*International Research Journal of Innovations in Engineering and Technology (IRJIET)*

ISSN (online): 2581-3048

Volume 3, Issue 5, pp 9-15, May-2019

# Development and Evaluation of Hybrid Grape Solar Dryer

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***Abstract*** **- The main objective of the present work was to develop and evaluate a medium scale green-house type solar dryer with capacity of 500 kg fresh grapes (Thompson seedless variety). The dryer was developed, manufactured, and tested under different operational conditions. The actual field tests for the studied dryer could give real results for the performance of the dryer. The quality evaluation tests showed the advantages of the tested dryer in giving high quality raisin based on the Egyptian Standard of dried grapes (Raisins) No., 285/2005 and the International standard ISO 21527 (2008). The results show that, drying grapes with the developed solar dryer gives high quality product competitive with the imported raisin with high safety in terms of microbial infection. The results also showed that the developed solar dryer could reduce the moisture content of grapes from 77.56 to 15.72% (w.b) within 19 hours. In general, the approach leads to improving the traditional sun drying methods of grape and also overcome the problem of higher energy consumption and capital intensive of the large scale industrial grape dryers.**

***Keywords:*** Solar drying, hybrid solar drying, grape drying, raisins, raisins quality.

## I. INTRODUCTION

Overall post-harvest losses of grapes in Egypt are estimated as about 30-35% of the production. In the peak season, the selling prices are usually at the minimum and this may lead to lower profits or even losses for the grower. Also, due to the abundant supply during the season, a glut in the market may result in the spoilage of large quantities.

The most important local varieties grown in Egypt are Superior, Flame seedless, Thompson seedless and Fiesta as seedless varieties and Early Muscat, Muscat of Alexandria, Roumy Ahmer and Fayomy as varieties with seeds [4].

In the north western coastal region and delta region, the producers of grape have been suffering from high percentage of fresh commodity losses, which reached up to 30 % especially in summer season due to higher maturity percentage at the end of the season [6].

An economical means of reducing the post-harvest losses in grapes is to convert some seedless varieties (Thompson seedless and Fiesta) to its dried face with a reasonable shelf-life [6].

World raisin production in 1995 was valued at over 1.072 million metric tons [5]. The increasing trend in raisin production makes it an important product in several countries. Also, increasing calorie consumption requires great efforts to increase a certain type of agriculture products such as raisin. Fresh grapes contain 68 kilos calories per 100 grams, which consist of carbohydrates, fats, protein, vitamins, organic acids and minerals. So it is a good source from the nutritional point of view [9].

Pre-treatment of grape prior to drying such as the application of an oil-surfactant emulsion (e.g. ethyloleat) has become a common practice to reduce the drying time of grapes [1]. Various chemical pre-treatments (hot and cold) have been used to increase the drying rate of grapes [3]. For all types of grape drying the dipping pre-treatment not only reduce the drying time (makes it more economical), in certain cases it also improves the quality (lighter color, sweeter flavor, nutritional quality and better sanitation) of the raisins produced.

The emulsion not only removes the waxy layer surrounding the skin but also diffuses into berry, thus improving external and internal water transport. Sulfuring alone was not enough to increase the drying rate.

The main objective of the present study was to develop and evaluate a medium scale green-house type solar dryer for in farm drying of grapes in medium scale farms. The approach leads to improving the traditional sun drying methods of grape and also overcome the problem of low quality dehydrated grapes and the capital intensive of the large scale industrial grape dryers.

International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 3, Issue 5, pp 9-15, May-2019

The specific objectives are:

1. Development of a medium capacity hybrid green-house type solar dryer for medium scale farms.
2. Test and evaluate the developed dryer under different operational conditions to approach the optimum working performance.
3. Determination of drying behavior and final quality of the dried grape (raisin) using the developed dryer.

## II. MATERIALS AND EXPERIMENTAL PROCEDURES

**a) Description of the hybrid (greenhouse type) solar dryer**

A green-house type solar dryer with auxiliary heaters (hybrid) and precise air distribution system was designed, constructed and installed at the experimental farm of Mansoura University. An overview of the developed solar dryer is presented in figure (1).

**Figure 1: An overview for the developed solar dryer**

**b) The Structure feature of the fabricated hybrid solar dryer**

***1. The dryer frame and beds structure:***

The dryer frame was constructed from 3.81 cm (1.5 inch) iron welded pipes. The distance between the vertical pipes is 220 cm and the pipes frame is supported on the ground via an iron foundation. The dimensions of the pipe structure are 1100 cm long 800 cm wide and 340 cm high. The front side of the pipe frame included an entrance door with dimensions of 250 x 225 cm while the rear side was arranged for supporting and installing the air distribution system. All the dryer frame was covered with 0.5 mm thick fiber glass sheets.

