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A STUDY ON ELECTRIC DRYER FOR CASH CROPS DRYING AS AN END-USE PROMOTION OF MICRO HYDRO POWER IN NEPAL & IT'S COMPARATIVE ANALYSIS WITH BIOMASS BASED DRYING SYSTEM

K. Gyanwali[1], P. Aryal[2], B. Adhikari[3*]

[1]Department of Automobile and Mechanical Engineering, Thapathali Campus, IOE, TU
[2]Alternative Energy Promotion Center, Ministry of Science and Technology
[3*]Department of Environmental Science and Engineering, Kathmandu University

*Corresponding author's e-mail: bikashadh044@gmail.com
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ABSTRACT
Electric dryers serve farmers as an efficient, environment friendly and proper technology with high performance for quality product drying than other types of conventional dryers. Development and implementation of electric dryers has become the must to bring socio-economic and technological change in rural Nepal. For performance testing and comparison with biomass based drying system, an electric dryer was designed and locally fabricated taking special care in insulation of the system and transported to Baletaksar-5, Gulmi.Performance testing was followed by individual parts testing with the observation of drying pattern.Two different performance testing was carried out with 25 kg of fresh ginger as input which was dried for 4.5 hours. The first test was 30% efficient consuming 40 kWh of electric power with output of 5.4 kg of dried ginger. When leakage of the hot and dry air from dryer was minimized in the second test, dryer was 37% efficient. Later on, electric dryer system was compared with biomass based dryer system which shows that the drying rate of electric dryer is stable and constant also the required temperature in this system can be maintained as per requirement like 60^0C in case of ginger drying. Temperature profile of drying air in biomass based system was unstable and inconsistent with periodical variation like a sinusoidal curve. The efficiency of the electrical dryer was much higher compared to biomass based system whichlies between 10 to 13% depending upon feedstock input for gasifier. Financial analysis was performed which shows an annual revenue of NRs. 2,340,000 with total breakeven sales of the 4379.5 kg dry ginger and corresponding payback period is 0.9357 years.

Keywords: Electric Dryer, Gasifier, Cash crops

1. INTRODUCTION
The majority of people are still dependent on inefficient use of biomass energy sources. Biomass and hydropower are two indigenous energy sources in Nepal. Biomass fuels (primarily fuel-wood) supply almost 86% of total energy demand and are extracted beyond the sustainable supply capability of the forests indicating continuing problem of forest depletion and localized deforestation [1]. When the biomass is directly combusted, we can get usable heat energy only 5-8 % efficiency where as using Electric Dryer we can get this efficiency at about 35 % so the rate of deforestation will be reduced by about 500 % of current rate [4]

Ginger, Coffee, Ginger, Cardamom are very sensible product. They catches odour very easily as well as it requires constant temperature and moisture removal rate while drying. The special necessities for the preparation and processing of those cash crops are not easily available to local farmers at affordable costs. So the farmers are liable to sell their fresh crops to factories. The production of the crops is higher than the capacity of the factories. Also the farmers living far from the factories are not able to bring fresh crops (raw crops for dried product) at right time. So they do not get proper price for their products. The traditional method of drying is very deplorable. Traditional method of drying may destroy the quality and flavor of the product. One of the requirements is the use of proper heat source. Directly combusted biomass is the main source of energy for the farmers which is not efficient and is also a source of pollution. On the other hand, in hilly region where the climatic condition is unsuitable for solar drying, biomass is the most suitable resource for the drying of ginger, cardamom, coffee, garlic and other herbal products. Nepalese ginger is superior in quality that is suitable for the production of dried ginger, or essential oils. But due to the lack of ginger processing facilities within the country, the farmers have to sell their product in fresh or traditionally dried form which lacks quality [2].

This paper presents developing an electrically powered cross flow tray dryer using micro hydro which can produce high quality of dried ginger and other agricultural products such as Ginger, coffee; cardamom etc so that our product can compete in the world market. This technology is highly used technology in industrial countries for producing quality products. This project is also aimed at increasing the end use of micro hydro in Nepal thus promoting the use and development of micro hydro and its sustainability. This will increase the local level industrial development thus improving the economy of the local people and giving them identity in the quality market.
Micro hydro is now a major developing area for rural development and many national and international organizations are involved in micro hydro development. The number of micro hydro is increasing day by due to rising awareness in rural area people. The major threat for micro hydro development is its sustainability since local people are unable to afford the maintenance cost. This can be solved by giving them community based drying and other agricultural processing systems thus increasing agricultural products and thus their economy by selling quality products

2. OBJECTIVES

The main objective of this paper is to design electrical dryer compatible for micro hydro power end use application and test for ginger drying in Nepal with following specific objectives:

- Design and fabricate electric dryer for ginger drying.
- Carry out field testing of electric dryer for ginger drying and evaluate the overall thermal efficiency.
- Compare the performance of electric dryer over traditional biomass based drying system in Nepal.

