ABSTRACT

Cooking devices with combustion of fuel have been used for time immemorial the world over. While human beings learnt to burn the available fuel for suiting their cooking needs, which also evolved with time, in the past five or more decades, the cookstove researchers have focussed on improving the combustion and heat transfer in cookstoves so as to improve their thermal efficiency and emissions. The documentation of this research has also happened in primarily last five decades or so. While many designs of improved cookstoves developed by researchers have evolved over a period of time with a hope to replace the traditional ones, acceptance of improved and advanced cookstoves in the field has been limited. One important factor in this regard has been the need to change fuel and/or cooking practices with the adoption of new devices—the lesser the need for these changes, the more has been the willingness to adopt any interventions. The present work is motivated by this factor—it aims to design simple retrofits to a traditional natural draught biomass cookstove, through thorough and systematic studies on existing cookstoves. While cookstove testing has evolved so much that even there is an availability of comprehensive ISO standards for testing cookstoves, scientific design process of one of the important equipment for testing, *viz.*, the emission hood, is not available in the literature. The present thesis also takes up this task to analyse emission hoods and present recommendations for its design.

The parameters affecting the airflow through a cookstove placed under two kinds of emission hoods, *viz.*, the closed emission hood and the open emission hood, have been studied through experimental measurements supported by analytical models and CFD models. Results of the analytical model show that a threshold value of negative gauge pressure at the inlet of the emission hood can be determined, beyond which the suction of the hood would affect airflow through the cookstove significantly

(change by more than 10%). For the chosen cookstove, this threshold pressure was found to be -0.15 Pa. The area of the inlet of the emission hood is determined by two factors: the area of the hood should be larger than that of the plume rising from the cookstove-vessel; for a given fan pressure rise, this area should not produce negative gauge pressures beyond threshold. In this thesis, using the turbulent plume entrainment theory, the rate of increase of plume width above the cookstove-vessel was calculated for different heights of the hood inlet above the cookstove, and a linear relation was established. Also, using CFD analysis of the hood-duct-fan region and cookstove-surrounding-hood inlet region, for the closed hood, the area of the hood inlet at which a given pressure rise at the suction fan could cause significant change of airflow through the cookstove was determined. Besides, to correct for re-circulations inside the hood making part of the area ineffective for suction, a correction is to be applied so that 85% of the actual hood area would be satisfying these two criteria. Using a combination of these results, recommendations have been made for design of an emission hood.

A traditional natural draught cookstove commonly used in the villages around Delhi was chosen for the analysis and retrofitting in the present work. Experiments on the cookstove showed that its operation was stable at input and output power values substantially higher than necessary for domestic cooking as defined by advanced biomass cookstove designs. Because of this, the efficiency was low and emissions were high. Introduction of a grate in the cookstove improved thermal efficiency, but further increased input power and had no effect on emissions. The cookstove was tested under the hood and without the hood, and no significant change in fire power was noticed between the two cases. The primary and secondary air flow rates through the stove were estimated for different fire power values by using a simple analytical model as well as a CFD model in ANSYS-Fluent.

Experimental cookstoves, which were used as laboratory analogues of the traditional cookstove with desired modifications, were tested in three phases—(i) a preliminary experiment phase to identify the feasible operating ranges of the parameters:

minimum mass of fuel bed (MMFB), primary airflow rate (PA) and ratio of total to primary airflow rates (TA/PA ratio); (ii) Experiments using central composite design over these ranges to characterise the cookstove and (iii) Out of these, conducting more experiments in the recommendable range of parameters where the cookstove operated more smoothly and efficiently. Analysing the results, the recommended range of parameters for the cookstove were identified as FBR of 20–35 g/min, PA of 10–25 slpm and SA such that total air is slightly above stoichiometric requirement for the FBR.

Based on the above, interventions were planned in the form of inserts to improve the performance of the traditional cookstove used commonly in northern part of India. The idea was to use an insert as a retrofit for the existing cookstove. Three inserts were designed and fabricated. For design of the inserts, a simplified fluid flow model through the cookstove with insert was used to get first estimates of dimensions for the desired airflow. It was observed that with the inserts, the cookstove performed more efficiently with less fire power. Particularly, with a square insert of size 12×12 cm^2, the fuel burning rates matched typical values used in advanced biomass cookstoves for domestic cooking—around 0.9 kg/hr (15 g/min). Thermal efficiency was increased to 25% from a value of 17% for the traditional cookstove, but the output power was about 25% lower than that in a traditional cookstove.

When the traditional cookstove was operated by an experienced operator, the emissions were quite low even without the inserts. When operated with the inserts, by the same operator, the cookstove could not perform better than the case without insert in terms of CO and PM emission factors. However, in terms of total mass of emissions of both CO and PM, the cookstove with insert had lower values than the one without it. Thus, the retrofit proposed in the present work, in the form of inserts, appears promising. With some more work, it could be an easy-to-fabricate and inexpensive intervention, capable of making the cookstove burn more efficiently and cleanly without demanding much change from the users in terms of fuel or cooking methods, and hence could be more acceptable in the field.