Experimental Investigation on Indirect, Natural and Forced Convection Mixed Mode Solar Dryer

S. Misha, Ahmed Alqadhi, M.A.M.Rosli, and A.A Yusof

***Abstract*— The installation of solar drying systems have been constantly developed in the last few years to acquire better effective results and drying performance. Baes on the previous designs, It might be concluded that the efficiency of the solar dryers is essentially depends on the thermal distribution and uniformity of flow inside the dryer chamber. There are various types of solar dryers that have been developed and they are classified based on the mode of air circulation (natural circulation and forced circulation), or based on the type of drying such as, direct solar drying, indirect solar drying and mixed mode solar drying etc. Several solar dryers have been utilized recently, however, they do not perform well in terms of high temperature and air distribution throughout the dryer which negatively affects the efficiency of the dryer. Moreover, relying on a single mode of these drying system might not provide the optimum results. Therefore, in this study a conceptual devise of a mixed mode solar dryer which includes direct, indirect, and forced convection solar drying is proposed and fabricated. An experimental investigation is performed on this device using an automated recording to plot the temperature profile at diverse positions in the dryer. This testing was conducted at five different stated of the dryer to attain the most suitable method for drying based on the resulted temperature and velocity. From the results of the experiments it can be concluded that the mixed mode solar dryer with forced convection is recommended among other states.**

***Index Term*— Solar dryer, Mixed mode solar drying, Data logger, Drying chamber.**

I. INTRODUCTION

THE crucial feature of the solar drying system can be visualized from the fact that they operate fully with renewable energy which environmentally friendly and free of pollution. Solar dryer systems can be categorized into three different classes which are direct, indirect and mixed mode in accordance to the passive mode of drying process. The construction of solar dryer system can be achieved simply with existed materials. Drying products by exposing them to the sun energy can be economic techniques since it reduces the cost of drying operation in comparison to the conventional drying machineries. In contrast, this method has many drawbacks including products spoiling due to rainy weather, winds, moistures and dusts. Also, possibility of product damage can occur due to animals, birds or any other objects hitting the products. Based on these, solar drying technology can be a promising system to be utilized as drying method. Several of dryers were utilized in the home and industrial fields, however, they don't perform well in terms of high temperature air distribution throughout the dryer. It was noticed that the products at the bottom of the bed of the chamber dries rapidly, while that at the top remains wet because of the condensation process. Therefore, in this study, the main aim of the design is to obtain the most possible uniform flow in parallel with achieving a high temperature by the solar panels. This design of the mixed mode solar dryer is developed and optimized up to a certain level that the drying rate could be reduced significantly taking in consideration the quality of product [1]. Solar dryers can be divided into two types which are the passive and active mode of solar dryer. In the passive mode dryer two sub-types are presented direct and indirect model. The direct sub-type dryer can be defined as a model in where the product is being exposed to the solar radiation in direct way. This occurs with the placement of the drying product in diaphanous enclosure of a glass or a plastic or inclusion of reflecting radiation like drying box. The purpose of using this reflecting radiation is to rise up the thermal value of the drying box. For the indirect sub-type of dryer, the product being dried subjected to the solar radiations in indirect way, where the products preheated using preheaters or collectors in order to increase the air thermal value in the drying champers. Passive solar drying systems can be referred as naturalistic convectors where the liquid motion is produced by the difference in the liquid densities occurring because of thermal values. In this paper, a design of the mixed mode solar dryer used for drying the agricultural products is fabricated and a testing under five different states of solar drying methods is conducted to evaluate the most convenient and efficient method that suitable for drying the diverse agricultural products.

II. RECENT DEVELOPMENTS OF SOLAR DRYING

Several of dryers were utilized in the home and industrial fields. The dryers which are well known are tray dryers, tunnel

This work was funded by research grant PJP/2016/FKM-CARE/S01507.
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dryers, drum dryers, and many more. Within all these types, the tray dryer is the most extremely utilized due to its simplicity and less cost construction. The food is expanded on the trays at a suitable density in which the food will be dried regularly. Heat might be generated by heated air steams through the trays, conducting from hot trays, or radiations from hot roofs. In a tray dryer, many items can be inserted as the trays are constructed at various stages. The reason behind the success of the process of the tray dryer is regular air flowing distributing on the trays. The tray dryers can be utilized to solar dryers or any traditional dryers that utilizes fossil fuels or electric energies. Better air flowing distributing will emphasize the last humidity value of the dried crops on the trays are regular. Usually the humidity value is obtained by using electronic balancing to obtain the variation between last and first mass of the crop. Bakhshipour et al [2], utilized a machine vision system incorporated with the neural networks to anticipate the humidity value of raisin.There some researches discussed and developed a stationary tray dryer system in order to dry products ,Among these researches is a study by Hallak et al[3], that develop and proposes a staircase solar drying system to dry fruits and vegetables.Shawik Das et al. [4] proposed and built aire-circulation cabinet dryer utilizing a centric air diffusion system. The capability of the system is 5 kg/ batch. Komilov and Murodov[5] develop and construct a greenhouse-type solar drying system with scree accumulation. The surfaces are made of bricks exception the south encountering slanted surface that is coated with window glass. Sengar (2009) [6], developed a cheap-price and easy model that utilized to dry fishes. It has been built for dried goods within heat and moisture states prevailing in Konkan area of Maharashtra where many of the agriculture crops require to be dried.

