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Study of Mini Solar Tunnel Drying of Ginger

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ABSTRACT

The mini solar tunnel dryer was designed and developed as a portable solar drying system for drying of ginger (Zingiber officinale). It was having loading capacity of 5 kg per batch with overall dimensions 120×60×50 cm3. Performance of the mini solar tunnel dryer was evaluated at no load and full load test. The ambient temperature, relative humidity, temperature inside the dryer, drying time and moisture content of product were measured during the test run. Maximum temperature inside the mini solar tunnel dryer was found to be 54.9°C. The mini solar tunnel dryer maintained nearly greater than 10-18°C temperature above the ambient temperature at the full load conditions. The drying of ginger was carried out from initial moisture of 88%, 79% and 69% (w.b), which was reduced up to 50% (w.b.) moisture. The maximum drying time of 20 hours was observed in mini solar tunnel dryer, whereas it was observed as 44 hours in open sun drying mode. The maximum and minimum drying rate for mini solar tunnel dryer was found to be 0.183 and 0.112 g of moisture per g of dry matter per hour respectively. The drying efficiency of mini solar tunnel dryer was observed as 28.87%.

Keywords: drying efficiency, drying rate, solar tunnel dryer.

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I. INTRODUCTION

The drying of any material involves the migration of water from interior of the material to its surface & then its removal from the surface. The rate of movement of water differs from one substance to another as it depends on volume, temperature, moisture content of the air passing over the material. Solar energy is the most readily available renewable energy used for drying of various agricultural products. On an average, 5 kwh/m² solar energy per day is available in India [1]. As traditional method of open sun drying is weather dependent, it encounters various problems like poor quality of dried product, product contamination, more drying time, chances of microbial attack & non uniformity in drying of products [2]. To avoid these problems, solar dryers are used for drying various food materials. In solar drying, drying is carried out in a closed structure & relatively controlled conditions by utilizing the thermal energy of sun. Different types of solar dryers are used depending upon the mode of heating, mode of operation, mode of air circulation etc.

Mini solar tunnel dryer is a polyhouse dryer having a semi cylindrical chamber with natural/forced air circulation used for drying various agricultural products. In the natural circulation, sunlight passes through transparent materials such as glass or plastic & air inside the dryer is heated due to greenhouse effect & this heated air inside the dryer removes the moisture from the product [3]. Mini solar tunnel dryer can be designed at cheaper cost & simple operation. Nowadays, drying of vegetables have received a great attention from numerous of researchers worldwide because of its high nutrition value and perishable nature. Various scientists namely [1][2] have studied the performance of mini solar tunnel dryer for drying of different vegetables like red chilli, fenugreek and medicinal plants according to their seasonal availability.

Ginger is an important spice crop of the world. It is one of the earliest known oriental spices and is being cultivated in India for both as fresh vegetable and as a dried spice. Ginger is obtained from the rhizomes of Zingiber officinale. Ginger and its products have varied applications in culinary preparation, bakery products, toiletry products, perfume industries, meat products, wine, and soft drinks making. Dried ginger is used both as a spice and medicine. It contains an essential oil, which imparts an aroma, an oleoresin responsible for the pungent smell, starch, gums, proteins, carbohydrate, mineral matter and fibre.

Usually solar dryers are being developed for industry purpose but they have high initial development cost. They are not useful for small land holding farmers & household purposes. Hence the necessity of development of mini solar tunnel dryer for Indian farmers/households will encourage them to start agriculture based small scale entrepreneurship for their sustainable livelihood. In view of this, the present investigation was made with the objectives to develop a mini solar tunnel dryer for drying of Ginger (Zingiber officinale) and study its performance.

II. MATERIALS AND METHODS

The experiment was conducted at Renewable Energy Engineering department of Shriram College of Agricultural Engineering, Paniv, Tal. Malshiras, Dist. Solapur (Maharashtra) during November 2020 to February 2021. It is geographically located at 17.8429° N and 74.9618° E. The maximum and minimum temperature recorded at Paniv was 45.6°C and 12°C respectively. Materials used for construction of mini solar dryer were MS sheet, ultraviolet stabilized polythene sheet (200µ thickness) and other fabrication materials. Digital humidity (range 1 to 99 %) & temperature meter (0 to 70°C), weighing balance (10 kg capacity with least count 0.01 mg) and hot air oven (5°C above ambient to 250°C maximum) were used to take experimental readings.