3. ELECTRIC DRYER CONSTRUCTION

3.1 Electric Ginger Dryer

Drying involves removing water from the food product into the surrounding air. For effective drying, air should be hot, dry and moving. These factors are inter-related and it is important that each factor is considered well [3]:

- Air must be dry, so it can absorb the moisture from the fruits and vegetables
- Heating the air around the product causes it to dry more quickly
- If the air is not moving across the food, it cannot get rid of the water vapor that it has collected. Fan or air blower is needed to keep the air circulating.

When hot dry air comes into contact with the food it absorbs water from the food and is moved away from the food. New dry air takes its place and the process continues until the food has lost all its water [3].

3.2 Constructional details

Drying Cabinet

Drying oven is fabricated out of rigid angle iron frame with best insulating material to reduce heat loss. A control panel is fixed in front of the oven to facilitate the operation.

Air Circulation:

A highly effective recirculation air system is provided. The heated air is re-circulated with fresh air in selected proportions for optimum drying. The system is designed so that the materials at the top & the bottom dry simultaneously. Uniform air circulation, controlled temperature, sturdy construction and large working space are the valuables of the oven which is suitably designed to cover wide temperature range, loading and unloading is faster and simple.

- **Economizer**

  Efficient heat exchanger is used at the outlet of the dryer so that inlet air can be preheated before contacting with the heater. This saves energy input to the dryer. More ever damper is provided to reuse the outlet air so that hot air can be re-circulated in the system decreasing electrical load.

- **Electrical System**

  The electrical system will be designed in 3 phase to improve performance. It reduces voltage loss and has better power distribution. Overload relay, phase safety system control system etc, are used for safety and better product quality.

- **Control System**

  In this model, digital temperature controller is provided with digital timer to facilitate working day and night. It can also be provided with digital humidity sensor and display to produce quality product according to product need.

4. DESIGN AND FABRICATION OF DRYER

The main components on the dryer that are to be considered while designs are

- Mass of fresh ginger per batch of drying
- Heater (capacity and number)
- Blower (capacity)
- Trays (area and number)
- Time period of drying

In electric dryer, the fresh ginger get dried by passing about 60 ^{0}C hot and dry air through the cabinet dryer. The fresh air through the blower is passed through heater where it gets heated to 60^{0}C. For the heat exchange purpose in heat exchanger, it is designed in such a way that the heat from the Gasifier burner is transferred to the fresh air through mild steel baffles.

Time period of drying
Let, time for the dried ginger preparation is 4 hr.

Mass of fresh ginger per batch of drying
Let, mass of fresh ginger (Mfg) = 50 Kg
Assuming that,
Moisture content in fresh ginger = 80%
Moisture content after drying = 10%
Now take 1 kg of fresh ginger
Final moisture content in output ginger = 0.1 Kg
So mass of water to be evaporated= 0.8-0.1=0.7 Kg
Average temperature of ginger before drying = 20^{0}C
During the drying process moisture is heated from 20 to 600C 0c,

Blower (Capacity)
From Q= ML (ASHRAE, 1989)
Where, Q = Amount of heat required (KJ)
M = Amount of water evaporated (kg)
L= latent heat of vaporization of water (2260 kJ/kg)
Q = 0.7× 2600 = 1820 kJ/kg
But for drying onebatch, energy supply should be for for50 kg fresh ginger. Therefore, total energy required in order to dry the ginger
= 50 * 1820 = 91000 kJ
This is the amount of energy that must be supplied by hot air Now let mass of air required = Mair
We have,
Mair × Cp, air × Δθ air = Mwater × Lwater (ASHRAE, 1989)
Where, Cp, air = specific heat capacity of air =1.005 kJ/kg0c
M air = mass of air required for 50 kg fresh ginger (kg)
Δθ air = temperature difference of air between
dryer inlet and outlet (0c)
We assume dryer outlet temperature = 45 0c
M air = Mwater × Lwater)/ (Cp, air × Δθ air) (ASHRAE, 1989)
= 91000/ (1.009 × (60 – 45))
= 6036.5 kg of dry air for 4Hr
So mass flow rate of air M˙air =6036.5 /(4×60×60) = 0.45 kg/sec
Now volumetric flow rate of air V= M’/ρ
= (0.45kg/sec) / (1 kg/m3) [ρ=1 for air]
=0.45 m3/sec
So air blower having volumetric capacity of 0.45 m3/sec

