Chapter 9

Conclusions and Recommendations

9.1. Conclusions

This research project has focused on reactive distillation for ETBE production. Design and control aspects of the complex behaviours of the reactive distillation have been extensively investigated via steady state and dynamic simulations. A rigorous reactive distillation model, which is accurate and efficient, has been successfully developed using the equilibrium-stage approach. The model incorporated with appropriate height equivalent to a theoretical stage, which was written in Aspen Plus and Aspen CM environment, has been shown to satisfactorily and realistically represent the pilot scale of a packed reactive distillation column, which is available in the Department of Chemical Engineering, Curtin University of Technology.

The model was used to demonstrate the design of various reactive distillation columns for ETBE production. The effects of operating conditions on the product composition and conversion were investigated. The steady state simulations were employed to study the conflicting effects of integrating reaction and separation on the overall performance of the reactive distillation column. Models of side reactors were then integrated with the reactive distillation column. Several column configurations including single-feed and double-feed columns, with and without the presence of a pre-reactor and/or side reactors were considered.

The model was then extended to investigate dynamic behaviours, control aspect and optimisation. Adaptive controllers were implemented on a standard (LV) control scheme with respect to the operation and control of reactive distillation. Several control schemes including multivariable inferential control were then assessed for their effectiveness and appropriateness for reactive distillation. Open-loop, one-point (composition) and two-point (composition and conversion) controls were considered.

9.2. Key Contributions

The following specific key contributions are made and/or demonstrated from this research:

- the equilibrium stage-model with appropriate height equivalent to a theoretical stage is a satisfactory basis for packed reactive distillation simulation;
- the commercial simulation packages, Aspen Plus and Aspen CM, were extensively used and permitted accurate modelling of reactive distillation operations;
- effective dynamic simulation models of reactive distillation were implemented within the Aspen CM simulation environment;
- the response of reactive distillation columns to changes in operating conditions sometime does not follow that of conventional distillation columns (e.g. the pressure should be optimised to compromise the reaction and separation performance);
- conservative approach of adding a few extra stages can be implemented to reactive distillation columns and the column performance does not degrade if the operating conditions are chosen appropriately;
- side reactors are feasible to be integrated with the reactive distillation column for etherification to potentially reduce the capital costs and to offer more convenient ways for shut down operation and catalyst replacement;
- the control performance of nonlinear PI and model gain-scheduling controllers is clearly better than that of the standard PI controller in both set-point tracking and disturbance rejection;
- the switching scheme in the model gain-scheduling controller may cause instability of the system due to too large values of noise or changes in the operating conditions;
- although the inferential variable is tightly controlled using an advanced controller, the primary control variable (e.g. product purity) can not be reasonably maintained at its set-point due to feed composition changes;
- inferential model using several secondary variables is required for the estimates of the product purity and reactant conversion;

- control of both the product purity and reactant conversion is possible with simple linear controllers if a suitable control scheme is applied (e.g. cascade LV control scheme);
- multivariable inferential control can ensure the process performance remains acceptable following process disturbances and set-point changes, and improve the control performance,
- maximum profitability does not correspond to maximum product purity;
- dynamically operating conditions, which can satisfy the process constraints, were obtained by slightly paying an economic penalty compared to maximum profit design;
- set-point optimisation can be used to maximise profitability and provide a basis for a supervisory control system;

9.3. Recommendations

The research has met the objectives outlined in Chapter 1 and no further work is required to achieve them.

However, there is significant potential to continue the experimental aspects of this research using the reactive distillation pilot plant. In particular, the experimental data can demonstrate the viability of reactive distillation for ETBE production. It can serve for checking the process modelling, controlled development and advanced control algorithms proposed in this thesis.

Chapter 10

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