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A COST EFFECTIVE SOLAR AIR-HEATER (SAH) WITH RECYCLED ALUMINUM CAN (RAC) COLLECTOR

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Abstract—*The main objective of the work was to use solar energy for air-heating, drying crops and agricultural needs. Present Solar Air-Heater (SAH) includes black painted recycled aluminum cans, wooden frame, tempered glass, and Al sheet, was design and built. The air enters into the collector gets heated by solar radiation. The collector is tilted in an optimum angle and natural draught occurs due to tilting. Due to the draught effect the air enters into collector, gets heated and goes upward. The performance of the system was estimated and results were discussed. The collector was made up of recycled aluminum soft drink cans to be built at a low cost. With an area of 15m x 0.5m collector setup is experimentally tested. It is compact in nature as it is easy to assemble and dissemble. Because of using country wood, recycled Al cans, and Al sheet in fabrication, it is lower in cost.*

1. INTRODUCTION

"Energy is neither be created nor be destroyed, but it transfers from one form to another form". Energy is the basis of human life. Every moment of the day, we are using energy [1]. Energy consumption has increased dramatically in last 35 years and the resulting increases in pollution (air, water and soil), emission of greenhouse gasses, water scarcity, depletion of fossil fuels, drastic climatic changes are serious consequences for human existence [2]. It is the need of today's world to concentrate on renewable energy sources to satisfy the demand and conserve our finite natural resources for the generations to come. There are many benefits of alternate sources of energy such as sustainability, eco-friendly environment, human health, and enhanced income [3-4]. Generating power using renewable energy sources is still facing many challenges. First, it is expensive due to the high capital cost. Also, storing renewable energy to be used when needed is still a matter of extensive research [5].

The sun that we see daily is the nearest star. It is one hundred earth diameters across and is ninety-three million miles away from the earth. Every day sun supplies the solar system with a tremendous amount of heat, light and energy [6]. The very tiny fraction of the sun`s energy that falls on the earth is about hundred million million times greater than all the energy used in the world`s industries. The energy the sun emits in one second is greater than the whole amount of energy the human species has consumed throughout its entire history [7].

The contemporary major and largely implemented applications associated to solar energy are electricity production from wet or dry steam generated in solar parabolic trough collectors and through photovoltaic cells, heat production for agriculture and environmental processes such as drying, and pollutants removal, high temperature processes obtained by solar water heaters, air heaters, solar cookers, solar furnaces and solar lasers for semiconductors processing, using parabolic dish collectors or heliostats [8]. Solar-thermal systems can play a key role in the sustainability scenario. However, implementing solar thermal system projects requires innovative solutions and able to exceed the barriers that currently limit the widespread of these types of systems. Therefore, several requirements have to be fulfilled, related to functionality (efficiency), feasibility (implementation and operation and & maintenance costs), architectural integration (giving use to roof, rooftops and suitably porticos), and users acceptance [9].

Solar energy collectors are a special kind of heat exchangers [10] that transform solar radiation energy to internal energy of the transport medium [11]. In Solar Air Heaters (SAH), air is being directly used as the working substance, the system is less complicated and is compact. The corrosion problem, which can become serious in solar water heater, is completely eliminated in solar air heaters. Hence light gauge steel or aluminum plates can easily be used. Hence, a solar air heater appears to be inherently cheaper and can last longer. Unlike liquid flat plate collectors, system is not pressurized and therefore, light gauge metal sheets can be used. In solar air heaters leakage is also not a big problem, unlike in liquid collectors [12]. Depending on the absorber plate, air heaters can be classified into two types [13]; porous collector and non-porous collector.

The current air heaters in the market today works with fuel or by electricity. Fuel prices are high and are predicted to increase even more. To save costs the present Recycled Aluminum Can (RAC) modeled. The RAC air heater is made of country wood, recycled Al cans, Al sheet in fabrication and no need of power supply. Two points considered to achieve are reduction in cost of equipment and ease of producing hot air in less time.

2. LITERATURE REVIEW

The most common types of solar collectors and are usually used as SAH for preheating the air in domestic or industrial heating, ventilation, and air conditioning systems. It is technically feasible to use solar heated air for providing energy for almost any application that uses solar-heated liquids. The important areas of applications are space heating and cooling of buildings, drying of agricultural products, for seasoning timber in timber industry, curing of plastic in industrial sector, dehumidifying agent and integrated desalination plants [14].

The SAH design generally all consist of four major parts: (i) a flat plate absorber, which absorbs the solar energy, (ii) a transparent cover that allows solar energy to pass through and reduces heat loss from the absorber, (iii) a heat-transport fluid (air or water) flowing through the collector to remove heat from the absorber, and (iv) a heat insulating backing [15]. Krishnananth., et.al. [16] investigated experimentally the performance of double pass solar air heater (SAH). They used paraffin wax encapsulated in six aluminum pipes and studied the behavior of solar heater for four different configurations. In configuration 2 and 3, the Al pipes filled with TSM were placed above and below the absorber plate, respectively. In configuration 4, those pipes were placed above the back plate. The maximum efficiency was observed for configuration 2 during night hours in the absence of sunlight due to the addition of TSM.

