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ORIGINAL ARTICLE **OPEN ACCESS**

Design and Fabrication of Convective Grain Dryer

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ABSTRACT
Drying is a one of the essential process for the preservation of agricultural food products. Especially grains require hot air in the temperature range of 35-50ºC for safe drying. In this, work has been made to develop the compact and portable forced convection solar dryer for drying wheat with solar air heater. The performance of the solar dryer has been tested experimentally. The system was constructed using local materials. The temperatures of 50, 45, 38 and 36ºC were reached at the collector unit, drying chamber, air outlet and ambient temperature, respectively. During the drying convection mode system, the drying time was 2.5 hours while the drying rate was 0.16kg/hr. The collector efficiency was 29% and the useful heat of 930.8 kJ was used to remove moisture from the grain product for about 0.4kg of water from the total product mass of 2kg.
Key Words: *moisture content, solar collector efficiency, drying rate, air flow rate discharge.*

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INTRODUCTION

Moisture content in cereal grain plays a vital role in chain of handling and storage. Germination, microbial growth, insect infestation, deterioration of colour, development of off-flavour, and lowering of nutritive value are some common quality factors associated with storage of high-moisture grain that render the commodity unfit for human consumption [7]. Thus, removal of moisture becomes a crucial step to provide extended storage life, facility of handling, retention or enhancement of quality, and new products for further processing. Commonly, the process of thermally removing small amounts of moisture from materials is referred to as drying, which can be accomplished in various ways-some of which are specific to the commodity, location, or the volume of the material to be handled [2]. Nevertheless, removal of moisture from the grain is a very energy–intensive process [6]; thus, the efficiency of a drying operation in terms of energy and time has economic consequences for commercial viability. In addition to these, maintenance of hygienic condition prevention or control of quantitative and qualitative losses of materials, and management of proper space utilization should be adhered. The final moisture content of the product to be achieved is largely decided by the storage environment and its storability or set tolerance limits on quality attributes so, this in turn, dictates the selection of a drying system, drying time, and the range of operating parameter values [3, 5]. In convection drying system the air is heated to a desired level of temperature and is used as a medium of convective heat transfer.
Convection drying is most popular grain-drying technique [1, 9]. In this system, the heat transfer for drying is accomplished by direct contact between the wet material and a stream of hot gas.The vaporized moisture is carried away from the grain by the heating medium. Convective dryer is described as the balanced manipulation control of air exchanges, heat, and of removal moisture from the inside of the product [6]. Convective dryer is used for large scale drying, in this dryer the solar radiation coming from the sun does not fall on the product directly to be dried. First the blower sucks air which is at ambient temperature from the environment to solar air heater, the air will be heated by the radiation which are absorbed by the solar collector then the heated air is circulates and forced in to the drying chamber in which the product to be dried is placed through the connecting pipes with the help of blower or due to the densities difference between the cold and hot air [2]. Solar drying provides higher air temperatures and lower relative humidity than simple sun drying. It hence the drying rates and lower final moisture content of dried products. As a result, the risk of spoilage is reduced, both during the actual drying process and subsequent storage. In many cases, solar drying can be feasible alternative wholly or partially to artificial

drying. In solar drying system, a source of motive power is required for some types but considerable saving in energy costs is possible [3, 10].
The drying of cereals is crucial to prevent grain spoilage. Grain has to be dried 10 to 15% moisture content for safe storage. For barley, Hellevang [9] recommended 14% moisture content for short term storage (less than 6 months) and 12% for long term storage (more than 6 months). Grain with damaged kernels needs to be stored at 1-2% lower moisture content.
The General objective of this study is to fabricate a convective dryer with high efficiency and desired performance.

- To design a convective grain dryer.
- To fabricate a convective grain dryer.
- Testing and evaluation of the fabricated convective dryer performance using wheat grain for storage purpose.

MATERIAL AND METHODS

Measurement instruments and devices

A digital anemometer is used to measure the relative humidity, ambient and wind velocity. A solar power meter is used to measure the hourly solar insulation, the instrument is place directly below the sun and the reading is show on the digital display calibrated in W per m^2 The samples are weight using a digital electronic balance, and it helps to find the moisture content of the product, the measurement will take before drying and after drying of the product. Temperature will take at different points, the initial temperature will measure at the air inlet that blows from the blower and the final temperature is after air passes through the solar collector. The velocity of air inlet can measure with the help of the vane type anemometer. The anemometer is placed at collector inlet to measure the velocity of the air at the inlet. This velocity then used to calculate the mass flow rate of the air, these reading take after every one hour.