A. Madhlopa et al. [7] designed an indirect model naturally convective solar dryer incorporated with collection storing and biomass-backing up heating device. Most elements of the drying system were biomass burning tool, collection storing thermal mass and dryer chamber. They summarized that then thermal weight was able of storage some of the absorbing solar energy and thermal from the biomass burning tool. It can dry a batch of pineapples utilizing solar energy only on sunny days. Subarna Maiti et al[8] proposed and built an indirect, naturally convective batching-type solar dryer suited with north-south reflection. They finalized that with the aid of reflections, the collectors effectiveness with no loading was improved from 40.0% to 58.5% with peak situation within a typical day.Othieno et al[9] proposed an indirect solar maize drying system .The dryer comprises of a single glaze passive solar air heating with 1 m2 single flat-plate collectors. The air heating was attached to an isolated dryer closets employed with a chimney .A.A. El-Sebaii [10] proposed an indirect type naturally convective solar drying system. The design comprises of a flatted sheet solar air heating attached to a cabinet working as a dryer cell. They discovered that the equilibrated humidity value for grapes without seeds was attained after 60 and 72 hours when the design is tested with and without storing items, subsequently. Hence, the storing items decrease the drying operation by 12 hours .M. Mohanraj et al.[11] designed an indirect coercive convective solar drying system integrated with sensed thermal storing elements to dry chilies. They sum up that the drying system incorporated with heating storing elements allows it to keep a constant air thermal rate within the drying system. Shalaby et al.[44] investigated thermal behavior of an indirect coercive convective solar drying system for drying mints and thymuses .They tried 14 mathematical design of thinly layer drying and obtained that Midilli and Kucuk design is suitable to illustrate the thinly layer solar dryer of mints. They also deduced that the unusual drying performance of thymuses require much study at varies masses flow rates and different thermal rate of the drying air. Lastly, they noticed the costing of dried mints and thymuses in the indirect-type coercive convective solar drying system to be 0.025 €/kg and 0.087 €/kg subsequently.

In addition, much regular drying of item in both of the trays is accomplished within desiccating drying. V. Shanmugam et al. [12] improve the designing much and integrated a reflecting mirror to enhance the regenerating of the desiccants and measured it to dried green peas and pineapples [13] .The measurements were also achieved with and without the presence of the reflecting mirror.

Abdul Jabbar N. Khalifa et al. [14] discussed the behavior of a basic solar dryer system and a system attached with an additional heating as a subsidiary to the solar heating for drying beans and peas. They make a comparison on the behavior of all to that of naturally dryer. They discovered that dry period for all beans and peas were minimized from 56 hours for naturally dryer to 12-14 hours for basic solar dryer and 8-9 hours for hybrid (solar and additional) dryer. Also, it was deducted that the effectiveness of the solar drying with additional heating was rise up by 25% to 40% in comparison to that of the basic solar dryer system. They noticed that the dry period was minimized by 33% for peas and 36% for beans.

III. MATERIALS USED FOR FABRICATION

Table I concludes the diverse materials used for the various parts of this device and their thicknesses.

TABLE I
CHARACTERISTICS AND MATERIALS OF THE DESIGNED SYSTEM.

Part	Material	Thickness	Thermal Conductivity
Casing	Stainless steel,	2 mm	51.9 W/m·K
Solar absorber	Aluminum	2 mm	205.0 W/m·K
Transparent cover materials	Antireflective coated glass	4 mm	0.8 W/m·K
Side Insulating Materials	Silicon rubber and polystyrene	2 cm	0.03 W/m·K
Back insulation	Fiberglass wool and polystyrene	4 cm	0.08 W/m·K
Feedback pipe	Polyvinyl chloride (PVC)	4 mm	.024 W/m·K
Solar Absorber Coating	Black chrome Selective coatings	1 mm	–

The casing of the drying device is made up of stainless steel with a thickness of 2 mm. Stainless steel is preferred amongst other materials due to its possession of some features such as, its conductivity is small compared to other metals such as copper and aluminum .Moreover, it is suitable to be used in tropical zones like Malaysia due to its ability to stand in rainy seasons and resists the corrosion up to some extended limit .Above from that ,the cost of stainless steel is cheaper than other metals of the same features .

IV. EXPERIMENTAL SETUP

In this part, we are going to perform various tests on the fabricated dryer as described by Ahmed, 2017 [15] to estimate the best method for drying among the five drying methods. For the moment, many thermocouples have been adjusted at eight different location of the dryer conditions. Moreover, there are some external devices used in the experimental work for testing this dryer. The first device is a pyrometer device for measuring the solar radiations. This device is simply exposed to the sun and then connected to a multi meter to give readings in the form of volts. These values are laterally converted in watts per kilometer square. The various experiments are run normally in a solar radians varied between 700 W/m^2 to 800 W/m^2.In addition, a handheld digital anemometer is used for measuring the temperature, velocity, humidity of the air. Fig 1 shows the instruments that used in the experimental wok.

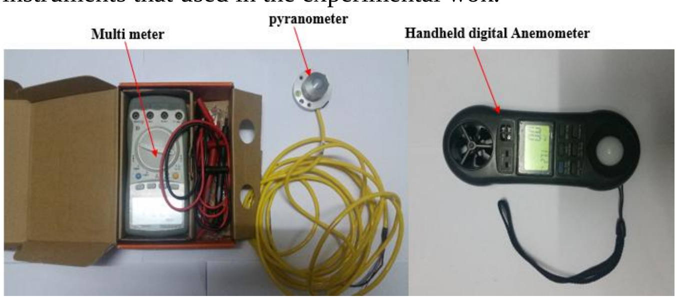

Fig. 1. Devices used in the experimental work of the designed system.

The configuration of the fabricated device is presented in the Fig 2 where it shows the dryer in connection with the photovoltaic panels and the storing battery. The Pico device also is connected to the computer to draw the graph and provide the temperature readings automatically.

Fig. 2. Configuration of the experimental set up

In this testing, several thermocouples are located at eight diverse locations of the dryer for the purpose of testing. Two on the solar collectors, one thermocouple at the surface of each tray inside the drying chamber, one at the outlet of the drying chamber, and one outside the dryer. All the thermocouples are connected to the Pico device which have 8 channels and then the Pico device is connected to the computer to run the software. Pico software can record all the data automatically and sketch all the graphs related to that data. Fig 3 shows the thermocouples locations in the dryer to measure the temperature at that position.

