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# **Introductory Chapter: Application of Exergy for All Energy Field and New Technologies**

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Additional information is available at the end of the chapter

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## **1. Introduction**

The subject of exergy is one of the most important topics of thermodynamics. It also defines the efficiency of the second law of exergy thermodynamics. Exergy is an important concept in itself that explains the availability of energy. Although there are many studies related to exergy about more theoretical studies, there are not many studies in terms of application. This book is a study that will complement the application of exergy in terms of implementation and will also inspire future works. Application of exergy is available in many areas. Exergy applications need to be clarified in these research fields. This book contains exergy applications in these research fields.

This book poses application of exergy with current and new technologies. The main scope of this book is to emphasise exergy efficiency for all field of industry and other fields. In addition, the research of exergy application can overcome many critical problems for an industry and other field energies. Furthermore, thermoeconomic (exergoeconomic) analysis is also investigated for the cost of application and industry. This book impresses on the importance of an exergy with an overview of all of the energy systems. Energy and exergy efficiencies within thermodynamic laws are carried out for every technology. This book will both encourage the research of the academic community to be this direction and will lead to the more efficient use of application, industrial processes and new technologies.

Energy and exergy efficiency is very important as a result of thermodynamic calculations thanks to the first and second laws of thermodynamics. In many engineering and science areas, it is necessary to achieve the maximum energy saving and minimal loss of exergy in many areas. Exergy applications should be used to save energy in all industrial processes of engineering information. Because, the laws of thermodynamics and heat transfer principle are

important for energy and exergy applications. Understanding and applying insufficient energy and exergy analyzes in many engineering applications leads to significant energy losses for factories. For the cause, loss of exergy is required to be minimised. This book aims to ensure a comprehensive overview of the application of exergy by finding solutions to these problems.

## 2. A brief of exergy and thermoeconomic analyses

Exergy is given according to the second law of thermodynamics, which defines exergy as the availability of energy [1]. The following explanations can be found in the literature regarding exergy: exergy is defined as maximum work and ensures that the system is balanced with the environment. In the exergy analysis, the final state is considered as the system's dead state. In this case, kinetic and potential energies are zero. Various enthalpy and other thermodynamic correlations can be taken from the steam thermodynamic diagrams [2].

Exergy destruction and loss of the system must be quantitatively calculated in the exergy analysis. Although this method is not a real improvement approach, it describes the efficiency of the system. Chemical energy defines the exergetic reaction related to the chemical degradation of the reaction. Thermal exergy is the maximum mechanical energy that can be measured, defined in the Carnot cycle. The maximum mechanical energy production is the heat that is caused by using the difference between the environment and the temperature. Energy conversion in control volume can be applied for energy, mass and types.

The irreversibility, which is the second law of thermodynamics, can also be understood as the amount of work accepted to bring the system to its original state. Entropy means the process of corruption. However, the amount of entropy formation in the system decreases with loss of exergy. Compound thermal and power plants are the best examples of the variation of exergy distribution. Heat and power can be produced from fuel.

However, the most exaggerated consumption of exergy is favourable for the combined heat production. When high-quality energy is used for energy production in turbines (exergy acquisition), combined heat production will have to use low-quality energy (low exergy) due to the relatively low temperature [3, 4]. The differences between energy and exergy are briefly summarised by Dincer and Cengel [5].

Exergy analysis is analysed in two parts as chemical and physical exergy [6]. Physical and chemical exergies are accounted for in exergy analysis calculations. For exergy calculations, various enthalpy and other thermodynamic correlations are taken from steam thermodynamic tables [4].

While thermodynamic laws are used for exergy analysis calculations, heat transfer equations are used for heat calculations. These calculations are used to analyse the applications of exergy. In exergy applications, cost analysis is performed by thermoeconomic analysis formulas taking these calculations into consideration.

### 3. Methods and equations for exergy analysis

Application of exergy calculations is based on energy and exergy efficiency. Prior to the exergy analysis, the input and output sections of the process flows are defined. Exergy calculations are based on input and output with mass flow rate, pressure, temperature, etc. parameters data in many applications by determining process flows. For the dead state, 25°C and 1 atm are assumed. If the mass input and output are equal in the control volume, the mass is preserved [3, 4]. It can be given, for instance, of control volume from thermodynamics equations. Exergy inputs and outputs are calculated. Exergy input and output are as follows [4]:

$$\sum Ex_i = m_i \left[ (h_i - h_\infty) - T_\infty (s_i - s_\infty) + \frac{V_i^2}{2} + gz_i \right] \quad (1)$$

$$\sum Ex_o = m_o \left[ (h_o - h_\infty) - T_\infty (s_o - s_\infty) + \frac{V_o^2}{2} + gz_o \right] \quad (2)$$

