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Performance analysis of solar dryer with thermal energy storage and without thermal energy storage for Whole and Sliced ficus carica (fig)

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ABSTRACT

Solar-drying technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment. In this work efforts have been made to develop the mixed mode forced convection solar dryer for fig drying with thermal energy storage. The performance of the dryer has been investigated experimentally. Dryer is designed with capacity of 25 kg and consist of the parabolic trough collector-based air heating system integrated with thermal energy storage which utilizes Paraffin wax (PCM) as phase change material. Effect of mass flow rate of air on moisture content, drying rate and drying time with and without incorporation of thermal energy system has also been evaluated. The pretreated sliced and whole figs are dried with developed solar dryer to check effect on drying time for different air flow rates. The thermal efficiency of dryer has been evaluated with the without use of thermal energy storage system for sliced and whole fig for different air flow rates. The dried figs are tested for final moisture content and its nutrition value with the commercially available dried fig in the market. The result shows that it is possible to dry the figs cultivated in India in accordance with international norms for moisture content and nutrition value for dried fig. The moisture reduction of fig obtained with developed dryer is from 79% to 18% for sliced fig in 7 sunshine hours and 79% to18% for whole fig in 12 sunshine hours with thermal energy storage system. Incorporation of thermal energy storage system reduces drying time from 9 sunshine hours to 7 sunshine hours for sliced fig with mass flow rate air 0.027 kg/sec. Drying time reduction is observed with increase in mass flow rate of air for sliced as well as whole fig. The sliced fig gives better dryer thermal efficiency and lower drying time for higher mass flow rate of air. For the maximum mass flow rate of air of 0.027kg/s, sliced figs drying gives about 37% dryer efficiency with implementation of thermal energy storage and the lowest drying time of 9 hours.For the same mass flow rate the drying of whole figs gives lower efficiency of about 22% and increase in the drying time up to 14 hours as compared to the drying of sliced figs.

1. Introduction

Solar drying has been used since time immemorial to dry plants, seeds, fruits, meat, fish, wood, and other agricultural, forest products. In order to benefit from the free in recent years to develop solar drying mainly for preserving agricultural and forest products. However, for large-scale production the limitations of open-air drying are well known. Among these are high labour costs, large area requirement, and lack of ability to control the drying process, possible degradation due to biochemical or microbiological reactions, insect infestation, and so on. The drying time required for a given commodity can be quite long and result in post-harvest losses (more than 30%). Solar drying of agricultural products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and low quality of dried products associated with traditional open sun-drying methods. In many rural locations in most developing countries, grid-connected electricity and supplies of other non-renewable sources of energy are unavailable, unreliable or, too expensive. In such conditions, solar dryers appear increasingly to be attractive as commercial propositions. During the last decades, several developing countries have started to change their energy policies toward further reduction of petroleum import and to alter their energy use toward the utilization of renewable energies. With very few exceptions, the developing countries are situated in climatic zones of the world where the insolation is considerably higher than the world average of 3.82 kWh/m2 day. An alternative to traditional drying techniques and a contribution toward the solution of the open-air drying problems is the use of solar dryers. Accordingly, the availability of solar energy and the operational marketing and economy reasons offer a good opportunity for using solar drying all over the world.

The practice of solar drying of fruits has been in existence from the beginning of civilization. The approaches used then were simple and often rudimentary but were effective nonetheless. Traditional solar drying, which has been carried out on the bare ground in open air, is the most widely used method of drying in developing nations because it is simple and inexpensive. However, there are numerous disadvantages to this method. This drying process exposes the product to unpredictable weather, dust, potentially damaging UV radiation, and infestation by insects. Many modifications have been attempted to eliminate the issues with traditional drying in such areas. However, past efforts to establish solar drying for produce remain either costly and complicated or are not easily maintained and operated by rural farmers with locally available materials and skill. Solar dryers have been reported to improve the taste, nutrition, and final value of produce compared to traditional drying but at the cost of greater initial capital investment and the requirement for extensive training.

Drying in earlier times was done primarily in the sun, now many types of sophisticated equipment's and methods are used to dehydrate foods. During the past few decades, considerable efforts have been made to understand some of the chemical and bio- chemical changes that occur during dehydration and to develop methods for preventing undesirable quality losses. The widest among drying methods is convective drying, i.e. drying by blowing heated air circulating either over the upper side, bottom side or both, or across the products. Hot air heats up the product and conveys released moisture to atmosphere. In direct solar drying called "sun drying" the product is heated directly by the sun's rays and moisture is removed by natural circulation of air due to density differences.

