temperature and pressure as well. Then an example is given to verify the prediction model in this study.

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1. 2D transient prediction model for wellbore temperature field

In the course of staged stimulation of high-pressure deep wells, the change of wellbore temperature field follows the energy conservation law [9]:

$$dQ_{\mathrm{tol}} + dW_{\mathrm{tol}} = dE_{\mathrm{tol}} \tag{1}$$

where, dQ_{tol} is the heat flowing into a wellbore volume unit per unit time, J/(s·m); dW_{tol} is the work done by outside the environment to the wellbore volume unit per unit time, J/(s·m); dE_{tol} is the energy variation in the wellbore volume unit per unit time, J/(s·m).

As is shown in Fig. 1, according to wellbore system units including fluid in tubing, tubing string, fluid between casing and tubing, casing string, cement sheath and formation, the wellbore system was divided into several control unit volume in axial and radial direction, then, the governing equation of wellbore temperature field transient prediction model was built based on theories of heat conduction and heat convection of all kinds of media in the wellbore system.

(1) Fluid unit in oil tubing. The physical model of heat transfer of the fluid in tubing is shown in Fig. 2. The heat flowing into the volume unit consists of the heat carried by fluid flowing in tubing, the heat transferred in both axial and radial direction on and cross the tubing wall, and frictional work done by viscosity of fluid when flowing inside the tubing. The energy conservation equation derived is [10]:

$$k_1\frac{\partial^2 T}{\partial z^2} + \frac{2h_{\mathrm{ti}}(T_{\mathrm{t}} - T_1)}{r_{\mathrm{ti}}} + \frac{Q_1}{A_1} = \rho_1 c_1\frac{\partial T}{\partial t} + \rho_1 c_1 v_1\frac{\partial T}{\partial z} \tag{2}$$

where, the subscripts l, t, and ti mean the fluid in tubing, tubing string and inner wall of the tubing respectively; k is the coefficient of thermal conductivity, W/(m·K); T temperature, K; z depth, m; and h convection coefficient of heat transfer, W/(m^2·K); r radius of the volume unit, m; Q heat caused by friction, J/s; A cross section area of the volume unit, m^2; ρ fluid density, kg/m^3; c specific heat, J/(kg·K); t time, s; v flow velocity, m/s.

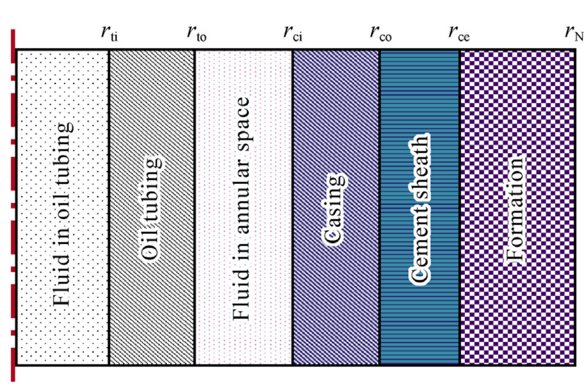

Fig. 1. Thermal transmission in radial direction in the 2D wellbore.

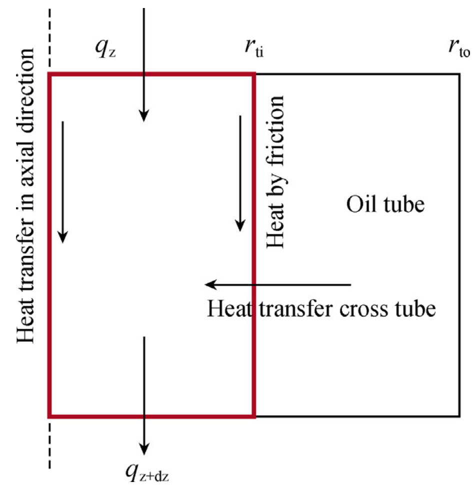

Fig. 2. Fluid unit inside the tubing.

(2) Tubing string unit. The physical model of thermal transfer on and cross tubing wall is illustrated in Fig. 3. The heat getting into tubing from outside includes heat transferred in the axial direction and radial direction on and cross the tubing wall. The environment does no work to the volume unit since the heat caused by friction has already been considered in fluid unit in tubing. Thus, the equation derived from energy conservation law is:

$$k_{\mathrm{t}}\frac{\partial^2 T}{\partial z^2} + \frac{4r_{\mathrm{to}}k_{\mathrm{cl}}(T_{\mathrm{cl}} - T_{\mathrm{t}})}{(r_{\mathrm{cl}} - r_{\mathrm{to}})\left(r_{\mathrm{to}}^2 - r_{\mathrm{ci}}^2\right)} + \frac{2r_{\mathrm{ci}}h_{\mathrm{ci}}(T_1 - T_t)}{\left(r_{\mathrm{to}}^2 - r_{\mathrm{t1}}^2\right)} = \rho_{\mathrm{t}} c_{\mathrm{t}}\frac{\partial T}{\partial z} \tag{3}$$

where, subscripts to, cl, and ci denote the outside wall of tubing, fluid in annular space and inner radius in annular space respectively.

(3) Other units. The energy conservation equation of all other units is the same:

$$k_{\mathrm{w}}\frac{\partial^2 T}{\partial z^2} + k_{\mathrm{w}}\frac{\partial^2 T}{\partial t^2} + \frac{k_{\mathrm{w}}}{r}\frac{\partial T}{\partial r} = \rho_{\mathrm{w}} c_{\mathrm{w}}\frac{\partial T}{\partial t} \tag{4}$$

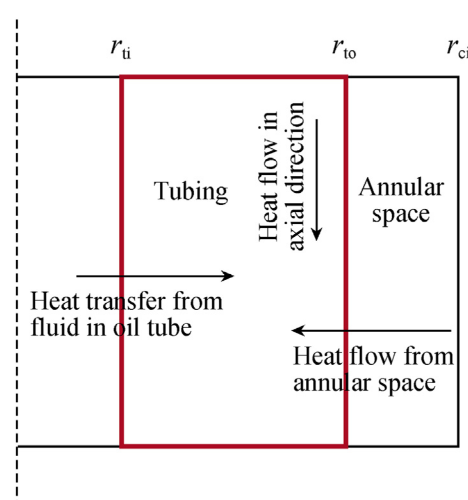

Fig. 3. Tubing string unit.