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CFD Study of Biomass Cooking Stove using Autodesk Simulation CFD to Improve Energy Efficiency and Emission Characteristics

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Poor people in Bangladesh suffer different diseases due to indoor air pollution produced by biomass based household traditional cook stoves. Biomass based household ‘improved’ cook stoves were developed and reported Rahman and Razia (2013). In this work, a computational fluid dynamics (CFD) analysis has also been carried out for the household single pot mud stove to analyse the flow behaviour of gas, heat transfer behaviour during the cooking period using Autodesk Simulation CFD 2015. The computational results were compared with the experimental data. These computational models with experimental validation will result in better energy efficiency and environmental friendly cook stove.

1. Introduction

Like other developing countries, the most of the poor people uses biomass fuel for household cooking in Bangladesh. Firewood, leaves, tree twigs, agricultural crop residues such as rice straw, rice husk, jute sticks, sugarcane bagasse, sawdust, cow dung etc. are common types of biomass. A traditional stove is usually a mud-built cylinder with three raised points on which the cooking utensil rests. The energy efficiencies of these traditional stoves vary from 5 to 15 % (Khan et al., 1995). This traditional biomass cook stove (Figure 1) usually lacks a chimney which releases the combustion products directly into the kitchen as smoke which causes Indoor Air Pollution. It has been reported by the World Health Organisation (WHO) that Indoor air pollution is responsible for death and diseases in developing countries (MacCarty et al., 2015).

Figure 1: Traditional Biomass Cook stove and its potential threat on human health

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Due to extensive use of above biomass for cooking in traditional stoves, Bangladesh's forests have decreased by 50 % since 1970 (Rahman and Razia, 2013). The Institute of Fuel Research and Development (IFRD) of the Bangladesh Council of Scientific and Industrial Research (BCSIR) and BUET have been pursuing R&D on stove technology for several decades and have developed a series of models of improved cook stoves. An improved stove can be designed to improve energy efficiency, remove smoke from the indoor living space, or lessen the drudgery of cooking duties (WB, 2011). Cook stove with chimneys and closed combustion chambers are usually considered 'improved'. By reviewing existing literature on stoves aimed at low-income populations, four types of mud built improved cook stoves were designed and installed in Chemical Engineering Department, BUET, Bangladesh.
Extensive literature review is carried out by MacCarty et al (2015) on role of Computational fluid dynamics (CFD) based modelling to analyse combustion process of cook stove. It shows that CFD play an important role for improving combustion process of cook stove (MacCarty et al., 2015), heat transfer efficiencies (Bryden et al., 2003), emission control (Moschandreas and Saksena, 2002), thermal comfort around stove (Skreiberg, 2015). CFD software such as Autodesk simulation CFD replaces the governing partial differential equations into numerical description of the problem and visualize the problem (Autodesk Simulation CFD, 2015).
In this work, an attempt was made to study the different temperature, flow and pressure profiles BUET single mouth cook stove using CFD software Autodesk Simulation CFD 2015.

2. Single pot mud stove description

The single pot mud stove was constructed with locally available materials (mud, metallic grate, 'O' ring, and concrete chimney). The single pot mud stove along with its dimensions is shown in Figure 2. This cook stove was designed by incorporating two concrete chimneys, pre-heating of combustion air in annular section and evenly distributed of preheated combustion air underneath the grate to increase thermal efficiency, reduce emission and indoor air pollution. This stove was fixed type. During different Laboratory tests such as Controlled cooking test and Water Boiling Test, Stack temperature, flame zone temperature, fuel bed temperature, and combustion air temperature were also measured using thermocouple with electronic reader. This model showed better performances with respect to heat transfer efficiency, combustion efficiency and overall thermal efficiency compared to BCSIR-single pot variant (Rahman and Razia, 2013).
Autodesk Inventor (Autodesk Inventor, 2015) is a pre-processor of Autodesk Simulation CFD software used to define the 3D geometry of the model of the cook stove and its surrounding. In Figure 2 isomeric view of cook stove within Autodesk Inventor. In Figure 3, of the cooking stove and its surrounding used for computational domain in Autodesk Simulation CFD is shown.