57 kg fresh and mature ginger available at local market was used for the experimental purpose fig.1. Firstly the percent moisture content (w.b) of ginger sample was determined by using standard hot air oven method [4] A mini poly house type structure has loading capacity up to 5 kg per batch, in which drying takes place through natural flow of hot air. The mini solar tunnel dryer was covered with ultraviolet stabilized polyethylene sheet of 200µ thicknessas shown in fig 2. The axis of solar tunnel dryer was kept to east-west direction so that maximum exposure of southern radiations can be obtained.


Fig 1: Ginger Sample


Fig 2: Mini Solar Tunnel Dryer

III. DESIGN OF MINI SOLAR TUNNEL DRYER

For drying 5 kg of ginger per batch, the floor area of mini solar tunnel dryer was calculated by measuring dimensions of ginger pieces & number of ginger pieces present in 5 kg sample. By using the probability multiplication factor for 2:1 (length: width) ratio of dryer, the dimensions of mini solar tunnel dryer was obtained as 120 cm X 60 cm with 30 cm height. By assuming the latent heat of vaporization of water (L) as 2260 kJ/kg, solar insulation (I_s) as 5kwh/m^2/day, solar dryer efficiency (η) as 50%, quantity of material to be dried (X) as 5000 gm, initial moisture content (%w.b) of Ginger (m_1) as 88.18% & final moisture content (%w.b) of Ginger (m_2) as 11.66%, other dimensions of mini solar tunnel dryer and its parts were calculated as per the methods described by [5].

$$\text{Amount of initial water content, gm (M)} = \left(\frac{m_1 \times X}{100}\right)$$

Where,

m_1 = initial moisture content on wet basis, %

X = quantity of product to be dried, gm

$$\text{Mass of dry matter, gm } (M_d) = (X - M)$$

Where,

X = quantity of product to be dried, gm

M = amount of initial water content, gm

$$\text{Initial moisture content in dry basis, \% } (M_{i,db}) = \left(\frac{m_1}{100 - m_1}\right) \times 100$$

Where,

m_1 = initial moisture on wet basis, %

$$\text{Final moisture content in dry basis, \% } (M_{f,db}) = \left(\frac{m_2}{100 - m_2}\right) \times 100$$

Where,

m_2 = final moisture on wet basis, %

$$\text{Mass of water to be removed, gm } (M_w) = M_d\left(\frac{M_{i,db} - M_{f,db}}{100}\right)$$

Where,

M_d = Mass of dry matter, gm

$M_{i,db}$ = Initial moisture content in dry basis, %

$M_{f,db}$ = Final moisture content in dry basis, %

$$\text{Area of solar collector}, m^2 \text{ (A)} = \frac{M_w \times \lambda}{I_s \times \eta}$$

Where,

M_w = mass of water to be removed, kg

λ = latent heat of vaporization, MJ/kg

η = efficiency of the dryer, % (50%)

I_s= daily solar insolation, MJ/m^2

IV. DESIGN OF CHIMNEY

Since air flow in the dryer takes places due to the draft caused by the density difference between outside cold air and inside hot air, a natural draft uses the basic law that warm air rises. Air as it is warmed expands and becomes lighter in mass. Colder, heavier air pushes in under it and forces it up. This causes a draft [5].

$$\text{Mass of air required, Kg } (q_a)\, i = \frac{M_w \times \lambda}{C_{pa} \times (T_c - T_a)}$$