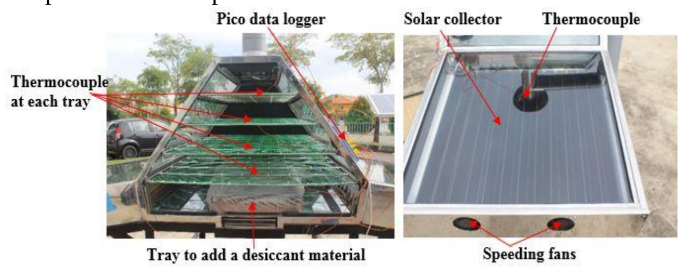

Fig. 3.Thermocouples locations in the dryer.

The experiment was hold at UTeM University, mechanical department laboratory. And the testing procedures are performed under the following conditions of the dryer

V. RESULTS AND DISCUSSION

1. Mixed mode solar dryer with natural convection.

In this type of setting, we use a mixed mode solar dryer which includes direct and indirect solar dryer but without using the fans located in the dryer for distributing the air. The heated air from the solar collector is transferred to the drying chamber by a naturally based on the buoyancy theory of the air. This experiment had been ran on the date of 20/08/2017 and started at 12:45 in the noon and it was run for one hour and 45 minutes and solar radiation of the sun was measured to be between 700 w/m^2 and 800 W/m^2.The configuration of the device and the testing set up is shown in the Fig 4.

Fig. 4 .Configuration of the mixed mode solar dryer with natural convection.

It can be seen that the readings are taken automatically by Pico software. The readings are recorded for one hour and 45 minutes. It was recorded that the maximum temperature among all channels was 83.04 ºC at the channel number 2 which is the left side solar collector and this was at the first time interval. The ambient temperature at the commencement of the experiment was recorded as 36.43 ºC and the humidity is 57.6

%. All these readings are plotted in a multiline graph as shown in the Fig 5.

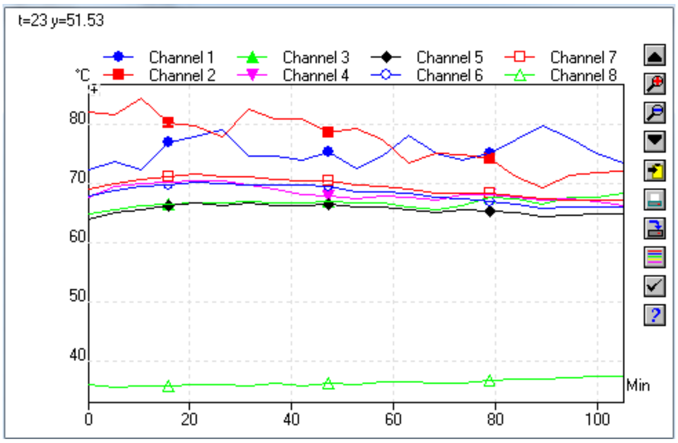

Fig. 5. The temperature graph of the first experimental condition.

The graph illustrates eight lines, one line for each channel. It can be seen from the figure that the trend of channels 1 and 2 are alternative unlike other channels which have one trend from the beginning till the end. It is noticeable that channel 2 begins with the highest temperature and then falls down gradually until the minute number 30 .While in opposite trend, the channel 1 starts relatively with low temperature value and then grows up steadily for the first 30 minutes. After the first 30 minutes, the channel 2 rises up whereas the channel 1 goes down in reverse method. This alternative style was repeated along the entire testing time. Moreover, it is easy to see that other channels are almost constant or variable by a slight value. Fig 6 represent the ranges of temperature for each channel that lies in between.

From the Fig 6, we may conclude that, the range of temperature for each channel in this is the mixed mode solar dryer without fans experiment are as follow:

Channel 1, (right side solar collector), the resulted temperature ranges between 70-78 ºC. Channel 2, (left side solar collector), lies between 81 ºC and 70 ºMoreover, the maximum temperature at channel 3 (tray 1) 69 ºC and the minimum temperature is 65 ºC. In addition, the temperature values for channel 4(tray 2) are between 70 to 67 º C. Also, the temperature at channels 6 and 7 (tray 3 and 4 respectively) varies between 66 and 71 ºC. At the exit of the chamber, the temperature are recorded by channel 5 and the resulted values are between 67 as a maximum and 63 as a minimum.

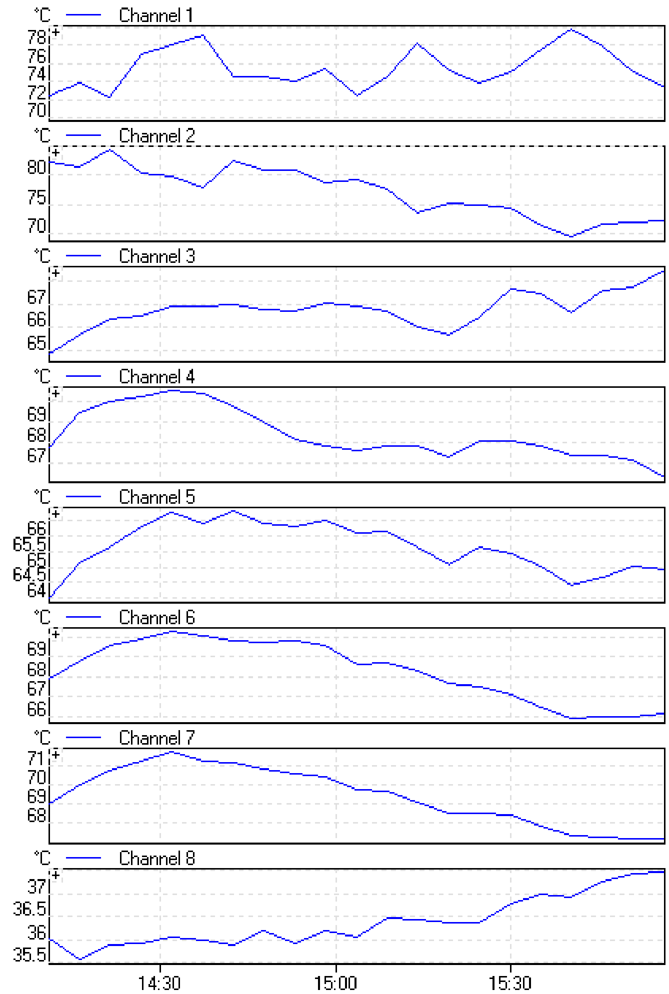

Fig. 6. Temperature ranges for each channel at the first experimental condition.

