A MIXED INTEGER LINEAR PROGRAMMING (MILP) MODEL FOR DESIGNING/RETROFITTING HEAT EXCHANGER NETWORK OF CRUDE FRACTIONATION UNIT

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ABSTRACT

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Today, an increasing trend of crude oil price is one of many causes of high production cost because oil is a major energy source used in industry. An effective design of heat exchanger network (HEN) is one of the solutions that can reduce production cost because the heat exchanger network can recover the energy. A crude fractionation unit consumes high energy about 30-40% of a refinery. In this thesis, a strategy to design efficient HENs of the refinery is proposed as the Mixed Integer Linear Programming (MILP) formulation based on the special transhipment structure concept. This methodology can generate networks where utility cost, heat exchanger areas and selection of matches are optimized simultaneously. And it can design the appropriate flow rate of pump-around. In addition, the simplicity in model assumption, non-isothermal mixing, comes with handling constraints such as stream splitting and allowed/forbidden matches which bring the model structure more convenient to use. This research gives the efficient HENs to a fractionation unit of light, intermediate and heavy crudes by saving the energy cost, capital cost and area cost about 123.91% from the existing network.

บทคัดย่อ

กิติศักดิ์ จุลโลบล: แบบจำลอง MILP เพื่อการออกแบบเครือข่ายแลกเปลี่ยนความร้อนของหอกลั่นน้ำมันดิบ (A Mixed Integer Linear Programming (MILP) Model for Designing/Retrofitting a Heat Exchanger Network for Crude Fractionation Column) อ. ที่ปรึกษา: ผศ. ดร. กิติพัฒน์ สีมานนท์ และ ศ. ดร. มิเกล บากาเฮวิซ 225 **หน้า** ISBN 974-9937-44-9

ในปัจจุบันนี้แนวโน้มการเพิ่มสูงขึ้นของราคาน้ำมัน เป็นหนึ่งในหลายสาเหตุที่ทำให้ค่าใช้จ่ายในกระบวนการผลิตเพิ่มสูงตาม เพราะน้ำมันเป็นแหล่งพลังงานหลักที่ใช้ในอุตสาหกรรม การออกแบบระบบแลกเปลี่ยนความร้อนที่มีประสิทธิภาพ ถือเป็นอีกหนึ่งทางเลือกที่สามารถช่วยลดค่าใช้จ่ายในกระบวนการผลิต เพราะการออกแบบเครือข่ายแลกเปลี่ยนความร้อนสามารถนำพลังงานกลับมาใช้ใหม่ได้ หอกลั่นน้ำมันดิบใช้ปริมาณพลังงานสูง ถึงประมาณ 30-40เปอร์เซนต์ของปริมาณความร้อนในโรงกลั่นน้ำมัน วิทยานิพนธ์นี้ นำเสนอวิธีการออกแบบเครือข่ายแลกเปลี่ยนความร้อนของหอกลั่นน้ำมันดิบ โดยอาศัยแบบจำลองทางคณิตศาสตร์ มิกส์อินทีเจอร์ลีเนียโปรแกรมมิง โดยอ้างถึงหลักการของ ทรานชิปเมนท์โมเดล โดยวิธีการที่ใช้จะสามารถคำนวณค่าใช้จ่ายทั้งหมดในเครือข่ายการแลกเปลี่ยนความร้อน ซึ่งประกอบด้วย ค่าใช้จ่ายของสาธารณูปโภค พื้นที่ และจำนวนของเครื่องแลกเปลี่ยนความร้อน ในเวลาเดียวกัน และยังสามารถออกแบบอัตราการไหลของปั๊มอะราวน์ที่เหมาะสม นอกจากนี้ การสมมุติค่าที่ทำให้โมเดลง่ายในการคำนวนแบบจำลองทางคณิตศาสตร์นี้ยังสามารถประยุกต์ใช้กับกระบวนการที่มีข้อจำกัดต่างๆ เช่น ข้อจำกัดในการจับคู่ของสายสตรีมร้อนและสายสตรีมเย็น การแบ่งสายสตรีมเพื่อเพิ่มความสามารถใน การแลกเปลี่ยนความร้อนเป็นต้น ในวิทยานิพนธ์ฉบับนี้ได้ แสดงระบบแลกเปลี่ยนความร้อนที่มีประสิทธิภาพของโรงกลั่นน้ำมัน สำหรับน้ำมันดิบแบบเบา กลางและหนักโดยได้ประหยัดค่าใช้จ่ายด้านพลังงาน ค่าติดตั้ง และค่าขนาดพื้นที่ของเครื่องแลกเปลี่ยนความร้อน ได้ถึง 123.91 เปอร์เซนต์

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ABBREVIATIONS

Sets

B = { (i,j) | more than one heat exchanger unit is permitted between hot stream i and cold stream j }

