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Recommendation proposal

Design, development and evaluation of biomass based composite unit for water heating and drying

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PART –I GENERAL INFORMATION

1.	**Project Code**	
2	**Project Title**	Design, development and evaluation of biomass based composite unit for water heating and drying.
3	**Name of Department Where the project was undertaken**	
	a) Name of Department	Department of Electrical and Other Energy Sources Faculty of Agricultural Engineering & Technology Dr.B.S.Konkan Krishi vidyapeeth, Dapoli
	b) Location of Project	Department of Electrical and Other Energy Sources Faculty of Agricultural Engineering& Technology Dr.B.S.Konkan Krishi vidyapeeth, Dapoli
4	**Name of Scientist**	Dr. A.G. Mohod, Associate Professor
5	**Name of Co-scientists**	Dr. Y.P. Khandetod , Professor and Head Er. H.Y. Shrirame, Sr. Research Assistant
	Supporting Department	Deptt. of Farm Machinery and Power, CAET, Dapoli
6	**Objectives**	1. Design and Development of biomass based composite unit for water heating and drying. 2. Techno-economic evaluation of biomass based composite unit for water heating and drying.
7	**Year of start**	2012-13

PART-II TECHNICAL INFORMATION

8. Background of Project:

In the context of growing of the various renewable energy sources available, biomass has a good potential in India in view of availability of agricultural residues in abundance and the availability of vast wastelands for carrying out plantation of trees. Almost every rural household, hotels, community cooking places, hospitals and many small-scale industries have various thermal applications such as hot water generation, low-pressure steam production and hot air generation for drying etc where direct burning of fuel wood is employed to produce the heat. The direct burning of fuel wood is not an energy efficient process and large amount of heat is wasted in to the atmosphere in the form of hot flue gases. The option available for heat generation via biomass combustion is complex, capital intensive and inefficient at low output levels. Hence, there is need for introduction of suitable technologies to harness the wood energy efficiently. The proper reutilization of hot flue gases liberated from the biomass combustor for the drying application will not only increase the thermal efficiency but also liberate the flue gases at lower temperature in the atmosphere.

9. Technical Details of Project:

Biomass based water-heating system:

The commercially available biomass based water heater suitable for the domestic utilization was selected for the evaluation. The biomass based water heater was procured and selected as a base unit for the design and development of composite unit for water heating and drying operation suitable for the domestic application. The technical specifications of biomass based water heater are summarized in Table 1.

Table1. Technical specifications of biomass based water heater

Sr.No.	Particulars	Specifications
1.	Type of heat exchanger	Shell and shell type
2.	Type of fuel	Wood fuel
3.	Maximum temperature limit,^{o}C	60
4.	Water holding capacity, lit.	27
5.	Diameter of boiler. Cm	25
6.	Height of boiler, cm	61

7.	Size of firing chamber	16cm x 15 cm (dia.)
8	Total height of water heater, cm	89
9.	Diameter of flue gas exit chimney, cm	09
10	Surface area of boiler, m^2	0.03

Fig.1 Pictorial view of biomass based water heater

Characterization of biomass selected for evaluation:

The fuel selected for evaluation of biomass heater viz; Mango*(Magnifera Indica.)* and babul (*acacia auriculformis*) was characterized in term of proximate analysis and calorific value. The proximate analysis of biomass was carried out using the analytical method ASTM-D- 3173 to 3175. The higher heating value of solid fuels was determined using of bomb calorimeter (ASTME-711). The proximate analysis and higher heating value of the selected fuel was determined for three samples. The result obtained from the characterization of the fuel selected for the testing is depicted in Table 2.

Table 2. Characterization of biomass

Sr. No.	Property	Method	Biomass	
			Mango	Babul
1	Moisture content, %	ASTM D-3173	12.2	7.05
2	Volatile matter, %	ASTM D-3174	66.9	69.65
3	Ash content, %	ASTM D-3175	2.06	2.03
4	Fixed carbon, %	By difference	18.84	21.26
5	Higher heating value, kcal kg^{-1}	Bomb calorimeter ASTME-711	2956	3040

Performance evaluation of biomass based water heater

The thermal evaluation of biomass water heater was carried out to estimate the thermal efficiency and output of water heater up to the temperature of 60 ^oC. The performance evaluation of water heater was carried out by conducting the three test runs of water heating using the selected fuel. The result obtained from the evaluation of the water heating system is summarized in Table 3. The overall efficiency of the water heating system was estimated by using direct method as input heat from fuel and the output of hot water from the heating system.

Table 3. Evaluation parameters of water heating system

S.N.	Particulars	Biomass	
		Mango	**Babul**
1	Quantity of water heated, lit	27	**27**
2	Initial temperature of water, ^oC	28	**28.5**
3	Final temperature of water, ^oC	61	**60.5**
4	Operating time, min.	35	**35**
5	Total fuel consumed, kg	1.15	**1.1**
6	Fuel consumption rate, kg/h	1.97	**1.89**
8	Thermal efficiency, %	25.4	**25.8**
9	Avg. flue gas temperature, ^oC	310	**330**
10	Avg. surface temperature, ^oC	52	**56**
11	Mass of ash. kg	0.06	**0.05**

Design of flue gas based drying system:

The design of flue gas based drying system was carried out by considering the proximate analysis of wood fuel babul (*acacia auriculformis*) and the performance of biomass water heater using babul (*acacia auriculformis*). The heat available in the flue gas and mass flow rate of hot flue gases were estimated as

Heat available in flue gas = 801.86 Kcal/kg of fuel x 1.89= 1515.5 kcal/h

Volume of flue gas = 17.07 m^3/kg of fuel x 1.89= 32.26 m^3/hs

Mass of flue gas = 10.84 kg/kg of fuel × 1.89 = 20.50 kg/h

Design of flue gas based dryer for food product

The design of flue gas based drying chamber was carried out by considering the shell and shell type heat exchanger with overall efficiency of 75 %. The initial design conditions and assumptions made for design of drying chamber is summarized in Table 4.

