Computational Study On Forced Draft Biomass Cookstove

Akshay V. Kolge

Abstract—An approach towards an Improvement in performance of cook stoves has been a great challenge to scientists and researchers as biomass cook stoves are one of the basic needs of people living in rural areas. In order to achieve ideal cookstove with lower emission, affordable price and high efficiency as LPG, modification is needed in the traditional cookstoves to deal with health problem and incomplete combustion. This paper consists of Design, calculation and CFD (Computational fluid dynamics) analysis on Forced Draft Biomass Cook stove to determine the velocity at primary and secondary holes when there is a zone of porous wood in the combustion chamber. The combustion chamber is divided into 5 separate zones and each zone has different temperature. The 2D CFD simulation were performed at constant velocity of fan, velocity results at primary and secondary is calculated to know how the physical model will work under actual condition.

Index Terms—Improved Biomass Cookstove, Forced draft, CFD, Performance, Modelling, Analysis.

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1 INTRODUCTION

Cooking food over a fire was invented 1 million years ago. During earlier ages, cooking was done in open fire, but it has a major drawback of heat dispersion during wind conditions. The invention of various shape and size of pot was the main reason for the evolution of other cookstoves. In case of balancing pot over the fire, shielded fire was used and later was modified to cookstove in a U-shaped mud enclosure considering an opening in front, for fire and air entry. Potholes were added later to increase the efficiency and to conserve the heat from flue gases. With their own experience user made innovation in their cookstove design. These consideration lead to an increase in the efficiency, however, the emission continued. People started switching to other fossil fuel such as LPG, kerosene due to low efficiency and poor indoor air quality. The threat of using fossil fuel is its low reliability and high cost. On the long run and for a sustainable path forward, biomass is seen as a potential fuel, however, the cookstoves require huge improvements in terms of efficiency and low emission. The traditional cookstoves have lower efficiency with higher emissions that cause many health problems mainly respiratory disorder and other health issues. According to researchers the lives of poor people depend on this cookstove despite of these problems, so it is necessary to give attention to its design and development [1].

Development and dissemination in improvement of cookstove to address the problem of poor in developing and undeveloped countries are one of the key areas for improvement and development in performance of biomass cookstove. The main goal was to reduce the energy gap between the supply of biomass fuel and the forest deforestation [2]. The assumption was made that there is only need of distribution of improved cookstove since improved cookstove can reduce the fuel consumption by 75% or even more and thus it is superior to traditional cookstove [3]. As a consequence of these assumptions, the attempt failed. After researches, they understand that only small branches were cut down to fire their cookstove so traditional cookstove is not directly responsible for stripping of a tree. For improving the efficiency of cookstove and to guide the user about firewood fetching activity the objective was modified and new objective was to reduce the indoor air pollution. Yet in rural areas these programs face several difficulties in acceptance [3].

Each year 1.6 million deaths and 4.3% of global disease are caused due to traditional cookstove which causes indoor air pollution [4]. In 2009 the national biomass cookstove initiative was started by the Indian government, learning from the outcome of Indian National Program on Improved Cookstoves (NPIC) [5,6], for providing the clean energy service comparable to source such as LPG, while still using same solid biomass fuel with the combined objectives of health protection, climate impacts and fuel efficiency. For clean cookstoves, Global Alliance in the year of 2010 was initiated [7]. It keeps a vision to provide 100 million clean cookstove by the year 2020 which will reduce the problems regarding health and other impacts of current cooking practices.

Starting with S. Varunkumar et al. [8] estimated that with increasing diameter of vessel efficiency also increases. It was found that 6%of total flaming mode efficiency of the stove was due to radiation heat transfer from char bed. M.R. Ravi et al. [9] performed CFD simulation of the heat transfer, pyrolysis, combustion, fluid flow in a simple sawdust stove. The pyrolysis model is a transient one, while the fluid flow, heat transfer and combustion model is a steady state model. During the period of steady-state operation of the stove, the combustion model is interfaced with pyrolysis model. Md. Tanvir Sowgath et al. [10] use Autodesk simulation CFD in which automatic sizing is used and Partial derivative equation (PDE) equation where discretized using "Segregated Solver". Autodesk simulation is used as a postprocessor to visualize and analyze the fluid flow.

