Towards a homogenous drying rate using a solar fruit dryer

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Abstract

Solar fruit drying has the potential to reduce food insecurity in developing nations. One possible technique for drying fruit is to use solar dryers. This technique is easy to use without requiring high investments. However, the drying technique can be challenging. One problem is that the drying rate could be different depending on where in the dryer the process takes place. At the beginning of the dryer, the air is dry and warm while at the exit it has picked up moisture from the products and has cooled down. This could result in severe problems for the user. One possible solution is to have an arrangement that inverts the direction of the airflow periodically. This means that the entrance and the exit of the air are shifted. Thus, the drying rate evens out. Results from the performed simulations shows that the difference in drying rate comparing the fastest with the slowest drying rate in the dryer can be reduced from approximately 110 % to 10 % with this approach. Furthermore, this paper also describes how weather condition for a design day was established. This weather condition can be used for more accurate estimates regarding drying rates and temperatures in the solar dryer.

Keywords: Solar drying, food processing

1. Introduction

Even though absolute/extreme poverty and starvation has decreased over the latest decades (UN 2010; The World Bank), there is still food shortage and malnutrition in many developing nations. This is despite a fast economic growth in some developing countries. One of these countries, Mozambique, had a Human Development Index (HDI) ranking of 180 out of 188 countries despite the HDI value being 75 % higher than in 1980 (UNDP, 2015). Food security is lowest in the south of the country where almost one third of the people suffers from food insecurity (World Food Programme, 2016). At first sight, this appears strange as there is plenty of food grown in the country. However, large amounts of the grown food are either not harvested or are lost after the harvest due to spoilage (FAO, 2011). As much as 25 % to 40 % of the harvested fruit is estimated to be lost, mainly due to a lack of small-scale preservation techniques that do not require infrastructure (Feed the Future, 2011).

Preservation techniques such as aseptic filling and canning would in principle be possible solutions, however, this would require large investments and infrastructure which are often not available in these areas today. Freezing and other techniques that require large amounts of electricity are not an option due to the lack of an electric grid in rural areas. In Mozambique, approximately 80 % of the population is not connected to the electric grid (SIDA 2014). Unfortunately this problem is the same for fruit drying using electrical heaters. Drying of, for instance, fruit is otherwise an attractive technique as it needs no energy after the actual drying. The fruit can also be stored for long periods of time ranging up to several years, depending on the type of fruit and final moisture content after drying (Rahman & Perera, 2007). Drying could become a viable solution in developing nations if the electricity problem could be overcome. Furthermore, in order to have a preservation technique that plays a role for a large part of the society, the technique must be scalable as well as easy to use, cheap and reliable.

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One possible solution for this is to use solar driven dryers. The technique uses little to no power to run, is cheap and is simple to use. The work presented in this paper is part of a larger project where an interdisciplinary research group is focusing on finding suitable technical and social solutions for this drying technology. The main objective in this project is to find solutions for drying fruit juices made from juicy fruits like tangerines and oranges that have high spoilage rates (Affognon et al., 2015). The technique that has been developed for drying juices is called Solar Assisted Pervaporation (SAP). It involves the use of semi-permeable membrane bags which are filled with juice, clamped shut and then placed horizontally in the sun to dry. With adequate solar irradiation and ventilation, water vapour is able to pass through the semi-permeable membrane layer of the bag resulting in a shelf-stable dried product after two to three days (Phinney et al., 2015). Solar drying has traditionally been seen as unhygienic since the product is fully exposed to the open air, but with the SAP technique, microorganisms and larger pests are not able to penetrate the bag which greatly reduces the food safety risk (Phinney et al., 2015). Earlier work within the project has shown that even if the bags are directly exposed to solar radiation, a cooler wind passing over the bags can drastically reduce the drying flux. This result supports the need of a solar dryer that can pre-heat the air that passes over the bags in order to maintain the highest drying flux possible. The pre-heat of air would increase the temperature to a level not favourable to microbial. In addition, not radiating the fruit directly could be beneficial as the sun light could activate the degradation of vitamin or pro-vitamin in the fruits. Direct irradiation could potentially also form a crust on the inside of the bags, which would then lead to lower drying rates (Mills-Gray, 2015). By using an indirect drying technique, the heating of the fruits become more adjustable and less fluctuating over time as the dimensions and materials of the solar collector will determine the drying conditions (Kumar et al., 2015).