Velmuruganl, et.al. [17] Investigated a double pass SAH and observed that the temperature of air at collector exit decreased at higher mass flow rate. Similar results were obtained for single pass experimental conditions. Further the glass plate temperature and absorber plate temperature was found to be lower at higher mass flow rate employing double pass.

Alvarez., et al. [18] developed an efficient single-glass air solar collector with an absorber plate made of recyclable aluminum cans. They compared the thermal efficiency of the collector with the reported ones. The efficiency of the RAC was compared with some of the other collectors as well and the results were that its efficiency was greater than the single air flow, double air flow and Double air pass solar collectors.

A periodic analysis of a double glass, single duct solar air heater with packed bed with upward air flow was investigated by Singh et al. [19]. They used different packed bed materials such as concrete, bricks, coal, copper, aluminum, etc. They found that coal gives as good performance as metallic materials. Donggen Peng et al. [20], studied a novel solar air collector of pin fin integrated absorber, designed to increase the thermal efficiency. In the performance analysis of varying flow rate on pin-fin array's collector, the correlation equation for a heat transfer coefficient is obtained.

3. PROPOSED SOLAR AIR HEATER

In the present work the experimental setup mainly comprises of black coated recycled aluminum cans (absorber plate), tempered glass (transparent cover), ambient air (heat transporter medium), thermocoal sealing (insulating), exhaust fan, wooden frame, solar panel for power supply and stand. A mathematical model was developed, sensitivity analyses were conducted to optimize the system and the design parameters obtained were then used in the dimensioning and sizing of the components for fabrication.

With the understanding of air heater operation was developed and depicted within the Fig. 1.

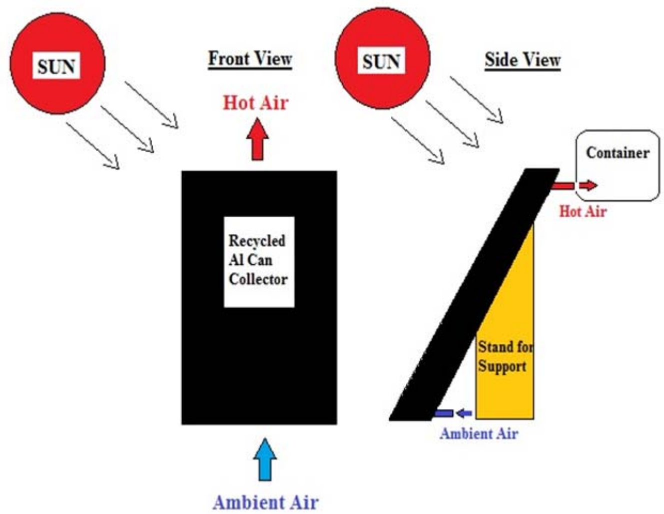

Fig. 1: Schematic diagram of solar RAC air heater.

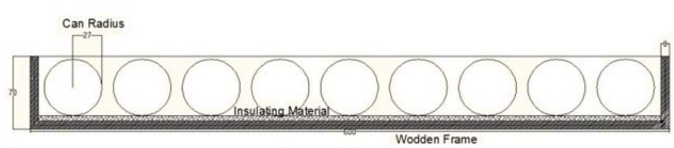

Fig. 2: Solar collector with 9 columns of recycled aluminum cans (front view)

4. FABRICATION PROCESS OF COLLECTOR

The country wood was cut into the dimensions (1.5m X 0.6m) for the outer frame of the collector and the thickness of wood frame is 15cm. A Plywood Sheet of 6mm thickness and 0.9m2 area fixed at the back of frame. Holes are marked and drilled with drill tool for air inlet. A hole of 16cm diameter was made at the top of the collector for air outlet and a 6mm guide way given on the side of the wooden frame for easy inserting of tempered glass.

Entire bottom of wooden frame sealed with thermocoal as insulation and a hole was made at the top as per the 16cm cut on wooden frame for air outlet. Al (30 gauge) metal sheet was taken with dimensions of 1.5m X 0.6m and inserted over insulation in the wooden frame for more heat absorption.

Every Al can's back and front lids are removed. The outer surface printing paint layer on al cans are removed by using sand paper for more heat absorption. One end of a can was attached with another one end with adhesive and fixed such that there is no gap for air loss at can joint. Black colour gas paint was coated over outer surface of each and every can for more heat transfer.

