Report on tests on reverse downdraft stoves (REDS) for stove applications – 2003 to 2008
ABETS, IISc, Bangalore

Abstract

This report consists of three parts. Part I deals with tests done on some chosen designs aimed largely at examining the efficiency of stove operation and developments towards enhancing the efficiency. These were done largely as a part of masters work of Ms Manikondana Sharma (shortened as Monica), a student from Tezpur university. Some additional tests were conducted after the technology transfer to BP took place.

Part II contains a discussion of the results posted by Mr. Dean Still on the internet and a book called "Comparison of stoves".

Part III contains a detailed emission study that was conducted to understand the role of the secondary air flow in the emissions.

Appendix I contains the test procedure followed in the water boiling tests.

All the test results are put together according the date of the test.

Part I: Early detailed tests on fixed fuel stoves (REDS)

Introduction

Reverse downdraft combustion systems were used initially in the project on Strategic development of bio-energy (SDB that was operational between 1999 and 2004) to characterize the ash fusion behavior of agricultural and other residues. This used a blower to deliver the air for gasification. Around 2002, several computer based fans became available at a cheap price largely because the disposed-of obsolete computers were cannibalized by the market. This led to the thought if such fans could indeed be a solution to problem of building fan based stoves that are efficient and with low emissions. Not much was known about the characteristics of the fans, even though the general behavior could be deduced from fundamental principles; tests had to be done on the fans.

But the first thought was to construct a stove and examine how it performs. Based on initial judgments, the areas of secondary holes for combustion were set out and the stove constructed. Subsequently several variants were also built. The first astonishing thing that was noted was that for typically meaningful vessels used for cooking in rural environment, the water boiling efficiencies were between 45 to 52%. These numbers were rarely achieved in the 1984 – 1988 research and development studies (the peak efficiency that was recorded was 40 % during this period) and this feature was traced to the near-uniform high temperatures (both spatially and temporally) that were achieved in the combustion process that allowed operation at near constant air-to-fuel ratio due to the fact that the gasification was the foundation of the solid-to-gas conversion process.

The fuels used were wood chips, waste marigold pellets (that was available from a source for which a gasification system was built to dry the retted marigold flowers), rice husk briquettes, coconut shell and in some instances coffee husk pellets.

The stoves that were built are shown in Table1.

Table 1. The stove dimensions and biomass used in tests

a. 100 mm stove, L/D=0.8

(M = Waste marigold pellets, RHB = Ricehusk briquettes, W = Wood chips}

Biomass	Density of biomass (kg/m^3)	Biomass to be loaded (g)	Stove diameter (mm)	Stove effective height (mm)	Volume (liter)	Height below grate (mm)	Height above holes (mm)
M	390	230	100	80	0.6	30	20
RHB	460	275	100	80	0.6	30	20
W	190	115	100	80	0.6	30	20

b. 135 mm stove, L/D=0.53

Biomass	Density of biomass (kg/m^3)	Biomass to be loaded (g)	Stove diameter (mm)	Stove effective height (mm)	Volume (liter)	Height below grate (mm)	Height above holes (mm)
M	390	390	135	72	1	30	20
RHB	460	460	135	72	1	30	20
W	190	190	135	72	1	30	20

c. 150 mm stove, L/D=0.55

Biomass	Density of biomass (kg/m^3)	Biomass to be loaded (g)	Stove diameter (mm)	Stove effective height (mm)	Volume (liter)	Height below grate (mm)	Height above holes (mm)
M	390	550	150	83	1.4	30	20
RHB	460	650	150	83	1.4	30	20
W	190	265	150	83	1.4	30	20

d. 200 mm stove, L/D=0.34

Biomass	Density of biomass (kg/m^3)	Biomass to be loaded (g)	Stove diameter (mm)	Stove effective height (mm)	Volume (liter)	Height below grate (mm)	Height above holes (mm)
M	390	850	200	69	2.2	30	20
RHB	460	1000	200	69	2.2	30	20
W	190	420	200	69	2.2	30	20

e. 200 mm stove, L/D = 0.58

Biomass	Density of biomass (kg/m^3)	Biomass to be loaded (g)	Stove diameter (mm)	Stove effective height (mm)	Volume (liter)	Height below grate (mm)	Height above holes (mm)
M	390	1325	200	110	3.4	30	20
RHB	460	1560	200	110	3.4	30	20
W	190	650	200	110	3.4	30	20

The properties of the fuels used is shown in Table 2

Table 2. the properties of the fuels used.