Nowadays many researchers are using CFD model to predict the design parameters, its analysis and optimization as it is time saving and cost effective.

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2 IMPROVED FORCED BIOMASS COOKSTOVE

In most of the cookstove, the draft is at the center however the design of improved cookstove consist of Draft tangentially connected with the body, providing swirl and turbulence as we are forcing air tangentially into the combustion chamber it will also lead to better heat conduction and mixing of air. To improve the combustion the number and diameter of primary holes are 9, 14(mm) and for secondary are 8, 6.5(mm) respectively for the combustion chamber to achieve air distribution ratio of 70:30. Using Bernoulli's equation the velocity calculated at primary and secondary inlet is 0.666m/s and 1.472m/s respectively [11]. Due to the considered dimensions for the fabricated cookstove as 165 mm wide and 194 mm in height, the model was easy to handle and had compact structure.

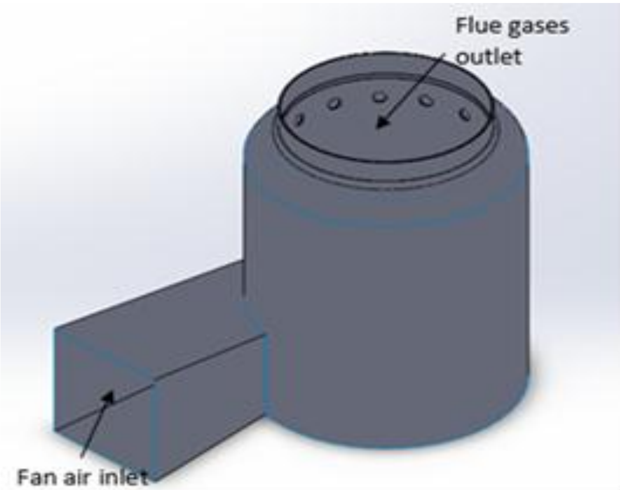

Fig.1 (a) 3D model

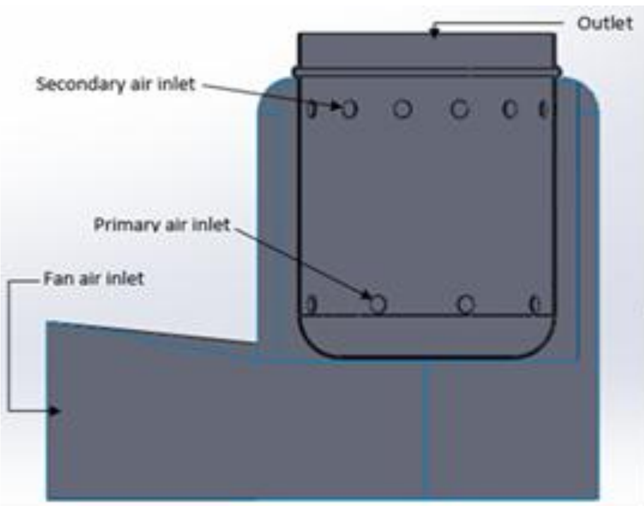

Fig.1 (b) Internal details

The "improved cookstove" are designed in such a way that the cost should be low so that even poor can buy it and easy to use while ensuring a better combustion and heat transfer. Air flow rate, diameter of combustion chamber, height of cookstove, a metal grate under the burning fuel, chimney provision above the fire, reducing thermal losses by insulation, provision of proper size and number of holes at secondary and primary for better mixing of air during combustion are some of the common design strategies. CFD analysis is done on 2-Dimensional geometry of Improved cookstove model for finding their velocity. As CFD simulation provides a better alternative to physical prototypes which are time consuming, moreover these involve more cost compared to CFD analysis.

3 VELOCITY OF FAN

The selection of fan also plays an equal role in forced biomass cookstove as the wrong selection of fan can result in incomplete combustion. Also input condition required for CFD Inlet_fan depend on fan CFM.

