THERMAL PERFORMANCE OF A MUSHROOM STEAMING STOVE USING BIOMASS AS FUEL

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ABSTRACT

The design, construction, testing and thermal performance analysis of a mushroom steaming stove system using biomass fuel was performed in this research work. The system was employed in order to activate microbes inside the mushroom prior to putting in line mushroom and uncovering. This system comprised of two compartments. Firstly a steam-generated system or boiler, which resulted in producing a small amount of pressure. The boiler in the study was 45 cm in diameter with a fire-tube type second return amounting to 22 tubes to increase the flue-gas circulation in the boiler, Secondly, a mushroom cup board steaming system. This stove can steam 200 mushrooms. From the boiling test, it is found theat most efficent level of the stove is 59.33 % by using 10 kg/hr of fuel and the improved efficiency is approximately three times higher than a conventional stove.

KEYWORDS : Biomass fuel / Steamed mushroom stove

1. INTRODUCTION

Thailand is mainly agriculture country, resulting in the crop by products from agriculture such as rice husk,corn husk etc. These materials are a source of biomass fuel and can be changed into heat energy. The industry of steamed and grilled products is interested in using this energy as well as the mushroom industry. Mushrooms are grown by local people, who first culture the mushroom. They know how to separate the varieties of mushroom and know how to grow and to take care of the mushroom. Currently, the mushroom cultures were being tried to imitate system of nature. The steaming system for steaming the mushroom plantlet using biomass energy is popular among the local producers. There are two types of these systems: a direct mushroom steaming stove (stove and boiling section are within the same unit) and a mushroom steaming stove with a lower pressure pot (separated stove and boiling pot).

The first types of direct mushroom steaming stove is less efficient than the other. The aim of using steam to produce mushrooms is to kill off microbes and fungi during ingredient mixing within the mushroom pieces. The steaming of mushrooms is not known well from an academic point of view. Its efficiency is low and approximately 13-18 % of energy is lost, its time consuming and has less economic aspects.

2. MATERIALS AND APPARATUS

The steam was used to kill microbes in the mushroom and mushroom housing. Usually the farmer built 2-3 boiler tanks, each having a size of 200 liters. Water was filled up half a tank which is sufficient to steam about 2-3 mushroom houses. In this study, design and construction of the mushroom steaming system were inline to the local use. They consisted of a stove, a boiler and a mushroom steaming house as shown in Fig. 1.

The stove was separated from the boiler. The material of the stove was made by Mon-brick with the sticky mud, sand and rice husk residue. The wall of the combustion room was covered with the sticky mud mixed with rice husk residue. The outside wall was covered with a cement combined with sand. The smoke stack was made of a long metal pipe having a diameter of 0.10 m and height of 3.00 m.

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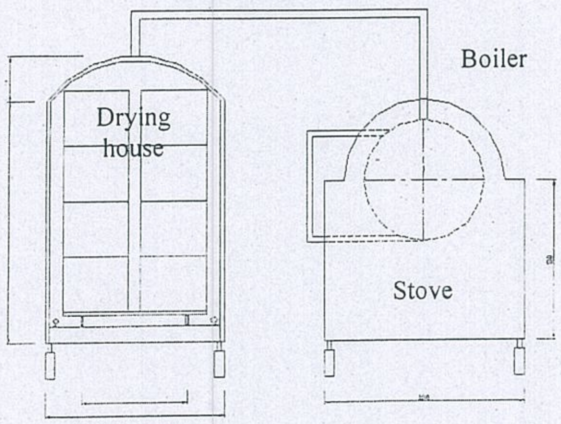
The biomass fuels were eucalyptus wood chip. They were cut into 50 cm pieces and dried under the sun for a humidity reduction. The weighted quantity of prepared eucalyptus, 10 kg were placed in the stove combustion room and then ignited. During the combustion period, temperatures in the combustion zone and the stove wall, the inlet air flow rate by natural convection and the flue gas were recorded every 5 min. The hazardous gases in the flue gas were measured using the combustion analyzer. Measuring devices such as a recorder Comark, thermocouples Type K (normal and high temperature types), flue gas Analyzer, Air flow system Testo 435 and Ultrasonic (OMEGA) Engineering and Weighting of biomass were employed. The procedure was repeated using 60 kg of eucalyptus. All testing were performed twice to calculate the average values.



The boiler was made of metal sheet, 3 mm thick, 0.45 m diameter and 1.00 m long. There were 22 fired tubes with inside diameter of 4.2 cm and 1.00 m long placed in two rows inside the boiler. The water quantity was 2/3 of the boiler capacity according to ASME standard. The boiler can hold 80 liters of water.

The mushroom steaming house was a closed container, made with a metal sheet, 3 mm thick. The generating steam from the boiler flew to the mushroom steaming house via a connecting pipe. The mushroom plantlets were packaged in the baskets hung in several rows inside the house. The system was well insulated. The temperature inside the container was controlled to not less than 95-100 °C.

