Performance of a hybrid Solar and Biomass Energy System to Supply Hot Water in Different Weather Conditions

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Key Words: hybrid system, Thermal solar energy, biomass, waste, hot water, CO_2 emissions reduction

Abstract

Due to increasing demand for energy and high consumption of gradually disappearing fossil fuels, and the increase of natural disasters, resulting from global warming, there is a growing interest in renewable energy sources as a clean and sustainable source of energy. One of the useful applications of renewable energy is the daily supply of hot water.

In this paper, a simulation for the provision of warm water by a hybrid system using solar and biomass energy has been carried out using "MATLAB" program. The simulation was validated with experimental results for the weather conditions in Homs in the Syrian Arab Republic (SAR) [1]. The abbreviated analysis and block diagrams have been provided for the simulation process. The results have been further elucidated through numeric values and diagrams [2]. The results have been applied to larger units using two other units with different specifications. A comparison between the different weather conditions in Homs (SAR) and Edinburgh (Scotland) is also presented. This hybrid system has been patented in SAR [3].

1. Introduction

This research focuses on the use of a hybrid system that uses thermal solar energy and the heat from a biomass energy reactor to supply hot water for Scottish and Syrian weather, continually, in all conditions. The heat pipe collector technology was used to make use of solar energy and the biomass reactor to benefit from domestic and plant waste. Some studies show the use of a hybrid system from solar energy and biomass for space heating, but they burn the biomass [4, 5], whereas this study is based on the use of a composting reactor. To the best of author's knowledge, no studies of this particular hybrid system have been carried out until now, although numerous studies are available that use a solar collector and biomass separately [6, 7, 8, 9, 10]. Detailed accounts of solar water heating systems were given by Junaidi [6], Streicher et al [7], Youhanis et al [8], Fisch [9] and Vajen et al [10]. A simulation program for all components of solar systems was also reviewed in [11]. Several experimental results for large scale solar thermal systems are available through the internet in the form on dynamic web pages that show real-time measurements [12]. On the other hand, Abbasi 2009 [13] has reported many methods and routes for obtaining different types of fuels that include hydrogen and hydrocarbon fuels. However, the hybrid system in this study is unique due to its biomass reactor, because about 75% of the domestic waste is bio-degradable and can be used readily in the reactor. Thus the carbon saving benefit of the reactor can be realized. Moreover, the waste produced by the reactor can be reused in fertilizer. This hybrid system has been patented in SAR [3].

2. Experimental studies

The experimental study for testing the hybrid system was conducted during the period of January 2007 to November 2008 in Homs (SAR).

Measurements were taken every hour, during daylight. The total experimentation time has been separated into four periods of three months each:

- Winter Test (01 December 2007 to 28 February 2008).
- Spring Test (01 March 2008 to 28 May 2008).
- Summer Test (01 June 2008 to 28 August 2008).
- Autumn Test (01 September 2008 to 30 November 2008).

The hybrid system consists of: a solar collector, a 500 Lt biomass reactor, a tank for warm water-size 113 liters, a tank for cold water, a temperature measurement and control system and weather-station with a pyranometer (See Figure 1) .

The solar collector is made from 9 heat-pipe tubes. For the interest of the reader, the detailed specifications of the collector are given in Table 1. The solar collector is self-regulating and makes use of thermosyphon effect. It was positioned to face due south, while the angle of the tubes was 35° from the horizontal. The biomass reactor has an internal heat exchanger to transfer the heat from biomass to water. In both the hot water tank and inside the reactor, the temperature was measured at three levels, while both the tank and reactor were insulated with 0.1 m thick glass wool all around. The range of temperatures measured by the sensors was between -20 to 150 °C.

Table 1: Specification of Solar Collector

Glass-tube Length/ Diameter		1.8m / 0.058m
Heat pipe	*Evaporator* Length/ Diameter	1.68m / 0.006 m
	Condenser Length/ Diameter	0.065m/0.0235m
Copper plate Length/ width		1.68m/ 0.014 m

As most other results were similar, the result from only the second period of experiment (spring time) is discussed in this work. For all testing periods, the experiments started by filling the biomass reactor with 95 kg of bio waste from domestic waste and plants[1].