Solar radiation in the form of solar thermal energy is an alternative source of energy for drying especially to dry fruits, vegetables, agricultural grains and other kinds of material, such as wood. This procedure is especially applicable in the so-called "sunny belt" world-wide, i.e. in the regions where the intensity of solar radiation is high and sunshine duration is long. It is estimated that in developing countries there exist significant post- harvest losses of agricultural products, due to lack of other preservation means. Drying by solar energy is a rather economical procedure for agricultural products, especially for medium to small amounts of products. It is still used from domestic up to small commercial size drying of crops, agricultural products and foodstuff, such as fruits, vegetables, aromatic herbs, wood, etc.

Application of Solar Dryer:

Solar dryers used in agriculture for food and crop drying ,for industrial drying process, dryers can be proved to be most useful device from energy conservation point of view. It not only save energy but also save lot of time, occupying less area, improves quality of the product, makes the process more efficient and protects environment also. Solar dryers circumvent some of the major disadvantages of classical drying. Solar drying can be used for the entire drying process or for supplementing artificial drying systems, thus reducing the total amount of fuel energy required.

Solar dryer is a very useful device for

- Agriculture crop drying,
- Food processing industries for dehydration of fruits, potatoes, onions and other vegetables,
- Dairy industries for production of milk powder, casein etc.
- Seasoning of wood and timber,
- Textile industries for drying of textile materials,
- Solar drying of marine products.

2. Principle of solar drying

Solar drying refers to a technique that utilizes incident solar radiation to convert it into thermal energy required for drying purposes. Most solar dryers use solar air heaters and the heated air is then passed through the drying chamber (containing material) to be dried. The air transfers its energy to the material causing evaporation of moisture of the material.

Drying basically comprises of two fundamental and simultaneous processes, heat is transferred to evaporate the liquid, and mass is transferred as liquid or vapour within the solid and as a vapour from the surface. The factors governing the rates of these processes determine drying rate. The different dryers may utilize heat transfer by convection, conduction, radiation, or a combination of these. However, in almost all solar dryers and other conventional dryers heat must flow to the outer surface first and then in too the interior of the solid, with exception for Fig (FicusCarica) is an important fruit, which has been under cultivation since ancient time. Fig was unattended crop till the date. But day by day, more and more land is being brought under cultivation of fig. Farmers who engaged in the fostering of this fruit were being benefited to a large extend. Fig contains minerals such as iron, copper and calcium in a large quantity and plenty of various vitamins. Food items like dry fig, sweetmeat, fig milkshake etc. are made from fig. Due to all these reasons, fig has become a significant fruit. As fig blooms rapidly after cultivation, it becomes possible to bloom the fig in the consecutive year, which facilitates the immediate earnings.

Dry fig stands at a higher position in dry fruit. An important food contents in a dry fig have been indicated, which brings a great significance to fig. Dry fig is important in many countries and is sold at much higher values in the domestic market. In India, the fig is cultivated in several dry areas. The largest area brought under the cultivation of fig is in the state of Maharashtra. However ripened fig cannot stay fresh more than 2-3 days; therefore, fig drying is a great opportunity for the farmers from commercial point of view.

Problem Statement

Technological development to produce dried fig is less attended in India due to the small amount of fig production. But still there are certain states like Maharashtra, in which fig cultivation and production is concentrated. Out of yearly total production of fig in India, near about 80% of fig production takes place in Pune (Maharashtra). Considering the commercial value of dried fig and concentrating on reduction in waste, if the renewable technology is available for local farmers then it will be economically benefited.

Currently available fig drying practices are economically not suitable for local farmers and unable to meet the international quality standards for dried fig. Hence it is necessary to develop the solar fig dryer for medium scale farmers which can dry the fig on daily basis at single stroke.

This work aims to develop the solar dryer with thermal energy storage for fig drying by utilizing concentrated parabolic trough collector in order to reduce drying time.