2. *Mixed mode solar dryer with forced convection.*

This experiment was hold for testing the temperature inside the solar dryer with the consideration of the use of all seven fans located in various loci of the dryer. This experiment was hold on 12th of sept 2017 and starts at 7 pm. The ambient temperature a the commencement of the test is 34.2 and the relative humidity is 56.6 %.By looking at the Fig7 below it might be noticed that this experiment set up differs from the previous one by the solar panels that has been attached to device. These panels are used to supply power needed to run the fans on the contrary with the previous test which has been run without turning on the fans. In his experiment all fans are turned on, two fans from each side of the chamber, two at the bottom of the chamber, and one fan at the exhaust of the chamber.

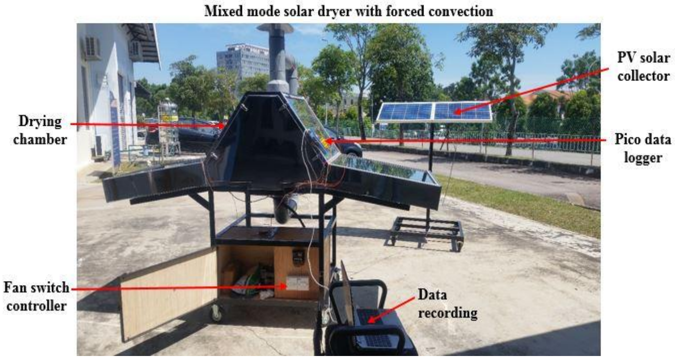

Fig. 7. The configuration of the mixed mode solar dryer with forced convection.

The recording of the experiment continued for 150 minutes at the sampling interval of 5 minutes. Eight thermocouples are installed at eight different location exactly same with the previous experiment. It was recorded in this experiment that the maximum value is 65.92 ºC which is at channel 1 (right side solar collector).This value was recorded after 50 minutes from the starting time. Whereas the minimum temperature is 44.93 ºC, and this value was measure at channel number 3 (tray 1) after 135 minutes from the beginning of the experiment. All these readings are plotted in a multiline graph .Each channel was presented in different color in the graph as shown in Fig 8.

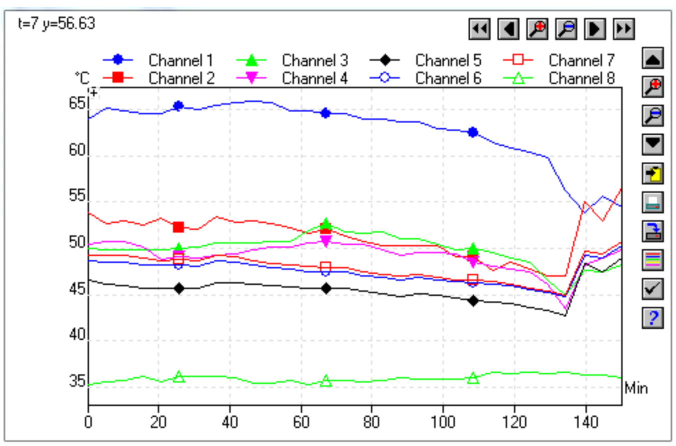

Fig. 8. The temperature graph of the second experimental condition

The graph shows almost one trend for all channels. Overall, we can see a slight downward trend in the temperature for all channels starting from the first minutes up to the minutes 130 of the test. In the following minutes, the total fall went up .The mean reason of this sudden increase in the increase in the solar radiation after the 130 minutes. It is noticeable that the ambient temperature kept almost constant with a slight variation over the time. Moreover, it is a plain that the line represents the channel number 1 is above all other channels and this might be due to the fact that the sun radians at this time fell perpendicularly on the right side solar collector which led to the rise of the temperature at this area. The range of the temperature maximum and minimum for each channels are demonstrated in the Fig 9.

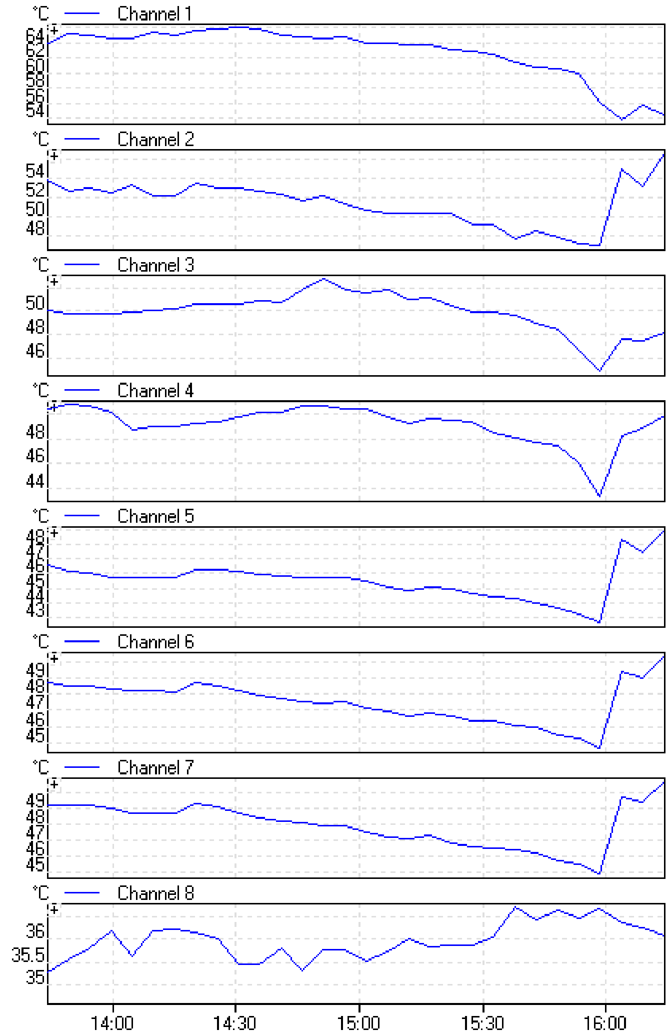

Fig. 9. Temperature ranges for each channel at the second experimental condition.

