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Total Thermal Energy Conservation Strategy during the Utilization of a Common Charcoal Stove

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Abstract
The proliferation and use of charcoal stoves is on the increase even in urban locations in Nigeria despite the environmental hazard associated with charcoal production. The rising cost of fossil fuel, smokeless nature of charcoal combustion and probably inexistent or ineffective legislation(s) against deforestation could be the reasons for this. This study aims at more efficient use of the energy available from the use of common charcoal stoves. A common slightly improved charcoal stove was placed in an enclosure with openings for air inflow and heating of the pot, and linked to a heat receiver through duct all of burnt brick. The stove enclosure, heat receiver inlet and outlet, and the ambient temperatures were measured during boiling of water for 3 periods/stages of 22 minutes per day for 6 days. The quantity of heat generated in the enclosure, the percentage reaching the heat receiver and the total heat losses from the system were computed under steady state conditions. A mean value of 93.85 kJ/kg of air was generated in the enclosure with about 34.33% reaching the heat receiver. The mean temperature within the heat receiver was 70.4^{0}C and the mean total heat loss from the system was about 6.4 kJ/kg of air. This strongly indicates great potentials for utilizing part of the thermal energy generated from the use of charcoal stoves for cooking for other alternative uses such as drying and other forms of preservation of foodstuff thereby improving their utilization efficiency and probably compensating in part for the adverse effect on the environment as a result of sustained charcoal production.

Keywords: Charcoal, thermal energy, energy conservation, energy utilization efficiency, stove, environmental hazard

1. Introduction

Fossil fuels still provide most of the world's energy needs presently. In Nigeria, energy from combustion of fossil fuels is a major concern as a result of unsustainable availability and the very often politically motivated activities related to it (Adegoke, 1991). More so, the depletion of relatively expensive oil and gas has spurred considerable interest in the search for alternative and economical energy sources. The search for alternative energy sources has led to the discovery and use of renewable dry biomass, the main one being wood. The main advantage of biomass fuels is that they are available in some form almost everywhere and can be burnt directly. They are usually cheaper than other fuels and when collected available at no monetary cost. Biomass is principally a renewable source of energy, if produced and used sustainably (Ahmed et al, 1991; UNDP, 2006).

The use of wood as source of fuel has many implications which include deforestation, erosion, inadequate wildlife conservation and game reserves, general wood scarcity for domestic as well as industrial purposes, etc. The problems highlighted lead to severe environmental hazards hence the need to properly conserve and utilize the use of wood as fuel source more efficiently. Very often biomass is burnt inefficiently in open three-stone fires and traditional cook stoves, which causes severe health problems in women and children and affects the environment (Smith et al, 2007). Every year, smoke from open fires and traditional stoves causes death of approximately 1.5 million people according to estimations from the World Health Organisation (WHO, 2006). The non-sustainable burning of wood fuels is furthermore contributing to climate change through CO_2 and methane emissions. It is estimated that the traditional energy supply and use causes 3% of anthropogenic CO_2 emissions and 5% of the methane flows to the atmosphere (Agenbroad et al, 2011). The role of black carbon is recently stated as playing even a major role in global warming. Between 25% and 35% of black carbon or soot in the global atmosphere comes from China and India, emitted from the burning of wood and cow dung in household cooking and through the use of coal-based household heating (Ramanathan & Carmichael, 2008; Holdren & Smith, 2000). Increasingly, the unsustainable harvesting of trees for firewood and charcoal is contributing to deforestation especially in Africa. Almost 90% of the wood removals are used for fuel. Soil erosion and water loss can be of further consequences (FAO, 2007; World Bank, 2009).