Exergy input and output differences show the exergy loss (irreversibility) in processes where the system is adiabatic and there is no work. Exergy loss can be defined as follows [4]:

$$Ex_\ell = I = \sum Ex_\ell = \sum Ex_o - \sum Ex_i = T_\infty \Delta S \quad (3)$$

Exergy equations are used in all application calculations of exergy. Besides, potential and kinetic energies can be neglected in practice because they are usually small. The specific flow exergy equations, which should be used for air and steam or other flows, can be given specific flow (steam or air) exergy as follows [1]:

$$\Psi = (h - h_\infty) - T_\infty (s - s_\infty) \quad (4)$$

Specific enthalpy can be given as

$$h = c(T - T_\infty) \quad (5)$$

Specific entropy can be given as

$$s = c \ln(T/T_\infty) \quad (6)$$

Specific exergy can be given as

$$\psi = c [T - T_\infty - T_\infty \ln(T/T_\infty)] \quad (7)$$

In the application of exergy, the efficiency of the second law of thermodynamics can be calculated as follows:

$$\eta_{ex} = \frac{\sum Ex_o (\text{Total exergy output})}{\sum Ex_i (\text{Total exergy input})} \%100 \quad (8)$$

Exergy calculations of the application process can be performed by exergy of the auxiliary applications of exergy.

#### 4. Application of thermoeconomic analysis

Thermoeconomic analysis is an analysis method that calculates the cost of exergy. In fact, it is a method of analysis that reveals the cost of energy availability. In other words, the thermoeconomic analysis is a detailed analysis of the cost of exergy. The cost of the exergy, which has many short definitions, is also called as the cost of the exergetic theory, exergy-economic cost or exergoeconomic. The most commonly used name is thermoeconomic. Thermoeconomic analysis approaches and methods are given by following steps.

The economic analysis of the exergy is excluded for exergy applications. Capital costs and operating costs are considered as investment costs. Capital investments are more strategic and have long-term effects. Since a capital investment often requires a large amount of money, the capacity of the project gains importance [7, 8].

The net present value method, using David Cantrell's approximate solution method [9, 10] to compare the economic cost effectiveness, is to calculate the interest rate ( $d_r$ ) as follows:

$$d_r = \left[ \left( 1 + \left( \frac{P}{A} \right) \right)^{1/q} - 1 \right]^q - 1 \quad (9)$$

where  $q = \log[1 + (1/N)]/\log 2$ ,  $N$  is a period ( $=n \times 12$ ),  $P$  is a payment amount,  $A$  is an initial cost and  $N$  is a number of payments.

The CRF factor, which is the capital recovery factor calculated using a discount rate ( $d_r$ ) and an amortisation (redemption) period ( $n$ ) that determines a uniform annual cost to pay a debt or initial cost, is as follows [7–16]:

$$a^c = \text{CRF} = \frac{d_r(1 + d_r)^n}{(1 + d_r)^n - 1} \quad (10)$$

The cost of life cycle method can be calculated for technoeconomic analysis as follows [7, 8, 17]:

$$\text{LCC}_n = I_n + E_n + M_n + R_n - S_n \quad (11)$$

Simple payback period can indicate the number of years required to recover the initial investment with the project. It is considered that the project life is longer than the simple payback period [7, 8, 12]. The simple payback period can be shown as follows:

$$\text{SPP} = \frac{I_n}{\text{energy savings} - \text{maintenance cost}} \quad (12)$$

Thermoeconomic analysis is a method and technique analysis that can be used to analyse energy costs through a combination of the second law of thermodynamics and economic

principles. Thermoeconomic analysis can be described as cost analysis and optimisation. This definition is the basis of thermoeconomic. The energy cost unit is expressed as [7, 18–21]

$$\dot{C}_{En} \text{ [$/kW]} = \frac{E_{cost} \text{ [\$]}}{\dot{E}_{net} \text{ [kW]}} \quad (13)$$

Since this book contains exergy applications, the thermoeconomic analysis of the turbine power plant can be determined. If a turbine power plant is considered as an exergy application, the unit of exergy cost can be defined as follows [7, 8, 12, 18]:

$$\dot{C}_{Ex} \text{ [$/kW]} = \frac{E_{cost} \text{ [\$]}}{E_x \text{ [kW]}} \quad (14)$$

## 5. The contents of the book of exergy applications

Exergy threads used in different ways in different areas can be seen that when taken applications in many fields. There are many similar field exergy applications such as factory production processes, many technological product design, biotechnologies, renewable energy sources, power plants, military applications, cooling and air-conditioning.