Air required for burning 1Kg of wood = 6Kg of Air

Combustion chamber is filled up to ¾ of the height of the combustion chamber = 800 gm

Mass flow rate of air = 4.8 kg/hr

Density of air at 25^o = 1.184 kg/m^3

M_a = 4.8 x 1.184 m^3/hr

M_a = 5.683 m^3/hr

M_a = 0.09472 m^3/min

1 ft^3 = 0.0283m^3

3.5 ft^3 = 0.09472m^3

3.5 CFM = 0.09472 m^3/min

Volume flow rate of air

= 0.09472/60 m^3/s

0.00165=A x V

V= 0.00165/ (0.082 x 0.082)

V= 0.2453 m/s

In ideal condition we get 0.2m/s of fan velocity.

4 CFD ANALYSIS

ANSYS software version 16.0 is used to conduct flow simulation on the model and 3D modelling of the stoves was done by using SolidWorks. Besides contour plots, important data is obtained from CFD analysis and it also allows us to know the actual velocity of air passing through primary and secondary holes at different temperature in combustion chamber.

4.1 Geometry Creation

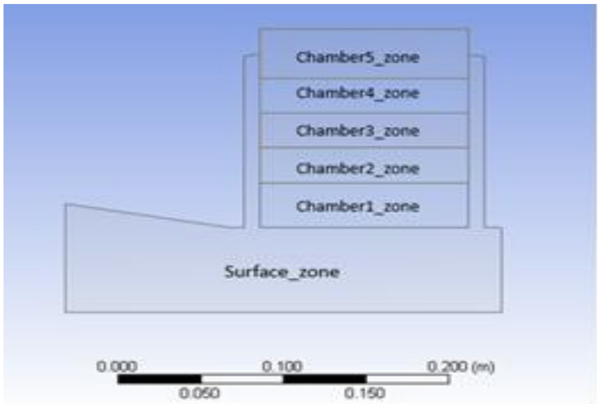

Fig.2 2D Computational domain

In computational fluid domain only the interior part of the model is considered for the fluid analysis along with the fan inlet, wall of the stove and primary and secondary air inlet.

The geometry was performed in ANSYS Design Modeler. The geometry is divided into 6 separate zones and each zone has a different temperature as shown in Fig.2

4.2 Mesh Generation

A fine mesh with 1945 nodes and 1670 elements was generated, the entire model is meshed into Quad and Tri element using automatic method in ANSYS FluidFlow (Fluent).

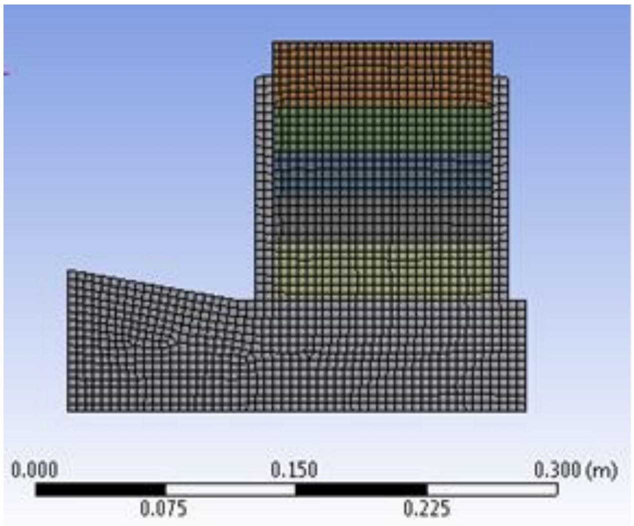

Fig.3 Computational mesh

4.3 Input boundary condition

The energy equation and in viscous model 'k-ε' model was turned on under 'Model' setting and the solver setting was set to general as shown in Table 1.

TABLE 1. SOLVER SETTING

Type	Velocity formulation	Time	Space
Pressure-based	Absolute	Steady	2D, Planer

The material selected was air and wood-volatiles. In cell zone condition each zone are given material as per the requirement and the porous condition is given to the zones where wood-volatiles is selected as material. In porous zone the parameters which has to be calculated are Relative Velocity Resistance Formulation, Inertia Resistance and fluid porosity.