Given the fact that biomass is and will remain the most important fuel for almost one third of the world's population and considering its negative impacts on people and environment, the challenge is how to make its use sustainable and non-polluting. Interventions usually focus either on the demand side, e.g. promoting the production and use of efficient cook stoves, or they deal with the supply side, e.g. in re-afforestation and forest management programs (Kees & Feldman, 2011; Mugo & Ong, 2006). Efficient and clean burning cookers range from artisanal or semi-industrially produced clay and metal wood fuel stoves to solar cookers, heat retainers as well as cookers using plant oil, ethanol or biogas. Due to the availability of wood fuels, stoves for firewood and charcoal are the most common ones. An industrial production of efficient stoves has just started in the last years. However, in many cases these products are far too expensive for poor people. Little experiences exist with the export to other countries where sales structures for large quantities of stoves still have to be set up. Due to these constraints the authors focus on artisanal or semi-industrially produced stoves. Improved woodstoves may take many shapes (Pine et al, 2011). However, two main technical principals are always the same: improved combustion and improved heat transfer to the pot. The best stoves optimize heat transfer and combustion efficiency at the same time. Increased heat transfer reduces fuel requirements, whereas increased combustion efficiency also decreases harmful emissions (Oparaku & Okonkwo, 2006).

Severe fuel scarcity in the early 90's in Nigeria led to desperate efforts to completely utilize the energy from wood by also using the charcoal obtained from the combustion of wood (Akinbode, 1996). This led to the proliferation of charcoal stoves (locally called the *June 12* or *Abacha stove*). The stove is constructed such that charcoal is loaded in an upper combustion chamber with supports for the cooking utensil and a lower cowl for collecting ash as well as permitting air flow to aid combustion (Danshehu & Sama, 2006). This configuration has evolved over time with the growing need for less cumbersome but more efficient stoves. Much of the heat energy generated in the charcoal stove is released in the lower cowl along with the falling ashes and by conduction to the surroundings through the walls (Ofoefule et al, 2006; Uzodinma et al, 2006). This energy is wasted as the common construction usually has no provision for its collection and probable utilization. Charcoal stoves provide smoke free burning thereby positively impacting the prevalence of respiratory infections resulting from indoor smoke from the use of other forms of fuel. However, it also impacts negatively on the environment because it is majorly obtained from felled trees (Danshehu et al, 1992). Obviously attempts to regulate tree felling are not yielding the desired results or probably not even there as charcoal is openly sold along the streets of urban locations like Makurdi and the business is well patronized. The proliferation of all manners of charcoal burning stoves without particular attention to efficiency of combustion and/or energy utilization is not helping matters.

This work attempts to provide a practically implementable strategy for more effective utilization of the energy generated during the use of charcoal stoves for normal cooking activities. It explores the functionality of the charcoal stove as dual purpose system by evaluating the percentage of the waste thermal energy generated which can be available for other profitable applications at a reasonably affordable cost even in rural homes. This should increase the efficiency of utilization of the thermal energy and partly compensate for the menace imposed on the environment by the boom in charcoal production. This work is limited to the erection of a burnt brick enclosure for a stove and a burnt brick heat receiver and providing a duct between them also made of burnt bricks in order to estimate the quantity of heat that could be conserved for alternative use when the stove is being used for normal cooking.

2. Materials and Methods

2.2 Materials

A common version of charcoal stove made wholly of mild steel was slightly modified. The stove was placed inside an enclosure of dimensions 59.5 × 73 × 33 cm made of burnt bricks of thickness 13 cm to trap heat generated in the vicinity of the stove during its normal operation. A heat receiver unit with walls of the same burnt bricks having dimensions 79.5 × 100 × 43 cm and the top essentially covered with 2.5cm thickness was linked to the enclosure with a duct of dimensions 24.5 ×24 × 16cm also made of the same size of burnt bricks. A PVC pipe of diameter about 4 cm serves as the outlet port for the heat receiver unit in order to constrain the heat to traverse it. The dimensions were arbitrarily chosen since the results obtained can be optimized for particular applications.

Plates 1 to 3 show views of the stove enclosure, heat receiver unit, the duct linking them and the pot used for the study. Plate 4 shows the front, rear and top of the stove. The stove is made of mild steel of thickness 2 mm with the basic dimensions shown in figure 1. The improvements introduced to for the study include few openings of random diameters at the back of the combustion chamber to facilitate the transfer of heat by convection from the enclosure to the receiver through the duct and the pot support doubling a partial hot plate with flat bars of width of about 3 cm used for the edges.