The initial indirect solar dryer design that was developed for SAP is shown in Fig. 1. The air is heated in the solar collector and this hot air passes to the drying tower.

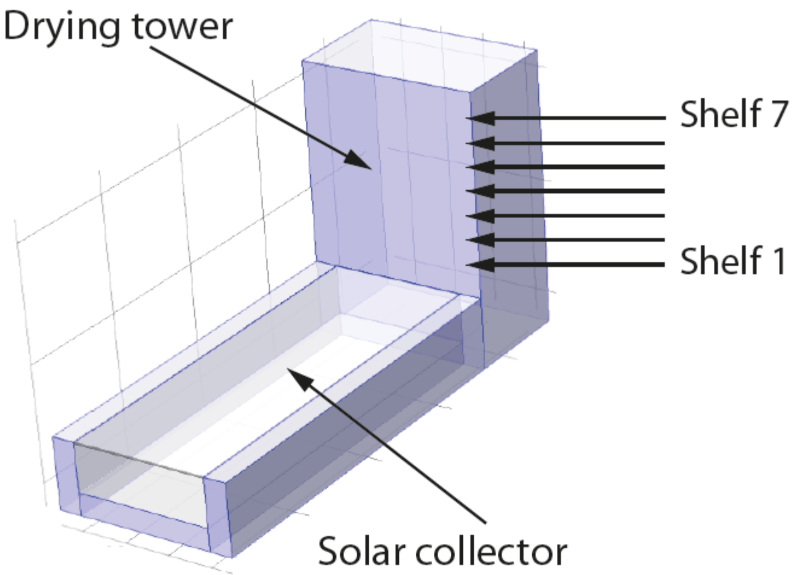

Fig. 1: The solar dryer with the solar collector and the drying tower.

Earlier reports have shown that the drying rate of the product (i.e. bag) is dependent on at least air temperature, air speed and the relative humidity of that air (Blanco-Cano et al., 2016; Phinney et al., 2015). Furthermore, Olsson (2016) showed that the drying rate in a passive drying tower, illustrated in Fig. 1, is strongly dependent on where the bag is placed in the drying cabinet. As the air is dryer and warmer at the entrance of the cabinet, the drying rate is also higher here. As the dry air picks up moisture from the bags at the entrance region, the relative humidity increases. Furthermore, as this process is energy demanding the temperature will also decrease. As a consequence of this, the drying rate is reduced for bags placed at the top of the cabinet. This is a serious problem for the successful implementation of this technique. The target group for the technique, i.e.

farmers in rural Mozambique, are too busy to spend time shifting bags around in the drying tower in order to reduce the uneven drying rates. Furthermore, keeping track of the time for when to shift the bags will also add problems for the user. A high drying rate reduces problems relating to mould growth and the evenness is important for a homogeneous quality of the dried products. It is therefore very important that the drying rate is both high and even.

Understanding the process of solar drying needs understanding of the physical boundaries and the driving forces, i.e. the weather conditions. Running simulations with full weather data is time consuming and often inconvenient during a development phase of a new collector type. In this type of process, rough estimates are often more suitable. In order to do this, a typical weather situation for the process is needed. This is not well established today. Earlier work presented is based on reasonable guesses for typical weather situations Olsson (2016).

Investigated problems:

Shifting the bags in the drying cabinet has the potential to increase the evenness in the drying rate. Furthermore, using real weather data rather than assumed values will affect the calculated drying rates in the cabinet. The research questions are therefore;

- To what extent can the evenness in drying rate be increased by either shifting the positions of the bags in the cabinet or reversing the flow in the dryer tower?
- To what extent is the drying rate affected by using real weather data? And, can a characteristic weather situation be identified?

The evenness is measured as a relative difference in drying rate between the bags that dry the fastest and the slowest.

