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Heat Transfer Analysis of Flat Plate Air Collector

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Abstract

Solar collectors of Flat Plate type is a thermal transfer device that absorbs solar radiation and converts it into heat, which is mainly used to increase the water temperature, heat and dryness, dryness of crops in the region, space heating and in industries where this hot fluid is required for many chemical reactions, and for applications requiring the temperature of the fluid to be less than 100°C. As non-renewable sources of energy are becoming depleted and will soon have the power crisis. So, referring to fatigue rates, we should use our entire renewable resources so that we can control the rate of decline. The main components of the flat plate air collector are, absorbing plate, top covering plate (glass cover), insulating material and channel pipes covered with insulating material. Absorber plates are covered with a high absorbent coating. The top cover should be made of a maximum transmittance. The effectiveness of the flat plate air collector is highly affected by the losses through the top covering material and also due to the low heat transfer coefficient between the absorber plate and the air flowing through it. Most of the experiments and studies have shown that efficiency can be increased by using different types of solar collector which include double pass, a single pass with fins etc. Based on the literature survey it has been found that most of the studies on the solar collector are done to increase its thermal efficiency by enhancing the rate heat transfer between air and the absorber plate by using rough surface on the absorber plate.

Keywords: Absorber plate, Flat plate air collector, Solar energy

1. Introduction

On earth, nature has given different forms of energy to explore and depending upon available type of energy sources, industrial and economic growth of any country can be predicted. It is seen in present scenario that due to continuous population growth and industrialisation increased the demand of energy. Presently, fossil fuels are main source for power production. On other hand, burning of fossil fuel leads harmful gasses density on our planet which is very dangerous for all living species on earth. In present era, lots of work is going on harnessing opportunities available through renewable and clean source of energy. Solar energy is a one of the renewable energy available on the earth which has unlimited scope and it is capable in meeting all energy requirements of human being. Also, solar energy is ever lasting and non-polluting [1]. Nearly, 175 petawatts (PW) of solar energy is received by the earth's upper atmosphere. The effortless way to utilize the solar energy for thermal applications is to convert the incoming solar radiations into heat energy using solar air collector. This low-temperature energy technology has attracted the attention of many scholars and scientists and many developments have been done to increase efficiency. Over the years, several designs for solar the air collector has been developed in order to improve its performance. Generally, there are two kinds of solar collectors



are used, liquid heating solar collectors and air heating solar collectors. The rate of development towards the performance of collector is slow as compared to water heating solar collector. This is mainly due to the low thermal efficiency and low ability of air to carry heat. But these air collectors have been widely used for purposes like space heating, textile industries, crop drying and for many more applications [2-4]. Various design and flow arrangement have been employed for improving the discharge of the flat plate solar air collector.

1.1 Flat plate collector

The most important parts of flat plate solar collectors include- the absorber plate (black coloured), a transparent cover that allows solar radiations to pass (maximum transmittance), fluid to carry heat (air, antifreeze or water) from the absorber plate and heat insulating back. The fluid should have a high heat transfer coefficient [5]. The absorber plate includes a sheet, which can be made of thermally stable polymers, aluminium or copper and on this sheet a coating of matte black colour or selective coating (chrome coating) is done. This absorber plate is placed in an insulated casing with a glass or polymer cover which allows the radiations to fall upon the absorber plate. Sometimes reflectors are used to improve the amount of incidence of solar radiations on the absorber plate so that the efficiency could be increased. Flat plate solar air collectors can reach a temperature of around 50 to 70°C. Higher temperatures are feasible using special surfaces, reflectors, paint and good insulating casing [6].

1.2 Types of Flat Plate Collector

The flat plate solar collectors can be divided on the basis of fluid or non-fluid. The fluid type of air solar collector mostly consists of water as medium which heats at the output outlet. This type of solar collector is widely used in many parts of the earth to easily heat the water and later use it for other purposes. We can also divide the type of solar air collector on the basis of channel flow of air configuration that is made. Basically, there are four types of air channel flow type namely as

- Single flow single pass
- Dual flow single pass
- Single flow dual pass
- Single flow recycled dual pass type.