2.3 Methods

The study was carried out for six days during which water was heated until it boils and then sustained till a total time of 22 minutes have elapsed. About 4.6 kg of charcoal was used for the period of the study divided into 6 parts and each part used for each day. The procedure was repeated each day until the quantity of charcoal for that day is completely used up. In this way, the procedure was repeated twice each day except on the 2nd and 5th day when it was repeated thrice. The temperatures of the interior of the stove enclosure, the duct and the heat receiver were measured at 2 minutes interval using mercury in glass thermometers which were calibrated using a standard thermocouple and inserted from the top of each compartment. The temperature of the heat receiver was measured by inserting two thermometers (3 and 4 in plate 1) from the top and computing the mean value. The respective changes in temperature with time were then computed and used to compute the thermal energy generated within the stove enclosure, heat receiver and the connecting duct. The temperature elevations of the stove enclosure, heat receiver and the duct above ambient were also computed.

Thermal energy generated was computed based on a unit mass of air. An average value of the specific heat capacity was obtained from the values between 20^0C and 100^0C and equation 1 used for computing the thermal energy.

$$Q = mc\Delta T \qquad (1)$$

where m = mass of air, c = specific heat capacity and ΔT = temperature change.

Heat transfer equations were applied for steady state conditions to compute the heat losses from the system through the walls of the stove enclosure and the heat receiver, and the pipe respectively. For conduction heat transfer, equation 2 was used.

$$q_{conduction} = \frac{kA(T_1 - T_2)}{L} \qquad (2)$$

where k = thermal conductivity of the material of the walls in W/m. K, L = the thickness of the material, A = cross-sectional area of the wall, T_1 = the temperature of the inner surface of the wall and T_2 = temperature of the outer surface. Standard mean values of k were used for the brick walls and for clay. Equation 3 was used convection heat transfer.

$$q_{convection} = h_c A\left(T_s - T_{f,\infty}\right) \qquad (3)$$

where h_c is the unit thermal convection conductance or average convective heat transfer coefficient at fluid to solid face (W/m^2K), A is the surface area in contact with the fluid measured (m^2), T_s is the surface temperature (K), and $T_{f,\infty}$ is the temperature of undistributed fluid far away from heat transfer surface. h_c was selected for free convection. For radiation heat transfer, equation 4 was used.

$$q_{radiation} = \varepsilon\sigma AT^4 \qquad (4)$$

where ε is the emissivity of the surface and σ Stefan Boltzmann's constant.

The computed quantities were then plotted against time while the quantity of heat generated in the stove enclosure was compared with the quantity that passes through the duct and eventually reaches the heat receiver.

3. Results and Discussion

3.1 Results

Tables 1 to 3 show the mean computed system thermal energy and the losses for the three stages. Q_1 represents the thermal energy generated in the stove enclosure, Q_2 the energy generated in the duct, Q_3 the energy reaching the heat receiver, Q_{LT} the total thermal energy lost from the system, Q_{13} the percentage energy generated in the stove enclosure that reaches the heat receiver and Q_{1L} the percentage energy generated in the stove enclosure that was lost. Figure 2 shows the variation of the thermal energy generated in the stove enclosure with time for the three stages. Figure 3 shows the corresponding variation of the thermal energy reaching the heat receiver with time. Figure 4 presents the variation of the percentage thermal energy generated in the stove enclosure that reaches the heat receiver with time for the three stages. Figure 5 shows the variation of the total thermal energy lost from the system with time for the three stages. Figures 6 to 8 show the respective the variations of the thermal energy lost from the system with the thermal energy in the heat receiver for stages 1 to 3.

