Solar Energy Applications Vis-à-Vis Renewable Energy Systems: An Exergy Analysis

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ABSTRACT

Despite the increase in pollution, global warming, ozone layer depletion and climatic changes caused by fossil fuels, its stocks available are finite. Solar energy is one among the renewable energy which is clean, cheap, easily available and abundant. Hence, utilization of solar energy in the proper and efficient manner aids in energy saving policy. The work presents, an extensive literature review which has been carried out on systems based on the exergy analysis. Systems include some typical renewable energy contrivance as well as some solar energy applications. Most of the analysis on renewable energy systems is based only on energy analysis. A summary of exergy analysis is presented along with some important conclusions. Hence renewable energy sources play a vital role in production of energy as these are environmental friendly and abundantly available.

KEYWORDS— Exergy Analysis, Solar Energy, Solar Photovoltaic Cell, Solar Water Desalination

I. INTRODUCTION

Population and income growth are the two most powerful driving forces behind the demand for energy. Over the last 20 years world population has increased by around 1.5 billion and is projected to rise by another 1.5 billion over the next 20 years. Moreover, world's income has risen by 87% over the past 20 years and is likely to rise by 100% over the next 20 years. At the global level, the most fundamental relationship in energy economics remains robust; more people with more income means that the production and consumption of energy will rise. Around 85% of the world's energy supply comes from the fossil fuels. Also, these fossil fuels are not environment friendly and cause serious environment issues like pollution, global warming, ozone layer depletion and climatic changes. Besides, the environmental issues, the stocks of fossil fuels available are finite. Hence renewable energy sources play a vital role in production of energy as these are environmental friendly and abundantly available. Even then, special consideration should be taken in using renewable energy sources in real life applications as these suffer from low conversion efficiency. Solar energy as an available, clean, cheap, environment friendly alternative source has been the subject of many theoretical and experimental studies. Combination of solar energy with different systems aids in energy saving policy. For example, integrating the photovoltaic and solar thermal components, both electricity and heat can be produced from the same system.

Energy is based on the first law of thermodynamics and it is quantitative in nature; whereas exergy deals with the second law of thermodynamics and gives the quality of this property. Exergy analysis identifies the causes, locations and magnitude of the system inefficiencies and provides the true measure of how a system approaches to the ideal. Exergy analysis evaluates the efficient usage of solar energy. By determining the sources and the magnitude of irreversibility, exergy analysis can be used to improve the efficiency of the system. Performance of most of the renewable energy conversion systems is based on energy analysis accounting only the energy entering and exiting. Numerous studies have been conducted in performance evaluation of different systems in residential, commercial, industrial, and transportation sectors. Some investigators have performed exergy analysis of refrigeration cycle. Exergy analysis is employed in different fields of solar power generation, solar water desalination, solar air heating, solar air conditioning and refrigeration systems and solar drying process. This paper deals with an extensive literature survey on exergy analyses of various renewable energy systems or solar applications and identifies the various sources involved in exergy destruction. This paper would be of great help for investigators on the field of exergy analyses in the future.

2. EXERGY ANALYSIS ON DIFFERENT SYSTEMS

This section includes the review of exergy analyses of various systems like solar air heater, solar water heater, solar photovoltaic, solar water desalination, solar drying process, solar air conditioning and refrigeration and solar power generation.

2.1 EXERGY ANALYSIS OF SOLAR POWER GENERATION

Suresh et al. investigated the performance of solar thermal aided coal-fired power plants based on energy and exergy analysis. The exergy efficiency of the plant was defined as

Ψ = The exergy performance index was also calculated as

ExPI = (Excess power generated over the design rated capacity/Exergy input through solar radiation)

The exergy efficiency of the plant was found to be seen around 33.5 – 38.5%. By comparing the energy and exergy analysis, they found that the application of solar energy for feed water heating is more efficient based on exergy analysis than by energy analysis. The exergy analysis of ammonia based solar thermo-chemical system was investigated by (Mohammadnejad *et al.,* 2011). The total exergetic efficiency was found to be 70.7%. The reaction and heat transfer were found to be the main sources of the irreversibility.

