HEAT EXCHANGER NETWORK SYNTHESIS/RETROFIT USING MINLP STAGE-WISE SUPERSTRUCTURE WITH NON-ISOTHERMAL MIXING

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ABSTRACT

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To enhance the energy recovery through heat integration, heat exchanger network (HEN) synthesis has been introduced for industrial processes. The design of an optimal-cost HEN is a challenging research topic in recently decade. This work modifies a mixed-integer nonlinear programming (MINLP) stage-wise model by commercial optimization software; GAMS, for simultaneous synthesis where the main objective is to minimize total annual cost composing of capital and operational expenses. The proposed model overcomes the area trade-off restriction caused by the assumption of isothermal mixing and allows any split stream flow through multiple exchangers in series as well as bypass stage before mixing non-isothermally for simultaneous synthesis. Dealing with the MINLP case, the initialization strategy is developed to find feasible starting point for the optimization problem resulting in better HENs compared to published results from the literatures. In addition, the retrofit of HENs is done by applying retrofit constraints to HENS model.

บทคัดย่อ

สุภิลักษณ์ โกระวิโยธิน : การออกแบบและปรังปรุงเครือข่ายเครื่องแลกเปลี่ยนความร้อนโดยใช้โปรแกรมทางคณิตศาสตร์ (Heat Exchanger Network Synthesis/Retrofit Using MINLP Stage-wise Superstructure with Non-isothermal Mixing) อ.ที่ปรึกษา : ผศ. ดร. กิติพัฒน์ สีมานนท์ 234 หน้า

การออกแบบเครือข่ายเครื่องแลกเปลี่ยนความร้อนอย่างมีประสิทธิภาพเป็นหนึ่งในวิธีการที่สามารถลดการสูญเสียพลังงานในกระบวนการทางอุตสาหกรรมให้น้อยที่สุดโดยการแลกเปลี่ยนพลังงานระหว่างสายร้อนและสายเย็นให้มากที่สุด ในปัจจุบันการออกแบบเครือข่ายเครื่องแลกเปลี่ยนความร้อนที่มีการใช้หลังกการทางเศรษฐศาสตร์ร่วมในการพิจารณาได้รับความสนใจเป็นอย่างมาก ดังนั้นในงานวิจัยนี้จำได้ทำการออกแบบและปรับปรุงเครือข่ายเครื่องแลกเปลี่ยนความร้อนโดยใช้โปรแกรมทางคณิตศาสตร์ (General Algebraic Modelling System; GAMS) ซึ่งวัตถุประสงค์หลักในการออกแบบเครือข่ายเครื่องแลกเปลี่ยนความร้อนเพื่อลดค่าใช้จ่ายซึ่งเกิดจากการลงทุนและดำเนินการ แบบจำลองที่สร้างขึ้นมานั้นสามารถลดพื้นที่ที่ใช้ในการแลกเปลี่ยนความร้อนของเครื่องแลกเปลี่ยนความร้อนและรวมถึงการต่อกันแบบอนุกรมของเครื่องแลกเปลี่ยนความร้อนในสายที่ทำการแยกย่อยออกไปก่อนที่จะมีการรวมกันเข้าเป็นสายหลัก วิธีการขั้นเริ่นต้นถูกพัฒนาขึ้นสำหรับการแก้ไขปัญหาระบบปัญหาที่ความสัมพันธ์ของตัวแปรไม่เป็นแบบเชิงเส้น (Mixed-Integer Nonlinear Programming; MINLP) เพื่อให้ได้ผลลัพธ์ที่ดีขึ้นเมื่อเปรียบเทียบกับเอกสารทางวิชาการ นอกจากนี้ การปรังปรุงเครือข่ายเครื่องแลกเปลี่ยนความร้อนสามารถทำได้โดยการใส่ขีดจำกัดให้กับแบบจำลองที่สร้างขึ้นมาก่อนหน้านี้

