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Numerical Simulation Analysis of Carbon Dioxide Storage During Cyclic Steam Stimulation in Heavy Oil Reservoir

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ABSTRACT

Global warming has slowly threatened the rapid development of mankind which makes CO_2 as the main greenhouse gas utilization research has attracted more and more attention owing to its excellent energy increasing effect, especially, it provides new ideas for the development of marine heavy oil resources. The steam injection effect of offshore heavy oil reservoirs with strong edge water is restricted by problems such as short oil production time and fast edge water coning speed, CO_2 assisted steam stimulation technology will effectively improve the production during steam injection in offshore heavy oil reservoirs with edge water.

The paper established a CO_2 assisted cyclic steam stimulation model for offshore strong edge water heavy oil reservoir based on the rock hydrothermal reaction under CO_2. Here the geochemical and fluid flow aspects are fully coupled such that the time dependent CO_2 rock hydrothermal reaction is strictly preserved. Secondly, the transformation from immovable sand to mobilized sand under specific conditions is described, and the sand migration mechanism varying with time is revealed, acquired the storage mechanism and influencing factors of CO_2 under steam injection. In addition, the edge water reservoir model with water rock reaction is established by CMG, which are benefited to optimizing injection production parameters of controlling water coning and increasing CO_2 storage in offshore edge water heavy oil reservoir

It can analyze the edge water coning characteristics under the condition of time-varying porosity and permeability, as well as the expansion of steam chamber in the steam development process of edge water heavy oil reservoir, and the analysis of CO_2 concentration distribution, to improve the utilization rate of steam energy and reduce energy consumption. Besides it provides theoretical support for the development of offshore strong edge water heavy oil reservoir and realizes the integration of carbon storage and crude oil production.

Keywords: offshore heavy oil reservoirs, edge water, CO_2 rock hydrothermal reaction, CO_2 storage, steam energy

NONMENCLATURE

Abbreviations

CCS	CO_2 Capture and Storage

Symbols

r	Reaction rate
A	Preexponential factor
Ea	Activation energy
R	Gas constant
T	Temperature
C	Rock concentration
ϕ	Porosity
x_{ij}	Component percentage
Sj	Saturation
ρ	Density
v_f	Flow speed
$\dot{m}$	Solid output
β	Erosion coefficient
μ	Viscosity
v_{cr}	Critical velocity
c	Heat capacity
λ_r	Thermal conductivity
q_L	Heat loss
K	permeability
k	Relative permeability
p_j	Pressure

1. INTRODUCTION

The CCS technology was first evolved by American oil companies using CO_2 to drive oil to improve oil recovery in the 1970s. After more than 50 years of development, CCS technology has gradually developed into a key measure to curb greenhouse gas emissions [1]. CCS includes three links: CO_2 capture, transportation and storage, that is, first separate and capture CO_2, then select transportation tools to send to appropriate storage sites, and finally use or inject underground, oil (gas) displacement, mineralization and other permanent storage, followed by long-term monitoring and management [2]. At present, CO_2 geological storage methods mainly include: injecting oil and gas wells to improve oil and gas recovery, injecting coal seams to obtain methane, injecting waste oil and gas fields, underground salt water layer and seabed storage. However, in the current research on CCS technology, there are relatively few studies on CO_2, transportation and storage technology. The storage of CO_2 is affected by the properties of storage medium, temperature, pressure and clay minerals, as shown in Figure 1[3].

