Developing a mixed solar drier for improved postharvest handling of food grains

Himanshu Kishor Dhande[1], Sagar Dnyaneshwar Shelare[2*], Pravin Balkrishna Khope[2]

(1. Mechanical Engineering Department, Dr. D. Y. Patil Institute of Technology, Pimpri, Pune, Maharashtra, 411018, India;
2. Priyadarshini College of Engineering, RTM Nagpur University, Nagpur, Maharashtra, 440019, India)

Abstract: Drying of grain is usually achieved by spreading grains on earth for solar radiation. This technique is moderate, but being unsecured from a downpour, dust, invasion of bugs, rodents, and distinct animals, items might be severely degraded to the degree that occasionally becomes contaminated and issued loss of nourishment excellence. To defeat this, solar drying is the greatest assuring technique for the protection of agricultural commodities. In the proposed research, the low-cost mixed-mode solar dryer was developed (Workshop of Dr. D. Y. Patil Institute of Technology, Pimpri, Pune, Maharashtra, India) using locally accessible, environmentally friendly materials, and the performance was evaluated. The solar dryer was developed using the components like a solar collector (reflector), adjusting slot, connector, air heater chamber, stand, drying chamber, helical screw assembly, handle, hopper, and hose pipe. The drier had a 10 kg loading capacity for wheat grains. The average temperature rise observed in the drying chamber was about 27.7°C above the ambient temperature at around 3 pm afternoon which is significantly higher than the ambient temperature. The dryer exhibited sufficient ability to dry food items relatively rapid to a safe moisture level, and together, it assures the excellent quality of the dried commodity.

Keywords: solar drying, mixed-mode, grains, performance evaluation, experimentation, postharvest drying.

Citation: Dhande, H. K., S. D. Shelare, P. B. Khope. 2020. Developing a mixed solar drier for improved postharvest handling of food grains. Agricultural Engineering International: CIGR Journal, 22(4): 166-173.

1 Introduction

Due to the short-lived nature of products of the soil are probably going to suffer a lot from substantial postharvest losses in the event that they are not used quickly following to its development. A portion of the purposes behind the higher loss are weak harvesting innovations, absence or immature handling and preparing techniques, and crash of the market to expend the majority of an inventory in harvesting season (Simate and Cherotich, 2017). Drying is performed either utilizing petroleum products in an affected mechanically process of drying process or by putting yield in open sun. Drying and storage of fruits and grains are the stages where improvement needs to achieve (Salvatierra-Rojas et al., 2017). The compelling techniques in lessening postharvest losses of various grains and fruits are drying. Drying procedures assume a significant role in the protection of horticultural items (Jawalekar and Shelare, 2020). They are described as a method to evacuate the moisture due to synchronous mass and heat exchange. It is likewise an old technique for food preservation, which gives a longer time of usability, lighter load to transport and littler storage space (Ajala et al., 2019). Throughout the

Received date: 2019-10-07 **Accepted date:** 2020-02-01
***Corresponding author: Sagar Dnyaneshwar Shelare,** Assistant Professor, Mechanical Engineering Department, Priyadarshini College of Engineering, RTM Nagpur University, Nagpur, Maharashtra, 440019, India Tel: +91-9890027265. E-mail: sagmech24@gmail.com.

world, there is creating care that economical power source has a significant errand to do in loosening up the technology to farmers in developing countries for building up profitability (Piyush et al., 2016). Sunlight based technology is recognizing as an optimized energy measure in horticultural areas (Mowade et al., 2019). It is liked another substitute to energy sources since solar energy is copious, limitless and pollution less (Guiné et al., 2016). Solar based drying is a significant system that is attracting more consideration the ongoing time.

