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Performance and Safety Evaluation of Gas Burner Using Fluid Structure Interaction (FSI) Study

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ABSTRACT

Performance and safety evaluation of cooking gas burners has been a very important phase of ensuring efficient and safe cooking processes in households and commercial kitchens. Gas burners performance and safety have been studied using the ANSYS Fluent with regards to heat management for three different materials aluminum, stainless steel and brass for 3,600 seconds. Propane that is the major component of Natural gas was used as the fuel and the gauge pressure for 12.5 kg gas cylinder of 18 bar was used with average gas mass flow rate of 0.07 kg/h. From the findings of these studies, it was observed that brass made the best material for cooking gas burner for safety purposes with regards to effective heat managements It was observed that stainless steel has the highest value of 0.01^0C/s followed by aluminum and brass with least value of 0.0044^0C/s and 0.00035^0C/s respectively over the period of 3,600 seconds of investigating the rate of heat transfer from the top of the burner in contact with the burning flame. The heat flux which represents the rate of heat loss to the surrounding for Aluminum, stainless steel and brass are $0.3392W/mm^2$, $0.3W/mm^2$ and $0.3403\ W/mm^2$ respectively.

Keywords :- ANSYS Fluent, Gas Burners, Aluminum, Safe Cooking

I. INTRODUCTION

Performance and safety evaluation of cooking gas burners is a crucial aspect of ensuring efficient and safe cooking processes in households and commercial kitchens. Gas burners are commonly used for cooking purposes due to their convenience and efficiency in providing heat for cooking.

Performance evaluation of gas burners involves assessing their heat output, fuel efficiency, and reliability. The heat output of a gas burner determines how fast it can heat up food and cook it evenly [8]. A higher heat output is usually preferred for faster cooking times. Fuel efficiency, on the other hand, evaluates how effectively the burner converts the gas fuel into heat energy, minimizing wastage [9]. Reliable burners should consistently provide the desired heat output and not malfunction during use [2].

Safety evaluation of gas burners is of utmost importance to prevent accidents, such as gas leaks and fires. Safety features such as flame failure devices (FFDs) and thermocouples are essential in preventing gas leaks by shutting off the gas supply if the flame goes out. Overheat sensors also play a crucial role in preventing potential hazards by automatically shutting off the burner if it overheats [4].

Proper ventilation and gas leak detection systems should be in place to ensure the safe operation of gas burners.

To evaluate the performance and safety of gas burners, various tests and assessments can be conducted. These may include measuring heat output and fuel efficiency under different cooking conditions, checking the reliability of flame controlled mechanisms, and assessing the effectiveness of safety features. Physical inspection and maintenance checks should also be conducted regularly to ensure burners are in good working condition and adhered to safety regulations.

By evaluating the performance and safety of cooking gas burners, individuals can make informed choices about the types and models of burners they should use in their homes or kitchens. This evaluation process ensures efficient cooking processes that save time and energy while prioritizing safety, preventing accidents, and promoting a secure cooking environment.

Most of the gas explosion incidences that had claimed lives and destroyed properties both at home and in industries are traced to gas leakages. Cooking gas burners play important role as it is the part where combustion takes place. The temperature distributions on this metallic part of gas stove has to be investigated over time to ensure safety of the user and to know when it has to be disposed or replaced.

In recent years, the application of Computer Aided Engineering (CAE) in evaluating the performance and safety of cooking gas burners has gained attention. Various studies have utilized computational techniques such as CFD simulations to assess different aspects of burner design and operation.

Adegbola A.*et al.,* (2016) designed and constructed a burner of a two self-ignited gas cooker made from locally sourced materials to improve its energy efficiency and got optimum conditions from the combustion performance.

Mana W. *et al.,* (2018) implored experimental and computational flow dynamics(CFD) techniques to investigate the flow features and combustion phenomena of an energy-saving cooking burner using three dimensional CFD. Combustion temperatures were experimentally and numerically investigated in order to validate the CFD and described the combustion phenomena. The results obtained from the temperature comparison showed that the CFD model was in consonant with the experimental results with error less than 5.86%.

