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Optimisation of environmental gas cleaning routes for solid wastes cogeneration systems Part I – Analysis of waste incineration steam cycle

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Abstract

Research of advanced technologies for energy generation contemplates a series of alternatives that are introduced both in the investigation of new energy sources and in the improvement and/or development of new components and systems. Even though significant reductions are observed in the amount of emissions, the proposed alternatives require the use of exhaust gases cleaning systems. The results of environmental analyses based on two configurations proposed for urban waste incineration are presented in this paper; the annexation of integer (Boolean) variables to the environomic model makes it possible to define the best gas cleaning routes based on exergetic cost minimisation criteria. In this first part, the results for steam cogeneration system analysis associated with the incineration of municipal solid wastes (MSW) is presented.

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

1. Introduction

Municipal solid wastes (MSW) nowadays are a serious problem in big cities, for their inadequate disposal may be harmful not only to human health but also to the environment itself. There are, in Brazil, remarkable difficulties concerning final industrial and domestic waste disposal, as well as useful material recycling and recovery.

One of the pieces of information available on the amount of waste in Brazil comes from a national research performed by IBGE (Geography and Statistics National Institute) in 1989 [1]. According to this study, 242,000 ton of garbage are produced in Brazil daily, and about 90,000 of them correspond to MSW.

Electrical energy generation linked to MSW incineration may bring some advantages both on the energetic and the economic point of view. The main objective is waste disposal; the production and sale of electrical energy as an additional product contribute, however, to lessening the incineration and garbage disposal cost.

The thermal incineration alternative has deserved prominence as a technique that seems to be adequate for solid waste disposal [2–5] for a series of reasons, such as the fact that waste dangerous components can be destroyed; waste reduction is immediate and does not need a long residence time; the waste can be incinerated "in situ", without the need of transportation long distances; the incineration needs a relatively small decomposition area compared to ponds and other methods of land deposition; the gaseous emissions can be effectively controlled to minimize their impact; and exploitation of the municipal waste energetic content through electrical energy generation and sale contributes to the MSW management and disposal economic balance.

This work aims to signalise, in relation to some scenarios, the best perspectives of performing MSW cogeneration

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Nomenclature

W_{pump}	pump consumed power
$E_{p,ST}$	energy produced by steam turbine
E_r	energy required by industrial site
y_{ij}	j element of entry for unit i
$y_{i.k}$	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
$\Gamma_{0,j}$	benefit of function $y_{0,j}$
$\Gamma_{0.k}$	cost of $y_{0.k}$ (k element of environmental resource going inside unit i)
$\Gamma^{op.anual}$	cost of operation
$\Gamma^{ext.anual(pols)}$	pollutant emission yearly external cost (SO2, PM and NO_x)
Ψ	specific exergy
υ	specific volume
P	pressure
$\dot{m}_{RSM}$	MSW mass flow
LHV_{RSM}	MSW lower heating value
h	enthalpy
$\dot{E}_{p,TOTAL}$	electric energy produced by cogeneration central
$\eta_{M(ST)}$	steam turbine mechanical efficacy
$\eta_{M(pump)}$	pump mechanical efficacy
s	entropy
s_0	water entropy in pressure and temperature of reference
T_0	temperature of reference
h_0	enthalpy of water in pressure and temperature of reference
$fe_{RSM}^{(pols)}$	factor of atmospheric pollutant emission for MSW burning
$\dot{pi}^{(pols)}$	atmospheric pollutant initial mass flow (prior to lessening in control routes)
$pf_{SD}^{(\dot{SO}_2)}$	final SO_2 mass flow (after SD reduction)
$pf_{WS}^{(\dot{SO}_2)}$	final SO_2 mass flow (after WS reduction)
$pf_{BH}^{(\dot{PM})}$	final mass flow (after BH reduction)
$pf_{EP}^{(\dot{PM})}$	final mass flow (after EP reduction)
$pf_{SCR}^{(\dot{NO}_x)}$	final NO_x mass flow (after SCR control)
$pf_{SNCR}^{(\dot{NO}_x)}$	final NO_x mass flow (after SNCR control)
b	binary variation
Z	cost of investment
FRC	capital recovering 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)

Superscripts

pols	atmospheric pollutants (SO_2, PM, NO_x)

Abbreviations

BH	baghouse
EP	electrostatic precipitator
HRSG	heat recovery steam generator
LHV	low 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

by selecting the best atmospheric pollutant emission control routes (rc) from calculation of yearly environmental costs considering configurations in accordance with the state of art that focus on industrial site thermal and electrical needs.

2. Environmental modelling

From the methodological standpoint, interesting initiatives are observed that aim to analyse suitable conditions for controlling and reducing atmospheric emissions. Bai and Wei [6] developed a multi-objective linear programming model to evaluate, in a scenario analysis, the best options for the Taiwan electrical sector regarding the maximum reduction of CO_2 emitted (for the year of 2000) at a minimum cost; such study, based in the year[1] 1990, estimated, for new electrical energy generation units, both the cost of control and the CO_2 emission reduction efficiency. However, the values of the externalities (in the form of environmental rates) and of the emission patterns were not taken into account by the authors because such elements, from the authors' standpoint, depend on the cost of control of the other options.

Saban, Elkamel and Gharbi [7] presented an integer linear programming model for atmospheric emissions control

[1] This is because the countries that are members of the OCDE (Organization for Economical Cooperation and Development), present in Annex 1 of the Kyoto Protocol, should fix their year 2000 CO_2 total emissions at levels closer to the ones for 1990.