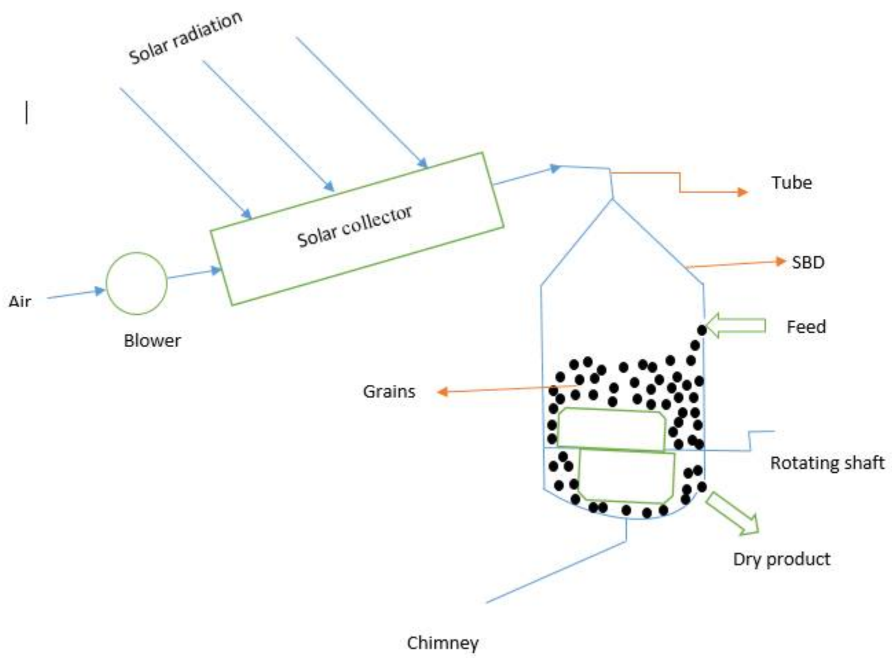

Figure-1 Schematic diagram of Convective dryer

Data Analysis

1. Determination of Moisture Content

The % of moisture content on wet basis (M_{wb}) is found using the formula

$$\%Mwb = (mi - mf / mi) * 100$$

Where: mi - initial mass of the sample, m_f - final mass of the sample

2. Determination of Drying Rate

The drying rate of product is determined using the formula

$$DR = \Delta M \backslash \Delta t$$

Where: ΔM - loss of the mass of the crop, Δt - interval of time

3.The energetic balances can be useful when showing the dryer condition diagnosis.

- Quantity of Heat needed for heating the product (Q_1)

$$Q1 = m'cp\Delta T$$

- Quantity of Heat needed to evaporate the water (Q_2)

$$Q2 = mhfg$$

- Total Quantity of Heat needed (Q)

$$Q = Q1 + Q2$$

Design of drying chamber

It is designed according to the amount of the product going to be dried and hot air that comes from the blower through the solar collector; it also design based on the pressure exerted by the hot air and the grain product on its wall.

Geometrical designing according to formulas: -

Circumference of cylinder: $C = 2\pi r$

Lateral area of cylinder: $Acy = 2\pi rh$

Volume of cylinder: $VCy = \pi r2h$

Area of cone: $Acone = \pi rs$

Volume of cone: $Vcone = 1/3\pi r2h$

Total surface area of drying chamber = $Acy + Acone + Acircle$

Total volume of drying chamber = $VCy + Vcone$

Design of solar collector

Solar air heating is a solar thermal technology in which the energy from the sun, insolation, is captured by an absorbing medium and used to heat air [10].It designed based on the amount of product to be dried and its initial moisture content of the product or the amount water to remove from the product, example for large amount of grains product to be dried requires large size solar collector and vice versa. Type of material going to be used as a solar collector is also affect the design of solar collector, materials with high capacity of absorbance and transitivity of radiation is better for solar collector. The cross sectional area of the solar collector is given by product of its width and length

$$Asc = Q/I\Delta t\eta$$

Selection of blower

The blower is selected according to the amount of air needed to remove moisture from grain product and diameter of tube inside the solar collector to pass a required mass flow rate of hot air for drying a grain product to the optimum moisture content for storage purpose.