3. STOVE EFFICIENCY

The stove efficiency was determined by a standard method of testing for small industry such as the water boiling test. The efficiency is calculated using an Eq. 1.

$$\text{Efficiency} = \frac{\text{Sensible Heat} + \text{Laten Heat}}{\text{Heat from Combustion}} \tag{1}$$

$$\text{Efficiency} = \frac{m_w C_{pw} (T_b - T_{wi}) + m_v H_{fg}}{m_f LHV}$$

in which m_w is mass of water, C_{pw} is specific heat of water, T_b is boiling point of water, T_{wi} is initial water temperature, m_v is mass of water vaporized, H_{fg} is latent heat of vaporization, m_f is mass of fuel and LHV is lower heating value of the fuel.

Heat losses from the mushroom steaming system can be classified into heat lost due to loss from the smoke outlet pipe, heat lost due to energy transfer to the stove wall, heat lost due to incomplete combustion, heat lost due to biomass moisture, heat lost due to air humidity and others. The equantitative heat is classified into three aspects such as heat lost due to loss from smoke outlet pipe, heat lost due to structure of stove and due to heat transfer from stove wall. The heat lost due to gas smoke outlet is shown in Eq. 2.

$$Q_{flue} = m_{flue} Cp_{flue} (T_{flue} - T_a) \tag{2}$$

The heat lost due to the structure of stove is shown in Eq. 3.

$$Q_s = m_s Cp_s (T_{sf} - T_{si}) \quad (3)$$

The heat lost due to heat transfer from stove wall can be calculated using the Congel equation in case of vertical wall and free convection as shown in Eq. 4.

$$Q_{conv} = hA (T_s - T_a) \quad (4)$$

4. EXPERIMENTAL RESULTS.

The experimental measurements of thermal performance are shown in Table 1 and 2.

Table 1. Experimental measurements of thermal performance

Time (Min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)
0	25.77	22.4	23.6	24.8	25.7
10	367.2	226.6	23.7	62.5	54.4
20	521.3	249.9	23.8	147.4	84.1
30	523.9	260.7	24.0	167.9	98.8
40	552.0	284.4	24.7	187.5	109.3
50	527.5	283.8	25.9	221.2	123.7
60	425.7	285.1	27.7	235.4	128.9
70	547.4	280.7	29.9	229.4	129.3
80	522.3	294.8	32.3	245.8	132.6
90	556.1	300.8	37.9	264.3	139.5
100	582.1	316.7	38.0	301.3	138.6
110	612.2	340.6	43.7	313.9	145.1
120	566.9	312.1	44.5	296.1	138.9
Average	487	266	31	208	111

Table 2. Experimental results of thermal performance (Ext)

Time (Min)	T_6 (°C)	T_7 (°C)	T_8 (°C)	T_9 (°C)	T_{10} (°C)
0	23.8	26.0	24.3	25.0	26.7
10	24.0	25.9	24.6	25.2	26.7
20	26.9	26.0	24.7	25.4	26.7
30	34.2	26.0	24.9	25.5	26.7
40	38.9	46.1	28.4	46.9	42.0
50	44.3	51.0	31.5	50.6	66.0
60	49.1	51.1	35.8	79.9	71.7
70	51.7	53.6	43.8	92.8	84.0
80	50.1	60.2	45.0	98.4	92.7
90	55.3	71.4	52.2	102.9	97.0
100	52.0	77.4	50.3	101.2	98.3
110	55.8	88.0	53.0	103.6	98.7
120	52.7	90.5	49.0	100.2	99.7
Average	43	53	38	68	66

Remark : T_1 = stove, T_2 = inside stove surface, T_3 = outside stove surface, T_4 = Fire tube in boiler, T_5 = Flue gas, T_6 = Top boiler surface, T_7 = inside mushroom plantlet, T_8 = mushroom house outside wall surface, T_9 = mushroom house inside wall surface, T_{10} = mushroom drying house.

5. ANALYSIS OF ENERGY DYNAMIC EQUILIBRIUM

The analysis of energy equilibrium was performed as following :Heat absorption by water within the boiler is calculated using Eq. 5.

$$Q_1 = \frac{m_s(h_s - h_w)}{m_f} \quad (5)$$

$$Q_1 = \frac{43.25 \times (2,676.1 - 104.89)}{10.09}$$

$$Q_1 = 11,020.29 \text{ kJ/kg}^{-}\text{fuel}$$

Heat lost due to flue gas outlet of stack pipe is calculated using Eq. 6.

$$Q_2 = m_g \bar{c}_{p,g}(T_g - T_a) \quad (6)$$

$$Q_2 = 17.17 \times 1.012 \times (212.5 - 25)$$

$$Q_2 = 3,258.75 \text{ kJ/kg}^{-}\text{fuel}$$

Heat lost due to incomplete combustion is calculated using Eq. 7.