Biomass	Moisture content (%)	Ash content (%)	Bulk density (kg/m^3)
Wood pellets (W)	15	0.8	200
Marigold pellets (M)	14	14	366
Rice husk briquette (RHB)	11	19	445
Coconut Shell (CS)	14	0.55	380

The cooking vessels were aluminum vessels of 10 liter volume (diameter of 320 mm, height of 160 mm, and 0.96 kg weight), 6 liter volume (diameter of 260 mm, height of 130 mm and weight of 0.61 kg) and 2.5 liter volume (diameter of 205 mm, height of 105 mm weight of 0.34 kg. The results of the experiments are summarized in Table 3

Table 3: Summary of the results of experiments

a. 10 liter carrying Al vessel

Date	Biomass	Biomass loaded (g)	Power (kW)	Eff. (%)	Burn time (min)	Water loss(g)	Ash (%)	Rise in temp (^{0}C)
20-10-04	(10%) W+ (90%) M	30+225	2.4	48.8	25	26	11.3	38
20-10-04	(10%) W+ (90%) M	30+225	2.1	49.1	27	23	11.2	38
25-10-04	W	130	2.5	52.5	16	10	1.1	23
25-10-04	W	130	2.1	52.6	19	11	1.1	23
27-10-04	(26%) W+ (74%) M	60+170	2.5	51	23	20	10.4	37
28-10-04	(42%) W+ (58%) M	85+115	2.5	57.2	21	20	7.5	35
28-10-04	(56%) W+ (44%) M	100+80	2.4	50.5	17	15	7	29
06-11-04	(42%) W+ (58%) M	85+115	1.9	60	26	15	7.5	37
06-11-04	(42%) W+ (58%) M	85+120	2.0	59.4	26	16	7.8	38
27-10-04	RHB	50+250	2.1	48.6	35	26	18.3	44
28-10-04	RHB	50+250	1.9	49.3	37	25	18.8	44
08-11-04	(10%) W+ (90%) CS	30+230	2.3	53.3	40	15	0.6	48
08-11-04	(10%) W+ (90%) CS	30+230	2.1	53.5	42	15	0.6	49
12-11-04	(22%)CS+(68%)M+ (10%)W	60+180+25	2.0	54.3	30	15	8.3	46
12-11-04	(36%)CS+(53%)M+ (11%)W	100+150+ 30	2.3	52.8	29	15	7	48
21-11-04	(6%)W+(94%)CHB	25+360	2.4	52.6	42	40	4	69

b. 6 liter water carrying Al vessel

Date	Biomass	Biomass loaded (g)	Power (kW)	Eff. (%)	Burn time (min)	Water loss(g)	Ash (%)	Rise in temp (^{0}C)
19-10-04	W	128	1.9	45.1	26	10	1.1	33
25-10-04	(10%) W+ (90%) M	30+225	2.5	48.7	24	20	10.4	62
8-11-04	(10%) W+ (90%) CS	30+242	2.1	45.8	43	35	0.5	70
8-11-04	(10%) W+ (90%) CS	30+242	1.6	47.1	48	38	0.9	71

2.5 kg Al vessel

Date	Biomass	Biomass loaded (g)	Power (kW)	Eff. (%)	Burn time (min)	Water loss(g)	Ash (%)	Rise in Temp (^{0}C)
25-10-04	W	130	1.6	40.8	22	20	1.1	69
02-10-04	(10%) W+ (90%) M	30+210	1.9	44.1	33	26	10.4	70,51

Subsequent to the technology transfer to BP, tests were carried out on stoves built by BP. These are shown in Table 4.

Table 4. Testing on BP-Orrja in 2007

Efficency test \ Power level	High	Medium	Low
Test date	02/08/'07	02/08/’07	03/08/’07
Nominal capacity of vessel used: (Liters)	**10**	**10**	**10**
Size of fuel chamber, mm	100	100	100
Height of fuel chamber, mm	130	130	130
Type of fuel used: Groundnut pellets			
Specific heat of water cp, *kJ/(kg K)*	4.187	4.187	4.187
Latent heat of water l *kJ/kg* at sea level	2235.0	2235.0	2235.0
Specific heat of Aluminum c_{pa} *kJ/(kg K)*	0.8	0.8	0.8
Ash fraction of heavier fuel	0.080	0.080	0.060
moisture fraction of heavier fuel	0.076	0.076	0.076
Ash fraction of kindling material	0.008	0.008	0.008
moisture fraction of kindling material	0.080	0.080	0.080
Mass of heavier fuel loaded into stove, kg	0.500	0.500	0.500
Total mass of fuel used, kg	0.550	0.550	0.550
	Vessels 1, 2	**Vessels 1, 2**	**Vessels 1, 2**
Initial temperature of water, *C*	24, 24	23, 24	23, 24
Mass of water filled kg	10, 10	10, 10	10, 10
Final temperature of water, *C*	87, 57	85, 53	85, 61
Water evaporated, *kg*	0.02, 0.007	0.02, 0.006	0.02, 0.006
Vessel weight including stirrer and lid, *kg*	**1.27, 1.05**	**1.27, 1.05**	**1.27, 1.05**
Output energy:			
Water sensible heat, *kJ*	4019.3	3851.9	4186.8
Vessel sensible heat, *kJ*	91.7	82.6	94.9
latent heat, *kJ*	64.8	55.9	46.9
Total output energy, *kJ*	4175.9	3990.3	4328.6
Overall power in g/min	12	8.94	7.5
Input energy	**GN pellets: 15.4 MJ;** **Wood chips: 16.5 MJ**		
Total input energy, *kJ*	8521.3	8521.3	8688.6
Water Boiling Efficiency (%)	**49.0**	**46.8**	**49.8**

