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Converting Vacuum Residue Into Light Fuels By Self-Fluidized Pump-Free Ebullated-Bed Hydrocracking

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Abstract: Vacuum residue (VR) is the heaviest distillation cuts of crude oil. Being very intractable, VR contains high amount of sulfur, metal and asphaltene. Conventional VR conversion technologies, including delayed coker and residue fluidized catalytic cracking, cannot remove those impurities efficiently, or have to employ strict pretreatments for feed stock to meet the equipment and catalyst requirements. Hydroprocessing and hydrocracking process can convert VR into lighter oils, and remove sulfur and metal content at high efficiency; the refining nature of hydrogenation reactions could also improve the molecular structures of product cuts, increasing the commercial values. According to the fluidization state of catalyst bed, the hydroprocessing reactor could categorized into fixed-bed, moving-bed and ebullated-bed reactors. Because of the high viscosity and sediment content of VR, ebullated-bed reactor (EBR) is preferred by petroleum refinery due to its fluidizing catalyst bed can prevent blockage while operating. Ebullated-bed residual oil hydroprocessing is one of the most efficient technology for vacuum residue (VR) conversion. SINOPEC has developed pump-free ebullated-bed reactor (PF-EBR), which is distinctive from conventional EBRs with expensive ebullated-promoting pumps. PF-EBR technology utilized structure-induced internal circulation to promote self-fluidization of micro-sphere catalyst, leading to significant reduce in CAPEX and energy consumption. SINOPEC has launched a 50 kta PF-EBR plant which validated the feasibility of this technology; the scale-up design still required intensive theoretical and engineering work to optimize the hydrcracking and sequential refining process. In this study, the operational results of the long-term test of the 50 kta unit were reported; the results demostrated PF-EBR was able to hydrocrack heavy vacuum residue into light oils with high conversion. A 5-lump axial-dispersion model was proposed for PF-EBR, which was further integrated with ASPEN HYSYS. With the aid of the efficiency and accuracy of the proposed model, a 3 million ton/year PF-EBR hydrocracking process with membrane-aided hydrogen recovery system was designed and simulated in HYSYS; the reaction kinetics and product distribution were validated and compared by batch and industrial experimental results, and the total liquid yield could reach 83.68% and 83.57% by EBR-DC (Delayed Coker) and EBR-FCC (Fluidized Catalytic Cracking) integration processes. This study reports the advances in ebullated-bed heavy oil hydrocracking technology, and provided efficient and model-based simulation tool for designing and optimizing PF-EBR hydrocracking processes.

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