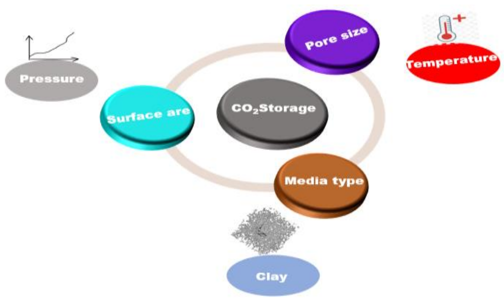

Fig 1 Schematic showing the complex relationship of impact factor and CO_2 storage in reservoir

The development difficulties of offshore heavy oil reservoirs are mainly deep buried reservoir, high porosity, fine lithology, thin single layer and complex oil-water relationship, resulting in high steam injection pressure, large heat loss, small steam spread range and poor development benefit, which makes CO_2 occupy a certain position in EOR of such reservoirs, which also provides good storage conditions for CO_2 storage [4].

2. METHODOLOGY

2.1 General assumptions

To illustrate the conditions for using the new model, the following basic assumptions are made:

(a) The oil layer is thick enough to ignore the heat loss to the surrounding formation;

(b) The rock reaches the fluid temperature instantaneously;

(c) The fluctuations of fluid properties and flow parameters along the horizontal section, such as temperature, pressure and steam quality, are ignored;

(d) The Free sand are oil wet particles.

2.2 Description of the model

The sand production model is revised, the traditional geomechanical model is transformed into a geochemical mechanism model, and the interaction between CO_2 and rock is considered in the sand production model, to store CO_2.

The mathematical description of CO_2 rock interaction is expressed by Arrhenius formula. CO_2 dissolves the reservoir rock under thermal conditions, and the dissolution process will cause the flow of reservoir solid phase, that is, the release of reservoir particles. The formula is as follows.

$$r = Ae^{\frac{-E_a}{RT}}C \qquad (1)$$

The porous media contains fluids (water, oil, gas) which together fill the void space. These fluids are multicomponent mixtures. The equations of continuity for these species are[5]

$$\frac{\partial}{\partial t}(\phi x_{ij} S_j \rho) + \nabla(\phi x_{ij} S_j \rho v_j) = \dot{m} \qquad (2)$$

In fact, as previous studies have shown, there is a critical flow rate in the model, beyond which failure can be expected. The coupling between the two failure mechanisms is mathematically expressed in the form of the above parameters. Porosity is selected as the coupling parameter. With the increase of porosity, it is assumed that the elasticity and strength (cohesion) of rock become weak.

$$\dot{m} = \beta(1-\phi)(v_f - v_{cr}) \qquad (3)$$

$$\beta = \begin{cases} 0 & v_f \le v_{cr} \\ \dfrac{r}{v_f} & v_f > v_{cr} \end{cases} \qquad (4)$$

The energy equation of steam injection is as follows

$$\frac{\partial \mathrm{T}(\rho c)_r}{\partial x} - \nabla T \bullet (\rho c v_f)_w = \nabla \bullet \lambda_r \nabla T + q_L \qquad (5)$$

The equation is a partial differential equation (PDE). The first term on the left side of PDE represents the accumulated heat in the reservoir, and the second term on represents thermal convection. For the previous model, the fluid velocity "V" is regarded as a constant value to avoid the complexity of solving partial differential equations. In fact, for flow in reservoir, the fluid velocity will gradually decrease with the increase of reservoir range. This term is modified by introducing a new thermal convection velocity, which varies with reservoir range. Therefore, a new energy conservation equation can be derived. In addition, the first item on the right represents heat conduction, and the second item on the right represents heat loss of surrounding layers [6].

Porosity change based on skeleton erosion is also the main result of CO_2 storage during cyclic steam stimulation in offshore heavy oil.

$$\phi(v_f - v_{cr}) = \frac{Kk}{\mu}\nabla p_j \qquad (6)$$

2.3 Solving method

Thermal recovery is the main way of onshore heavy oil reservoir development. For offshore heavy oil fields, due to the limitation of platform space and high thermal recovery cost, the research in this field started late. At present, the evaluation of thermal recovery development effect of offshore heavy oil reservoir in the literature is mainly based on field pilot test analysis and numerical simulation analysis, but there are few achievements in production mechanism and experimental research, which makes the design of gas injection parameters lack of scientific.