Where,

M_w = quantity of water to be removed from product, Kg

λ = Latent heat of vaporization of water, kJ/kg

C_{pa} = specific heat of air, kJ/kg °C

T_c = chimney temperature, °C

T_a = ambient temperature, °C

$$\text{Mass of exit air from dryer, Kg (q)} = M_w + q_a$$

Where,

M_w = quantity of water to be removed from product, kg

qa = mass of air required, *kg*

Actual draft produced, kg/m/s^2

$$(Dp) = H \times g \times (p_i - p_e)$$

Where,

H = height of chimney, m

g = gravitational constant

p_i = density if inlet air, kg/m^3

p_e = density of exit air, kg/*m*^{3}

Actual draft, kg/m/s^2 (D_a) = 0.75 × D_p

Where,

D_p= actual *draft produced, kg/m/s*^{2}

$$\text{Velocity of exit air, m/s (V)} = \sqrt{\frac{2 \times D_a}{\rho_e}}$$

Where,

D_p= actual draft produced, kg/m/s^2

p_e = density of exit air, kg/*m*^{3}

$$\text{Volume of exit air, } m^3 (V_e) = \frac{q}{\rho_e}$$

Where,

q = Mass of exit air from dryer, kg

p_e = density of exit air, *kg/m*^{3}

$$\text{Rate of air exit, } m^3/hr\ (Qa) = \frac{V_e}{t}$$

Where,

t = time of drying in, hr

$$\text{Rate of exit air in single chimney, m3/hr } (Qc) = \frac{Q_a}{n}$$

Where,

n = number of chimneys

Q_a= Rate of air exits, m^3/hr

$$\text{Area of chimney, } m^2\ (A_c) = \frac{Q_c}{v}$$

Where,

Q_c = rate of exit air in single chimney,m^3/hr

V = velocity of exit air in, m/s

$$\text{Diameter of chimney, m } (\mathbf{D_c}) = \sqrt{\frac{5 \times A_c}{\pi}}$$

DESIGN OF DRYING TRAY

$$\text{Drying tray area, } m^2 = L \times W$$

Where,

L = Interior length of dryer, m

W = interior width of dryer, m

V. PERFORMANCE EVALUATION OF MINI SOLAR TUNNEL DRYER

After development of mini solar tunnel dryer, its performance evaluation was made by conducting no load test and full load test as below.

No Load test: No load test was conducted for 1-2 days between 10 am to 4 pm every day by taking readings for every 1 hr interval. During that test, temperature and relative humidity inside and outside the mini solar tunnel dryer was measured at every 1 hr interval.

Full Load test: Before starting this test, moisture content of ginger sample was measured. 5 kg of ginger sample was taken & put it in the mini solar tunnel dryer. The test was conducted for 5-8 days between 10 am to 4 pm every day and readings were taken every after 1 hr interval. Temperature and relative humidity inside and outside the mini solar tunnel dryer was measured at every 1 hr interval.

Experimental design

For determining the final acceptance of ginger sample, dried sample with 50% moisture along with its accepted texture was considered.

T1- Sample with 88 % moisture content (control)

T2- Sample with 88 % moisture
T3- Sample with 79 % moisture content (control)
T4- Sample with 79 % moisture
T5 - Sample with 69 % moisture content (control)
T6 - Sample with 69 % moisture

VI. STUDY OF DRYING CHARACTERISTICS

The drying characteristics of ginger were determined by using method given by [6].

Moisture content, % wet basis = $\frac{(W_1 - W_2)}{W_1} \times 100$

Where,

W_1 = weight of sample before drying, gm

W_2 = weight of sample after drying, gm

Drying Rate, g of moisture per hr per 100 g of bone-dry

Matter (R) = $\frac{Q_{rem}}{t \times W_d}$

Where,

Q_{rem} = quantity of moisture removed, g

t = drying time, hr

W_d = weight of dry matter present in the sample, kg

Moisture Ratio (MR) = $\frac{M - M_e}{M_0 - M_e}$

Where,

M = moisture content at time %,

M_0 = initial moisture content %,

M_e = equilibrium moisture content %.

Drying Efficiency (η_d) = $\frac{(M_W \times \lambda)}{I \times A_C} \times 100$

Where,
M_W = mass of water evaporated, kg
λ = latent heat of vaporization, MJ kg-1
I = incident solar radiation on collector, MJ m^{-2}
A_c= area of collector m^2

VII.RESULTS AND DISCUSSION

Initial and final moisture of ginger was found to be 88.18 % (w.b) & 11.66 % (w.b) respectively. The height of chimney was 20 cm with its diameter as 14 cm, whereas length & width of tray was 120 cm and 60 cm respectively.

NO LOAD TEST
For the no load test, the maximum difference between the temperatures inside the dryer and outside the dryer was found as 12.7 °C to 17 °C whereas the minimum difference between the temperatures inside the dryer and outside the dryer was found as 10.4 °C to 11.9 °C.

FULL LOAD TEST
The drying of ginger samples was continued till the moisture content was reached to 50% (w.b.). The results obtained are summarized below in terms of moisture reduction, drying rate, moisture ratio & drying efficiency.

a) Moisture reduction

It was observed that the moisture removal from the ginger sample was exponential in nature and nearly uniform. From fig 4, it was observed that initially moisture removal from ginger was rapid. Time required for drying the ginger having initial moisture of 88 % was found to be 20 hours & 44 hours in mini solar tunnel dryer and open sun drying respectively. For drying the ginger having initial moisture of 79 %, the time required to dry in mini solar tunnel dryer was found to be 18 hours whereas the time required to dry in open sun drying was found to be 40 hours (fig 5). Fig 6 indicates that the time required to dry ginger having initial moisture of 69 % in mini solar tunnel dryer was 15 hours & it was 32 hours for open sun drying.

