DESIGN AND OPTIMIZATION OF CRYOGENIC PROCESS

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ABSTRACT

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Refrigeration system is widely used in the industry, especially in cryogenic process. The main problem of refrigeration system is high energy consumption from shaft work resulting in high operation cost. To minimize the amount of shaft work, it is accomplished by a combination of pinch and exergy analysis. The strength of pinch analysis is graphical representation by using simple diagrams of composite curves and grand composite curve for process modifications. However, limitation of pinch analysis is that it only deals with thermal system, not including power or shaft work. Exergy analysis is a tool to utilize power or shaft work and identify thermodynamic imperfection of process. Both strengths are combined to help improve process efficiency. In this study, this methodology is applied for case study of LNG to improve processes such a reducing shaft work and increasing the exergy efficiency. Furthermore, the cascade refrigeration system is designed by mathematical programming.

บทคัดย่อ

จุฑาทิพย์ ท่าทราย : การออกแบบและหาค่าสภาวะที่เหมาะสมที่สุดของกระบวนการที่ดำเนินการภายใต้อุณหภูมิที่ต่ำ (Design and Optimization of Cryogenic Process) อ. ที่ปรึกษา : ผศ. ดร. กิติพัฒน์ สีมานนท์ 115 หน้า

ในปัจจุบันระบบทำความเย็นใช้กันอย่างแพร่หลายในโรงงานอุตสาหกรรม โดยเฉพาะอย่างยิ่งกระบวนการที่ดำเนินการภายใต้อุณหภูมิที่ต่ำ ปัญหาหลักที่พบในระบบทำความเย็นคือ ค่าดำเนินการของกระบวนการที่ดำเนินการภายใต้อุณหภูมิที่ต่ำนั้นจะขึ้นกับงานที่เครื่องอัดอากาศต้องการ ดังนั้นการลดงานที่เครื่องอัดอากาศต้องการเป็นผลช่วยลดค่าดำเนินการได้ งานวิจัยนี้ได้เสนอวิธีการที่ใช้การออกแบบกระบวนการเพื่อลดความต้องการของงานโดยใช้ระบบอนุรักษ์พลังงาน (Pinch Analysis) และ เอ็กเซอร์จี (Exergy) ในการวิเคราะห์ ซึ่งข้อดีของการใช้ Pinch Analysis คือการแสดงผลที่เข้าใจได้ง่ายโดยการใช้เส้นโค้งคอมโพสิท (Composite Curve)ในการปรับปรุงกระบวนการ อย่างไรก็ตาม Pinch Analysis มีข้อจำกัดเนื่องจาก Pinch Analysis จะพิจารณาแค่ปริมาณความร้อน ซึ่งในกระบวนการดำเนินการภายใต้อุณหภูมิที่ต่ำนั้นงานก็เป็นตัวแปรสำคัญเช่นกัน ดังนั้น Exergy Analysis จึงถูกใช้เป็นเครื่องมือในการออกแบบ เนื่องจาก เอ็กเซอร์จีมีความสัมพันธ์กับงาน การนำจุดเด่นของทั้ง Pinch Analysis และ Exergy Analysis จึงช่วยกระบวนการมีประสิทธิภาพที่ดีขึ้นทั้งยังลดความต้องการของพลังงานและงาน ดังนั้นงานวิจัยนี้ได้ใช้หลักการดังกล่าวมาประยุกต์ใช้ในการออกแบบกับกรณีศึกษาของการเปลี่ยนสถานะก๊าซธรรมชาติให้กลายเป็นก๊าซธรรมชาติเหลว นอกจากนั้นได้นำโปรแกรมทางคณิตศาสตร์ (General Algebraic Modelling System; GAMS) มาใช้ในการออกแบบโครงสร้างเครือข่ายเครื่องแลกเปลี่ยนความร้อนอย่างมีประสิทธิภาพและลดความต้องการของงาน

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LIST OF ABBREVIATIONS

C	Cold streams
C1	Methane
C2	Ethylene
C3	Propane
CCs	Composite curve
CO_2	Carbon dioxide
COP	Coefficient of performance
EA	Exergy analysis
ECCs	Exergy composite curve
EGCCs	Exergy grand composite curve
EMAT	Exchanger minimum approach temperature
ExPAnD	Extended Pinch Analysis and Design Methodology
GAMS	General Algebraic Modeling System
GCCs	Grand composite curve
H	Hot streams
H_2S	Hydrogen sulfide
HCFC	Hydrochlorofluorocarbon
HEN	Heat exchanger network
Hg	Mercury
HRAT	Heat recovery approach temperature
HRS	Heat recovery system
iC4	Iso - butane
iC5	Iso - Pentane
LNG	Liquefied natural gas
MDEA	Methyldiethanolamine
MILP	Mixed-integer linear programming
MINLP	Mixed-integer nonlinear programming
N_2	Nitrogen
nC4	Normal – butane