Table 4. Design Consideration and assumptions

S.N.	Parameters		Range	Assumption
1.	Location CAET, Dapoli, Maharashtra	Φ L		$17^0 45'$ N Latitude, $73^0 26'$E Longitude
2.	Product to be dried			Food-Vegetable etc
3.	Bulk density of material	ρ_{ck}	300-800 kg/m^3	600 kg/m^3
4.	Specific heat of product	Cp_{ck}	0.6-0.9 Kcal/Kg^0C	0.8 Kcal/Kg^0C
5	Initial moisture content	M_i	65-75 % (w. b.)	70 % (w. b.)
6	Final moisture content	M_f	12-17 % (w. b.)	15 % (w. b.)
7	Drying duration per batch	t_d		3 hr
8	Operating temperature	T	50- 70°C	60°C
9	Ambient air temperature	T_{amb}	20-30°C	25°C
10.	Ambient Relative humidity	Rh_{amb}	70-90 %	70 %
11	Latent heat of vaporization	λ		587 Kcal/kg
12	Moisture pickup efficiency	η		75 % (Assumed)
13	Heat available in flue gas	Q	75% HE efficiency	1000 Kcal/h

Drying with heated air using Psychometric chart (N.K. Bansal & M. Klemann, R.E.S. & conversion tech. 442:445)

	Properties	**Ambient air**	**Drying air**	**Exit air**
I.	Temperature	25 °C	60 °C	35 °C
II.	Relative humidity	70 %	11 %	70 %
III.	Sp.Volume, m3/kg	0.865	0.963	0.905
IV.	Humidity ratio,	0.014	0.014	0.0245 kg/kg of air
V.	Enthalpy, kcal/kg	14.5 (60.71 KJ/kg)	23.7 (99.20 KJ/kg)	23.7 (99.7 KJ/Kg)

1. The mass of water to be removed during drying, M_w kg

$$M_w = \frac{m_i - m_f}{100 - m_f} \times W$$

$$M_w = \frac{(70-15)}{(100-15)} \times 1 = 0.6Kg \text{ /kg of product}$$

Final weight of product at 15 % moisture = DM x 100/100-15 = 0.353 Kg

2. Total energy required Q kcal

$$Q = (W.C_{ck}.\Delta T) + (M_w.C_p.\Delta T) + (M_w.\lambda)$$

$Q = 373Kcal/kg$ of product

Where, W = Weight of product, kg

C_p = Specific heat of water, kcal /kg °C

C_{ck} = Specific heat of product, kcal /kg °C

T_d = Drying temperature, °C

T_a = Ambient temperature, °C

M_w = Mass of water to be removed , kg

λ = Latent heat of vaporization, kcal/kg

3. Estimated quantity of product to be dried:

Considering heat available from flue gas as 1000 kcal/ hr and assuming moisture pickup efficiency as 75 %,

$$Q_p = \frac{1000}{373} \times 0.75 = 2 \ kg/hr$$

Considering the operation of water heater continuously for 3 hr in a day

Total drying capacity = 2× 3 = 6 kg/hr of product

4. Volumetric flow rate of air, Q_a, M^3 / hr.

$$Q_a = \frac{m_w}{\rho a(Hf - Hi)}$$

$$Q_a = \frac{0.6}{1.252(0.0245 - 0.014)} = 45.64\ m3/hr \text{ .kg of product}$$

Total volume of air flow rate = 45.64 x 2 = 92 m^3/h

Where, m_w = Mass of water removed per hour, kg/hr
H_2= Humidity ratio of dryer exhaust air, kg of water per kg of dry air
H_1= Humidity ratio of ambient air, kg of water per kg of dry air
ρ a = Density of air, 1.252 Kg/m^3

4. Drying area:

Considering No. of tray = 2 and 3 kg product of each tray

Size of drying tray L = 0.5 m, W= 0.5 m

Based on the design data, the drying chamber was fabricated and evaluated for thermal performance.

Development of biomass based composite water heater and dryer

The development of biomass based composite water heater and dryer was carried out based on performance of biomass based water heater system. The quantity of fuel burnt in operating time, type of fuel, efficiency of water heater, flue gas temperature and quantity of flue gas were considered while developing the biomass based composite water heater and dryer. The biomass based composite unit was fabricated using locally available material. The flue gas based drying unit consists of following components,

Drying chamber:

Drying chamber of the composite unit was made up of GI sheet (16 SWG). It consist of outer body and inner body with the dimensions of 550 mm × 550 mm × 350 mm and 500 mm × 500 mm × 300 mm, respectively. The inner passage of 25 mm from each side was used as passage for hot flue gases.

Heat exchanger:

The flue gases from the water heater were passed through the 1200 mm long square GI duct (100 mm × 100 mm) made up of GI material (16 SWG) to the flue gas passage of drying chamber. A 1200 mm long circular MS pipe (50 mm Ø) was placed inside the duct to absorb the heat from flue gases and passed into the drying chamber.

