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Research Article

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# Evaluation of Temperature and Relative Humidity Stratifications in a Solar Drying Chamber

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**Abstract** A solar drying chamber has been designed and evaluated with five trays for different products items. The drying cabin dimensions are 50 cm × 50 cm × 100 cm length, width, and height, respectively. The chamber is integrated with the solar collector by a small duct (indirect drying), then the exit heated air from the collector enters the chamber with high temperature and low humidity. The product sample, which used through this study is apple. The constructed drying chamber integrated with solar air collectors and mounted to the South on an iron simple frame. The system designed, manufactured and installed in the open laboratory area of Department of Physics and Process Control, Szent István University. The results showed that the values of temperature in the five trays of drying chamber increased with the time to reach the maximum peak values 29.4, 28.4, 27.8, 26.8, 25.5 $^{o}$C respectively at 13:20. The maximum value of relative humidity in every tray were 38, 39, 44, 48 and 50% from the first to the fifth tray respectively at the first record at 10:00 due to the high ambient temperature and low solar radiation intensity.

**Keywords** solar collector, drying, efficiency, radiation, experimental

## 1. Introduction

In a lot of industrialized countries, about 7 to 15% of industrial consumption energy for drying process. For example, according to a report that energy consumption for drying processes are ranging from 10 to 15% for United States, Canada, France, and United Kingdome and about 20 to 25% for Germany and Denmark. Most of drying energy consumption is used for paper and pulp industry, it is about 35% [1]. The use of solar dryers in the drying of different products can significantly reduce or eliminate product wastage, food poisoning and sometimes improve productivity of the farmers towards better revenue derived [2].

An indirect solar drying system of potato studied with two different mathematical models [3]. The two models are developed separately; the first allows the estimation of the thermal performances of the solar collector with offset rectangular plate fin absorber plate and the second, allows determining the kinetics of drying for the data input of the air at the exit of the collector. Also, an indirect-mode forced solar dryer to dry the fruit and vegetable in Iraq has constructed and tested [4]. The drying system consisted of three main parts are: solar air collector, blower, and a solar drying chamber.

Two air solar V-groove absorption plates collectors were used; two air passes and a single glass cover. The cabinet is divided into six separated trays by five shelves. The effect of speed variation of air inside the drying chamber was small and can be neglected. Also, the relative humidity of air exit from the chamber was low between (25 and 30%), and therefore there is no need for high-velocity air inside the chamber.

An indirect forced convection solar dryer integrated with different sensible heat storage material for copra drying have been developed [5]. The drier consists of a solar flat plate air heater integrated with a heat storage unit, a drying chamber and a centrifugal blower. The experiments have done with and without the integration of heat storage materials. The results also proved, the time to reduce the moisture content of copra from about 52%

to about 8%with heat storage materials was about 80 hour that is mean faster than without using storage materials with 104 hours. A forced convection solar dryer having an evacuated tube collector to estimate its performance on the bitter gourd was designed and developed [6]. The solar drying system mainly consists of a drying chamber, evacuated tube solar collector, a blower, and a chimney. The results showed that the moisture removal is high initially and then gets reduced exponentially, that is because of the removal of moisture content from the surface first followed by the movement of moisture from the internal part of the product to its surface.

The drying behaviour of sponge cotton by using an indirect solar dryer forced convection for different temperatures and air flow rates have been studied. A solar dryer chamber designed and operated for five days of July 2008 for this purpose. A painted black cylindrical chimney, made from galvanized iron, with 0.4 m height and 0.1 m diameter connected to the top of the drying chamber to increase the speed of air flow. The results showed that the temperature of the drying air inside the chamber decreases as it flows horizontally and vertically along the dryer chamber [7].

A flat-plate solar air heater having different obstacles on absorber plates was designed, analysed and experimentally investigated. The experiments were carried out at two different air mass flow rates of 0.0074 and 0.0052 kg/s. The efficiency of the collector has been found to be increasing function of mass flow rate. The energy efficiency was found to be varied between 20% and 82% while those of exergy efficiency changed from 8.32% to 44 % at the mentioned mass flow rates [8]. After two years, the performance and the cost of double duct air solar collector studied and analysed. They developed a model to estimate the effect of mass flow, channel depth and length of the collector on the thermal performance and cost ratio for two types of solar air heaters in double flow mode, flat plate collector with porous media and V-groove absorber plate [9].

