

CHAPTER 4

Conclusion

4.1 Batch ultrasonic experiments

The optimum conditions for batch acid catalyzed esterification of CPO with ethanol assisted by ultrasonic irradiation in descending order are catalyst amount of 60 wt% of FFA, molar ratio of ethanol to FFA at 30:1, temperature at 60°C, reaction time of one hour and amplitude of acoustic power at 75%, consequently reduce FFA content from 6.0 to 0.5 wt% in the batch size of 300 g (mixture of CPO and ethanol) irradiated by the ultrasonic generator model UP400S, 24 kHz, 400 W, Hielscher, Germany. The final FFA content of 0.5 wt% shows equilibrium of this reaction system which pertaining to hydrolysis of ester. If this water content can be abolished, the equilibrium will shift to the product side that showing FFA reduction to 0.22 wt% in 2 steps esterification. The water seems to play the role as a reaction inhibitor. The hydrolysis under strong acid condition can happen in a high degree, especially at a higher temperature at 80°C. Therefore to avoid this hydrolysis, the esterification should be conducted at a lower temperature of 60°C which is optimized temperature because CPO is melted between 45-50°C. However, it is hardly to get homogeneity of the reaction under a lower temperature unless having a good mixing condition.

4.2 Continuous ultrasonic experiments

The optimum conditions for continuous acid catalyzed esterification of CPO with ethanol assisted by ultrasonic irradiation in descending order are catalyst content of 60 wt% of FFA, molar ratio of ethanol to CPO at 30: 1, retention time of one hour, reaction temperature at 60°C and horizontal reactor configuration, consequently reduce FFA content from 6.2 to 0.35 wt% in the 1.47 L reactor irradiated by the ultrasonic generator model YPSH1020204, 20 kHz, 1000 W, Hangzhou Success Ultrasonic Equipment Co., Ltd., China. There are no doubts for catalyst content, molar ratio and retention time, but for horizontal arrangement is to provide the best

mixing condition of ethanol with CPO which ethanol inclines to flow upward by its low density under a lower mixing condition by micro jet of cavities' implosion.

4.3 CSTR experiments

The optimum conditions for continuous acid catalyzed esterification of CPO with ethanol conducted by CSTR at 60°C in descending order are retention time of one hour, molar ratio of ethanol to CPO at 30: 1 and catalyst content of 60 wt% of FFA in the 87 L reactor, obtaining FFA content of 0.81 wt% from the initial FFA of 7.5 wt%. The FFA reduction capacity of the CSTR is inferior to ultrasonic method probably caused by mixing effect under a viscous mixture. It seems to be a quasi-homogeneous system with viscous mixture of CPO-ethanol. To increase the mixing effect, it needs more CSTR series or more blades. However this CSTR esterification requires further study to reduce a lower FFA content.

4.4 The energy consumption

As for comparing the energy consumption shows that batch ultrasonic, continuous ultrasonic and CSTR experiments have an energy efficiency of 8.23, 6.85 and 79.70%, respectively. The CSTR esterification has the highest energy efficiency probably because of a large size of the reactor and good insulation system. The ultrasonic method is suitable for a shorter reaction time to compensate the inferior energy efficiency or both of them can be processed together. By starting with CSTR followed by ultrasonic irradiation is probably suitable by mean of FFA reduction and energy efficacy.

The continuous acid catalyzed esterification of CPO with ethanol assisted by ultrasonic irradiation is suitable for CPO pretreatment before the base catalyzed transesterification. It can reduce FFA and phosphorus content to 0.35 wt% and 1.46 mg/kg, respectively. This phosphorus content also meets the new version of EN 14214: 2008. The obviously advantage of ultrasonic irradiation over the conventional method are that no external heating source is required for the reaction, resulting in saving the heating unit and a shorter time to achieve a lower FFA content.

4.5 Suggestions

4.5.1 Ultrasonic method

The acid catalyzed esterification of CPO with ethanol assisted by ultrasound is not an easy process because the reaction take place with roughly 5 wt% of FFA dissolved in the whole matrix. Apparently, the difficulties of the process still consist of its high viscosity matrix, limited under 60°C according the hydrolysis reaction and mixing effect as well. However, its capability on FFA reduction is superior to other methods. Disadvantages of this method are low energy efficiency and capacity involved retention time about an hour. To increase its energy efficiency it may redesign the sonotrode to a longer one followed by reactor expansion in order to increase the flow rate of reactants which can efficiently consume the radiated energy, it is consequently increased the capability. Although the ultrasonic method can insure the final FFA content, but it is probably to be appropriate for the shorter time processes such as transesterification etc.

4.5.2 CSTR method

The acid catalyzed esterification of CPO with ethanol using CSTR is conventional process which widely used in various industries, especially transesterification for biodiesel production. But for the esterification of CPO under the optimized conditions at 60°C, still has a critical limitation on mixing effect due to low reaction temperature and high viscosity, as well. Therefore, the reactor should be redesign to have more CSTR systems by putting more blades with a separation plate in between to create each CSTR system. That should be an ideal homogeneous mixing under the CSTR system, subsequently it should have a higher capability to reduce FFA content, as well.