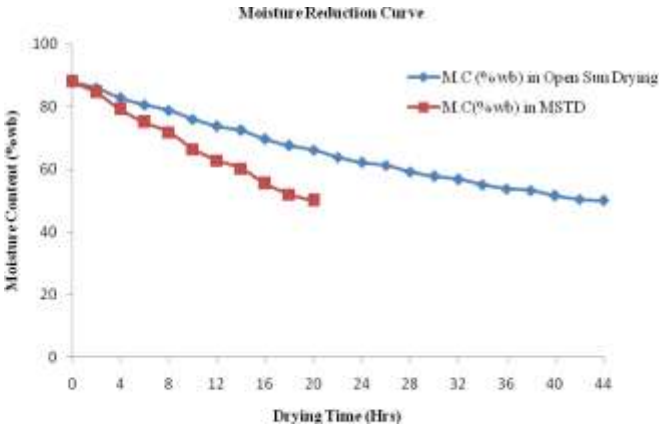

Fig 4: Moisture reduction curve at 88% of initial moisture of ginger

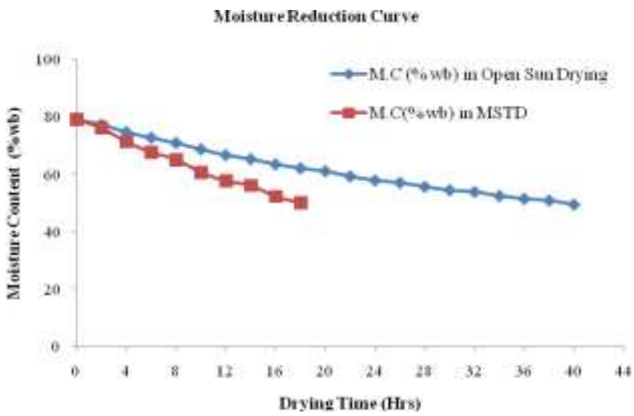

Fig 5: Moisture reduction curve at 79% of initial moisture of ginger

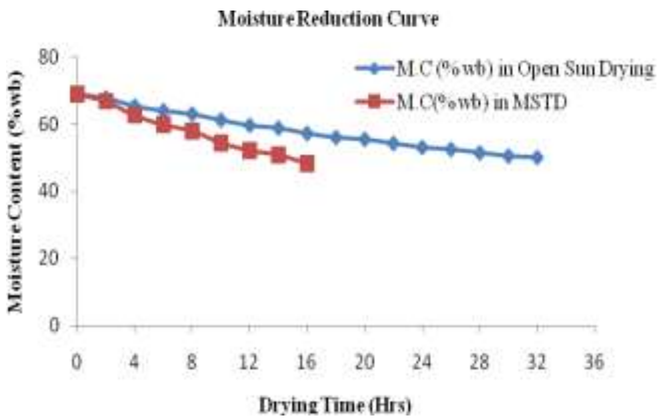

Fig 6: Moisture reduction curve at 69% of initial moisture of ginger

b) Drying rate

At the beginning of drying process, surface moisture was evaporated rapidly and thus the drying rate was observed to be high. It was decreased with an increase in the drying time. This may be due to the high evaporation of free moisture from outer surface layer of ginger initially and it gets reduced afterwards as it takes time to migrate the internal moisture from inner layer of ginger to the surface. Fig 7 indicates that at 88% initial moisture of ginger, the maximum drying rate for mini solar tunnel dryer was 0.183 g of moisture per g of dry matter per hour whereas, it was observed as 0.108 g of moisture per g of dry matter per hour for open sun drying. Minimum drying rate was found to be 0.141 & 0.071 g of moisture per g of dry matter per hour for mini solar tunnel dryer & open sun drying respectively. From fig 8 we can see that at 79% initial moisture of ginger, the maximum drying rate for mini solar tunnel dryer was 0.092 & for open sun drying, it was 0.052 g of moisture per g of dry matter per hour. Minimum drying rate was found to be 0.071 & 0.035 g of moisture per g of dry matter per hour for mini solar tunnel dryer & open sun drying respectively.