Two separate rectangular drying beds were installed inside the dryer at a distance of 100 cm from the frame sides and distance of 200 cm between the two beds. Each drying bed consists of a plenum chamber with dimensions of 1000 cm long, 200 cm wide and 100 cm high. The frame of each plenum chamber was constructed from 3.81 cm (1.5 inch) iron angles covered by a black painted 0.5 mm thick iron sheets. All the sides of the plenum chambers were preciously sealed for avoiding any air leakage and pressure drop inside the plenum chambers.

For each drying bed, 10 wire netting trays with frames dimensions of 200 cm long and 100 cm wide were installed over the surface of drying beds for accommodating the pre-treated grape vines. Figure (2) presents a front view of the dryer frame and bed structure.

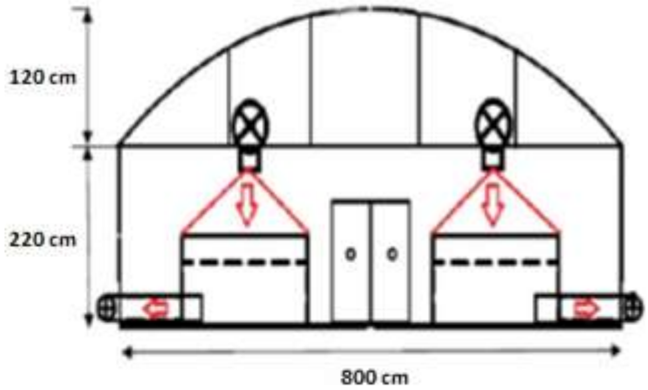


**Figure 2: Front view of the dryer frame and bed structure**

***2. Air Distribution System:***

The air distribution and control system was divided into two identical parts. Each part can supply and distribute the air in a separate manner. The design of air distribution system was assigned for precise control of the air distribution system, possibility of operating both or only one side of the drying bed and also for energy saving purpose. The structure of the air distribution system could be presented as follows:

The air supply system consists of two centrifugal fans with capacity of 2500 CFM and static pressure of 2.5 WG. Each fan was installed at the rear end of each plenum chamber via 127 cm (50 inch) galvanized iron pipe. The two fans were assigned to supply the heated air over the surface of the perforated drying trays through horizontal perforated galvanized iron pipes (one pipe for each drying bed). The two pipes were installed inside the green house facing the long axe of each drying bed at a distance of 110 cm from the bed surface. Each pipe was supplied by an air gates and grilles for convenient control of air distribution over the surface of each drying bed.

The dryer was also supplied by air suction system consists of two centrifugal fans with capacity of 2000 CFM and static pressure of 2 WG. The exhaust fans were installed at the sides

International Research Journal of Innovations in Engineering and Technology (IRJIET)

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ends of the green house. The two exhaust fan were assigned for air suction from the plenum chambers of the drying beds in an convenient manner matching with the air supply system. Each main pipe was supplied by an air control system and dampers for possible of mixing part of the exhaust heated air with the fresh ambient as an option for heat energy saving. Figure (3) present the general feature of the air distribution system.