Utilization of a solar-based dryer safeguards the food items to more drawn out time (Aliyu et al., 2013). The decision of solar-based drying over different methods is a result of its accessibility, inexpensiveness, and natural friendliness. A solar-based drying facility joins the benefits of traditional and modern techniques with minimal price and high quality (Oko and Nnamchi, 2013). Most of India gets 4 to 7 kW h of solar radiation every day per square meter in 250 to 300 sunny days during the year. Yearly global radiation changes between 1600-2200 kW h h^{-1} (Ronoh, 2017). As per (Kumar et al., 2016), solar oriented drying can satisfy a developing need for healthy, however minimal price natural foods and giving pay in an economical manner. But, solar-powered dryers need a cautious plan and testing for deciding a time to dry, solar radiation, and feasible air environment, for example, relative humidity, velocity and temperatures for ideal drying to get excellent output. Solar-based dryers are mainly classified into natural convection solar dryer (NCSD) and forced convection solar dryer (FCSD) (Pirasteh et al., 2014). NCSD technologies rely on solar-power for any performance (Perussello et al., 2014). The air heated by the sun turns out to be less thick than surrounding air bringing about the distinction in air densities which thus makes the buoyancy force. A wind pressure, buoyancy force or both reason for driving air all through a dryer (Ronoh and Rath, 2015). Forced convection technology, be that as it needs a fan driven by network power or generator for moving air inside the dryer (Hossain and Bala, 2007). Even if forced convection technology has larger proficiency than natural technology, its application in provincial regions displays a few difficulties. The prerequisites for a fan and a source of power to drive the fan make FCSD more unpredictable and generally costly compared to natural dryers. In most provincial regions in developing nations, access to lattice power is as yet missing while regions with access to power are inclined to load shading (Khope and Modak, 2013; Undirwade et al., 2015; Waghmare et al., 2019). Along these lines, utilization of solar-based dryers develops as a reliable option for little farmers because of lower consumption of energy just as sensible speculation and working expenses contrasted with commercial dryers that utilize petrol to heat air (Janjai and Tung, 2005). In the present study, low-cost mixed-mode solar dryer was designed and constructed using locally accessible environmentally friendly materials and its performance was evaluated.

2 Development of mixed-mode type solar dryer

The mixed-mode type solar dryer was developed using the components like a solar collector (reflector), adjusting slot, connector, air heater chamber, stand, drying chamber, helical screw assembly, handle, hopper, and hose pipe at Pune within the association between Dr. D. Y. Patil Institute of Technology, Pimpri, Pune, and the Priyadarshini College of Engineering Nagpur. The design process of the dryer previously included the accumulation of the climatic information of the research location (Hegde et al., 2015), i.e. Pune. For defining the various parameters, several contemporary designs were examined. The physical model has been developed at the Workshop of Dr. D. Y. Patil Institute of Technology, Pimpri, Pune. Low-cost materials having high rigidity, extended life and prevalent qualities have been utilized for development (Hegde et al., 2015).

As in Figure 1, provides an exploded view of a mixed-mode type solar dryer. It is comprised of the solar collector (reflector), adjusting slot, connector, air heater chamber, stand, drying chamber, helical screw assembly, handle, hopper, and hose pipe.

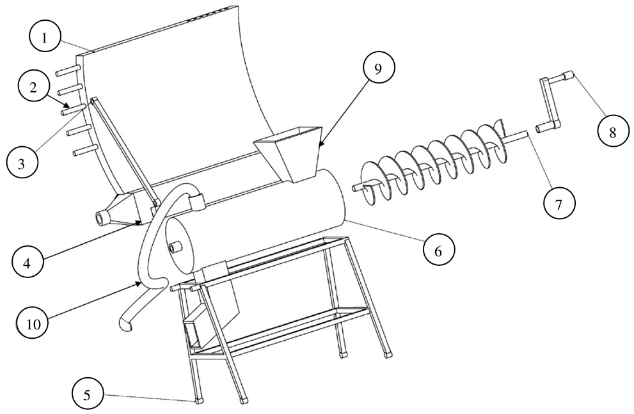

Figure 1 An exploded view of a mixed-mode type solar dryer

Note: 1: Solar collector (reflector), 2: Adjusting slot, 3: Connector, 4: Air heater chamber, 5: Stand, 6: Drying chamber, 7: Helical screw assembly, 8: Handle, 9: Hopper, 10: Hosepipe.