- Mass flow rate of air (kg/hr):

$$\dot{m}a = Q\backslash(hf - hi)\Delta t$$

- Discharge of air (m^3/hr):

$$Qv = \dot{m}a/\rho a$$

- Quantity of drying air (m^3):

$$Va = Qv * \Delta t$$

Where: Q_v - Volumetric flow rate (m^3/hr), V_a – Volume of drying air (m^3), h_f – Final enthalpy of drying air (kJ/kg), h_i – Initial enthalpy of drying air (kJ/kg),Δt – Time interval (hr)

Solar collector efficiency

The efficiency of flat plate collector is influenced by many factors such as the size of collector, geographical location, velocity, humidity, the temperature of the surrounding air etc. The thermal efficiency for solar collector can be determined by;

$$\eta_c = \frac{\dot{m}_a C_{pa}(T_c - T_i)}{A_c I}$$

Where:$\dot{m}_a$ - Air mass flow rate, C_{pa} - Specific heat capacity of air, T_C - Temperature of solar collector, T_i- Inlet temperature of solar collector

Determination of drier efficiency

The efficiency of the solar drier is given as;

$$\eta_d = \frac{m_w h_l}{A_c It}$$

Where :M_w - mass of the water evaporated from the crop,I - solar isolation, h_l - latent heat of vaporization of water, t - time of drying , A_c = effective area of the collector

RESULT AND DISCUSSION

Convective drying method

In this method a clean 2kg of wheat grain with a moisture content of 20% is placed inside the drying chamber, and a hot air which is heated in the solar collector came to the drying chamber at a temperature of 65^{0}C. The loss of moisture was recorded at every 10 minutes for first one-hour, at every 20 minutes for next an hour and at every half-hour for rest of drying period.

Table-1 Variation of Moisture Content and Drying Time during Drying Of Wheat Grain under Convective Drying Method

Sample No	Initial mass (kg)	Initial temperature (°C)	Drying rate (min)	Final temperature (°c)	Final mass (kg)	Moisture content (kg)	Moisture content (wb)%	Moisture content (db) %
1	2.0	31	10	32	1.6	0.4	20	25
2	2.0	31	10	32.5	1.63	0.37	18.5	22.7
3	2.0	31	10	33.6	1.66	0.34	17.1	20.6
4	2.0	31	10	35.2	1.68	0.32	15.8	18.8
5	2.0	31	10	36.4	1.71	0.29	14.6	17.1
6	2.0	31	10	37.1	1.73	0.27	13.5	15.6
7	2.0	31	20	38	1.75	0.25	12.5	14.3
8	2.0	31	20	39.1	1.76	0.24	11.8	13.4
9	2.0	31	20	40.9	1.78	0.22	11.2	12.6
10	2.0	31	30	42	1.80	0.20	10	11.1

The variation of moisture content is recorded with dying time of 2.5 hours during convective drying. The average moisture content of the grain was reduced from about 20% to 10%.The initial and final temperature were recorded of convective dryer from 31^{0}C to 42^{0}C respectively. The higher moisture reduction during the initial stages of drying was observed due to evaporation of free moisture from the outer surface layers and then gets reduced due to internal moisture migration from inner layers to the surface, which results in a process of uniform dehydration. As compare to sun drying to convective dryer was more efficient. The evaporation of moisture content was faster than sun drying

Energy analysis of the convective dryer

From the above given data,the total mass of the sample (initial mass) is 2kg at a moisture content of 20% (wb) and temperature of 31^{o}c, finally reduced to 1.6kg with moisture content of 10% (wb) and temperature reach's 42^{o}c with the help of the dryer during the drying period (Δt) of 2.5 hours. The h_{fg} of water is 2.257MJ/kg, and the specific heat capacity of product is 1.40kJ/kg.^{o}c.

