A NEW GRAPHICAL METHODOLOGY FOR THE DESIGN OF HEAT RECOVERY SYSTEMS IN CHEMICAL/ REFINING INDUSTRIES

By

Dina Ahmed Mohamed Kamel

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Chemical Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

Prof. Dr. Fatma El Zahraa Hanafy Ashour

………………………………..

Professor of Chemical Engineering
Chemical Engineering Department
Faculty of Engineering, Cairo University

Dr. Mamdouh Ayad Gadalla

………………………………..

Associate Professor
Chemical Engineering Department
Faculty of Engineering, British University in Egypt

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Approved by the
Examining Committee

____
Prof. Dr. Fatma El Zahraa Hanafy Ashour

____
Dr. Mamdouh Ayad Gadalla

____
Prof. Dr. Mahmoud A. El Rifai

____
Prof. Dr. Mahmoud Mokhtar El Halwagi
Texas A&M University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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2016

Engineer's Name: Dina Ahmed Mohamed Kamel
Date of Birth: 27/07/ 1987
Nationality: Egyptian
E-mail: Dina.ahmed@bue.edu.eg
Phone: 01001819010
Address: Villa 73, 1st district east, El Sherouk City, Cairo

Insert photo here

Registration Date: 01/10/2012
Awarding Date: …./…./2016
Degree: Doctor of Philosophy
Department: Chemical Engineering

Supervisors:

Prof. Fatma El Zahraa Hanafy Ashour
Dr. Mamdouh Ayad Gadalla (British University in Egypt)

Examiners:

Prof Mahmoud Mokhtar El Halwagi (Texas A&M University)
Prof. Mahmoud Abdel Hakim El Rifai
Prof. Fatma El Zahraa Hanafy Ashour
Dr. Mamdouh Ayad Gadalla (British University in Egypt)

Title of Thesis:

A new graphical methodology for the design of heat recovery systems in chemical/refining industries

Key Words:
Graphical revamping, Heat exchanger network, Energy saving, Grassroots design, Pinch analysis

Summary:
This thesis proposes a new graphical methodology for the grassroots and the revamping of heat exchanger networks. The new graphical technique is based on pinch analysis rules. The energy analysis of exchanger networks is represented on a simple graph of temperature driving forces (TDF) across exchangers plotted versus the temperature of cold streams entering/leaving the exchangers. Accounting for temperature driving forces within the graphical technique is an important factor in both revamping and new design phases since TDF is strongly related to heat transfer rates and exchanger areas. Thus, such a consideration impacts capital costs and consequently overall expenses. For heat recovery systems, exchanger units are represented as straight lines whose y-axis values describe TDF, while the x-axis values give the cold stream temperatures. Length and location of exchanger lines in a network are significant in design. With a systematic procedure, TDF graphs are employed to generate new designs of exchanger networks and also to modify existing ones for better performances.

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Nomenclature

ΔT: temperature driving force of exchanger (˚C, K)

ΔT_c: temperature difference of cold stream (˚C, K)

ΔT_{ce}: cold end temperature driving force (˚C, K)

ΔT_h: temperature difference of hot stream (˚C, K)

ΔT_{he}: hot end temperature driving force (˚C, K)

ΔT_{min}: minimum temperature approach difference (˚C, K)

C: cold stream

CP_c: heat capacity flow for cold stream (kJ/s·˚C)

Cp_c: specific heat of cold stream (kJ/kg·˚C)

CP_h: heat capacity flow for hot stream (kJ/s·˚C)

Cp_h: specific heat of hot stream (kJ/kg·˚C)

H: hot stream

HEN: heat exchanger network

L: length of exchanger line (m)

mc: mass flow rate of cold stream (kg/s)

mh: mass flow rate of hot stream (kg/s)

PA: pinch analysis

PDM: pinch design methods

Q: heat duty or flow

T_c: temperature of process cold stream (˚C)

T_{ci}: intermediate cold temperature (˚C)

T_{cp}: cold pinch temperature (˚C)

T_{cs}: temperature of inlet cold stream to exchangers (˚C)

T_{ct}: temperature of outlet cold stream from exchangers (˚C)

T_h: temperature of process hot stream (˚C)

T_{hp}: hot pinch temperature (˚C)

T_{hs}: temperature of inlet hot stream to exchangers (˚C)

T_{ht}: temperature of outlet hot stream from exchangers (˚C)

Abstract

Chemical processes are energy-intensive industry; the majority of energy consumed in industrial processes is mainly used for heating and cooling requirements. This results in increasing the interest in obtaining the optimum design of the heat exchanger networks to reduce the energy consumption and face the growing energy crises.

Most of the published literature over the last fifty years promotes the process integration technology as a main part of the process system engineering science. Heat integration using pinch analysis is a systematic technique for identifying the heat recovery opportunities for heat exchangers in complex processes, and also for the design of thermally efficient systems by obtaining the targets of the process. The energy targets of the process were calculated graphically by the composite curves, or numerically by problem table algorithm. Graphical pinch analysis method normally includes two key steps; firstly, obtaining the energy targets which include the minimum energy required for the HEN design, then designing the heat exchanger network (HEN).

The refining process is an energy-intensive industry, consuming most of the energy in heating and cooling equipment. Revamping or retrofitting of existing refineries is an appropriate opportunity for improving actual energy efficiencies and thus enhancing the performance of the existing HENs. Revamping is commonly used to modify the existing process for many objectives, such as saving energy, reducing environmental emissions and increasing the productivity of the plant. Many researchers dedicated their work to developing and improving the revamping methodologies. Process integration using pinch analysis principles is very popular and is used to revamp existing heat exchanger networks by maximizing the use of the existing hot and cold streams as well as minimizing the external utilities' requirements.

This thesis introduces a new graphical approach for the design of new heat exchanger networks (HENs) and the revamping of existing heat exchanger networks based on pinch analysis rules. The HEN is represented on a simple graph, where the cold stream temperatures are plotted on the X-axis while the driving forces for each exchanger are plotted on the Y-axis.

This graphical technique can describe the energy analysis problems in terms of temperature driving force inside the heat exchanger, which is an important factor in the revamping process as the differences in these driving forces are involved in calculating the area of heat exchangers, and consequently, affecting the cost. Also, each exchanger is represented in this graph as a straight line with a slope related to the heat capacity flows and length function of the heat duty. The graphical representation only requires very simple data that are readily available in every refinery site. Such data include temperatures of process streams, feed flows, and heat duties.

The new graphical representation is simple to use and needs no simulation tools or software packages to perform revamping calculations and is considered valuable for conceptual applications.

The temperature driving force's new representation is applied to four case studies for different objectives. In the revamping of an existing HEN in an Egyptian refinery (MIDOR) to boost its energy efficiency, the graphical

revamping in application on the HEN shows savings of approximately 10% in the energy demand with minor structural modifications. Also, the new graphical approach is applied for the design of the new HENs for several objectives such as the design with optimum area, optimum energy and optimum cost.