Exergetic Studies on Domestic and Industrial Solar Water Heaters

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Abstract: For a Solar Water Heater ,solar energy coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on any absorbing surface, then they gets converted into the heat, this heat is used for heating the water. Present study based on exergy theory. Exergy analysis is conducted with an objective of providing methods to save cost and to increase the efficiency of solar water heater. The calculation of exergy losses is also done. To optimize and allocate losses in energy systems exergy analysis has been widely used. Exergy is the indication for loss of available energy due to the creation of entropy in irreversible thermal systems or thermodynamic processes. The exergy loss in a system or process component is decided by multiplying the absolute temperature of the surroundings by the entropy increase. Exergy is defined as a maximum useful work that can be done by a system interacting with an environment. In the design, simulation and performance evaluation of energy systems Exergy analysis has been widely used.

Keywords: Thermodynamic process, exergy analysis, energy systems.

I. Introduction

The most competent of the unconventional energy sources is solar energy. Although the characteristic of low density and unsteady in nature, solar energy focus is more significant in recent years. By increased demand for energy and risen cost of fossil type fuels (i.e., gas or oil) solar energy is considered an eye-catching source of renewable energy that can be used for water heating in both domestic homes and industry. For an average family hot water consumed is nearly 25% of total energy consumption. The Solar water heating systems (SWH) are the cheapest and most reasonable clean energy available to homeowners that may provide most of hot water requisite by a family.

A Solar heater is a device which is used for heating the water, for producing the steam for household and industrial purposes by utilizing the solar energy. Solar energy is the energy which is coming from sun in the form of solar radiations in endless amount, when these solar radiations falls on absorbing surface, then they gets converted into the heat, this heat is used for heating the water. This type of thermal collector undergo from heat losses due to radiation and convection. Such losses increase rapidly as the temperature of the working fluid increases.Exergy is a quantifying of the maximum useful work that can be done by a system which is at constant pressure and temperature with an environment interaction.
Exergy is the term for loss of available energy due to the creation of entropy in irreversible processes. The analysis is based on the three procedure theory given by Professor Hua Ben, conversion procedure, utilization procedure, and recycling procedure respectively.

II. Characteristics of Exergy and Problem Statement

When energy loses its quality, exergy is destroyed. Exergy is the part of energy which is useful and therefore has economic value and is worth managing carefully. Exergy by definition depends not just on the state of a system or flow, but also on the state of the environment. Exergy efficiencies are a measure of approach to ideality (or reversibility). This is not necessarily true for energy efficiencies, which are often misleading. Exergy can generally be considered a valuable resource. There are both energy or non-energy resources and exergy is observed to be a measure of value for both.

Energy forms with high exergy contents are typically more valued and useful than energy forms with low exergy Fossil fuels, for instance, have high energy and energy contents [1].

III. About Solar Water Heating System

A working fluid (liquid) is brought into contact with a dark surface exposed to sunlight which causes the temperature of the fluid to rise. Generally this fluid may be the water being heated directly, also called a direct system. In an indirect system heat transfer fluid such as a glycol/water mixture that is passed through some form of heat exchanger. The classification of these systems can be three main categories mainly (a) Active systems (b) Passive systems (c) Batch systems.

3.1 Forced Circulation or Active Systems

Forced circulation or Active systems use electric pumps, valves, and controllers to circulate water or other heat-transfer fluids through the collectors. So, forced circulation systems and can be direct or indirect categories namely (a) Open-loop (Direct) Active System (b) Closed-loop (Indirect) Active System

3.1.1 Open-Loop Forced Circulation Systems

Open-loop active systems use pumps to circulate water through the collectors. This design is efficient and lowers operating costs but is not appropriate if the water is hard or acidic because scale and corrosion quickly disable the system. These open-loop systems are popular in non-freezing climates.

