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EXERGETIC ANALYSIS OF THERMOSYPHON SOLAR WATER HEATING SYSTEMS

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Abstract — Exergetic analysis was carried out on two thermosyphon solar water heating systems to evaluate their thermal performances. The two systems are of similar design but system B with the storage tank insulated is an improvement on System A with an uninsulated storage tank. In comparison with system A, system B absorbed more energy with about 62.4% of the absorbed energy available as useful energy. On the other hand, system A absorbed less energy and only about 31.1% of the absorbed energy is available as useful energy.

1. INTRODUCTION

At the present age, there is a greater awareness of the energy problems facing the world than at any other period in history. It is now widely accepted that the growth in energy consumption that has been experienced for many years cannot continue indefinitely as there is a limit to our fossil fuel reserves. For this reason, the search for alternative energy sources becomes necessary.

Solar energy is an ideal alternative source of energy because it is abundant and inexhaustible with the earth receiving each year solar energy equivalent to 75 times the present proven fossil fuel reserves [1]. It has been calculated that the solar radiation falling on the earth's atmosphere every hour could (if fully exploited) meet the annual energy needs of the world. Even in the United Kingdom, where lack of sunshine, particularly in winter, is notorious, the amount of solar energy received is eighty times the present total primary energy requirement [2]. Solar energy is not only abundant but many of the more promising strategies for tapping the solar energy resources also have much less damaging impacts on the environment, public health and global security.

Water heating application is one of the direct uses of solar energy. Most solar hot water systems have the ability to absorb the energy from the sun, transmit it to water and then store the hot water until it is needed. The solar water heating system in which the functions of absorbing and storing the energy from the sun are in separate units was designed, constructed using local materials and tested in Akure (Latitude 7.25°N).

The ideal thermodynamic efficiency of a process is the ratio of useful work performed to the amount of energy supplied to the process. If solar energy is absorbed at higher temperature in the solar collector than the prevailing environmental temperature, the energy will be partly converted to thermal energy of water and partly lost to the environment.

In order to evaluate the thermal performance of the system, therefore, a descriptive parameter that rates the quality of energy is desirable. Exergetic analysis, which employed heat energy as a descriptive parameter was used to rate the availability of energy in the systems.

In an ideal heating system, there will be no loss of exergetic potential thus resulting in an exergetic efficiency of 100%. This is clearly impossible to attain in real situations since the input energy will always be greater than the useful output energy and also some degradation of the quality of energy must occur to allow heat to be transferred. Therefore, the exergetic analysis was used for rating the effectiveness of the solar heating systems.

2. EXERGETIC ANALYSIS

In energy systems, not all the energy supplied is available to do work. The part of the supplied energy available to do the required work is known as "Heat exergy" whilst the unavailable energy is known as "Heat energy".

Total energy, E is

E = Heat Exergy, X + Heat Anergy, Y

$$\text{i.e } E = X + Y \quad (1)$$

Heat exergy, X is given by

$$X = \frac{T - T_a}{T} \times q \quad (2)$$

Exergetic potential, γ, is defined by the equation:

$$\gamma = \frac{T - T_a}{T} \quad (3)$$

Thus,

$$X = \gamma q \quad (4)$$

Exergetic efficiency, ηx is defined by the equation:

$$\eta_x = \frac{\text{output exergy}}{\text{input exergy}}$$

$$\eta_x = \frac{X_{out}}{X_{in}} = \frac{\gamma_{out}}{\gamma_{in}} \cdot \frac{q_{out}}{q_{in}} \times 100\% \quad (5)$$

Thermal efficiency, η_{th} is given by the relationship:

$$\eta_{th} = \frac{\text{useful output energy}}{\text{input energy}} = \frac{q_{out}}{q_{in}}$$

Therefore,

$$\eta_{th} = \frac{q_{out}}{q_{in}} \quad (6)$$

$$\text{and } \eta_x = \frac{\gamma_{out}}{\gamma_{in}} \cdot \eta_{th} \quad (7)$$

Duffie and Beckman [4] gave the useful energy gain as:

$$q_u = \frac{Q_u}{A_c} = F_R[S - U_L(T_{fi} - T_a)] \quad (8)$$

These parameters were computed and used to rate the quality of energy in the systems.

