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A review on exergy analysis of industrial sector

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ABSTRACT

Performance analysis of industrial sector with high-energy consumption, about 30–70% of total energy use of the countries, is taken into consideration recently. A number of studies have been conducted on energy analysis of different industries and during the last decades exergy analysis applied to offer more realistic suggestions for optimization and improvement of the industrial sector. The present study reviews the existing studies on exergy analysis of industrial sector. The irreversibility and losses of industrial processes are also determined. It is concluded that industrial sector has a high potential of improving in order to reduce the energy consumption and emissions.

Contents

1. Introduction

Nowadays, industrial sector as one of the largest energy consumers is taken into accounts in several projects and researches. It was reported that 37% of the world's total delivered energy is consumed by the industrial sector [1]. The share of energy consumption of the industrial sector varies between 30% and 70% [2] based on different applications and locations. For instance, the share of energy consumption of the industrial sector of Jordan was reported to be around 31% [3], 30% for Slovenia [4], 35% for Turkey [5] and 70% for China [6].

Diversification and complexity of industrial sector, makes the calculation of the exact condition (operating temperature pressure) of each process almost impossible. Therefore, in order to analyze the performance of the industrial process based on the first and second law of thermodynamics, the operating temperature is divided into three sub-sectors of low, medium or high temperatures [7,8].

Typically, in the industrial sector, the energy flows through the different macro-system which can be named as iron–steel industry, cement industry, chemical and petrochemical industry, sugar industry, fertilizer industry, non-iron metal industry and other industries. This classification is illustrated in Fig. 1.

Exergy as a measure of the quality of energy can be considered to evaluate, analyze and optimize the industrial processes. Justifying the system's performance based on the exergy analysis is more realistic than energy analysis. To determine the importance of the

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Nomenclature

B	Exergy
CG	Cogeneration
E	Electricity
$\dot{E}x_{in}$	Exergy input (W, kW)
$\dot{E}x_{out}$	Exergy output (W, kW)
$\dot{E}x_{work}$	Exergy of work rate (W, kW)
$\dot{E}x_{Q}$	Exergy of thermal energy (kW)
$\dot{E}x_{ch}$	Chemical exergy (W, kW)
$\dot{E}x_{k}$	Kinetic exergy (W, kW)
$\dot{E}x_{p}$	Potential exergy (W, kW)
$\dot{E}x_{ph}$	Physical exergy (W, kW)
f	Fuel
h_f	Heating values
I	Irreversibility
γ_f	Exergy grade functions
η_{energy}	Energy efficiency
ψ_a	Specific exergy
ε	Exergetic efficiency

exergy analysis, energy and exergy efficiencies of some industrial processes are compared in Table 1. Exergy analysis prepares the right platform to specify the maximum performance of a system and the sources of irreversibility within the system. Since all industrial processes are irreversible, the exergy loss can be decreased by decreasing reaction rate and consequently exergy efficiency would be enhanced [10].

Recently, the interest of applying exergy analysis to different kind of systems in various sectors has been increased [12–15]. The performance evaluation of a system based on the second law of thermodynamics in the industrial sector has been done on cement [16–18], chemical industry [19] and iron–steel industry [20] much more than the others. These industries were known as the most energy intensive industries in comparison with other common industries [21]. For instance, it was observed that cement industry in Malaysia consumes around 12% of the total energy consumption of the country [22].

Being one of the largest energy consumers, determines the necessity of investigating the exergy analysis of the industrial sector. On the other hand, from the environmental point of view, the industrial sector is one of the major contributors of greenhouse gases emissions. It was reported that about one-third of the carbon dioxide emission released is associated with industrial sectors [23,24].

In the context of this work, the studies on exergy analysis of the industrial sector are reviewed. It may be reported that to the best of authors' knowledge, there is no work on the review of exergy analysis of the industrial sector. Therefore, this review is expected to fill this gap.

2. Studies conducted on exergy analysis of industrial sector

The conducted studies on exergy analysis of the industrial sector are classified into three main subsections of exergy analysis of the industrial sector of different countries, exergy analysis of different industries and exergy analysis of industrial devices.

2.1. Energy analysis of industrial sector in different countries

The exergy of the industrial sector of South Africa, which consumes about 44% of the total national energy use, was analyzed by Oladiran et al. [25]. The exergy balance and exergy efficiency equations were applied to different sub-sectors of the country, namely, iron and steel, chemical and petrochemical, mining and quarrying and non-ferrous metals. The exergy balance for the closed system was evaluated by applying Eq. (1):

$$\sum_r E^{Qr} - E^w - I = 0 \tag{1}$$

where E^{Qr} and E^w are associated with the exergies of heat transfer [7] and work and they can be calculated by Eqs. (2) and (3), respectively

$$E^{Qr} = (1 - T_0/T_r)Q^r \tag{2}$$

$$E^w = w \tag{3}$$

The exergetic efficiency of heating by fossil fuels and electricity was evaluated based on Eqs. (4) and (5), respectively [25]

$$\psi_{hf} = \frac{E^{Qp}}{m_f \varepsilon_f} \tag{4}$$

$$\psi_{he} = \frac{E^{Qp}}{E^{we}} \tag{5}$$

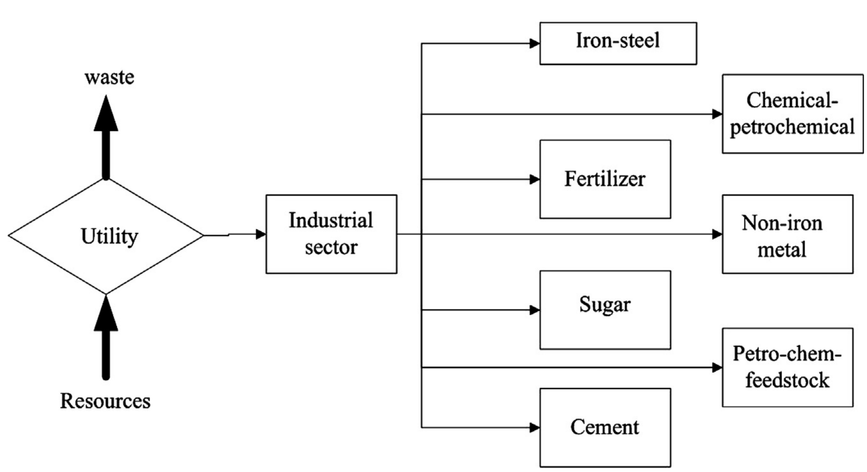

Fig. 1. Illustrative presentation of sub-systems of the industrial sector [9].