Mana W*., et al.,* (2020), investigated the Thermal efficiency of LPG cooking burner using computational fluid to analyze the thermal performance of a gas burner. The researchers assessed the heat transfer characteristics and temperature distribution within the burner, optimizing the design for improved efficiency and safety.

Michael K. *et al*., (2022), studied and analyzed the performance of a Flat bottom Institutional Cook stove, a water boiling test experiment was used to test for the stove's power and efficiency followed by a computer modeling analysis with Computational Fluid Dynamics using ANSYS Fluent simulations. The computer model was validated using statistical evaluation with four metrics and concluded that CFD method can be used as a complement to conventional methods of assessing and improving the Flat Bottom Institutional cook stove design.

Martin G.,(2023) published his research work highlighting the different areas where CFD can be applied in burner design such as Optimizing Combustion Processes, Heat Distribution and Uniformity, Reducing Energy Waste, Enhancing

Safety, Innovation in Biomass Stove Design and Future Trends and Sustainability

Bezuayehu M, *et al.,* (2017) studied the Design and optimization of a biomass burner was studied using computational fluid dynamics (CFD) simulations of the burner by varying number and size of flame ports to increase the diameter of manifold prior to actual fabrication, this study was done to alleviate the Ethiopian urban and rural communities suffering from different diseases due to indoor air pollution as they were still using traditional biomass based 'injera' or bread backing activities.

In order to create a comfortable environment in the work place around commercial kitchen, it was desirable to accurately predict the capture efficiency of exhaust from the cooking appliance by CFD [10]. Due to insufficient diffusion in buoyant plume, however capture efficiency tends to be overestimated in the k-ε model. In their study, they confirmed that the problem of the k-ε model in the prediction of plume originated from the buoyancy production of the turbulent kinetic energy by comparing among the measurement value, simulated results using the LES model and the k-ε model, and possible remedy discussed.

Temperature distribution and flow pattern in a biomass cooking stove designed for household have been studied using CFD simulation. The minimum height of chimney required at the highest temperatures of the pots was determined to be 1.65 m, this results were also validated experimentally [15]. CFD assisted optimization study on biomass cooking stove for implementing geometric design modifications to achieve uniform air- fuel distribution have been studied in an independent investigations. The work involved numerical investigations of fluid phase hydrodynamics and air-fuel homogeneous phase combustion. The study showed that the homogeneous combustion have linear dependence of power and temperature on the air velocity and air-to-fuel ratio [13].

However, an investigative research work showed that Porous media burners could serve as an alternative technology in order to improve the thermal efficiency and emission characteristics of domestic cooking stoves [5]. These studies have potentials to turn around burner technology for both domestic and industrial applications.

These studies demonstrate the potential of CAE in evaluating the performance and safety of cooking gas burners. By utilizing virtual testing and simulations, CAE can provide valuable insights into burner design, combustion efficiency, emission control, thermal performance, fire and explosion risks, and overall reliability and durability [1].

Although specific studies related to cooking gas burners may vary in their focus and methodologies, the application of CAE in this field holds promise for enhancing the performance and safety of gas burner systems.

II. METHODS AND MATERIAL

The burner was modeled on solidworks and the CFD part with Midas NFX and simulated with ANSYS fluent. Propane that is major component of Natural gas was used as the fuel and gauge pressure for 12.5 kg gas cylinder of 18 bar was used with average gas mass flow rate of 0.07 kg/h [20]. The ratio of 10:1 of air to fuel for combustion was used to estimate the flow rate of air [21]. The burner was simulated using transient CFD and transient heat transfer analysis for 240, 3600 seconds. Common gas burner materials such as stainless steel, Aluminum and Brass were investigated to see how it acquire heat over the time. The combustion was modeled as non-premixed with k-e model for the turbulence. The combustion part (CFD) was coupled with transient heat analysis to complete fluid structure interface (FSI) in which the combustion temperature serve as the load for the structural part. A mesh density of 131,179 Nodes and 641,930 elements for the CFD part and 32,068 nodes and 15,492 elements adopted for structural parts.