Figure 2 shows the amount of biomass during the experiment, the outside temperature and the temperature in the reactor during the second experimental period. After filling 95 kg of biomass fuel at the start, an additional 28 kg was supplied to aid the reactor process during the first week of the experiment. After the first week, a total of 203 kg was further added in the reactor until the end of this period. Thus the total biomass used for this period of experiment was 326 kg.

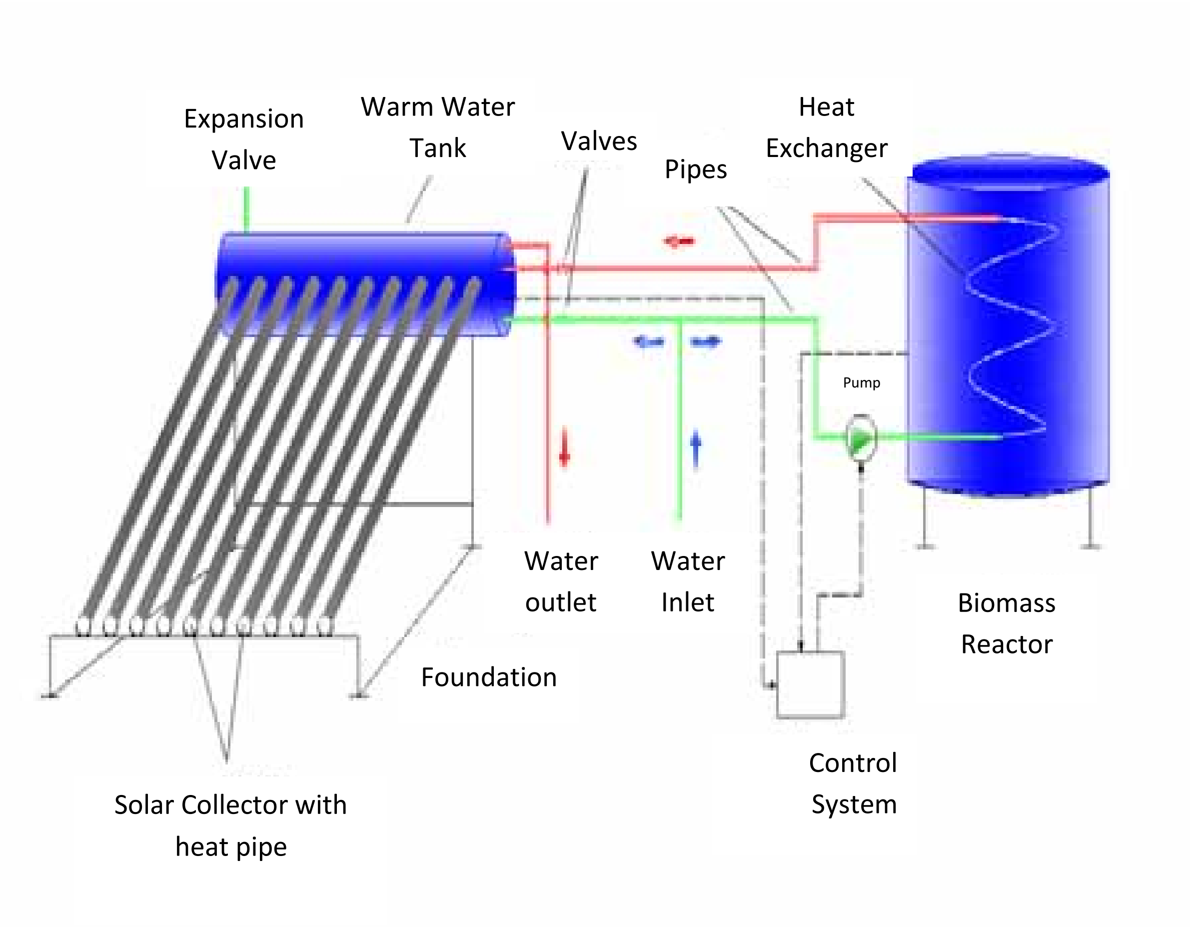

Figure 1: System and circuit diagram of the plant.

