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Optimal design for heat-integrated water-using and wastewater treatment networks

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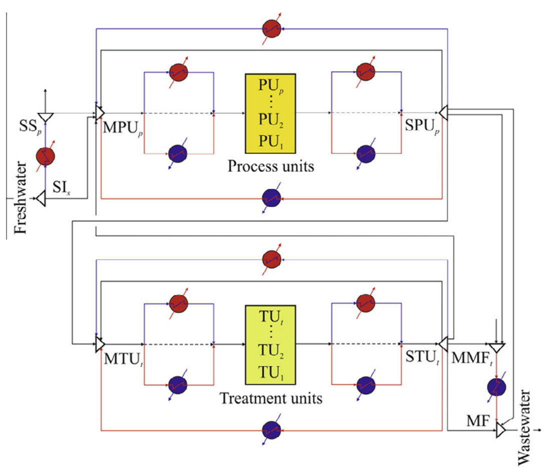
HIGHLIGHTS

- Synthesis of a heat-integrated water and wastewater treatment networks is addressed.
- A novel general superstructure and a simultaneous optimisation model are presented.
- Overall synthesis problem is solved using two-step solution strategy.
- Improved results and novel network designs are reported.

GRAPHICAL ABSTRACT



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ABSTRACT

This work proposes a novel general superstructure and a simultaneous optimisation model for the designing of a heat-integrated water-using and wastewater treatment network (HIWTN) by combining a water-using network (WN), a wastewater treatment network (WTN), and a heat exchanger network (HEN). The proposed work is an extension of our previous studies that considered only heat-integrated water networks (HIWNs) or combined WN and HEN without WTN. The new proposed superstructure of this work combines water integration (water-usage, wastewater treatment, and recycling) and heat integration (direct and indirect heat exchanges) within an overall network. The simultaneous optimisation model of the proposed superstructure is formulated as a non-convex mixed integer non-linear programming (MINLP) problem for minimising the total annual network cost (TAC). This model enables appropriate trade-offs between freshwater usage, hot and cold utilities consumption, and capital cost of heat exchangers (HEs) and wastewater treatment units (TUs). Three literature examples are used to test the proposed model. The improved results of the first two examples are given whilst for the third modified example a novel network design is presented in order to include wastewater treatment.

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Nomenclature

Indices

c	contaminant
i	hot process stream
j	cold process stream
k	index for stage and temperature location
p	process unit
s	freshwater source
t	treatment unit

Sets

CC	contaminants
HP	hot process streams
CP	cold process streams
ST	stages in the HEN superstructure
PU	process units
SW	freshwater sources
TU	treatment units

Parameters

AR	annualized investment factor for TUs
B	exponent for area cost
C	area cost coefficient, $/m^2
C_{CU}	per unit cost for cold utility, $/(W y)
CF	fixed charge for exchangers, $
CFW_s	cost of freshwater from source s, $/kg
C_{HU}	per unit cost for hot utility, $/(W y)
C_p	heat capacity of water, J/(kg K)
EMAT	exchanger minimum approach temperature, K
H	hours of plant operation per year, h
h	individual heat-transfer coefficients, W/(m^2 K)
IC_t	investment cost coefficient for TU t, $/kg
$LPU_{p,c}$	load of contaminant c in PU p, kg/s
OC_t	operating cost coefficient for TU t, $/kg
R_p	local recycle around PU p ($R_p = 0$ does not exist, $R_p = 1$ if exists)
$RR_{t,c}$	% removal of contaminant c in TU t
R_t	local recycle around TU t ($R_t = 0$ does not exist, $R_t = 1$ if exists)
α	exponent for investment TU cost
TFW_s	temperature of freshwater source s, K
TPU_p^{in}	temperature at the inlet of PU p, K
TPU_p^{out}	temperature at the outlet of PU p, K
TIN	inlet temperature of utility stream, K
$TOUT$	outlet temperature of utility stream, K
$TIP_{s,p}$	temperature of freshwater stream from source s to mixer PU, K
T^{out}	temperature of outlet stream from final mixer, K
$T^{\max}$	maximum temperature of the water streams within the network, K
$T^{\min}$	minimum temperature of the water streams within the network, K
U	overall heat transfer coefficient, W/(m^2 K)
$xPU_{p,c}^{in,\max}$	maximum concentration of contaminant c in inlet stream to PU, ppm
$xPU_{p,c}^{out,\max}$	maximum concentration of contaminant c in outlet stream from PU, ppm
$xSS_{p',c}^{out}$	concentration of contaminant c in freshwater in outlet stream from freshwater splitter, ppm
$xW_{s,c}^{in}$	concentration of contaminant c in freshwater source s, ppm
Γ	upper bound for temperature difference
Ω	upper bound for heat exchange