The numerical model is shown in Figure 2 below. The length and width of the rectangle are 104 m, 42 m, respectively. The thickness of the rectangle is 24m. For a single microelement, the length and width are 2 m and 1 m, respectively, and the thickness is 2 m. the porosity of the reservoir is 0.37. The permeability in the I-direction is 2000 mD, and the permeability in the J- and K-directions are 2000 mD and 600 mD, respectively. The initial reservoir pressure is 2360 kPa. The initial reservoir temperature is 289K. the injection rate is 10 m3/day and the production pressures for the four producers are 101 kPa.

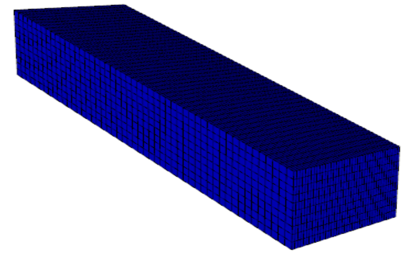

Fig 2 Model cotruction

3. RESULT AND DISCUSSION

3.1 Characteristics of edge water intrusion during steam huff and puff and gas injection

Figure 3 shows the oil saturation field of the mechanism model of offshore edge water heavy oil reservoir. The edge water intensity of this kind of reservoir is large. It can be seen from the figure that water invasion is very easy to occur. During the development process, the steam heat loss is large and the water breakthrough time is early. After three cycles of steam huff and puff, the edge water of the basic reservoir almost fills the bottom of the well, resulting in a decline in production. When the water cut exceeds 90%, CO_2 is injected into the reservoir, and then steam huff and puff is carried out, as shown in Fig. 5. It is obvious that the oil saturation at the bottom of the well increases and the edge water is controlled within a certain range. Therefore, CO_2 assisted steam huff and puff has a significant effect on water control and oil increase, especially for offshore edge water heavy oil reservoirs.