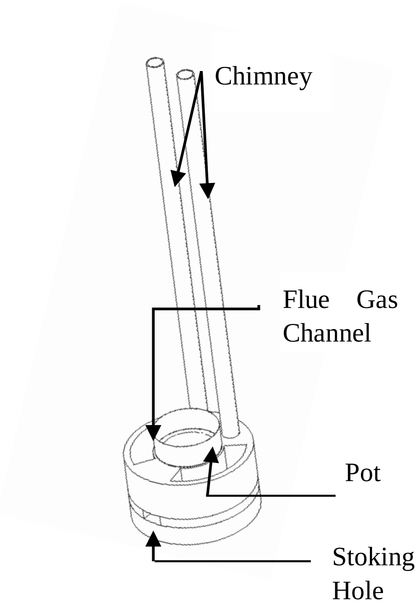

Figure 2: BUET single pot mud cooking stove and its isometric view within Autodesk Inventor

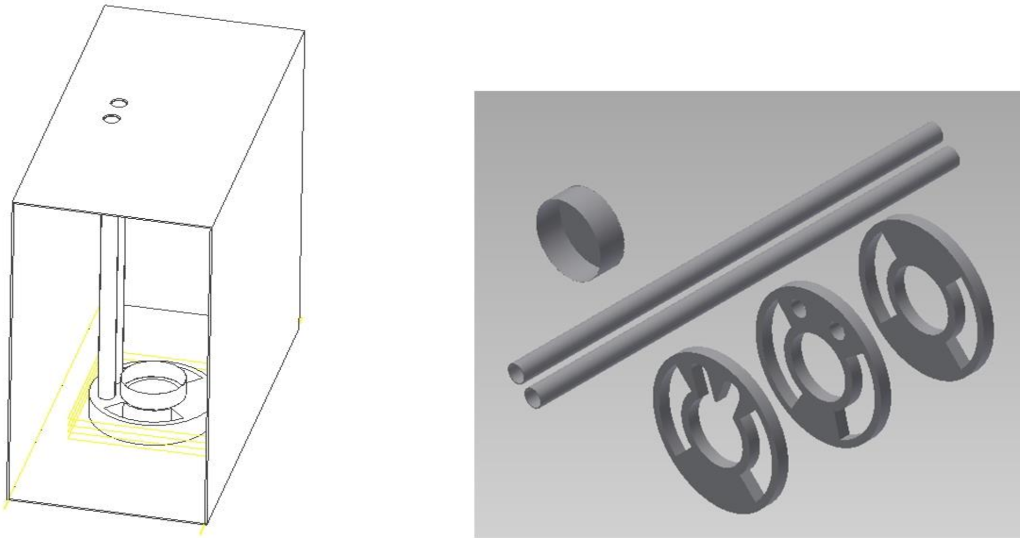

Figure 3: Isometric view of the 3D model of cooking stove and its different parts within Autodesk Inventor

3. CFD simulation using the Autodesk Simulation CFD

Autodesk Simulation CFD (Figure 4) is a state-of-the-art pre-processor for engineering analysis with advanced geometry and meshing tools in a powerful, flexible, tightly-integrated, and easy-to use interface (Autodesk Simulation CFD, 2015). It also provides the organization and interpretation of the predicted flow data and the production of CFD images and animations. Autodesk Simulation CFD solves the CFD model generated after various initial parameters are set. Autodesk Simulation CFD may also be used as a postprocessor to visualize and analyse the fluid flow.