An air solar flat plate heater worked with different convection modes was analysed. The absorber plate was made from steel with thickness of 0.5 mm and painting by black. A standard glass with a thickness of 4 mm used as a transparent collector cover. The experiments were done with two convection modes; natural and forced convection and the data was collected from 18 to 24 June when the atmospheric conditions were almost uniform for the day.

The results showed that the average airspeed in the forced convection case was about 21% higher than natural convection case [10]. The moisture-removal efficiency varies from product to another according to product nature, shape and moisture content of dried product. Moisture removal (%) reduced exponentially with time that is because removal of moisture content from the surface first followed by the movement of moisture from internal part of the product to its surface. Also, the moisture content of product with forced convection solar dryer reduced, so faster than natural direct sun drying [11].

An experimental investigation is carried out on solar test rig consists of many principal components to achieve study objectives. Solar drying system consists mainly of solar air collector, drying chamber and inline air blower.

## 2. Experimental Procedure

In this study, the drying cabin dimensions are 50 cm × 50 cm × 100 cm length, width, and height, respectively as shown in Fig. 1. Dryer walls have been made from polystyrene, except the front wall of the chamber made from 4 mm plastic glass sheet for observing. The polystyrene blocks were with 5 cm thickness and thermal conductivity of 73 W/m.K. This material was used due to many important reasons; which are low thermal conductivity (insulated), cheap, easy to perform it and light.

The five trays of the chamber made from plastic nets and fixed with 10 cm distance between them as shown in Fig. 2. The dimensions of every tray are 38 cm × 40 cm length and width respectively. The chamber is integrated with the solar collector by a small duct (indirect drying), then the exit heated air from the collector enters the chamber with high temperature and low humidity. The moist and hot air rises and escapes from the upper vent of drying chamber. Inlet and outlet of drying chamber have a diameter 10 cm with a small slop angle for the upper side of the chamber to keep the smooth movement of the air.

Also, all air leakages from drying space closed totally as possible. The product sample which used through this study is apple. Apple selected as a sample because of its high initial moisture content and its high maximum allowable temperature. The initial moisture content and maximum allowable temperature for apple during drying process are 80% and 70 °C respectively [12]. The total required energy for drying process for given quantity of any products (apple slices) items can be determined by using the basic energy balance equation for the evaporation of water [13].