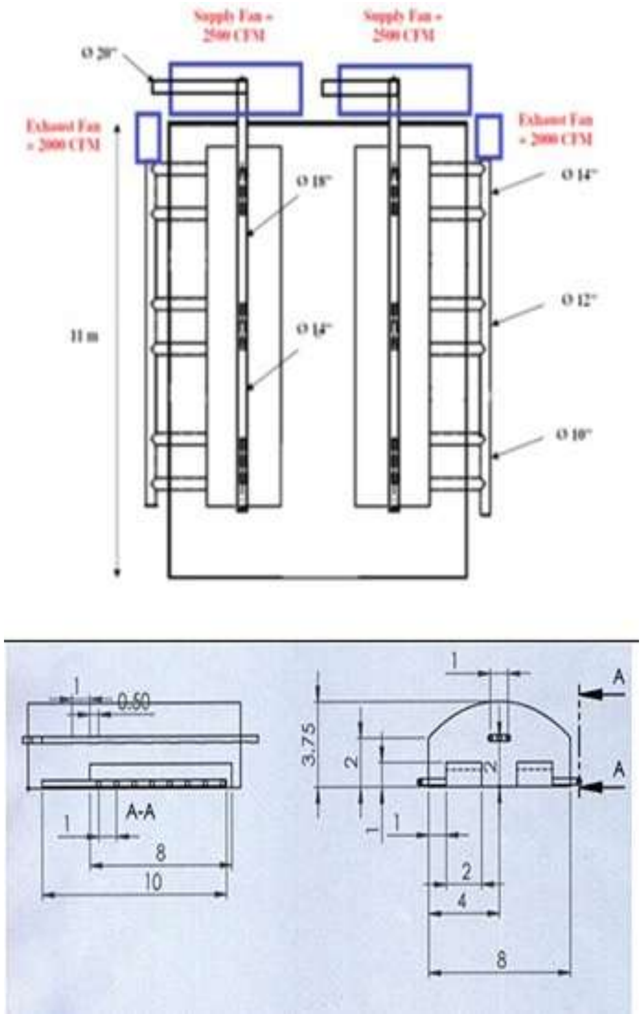

**Figure 3: General feature of the air distribution system**

### *3. The auxiliary heaters and operational control system:*

Two units of auxiliary heaters (50 Kw for each heater) were assembled with the air supply system facing the exhaust area of each fan. For precise control of air temperature, two digital thermostats connected with overload devices were used. The auxiliary heaters were used as an additional heat source for the drying air during the early stage of the drying process or in case of bad weather condition and also for extending the drying time after sunset to complete the drying process in the same day. Figure (36) presents the auxiliary heaters used for controlling the air temperature.

The dryer was supplied with an electric control panel for air and temperature control system and also the operation devices. The control panel included switches, thermostats, temperature digital monitor and protection circuits. Figure (4) presents the auxiliary heaters and the dryer control system.


**Figure 4: The auxiliary heaters and the dryer control system**

### c) Sample Preparation

Fresh, ripe hand harvested seedless Thompson (Banaty) grape was used for field testing of the drying process. The initial moisture content of the freshly harvested grape barriers was ranged from 77.00 % to 78.16 % (wet basis) and the sugar content was at Brix value of 23 as measured by the hand refract meter, and the TSS is 20.50.

For ensuring the uniformity of the grapes used for different field tests, the berries of the freshly harvested grape were cut into bunches and cleaned with tap water to make it free from dust and foreign materials.

The outer waxy cuticle affects the moisture diffusion from the grapes during the drying process. A chemical pre-treatment is generally applied to decrease the skin resistance and hence improving moisture diffusion through the waxy cuticle.

The pre-treatments prior to the drying process included immersion in NaOH (0.2%) at solution temperature of 90oC and dipping times of 1 min. After immersion of samples, the samples were taken out from NaOH solution and washed under tap water until full removal of alkaline. Then the washed samples were immersed in 3% sodium meta bisulphate solution for 5 min.

### d) Measuring Equipment

During the course of field testing, several measurements were conducted either directly or indirectly, depending on the natural of the measurement.

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***1. Moisture content:***

The moisture content of grapes was determined using an electric oven method at 105 °C for 5 – 7 h according to the method recommended by [2].

***2. Air velocity:***

The velocity of drying air was adjusted at 2 m/sec over the surface of trays using a digital air velocity meter Model (TSI 9515, USA).

***3. Weight of grape samples:***

Weight of grape samples was conducted using an electrical digital balance model D-type with a maximum capacity of 6000 g and 0.1 g accuracy.

***4. Air temperature and relative humidity:***

A temperature and relative humidity meter model (HT-315, Taiwan) was used for measuring both parameters during the experimental work.

***5. Solar Energy Measurement:***

The solar radiation data were collected from the weather station installed on the roof of the Agriculture Engineering Department, Mansoura University.

**e) Testing methodology of the developed solar dryer**

Before each drying run, the dryer was adjusted for the required level of drying air temperature using the auxiliary heaters (70 oC) and the air velocity over the trays surface was also adjusted (2m/sec). After making sure that the dryer working at stable condition, the dryer beds were loaded with pre-treated grape which was distributed uniformity in a single layer. The dryer beds divided into two sections, each section consists of eight trays and a separate plenum chamber. The two section of the drying bed were installed at the sides of the dryer with 1.5 m distance between them. For each drying bed, one auxiliary heater and two fans were used for air heating, charging the heated air through the drying bed and discharging the exhaust air out of the dryer.