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should be selected that is 0.45 * 3.280843
= 15.8916 cubic feet per second
= 15.8916 * 60 = 953.5 cfm
Therefore blower capacity = 953.5 CFM

Heater (capacity and number)
Heat gained by fresh air Q = m cp Δt (ASHRAE, 1989)
= 91000 kJ
As we have drying period = 4 Hr.
Heater Capacity for ideal drying = 91000 kJ/(4*3600)sec
= 6.32 kW
But for practical purpose, assuming efficiency 35 % only
Total Heater Capacity = 6.32/0.35 = 18 kW

Trays (area and number)
Total No of trays = 10
Tray length = 90 cm
Breadth of tray = 60 cm
Area of tray = 15400 cm2
Total tray area = 15400 * 10 = 154000
Spread of drying = 50 * 1000/154090 = 0.324 gm/cm2

Figure 2 shows the design layout for control panel and figure 3 shows the schematic diagram for dryer.

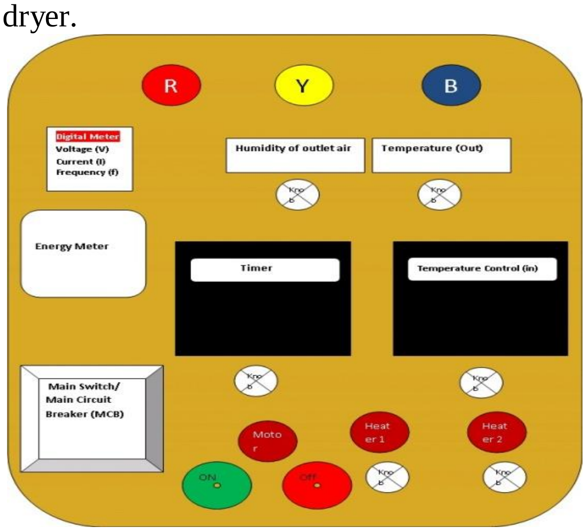

Figure 1: Design layout for control panel

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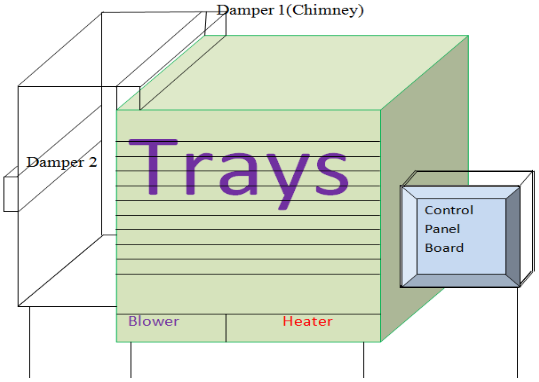

Figure 2: Schematic diagram for complete dryer

The whole drying system as fabricated was transported to the site as mentioned below:
District: Gulmi
VDC: Baletaksar
Ward No: 5
Local Organization: LekBesi Agricultural Multiple Co-operative Ltd.

6. TESTS AND RESULTS

6.1 First test

First test was conducted connecting the four heaters in the system and the temperature of hot air inlet to the dryer and corresponding outlet moist air temperature was noted and plotted in the figure 3 and corresponding moisture removal rate with time is plotted in figure 4 as below:

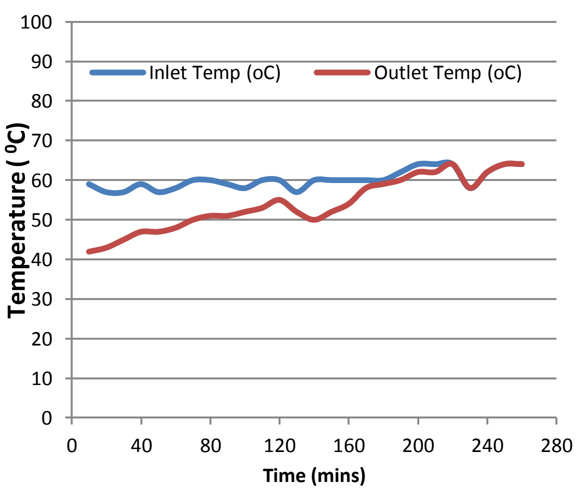

Figure 3: Time vs. temperature of inlet and exit air to the dryer

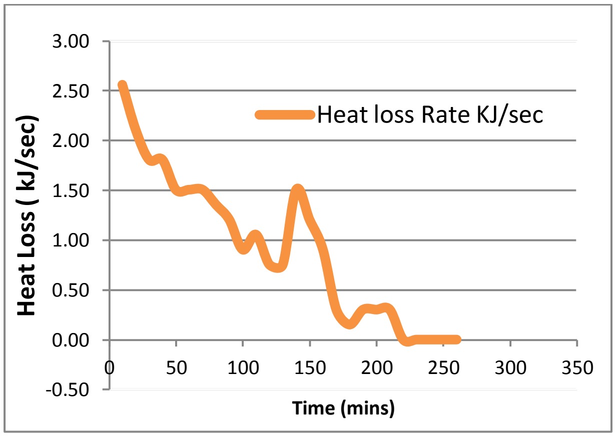

Figure 4: Graph of time vs. moisture removal rate

Calculation: Based on the field testing I

Blower air flow condition:

Air velocity = 2400 feet/min

Area of air flow = 0.347 sq. feet

Flow rate = 833 cfm

Testing Data:

1. Atmospheric temperature (22 ^{o}C)
2. Dryer inlet temperature (60 ^{o}C)
3. Outlet temperature (^{o}C)
4. Time period of drying (4.5 hrs)
5. Heat loss rate (varies with time see table)
6. Damper opening (100% to 0 % +leakages oC)
7. Initial reading on energy meter 107.6 kWh
8. Final reading on energy meter 156.4 kWh
9. Air flow rate 850 cfm
10. Initial weight of ginger pieces put in to dryer pealed 25 kg
11. Final weight of dry product 5.4 kg

Energy consumed = 156.4 - 107.6 = 48.8 kWh

= 48.8 kJ/sec * 3600 sec = 175680 kJ

Efficiency of the dryer (η) =?

As we have,

Efficiency (η) = (moisture removed)/ (Input energy)

Moisture removed= 25 - 5.4 = 19.6 kg

Energy required for moisture removal = {19.6 *4.2*(60-22)} + {19.6*2600kJ/kg}

= 54088.16 kJ

Efficiency (η) = energy required for moisture removal/ energy supplied

=54088.16/175680= 0.3078=30.78%

The efficiency can be improved by reducing losses from gaps. The proper use of moisture controller can assist to maintain damper opening for maximum utilization of air heat energy. Better insulation and good economizer can save heat loss. The proper timing for actual moisture content in dryness basis can help to reduce drying time thus saving energy.

6.2 Second test results

In the second field testing, the recommendation from the field testing first was implemented. That is this time proper care was taken for the controlling of the leakage of the hot dry air that goes from the heater to the drying chamber. Thus the data observed was noted and corresponding calculation was made as shown in Figure 5 below:

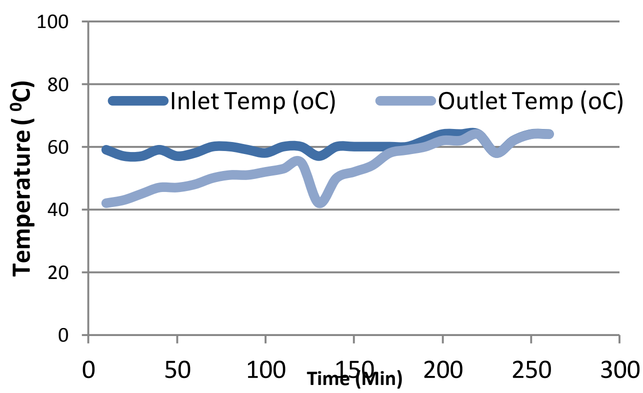

Figure 5: Time vs inlet & outlet Temperature

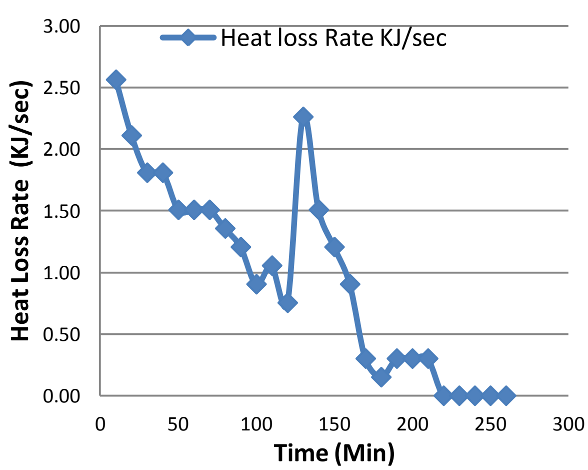

Figure 6: Time vs. moisture removal rate

Calculation: Based on the field testing II

Blower air flow condition:
Air velocity 2400 feet/min
Area of air flow = .347 sq. feet
Flow rate = 833 cfm