3. Objectives

The present work planned with following objectives

- **i.** Development and performance evaluation of mixed-mode forced convection concentrated solar dryer with thermal energy storage for fig.
- **ii.** To study variation of moisture content (dry basis) versus time.
- **iii.** Determination of Drying Rate with time.
- iv. To study of variation of drying efficiency for performance methodology
- **v.** Study of effect on drying time with and without the use of thermal energy storage

4. Design and development of solar dryer

The developed solar dryer is as shown in Figure 1 consist of the different components like concentrating collector (PTC), thermal energy storage system, dryer cabinet and blower. On the basis of the criteria mentioned the design of the individual component was prepared and corresponding parameter (i.e. relative dimensions and material for solar concentrator, dryer cabinet and PCM storage) were calculated.

Figure: Overall view of solar dryer (Sunshine)

4.1 Thermal Energy Storage System:

The total heat energy to be supplied for the drying purpose will be the heat retracted from the thermal energy storage and supplied through the parabolic trough collector. But for knowing the exact proportionate of energy supplied from the either energy sources it is necessary to carry out the calculations of thermal energy storage initially.

For the purpose of thermal energy storage Phase Change Material type is used. The material selected for PCM is paraffin wax.

The PCM material is stored in the aluminium pipes. Depending on the dimensions of the storage pipes the quantity of PCM stored was determined. Further from the quantity of PCM stored the energy stored in it is calculated.

Thermal energy storage system, aluminium tubes colored with black paint.

5. Testing Methodologies

The experiment was carried out using different method. The mass flow rate of air was varied and the subsequent effects on the drying time were calculated. Also study of effect of use of thermal energy storage on the drying time is studied by carrying out the experiment with thermal energy storage and without thermal energy storage. The experiment was carried out for whole as well as sliced fig.

The mass flow rates of air were varied from 0.027kg/sec to 0.022 kg/sec. Study on pretreatment analysis showed considerable decrease in the drying time of figs. Hence, the figs were pretreated by dipping in the boiling water effecting in skin cracking of the figs and helping the cause of moisture removal.

6. Results and Discussion

The results obtained from the experimentations carried out on the solar dryer by the mentioned testing methodology are presented in the following section. Various graphs are plotted for the study of variation moisture content on dry basis with time, variation of drying rate with time , variation of dryer thermal efficiency etc.

The results are obtained from the experimentation are taken at the flow rate of 0.027kg/s, 0.025kg/s, 0.024kg/s & 0.022kg/s with thermal energy storage and without thermal energy storage for whole and slice figs.

The experiments were conducted for several days, so in accordance to study intensity of the solar radiation on the day of the experiment performance, the intensity of solar radiation was measured using Pyranometer .

6.1 Variation of moisture content on dry basis with time:

The study of variation is the moisture content on dry basis is done by plotting the graph of moisture content calculated on dry basis versus time. The moisture variation is calculated for the considered mass flow rates, it also gives an idea of effect of mass flow rate on drying rate.

The comparison study is done by plotting the moisture content on dry basis for the flow rates M_1=0.027kg/sec, M_2=0.025kg/sec, M_3=0.024kg/sec and M_4=0.022kg/sec versus the drying time. The same comparison study is carried out for whole fig with and without TES as well as sliced figs with and without TES. The graph easily interprets the effect of the flow rate on the drying time.

6.1.1 Variation of the moisture content on dry basis for whole figs without TES:

The variation in the moisture content of the whole figs without TES is studied by plotting of the moisture content calculated on dry basis versus time.

Variation of the moisture content on dry basis for whole figs without TES:

