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Flow visualization of heavy oil in packed bed reactor by neutron radiography

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The demand for petrochemical feedstock and middle distillate is increasing. Although utilization of heavy oils such as atmospheric or vacuum residue is also necessary, the heavy oils have not been used due to the high viscosity and low quality. Thus, desulfurization and upgrading processes are required to use the heavy oils effectively. A trickle bed reactor, in which a heavy oil and a gas are flowed concurrently through a packed bed of catalytic particles, is generally used as the upgrading process. In the reactor, channeling and consequent hot spots decrease the performance. Hence, the understanding of flow behavior in the reactor is significant. Recently, the development of CFD simulator of hydrodynamics and reactions in the reactor has been advanced to clarify the flow behavior. On the other hand, the experimental works on flow visualization of the heavy oils have not been conducted. This is because the reactor was made of metal for operation at high pressure and high temperature, and consequently the visualization using visible light was not available. Therefore, the objective of this work is flow visualization of heavy oil in the packed bed reactor by neutron radiography.
In the experiment, the Kyoto university research reactor (KUR) was utilized as neutron source. KUR was operated at either 1 or 5 MW with a neutron flux of 1 or 5×107 n/cm2·s, respectively. The heavy oil and N2 gas were supplied concurrently to a packed bed reactor, i.e., a 1/2-inch stainless steel tube filled with Al2O3 particles having the diameter of 1 or 3 mm. Atmospheric residue (AR) was used as the heavy oil sample. The reactor was heated to temperatures of 100℃ and 250℃ to change the viscosity of heavy oil. The flow rate of heavy oil was 2.5 mL/min and that of N2 gas was set at 1 L/min at 25℃. Hence, the flow rates of N2 gas in the reactor changed depending on the reactor temperatures. An image intensifier and a CCD camera at the framerate of 30 fps were used to obtain visualization images of the unsteady flow behavior. An image processing to reduce noises was performed for the obtained images.
The flow behavior of heavy oil in the reactor varied depending on the experimental conditions. Since the viscosity of heavy oil markedly varies with temperature, that is, the viscosity of heavy oil at 100℃ is 10 times larger than that at 250℃, the head velocity of heavy oil flowing down at 100℃ became approximately half that at 250℃ for the particle diameter of 1 mm. In addition, the heavy oil at 100℃ spread radially to the wall of the tube, whereas the heavy oil at 250℃ did not spread. In the case of 3 mm particle diameter, the heavy oil did not spread at both 100℃ and 250℃ compared with the case of 1 mm particles, and the flow channeling occurred in the packed bed.

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