DEVELOPING AND TESTING AN AIR FLOW DISTRIBUTOR OF SOLAR DRYER FOR DRYING MORINGA OLEIFERA IN ARID CLIMATE

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ABSTRACT
This study was aimed to investigate an air-flow distributer of a solar dryer. This study was contained two factors: First, the air outlet throttle (three angles, 30°, 60°, and 90°). Second, the design of the air inlet with three levels (new design (I2), without (I1), and half-opening air inlet gate of the new design (I3)). The results show significant effects on these parameters, where the highest efficiency (51.7%) was obtained at (I1) and (30°) angles. While the temperature changes between the inlet and outlet had a significant effect on the pressure difference, the pressure difference increased, reaching (1.65 Pa). Also, the drying rate was affected by the temperature and the amount of air entering the dryer. The highest drying rate gave (0.165 kg/h) when used the air discharge angle (30°) with the (I3), where this increased the temperatures of the air in the dryer reduced the air entering.

Key words: Solar dryer, solar collector, solar collector efficiency, drying rate, moringa, magnesium,
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تطوير واختبار منظم حركة الهواء للمجفف الشمسي لتجفيف نبات المورنجا للمناخ الجاف

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المستخلص

تهدف الدراسة الى تقييم الاداء للمجفف الشمسي المصنع والمطور محليا بإضافة منظم هواء لتنظيم حركة الهواء الداخل الى المجفف الشمسي. حيث تم التصنيع بعد اجراء الحسابات وفق المعادلات المعتمدة للتصميم وبعدها تم اختبار الاداء الذي تبين وجود تأثير معنوي واضح عند تغيير معاملات الدراسة حيث تم الحصول على اعلى كفاءة (51.7%) عند ازالة منظم الهواء (I1) واستعمال زاوية (30°) لتصريف الهواء , بينما كان لتغير درجات الحرارة تأثير واضح على مساحة فرق الضغط حيث كلما زاد الفرق بين درجات الحرارة كلما زاد فرق الضغط وسجل اعلى فرق ضغط عند تداخل زاوية تصريف الهواء (30°) مع تركيب منظم هواء بنصف تغذية (I3) وسجل (1.65Pa). كما ان معدل التجفيف يتأثر بدرجات الحرارة وكمية الهواء الداخل الى المجفف حيث تم تسجيل اعلى معدل تجفيف عند استعمال زاوية تصريف الهواء (30°) مع تركيب منظم هواء بنصف تغذية (I3) واعطى (0.165 kg/h) حيث ان هذه المعاملات زادت من درجات حرارة الهواء الداخل الى المجفف.

الكلمات المفتاحية: المجفف الشمسي، كفاءة المجمع الشمسي، معدل التجفيف، مورنجا، المغنيسيوم، المجمع الشمسي،

*جزء من رسالة ماجستير للباحث الاول.