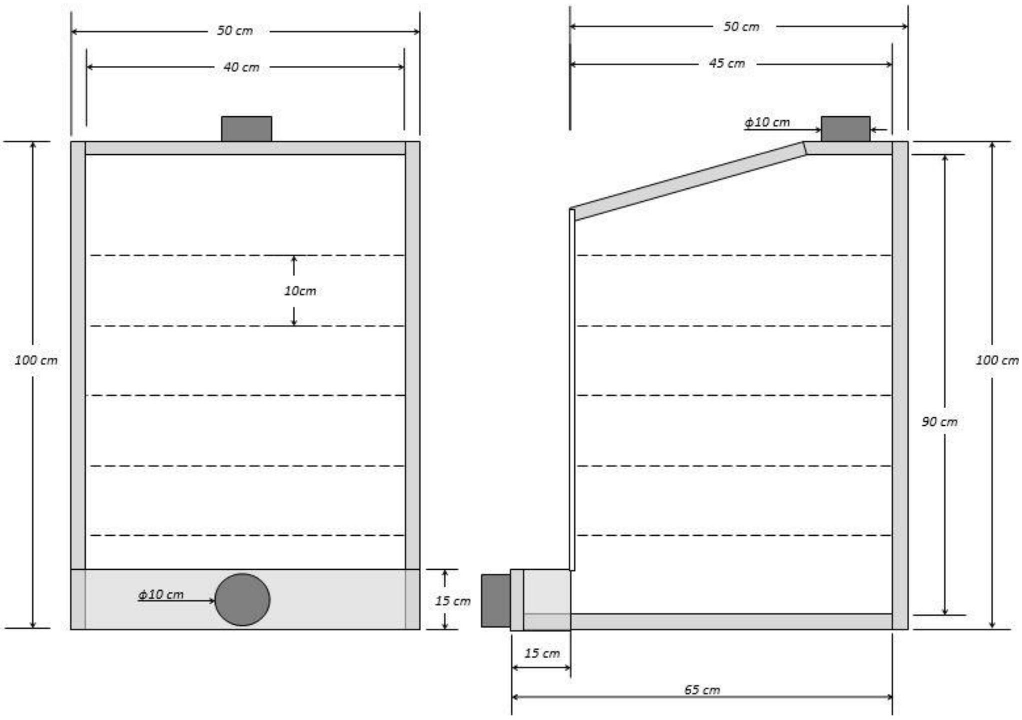


*Figure 1: Drying chamber dimensions and illustration*

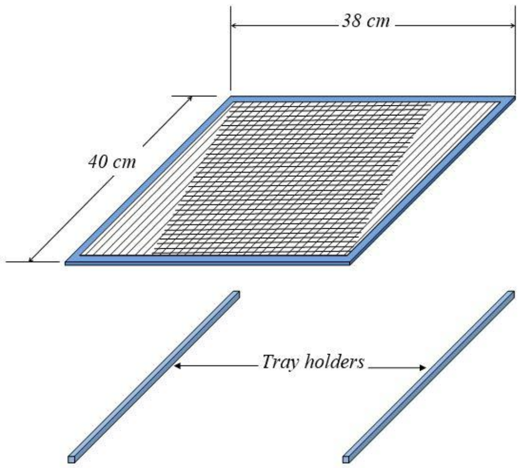


*Figure 2: Tray dimensions and installation*

The external dimensions of solar heater are 120×50×15 cm length, width and thickness respectively. The external box of solar collectors is made from wood sheets and bars with different thicknesses with dimensions. Wood had been chosen for many important reasons that were taken into account; which are lighter in weight rather than using metal, the low cost, easy to form and can be considered as insolation specially at very low temperatures. The second air channel of double pass solar collector was designed with many attached buffers which fixed on back surface of solar collector.

For study purpose, absorbing surface is made from copper plate sheet with 1.2 mm thickness and thermal conductivity 385 W/m.K as shown in Fig. 3. To enhance these surfaces (selective surface) a black matt paint (black chrome) used to coat copper absorbing surfaces. Selective surfaces combine a high absorptance for radiation with a low emittance for the temperature range in which the surface emits radiation. Black paint also enables much of the absorbed energy to be lost by emittance.