2.1 Drying cylindrical chamber with helical screw assembly

2.1.1 Cylindrical chamber

Drying is a continuous procedure to transfer mass and heat (Bahnasawy and Shenana, 2004). The cylindrical drying chamber comprises a helical screw and handle. Cylindrical chamber is built from a mild steel sheet having 1.5 mm thickness in cylinder form. An inlet hole is provided in the form of hopper at upper side to feed the grains in the chamber, and outlet hole is provided at opposite side to encourage and control air flow in dryer. Black color is painted for this cylinder to become black body to absorb maximum heat from solar radiation and solar reflector. It also protects from corrosion (Sevda and Rathore, 2007).

2.1.1.2 Helical screw

The helical screw fabricated from mild steel sheet of thickness 1.5 mm. Its profile is in the form of helix and works as screw hence it is called helical screw. Its left end is fixed in bearing to facilitate the rotary motion, and at other end handle is provided.

2.1.1.3 Handle

The mild steel L shaped handle is fabricated from rod diameter 20 mm. Rotary motion to the helical screw is provided with the help of this handle manually. For a large scale, by providing suitable power transmission arrangement to the shaft, it can be run on electric motor also.

2.1.2 Hot air chamber

The hot air chamber is constructed using the reflector wall at an upper side and thin-wall sheet at bottom side. The 55 mm gap is provided between these two walls to form air chamber. The air inside the chamber is heated through the reflector wall which reflects solar energy through radiation. The hot air from this chamber is supplied to cylindrical chamber with the help of fan (forced circulation), and due to temperature difference, air sucked from the atmosphere inside the chamber. This provides additional heat to cylindrical chamber.

2.1.3 Solar collector (reflector)

Solar reflector is constructed of 1mm thick Aluminium sheet. The functions of this collection of the sun rays and reflect it to the cylindrical chamber. The collector is fabricated in parabolic shape.

2.1.4 Stand

The mild steel stand is made to give the support to cylindrical chamber and also helps to provide proper position to reflector. Rollers also provided for secure handling (Oluwole et al., 2007).

Figure 2 shows the actual fabricated model of a mixed-mode type solar dryer at experimentation location and Table 1 shows the dimensions of various parts in mixed-mode type solar dryer.

Figure 2 Actual developed model of a mixed-mode type solar dryer

Table 1 Dimensions of various parts in mixed-mode type solar dryer

S.N	Dryer Part / Part Name	Material / Material Type	Length (mm)	Diameter (mm)	Thickness (mm)
1	Cylindrical chamber	M.S. Sheet	700 mm	220 mm	1.5 mm
2	Helical screw	M.S. Sheet	650 mm	200 mm	1.5 mm
3	Handle	M.S. Rod	240 mm	20 mm	--
4	Solar collector (reflector)	Aluminum Sheet	700 mm	1000 mm	1 mm

2.2 Mode of operation of the dryer

In dryer, the drying cylindrical chamber assimilates solar energy straightforwardly through transparent reflector, and heated air by hot air chamber solar collector is forwarded to drying cylindrical chamber simultaneously.

As in Figure 3, provides a schematic diagram with illustration the drying path.

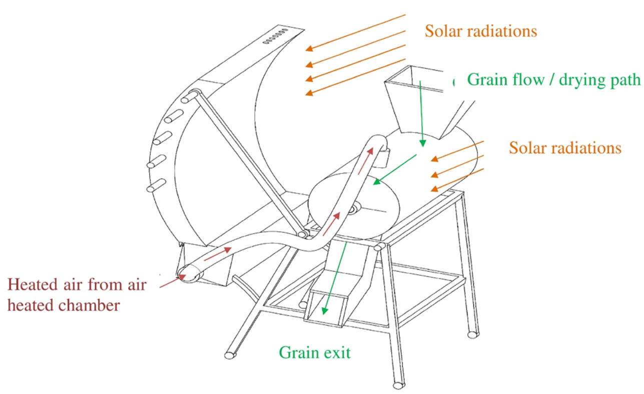

Figure 3 Schematic diagram of a mixed-mode type solar dryer with drying path.