Sometimes the design of air flow channel in the collectors plays a vital role in deciding the type of air collector. So, on the basis of design configuration of the channel three main types of solar air collector is made.

- Flat plate
- Porous media assisted channel
- Extended surface assisted [6].

2. Classification According to Air Channel Flow

Different scholars, researchers, engineers and scientists have done their researches on this very important topic and studied different types of air flow channel layouts. The basic purpose of all these researches and studies have concluded many results and explained different type of channel pass layouts. These studies have revealed how we can increase the performance of the flat plate air collector [7].

2.1 Single Flow Single Pass

This type of flat plate solar air collector is most commonly found and simplest type of air heating appliance. This type of air collector consists of duct for air flow passage, insulation for saving waste heat energy and converting it into a useful one, glazing material (glass cover for transmitting solar radiation on absorption plates). For absorber plate, aluminium or copper which have higher thermal conductivity and high absorptivity values in single flow pass insulation can be done by using clay or glass wool which is a very good insulator for preventing loss of heat to environment.

Heat is transferred from absorber plate which heats the air above it which is coming from the inlet and then heated air is taken out to further processes through outlet. This type of air collector is the

mostly used in space heating or room heating purposes in cold regions of the earth. The use of air collector saves electricity consumed during the day time [7, 8-13].

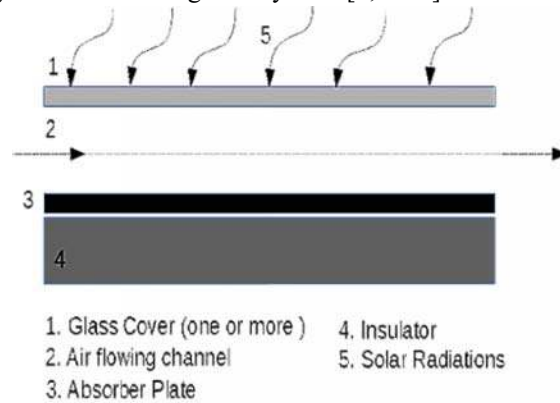


Fig. 1 Single flow single pass air collector

2.2 Double Flow Single Pass

It is very similar to single flow single pass type the main difference is just that there are two absorber plates used in between of the glazing material and insulating material. The air coming into the collector divides into two part and hence increases the thermal heat transfer from absorber plates to increase the temperature of air at outlet. For upper and lower channel air outlet is in same direction and of same area as outlet that's why it is double flow single pass type [9, 13].

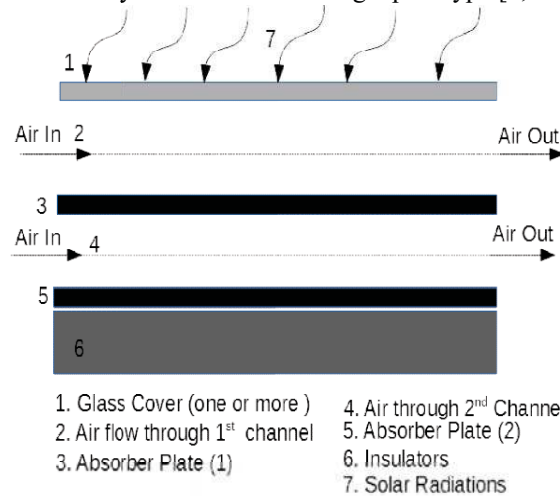


Fig. 2 Double pass single flow air collector

2.3 Single Flow Double Pass

In single flow double pass flat plate air collector there are two overlapping channels of air flow. The direction of flow of air is from upper channel, changes its direction at the end of the channel and then flows back through the lower channel. This is the reason for naming this type of air collector as “single flow double pass”. As per the literature review there can be two types of construction for this kind of solar air collector. The first one includes two air channels that are divided from one another by glass sheet (any transparent cover) and at the lower base the absorber plate is placed (figure 3.1). Flow of air takes place firstly through the glass sheet and then passes through the base absorber plate. The absorber plate is insulated from the backside of the plate. Figure 3.2 show the other construction of this kind of air collector which has the same construction as the first types except the place of the

lower glass sheet and absorber plate is interchanged. Now the upper channel is configured as glass cover and absorber plate and second channel include the plate and other glass sheet as shown in the figure. Both the configurations increase area of contact, as a result of which air is preheated or post-heated respectively. But due to the introduction of extra sheet the absorption done by the is less [9, 10, 13].

