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ijirset@gmail.com

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Thermal Analysis of Burner for Frying Food Product

Dhairiyashil Patil¹, Hanmant Shete², Eknath Aitavade³

M.E. Scholar, Department of Mechanical Design Engineering, BMSPM'S Ashokrao Mane Group of Institutions, Vathar Tarf Vadgaon, Tal- Hatkanangale, Dist.-Kolhapur, Maharashtra, India¹

Professor, Department of Mechanical Engineering, BMSPM'S Ashokrao Mane Group of Institutions, Vathar Tarf Vadgaon, Tal- Hatkanangale, Dist.-Kolhapur, Maharashtra, India²

Professor, Department of Mechanical Engineering, BMSPM'S Ashokrao Mane Group of Institutions, Vathar Tarf Vadgaon, Tal- Hatkanangale, Dist.-Kolhapur, Maharashtra, India³

ABSTRACT: In this paper thermal analysis of a biomass burner was performed using theoretical approach, simulation and physical model approach. From theoretical approach, output wall temperature was obtained as 35.5°C, flame height was determined as 500 mm, maximum flame temperature was 1350°C and minimum flame temperature was 950°C. It was observed that the parameters determined and thermal analysis results obtained were quite accurate, and hence it is suggested to employ the burner manufactured based on the parameters obtained by this investigation.

KEYWORDS: Thermal analysis, Biomass pellet, Design, Burner, combustion, temperature

I. INTRODUCTION

Reduction in production cost by reducing fuel consumption is an inevitable trend for manufacturing industry to meet the strategic requirements of energy saving and environment protection. For conserve natural resources and minimize use of energy optimized design of burner is important for manufacturers in the present scenario. Fuel consumption reduction can be achieved by the introduction of better design, better manufacturing processes, better fuel and better use of burner fuel. Biomass burner are applicable in heat supply, biomass boilers, biomass power generation and food manufacturing industries.

Design of biomass burner it basically involves the choice of various geometric dimensions of the burner for achieving desired range of operating condition of the burner with the best possible thermal efficiency and the minimum possible harmful emission. For that it is required first calculating various burner parameters such as burner dimensions, thickness of burner, fuel flow rate, air-fuel ratio, energy demand, energy input etc. After calculating this parameters instead of construction we simulated the model of burner using Ansys thermal analysis (CFD). After simulation results were used to optimize the burner design to improve the performance.

II. LITERATURE SURVEY

Daniel Mulugeta et al. [1] has discussed about CFD analysis of porous medium burner for domestic cooking application for our project this paper is helpful for to calculating various physical parameters such as air flow rate, superficial gasification rate etc. which required for analysis. Joao Silva et al. [2] has discussed about CFD Modelling of Combustion in Biomass Furnace By this paper to understand CFD is efficient tool for the optimization of biomass combustion in burner and overall combustion mechanism reasonably predicts the emission of carbon monoxide and carbon dioxide inside the burner. Pamela Jagger et al. [3] has discussed about biomass pellets and a fan micro gasification improved cook stove as a clean cooking alternative to charcoal. Consumers purchase locally produced biomass pellets and receive the improved cook stove on a lease basis. The cost of the pellets and stove(s) is lower than the cost of cooking with charcoal in the urban setting where their study takes place. Robert Scharler et al. [4] has discussed about wood logged fired stoves in which they optimized wood fired stoves performance by using simulating technique for that they apply computational fluid dynamic by the using this technique they optimized there stove performance. Miguel A. Gomez et al. [5] has discussed about a methodology to simulate the combustion of fixed beds of biomass particles using



computational fluid dynamics (CFD) techniques. The models presented were used in the simulation of a domestic pellet boiler working under operating conditions and the model predictions were compared with measurements of heat transfer, temperature and species concentration. M. R. Ravi et al. [6] use of CFD simulation as a design tool for biomass stoves. Paper describes the development of the building-blocks of the detailed simulation model and its use in the derivation of simple model equations relating design and performance parameters. Francesco Fantozzi et al. [7] the paper described a computational fluid dynamics (CFD) simulation of the burner was carried out considering the combustion of propane to investigate temperature and pressure distribution, heat transmission and distribution of the combustion products and by products.