Outlet chimneys:

The flue gas exit chimney (25 mm Ø) and moist air exit chimney (25 mm Ø) installed to drying chamber to expel the flue gases and moist air respectively.

Drying tray:

Two drying trays (500mm × 500mm) made up of MS wire mesh, were placed 100 mm apart inside the drying chamber.

Opening door:

An opening door (300mm × 250mm) was provided to the drying chamber with the handle.

Stand:

Stand of the composite unit was made up of MS angle (Height- 1100 mm) to support the drying chamber.

Technical specifications of dryer are depicted in Table 5. The schematic view of composite unit of water heater and dryer is shown in Fig. 1. The pictorial view of composite unit is shown in Plate 1.

Table 5 Technical specifications of flue gas based dryer

Sr. No.	Particulars	Specifications, mm	Material
1.	Drying chamber Inner box Outer box	 500×500×300 550×550×350	GI sheet 18 SWG 16 SWG
2.	Heat exchanger Square duct Circular pipe	 1200 × 100 × 100 50 mm Ø	 GI 16 SWG MS
3.	Outlet chimneys Flue gas exit Moist air exit	 25 mm Ø 25 mm Ø	 GI pipe
4.	Drying trays (2 Nos.)	500×500	MS wire mesh
5.	Opening door	300 × 250	GI 16 SWG
6.	Stand	Height- 1100	MS angle

Cost of composite unit:

The cost of biomass water heater was ₹6000 /- and the fabrication cost of flue gas based dryer was computed as ₹ 9500 /- includes labor and installation charges. The overall cost of composite unit was ₹ 15500 /-.

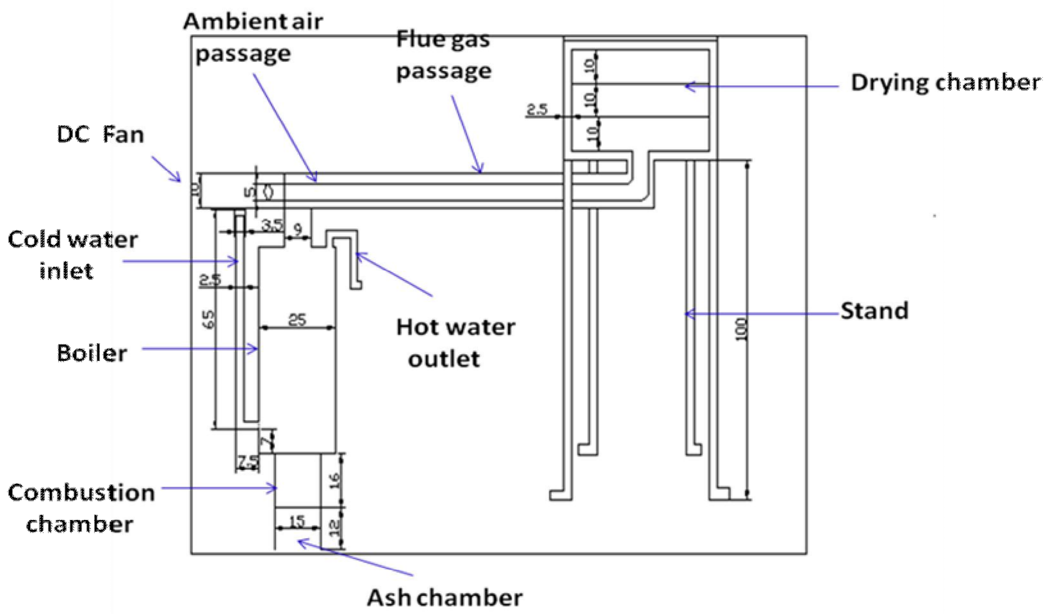


Fig.1. Schematic view of composite unit of water heater and dryer

Plate 1. The pictorial view of composite unit

Evaluation of biomass based composite unit for water heater and dryer

The performance evaluation of newly developed flue gas based dryer coupled with the biomass based water heater was carried out by conducting test runs using subabul (*Acacia auriculiformis*) as a fuel. The thermal performance of composite unit was carried out in terms of no load test (Without loading the product) to record the different parameters of water heater viz; quantity of water heated, temperature rise, fuel consumption rate, operating time etc along with the operating parameter of flue gas based dryer as follows (Fig.2)

i. Inlet flue gas temperature, T_{fg1}, ºC
ii. Temperature of exit flue gas, T_{fg2}, ºC
iii. Ambient air temperature, T_{amb}, ºC
iv. Inlet air temperature, T_i, ºC
v. Temperature on 1st tray, T_{t1}, ºC
vi. Temperature on 2nd tray, T_{t2}, ºC
vii. Exit air temperature, T_{ex}, ºC