The Fig 9 gives clear limits of the temperature for each channel. It is easy to illustrate that the channel number gives a measured temperature ranges between 65 and 53 ºC which is the highest limits among all other channels. In other hand the range of the resulted temperature in the second channel which represents the temperature in the left side solar collector is variated between 55 and 47 ºC which is a relatively lower than that in the first channel. The maximum limit of the temperature in the third channel that represents the temperature at the first lower tray is 52 ºC while the minimum limit for this channel is 44 ºC. The Line of the Forth channel illustrates the temperature values at the second tray in the chamber and it is easy to see that these values ranges from 43 to 50ºC.The temperature variation with time at the exit of the chamber is presented by the fifth line that names as channel 5.It might be seen that the values of the temperature at the point varies between 42 and 50 ºC. Moreover, the sixth line gives temperature values range between 44 and 51 ºC. These readings provides the variation of the temperature on inside the chamber specifically on the third tray .In addition, The variation of temperature with time on the forth tray are presented by the seventh range line which have the limits of 51ºC up and 43ºC down. The ambient temperature has been measured by a thermocouples located out of the drying chamber and the temperature ranged between 34 and 36 º C.

3. Mixed mode solar dryer with forced convection but without the bottom and top fans in the chamber.

The setup of this experiment is similar to the second type but with the difference that in this test was run without using the bottom fans at the bottom of the chamber and the fan at the outlet of the drying chamber. The heated air b the both sides solar collectors is transferred forcedly by the fans on both side .The total fans implemented in this experiment are four only unlike the previous one where we used seven fans in total.

The performance of the experiment was hold at the date of 24/09/2017 and it started recording at 12 pm. The ambient temperature at the commencement of the testing was 34.2 ºC and the relative humidity was 56 %.

The configuration of this experiment is almost same with the previous one where we use the photovoltaic panels to generate power that required to run the fans. Fig 10 shows the location of the bottom and top fans inside the chamber that are turned off while running the testing.

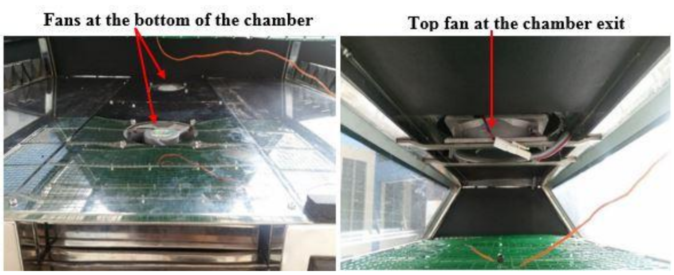

Fig. 10. Location of the bottom and top fans inside the chamber.

The main purpose of adding those fans at the bottom of the chamber is to provide a uniform air flow throughout the chamber. However, they affect negatively on the temperature inside the chamber. Therefore, by switching those fans off it would be easy to evaluate this affection on the total temperature by comparing the result of this experiment with the second experiment. The temperature values are recorded for 150 minutes continuously.

In this experiment, the highest temperature values were recorded at the right solar collector (channel 1).The maximum temperature measured in this experiment is 68.93 ºC which is at the channel number 1 after 90 minutes from the commencement of the experiment. While the minimum temperature among all channels connected with the thermocouples in the drying chamber is 48.75ºC which has been acquired at the third tray in the chamber after 25 minutes from the beginning of the testing. At the last, the maximum ambient temperature during the experiment is 38.04 ºC. All readings recorded in the table 4 are plotted in the graph at the Fig 11.

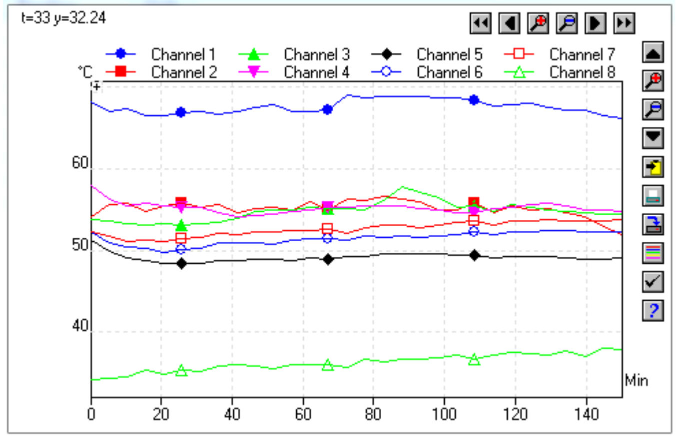

Fig. 11. the temperature graph of the third experimental condition.

In the same way, eight lines with different colors are implemented to present the temperature behavior along time at the various locations of the solar dryer. From the figure, it can be seen that all the channels are likely to be almost constant and the variation range is quite low. Blue line in the figure which represent the temperature behavior in the right solar collector was plotted above all other line and this indicates that the temperature at this position is higher than all other channel. Moreover, channel 2, 3, and 4 appears above the remaining channels, and these lines present the temperature variation at the left side solar collector, first tray, and the second tray in the chamber respectively. In addition, the line of channel 7 which represents the behavior at the fourth tray in the chamber appears in top of the line represents the behavior of temperature at the third tray (channel 6) as well as the fifth channel (outlet of the chamber). This means that the temperature gained among the time at the fourth tray higher than that the third tray as well as at the outlet of the chamber. The lowest line in green color provides the variation of the ambient temperature. The figure 12 provides more detailed data regarding the temperature variation among the time at the diverse locations.