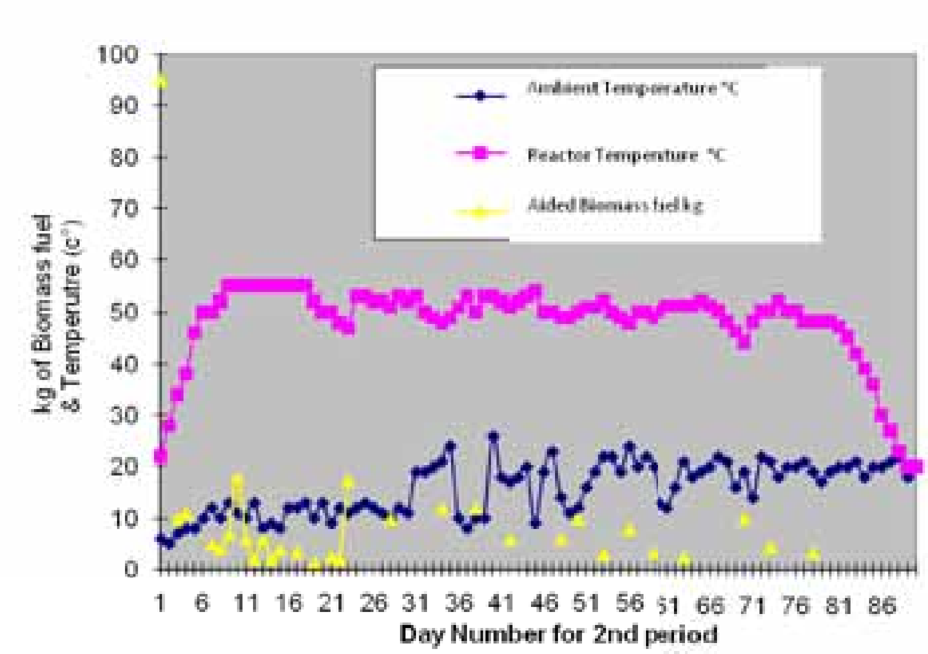

Figure 2: The biomass reactor and the ambient temperature and the amount of added biomass [1]

Figure 2 shows the increase in the reactor temperature up to 54 °C in the first week of the experiment. The temperature remained at approximately 50 °C up to the end of the day before the last week .Then it returned to an ambient temperature 23 °C because no biomass was being added. The outside temperature has no effect on the inside temperature.

For the solar collector, however, the relation between the solar radiation and the temperature of the heat pipe condenser wall is represented in the diagram for day time. It should be noted that this relationship prevailed for all days of experimental study and therefore the relationship for only one day has been presented here. An increase of solar radiation was noticed from the beginning of day and it reached its maximum (about 900 to 1000 W/m^2) at about mid-day. Then it returned to zero at the end of the day. It was also noticed that the temperature of the condenser is in proportion with solar radiation at most times (except at the beginning and end of the day). The maximum temperature of the condenser was about 100 °C. It should be noted that in a period of three months it was not possible to combust all biomass fuel placed in the reactor.

From the measured data, the following relationships were developed for quantification of energy:

Total energy in warm water tank $Q = m.c_p.\Delta T$

Energy from solar collector $Q_1 = \alpha.\ A.\ \Delta T_1$

Energy from biomass reactor $Q_2 = Q - Q_1$

where:

m is the mass of water in tank

c_p is the specific heat of water

ΔT is the average temperature difference in the warm water tank

α is the heat transfer coefficient

A is the condenser area

ΔT_1 is the temperature difference between the condenser wall and the water in the tank

Using the above relationships, Table 2 was generated. From the table it can be noticed that most of the energy produced came from solar collector and only about 10% was contributed by biomass reactor. However the contribution of the reactor is crucial as it furnishes energy when solar energy is not available such as during the night or in winter and thus is instrumental in maintaining consistent output by the system. The temperature of the condenser remains consistent, between 86 – 111 °C.