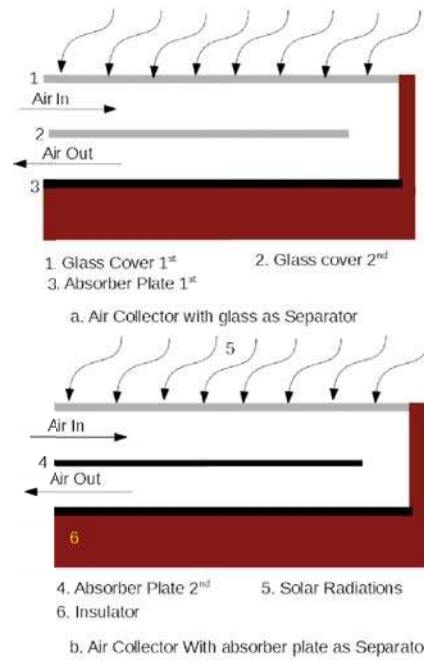


Fig. 3 Single flow double pass

2.4 Single Flow Recycled Double Pass

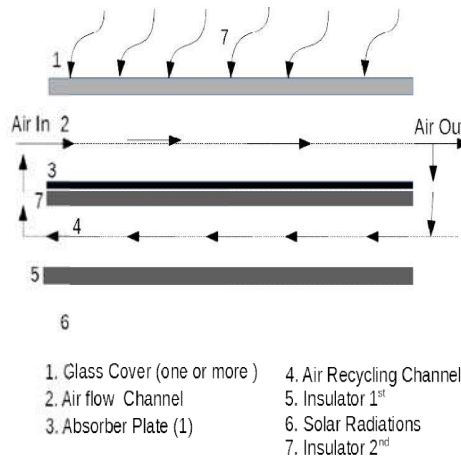


Fig. 4 Single flow recycled double passed air collector

Single flow recycled double pass flat plate air collector has the ability to enhance its effectiveness and regulate the outlet temperature. The required temperature of the air at the outlet can be achieved by partial circulation of the heated air. The collector has two air flow routes as shown in fig.4. The upper route consists of transparent cover at the top and absorber plate below it. The lower route is well insulated. Now partial air is made to flow back through the lower route into the main channel. As a result, there is preheating of the air [10-13].

3. Classification According to Air Channel Design

The Flat plate air collector are also classified on the basis of air design channel. There are four different configurations of the solar air heater on the basis of design of air channel. The solar air heater's efficiency can be significantly enhanced by altering the air channel design. Different types of air channel designs are explained in this part.

3.1 Flat Plate

These are the most common and simplest types of air solar heater. One or more glass covers are there in this type of air solar heater and a plate absorber (Figure 5). To prevent heat loss from the solar air collector apart from the transparent cover all the other sides of the air collector should be well insulated. Flow of air can be either under or over the absorber plate. There is single pass, dual pass, dual flow or recycled flat plate air collector designs. The absorber plate is a flat plate and it doesn't contain any obstacle, finned or roughened surface. Due to that reason these types of solar air collector are called as "Flat plate Air Channel". These types of Flat Air route solar air collector have simplest construction; so, it has a lower construction cost. The performance of this kind of solar air collector is lower than other types because no other processes or methods are used to increase the heat transfer in air channel [7-8, 13].

