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Simulation of Casing Stress in Thermal Recovery Production Wells

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Abstract

Thermal well technologies, such as Cyclic Steam Stimulation (CSS) and Steam Assisted Gravity Drainage (SAGD), have been widely used in the production of heavy oil reservoir. Casing failure generally exists in heavy oil thermal recovery production and becomes more and more serious. The three-dimension finite element model was developed by using ANSYS software, which applied in thermal structure coupling condition for casing, cementing hoop and rock. The influence of the parameters change on casing stress in thermal-structure coupling condition was studied. The results show that the equivalent stress can be significantly reduced by the application of high-quality insulated casing tube, borehole curvature should be as small as possible to minimum casing failure in heavy oil thermal recovery wells, casing tubes with low elastic modulus should be chosen.

Key words: Casing damage; Thermal recovery production; Finite element model; Elastic modulus; Cementing

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INTRODUCTION

Production of heavy oil reservoir, which is increasing around the world as conventional oil resources are depleted, often uses thermal well technologies such as Cyclic Steam Stimulation (CSS) and Steam Assisted Gravity Drainage (SAGD)[1]. Past experience in thermal projects has shown that steam, in addition to heating the heavy oil, can cause very high temperatures and corrosive conditions that may impose considerable thermal stress and chemical attack on casing and cement sheaths[2-4]. Casing failures and sand production problems lead to reduced well performance and the loss of many production and injection wells each year. Preventing casing damage requires reducing the casing temperature and/or the thermal compressive stresses[5-6]. In new completions this is normally achieved by selecting a suitable combination of materials, controlling casing temperature and cementing the casing in tension[7-8]. In existing wells, only the casing temperature can be controlled. Casing failures are expensive to repair, result in decreased production and lost reserves, can damage adjacent wells and have been associated with blowouts. In this paper, the three-dimension finite element model was developed and casing Mises stress was studied under thermal-structure coupling condition, the research result can provide reference to take appropriate precautions to prolong casing life.

1. FINITE ELEMENT ANALYSIS OF CASING DAMAGE IN THERMAL RECOVERY WELLS

By studying stratum-cement sheath-casing combination of 1200 m depth and wellbore axis as center, 1/4 3D finite element model of tubing-casing-cement sheath-stratum were built, as shown in figure 1. Height of the model was 10m and its length and width were both 10m. Assuming the oil well was under good cementing condition during steam injection, so casing, cement sheath and stratum cannot separated or slipped each other. Then temperature field and stress field of the model were solved.

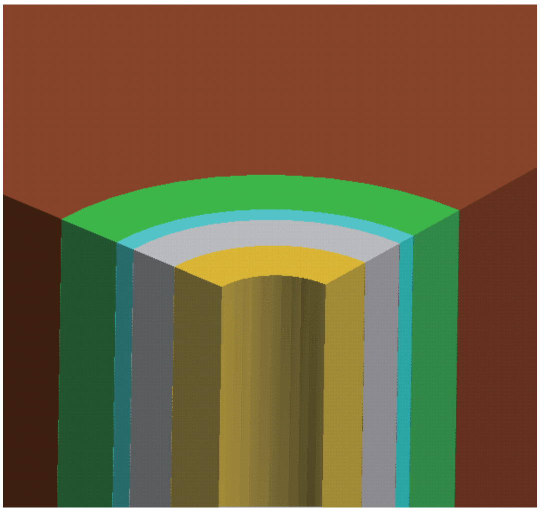

Figure 1
Finite Element Model

1.1 Model Structure and Material Properties

Inner radius of insulated tubing is 31 mm and its outer radius is 57.15 mm. Inner radius of N80 casing is 79.71 mm and its outer radius is 88.9 mm. So annular thickness is 22.56 mm between tubing and casing. Cement thickness is 30 mm. All material characteristic parameters are shown in Table 1.

Table 1
Material Characteristic Parameters

Material	Tubing	Annulus	Casing	Cement	Stratum
Density(kg/m^3)	7850	1	7850	1830	2390
Coefficient of thermal conductivity(w/m×℃)	56.5	0.62	43.27	0.81	1.687
Elastic modulus (GPa)	122	-	120	20	25
Poisson ratio	0.3	-	0.3	0.15	0.21
Coefficient of linear expansion (10^{-6}℃$^{-1}$)	12	-	11.7	10.3	10.3

1.2 Boundary Conditions

Temperature load includes steam injection temperature acted on the inner wall of tubing and original formation temperature (40 ℃) acted on formation boundary. Stress load consists of steam injection pressure acted on the inner wall of tubing and in-situ stress acted on the model boundaries.

The main effect of temperature on casing has three aspects, one is the casing itself with the increase of temperature and strength reduction, two is the rise in temperature of casing expansion caused by compression stress and the bending stress of the casing reduced, three is closed annulus fluid expansion causes casing internal pressure to increase and cause casing strength reduction.