2. Method

The performed simulations are based on a program described in Olsson (2016). The program is built in Maple 2015 (Maple) which is a software mainly used to analytically solve and evaluate mathematical problems, but can also be used as a programming tool. The model consists of two parts; the solar collector and the drying tower, see Fig. 1. The solar collector has a constant airflow going through it, user defined insulation on the sides and bottom and a single layer of glazing on the top which can let through sunlight. The absolute humidity and the air temperature calculated at the outlet of the collector will then act as input values for the drying tower and thus determine the initial drying conditions. The drying cabinet consists of four walls impermeable to sunlight and has an airflow going from its bottom to its top. Inside the cabinet, a certain amount of shelves are located on which SAP-bags can be placed. The drying rates of the SAP-bags are then calculated for each shelf depending on the air velocity and the relative humidity at each shelf.

The program was used in order to calculate the drying rate for bags placed at seven different shelves in the drying tower. The placement is indicated in Fig. 1. The drying rate was used in order to calculate the evenness depending on shelf position in the tower. Furthermore, the consequences of shifting around the bags in the drying tower were also calculated. For this shifting simulation: the bags placed on shelf 7 were shifted with the bags on shelf 1 after 30 minutes. Bags on shelf 6 were shifted with bags on shelf 2 and the bags on shelf 5 were shifted with the bags on shelf 3. The bags on shelf 4 were left without being shifted.

The characteristic weather for fruit drying in Mozambique was found by creating a constant weather condition that results in the same total drying over a three months period as would be the result using the real measured weather over the same three months. The point in doing this is mainly to have a typical design condition for the solar drying technology. Using the characteristic weather will result in better estimations for drying capacities. Included in the characteristic weather is radiation, temperature and relative humidity. As can be seen in Fig. 2 the temperature and the relative humidity varies considerably less than the irradiation. Therefore these two parameters where calculated to be the arithmetic mean value during the period. After these values were established, the irradiation level for the characteristic weather situation was calculated. This was carried out by means of iteratively running simulations changing the characteristic radiation. When the total drying over the three month period was the same using the characteristic weather situation as using the real weather data the characteristic radiation was found. Fig. 2 shows a typical weather situation during two days. The black line shows the irradiation on a horizontal surface, the blue line shows the ambient temperature and the red line shows the relative humidity. The dashed blue and red lines are the arithmetic mean values of the temperature and the relative humidity during the active time of operation, in this case from 8:00 to 16:00. The dashed black line is the irradiation used in the calculation program in order to get the same total drying during operation (i.e. running a simulation using the fixed values shown with dashed lines or running a simulation using the weather data will produce the same total drying effect). The grey shaded area indicates the time that the solar dryer is assumed to be in operation. The figure is used only as an illustrative example of the method.

The drying of the SAP bags in not a linear function of the irradiation or the temperature or even the relative humidity Olsson (2016). Therefore, a change in for instance the relative humidity in the drying tower will lead to a compensation of the irradiation in the calculated characteristic weather. In order to evaluate how important this none linearity is the characteristic weather was calculated for two different versions of the solar dryer. The two different versions of solar dryers will create two different drying conditions and therefore two different characteristic weathers. One with a drying tower with a cross section measuring 0.2 m · 0.2 m with 2 SAP bags per shelf. The other tower with a cross section that measures 0.4 m · 0.4 m and has 10 SAP bags per shelf. Both cases use a 2.4 m² large solar collector unit. This creates two different conditions in the dryer. In the larger tower, the air will move with a lower speed and the air will also become more humid in the upper layer. Other details on the dryer are discussed in Olsson (2016). This test was carried out in order to see how sensitive the characteristic weather is to changes in the solar collector.

The simulations were performed assuming a horizontal collector. Furthermore, the characteristic weather was evaluated for two operation times, 8 hours per day and for 4 hours per day. Fig. 2 is an illustration of the characteristic weather for the 8 hour case.

