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An efficient heuristic procedure for the optimal design of wastewater treatment systems

Pedro M. Castro [a,b,*], Henrique A. Matos [b], Augusto Q. Novais [a]

[a] *Departamento de Modelação e Simulação de Processos, INETI, 1649-038 Lisboa, Portugal*
[b] *Departamento de Engenharia Químicae Biológica, IST, 1049-001 Lisboa, Portugal*

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Abstract

This paper presents a new approach for the optimal design of wastewater treatment systems. An algorithm that can be divided in two parts is proposed for finding global optimal solutions to the problem. The first part comprises a new linear program formulation that is used to generate good starting points for the solution of the general non-linear program (second part). Since the starting point is dependent on the treatment sequence, all possible treatment sequences are considered and thus multiple starting points are generated. The best solution of the several non-linear problems that are solved is then assumed to be the global optimal solution, although there is no theoretical guarantee that this is so. The proposed algorithm has been compared to a global optimisation solver on a set of example problems taken from the literature and the results show that the same global optimal solutions can be obtained in significantly less time when our approach is used.

Keywords: Water network; Effluents; Pollutants; Recycling; Distributed treatment; Mathematical programming; Optimisation solvers

1. Introduction

Water is a vital resource for the normal operation of every industrial process. Water is used for many different purposes: as a mass separating agent, reactant, heating (steam) or cooling

* Corresponding author at: Departamento de Modelação e Simulação de Processos, INETI, 1649-038 Lisboa, Portugal. Tel.: +351 210924643; fax: +351 217167016.
E-mail address: pedro.castro@ineti.pt (P.M. Castro).

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Nomenclature

Sets/indices

C/c process contaminants
MX process mixers
MX_d final discharge mixer
MX_t subset of mixers located before the treatment units
MX_x subset of mixers located before the treatment systems
S/s wastewater streams entering the treatment system
SP process splitters
SP_s subset of splitters located after the inlet wastewater streams
SP_t subset of splitters located after the treatment units
T/t, t' process treatment units
W/w treatment sequences
X/x treatment systems

Parameters

$cenv_c$ maximum environmental discharge limit for contaminant c
$cmax_{t,c}$ maximum inlet concentration in treatment t for contaminant c
$cmx_{x,c}$ maximum inlet concentration in treatment system x for contaminant c
$cw_{s,c}$ concentration of wastewater stream s in contaminant c
fw_s total flowrate of wastewater stream s
p_t position of treatment unit t on a particular sequence of treatment processes
$rr_{t,c}$ removal ratio of treatment t for contaminant c
$\mu_{t,x}$ indicates (equal to 1) if treatment unit t is a part of treatment system x
$\nu_{t,w}$ position of treatment unit t in sequence w

Variables (all non-negative)

$Cin_{t,c}$ inlet concentration in treatment t for contaminant c
$Cout_{t,c}$ outlet concentration from treatment t for contaminant c
$FBT_{t,t'}$ total flowrate from treatment unit t into unit t'
FBY_s total flowrate of wastewater stream s that bypasses the treatment system
FD_t total flowrate from treatment unit t heading for discharge
$FS_{s,t}$ total flowrate of wastewater stream s heading for treatment t
$FSS_{s,x}$ total flowrate of wastewater stream s heading for treatment system x
FTD total discharge flowrate
FTS_x total flowrate entering (leaving) treatment system x
FTU_t total flowrate entering (leaving) treatment unit t
$MBT_{t,t',c}$ mass flow of contaminant c going from treatment unit t to t'
$MBY_{s,c}$ mass flow of contaminant c in wastewater stream s that bypasses the treatment system
$MD_{t,c}$ mass flow of contaminant c from treatment unit t heading for discharge
$MS_{s,t,c}$ mass flow of contaminant c in wastewater stream s heading for treatment unit t