Table 2: Experimental result of second period

Day number (second period)	Reactor temp °C	Temp of condenser wall °C	Q Wh/day	Q_1 Wh/day	Q_2 Wh/day
2	25	86	4336	4205	131
54	53	100	5516	4856	660
63	51	101	5518	4865	653
76	48	106	5500	4916	584
87	28	111	5310	5204	106

3. Theoretical Analyses

A theoretical study was also carried out, to ascertain an optimal system design. For this purpose, a computer program was created and MATLAB was used for simulations. The equations for the system utilized empirical relationships for free and forced convection as well as other heat transfer relationships. Additional design parameters were introduced to determine the characteristics of a better performing system, which included changing the number of heat pipes in solar collector, size of hot water tank and the size of biomass reactor. Similarly, the program could also incorporate changes made to the amount of biomass fuel. The program is able to handle even more parameters (e.g. changing weather conditions), and all other influencing parameters. Three different design configurations are presented in Table 3. For bench-marking purposes, the first configuration is the same as the experimental system. For the interest of the reader, the detailed specification of the simulation program, used here is given in [2].

Table 3: Theoretical result

Model	Number of Collector Tubes	Size of Hot water tank (Liters)	Biomass reactor size (Liters)	Rate of supplement of biomass fuel kg/day	Total Energy yielded kWh/day
1	9	113	500	3.5	5.69
2	20	240	500	3.5	12.01
3	30	380	1000	10	19.14

4. Comparison between theoretical and experimental results

In this section, a comparison is made between the theoretical and the experimental studies described in the above passages. It can be noticed that the percentage difference between the measured and theoretical value for solar radiation is only 1%. The conformance for energy parameters is good and a maximum difference of only 3.5% was noted. Thus the simulation can be used for system design and assessment of the influence of different parameters on the system output.

5. System performance comparisons for Syrian and Scottish weather conditions

To assess the performance of the hybrid system in different weather condition, the simulation program was used again and showed good agreement between the predicted and measured results. For this purpose Scottish weather conditions were used in the program input. To calculate the true impact of this change, the orientation as well as the solar flux during the whole year was accounted for. Latitude of 55° in line with Edinburgh and 35° for Homs was used in the simulation program. Similarly corresponding longitudes for the cities were also keyed-in as inputs.

In order to present the comparison, one day from each period of study was chosen and the results are as follows:

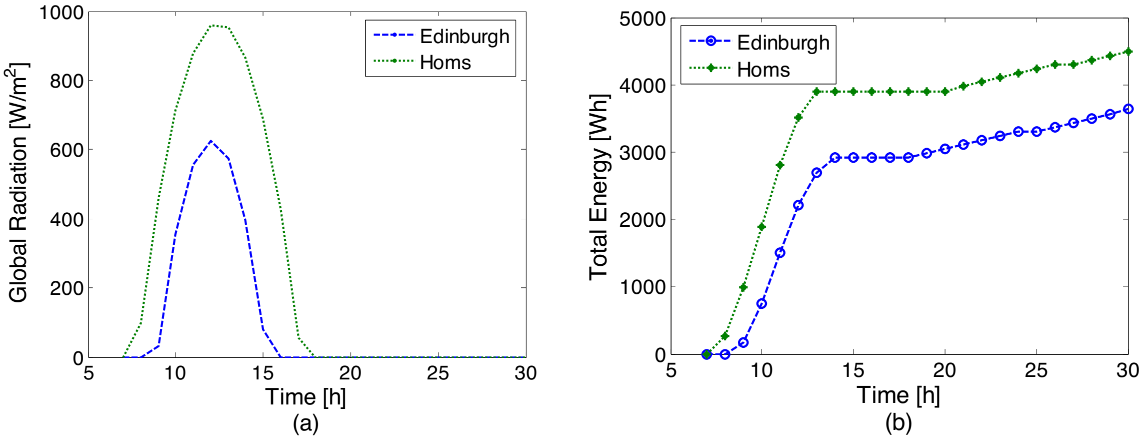

Figure 3:

a) Solar radiation in Homs (SAR) and Edinburgh (Scotland) on 6th December (1st period)