3.2 Extended Surface Assisted

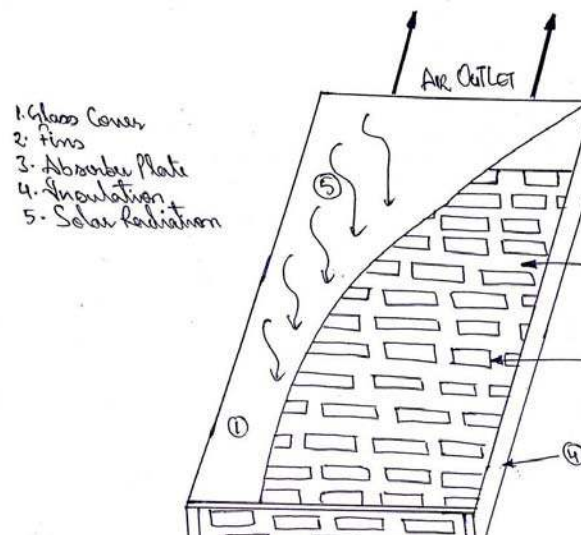


Fig 5. Fin assisted air heater collector

The most critical parameters that can affect the thermal efficiency of flat plate air collector are these types of absorber plate. The absorber plate can be extended to improve its performance. Fig.6 shows the surface area of the flat plate air collector will be extended by using ribs, fins, obstacles or any other type of roughness on absorber plate. A collector aided by extended projections of air channel has a glass cover, insulating material and a rough absorber plate that absorbs the solar radiation coming from the sun. The area of absorption of absorber plate can be extended by the use of rough elements and fins and also the flow of changes to turbulent in the channel provided and the heat transfer coefficient is increased. A solar air collector whose channel consists of a rectangular surface can be constructed as a double pass, single pass, dual flow or recycled. Although the surface area and heat transfer coefficient are increased by use of fins and rough elements, there is a drop in the pressure which increases with roughness through the channel that will result in increment in power consumption by the fan or blower [13].

3.3 Porous Media Assisted

For increasing the temperature of air which in turn will enhance the effectiveness is to make use of penetrable (porous) means between the circulation of air. The introduction of the penetrable means makes the flow air turbulent which increases the ability of air to collect more heat, as a result the area of heat convected is increased. Figure 6 shows double pass collector with porous media as an extra installation. This porous medium is fixed in the flow route of the collector. Air is made to pass through the route consisting this porous medium and this porous medium is in junction with the absorber plate as illustrated in the fig. 6. This kind of flat plate air collector can either conventional single pass, double or recycled flow collector but in general single flow double pass system is preferred. To escalate the heat convection between the porous medium and the air, a high conductive material is used. There is pressure drop in flow route due to the use of porous media so it is very important to select the proper size of holes in porous material. Pressure drop is increased by decreasing the porosity but by decreasing the porosity increases the effective heat transfer coefficient. Due to these reasons experiments and studies has been done to know more about the attributes of the porous media. The optimum physical characters of the porous medium will increase the efficiency [13, 14].

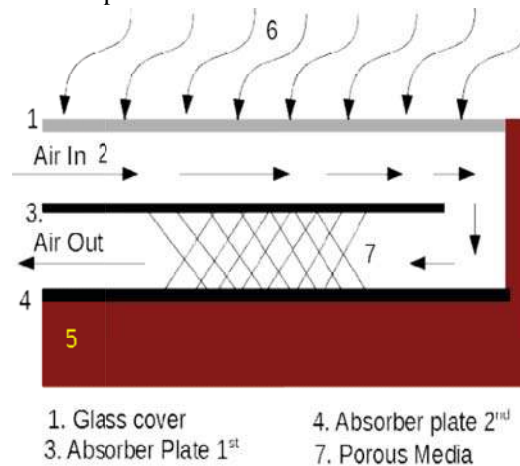


Fig. 6 Porous media assisted air heater collector

4. Literature survey

4.1 Single Flow Single Pass Studies

Varshney et al. [15] researched about the attributes of the fluids used in the collector and the convection properties of the fluid. He also studied about the impact of wire meshed tubes used for transport of fluid. The experiments were conducted using different geometrical parameters of wire mesh screen like wire dia., pitch and layering of the wire mesh. The dimensions taken by him was 2390 X 250mm. He used two glass cover with 20mm distance between them. The wire mesh screen was fixed between the second glass sheet and absorber plate. Colburn-j factor was used to represent the heat transfer. He concluded that the efficiency is highly depended on the heat transfer coefficient, physical parameters of wire mesh (wire dia., pitch etc.).