INTRODUCTION

One of the crucial issues for the farmer, retailer and consumer is the significant losses that occur to crops during post-harvest operations, including crop damage, pollution, and the deterioration of crops during storage. The main reason for the deterioration of crops during storage caused by the high percentage of moisture content (HMC%), where most agricultural products at harvest time contain a (HMC%), that causes damage to crop, because of fungal and bacterial growth, and this may lead to the spoilage of agricultural products quickly and reduce the nutritional content in them. Therefore, it was necessary to reduce the (HMC %) of crops to the storage safety limits, to preserve the crops as long as possible, (4). The awareness raises in many parts of the world around renewable energy and the essential role in expanding the scope of technology for farmers in developing countries to increase their productivity. The importance of drying rises because of its great economic value, as solar energy is gaining rapid acceptance as an energy-saving in many applications. It is preferred over other alternative energy sources such as wind and oil shale because it is abundant, inexhaustible and non-polluting (20). There are many ways to preserve agricultural food, and drying is one of the most traditional methods for preserving food; and it is known as a simple process in which the excess moisture content is removed from an agricultural product. The moisture content of most agricultural products ranges between (25-80%), but in general agricultural products have a moisture content of about (70%), and this value is much higher than the value required to preserve agricultural products for a long period (5). Reducing the moisture content of crops in the drying process and at a recommended temperature helps reduce the weight and size of crops, which results in safe storage and transportation and prevents the germination and growth of fungi, thus preserving the quality of the product for a specific period (more than a year) without any losses in qualities and with minimal expenditure energy (10). One of the most important reasons for the popularity of dried products is the long shelf life, variety of products, and a significant size reduction, in addition to the fact that dried foods regain their original condition after being rehydrated whenever necessary to use them (2). There are two main methods for drying agricultural products; direct solar drying and indirect solar drying using solar dryers, where heating is done either by natural convection or forced convection. Both direct and indirect drying methods can be combined, which is called mixed drying (6). Agricultural products are dried in tropical and subtropical countries using the direct solar drying method, mainly farmers in rural areas with small agricultural areas, where farms do not need to provide electrical energy, and this method is more efficient in drying crops, fruits, and vegetables on a small and limited scale. This method has a long drying period, and low product quality, spoilage caused by weather fluctuations, pollution, insects, birds, and rodents. So, most farmers in these countries use locally manufactured natural load solar dryers because they are inexpensive to set up, easy to install and operate, the drying period is short compared to direct solar drying and does not need to provide electrical energy. This method is used to dry most agricultural products such as tomatoes, mango slices and grains (7). Moringa is one of the most nutrients that contains nutritious minerals and vitamins, can be taken as food, or taken as a treatment (11) and are also used as nutritional supplements.(9,10) As well as being used as a growth stimulator for the propagation of some other crop (13, 14, 19). In this study, the Moringa leaf was selected to be dried using a natural convection solar dryer, manufactured locally. A new design of inlet air and control outlet air was added to evaluate the developed solar dryer's performance for investigating the new designs effectiveness on the efficiency of the solar dryer.

MATERIALS AND METHODS

In this study the performance evaluation has been done on a solar dryer locally constructed and developed, where added an airflow distributor adjusts the inlet air and the outlet air of the solar dryer. The process of designing the dryer included first collecting climatic data for the experiment site (Baghdad, Iraq) then studying all the available designs and identifying the advantages of each type of

solar dryer. It chooses the product to be dried to obtain the appropriate temperatures for the drying process by the solar dryer. The solar dryer consists of two main parts, the solar collector, and the drying room. The two parts designed to be detachable when transporting and performing maintenance operations. The solar dryer consists of two parts:

1- The solar collector was responsible for converting the sun's rays falling on it into thermal energy used in the drying process. It consists of a galvanized iron structure with a thickness of 1 mm and a structure of plywood with a thickness of 1 cm. Wood has advantages in being an insulator more than metal materials with higher thermal conductivity, cheaper, and lighter weight. It also considered a non-carcinogenic and environmentally friendly material. The collector was designed with dimensions of length (2 m), width (0.75 m), and height (0.15 m), as in Figure (1a). A piece of zigzag steel coated iron was placed inside the solar collector. It is painted in matte black to collect the largest solar radiation and generate the necessary energy. The solar collector was covered with a piece of the transparent plastic sheet because of its safety against breakage and easier handling and maintenance with a thickness of 4 mm, this thickness is the best according to what was stated (3).

2- An air distributor with a feeding gate was installed to control the solar dryer air entering. The air distributor was designed to be removable and installed when needed. It regulates the speed and movement of the air entering the collector by reducing the air speed, which makes the drying air touch the absorbent plate for an extended period, which helps to raise the temperature of the drying air and thus raise the drying rate.

