Renewable and Sustainable Energy Reviews 29 (2014) 96–107

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Thermoeconomic and ecological analysis applied to heating industrial process in chemical reactors

Sergio Alencar de Souza [a], Wendell de Queiroz Lamas [a,b,*]

[a] Post-graduate Programme in Mechanical Engineering, Department of Mechanical Engineering, University of Taubate, Taubate, SP, Brazil
[b] Department of Basic and Environmental Sciences, School of Engineering at Lorena, Campus I, University of Sao Paulo, Estrada Municipal do Campinho, s/n Caixa Postal 116, CEP: 12.602-810 - Lorena, SP, Brazil

ARTICLE INFO

Article history:
Received 13 July 2012
Accepted 25 August 2013
Available online 17 September 2013

Keywords:
Ecological efficiency
Greenhouse effect gases
Solar energy heating
Thermoeconomic models

ABSTRACT

In this work is presented the case that evaluates the possible environmental and economical gains with the application of water solar heating as an alternative for the consumption of natural gas in chemical reactors from cosmetic industries. The proposal consists of pre-heating of water for a boiler producing steam to heat several reactors from an industrial unit and measure the impacts caused by this application. It is used an analysis methodology based on thermoeconomic optimisation for a steam generation unit and production reactors heating in a chemical plant. This methodology consists at first in identifying the system functions as a whole and then individually for each unit, creating the thermoeconomic functional diagram, formulating the cost problem and solving the mathematical equations associated to the system. Based on the investment demands, expected results for fossil fuel consumption reduction and a consequently beneficial impact on the amount of greenhouse effect gases emission and a payback of approximately two years, this solution in study might be consider attractive.

Contents

* Corresponding author. Tel./fax: 55 12 3159 5064.
E-mail addresses: lamaswq@aol.com, wendell.lamas@unitau.com.br (W.Q. Lamas).

1364-0321/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2013.08.095

Nomenclature

$c_{annual\text{-}ng}$ natural gas annual cost [US$/year]
$c_{annual\text{-}ng2}$ natural gas annual cost in scenario 2 [US$/year]
c_{ng} natural gas cost [US$/kW h]
c_{ng2} natural gas cost in scenario 2 [US$/kW h]
c_{OMcb} cost for conventional boiler operation and maintenance [US$/kW h]
c_{OMcb2} cost for conventional boiler operation and maintenance for scenario 2 [US$/kW h]
c_{OMso} cost for softening operation and maintenance [US $/kW h]
c_{OMws} cost for water softened operation and maintenance [US$/kW h]
c_p water specific heat [kJ/kg °C]
c_s steam cost [US$/kW h]
c_{so} softening water cost [US$/kW h]
c_{so2} softening water cost for scenario 2 [US$/kW h]
e_{annual} annual natural gas reduction [kW h/year]
$e_{annual\text{-}ng}$ annual natural gas cost reduction [US$/year]
EPC exergetic production cost [US$/kW h]
f annuity factor [year^{-1}]
H operation period for the system [h/year]
HHV high heat value [kJ/kg]
I_{cb} conventional boiler investment [US$]
I_{cb2} conventional boiler investment for scenario 2 [US$]
I_{so} softening investment [US$]
I_{so2} softening investment for scenario 2 [US$]
m mass of water [kg]
P power installed [kW]
Q energy amount [kJ/day]
Q_{ng} natural gas—annual consumption [kW h/year]
Q_{ng2} natural gas—annual consumption with solar heating [kW h/year]
Q_{ng3} natural gas—annual consumption with solar heating and economizer [kW h/year]
R_{CO_2e} greenhouse effect gases reduction [t_{CO_2e}]
T_{in} inlet temperature [°C]
T_{out} outlet temperature [°C]

1. Introduction

The water heating technology through solar panels has been largely diffused and its use has experienced a moment of great expansion around worldwide. In Brazil, this recent expansion is directly associated to the electrical power cost increase during the last decade. This power source is commonly applied to water heating, especially for replacement of electrical showers use in the Brazilian houses. This expansion can be highlighted by the case of several Brazilian cities like Sao Paulo and Belo Horizonte, for example, which have sanctioned laws to incentivise the use of solar energy, both photo-thermal and photovoltaic.

However, other important possibilities are economical and environmental gains obtained by solar heating, such as reduction of greenhouse gases effect and its consequent impact into global warming that is not realised by the majority of common users, but can represent important opportunities for advance in the Brazilian balance of atmospheric emissions.

The water heating involves a great energy demand for its production and oil derivatives are used as fuel for heating systems, highlighting the use of natural gas for boilers. Nowadays, the natural gas offers clear economical and environmental advantages. There are great opportunities for cost reduction with the solar heating usage as an alternative for heating by electrical power; there are also significant opportunities for cost reductions with the application of this same renewable source, because reduction of fossil fuel consumption and greenhouse effect gases emission, especially the carbon dioxide. It can also be highlighted the opportunities represented by the possible use o solar energy for heating buildings sourced by natural gas as a contribution element against greenhouse effect gases emission.

Several works based on development of methodologies to model and to optimise thermal energy systems had been looked up to obtain information about techniques used in these evaluations [1–7].

Development of models for thermoeconomic design and operation optimisation had also evaluated. These works appoints to thermoeconomic optimisation and the best way to obtain the balance between exergy balance and energy production/generation costs [8–15].

Thermoeconomics had been explained through several works that relate exergy balance analysis and costs minimisation. This literature was important to materialise basic fundamentals that are very important to develop the proposed methodology [16–24].

Photovoltaic applications associated to solar water heating into rural zones, residences, commerce, and industries have been studied by several authors highlighting optimal performance of solar panel [25–32], also hybrid systems with other renewable sources such as hydrogen and biogas [33], photovoltaic panel control [34], and design optimization have been studied [35–38].

Some authors have developed works about modelling and measurement of greenhouse gases (GHG) emissions, i.e., based on trigeneration systems for cooling, heating and electricity purposes [39] and on carbon dioxide emissions matrix due to an increase of electricity demand in buildings as well as solid and liquid wastes treatment [40].

The Intergovernmental Panel on Climate Change (IPCC) has a methodology to estimate the methane emissions called IPCC protocol, which had been studied and applied to municipal solid wastes landfills [41]. Also this impact into science had reviewed [42] and its structure had analysed [43].

Some concepts of eco-efficiency had been applied to optimal performance evaluation of thermal cycles by [44] and to residential development at city level [45], where environmental impacts had been evaluated through carbon dioxide footprints evaluation.

The ecological efficiency levels of each type of power plant was considered in their works by [46,47], presenting the emissions of particulate material, sulphur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen oxides (NO_x) emitted by power plants. Expanding this application, the evaluation and quantification of the environmental impact from the use of some renewable fuels and fossils fuels in internal combustion engines had been studied by [48].

Hence, in this work is presented the case that evaluates the possible economical and environmental gains with the application of water solar heating as an alternative for the consumption of natural gas in chemical reactors from cosmetic industries.

The proposal consists of pre-heating of water for a boiler producing steam to heat several reactors from an industrial unit and measure the impacts caused by this application.

Applying methods for identifying opportunities for optimisation of natural resources consumption, atmospheric emissions, and operational costs, this work has as its aim to study and to improve a process that consumes non-renewable natural resources (natural gas) and decreases greenhouse effect gases emission during its operations for steam production.