3.2 Discussion

Throughout the period, the mean temperatures within the stove enclosure and the heat receiver varied linearly with time as expected with the interval being wider initially and becoming lower as time increases for all the stages of the study period. Each stage refers to a period of 20 to 22 minutes and the three stages were only completed for the 2nd and 5th days of the study period. Both days gave a strong indication that during stage 3, the temperatures within the units of the system were more stable and had a very linear dependence on time (R^2 = 0.99 in both cases). The temperatures during the 1st stage were more erratic probably due to the initial adjustment period of the system compartments. The trend lines for the 1st stage were steeper. This is expected because the rate of temperature change with time is higher due to the difference between the temperatures of the various system compartments with that of the charcoal burning in the stove.

On a 22-minutes interval basis, the observed mean ambient temperatures for the period of the study were 31.6, 37.3 and 36.6^0C for stages 1, 2 and 3 respectively. While being operated to boil water, the corresponding mean temperatures attained in the stove enclosure (heat receiver) were 78.3 (46.4), 128.5 (72.9) and 169.8 $(91.8)^0$C.

They all indicated a steady rise in temperature which is beneficial for the purpose of the study. The incorporation of the enclosure for this study was intended to prevent the heat usually generated in the vicinity of a common charcoal stove during operation and lost to the environment from being wasted. The almost linearly perfect relationships indicate that the arrangement adequately ensured the concentration and eventual transfer of the energy to the heat receiver unit.

The mean daily stove enclosure temperature was consistently the highest in magnitude followed by the temperature within the duct linking it to the heat receiver which had the lowest value. This is also as expected because of their respective positions from the source of the heat. However, the values for stage 2 showed a better relationship than those for stage 1. It could mean that closer positions and better material selections for any given capacity of stove can result to a greater percentage of the waste heat being conserved for other applications. This will be an aspect for particular attention in subsequent studies bearing in mind that the greater the quantity generated, the more complex will be the requirement for insulation thereby increasing the unit cost.

Figures 2 and 3 are plots of the computed thermal energy generated in the stove enclosure (Q_1) and the quantity that reached the heat receiver (Q_3) resulting from the temperature changes for the 3 stages. The relationships between these values with time are strongly linear (R^2 values > 0.9). However, the plots for stage 1 in the case of the stove enclosure had a higher slope than the one for the 1st stage in the heat receiver. This could be as a result of the greater proximity of the stove enclosure to the stove as compared to the heat receiver. The mean values of the computed thermal energy generated in the stove enclosure for the 1st, 2nd and 3rd stages are shown in Tables 1, 2 and 3 to be 48.6, 94.35 and 138.6 kJ/kg of air as against the corresponding heat receiver values of 15, 36.5 and 55.1 kJ/kg of air. They both showed steady rates of increases as expected. This increase indicates that more significant quantities could be generated for longer periods of utilization of the stove as is the case with rural (or many urban) households. However, a slight tendency of the temperature changes to be lower towards the end of the period for which the daily test was terminated (that is above 18 minutes). This is indicated in the figure by a tendency of curving downwards by the last points. This tendency is instructive to would be users of this measure of conserving thermal energy from charcoal and other stoves' operation. It means that the longer the operation of the stove the less the advantages in terms of efficient energy utilization because more fuel will be burnt while the percentage of energy stored or conserved from the waste heat reduces. These estimated values of thermal energy represent some reasonable savings from the thermal energy that would have been wasted but is made available for utilization. Possible areas of use could be in drying of produce or meat/fish, preservation of materials, warming or maintaining a particular range of temperature in prepared food for later consumption, etc. This confers better energy utilization efficiency to the system and is in line with general current practices with regards to the operation of biomass stoves (Champier et al, 2011; Kausley & Paudit, 2011).

From the trend line equations in fig. 2, the rates of energy generated in the stove enclosure for the 3 stages are respectively 2.364, 1.997 and 1.759 kJ/kg of air/minute, representing an average of 2.04 kJ/kg of air/min. In the same way from fig. 3, the corresponding average value in the heat receiver is 1.04 kJ/kg of air/min. This means that thermal energy generation within the heat receiver may be conveniently assumed to be at a rate of about 51% of the rate of its generation in the stove enclosure. These rates become useful when the application of the conserved heat is time based or necessarily intermittent. Also, this will play a major role when this strategy is implemented for a particular application particularly with reference to the ratio of their dimensions and proximity to each other.