3- The drying chamber, which was the upper part of the solar dryer, was designed to be suitable for most medicinal plants. It was also made of a structure of galvanized iron and plywood with a thickness of 1 cm, with dimensions of length (0.5 m), width (0.75 m), and height (0.6 m) as in Figure (2a), the drying room was isolated from the inside with a thermal insulator (Armaflex) to prevent internal heat loss. The drying room contains two shelves with a distance between them (0.15 m) to spread the agricultural materials for drying. The shelf is detachable for cleaning and maintenance operations. The shelf consists of a wooden frame and metal sieves were placed above the drying chamber. The room for expelling the moist air; this chamber contains an outlet gate (throttle) that moves at different angles according to the levels of the experiment.
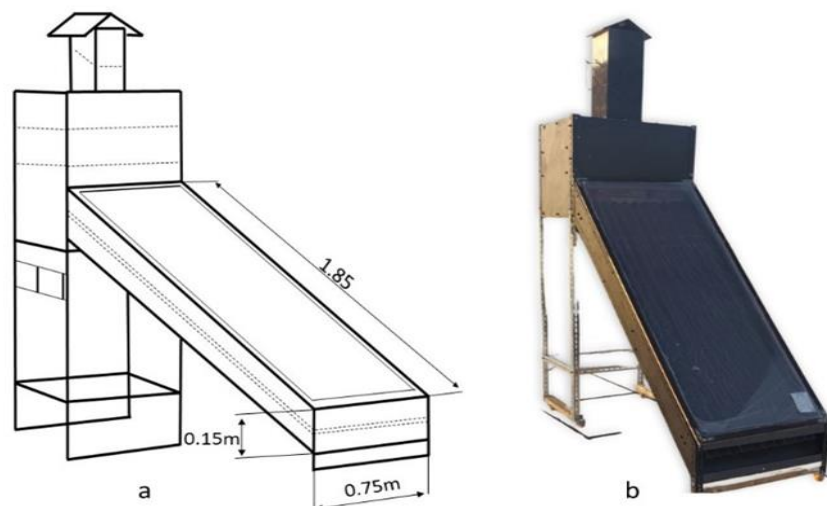

Figure 1. The front view of the solar dryer (a) the layout and dimensions (b) the implementation

The entire dryer was painted black to collect as much heat as possible (Mokhtarian et al., 2020). The readings were recorded by a set of thermal sensors (dht22) connected to six positions of the solar dryer, one of them outside the dryer to measure outside temperature and other at the absorbent panel for displaying the plate temperature, and another at the air entry of the drying chamber, above each drying rack, and at expelling moist

air opening from the dryer. The study included two factors, the first was the design of the air inlet with three levels, which was without an air outlet (I1) and with a new design air outlet (I2), and the last was a new design air outlet with a half-feed (I3). The second factor had three levels of the humid air outlet throttle angle, which were (30°, 60°, and 90°).
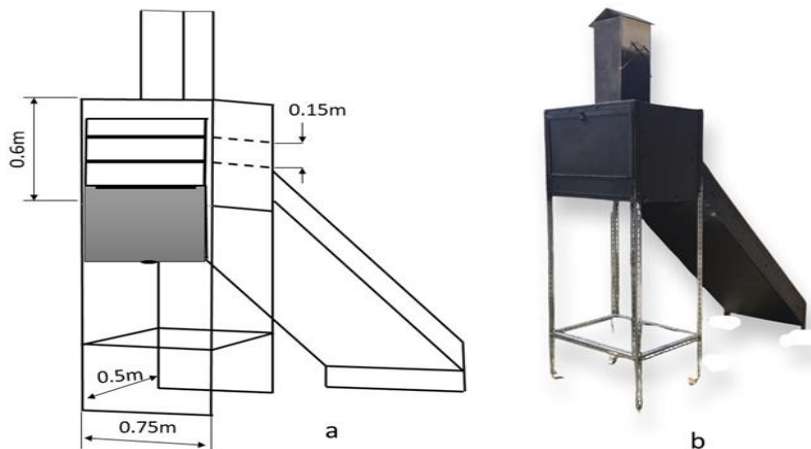

Figure 2. Back view of the solar dryer (a) layout and dimensions (b) the implementation

Tilting solar collector

Improving the solar collector requires setting an appropriate slope as larger amounts of solar energy are collected with the collector surface positioned perpendicular to the sunlight. The tilt of the solar collector also helps the airflow through the principle of natural convection as warmer and less intense air rises through the system the tilt angle and direction were set using the following equation

$$\beta=(\Phi-\delta) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

$$\delta=23.45\sin\left\{\frac{360}{365}(284+N)\right\} \dots\dots\dots (2)$$

Where:

β is the angle of the solar collector with the horizon (º),

Φ is the degree of latitude (º),

δ is the angle of declination (º) with the direction south,

N is the number of the day (in January N = 1 and in December N = 365).(15)

According to the above equation and (1), the solar collector was tilted at an angle of (45) degrees to the horizon so that the sun would be perpendicular to the solar collector and collect an enormous sunlight amount.