In addition, application of exergy introduces many exergy subjects in the book's chapter. The chapters of the book cover the topics as follows: exergetic cost for thermal systems, exergy methods for commercial aircraft, thermodynamic performance of ice thermal energy storage systems, exergetic assessment in dairy industry, exergetic perspectives of various typical bioenergy systems, advanced exergy analysis of an integrated SOFC system, exergy analysis of wind turbine, applications of exergy analysis, application of exergy for vacuum cooling, exergy analysis in shell and helically coiled finned tube, human thermal behaviour and exergy consumption rate, low exergy solution to building heating and cooling, new exergetic methodology to promote improvements and performance of solar PV plant for exergy approach.

## 6. Conclusion

This book poses application of exergy and its technology in terms of development with new technologies. The main idea of this study is to research exergy application of all engineering and science field with current and new technologies. In addition, the research of the exergy application can indicate many critical issues for an engineering and science enhancement.

Moreover, compared to many types of exergy application, this book also researched many science areas. This book is both a source of inspiration for similar exergy applications and studies and can contribute to the resolution of energy problems.

This book emphasises that mass and energy balances will optimise exergy efficiency with the help of many design parameters. This study shows that energy problems, industrial and building energy savings, energy use in medical fields, cooling-heating-ventilation systems,

power plants, many different energy systems, renewable energy systems and many other scientific problems can be solved by exergy optimisation.

This book will provide solutions to these types of energy problems through exergy applications that are aircraft, cooling, heating, fuel cell, wind energy, solar energy, motor vehicles, power plant and various different energy fields.

## Nomenclature

$Ex_i$	Exergy input, kJ/kg
$Ex_o$	Exergy output, kJ/kg
$h_\infty$	Dead state enthalpy, kJ/kg
$h_i$	Enthalpy input, kJ/kg
$h_o$	Enthalpy output, kJ/kg
$s_\infty$	Dead state entropy, kJ/kg K
$s_i$	Entropy input, kJ/kg K
$s_o$	Entropy output, kJ/kg K
$T_\infty$	Dead state temperature, K
$z_i$	Inlet height difference, m
$z_o$	Outlet height difference, m
$\eta_{ex}$	Exergy efficiency, %
$c$	Specific heat of the substance, kJ/kg K
$g$	Acceleration of gravity, m/s <sup>2</sup>
$h$	Specific, air or steam enthalpy, kJ/kg
$I$	Irreversibility, kJ/kg
$s$	Specific, air or steam entropy, kJ/kg K
$T$	Sugar temperature, K
$v_i$	Fluid inlet velocity, m/s
$v_o$	Fluid outlet velocity, m/s
$\Psi$	Specific, air or steam specific flow exergy, kJ/kg
$\dot{C}_{En}$	The unit of energy consumption, \$/kW
CRF	Capital recovery factor, $CRF = a^c$



$d_r$	Discount rate (interest rate)
$E_{\text{cost}}$	Total energy cost, \$
$E_n$	The present value of energy costs, \$
$Ex_i$	Exergy input, kJ
$Ex_o$	Exergy output, kJ
$I_n$	Initial investment, \$
$i$	Input (Inlet)
LCC	Life cycle cost, \$
$M_n$	The present value of nonfuel operating and maintenance cost, \$
$\dot{m}$	Mass flow rate, kg/s
$\dot{m}_i, m_i$	Mass input, kg
$\dot{m}_o$	Mass output, kg
$n$	Amortisation period, year
$o$	Output (Outlet)
$R_n$	The present value of repairing and replacement costs, \$
$S_n$	The present value of resale or salvage value, \$
SPP	Simple payback period, year
$\infty$	Dead state

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## References

- [1] Yang S, Yang Q, Qian Y. A composite efficiency metrics for evaluation of resource and energy utilization. *Energy*. 2013;**13**:455-462. DOI: 10.1016/j.energy.2013.08.058
- [2] Dalsgard H. Simplification of process integration in medium-size industry [dissertation]. Ford Collins, CO: Colorado State University Ford Collins; 2002