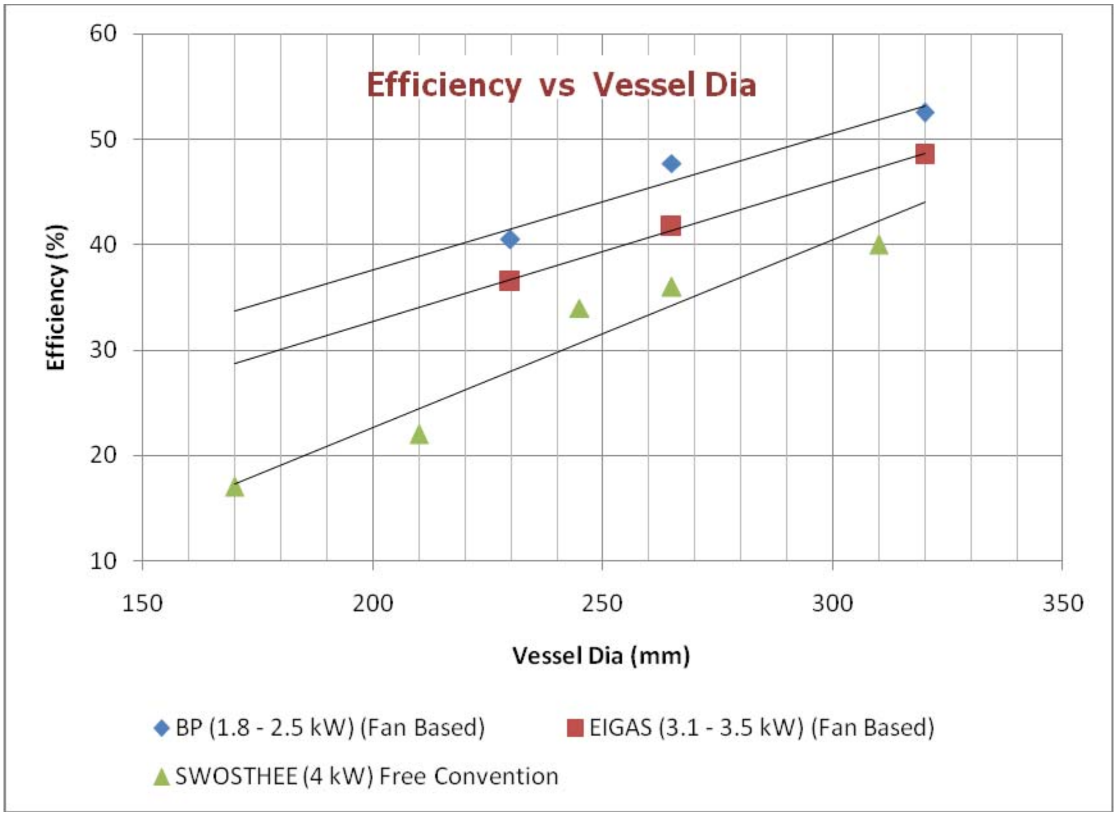
Part II: Notes on comparison of results with other stove data and some analysis

	Calculations for boiling 5 L water; other data drawn from Dean Still's book, Comparison of stoves, 2007							
	Stove	Fuel g	Time mins	Power kW	CO g	PM mg	CO g/MJ	PM g/MJ
1	Three stone Fire	1118	26.7	5.93	56	2363	3.13	0.1338
2	Ghana Wood	996	21.8	5.00	50	4287	3.14	0.2724
3	20L Can Rocket	733	22.3	4.18	15	1289	1.28	0.1113
4	Mud/Sawdust	793	16	6.23	49	2352	3.86	0.1877
5	Wood Gas Fan	459	23.7	2.56	7	27	0.95	0.0037
6	Mali Charcoal	674	38.6	4.38	113	260	10.48	0.0093
7	VITA	689	14	6.50	43	2150	3.90	0.1734
8	Gyapa Charcoal	694	28.03	5.19	135	587	12.16	0.0338
9	Propane	139	23.00	2.08	1	5	0.45	0.0008
10	Kerosene	247	41.8	1.92	8	10	2.02	0.0395
11	**BP Stove**	190	**23.7**	**2.1**	2.2	166	**0.75**	**0.0625**

