Thermal Energy Evaluation of Biomass Heating System

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ABSTRACT

The drying capacity of the system, fuel and air required for the drying was estimated. Based on the quantification of fuel and air required in the drying application, the dryer surface area and combustor furnace size were computed. The net heat duty of the heat exchanger for the parallel flow type exchanger was estimated in the experimentation. The exchanger design parameters were computed for the LMTD, net heat transfer area, number of tubes and diameter, and heat transfer coefficient was determined in the study. The system was developed as per the design specification in respect of each component. The biomass-based air heating system consisted of biomass combustor equipped with pre-heating arrangement and smoke tapping unit, air distribution system and rotary tray drying bin. The power transmission system was designed and developed for rotating tray arrangement for the live and static load during the operation. The thermal energy performance of the system was worked out during the experimentation for drying of green gram for the set operational parameters like air flow rate, temperature and fuel feed rate for the various combination of treatment. In investigation, the heat supplied by the combustor in various treatments for the set air flow rate, temperature and fuel feed rate is estimated in drying application. The heat gain by air, heat supplied to the drying bin, net heat utilized in the various treatments is estimated. The loss of heat from the combustor, in air distribution system and total system heat loss is computed in the experimentation for drying application. The component wise heat loss was estimated during the operation for the treatments. The overall energy balance for the drying was examined during the study.

Keywords-- Thermal Energy, Biomass Heating System, Heat

I. INTRODUCTION

The most common application of biomass energy in developing countries is its use as a source of heat for cooking, sometimes called traditional biomass use. Industrial use of biomass combustion takes place in a combustor or furnace with the heat being used to in a manufacturing process (Dasappa *et al*., 2003). Combustion is a process in which the fuel is burnt with the oxygen from the air to release the stored chemical energy as heat in burners, boilers, internal combustion engines and turbines (Yunus *et al*., 2011). Consequently, in many industrial drying processes, a large fraction of energy is wasted Energy management is therefore an essential part of any drying process and energy conservation can significantly lower the overall operating costs. Biomass is energy from organic matter, i.e. all materials of biological origin that is not embedded in geological formations. Biomass can be used in its original form as fuel, or be refined to different kinds of solid, gaseous or liquid biofuels. These fuels can be used in all sectors of society, for production of electricity, for transport, for heating and cooling, and for industrial processes (Tripathi *et al*., 1998).

II. METHODOLOGY

The biomass combustion system has been designed accordingly the system utility and the energy requirement for the thermal used in term of the grain drying. The energy required for the drying in the absolute from has been determined for the specific quantity of drain to be dried. The total heat duty of the combustor heat exchanger has been determined by evaluating the energy load of dryer, losses in the process. The air required for the thermal application in drying for the drying chamber is determined. The fuel consumption rate of the biomass combustion system is determined. The power requirement for the air supply system and the blower capacity as per the calculated air requirement is determined. The specification of the heat exchanger using the thermal heat analysis has been worked out for the total heat requirement of the developed system.

Methodology for Combustion Flue Gas Analysis

The combustion flue gases behaviors have been determined for the thermal energy transport by the flue gases, like heat carried and heat away by the flue gases. The heat losses due to the incomplete combustion, unburnt fuel and unaccountable has been determined by using the following procedure (BEE A, 2019; BEE B, 2019).

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Sensible Heat Loss in Flue Gas

The heat loss due the dry flue gases in the combustion process for the developed system in furnace is computed by the relation of air required for the complete combustion of 1 kg fuel.

Sensible heat loss = m x Cp × ΔT

Where m = Weight of flue gas (Air +fuel)

Cp = Specific heat

ΔT = Temperature difference

Loss Due to Evaporation of Moisture in Fuel

The thermal energy carried out by the moisture present in the fuel is determined by using the following equation;

$$\% \text{ Heat Loss} = \frac{M \times \{584 + C_p(T_{fg} - T_{amb})\}}{GCV\ of\ Fuel} \times 100$$

where,

M = kg of moisture in 1 kg of fuel oil (0.15 kg/kg of fuel oil)

T_{fg} =Flue Gas Temperature, °C

T_{amb} = Ambient temperature, °C

GCV = Gross Calorific Value of Fuel, kcal/kg

Loss Due to Evaporation of Water Formed Due to Hydrogen

The heat loss due to the evaporation of water formed by the hydrogen content in the fuel computed by the following relation;

$$\% \text{ Heat Loss} = \frac{9 \times H_2 \times \{584 + C_p(T_{fg} - T_{amb})\}}{GCV\ of\ Fuel} \times 100$$

Where, H_2 – kg of H_2 in 1 kg of fuel (0.059~0.06 kg/kg of fuel)

Heat Loss Due to Openings

If a furnace body has an opening on it, the heat in the furnace escapes to the outside as radiant heat. Heat loss due to openings can be calculated by computing black body radiation at furnace temperature, and multiplying these values with emissivity (usually 0.8 for furnace), and the factor of radiation through openings. Factor for radiation through openings can be determined with the help of graph suggested by BEE, 2019. The black body radiation losses can be directly computed from the curves as given in BEE, 2019.

Heat Loss through Furnace Skin

The heat loss through the furnace skin is determined for the heat loss through the roof and sidewall and the total average of surface temperature of are other than heating and soaking zone.

Unaccounted Loss

These losses comprises of heat storage loss, loss of furnace gases around charging door and opening, heat loss by incomplete combustion, loss of heat by conduction through hearth, loss due to formation of scales.