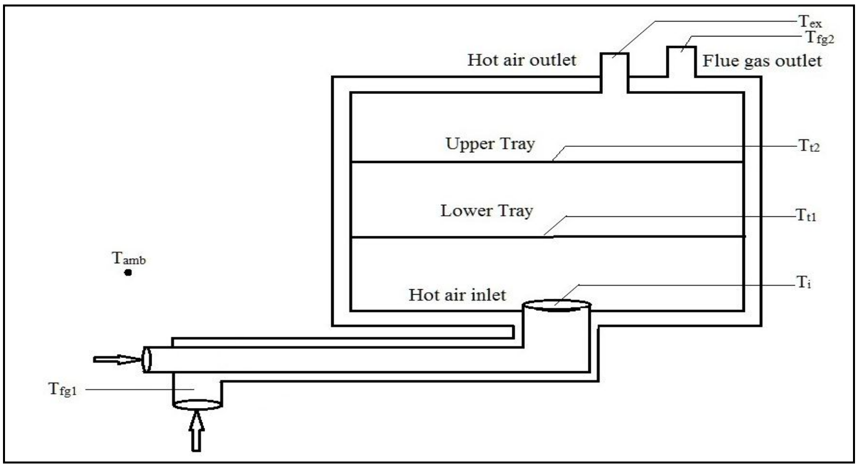


Fig.2. Thermal profile of flue gas based dryer

The performance evaluation of composite unit on no load condition was carried out by conducting the test runs with following operating condition

1. **Stagnation temperature**

The inlet and outlet of air was closed throughout the test runs.

2. **Partial air flow (Natural convection)**

The inlet and outlet of air supply were partially opened (50 %) during the test and air was circulated by natural convection.

3. **Free air supply (Natural convection)**

The inlet and outlet of air supply were fully opened and air was circulated by natural convection.

4. **Forced circulation mode**

The inlet and outlet of air supply was fully opened and air circulation was carried out using D.C. fan provided at one end of air supply system (0.19 m^3/min).

Thermal analysis of composite unit at No load

Thermal analysis of the composite unit was estimated in terms of water heating efficiency, heat gain efficiency and overall efficiency as,

Thermal efficiency of boiler

$$\eta_{boiler} = \frac{m \times C_{pw} \times \Delta T}{mf \times HCV}$$

Heat gain efficiency

$$\eta_{dryer} = \frac{(m_a \times C_{pa} \times \Delta T1)}{(m_{fg} \times C_{pfg} \times \Delta T2)}$$

Overall efficiency

$$\eta_{overall} = \frac{(m \times C_{pw} \times \Delta T) + (m_a \times C_{pa} \times \Delta T1)}{m_f \times HCV}$$

Thermal profile of composite unit

i. **Stagnation temperature**

It was observed that, the average flue gas temperature (T_{fg1}) at outlet of water heater was found to be 207.08 ºC. The average flue gas temperature (T_{fg2}) at outlet of flue gas at exit chimney was found to be 48.80 ºC.

It was observed that the average inlet air temperature (T_i) was found to be 60.77 ºC. The average temperature over the 1st tray (T_{t1}) was fond to be 47.31 ºC. The average temperature over 2nd tray (T_{t2}) was fond to be 49.06 ºC. The average exit air temperature (T_{ex}) was fond to be 41.79 ºC. The suitable air temperature (above 45 ºC) for drying of agriculture products was achieved after 25 minutes of operation and remains constant throughout the test run.

ii. Partial air flow test

It was observed that, the average flue gas temperature (T_{fg1}) at outlet of water heater was found to be 222.36 ºC. The average flue gas temperature (T_{fg2}) at outlet of flue gas at exit chimney was found to be 50.90 ºC. The mass of flue gas liberated from the water heater was estimated to be 40.97 kg. The average temperature absorb in the drying system was about 171.46 ºC, which was used to generate the hot air for drying application.

It was observed that the average inlet air temperature (T_i) was found to be 62.82 ºC. The average temperature over the 1st tray (T_{t1}) was found to be 50.40 ºC. The average temperature over 2nd tray (T_{t2}) was found to be 50.48 ºC. The average exit air temperature (T_{ex}) was fond to be 47.41 ºC. The suitable air temperature (above 45 ºC) for drying of agriculture products was achieved after 20 minutes of operation and remains constant throughout the test run.

iii. Free air supply test

It was observed that, the average flue gas temperature (T_{fg1}) at outlet of water heater was found to be 234.62 ºC. The average flue gas temperature (T_{fg2}) at outlet of flue gas at exit chimney was found to be 49.96 ºC. The mass of flue gas liberated from the water heater was estimated to be 40.97 kg. The average temperature absorb in the drying system was about 184.66 ºC, which was used to generate the hot air for drying application.

It was observed that the average inlet air temperature (T_i) was fond to be 70.32 ºC. The average temperature over the 1st tray (T_{t1}) was found to be 49.69 ºC. The average temperature over 2nd tray (T_{t2}) was found to be 51.69 ºC. The average exit air temperature (T_{ex}) was fond to be 46.52 ºC. The suitable air temperature (above 45 ºC) for drying of agriculture products was achieved after 20 minutes of operation and remains constant throughout the test run.

iv. Forced circulation test

It was observed that, the average flue gas temperature (T_{fg1}) at outlet of water heater was found to be 194.66 ºC. The average flue gas temperature (T_{fg2}) at outlet of flue gas at exit chimney was found to be 48.98 ºC. The mass of flue gas liberated from the water heater was estimated to be 40.97 kg.

It was observed that the average inlet air temperature (T_i) was found to be 74.28 ºC. The average temperature over the 1st tray (T_{t1}) was found to be 54.13 ºC. The average temperature over 2nd tray (T_{t2}) was found to be 52.87 ºC. The average exit air temperature (T_{ex}) was fond to be 48.52 ºC. The suitable air temperature (above 45 ºC) for drying of agriculture products was achieved after 10 minutes of operation and remains constant throughout the test run. The variations of flue gas and air temperature at different conditions of airflow are shown in Fig. 3-10.

