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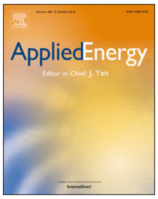

Optimal synthesis of work and heat exchangers networks considering unclassified process streams at sub and above-ambient conditions

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HIGHLIGHTS

- New optimization model for work and heat exchanger networks with unclassified streams.
- Energy integration is improved via mathematical programming and pinch location method.
- Disjunctive operators are used for optimal unit selection and streams classification.
- Optimal streams classification can be promising for sub and above-ambient conditions.
- In a subambient process, energy analysis shows reductions in energy demands up to 89%.

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ABSTRACT

Work and heat exchanger networks have recently drawn increasing attention due to their paramount importance in achieving energy savings. In this work, we introduce a new optimization model for the cost-effective synthesis and energy integration of work and heat exchanger networks considering unclassified process streams (*i.e.*, streams whose classification as hot or cold streams cannot be defined *a priori*). Our innovative modelling approach combines mathematical programming techniques and the pinch location method to obtain an optimal network design with minimal cost, while adjusting pressure and temperature levels of unclassified streams. We propose disjunctive operators for the selection of pressure manipulation equipment, and streams identity classification depending on energy requirements and process operating conditions. In addition, our approach addresses previous shortcomings by eliminating the need for: (*i*) assigning a specific route of pressure manipulation; and, (*ii*) classifying streams as low or high-pressure streams; which provides further flexibility to the system. Our methodology is also able to effectively deal with variable inlet and outlet streams temperatures to reach specific optimization goals. The model is solved to global optimality through the minimization of the process total annualized cost. Besides improved computational performance, results from energy analyses reveal that streams classification during process optimization can be greatly advantageous for both subambient and above-ambient applications. In the liquefied natural gas process, it reduces up to 89% the energy demand when compared to literature records.

1. Introduction

Work and heat exchanger networks (WHENs) have become increasingly important for the field of process system engineering in the past few years. Growing research has distinctly shown that work and heat integration plays a critical role for reaching significant energy and cost savings, while enhancing system energy efficiency [1] and reducing environmental impacts [2]. This is especially relevant for energy-intensive processes in oil refineries and cryogenic technology, such as the air separation, hydrogen liquefaction and production of liquefied natural gas (LNG). In LNG plants, excessive energy consumption is associated with compressing and cooling streams at subambient conditions [3]. In addition, the continuous rise in global energy demand, highly volatile energy prices, and stricter environmental policies towards the reduction of carbon emissions, have also boosted the development of more efficient process integration techniques [4] and work

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Nomenclature

Acronyms

CEPCI	Chemical Engineering Plant Cost Index
ExPAnD	Extended Pinch Analysis and Design
GAMS	General Algebraic Modeling System
GDP	Generalized Disjunctive Programming
HEN	Heat Exchanger Network
HP	High-Pressure
LCO_2	Liquid Carbon Dioxide
LIN	Liquid Inert Nitrogen
LNG	Liquefied Natural Gas
LP	Low-Pressure
MEN	Mass Exchanger Networks
MILP	Mixed-Integer Linear Programming
MINLP	Mixed-Integer Nonlinear Programming
NG	Natural Gas
PLM	Pinch Location Method
SSTC	Single-Shaft-Turbine-Compressor
WEN	Work Exchanger Network
WHEN	Work and Heat Exchanger Network