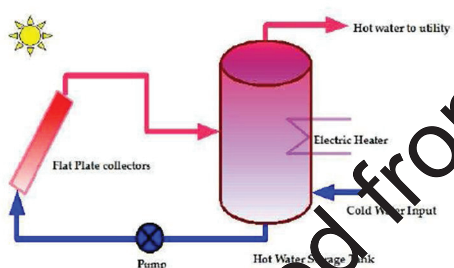


Fig1. Open-Loop Active Systems

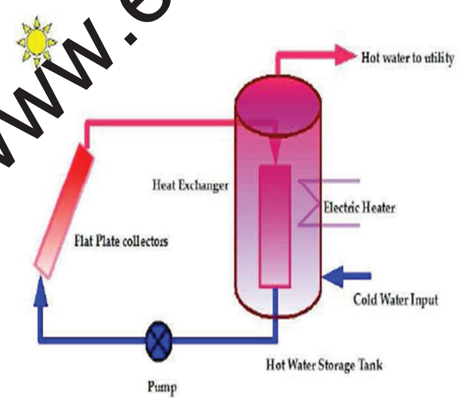


Fig2. Closed loop Active System

3.1.2 Closed-Loop Forced Circulation Systems

These systems pump heat-transfer fluids (usually a glycol-water antifreeze mixture) through collectors. Heat exchangers transfer the heat from the fluid to the household water stored in the tanks. Closed-loop glycol systems are popular in areas subject to extended freezing temperatures because they offer good freeze protection.

3.2 Passive Systems

Passive systems simply circulate water or a heat transfer fluid by natural convection between a collector and an elevated storage tank (above the collector). The principle is simple, as the fluid heats up its density decreases. The fluid becomes lighter and rises to the top of the collector where it is drawn to the storage tank. The fluid which has cooled down at the foot of the storage tank then flows back to the collector. Passive systems can be less expensive than active systems, but they can also be less efficient. Thermo siphon system is the best example of passive systems.

 ISBN : 978-81-925233-3-0

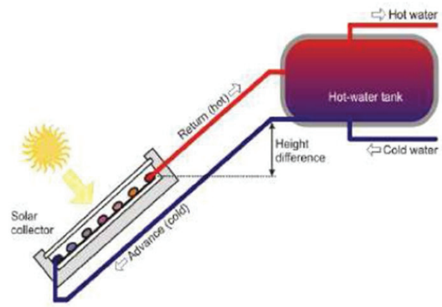


Fig3. Thermo siphon System

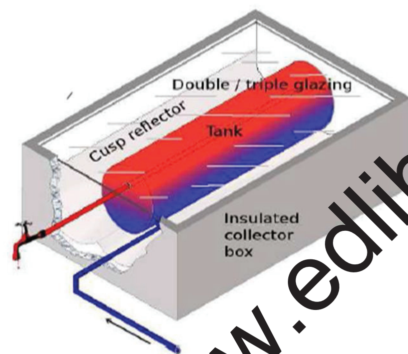


Fig4. Batch System

IV. Components of Solar Water Heater

SWH generally consists of a solar radiation collector panel, a storage tank, a pump, a heat exchanger, piping units, and auxiliary heating unit. Some of important components are described in the next sections.

4.1 Solar Collectors

The choice of collector is determined by the heating requirements and the environmental conditions in which it is employed. There are mainly three types of solar collectors like flat plate solar collector, evacuated tube solar collector, concentrated solar collector.