Furnace Efficiency (Direct Method)

The furnace efficiency of the developed system is computed by the directed method by using the heat input and the heat output by the system.

Furnace efficiency (%)= (Heat input/Heat out put) X 100

Furnace Efficiency (Indirect Method)

The furnace efficiency of the developed system is also computed by the heat loss evaluation in the combustion process. The estimated heat loss computed in the above section are considered for evaluation of furnace efficiency in indirect method.

Furnace Efficiency = 100 – All heat losses in furnace

But in present case heat loss through skin is tapped in the process so furnace efficiency is computed as below,

= 100-(All heat losses in furnace- Heat loss through skin)

Estimation of Fuel Saving

By using preheated air for combustion, fuel can be saved. The fuel saving rate is given by the following formula:

$$S = \frac{P}{F + P - Q} \times 100$$

Where, S: fuel saving rate, %

F: calorific value of fuel (kcal/kg fuel)

P: quantity of heat brought in by preheated air (kcal/kg fuel)

Q: quantity of heat taken away by exhaust gas (kcal/kg fuel)

The heat brought by pre heater can be computed by following equation,

P = m × Cp × ΔT

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III. RESULT AND DISCUSSION

Combustion Flue Gas Analysis

The combustion flue gas analysis of the fuel in the furnace is evaluated as per the procedure given in chapter III. The sensible heat loss in flue gas, loss due to evaporation of moisture, loss due to evaporation of water formed due to hydrogen in fuel, heat loss due to opening, heat loss through furnace skin. The detail of the losses in the flue gas is given in Table 1.

Table 1: Combustion flue gas analysis in furnace

SN	Losses type	Quantity, kcal/kg of fuel	Percentage
1	Sensible heat loss	1243	29.81
2	Loss due to moisture	69.2	1.66
3	Heat loss due to hydrogen	373.68	8.96
4	Heat loss due to opening	5204.16	15.06
5	Heat loss through furnace skin	1448	34.72

Furnace Efficiency

The furnace efficiency of the system based on the heat loss is computed as per the standard procedure. It is found that system has furnace efficiency in direct method is computed 36.74 % and in indirect method is found to be 44.87. The heat loss through skin of the system has been utilized by circulating air through the furnace side wall. Hence, this loss is eliminated in the design.

Energy and Air Requirement in Drying Process

Selection of an efficient drying system is necessary in order to reduce energy consumption of a crop dryer during dehydration process and also minimize the quality degradation of dried products. The drying process should be in such a way that would apply minimum changes in products qualitative indexes. These indexes include physical aspects such as dimensions and size, texture, shape, wrinkles, and stiffness, as well as chemical changes such as browning reactions, discoloration, changes in vitamins, amino acids, and oxidation of substances (Okos et al., 1992). In this investigation, the dryer capacity set for the combustion system is about 200 kg. Based on the information provided in the Chapter III in section 3.4.2 to 3.3.6, the net heat required in drying process was found to be 8465 kcal. The system developed for the experimentation is biomass-based air heating system for the drying. The quantity of air required for the drying of product was estimated and found to be 2.57 kg/min. The air requirement per m^2 to the total surface area of drying chamber was computed as $0.30 m^3/min/m^2$.

Fuel Requirement for Drying Application with Combustor Furnace Size

The complete combustion of fuel based on the estimated air requirement is possible in the system. The total energy load on the combustor is workout for the drying. To establish the relationship of fuel requirement for the process, the combustion analysis of the one kg fuel is worked out. The various losses are estimated in the process. The major heat loss through the skin of furnace (34.72) is tap in proposed design as the air is circulated through the furnace for achieving the higher furnace efficiency. For estimation of fuel the maximum heating load (15 kg of water removal) with furnace efficiency of 15 % is considered and comes to be 33.77 say 40 kg. Looking in to the future extension of capacity of thermal application for the drying purpose (in this case 200 kg), its capacity could be increased up to 500 kg in batch. Hence for removal of moisture in large capacity grain of 400 kg, the estimated fuel required was considered as 80 kg. Table 1 indicated that, net air required on weight basis for the complete combustion of fuel was estimated to be 84kg/h and on volume basis it is 64.88 Nm^3/kg.

Determination of Size of Combustor Furnace and Furnace Efficiency

The size of biomass combustor furnace is determined over the quantity of fuel required in the process. The estimated height of the furnace is calculated to be 150 mm for the volume of $0.095 m^3$ biomass fuel with considering the 250 mm radius of the furnace. The estimated furnace efficiency in direct method was found to be 36.74 % and in indirect method is found to be 44.87 %. The reason for the more furnace efficiency in indirect method is that in proposed system the losses through the skin of furnace is tapped by augmenting air flow through the core of furnace i.e., from soaking and top zone of the furnace (34.72 %). The estimated fuel saving by adopting such innovative biomass furnace with the preheated chamber is found to be 15.62 %.

IV. CONCLUSIONS

Based on the results following conclusions could be drawn;

1. The heat losses in the furnace for the other than heating and soaking area was tapped and found to be 34.72 per cent.

2. The furnace efficiency for indirect method was observed to be 44.87% and for direct method it was 36.74%.
3. Based on pre-heating arrangement of feed air to heat exchanger, the fuel saving has been estimated and it was found to be 24.08%.
4. The net heat transfer area of the heat exchanger was found to be 9.87 m^2 for that number of tubes for the net heat transfer area (9.87 m^2) was found to be 16 with the tube diameter of 30 mm with heat transfer coefficient is calculated to be 46.40 $W/m^{2o}K$.

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