



Design and construction of a solar energy amplifier for solar dryer

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Abstract

Solar energy is radiation from the Sun that is capable of producing heat and generating electricity. The thermal section is applicable for drying of agricultural productions. As the absorption of radiation energy is changing regarding to season, geographical location, daytime, etc., amplifying the radiation energy could be helpful to have higher and more stable condition for using this renewable energy. A system was designed, constructed and tested to amplify the absorption of solar energy by using a room similar to greenhouse, which is isolated and filled by a gas. The system consists of three sections, all covered by glass and a closed circulated copper pipeline passes through the sections. The solar radiation absorbs, amplifies and heats the air inside the pipeline in the first section, which is filled by a gas. In the second the heated air insides the pipeline heats the air inside the second room and the heated air blows to the third room, as the drying chamber to dry the product which is located in this section. Three gases of ambient air, CO₂ and N₂O were used to fill the first room and their effects were tested during the day from 6 to 18.

Keywords: amplifying system, drying, greenhouse effect, solar energy.

Introduction

The growing energy demand in contemporary societies, coupled with the environmental detriments of conventional energy sources, necessitates a shift towards fossil fuels or sustainable alternatives such as solar energy [1]. This demand in 2040 is suggested to be 48% more than the demand in 2023 [2]. Renewable energies are going to be more popular source of energy than before in all over the world because of the problems, which comes after using fossil fuels. When fossil fuels are burned, they release large amounts of carbon dioxide, a greenhouse gas into the air. Greenhouse gases trap heat in our atmosphere, causing global warming. The most important available renewable energy sources are solar energy, wind, geothermal, biomass and biofuel. Each of them is relevant for certain area. Solar energy is the most used one which is almost available in all locations, although there are some limitations to use this kind of energy.

Solar thermal energy is one of these technologies that is extensively used in several significant applications, including space heating, water heating, drying, and cooling systems. Solar thermal collector and absorber plate are used to absorb and convert the solar energy to thermal energy [3]. Non-concentrating solar collectors, sometimes referred to as flat-plate collectors, focus sunlight without the use of mirrors or lenses. As an alternative, they directly absorb solar energy due to their massive surface area. Typically, flat plate collectors include a clear cover, an absorber plate with a dark color, and insulation to reduce heat loss. In a non-concentrating solar collector, sunlight is transformed into heat as it hits the absorber plate. After that, heat is transmitted to a fluid (usually water or a heat transfer fluid) that is travelling via tubes or channels inside the collector [4]. The solar collector stands as a pivotal component within the solar thermal system, offering various types tailored to meet diverse temperature requirements. These include flat-plate collectors, unglazed collectors, evacuated tube collectors, and concentrating solar collectors. Among these, flat-plate collectors possess distinctive bearing strength and efficiency characteristics, making them highly suitable for applications in solar thermal systems [5].

Drying has evolved into one of the most advanced techniques for human preservation. Drying process is one of the most energy consumption among different kind of processing. In the case of fossil fuel consumption for this process, many negative consequences. To avoid these negative consequences, shifting to a cleaner and more sustainable energy source, such as solar energy, is critical. Solar drying has many benefits, including addressing significant challenges in developing countries, such as rising fossil fuel costs and environmental emissions concerns. Solar energy can be used for drying of agricultural products as direct or indirect forms. One of the most popular drying methods is sun drying which is a kind of direct solar drying. Indirect solar drying is another method, which represents a clean and sustainable solution for reducing the moisture content of a variety of food and agricultural products.

Greenhouse dryers are affordable, simple to construct, and adaptable for application anywhere in the world especially. A greenhouse is a well-known enclosed structure that principle is based on trapping short-wavelength solar radiation. By applying a series of changes to a greenhouse structure, it can be used for drying the agricultural productions at low temperatures, in the regions with high sunny days. Greenhouse solar dryers assisted by thermal storage are superior to standalone greenhouse dryers for all types of crops. Solar greenhouse dryers offer a superior alternative to open sun drying methods, producing dried products of higher quality. These technologies are versatile and capable of operating in both natural and active modes [6]. A system which could amplify the absorbed solar energy helps to increase the efficiency of such drying systems. The greenhouse dryer is one of the newest systems in the solar dryer sector, which is included in the group of direct and sometimes indirect and compound dryers. The working mechanism of a greenhouse dryer is such that the product placed on the tray or internal shelves of the greenhouse to receive sunlight through the transparent cover of the greenhouse. Evaporated water is directed to the outside of the greenhouse by natural or forced convection [7].