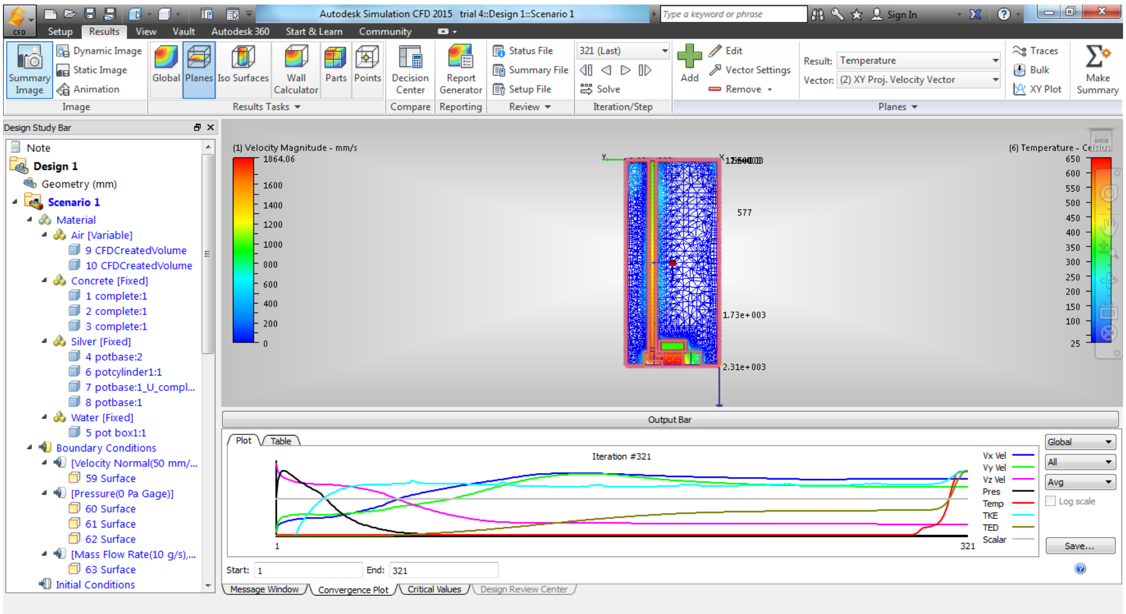

Figure 4: Automatic Mesh Sizing in Autodesk Simulation CFD

4. Results and Discussion

In this work, a 3D single mouth cook stove and surrounding is simulated using Autodesk Simulation CFD. One heat source is simulated in the flame zone of the Autodesk Simulation CFD model. Automatic Sizing in Autodesk Simulation CFD is based on the mesh distribution on edge and surface curvature is used for defining the computational domain for this work. The PDE equations (continuity equation, the Navier-

Stokes equations and the energy equation) were discretized using "Segregated Solver" within Autodesk simulation CFD 2015. Autodesk Simulation CFD may also be used as a postprocessor to visualise and analyse the fluid flow. The simplified inventor design is used for cook stove model development. Colour Temperature and pressure change with time is observed in vector created for pressure and temperature profile within Autodesk Simulation CFD. But after some time no significant change in the profile is observed. This indicates that the cook stove has come to a quasi-steady state. Simulation should be carried out till there no significant change in the profile is found. The final temperature profiles with their mesh geometry are shown in Figures 5.

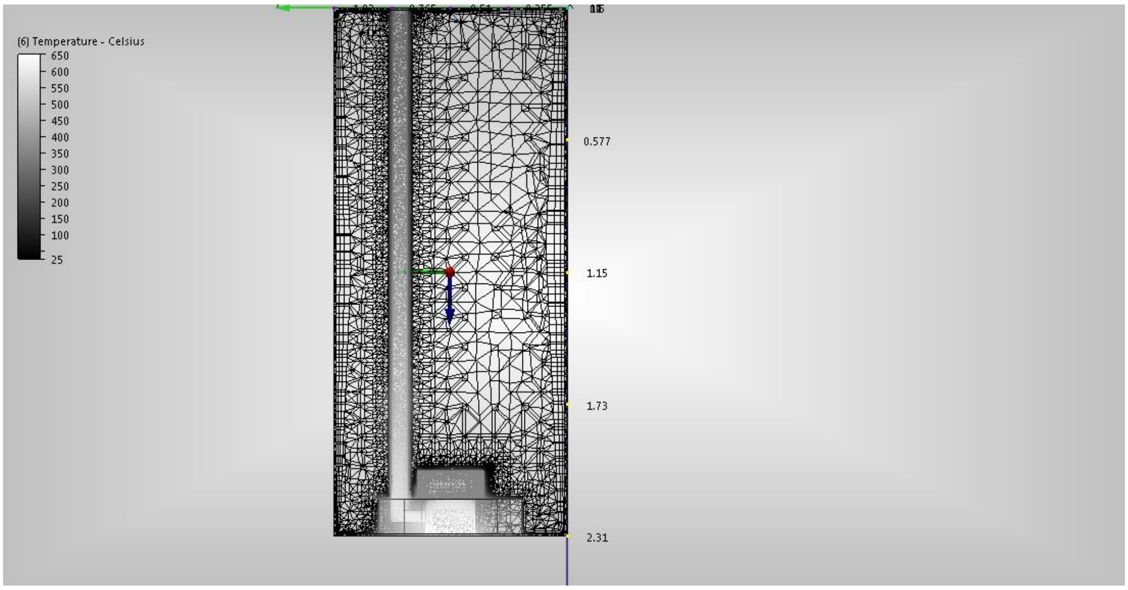

Figure 5: Final Mesh geometry of the temperature profile within Autodesk Simulation CFD

