CHAPTER VI
CONCLUSIONS

6.1. Conclusions

1. The reaction kinetics was found to be a strong function of the pH of the solution, which is typical for oxidation-reduction reactions. This important characteristic provides high flexibility for controlling the rate of reaction or in other words, the release of heat by changing pH of the solution.

2. The release of the catalyst encapsulated in EUDRAGIT S-coated hard gelatin capsules is controlled by the dissolution of the polymeric coat. The polymer dissolution is limited by the ionization of the polymer at the surface; its rate is a function of temperature and pH of the reactive solution as follows:

$$\gamma = -\frac{dl}{dt} = kp[H^+]^{-q}[P]^r$$

where the rate constant, k, can be expressed in the Arrhenius form as below:

$$kp = kp_0 e^{-\frac{Ep}{RT}},$$

whereas the activation energy, E, is 2.3 kcal/mole, and kp_0 is 0.001 mm/h.

3. Encapsulation technique using soluble polymer like EUDRAGIT S® is a very promising technique for delaying the release of heat from exothermic reaction. Experimental results clearly show that the release of heat can be delayed as long as 50 hours which, in normal operating conditions of the pipeline, is equivalent to approximately 100 kilometers of the pipeline. More important, both the delay time and the rate of releasing heat are controllable so that a desired temperature-length profile in the pipeline can be achieved easily.

4. The polymer dissolution was found independent of the degree of mixing which means the lag time is not influenced by the flow regime of the reactive solution in a flowloop or a pipeline. Therefore, when applying this method to a field-scale pipeline, an operator has full flexibility to select the flowrate and by that, can delay the release of heat till the desired point. Because the temperature-time profile in a batch reactor corresponds to a temperature-distance profile in the flowing system at steady state, the delay length where the temperature starts to shoot up is then basically equal to the delay time of the reactive solution times the velocity of the flow.

5. Simulations successfully predicted the delay time as well as the temperature-time profiles in an adiabatic batch reactor at different initial conditions. Therefore, system parameters such as thickness of the polymeric coat, initial temperature and/or pH, and the number of capsules added in a unit volume of the reactive solution required for a desired temperature-time profile can be determined.

6. Simulation also showed the feasibility of using fused chemical reaction with encapsulation to provide a desired temperature- distance profile in a pipeline. Results show that the encapsulation technique can provide sufficient heat to the vicinity in a sub-sea pipeline as far as 100 kilometers. Moreover, the effective heating distance is in the range of 25 kilometers. Those two properties make this technique especially favored for solving wax deposit problems in long sub-sea pipelines.

6.2. Future Works

- Achieve a better understanding of the reaction kinetics.
- More experiments to verify the mechanism of the polymer dissolution.
- Use population balance theory to study the effect of a distribution of capsules with different thickness or distribution of capsules coated with different kinds of polymer.
- Study the release of catalyst from partly dissolved capsules.

- Theoretically model for a lab scale pipe and verify by flow-loop experiments.
- Scale up the results in the flow-loop for a field scale pipeline using several methods, such as residence time and dimensionless numbers.
- Use other encapsulation techniques.