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Optimisation of environmental gas cleaning routes for solid wastes cogeneration systems. Part II – Analysis of waste incineration combined gas/steam cycle

Marcelo R. Holanda [a,*], José A. Perrella Balestieri [b]

[a] Sao Paulo University/EEL-USP, P.O. Box 116, 12.602-810 Lorena, SP, Brazil
[b] UNESP, São Paulo State University, P.O. Box 205, 12516+-410 Guaratinguetá, SP, Brazil

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Abstract

In the first paper of this paper (Part I), conditions were presented for the gas cleaning technological route for environomic optimisation of a cogeneration system based in a thermal cycle with municipal solid waste incineration. In this second part, an environomic analysis is presented of a cogeneration system comprising a combined cycle composed of a gas cycle burning natural gas with a heat recovery steam generator with no supplementary burning and a steam cycle burning municipal solid wastes (MSW) to which will be added a pure back pressure steam turbine (another one) of pure condensation. This analysis aims to select, concerning some scenarios, the best atmospheric pollutant emission control routes (rc) according to the investment cost minimisation, operation and social damage criteria. In this study, a comparison is also performed with the results obtained in the Case Study presented in Part I.

Keywords: Gas cleaning routes; Municipal solid wastes; Cogeneration system; Combined cycle; Optimisation; Environomic analysis

1. Introduction

This paper focuses on the search for the optimum exhaust gases cleaning routes for cogeneration systems with municipal solid wastes burning by environmic optimisation modelling. In Part I, the question was settled of using municipal solid waste in energy generation, as well as describing the main cogeneration systems configurations with that energetic source available in the literature. Afterward, the environmic formulation was established and the conditions analysed for optimisation of the exhaust gases cleaning routes for a cogeneration thermal central plant based on the steam cycle.

In this Part II, an environomic model is presented to perform the selection of the control route (rc) that presents the smaller sum of yearly environment costs (that is, environment control cost + social damage cost) based on a combined cycle with commercial gas turbines in the topping cycle and an incineration unit integrated with a conventional steam generator and steam turbines in the bottoming cycle. The basis of such model is the thermoeconomic and environomic model developed by Frangopoulos [1–4] that is associated with the use of integer programming for help in ranking the best control routes. LINGO 7.0 [5], a well recognised optimisation software, was also used for performing this analysis.

2. Case Study 2: combined cycle

The flow and functional diagrams for this second case study are found in Figs. 1 and 2, respectively. For the thermodynamic analysis, the data of Table 1, Part I will be used. Also, as part of this second environomic analysis,

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* Corresponding author. Tel.: +55 12 31595098; fax: +55 12 31533402.
E-mail addresses: marcelo@debas.eel.usp.br (M.R. Holanda), perrella@feg.unesp.br (J.A. Perrella Balestieri).

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Nomenclature

W_{pump}	pump consumed power
Ep_{ST}	energy produced by steam turbine
E_r	energy required by industrial site
y_{ij}	j element of entry for unit I
$y_{i \cdot k}$	k element of exit for unit i
m_v	steam flow
δ	reduction/control efficacy
$C^{contr.unit.}$	cost of unitarian control (or operational cost)
$Z^{anualizado}$	yearly capital cost
$\Gamma_{o,j}$	benefit of function $y_{o,j}$
$\Gamma_{o \cdot k}$	cost of $y_{o \cdot k}$ (k element of environmental resource going inside unit i)
$\Gamma^{op.anual}$	cost of operation
$\Gamma^{ext.anual(pols)}$	pollutant emission yearly external cost (SO_2, PM and NO_x)
Ψ	specific energy
υ	specific volume
P	pressure
m_{RSM}	MSW mass flow
LHV_{RSM}	MSW lower heating value
h	enthalpy
Ep_{TOTAL}	electric energy produced by cogeneration central
$\eta_{M(ST)}$	steam turbine mechanical efficacy
$\eta_{M(pump)}$	pump mechanical efficacy
s	entropy
s_o	water entropy in pressure and temperature of reference
T_o	temperature of reference
h_o	enthalpy of water in pressure and temperature of reference
$fe_{RSM}^{(pols)}$	factor of atmospheric pollutant emission for MSW burning
$pi^{(pols)}$	atmospheric pollutant initial mass flow (prior to lessening in control routes)
$pf_{SD}^{(SO_2)}$	final SO_2 mass flow (after SD reduction)
$pf_{WS}^{(SO_2)}$	final SO_2 mass flow (after WS reduction)
$pf_{BH}^{(PM)}$	final mass flow (after BH reduction)
$pf_{EP}^{(PM)}$	final mass flow (after EP reduction)
$pf_{SCR}^{(NO_x)}$	final NO_x mass flow (after SCR control)
$pf_{SNCR}^{(NO_x)}$	final NO_x mass flow (after SNCR control)
b	binary variation
Z	cost of investment
FRC	capital recovery factor
t_m	maintenance rate
$\$_{RSM}$	price of MSW
TAFS	yearly time of functioning in seconds
c_{elcp}	price of electricity acquired from concessionaire
c_{elvd}	price of electricity sold for industrial site
TAFH	yearly time of functioning in hours
$\$^{(pols)}$	price of environmental rate/externality for emissions (SO_2, PM, NO_x)
F	objective function

Subscripts

i	unit
$i = 0$	(environment)

Superscript

pols	atmospheric pollutants (SO_2, PM, NO_x)

Abbreviations

BH	bag-house
EP	electrostatic precipitator
HRSG	heat recovery steam generator
LHV	lower heating value
MSW	municipal solid waste
PM	particulate matter
SCR	selective catalytic reactor
SD	spray drier
SNCR	selective non-catalytic reactor
ST	steam turbine
WS	wet scrubber

several gas turbines were considered for the analysis, but only Nuovo Pignone PGT2 was taken for the analysis [6]. Some data were drawn from manufacturer's catalogues, aiming to extract some important parameters to be used in the analysis [7].

Gas turbine selected: Nuovo Pignone PGT2

$$m_{NG} = 0.16\ \text{kg/s}$$

$$m_{gases} = 10.19\ \text{kg/s}$$

$m_{v(NG)} = 5.1$, $t/h = 1.42$ kg/s (for the system that works at $P = 4.2$ MPa and $T = 400$ °C) Exhaust temperature (T_4) = 550 °C.

Heat rate = 14,401 kJ/kW h.

The set of decision variables herein adopted is the same as Case Study 1 with only m_v for $m_{v(MSW)}$ and m_p (whose range of values remains the same, that is, $1.0 \leqslant m_{v(MSW)} \leqslant 1.42$ and $1 \leqslant m_p \leqslant 1.42$) being changed.

$$\begin{aligned}\min_x F = {} & Z_{GT}^{anualizado} + Z_{HRSG}^{anualizado} + Z_{boiler}^{anualizado} + Z_{ST1}^{anualizado} \\ & + Z_{ST2}^{anualizado} + Z_{condenser}^{anualizado} + Z_{pump}^{anualizado} + \Gamma_{0.1} \\ & + \Gamma_{0.2} - \Gamma_{0,1} - \Gamma_{0,2} + \sum_{n=1}^{8} Z_{rcn}^{anualizado} \cdot b_{rcn} \\ & + \sum_{n=1}^{8} \Gamma_{rcn}^{op.anual} \cdot b_{rcn} + \sum_{n=1}^{8} \Gamma_{rcn}^{ext.anual(pols=SO_2,PM,NO_x)} \cdot b_{rcn} \end{aligned} \quad (1)$$