Continuous variables

fh_i	heat capacity flow rate of hot stream i, W/K
fc_j	heat capacity flow rate of cold stream j, W/K
$FIP_{s,p}$	mass flow rate of water stream from freshwater source s to PU p, kg/s
FMM_t^{in}	mass flow rate of inlet stream to wastewater mixer, kg/s
FMM_t^{out}	mass flow rate of outlet stream from wastewater mixer, kg/s
$FSMM_{t',t}$	mass flow rate of water stream from TU to wastewater mixer, kg/s
FSS_p^{in}	mass flow rate of inlet freshwater stream to HE, kg/s
FSS_p^{out}	mass flow rate of outlet freshwater stream from HE, kg/s
$FSSM_{p,p'}$	mass flow rate of freshwater stream from splitter SS to mixer PU, kg/s
$FP_{p',p}$	mass flow rate of water stream from PU p' to PU p, kg/s
$FCP_{p',p}$	mass flow rate of cold water stream from PU p' to PU p, kg/s
$FHP_{p',p}$	mass flow rate of hot water stream from PU p' to PU p, kg/s
$FCT_{t',t}$	mass flow rate of cold water stream from TU t' to TU t, kg/s
$FHT_{t',t}$	mass flow rate of hot water stream from TU t' to TU t, kg/s
$FTP_{t,p}$	mass flow rate of water stream from TU t to PU p, kg/s
$FT_{t',t}$	mass flow rate of water stream from TU t' to TU t, kg/s
$FPO_{p'}$	mass flow rate of water stream from PU p' to final mixer, kg/s
$FPT_{p,t}$	mass flow rate of water stream from PU p to TU t, kg/s
$FPOMM_{p,t}$	mass flow rate of water stream from splitter PU p to wastewater mixer after TU t, kg/s
FPU_p^{in}	mass flow rate of inlet water stream to PU p, kg/s
FPU_p^{out}	mass flow rate of outlet water stream from PU p, kg/s
FTU_t^{in}	mass flow rate of inlet water stream to TU t, kg/s
FTU_t^{out}	mass flow rate of outlet water stream from TU t, kg/s
FTO_t	mass flow rate of water stream from TU t' to final mixer, kg/s
F^{out}	mass flow rate of outlet wastewater stream from final mixer, kg/s
FW_s	mass flow rate of water from freshwater source s, kg/s
FW_s^{out}	mass flow rate of water stream from freshwater source s to heating stages, kg/s
$thin_i$	inlet temperature of hot stream, K
$thout_i$	outlet temperature of hot stream, K
$tcin_j$	inlet temperature of cold stream, K
$tcout_j$	outlet temperature of cold stream, K
TSS_p^{in}	temperature of inlet freshwater stream to HE, K
TSS_p^{out}	temperature of outlet freshwater stream from HE, K
$TSPU_p^{out}$	temperature of outlet water stream from splitter PU, K
$TCPU_p^{out}$	temperature of outlet process-to-process cold stream from HE, K
$THPU_p^{out}$	temperature of outlet process-to-process hot stream from HE, K
$TCTU_t^{out}$	temperature of outlet treatment-to-treatment cold stream from HE, K
$THTU_t^{out}$	temperature of outlet treatment-to-treatment hot stream from HE, K
$TSTU_t^{out}$	temperature of outlet water stream from splitter TU, K
TPU_p^{mix}	temperature of outlet stream from mixer PU, K
TTU_t^{mix}	temperature of outlet stream from mixer TU, K
TMM_t^{in}	temperature of inlet wastewater stream to wastewater mixer, K
TMM_t^{out}	temperature of outlet wastewater stream from wastewater mixer, K