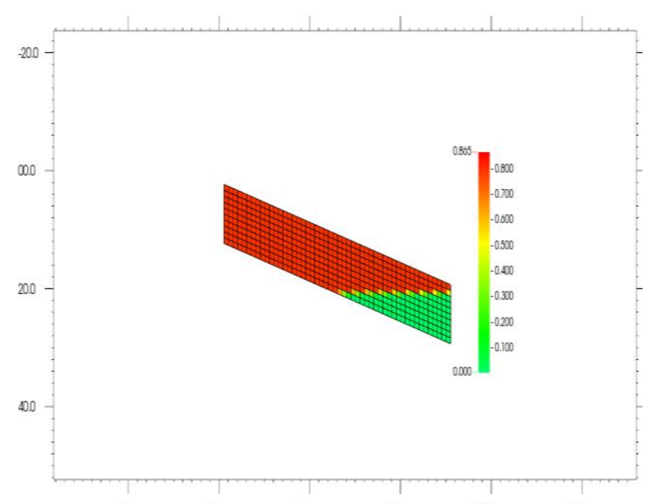

Fig 3 Initial oil saturation

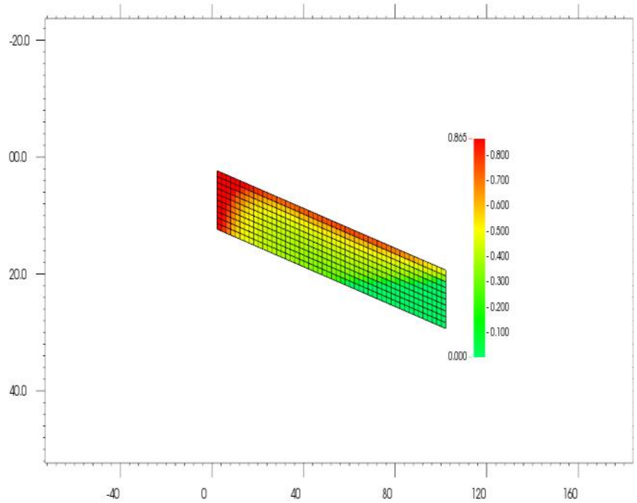

Fig 4 Oil saturation after 3 cycle of steam huff and puff

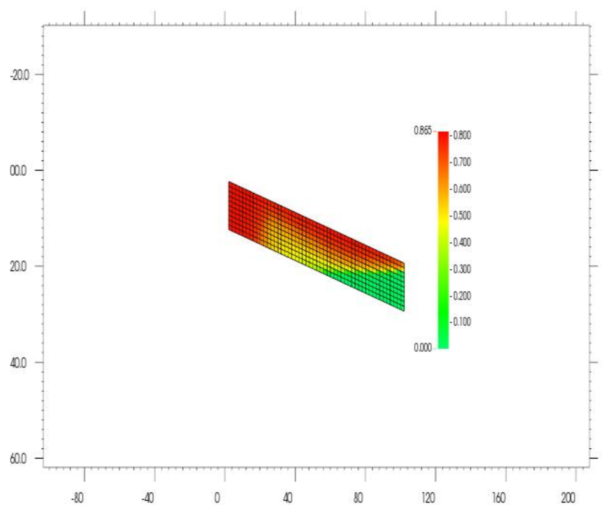

Fig 5 Oil saturation after CO_2 injection

3.2 Porosity change after gas injection

As shown in figures 6 and 7, CO_2 injection first acts with formation fluid to increase the elastic energy of crude oil on the one hand and supplement bottom hole energy on the other hand, to control the invasion of edge water. However, when the injection amount of CO_2 continues to increase, CO_2 will react with the reservoir rock to produce secondary pores, and lead to the weakening of the rock skeleton strength of the reservoir, so the initial pores change little. As shown in Fig. 8, when CO_2 injection is stopped and steam huff and puff production is carried out again, due to the decrease of CO_2 solubility under high temperature, a large amount of gas diffuses around the well, resulting in the increase of dissolution pores, and particle migration with crude oil production and storage, resulting in the increase of porosity

