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Modeling of Enhanced Oil Recovery

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ABSTRACT: *The demand for energy has been increasing exponentially and at present time, this cannot be fulfilled by renewable energy alone. Crude oil has remained one of the major mineral resources for energy. It is difficult for a populated developing country like Nigeria, to keep a balance between the supply and demand of crude oil. In recent years, considerable studies have been conducted to search for efficient technologies for recovering oil from old oil reservoirs since about two-thirds of the oil in the reservoir cannot be recovered by conventional methods. The trapped oil in the reservoir can be recovered by enhanced oil recovery (EOR) methods such as chemical, thermal, gas, and microbial methods. Nanofluid flooding is found to be one of the efficient methods that have gained importance as nanoparticles have been found to alter the rock wettability which helps in oil recovery. It has also been found that the use of modeling to evaluate the performance of any process before conducting any experiments is found to be a more economical and effective practice. Therefore, the present modeling work was carried out to explore the application of nanofluid in EOR using COMSOL Multiphysics.This study investigates the effect of different parameters on EOR such as the addition of nanoparticles (Al2O3) in water, the porosity of the reservoir, and diffusion coefficients of nanofluid on oil saturation in reservoirs. Velocity contours, temperature contours, and oil saturation contours within the reservoir were investigated.*

KEYWORDS: modeling, crude oil, recovery

INTRODUCTION

The amount of oil produced globally is decreasing as oil reservoirs get older. Production and consumption of oil are crucial factors in the economic growth of developing nations like Nigeria. To meet the need for energy, however, domestic oil production is insufficient. Therefore, reducing the difference between supply and demand for crude oil is a difficult task. The process of extracting as much oil and gas as feasible from reservoirs that contain hydrocarbons is known as oil production. For optimum oil recovery, various approaches are employed across several stages based on the well's age, the formation's properties, and the operating expenses. Oil production during primary recovery is mostly a result of base pumping through the production casing and natural reservoir formation pressure. However, only about 30% of the original oil in place (OIIP) is recovered using basic oil recovery procedures. To recover more oil into the production shell, the operator can pump gas or steam into the storage tank via the injection well.

Operators can recover up to 60% using secondary oil recovery techniques OIIP. Tertiary oil recovery strategies assist operators to recover up to 75% of the original oil in situ (OIIP) in unconventional oil and gas fields. There are various kinds of hydrocarbon storage tanks, including those for light oil, brown oil, heavy oil, and ultra-heavy oil. In situ, reservoir characteristics can differ amongst oil fields. The four main categories of EOR techniques are chemical injection, gas flood, microbiological injection, and heat injection. Through a variety of mechanisms, EOR techniques aim to affect the characteristics of rock and oil formations. When it comes to fluid and rock properties, oil elds have varied features. Understanding how EOR techniques apply to certain reservoir conditions is crucial. Oil permeability, viscosity, and reservoir depth serve as the basis for EOR selection criteria.

METHODOLOGY

The current study has made use of the FEM method, one of the popular methods for CFD investigations.
The simulation software COMSOL Multiphysics, whose primary architecture is entirely based on FEM as a numerical technique, was employed in the present work. The following presumptions form the foundation for the proposed model's computation.

The aqueous phase and the nanoparticles have negligible relative velocities. Porous media in the reservoir were considered homogeneous. The two-phase Darcy law governed how nanofluid and oil phases moved through porous media. The flow of injectant through porous media containing oil was very low so the two-phase Darcy model was considered. The equations defined for the pressure distribution and phase saturation in the medium during water flooding are as follows.

For pressure:
1

$$\partial \epsilon_p \rho / \partial t + \nabla . (\rho u) = 0$$

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Where p is the porosity of the matrix & is the density of the fluid (kg/m3)

2

$$u = u/ k \nabla. (p)$$

Where μ is Darcy's velocity in the porous medium (m/s), is the permeability of the oil reservoir (m2), is viscosity of the fluid (Pa.s) and p is the fluid's pressure (Pa)

For Fluid content is

$$\partial \epsilon p c1/\partial t+\nabla. (c1u) = \nabla. (Dc\nabla c1)$$

Where Dc is capillary penetration coefficient (m2/s), C1 =s1 ρ1 is fluid content (kg/m3), S1is saturation of the Fluid and ρ1 is the density of the fluid (kg/m3)

For Nano Fluid properties

Multiphase mixture model was used to assess the properties of nanofluid which contained solid Al_2O_3 and liquid water. The following equations were applied to ascertain the nanofluid's thermophysical characteristics.

Nano Fluid density

The density of a nanofluid was related to the density of the liquid, the density of the nanoparticles, and the volume fraction of the nanoparticles. According to this equation, the density of nanofluids increased with increasing volume fraction.

$$\rho =(1-\emptyset)\rho w +\emptyset \rho s$$

The density of nanofluid (kg/m3), is the volume fraction of the solid nanoparticle, is the density of the water (kg/m3) and is the density of the solid nanoparticle (kg/m3).