Figure 6 shows the final temperature profile and pressure profile. In the flame zone the air after combustion is 650 °C at a pressure slightly higher than the atmospheric pressure. It is taken as the inlet stream for the simulation. The temperature decreases to about 573 °C where it touches the silver pot which is kept upon the stove. For simplicity in the Autodesk Simulation CFD, the water is heated to about 350 °C in a closed vessel type pot as shown in the Figure 6 Phase change are ignored in the simulation. However, water is boiled at atmospheric condition in open condition in laboratory test. Colour vector is created for pressure and temperature, to assist in giving a visual representation of the combustion fluid. In Figure 6, shift of high temperature flow towards the left corner is observed. Because, it is assumed that air flow is right left (chimney)

Finally, prediction by the Autodesk Simulation CFD (Figure 6) and those experimental data reported by Rahman and Razia, (2013) are shown in Table 1. An agreement was found between both data.

Table 1: Comparison of Autodesk prediction and Experimental Data

	Experimental	Simulation
Fuel bed temperature	673 °C	650 °C
Stack flue gas temp	342 °C	335 °C

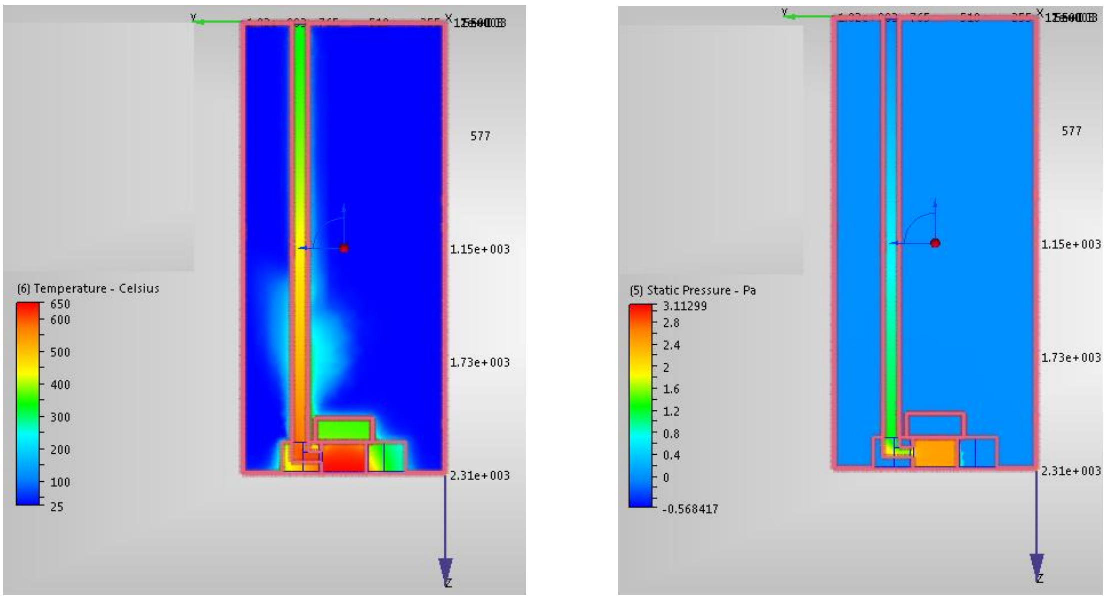

Figure 6: Final Temperature and Pressure gradient

Figure 7 and 8 show the change of temperature of the stack air temperature as it moves to the inlet through the chimney to the outlet. The air is flowing through the chimney inlet holes at high temperature. The temperature then decreases as the air flows upward through the chimney and at the chimney outlet the temperature of the stack air is about 342 °C at the atmospheric pressure.