Testing Data:
1. Atmospheric temperature (22 oC)
2.Dryer inlet temperature (60 oC)
3.Outlet temperature (oC)
4.Time period of drying (4.3 hrs)
5.Heat loss rate (varies with time see table)
6.Damper opening (100% to 0 % +leakages oC)

7.Initial reading on energy meter 67.3 kWh
8.Final reading on energy meter 107.5 kWh
9.Air flow rate 850 cfm
10.Initial weight of ginger pieces put in to dryer pealed 25 kg
11.Final weight of dry product 5.6 kg

As we have efficiency (η) = $\frac{\text{Output power(Po)}}{\text{Input Power(Pi)}}$
Energy consumed = 107.5-67.3
= 40.2 kWh
= 40.2 kJ/sec * 3600 sec
= 144720 kJ
Efficiency of the dryer (η) =?
As we have, efficiency (η) = (moisture removed)/ (Input energy)
Moisture removed = 25 - 5.6= 19.4 kg
Energy required for moisture removal = {19.4 *4.2*(60-22)} + {19.4*2600kJ/kg}
= 53536.24 kJ
Efficiency (η) = energy required for moisture removal/ energy supplied
=53536.24/144720
= 0.36999 =37%

The efficiency can be still improved by more reducing losses from gaps. The proper use of moisture controller can assist to maintain damper opening for maximum utilization of air heat energy. Better insulation and good economizer can save heat loss. The proper timing for actual moisture content in dryness basis can help to reduce drying time thus saving energy.

6. BIOMASS BASED DRYING SYSTEM

For comparison of electric dryer with the biomass based drying system, the most efficient and effective system based on biomass as a energy source and recently developed and implemented in Nepal, the biomass based Gasifier based cash crops drying system was chosen.

6.1 Tests and results of biomass based gasifier dryer

The testing of Gasifier based dryer was done by using woodchips and charcoal as fuel. The four tests were carried out in the evaluation period. Three tests were carried by using woodchips as fuel whereas final test was carried out by using charcoal as fuel. The system was assembled which includes Gasifier, heat exchanger and chimney. Then the tests were carried out. Temperatures of various locations were noted periodically. The air temperature through the heat exchanger was mainly focused during the tests. [2]

Table 2**:** Details of each test for the system[2]

Test	Fuel	Amount (kg)	Ignition Time	Duration (hrs)
1	Wood chips	19	3:35 P.M.	2.5
2	Wood chips	23	4:50 P.M.	2
3	Charcoal	8	3:50 P.M.	2.25

6.2 Analysis of biomass gasifier based drying system

Analysis of gasifier was done by means of various fuels used and on the basis of output temperature of air obtained from the heat exchanger.

Table 2: Amount of woodchips in [2]

Tests	Weight of fuel (kg)	Combustion period(hrs)	Max.Air temperature (°C)
Test 1	19	2.5	145
Test 2	23	2	111
Average	15.67	1.83	115.33

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The table 2 lists the data obtained from various tests carried out in gasifier using woodchips as fuel. The supply of primary air was varied and various temperature of air was obtained from the heat exchanger. The maximum temperature of air observed during the test was 145°C.

Table 3: Table for charcoal in gasifier [2]

Test	Weight of Fuel used (kg)	Combustion period (hrs)	Max. Air temp (°C)	
Test 1	8	2.25	145 (1 blower used)	110.8(2 blower used)

The table 3 shows the data recorded in gasifier using charcoal as fuel. The maximum temperature of air observed during the test was 110.8°C when both blower of heat exchanger was used at a flow rate of 7.0 m/sec.