Comb. Space **dia, m**	Comb space **ht, m**	Comb space **Vol, liters**	To boil **Fuel kg**	Top area **Sq. cm**	Vessel **dia, cm**	Power **kW**	Top Re	Res time **s**	eff
0.15	0.04	0.71	0.601	200	24	5.93	61.28	0.81	0.16
0.26	0.15	7.96	0.422	530.93	24	5.00	32.34	10.58	0.22
0.12	0.30	3.39	0.361	113.10	24	4.18	58.61	5.39	0.26
0.36	0.06	6.11	0.386	1017.88	16	6.23	29.11	6.51	0.25
0.1	0.09	0.71	0.235	78.54	24	2.56	43.08	1.83	0.40
0.25	0.05	2.45	0.406	490.88	25	4.38	18.28	6.00	0.2
0.27	0.19	10.88	0.352	572.56	24	6.50	40.45	11.13	0.3
0.24	0.03	1.36	0.342	452.39	24	5.19	22.09	2.86	0.2
0.14/0.12	0.02	0.10	0.064	52.00	24	2.08	14.86	0.96	0.5
0.16/0.14	0.08	0.38	0.115	47.1	24	1.92	15.43	3.55	0.3
0.1	**0.09**	0.707	**0.19**	**100**	**30**	**2.1**	30.86	2.27	0.5

1. Comparisons are made on an as available basis with no specific revealing observations on the power of the stove. For instance, a 3 kW stove at 40 % efficiency is superior to a 4 kW stove at 30 % efficiency even though the delivered power is the same – 1.2 kW because one uses 75 % less fuel. This message is to be seen nowhere in the document.

2. A reference power level is the LPG stoves prevalent in most countries. The power level in the domestic stoves is about 2 to 3 kW. The efficiency of these stoves is about 65 %. This implies that a wood stove could have a power level of 3 to 4 kW if the efficiency is in the range of 30 to 50 %. Designing larger power level stoves may bring down the time to boil, but at the expense of efficiency.
3. The document seems to overlook the vessel diameter. The vessel is termed “international standard 7 liter vessel”. It is not clear who created such a standard and how?



4. Figure on efficiency vs, vessel dia shows the data on the efficiencies as a function of vessel size. The 320 mm Aluminum vessel is used to heat up 10 liters water. The 265 mm Aluminum vessel is used to heat up 6 liters of water and the 230 mm vessel is used to heat up 2.5 liters of water. This range is used as it covers a range of utility in the rural environment. The influence of vessel diameter on the efficiency is significant as can be noticed from this figure.
5. The argument that the volume of 5 liters in a 7 liter vessel is standard does not imply that the vessel diameter is specified. Unless this is specified, there is no point in talking about standardization.
6. The earlier standards like the Indian standard on stoves derived partly from the British standards used an Aluminum vessel based, perhaps, on two observations. Its heat conductivity is high and prevalent rural practice assessed by the standards’ committee. These were the basis of the work done on vessel size at the Indian Institute of Science.

Part III: Report on re-testing of BP – Oorja stove

Mr. Srinath, Anup have taken significant efforts to conduct the experiments with diligence and it is their efforts that have led to this report

Inroduction

The BP-Oorja stove was tested in 2006 when the stove was launched in Tamilnadu and Maharashra. After two years with more than 280,000 stoves in the field, with modified stove designs contemplated for release, not only in India, but China, some issues were raised. Principally, these were related to concerns whether indoor air pollution (IAP) standards in India and elsewhere were being met with by the stove. It was clear that the way indoor air pollution issues were debated in international circles combined the stove with the kitchen, for what matters was whether the cook in the kitchen was subject to pollution levels higher than allowed. It did not appear that the links between these two aspects were understood. *A reasonably good stove (in terms of emissions) with a bad kitchen could be portrayed as bad and equally well a reasonably bad stove with a very well ventilated kitchen could pass off as a good stove (from the point of view of emissions only).* The stove designer uses thermodynamics and combustion to get the emissions low. A computational fluid dynamics specialist and a civil engineer should contemplate designing a kitchen (or a series of kitchens to cater to a variety of situations) to ventilate the kitchen well.