$$Q_3 = \left(\frac{CO}{CO + CO_2}\right) m_c \times 23,560 \quad (7)$$

$$Q_3 = \left(\frac{0.2784}{6.9 + 0.2784}\right) \times 0.4402 \times 23,560$$

$$Q_3 = 402.13 \text{ kJ/kg}^{-}\text{fuel}$$

Heat lost due to heat transfer to the stove wall is calculated using Eq. 8.

$$Q_4 = \frac{(T_{Si} - T_{SO})}{R} \quad (8)$$

$$Q_4 = \frac{\left[\frac{(545.4 - 304.2)}{0.198} \text{ x } (2)\right] + \left[\frac{(545.4 - 304.2)}{0.401}\right]}{10.09} \text{ x } 3.6$$

$$Q_4 = 1,083.87 \text{ kJ/kg}^{-}\text{fuel}$$

in which 3.6 is the conversion factor to change the calculated value to kJ/kg¯fuel.
Heat lost due to heat transfer to the boiler is calculated using Eq. 9.

$$Q_5 = \frac{(T_i - T_o)}{R_{tol}} \quad (9)$$

$$Q_5 = \frac{\left[\frac{(100 - 43.9)}{0.372}\right]}{10.09} \text{ x } 3.6$$

$$Q_5 = 53.52 \text{ kJ/kg}^{-}\text{fuel}$$

Heat lost due to stove wall heat absorption is calculated using Eq. 10.

$$Q_6 = MC_{p,w} \frac{\Delta T}{\Delta t} \quad (10)$$

$$Q_6 = \frac{\left[2 \text{ x } (1,930 \text{ x } 0.184) \text{ x } 0.835\left(\frac{267.6 - 259.7}{(120 - 40) \text{ x } 60}\right)\right] + \left[(1,930 \text{ x } 0.091) \text{ x } 0.835\left(\frac{267.6 - 259.7}{(120 - 49) \text{ x } 60}\right)\right]}{10.09} \text{ x } 3,600$$

$$Q_6 = 434.35 \text{ kJ/kg}^{-}\text{fuel}$$

in which 3,600 is the conversion factor to change the calculated value to kJ/kg⁻fuel.

Heat lost due to heat radiation is calculated using Eq. 11.

$$Q_7 = \varepsilon\,\sigma A\left(T_h^{\,4} - T_c^{\,4}\right) \quad (11)$$

$$Q_7 = \frac{\left[0.56 \times 5.67 \times 10^{-8} \times 0.8168 \times \left(316.9^4 - 298^4\right)\right] + \left[0.56 \times 5.67 \times 10^{-8} \times 1.152 \times \left(304.2^4 - 298^4\right)\right] + \left[0.56 \times 5.67 \times 10^{-8} \times 0.5688 \times \left(304.2^4 - 298^4\right)\right]}{10.09} \times 3.6$$

$$Q_7 = 33.27 \text{ kJ/kg}^{-}\text{fuel}$$

Heat lost due to other aspects is calculated using Eq. 12.

$$Q_8 = (LHV) - (Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7) \quad (12)$$

$$Q_8 = [18{,}573.53] - \left[\begin{matrix}(11{,}020.29 + 3{,}258.75 + 402.13 + \\ 1{,}083.87 + 53.52 + 434.35 + 33.27)\end{matrix}\right]$$

$$Q_8 = 2{,}287.35 \text{ kJ/kg}^{-}\text{fuel}$$

The analysis of energy equilibrium was performed as above and the result was shown by Shanky diagram in Fig. 2.

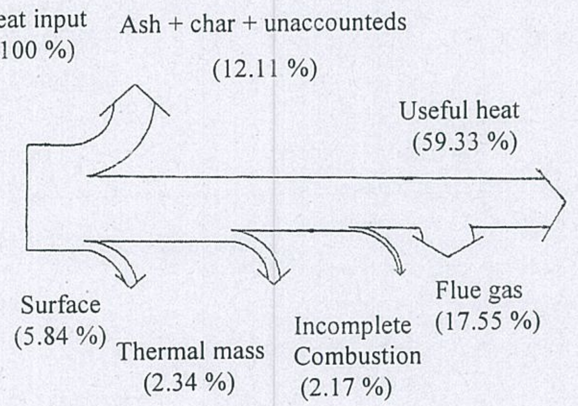


Fig.2. Shanky Diagram Energy dynamic equilibrium of mushroom steaming system using biomass fuel.

6. CONCLUSION

This designed stove has a thermal efficiency of 59.33 %. Heat loss in the flue gas accounts for 17.55 % which is considered to be a significant loss compared to other losses. The loss of 2.17 % under the incomplete combustion reveals a good combustion considering for the small scale stove.

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