Dessie Bantelay et al. [8] has discussed about utilization of biomass in a clean and efficient manner to deliver modern energy service to the world's poor remains an imperative for the development of community. One possible approach to do this is through the use of efficient biomass gasifier & they successfully made household gasifier stove with high efficient and less emission, with the help of this paper we understood of design construction of stove. Sae Byul Kang et al. [10] they developed boiler which worked on wood pellets as fuel for the combustion chamber of a wood pellet boiler, they have developed an air-fuel control system for a domestic wood pellet boiler by using flue gas oxygen concentration measurement and a PID controller. Widodo Wahyu et al. [11] has discussed about biomass is potential alternative energy replacing oil and gas. This experiment are prepared and tested pellets in order to create fuels with good combustion performance and low emission. In R.K. Rajput. [12] Author explained about thermodynamics, heat convection, conduction & radiation this book is helpful for our experiment for the finding of the material design and its properties and understood the burner required calculation formulae was taken by this book.

III. THEORETICAL THERMAL ANALYSIS

Air-fuel ratio – Fuel for burner used as biomass pellet having heating value is 17330.13 KJ/kg, Air-fuel ratio value is determined from the biomass pellet testing report. Proximate and ultimate analysis way to determined oxygen value. O_2 Is required / kg of pellet = 2.2 kg, air required / kg of pellet = 9.4 kg

Energy demand is calculated by,

$$Q_n = FCR \times HV_f \times \xi_g \dots (1)$$

Where,

FCR - Fuel consumption rate, 4.5 Kg/hr

Q_n - Heat energy needed, KJ/Kg

HV_f - Heating value of fuel, 17330.13 KJ/Kg

ξ_g - Biomass burner efficiency, 40 %

$$Q_n = 4.5 \times 17330.13 \times 0.4$$

Thus, $Q_n = 31194$ KJ/kg

Airflow rate-Airflow rate required for combustion was estimated to determine the size of fan required to air flow the air flow per unit mass of fuel is dependent on stoichiometric air (theoretical air) required to burn pellet. Air flow rate can be calculated using formula,

$$AFR = \frac{\varepsilon \times FCR \times SA}{\rho_a} \dots (2)$$

Where,

AFR = air flow rate, m^3/hr

ε = equivalence ratio, 0.3 to 0.4

SA = stoichiometric air of pellet is 9.4217 kg of air for 1 kg of pellet

ρ_a = air density, 1.25 kg/m^3

$$AFR = \frac{0.35 \times 4.5 \times 9.4217}{1.25}$$

$$AFR = 11.9 \text{ m}^3/hr$$

Superficial gas velocity-

The velocity of air moving through a pipe defined as the volumetric flow rate of that air flow rate divided by the cross-section area. Superficial velocity is used in many engineering equation because it is the value which is usually readily know and unambiguous, whereas real velocity is often variable from to place,

$$\text{Superficial gas velocity } (v_s) = \frac{\text{AFR}}{\text{area of inner combustion chamber}} \dots (3)$$

Where,

V_s = superficial gas velocity, m/s

AFR = air flow rate m^3/hr ,

$$V_s = \frac{11.8713}{0.2726}$$

$$V_s = 43.5 \text{ m/s}$$

Thickness of burner- Burner thickness are shown in fig. 1.