Calculation for Relative Resistance Formuation and Inertia Resistance

- Fluid porosity
  $\varepsilon = 1/(Dp/d)2 + 0.375$
  Dp=0.126(Diameter of combustion chamber)
  $\varepsilon = 1/(0.126/0.0451)2 + 0.375$
  $\varepsilon = 0.5031$
- Relative Velocity Resistance Formulation
  $\alpha = Dp/150 \times \varepsilon 3/(1-\varepsilon)2$
  $= 0.04512/150 \times (0.503)3/(1-0.503)2$
  $= 6.955 \times 10\text{-}6$
  $1/\alpha = 143781.455$
- Inertia Resistance
  $C2 = 3.5/Dp \times (1-\varepsilon)/\varepsilon 3$
  $= 3.5/0.0451 \times (1-0.503)/(0.503)3$
  $= 303.744$

To perform the simulation the five zones of the combustion zone are to be fused together, for which the edge common to both the corresponding zone is selected and fuse together using the fuse option in mesh command.

TABLE 2. BOUNDARY CONDITION

Boundary Conditions	Type	Temp (T)	Velocity	Relative Pressure (Pa)
Inlet_Fan	Velocity inlet	300	0.2	0
Wall	Wall	300	0	0
Chamber_zone1	Wall	573	0	0
Chamber_zone2	Wall	673	0	0
Chamber_zone3	Wall	773	0	0
Chamber_zone4	Wall	973	0	0
Chamber_zone5	Wall	1073	0	0
Outlet	Pressure Outlet	0	0	0.2

The setting of boundary condition were shown in Table 2. The solution was then initialize and the iteration was set to 500 to increase the accuracy of the result. Almost 82 iteration were necessary to obtain converge solution.

4.4 Results

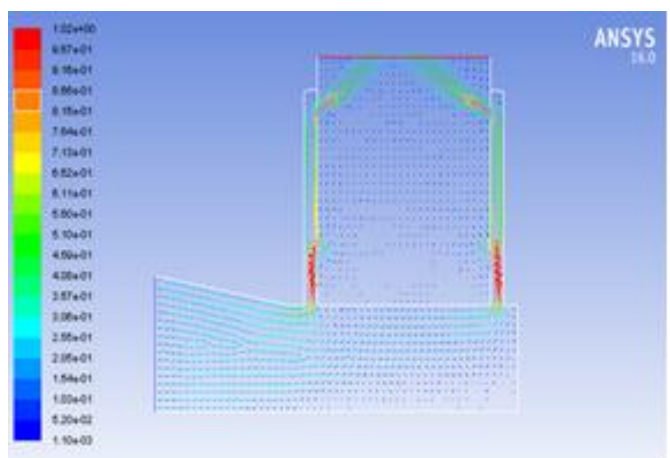

Fig.4 Velocity vector

The result provides us the velocity of air passing in primary and secondary at different temperature. The velocity of the air increases as the air flows through the duct, and at the neck velocity obtained is 0.4m/s, and the velocity further increases. Fig.4 illustrates the velocity in vector form at different regions in the domain. It is obtained that velocity of air passing into primary hole is 0.4m/s and in secondary hole is 0.9m/s by CFD analysis.

5 Conclusion

Although this work describes the modification in the cookstove, the false assumption made in the past, design and CFD modelling. Many alternative fuels are available but the cost is very high so it is necessary to develop an affordable and efficient biomass cookstove. CFD simulation is done on the improved Forced Biomass cookstove to find out the velocity of air, as it is time and cost saving then the physical prototype. The chamber is divide into 5 separate zones and the behavior of air flow under the actual condition is studied to determine the velocity. The velocity of air passing in primary and secondary are calculated using mathematical method. Mathematically it is found that the air flow through the primary and secondary holes is in the ratio of 70:30. The duct for passage of air forms a convergent nozzle, increasing the velocity of air. CFD results for the cookstove showed that air flows through primary and secondary holes with a velocity of 0.4m/s and 0.9m/s respectively. Thus, the modified cookstove will perform efficiently during practical applications.

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