From fig. 4, the percentage of the energy from the stove enclosure that reaches the heat receiver shows a sharp increase during the first few minutes of the first stage before becoming slightly steady. The variations for the 2nd and 3rd stages are relatively steadier as expected. The mean percentage of generated energy that eventually reached the heat receiver for the period was stage 1, 28.7%, stage 2, 38.4% and stage 3, 35.9% as shown in Tables 1, 2 and 3. This represents an average of 34.33%. On a daily basis, the respective percentages are 33.25%, 41.23% and 44.53%. These represent an average of 39.67%. These percentages may be increased by more elaborate and precise design. However, the status of the average user of charcoal stove users must be borne in mind with regards to the unit cost of the final product. As is the usual practice in all cases of engineering design, a useful balance or compromise must be aimed at vis-à-vis the cost and the efficient utilization of energy available especially for new installations. For already existing stoves, the cost will only be for the additional erection of the appropriate enclosure and the heat receiver, and the link between them. Obviously the size of the stove and the shape or configuration will be significant for effective implementation.

On a daily basis, 40.87, 23.4 and 32.97% of the energy generated in the stove enclosure is directly available for cooking. This represents an average of 32.41% for the 3 stages available for cooking. This could affect cooking time for some foodstuff but not adversely since it was adequate to boil off a reasonable quantity of water during the period of the study. However, it implies that theoretically, it is possible to harness up to 67% of the total energy generated in the stove enclosure for other useful purposes depending on the level of prevention of overall losses.

The total heat loss characteristics of the system are shown in figure 5. The heat loss characteristics for the 3 stages with respect to time show very linear relationships as expected as shown by the R^2 values indicated. The relationship was best for stage 1 (R^2 = 0.994). Also, the rate at which heat was lost for this stage (0.217 kJ/kg air/minute) was the highest most likely because ambient conditions should also more suitable for losses during the 1st stage. The rates for stages 2 and 3 (0.101 and 0.092 kJ/kg air/min respectively) were very close and the R^2 values were also similar. This could be as a result of the fact that the thermal behavior of the system had become more stable after the first stage which again affirms the assertion earlier made that greater savings of would-be waste energy could be attained with more extended periods of utilization.

The mean total quantity of heat lost for the 3 stages were respectively 3.6, 7 and 8.6 kJ/kg (Tables 1 – 3). These represent a mean loss about 6.4 kJ/kg or 6.49% on the stage basis (7.4% on daily basis) of the energy generated in the stove enclosure. The sharp increase seen between stages 1 and 2 is again obvious but the change became less drastic between stages 2 and 3. Apart from the thermal properties, the heat loss from the heat receiver was highest due to the fact that it has the larger surface area available for heat transfer. This emphasizes the fact that the size of the heat receiver and the provision of adequate or suitable insulation are critical in the implementation of this energy conservation principle for any particular application. The percentage of the generated heat lost from the system is negligible when compared to the useful thermal energy in the heat receiver. Figures 6 to 8 compare the total energy loss to the useful thermal energy in the heat receiver for stages 1 to 3. Stages 2 and 3 showed better linear dependence of energy loss on time than stage 1 (R^2 values of 0.989 as against 0.84). Also, the respective ratios inferred from the trend line equations were 0.214, 0.086 and 0.069, with an average estimate being 0.123. this translates to more than 8 kJ/kg of thermal energy in the heat receiver for every 1 kJ/kg lost from the system. This a good return with the possibility of increasing the ratio with more precise designs thereby increasing the potentials of more efficient utilization of the energy available from the charcoal using this strategy.

In an earlier unpublished study, the outlet port of the heat receiver was deliberately selected to be small (2 cm diameter PVC pipe) with the intention that the resident time of any quantity of heat transferred into it will be increased while not allowing an unnecessarily drastic pressure build up. The pipe used for this study was about 4cm in diameter to further promote the transfer of heat through the heat receiver. However, this is still not precise because the heat received is not being utilized for any particular application in this study. Its location and size become critical when the issue of the regulation of the receiver temperature is to be handled for a particular application. This again is a subject for another study in the future.