Table 4: Table for comparison of various fuels in Gasifier[2]

Fuel	Fuel consumption rate(kg/hr)	Specific gasification rate(kg/m^2-hr)
Woodchips	8.563	30.258
Charcoal	3.56	12.58

From the table above, the fuel consumption rate and specific gasification rate of Gasifier for different fuel can be seen, which can be clearly seen in figure 7:

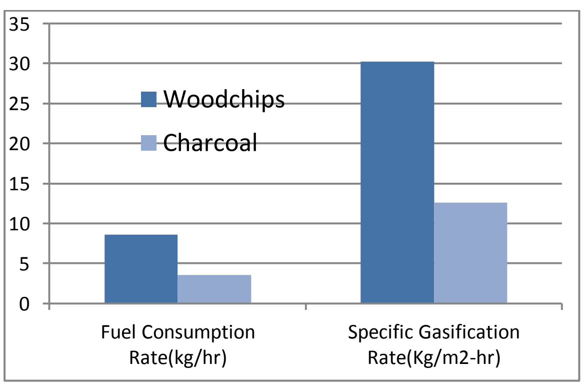

Figure 7: Comparison chart between different fuels for gasifier [2]

From the above table and chart, it is found that the specific gasification rate is highly dependent on the fuel consumption rate. The FCR of Gasifier is higher in case of woodchips than charcoal. Specific gasification rate, thus, is higher in woodchips than in charcoal. Since the gasification rate is lower in charcoal, forced draft is compulsion for increasing the FCR.

6.3 Performance of the biomass based drying system

Specific gasification rate

Specific gasification rate (SGR) was calculated using the weight of dry rice husk gasified for a run, net operating period and the cross sectional area of the reactor using the following relation.

SGR=Weight of the fuel wood used (kg/h^{-1})/Cross sectional area of the reactor (m^2)

- **For woodchips**

Fuel consumption rate = Weight of woodchips (kg)/ Duration (hrs)

= 15.67/1.83= 8.563 kg/ hr

Cross-sectional area of Reactor (A)= πr2

= π x .32=.283 m^2

SGR = 8.563/.283 kg/m^2-hr= 30.258 kg/m^2-hr

- **For charcoal**

Fuel consumption rate = 8/2.25= 3.56 kg/hr

SGR= 3.56/.283= 12.58 kg/m2-hr

6.4 Overall efficiency of the system

The system efficiency (η_{system}) = output power /input power

$$= \frac{\text{Heat energy gained by heating air per second}}{\text{Energy produced by gasifier per second}}$$

$$= \frac{(\text{Mair} \times \text{Cp,air} \times \Delta\theta\text{air})}{\text{Mfw/coal} \times \text{Ccal}} \, [3]$$

Where,

Mair = mass flow rate of drying air

Cp,air = specific heat capacity of drying air

Δθair = temperature difference between fresh air inlet and heated air outlet

Mfw/coal = fuel wood / charcoal consumption rate

Ccal = calorific value

Testing with fuel wood

While the system was tested with fuel wood as a fuel

$$\eta\text{system} = \frac{(\text{Mair} \times \text{Cp,air} \times \Delta\theta\text{air})}{(\text{Mfw} \times \text{Ccal})} [3]$$

$$= \frac{(0.08 \times 1.009 \times 90)}{0.00555 \times 13000} \times 100\% \qquad = 10.16\ \%$$

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Testing with charcoal

While the system was tested with charcoal as a fuel

$$\eta system = \frac{(Mair \times Cp, air \times \Delta\theta air)}{(Mcoal \times Ccal)}$$

$$= \frac{(0.08 \times 1.009 \times 90)}{(0.00194 \times 28000)} \times 100\%$$

= 13.37 %

7. COMPARISON OF BIOMASS BASED AND ELECTRIC DRYING SYSTEM

After field testing of the electric ginger dryer and its performance evaluation, the desk study has been carried out in order to compare it with the biomass based gasifier dryer for tea drying. The data and graph for gasifier based drying system is taken from the report submitted by department of Mechanical Engineering, Institute of Engineering Pulchowk Campus to AEPC/ESAP in 2009.