3. THE EXPERIMENTAL SET-UP

A solar water heating system (A) consists of a flat - plate solar collector and a separate uninsulated storage tank, together with connecting pipes. In order to achieve better performances of the system, the following modifications were carried out in system A, to obtain the modified system B:

(i) The storage tank was properly insulated using dry wood shaven to reduce the heat loss form the tank.

(ii) The space between the water pipes was reduced from 8.3cm to 5.5cm in order to minimise the temperature difference between the tip of fin and the base. These water pipes were properly welded to the absorber sheet to minimise the thermal contact resistance.

(iii) The diameter of the collector water pipes was reduced from 2.0cm to 1.7cm and their number increased from 6 to 9. This gives even spread of water along the absorber, thereby increasing the total heat gain.

(iv) The height between the storage tank and solar collector was increased from 50cm to 70cm to increase the flow rate.

Fig. 1 shows a schematic diagram of the thermosyphon solar water heating system.

The basic parts of the solar collector are: absorber plate; water pipes (or tubes); transparent glass cover and an insulated box. The surface of the tubes and the absorber plate are coated with black enamel paint. The assembly is mounted in a wooden box. The space between the collector assembly and the containing wooden box is filled with wood shaven as insulating material. The top surface of the box is covered with a 0.4cm thick clear glass with the air gap between the absorber plate and glass cover being 7cm. The overall dimensions o the collector was 113cm x 83cm x 19cm with an effective aperture area of 7000cm^2. A section through the flat-plate solar collector is shown in Fig. 2.0.

4. EXPERIMENTAL PROCEDURE

The solar water heating systems were tested at the observatory garden of the department of Meteorology, Federal University of Technology, Akure. During the test period, the parameters needed to evaluate the systems performance were measured. A Pyranometer was used to measures the incident solar radiation intensity whilst the inlet and outlet temperatures of the collectors and storage tanks were measured with mercury-in-glass thermometers. A humidity/temperature multimeter was used to measure the ambient air temperature and the relative humidity.

