Simulation study of emulsion feeding technology in RFCC riser reactor

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Highlights

- Secondary atomization effect of emulsion feeding technology in riser reactor has been demonstrated.
- Micro-explosion development of emulsion droplets has been revealed.
- Influence of operating conditions on micro-explosion and product yield has been summarized.

1. Introduction

Residue fluidized catalytic cracking (RFCC) process is one of the most important processes for lightening heavy oil in refineries. In recent years, China has been rapidly promoting carbon neutrality actions and developing new-energy automobiles and the transformation and upgrading of the refineries is urgent. In RFCC process, the further cracking of gasoline and diesel in the riser reactor will produce more low-carbon olefin products, i.e. propylene and butene. Therefore, the RFCC is expected to be a key equipment to produce more chemical products. But, the production of low-carbon olefin by RFCC is extremely challenging. The feedstock of RFCC generally contains residual oil components, resulting in high boiling point, high viscosity, high residual carbon value, heavy metal content and low hydrogen content. As a result, the oil droplets are difficult to atomize and vaporize in the riser reactor, resulting in incomplete vaporization on the catalyst surface. The slow and incomplete vaporization usually leads to reduced cracking reaction and low olefin yield in RFCC. Smaller droplets represent a larger specific surface area, which can effectively increase the droplet vaporization rate. Emulsion feeding technology injects liquid feedstock as water-in-oil emulsion droplet inside the reactor and can provide a secondary atomization of the oil droplets through the micro-explosion phenomenon. The micro-explosion can further break the droplets into secondary tiny droplets, thus enhancing the dispersion and vaporization of the feedstock of RFCC. However, the mechanism of the enhanced effect of emulsification feeding technology is still unclear, and the process of micro-explosion of tiny oil droplets is uncertain. Therefore, it is urgent to investigation of RFCC emulsion feeding technology. In this paper, CFD simulation is used to investigate the emulsion feeding technology from both micro and macro perspectives. The micro-explosion development process of emulsion droplets inside the reactor is examined and the conclusions are coupled to the macro-simulation. A pilot riser reactor was simulated to explore the mechanism of the emulsion feeing process on the droplet motion and vaporization process. The simulation results provide theoretical guidance for the further development and operation of emulsion technology.

2. Methods

In order to take into account the micro-explosion development process of emulsion droplet and the vaporization and reaction process in the reactor. Two scales of simulation were coupled and established. At the microscopic scale, the micro-explosion process of emulsion liquid droplet within the riser reactor is examined. The simulation object is an emulsion droplet with a diameter of 60 μm and a larger number of randomly distribution water droplets inside it. These water droplets have diameters of 4-8 μm, and their positions are randomly generated by a script. These water droplets have a much lower boiling point and therefore undergo the vaporization process prior to the liquid feedstock. Pressure outlet boundary conditions are chosen and mesh adaptive refine technology was used to more accurately capture phase interface. A pilot riser reactor with a diameter of 0.6 m and a height of 32.8 m was simulated in the macroscopic scale. The MP-PIC method was used to investigate the internal gas-liquid-solid three-phase moment and heat transfer and reaction processes. The liquid feedstock is divided into five droplets according to the real boiling point distillation experiment, and they have different boiling points, vaporization rates and four-component compositions. According to the established model, the micro-explosion development process of emulsified droplet will be simulated in detail to reveal the mechanism of emulsified droplets, enhance the vaporization rate and realize the secondary atomization. The effects of the emulsion feeding technology on the vaporization rate and reaction rate of the droplets with different boiling points will also be comparatively investigated, and the product yields will be compared.

3. Results and discussion

When the emulsified droplets enter the riser reactor, a remarkable heat transfer will be occur between the droplet and high temperature environment. The water droplets inside the droplet will absorb heat and vaporize to form emulsified steam bubbles, which will expand and aggregate inside the emulsion droplet. As shown in Figure 1, when the pressure inside the bubbles exceeds the liquid film surface tension, the liquid film has been broken and micro-explosion phenomenon occurs. When the micro-explosion phenomenon occurs, a large number of steam gathered inside the bubbles are ejected. Droplets become liquid film shape under the action of the bubbles. A large number of secondary small droplets are ejected by the high-speed emulsified steam, and the edge of the liquid film is gradually broken. Eventually, the droplets disintegrate and the diameter of droplet decreases considerably.

Figure 2 compares the distribution of liquid feedstock in the riser reactor under atomized and emulsified feeding technology. It can be observed that the light distillate droplets have shorter lifetime and retention region under the emulsified feeding technology, with only partial liquid droplet aggregation near the feeding nozzles. In contrast, the heavy distillate droplets are not fully vaporized under both feeding methods and unvaporized oil droplet is generated remarkable. However, the unvaporized oil droplet in the emulsified feeding technology have smaller diameters and smaller volume fractions. Meanwhile, the volume fraction of liquid droplet near the wall has been significantly reduced, which indicates that the emulsified feeding technology achieves the effect of secondary atomization. Due to the increase of the vaporization rate, the radial distribution of particle in the riser is more uniform, and the light oil yield is effectively increased by more than 0.6 percentage points.

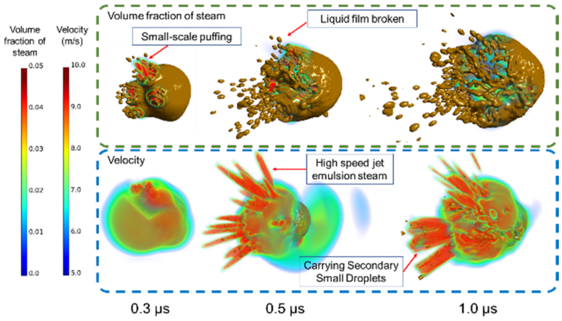

Figure 1. Micro-explosion of emulsified droplet

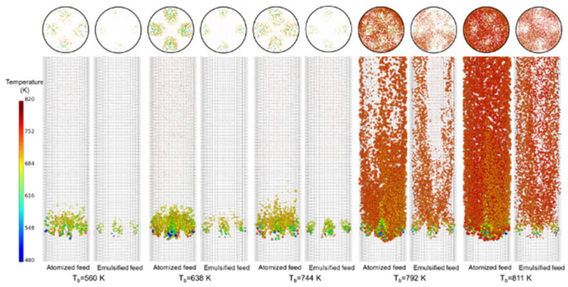

Figure 2. Distribution of liquid droplets with different boiling points

4. Conclusions

In order to investigate the droplet vaporization and cracking reaction characteristics with the emulsion feeding technology in FCC riser reactor, CFD models combining both microscopic and macroscopic aspects were developed. It was found that water droplet will preferentially vaporize and produce bubbles, and the fate of the bubbles is related to their location. Bubbles near the center of the droplet will undergo expansion and aggregation, and ultimately dominate the micro-explosion process of the emulsion droplet. The emulsified droplet achieves a secondary atomization effect and the droplet diameter decreases significantly. The lifetime and retention region of the liquid material in the riser reactor are significantly reduced, and the risk of coking caused by the residual liquid material is reduced.

References

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Keywords

Emulsion Feeding Technology, CFD, Micro-explosion