The Experiment A Factorial experiment was done using a completely random design (CRD) with two factors: three levels with three replicates, 27 experimental units for each factor. The least significant difference (LSD) was applied at a 0.01 probability level to compare the means. *Moringa Oleifera* leaves were brought from the College of Agricultural Engineering Sciences orchard at the University of Baghdad, in the 2021 season. The leaves were picked from the twigs and after cleaning them from the dust, a sample of the leaves was weighed and placed in a thermal oven to estimate the moisture content of leaves, (77% wet basis), and moisture content was done using oven method at a temperature 105 °C for 6 hours according to (AOAC 1990). As for drying by the solar dryer, samples of the plant were weighed, and samples were placed inside perforated aluminum containers to facilitate the circulation of *moringa* leaves and to facilitate the process of weighing the sample before and after the drying process to estimate the moisture content. The air temperatures inside and outside were recorded every 15 minutes by temperature sensors. The solar radiation was measured by the (solar power meter), and the airflow outlet velocity of the solar dryer was also recorded the flow meter by (fluke 922) every 15 minutes to study the efficiency of the solar collector, drying rate, and pressure difference, and the magnesium concentration in the sample.

Table 1. Air mass flow discharge from the outlet gate (kg.h⁻¹)

Air Inlet design	the angles of the air outlet gate		
	30°	60°	90°
I1	123.26	133.62	146.59
I2	100.26	108.1	118.37
I3	81.38	93.42	103.81

Study parameters: The amount of water to be evaporated represents the amount of water to be removed to reach the safe moisture percentage for storage, and it was calculated by the equation below (18)

$$M_w = Mp * \frac{(Mi-Mf)}{(100-Mf)} \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

M_w = The amount of water evaporated (kg)

Mp = Mass of the material to be dried (kg)

Mi = initial moisture content (% w.b.)

Mf = final moisture content (% w.b.)

1- The drying rate is the amount of water evaporating in a specific time (18)

$$mdr = \frac{Mw}{td} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

mdr = average drying rate (kg h^{-1})

td = drying time, sunshine hours (h)

2- The amount of energy extracted from the solar collector, and can be calculated by the equations below (18)

$$E = ma * (hf - hi)td \dots\dots\dots\dots\dots..(5)$$

$$Q = ma * cp * (ti - to)td \dots\dots\dots.. \quad (6)$$

E, Q = total useful energy (kJ)

h_f = final specific enthalpy (kJ kg^{-1}),

h_i = initial specific enthalpy (kJ kg^{-1}).=

ma = mass airflow rate (kg h^{-1}),

cp = Air specific heat (kJ.kg^{-1}.C^{-1})

ti, to = internal & external temperature (C)

3- Efficiency of the solar collector

The efficiency of the solar collector is directly proportional to the amount of energy required for drying and inversely with the area of collection and the solar radiation falling on the unit area, and it can be calculated by the following equation (18)

$$\eta c = \frac{E}{Ac\, I} \dots\dots\dots\dots\dots\dots\dots\dots\dots (7)$$

ηc = collector efficiency (%)

Ac = solar collector area (m^2)

I = incident solar radiation (kWh.m^{-2})

4- Pressure difference It is a function that expresses the pressure difference between the outside (surroundings of the dryer) and the pressure inside the dryer, and this difference or difference results from the difference in temperatures and is calculated by the equation below (11)

$$\Delta p = 0.00308 * g * (Ti - Tatm)h \dots\dots\dots(8)$$

ΔP = pressure difference area (Pa),

g = gravitational acceleration (9.81 m s^{-2}),

T_i = inlet temperature (°C),

T_{atm} = ambient temperature (°C)

h = height of the dryer (m).