b) Total energy yield from the hybrid system for Homs and Edinburgh

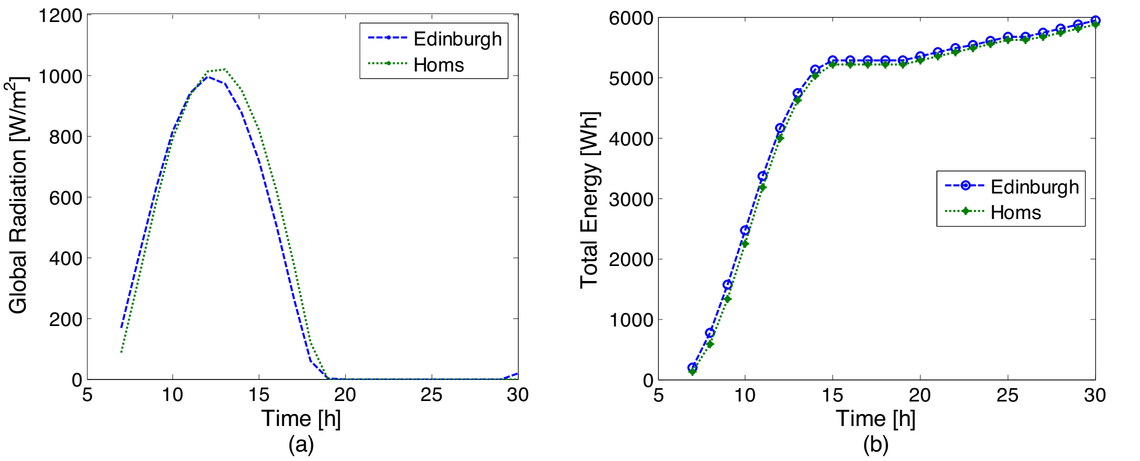

Figure 4:

a) Solar radiation in Homs (SAR) and Edinburgh (Scotland) on 15th April (2nd period)

b) Total energy yield from the hybrid system for Homs and Edinburgh

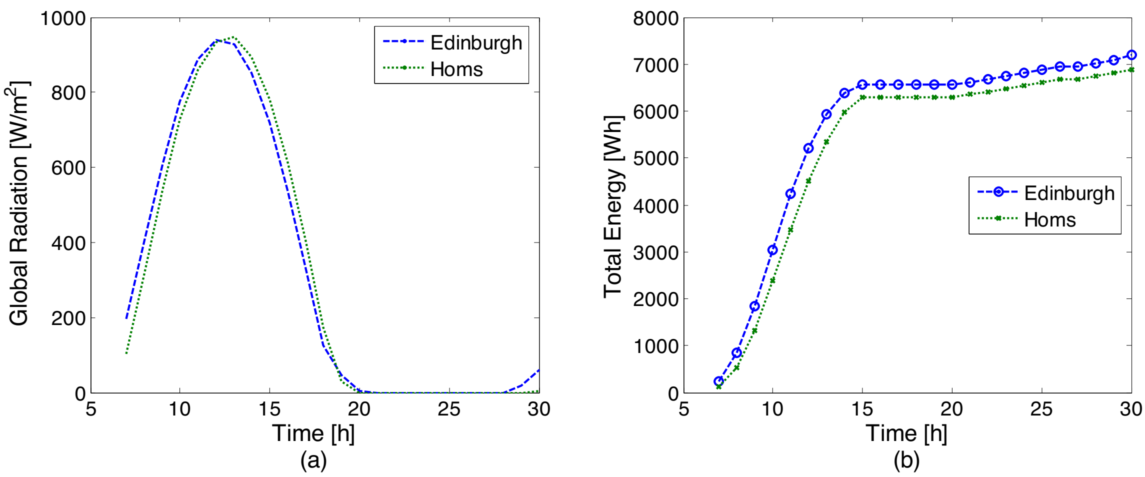

Figure 5:

a) Solar radiation in Homs (SAR) and Edinburgh (Scotland) on 23rd July (3rd period)