Fig. 3: Step wise process of preparing a wooden frame

Fig. 4: Step wise process of preparing a wooden frame

Fig. 5: Coke cans cutting, attaching and painting

Fig. 6: Fixing of cans, tempered glass, induced fan

Cans are placed in wooden frame and all can ends are fitted for ambient air passage into Al cans without losses. Tempered glass was inserted through the guide as transparent cover and sealed at sides such that no airs enter through it. For forced convection an induced fan is inserted (runs by solar photovoltaic cell) at the collector outlet.

5. EXPERIMENTAL SET-UP

The collector was made up of recycled aluminum soft drink cans to build at a low cost. The baffle plate of the collector consists of 9 circular section air flow channels each made by joining 8 recycled Al cans (Figs.5& 6). Table 1 shows the specifications of the solar collector. For ensuring forced convection, an exhaust fan, which runs with solar energy, was used. Tempered glass and Al sheet were used at the bottom of collector to ensure more heat absorption and reflection. Optimum Tilt angle of collector is obtained from Ulgan K [21].

Table 1: Dimensions and specifications of RAC solar collector

S. No	Assumption(s)	Specification(s)
1	Solar irradiation	1000W/m^2
2	Collector area	1.5 x 0.6m^2
3	Base plate temperature	Constant
4	Absorber plate material	Black painted aluminum
5	Ambient temperature	28°C
6	Inlet air temperature	32°C
7	Double glazing	Applied
8	Wind velocity	2m/s
9	Tempered glass emissivity	0.88
10	Tempered glass transmissivity	0.85
11	Tilt angle of collector	80°
12	Testing Time	8 hours per a day
13	Black paint absorber plate emissivity	0.09

5.1 Performance of RAC Solar Collector

The performance of solar air collector was calculated using the data shown in Table 2. Alvarez. G et.al. [18] calculated RAC air solar collector thermal efficiency as the ratio of the total useful specific enthalpy flux and the total incident solar radiation flux.

$$\eta = \frac{\int_{t_1}^{t_2} \dot{m} C_p}{A_c} \frac{(T_o - T_i)\,dt}{\int_{t_1}^{t_2} G.dt} \quad \text{(a)}$$

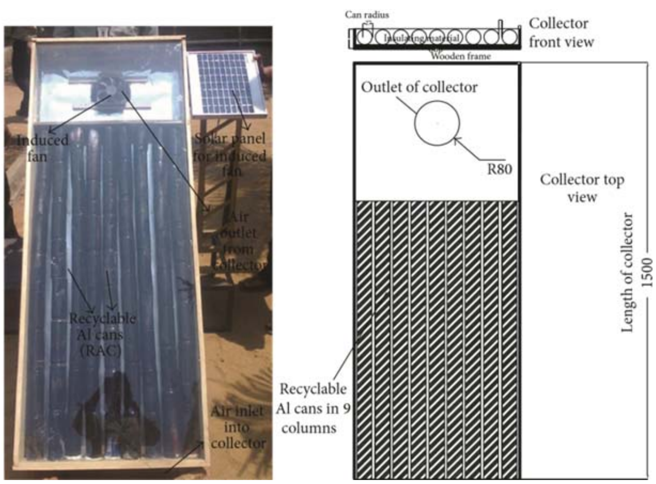

Fig. 7: Solar collector made of recycled aluminum cans (RAC collector)

Table 2: Dimensions and specifications of RAC solar collector

Data Assumed	Value(s)
Length of collector	1.5m
Width of collector	0.6m
Length of absorber plate (L_1)	1.5m
Width of absorber plate (L_2)	0.6m
Spacing between absorber plate and bottom plate (L)	1.5cm
Air flow rate ($\dot{m}$)	200kg/hr
Air inlet temperature (T_{fi})	30°C
Ambient temperature (T_a)	28°C
Solar flux incident on the collector face (I_T)	950 W/m^2-°C
Transmissivity $(\tau_\alpha)_{avg}$	0.85
Top loss Coefficient (U_t)	6.2 W/m^2-°C
Bottom loss Coefficient(U_b)	0.8 W/m^2-°C
Emissivity top plate and bottom plate surfaces $\varepsilon_p = \varepsilon_b$	0.95

5.2 Experimental conditions

The experiment was conducted for 8 hr. The values were taken at following conditions

Location : Tadepalligudem, AP, India

Local Time : 11:00 AM to 1:00 PM,

Date : 10th April 2014

Latitude : 16° 50' 10.18"

Longitude : 81° 31' 1.81"

Readings for the solar panel connected:

V=30 volt; i=0.028 amp

Following are solar parameters prevailing in the place of work. Sukhatme and Nayak [22] has given a detailed procedure for calculating solar irradiance of a system at a location:

Latitude (ϕ)= 16.50 deg

Day Number (n)= 100

Array Tilt (Slope)(β)= 80 deg (but, optimal for that month is at 81 degrees)

