CHAPTER II

LITERATURE REVIEW

The concept of plantwide control structure synthesis is not new to the chemical process industry. The research in this area grew, in part because of the number of heat management systems that were being installed. Before the details of the present study are given, a brief of the other previous work on the conceptual design of chemical process, heat exchanger networks design, and plantwide control design are reviewed first in this chapter.

2.1 A Hierarchical Approach to Conceptual Design

A synthesis/analysis procedure for developing first flowsheets and base-case designs had been established by J. M. Douglas(1985). The procedure was described in terms of a hierarchy of decision levels , as (1) Batch versus continuous, (2) Input-output structure of the flowsheet, (3) Recycle structure of the flowsheet, (4)Separation system specification, including vapor and liquid recovery system, (5) Heat exchanger network (HEN).

J. M. Douglas(1985) considered a continuous process for producing benzene by hydrodealkylation of toluene (HDA Process) to illustrate the procedure. The complete process was always considered at each decision level, but additional level terminates in an economic analysis. Experience indicated that less than one percent of the ideas for new designs were ever commercialized, and therefore it was highly desirable to discard poor projects quickly. Similarly, the later level decisions were guided by the economic analysis of the early level decisions.

D. L. Terrill and J. M. Douglas (1988) have studied HDA process from a steadystate point of view and determined that the process can be held very close to its optimum for a variety of expected load disturbances by using the following strategy: (1) Fix the flow of recycle gas through the compressor at its maximum value, (2) Hold a constant heat input flow rate in the stabilizer, (3) Eliminate the reflux entirely in the recycle column, (4) Maintain a constant hydrogen-to-aromatic ratio in the reactor inlet by adjusting hydrogen fresh feed, (5) Hold the recycle toluene flow rate constant by adjusting fuel to the furnace, (6) Hold the temperature of the cooling water leaving the partial condenser constant.

In plantwide control systems and strategies papers , Downs and Vogel (1993) described a model of an industrial chemical process for the purpose of developing, studying and evaluating process control technology. It consisted of a reactor/separator/recycle arrangement involving two simultaneous gas-liquid exothermic reactions. This process was well suited for a wide variety of studies including both plant-wide control and multivariable control problems.

Tyreus and W.L. Luyben (1993) considered second-order kinetics with two fresh-feed makeup streams. Two cases are considered: (1) instantaneous and complete one-pass conversion of one of the two components in the reactor so there is an excess of only one component that must be recycled and (2) incomplete conversion per pass so there are two recycle streams. It is shown that the generic liquid-recycle rule proposed by Luyben applies in both of these cases: "snowballing" is prevented by fixing the flow rate somewhere in the recycle system. An additional generic rule is proposed: fresh feed makeup of any component cannot be fixed unless the component undergoes complete single-pass conversion. In the complete one-pass conversion case, throughput can be set by fixing the flow rate of the limiting reactant. The makeup of the other

reactant should be set by level control in the reflux drum of the distillation column.

Yi and Luyben (1995) presented a method that was aimed at helping to solve this problem by providing a preliminary screening of candidate plant-wide control structures in order to eliminate some poor structures. Only steady-state information was required. Equation-based algebraic equation solvers were used to find the steady-state changes that occur in all manipulated variables for a candidate control structure when load changes occur. Each control structure fixed certain variables: flows, compositions, temperatures, etc. The number of these fixed variables was equal to the number of degrees of freedom of the closed-loop system. If the candidate control structure required large changes in manipulated variables, the control structure was a poor one because valve saturation and/or equipment overloading will occur. The effectiveness of the remaining structures was demonstrated by dynamic simulation. Some control structures were found to have multiple steady states and produce closed- loop instability.

2.2 Heat Exchanger Network (HEN)

Energy conservation has always been important in process design. Thus it was common practice to install feed-effluent exchangers around reactors and distillation columns. The starting point for an energy integration analysis is the calculation of the minimum heating and cooling requirements for heat exchanger network (HEN). The design of heat exchanger networks is based on analysis of the heat fluxes in the network as a work as a whole. One representative of such methods is the Linnhoff "pinch" method. This technique uses the H/T diagram with cumulative curves for the quantities of heat dissipated and absorbed in various sections of the plant at defined temperatures. The method can be applied to utility systems and to the integration of thermal engines.

