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Assessment of energy utilization in Iran's industrial sector using energy and exergy analysis method

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ABSTRACT

The purpose of this study is to assess the use of quality of energy in Iran's industrial sector. The exergy analysis has been performed along with energy analysis, in order to gain deeper and more realistic understanding of the sector's condition. Primary energy utilization from seventeen different industries has been considered for calculation of the exergy and energy efficiencies for each industry, and later for Iran's industrial sector. The exergy efficiency is much lower than energy efficiency in all industries and also in the industrial sector. It is shown that based on the results from exergy analysis the priorities for efficiency improvement are different from that of energy analysis; this in turn suggests that exergy analysis as a proper tool for policy makers. The sources of energy degradation and the mechanisms which cause degradation of quality of energy have been identified. Moreover remedial actions for better utilization of quality of energy are proposed. The energy and exergy efficiencies for the entire industrial sector of Iran were approximated as 63% and 42%, respectively. The oil, iron and steel, plastic and cement industries are found to have the highest share in destruction of quality of total input energy to the industrial sector. The aluminum industry has the highest exergy efficiency of 52.5%. Mean entropic temperature is also proposed as a tool for understanding the degree of quality of energy required in each industry and consequently better quality matching which leads to better energy quality utilization.

1. Introduction

The population of the human society demanding better living standards is growing with rapid pace. This development relies heavily on use of high quality energy which mainly comes from finite (depleting) fossil fuel resources. In addition environmental problems such as global warming are result of unwise use of natural resources —in particular those of fossil fuel energy resources. It is in light of these realities, that global consensus for considering the needs of the present without compromising the needs of the future generations (sustainable development) has been reached [1]. Sustainable energy development has been defined as: The harnessing of energy resources for human use in a manner that supports lasting development [2]. More efficient use of energy is recognized as a key factor for sustainable development [1,2]. By accepting this fact, it becomes increasingly important to identify the true causes of deficiency and energy degradation mechanisms to be able to develop systematic approaches for designing more sustainable energy systems. The concept of exergy as it represents the degree of usefulness or quality or potential of an energy form is an appropriate tool for finding the true causes of deficiency and energy degradation mechanism in various sectors of society. The industrial sector uses a great portion of energy resources, much of which is wasted due to variety of inefficiencies and poor practices [3–8]. The exergy analysis as a powerful tool —which overcomes the limitations of energy analysis- is useful for identifying the locations of energy degradation in any energy system (such as industrial sector) and rank them in terms of their significance [9]; This knowledge is useful for directing the attention of the design engineers to those components of the system being analyzed that offer the greatest opportunities for improvement [8]. The insight provided by this analysis can be of aid for policy makers in field of energy to take the necessary decisions and actions for improving the present condition of energy utilization in the sector and also direct the development of the sector's structure into a structure which makes more advantage of the limited high quality energy resources: A path to more sustainable energy use.

The concept of exergy has been recognized by researchers as an effective tool for analyzing various types of energy systems of different scale. This concept has been used for analyzing energy utilization in countries. A qualitative assessment of all sectors of US

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Nomenclature

$\dot{Q}$	energy rate in the form of heat (kW)
$\dot{W}$	energy rate in the form of work (kW)
$\dot{m}$	mass flow rate (kg/s)
h	enthalpy per unit mass (kJ/kg)
h^*	energy content per unit mass (kJ/kg)
$\dot{E}$	exergy rate (kW)
$\dot{S}_{gen}$	entropy generation rate (kW/K)
s	unit mass entropy (kJ/kg K)
T	Temperature (K)
T_0	environment temperature (K)
$\tilde{T}$	mean entropic temperature (K)
P	pressure
H_f	higher heat value (kW)
e	exergy per unit mass (kJ/kg)
V	speed (m/s)
z	height (m)