7.1 Comparison of drying air temperature profile

The following graph shows the comparative drying air temperature Vs time for electric and biomass based system respectively for first and second test:

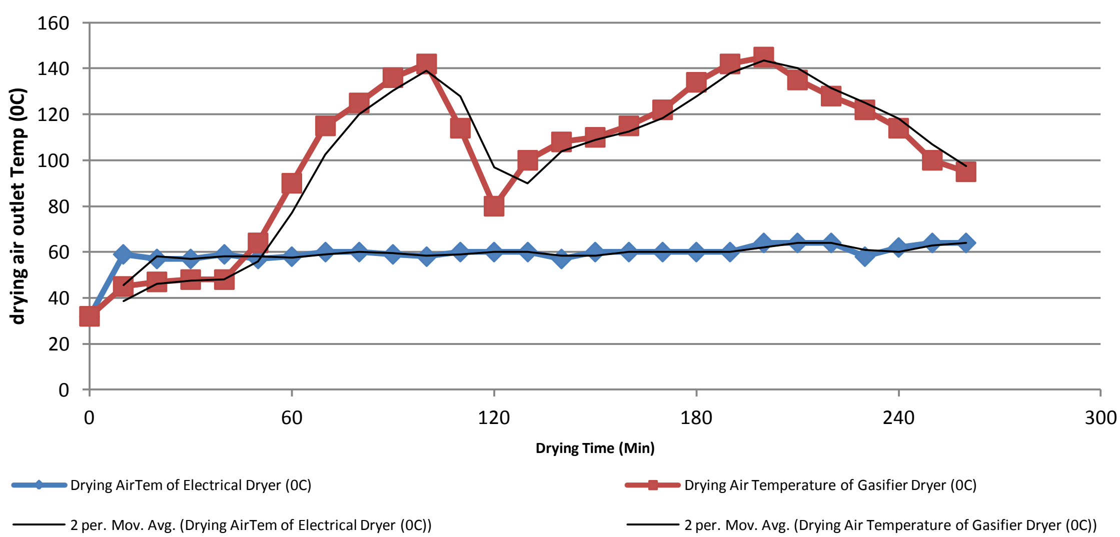

Figure 8: Comparison of drying air temperature for electric and biomass based dryer from first test

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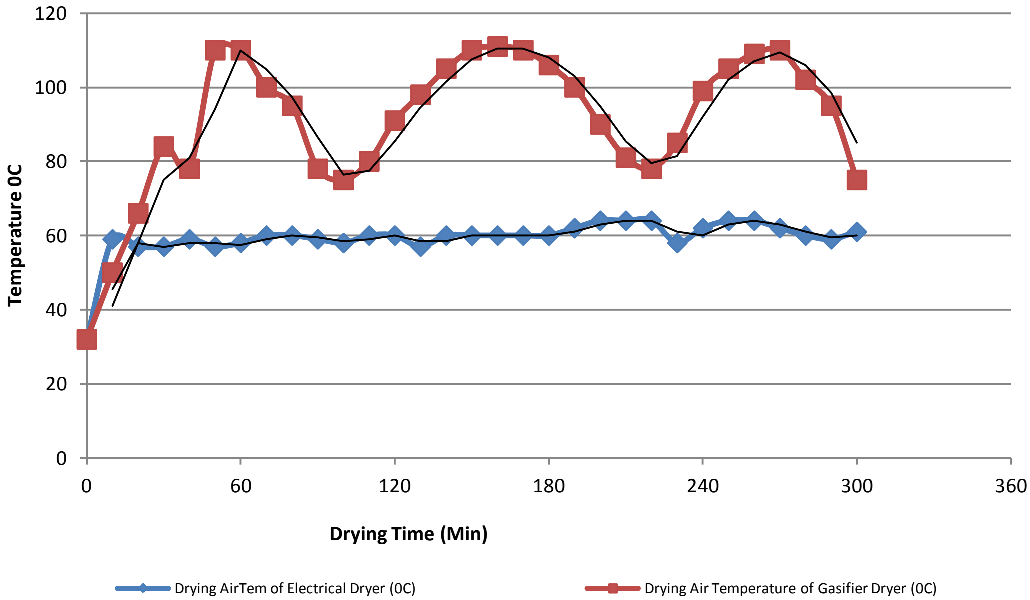

Figure 9: Comparison of drying air temperature for electric and biomass based dryer from second test

Above two graph shows that the temperature profile of the drying air from electrical dryer is almost steady and is maintained at around 60 0C which is the required standard drying temperature for the ginger drying. The temperature profile of the drying air for biomass based dryer is like sine curve because in that case biomass based system, burning in case of direct combustion system or pyrolysis in case of gasifier based system takes some time after feeding new lot of biomass feed. Not only some time elapses meanwhile a portion of the heat energy is lost while drying that new lot of biomass before combustion or pyrolysis so temperature profile some times rises and some times it falls periodically. With this reason it is difficult to maintain any constant temperature for the drying purpose of any cash crops or any other input using biomass based dryer. Since different cash crops needs different drying temperature, electric dryer is best suitable for that case because we can control and maintain the drying air temperature either using automatic comtrol system or manually simply by turning on/off botton placed on the control board.

