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PERFORMANCE ANALYSIS OF INTEGRATED PACKED BED SOLAR FLAT PLATE COLLECTOR

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ABSTRACT

The main objective of this paper is to study the performance of a solar flat plate collector-packed bed system by using various secondary working fluids such as water, air. In the present work, packed beds are used to store the thermal energy in the form of sensible heat over a period of time and utilize whenever it is required. Basically packed bed consists of materials like gravels, possessing high thermal conductivity. Air is used as the secondary working fluid in the system.

The system consists of two cycles. Primary cycle consists of solar flat plate through which primary working fluid (water) flows. Secondary cycle consists of packed bed (placed beneath the solar plate collector) through which secondary working fluid flows. A collector absorbs the solar radiation incident on them and converts into heat energy. A part of heat energy is carried away by water flowing through collector plate and remaining is absorbed by packed bed. Secondary fluid flowing through copper tube in packed bed absorbs heat energy from the packing material. For a continuous input of solar radiation, performance of system is determined and a comparison is made. From the calculations it is observed that the efficiency of packed bed Solar Flat Plate Collector is higher than the simple flat plate water heater.

KEYWORDS: Flat plate collector, packed bed, performance of flat plate collector

INTRODUCTION

Solar energy is most important among renewable energy sources due to its quantitative abundance. In order to face the problem of energy crisis and environmental threat as a result of continuous use of fossil fuels, scientists and researchers are putting efforts to develop technologies for an effective use of solar energy.
People may use energy for many purposes, but a few general tasks like heating, cooling, electricity generation, transport and industry consume most of the energy. Solar energy can be applied to all these tasks with different levels of success. However, intermittent nature of solar energy demands an integration of energy storage system with the solar collectors in order to make solar energy source more reliable.

PACKED BED

Packed bed or rock bed system is well known for various engineering applications. It can also be used with solar air heating system for storing thermal energy of hot air. Thermal energy stored in the packed bed may be useful to have uninterrupted supply of energy in the absence of solar radiation and also to fulfil the peak load energy demands even in the presence of solar radiation. Packed bed consists of energy storage material elements packed in a container. Energy stored in the bed can be extracted by making flow of air through the bed from bottom to top during discharging phase. Heat transfer to and from a flowing fluid in a packed bed has been the subject of many theoretical and experimental investigations for various engineering applications.[1,2]

In this paper an attempt is made to utilise the thermal energy lost at the bottom surface of the solar flat plate water heater to obtain the hot air their by increasing the efficiency of whole setup with the help of packed bed and using air as secondary working fluid inside packed bed.

THERMAL LOSSES IN A FLAT PLATE COLLECTOR

Heat losses from any solar water heating system take the three modes of heat transfer: radiation, convection and conduction. The conduction heat losses occur from sides and the back of the collector plate. The convection heat losses take place from the absorber plate to the glazing cover and can be reduced by evacuating the space between the absorber plate and the glazing cover and by optimizing the gap between them. The radiation losses occur from the absorber plate due to the plate temperature. Figure below shows the heat loss pattern in a typical flat-plate collector.

The heat losses from the transparent cover to the ambient air are due to radiative and convective exchanges which are affected by the wind velocity, ground, and surrounding, condition and by long wave radiation from the sky.[3,4]

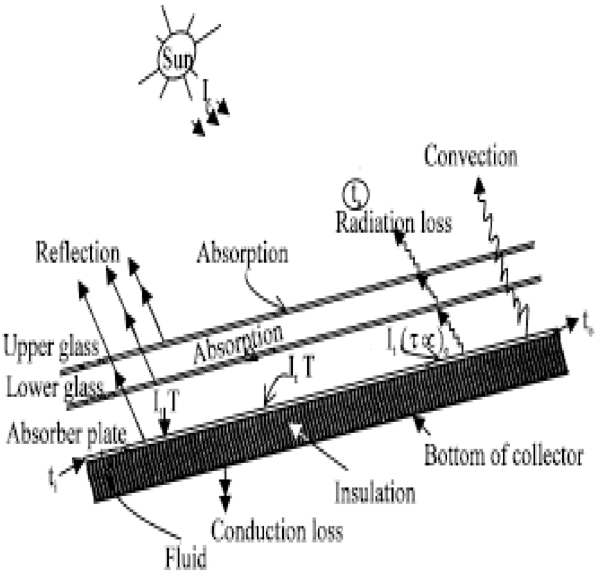

Figure 1: Thermal loses in SFC

EXPERIMENTAL SETUP

The objective of preparing this type of setup is that effective thermal energy loss about 39-45% from SFPC is from bottom surface and by having a simple modification the energy from bottom surface can be utilized for heating the air.[5,6]