There are different methods to amplify or save the solar energy in order to increase the efficiency of solar absorber systems in solar dryers. Researchers have already studied the effect of reflectors [8], PCM [9], concentrated solar power [10], etc. on the performance of dryers. The main objective of this research is to design and construction of a system to amplify the absorption of solar radiation energy and study the effect of the system which consists of an isolated room covered by glass (similar to greenhouse), filled by certain gas like CO₂ and N₂O.

Materials and Methods

A system including three rooms and a water pipeline circulation was made to amplify the solar absorption. The initial design of the system is shown in Figure 1. The system consists of three main boxes or rooms, which are named absorber room, exchanger room and dryer in this article and all of them are covered by glass to absorb solar energy. A copper pipeline passes through the three rooms to flow water in this system. A pump was used to circulate the water inside the pipeline in order to transfer and exchange energy between the rooms.

Six sensors were installed on the system to measure the parameters of ambient air temperature, water temperature at input and output of absorber room, water temperature at output of exchanger room, temperature inside the dryer and the relative humidity of the dryer. During experiment the data of each sensor was recorded every five minutes and transferred to a PC and saved for analysis.

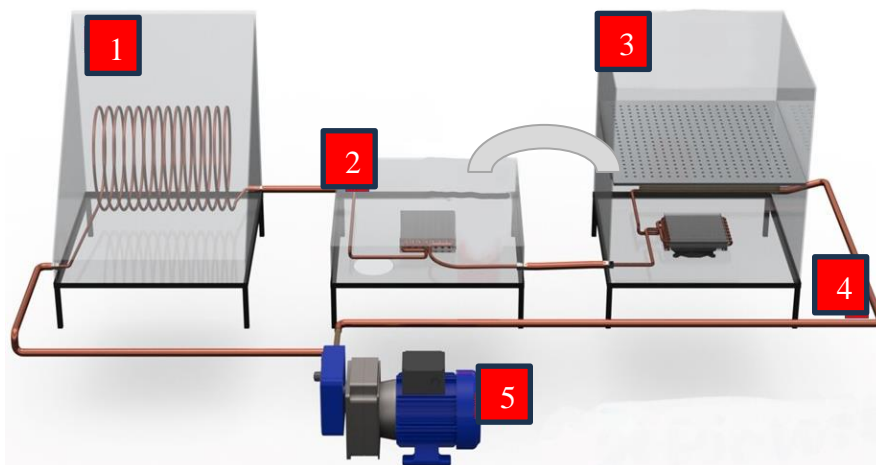


Figure (1) the initial design of the solar energy amplifying system. 1) absorber, 2) converter, 3) dryer, 4) pipeline, 5) pump

The absorber room was made and its dimensions was determined based on the required space for conversion of solar energy to thermal energy (Figure 2). The roof was design with certain tilt to have solar ray direction perpendicular to the roof surface of the absorber room. Then the walls and the roof were covered by securite glass with 8 mm thickness to protect against the pressure. The effective area of the room for absorption of solar radiation was 70 cm². For each test the room was vacuumed and filled by desired gas. The idea was to fill the room with certain gas (ambient air, N₂O and CO₂). This room sections acts as the greenhouse to trap the solar radiation energy and amplify the absorbed energy per certain area compare to the normal conditions. The solar radiation passes through the roof and walls and comes inside the room and increase the thermal energy inside the room. There is a copper pipeline inside the room with the length of 15 meter and diameter of 13 mm. The copper pipeline was bended and turned as a coil (Figure 2) to increase the area for exchange energy between the room and the water inside the pipe line and give more possibility for temperature increase of the water inside the pipeline and increase the efficiency of the system. As the water inside the pipeline circulates through the system, so the longer time remaining inside the room causes more increase of water temperature inside the pipeline. Solar energy increases the air temperature inside the room and then increases the water inside the pipeline.