Declination angle (δ (in deg))= $23.45 \sin\left[\frac{360}{365}(284+n)\right]$ = 23.08 deg (1)

Hour angle (ω) = $\cos^{-1}(-\tan\phi . \tan\delta)$ (2)

Monthly avg. radiation (I_o)=

$I_{sc}\,(1+0.033\cos(\frac{360n}{365}))$kw/m^2 (3)

Solar irradiance on a tilted surface with no atmospheric effects (H_{ot}) =

$\frac{24\,I}{\pi}(\cos(\phi-\beta)\cos\delta . \cos\omega + \omega\sin(\phi-\beta)\sin\delta)$

kwh/m^2/day (4)

Solar energy with no atmosphere (H_o) =

$\frac{24\,I}{\pi}(\cos\phi\cos\delta\cos\omega + \omega\sin\phi\sin\delta)$ kwh/m^2/day (5)

The above input values were submitted in Eqs 1, 2, 3, 4 and 5 and irradiance was calculated as 6.39 kWh/m^2.

However, a minimal value of 1.0 kWh/m^2 was considered in the calculations.

6. RESULTS AND DISCUSSIONS

The ambient air entered in the collector was heated through the black painted cans with minimum solar irradiation of 1000W/m^2 applied. Due to use of constant air flow thrown by the induced fan, mass flow rate remains constant and due to it, uniform temperature rise occurs inside the SAH consist of aluminum absorber plate as well as RAC. With help of Aluminum Cans, aluminum as material, it has good heat transfer coefficient, hence temperature rise will occurs, and this is main reason for increasing temperature of absorber plate inside SAH. The temperature distributions along the collector were recorded in Tables 3 by using laboratory thermometer and relation between Time vs temperature of collector represented graphically in Fig.8.

Table 3: RAC collector temperature distribution

Time	Inlet temperature of collector (°C)	Outlet temperature of collector (°C)
11:30AM	30	43
11:45AM	31	49
12:00PM	32	53
12:15PM	32	59
12:30PM	34	64
1:00 PM	35	74

Graph shows that, when time goes, collector temperature increases from morning 11:30 am to afternoon 1 pm. Thermal efficiency is also play vital role in performance of solar air heater. Because it is nothing but the ratio of work done per heat supplied in form of solar insolation as well as blower. Hence, it is seen that, thermal efficiency gradually increases from morning to evening because it depends on solar radiation.

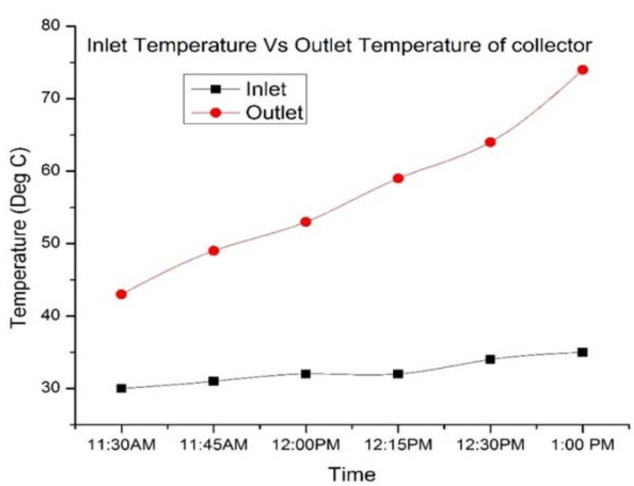

Fig. 8: Inlet and outlet temperature of collector

7. CONCLUSIONS

The daily efficiency of RAC collector depends on the heat energy which was gained from solar energy to heat input ambient air and absorber plate temperature. .The primary goal of the project was achieved through the feasible RAC collector for air heating. With the specified design parameters at a minimum solar irradiation of 1000 W/m^2, experimental testing was done on the prototype system. SAH using Recycled Aluminum cans as well as Al absorber plate is also cost effective. Thermal efficiency of solar air heater greatly depends on time, solar insulation and mass flow rate. Present RAC air heater can be applied in used in Therefore, the requirements such as functionality, implementation, operation & maintenance costs and architectural integration are fulfilled and which leads to user's easy acceptance.

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9. ABBREVIATIONS

SAH = Solar Air Heater

RAC = Recycled Aluminum Can

TSM = Thermally Storage Materials

10. NOMENCLATURE

A_c = collector area (m^2)

G = incident solar radiation (W/m^2)

η = thermal efficiency of the collector

C_p =specific heat (J/kg K)

t = time (s)

T_o = mean out let temperature of the collector (°C)

T_i = mean inlet temperature of the collector (°C)

$\dot{m}$ = mass flow rate (kg/s)

ϕ = latitude

n = day number

β = array tilt (slope)

δ = declination angle

ω = hour angle

I_o = monthly avg. radiation

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