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Industrial wastewater treatment network based on recycling and rerouting strategies for retrofit design schemes

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ABSTRACT

The advent of complex industrial water/wastewater management problems points to a need for effective systematic design for a sustainable solution. The objective of this work is to extend the research in the area of systematic design of water/wastewater management by further developing and extending a generic model-based synthesis and design framework for retrofit wastewater treatment networks (WWTN) of an existing industrial process. The developed approach is suitable for grassroots and retrofit systems and adaptable to a wide range of wastewater treatment problems. A sequential solution procedure is employed to solve a network superstructure-based optimization problem formulated as Mixed Integer Linear and/or Non-Linear Programming (MILP/MINLP). Data from a petroleum refinery effluent treatment plant together with special design constraints are employed to formulate different design schemes based on recycling and rerouting strategies focusing on completely splitting system and zero liquid discharge (ZLD) opportunity. The base case design of the existing process has been verified against the refinery data, while the grassroots and the retrofit options are generated and compared with the existing process. The network design solutions obtained with effectively computational time from the case study shows an improvement in the reduction of a total annualized cost (TAC) and wastewater discharge rate (WWDR) as a result of water recycling and rerouting options. Pareto plot (trade-off solution graph) for the analysis of such optimal solutions has been applied to implicitly verify the optimality of the solution based on all possible scenarios. Superior retrofit alternatives have been identified based on their performance including cost and environmental impacts and can be used as efficient design guidelines for the future development of the existing wastewater treatment process.

1. Introduction

Water is intensively used in most industrial processes, and the concern about shortage of water supply in several areas is increasing. Thus, the challenge and problem regarding sustainability of water resources and optimal water consumption as well as wastewater management have to be addressed more efficiently and effectively through advanced strategies and technologies (Bagatin et al., 2014). One of the interesting approaches to deal with such a problem is to minimize the water consumption as proposed by Wan Alwi and Manan (2006) with respect to different levels of water management hierarchy. In addition, the cost of freshwater together with wastewater treatment processes and more rigorous environmental regulations have also motivated the industrial sector to move from a conventional end-of-pipe treatment towards better sustainable solutions (Foo, 2008). Hence, water management is of significance to employ water resource in the most efficient way. Furthermore, retrofit designs in wastewater treatment systems are significant to be addressed systematically because of the change towards new stringent environmental law, the lack of the available freshwater source and so on. Since in any general plants a wastewater system has already been installed, retrofit application is likely to be a more common activity than a grassroots design or synthesis. Selectively recycling of treated wastewater is one of the best alternatives to minimize the amount of freshwater usage and water

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Indices

i, ii	Component
k	Block (origin)
kk	Block (destination)
react	Key reactant component
rr	Reaction
s	Network step (origin)
ss	Network step (destination)
tw	Type of waste disposal

Sets

I	Contaminants, utilities, species generated
K	Process blocks
R	Reactions
S	Network steps
T	Waste disposal types

Parameters

$\alpha_{i,kk}$	Fraction of utility component flow mixed with process stream
$u_{ii,i,k}$	Specific utility component
$\gamma_{i,kk,rr}$	Reaction stoichiometry
$\theta_{react,kk,rr}$	Conversion of key reactant
$WF_{i,kk}$	Waste fraction
$PC_{k,kk}$	Process connection
$NS_{kk,ss}$	Network step
$F_{i,kk}^{MAX}$	Maximum flow rate
$C_{i,kk}^{MAX}$	Maximum composition of pollutant
$\pi_{i,kk}$	Flow specification of component i of wastewater source
a_{kk}, b_{kk}	Coefficients for capital cost estimation
C_i^U	Utility cost
C_{tw}^W	Waste disposal cost
C_{kk}^{Re}	Recycling water cost

Variables

$R_{i,kk}$	Utility flow
$F_{i,kk}^{In}$	Inlet flow of component i
$F_{i,k,kk}^{In}$	Inlet flow of component i from process block k to process block kk
$F_{i,kk}^{M}$	Component flow after mixing
$F_{i,kk}^{R}$	Component flow after reaction
$F_{i,kk}^{W}$	Component flow of waste separated with waste separator
$F_{i,kk}^{out}$	Outlet flow of component i after the waste separation
$F_{i,kk,k}^{Out}$	Outlet flow of component i from process block kk to process block k
$SF_{kk,k}$	Split fraction
y_k	Selection of process block k (binary variable)
Inv_{kk}	Investment cost for process block kk
UC_{kk}	Total utility cost for process block kk
WC_{kk}	Total waste disposal cost for process block kk

Abbreviations

AirS	Air stripper
API	American Petroleum Institute separator
AS	Activated sludge
AsOx	Arsenic oxidation and precipitation
BFW	Boiler feed water
BOD	Biological oxygen demand
BP	Bypass
CAPEX	Capital expenditure
CDU	Crude distillation unit
COD	Chemical oxygen demand
CPI/PPI	Corrugated/Parallel plate interceptor
CW	Cooling water
DAF	Dissolved air flotation
DS	Water consumed in a desalter
ED	Electrodialysis
EL	Electricity
FFU	Flocculation—flotation unit
FSS	Fixed suspended solid
G-	Network G's (grassroots system)
GAC	Granular activated carbon adsorption
GAMS	General algebraic modeling software
IAF	Induced air flotation
IE	Ion exchange
LPS	Low pressure steam
MAX	Maximum limitation
MBR	Membrane bioreactor
MF/UF	Microfiltration/Ultrafiltration
MILP	Mixed integer linear programming
MINLP	Mixed integer non-linear programming
MO	Microorganism
MOGAS	Motor gasoline
NF/RO	Nanofiltration/Reverse osmosis
NG	Natural gas
NLP	Non-linear programming
NS	Ammonia stripper
O&G	Oil and grease
OPEX	Operational expenditure
P-	Network P's (Existing wastewater treatment process of the case study)
PACT	Powdered activated carbon treatment
RBC	Rotating biological contactor
SS	Hydrogen sulfide stripper
SWS	Sour water stripper
TAC	Total annualized cost
TF	Trickling filter
TSS	Total suspended solid
TWN	Total water network
UOM	Unit of measurement
UP	Upper bound
WAO	Wet air oxidation
WEF	Water effluent fraction
WUN	Water-using network
WWD	Wastewater discharge
WWDR	Wastewater discharge rate
WWTN	Wastewater treatment network
ZLD	Zero liquid discharge

discharged. However, the industrial wastewater involves a wide variety of contaminants that depend on specific characteristics of the process. Also, there exist rigorous limitations due to environmental regulations and economics. Therefore, the type and sequence of treatment technologies have to be considered prudently to overcome those restrictions to identify the most effective water/wastewater minimization and management in terms of releasing and recycling.