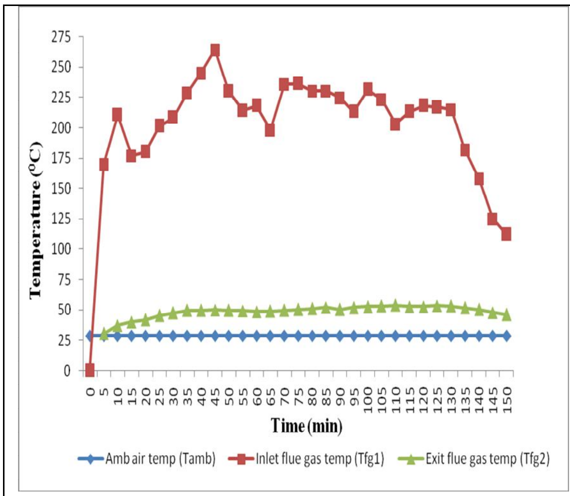


Fig. 3. Variation of flue gas temperature (Stagnation temperature)

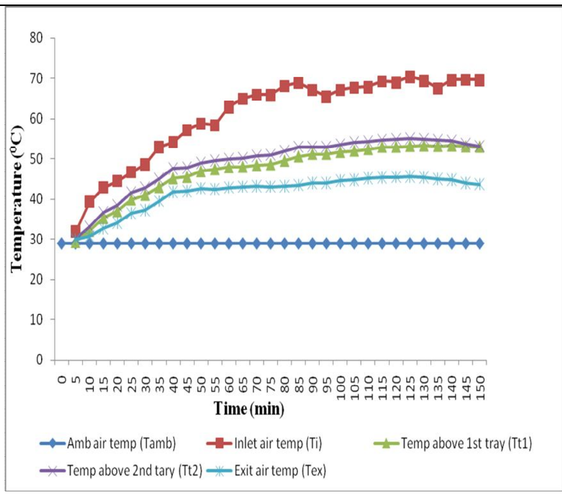


Fig.4.Variation of air temperature (Stagnation temperature)

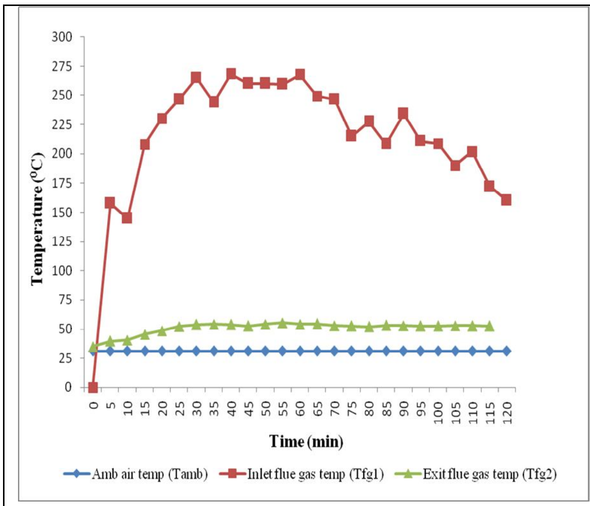


Fig.5. Variation of flue gas temperature (Partial air flow)

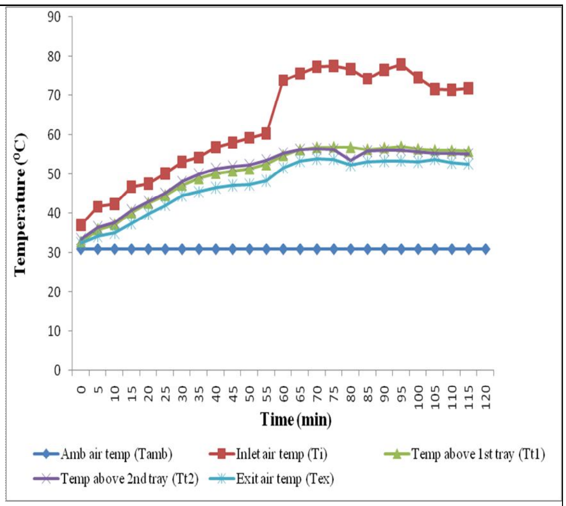


Fig.6. Variation of air temperature (Partial air flow)

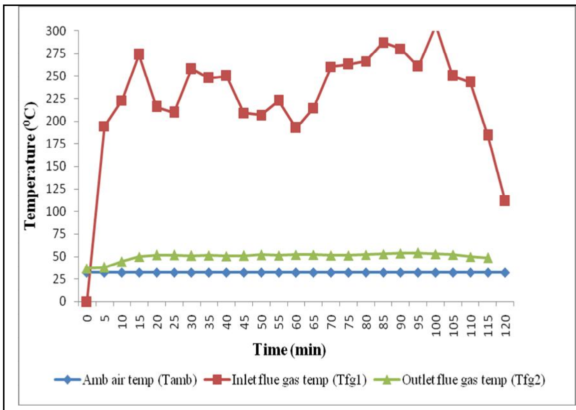


Fig.7 Variation of flue gas temperature (Free air supply)