The graph in Fig 12 demonstrates the values of highest and lowest limit of the temperature in all channels connected to the thermocouples. It is easy to see that the left side solar collector (channel 1) measures temperature values lies between 69 ºC and 65ºC.While the right side solar collector (channel 2) gives temperature values limited between 56 ºC and 51 ºC. Moreover, the third channel which measures temperature at the first tray shows higher values compared to the second channels and these values ranges between 57 ºC and 53 º C. In addition, the limits of the temperature at the second tray (channel 4) are 58 ºC as maximum value and 54 as a minimum value. The limits of temperature at the outlet are presented by the range from 48 ºC to 51 ºWhereas the temperature range at the third tray in the chamber(channel 6) is limited between the 57 ºC and 50 ºC .Also, the maximum value at the fourth tray (channel 7) is 54 ºC and the minimum temperature value is 51 ºC. The ambient temperature in this experiment ranges between 34 ºC and 37 ºC.

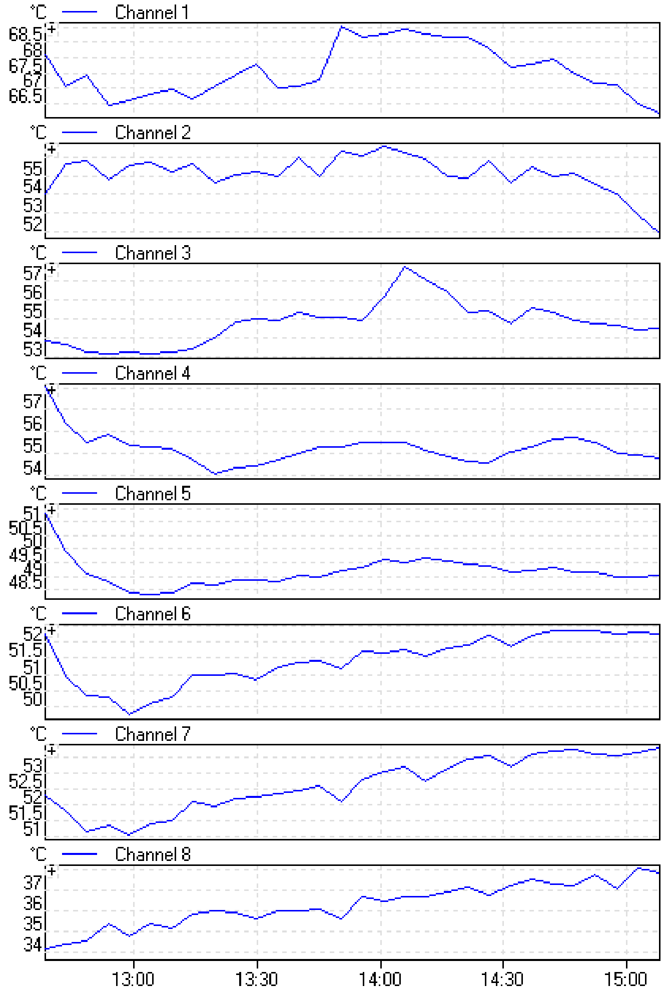

Fig. 12. Temperature's ranges for each channel at the third experimental condition.

4. *Mixed mode solar dryer with forced convection from one side of the chamber only*

In this experiment, the setup is conducted along with the photovoltaic solar panels used to run the fans, however, one solar collector is implemented in the experiment only. The other side of the chamber connected to the left side solar collector is blocked with a sheet of metal to avid the flow of the air into the chamber from that side as shown in the Fig 13.

Fig. 13. Configuration of the mixed mode solar dryer with forced convection from one side of the chamber only

The aim of this experiment is to estimate the effect of the second solar collector on the supplied heat to the chamber. In order to evaluate this effect we are going to compare the temperature inside the chamber of this experiment with that in the second experiment. This experiment has been run on 24th of September 2017 at 3 pm .The ambient temperature at the commencement of the experiment is 32º C and the relative humidity is 58.3 %.

The readings indicate that the temperature at the left side solar collector (channels) possess high values greater than all other channels at the remaining locations. It is noticeable at this experiment that the temperature fells significantly with the passage of time. The temperature at the outlet of the chamber (channel5) was slight lower and the highest value was 49.56 ºC. Moreover, the temperature values at the third and fourth trays in the chamber were lower than that at the first and second tray in the chamber. The highest ambient temperature in this experiment is 36.83 ºC. The graph line in the Fig 14 shows the variation of the temperature in all channel within the time of the test.

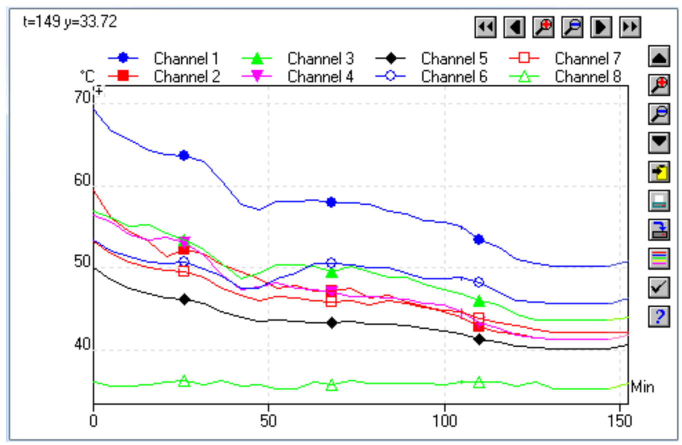

Fig. 14. Temperature graph of the fourth experimental condition.

From the figure above it might be seen that, the temperature in all locations decreases continuously from the beginning till near the end. It is easy to see that there is a significant fell of the temperature starts from the first minute and keeps in the same manner up to almost the half time of the test. The consequence of the lines from the top starts with the first channel and ends up with the fifth channel which connected to the outlet of the chamber. There is only one trend in this test which is fell down trend except for the sixth channel at the third tray of the chamber. AS it can be seen from the figure that, the line of the sixth channel fells down sharply from the beginning for about 50 minutes, then goes up for about 25 minutes before it slightly decreases again till the end of the experiment. There is a special behavior in this test where all line kept almost constant from the minute 135 of the experiment till the end. The Fig 15 provides a clear idea about the ranges of temperature in the all locations of the drying chamber.