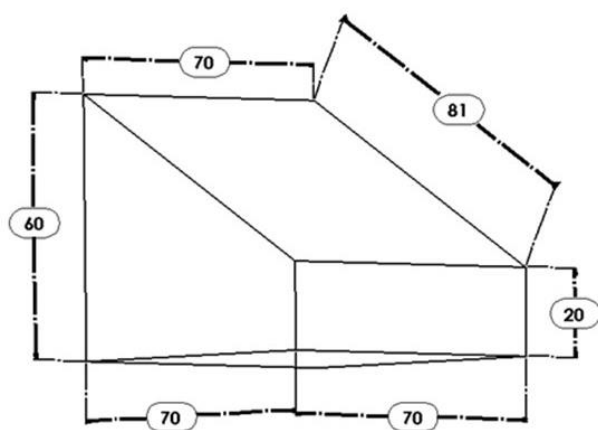


Figure (2) schematic diagram of the absorber room: dimensions, shape and copper pipeline conditions.

In the exchanger room a system similar to radiator was used to exchange thermal energy between the water inside the pipeline and the air inside the exchanger room. It is a kind of radiator with the dimension of 20 by 20 cm, which is used for heating system in Pride car (Figure 3). The heated water inside the absorber room moves to the exchanger room first and then to the dryer. There is also an air connection between the exchanger room and the dryer to exchange air between these rooms, so exchange of thermal energy occur always during the process between the air inside the exchanger room and water inside the pipeline.

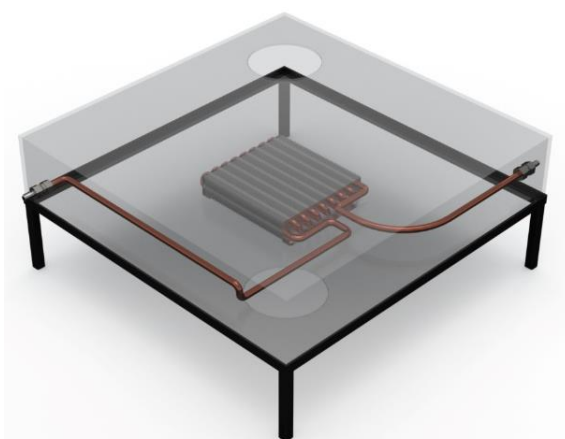


Figure (3) schematic diagram of the exchanger room.

The dryer room was made in a cubic structure with dimensions of $70 \times 70 \times 70$ mm covered by glass (Figure 4). The pipeline passes through this room and then passes then the second radiator inside the dryer and the returns to the absorber room. A pump is installed on the pipeline between the dryer and the absorber room where the water returns to the absorber room. There is also a tray for sample inside the dryer, which is located above the radiator. A gate was made on the dryer wall for putting in and taking out the samples to be dried. As mentioned before an air canal is connects the dryer to exchanger room to exchange air between dryer and exchange room by using a fan which was located and fixed on the air canal.

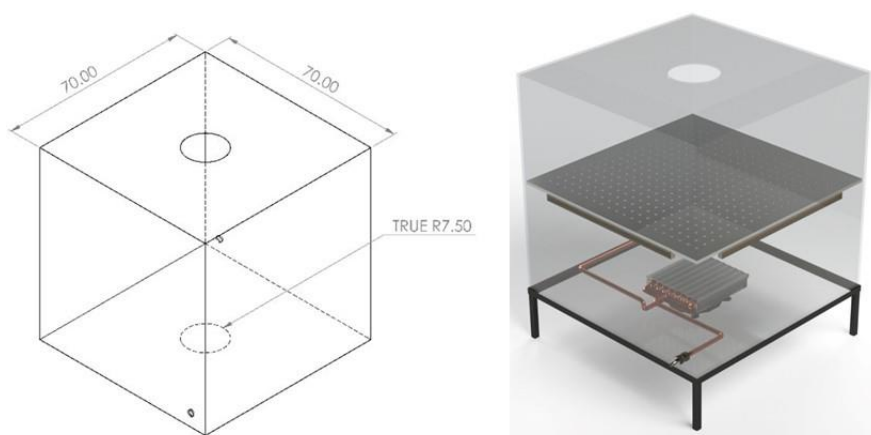


Figure (4) schematic diagram of the dryer room: dimensions and details.