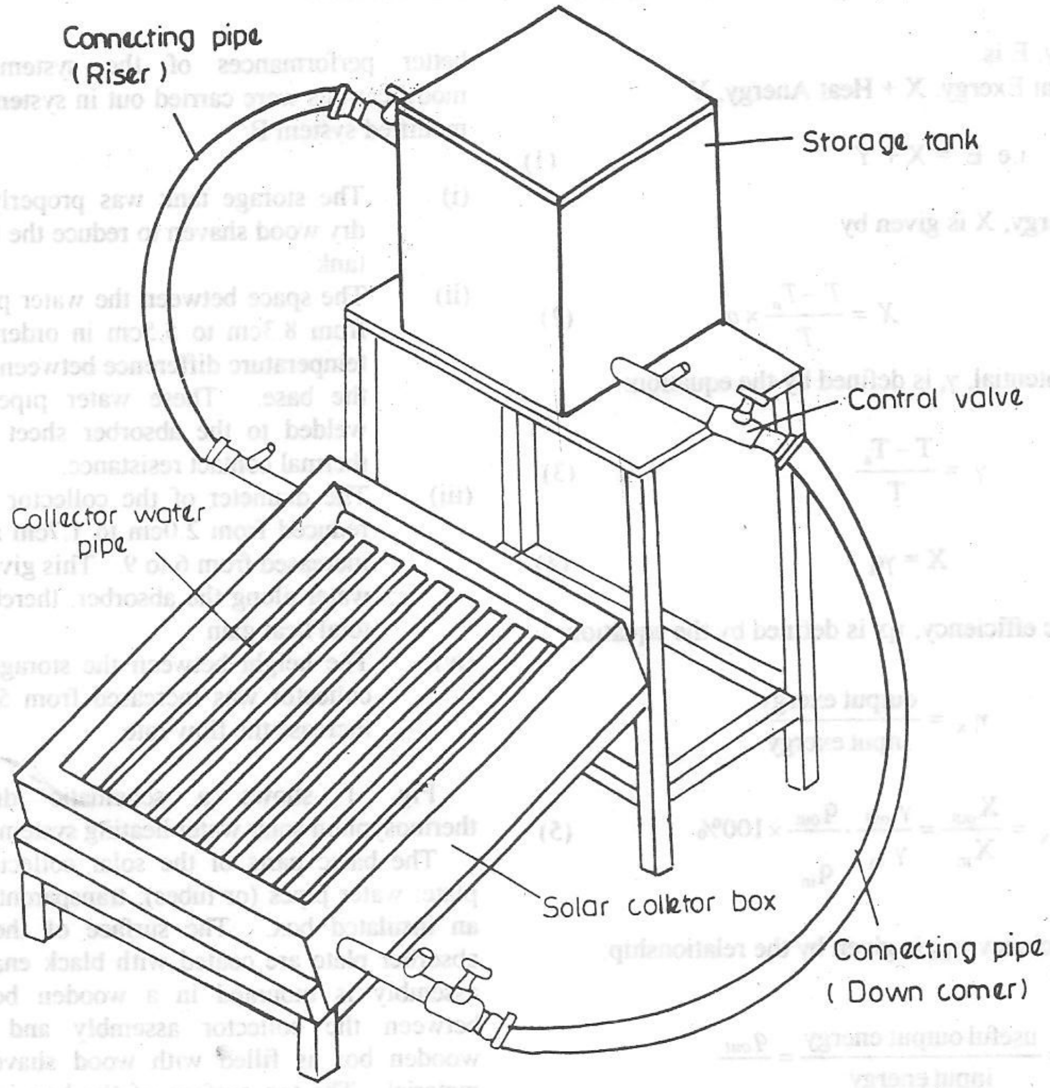

Fig. 1: Thermosyphon solar water heating system

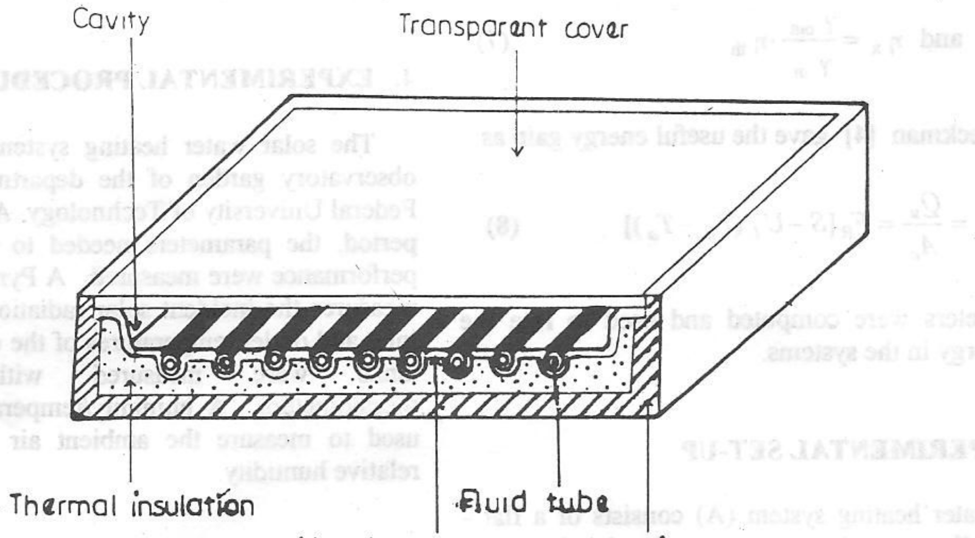

Fig. 2: Section through a flat plate collector

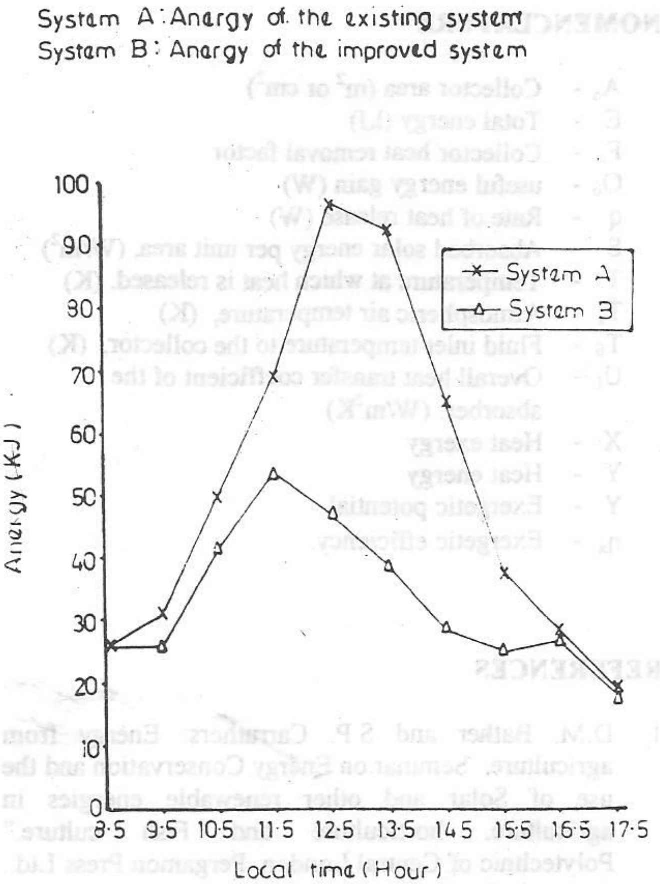

Fig. 3: Variation of Anergy with time

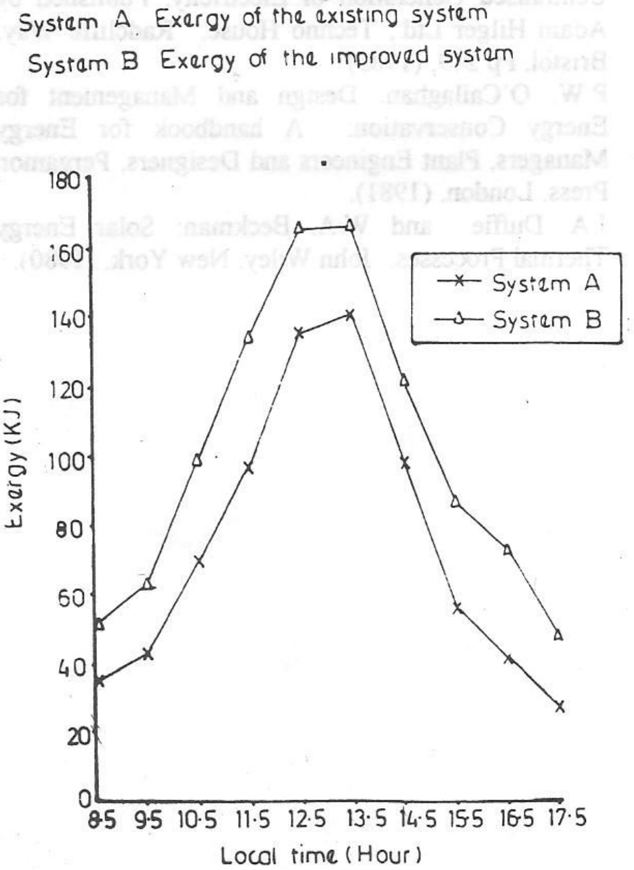

Fig. 4: Variation of exergy with time

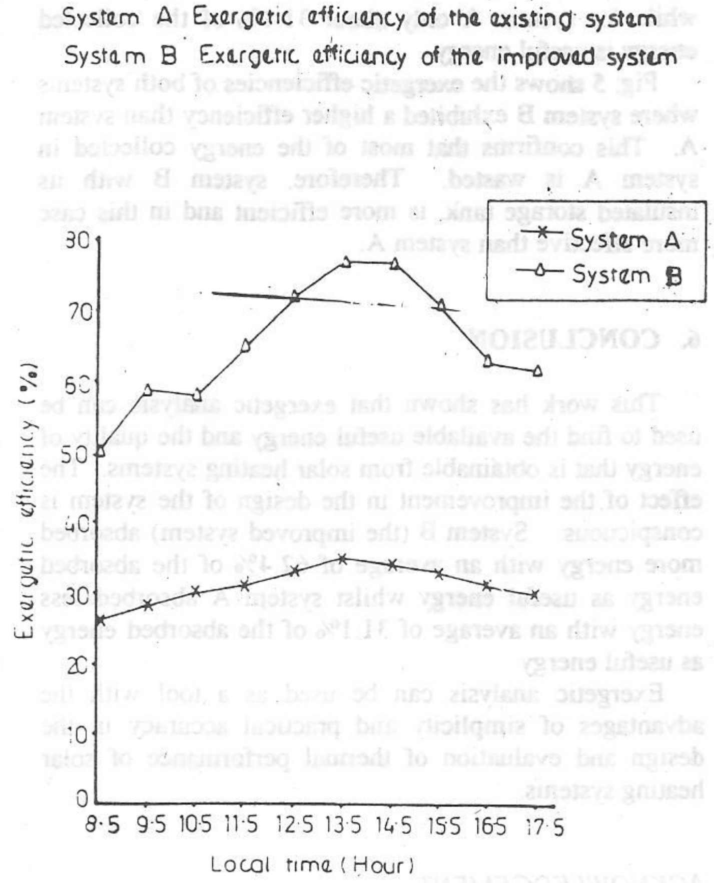

Fig 5·0: Variation of Exergetic efficiency with time.

5. RESULTS AND DISCUSSION

An exergetic analysis of systems A and B were carried out to find out the effect of available energy (heat exergy) on the performance of the systems. Fig 3.0 shows the hourly variation of energy for both systems for a typical day, both systems being exposed to the same environmental conditions. It was observed that the energy in system A increased drastically reaching peak value of 97kJ between 12.00 noon and 1.00 p.m. On the other hand, the energy was relatively smaller in system

This is clearly shown by the wide ga_ between the curves of the two systems. This is an indication that system A wasted more energy than system B. The energy loss is as a result of not insulating the storage tank and connecting pipes.