- ***Determination of Moisture Content (MC)***

$$MC = \text{initial mass} - \text{final mass}$$
$$=2kg -1.6kg= 0.4kg$$

- ***Drying Rate (DR)***

$$DR = MC/\Delta t$$
$$=0.4kg/2.5hr=0.16kg/hr=160g/hr$$

- ***Quantity of Heat needed for heating the product (Q_1)***

$$Q1 = mcp\Delta T$$
$$= 2kg * 1.402kJ/kg.^oc * (69-59)=28kJ$$

- ***Quantity of Heat needed to evaporate the water (Q_2)***

$$Q2 = mhfg=0.4kg*2257kJ/kg=902.8kJ$$

- ***Total Quantity of Heat needed (Q)***

$$Q = Q1 + Q2$$
$$= 28kJ+902.8kJ= 930.8kJ$$

Solar Collector (Air Heater):*Area of the solar collector (A_{sc})*

$$Asc = Q/I\Delta t\eta$$
$$= (930.8kJ)/950w/m^2 * (2.5*3600) s*0.30$$
$$= 0.36m^2$$

Design of drying chamber

The result dimensions of the drying chamber in the experiment are found:

Total height (h_t) which is height from the inlet of hot air to the outlet is 0.60m, height of the cylinder (h_{ay}) is 0.42m, and its diameter is 0.32m, and the slant height of the cone is 0.24m. The drying chamber has an inlet hopper, discharge outlet and their dimensions are: the inlet length is 0.1m, the width is 0.09m and the length of the outlet is 0.075m, the width is 0.055m.

According the data above: -

- Circumference of the drying chamber is determined by:

$$C = 2\pi r$$
$$= 2*\pi*0.16m$$
$$= 1m$$

- Height of the cone shaped can be calculated by Pythagoras theorem method:

$$S2 = r2 + h2$$
$$h2 = S2 - r2h^2$$
$$h^2 = (0.24m)^2 - (0.16m)^2$$
$$h^2 = 0.032m^2$$
$$h = 0.18m$$

- Total surface area of the drying chamber of the dryer is sum of the three different figures.

$$At = Acone + Acylinder + A\ circle$$
$$Acone = \pi\ rs A\ circle = \pi r2$$
$$= \pi*0.24m*0.16m \quad = \pi*0.16m^2$$
$$= 0.121m^2 \quad = 0.08m^2$$

$$Acy = 2rhAt = Acone + Acylinder + Acicle$$
$$= 2\pi*0.16m*0.42m = 0.121m^2 + 0.422m^2 + 0.08m^2 = 0.422m^2 = 0.623m^2$$

- Capacity or volume of the drier chamber:

$$Vchamber = Vcone + Vcylinder$$
$$= 1/3\ \pi r2hc + \pi\ r2hcy$$
$$= 0.3333*\pi*(0.16m)^2*0.18m* + \pi*(0.16m)^2*0.42m$$
$$= 0.005m^3 + 0.0338m^3$$
$$= 0.0388m^3.$$

The spot bed dryer is made of metal sheet and it is painted a black colour, its purpose is to absorb and conserve heat energy as well as cools slowly. Inside the drying chamber there is also a rotating shaft with three set of metal blade which is used for mixing of the grain product to dry uniformly to the desired moisture level. The shape of the blades is a semi-circle with a diameter of26cm and vertical height of 14cm.At the base of chamber a tube with diameter of 12mm is provided as a chimney for the hot gas exist to prevent from accumulating moisture and pressure of the gas inside the chamber.

Determination of air flow rate

From the psychometrics chart the initial and final humidity ratio is 0.0018kg H_2O/kg dry air,0.014kgH_2O/kg dry air respectively [6-9]. From the result of preliminary experiments on the crop, the initial and final enthalpy is 34.5kJ/kg dry air, 65.5kJ/kg dry air respectively. The optimal drying temperature was 42ºC and final moisture content of wheat for storage is 10% wb.

- Mass flow rate:

$$\dot{m} = Q\backslash(hf - hi)Td$$
$$(930.8kJ) \backslash (65.5kJ/kg\ dry\ air - 34.5kJ/kg\ dry\ air)\ 2.5hr = 12.01kg/hr = 0.0033kg/s$$

- The total amount of dry air mass is:

$$Ma = \dot{m}Td = 12.01kg/hr.2.5hr30kg$$

- Total volume of air required:

$$Va = Ma/\rho a = 30\ kg/1.2\ kg/m^3 = 25m^3$$

- Volumetric air flow rate (Discharge):

$$Qv = Va/\Delta t = 25m^3/2.5hrs = 10m^3/hr = 0.00278\ m^3/s$$

- Velocity of air flow through the tube of 10mm diameter:

$$V = Va/A$$
$$A = \pi r^2 A = 3.142*(0.005m)^2 = 7.854*10^{-5}m^2$$
$$V = 0.002768m^3/s/7.854*10^{-5}m^2 = 35.4\ m/s$$