Linhoff, B. and Hindmarsh, E. (1983) presented a novel method for the design of HEN. The method is the first to combine sufficient simplicity to be used by hand with near certainty to identify "best" designs, even for large problems. Best design feature the highest degree of energy recovery possible with a given number of capital items. Moreover, they feature network patterns required for good controllability, plant layout, intrinsic safety, ect. Typically, 20 -30 % energy savings, coupled with capital savings, can be realized in state-of-the art flowsheets by improved HEN design. The task involves the placement of process and utility heat exchangers to heat and cool process streams from specified supply to specified target temperatures.

Generally, minimum cost networks feature the correct degree of energy recovery and the correct number of units. This is achieved in two stages. First, the method aims for a minimum energy solution, corresponding to a specified , with no more units than is compatible with minimum energy. This task is achieved through understanding of the pinch phenomenon, hence the method is called the pinch design method. Second, the method involves a controlled reduction in number of units. This may require "backing-off" from minimum utility usage.

Linhoff, B., Dunford, H., and Smith, R., (1983) studied heat integration of distillation column into overall process. The result show good integration between distillation and the overall process can result in column operating at effectively zero utility cost. Generally, the good integration is when the integration as column not crossing heat recovery pinch of the process and either the reboiler or the condenser being integrated with the process. If these criteria can be met, energy cost for distillation can effectively be zero.

In a series papers, studies of the sensitivity of the total processing cost to heat exchanger network alternatives and steady state operability evaluation were undertaken by D. L. Terrill and J. M. Douglas (1987a,b,c). They considered a heat exchanger network for HDA process. The T-H (temperature-enthalpy) diagram was considered and obtained six alternative heat exchanger networks, all of which had close to maximum energy recovery. Most of the alternatives include a pressure shifting of the recycle column, and the other distinguishing feature is the number of column reboilers that are driven by the hot reactor products. The benefit obtained from energy integration with the base-case flow rates for the six alternatives, the energy saving from the energy integration fall between 29 and 43% but cost savings were in the range from -1 to 5%. The cost savings were not as dramatic because the raw material costs dominate the process economics.

Wongsri (1990) studied a resilient HEN design. He presented a simple but effective systematic synthesis procedure for the design of resilient HEN. His heuristic design procedure is used to design or synthesize HENs with pre-specified resiliency. It used physical and heuristic knowledge in finding resilient HEN structures. The design must not only feature minimum cost, but must also be able cope with fluctuation or change in operating conditions. The ability of a HEN to tolerate wanted changes is called flexibility. A resilient HEN synthesis procedure was developed based on the match pattern design and a physical understanding of the disturbances propagation concept. The disturbance load propagation technique was developed from the shift approach and was used in a systematic synthesis method. The design condition was selected to be the minimum heat load condition for easy accounting and interpretation. This is a condition where all process stream are at their minimum heat loads, e.g. the input temperature of hot streams are at the lowest and those of cold stream are at the

highest. Thus, only the positive disturbance loads of process streams were considered.

2.3 Design and Control of Energy-Integrated Plants

Renanto Handogo and W. L. Luyben (1987) studied the dynamics and control of heat-integrated reactor/column system. An exothermic reactor was the heat source, and a distillation column reboiler was the heat sink. Two types of heat-integration systems were examined: indirect and direct heat integration. Both indirect and direct heat integration systems are found in industry. In the indirect heat-integration system, steam generation was used as the heating medium for the reboiler. The direct heat-integration system used the reactor fluid to directly heat the column. The indirect heat-integration system was found to have several advantages over the direct heat-integration system in term of its dynamic performance. Both systems were operable for both large and small temperature differences between the reactor and column base.

M.L. Luyben, and W.L. Luyben (1995) examines the plantwide design and control of a complex process. The plant contains two reaction steps, three distillation columns, two recycle streams, and six chemical components. Two methods, a heuristic design procedure and a nonlinear optimization, have been used to determine an approximate economically optimal steady-state design. The designs differ substantially in terms of the purities and flow rates of the recycle streams. The total annual cost of the nonlinear optimization design is about 20 % less than the cost of the heuristic design. An analysis has also been done to examine the sensitivity to design parameters and specifications. Two effective control strategies have been developed using guidelines from previous plantwide control studies; both require reactor composition control as well as flow control of a stream somewhere in each recycle loop. Several alternative

control strategies that might initially have seemed obvious do not work.