Quite often, it is thought that a stove with chimney is a good solution to the problem, no matter what the emissions are. This is also not correct. There are two points here. Firstly, all such designs should allow for vessels to be taken off from the stove to be replaced by another. During this period emissions *would be into the kitchen*. Secondly, emissions taken out of the kitchen will imply emissions into the atmosphere. It has been thought that it does not matter if the emissions are introduced into the atmosphere, as long as the user of the kitchen does not have to inhale these emissions. This makes the design efforts being less sensitive to the way combustion process is managed and inevitably, the emissions will be higher. Further, the use of chimney always implies that the air flow is based on natural convection. This air flow is a non-constant function of time including the fact that the vessel (s) will get removed from above the stove during the cooking period.

Finally, emissions into the atmosphere are a subject of debate vis-à-vis the use of gas stoves. It has been pointed out, rightly, that GHG emissions from a poorly-burning biomass stove are worse than from a well-burning gas stove. All in all, it is vital to contemplate and conduct the combustion process with high efficiency to ensure burn out of all undesirable chemical constituents. If this is done the job of the stove designer is complete. It is then the job of the kitchen designer to deal with the rest and not attempt to pass on the problems of IAP to stoves.

The retesting effort was further necessitated by some tests on ceramic version of Oorja stove termed Oorja 3 that showed higher emissions. The first thought was that the process of ceramic stove manufacture may have caused shrinkage of the secondary holes and it was a matter of resetting the die design to ensure the right dimensions of the secondary holes. But then, when a recently manufactured Oorja 1 (the original oorja stove) also showed higher emissions. This led to several speculations including whether the measurement system (quintox) was indeed calibrated and could the measurement error not have contributed to this perception. Added to this was the fact that some measurements were done in a different laboratory that showed satisfactory results on emissions. A sequence of tests was therefore conducted. To establish the credibility of measurements of emissions, the measurements were made on a LPG gas stove. These showed that the emissions were very small. The details are as under.

Tests done on LPG stove on 14th Aug 2008; LPG flow rate 2.44 g/min = 0.047 g/s = 0.047 x 45 kJ/g = 2.115 kW The CO level is 0.013 % and CO_2 level is 1.3 % and oxygen is 19.4 %

Measured CO_2/fuel ratio is 3.1 while the theoretical value is 44/14.5 = 3.03 (Note that the fuel is approximated by $CH_{2.5}$). The CO/CO_2 ratio is 0.01 (v).

The fact that CO/CO_2 ratio is 0.01 appeared consistent with expectations of clean combustion of the stove and hence it was concluded that the measurement system was in good condition.

It was then decided to check if the secondary holes were rightly sized. It was uncovered that they showed a diameter of 4.75 mm and there were 18 holes. This appeared quite small compared to the original dimensions of 6 mm+. Tests were performed with increased dimensions – 5.2 mm x 18 holes and then 6 mm x 18 holes. The dramatic effects of reduction in emissions will be presented below.

A strange behaviour of emissions of CO was noticed (will be presented below). It was found that the emissions of the stove with 4.75 mm dia holes for the secondary air remained about constant (as expected) till some time and started rising significantly. This looked puzzling because one would expect that the emissions would remain constant throughout, at least till the char burn condition was reached. This led to the speculation that that the airflow would have been reducing with significant effects after some time. That this was entirely possible in this configuration is not a surprising matter. Air flowing in the annular space would pick up heat from the walls. To determine the temperature – time behaviour a special experiment was designed and conducted. A small hole of 3 mm was drilled on the outer metal wall and temperature of the air being fed into the combustion zone was measured by allowing a small leak into the ambient. This was done with a 0.1 mm Pt- Pt-13%Rh (R type) that was placed in the centre of the issuing jet about 3 mm from the wall. This showed (data will be presented subsequently) that the temperature increased steadily to 245 ºC, leading to a reduction in density of 60 % and hence a corresponding flow rate. This being substantial, one could expect enhanced emissions. All the data would be presented now.

Table 1. Summary of emission data on BP-Oorja stoves

Test no.	Date	A_s mm^2	m_f g	Ash g	Ash g	t_v min	Water boiling η, %	m_{CO} g	m_{CO2} g	m_{NO} g	m_{SO2} g	remarks
1	11/8/08	320	650	75	11.5	40		59.1	1039	0.027	1.18	full power
2	14/8/08	320	650	71.5	11	47	53.2	62.3	1008	0.037	2.13	12 g/min
3	18/8/08	320	650	85	13.1	48		89.2	939.2	0.027	2.14	11 g/min
4	19/8/08	320	650	68.5	10.5	44		53.6	953.8	0.030	1.10	os Full power
5	19/8/08	382	650	79	12.2	40		32.5	1029	0.035	0.53	os 5.2mm X 18
6	20/8/08	510	650	78	12	38		9.6	879.2	0.037	BDL	6mm X 18
7	20/8/08	510	650	73.5	11.3	41	52.6	10.6	814.6	0.037	BDL	6mm X18, 12g/m

As = secondary area for air, m_f = fuel mass, t_v = time for high burn The high burn rate period is the period during the pellet combustion and the low burn rate period is when the pellet char is burning; m_i = masses of CO, CO_2, NO and SO_2. os = tests done outside, others inside a room. This test was not considered good due to continuous operation of the air control valves to maintain a certain power level.