The setup consists of a simple flat plate collector and integrated with a box at the bottom surface of the SFPC in order to fill it with the packed bed material. The system consists of primary circuit and secondary circuit. In primary circuit water as a working fluid and in secondary circuit air as working fluid.

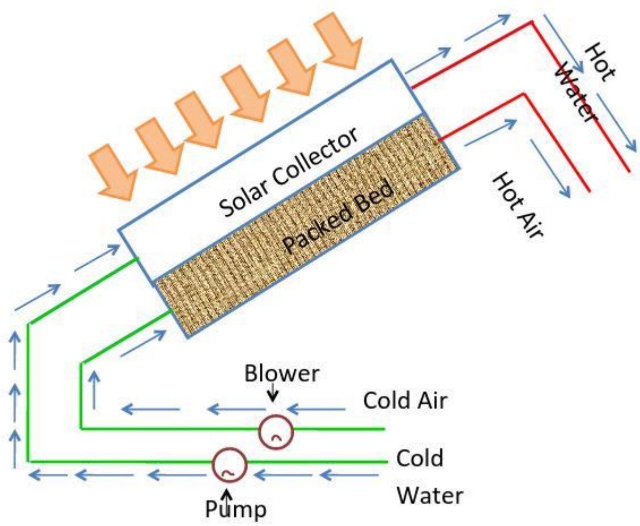

Figure 2: SFPC with packed bed

EXPERIMENTAL INVESTIGATIONS

The experiment is carried in three modes

1. With SFC
2. SFC with empty box (Air inside)
3. SFC with packed bed (material: gravels)

With SFPC

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Efficiency, $\eta_{SFC}=Q_w/(I_t*A)$
Heat gain by water, $Q_w= m_w*C_{pw}*(T_{out}-T_{in})$
T_{out}, T_{in}= outlet and inlet temperatures of water in collector
Specific heat of water, C_p=4.18J/KgK
Useful heat gain, $Q_u= Q_w$

SFPC with empty box (Air inside)

Efficiency, $\eta_{SFCE}= Q_u/(I_t*A)$

SFPC with packed bed (material: gravels)

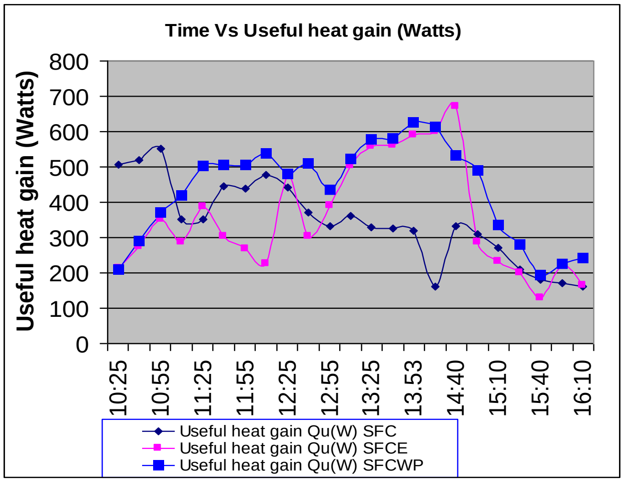
Efficiency, $\eta_{SFCWP}= Q_u/(I_t*A)$
Heat gain by air, $Q_a=m_a*C_{pa}*(T_{out}-T_{in})$
Useful heat gain, $Q_u=Q_w+Q_a$

RESULTS AND DISCUSSIONS

The table shows the useful heat gain and the efficiency of SFPC with packed bed (material: gravels) with respective tine and the intensity.