NG	Natural gas
NLP	Nonlinear programming
OPD	Ozone depletion potential
P	Absolute pressure
P_0	Ambient pressure
PA	Pinch analysis
T	Absolute temperature
T_0	Ambient temperature
TAC	Total cost associated in heat exchanger network
TEG	Triethylene glycol
$TH_{i,IN}$	Supply temperature of hot process stream i
T_{min}	Minimum temperature
W	Approximately shaft work

LIST OF SYMBOLS

$(\sigma T_0)_{HEN}$	Exergy lose due to heat transfer equivalent to shaft work
$\dot{E}^P$	Pressure based exergy
$\dot{E}^Q$	Exergy of heat
$\dot{E}^T$	Temperature based exergy
$\dot{E}^{TM}$	Thermo – mechanical exergy
$\dot{W}_{rev}$	Work in reversible process
$\dot{W}_u$	Useful work
$\dot{Q}_0$	Heat rejected
$\dot{S}_{gen}$	Entropy generation
$\dot{E}_{in}$	Incoming exery stream
$\dot{E}_{out}$	Outing exergy stream
$\dot{E}_{Deficit,min}$	Minimum exergy deficitt
$\dot{E}_{Destruction,min}$	Minimum exergy destruction
$\dot{E}_{Rejection,min}$	Minimum exergy rejection
$\dot{E}_{Requirement,min}$	Minimum exergy requirement
$\dot{E}_{Surplus,min}$	Minimum exergy surplus
$\dot{I}_e$	Exergy destruction in ethane
$\dot{I}_m$	Exergy destruction in methane
$\dot{I}_n$	Exergy destruction in natural gas
$\dot{I}_p$	Exergy destruction in propane
$\dot{m}_e$	Mass flowrate in ethane
$\dot{m}_m$	Mass flowrate in methane
$\dot{m}_n$	Mass flowrate in natural gas
$\dot{m}_p$	Mass flowrate in propane
T^{E^T}	Temperature based exergetic temperature
$\dot{W}_{1,2,3}$	Amount of power for supplying in each cycle namely 1,2 and 3
$\dot{W}_{actual}$	Actual work
$\dot{W}_{min}$	Minimum work

$\Omega_{i,j}$	Upper bound of heat content for heat exchanger
CCU_i	Cost of cooling utility cu
$CFHX_{i,j}$	Fixed charges for exchanger$i-j$
$CW_{i,j}$	Cost of work consumption of compressor
C_p	Average molar heat capacity
FC_i	Heat capacity of cold process stream j
FH_i	Heat capacity of hot process stream i
$FW_{i,j}$	Heat capacity of stream between compressor $i-j$
$\dot{Q}$	Heat absorbed
T^{E^P}	Pressure based exergetic temperature
$TCU_{CU,IN}$	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
$TH_{i,OUT}$	Target temperature of hot process stream i
$dthu_j$	Temperature approach for match of heating utility hu and cold process stream j
$dtcu_{i,cu}$	Temperature approach for match between cooling utility cu and hot process stream i
$dt_{i,j,k}$	Temperature approach for match $i-j$at the left of heat exchanger
qhu_j	Heat exchanged between hot utility hu and cold process stream j
$qcu_{i,cu}$	Heat exchanged between cold utility cu and hot process stream i
$q_{i,j,k}$	Heat exchanged between hot process stream $i$and cold process stream j in stage k
$th_{i,k}$	Temperature of hot process stream i at "hot end" of stage k
$tc_{j,k}$	Temperature of cold process stream j at "hot end" of stage k
zhu_j	Existence of an exchanger for match between heating utility and cold process stream j stream i
$zcu_{i,cu}$	Existence of an exchanger for match between cooling utility cu and hot process

$z_{i,j,k}$	Existence of an exchanger for match $i - j$ in stage k
η_c	Carnot factor
ΔT_{lm}	Log mean temperature difference
Δe	Change of exergy
ΔEx_p	Process receive exergy
ΔEx_r	Refrigeration system supply exergy
ΔW	Reduction in shaft work
A	Area
CHU_j	Cost of heating utility
e	Exergy of process stream per unit mass
E_{CV}	Energy in control volume
$E_{destruction}$, $\dot{I}$	Exergy destruction
h	Enthalpy per unit mass
H	Enthalpy
h^*	Enthalpy of ideal gas ($P_0 = 0$)
h_0	Enthalpy per unit mass at dead state
m	Mass flowrate
P	Absolute pressure
P_0	Ambient pressure
P_C	Critical pressure
P^{vap}	Vapor pressure
Q	Heat duty
R	Gas constant
s	Entropy per unit mass
S	Entropy
s_0	Enthalpy per unit mass at dead state
S_{gen}	Generated entropy
T	Absolute temperature
T_0	Ambient temperature
T_C	Critical temperature
U	Overall heat transfer coefficient

W, Wc, W_{shaft}	Shaft work
$\dot{W}_{min}$	Minimum work input to cycle
Z	Compressibility factor
ε, η_{ex}	Exergy efficiency
η_i	Compressor's isentropic efficiency
ω	Acentric factor
$EMAT$	Minimum-approach temperature difference
ST	Number of stage (often chosen as maximum between number of hot and cold streams)
k	Specific heat ratio
Γ	Upper bound for temperature difference
κ	Dimensionless parameter