Study on Borehole Stability of Shale Gas Well under Multi-field Coupling

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Introduction

The mechanical response of mud shale under the action of multiple field coupling is always a hot topic in the field of drilling engineering. In this paper, a multi-field coupled model is established, using the solid mechanics module embedded in COMSOL and combined with the General form in PDE module to complete the setting of the model. The grid encryption function is used to encrypt the area around the well, which makes the calculation results more advanced and more in line with the actual situation on site. The results show that the collapse process of rock around the shaft wall is a dynamic evolution process involving space and time, and COMSOL can well simulate the above 4-D process. The simulation results can be used to analyze and simulate the effect of time dependence on wellbore stability during drilling. It can also help drilling engineers design drilling plans (including design and calculation of mud safety density window, mud salinity, etc.).

Coupling model

Navier equations for displacements: A momentum balance equation is employed to derive the Naviertype equation for displacements as:

$$(K+\frac{G}{3})\nabla(\nabla u)+G\nabla^2 u-\alpha\nabla p+\omega_0\chi a\nabla C^S-\gamma_1\nabla T=0 \qquad (1)$$

where K and G are bulk and shear moduli, u is the rock displacement and T is the temperature of the porous medium.

Pressure diffusion equation: Using conservation of mass for a weakly compressible fluid along with the expression for the flux gives a coupled fluid diffusion equation as:

$$\frac{\alpha\partial\varepsilon_{ii}}{\partial t}+(Q+B)\frac{\partial p}{\partial t}+\beta\chi\frac{\partial C^S}{\partial t}-\gamma_2\frac{\partial T}{\partial t}=\frac{k}{\mu}\nabla^2 p-\frac{k\Re\rho_f aRT}{\mu c M^S}\nabla^2 C^S-K^T\nabla T \qquad (2)$$

where α is the Biot's Coefficient, p is pore pressure, k is permeability, the fluid viscosity is μ . ε_{ii} and C^S are the components of total strain tensors and solute mass fractions. Also, $\Re$ is the standard solute reflection coefficient (or membrane efficiency), R is the universal gas constant. M^S is the molar mass of the solute. K^T is the thermal osmosis coefficient.

Equation for solute diffusion: Conservation of a solute mass in rock yields the following equation for solute transfer:

$$\phi\frac{\partial C^S}{\partial t}-D\nabla^2 C^S-C^S D^T\nabla^2 T=0 \qquad (3)$$

Where D is the solute diffusion coefficient and K^T is the coefficient of thermal diffusion.

Equation for thermal conduction: Conservation of energy balance in the rock yields the following equation for thermal conduction:

$$\frac{\partial T}{\partial t}-c^T\nabla^2 T=0 \qquad (4)$$

Where c^T is thermal diffusivity.

The coefficients in the governing equations are:

$$\chi=(1-\frac{C^S_{mean}}{cRT\rho_f}) \qquad c=C^D_{mean} \qquad a=\frac{1}{C^S_{mean}} \qquad \alpha'=(\alpha-\frac{M^S\omega_0}{cRT\rho_f})$$

$$B'=\frac{\omega_0(\alpha-1)}{K}\frac{M^S}{cRT\rho_f} \qquad Q'=(Q+\frac{\phi}{K_f}) \qquad Q=\frac{(\alpha-\phi)}{K_S}$$

$$\gamma_1=K\alpha_m+\frac{s_0\omega_0M^S}{RTC^D_{mean}} \qquad \gamma_2=\alpha\alpha_m+(\alpha_f-\alpha_m)\phi+\frac{s_0\omega_0(\alpha-1)M^S}{KRTC^D_{mean}}$$

boundary conditions

It is assumed that compressive stress is positive and tensile stress is negative. The rock is considered as a homogenous porous medium. The plane strain hypothesis and instantaneous drilling are used to solve the non-linear system of equations. Solving the non-linear system of equations requires knowledge of the initial solute concentration, temperature and pore pressure within the flow domain:

$$C^S(x,y,t)=C^S_{Mean}(x,y) \quad \text{for t=0}$$

$$P(x,y,t)=P_i(x,y) \quad \text{for t=0}$$

$$T(x,y,t)=T_i(x,y) \quad \text{for t=0}$$

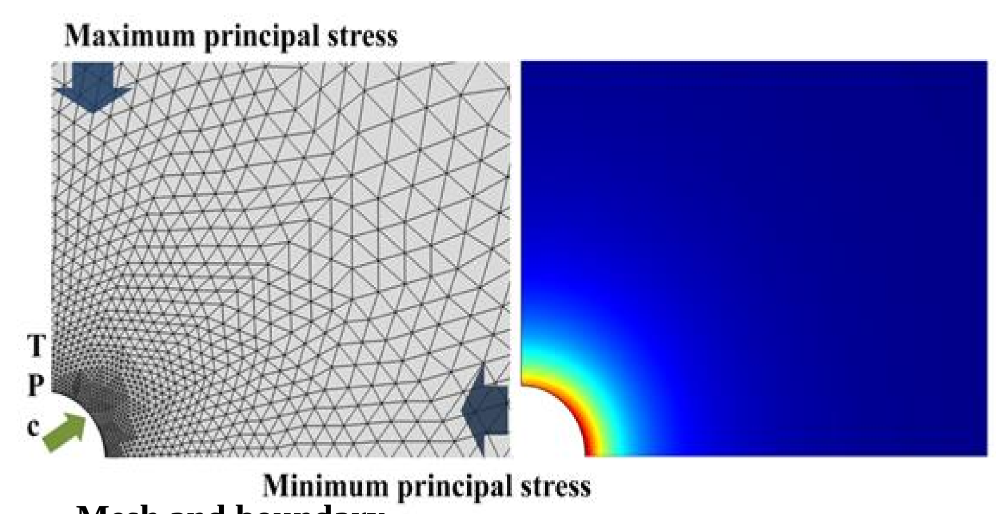
Dirichlet type boundary condition is applied to the inner boundary for the solute concentration, temperature and pore pressure as follows:

$$C^S(x,y,t)=C^S_1(x,y,t) \quad \text{on boundary}$$

$$P(x,y,t)=P_1(x,y,t) \quad \text{on boundary}$$

$$T(x,y,t)=T_1(x,y,t) \quad \text{on boundary}$$

Calculation results



Mesh and boundary condition loading

Rock mechanical parameters	
Drained Poisson's ratio	0. 219
Undrained Poisson's ratio	0. 416
Skempton coefficient	0. 915
Bulk Young's modulus	4. 4GPa
Maximum horizontal stress	23MPa
Minimum horizontal stress	20MPa
Solid bulk modulus	77. 5GPa
Hydraulic parameters	
Drilling fluid pressure	26MPa
Initial reservoir pressure	21MPa
Fluid bulk modulus	2. 5GPa
Chemical parameters	
Average solute mass fraction in formation	0. 1
Average solute mass fraction in drilling fluid	0. 2
Molar mass of solute	0. 0585Kg/mol
Solute diffusion coefficient	5e-9m²/s
Membrane efficiency or reflection coefficient	0. 1
Othe parameters	
Formation temperature	353. 15K
Drilling fluid temperature	333. 15K
Wellbore radius	0. 1m
Fluid viscosity	3e-4Ps˙S
Fluid density	1211. 21Kg/m³
Porosity	0. 218

Table 1. Basic Parameters

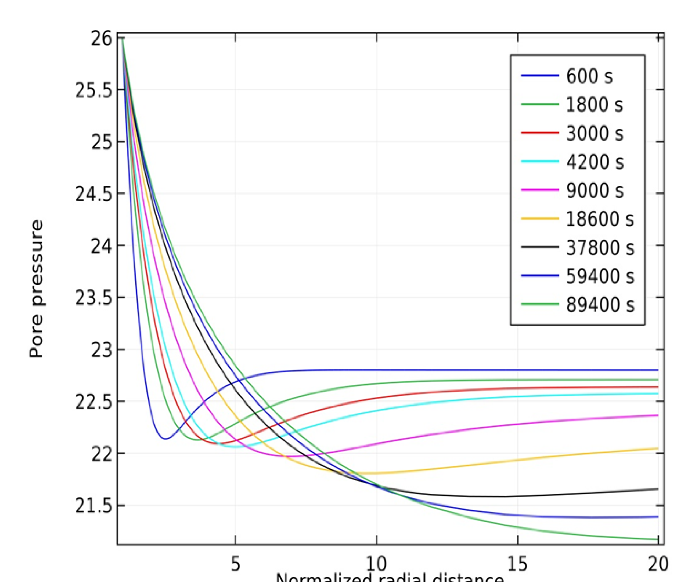
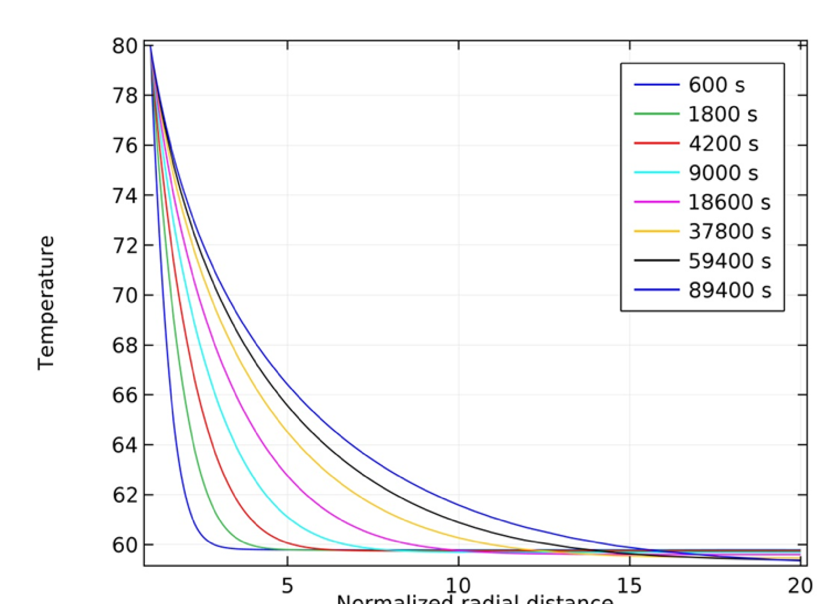