For checking the performance of the system, the experiment was started early in the morning. Each experiment was started before sunrise and the data were recorded from 6 Am to 6 Pm in 5 min time interval. All the data were recorded and analyzed to find the effect of each part on the temperature rise.

Results and discussion

The real view of the constructed system is shown in Figure 5. The system consists of absorber room (1), exchanger room (2), dryer (3), water circulation system including water container, pipeline and pump (4), and measurement system (sensors). The whole system somehow is a closed system and water inside the pipeline circulates through the whole system parts for exchanging thermal energy between the ambient air and water inside the pipeline and also different parts of the system.



Figure (5) schematic diagram of the dryer room: dimensions and details.

The schematic diagram of water circulation and energy exchange is shown in Figure 6. Radiation energy influence on each room separately but the main absorption occurs in the absorber room. The temperature of water increases when passes through the system from absorber room to dryer but mainly in the absorber room because of the longer line and more opportunity to gain thermal energy. The gained thermal energy moves to the dryer room and applies in this room for drying of the samples on the tray inside the dryer. After using the thermal energy for drying, the water temperature drops inside the dryer and flows back to the absorber room again to absorb thermal energy for next cycle. The air inside the dryer, which is warmed up also flows to the exchanger room to use the outgoing thermal energy for warming the fluid in this room via the first radiator. The water pump is located in the return path of the fluid between dryer to absorber room, which the fluid is a bit colder than the other parts.

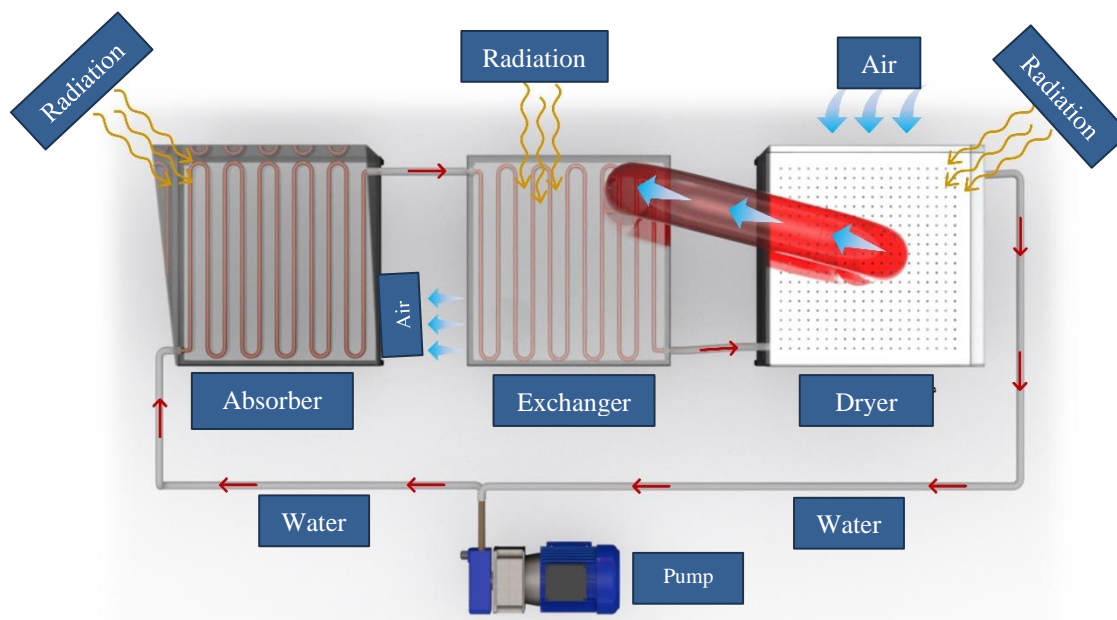


Figure (6) schematic diagram of the dryer room: dimensions and details.