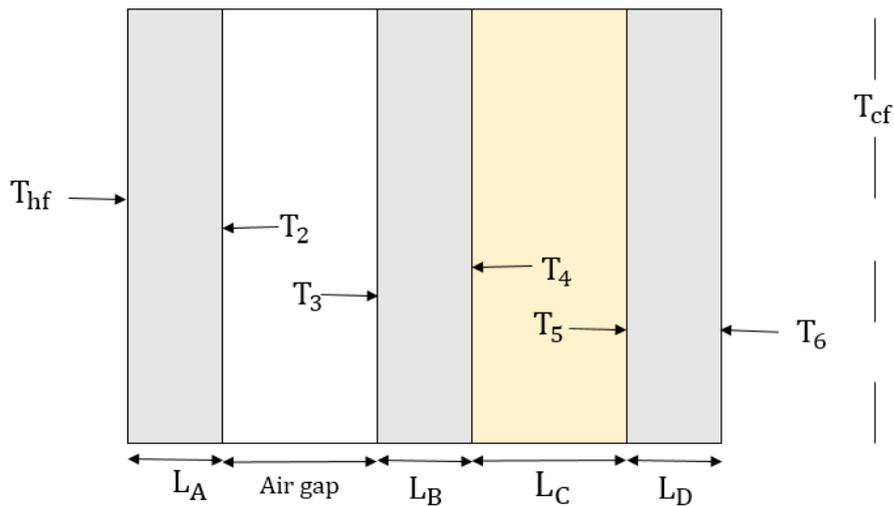


Fig 1. - Thickness of burner

Where,

Thickness of M.S. $L_A = 5\text{mm}$

Resistance of air gap to heat flow = 0.16 K/W

Thickness of M.S. $L_B = 5 \text{ mm}$

Thickness of Insulating material ceramic fiber (L_C) = 35 mm

Thickness of M.S. $L_D = 5 \text{ mm}$

Heat transfer coefficient from the outside wall surface to the air in the room,

$h_{cf} = 18 \text{ w/m}^2\text{°C}$

Thermal conductivity -

M.S. $K_A, K_B, K_D = 46.2 \text{ W/ m}^\circ\text{C}$

Insulating Material Ceramic Fiber $K_C = 0.003 \text{ W/ m}^\circ\text{C}$

Temperatures -

Inner combustion chamber temperature $T_{hf}(T_1) = 1000^\circ\text{C}$;

Atmospheric temperature near to wall $T_{cf} = 30^{\circ}\text{C}$.

Heat transfer coefficient from the outside wall surface to the air in the room $h_{cf} = 18 \text{ W/m}^2\text{C}$

i) **Rate of heat loss per m^2 of surface area, Q :**

$$Q = (T_{hf} - T_{cf}) \div \left\{ \frac{L_A}{K_A} + \text{Air gap resistance} + \frac{L_B}{K_B} + \frac{L_C}{K_C} + \frac{L_D}{K_D} + \frac{1}{h_{cf}} \right\}$$

$$Q = (1000 - 30) \div \left\{ \frac{0.005}{46.2} + 0.16 + \frac{0.005}{46.2} + \frac{0.03}{0.003} + \frac{0.005}{46.2} + \frac{1}{18} \right\}$$

$$Q = 94.9 \text{ W (Ans.)}$$

ii) **Temperatures at Interfaces T_2, T_3, T_4, T_5**

$$Q = 94.9 = \frac{(1000 - T_2)}{\frac{L_A}{K_A}} = \frac{(1000 - T_2)}{\frac{0.005}{46.2}}$$

$$\therefore T_2 = 999.9^{\circ}\text{C (Ans.)}$$

$$\text{Also, } Q = 94.9 = \frac{(T_2 - T_3)}{\text{Air gap resistance}} = \frac{(999.9 - T_3)}{0.16}$$

$$\therefore T_3 = 984.71^{\circ}\text{C (Ans.)}$$

$$\text{Again, } Q = 94.9 = \frac{(T_3 - T_4)}{\frac{L_B}{K_B}} = \frac{(984.71 - T_4)}{\frac{0.005}{46.2}}$$

$$\therefore T_4 = 984.6^{\circ}\text{C (Ans.)}$$

$$\text{Again, } Q = 94.9 = \frac{(T_4 - T_5)}{\frac{L_C}{K_C}} = \frac{(984.6 - T_5)}{\frac{0.03}{0.003}}$$

$$\therefore T_5 = 35.6^{\circ}\text{C (Ans.)}$$

iii) **Temperatures of outside surface of the wall, t_6**

$$Q = 94.9 = \frac{(T_5 - T_6)}{\frac{L_D}{K_D}} = \frac{(35.6 - T_6)}{\frac{0.005}{46.2}}$$

$$\therefore T_6 = 35.5^{\circ}\text{C (Ans.)}$$

So, we assumed design is safe that is outside wall temperature is 35.5°C which is below than 60°C [12]

IV. THERMAL ANALYSIS BY ANSYS

ANSYS software is used to simulate the model of burner. In ANSYS software using design modular. In this 3D model of burner on the scale of 1:1 is generated as shown in fig 3 & 4