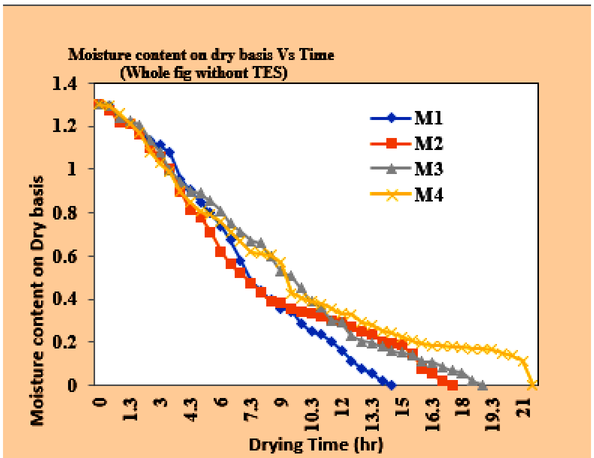
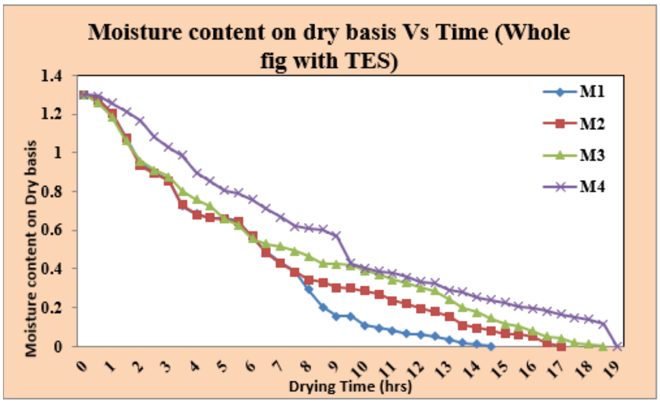


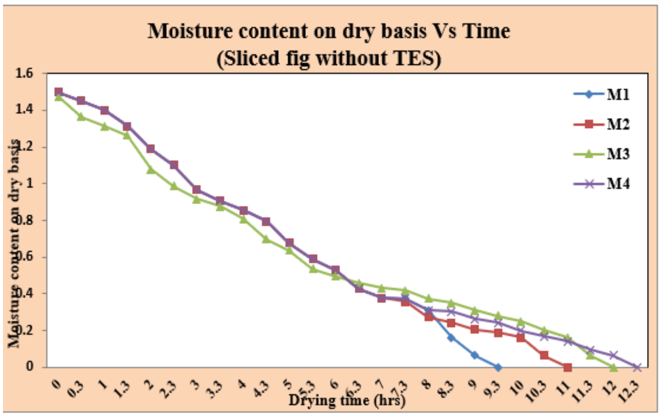
Figure: Variation in moisture content (dry basis) vs. time for whole fig without TES

Variation of the moisture content on dry basis for whole figs with TES:



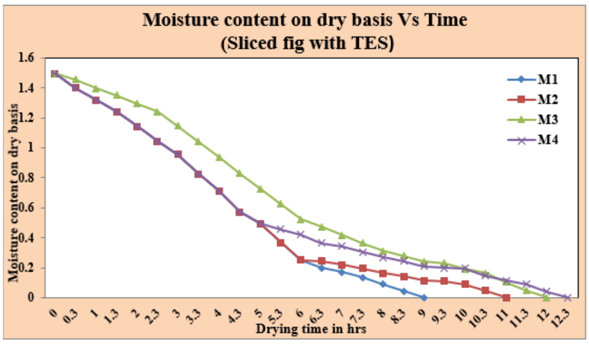
Variation in moisture content (dry basis) vs. time for whole fig with TES

Variation of the moisture content on dry basis for sliced figs without TES:



Variation in moisture content (dry basis) vs. time for sliced fig without TES

Variation of the moisture content on dry basis for sliced figs with TES:



Variation in moisture content (dry basis) vs. time for sliced fig with TES

From the above graphs of moisture content on dry basis for whole and sliced figs, with and without TES versus time for the four mass flow rates, it is easily depicted that the moisture content decreases considerably with increase in the mass flow rate of air. The minimum drying time required for whole figs is 14.30 hours for the maximum mass flow rate of 0.027kg/sec. and the maximum required drying time is 19 hours for the lowest mass flow rate of 0.022kg/sec.

Similarly, for the sliced figs the minimum drying time required is 9 hours for the maximum mass flow rate of 0.027kg/sec and maximum required is 12.3 hours for the lowest mass flow rate of 0.022kg/sec.