Developed model of a dryer is utilized to dry the grain for the preservation of the food. The entire structure of the dryer is supported on a stand. The stand is comprised of mild steel square bar, and drying chamber along with helical screw assembly are thread bolted to the square mild steel bar. The air heater chamber is also thread bolted to the downside of the stand. Solar collector (reflector) is clamped to air heater with the help of screw. A connector is provided on a frame to adjust the angle of solar collector (reflector) by changing its position in regulating slot. The hot air of air heater is passed through the nozzle via a hose pipe to the drying chamber to dry the food grains. Grains need to be dried, inserted through the trapezoidal hopper provided on the top surface drying chamber. Grains are forwarded through the helical screw assembly which is rotated manually with the help of handle. Exit for food grains is given to lower portion of drying chamber. In this developed solar dryer, heated air which is received via solar collector is transferred to the grain bed; similarly, the drying cabinet receives solar energy legitimately inside a reflector at same instant. The dryer displayed an adequate capacity to dry nourishment things sensibly quickly to the sheltered moisture level and at the same time, it guarantees a supreme quality of dried food.

3 Experimentation

The experiments were carried out during the mid of April 2019 at the Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Technology, Pimpri, Pune, Maharashtra, India with the following coordinates: latitude N 18° 39' 47.376"; longitude E 73° 45' 16.162". The solar dryer was installed on a top floor of a Mechanical Engineering Department building based on the design. The experiments of the dryer were conducted by considering no-load and full-load conditions (Dulawat and Rathore, 2012). The drier had a 10 kg loading capacity for wheat grains. The tests were performed daily from 9:00 am to 6:00 pm. The temperature was recorded for every hour from morning 9:00 am to evening 6:00 pm to obtain the value of ambient temperature, wet bulb temperature, collector temperature, air chamber temperature and drying chamber temperature. For measurement of various temperatures thermocouples were used (Fagunwa et al., 2009).

3.1 Zero-load experiments:

During zero load experimentation, the dryer was tested at 9:00 am morning to 6:00 pm for three days with no product. The values of significance, i.e. ambient, wet bulb, collector, air chamber and drying chamber temperature were recorded hourly.

3.2 Wheat grains drying experimentation:

During experimentation, the dryer has been run with the wheat grains. The freshly harvested 3000 g wheat was tested put inside the dryer for a hour and its weight was tested. This process was carried out hourly from morning

9:00 am to evening 6:00 pm for seven days, and weight of the grains was measured.

Percentage of moisture content loss was calculated based on the weight of wheat before and after drying using the relationship (Ishola et al., 2011).

$$Percentage\ of\ Moisture\ loss = \frac{Weight\ of\ grain\ before\ drying - Weight\ of\ grain\ after\ drying}{Weight\ of\ grain\ before\ drying} \times 100\%$$

4 Result and discussion

4.1 Variation of the temperature in the solar dryer (april month)

Table 2 A Typical day results of the variation of the temperature in the solar dryer

Time	Ambient Temperature °C	Wet-bulb Temperature °C	Collector Temperature °C	Air chamber Temperature °C	Drying chamber Temperature °C
9:00 am	28	26	30	28	28
10:00am	30	28	34	30	32
11:00am	34	30	44	35	38
12:00am	38	34	58	44	54
1:00pm	39	35	64	48	60
2:00pm	40	37	69	52	65
3:00pm	40	37.5	70	54	68
4:00pm	38	35.5	68	48	64
5:00pm	34	31	60	41	59
6:00pm	32	28	48	35	48

Table 2 shows the average of three days values of recorded temperature for ambient/wet bulb/ collector/air chamber/drying chamber temperature. The 3000 g wheat was kept inside the dryer for a hour. Temperature was recorded hourly from 9:00 am morning to 6:00 pm evening alternately for three days in a week.

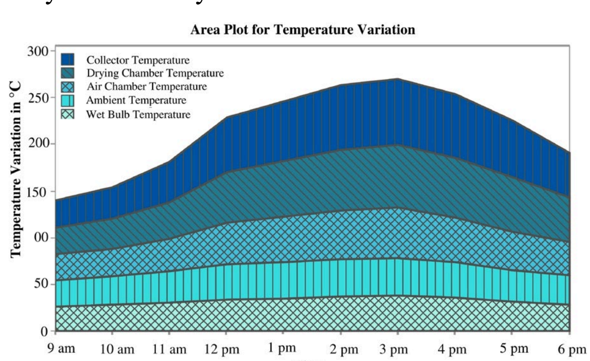

Figure 4 Area plot for average results of the hourly temperatures variation

Figure 4 shows an average of typical day recorded temperatures readings in solar collector, hot air chamber, and cylindrical drying chamber as comparing with an ambient temperature. When sun is normally above head, dryer found most heated.