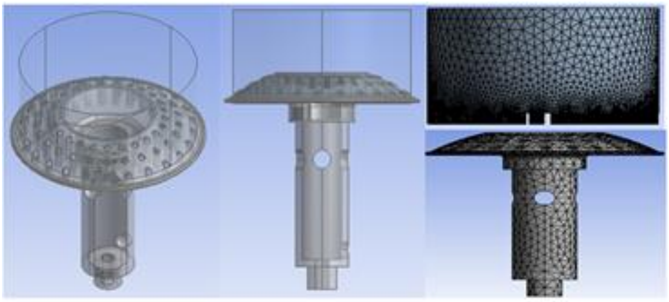

Fig 1 : Model of Gas Burner & CFD part Isometric view, Front view and Mesh

III. DISCUSSION OF RESULTS

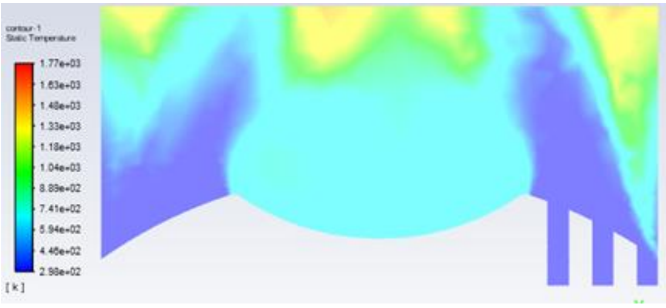

Fig 3.1 : Flame Temperature

The maximum flame temperature from the combustion study was 1770 K (1742.85 °C) as shown in the fig3.1. The combustion temperature transferred to the structural part as the thermal load 78 °C for the period of study.

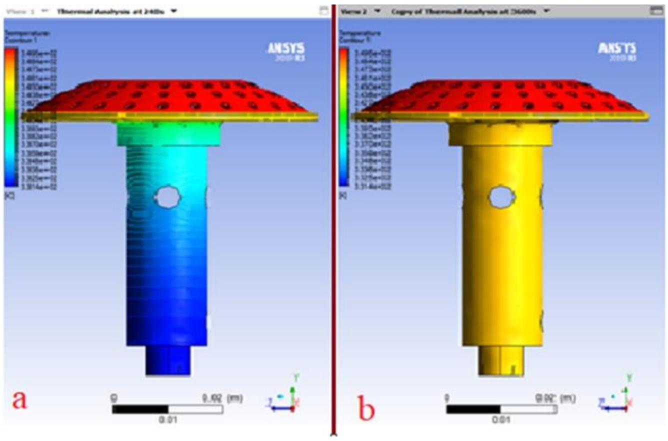

Fig 3.2: (a) Temperature Distribution over period of 240 seconds, (b) Temperature Distribution over period of 3600 seconds

The temperatures at the top and bottom of the burner after 240 seconds were 76.941°C and 58.205°C, 76.937°C and 73.142°C after 3,600 seconds as shown in the fig3.2a and fig3.2b respectively. The heat acquired from the combustion temperature over the period of investigation by the top burner. The combustion temperature transferred to the structural part as the thermal load 78°C for the period of study transferred to the bottom by conduction until equilibrium. The combustion temperature transferred to the structural part as the thermal load 78°C for the period of study maintained. The rate of transfer depends on the time and material of the burner. It can be deduced that for aluminum material the rate at which transferred to the bottom from the top where combustion took place was 0.0044°C/s. This rate plays important role on the safety of the cooking gas cylinder and rate of heat flux as the surrounding air serve as coolant to dissipate the heat.

The average heat flux observed over the same period was 0.3392w/mm^2 for the period of study. The heat flux is a measure of how heat energy is lost from the surface of the burner in order to maintain its temperature at a safe level, the heat flux have to be high enough it is a function of not only the material but also the prevailing environment conditions in terms of prevailing air velocity. The temperature plot in the fig 3.2, show that the entire burner approximately becomes uniform over time. The temperature drop sharply within the 25seconds and then gradually from 25seconds to around 120seconds and later become stable at a value of 76.875°C. This shows that the material is a good conductor, transferring the heat from a region of high temperature until equilibrium was maintained.