Table 2 Emissions reflected in terms of mass per unit energy

A_f, mm^2	mCO_2/kg	mCO/MJ	mNO/MJ	mSO_2/MJ
320	1.81	6.51	0.0029	0.130
320	1.74	6.82	0.0041	0.233
320	1.66	9.99	0.0030	0.239
320	1.64	5.83	0.0032	0.119
382	1.80	3.60	0.0039	0.059
510	1.54	1.07	0.0041	-
510	1.41	1.16	0.0040	-

It can be noted from Table 1 that the secondary area has got recued to 320 mm^2 compared to the original value of 560 mm2 (6.3 mm holes, 18 in number) found on stoves that were used in the early stages of BP marketing. The ash content is also large. Table 2 shows the emission measures in terms of g/kg for CO2 and g/MJ for others. The g/kg for CO2 will depend on the actual C-H-N-O composition of the fuel pellets. This will vary depending on the actual agro-residue used to make the pellets. There appears a need for actually measuring the C-H-N-O composition of the pellets to ensure that these are properly reproduced. Figure 1 shows the CO emitted in g/MJ with area of secondary air (the data are in table 2). The dramatic decrease of CO emitted with increase in secondary area cannot be missed and should be kept in mind in the design. The efficiency drop, if any, because of this, is marginal. Hence it is very important to keep the secondary area above a minimum. It is recommended that it be 6.2 ± 0.2 mm, 18 in number. This should be strictly monitored, particularly in ceramic stoves.

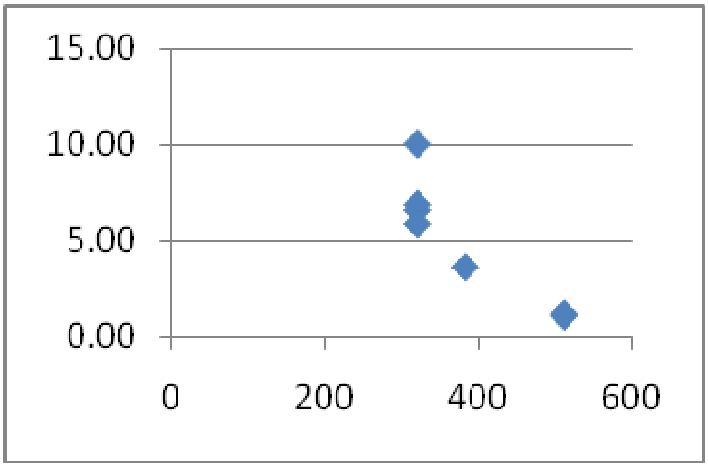


Figure 1. The CO emissions in g/MJ with secondary hole area

The measured temperature –time curve of the hot are entering the secondary holes is shown in Figure 1. The density drop will be inversely proportional to the temperature ratio between start and at any time. The peak ratio of temperatures in about 1.6 and this will be the density drop ratio as well.