Moisture content was measured before the drying process and throughout the drying period at one hour intervals at different places of the drying bed by taking (500g) of grape samples in three replicates and using the electric oven moisture determination method as previously mentioned. The drying process was kept running until the moisture content of grapes almost ceased to approach the final moisture content of about 16-17% w.b.

**f) Tests to Evaluate Raisins Quality**

The quality evaluation tests for the produced raisins during the performance tests of the fabricated solar dryer included raisin moisture content, total soluble solids, total sugars, reducing sugars, So2 residual, PH value, Crude fibers, ash content, and Non enzymatic browning. Microbiological tests were also conducted for assessment of total bacterial count, yeast and molds. All tests were conducted at the laboratories of the Food Technology Research Institute- Agricultural Research Center A.R.C).

## III. RESULTS AND DISCUSSIONS

**a) Field performance of the solar dryer**

The actual solar radiation recorded on a horizontal plane outside and inside the solar dryer varied from hour to hour and day to another due to influence of atmospheric clearness index (KT) and effective transmittance of the dryer cover. Therefore, the solar radiation recorded inside the solar dryer was always lower than that outside the dryer. The hourly average solar radiation outside and inside the solar dryer were 518.8 and 338.3 W/m2 respectively. Consequently, the hourly average effective transmittance of solar dryer cover was 0.6521.

The direct and reflected components of heat radiation were absorbed by the grape vines, floor of dryer and other objects in the solar dryer. These objects experience a rise in temperature, but since their temperature was not very high, auxiliary heaters were assigned for raising the drying air temperature to a minimum level of 48$^{o}$ C and a maximum level of about 70$^{o}$ C as a matter of fact the indoor air temperature is the precious factor in drying process.

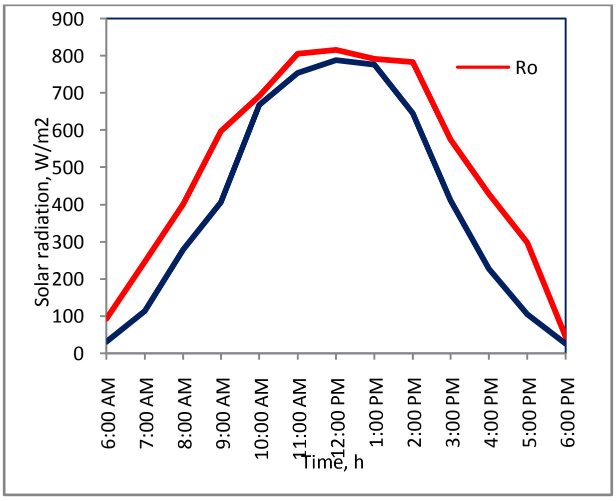


**Figure 5: Distribution of the average solar radiation flux incident outside and inside the solar dryer during the field tests**

 

ISSN (online): 2581-3048
Volume 3, Issue 5, pp 9-15, May-2019

**b) Ambient and drying air temperatures**

The main function of drying air during solar drying process is transferred part of heat energy accumulated inside the solar dryer due to greenhouse effect into the agricultural product being drying and removed moisture in the form of water vapor to outside the solar dryer until the product reaches the final moisture content (safety level). The other part of heat energy comes from an electric auxiliary heaters provided to the dryer heating system. The capability of drying air to carry water vapor depends on the overall heat energy (solar and electric heat energy from the auxiliary heaters in raising the drying air temperature and consequently, in decreasing air relative humidity.

Therefore, the indoor air temperature changed from hour to hour and day to another depending on the change in macroclimatic conditions (solar radiation, ambient air temperature, and relative humidity). The hourly average air temperatures of outdoor (Tao), indoor (Tai), and bulk temperature of grapes (Tbulk) during the performance tests of the solar dryer are presented in Figure (6).

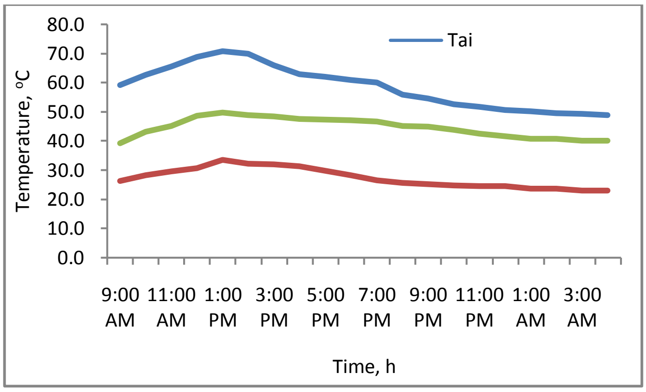


**Figure 6: Indoor, outdoor air temperatures and grape bulk temperature during solar drying process**

The highest mean value of indoor air temperature (70.9ºC) whilst, the highest value of outdoor air temperature in the same day was 33.6ºC. Thus, the used heating system increased the indoor air temperature over the outdoor by 37.3ºC. The highest mean value of grapes bulk temperature was (49.7ºC) due to reduction in moisture content of grapes.

