Exergy and exergoeconomic assessment of hydrogen and cooling production from concentrated PVT equipped with PEM electrolyzer and LiBr-H₂O absorption chiller

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A novel solar based combined system is proposed to produce hydrogen and cooling. The presented cogeneration system is analyzed in detail from the viewpoints of exergy and exergoeconomic (exergy based economic analysis). The proposed system includes a concentrated PVT (CPVT), a single effect LiBr-H₂O absorption chiller and proton exchange membrane electrolyzer (PEM). Produced electrical power is consumed in the PEM electrolyzer to split water into oxygen and pure hydrogen while heat removal from the CPVT is done by the absorption chiller to guarantee its better performance. Second law analysis showed that, among the three different parts of the system, the most part of exergy destruction refers to the CPVT followed by absorption chiller unit and PEM electrolyzer. Also, it is observed that, among the absorption units’ components, the highest percent of exergy destruction belongs to the generator which absorbs the heat from the CPVT. Moreover, exergoeconomic analysis revealed that the most important unit from the viewpoint of economic is the CPVT with the capital investment cost of 0.08946 $/h and an exergoeconomic factor of 28.82%.

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Introduction

Energy consumption increasing in and environmental pollution are the challenges that the contemporary and futuristic men are struggling with them. Procedural unity, precise planning and technical knowledge development are necessary to meet these challenges. According to the statistics provided by the World Business Council, about 40% of the world's energy consumption is related to cooling, heating and power. Due to this, more attention is needed to reduce fossil fuel consumption and diversify into the energy generation sources [1]. In this work, a co-generation solar-based energy system is proposed and its subsystems are described in point of view of other researchers.

Photovoltaic/thermal (PVT) systems

One of the direct energy convertor technologies is Photovoltaic (PV) cells. These modules convert solar energy into the...
electricity. In order to increase the energy output of the PV technologies, several strategies are employed until now, such as new material employment and reduce the temperature of PV cells by the active and passive methods [2]. One of the active methods that help us to achieve the target is the use of Photovoltaic/Thermal (PVT) technology. PVTs are adaptive technologies that are improved by active heat removal from photovoltaic modules, in order to reduce cell temperature (thereby also increasing the electrical conversion efficiency) [3,4]. The energetic efficiency of the PVT systems can achieve in the range of 53%–68% by the utilization of the module waste heat [4]. The captured waste heat is typically used for heating, cooling and hot water production by applying the waste-to-energy concepts that have been introduced by precise works. Moreover, the concentration of sun irradiation reduces the required cell area. The feasibility of such systems has been demonstrated in a number of studies [5–8].

Cooling systems

For the part of PVT, removing heat and utilizing it as a waste heat source, Absorption refrigeration cycle is a suitable choice in order to achieve a low energy level cooling [9]. Meanwhile, absorption single effect cooling chillers have a wider application with small and medium cooling capacities [10,11]. It is proved that a heat source with temperature over 70 °C can drive a single effect absorption chiller [12]. Consequently, a single effect absorption chiller can also be a feasible select for domestic using. The coolant of the absorber and the condenser can be either water or air while most of the commercialized products are water-cooled. There are two main disadvantages in water-cooled systems: the difficulty of configuring the cooling tower in domestic areas and the risk of legionnaire’s disease [13]. From the other hand, air-cooled absorption chillers can be built as a single unit that saves both space and water in domestic utilization [14].

Hydrogen production

Increasing the standard of livings in modern and developed human societies and quick population growth in the industrialized countries along with high value of greenhouse gas emission (specially CO₂ concentration) clear the importance of changing the fuels to the clean and environmentally friendly ones. From the other hand, due to global warming caused by the CO₂ emission (resulting from fossil fuel utilization); it is necessary to introduce reliable, novel and sustainable source of fuels [15]. Consequently, hydrogen has been introduced as a promising option to store clean, environmentally friendly and alternative energy sources [16]. Recently, a wide variety of researches have been done by the investigators in the field of hydrogen production using different methodologies. Penkuhn et al. conducted an exergoeconomic analysis for a small scale PEM electrolyzer [17]. Their proposed system utilizes an LPG steam reforming process in order to produce hydrogen with the aim of employing in mobile and stationary off-grid electricity generation. They showed the sources of the high cost of electricity by comparing the capital costs and costs of exergy destruction. Khanmohammadi et al. evaluated a renewable energy based novel integrated system for hydrogen production using exergoeconomic technique [18]. They studied effects on the system performance of the different key variables. Inconsistent effects of the decision variables on the exergy efficiency and cost of the system have led them to apply an evolutionary based optimization. They resulted that, under the optimum condition the exergy efficiency of the system can be enhanced up to 1.5 points and while the system cost increases from 19.59 $/h to 22.8 $/h. Caliskan et al. studied another renewable (including wind and solar) energy based hydrogen production system from the viewpoints of exergoeconomic and environmental impact [19]. They observed that, the sustainability index and the energy and exergy efficiencies for the solar photovoltaic (PV) are lower than those of the wind turbine. Moreover, they stated that, wind turbine with 60 gCO₂/month is more environmentally-benign than the solar PV system with 75 gCO₂/month.

Multi-generation energy systems

A literature review of co-generation systems that can be enabled to produce several useful forms of energy such as cooling, heating, drinking water, hydrogen as an energy carrier and etc. is presented in the following. Oruç et al. [4] provided a power/hydrogen production system with a novel architectural PVT technology. Also, they carried out a finite-element analysis to optimize the operating condition and maximize the rate of hydrogen production. They estimated that the overall energetic efficiency of the proposed system is around 56–59%. A new multi-generation system was designed by Calise et al. [7] that comprises of photovoltaic/thermal collectors for seawater desalination, electrical energy and cooling generation. Applying a thermo-economic analysis, the optimized conditions were provided for some important design variables. Buonomano et al. [20] employed a new solar based co-generation system to produce heating and cooling. In their study, a transient simulation methodology was conducted to demonstrate the energy saving up to 74%, for the system that comprises of three main parts: single stage LiBr–H₂O absorption chiller, evacuated tube (ET) and concentrating photovoltaic thermal (CPVT) solar collectors. Domestic heating and cooling is an approach that Vokas et al. [21] introduced it, in order to provide domestic energy consumption for obtaining thermal comfort conditions. The proposed solution utilized a hybrid photovoltaic-thermal system which is connected to a cooling system and the authors attempted to provide a theoretical approach. Moreover, Calise et al. [22] has also studied the combination of photovoltaic/thermal collector, a single-stage LiBr–H₂O absorption chiller, auxiliary heaters and storage tanks. The proposed concept is developed by a zero-dimensional transient model. The economically profitable results had come out from the related simulation.

As a fact and as presented in the literature review, effective use of energy has been the focus of researcher’s attention in the recent years. In this regard various combined systems have been suggested and analyzed thermodynamically and economically. Nevertheless, there is no standard configuration with which the most effective way of producing hydrogen and cooling is accomplished simultaneously. In this study a new combination of a concentrating photovoltaic thermal (CPVT)
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