b) Total energy yield from the hybrid system for Homs and Edinburgh

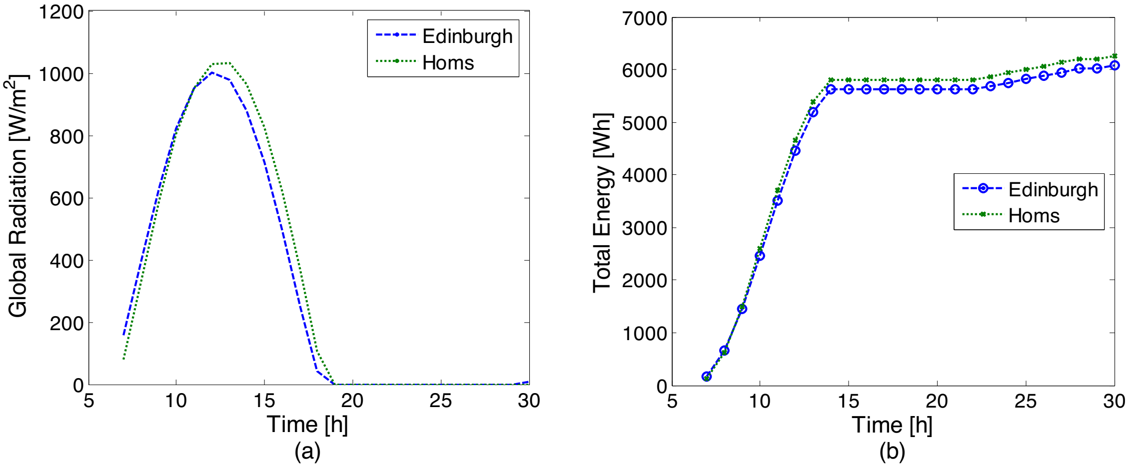

Figure 6:

a) Solar radiation in Homs (SAR) and Edinburgh (Scotland) on 2nd September (4th period)

b) Total energy yield from the hybrid system for Homs and Edinburgh

Looking at Figures3, 4,5,and6, it can be noticed that:

1. In the winter period, the hybrid system in Homs conditions outperforms that in the Edinburgh conditions by 25% in energy yield. This result was expected as there is a distinct difference in solar radiation between the two regions during this period.
2. For the second period i.e. spring time, the results for the system output are very similar, despite slightly higher levels of radiation in Homs for that time.
3. During summer time i.e. the third period, the system performs better in Edinburgh as compared to Homs by about 5%.
4. For the autumn (4th period), the energy yielded by the system in Homs is about 5% better compared to Edinburgh.

6. Conclusions and Results

The use of solar energy and biomass energy together in a hybrid system helps to reduce of the use of conventional energy and thus CO_2 emissions. The main advantage of this system is that it can be used to supply hot water not only for domestic usage but also for any application functioning at a lower temperature range < 150°C.

This system makes use of waste, thus helping in reuse and the by-product of the biomass reactor can be used again to produce fertilizer. As locally available waste can be used directly in the reactor, the cost of waste disposal is saved. Moreover, only a minimal amount of maintenance is required for running such a system.

For the whole duration of the test (1 year), the total energy output by the hybrid system was found out to be 1914 kWh. On the basis of present the diesel price in Syria of 0.45 USD and the cost of the hybrid system and the energy output, the payback period was found to be 6 years. In terms of CO_2, approximately 500 -2000 kg/year can be expected to be saved, depending upon the source of energy replaced.

The theoretical module developed for estimation purposes showed good conformance with actual measured results. The difference between the predicted and measured solar radiation was found to be less than 1% while a maximum difference of only 3.5% was noted in energy yield.

It was also noted that the difference in temperature between the condenser wall and water was as high as 30°C. This points towards a larger condenser area or forced convection mechanism to improve heat transfer from the solar collector to the water.

By testing the theoretical system performance for different weather conditions it was found that the system also performed well in Scottish conditions. Comparing Homs and Edinburgh, the system performed within 5% of energy yield throughout most of the year. Only in winter a 25% reduction of energy yield was noted for Edinburgh conditions, due to poor solar radiation during that time.

Acknowledgements

This research was initiated and supported by Albaath University, SAR. The authors would like to extend their gratitude towards all people who collaborated in producing this work.

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