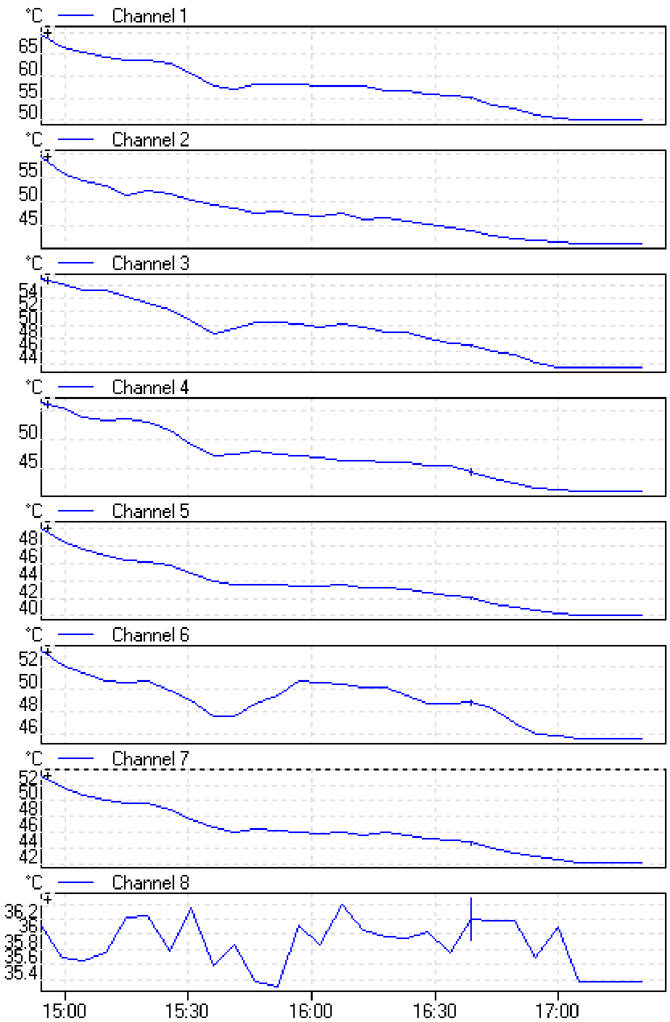

Fig. 15. Temperature's ranges for each channel at the fourth experimental condition.

It might be seen that Fig 15 demonstrates that the variation of the temperature at the right side sola collector (channel 1) lies between the upper limit 68 ºC and the lower limit 50 ºC. Moreover, the maximum limit at the left side solar collector (channel 2) is 59 º C and the minimum limit is 41 ºC. On other hand, the temperature at the first tray of the chamber (channel 3) varies between 59 ºC and 44 º C. While in the second tray of the chamber (channel 4), the temperature ranges from 41 ºC as lowest value and 59 ºC as the highest .In addition, the temperature at the third tray (channel 6) lies between the maximum limit 58 ºC and the minimum limit 46 º.Temperature a the forth tray in the chamber (channel 7) have almost the same limits of the third tray (channel 6) and ranges between 47 ºC and 57 ºC. Furthermore, the temperature at the outlet of the chamber have the maximum and minimum limits of 50 ºC and 40 ºC respectively. During the testing of the dryer in this set up, the ambient temperature varied between 35 ºC and 37.5 ºC.

5. *Indirect forced convection solar dryer.*

The setup of this experiment is quite different from the former experiments. In this test, indirect force of solar heat from both solar collectors at the sides of the chamber are implemented to produce heated air while the transparent walls of the drying chamber are replaced by opaque once. Therefore, the drying process depends mainly on a process called indirect forced solar collector while the process of direct solar drying through the glass at the walls of the chamber is ignored. The configuration of the test is shown in the Fig 16.

Fig. 16. The configuration of Indirect forced convection solar dryer.

It can be seen from the figure that the glass of the drying chamber is covered with a carton material to prevent the solar radians from passing through the chamber. Moreover, the photovoltaic panels are connected with the device to run the seven fans inside the body of the dryer. This test has been run on 24th of September 2017 at 12 pm .The ambient temperature at the commencement of the experiment was 30.8 ºC and the relative humidity is 67.1 %.It is expected from this experiment to evaluate the effect of the existence of the direct solar on the temperature along with the indirect solar dying. The results of the testing are taken for 150 minutes and they are presented in the table 6.

The readings of this experiment indicate that the temperature at the right solar collector (channel1) is the highest among all other locations in the dryer. Overall, it is noticeable that the average of the resulted temperature in the drying chamber of this setup is lower than that of the mixed mode solar drying tested in the previous experiment. The maximum temperature recorded in this test was 60.77 ºC at the first channel after 115 minutes from the beginning. On other hand, the highest temperature measured at the left side solar collector (channel 2) was 53.96 º.Moreover, the maximum temperature value at the first tray in the chamber(channel 3) was 47.46 ºC and it was recorded after 115 minutes whereas the maximum temperature at the second tray (channel 4) has been measured after 5 minutes as 47.17 ºC .At the outlet of the chamber (channel 5),the maximum temperature has been recorded as 43.41 which is in the first 5minutes of the test. In addition, the highest ambient temperature during the test was 34.60 ºC. Fig 17 shows the variation line for each channel during the testing time.

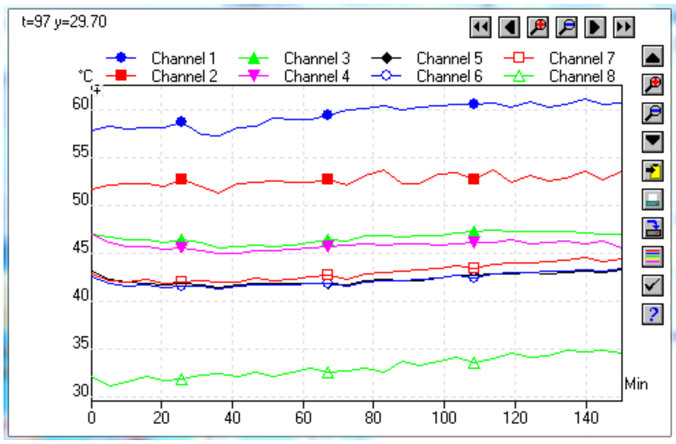

Fig. 17. Temperature graph of the fifth experimental condition.