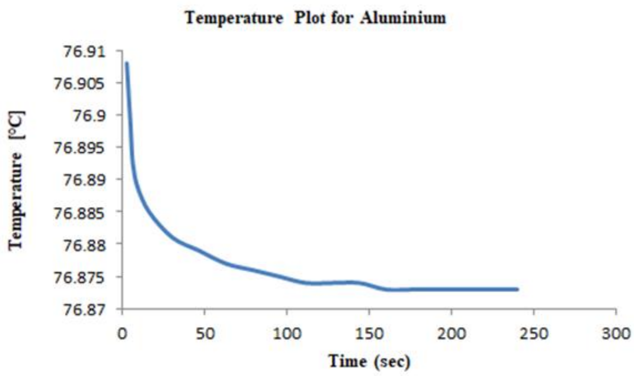

Fig 3.3 : Temperature – Time Plot for Aluminum

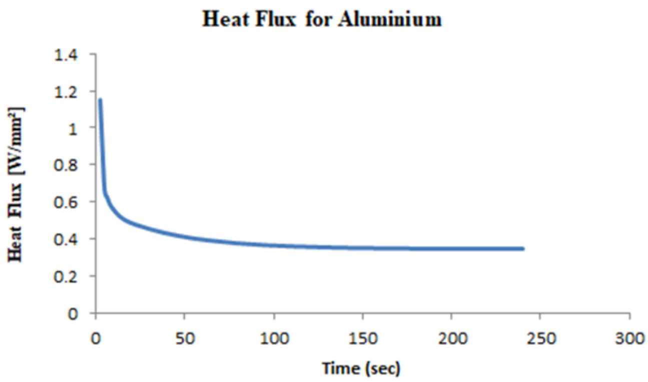

Fig 3.4: Heat Flux – Time Plot for Aluminum

At the same rate the heat flux dropped sharply within the first 15seconds and begins to be eased off gradually from a maximum value of 1.2w/ mm^2 to around 0.4w/ mm^2 as shown in fig 3.4. The heat flux is a measure of heat loss to the surrounding which is expected to Be responsive to temperature.

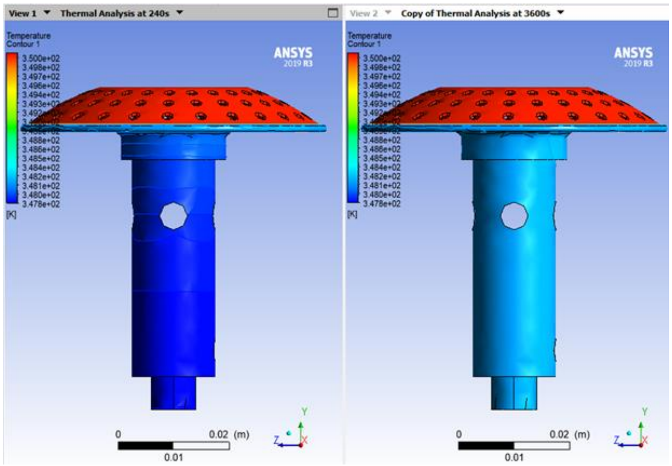

Fig 3.5 : Brass Material Temperature Distribution over period of 240 & 3600seconds

Fig 3.5 above, show that the temperature at the top of the burner where combustion took place and the bottom was 76.899°C and 74.685°C after 240second respectively. It maintained 76.899°C and 74.77°C approximately the same temperature after 3,600second of investigation. The heat flux was approximately the same over the same period of time with an average value of 0.3403w/ mm^2.