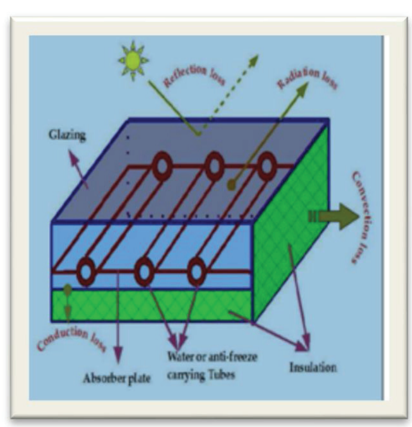


Fig5. Flat plate collector

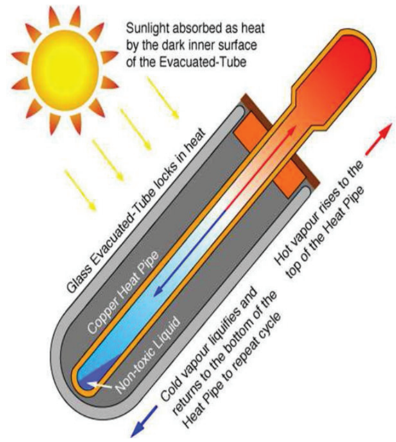


Fig6. Evacuated tube collector

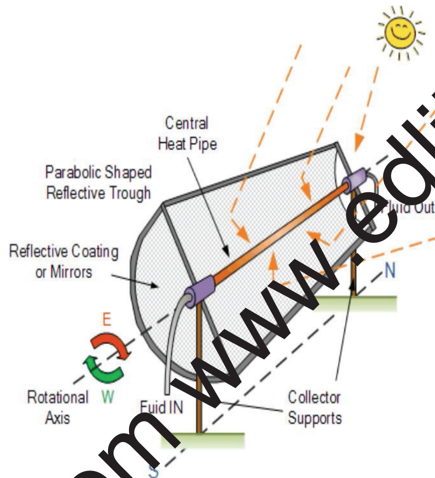


Fig7. Concentrating Collectors

The schematic diagrams of Fig.1 to Fig.7 describe the components of different solar collectors and their principles of operations respectively [2].

4.2 Storage Tank

Most commercially available solar water heaters require a well-insulated storage tank. Thermal storage tank is made of high pressure resisted stainless steel covered with the insulated fiber and aluminum foil. Some solar water heaters use pumps to recirculate warm water from storage tanks through collectors and exposed piping. This is generally to protect the pipes from freezing when outside temperatures drop to freezing or below.

4.3 Heat Transfer Fluid

A heat transfer fluid is used to collect the heat from collector and transfer to the storage tank either directly or with the help of heat exchanger. In order to have an efficient SHW configuration, the fluid should have high specific heat capacity, high thermal conductivity, low viscosity, and low thermal expansion coefficient, anti-corrosive property and above all low cost. Among the common heat transfer fluids such as water, glycol, silicon oils and hydrocarbon Oils, the water turns out to be the best among the fluids. Water is the cheapest, most readily available and thermally efficient fluid but does freeze and can cause corrosion.

V. An Exergy Analysis

The method, Exergy analysis is employed to detect and evaluate quantitatively the causes of the thermodynamic imperfection of the process. Exergy is also a measure of the maximum useful work that can be done by a system interacting with an environment which is at a constant pressure and temperature. An expression for loss of available energy due to the creation of entropy in irreversible processes is exergy.The exergy loss in a system or component is determined by multiplying the absolute temperature of the surroundings by the entropy increase. The concepts of exergy, available energy, and availability are essentially similar. Similar concepts are exergy destruction, exergy consumption, irreversibility, and lost work.

5.1 Three Procedure Theory

The Professor Hua Ben [3] presented energy analysis entitled 'Three Procedure Theory'. Among all theories of energy analysis, three procedure theory is good platform to perform energy analysis. The three different procedures of this theory are conversion, utilization, and recycling. In Fig. 8. Three procedure theory energy conversion procedure takes places at the sun are shown. The nuclear reaction in the sun makes it possible for the sun to emit a great quantity of power, which is transmitted in the form of electromagnetic waves. Utilization of energy is carried out in the collector. Solar radiation penetrates the cover and is incident on the black-color plate where it heats water flowing through the pipe. Energy recycling procedure takes places between the collector and the storage tank which corresponds to the storage tank keep hot water is pumped to users and cold water fills the storage tank from the bottom pipe simultaneously.

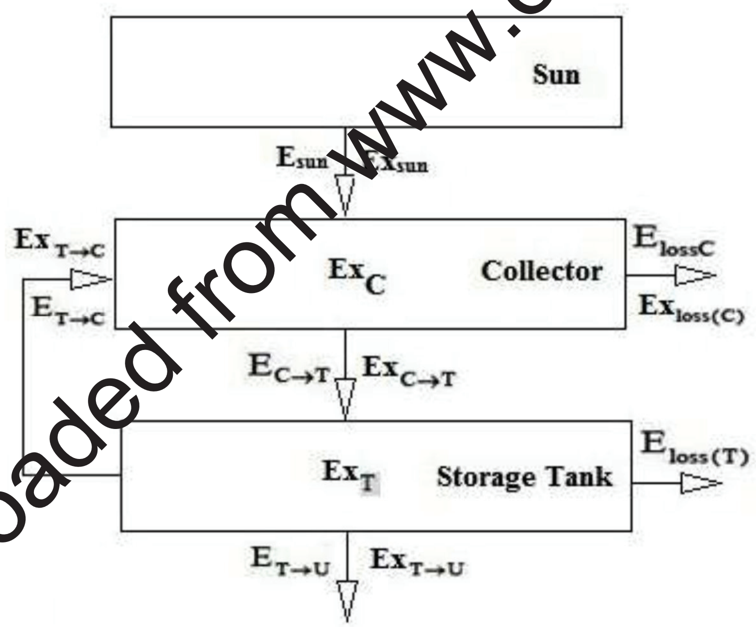


Fig8. Three procedure theory for the solar water heater

A) Energy balance equations:

At Collector:

$E_{sun} + E_{T\to C} = E_{lossC} + E_{C\to T}$ -- (1)

Where,

E_{sun} = Energy from Sun (input Energy) (W)

$E_{T\to C}$ = Energy from storage tank to collector associated with water recycle (W)

E_{lossC} = Energy losses due to imperfectly thermal insulation in collector (W)
$E_{C->T}$ = Energy from collector to storage tank (W)

At Storage Tank:

$E_{C->T} = E_{loss(T)} + E_{T->U} + E_{T->C}$ --(2)
Where,
$E_{loss(T)}$ = Energy losses due to imperfectly thermal insulation in storage tank (W)
$E_{T->U}$ = Energy from storage tank to user (output Energy) (W)

B) Exergy balance equations:

At Collector:

$E_{Xsun} + E_{X(T->C)} = E_{X\ lossC} + E_{X(C->T)}$ --(3)
Where,
E_{Xsun} = Exergy from sun (input power) (W)
$E_{X(T->C)}$ = Exergy from storage tank to collector associated with water recycle (W)
$E_{X\ lossC}$ = Exergy losses due to imperfectly thermal insulation in collector (W)
$E_{X(C->T)}$ = Exergy from collector to storage tank (W)

At Storage Tank:

$E_{X(C->T)} = E_{X\ loss(T)} + E_{X(T->U)} + E_{X(T->C)} + E_{XT}$ --(4)
Where, $E_{X\ loss(T)}$ = Exergy losses due to imperfectly thermal insulation in storage tank (W)
$E_{X(T->U)}$ = Exergy from storage tank to user (output exergy) (W)
E_{XT} = Energy losses due to irreversibility in storage tank

In utilization procedure, we assume the change in kinetic energy are very small since the solar water heater is driven by the difference of density of water, namely no great decrease in pressure is involved, so we can calculate exergy from collector to storage tank ($E_{X(C->T)}$) by use the following equation.

$E_{X(C->T)} = m_{fw} C_p (T_{CT} - T_a) + m\ C_p\ T_a\ \ln (T_{CT} / T_a)$ --(5)

Where, m_{fw} = Mass flow rate of water (kg/s)
T_{CT} = Outlet temperature of water from collector to storage tank (K)
T_a = Ambient temperature (K)
C_p = Specific heat of water {J/ (kg.K)}

Assuming the temperature distribution in the storage tank is linear (ΔT α ΔL), where L is the height of the storage tank), we get; $T_X = [(T_L - T_o)/L] X + T_o$ --(6)

Where T_x, T_L and T_o are the temperature of water at position X, L and O from the bottom of the storage tank. Then

We obtain the exergy from storage tank to users ($E_{X(T->U)}$) by use the following equation:

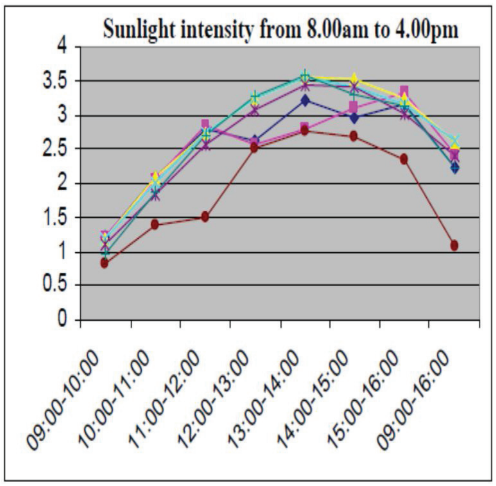
$$E_{X(T->U)} = \int_o^L dE_X = \int_o^L Apdx\ Cp\ \{(T_x - T_a) - T_a \ln(T_x \div T_a)\} / \int_o^t dt$$

$E_{X(T->U)} = m_{fw}C_p\{(T_L - T_a)/2 - T_a\} - m_{fw}C_pT_a\{\ln(T_L / T_a) - 1\} - m_{fw}C_p\{(T_a T_o)/(T_L - T_o)\}\ln(T_L/T_a)$ ---------------(7)

The Exergy based equations from equation (1) to equation (7) denotes different thermal energy sub systems and their relations with each other [2].