RESULTS AND DISCUSSION

1. Drying rate

The results show the effect of changing the air outlet opening angle had the greatest effect on the drying rate, as the drying rate increased from (0.1 kg/h) to (0.144 kg/h) when decreasing the air outlet angle from (90◦) to (30◦) by an increase of (30%), as shown in Figure 3. Also, shows that there was a significant effect when changing the design of the drying inlet air on the drying rate, as the drying rate increased from (0.11 kg/h) to (0.14 kg/h) when installing the air inlet gate with a half-feed (I3), by an increase of (21%). This diagram also shows that there was a significant effect of the interaction between change in outlet angles and the change in the design of the inlet holes on drying rate, where the lowest drying rate was recorded at the overlap of (I1) with the angle (90°) of (0.1 kg/h). in comparison, the highest drying rate at the overlap of (I3) with (30°) was (0.165 kg/h), an increase of (39%) and the reason was that reducing the angles of outlet air led to an increase in the temperatures inside the dryer as it acts to reduce the amount of outside air getting out, as shown in Table (1). And thus, increasing the contact of the air with the absorbent plate leads to rapid heat exchange between it and the surrounding air, thus raising the temperature of the drying air. Food helped reduce air speed and turbulence, which helped raise the air temperature and thus raise the drying rate which is consistent with what was stated (12) when removing the air inlet design (I1) and expanding the air outlet hole to (90°) which increased the air velocity and turbulence in its movement, thus reducing the drying air temperature, which led to a decrease in the drying rate.
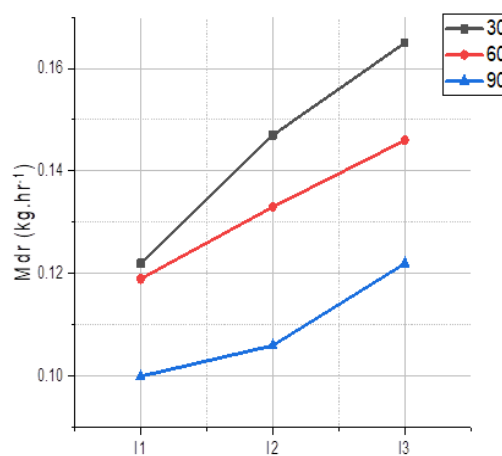

Figure 3. The effect of inlet and outlet opening and the interaction between them on the drying rate

2- **Efficiency of the solar collector**

Figure 4 shows the effect of the air inlet design had the greatest impact on the efficiency of the

solar collector. When (I2) was removed, the efficiency of the solar collector increased from 39.1% to 47.9%, by an increase of 18% approximately. This was due to the increase in the amount of air entering the solar collector, as the air velocity and turbulence increased, which increased energy and thus increased efficiency. It is also clear that the efficiency of the solar collector increased from 39.4% to 44.9% when reducing the inlet gate opening angle from (90°) to (30°), by an increasing of (12%). The small amount of outside air, led to gain the largest thermal energy from the solar collector, leading to an increase in the extracted energy (18), and thus an increase in the efficiency of the solar collector. This was because the efficiency of the solar collector was proportional to the energy extracted in a direct proportion. When the energy increases, the efficiency of the collector increases. When the amount of energy extracted from the collector is reduced, the efficiency of the solar collector decreases, and this was obvious from Equation No. (7) and which is consistent with what was stated (8). The diagram also shows that there was a significant effect from the interaction of the study parameters, as the lowest efficiency was recorded from the interference of the full opening of the outlet gate (90°) with the air regulator (I2) and it was estimated at (37.3%), while the highest efficiency was recorded from the interference of the lowest drainage hole with an angle of (30°). And the removal of the (I1) amounted to (51.7%), an increase of (28%), and the reason was the same as explained above.
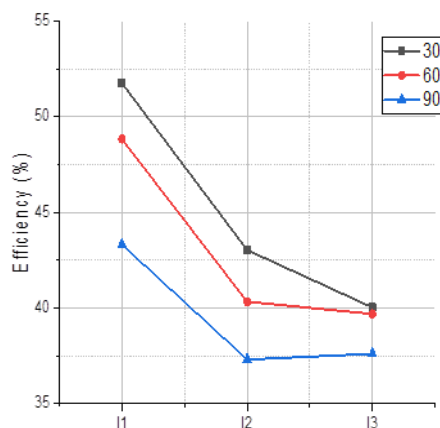