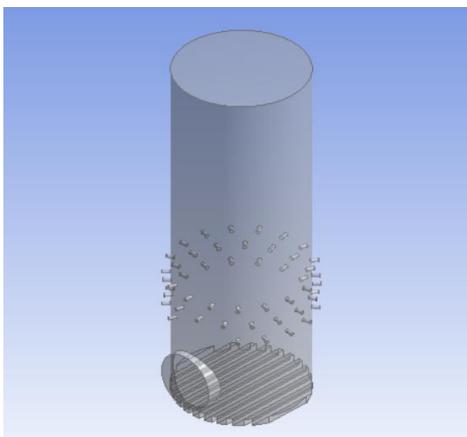


Fig. 2 - first isometric view burner

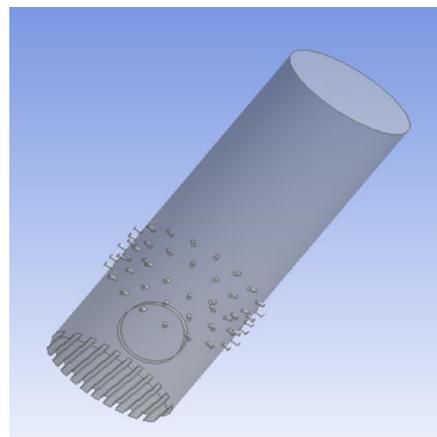


Fig. 3- Second isometric view of burner

In the process of meshing automatic meshing (quadrilateral dominant) element used for meshing as shown in fig.2 & 3. After meshing the Number of elements is 786961. And Number of nodes is 139977.

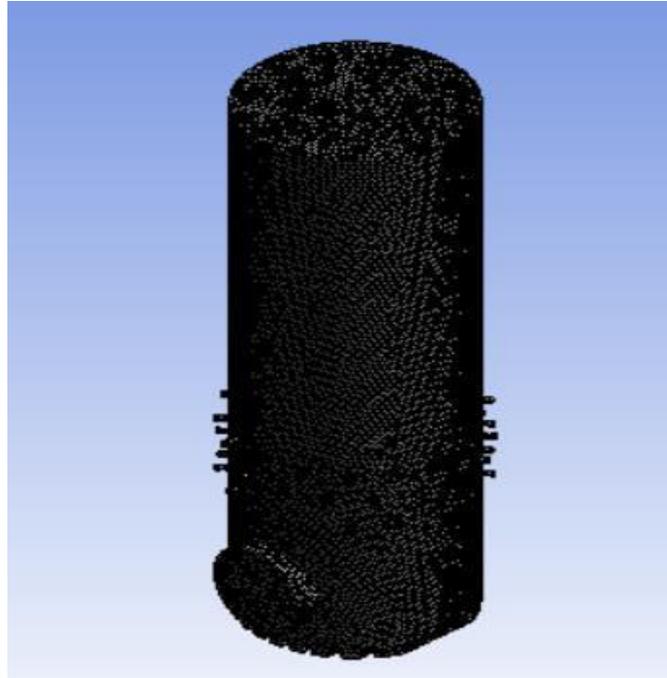


Fig.4 - Meshing of burner front view

Mass flow rate of air and fuel is applied as boundary condition. Solver setup simulation we have actuate energy equation-on, turbulently-on, radiation- model (p₁) on, combustion- non premixed species on after solving 100 Iteration we got results as shown in below,so finally we take 350 CFM value which gives as per required flame height value instead of anotherparameter we take as it is by design. The ANSYS Thermal analysis (CFD) is shown in fig. 5 &6.