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2.2 EXERGY ANALYSIS OF SOLAR WATER DESALINATION

Saidur, Khaliq and Masjuki (2006) studied the exergy efficiency and exergy destruction of solar powered membrane distillation unit. They study was carried out to determine the efficiencies of each component and to improve the total efficiency of the desalination unit. The second law efficiency was found to be 3-6%. They concluded that the exergy efficiency of the compact system was a bit higher than the larger system. The major source of exergy losses was detected to occur in the membrane distillation. Hacihafizoglu (2011) studied the exergy analysis of solar multi effect humidification and dehumidification desalination process and the exergy balance equation is given as

S = Lex, collector + Lex, h + Lex, d + Exsaline water

The exergy efficiency of solar collector was defined as the ratio of collector exergy rate to the total exergy rate of the system. It was found that the solar collector exergy efficiency was 86% whereas the exergy efficiency of the humidifying process was 91%. Saidur *et al.* (2007) studied the exergy analysis of combination of a solar collector, heat transformer and desalination unit. The exergy was considered as the combination of physical and chemical exergy thereby neglecting the effects of kinetic and potential exergy. The exergetic efficiency was calculated using the equation;

$$\Psi = \frac{\text{Qab}\,\frac{1-\text{To}}{\text{Tab}}}{\text{IG Ac Nc}\,\frac{1-\text{T0}}{\text{Ts}}} + \text{Wpumps} \qquad [1]$$

The flat plate collector was detected as the component with higher exergy loss.

2.3 EXERGY ANALYSIS OF SOLAR AIR CONDITIONING AND REFRIGERATION

Ahamed, Saidur and Masjuki (2011) studied the exergy analysis of a solar assisted absorption cooling system. The calculation was based on two different dead states of standard temperature and environment temperature. Applying the formula generated by Dikmen, Sencan and Selbas (2011). The second law efficiency of solar collector was calculated and found to have a maximum value of 11.98%. The equation is;

$$\Sigma (1 - (T\infty/T)) Q - W + \Sigma (mi\psi i) - \Sigma(mo\psi o) = Ex\ dest \quad [2]$$

Exergy destruction was mainly found at solar collectors and generator of absorption chillers. Nwosu (2010) considered a refrigeration cycle consisting of an ejector, a generator, an evaporator, a condenser, a pump and expansion device; and they studied the optimum operating conditions of solar driven ejector refrigeration system. The exergy balance of the system is given as;

$$Es, h + Ee + Wp, el = Ec, out + Itotal \quad [3]$$

The exergy efficiency of the solar collector was reported to be 0.66% and the solar collector was found to be the main source of irreversibility. Shukla, Buddhi and Sawhney (2009) investigated the performance of solar air conditioning system by application of exergy analysis and the exergy efficiency of the system was computed as;

$$\eta = 1 - \frac{\sum X_{lost}}{\sum X_{in}} \quad [4]$$

Results obtained where compared with that of Gomri (2009) and was found to be in good agreement. They found that the exergy efficiency decreases with increase in temperature of heat source. Moreover, generator and absorber were found to be the main sources for exergy destruction.

2.4 EXERGY ANALYSIS OF SOLAR AIR HEATER

Solar air heaters are those devices wherein air is used as the circulating fluid for air heating, space heating and crop drying applications. Several investigations were carried by many investigators on solar air heater.
Neglecting the changes in gravitational force, momentum and pressure the exergy balance equation for the solar air heater can be given as

$$Exergy = Cp [(T - T\infty) - T\infty \ln (T/T\infty)] \quad [5]$$

Exergy received by collector is given as:

$$Exc = Qc [1 - (Ta/Ts)] \quad [6]$$

Exergy received by the fluid is given as:

$$Exf = m(E_0 - Ei) = m[(h_0 - hi) - Ta (s_0 - si)] \quad [7]$$

Thus the exergy efficiency of solar air heater is

$$\Psi = Exf / Exc \quad [8]$$

2.5 EXERGY ANALYSIS OF SOLAR WATER HEATER

Solar water heaters are carbon-free process to get heated water, and find many uses such as domestic, industrial and commercial applications. It consists of a collector, for collecting solar radiation from sun, and insulated storage tank, to store hot water. Exergy received by the collector is given by;