Maximum drying rate of ginger having initial moisture of 69 % was found to be 0.051 & 0.0269 g of moisture per g of dry matter per hour for mini solar tunnel dryer and open sun drying respectively. Minimum drying rate for mini solar tunnel dryer was found to be 0.041 & for open sun drying it was 0.019 g of moisture per g of dry matter per hour (fig 9).

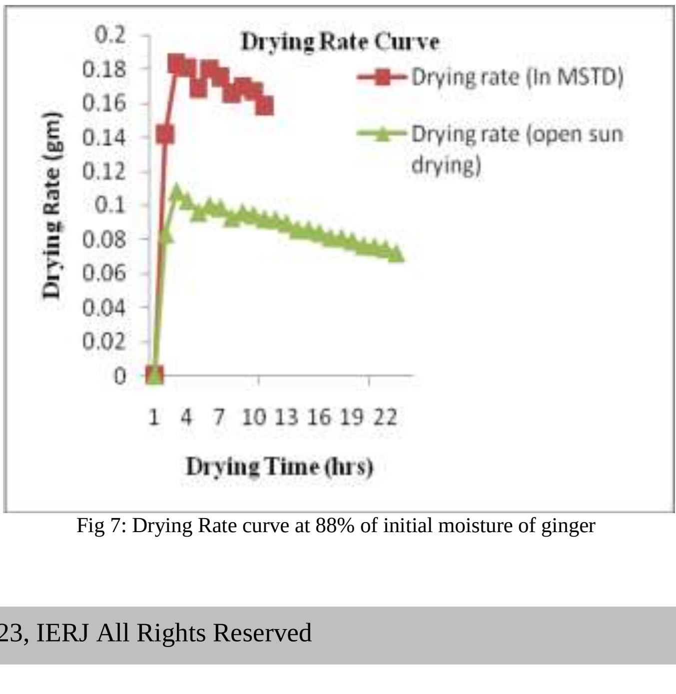

Fig 7: Drying Rate curve at 88% of initial moisture of ginger

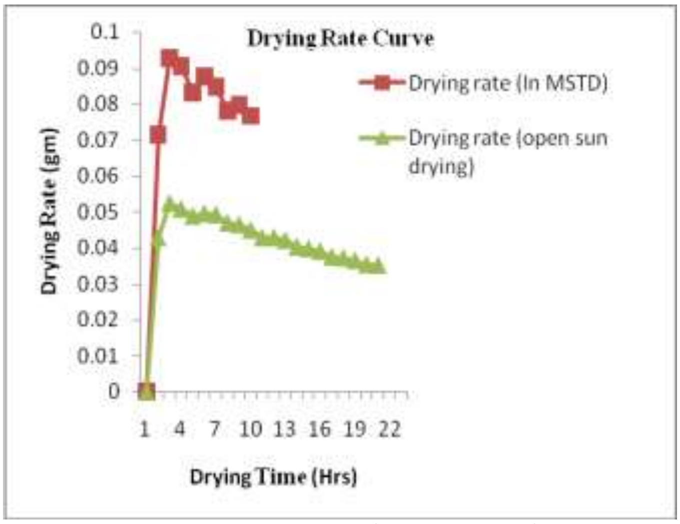

Fig 8: Drying Rate curve at 79% of initial moisture of ginger

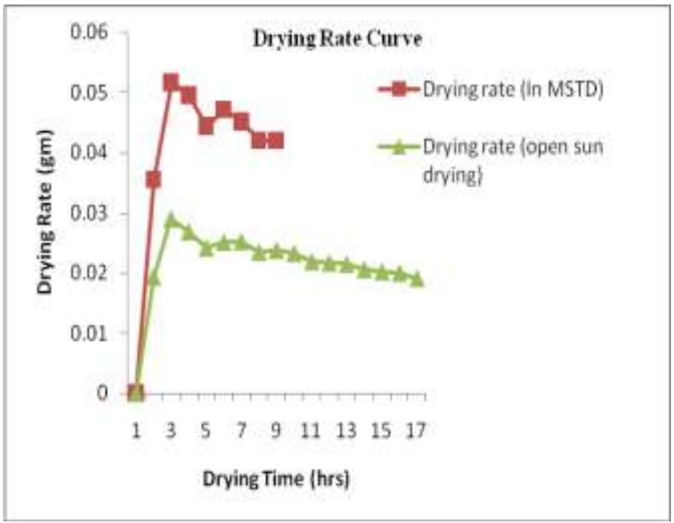

Fig 9: Drying Rate curve at 69% of initial moisture of ginger

a) Moisture ratio

It was observed that the moisture ratio of ginger reduced exponentially as the drying time increased for all the initial moistures of ginger and the drying of ginger was not uniform during entire the drying period. (fig.10, 11, 12)

