Energy 35 (2010) 3474–3482

Contents lists available at ScienceDirect

Energy

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

# A new criterion for the allocation of residues cost in exergoeconomic analysis of energy systems

Seyyed Masoud Seyyedi*, Hossein Ajam, Said Farahat

*Department of Mechanical Engineering, University of Sistan and Baluchestan, Zahedan 98164, Iran*

A R T I C L E I N F O

*Article history:*
Received 26 November 2009
Received in revised form
5 March 2010
Accepted 27 April 2010
Available online 2 June 2010

*Keywords:*
Exergoeconomic
Residues
Cost allocation
Negentropy

A B S T R A C T

In any energy system that produces work, heat and so on, disposal remaining flows of matter or energy, which are called residues, will appear. In the exergoeconomic analysis of these systems, one of the complex problems is residues cost allocation in a rational way. Two more important criteria of the residues cost allocation are distribution of the cost of the residues proportional to the exergy as well as proportional to the entropy generation or negentropy. In this paper, a new criterion for the residues cost allocation is proposed that it is based on the entropy distributed in the components, and not on the entropy generated along the process. This new criterion uses the fuel–product (FP) table, a mathematical representation of the thermoeconomic model, as input data. The important characteristic of this new criterion is the use of a new FP table ($FP^{(S)}$ table) which is constructed using energy and exergy of flows. The proposed criterion is applied to a combined cycle and results are compared with the two other criteria. Results show that this criterion is more suitable and rational than the two other criteria.


## 1. Introduction

In thermodynamic analysis, study is generally focused on describing the processes and relationship between mass flow streams and energy exchanges [1]. Analysis of energy systems based on the second law of thermodynamics is called exergy analysis. Exergy is one of the important concepts of the second law of thermodynamics, which is the maximum useful work that we can obtain from flow of matter or energy. The main goal of exergy analysis is determination of location and amount of irreversibility of a system. With this knowledge the system can be optimized. Exergy analysis usually predicts the thermodynamic performance of an energy system and the efficiency of the system components by accurately quantifying the entropy generation of the components [2]. Exergoeconomics (thermoeconomics) is the branch of engineering that combines exergy analysis with economic constraints to provide the system designer with information not available through conventional energy analysis and economic evaluation [3]. The objective of a thermoeconomic analysis might be: (a) to calculate separately the cost of each product generated by a system having more than one product; (b) to understand the cost formation process and the flow of costs in the system; (c) to optimize specific variables in a single component; or (d) to optimize the overall system [4]. A critical review of relevant publications regarding exergy and exergoeconomic analysis can be found in articles by Vieira et al. [5–7], Sahoo [3], Zhang et al. [8], and Lazzaretto et al. [9].

In any productive process, along with the functional products, there will appear unintended remaining flows of matter or energy, which are called residues [10]. It is more important that we allocate appropriately the cost of products in poly-generation systems. In conventional thermoeconomic methods, such as exergetic cost theory (ECT) [11], average cost theory (ACT) [12], specific cost exergy costing method (SPECO) [13] and modified productive structural analysis (MOPSA) [14,15], the problem of the cost of residues has not been considered soundly. Works based on the structural theory [16] and other thermoeconomic methodologies [9,17] provide different approaches to residue analysis, but none of them give a general solution to the problem. One of the most complex problems in the thermoeconomic analysis of energy systems is residue cost allocation because it depends on the nature of such flows and how they have been formed. A more complete analysis for residues cost allocation has been performed by Torres et al. [10]; they have presented the mathematical basis for the cost assessment and the formation process of residues. In order to perform this, they have extended the ECT cost propositions to include a new concept: the cost of the residues generated by a productive component, and also have developed, the equations provided by symbolic exergoeconomics to include the cost formation process of residues. Based on the

* Corresponding author. Tel.: +98 541 2426206; fax: +98 541 2447092.
*E-mail address:* s.masoud_seyedi@yahoo.com (S.M. Seyyedi).

0360-5442/$ – see front matter 
doi:10.1016/j.energy.2010.04.047

**Nomenclature**

| | |
|---|---|
| $c$ | unit exergoeconomic cost (¢/kWh) |
| $C$ | exergoeconomic cost (€/h) |
| $E$ | exergy of a flow kW |
| $F$ | fuel exergy of a component kW |
| $h$ | specific enthalpy kJ/kg |
| $H$ | enthalpy of a flow (kW) |
| $I$ | irreversibility of a component (kW) |
| kB | unit exergy consumption |
| kI | specific exergy destruction |
| $m$ | mass flow rate (kg/s) |
| $n$ | number of components |
| $p$ | pressure (bar) |
| $P$ | product exergy of a component (kW) |
| $Q$ | heat flow rate (kW) |
| $s$ | specific entropy (kJ/kg k) |
| $T$ | temperature (°C) |
| $W$ | work flow rate (kW) |
| $y$ | distribution exergy ratios |
| $Z$ | Capital cost rate of a component (€/h) |
| $V_P$ | set of productive components |
| $V_D$ | set of dissipative components |