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TABLE OF CONTENTS

CHAPTER PAGE

CHAPTER PAGE

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

FIGURE **PAGE**

LIST OF ABBREVIATIONS

A	Exchange area
AC	Total area cost
C	Cold stream
CAT	Constant approach temperature
CDU	Crude Distillation Unit
CU	Cold utility
DE	Differential evolution
EA	Evolution Algorithms
EMAT	Exchanger minimum approach temperature
ERS	Exchanger reassignment strategies
FC	Total fixed cost
F_{Cp}	Heat content
GA	Genetic algorithm
GAMS	General Algebraic Modeling System
H	Hot stream
HEN	Heat exchanger network
HIT	Heat integration transportation
HRAT	Heat recovery approach temperature
HU	Hot utility
IBMS	Interval-based mixed integer nonlinear program superstructure
IDE	Integrated differential evolution
k	Stage or temperature location
LMTD	Log mean temperature difference
LP	Linear programming
MAT	Minimum approach temperature
MILP	Mixed-integer linear programming
MINLP	Mixed-integer nonlinear programming
MOO	Multi-objective optimization
MP	Mathematical programming

MP	master problem
NLP	Nonlinear programming
NPV	Net present value
NSGA	Non-dominated sorting genetic algorithm
OA/ER/AP	Outer approximation with equality relaxation and augmented penalty
PT	Pinch technology
SA	Simulated Annealing
sk	Sub-stage within each main stage k
SOO	Single objective optimization
STEPS	Stream Temperature vs. Enthalpy Plot Supertargeting
TAC	Total annualized cost
UC	Total utility cost
WAP	Water allocation planning
WN	Water network

LIST OF SYMBOLS

ΔT^{min}	Minimum temperature difference
$\Omega_{i,j}$	Upper bound of heat content for heat exchanger
Ω_i	Upper bound of heat content for cooling utility and hot process stream i
Ω_j	Upper bound of heat content for heating utility and cold process stream j
$ACCU_{i,cu}$	Area cost coefficient of cooling utility cu
$ACHU_{j,hu}$	Area cost coefficient of heating utility hu
$ACHX_{i,j}$	Area cost coefficient of heat exchanger$i-j$
C_{CU}	Cost of cold utility
CCU_i	Cost of cooling utility cu
$CFCU_{i,cu}$	Fixed charges for cooling utility cu
$CFHU_{j,hu}$	Fixed charges for heating utility hu
$CFHX_{i,j}$	Fixed charges for exchanger$i-j$
C_{HU}	Cost of hot utility
CHU_j	Cost of heating utility hu
FC_i	Heat capacity of cold process stream j
FH_i	Heat capacity of hot process stream i
F_{In}	Inlet flowrate
F_{out}	Outlet flowrate
Q_{CU}	Heat load of cold utility
Q_{HU}	Heat load of hot utility
$TCUcu_{,IN}$	Inlet temperature of cooling utility cu
$TCU_{cu,OUT}$	Outlet temperature of cooling utility cu
$TC_{j,IN}$	Supply temperature of cold process stream j
$TC_{j,OUT}$	Target temperature of cold process stream j
$THU_{hu,IN}$	Inlet temperature of heating utility hu
$THU_{hu,OUT}$	Outlet temperature of heating utility hu

$TH_{i,IN}$	Supply temperature of hot process stream i
$TH_{i,OUT}$	Target temperature of hot process stream i
$UCU_{i,cu}$	Overall heat transfer coefficient of cooling utility cu and hot process stream i
$UHU_{j,hu}$	Overall heat transfer coefficient of heating utility hu and cold process stream j
$U_{i,j}$	Overall heat transfer coefficient of heat exchanger of process stream $i-j$
$ahui_{j,hu}$	Area for heating utility hu raised to the power of β (for model A1)
$ahu_{j,hu}$	Area for heating utility hu raised to the power of β (for model A2)
$acu_{i,cu}$	Area for cooling utility cu raised to the power of β (for model A2)
$acui_{i,cu}$	Area for cooling utility cu raised to the power of β (for model A1)
$a_{i,j,k,bh,bc,sk}$	Area for heat exchanger$i-j$ in stage k raised to the power of β (for model A2)
$ai_{i,j,k}$	Area for heat exchanger$i-j$ in stage k raised to the power of β (for model A1)
$dth_{i,j,k,bh,bc,sk}$	Temperature approach for match $i-j$at hot end of heat exchanger in sub-stage sk and stage k (for model A2)
$dthi_{i,j,k}$	Temperature approach for match $i-j$at hot end of heat exchanger (for model A1)
$dthui_{j,hu}$	Temperature approach for match of heating utility hu and cold process stream $j$after heat exchanger (for model A1)
$dthu_{j,hu}$	Temperature approach for match of heating utility hu and cold process stream $j$after heat exchanger (for model A2)