Nanofluid viscosity

According to Pak and Chu's model, the viscosity of the nanofluid is given by

$\mu nf = \mu w(1 + 39.11Ø + 533.9Ø2)$

Where µnf Ø is the viscosity of nanofluid (Pa.s), is the volume fraction of the solid nanoparticle and is the viscosity of the water (Pa.s).

In this study, a porous cylindrical core with a diameter and length of 0.04 m was treated with Al2O3 nanoparticles with water to enhance oil recovery. The process condition and materials of the model considered in this study were referred from the literature so that the model could be validated. The diffusion coefficient was set at 3e-9 m2/s. The grid independency test was conducted to obtain the optimum mesh needed for computation. The results from the model for the percentage of oil extracted from the medium over time were compared with the findings from the literature. Further computations were carried out with this model to investigate the oil recovery factor at varying porosity and diffusion coefficients. The velocity contours, temperature contours and oil saturation contours of the fluid flow were also investigated.

RESULTS AND DISCUSSION

Velocity contours

The velocity was constant at the start of the injection, however after 16 minutes the contours were found to be parabolic which showed that the ow was laminar. Velocity was maximum at the reservoir's center and minimum at the surface wall. The velocity was zero near the wall of the reservoir due to the no-slip boundary condition.

Temperature contours

The inlet temperature of injectant was 300 K. The temperature contours show that the temperature of the reservoir decreased as the cooler injectant was injected into the reservoir. The red color at time t=0 showed that the temperature of the reservoir was initially 350 K. At time t=2 minutes, the blue color indicates that the cooler injectant has passed through some distance in the reservoir. The injectant penetrated forward towards the outlet of the reservoir and gradually by time t=8 minutes, the major section of the reservoir was cooled to 300 K. It was found that the temperature of the reservoir decreased more quickly for nanofluid ow by the time t=8 minutes. This may be because of the higher thermal conductivity of Al2O3 nanoparticle present in nanofluid which enhanced heat transfer in the reservoir.

Oil saturation distribution pattern

At initial time t=0, the oil saturation was 0.763 throughout the reservoir and marked orange color. At the inlet, nanofluid or water was injected which is represented in blue color respectively. When the time increased, nanofluid or water dispersed through the reservoir and the oil saturation in

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reservoir decreased. The injected nanofluid/water displaced the trapped oil which was present in the pores of the oil reservoir. There was an insignificant difference in oil saturation by the time of 6 minutes in the case of nanofluid flooding. The oil saturation contours showed that oil recovered faster with nanofluid as compared to water flooding. This may be due to the reason that addition of nanoparticle altered the properties of water and was more viscous than plain water. Recovery factor of oil was estimated by computing the ratio of total amount of oil recovered from the reservoir over specified period of time to the total original oil in the reservoir. The oil recovery factor was observed for water as well as nanofluid flooding to check the effect of adding nanoparticles. The oil recovery factor using water as well as nanofluid flooding were compared for 90-minutes run. The recovery factor of nanofluid flooding became maximum within 25 minutes but in the case of the water flooding the maximum oil recovery was found to be at 60 minutes. This shows that the nanofluid was more efficient to recover oil as compared to water flooding.

Effect of porosity of oil reservoir

To study the effect of porosity of the porous media, the oil recovery factor in the nanofluid flooding process using Al_2O_3 nanoparticles ($\phi = 0.01$) were studied for different core porosity of 0.217, 0.3, 0.4, and 0.5 respectively. Oil recovery was delayed when the porosity of the reservoir increased. The increased porosity of the medium meant more volume was available for the fluid flow. The nanofluid may have passed through the reservoir without extracting oils from the medium due to the increased porosity of the medium. The increasing the porosity of the oil reservoir decreased the oil recovery factor and more time was required to extract the trapped oil present in the oil reservoir.

Effect of diffusion coefficient

With an increase in the diffusion coefficient of nanofluid from 3e-11 to 3e-6 m2/sec., the capillary pressure in porous media may have decreased. This may have led to a higher oil recovery for diffusion coefficient 3e-6 m2/sec. The diffusion of nanofluid was low at 3e-8 and below so oil recovery took more time and no significant difference in the oil recovery factor was found. The penetration of nanofluid into the reservoir was too low due to the lower diffusion coefficient so the oil recovery may have decreased.

CONCLUSION

Modeling can be considered an important tool for screening EOR agents before conducting experiments on a lab scale. In the present study, a model was developed to study the effect of nanofluid flooding in EOR. Results obtained from the developed model were validated with literature and found to be in good agreement. Velocity contours, temperature contours, and oil distribution contours of the fluids were obtained which helped to understand the hydrodynamics of the system. It was found that nanofluid flooding was more effective in oil recovery factors as compared to water flooding. The oil recovery factor decreased with the increase in the porosity of the reservoir medium. When the diffusion coefficient was increased, the oil recovery factor also increased. In the future, this model may help to further compare and screen different agents for EOR.

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