Figure.1 shows the pressure distribution near the well with time.Is the classical pressure wave transfer curve.With the time of drilling and opening the hole, the pressure wave front gradually moves along the hole radial direction from the hole wall.Meanwhile, as can be seen from the figure, its size gradually decreases.This phenomenon is caused by energy dissipation.

Figure.2 shows the typical transient temperature distribution of heat conduction.This indicates that the formation is gradually cooled by drilling fluid injected from the surface.



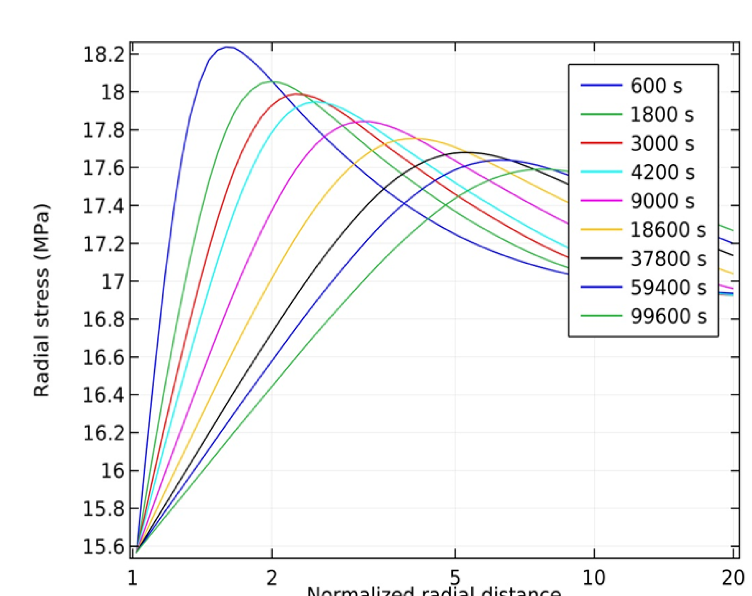
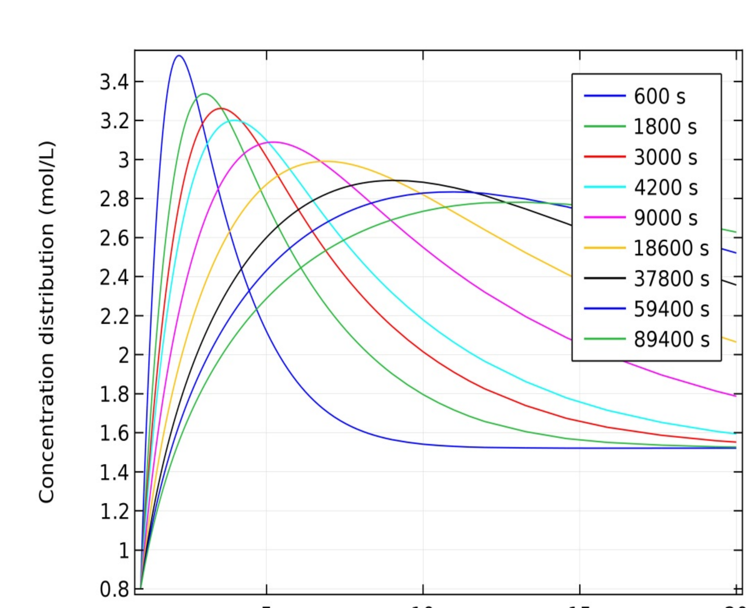


Figure.3 shows the distribution of radial stress around shale gas Wells over time.From the solution results, the stress peak is not in the hole wall out, but in the formation with a certain distance from the hole wall.This is quite consistent with reality.In actual drilling, there are large collapse slabs in the mud returned from the top, which fully shows that the fracture point of mud shale section is at a certain distance from the well wall.This result is consistent with Ghassmi's paper results.

Figure.4 shows the spatial and temporal distribution of the solute of the drilling fluid around the well.As the salinity of the drilling fluid is higher than that of the formation, solutes in the solution gradually spread to the formation and finally reach stability.



The drilling engineer is very concerned about the stress and chemical physical state around the well. The stress state around the hole can be simulated well by using COMSOL software.This can help engineers solve engineering problems.

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