Each line in the graph represents the variation of the temperature in a specific location of the dyer. It might be notice in this figure that the consequence of the lines which appears separated from each other unlike the former experiments. It can be seen that the line of the first channel that presents the variation of the temperature at the right side solar collector plotted on top of all other lines. In the second order comes the line of the variation of the temperature at the left side solar collector (channel). It is known that upper line in the figure possess higher temperature values. Therefore, the line of the first tray in the chamber (channel3) is above that of the line represents the second tray (channel 4) which is in green color. On other hand, the line of the fourth tray (channel 7) is above the line of the third tray (channel 6).It might be noticed that the line of the outlet of the chamber (chamber5) is in coincides with that of the third tray (chamber6) which means that the values of the temperature along the time are almost same. The lowest line in green color at the bottom of the graph demonstrates the variation of the ambient temperature. The range of the divergence of the temperature at all channels is shown in the Fig 18.

It is evident from the figure that the temperature variance at the right side solar collector (channel 1) lies between 61 ºC and 57 ºC .Whereas the temperature in the left side solar collector (channel2) varies between quite lower limits 51 ºC to 53.5 º .Moreover ,the temperature divergence at the first tray (channel 3) ranges between 45.5 ºC and 47.5 ºC .Also, the range of the temperature variance in the second tray in the chamber(channel 4) is between 45 ºC and 47 ºC. On other hand, the temperature at the outlet of the chamber (channel 5) confined between the upper limit of 43.5 ºC and the lower limit of 41.5 º. Furthermore, the limits of the temperature variance at the third tray (channel 6) are 41 ºC and 43.5 ºC. In addition, the maximum temperature limit at the fourth tray (channel 7) is 44.5 º C while the minimum limit is 42 ºC. In regard of the ambient temperature during this test, it ranged between 31 ºC and 35 º C.

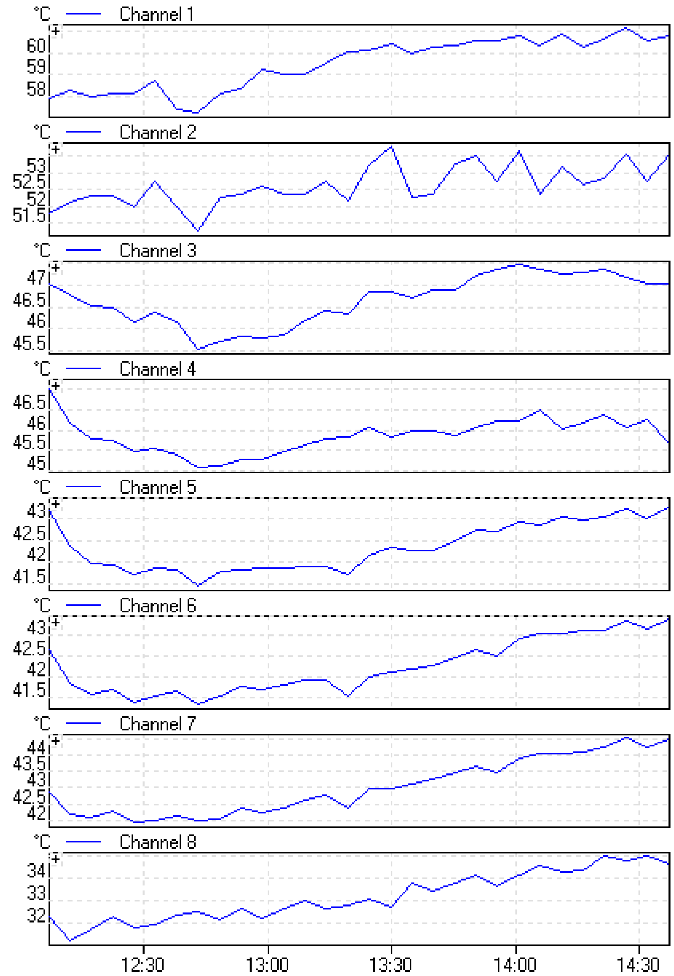

Fig. 18. Temperature's ranges for each channel at the first experimental condition.

VI. Conclusion

The main aim of this experiment is to obtain the most possible uniform air flow in parallel with achieving a high temperature by the solar panels in order to get an efficient mixed mode solar dryer used for drying the diverse agricultural products . In another meaning, we were not seeking for the highest temperature gained only, but both the two important parameters which are the air uniformity and high temperature. Therefore, this design of the mixed mode solar dryer is developed and optimized up to a certain level that the drying rate have been reduced significantly taking in consideration the quality of product. Therefore, this initial study was carried out to find out the best solar drying method could be implemented to achieve high performance. In this study, we have tested various types of solar drying including direct and indirect (mixed mode) with forced and natural convention, drying by using one side solar collector only and drying using indirect forced convection method . The results of the testing was recorded automatically using Pico software. From the testing results it can be concluded the following:

1. The highest temperature achieved was in the first condition which the natural is mixed mode solar dryer.

However, the air velocity and hence air uniformity inside the chamber was not perfect therefore, this method was not preferable.

2. It can be seen that the temperature is most uniform in the third testing which is the drying by mixed mode solar dryer but without the top and the bottom fans, however, the velocity of the air inside the chamber is quite low compared to the second state which effect the efficiency.

3. The forth test which is drying by using one side solar dryer only provided ununiformed temperature inside the chamber which is unwanted results.

4. The forth testing where it was used indirect drying only gives quite uniform temperature inside the chamber along with the time, however, these values of the temperature are lower than other states.

5. The second condition of testing which is a mixed mode solar drying with forced convection where all the seven fans in the device are used might be the most suitable and efficient method. The temperature achieved in this condition is higher than that of the third and fifth state and the velocity of the air is higher as well which will result in higher efficiency. Moreover, the temperature of the second experiment is lower than that of the first experiment however, the air velocity and uniformity is much better than that in the natural convection. Therefore, this condition is advisable to be implemented for better drying and higher efficiency.

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