Fig. 4 shows the heat exergy for both systems. This indicates that more useful heat energy is available in system B than in system A. The insulation level in the collectors of both systems are the same but with the insulation of storage tank of system B, the inlet temperature of the water to the collector is higher, which will result in higher exergetic potential and consequently the heat exergy in system B. This desirable effect can also be attributed to the insulation of the storage tank of system B that also contributed to reduced energy in the system (Fig. 3.0). Further analysis shows that for system B, about 62.4% of the collected energy is useful energy while for system A only about 31.1% of the collected energy is useful energy.

Fig. 5 shows the exergetic efficiencies of both systems where system B exhibited a higher efficiency than system A. This confirms that most of the energy collected in system A is wasted. Therefore, system B with its insulated storage tank, is more efficient and in this case more effective than system A.

6. CONCLUSION

This work has shown that exergetic analysis can be used to find the available useful energy and the quality of energy that is obtainable from solar heating systems. The effect of the improvement in the design of the system is conspicuous. System B (the improved system) absorbed more energy with an average of 62.4% of the absorbed energy as useful energy whilst system A absorbed less energy with an average of 31.1% of the absorbed energy as useful energy.

Exergetic analysis can be used as a tool with the advantages of simplicity and practical accuracy in the design and evaluation of thermal performance of solar heating systems.

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NOMENCLATURE

A_o - Collector area (m^2 or cm^2)
E - Total energy (kJ)
F_o - Collector heat removal factor
Q_o - useful energy gain (W)
q - Rate of heat release (W)
S - Absorbed solar energy per unit area, (W/m^2)
T - Temperature at which heat is released, (K)
T_a - Atmospheric air temperature, (K)
T_{fi} - Fluid inlet temperature to the collector, (K)
U_L - Overall heat transfer coefficient of the absorber. (W/m^2K)
X - Heat exergy
Y - Heat energy
Y - Exergetic potential
η_x - Exergetic efficiency.

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