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Research Paper

Exergoeconomic analysis of a rotary kiln used for plaster production as building materials

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HIGHLIGHTS

- The exergoeconomic analysis of the rotary kiln used for plaster production was carried out by using actual operational data.
- The exergy cost is 593.6 US$/h and the cost per unit exergy is 1502.4 US$/GJ of the plaster produced by the system.
- The exergoeconomic factor of the rotary kiln is calculated as 70%.
- The specific manufacturing cost of the CSH is found as 0.03 US$/kg.

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ABSTRACT

This study has been proposed to determine the production of the cost of the plaster production and present some solutions, techniques and processes especially for rotary kiln to reduce the cost of plaster production which is used as building material. The rotary kilns consume the highest energy in any processes. Thus, the exergoeconomic analysis of the rotary kiln used for plaster production was carried out by using actual operational data to see its effectiveness. The exergy cost is 593.6 US$/h and the cost per unit exergy is 1502.4 US$/GJ of the Calcium sulfate hemihydrate (CSH) or plaster produced by the system. The capital cost flow is very high due to the hourly levelized operating and maintenance cost. Especially, the transport cost of the raw materials or the CSD is very high due to be far away of distance between the gypsum quarry and the plaster plant. The exergoeconomic factor of the rotary kiln is calculated as 70%. The exergy loss and destruction should be considered for reducing production cost. The results of the exergoeconomic analysis are evaluated different perspectives for reducing the production cost. The specific manufacturing cost of the CSH is found as 0.03 US$/kg.

1. Introduction

Energy consumption increases due to increasing of population and industrialization. This rapid increase in the world's energy consumption also leads to an increase in the polluting effect and concepts such as energy, exergy efficiency and sustainability gain importance. In this perspective, important results are obtained from analysis of energy production and consumption systems are obtained by detailed analysis methods such as exergy analysis. Moreover, the production costs for carrying out the sustainable production must be taken into account. Companies have their own methods for determining economic parameters and calculating the cost of the main product. The operators of the plants want to know the exact cost [1]. Exergoeconomics is a very useful tool to optimize of different industrial sectors and energy systems, and it is considered as a tool for determining cost of materials produced by different industrial sectors. The application fields of exergoeconomic analysis are the evaluation of utility cost for systems which can be applied the concept of exergy. Results obtained from exergoeconomic analysis can be discussed and obtained useful data according to economic and technical practicability investigations, evaluating the investment case, different alternatives encountered, considering modern technologies, techniques and operating conditions, determining cost of components of systems [2]. Also, results obtained from the exergoeconomic analysis of several combined cycle power plants have been used for comparison [3].

The exergoeconomic concept can be applied to the complex energy systems and some of them are discussed in following literature survey. In the literature, number of studies on the exergoeconomic analysis of rotary kiln is too few. Generally, the exergoeconomic analysis has been applied to energy and power

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Nomenclature

$\dot{C}$	exergy cost (US$/h)
$\dot{Z}$	capital cost flow (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$)
TCRM	transport cost of the raw materials (US$)
MR	cost of maintenance and repairing (US$)
PEC	price of electricity consumption (US$)
CE	cost of employees (US$)
c	unite exergy cost (US$/GJ)
$\dot{E}x$	the exergy flow (GJ/h)
T	temperature (K)
$\dot{Q}$	heat transfer rate (kW)
$H\dot{C}F$	hourly cost of the fuel (US$/h)
$\dot{m}$	mass flowrate (kg/h)
EUM	exergy of a unit mass of the fuel (kJ/kg)
X	mass fraction of the components of the fuel
Ex	exergy of a unit mass of the components of the fuel (kJ/kg)
M	molar mass (kg/kmol)
MC	specific manufacturing cost (US$/kg)
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

Sub- and superscripts

CSH	calcium sulfate hemi-hydrate or plaster
k	*k*th content
q	loss
D	destruction
0	reference environment
s	surface
PH	physical
CH	chemical
OM	operating and maintenance
CI	capital investment
–	molar unit

Abbreviations

CSD	calcium sulfate di-hydrate or gypsum
CSH	calcium sulfate hemi-hydrate or plaster

plants in the literature. For example, the exergoeconomic methods have been used for evaluating and optimizing the complex energy systems [4]. In this context, Sahoo [5] performed exergoeconomic analysis and optimization of a cogeneration system having production capacity of 50 MW of electricity and 15 kg/s of steam. Specially, many the analysis of complex thermal systems having high capacity can be found in the literature. In the one of the these studies, Ahmadi and Dincer [6] studied the exergoenvironmental analysis and optimization of a cogeneration plant system having production capacity of 50 MW and 33.3 kg/s of steam. They used multimodal genetic algorithm for optimization.

Important values and parameters about components of those complex thermal systems can be obtained by using the exergoeconomic analysis. For example, Balli et al. [7] studied the exergy cost balance for components of the system. Their results showed that the unit exergy cost of products of the combined heat and power system calculated as 18.5 US$/GW.

The exergoeconomic analysis is used for optimization. Sayyaadi and Saffari [8] performed an optimization study of desalination system and they used thermoeconomic methodology for optimization. They presented a model based on the energy and exergy analysis. The authors developed an economic model which is total revenue requirement method.

The exergoeconomic analysis can be used for comparison of two different systems. It is very useful tool for comparison analysis [9]. Some researchers developed different methods for exergoeconomic analysis and they applied to these techniques to complex energy systems. Among these studies, Kim et al. [10] proposed a combination of exergetics and economic analysis. Under this objective, the method obtained by them was applied to different energy systems. They derived a general cost balance equation applied to any component of a thermal system.

Different methods can be used for comparison analysis and results obtained from these methods show important cost parameters. In this perspective, Kwon et al. [11] presented a thermodynamic study. The purpose of that study is the effect of the annualized cost of a component on the production cost in cogeneration plant. They also made a comparison among typical exergy costing methodologies. They found that the cost of products is depended on the change in the annualized cost of the component of the system. Kalinci et al. [12] studied on exergoeconomic analysis of biomass-based hydrogen production. The authors evaluated components and associated streams using a method which considers exergy, cost, energy and mass and called as EXCEM. They investigated how key parameters of the system affected from the unit of hydrogen cost. The results obtained by the authors show that the system produces the unit hydrogen costs between 5.3 US$/kg and 1.5 US$/kg.

The authors considered both the exergoeconomic methodology and optimization methods, such as fuzzy mathematics, genetic algorithm and artificial intelligence [13]. Exergoeconomic studies for rotary kilns are extremely limited. In this context, Camdali et al. [14] made a discussion for these thermal systems. In the other study, Atmaca and Yumrutaş [15] studied on the energy, exergy and exergoeconomic analysis of a cement factory.

Based on above literature survey and authors' knowledge there is no work on exergoeconomic analysis for rotary kiln on plaster production. In this work, measured values from a plaster plant, which is installed in Turkey, is used. A brief description will be shared information about exergoeconomic analysis, description of the plaster and gypsum production. The exergoeconomic analysis can be considered as an economic feasibility study. This study has been proposed to determine the production of the cost of the plaster production and present some solutions, techniques and