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Comparison of exergoeconomic analysis of two different perlite expansion furnaces

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ABSTRACT

In this study, exergoeconomic analyses of two different perlite expansion furnaces are performed based on the actual operational data. The exergy cost and the cost per unit of exergy of the expanded perlite produced by the Former Perlite Expansion Furnace (FPEF) are determined to be 62.886 US$/h and 648.309 US$/GJ while those produced by the New Perlite Expansion Furnace (NPEF) are obtained to be 106.734 US$/h and 503.463 US$/GJ, respectively. Additionally, the production costs based on exergy are calculated to be 0.153 US$/kg for the FPEF and 0.102 US$/kg for the NPEF. The production costs based exergy and exergoeconomic factor of the FPEF are found to be 0.153 US$/kg and 45%. Those of the NPEF are obtained to be 0.102 US$/kg and the 67%. A novel method is also proposed for calculating the exergy cost per unit of the fuel.

1. Introduction

The exergoeconomic analysis offers useful information for sustainable and environmentally sensitive production. It plays an important role in finding ways of improving the performance of complex thermal systems. It is also a combination of exergy and economic analysis methods, which provide a technique to evaluate the cost of inefficiencies or the costs of individual process streams, including intermediate and final products [1]. In other words, the exergoeconomic analysis can be considered as an economic feasibility study. Effect of some parameters on the product cost, such as exergy destruction and losses, can be better understood through the exergoeconomics analysis.

Exergoeconomic analysis has been applied to different energy and power plants by various investigators. In this context, Utlu and Hepbaşlı [2] studied on exergoeconomic aspects of sectorial energy utilization for the Turkish industrial sector and their impact on energy policies. They investigated the relations between capital costs and thermodynamic losses for subsectors in the industrial sector. They reported that the energy and exergy utilization efficiency values for this entire sector varied between 63.45% and 70.11%, and 29.72%–33.23%, respectively. The ratio of thermodynamic loss rate-to-capital cost values ranged from 0.76 to 1.01. Lian et al. [3] presented a methodology based on the second law of thermodynamics to evaluate the thermoeconomic potential of a trigeneration plant employing biomass as its energy source. Four different plant configurations were assessed to generate varying degrees of heat, electricity and/or cooling while their cost effectiveness was evaluated using varying economic and operating parameters. Exergy destruction was determined to be most extensive in the furnace, with nearly 60% of net exergy loss and exergy destruction. This was followed by the steam drum with a range of 11%–16%. Yao et al. [4] performed an exergoeconomic analysis of a combined cycle system, utilizing associated gases (blast-furnace gas, coke oven gas and sintering waste gas) from the steel production process based on structural theory of thermoeconomics. They calculated three exergoeconomic indexes (the cost difference, the relative cost difference and the exergoeconomic factor) to evaluate the thermoeconomic performance of each component. Moreover, they investigated the influences of the decision variables and the capital costs on the unitary exergetic and monetary costs of production. Their analysis indicated the deep relations of the unitary costs to the changes in these parameters and the superiorities of the proposed system emerging gradually through comparing with other systems. Modesto and Nebra [5] assessed a

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Nomenclature

$\dot{C}$	exergy cost rate (US$/h)
$\dot{Z}$	capital cost flow rate (US$/h)
PW	present worth (US$)
S	salvage value (US$)
J	salvage value ratio
PWF	present value factor
i_{eff}	effective discount rate
n	life time
p	number of interest compounding per year
i	cost of money
AC	annual capital cost (US$)
CRF	capital recovery factor
OM	cost of operating and maintenance (US$)
TCRM	transport and purchasing cost of the raw materials (US$)
MR	cost of maintenance and repairing (US$)
PEC	price of electricity consumption (US$)
CE	cost of employees (US$)
c	unit exergy cost (US$/GJ)
$\dot{E}$	exergy rate (GJ/h)
T	temperature (°C or K)
$\dot{Q}$	heat transfer rate (kW)
$H\dot{C}F$	hourly cost rate of the fuel (US$/h)
$\dot{m}$	mass flow rate of the fuel (kg/h)
EUM	exergy of a unit mass of the fuel (kJ/kg)
X	mass fraction of the components of the fuel
E	exergy of a unit mass of the components of the fuel (kJ/kg)
ER	exchange rate (TL/US$)
LHV	lower heating value (kJ/kg)
Pr	fuel selling price (TL)
M	molar mass (kg/kmol)
f	exergoeconomic factor