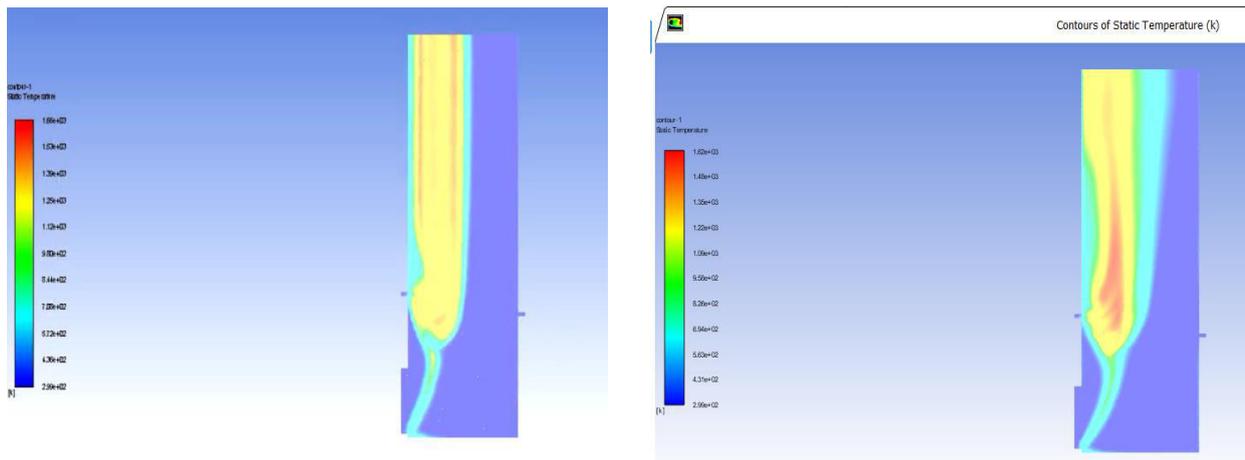


Fig.5 and 6- Flame temperature using Ansys

From Above fig. 5 & 6 we got following result,

- Red zone shows maximum temperature of inside burner flame and is **1350°C**
- Blue zone shows minimum temperature of inside burner near to wall and is **950°C**
- Top flame temperature from outside of burner and is **950°C**



The parameters determined works from theoretical and thermal analysis reading are used for manufacturing of burner are shown in table 1.

Table1.–Theoretical and thermal analysis results

Sr. No	Design parameters of burner	Values
1.	Diameter of reacting chamber	210 mm
2.	Total Air flow rate of primary and secondary air	350 CFM
3.	Mass flow rate of fuel flow	4.5 Kg/hr
4.	Inside burner temperature (red to blue)	1350°C to 950°C
5.	Outside flame temperature	950°C
6.	Outside wall temperature of burner	35.5°C
7.	Thickness of M.S material	5 mm
8.	Thickness of insulating material	35 mm
9.	Total flame height	500 mm
10.	Total height of burner	410mm

Using parameters readings burner is manufactured as shown in fig.8,

V. RESULTS

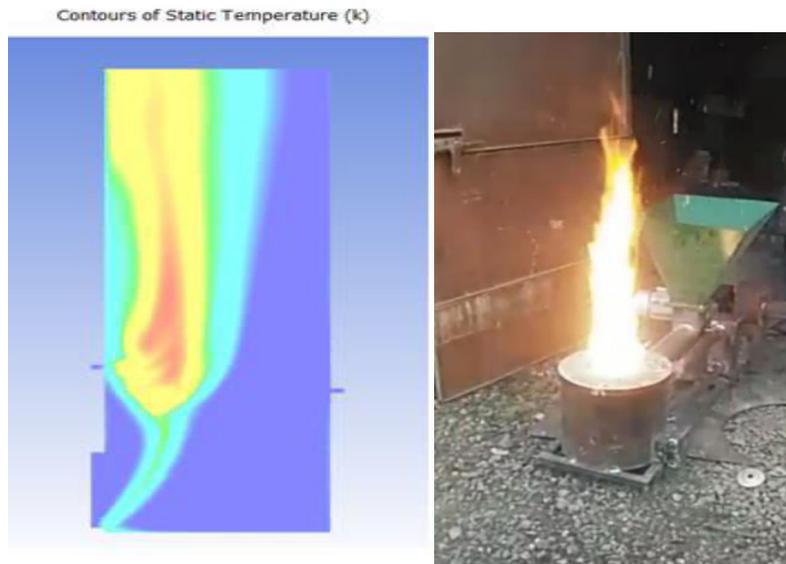


Fig.7 Simulation model Fig.8– Actual flame model

Table 2. - Simulation/ theoretical and Actual model results comparison

Sr. No	Parameter	Simulation / Theoretical results	Actual model results	% deviation
1.	Flame height (mm)	500 (Simulation)	560	0.12
2.	Outer wall temperature (°C)	35.5 (Theoretical)	42	0.18



V. CONCLUSION

Based on thermal analysis using theoretical approach, simulation analysis and physical model, following results were obtained,

- 1) The present burner is applicable for maximum flame temperature of 1350°C and minimum flame temperature of 950°C.
- 2) The outer wall temperature of burner was 35.5°C by simulation analysis and 42 °C by physical (actual) model analysis, which was well below 60°C. Hence thermal analysis results are acceptable.
- 3) The burner manufactured based on parameters determined by the present work is safe and practically suitable for food industries.

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