**c) Air relative humidity**

Air relative humidity is in general the dominant parameters that affect drying process of any agricultural product. It plays an important role in carrying on the moisture evaporating from the agricultural product according to its capability to do that. As the air relative humidity is lowered under the moisture content of the agricultural product, its ability to carry on moisture increased. It has an inversely relationship with indoor air temperature particularly during daylight-time. The hourly average air relative humidity of outdoor (RHo) and indoor (RHi) during the drying process are shown in figure (7).

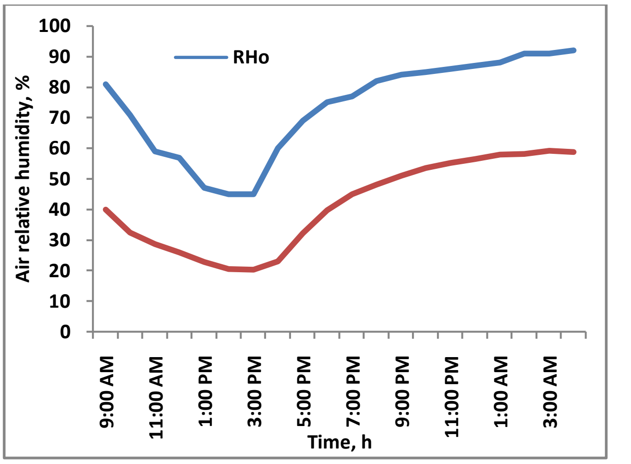


**Figure 7: Indoor, outdoor air relative humidity during solar drying process**

The average value of indoor air relative humidity (41.41%) was realized whilst; the average value of outdoor air relative humidity was 73.6%. Thus, the solar dryer with auxiliary heaters lowered the indoor air relative humidity under the outdoor by 32.2%.

**d) Behavior of moisture reduction of grapes during solar drying process**

Initial moisture content of grape vines varied depending on their maturity stage. Based on the previous characteristics, the average moisture content of grapes was about 77.56% (w.b.). The final moisture content was approached about 15.72% w.b. The drying time was 1 day (19 hours). While, in open-sun drying (control experiment) drying time was about 9 days (78 hours).

Changes in the moisture content (w.b.) with drying time for grape vines at six different drying trays represent different locations inside the solar dryer are shown in and Figure (8). Figure (8) evidently clarified that, the grape vines at beginning of testing day particularly during the first two hours the moisture content was slightly decreased and thereafter the moisture content decreased rapidly due to increasing in the intensity of solar radiation. Same behavior was also observed prior to sunset due to the same reason. It was also observed that, the moisture reduction rate was nearly similar in different locations of the dryer which means homogeneous drying of grapes. This was a reflection of proper distribution of air temperature, relative humidity and air velocity over the trays surfaces.

 