2. RESULT ANALYSIS

2.1 Influence of Different Insulation Measures on Casing Stress

For ordinary tubing, the coefficient of thermal conductivity is 56.5 W/(m·℃). The coefficient of thermal conductivity of ordinary insulated tubing is 0.06 W/(m·℃). For high vacuum insulated tubing, the coefficient of thermal conductivity is lower than 0.003 W/(m·℃). Assuming steam temperature of 350 ℃ and steam injection pressure of 20 MPa, Influence of different coefficient of thermal conductivity (k_{xx}) on Mises stress of casing were studied (Figure 2). As can be seen from Figure 2, different insulation measures have great effect upon casing stress, and high-performance insulated tubings can significantly decreases equivalent stress on casing wall.

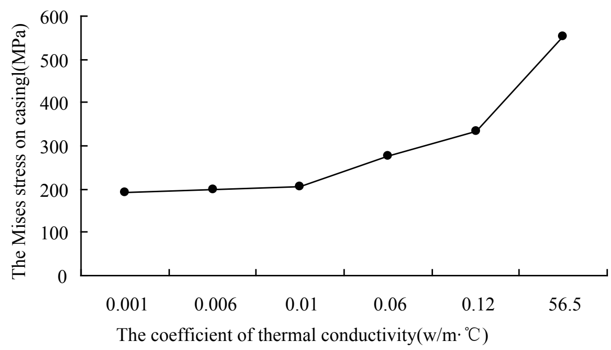

Figure 2
The Stress Distribution of Casing Under Different Insulation Measures

2.2 Influence of Steam Injection Temperature on Casing Stress

Mises stress on casing inner wall under different steam injection temperature and different thermal insulation measures was simulated. As can be seen from Figure 3, with the increase of steam injection temperature, Mises stress on casing inner wall increases rapidly. When steam injection temperature is 350 ℃, the Mises stress is 576 MPa.

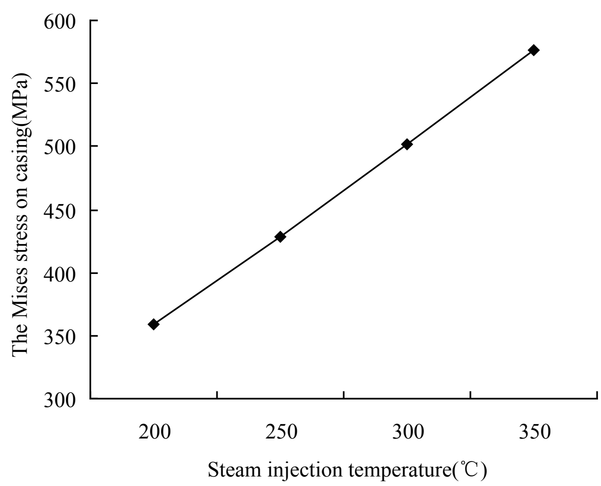

Figure 3
Mises Stress of Casing Under Different Steam Temperature

2.3 Influence of Casing Elastic Modulus on Casing Stress

With the increase of casing elastic modulus, Mises stress of casing increases linearly (Figure 4). However, during steam injection, casing elastic modulus decreases with the increase of steam injection temperature, so while considering the influence of steam injection temperature on casing stress, changes of casing elastic modulus in different steam temperature should be considered. Also, it should be noted that the influence trend of steam temperature on them is opposite. In a word, in order to prevent casing from damage, casing with low elastic modulus in high temperature should be used in thermal recovery well.

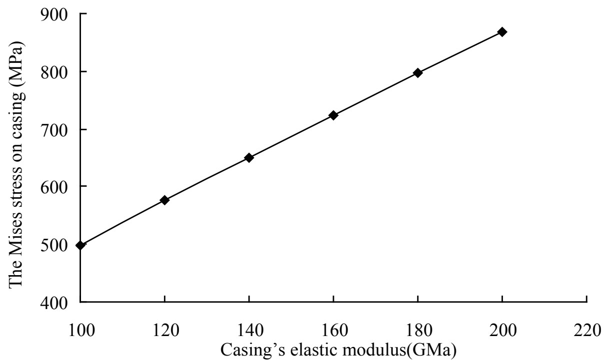

Figure 4
Relationship Between Casing Mises Stress and Casing Elastic Modulus

2.4 Influence of the Layer'S Elasticity Modulus on Case Stress

Most of thermal production wells were drilled in unconsolidated sandstone reservoir, it is easy to have sand production phenomenon in these wells. The layer's elasticity modulus will automatically decline. The relationship between casing Mises stress and layer's elastic modulus was shown in Figure 5. It can be drawn that the Mises stress on the case reach up to 1023 MPa when the modulus of elasticity dropped to 2.5 GPa. In this situation, the case will be damaged, because yield strength of 110H is about 734 MPa at 350 ℃.