Figure 7 shows the variation of the recorded parameters for a whole day running test. Ambient air temperature was about 10 °C at 6 in the morning, after that increased and reached to its maximum level (28 °C) at about 13 to 14 and then decreased and reached to 17 °C at 18 and the test was stopped at this time. The relative humidity of the air was also recorded during the experiment, while it was at higher value (53%) at 6 in the morning and reached to the lowest

level at about 14 and then increased again and reached to 23% at 18. All the temperature sensors recorded almost the same value (about 10 °C) at 6 and increased with different rate and reached to the highest value at about 14. The highest rate was for the dryer which reached to 51 °C at around 14. The cumulative absorbed energy in absorber room, exchanger room and dryer caused to have the highest temperature in the dryer room. The gained thermal energy and increase of temperature for each section is accessible by subtracting of the subsequent temperature levels in the process line.

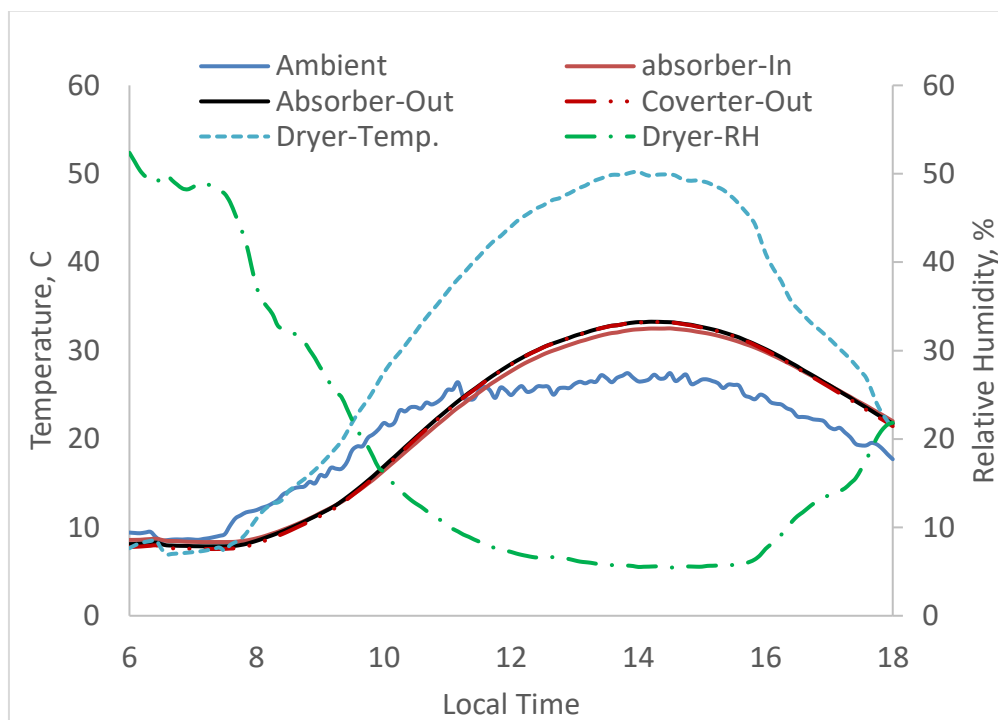


Figure (7) a sample of the recorded data test.

Conclusion

A system was designed and constructed to study the effect of isolated room covered by glass (similar to greenhouse), filled by certain gas (air, CO₂, N₂O, ...) on absorption of solar energy. Three rooms were connected to each other in a cycle by a copper pipeline and water was circulated inside the pipeline to exchange thermal energy. The temperature of water and air was recorded at different points of the rooms. The temperature differences between two consequent points were calculated and the effect of each section on absorbed solar energy was determined. The results showed that this kind of system is relevant to amplify the absorbed solar energy and convert it to thermal energy for different goas like accelerating drying of agricultural productions.

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