C^z = { j | j is a cold stream present in zone z }

C_n^z = { j | j is a cold stream present in temperature interval n in zone z }

CU^z = { j | j is a heating utility present in zone z } $(CU^z \subset C^z)$

H^z = { i | i is a hot stream present in zone z }

H_m^z = { i | i is a hot stream present in temperature interval m in zone z }

HU^z = { i | i is a heating utility present in zone z } $(HU^z \subset H^z)$

M^z = { m | m is a temperature interval in zone z }

M_i^z = { m | m is a temperature interval belonging to zone z, in which hot stream i is presented }

m_i^0 = { m | m is the starting temperature interval for hot stream i }

m_i^f = { m | m is the final temperature interval for hot stream i }

N_j^z = { n | n is a temperature interval belonging to zone z, in which cold stream j is presented }

NI^H = { i | non-isothermal mixing is permitted for hot stream i }

NI^C = { j | non-isothermal mixing is permitted for cold stream j }

n_j^0 = { n | n is the starting temperature interval for cold stream j }

n_i^f = { n | n is the final temperature interval for cold stream j }

P = { (i,j) | heat exchange match between hot stream i and cold stream j is permitted }

P_{im}^H = { j | heat transfer from hot stream i at interval m to cold stream j is permitted }

P^C_{jm} = { i | heat transfer from hot stream i to cold stream j at interval n is permitted }

PA^z ={ i | I is a hot stream present in zone z and is a pump around stream)

S^H = { i | splits are allowed for hot stream i }

S^C = { j | splits are allowed for cold stream j }

Z = {z| z is a heat transfer zone}

Parameters

$A^{a^0}_{ij}$	Area of an existing exchanger between streams i and j in zone z prior to retrofit
A^{z,k^0}_{ij}	Area of the k-th existing exchanger between streams i and j in zone z prior to retrofit
$A^z_{ij\max}$	Maximum shell area for an exchanger matching hot stream i and cold stream j in zone z
$A^{z^N}_{ij\max}$	Maximum area for a new heat exchanger matching hot stream i and cold stream j in zone z
$\Delta A^{z^0}_{ij\max}$	Maximum area addition for an existing heat exchanger matching hot stream i and cold stream j in zone z
$\Delta A^{z,k^0}_{ij\max}$	Maximum area addition for the k-th existing heat exchanger matching hot stream i and cold stream j in zone z
$\hat{C}_{im}$	Heat capacity of hot stream i at temperature interval m
$\hat{C}_{jn}$	Heat capacity of cold stream j at temperature interval n
c^H_i	Cost of heating utility i
c^C_j	Cost of cooling utility j
c^F_{ij}	Fixed charge cost for a heat exchanger matching hot stream i and cold stream j

$c_{ij}^{A^N}$	Variable cost for a new heat exchanger matching hot stream i and cold stream j
$c_{ij}^{A^0}$	Area addition cost for an existing heat exchanger matching hot stream i and cold stream j
$CHEAD_{im,jn}$	Temperature difference between interval m of hot stream i and interval n of cold stream j at cold end
F_i	Flow rate of hot process stream i
F_j	Flow rate of cold process stream j
F_i^U	Upper bound for the flow rate of heating utility i
F_j^U	Upper bound for the flow rate of cooling utility j
$FPR_{i,r}^H$	Candidate values for pump around flowrate i
h_{im}	Film heat transfer coefficient for hot stream i in interval m
h_{jn}	Film heat transfer coefficient for cold stream j in interval n
$\Delta H_{im}^{z,H}$	Enthalpy change for hot stream i at interval m of zone z
$\Delta H_{jn}^{z,C}$	Enthalpy change for cold stream j at interval n of zone z
$HHEAD_{im,jn}$	Temperature difference between interval m of hot stream i and interval n of cold stream j at hot end
$k_{\max}$	Maximum number of heat exchangers allowed between hot stream i and cold stream j in zone z when $(i,j) \in B$
k_e	Number of existing heat exchangers between hot stream i and cold stream j in zone z when $(i,j) \in B$
k_e^I	Number of existing heat exchangers in the original network
q_{ijm}^L	Lower bound for heat transfer from hot stream i at interval m to cold stream j

q_{ijn}^{L}	Lower bound for heat transfer from hot stream *i* to cold stream *j* at interval *n*
Q_{PA}	Total PA load
T_{m}^{U}	Upper temperature of interval *m*
T_{m}^{L}	Lower temperature of interval *m*
T_{n}^{U}	Upper temperature of interval *n*
T_{n}^{L}	Lower temperature of interval *n*
ΔT_{i}	Temperature range of stream *i*
ΔT_{j}	Temperature range of stream *j*
ΔT_{mn}^{ML}	Mean logarithmic temperature difference between intervals *m* and *n*
$U_{ij}^{z^0}$	Number of existing heat exchangers between hot stream *i* and cold stream *j* in zone *z*
$U_{ij}^{z^N}$	Maximum number of new heat exchangers allowed for the retrofit design
$\Gamma_{im,jn}^{z,H}$	Upper bound