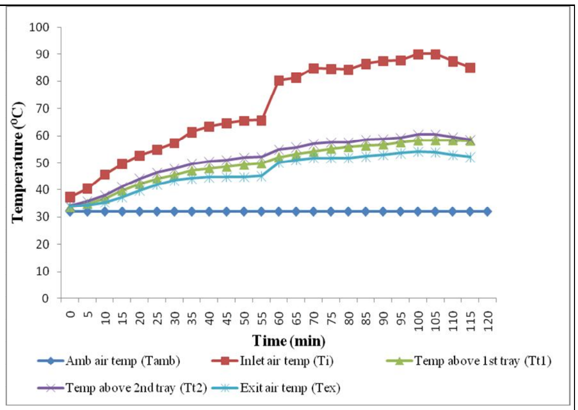


Fig.8 Variation of air temperature (Free air supply)

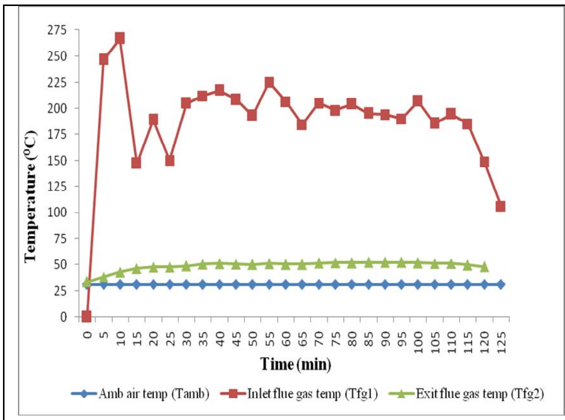


Fig.9 Variation of flue gas temperature (Force circulation)

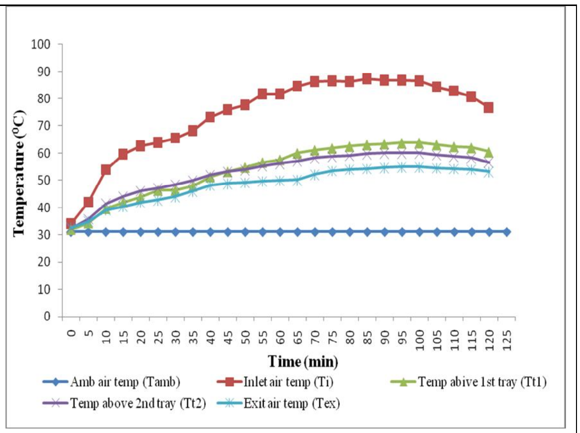


Fig.10 Variation of air temperature (Force circulation)

Effect of air supply on performance of composite unit

Effect of air supply on performance of composite unit was estimated by comparison within 4 combinations of test at no load condition as shown in Table 6.

Table 6. Testing parameters of composite unit

Test / Parameters	Stagnation temperature	Partial air flow test	Free air supply test	Forced circulation
Air flow rate, Q_a , kg/hr	4.83	6.49	7.09	8.18
Boiler efficiency, %	32.1	31.57	31.95	31.01
Heat in air, kcal	92.06	99.68	118.37	168.83
Heat in flue gas, kcal	1863.16	1620.97	1743.49	1375.94
Heat gain efficiency, %	4.94	6.15	6.78	12.27
Overall efficiency, %	32.76	32.44	32.98	32.48

It was observed that, the mass of air at stagnation temperature test, partial air flow test, free air supply test and forced circulation test was found to be 4.83 kg/hr, 6.49 kg/hr, 7.09 kg/hr and 8.18 kg/hr, respectively. Boiler efficiency was found to be 32.1 %, 31.57 %, 31.95 % and 31.01 % at stagnation temperature test, partial air flow test, free air supply test and forced circulation test respectively. Heat in air was found to be 92.06 kcal, 99.68 kcal, 118.37 kcal and 168.83 kcal at stagnation temperature test, partial air flow test, free air supply test and forced circulation test respectively.

It was revealed that, heat in air was increased with the increase in mass flow of air inside the drying chamber. The heat gain efficiency of flue gas based dryer was found to be maximum (12.27 %) at forced circulation tests. The overall efficiency of composite unit was found to be 32.76 %, 32.44 %, 32.98 % and 32.48 % at stagnation temperature test, partial air flow test, free air supply test and forced circulation test, respectively.

Load testing of composite unit

Load test was carried out to dry the onion slices and nutmegs by operating the unit on forced circulation mode (0.19 m^3/min.)

Thermal profile at load condition

The variation of flue gas temperature and air temperature at different location as described during no load testing was recorded from starting of the test to the end of the test of composite unit. The variation of flue gas temperature with respect to operating time is shown in Fig.11. It was observed that, the average flue gas temperature (T_{fg1}) at outlet of water heater was found to be 199.75 ºC. The average flue gas temperature (T_{fg2}) at outlet of flue gas at exit chimney was found to be 45.05 ºC. The average temperature absorb in the drying system was about 154.7 ºC, which was used to generate the hot air for drying application. The exit flue gas temperature was observed to be constant due to proper flue gas channeling and retention of heat in drying system.

The temperature of the air was recorded at different locations of the composite unit during load. The air temperature at inlet of drying chamber (T_i), temperature above the 1^{st} tray (T_{t1}), temperature above the 2^{nd} tray (T_{t2}) and temperature at exit chimney (T_{ex}) was measured and variation is shown in Fig 4.10. It was observed that, the average inlet air temperature (T_i) was found to be 76.32 ºC. The average temperature over the 1^{st}

tray (T_{t1}) was fond to be 56.66 ºC. The average temperature over 2nd tray (T_{t2}) was fond to be 56.51 ºC. The average exit air temperature (T_{ex}) was fond to be 47.17 ºC.