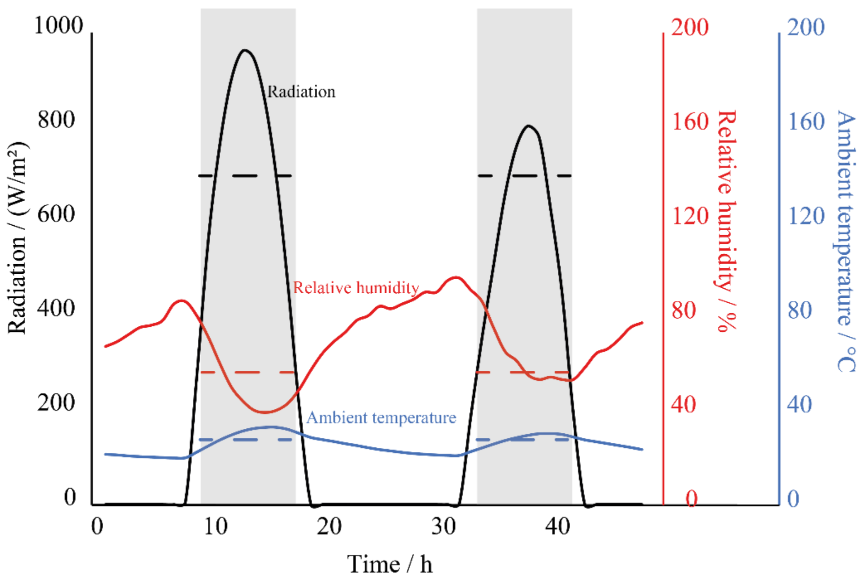

Fig. 2: Illustration of the characteristic weather for the 8 hour drying case during a two day period. The black line shows the radiation, the red line shows the relative humidity and the blue line shows the ambient temperature. The dashed lines shows the characteristic weather during this period.

Hourly weather data was obtained for Maputo, Mozambique using Meteonorm 7.0. Data was selected from beginning of May to end of July as this is the period for tangerines in Mozambique.

3. Results

Fig. 3 shows the results from a simulation where the drying rate per square metre of SAP-bag per hour was calculated over one week in the beginning of May. The results are based on a simulation that uses real weather data. The drying tower was set to be 0.4 m · 0.4 m and there was 10 bags placed per shelf. The left figure shows the drying rate for the SAP bags placed on the different shelves. The placement of the shelves is shown in Fig. 1. The results show the highest drying rate at the first shelf and a decreasing drying rate moving up in the tower. During the peak hour on the first day, the difference in drying rate between shelf 1 and shelf 7 is approximately 110 %, i.e. bags on shelf 1 dry more than twice the rate of bags placed on shelf 7. To the right is a calculation where the bags have been shifted every 30 minutes. The mixed mode, i.e. the right figure, shows that this difference in drying rate is reduced to 10 % between bags placed on shelf 4 and bags placed and shifted on shelf 1 and shelf 7.

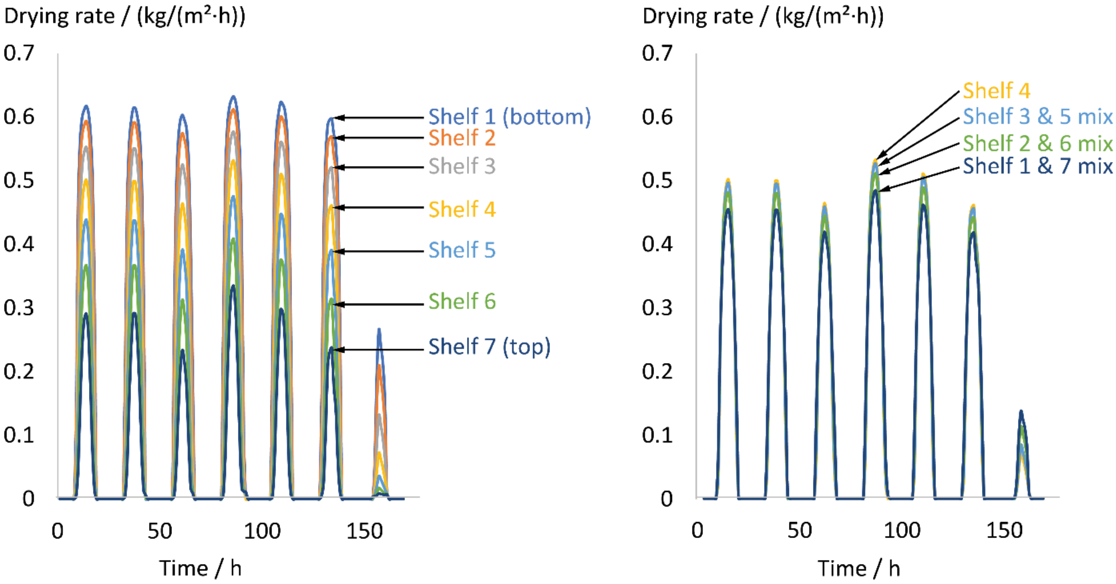

Fig. 3: The drying rate at different shelves during one week. The left figure shows constant position (shelf) for the bags. The right figure shows drying rate where the bags are shifted continuously over the week.

