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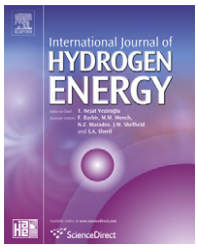

Hydrogen as a renewable and sustainable solution in reducing global fossil fuel consumption

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ABSTRACT

In this paper, hydrogen is considered as a renewable and sustainable solution for reducing global fossil fuel consumption and combating global warming and studied exergetically through a parametric performance analysis. The environmental impact results are then compared with the ones obtained for fossil fuels. In this regard, some exergetic expressions are derived depending primarily upon the exergetic utilization ratios of fossil fuels and hydrogen: the fossil fuel based global waste exergy factor, hydrogen based global exergetic efficiency, fossil fuel based global irreversibility coefficient and hydrogen based global exergetic indicator. These relations incorporate predicted exergetic utilization ratios for hydrogen energy from non-fossil fuel resources such as water, etc., and are used to investigate whether or not exergetic utilization of hydrogen can significantly reduce the fossil fuel based global irreversibility coefficient (ranging from 1 to $+\infty$) indicating the fossil fuel consumption and contribute to increase the hydrogen based global exergetic indicator (ranging from 0 to 1) indicating the hydrogen utilization at a certain ratio of fossil fuel utilization. In order to verify all these exergetic expressions, the actual fossil fuel consumption and production data are taken from the literature. Due to the unavailability of appropriate hydrogen data for analysis, it is assumed that the utilization ratios of hydrogen are ranged between 0 and 1. For the verification of these parameters, the variations of fossil fuel based global irreversibility coefficient and hydrogen based global exergetic indicator as the functions of fossil fuel based global waste exergy factor, hydrogen based global exergetic efficiency and exergetic utilization of hydrogen from non-fossil fuels are analyzed and discussed in detail. Consequently, if exergetic utilization ratio of hydrogen from non-fossil fuel sources at a certain exergetic utilization ratio of fossil fuels increases, the fossil fuel based global irreversibility coefficient will decrease and the hydrogen based global exergetic indicator will increase.

1. Introduction

Energy is a key element of the interactions between nature and society and is considered a key input for economic development. However, exergy is defined as the maximum obtainable potential of work of an energy or energy flow in relation to the reference environment. Exergy analysis is an effective thermodynamic method for using the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the design and analysis

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of thermal systems, and is an efficient technique for revealing whether or not and by how much it is possible to design more efficient thermal systems by reducing the inefficiencies [1,2]. Particularly, it is possible to seek opportunity to see the role that exergy is an essential tool to expose the advantage or disadvantage of a fuel or a system or a process.

Energy resources are essentially used to satisfy human needs and improve quality of life, but may generally lead to environmental impacts [3]. For instance, the United Nations [4] indicates that effective atmosphere-protection strategies must address the energy sector by increasing efficiency and shifting to environmentally benign energy systems. Reduced CO_2 emissions can be achieved directly via increased efficiency, reductions in the fossil fuel component of the energy mix and the introduction of alternative energy sources [3].

The motivation behind this paper is to outline some key facts: (i) sustainable energy sources and energy carriers are required due to the limited availability of fossil fuel reserves and some unavoidable environmental impacts of their utilization; (ii) hydrogen will play a key role in replacing fossil fuels [5–7]; (iii) hydrogen as a fuel is more exergetically efficient in power generation systems (including fuel cells) [8]; (iv) environmentally benign and sustainable hydrogen production and utilization will be one of the potential solutions in combating global warming [9].

It is obvious that current use of fossil fuels in various sectors for heat and power generation (including hydrogen production from them) continues threatening global stability and sustainability. These are locally, regionally and globally more evident than before. This concern is even further compounded by increasing world population, rapid technological development, increasing energy demand, etc. Although in the past fossil fuels were prime in meeting the energy needs, the current global picture does not allow any further potential use. So, there is an urgent need to switch to sustainable energy carriers, such as hydrogen [10].

Hydrogen may be produced from many fossil based sources including coal, natural gas, hydrocarbons, etc., by applying different production techniques such as gasification, reforming, pyrolysis, etc. However, it should be particularly known that, in this century, the required energy for hydrogen production, storage, distribution and transportation is mostly supplied from fossil fuel sources. In such a way that, given the advantages inherent in fossil fuels, such as their availability, relatively low cost, and the existing infrastructure for delivery and distribution, they are likely to play a major role for hydrogen production in the near to medium-term future [11]. If so, the fossil fuel use for hydrogen production will not decrease, on the contrary, may increase. In this case, as a result of fossil fuel consumption, CO_2, NO_x, SO_x and other pollutants will cause considerable damage to the environment [12]. Therefore, in order to reduce the utilization of fossil fuel sources for hydrogen activities such as production, storage, etc., and thus to save fossil fuel sources, the sustainable energy based hydrogen production, storage, distribution and transportation should be commonly encouraged, and also, the use of sustainable energy resources required for hydrogen activities should be absolutely increased and diversified. If done, hydrogen produced through non-fossil fuel sources such as water by using the different forms of sustainable energy sources and process heats (even nuclear based process heat) may then be considered to be a prime fuel in meeting energy supply and security, transition to hydrogen economy, environmental betterment, and social, societal, sectoral, technological, industrial, economical and governmental sustainabilities. In this regard, considering long-term environmental damages created by consumption of fossil fuels, sustainable energy based hydrogen energy systems that enable us to store the sustainable energy sources in the form of hydrogen should be particularly put into practice. If so, it can be considered that hydrogen will play an important role in future energy scenarios and the foremost factor that will determine the specific role of hydrogen energy and technologies will likely be energy demand. However, it should be noted that, in the next one-to-two decades, the sustainable energy based hydrogen production processes be unlikely to yield significant reduction in hydrogen costs [11]. However, the key may be the sustainable energy based hydrogen to reduce the environmental effects of fossil fuel consumption since:

- Hydrogen may have particularly attractive characteristics with regard to exergetic performance during its use as a fuel, because its combustion reaction is one of a combination of two relatively simple molecules into a more complicated one [13].
- Hydrogen generally causes less or no environmental impact. The variety of hydrogen energy resources provides a flexible array of options for their use.
- Hydrogen cannot be depleted. If used carefully in appropriate applications, hydrogen energy system can provide a reliable and sustainable supply of energy almost indefinitely.
- Hydrogen favors the system decentralization and local solutions that are somewhat independent of the national network, thus enhancing the flexibility of the system and providing economic benefits to small isolated populations. Also, the small scale of the equipment often reduces the time required from initial design to operation, providing greater adaptability in responding to unpredictable growth and/or changes in energy demand.

If so, the advantages of sustainable energy based hydrogen energy system can be enumerated as follows:

- It can provide environmental sustainability because hydrogen is high quality and environmental benign energy and a non-toxic clean energy carrier, and produces non-toxic exhaust emissions.
- It can also provide environmental stability because hydrogen can be safely transported in pipelines.
- It can be appropriate for the utilization of the sustainable energy sources and present long period-energy use, and thus ensure energy resource sustainability because hydrogen can be produced from non-fossil fuel sources by using different production techniques, and can be stored over relatively long periods of time, compared to electricity.
- It creates many additional industrial working fields, and thus ensures industrial sustainability because hydrogen is possible to advantageously use as a chemical feedstock in the petrochemical, food, microelectronics, ferrous and non-ferrous metal, chemical and polymer synthesis, and metallurgical process industries, and as an energy carrier in clean sustainable energy systems.