Also, in the earlier study, the values of temperatures used, particularly for the heat receiver and the PVC connecting pipe were estimates based on measurement carried out at their inlet and outlet ports. In this study means of carrying out the temperature measurements at more points were provided so that the temperature values are more realistic. When this strategy is applied to a particular application, a more precise way of monitoring the variation of temperature across the system will have to be incorporated. This issue will be highlighted in subsequent studies.

Finally, an estimated cost of energy is about ₦2.25/J/kg, assuming that all the expenses on the project only achieved the mean quantity of energy earlier obtained. This seems to be reasonably affordable although enough data is not available to make a final conclusion.

4. Conclusions and Recommendations

The main objective of this study was to conserve heat energy from the operation of a charcoal stove for other purposes was reasonably achieved. The system was able to generate a mean thermal energy of about 93.85 kJ/kg of air arising from a mean temperature of about 125.53 ^{0}C. About 35.53 kJ/kg of air of this or 34.33% of this was transferred to the heat receiver the mean temperature being 70.4 ^{0}C. The total heat loss from the system was about 6.4 kJ/kg of air and was adjudged negligible compared to the generated value. Hence, a great potential exists for applications such as drying and other preservation activities. These values will be optimized by further research particularly in the area of implementation of this strategy of conservation of the waste energy from the operation of a charcoal stove for real time cooking of local delicacies. It will further enhance efficient utilization as a means compensating for the degradation of the environment by the charcoal production process.

More precise work vis-a-vis the sizing of the heat receiver to suit particular applications, closer temperature variation monitoring within the receiver and optimization relative locations of the stove enclosure and the heat receiver and the linkage between them are areas for further studies. It is finally recommended that the use of dual purpose charcoal stove should be encouraged through greater participation of Local Government Councils and NGOs. A starting point is the creation of much needed awareness in order to bring the critical issues to light. Also, a definite compromise must be reached by legislation and/or otherwise concerning the production of charcoal from wood. Tree planting and selective tree cutting for charcoal production can be properly organized and controlled.

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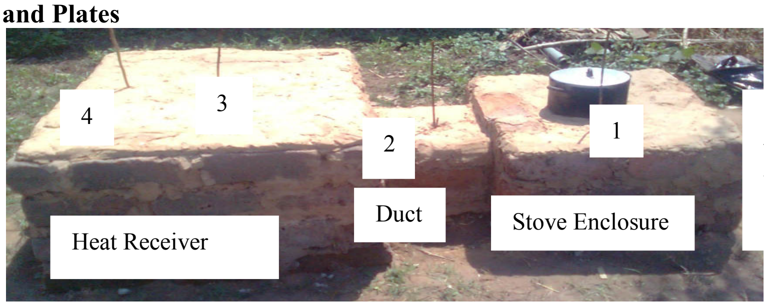
Figures and Plates