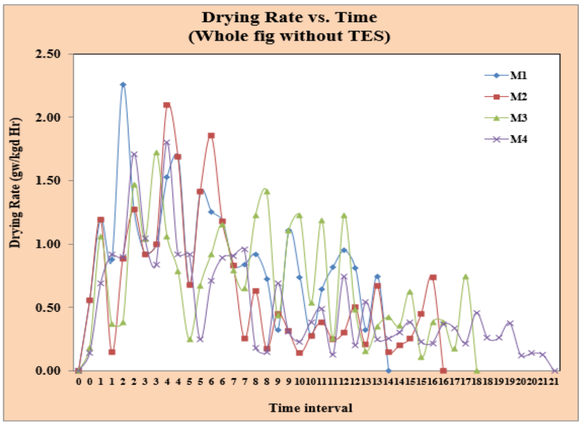
For the maximum mass flow rate of air that is M_1=0.027kg/sec the drying time is almost less than 4 hours for whole figs and almost 3 to 4 hours for sliced figs than for the minimum mass air flow rate of M_4= 0.022kg/sec. So, increase in the mass flow rate of the air the drying time reduces subsequently.

Similarly the moisture content for wet bais is calculated and plotted.

6.1.2 Variation of drying rate with time:

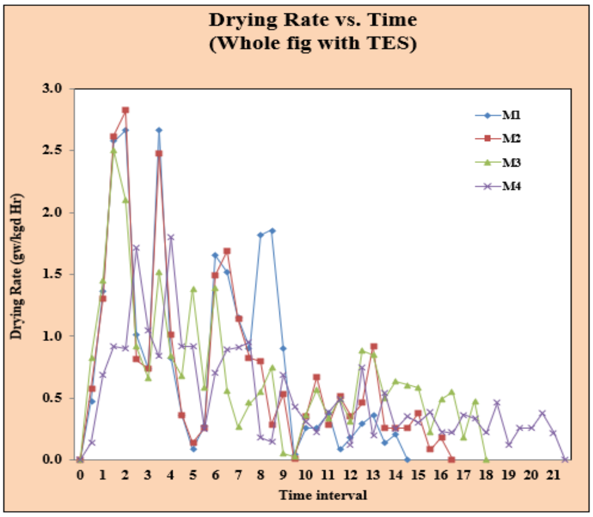
The variation in the drying rate with respect to the time is analyzed by plotting the graph of drying rate vs. time. The graphs are plotted for four different mass flow rates of M1=0.027kg/sec, M2=0.025kg/sec, M3=0.024kg/sec and M4=0.022kg/sec. The drying rate varies with the variation in the mass flow rate of air.

Variation of drying rate with time for whole figs without TES:



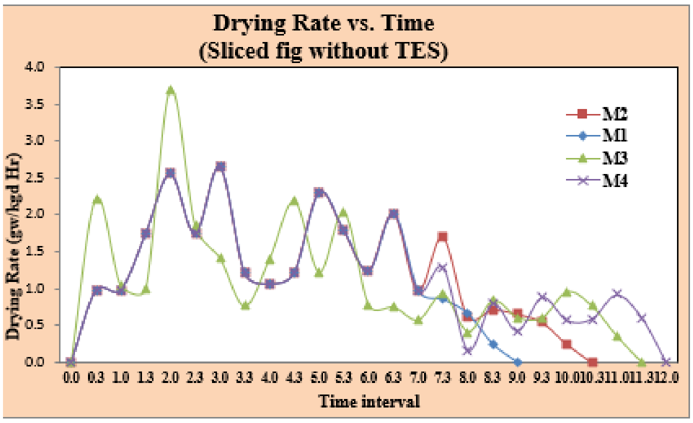
Variation in drying rate with time for whole fig without TES

Variation of drying rate with time for whole figs with TES:



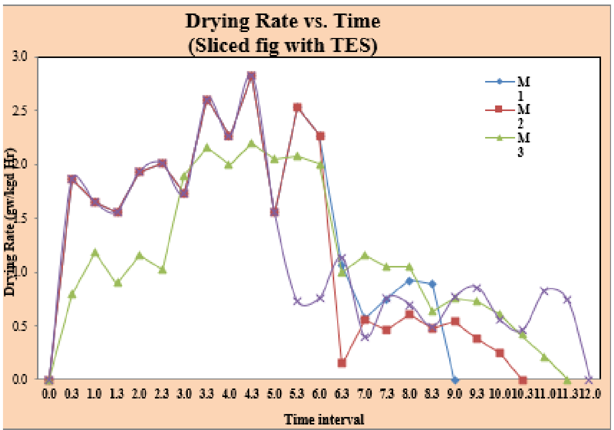
.Variation in drying rate vs time for whole fig with TES

Variation of drying rate with time for sliced figs without TES:



Variation in drying rate vs time for sliced fig without TES.