Greek letters

τ	total annual number of hours of the system operate (h)
$\bar{\varepsilon}^o$	standard chemical exergy (kJ/kmol)
ϕ	factor of operating and maintenance cost

Subscripts

k	k-th content
q	loss
D	destruction
0	reference environment
s	surface

Superscripts

PH	physical
CH	chemical
OM	operating and maintenance
CI	capital investment
–	molar unit

Abbreviations

FPEF	former perlite expansion furnace
NPEF	new perlite expansion furnace

proposal of a power generation system in a steel mill plant. The current system was based on a regenerative Rankine cycle using two gases from the steel production, the blast furnace gas and the coke oven gas, to generate electric power and occasionally steam for the process. The system was assessed through two thermoeconomic methodologies by calculating exergetic and monetary costs of the power production and comparing to the respective values of the current system. Mert et al. [6] presented the exergoeconomic analysis of a cogeneration plant. They gave the mass, energy and exergy balances, and performed the exergoeconomic analysis of a plant with a 39.5 MW electricity and a steam production mass flow rate of 80 ton/h. Balli et al. [5] carried out exergoeconomic analysis of a CHP (combined heat and power) system along its main components installed in the city of Eskisehir, Turkey. They considered the quantitative exergy cost balance for each component and the whole CHP system while they determined exergy cost generation within the system. Their exergoeconomic analysis results indicated that the unit exergy cost of the electrical power produced by the CHP system accounted for 18.51 US$/GW. Colpan and Yeşin [6] presented a case study of thermodynamics and economics analyses and applied them to an existing gas/steam combined cycle cogeneration plant. They used cost balances and auxiliary equations to several subsystems in the plant. Additionally, they calculated the cost rate of each product in the plant. Some researchers developed different methods for exergoeconomic analysis and applied them to various complex energy systems. Lamas et al. [9] developed a methodology for the determination of costs associated with the products generated in a small wastewater treatment station. The methodology identified the plant units in terms of their fluid and thermodynamics features. The methodology was applied to a hypothetical system based on wastewater treatment station plants while the results obtained were compared. Valero et al. [10] presented new methods and proposed two decomposition strategies for exergy costs according to irreversibility and origin of resources. They presented a fuel impact approach for locating and quantifying the origin of resources savings due to integration. They used a simplified version of the Kalundborg eco-industrial park as a test-bench for the presented methodologies. Kim et al. [11] proposed a combination of exergetic and economic analysis for complex energy systems. They derived a general cost–balance equation, which could be applied to any component of a thermal system. In their study, the exergy of a material stream was decomposed into thermal, mechanical and chemical exergy flows and an entropy-production flow. They stated that the lost costs of each component of the system could also be obtained by this method. They applied the proposed exergy-costing method to a 1000-kW gas turbine cogeneration system. Sala et al. [12] presented the engineering design and theoretical exergetic analyses for a container-housed reciprocating engine. The exergy analysis conducted was based on the first and second laws of thermodynamics for power generation systems. Using thermographic inspection, they assessed the heat dissipated by each one of the 28 elements under consideration in the engine container, together with the mass flow rate of air supplied to the cab and the air temperature at the inlet and outlet. Kwon et al. [13] thermodynamically studied the effect of the annualized cost of a component on the production cost in a gas-turbine cogeneration system with a capacity of 1000 kW. They utilized the generalized exergy