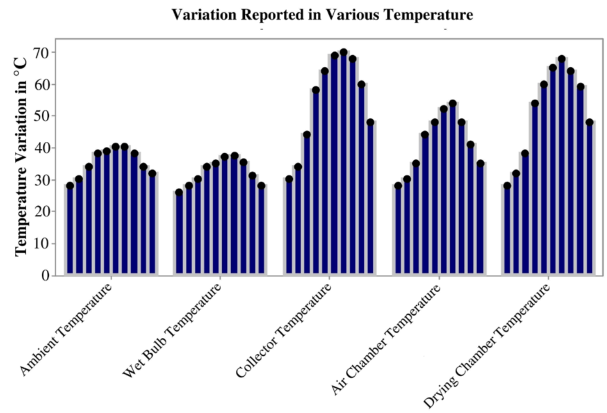

Figure 5 Hourly variation reported in temperatures

The internal temperature of a dryer and solar collector was comparatively high as comparing with ambient temperature throughout the day. A rise of temperature up to 54°C to 68°C was noted inside drying cabinet between 12:00 pm to 03:00 pm. This recorded result shows excellent performance compared to open-air sun drying.

Figure 5 shows, graph for variation in ambient/wet bulb/collector/air chamber/drying chamber temperature. Graph shows maximum temperature at the collector. After collector maximum temperature was recorded at drying and air chamber.

4.2 Variation of the relative humidity of the temperature drying chamber and ambient air on wet bulb temperature

Table 3 Average of the variation of the temperatures and relative humidity.

Time	Drying chamber temperature °C	Wet-bulb temperature °C	Relative humidity %
9:00 am	28	26	86.0
10:00am	32	28	74.0
11:00am	38	30	55.6
12:00am	54	34	26.1
1:00pm	60	35	19.4
2:00pm	65	37	19.4
3:00pm	68	37	15.0
4:00pm	64	35	15.7
5:00pm	59	31	13.3
6:00pm	48	28	21.4

Table 3 shows the average of seven days values of recorded temperature for drying chamber temperature, wet bulb temperature, and relative humidity.

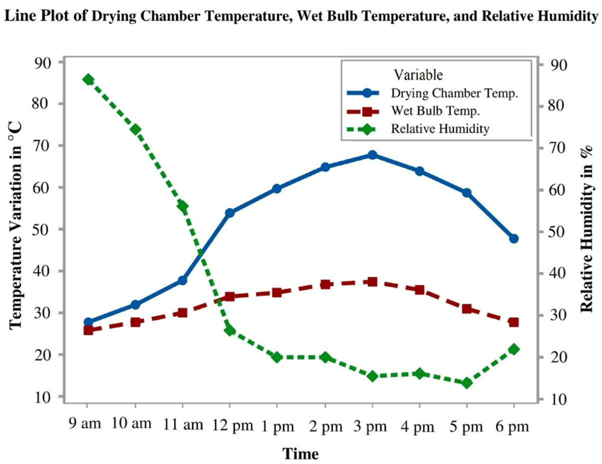

Figure 6 Variation of the temperature and relative humidity

Figure 6 shows, the line plot for drying chamber temperature, wet bulb temperature, and relative humidity. The chart shows maximum relative humidity 86 at morning hours, which reduces considerably up to 21.4 in evening hours. The drying process enhanced much more with the effect of heated air at comparatively lower humidity.

Figure 7 shows, the chart for the variation drying chamber temperature, wet bulb temperature, and relative humidity. Chart shows the continuous fall of relative humidity from morning hours to evening hours. The maximum amount of drying chamber temperature and wet bulb temperature was found around 4 pm.