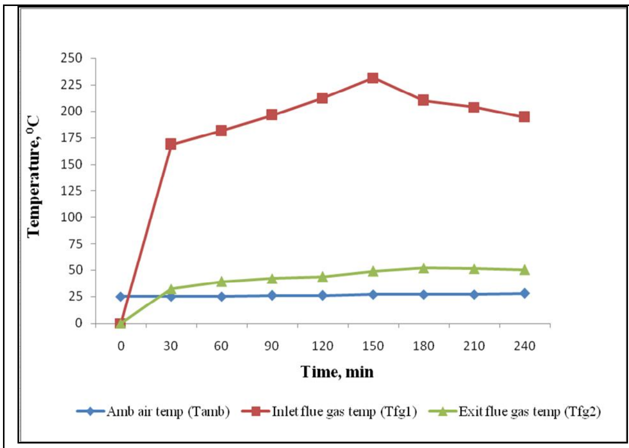


Fig.11 Variation of flue gas temperature(load test

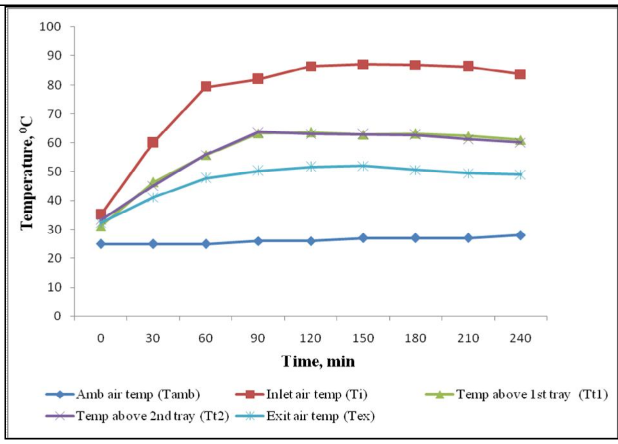


Fig.12 Variation of air temperature (load test)

Drying of product in flue gas based dryer (Onion Slices)

The drying of 5 kg onion slices was carried out in the flue gas based drying to reduced the moisture content. The moisture reduction at an interval of 30 min. was observed during the drying test run. It was observed that, moisture content (% wb) of the onion slices reduced from 83% (wb) to 30.4% (wb) in 4 hr duration inside the biomass dryer. The overall mass of water evaporated during the drying test was estimated to be 3.05 kg. The overall moisture removal rate was observed to be 761 gm of water per hour.

The average thermal efficiency of water heater during load test was found to be 31.95 %. The average drying efficiency of flue gas based dryer during load test was found to be 23.99 %. The overall efficiency of composite unit at load test was estimated as 34.99 % during drying of onion slices and water heating.

The increase in efficiency of composite unit (23.99 %) over thermal efficiency of water heater (31.95 %) revealed the advantage of reutilization of flue gases for drying application with liberation of cold flue gases (45.05 ºC) into atmosphere as compared to 300 ºC during single unit for water heating.

Drying of nutmeg in flue gas based dryer

Nutmeg *(Myristica fragrans)* is an important spice tree in India, Though, the production of nutmeg *(Myristica fragrans)* is around the year, but maximum production is obtained in the period of July to September, which coincides with monsoons conventionally after harvest. The nutmeg fruit consist of rind seed kernel and mace, which, is separated manually. The well-drained nutmeg seed kernel and mace is subjected to sun drying required 15-20 days and 7 days, respectively to reduce the moisture content up to 15%. During off period, the firewood combustor is used to remove the moisture from product at the temperature of 50 – 60 ^{0}C. The performance evaluation of composite unit was carried out to dry: Nutmeg (*Myristica fragrans)*) a. Pericarp b. Nutmeg seed c. Mace

Sr. No.	Product Name	Weight on 1st tray (g)	Weight on 2nd tray (g)	Total weight (g)
1.	Pericarp	1359.75	1106.50	2466.25
2.	Mace	36.75	37.50	74.25
3.	Nutmeg	143.50	139.00	282.50
				2823.0

The variation of weight reduction in pericarp, nutmeg seed and mace drying in composite unit is shown in Fig 13-15. The drying performance of pericarp nutmeg seed and mace was carried out for period of 9 hr in flue gas based dryer. The drying of 2.82 kg nutmeg seed kernel was carried out in the flue gas based drying to reduce the moisture content. The moisture reduction at an interval of one hour was observed during the drying test run. It was observed that, moisture content (% wb) of the netmeg products reduced from 65% (wb) to 16% (wb) in 9 hr duration inside the biomass dryer. The overall moisture removal rate was observed to be 627 gm of water per batch.

The average thermal efficiency of water heater during load test was found to be 30.75 %. The average drying efficiency of flue gas based dryer during load test was found to be 22.49 %. The overall efficiency of composite unit at load test was estimated as 32.99 % during drying of nutmeg products and water heating. The increase in efficiency of composite unit (22.49 %) over thermal efficiency of water heater (30.75 %) revealed the advantage of reutilization of flue gases for drying application with liberation of cold flue gases (45.05 ºC) into atmosphere as compared to 300 ºC during single unit for water heating.

