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論文内容要旨

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学位論文題目	Study on Multiphase Phenomena in Oil Production at a Pore Scale by Microtomography 空隙スケールでのマイクロトモグラフィーを用いた原油生産における混相流現象に関する研究

内容要旨

Oil production is an inefficient process. During water flooding process, oil continuity may be disrupted and oil is trapped inside pore space. Capillary forces between the water and oil holds the oil blob in the pore space, making extraction difficult. Oil company did so much efforts to produce trapped oil, but lack of knowledge about what actually happen in oil reservoir becaome major issue. Developing an efficient waterflooding scheme is a difficult task.

Multiphase flow phenomena in porous medium have been observed from a microscopic viewpoint by using a micromodel (Chang et al. 2009; Jamaloei et al. 2010) or a simulation (Blunt and King 1992; Kang et al. 2004). Micromodels usually describe the 2D process, and the simulation needs precise determination of many parameters. An additional scheme is required to study the process more realistically. Pore-scale observation in 3-D porous media is a solution because pore-scale processes govern the fundamental behavior of the multiphase flow phenomena in porous media (Al-Raoush and Willson 2005). Because of the development of microfocused X-ray CT scanner technology, the nondestructive visualization of the phenomenon is possible (Kumar et al. 2010), and the application of this technology is a critical first step for understanding fluid transport in porous media.

In this research, water flooding and oil trapping processes were described comprehensively in packed glass beads by utilizing micro focused X-ray CT scanner. Visualization scheme was developed so that 3D and real-time pore-level water flooding process and oil trapping mechanism can be clearly observed. To eliminate graphical errors, such as illusory oil/water films, that can be caused by X-ray broadening effects, the oil and water phases were carefully selected so that images produced using the

X-ray CT scanner gave separate brightness distributions for each phase. The boundary of each phase could then be determined with high precision, even in a single pore. The shape of the trapped oil and the interface between the water and oil were visualized clearly.

The oil trapping mechanism during water flooding in the upward and downward water injections is nearly the same and is dominated by the water invasion speed differences in some channels. The difference in water invasion speed because of variation of channel size disrupts oil continuity. Discontinued oil blob is trapped inside pore space because interfacial tension prevent its migration. Oil is trapped not only in single pore but also in pore-space clusters. Cluster trapping is possible if the configuration meets the trapping criteria. The size of cluster trapping is mainly determined by the size of water fingers which may occurs due to difference in bouyancy force, difference in viscosity, and variation of channels connected to water displacement front.

The effect of wettability variation of porous media was also observed. The "overtaking-like" water invasion caused by different water invasion speeds in different channels breaks the continuity of the oil phase. It is the most common oil trapping process in water-wet and oil-wet porous media. In water-wet porous media, an actual water film on the surface of the glass beads was accumulated in the pore throat and snapped-off the continuity of the oil phase. The contact angle and pore throat radius were measured from direct observations. Those data were used to calculate the capillary pressure during the snap-off and piston-like displacement processes in water-wet and oil-wet porous media. Piston-like displacement is more favorable, because, for a given pore throat radius, the threshold pressure is always higher for piston-like displacement than for snap-off.

The existence of connate water also significantly affects water flooding. In the porous media without connate water, water flooding was able to produce approximately 1.5 times more oil that in the case of the porous media with connate water. In the porous media without connate water, the local velocity of oil reduced gradually with time as the water invaded the pore space. The water displacement front was dominated by very large water fingers, leading to better displacement stability. When water flooding experiment was conducted in the porous media with connate water, water not only flowed through preexisting connate water, but also occupied neighboring pores. However, less than half of the original oil was produced. When injected water came into contact with connate water contained in pore clusters or with a volume of more than 100 pore spaces, the displacement front suddenly expanded and moved to the end of the connate water channel, leaving the other water fingers behind. The consequent jump-like movement helped water move faster and reach the outlet earlier than that in the porous media without connate water. Water breakthrough occurred faster so the local velocity of oil was dramatically reduced. The shape of connate water also deflects the movement of injected water, creating oil entrapment.

The flow phenomena around trapped oil blobs were also observed in this research. Three dimensional water flow phenomena around trapped oil blob were visualized by utilizing water doped by NaI as replication of water flooding and pure water as tracer showing its flow pattern around trapped oil blob. In 3D porous media, after water flooding process, injection of additional miscible fluid was able to invade most pores almost homogenously. No significant effect of the existence of trapped oil to deflect the flow field. That additional miscible fluid was able to invade pores located just next to trapped oil. However, in closer inspection, there is a small amount of stagnant water film comes from water flooding process, that prevent the contact between additional miscible fluid and trapped oil. The size of stagnant water film from water flooding process in unconsolidated packed glass beads case was less than 1 pore size. This stagnant water from water flooding process will act as a barrier preventing the contact between additional miscible fluid and trapped oil blob. In case of surfactant incjection in actual oil reservoir, the stagnant water film surrounding trapped oil blob reduces significantly the effectiveness of surfactant injection. Surfactant will be able to make direct contact with trapped oil blob only by means of molecular diffusion and convection.

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論文審査の結果の要旨

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学位論文題目

Study on Multiphase Phenomena in Oil Production at a Pore Scale by Microtomography
（空隙スケールでのマイクロトモグラフィーを用いた原油生産における混相流現象に関する研究）

審査結果の要旨

現状の原油生産では非効率的なプロセスを含み，その効率向上が強く望まれている。原油生産時の水攻法では，原油が土や孔隙（土壌の間の細かな空間）に取り残されてしまう現象が生じる。原油生産効率向上にはこの現象の解明が不可欠であるが，本現象は土壌中の複雑な現象を含み，その学術的な解明には至っていない．

本研究では，原油が土壌の孔隙に取り残される現象を解明するため，Ｘ線ＣＴスキャナーを用いて，土壌の孔隙を模擬した3次元孔隙中の原油トラップ現象を可視化し，その機構を解明した。孔隙にトラップされた原油を取り出す上で主な物理現象は分子拡散及び対流となり，界面活性剤などを利用した原油生産向上に対して有用な知見を得た。

以上，本研究は，微量元素成分をリアルタイムにモニタリングする新しいコンセプトの計測技術を提案すると共に，その実験的検証を提示するものであり，本論文は博士（工学）の学位授与に値するものと判定する。