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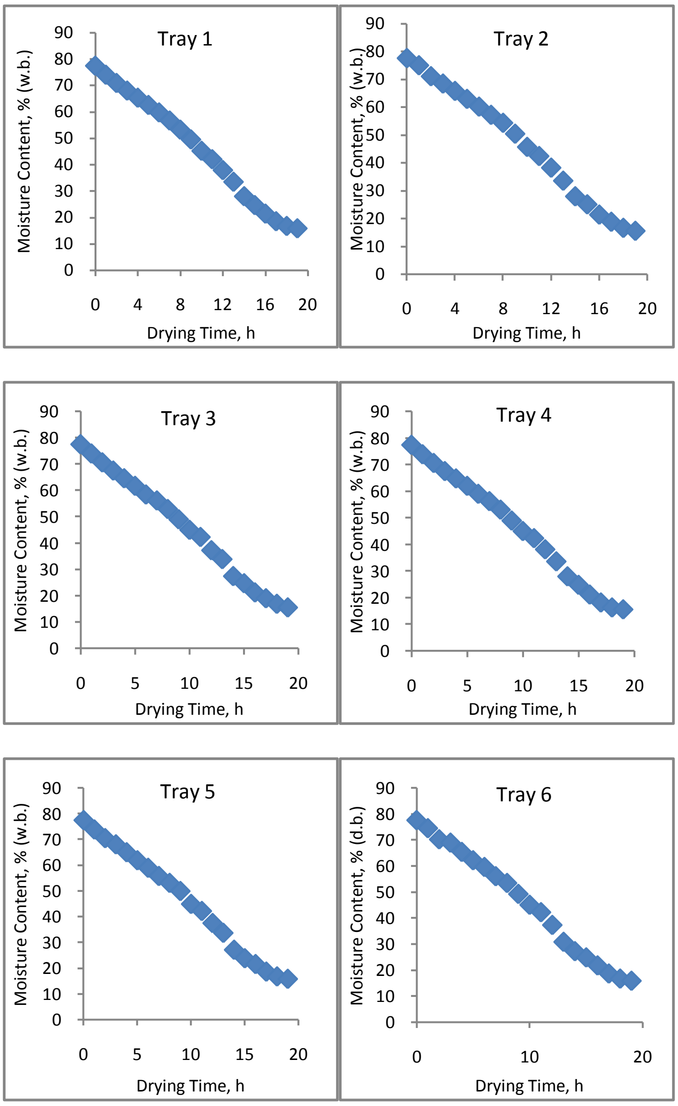


**Figure 8: Changes in the moisture content of grapes (w.b.) with drying time at six different drying trays inside the solar dryer**

### e) Quality evaluation tests

Table (1) presents the results of quality evaluation tests of the produced raisin. As shown in the table, the final moisture content of the raisin approached about 16.52 % w.b. with total and reducing sugars of 59.65 and 49.24 g/100g respectively. Meanwhile the samples content of $So_2$ was 548.70 ppm, PH value of 4,510, T.S.S of 76.5%, crude fiber of 2.43 g/100g, ash content of 2.65 g/100g and non-enzymatic browning of 0.056 absorbed at 420 Nano meter. However, the microbial examination for the produced raisin showed a bacterial count of 20 cfu/g and yeast & mold count of 20 cfu/g.

In general, it could be said that, drying grapes with the developed hybrid solar dryer gives high quality product with high safety in terms of microbial infection.

**TABLE 1 (a & b)**

**The results of quality evaluation tests of the produced raisin**

**(a) Chemical analysis**

| Sample | *Test methods | Test results% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Moisture, % (w.b) | T.S.S, % | Total sugars, g/100g | Reducing sugars, g/100g | $So_2$, ppm | pH value | Crude Fibers, g/100g | Ash, g/100g | Non enzymatic browning |
| Fresh grape | [2], [10] | 78.16 | 20.50 | ND | ND | ND | ND | ND | ND | ND |
| Raisins | | 16.52 | 76.5 | 59.65 | 49.24 | 548.7 | 4.51 | 2.43 | 2.65 | 0.056 |

**(b) Microbiological examinations**

| Test type | *Test methods | Test result of raisins |
|---|---|---|
| Total bacterial count | ISO 4833 | 20 |
| Yeast and Mould | ISO 21527 | 20 |

## IV. CONCLUSION

1. The developed solar dryer could reduce the moisture content of grapes from 77.56 to 15.72% (w.b) within 19 hours.
2. The moisture reduction rate was nearly similar in different locations of the dryer which means homogeneous drying of grapes. This was a reflection of proper distribution of air temperature, relative humidity and air velocity over the trays surfaces.
3. Drying grapes with the developed hybrid solar dryer gives high quality product with high safety in terms of microbial infection.

## ACKNOWLEDGEMENT

The authors of this research would like to express their sincere thanks and most appreciation for the Science and Technology Development Fund (STDF) for financial support, follow-up of the current research work which has been extracted from the project of “Design and manufacture of grape dryers suitable for medium and small scale farms”.

ISSN (online): 2581-3048
Volume 3, Issue 5, pp 9-15, May-2019

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**Citation of this article:**

Dr.Ahmed M. Matouk, Dr.Mohammed M. El-Khouly, Dr.Ahmed Tharwat, Dr.Samy E. El-Far, "Development and Evaluation of Hybrid Grape Solar Dryer" Published in *International Research Journal of Innovations in Engineering and Technology (IRJIET)*, Volume 3, Issue 5, pp 9-15, May 2019.

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