ME – PhD Thesis Colloquium

Development of a novel LPG/PNG domestic burner for high efficiency and low emissions

S. Rahul Kashyap, Department of Mechanical Engineering, IISc Bengaluru

April 2nd, 2025, at 10.30 AM

Venue: Conference Room, ME @ IISc

ABSTRACT

Domestic cooking is one of the basic human needs, and cookstoves based on fuel combustion are widely used. LPG (Liquified Petroleum Gas) is the most common cooking fuel, followed by PNG (Piped Natural Gas), which has an increasing consumer base in India. Thus, even a slight improvement in domestic burner efficiency can save large quantities of fuel to benefit the national economy. Also, since PNG is about three times less dense than LPG with very different combustion characteristics, dedicated burners must be designed and optimized for PNG. The present study explores novel burner designs to improve thermal efficiency and reduce pollutant emissions.

In the first part, validated three-dimensional Computational Fluid Dynamic (CFD) modelling is used to simulate the flow and fuel combustion above the burner and heat transfer from the hot gases to the vessel. A simulation with the conventional LPG burner showed that the convective heat flux profile directly correlates with the temperature and velocity distributions in the vicinity of the vessel and shows multiple peaks with very low heat transfer at the centre. Thus, a novel burner design was conceptualized by orienting the flow towards the centre to increase the near-vessel gas temperature and residence time. The burner diameter and hole inclination angle were optimized for maximizing convective heat flux, leading to about 7-9% higher predicted efficiency.

In the second part, the novel burner was designed, fabricated and evaluated in a test rig which enables precise control of the fuel and air flow rates, loading height and equivalence ratio (f). To quantify the heat flux distribution and the burner efficiency, an infrared camera was used to measure the temperature distribution on an aluminum plate. The heat flux distribution was calculated using the heat balance equation. The emissivity of the anodized aluminum plate was calibrated by measuring the heat flux from an electric heater with a set heating rate. The pollutant emissions and OH* distributions were also measured. The novel burner was observed to stabilize much leaner LPG flames up to an equivalence ratio ⍰ = 0.8. Heat flux measurements depicted a higher and more uniform heat flux with the novel burner. The burner efficiency is defined as the ratio of area-integrated heat flux on the plate to the input power. The measured efficiency of the conventional burner with LPG at an equivalence ratio of 1.4 is taken as the baseline value for comparison, and its value is 58.2% at a flow rate of 45 slph and 55.4% at a flow rate of 75 slph. At the cookstove-like condition of ⍰ = 1.4 and a loading height of 25 mm, the novel burner shows 4.5% and 2.7% higher efficiency over that of the conventional burner at LPG flow rates of 45 and 75 slph, respectively. Reducing the equivalence ratio to values of 1.2 and 1 achieved a maximum improvement in efficiency of 4.3% and 5.6% higher efficiency, respectively. The maximum reduction in CO emissions is observed to be 76% for an equivalence ratio of 1. Next, the novel burner was evaluated with PNG fuel. The stable flame regime and heat flux profiles were found to be similar to those with LPG. At ⍰ = 1.2 and 1, the maximum improvement in efficiency was observed to be 5.2% and 4.7%, respectively. CFD simulations using reduced mechanisms accurately captured the flame structure (OH* distribution) and heat flux trends observed with both LPG and PNG fuels.

In the final part, two design additions were evaluated, i.e., inclusion of a radiative disc and a heat-collecting shield around the burner. Heat flux measurements revealed that the radiative disc reduces the heat flux due to the disruption of the flow field near the vessel. On the other hand, the heat-collecting shield led to a maximum improvement in efficiency of 4.8% and 3.7% over that of the novel burner with LPG and PNG fuels, respectively. Consequently, a maximum improvement in burner efficiency of around 10.5% and 8.4% over that of the conventional burner is observed with LPG and PNG fuels, respectively. The CO emissions were less or on par with those of the conventional burner. Finally, the efficiency of the novel burner was assessed in the actual cookstove following the Indian Standard tests (IS 4246, IS 17153). The combination of the novel burner and the shield yields the highest thermal efficiency of 68.9% and 72.2% with LPG and PNG, respectively, resulting in corresponding fuel savings of 4.6% and 7.9%. Thus, a fundamental understanding of the fluid flow, combustion and heat transfer phenomena have successfully guided the optimization of the burner design, leading to a high-efficiency, low-emission burner suitable for use with both LPG and PNG fuels. Additionally, the study has provided a robust methodology for designing burners for heating applications.

ABOUT THE SPEAKER

S. Rahul Kashyap is a direct PhD student in the Department of Mechanical Engineering at IISc Bangalore. He completed his B.Tech. in Mechanical Engineering from PES University, Bengaluru in 2018. He then joined IISc as a direct PhD student. He was awarded the Prime Minister's Research Fellowship. His research interests include computational fluid mechanics, combustion and heat transfer.