Variation of drying rate with time for sliced figs with TES:



Variation in drying rate vs time for sliced fig with TES.

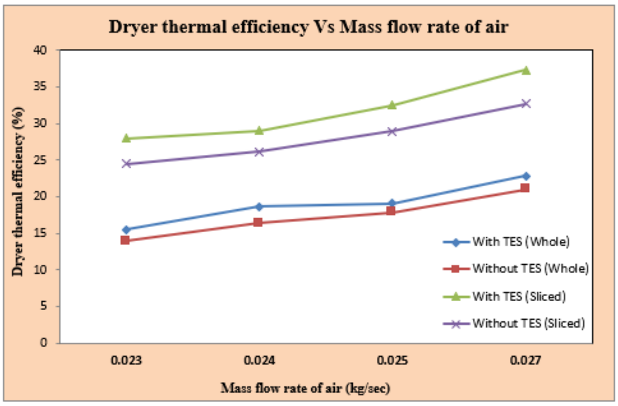
The four graphs show the drying rate (in terms of gram of water loss to kg of dry product per hour) versus drying time. The drying rate for the whole figs is at its peak value initially and goes on decreasing with time and after a long period seems to have come to halt. The drying rate is the function of the amount of moisture remaining in the fig. Drying rate heavily relies on the quality of the air supplied. From the above graphs it is easily understood that the drying rate is high during the peak temperatures and lowers with the variation in the temperatures and also the amount of atmospheric humidity.

For the initial phase of drying (i.e. for almost first 6 to7 hours of drying time) the drying rate is about 1.75 to 2.75 gw/(kgdHr) which decreases to about 0.5 to 1 gw/(kgdHr) for next phase of drying . This further decreases and almost becomes zero due negligible amount of moisture removal for significant drying time duration.

For the whole figs the drying rate reaches to almost zero in 14 hours for mass flow rate of air of 0.027kg/sec compared to 21hours for mass air flow rate of 0.022kg/sec. Also for the sliced figs the drying rate reaches to almost zero in 9 hours for mass air flow rate of 0.027kg/sec as compared 12 hours required for mass air flow rate of 0.022kg/sec. This explains the effect of the mass air flow rate on the drying time.

7.1.3 Variation of drying efficiency for performed test methodologies:

The variation in the drying efficiency is studied by plotting efficiency against the variation of mass flow rates of the air.



The dryer efficiency was analyzed at four different mass air flow rates being M1=0.027kg/sec, M2=0.025kg/sec, M3=0.024kg/sec and M4=0.022kg/sec. The graph 6.8.1 shows the variation in the dryer efficiency for the different mass air flow rates used for drying whole and sliced figs with and without TES. From the graph for each type of application the dryer efficiency is maximum for the higher mass air flow rate. The efficiency of the dryer increase almost by 5% for the mass air flow rate of 0.0027kg/sec over the mass flow rate of 0.0022kg/sec for each application.

The maximum dryer efficiency was obtained for the sliced figs drying with TES which is around 37 to 38% for the mass air flow rate of 0.027kg/sec. The lowest is for the drying of whole figs without TES for mass air flow rate of 0.022kg/sec, which is around 14%.

Also the fact that inclusion of the TES adds to the dryer efficiency and increases it significantly, is interpreted from the graph. Hence the use of the TES not only increases the drying time for a day but also enhance the efficiency of the dryer. For the sliced figs the dryer efficiency is greater than the whole figs by 10%.

7. Conclusion

Mixed mode forced convection solar dryer for fig drying with thermal energy storage has been developed and tested experimentally. The effect on drying time for sliced fig and dried fig with variation in mass flow rate of air and with and without incorporation of thermal energy storage system has also be investigated.

The following conclusions have been arrived at, from the experimental investigation carried out in the present work on solar fig dryer.

- The drying time is greatly reduced for sliced fig as compared whole fig
- With implementation of thermal energy storage, the drying time for particular day can be extended from sunshine hours to non-sunshine hours. Hence it increases the quantity of products dried (i.e. increase in number batches).
- With incorporation of the thermal energy storage the sliced figs can be dried in a day, (i.e. use of 7sunshine hours and 2 hours of thermal energy utilization) for the mass air flow rate of 0.027kg/sec.
- With increase in the mass flow rate of air the drying is reduced remarkably.

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