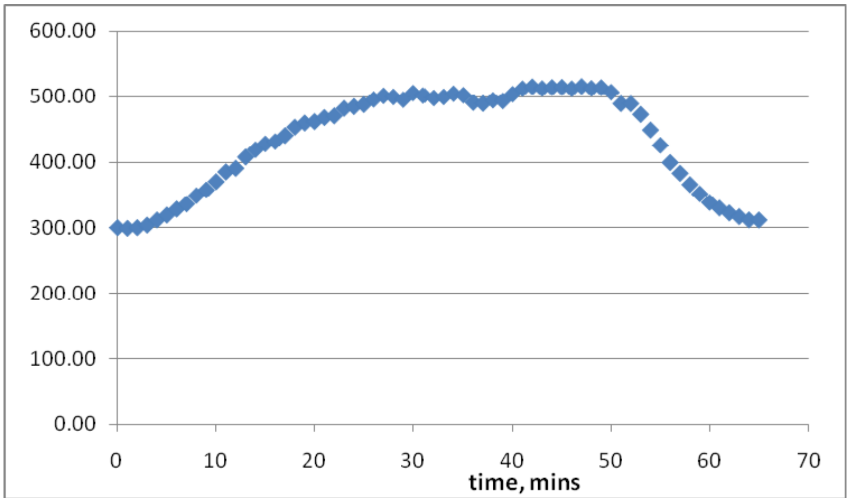


Figure 2. Secondary air temperature (K) vs. time of stove operation

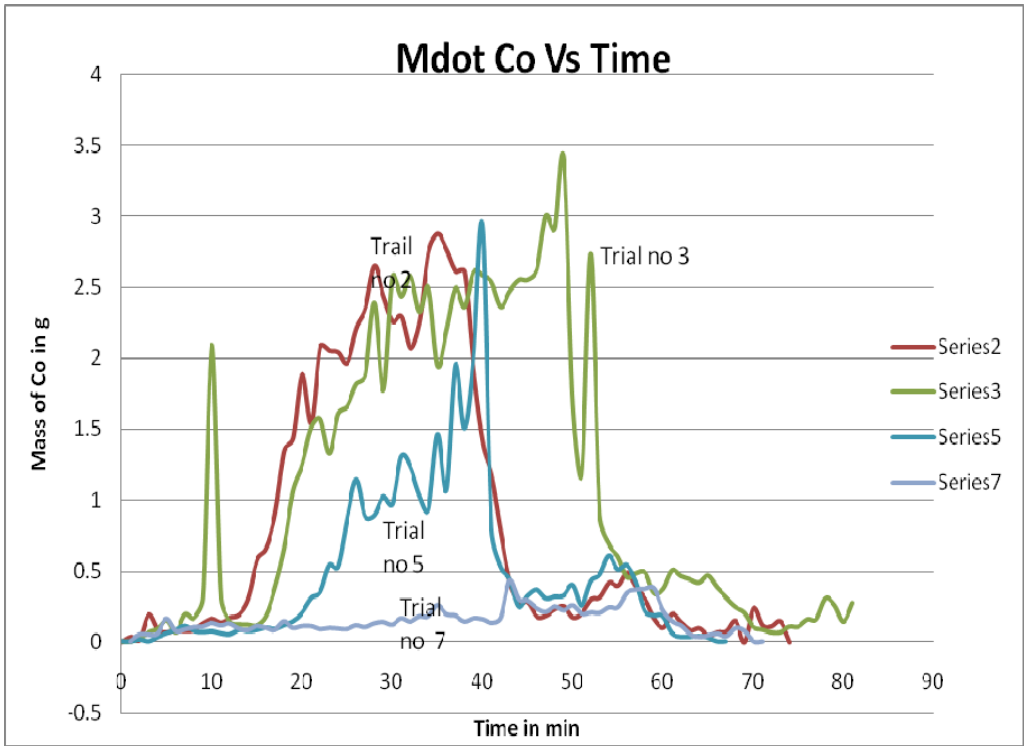


Figure 3. The plot of CO measured with time during the stove operation

A representative set of data for CO for four tests is presented in Fig. 3. It can be noted that during the first fifteen minutes or so little variation in emissions occur. It is only in the case (test 7) where the hole size is 6 mm that the emissions do not go up at all. In all the earlier cases, it appears to rise at some time or the other. This is dependent on the way the power level rose in the tests. This information is presented in Fig. 4. It can be noted that for tests 2, 5 and 7 the mass burn pattern is similar. In test 5, the air hole diameter is increased to 5.2 mm and that that is why the CO emissions are lower. Tests 2 and 3 are about sam in tems of Co emissions till their high burn rate period.

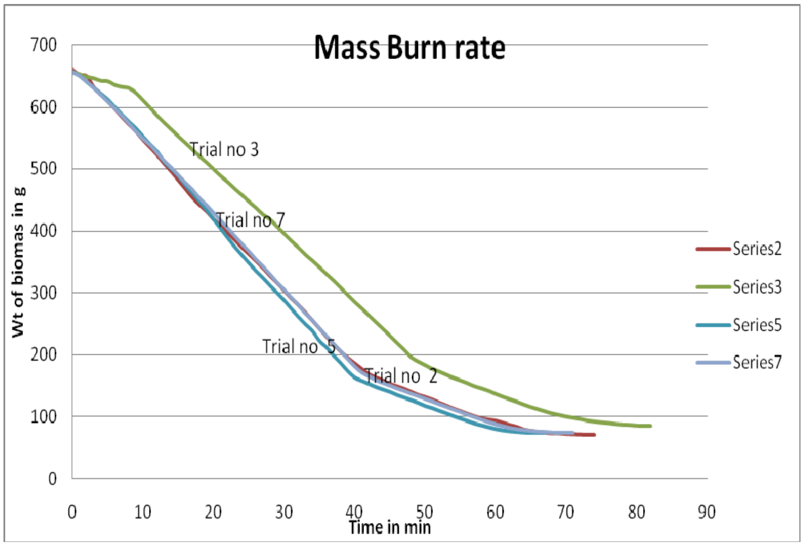


Figure 4. The mass burn vs. time for the selected tests.