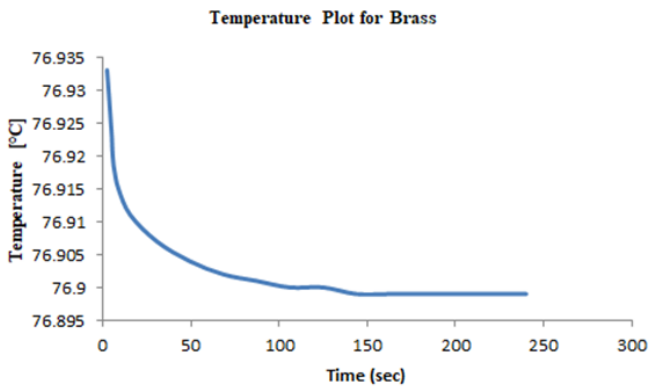

Fig 3.6: Temperature – Time Plot for Aluminum

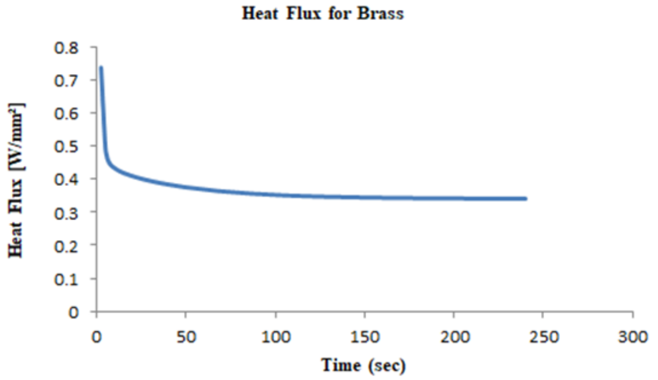

Fig 3.7 Heat Flux – Time Plot for Aluminum

The plot from the brass material as shown in fig 3.6 above, have the same pattern of dropping over the same period but with a smaller negative temperature gradient of about 0.00035°C/s. The conduction of heat from the top to the bottom of the brass burner was slower compared to other materials, suggesting that it was the poorest conductor of heat among the three materials studied. This made it better in terms of heat management for safety purposes as a burner material. The fig 3.7 shows the behaviour of the heat flux over time as the initial drop of heat loss from 0.75 w/ mm^2 to 0.4w/ mm^2 within 10seconds into the investigation and later become stable at the same value.

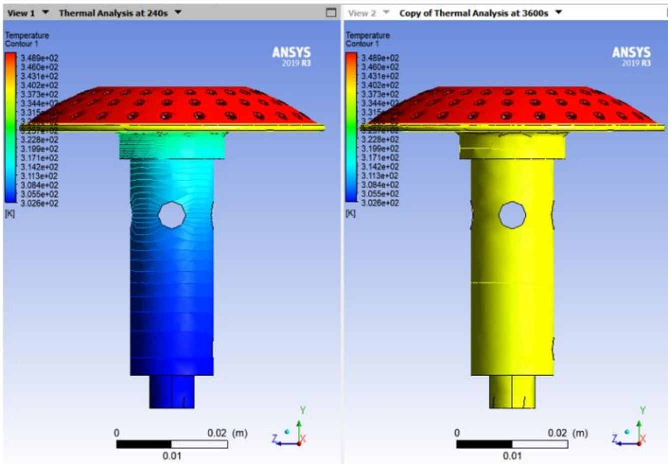

Fig 3.8 ; Stainless Steel Material Temperature Distribution over period of 240 & 3600seconds

The temperature distribution of 77.177°C and 29.434°C was initially observed from the stainless steel burner after 240second and later the top still maintained 77°C while the bottom rose to 63.372°C after 3,600seconds representing a positive slope of about 0.01°C/s which is the highest compared to the remaining two materials. The stainless steel as burner material showed the poorest heat management as it will become very hot over time, then susceptible to hazard to the user.