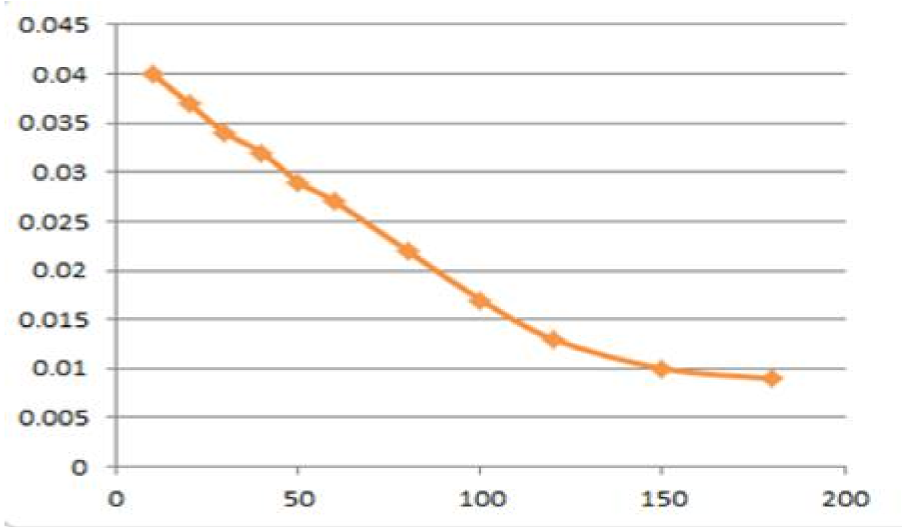

Figure-2 Relationship of drying rate verses time

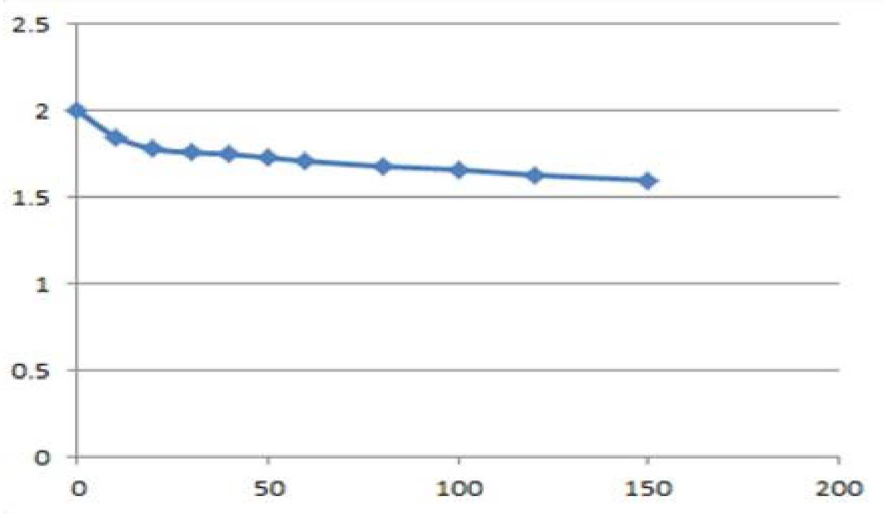

Figure-3 Relationship of mass of grain product verses time

CONCLUSION

Solar dryer is beneficial than the sun drying techniques. Solar dryers work well during fair weather but have little use during cloudy weather. Although solar dryers involve an initial expense, they produce better looking, better tasting, and more nutritious foods, enhancing their food value, quality and their marketability. They are also faster, safer, and more efficient than traditional sun drying techniques

The performance analysis of the solar drying system for wheat were performed in this study. Given the results from these analysis, the following remarks concluded:

- Drying wheat grain via solar drying reduced the moisture content from 20% (wb) to 10% (w.b) in 2.5 hours.
- The solar drying system was compared with open sun drying 71.4% saving in drying time was obtained for the solar drying system.
- The solar radiation of 950 W/m^2 and an air flow rate of 0.033 kg/s is obtained.
- The average collector and dryer efficiencies were 29 %, 73.3%respectively.
- Pressure inside the drying chamber is 0.0145 pas.
- The drying temperature varied between 31^{o}C and 42^{o}C with an average of 37.5^{o}C.

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