VI. Experimental Outcomes

An experiment [4] of studying the efficiency of the light divergence solar water heater was achieved during December - April. All data are collected from 8.00am – 4.00pm at the Solar energy research unit of Physics department in Nakhon Pathom. An example of the result is shown in Figure 9 and Figure 10 [4]. We found that the water temperature is depended on the intensity of the sunlight. An approximate temperature of the day is about 51 ^{o}C. Between noon to 3.00pm, the water temperature is between 50 – 70^{o} C, which is the range of a very useful water temperature.



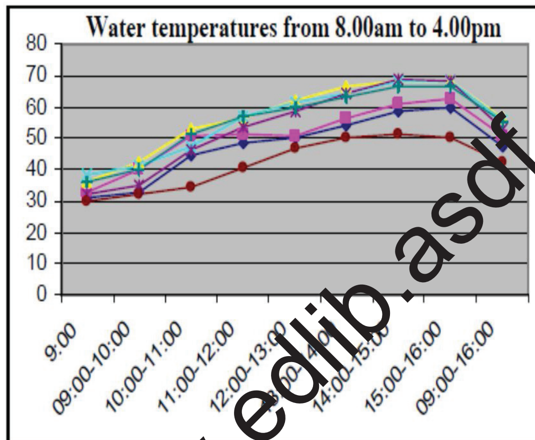


Fig 9. Sunlight intensity from 8.00am to 4.00 pm Fig 10. Water temperatures form 8.00am to 4.00 pm

6.1 Relation Between E_X and Q :

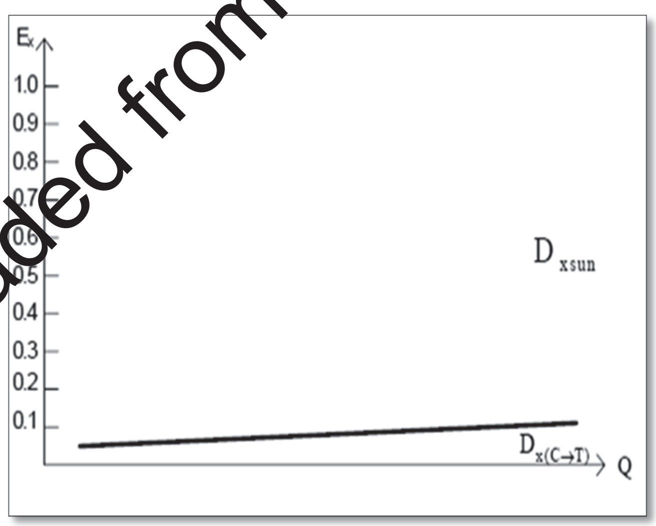


Fig 11. Graph between E_x and Q

The relation between Q and E_x indicated in Fig.11 geometrically interpreted as total exergy loss occurring in the system between curves D_{xsun} and $D_{x(T->U)}$,where D_{xsun} is the input power(exergy from sun) in Watts,$D_{x(C->T)}$ is exergy from collector to storage tank in Watts. Q is heat transferred between the system and environment and Ex is thermal exergy content [4].

V I I. Conclusion

The conversion of solar radiation in the evaluation of direct-solar systems leads to extremely high exergy losses in the direct solar systems. The optimization of these systems should be oriented so as to reduce the magnitude of exergy losses in the conversion device. Solar system exergy efficiency is highly dependent on the daily solar radiation and radiation intensity. For increasing the exergy efficiency, material selection, number of layers of transparent cover, pipe length is mandatory. Due to more exergy losses in the storage tank new design of storage tank is required.

VII. Future Work

In this work, the flat plate collector is analyzed and it would be a good initiative to explore the impact of other types of solar collectors like an evacuated tube or a concentrated types. In the present work only two components of the solar water heater are analyzed, other components such as a pump, piping system etc., could also be studied. For Optimization, pressure drop across the system and selection of pump, piping size are considered.

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