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Designing a Total Site for an entire lifetime under fluctuating utility prices

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ABSTRACT

This paper describes a synthesis of Total Site in order to obtain additional energy savings by process-to-process heat integration. Enhanced Heat Integration and economically viable designs can be obtained by establishing an appropriate trade-off between the operating cost and the investment. The aim of this work was to improve the modeling of the Total Site by including proper pressure levels selection for intermediate utilities, preheating of intermediate utilities because of incomplete condensate recovery, pipeline layout design, and optimal pipe design with optimal pressure/temperature drops and optimal insulation thickness and heat losses during transportation along the pipes. Additionally, future utility prices are considered when synthesizing the Total Site as they are expected to influence the trade-off between investment and operating cost. A stochastic multi-period mixed-integer nonlinear programming model for the optimal synthesis of Total Site over its entire lifetime has been developed by including all the above-mentioned design aspects.

1. Introduction

Future energy demand shows an increasing tendency that might have a profound impact regarding the socio-economic problems (e.g. increasing energy consumption, disparity amongst nations regarding energy consumption, wealth and human development) of the world over the coming decades (Ugursal, 2014). The applications of Heat Integration (HI) are becoming increasingly more important, as they are contributing significantly to the solution of some the most severe problems of our modern society – energy and water, e.g. desalination of sea water applying HI to the geothermal desalination plant (Manenti et al., 2013). Heat Integration of processes can notably contribute to their sustainability by decreasing their energy consumption. This contribution is even more significant when process-level integration is extended to the Total Site (TS) level. The concept of TS includes various processes connected through a central utility system that enables heat recovery between these different processes. Three approaches can be used in order to perform Heat Integration analysis, namely: (i) the thermodynamic approach by applying Pinch Analysis that sets the targets by determining the thermodynamic maximal possible rate of heat recovery, (ii) mathematical programming that evaluates trade-off between investment and operating cost, and (iii) a combination of these two methods. A review of the Heat Integration development and its current state can be found in more detail in Klemeš and Kravanja (2013).

Heat Integration by applying Pinch Analysis has become a rather well-developed approach and several authors have dealt with it (for an overview, see Klemeš et al., 2010). The concept of TS was pioneered by Dhole and Linnhoff (1993). In their work Site Sink and Site Source Profiles were introduced based on graphical tools applied for the evaluation of fuel consumption, cogeneration, emissions, and the cooling needs of an industrial site. Klemeš et al. (1997) extended this methodology by introducing Total Site Profiles (TSPs) and Site Utility Grand Composite Curves (SUGCCs). These curves serve for evaluating the heat recovery potentials between different processes. In earlier times the TS concept was only applied for industrial processes. Perry et al. (2008) further developed the concept of TS by also including processes from other sectors – residential, business, service, and agricultural. Fodor et al. (2010) extended TSP methodology

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Nomenclature

Abbreviations

CU	cold utility
CS	Sink Side of Total Site
ENPV	Expected Net Present Value
HE	heat exchanger
HEN	heat exchanger network
HS	Source Side of Total Site
HU	hot utility
MINLP	mixed-integer nonlinear programming
NPV	Net Present Value
TS	Total Site
TSP	Total Site Profile

Indices

ap	index for all the processes included in the TS, $ap \in AP$
i	index for hot streams in different processes, $i \in I$
j	index for cold streams in different processes, $j \in J$
iu	index for different intermediate utilities, $iu \in IU$
k^{CS}	index for temperature locations on the Sink Side, $k^{\mathrm{CS}} \in K^{\mathrm{CS}}$
k^{HS}	index for temperature locations on the Source Side, $k^{\mathrm{HS}} \in K^{\mathrm{HS}}$
n	index for the periods observed, $n \in N = \{1, 2, \ldots, t_{\mathrm{LT}}\}$
pc	index for processes that have heat demands, $pc \in PC \subset AP$
ph	index for processes that have heat surpluses, $ph \in PH \subset AP$
u	price for different utility prices' projections to jump from, $u \in U$
v	index for different utility prices' projections, $v \in V$

Constants

Al	allowance for threading, mechanical strength, and corrosion (m)
A, B, C	Antoine constants for pressure/temperature relationship
ac	cost exponent for HE between process stream and intermediate utility
cc	cost exponent for HE between cold utility and process stream
c^y	coefficient for accounting for the condensate pipeline
cf^{CU}	fixed charge for HE between process stream and cold utility (€)
cf^{HU}	fixed charge for HE between process stream and hot utility (€)
cf	fixed charge for HE between process streams (€)
$CP_{ph,i}$	heat capacity flow-rate of hot stream i for process ph (W/K)
$CP_{pc,j}$	heat capacity flow-rate of cold stream j in process pc (W/K)
cv	variable charge of HE between two process streams (€/(m^2 y))
cv^{CU}	variable charge of HE between process stream and cold utility (€/(m^2 y))
cv^{HU}	variable charge of HE between process stream and hot utility (€/(m^2 y))
$c_{n,v}^{\mathrm{CU}}$	cost of cold utility in period n and projection v (€/J)
$c_{n,v}^{\mathrm{HU}}$	cost of hot utility in period n and projection v (€/J)
c^{P1}	pipe cost per unit weight (€/g)
c^{P2}	installation cost (€/m)
c^{P3}	right-of-way cost (€/m)
c^{P4}	insulation cost on a volume basis (€/m^3)
f^{rec}	fraction of condensate returned to source side processes
h_{iu}	heat transfer coefficient of intermediate utility iu (W/(m^2 K))
$h_{ph,i}$	heat transfer coefficient of hot stream i in process ph (W/(m^2 K))
$h_{pc,j}$	heat transfer coefficient of cold stream j in process pc (W/(m^2 K))
hc	cost exponent for heat exchangers between cold utility and process stream
$L_{ph,pc}$	length of potential pipeline between Source Side process ph and Sink Side process pc (m)
Ns	number of stages
$p_{n,v}$	probability of projections v in period n (%)
$pipe_{ph,pc,iu}^{\mathrm{inst,UP}}$	upper bound on variable for calculation of installation cost of source side process ph, to sink side process pc, for intermediate utility iu (m)
$q_{ph,pc}^{\mathrm{UP}}$	upper bound for amount of heat for transfer from process ph to process pc (W)
$q_{ph,pc}^{\mathrm{LO}}$	lower bound for amount of heat for transfer from process ph to process pc (W)
r_{D}	sum of discounted rate and inflation (%)
r_{T}	tax rate (%)
SE	maximum allowable stress in material caused by internal pressure and joint efficiency at design temperature (Pa)