M.L. Luyben, B.D. Tyreus, and W.L. Luyben (1997) presented A general heuristic design procedure is presented that generates an effective plantwide control structure for an entire complex process flowsheet and not simply individual units. The nine steps of the proposed procedure center around the fundamental principles of plantwide control: energy management; production rate; product quality; operational, environmental and safety constraints; liquid-level and gas-pressure inventories; makeup of reactants; component balances; and economic or process optimization. Application of the procedure is illustrated with three industrial examples: the vinyl acetate monomer process, the Eastman plantwide-control process, and the HDA process. The procedure produced a workable plantwide control strategy for a given process design. The control system was tested on a dynamic model built with TMODS, Dupont's in-house simulator.

From the W.L. Luyben (2000) studied the process had the exothermic, irreversible, gas-phase reaction A + B C occurring in an adiabatic tubular reactor. A gas recycle returns unconverted reactants from the separation section. Four alternative plantwide control structures for achieving reactor exit temperature control were explored. The reactor exit temperature controller changed different manipulated variables in three of the four control schemes: (1) CS1, the set point of the reactor inlet temperature controller was changed; (2) CS2, the recycle flow rate was changed; and (3) CS3, the flow rate of one of the reactant fresh feeds was changed. The fourth control scheme, CS4, uses an "on-demand" structure. Looking at the dynamics of the reactor in isolation would lead one to select CS2 because CS1 had a very large deadtime (due to the dynamics of the reactor) and CS3 had a very small gain. Dynamic simulations demonstrated that in the plantwide environment, with the reactor and separation operating together, the CS3 structure gave effective control and offered an attractive alterna-

tive in those cases where manipulation of recycle flow rate was undesirable because of compressor limitations. The on-demand CS4 structure was the best for handling feed composition disturbances.

Wongsri and Kietawarin (2002) presented a comparison among 4 control structures designed for withstanding disturbances that cause production rate change of HDA process. The changes had been introduced to the amount of toluene and feed temperature before entering the reactor. Compared with the reference control structure using a level control to control toluene quantity in the system, the first control scheme measured toluene flow rate in the process and adjusted the fresh toluene feed rate. This structure resulted in faster dynamic response than the reference structure. The second control scheme was modified from the first scheme by adding a cooling unit to control the outlet temperature from the reactor , instead of using internal process flow. The result was to reduce material and separation ratio fluctuations within the process. The product purity was also quite steadily. In the third control scheme, a ratio control was introduced to the secon control scheme for controlling the ratio of hydrogen and toluene within the process. This scheme showed that it could withstand large disturbances. Dynamic study showed that the control structure had significant effect on process behavior. A good system control should quickly respond to disturbances and adjust itself to steady state while minimizing the deviation of the product quality. The control structures were compared with reference on plantwide process control book, Luyben 1998, the result was performance of these structures higher than reference.

Wongsri and Thaicharoen (2004) presented the new control structures for the hydrodealkylation of toluene (HDA) process with energy integration schemes alternative 3. Five control structures have been designed, tested and compared the performance with Luyben's structure (CS1). The result shows that hydrodealkylation of toluene

process with heat integration can reduce energy cost. Furthermore, this process can be operated well by using plantwide methodology to design the control structure. The dynamic responses of the designed control structures and the reference structure are similar. The CS2 has been limited in bypass, so it is able to handle in small disturbance. CS3 has been designed to improve CS2 in order to handle more disturbances by using auxiliary heater instead of bypass valve to control temperature of stabilizer column. The recycle column temperature control response of the CS4 is faster than that of the previous control structures, because reboiler duty of column can control the column temperature more effective than bottom flow. CS5 on-demand structure has an advantage when downstream customer desires immediate responses in the availability of the product stream from this process. The energy used in CS6 control structure is less than CS1 and CS4.

Wongsri and Hermawan Y.D. (2004) studied the control strategies for energy-integrated HDA plant (i.e. alternatives 1 and 6) based on the heat pathway heuristics (HPH), i.e. selecting an appropriate heat pathway to carry associated load to a utility unit, so that the dynamic MER can be achieved with some trade-off. In they work, a selective controller with low selector switch (LSS) is employed to select an appropriate heat pathway through the network. The new control structure with the LSS has been applied in the HDA plant alternatives 1 and 6. The designed control structure is evaluated based on the rigorous dynamic simulation using the commercial software HYSYS. The study reveals that, by selecting an appropriate heat pathway through the network, the utility consumptions can be reduced according to the input heat load disturbances; hence the dynamic MER can be achieved.