Pakdaman et al. [16] investigated about the effect of use of finned absorber plate in a naturally convected flat plate air collector. The main objective of the experiment was to predict different significant variable for this kind of collector. In this experiment the Nusselt number correlation for finned surface was also obtained. The condition for maximum efficiency of the collector was calculated using exergy analysis. He chooses 2000 X 1000 X 150mm as the length, breadth and height of the collector. Galvanised iron coated with black paint was used and the thickness of the iron sheet was 1mm. The absorber plate was fixed with 46 rectangular fins and each fin was positioned 20mm

apart. For covering the plate 4mm thick glass plate was used. The conclusion stated there was a increase in the efficiency by 66% as compared normal flat plate air collector.

Peng et al. [17] hypothetically and experimentally analysed the working of the solar air collector with fins fixed to the absorber plate. The aim of this experiment was to improve the outlet temperature of the collector using cheap and readily available material and design having long life. An investigational framework was constructed which contained 25 pin-finned plate. Length of the fins were- 10,20,30,40,45mm and the width of the fins were 12,16,20,24,28mm. The dimensions of the glass plate include thickness of 4mm and 1100 X 580mm length and breadth. A black painted stainless steel was used as the absorber plate. To assess the effectiveness a mathematical model was constructed. The conclusion stated the efficiency can be increased by controlling the mass flow rate of the air and by using finned absorber plate. It has been stated that it is more efficient than conventional air collectors.

4.2 Double Flow Single Pass Studies

Madhlopa et al. [18] constructed a setup which was just like the conventional collectors but with a composite absorber plate (a transportable mild steel plate and a wooden plate). Under the given weather conditions different types of absorber plates were used preferably composite of metal, plastic and wood. These plates were used to attain the maximum possible temperature at the exit of the collector. The collector setup was also checked without using the absorber plate and the performance was very poor. A crop drying setup was also attached to the solar air collector. The objective of the experiment was protecting the fruits from being spoiled and rotten. The length and breadth include 810 X 625mm respectively. The efficiency of the crop dryer was evaluated on the basis of moisture content, pH and chemical properties of the fruit. It was found that temperature nearly reached 31.8 to 40°C at noon. This helped the fruits to reduce their moisture content to a greater extent.

Ozgen et al. [19] evaluated experimentally the performance of aluminium canisters as obstruction in the air flow route. This construction was done for all the three types of double flow air collector and their energy efficiencies were calculated. The plates that were used as absorber were of three kinds, made of stainless steel with a black selective coating of chrome. The three collectors were 2140m X 840m in length and width respectively. For covering the top, a common window glass of thickness 5mm was used. Only one glass plate was used for all the three collectors. In first type of absorber plate the aluminium canisters were arranged in zigzag pattern, while in the second type the canisters were arranged in straight line order. The third type of absorber plate was without canisters. It was concluded that the plates with aluminium canisters had larger heat transfer area, as a result the performance of collectors with obstacles was increased. The highest performance was shown by first type of collector at 0.05 kg/s mass flow rate. Higher end temperature was obtained from the first type of air collector as compared to third type of collector (without canisters).

Alvarez et al. [20] investigated the working of the collector using recycled aluminium cans (RACs) on the absorber plates. A simulations model was made and examined to get the design variables for the construction of the framework. Mathematical modelling was also done for the defining the flow parameters. The size of the collector is 2000 X 700 X 180mm. Approx. 128 recycled aluminium cans were used in the construction of the absorber plate. The cans were painted black and were pasted using glue. The construction had 8 circular cross-section air flow routes. A glass plate of 4 mm thickness is used as top cover. The conclusion states the performance can be easily improved at lower cost using aluminium cans. The efficiency of this kind of collector was greater than the normal flat plate air collector..

5. Conclusion

From the above discussion, the derived conclusion is that there are many types of flat plate air collectors with different designs and configurations. The main concern with the collector is the heat

loss, low heat transfer coefficient of the air as a result air is not able to gain much heat from absorber plate. The ways in which the efficiency could be enhanced are by making use of double pass construction, by using porous medium in flow channel, by using fins mounted on the absorber plate. Various medium can be used like honey comb structure to increase the turbulence in the flow of air, so that it is able to carry more heat. Mass flow rate is greatly responsible for determining the temperature at the outlet of the collector.

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