The characteristic weather found for the two different solar dryers using the 4 hour and the 8 hour daily drying period is presented in Table 1. By using the values presented in Table 1, the same total drying as using a full weather file in the simulation tool is obtained.

Tab. 1: Characteristic weather for two types of dryers and for two drying times

Calculated value	Low concentration of SAP bags in the dryer		High concentration of SAP bags in the dryer	
	4 hour period	8 hour period	4 hour period	8 hour period
Temperature / °C	25	25	25	25
Relative humidity / %	50	50	50	50
Irradiation / (W/m²)	700	530	740	575

4. Discussion

The calculations performed in order to evaluate the effects of shifting the positions on the bags in the dryer showed great potential in order to get a more even drying rate. However, shifting the bags manually will be very time consuming and this will likely not be carried out by the user. This could lead to accidental spoilage of fruit. Instead, it would be preferable if the dryer was built in such way that this was carried out automatically. One alternative could be to build a collector that has double collectors, one before the drying section and one after the drying section. The airflow can then be controlled with a fan to change the direction of the flow every 30 minutes. Doing so will give the same result as continuously shifting the bags, i.e. shelf 1 will be shelf 7 as the airflow direction changes. The price for such a product will be higher but it will likely allow for operation without causing unnecessary work for the user. Alternatively, a small fan can be installed inside the drying tower in order to mix the air. Other techniques could be possible.

The characteristic weather was concluded from an analysis based on using all the days during May, June and July. Doing so also includes cloudy cold days. During such days the user is not as likely to start drying fruits. Therefore it might be more reasonable to establish a characteristic weather not based on days including such weather. Such selective picking of suitable drying days would lead to a higher characteristic radiation for the collector. However, if the drying process is longer, for instance a couple of days, then the cloudy day might come in the middle of the drying process and there is no chance to abort the drying and start over. Instead the cloudy days will be included. This analysis can be stretched further for a more complete conclusion. Furthermore, the analysed weather data comes from Maputo in the south of Mozambique. Using weather from the central or the northern parts might result in a different characteristic weather. Nevertheless, it was decided that the reached values are accurate enough for the purpose of preliminary design considerations.

However it is also important to understand that there are many characteristic weather situations that will result in a specific total drying over the three months. For instance reducing the temperature but increasing the solar radiation simultaneously will keep the drying constant. Therefore it’s impossible to find one specific weather situation that is the only solution to the given problem.

There is a small difference in what characteristic weather should be used depending on the setting of the dryer. More SAP bags and thus higher relative humidity combined with a lower airflow in the tower results in a somewhat higher characteristic irradiation. However, this difference is very small, in the order of 5 % to 10 %. This is seen comparing the irradiation levels in Table 1, 700 W/m² compared to 740 W/m² and 530 W/m² compared to 575 W/m². Thus, this difference can be neglected.

5. Conclusion

The uneven drying rate can be drastically reduced if the SAP bags are shifted within the drying tower. Shifting the bags every 30 minutes, or more realistically changing the airflow direction, was shown to reduce the difference in drying rate from approximately 110 % to 10 % between the highest and lowest drying rates.

A characteristic weather could be determined and are presented in Table 1. For longer drying periods, i.e. longer than 8 hours, the characteristic weather is typically 25 °C a relative humidity of 50 % and approximately 550 W/m² of solar radiation. For shorter drying periods where only the peak hours of the day is used the solar radiation can be assumed to be somewhat more than 700 W/m². The none-linearity in the drying process discussed in the method section was indicated to have only small effects. Varying the drying tower cross sectional area and number of SAP bags per shelves within the above stated limits will not affect the characteristic weather to a significant degree and this effect can be ignored.

6. Acknowledgement

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