- [3] Dincer I, Rosen MA. Exergy. 2nd ed. Oxford: Elsevier; 2013. ISBN: 978-0-08-097089-9.
- [4] Taner T, Sivrioglu M. Energy-exergy analysis and optimisation of a model sugar factory in Turkey. *Energy*. 2015;**93**:641-654. DOI: 10.1016/j.energy.2015.09.007
- [5] Dincer I, Cengel Y. Energy, entropy and exergy concepts and their roles in thermal engineering. *Entropy*. 2001;**3**(3):116-149. DOI: 10.3390/e3030116
- [6] Taner T. Energy and exergy analyze of PEM fuel cell: A case study of modelling and simulations. *Energy*. 2018;**143**:284-294. DOI: 10.1016/j.energy.2017.10.102
- [7] Taner T. Optimisation processes of energy efficiency for a drying plant: A case of study for Turkey. *Applied Thermal Engineering*. 2015;**80**:247-260. DOI: 10.1016/j.applthermaleng.2015.01.076
- [8] Wang L. Energy project management in food processing facilities. In: *Energy Efficiency and Management in Food Processing Facilities*. New York: CRC Press; 2009. ISBN: 978-1-4200-6338-7
- [9] Taner T, Sivrioglu M. A techno-economic & cost analysis of a turbine power plant: A case study for sugar plant. *Renewable and Sustainable Energy Reviews*. 2017;**78**:722-730. DOI: 10.1016/j.rser.2017.04.104
- [10] Esen M, Yuksel T. Experimental evaluation of using various renewable energy sources for heating a greenhouse. *Energy Building*. 2013;**65**:340-351. DOI: 10.1016/j.enbuild.2013.06.018
- [11] Erbay Z, Koca N. Energetic, exergetic, and exergoeconomic analyses of spraydrying process during white cheese powder production. *Drying Technology*. 2012;**30**:435-444. DOI: 10.1080/07373937.2011.647183
- [12] Taner T, Sivrioglu M. Thermoeconomic analysis for the power plants of sugar factories. *Journal of the Faculty of Engineering and Architecture of Gazi University*. 2014;**29**(2):407-414. DOI: 10.17341/gummfd.73993
- [13] Erbay Z, Koca N. Exergoeconomic performance assessment of a pilot-scale spray dryer using the specific exergy costing method. *Biosystems Engineering*. 2014;**122**:127-138. DOI: 10.1016/j.biosystemseng.2014.04.006
- [14] Ganjehkaviri A, Mohd Jaafar MN, Ahmadi P, Barzegaravval H. Modelling and optimization of combined cycle power plant based on exergoeconomic. *Applied Thermal Engineering*. 2014;**67**:566-578. DOI: 10.1016/j.applthermaleng.2014.03.018
- [15] Silveira JL, Martinelli VJ, Vane LF, Freire Junior JC, Vigouroux RAZ, Tuna CE, Lamas WQ, Paulino RFS. Incorporation of hydrogen production process in a sugar cane industry: Steam reforming of ethanol. *Applied Thermal Engineering*. 2014;**71**:94-103. DOI: 10.1016/j.applthermaleng.2014.06.032
- [16] Chew IML, Foo DCY, Bonhivers JC, Stuart P, Alva-Argaez A, Savulescu LE. A model-based approach for simultaneous water and energy reduction in a pulp and paper mill. *Applied Thermal Engineering*. 2013;**51**:393-400. DOI: 10.1016/j.applthermaleng.2012.08.070

- [17] Esen H, Inalli M, Esen M. Technoeconomic appraisal of a ground source heat pump system for a heating season in eastern Turkey. *Energy Conversion and Management*. 2006;**47**:1281-1297. DOI: 10.1016/j.enconman.2005.06.024
- [18] Kim DJ. A new thermoeconomic methodology for energy systems. *Energy*. 2010;**35**:410-422. DOI: 10.1016/j.energy.2009.10.008
- [19] Valero A, Cuadra CS. Thermoeconomic analysis. In: *Exergy, Energy System Analysis and Optimization*. Vol. II. Oxford, United Kingdom: EOLSS Publishers; 2006. pp. 1-30. ISBN: 978-1-84826-165-5. Available from: [www.eolss.net](http://www.eolss.net) [Accessed: 3 January 2015]
- [20] Valero A, Serra L, Uche J. Fundamentals of exergy cost accounting and thermoeconomics. Part I: Theory. *Journal of Energy Resources Technology*. 2006;**128**(1):939-960. DOI: 10.1115/1.2134732
- [21] Abusoglu A, Kanoglu M. Exergoeconomic analysis and optimization of combined heat and power production: A review. *Renewable and Sustainable Energy Reviews*. 2009;**13**:2295-2308. DOI: 10.1016/j.rser.2009.05.004