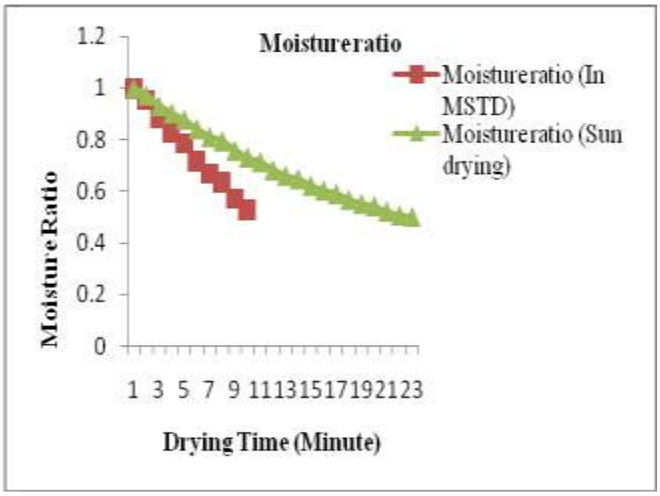

Fig 10: Moisture Ratio curve at 88% of initial moisture of ginger

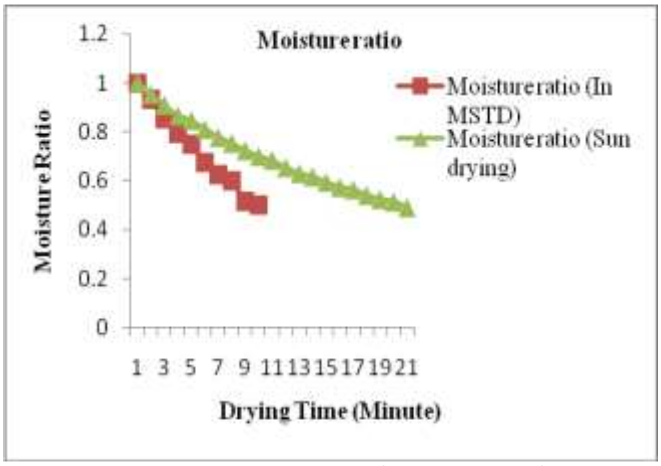

Fig 11: Moisture Ratio curve at 79% of initial moisture of ginger

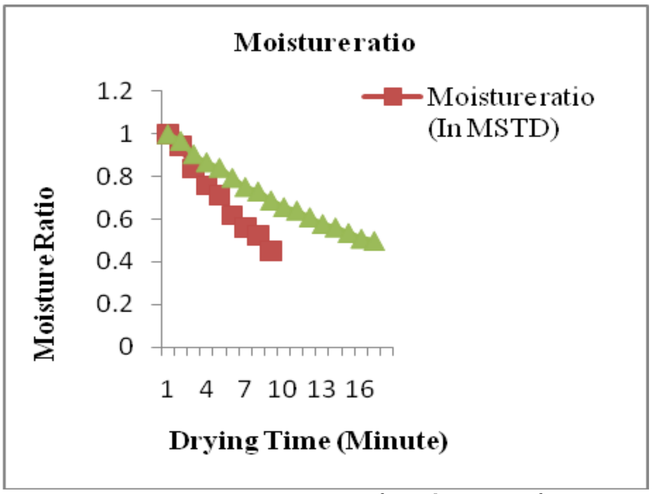

Fig 12: Moisture Ratio curve at 69% of initial moisture of ginger

a) Drying efficiency

Drying efficiency of the mini solar tunnel dryer based on experimental data was calculated by considering the total moisture evaporated associated with heat input and heat gain by the product. It is revealed that the drying efficiency of mini solar tunnel dryer was found to be 27.76 % for drying the ginger up to its 50% moisture.

VIII. CONCLUSIONS

1) The mini solar dryer can be developed for drying the ginger up to its 50% moisture with its drying efficiency as 27.76 %.
2) The mini solar tunnel dryer maintains nearly 10-18 °C temperature above the ambient temperature at full load condition.
3) Time required for drying the ginger in mini solar tunnel dryer is on an average 54.22% less than that of open sun drying.
4) The minimum drying rate in solar tunnel dryer is high as compared to maximum drying rate in open sun drying.

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