The mass of CO_2 emitted by the stove is presented in Figure 5. The amount of CO_2 emitted during the char burn duration is lower due to reduced combustion rate and the actual mass.

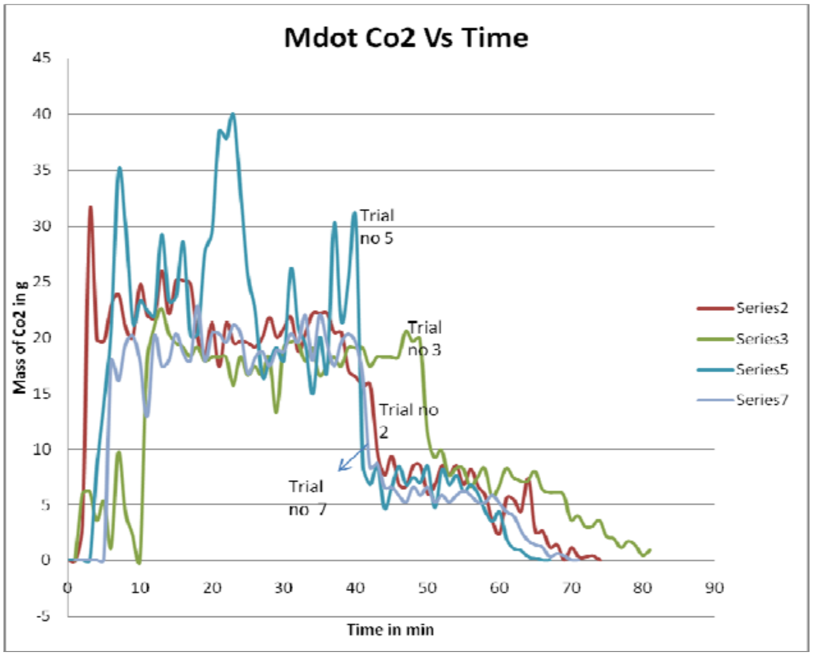


Figure 5: Mass of CO_2 emitted vs. time during the stove operation

The plots of NO and SO_2 are not shown here as they are similar to the above.

Summary

The importance of the secondary hole area is brought out in this study. Detailed emissions during the operation of the stove are also presented. These data can be used for predicting indoor air pollution in any kitchen under appropriate atmospheric conditions (wind).

Appendix 1: The method for determining water boiling efficiency

As already indicated, three cooking vessels were used for determination of the thermal utilization efficiency. The consideration behind this choice is that small families may use smaller vessels and larger families, larger vessels. It would be valuable to determine the efficiency with vessel size. It can be expected that larger diameter vessels extract more heat compared to smaller vessels and hence designs that allow greater heat extraction from the same stove would be the appropriate choice.

The standard procedure used for conducting the experiments was that the stove was lit and a suitable vessel filled with water and was placed on it after weighing the vessel with water in it on a balance that provided the accuracy of 0.1 g over a total mass of 10 kg. The gasification air (primary air) was at a minimum and the combustion air (secondary air) closed for about a minute to minute-and-a-half to ensure that the combustion process got stabilized. After the flame had stabilized combustion air was raised to a level to provide for the required power. In the experiments, the stove and the cooking vessel with water were placed on an accurate electronic balance to obtain the weight loss with time. This was used to infer the instantaneous power level. The vessel with water had a stirrer and a thermometer to obtain the temperature of the water over time. To measure the loss of water due to evaporation that is usually very small, typically 0.6 to 1 g/min, the vessel was taken off the stove and weighed on the balance to determine the amount of water evaporated. This was used in the calculations to account for the heat utilized. The heat utilization efficiency was calculated by dividing the heat extracted by the heating value of the biomass. The heat extracted has three components – the heating of the water, loss of water by evaporation (even below the boiling point), and the heating of the vessel. These heats were calculated and added. The heating value of the biomass is dependent on the moisture in the biomass and the ash content. Moisture was measured by a separate means by taking a part of the biomass used in the experiment for moisture determination. This was done by measuring the initial weight and putting the biomass into a furnace at 100^{o}C for a minimum of six hours. The material was taken out and weighed and again put into the furnace. It was removed after another three hours and cooled and weighed. The difference between the initial weight and the final weight divided by the final weight gave the moisture fraction on dry basis. In the experiments several other measurements were also made – to determine the gas temperature and the oxygen fraction in the bottom section of the vessel towards the exit zone. These gave corroborative evidence to the heat utilization efficiency.