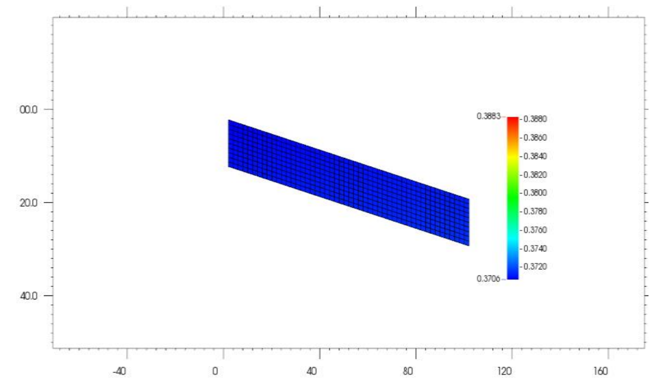

Fig 6 Initial Porosity

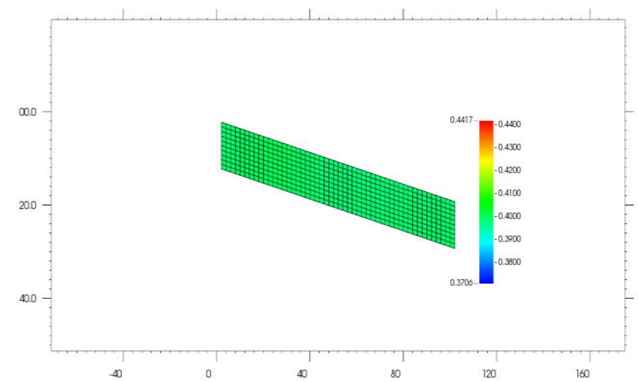

Fig 7 Porosity change during CO_2 injection

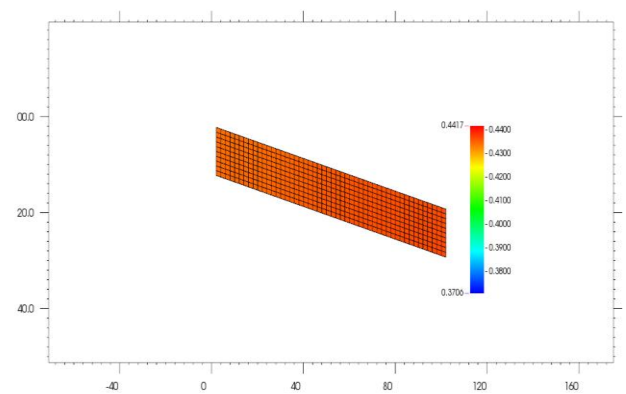

Fig 8 Porosity change during CO_2 injection with steam

3.3 Characteristics of CO_2 storage during steam huff and puff and gas injection

It can be seen from figure 9-10 that CO_2 injection can achieve the purpose of storage for offshore edge water reservoir. In addition, after heat injection, it will increase the hydrothermal effect of rock and the diffusion of CO_2 to deep layer, to improve the CO_2 storage efficiency.

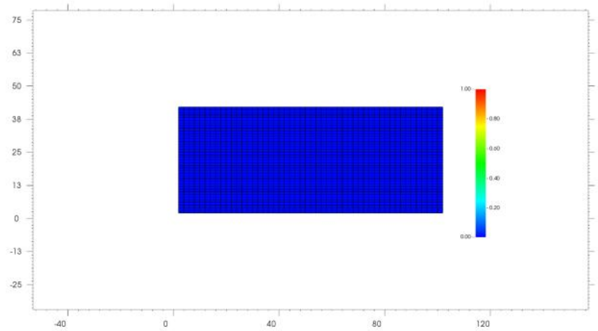

Fig 9 CO_2 molar factor

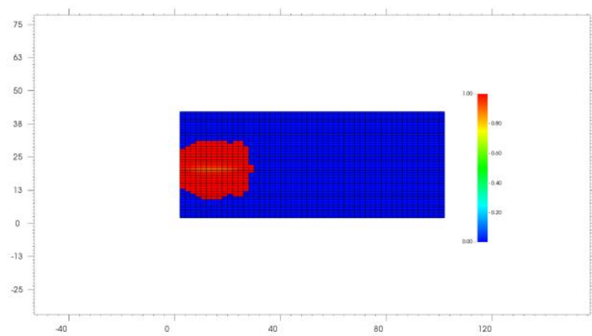

Fig 10 CO_2 molar factor during soak

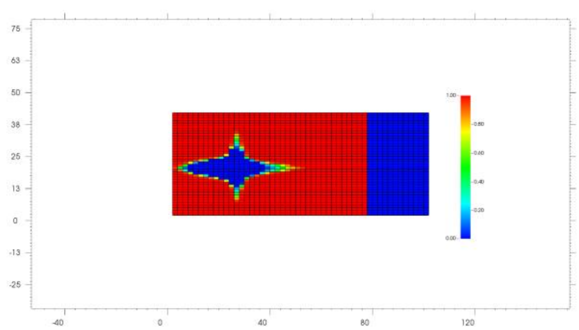

Fig 11 CO_2 molar factor after steam injection

4. *CONCLUSION*

(1) Steam CO_2 slug injection has obvious effect on water control and oil increase, which is widely used in offshore edge water heavy oil reservoir.

(2) CO_2 first interacts with reservoir fluid and then with reservoir rock， besides, interaction of CO_2 and rock is the main principle of CO_2 storage.

(3) Temperature is conducive to CO_2 storage but not conducive to displacement oil efficiency. Therefore, integration of CO_2 storage and oil recovery is feasible for offshore strong edge water reservoirs.

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