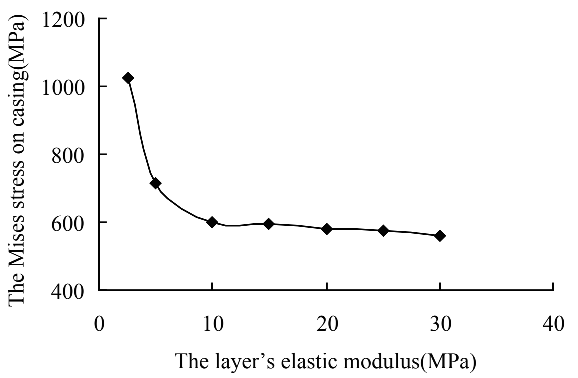

Figure 5
Relationship Between Casing Mises Stress and Layer's Elastic Modulus

2.5 Influence of Cement Elasticity Modulus on Case Stress

Case and layer will be combined as one body by concrete after well completion. The function of cement included that isolating layer, decreasing the pressure of surrounding rock to case and improving the stress situation in case. The relationship between casing stress and cement elasticity modulus was shown in Figure 6. From Figure 6, it is known that the Mises stress will rise sharply with cement elasticity modulus increasing, and drop slowly after up to the maximum, and the change frequency is not more obviously than before. That means the effect will be improved greatly in the same stiffness when the cement elasticity modulus is less than layer's modulus. Meanwhile, it can be known that casing stress situation will change once cement was damaged (Figure 7). When cement damage angle is up to 40°, the casing stress will rise to 960 MPa, which beyond the yield strength of 110H case at 350°.

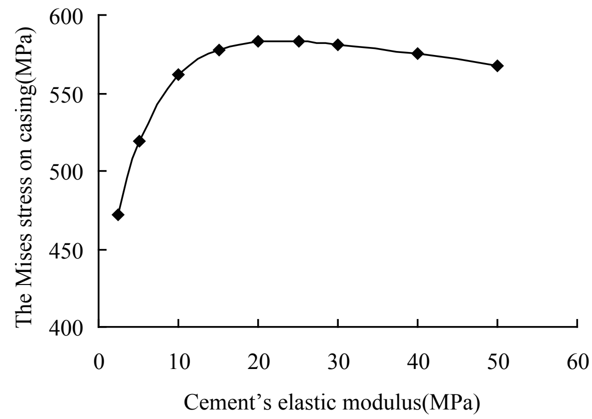

Figure 6
Relationship Between Casing Mises Stress and Cement Elasticity Modulus

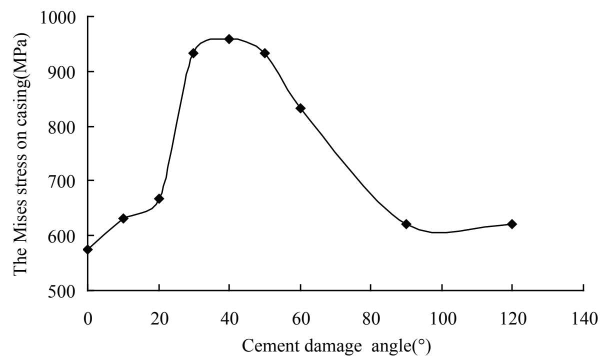

Figure 7
Relationship Between Casing Mises Stress and Cement Damage Angle

2.6 Influence of Borehole Curvature on Case Stress

The relationship between casing Mises stress and cement damage angle is shown in Figure 7. It can be drawn that with the increase of borehole curvature, casing stress increases linearly. The reason is that there are compressive stress and tensile stress at the inner side and outer side of casing when casing is bent, and bending moment and bending stress of casing increases gradually with the increase of borehole curvature which result in the increase of casing equivalent stress. Therefore, the curvature of borehole trajectory in thermal recovery directional and horizontal well should be designed a little lower than non-heavy oil wells.

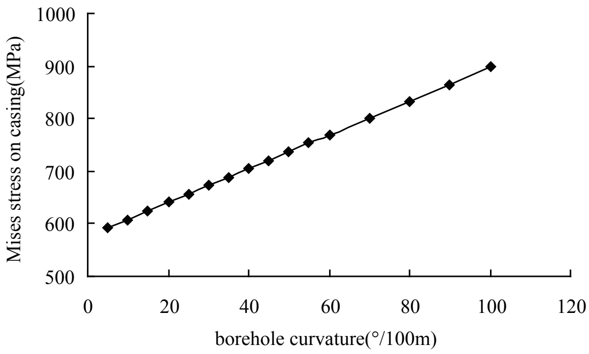

Figure 8
Relationship Between Casing Mises Stress and Cement Damage Angle

CONCLUSION

a. Casing failure in heavy oil thermal recovery wells is serious, which greatly restricts high effective development of heavy oil reservoir. The work in this paper developed a finite-element model, the relationship between casing Mises stress with some surrounding environment is simulated.

b. The factors inducing casing damage of thermal recovery well mainly come from casing weakened strength in high temperature, sand flow over of oil formation, bad quality of cementation, non-effective thermal insulation treatment, and material quality of casing tube.

c. In order to slow down the rate of thermal recovery wells casing damage, some measures should be taken, such as development of new thermal recovery well casing, high temperature slurry system.

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