7.2 Comparison in terms of efficiency

From the above calculation of efficiencies in case of electrical as well as biomass based dryer, the overall system efficiency for the electric dryer was found to be 30% from first test and 37 % from second test. Similarly that for biomass based system was found to be 10 % for wood chips test and 13% for charcoal test. The efficiency comparision chart is as shown below:

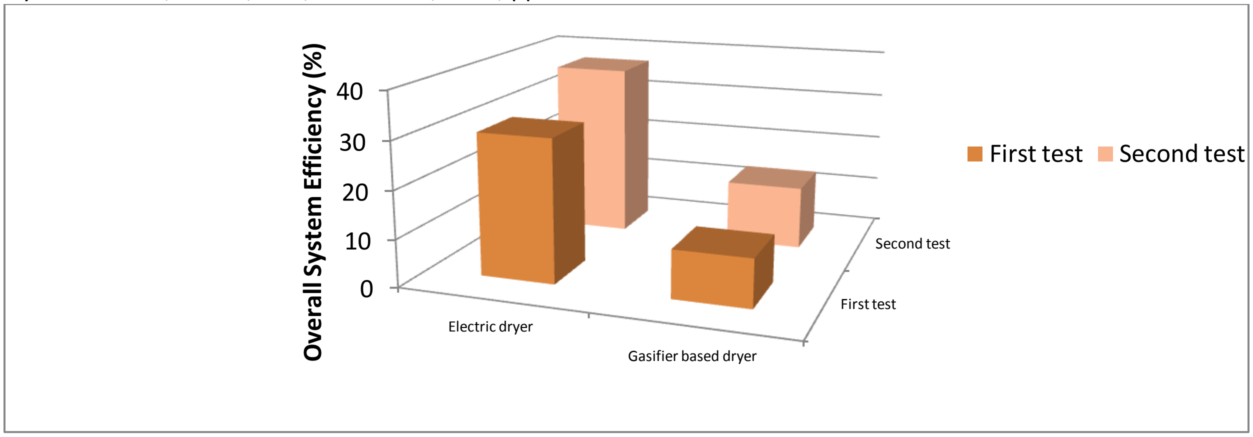

Figure 10: Efficiency comparision between electric and bimass based gasifier system

From the above efficiency chart, it is clear that in both tests, the overall efficiency of the electric dryer is higher (more than 3 times) than that of the biomass based gasifier dryer. Hence we can conclude that more than 200% of the energy consumption can be reduced by using electric dryer for the cash crops and any other product drying purpose.

8. CONCLUSION AND RECOMMENDATIONS

The performance of the designed electrical drying system for cash crops drying at community level has demonstrated technically feasible. From the field testing of the system, it was found that 25 Kg of fresh ginger pieces was dried within 4.5 hours and the final product weight was around 5.4 Kg there by consuming around 40 kWh of electricity. The efficiency of the electrical dryer was found to be 30% at first and in second test it was 37% because at second test proper care was taken for leakage of the hot and dry air from the dryer. So in second it was almost leakage proof. Comparative analysis of the electric dryer with that of biomass based dryer shows that the drying rate of electric dryer is stable and constant also the required temperature in this system can be maintained as per requirement like 60 ^{0}C in case of ginger drying. In case of biomass based system temperature profile of drying air is not stable and constant rather it varies periodically like a sinusoidal curve. Efficiency of the electrical dryer is 37% while that for biomass based system lies between 10 % to 13% depending upon feedstock input for gasifier.

The testing of the full capacity of the dryer with as much variety of cash crops as possible should be done. These are some of the recommendations necessary for the enhancement of this technology which can play important role in upliftment of socio economic status of rural society.

- Local people in organized group could push for a strong position in market negotiation.
- The use of new technologies in production & processing of agricultural products should be encouraged by the government as a support to renewable energy implementation.
- Subsidy plan should be formulated by the government for cash crops industries installing this system for drying of cash crops in order to encourage the local farmers.
- Other types of dryer should also be studied for the selection of proper technologies.
- The design parameters should be selected based on actual field condition.
- Proper insulation should be done to avoid losses.

- Only four testing has been carried out which is not enough to evaluate the performance of the system. More testing should be carried out.
- Different fuel like briquettes, agriculture waste should also be tested in the system.
- The complete drying pattern and chemistry analysis should be done.

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