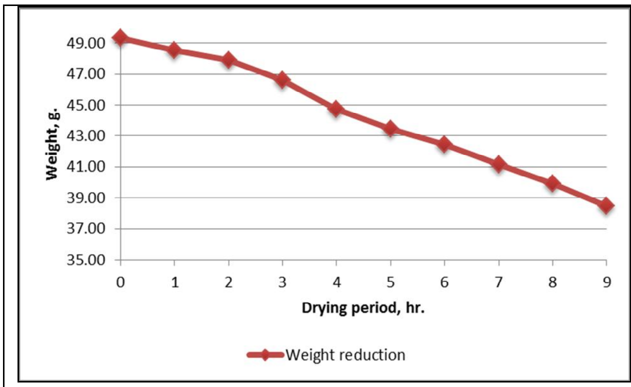


Fig. 13. Weight reduction of pericarp

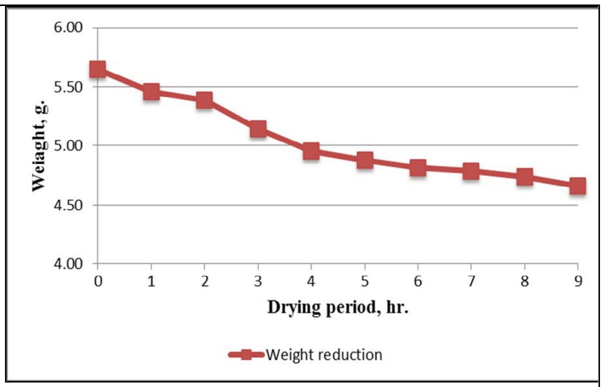


Fig. 14. Weight reduction of nutmeg seed

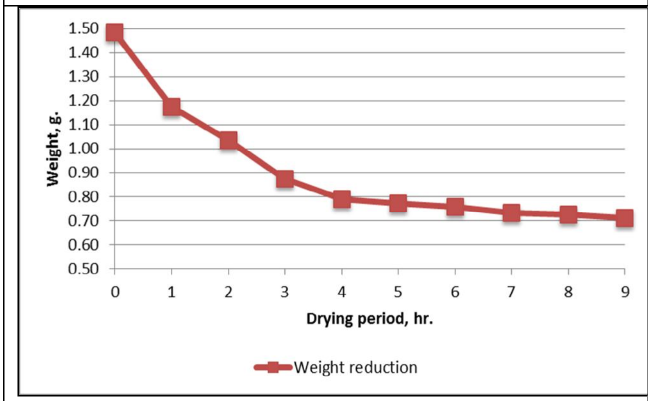
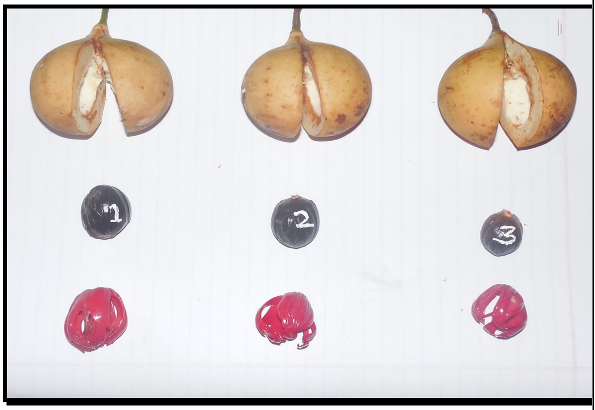


Fig.15. Weight reduction of mace



Product of nutmeg

Summery :

The design, development and performance evaluation of biomass based composite unit for water heating and drying revealed that,

1) The biomass water heater has thermal efficiency of water heater was found to be 26.64 %.
2) The average flue gas temperature, heat available in flue gases and mass of flue gases was found to be 333 ºC, 1515.5 kcal/hr and 20.50 kg/hr respectively. The heat available in the flue gases (> 150 ^{0}C) can be utilized for the drying of fruits, vegetables and other agricultural products.
3) During no load testing of flue gas based dryer at different flow rate and damper opening, forced circulation method was more efficient than others.

4) During no load testing, the average temperature over the 1st tray (T_{t1}) was found to be 54.13 ºC. The average temperature over 2nd tray (T_{t2}) was found to be 52.87 ºC.
5) During load test, the average inlet air temperature (Ti) was found to be 76.32 ºC. The average temperature over the 1st tray (Tt1) was fond to be 56.66 ºC. The average temperature over 2nd tray (Tt2) was fond to be 56.51 ºC.
6) It was observed that, moisture content (% wb) of the onion slices reduced from 83% (wb) to 30.4% (wb) in 4 hr duration inside the biomass dryer. The overall moisture removal rate was observed to be 761 gm of water per hour.
7) The moisture content (% wb) of the netmeg products were reduced from 65% (wb) to 16% (wb) in 9 hr duration inside the biomass dryer. The overall moisture removal rate was observed to be 627 gm of water per batch.
8) The thermal efficiency of water heater during load test (Onion slices) was found to be 31.95 %. The average drying efficiency of flue gas based dryer during load test was found to be 23.99 %.
9) The average thermal efficiency of water heater during load test was found to be 30.75 %. The average drying efficiency of flue gas based dryer during load test was found to be 22.49 %.

10. Conclusion:

The study revealed that, the increase in efficiency of composite unit (23.24 %) over thermal efficiency of water heater (25.8 %) revealed the advantage of reutilization of flue gases for drying application with liberation of cold flue gases (45.05 ºC) into atmosphere as compared to 300 ºC during single unit for water heating.

11. Recommendation:

DBSKKV developed drying unit is recommended as a attachment for commercially available biomass fired water heating system.

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