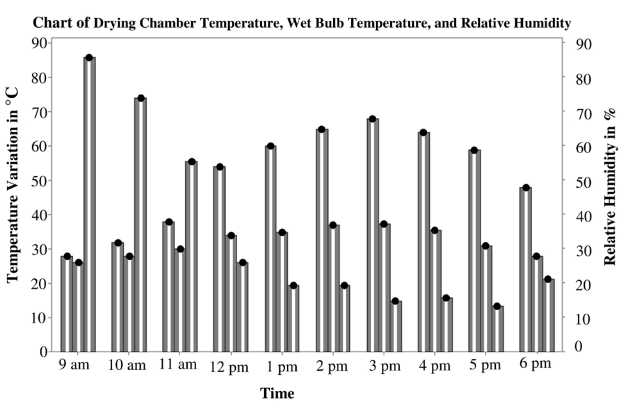

Figure 7 Chart for the variation of the temperature and relative humidity

4.3 Hourly variation of moisture loss (%) and mass of grain

Table 4 shows the experimental results of the average moisture loss percentage for 3000 g of input wheat grains hourly. The average rate of wheat considered for testing contents 22% moisture.

Table 4 Average of hourly moisture loss (%)

Time	Weight of grain before drying (g)	Weight of grain after drying (g)	Moisture loss (%)	Total Moisture (%)(Average moisture content 22%)
9:00 am	3000	2900	3.33	18.67
10:00am	3000	2880	4	18
11:00am	3000	2860	4.67	17.33
12:00am	3000	2845	5.16	16.84
1:00pm	3000	2800	6.67	15.33
2:00pm	3000	2775	7.5	14.5
3:00pm	3000	2800	6.67	15.33
4:00pm	3000	2840	5.33	16.67
5:00pm	3000	2875	4.16	17.84
6:00pm	3000	2890	3.66	19.67

4.4 Variation of the relative humidity and moisture loss (%) and total moisture (%)

Figure 8 shows the variation of the relative humidity of the temperature of the drying chamber and wet bulb temperature. Figure 6 shows, drying process enhanced much more with the effect of heated air at comparatively lower humidity.

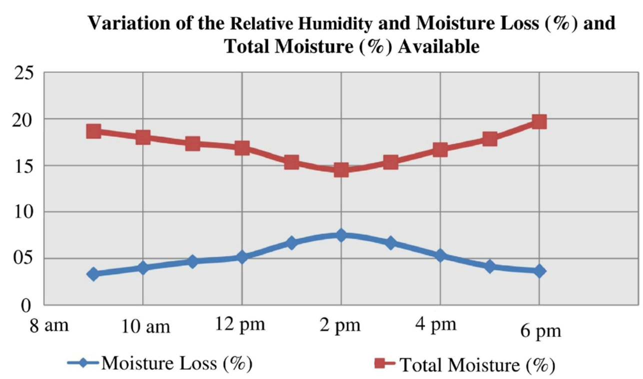

Figure 8 Variation of the relative humidity and moisture loss (%) and total moisture (%) available

It is observed the rate of moisture absorption is high hours after 12.00 noon.

5 Conclusion

A mixed-mode type solar dryer was developed, and its performance was evaluated at latitude N 18° 39' 47.376"; longitude E 73° 45' 16.162" using about 81 kg of freshly harvested wheat grains. The overall time required for drying was minimized against sun drying as developed mixed-mode solar dryer set up took an hour only to dry the wheat grains to a moisture content of 14.5% from 22%. The 3000 g were successfully dried in an hour using solar energy which is available at free of cost.

The average temperature rise observed inside drying chamber was about 27.7°C over an ambient temperature at around 3 pm afternoon which is significantly higher than the ambient temperature.

Developed mixed-mode type dryer is found more cost-effective for farmers in rural communities as dryer doesn't utilize the power and can be easily fabricated using locally accessible resources.

The solar dryer intended for the reason has the benefits of decreasing the harms caused to the item by bugs, birds, rodents, small insects, and an unfriendly atmospheric situation. The drying time is likewise decreased significantly.

The moisture content dissemination of wheat in a dryer is progressively homogeneous because of extra drying from direct radiation.

In these conditions, developed solar drying technique is much quick in time to the traditional technique, and also dried wheat grains looked cleaned physically.

The developed mixed-mode solar dryer could be technically suitable to dry the maximum type of food grains.

In the future, the evaluation of the dryer should be carried out for a more extended period because of changes in climate to find out its most significant exhibition.

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