MICROSCOPIC STUDY OF EMULSION FLOW IN POROUS MEDIA

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DEDICATION

I dedicated this Ph D Thesis to my lovely parents; Hj. A.Manan Hitam and Hjh. Hasnah Janom, to my parent-in-laws; Hjh. Habibah Sepit and late Hj. Maarof Rumit, to my wife; Nathrah, to my children; Pali, Munah and Ain, and to my other family members. Your deep understanding, patience and continuous support have encouraged me to complete this thesis.

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ABSTRACT

Emulsion applicability as an oil recovery agent has long been recognized in petroleum industry. However, investigations of emulsion flow in porous media for petroleum recovery applications are scarce; particularly the flow effects have not been explained in detail in term of events occurring at the pore level. Thus, this research was carried out to investigate the physics of emulsion flow in porous media. The objectives of the experiments are to study the behavior and mechanism of emulsion flow in porous media, to evaluate the effectiveness of emulsion as an oil recovery agent, and to determine the emulsion blocking processes. In this research, well characterized emulsions of water-in-oil emulsion (model oil of 86.5% dibutylphthalate + 13.5% n-heptane, and distilled water system) and oil-in-water emulsion (paraffin oil, distilled water, and Triton-X100 surfactant system) were injected into two-dimensional etched glass micromodels. Visualization experiments by using microscope on the micromodels were conducted to observe and record the emulsion droplet motion, captured mechanisms, and blockage processes. The results demonstrate the three possible flow regimes that may occur when emulsion flow in porous media are mainly due to the difference of emulsion droplet size to pore throat ratios. Flow phenomena of emulsion droplet formation, deformation and destruction, blob and rivulet were observed to be associated with less stable emulsion system. Other emulsion flow phenomena were the microstructures of droplets adhesion and entrainment from the solid surface, and droplets undergone snap-off and division from pore-to-pore. The results show that the emulsion droplets were found to be captured at the throat and the pore body according to straining and interception capture mechanisms. Also, the results indicate that wettability has a direct influence on the droplet capture mechanism. Emulsion water droplet colliding with the water-wet surface could easily adhere to the surface and formed thick water films. On the other hand, emulsion water droplet contacting oil-wet surface could be displaced from the surface by the continuous oil phase. Moreover, the results reveal that continuous emulsion injections could provide additional oil recovery, but by injecting smaller size emulsion slugs prior to water injection would result in insignificant additional oil recovery. Microscopic mobility control was found to contribute to the oil recovery processes in homogeneous porous media, while macroscopic mobility control due to the emulsion blocking effect would contribute to the oil recovery processes in heterogeneous porous media. The emulsion blockage process was observed to be accelerated with large ratio of emulsion droplet-to-pore throat, coalescence of captured droplet, low emulsion flow rate, more viscous emulsion droplets, and emulsion droplet wetting the solid surface. In conclusion, this research characterizes the physics of emulsion flow in porous media and demonstrates its application as an effective oil recovery agent through emulsion blocking mechanisms. The novelty is the revelation of the process for emulsion droplet blockage effects in porous media.

ABSTRAK

Kegunaan emulsi sebagai agen perolehan minyak sudah lama diiktiraf dalam industri petroleum. Walau bagaimanapun, penyiasatan tentang aliran emulsi di dalam media poros dalam aplikasi perolehan minyak masih berada pada tahap yang kurang sempurna; terutama kesan aliran emulsi yang masih tidak dijelaskan secara terperinci dari aspek perlakuan kejadian pada tahap liang. Oleh itu, penyelidikan ini dijalankan untuk menyiasat perlakuan fizik aliran emulsi di dalam media poros. Objektif kajian adalah untuk mengkaji tingkahlaku dan mekanisme aliran emulsi di dalam media poros, menilai emulsi sebagai agen perolehan minyak yang berkesan, dan menentukan proses penyekatan emulsi. Dalam penyelidikan ini, emulsi air-dalam-minyak (sistem model minyak 86.5% dibutilfatalat + 13.5% n-heptana, dan air suling) dan emulsi minyak-dalam-air (sistem minyak parafin, air suling, dan surfaktan Triton-X100) yang mempunyai ciri tertentu disuntik ke dalam mikromodel gelas tersurih dua dimensi. Ujian gambaran dengan menggunakan mikroskop ke atas mikromodel dilakukan untuk memerhati dan merakam pergerakan titisan emulsi, mekanisme pemerangkapan, dan proses penyekatan. Keputusan ujian menunjukkan bahawa tiga jenis regim aliran boleh berlaku terutama bila emulsi mengalir di dalam media poros adalah berpunca daripada perbezaan nisbah saiz titisan emulsi terhadap leher liang. Fenomena aliran misalnya pembentukan titisan emulsi, ubah bentuk dan pemusnahan, titisan besar, dan sungai titisan emulsi hanya berlaku pada sistem emulsi yang kurang stabil. Tingkahlaku aliran emulsi yang lain ialah terdapat mikrostruktur rekatan dan pembebasan titisan emulsi dari permukaan pepejal, dan titisan emulsi mengalami pemutusan dan pembahagian dari satu liang ke liang yang lain. Keputusan menunjukkan bahawa titisan emulsi terperangkap di leher liang dan jasad liang berdasarkan mekanisme penyekatan dan pemintasan. Keputusan juga mempamerkan bahawa keterbasahan mempunyai kesan langsung terhadap mekanisme pemerangkapan titisan. Titisan air emulsi berlaga dengan permukaan basah air mudah terekat pada permukaan dan membentuk lapisan air yang tebal. Sebaliknya, titisan air emulsi yang berlaga dengan permukaan basah minyak dianjakkan dari permukaan oleh fasa minyak yang berterusan. Selanjutnya, keputusan mendedahkan bahawa suntikan emulsi secara berterusan mampu menghasilkan perolehan minyak tambahan, tetapi suntikan slug emulsi yang kecil sebelum suntikan air tidak memberi kesan terhadap perolehan minyak. Kawalan pergerakan secara mikroskopik didapati menjurus kepada proses perolehan minyak dalam media poros homogen, sementara kawalan pergerakan secara makroskopik yang disebabkan oleh kesan penyekatan emulsi menjurus kepada perolehan minyak dalam media poros tak homogen. Proses penyekatan emulsi mampu dipercepatkan oleh nisbah titisan emulsi terhadap leher liang yang besar, penautan titisan yang terperangkap, kadar aliran yang rendah, titisan emulsi yang lebih likat, dan titisan emulsi yang membasah permukaan pepejal. Kesimpulannya, penyelidikan ini berjaya mencirikan fizik aliran emulsi di dalam media poros dan menunjukkan kegunaannya sebagai agen perolehan minyak yang berkesan melalui mekanisme penyekatan emulsi. Keaslian kajian ialah pendedahan kesan penyekatan emulsi di dalam media poros.