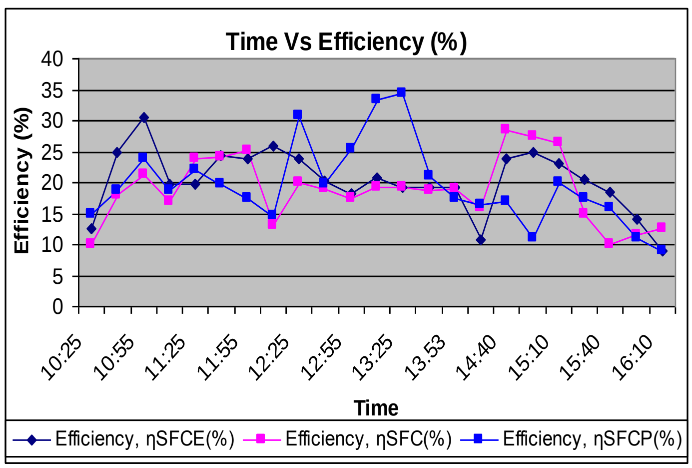
Table 1: SFPC with packed bed

S.No	Time	Intensity (W/M^2)	Useful Heat Gain Qu(W)	Efficiency η_{sfcwp}(%)
1	10:25	710.65	212.89	14.75
2	10:40	718.65	274.29	18.8
3	10:55	727.17	351.78	23.8
4	11:10	747.67	285.65	18.8
5	11:25	751.46	386.26	22
6	11:40	754.55	304.65	19.8
7	11:55	756.95	267.37	17.4
8	12:10	759.87	226.09	14.6
9	12:25	759.07	473.65	30.7
10	12:40	757.59	304.64	19.8
11	12:55	755.43	391.39	25.5
12	13:10	741.51	501.68	33.3
13	13:25	736.04	556.9	34.27
14	14:40	668.14	682.81	21.13
15	14:55	565.6	286.64	17.5
16	15:10	601.27	232.91	16.3
17	15:25	584.04	199.41	16.8
18	15:40	565.67	128.49	11.1
19	15:55	546.16	222.3	20
20	16:10	463.87	164.76	17.4



Graph 1

It is observed from the above graph that there is a gradual increase in the useful heat gain till 03:00PM. The maximum heat gain for SFCWP is 682.81Watts.



Graph 2

It is observed from the above graph that there is a gradual increase in the efficiency of the setup till 03:00PM.

The maximum efficiency for SFCWP is 33.3%

The efficiency of SFCE and SFCP drop drastically after 03:00PM when compared with SFC as the maximum radiant energy incident on the collector is gained by the primary fluid (water) and the energy available at the bottom surface is very low.

η_{SFC}=28.48%,η_{SFCE}=30.42%,η_{SFCWP}=33.3%

CONCLUSIONS

The maximum useful heat gain is observed during the time interval 12:00AM to 2:00PM.
The maximum efficiencies are observed during the time interval 12:00AM to 2:00PM.
Efficiency of SFPC with packed bed is more when compared with the SFPC with empty box and SFPC.
The rise in efficiency of SFCWP is 5% when compared with SFC.
The rise in efficiency of SFPCWP is 3% when compared with SFC

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NOMENCLATURE

Efficiency of Simple flat plate collector: η_{SFC} (%)

Efficiency of Simple flat plate collector with empty box: η_{SFCE} (%)

Efficiency of Simple flat plate collector with packed bed: η_{SFCWP} (%)

Useful heat gain: Q_u Watts
Heat gain by water: Q_w Watts
Heat gain by air: Q_a Watts
Intensity on tilted surface: I_t Watts/m^2
Collector area: A (m^2)
Mass flow rate of water: m_w (kg/sec)
Mass flow rate of air: m_a (kg/sec)
Specific heat of Water: C_{pw} (KJ/kgK)
Specific heat of air: C_{pa} (KJ/kgK)
Out let temperature of fluid: T_{out} (^{O}C)
Inlet temperature of fluid: T_{in} (^{O}C)

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