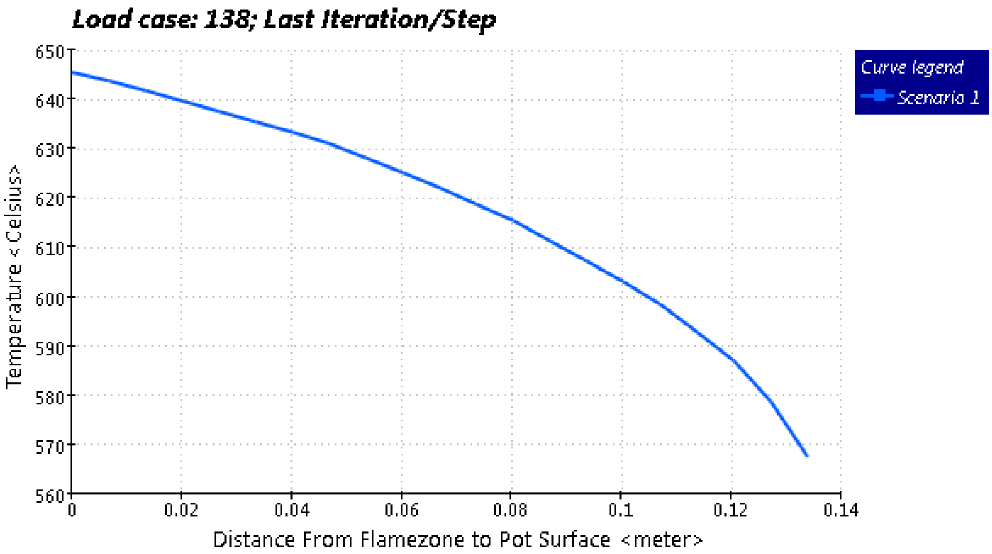

Figure 7: Temperature vs distance from the flame zone air inlet to the pot

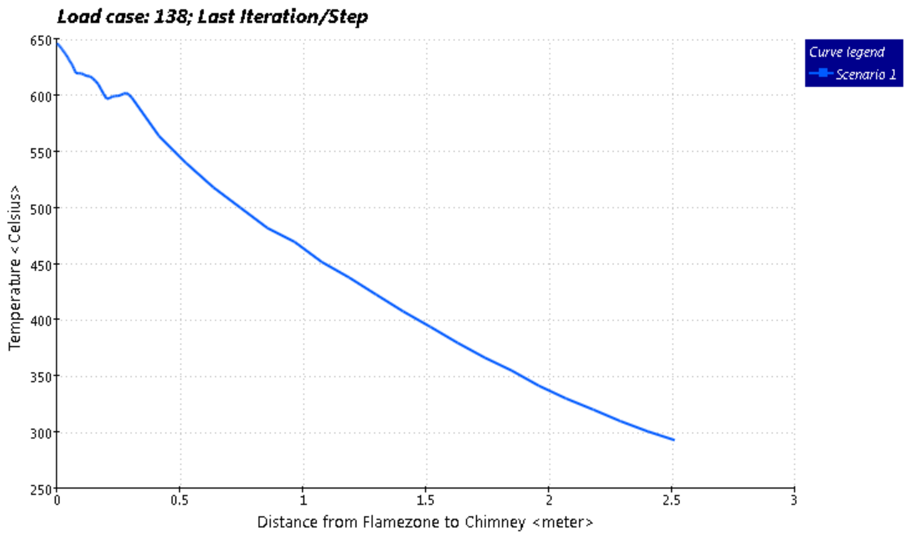

Figure 8: Temperature vs distance from the flame zone air inlet to through the chimney

5. Conclusion

The BUET cooking stove saves fuel (energy) and reduces pollution and cooking time. An attempt has been made to simulate using CFD a simplified structure of single pot BUET cooking stove to analyze the 3D temperature profile and pressure profile. Agreement was found between experimental temperature profile and CFD prediction. Based on the preliminary result and visual profile of parameters, it can be concluded that CFD model developed can be used to study the optimised emission characteristics and the geometry of the cook stove. In future, it is expected to vary the different zones in the stove and optimize heat transfer efficiency of the stove.

Acknowledgement

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