Greek letters

γ	heat capacity ratio
η	isentropic efficiency
μ	Joule-Thomson coefficient

Roman letters

$CAPEX$	capital cost
Cp	heat capacity at constant pressure
CPO	unitary cost of equipment
Cv	heat capacity at constant volume
F	heat capacity flowrate
fac	annualization factor for capital cost
FBM	correction factor for capital cost
$OPEX$	operational expenses
PIN	inlet streams pressure in stages of the superstructure
Pin^B	inlet streams pressure in a bypass
Pin^C,Pin^T,Pin^V	inlet streams pressures in a compressor, turbine and valve, respectively
Pin^{PM}	inlet streams pressure in a pressure manipulation equipment
P_{IN}^S	inlet streams pressure from the superstructure
$POUT$	outlet streams pressure from stages of the superstructure
$Pout^B$	outlet streams pressure in a bypass
$Pout^C$,$Pout^T$,$Pout^V$	outlet streams pressures in a compressor, turbine and valve, respectively
$Pout^{PM}$	outlet streams pressure from a pressure manipulation equipment
P_{OUT}^S	outlet streams pressure from the superstructure
Q^{COLD}	heat removed by the cold utility
Q^{HOT}	heat provided by the hot utility
T^+	variable that takes positive values for hot streams
T^-	variable that takes positive values for cold streams
T^{Pi}	pinch point temperature
TAC	total annualized cost
TIN	inlet streams temperature in stages of the superstructure
Tin^B	inlet streams temperature in a bypass
Tin^C,Tin^T,Tin^V	inlet streams temperatures in a compressor, turbine and valve, respectively
Tin^{PM}	inlet streams temperature in a pressure manipulation equipment
T_{IN}^S	inlet streams temperature from the superstructure
Tin^{Sh}	shifted inlet temperature
$TinC^{Sh}$	disaggregated variable for the shifted inlet temperatures of cold streams
$TinH^{Sh}$	disaggregated variable for the shifted inlet temperatures of hot streams
$TINC$	disaggregated variable for the actual inlet temperatures of cold streams
$TINH$	disaggregated variable for the actual inlet temperatures of hot streams
$TOUT$	outlet streams temperature from stages of the superstructure
$Tout^B$	outlet streams temperature in a bypass
$Tout^C$,$Tout^T$,$Tout^V$	outlet streams temperatures in a compressor, turbine and valve, respectively
$Tout^{PM}$	outlet streams temperature from a pressure manipulation equipment
T_{OUT}^S	outlet streams temperature from the superstructure
$Tout^{Sh}$	shifted outlet temperature
$ToutC^{Sh}$	disaggregated variable for the shifted outlet temperatures of cold streams
$ToutH^{Sh}$	disaggregated variable for the shifted outlet temperatures of hot streams
$TOUTC$	disaggregated variable for the actual outlet temperatures of cold streams
$TOUTH$	disaggregated variable for the actual outlet temperatures of hot streams
$\Delta T_{\min}$	minimum temperature approach
W^C	consumed work by a compressor in the superstructure
W^T	performed work by a turbine in the superstructure
W^{PM}	work of pressure manipulation equipment in the superstructure
Y^B	Boolean variable that takes the logic «*True*» value if a given stream passes through a bypass in the superstructure
Y^C,Y^T,Y^V	Boolean variables that take the logic «*True*» value if a given compressor, turbine and valve is respectively used by a stream in the superstructure
Y^{COLD}	Boolean variables that take the logic «*True*» value if an unclassified stream is classified as a cold stream
Y^{HOT}	Boolean variables that take the logic «*True*» value if an unclassified stream is classified as a hot stream
Y^{PM}	Boolean variable that takes the logic «*True*» value if a given pressure manipulation equipment is used by a stream in the superstructure
y^B	Binary variable that assumes the value 1 if a given stream passes through a bypass in the superstructure
y^C,y^T,y^V	binary variables that assume the value 1 if a given compressor, turbine and valve is respectively used by a stream in the superstructure
y^{COLD}	binary variables that assume the value 1 if an unclassified stream is classified as a cold stream
y^{HOT}	binary variables that assume the value 1 if an unclassified stream is classified as a hot stream
y^{PM}	binary variable that assumes the value 1 if a given pressure manipulation equipment is used by a stream in the superstructure

Subscripts

i	hot process streams
j	cold process streams
k	unclassified process streams
n	superstructure stages
p	process streams that are pinch candidates
s	process streams