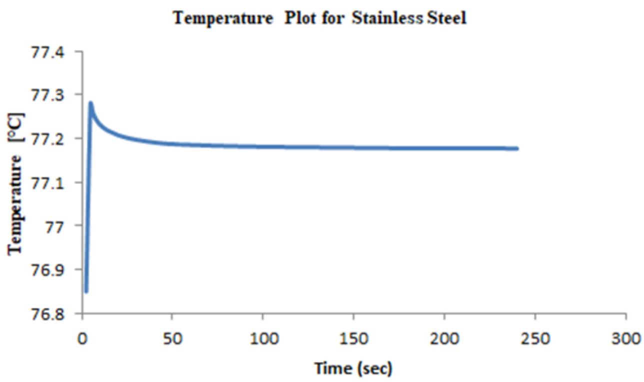

Fig 3.9 Temperature – Time Plot for Aluminium

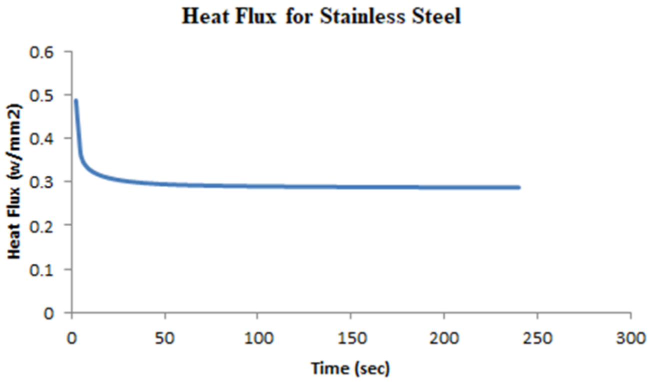

Fig 3.10 Heat Flux – Time Plot for Aluminium

The fig 3.9 above shows that stainless steel burner acquired the combustion temperature faster and conducts it the other parts within a short period of time and later stable at approximately 77°C which was the combustion temperature. This anomalous behaviour Is not good enough for a material used for the production of a burner. The fig 3.10 above shows that the heat flux was approximately stable at 0.3w/mm² after it dropped from the pick of about 0.5 W/mm². The rate of heat lost to the surrounding was the slowest among the two other materials studied.

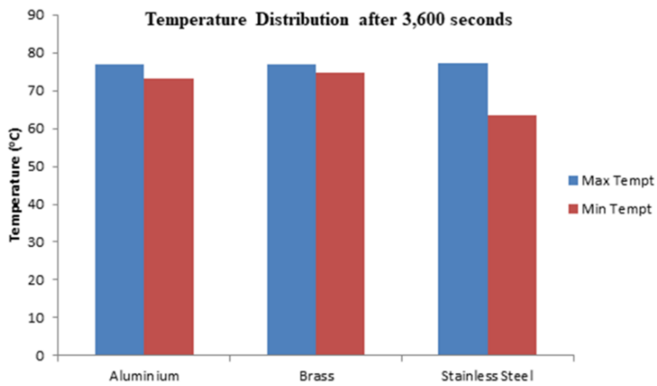

Fig 3.11 Comparison of Temperature Distribution over period of 3600seconds for different Materials

Fig3.11 above show the temperature difference between the least heated and most heated part of the burners for a period of 3,600second. The rate of heat transfer and heat loss to the surrounding may be different and varies due to material and environmental factors.

IV.CONCLUSION

The performance and safety evaluation of cooking gas burner using fluid structure interaction (FSI) have been studied with ANSYS FLUENT and Transient Thermal in terms of its ability to manage heat distribution or heat loss to the surrounding as it could posed danger of burnt, explosion if used for a long time. It was observed that stainless steel has the highest value of 0.01^{0}C followed by aluminum and brass having the least with the value of 0.0044^{0}C and 0.00035^{0}C respectively for the rate of heat transfer from the top of the burner in contact with the burning flame for the period of 3600 seconds of the investigation.

The heat flux which represents the rate of heat loss to the surrounding for Aluminum, stainless steel and brass are 0.3392w/mm^2, 0.3w/mm^2 and 0.3403w/mm^2. The maximum and minimum temperature on the burner for Aluminum material was76.937^{o}C and 73.142^{o}C, for stainless steel; 77.168^{o}C and 63.372^{o}C, and for Brass 76.899^{o}C and 74.77^{o}C the rate of heat loss to the surrounding was highest in brass compared to the other two materials. From the findings of these studies, it can be deduced that brass make the best material for cooking gas burner for safety purposes with regards to effective heat managements.

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