Variables

A_{ij}^{z}	Total required area for a match between hot stream *i* and cold stream *j* in zone *z*
A_{ij}^{z,k^0}	Area of the *k*-th existing heat exchanger between hot stream *i* and cold stream *j* in zone *z* after retrofit
$A_{ij}^{z^N}$	Area of a new heat exchanger between hot stream *i* and cold stream *j* in zone *z*
$\Delta A_{ij}^{z^0}$	Area addition for an existing heat exchanger between hot stream *i* and cold stream *j* in zone *z*

$\Delta A_{ij}^{z,k^0}$	Area addition for the *k*-th existing heat exchanger between hot stream *i* and cold stream *j* in zone *z*
FP_i^H	Flowrate of pumparound stream
$K_{ijm}^{z,H}$	Determines the beginning of a heat exchanger at interval *m* of zone *z* for hot stream *I* with cold stream *j*. Defined as binary when $(i,j) \in B$ and as continuous when $(i,j) \notin B$
$K_{ijn}^{z,C}$	Determines the beginning of a heat exchanger at interval *n* of zone *z* for cold stream *j* with hot stream *i*. Defined as binary when $(i,j) \in B$ and as continuous when $(i,j) \notin B$
$\hat{K}_{ijm}^{z,H}$	Determines the end of a heat exchanger at interval *m* of zone *z* for hot stream *i* with cold stream *j*. Defined as binary when $(i,j) \in B$ and as continuous when $(i,j) \notin B$
$\hat{K}_{ijn}^{z,C}$	Determines the end of a heat exchanger at interval *n* of zone *z* for cold stream *j* with hot stream *i*. Defined as binary when $(i,j) \in B$ and as continuous when $(i,j) \notin B$
k_e	Number of existing heat exchangers between hot stream *i* and cold stream *j* in zone *z* when $(i,j) \in B$
$q_{im,jn}^{z}$	Heat transfer from hot stream *i* at interval *m* to cold stream *j* at interval *n* in zone *z*
$\overline{q}_{imn}^{z,H}$	Non-isothermal mixing heat transfer for hot stream *i* between intervals *m* and *n* in zone *z*
$\overline{q}_{jmn}^{z,C}$	Non-isothermal mixing heat transfer for hot stream *i* between intervals *m* and *n* in zone *z*
$\hat{q}_{ijm}^{z,H}$	Heat transfer from hot stream *i* at interval *m* to cold stream *j* in zone *z*
$\hat{q}_{ijn}^{z,C}$	Heat transfer to cold stream *j* at interval *n* from hot stream *j* in zone *z*
$\widetilde{q}_{ijm}^{z,H}$	Auxiliary continuous variable utilized to compute the hot side heat load of each heat exchanger when several exchangers exist between hot stream *i* and cold stream *j* in zone *z*

$\widetilde{q}_{ijn}^{z,C}$	Auxiliary continuous variable utilized to compute the cold side heat load of each heat exchanger when several exchangers exist between hot stream i and cold stream j in zone z
$\widetilde{q}_{im,jn}^{z,H}$	Auxiliary continuous variable utilized to compute the area of individual heat exchangers between hot stream i with cold stream j in zone z when $(i,j) \in B$
QP_i^z	Pumparound load
U_{ij}^z	Number of heat exchangers between hot stream i and cold stream j in zone z
$X_{im,jn}^z$	Auxiliary continuous variable equals to zero when an exchanger ends at interval m for hot stream i and at interval n for cold stream j. A value of one corresponds to all other cases
$\hat{X}_{ijm}^{z,k}$	Auxiliary binary variable that determines whether the k-th between hot stream i with cold stream j in zone z exists at interval m of when $(i,j) \in B$
$Y_{ijm}^{z,H}$	Determines whether heat is being transferred from hot stream i at interval m to cold stream j. Defined as binary when $(i,j) \notin B$ and as continuous when $(i,j) \in B$
$Y_{ijn}^{z,C}$	Determines whether heat is being transferred from hot stream i to cold stream j at interval n. Defined as binary when $(i,j) \notin B$ and as continuous when $(i,j) \in B$
$\delta_{ij}^{z,k}$	Auxiliary binary variable used for heat exchanger relocation. Auxiliary binary variable that determines whether the k-th original heat exchanger of zone z has is serving the match between hot stream i and cold stream j, when $(i,j) \notin B$
$\delta_{ij}^{z,hk}$	Auxiliary binary variable used for heat exchanger relocation. This variable determines whether the k-th original heat exchanger of zone z has is serving the h-th exchanger streams i and j, when $(i,j) \in B$

$\alpha_{ijm}^{z,H}$	Auxiliary continuous variable equal to one when heat transfer from interval m of hot stream i to cold stream j occurs in zone z and it does not correspond to the beginning nor the ending of a heat exchanger. A value of zero corresponds to all other cases
$\alpha_{ijn}^{z,C}$	Auxiliary continuous variable equal to one when heat transfer from hot stream i to interval n of cold stream j occurs in zone z and it does not correspond to the beginning nor the ending of a heat exchanger. A value of zero corresponds to all other cases