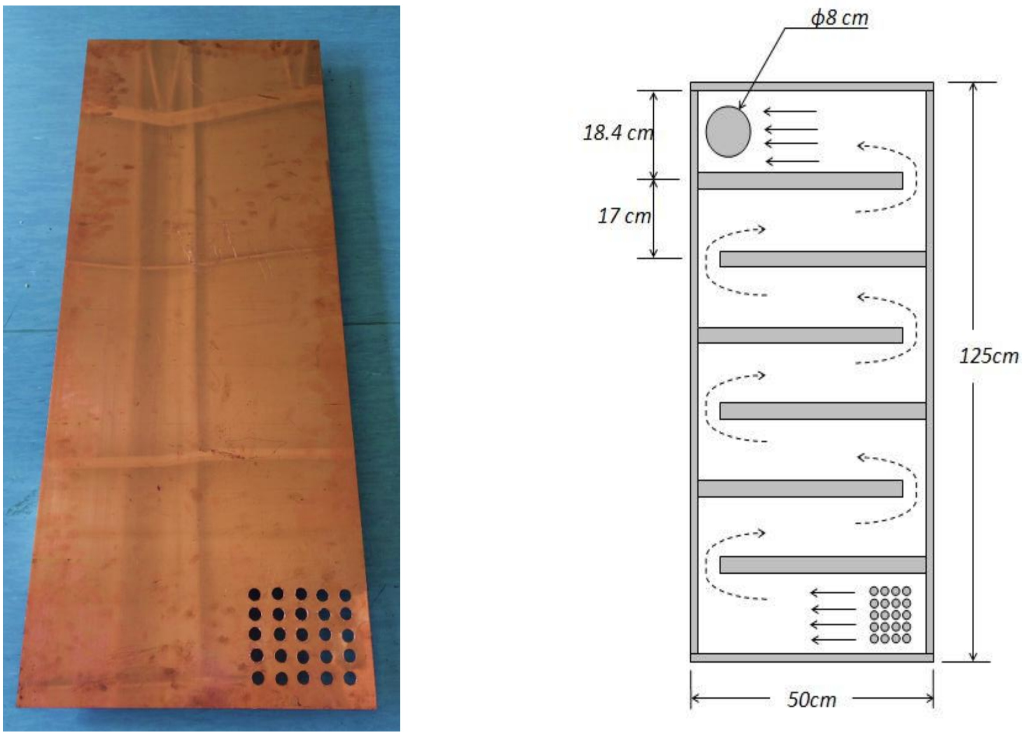


*Figure 3: Absorbing surface and external case*

### 3. Results and Discussion

The drying system tested on 2nd of October 2017, with air mass flow rate and clear weather. The measured solar radiation intensity irradiance curve and calculated total useful heat during 5 hours of experiments days are shown in Fig. 4. The maximum radiation intensity was 948 W/m$^2$ at noon. The solar radiation blocked by some sporadic clouds between 12:40 and 13:40. The useful heat power consists of two components; first is upper channel useful energy gained and the second is the lower channel useful energy gained.

The figure obtained that the useful heat power gained curves were proportional directly with the solar radiation intensity and air temperature difference through the collector. The two channels useful heat increases to reach the maximum values 166.5 and 112.2 W/m$^2$ at the same time of maximum temperature differences. The total useful heat power of solar collector is the summation of two channels useful heats.

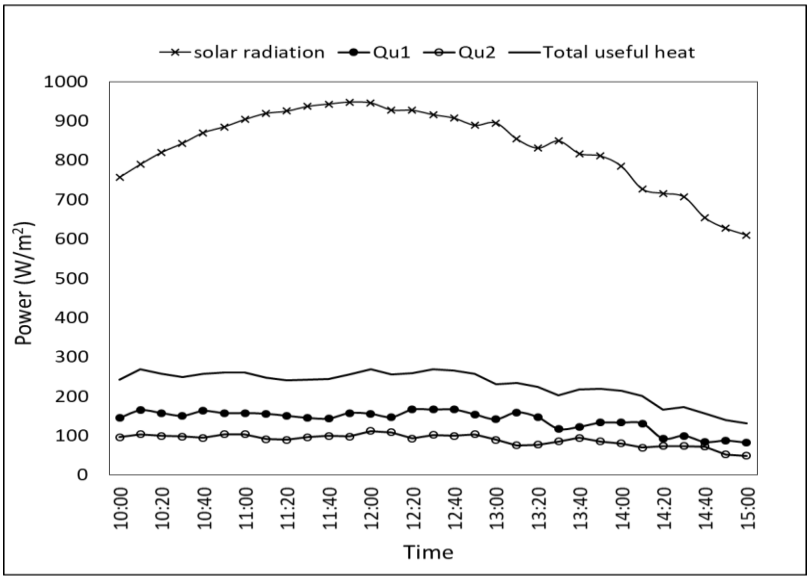


*Figure 4: Useful gained heat power and solar radiation vs time*

The stratifications of temperatures in drying chamber are shown in Fig. 5. The shapes of temperature curves are hardly affected by the curve of solar radiation in Fig. 4. The temperature difference between the first two trays T1 and T2 is higher than the difference between the last two trays T4 and T5 due to the thermal capacity of heated air decrease. It is obvious the agreement between the behaviour of drying chamber temperatures and absorbing surface, collector's inlet and outlet temperatures. In the first 10 minutes of the experiment, the temperature fluctuated down because of the small decrease in ambient temperature.

After that, the values of temperature in five trays increased with the time to reach the maximum peak values 29.4, 28.4, 27.8, 26.8, 25.5 $^{o}$C respectively at 13:20. At the end of the experiment, the values of temperature are more close to the values of ambient temperature. After 13:20, the temperature differences between the five trays fluctuate with the approximately constant rate except for the temperature in the first tray.

