



# **THESIS**

**DEVELOPMENT OF CONTROL STRUCTURE DESIGN  
AND STRUCTURAL CONTROLLABILITY  
FOR HEAT EXCHANGER NETWORKS**

**VEERAYUT LERSBAMRUNGSUK**

**GRADUATE SCHOOL, KASETSART UNIVERSITY**

**2008**





**THESIS APPROVAL**  
**GRADUATE SCHOOL, KASETSART UNIVERSITY**

Doctor of Engineering (Chemical Engineering)

**DEGREE**

Chemical Engineering

**FIELD**

Chemical Engineering

**DEPARTMENT**

**TITLE:** Development of Control Structure Design and Structural Controllability  
for Heat Exchanger Networks

**NAME:** Mr. Veerayut Lersbamrungsuk

**THIS THESIS HAS BEEN ACCEPTED BY**

\_\_\_\_\_  
**THESIS ADVISOR**

( Associate Professor Thongchai Srinophakun, Ph.D. )

\_\_\_\_\_  
**COMMITTEE MEMBER**

( Associate Professor Thumrongrut Mungcharoen, Ph.D. )

\_\_\_\_\_  
**COMMITTEE MEMBER**

( Assistant Professor Siripon Anantawaraskul, Ph.D. )

\_\_\_\_\_  
**DEPARTMENT HEAD**

( Associate Professor Paisan Kongkachuichay, Ph.D. )

**APPROVED BY THE GRADUATE SCHOOL ON** \_\_\_\_\_

\_\_\_\_\_  
**DEAN**

( Associate Professor Vinai Artkongharn, M.A. )

THESIS

DEVELOPMENT OF CONTROL STRUCTURE DESIGN  
AND STRUCTURAL CONTROLLABILITY  
FOR HEAT EXCHANGER NETWORKS

VEERAYUT LERSBAMRUNGSUK

A Thesis Submitted in Partial Fulfillment of  
the Requirements for the Degree of  
Doctor of Engineering (Chemical Engineering)  
Graduate School, Kasetsart University  
2008

Veerayut Lersbamrungsuk 2008: Development of Control Structure Design and Structural Controllability for Heat Exchanger Networks. Doctor of Engineering (Chemical Engineering), Major Field: Chemical Engineering, Department of Chemical Engineering. Thesis Advisor: Associate Professor Thongchai Srinophakun, Ph.D. 94 pages.

Heat exchanger networks (HENs) are the heart of heat-integrated plants. This thesis is devoted to two issues on HENs. The first issue concerns optimal operation of HENs, whereas the second issue concerns controllability improvement in HEN synthesis.

In the first issue, the term “optimal operation of HENs” requires that (a) all target temperatures can be satisfied and (b) utility cost is minimized. For certain HENs in which only single bypasses and utility duties are considered as manipulated variables, the optimal operation problem can be categorized as an active constraint control problem. To handle this problem is to propose a robust rule for switching among active constraint regions. A simple split-range control scheme was suggested to implement the switching. Two approaches to design an optimal split-range control structure were studied. The first approach is based on the information of directional effect among manipulated variables and controlled variables. The second approach requires the information of active constraint regions in a given disturbance window that is used in the proposed integer linear program (ILP) to determine an optimal split-range control structure. Three case studies were used to illustrate the application of the proposed approaches.

In the second issue, two methods to improve controllability in HEN synthesis stages were proposed. The first method is based on a sequential approach, that is, among the economically reasonable solution set obtained from a number of HEN synthesis techniques, the solution with the best structural evaluation is more favorable. The structural analysis tools used are structural singularities, parallel opposing effects, relative orders and decoupling indices in which the evaluation is formulated as an ILP problem. The second method is based on a simultaneous approach. The concept is to search for the HEN structure with a number of subnetworks. Additional binary variables and corresponding constraints are introduced into the MINLP HEN synthesis models, such as the single-period model of Yee and Grossman and the multi-period model of Aalota, to enforce solutions to have at least user-specified number of subnetworks. With a number of runs of varying user-specified number of subnetworks, the economically reasonable solution with the highest number of subnetworks is favorable.

---

Student's signature

---

Thesis Advisor's signature

## ACKNOWLEDGEMENTS

I would like to gratefully thank to Assoc. Prof. Dr. Thongchai Srinophakun, my thesis advisor, for his advice, encouragement, and valuable suggestion to complete the writing of this thesis. I would sincerely like to thank Assoc. Prof. Dr. Thumrongrut Mungcharoen, Asst. Prof. Dr. Siripon Anantawaraskul, and Assoc. Prof. Dr. Peerayuth Chansethikul for their valuable comments and suggestions.

I would like to gratefully thank to Prof. Dr. Sigurd Skogestad for the opportunity to visit his research group at the Department of Chemical Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway in May to September 2006. The five months spent in Norway certainly changed the slope of my learning curve. This visit also initiated me to the topic of “optimal operation of heat exchanger networks”, the first part of my thesis. I would also like to thank to Dr. Sridharakumar Narasimhan for his many suggestions, especially on optimization techniques.

Finally, I would like to thank to my family for their continuing encouragement. Unfortunately, I cannot celebrate my doctoral degree with my love mother since she passed away during my Ph.D. study.

Major support for this research came from the Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program (Grant No. PHD/0145/2547). Some partial education fee of my Ph.D. study was supported by the Department of Chemical Engineering, Kasetsart University through CHE ADB scholarship.

Veerayut Lersbamrungsuk

February 2008