A MATHEMATICAL MODEL FOR WATER AND ENERGY NETWORKS

MOHAMMAD REZA ABBASI

UNIVERSITI TEKNOLOGI MALAYSIA

A MATHEMATICAL MODEL FOR MINIMUM WATER AND ENERGY NETWORKS

MOHAMMAD REZA ABBASI

A dissertation submitted in partial fulfilment of
the requirements for the award of the degree of
Master of Engineering (Chemical)

Faculty of Chemical Engineering

Universiti Teknologi Malaysia

MAY 2013

I lovingly dedicate this thesis to my parents who have always been my nearest and supported me in each step of the way wherever I needed them. I also dedicate this work to my sweet sister and brother, Elahe and Ali Reza.

ACKNOWLEDGEMENT

All praises are to Allah Al-Mighty for his grace and blessing and bestowing me with health and opportunity to gain this treasure of knowledge. Apart from the efforts of the author, the success of any research project depends largely on the encouragement and guidelines of many others. I take this opportunity to officially express my gratitude to the people who have been instrumental in the successful completion of this thesis.

Foremost, I would like to express my sincere gratitude to my supervisor, Assoc. Prof. Ir. Dr. Sharifah Rafidah bt. Wan Alwi for the continuous support of my Master study and research, for her patience, motivation, enthusiasm, and immense knowledge. Her guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better supervisor and mentor for my Master study. Besides my supervisor, I would like to thank my co-supervisor, Prof. Dr. Zainuddin Abdul Manan, for his encouragement, insightful comments, and challenging questions.

I thank staffs and my fellow lab mates in Process Systems Engineering Centre (PROSPECT), for all their helps. Also I am grateful to my friends and classmates, especially Hamid Ilbeygi and Mohsen Chezghani for their supports.

Last but not the least, I would like to thank my parents for their selfless love and for supporting me both spiritually and financially throughout my life.

ABSTRACT

Mathematical programming is one the most used techniques in process integration, especially in water and energy network designs. Unlike conceptual and graphical approaches, mathematical programming is a better option in dealing with complex industrial water and energy systems, involving multiple contaminants and mass transfer based and non-mass transfer based operations. This thesis presents the development of a mathematical model for minimum water and energy networks considering direct heat transfer. The approach optimizes a superstructure which represents a set of all potential water minimisation arrangements together with direct heat transfer options and water and energy network configurations in a process system. The model has been set to minimize fresh water and energy consumption, cost applied to the system and wastewater discharged from the system. The model formulation is a mixed integer nonlinear program (MINLP) that is used to optimize an existing design. It considers all stages of water management hierarchy (i.e. elimination, reduction, reuse, outsourcing and regeneration) and operating cost factors simultaneously to bring about the lowest total cost. In this work fresh water contaminant concentration can be assumed as either zero or non-zero. The constraint for waste water temperature has been considered in the model. The model has been tested with a case study of a paper mill plant for retrofit case. The results show a minimization of 20.3% in annual operating costs which is roughly a 5 million dollar savings per year for the plant. The model showed that 97.96% reduction in wastewater generation and 60.2 % in utility consumption is achievable in compare with the previous graphical method. This shows that the model is very beneficial for the retrofit of industrial water and energy networks.

ABSTRAK

Pengaturcaraan matematik adalah salah satu teknik yang paling banyak digunakan dalam proses integrasi, terutamanya dalam reka bentuk rangkaian air dan tenaga. Berbeza dengan pendekatan konsep dan grafik, pengaturcaraan matematik adalah pilihan yang lebih baik dalam berurusan dengan system air dan haba industri yang kompleks dan, yang melibatkan pelbagai bahan cemar dan operasi berasaskan pemindahan jisim dan bukan berasaskan pemindahan jisim. Tesis ini membentangkan pembangunan model matematik untuk rangkaian minimum air dan tenaga mergambil kira pemindahan haba terus. Pendekatan ini mengoptimumkan superstruktur yang mewakili satu set bagi semua pengaturan pengurangan air yang berpotensi bersama-sama dengan pilihan pemindahan haba terus dan konfigurasi rangkaian air dan tenaga dalam sistem proses. Model ini telah ditetapkan untuk mengurangkan penggunaan air bersih dan.tenaga, kos yang digunakan untuk sistem dan air sisa yang dilepaskan dari sistem. Pembentukan model adalah program linear integer campuran (MINLP) yang digunakan untuk mengoptimumkan reka bentuk yang sedia ada. Ia mengambil kira semua peringkat hierarki pengurusan air (iaitu penghapusan, pengurangan, penggunaan semula, penyumberan luar dan perjanaan semula) dan kos operasi serentak untuk memperoleh jumlah kos terendah. Dalam kajian ini kepekatan pencemar air bersih boleh dianggap sebagai sama ada sifar atau bukan sifar. Kekangan untuk suhu air sisa telah diambil kira dalam model. Model ini telah diuji dengan satu kajian kes loji kilang kertas untuk kes retrofit. Keputusan menunjukkan pengurangan sebanyak 20.3% dalam kos operasi tahunan iaitu kira-kira satu 5 juta simpanan dolar setiap tahun untuk kilang. Model ini menunjukkan bahawa pengurangan 97,96% dalam penjanaan air kumbahan dan 60.2% dalam penggunaan utiliti boleh dicapai di bandingkan dengan kaedah graf sebelumnya. Ini menunjukkan bahawa model ini adalah sangat bermanfaat untuk retrofit rangkaian air dan tenaga industri.