*Greek letters*

| | |
|---|---|
| $\Delta$ | Increment |
| $\epsilon$ | exergetic efficiency |
| $\psi$ | residue cost distribution ratio |

*Matrices and vectors*

| | |
|---|---|
| $\mathbf{Z}$ | capital cost vector ($n \times 1$) |
| $\mathbf{C}_F$ | fuel cost vector ($n \times 1$) |
| $\mathbf{C}_P$ | product cost vector ($n \times 1$) |
| $\mathbf{C}_R$ | residue cost vector ($n \times 1$) |
| $\mathbf{U}_D$ | identity matrix ($n \times n$) |
| $\langle FP \rangle$ | matrix ($n \times n$) which contains the distribution ratios |
| $\langle RP \rangle$ | matrix ($n \times n$) which contains the residue ratios |

*Subscripts*

| | |
|---|---|
| 0 | environment |
| in | inlet |
| out | outlet |
| $e$ | system inlet |
| $r$ | index for dissipative components |
| $i, j$ | indexes for productive components |
| T | total |
| F | related to fuel |
| P | related to product |
| R | related to residue |

*Superscripts*

| | |
|---|---|
| e | related to external resources |
| $z$ | related to capital cost |
| r | related to residues |
| E | related to exergy |
| $H$ | related to energy, heat and enthalpy |
| G | related to gas |
| $S$ | related to entropy |

work presented in their paper, a residue cost distribution ratio should be defined that determines how the cost of the residue that leaves the system should be decomposed into several costs. A cost balance is written for each component that includes the term of cost of the residues. This residue cost distribution ratio can be made in several ways, depending on the type and nature of the residue but there is not a general criterion to define the residue cost distribution ratios. Two more important criteria of the residue cost allocation are distribution of the cost of the residues proportional to the exergy [10] and distribution of the cost of the residues proportional to the entropy generation or negentropy [18,19]. The choice of the best residue distribution among possible alternatives is still an open research line. In this paper, a new criterion for the residues cost allocation is proposed. This new criterion is based on the entropy distributed in the components that is different to the entropy generated along the process. In this proposed criterion, the concepts of distribution of the cost of the residues proportional to the exergy and distribution of the cost of the residues proportional to the entropy generation are combined in order to achieve a more rational distribution of the cost of the residues. A combined cycle, which is fully described in Ref. [20], was selected to show this new criterion and comparison of results with two other more important criteria. Fig. 1 shows the physical model of the combined cycle and Table 1 represents the thermodynamic properties of the combined cycle. The results show that the proposed criterion is more suitable and rational than the other criteria.

## 2. Thermoeconomic model

Physical structure of an energy system represents how components are linked to each other and to the environment by means of a set of flows of matter, work or heat. Thermodynamic model of an energy system, which is represented through a set of equations such as mass, energy and entropy balances for each component, is used to obtain some parameters such as pressure, temperature, enthalpy, entropy and exergy of flows. In order to carry out a thermoeconomic analysis of an energy system the

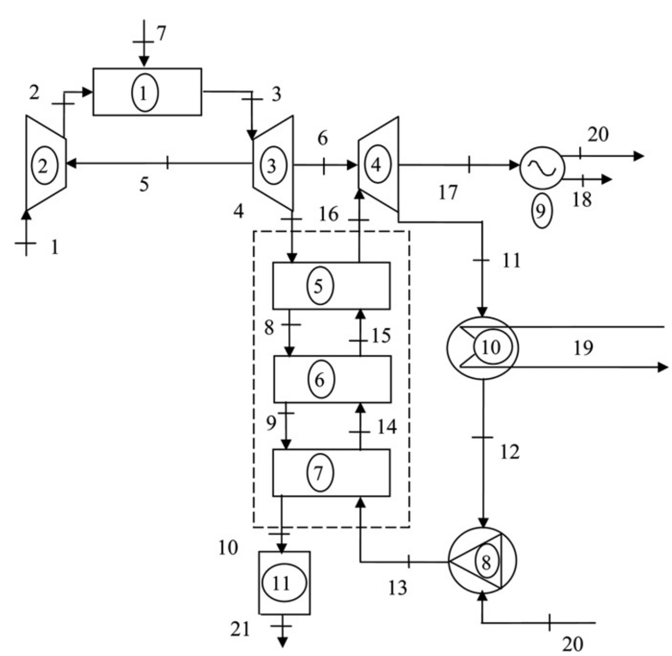

**Fig. 1.** Physical structure of a simple combined cycle.