$$Exc = Is A[1 - (T/Ts)] \quad [9]$$

Exergy received by the fluid is given by;

$$Exf = m (Eo - Ei) = m [(ho-hi) - T (so-si)] \quad [10]$$

Exergy received by fluid can also be given by;

$$Exf = m Cp,w (T-Ti) [1-(T/Tf)] \quad [11]$$

The exergy efficiency of the system is then given as;

$$\Psi = m [(ho-hi) - T (so-si)] / Is A[1 - (T/Ts)] \quad [12]$$

2.6 EXERGY ANALYSIS OF SOLAR PHOTOVOLTAIC

The exergy of solar radiation or the input exergy is given by the equation;

$$Exin = [1 - (Ta/Ts)] Is A \quad [13]$$

The exergy output of SPV systems is;

$$Exout = Exelec + Extherm + Exd = Exelec + I' \quad [14]$$

The exergy output of SPV systems can be given as;

$$ExPV = VmIm - [1-(Ta/Tcell)]\ hca\ A\ (Tcell - Ta) \quad [15]$$

The power conversion efficiency can be defined as the ratio of actual electrical output to the input energy on the SPV surface and is given as:

$$\eta\ pce = (VmIm) / (Is\ A) \quad [16]$$

The exergetic efficiency of a solar photovoltaic is normally given by the equation;

$$\Psi = [VmIm - \{1 - (Ta/Tcell)\}hca\ A\ (Tcell - Ta)] / [\{1 - (Ta/Ts)IsA] \quad [17]$$

2.7 EXERGY ANALYSIS OF SOLAR DRYING PROCESS

Koroneos, Nanaki and Xydis (2010) performed exergy analysis of olive-mill waste-water solar-drying-process. They carried out number of experiments on the designed model. The total exergy included kinetic, potential, physical and chemical exergy. The general form of total exergy equation is given by;

$$E = mdacp\ [(T - T_0) - T_0 \ln\ (T/T_0)] \quad [18]$$

The exergetic efficiency was found using the equation;

$$\Psi = 1 - (E1/Ei) \quad [19]$$

The experiment was conducted for two days and the maximum input exergy was found to be 0.345kJ/kg and 0.27kJ/kg for the first day and second day respectively. They also proved that the exergetic efficiency decreases with increase in inlet temperature. The variation of exergetic efficiency with drying time was also investigated. Basunia and Abe (2001) conducted exergy analysis of shelled and unshelled pistachios by utilizing a solar drying cabinet. Exergy was calculated using the following equation;

$$Exergy = cp\ [(T - T\infty) - \{(T\infty \ln T)/T\infty\}] \quad [20]$$

They performed thirteen experiments and maximum exergy input was reported to be 3.72kJ/kg at a temperature of 320C. It was also seen that the exergy inflow kept increasing linearly with increase in inlet temperature. Saidur *et al.* (2007b) conducted a study on modeling and performance analysis of solar drying process of mint leaves. The general exergy balance was as;

$$\Sigma\ (1 - (T\infty/T))\ Q - W + \Sigma\ (mi\psi i) - \Sigma mo\psi o = Exdest \quad [21]$$

The exergetic efficiency varied from 34.76% to 87.71% based on daily solar radiation. There was no significant difference observed in quality of dried leaves when compared with forced solar drying and open sun drying. Koroneos *et al* (2010) conducted energy and exergy analysis of forced solar drying process of mulberry. The moisture content of mulberry was found to decrease from 80% to 8%. They also found that decrease in difference between the inlet and outlet section resulted in increment of exergy efficiency. Moreover, increasing mass flow rate leads to decrement of drying time.

3. CONCLUSION

It may be concluded, from the literature review of exergy analysis of various renewable energy conversion systems that:

a) Exergy efficiency is highly dependent on incident solar radiation and radiation intensity.
b) Increasing the mass flow rate leads to an increase in the exergetic efficiency of photovoltaic thermal systems.
c) Thermal efficiency itself is not self sufficient in choosing a desired system. Along with thermal efficiency, exergetic efficiency should also be considered.
d) Higher exergy destruction was found to be seen in the solar collectors in most of the systems.
e) Mass flow rate, inlet temperature and time were the parameters taken mostly into consideration for exergy efficiency studies.

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