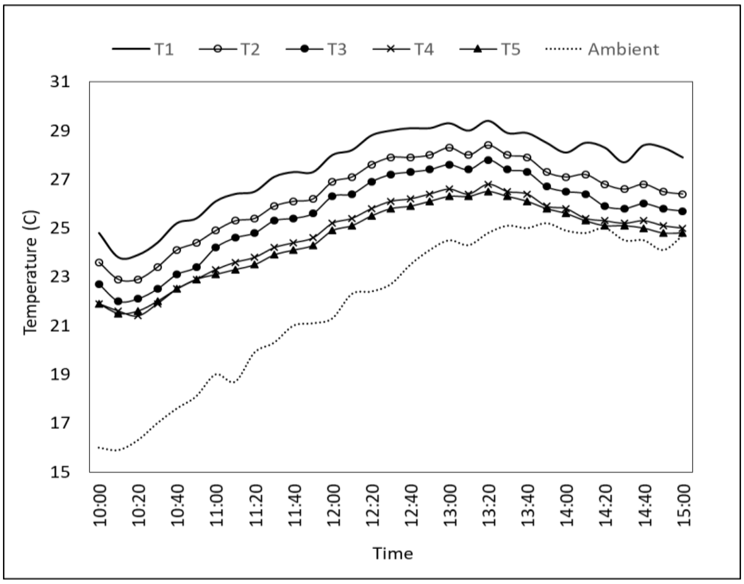


*Figure 5: Temperature stratification of drying chamber by using flat plate double-pass solar air collector*

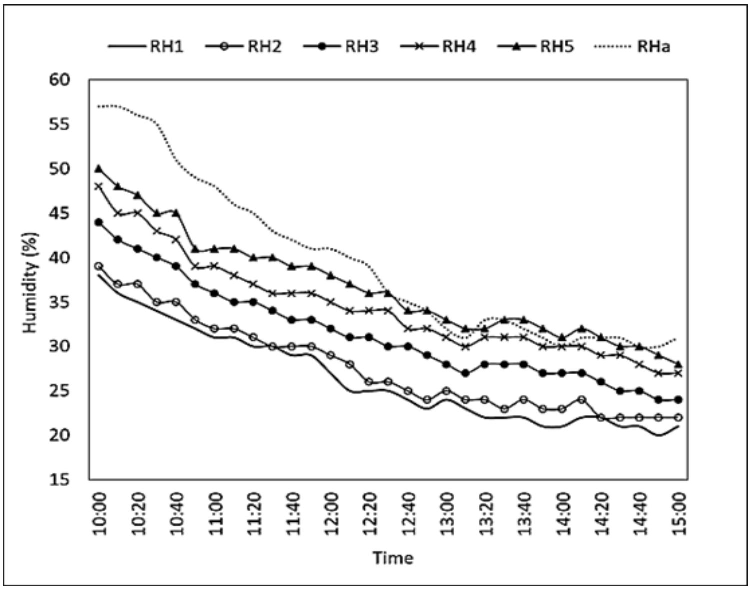


*Figure 6: Relative humidity stratification of drying chamber by using flat plate double-pass solar air collector*

The relative humidity stratification in drying chamber trays are shown in Fig. 6. At the beginning of the drying process the moisture content of the product is high which leads to very high moisture loss rate, so the ability to catch more moisture by heated air higher at the beginning of experiments. It is clear that the product loses its moisture faster from the beginning of the process to the noon, afternoon much time is needed for the moisture content to be lost.

The differences between five curves are more sufficient than the curves which gained by using single-pass solar air collector. The maximum value of relative humidity in every tray were 38, 39, 44, 48 and 50% from the first to the fifth tray respectively at the first record at 10:00 due to the high ambient temperature and low solar radiation intensity. The minimum values were 12, 22, 24, 27 and 28% from the first to the fifth tray respectively at the end of the experiment. After 12:20, the values of relative humidity in the fifth tray are lower than ambient relative humidity in some time intervals because of the high-temperature values at these times.
The final moisture content showed a good agreement for the short time of drying process (5 hours) and compared with 24% as a desired final moisture contents for apple [12]. Actually, the drying process for any product leads to a physical and chemical changes in the product items. The high working temperature is damaging some products like meat and fish, so the temperature must be controlled for some types of products.

**4. Conclusions**

Based on the evaluation of the measurements it has been concluded that:

1. The useful heat power gained proportional directly with the solar radiation intensity and air temperature difference through the collector.
2. The behaviour of drying chamber temperatures and absorbing surface, collector's inlet and outlet temperatures are agreed.
3. The product loses its moisture faster from the beginning of the process to the noon, afternoon much time is needed for the moisture content to be lost.
4. The final moisture content for five hours of drying process showed a good agreement compared with 24% as a desired final moisture contents for apple.

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