Figure 4. The effect of inlet design and outlet opening angle and the interaction between them on the efficiency of the solar collector

3- pressure difference
Figure 5 shows that the pressure difference increased from 1.12 Pa to 1.56 Pa when decreasing the opening of the air discharge gate from (90°) to (30°), that was, by an increase of 28%. The pressure difference also increased from 1.25 Pa to 1.45 Pa when installing (I3), which was an increase of 14%. The diagram shows that the effect of changing the outlet opening has a greater effect than changing the inlet openings. As for the interference, it had a significant difference as well, where the highest-pressure difference was recorded as at least interference. An air outlet angle (30°) with the installation (I3) and its amount (1.67 Pa), while the lowest pressure difference occurred when the highest amount of air outlet at an angle (90°) was overlapped with (I1) and its amount (1.01Pa). That was, an increase of (39%) and the reason was due to the increase in the temperature difference between inside and outside the dryer, as the pressure difference was directly proportional to the temperature difference, as the greater the temperature difference, the greater the pressure difference with it, and this supports what was stated (9).
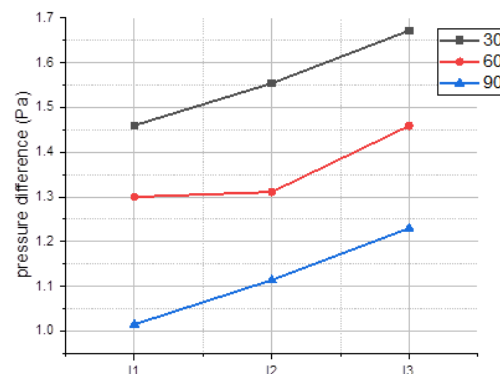

Figure 5. The effect of inlet design and outlet opening angle and the interaction between them on the pressure difference

4- **The percentage of magnesium**
Figure 6 shows the effect of changing the design of the air inlet and the change of the air outlet opening on the proportions of magnesium in *Moringa Oleifera* leaves, where the highest percentages of magnesium were recorded when using the outlet gate angle (60°), which gave (407.6ppm), while the lowest percentages of magnesium were recorded when using the outlet gate angle (30°) and its (382.7ppm) at the air outlet factor of the dryer. While the highest percentages of

magnesium were recorded when removing the air regulator (I1) and it gave (410ppm), and the lowest percentages when installing the air regulator with half feeding (I3) and it was recorded (384.6ppm). The reason was that the increase in temperature, it led to a decrease in the percentage of magnesium in the plant sample with a high percentage of ash, and this was consistent with what was stated (17).
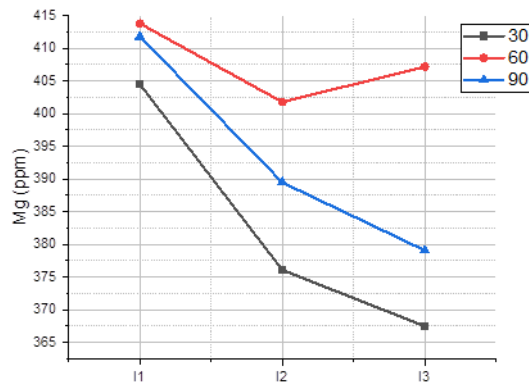

Figure 6. The effect of inlet design and outlet opening angle and the interaction between them on the percentage of magnesium (ppm)

CONCLUSIONS
1- The less amount of incoming air and the quantity of outgoing air, the higher the interior temperatures of the dryer.
2- reducing the air outlet opening results the highest drying rate, pressure difference, and efficiency of the solar collector
3- Using (I2) or (I3) increases the drying rate and pressure difference significantly while reducing the efficiency of the collector
4- The minerals and vitamins in agricultural products are affected by the surrounding conditions such as temperature.

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