Greek

γ_f	grade function
η	energy efficiency
ε	exergy efficiency
α	weight factor

Subscripts

CV	control volume
D	destruction
q	heat
i	entering
j	dummy index corresponding to boundary or component
f	fuel
CH	chemical
e	exiting
p	process

economy in 1970 was the first use of exergy in country scale [10]. Since then the concept of exergy has been used for making assessment of the utilization of energy in various countries. Reference [11] has summarized the various exergy analysis performed in literature for various countries and compared them with each other. Also main important sectors of the countries have also been analyzed individually using exergy analysis; Sectors such as: industrial sector [3,5–8], residential and commercial sector [11–13], transportation sector [14–16], and agriculture sector [17–19]. The industrial sector consumes a large portion of the energy produced in Iran. Therefore any attempt for improvement of energy utilization would necessarily demand in deep analysis of the energy utilization in this important sector. Exergy analysis has the ability to fulfill this requirement; however, to the best of authors' knowledge no comprehensive exergy study for the Iran's Industrial sector has appeared in the literature. The main objective of this paper is to have qualitative assessment of the energy utilization in Iranian Industrial sector. This will help to understand in which industries energy's potential is being destroyed more (lower exergy efficiency), and also to identify the mechanisms that can be held responsible for degrading energy in each industry. Also best practices can be concluded from the outcome of this analysis.

Qualitative understanding of the flow of energy is the essence of the approach used in this paper. By considering one unit of energy (say 1 J) in the form of heat, available in different temperatures we realize that the heat energy in higher temperatures has more potential to do useful work (more exergy); and therefore higher quality. This distinction can only be made using the concept of exergy (which provides a qualitative point of view).

From qualitative point of view energy is available in nature in different quality (or potential) levels. High quality forms of energy in form of electricity and fossil fuels enter different sectors of the society to facilitate our lives and produce useful work. It is not a coincidence that these high quality energy forms have high economic values [20]. As a consequence of such realities, special care should be taken about how this potential is utilized. In this paper the degree of utilization of the quality of energy streams entering the industrial sector of Iran is assessed.

2. Energy and exergy modeling

It is intended to introduce the thermodynamic concepts and formulations for performing energy and exergy analysis in this section. Since the objective of this paper is to have a qualitative assessment of the flow of energy and its conversion in each sector, it seems necessary to clarify what is meant by quality of energy. However before that, we need to define the concept of dead state or reference environment.

2.1. Reference environment

Exergy is the potential of an energy form to perform useful work. This potential is measured with respect to a dead state or reference environment (which is normally chosen as the environmental conditions). So exergy can also be defined as the measure of the departure of the state of the system from that of the environment [20]. Following reference [3] which has chosen 10 °C as the temperature of reference environment for analyzing industrial sector of Saudi Arabia, the temperature of reference environment of 10 °C has been chosen in this study. This choice is justifiable since Iran's climate is mainly arid and semi-arid.

2.2. Energy and exergy formulation

The basis of the first law of thermodynamics is concept of conservation quantity of energy. Whereas exergy balance equation speaks about degradation of the quality of the energy. These concepts can be clearly demonstrated as below [20]:

$$\textit{Energy input} - \textit{Energy output} - \textit{Energy loss} = \textit{Energy accumulation} \quad (1)$$

$$\textit{Exergy input} - \textit{Exergy output} - \textit{Exergy destroyed} - \textit{Exergy Loss} = \textit{Exergy accumulation} \quad (2)$$

There is no energy and exergy accumulation in case of steady state conditions. Irreversibility or exergy destruction is directly related to entropy generation with in the process. The created entropy is the difference between the actual process change of entropy and that of its corresponding ideal process. The process inefficiency (irreversibility) is measured as a lost work potential ($= T_0\dot{S}_{gen}$) [21]. Exergy formulation has been formulated using different nomenclature by researchers. The nomenclature and formulation proposed in reference [20–22] is used for presenting the exergy formulation in this paper. Since the steady state operation of the processes is analyzed in this work; the formulation of