$dthup_{j,hu}$	Temperature approach in hot end of heating utility hu
$dtc_{i,j,k,bh,bc,sk}$	Temperature approach for match $i-j$at cold end of heat exchanger in sub-stage sk and stage k (for model A2)
$dtci_{i,j,k}$	Temperature approach for match $i-j$at cold end of heat exchanger (for model A1)
$dtcu_{i,cu}$	Temperature approach for match between cooling utility cu and hot process stream $i$before heat exchanger (for model A2)
$dtcui_{i,cu}$	Temperature approach for match between cooling utility cu and hot process stream $i$before heat exchanger (for model A1)
$dtcup_{i,cu}$	Temperature approach in cold end of cooling utility cu
$fhp_{i,k,bh}$	Fractional flow of branch bh of hot process stream i stage k (for model A2)
$fcp_{j,k,\mathrm{bc}}$	Fractional flow of branch $bc$of cold process stream $j$in stage k (for model A2)
$f_{i,j,k}$	Fractional flow of hot process stream $i$exchanged with coldprocess stream $j$in stage k (for model A1)
$g_{i,j,k}$	Fractional flow of cold process stream $j$exchanged with hotprocess stream $i$in stage k (for model A1)
$qhui_{j,hu}$	Heat exchanged between hot utility hu and cold process stream j (for model A1)
$qhu_{j,hu}$	Heat exchanged between hot utility hu and cold process stream j (for model A2)
$qcu_{i,cu}$	Heat exchanged between cold utility cu and hot process stream i (for model A2)
$qcui_{i,cu}$	Heat exchanged between cold utility cu and hot process stream i (for model A1)
$q_{i,j,k,bh,bc,sk}$	Heat exchanged between branch BH of hot process stream $i$and branch BC of cold process stream j in sub-stage sk in stage k (for model A2)
$qi_{i,j,k}$	Heat exchanged between hot process stream $i$and cold process

	stream j in stage k (for model A1)
$th_{i,k}$	Temperature of hot process stream i at "hot end" of stage k
$thp_{i,k,bh,sk}$	Temperature of fractional hot process stream i at "cold end" of heat exchanger at the stage k(for model A2)
$thpi_{i,j,k}$	Temperature of fractional hot process stream i at "cold end" of heat exchanger at the stage k(for model A1)
$tc_{j,k}$	Temperature of cold process stream j at "hot end" of stage k
$tcpi_{i,j,k}$	Temperature of fractional cold process stream $j$at "hot end" of heat exchanger at the stage k (for model A1)
$tcp_{j,k,bc,sk}$	Temperature of fractional cold process stream $j$at "hot end" of heat exchanger at the sub-stage sk in stage k (for model A2)
$zhui_{j,hu}$	Existence of an exchanger for match between heating utility hu and cold process stream j (for model A1)
$zhu_{j,hu}$	Existence of an exchanger for match between heating utility hu and cold process stream j (for model A2)
$zcu_{i,cu}$	Existence of an exchanger for match between cooling utility cu and hot process stream i (for model A2)
$zcui_{i,cu}$	Existence of an exchanger for match between cooling utility cu and hot process stream i (for model A1)
$z_{i,j,k,bh,bc,sk}$	Existence of an exchanger for match $i-j$ in sub-stage sk and stage k (for model A2)
$zi_{i,j,k}$	Existence of an exchanger for match $i-j$in stage k (for model A1)
β	Exponent for area costs of heat exchanger$i$–j, hot and cold utility
$EMAT$	Minimum-approach temperature difference
Q	Heat load
ST	Number of stage (often chosen as maximum between number of hot and cold streams)
ST	Number of stage
$STSK$	Number of sub-stage

U	Overall heat coefficient
Γ	Upper bound for temperature difference