1, 2, 3 and 4 are thermometers used to measure the temperatures

Plate 1: Picture showing the Side View of the System

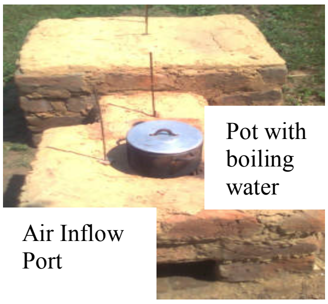


Plate 2: Picture of the set up showing the air inflow port

Plate 3: Picture of the set up showing the exit port

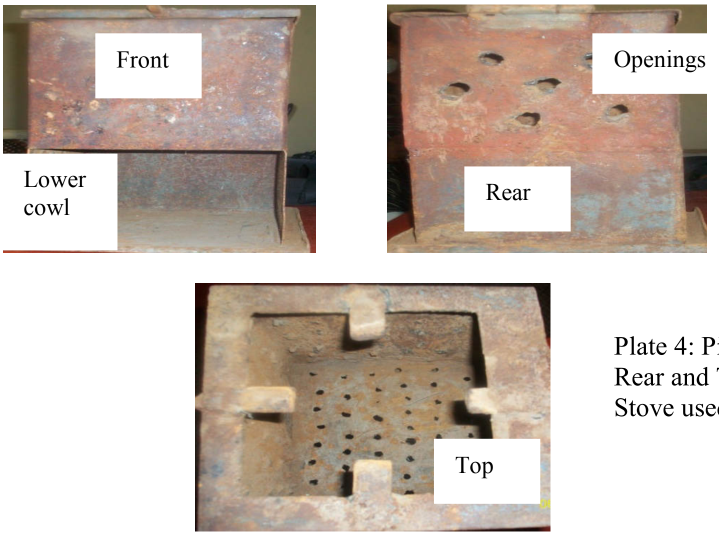


Plate 4: Picture of the Front, Rear and Top Views of the Stove used

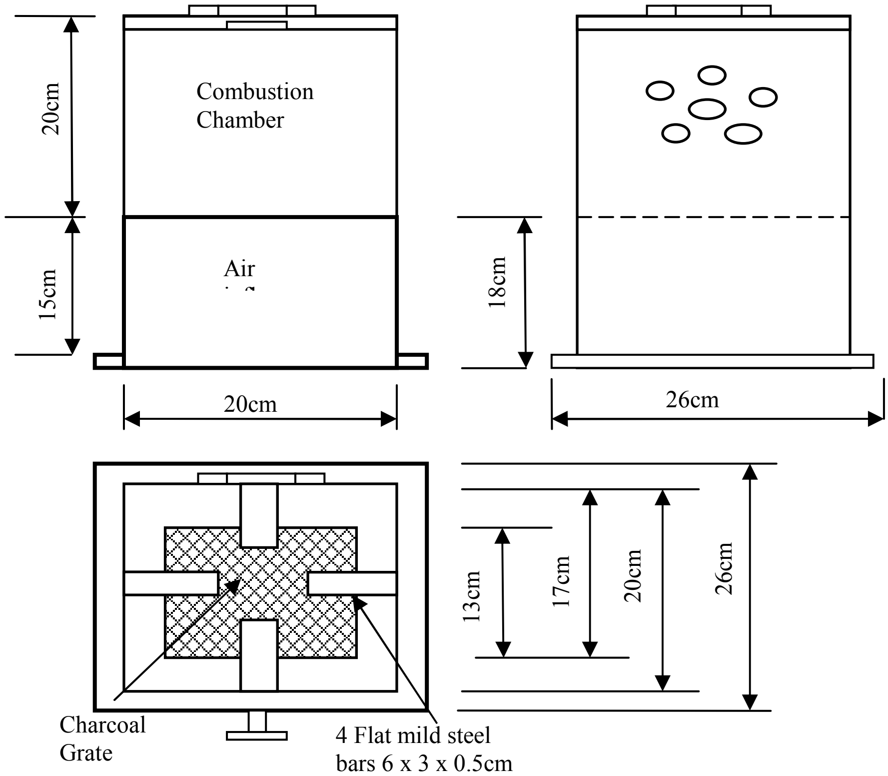


Figure 1: First Angle Representation the basic features of the Stove used for the Study

Tables

Table 1: Mean Computed System thermal Energy and Losses for the 1st stage

Q_1 (kJ/kg)	Q_2 (kJ/kg)	Q_3 (kJ/kg)	Q_{LT} (kJ/kg)	Q_{13} (%)	Q_{IL}(%)
0	0	0	1.34	0	0
24.82	19.38	10.54	2.04	42.5	8.22
36.44	26.18	12.58	2.06	34.5	5.65
45.39	29.24	13.35	2.84	29.4	5.65
49.81	30.26	14.86	3.18	29.8	6.38
54.91	32.64	15.81	3.51	28.8	6.39
56.95	34.00	16.24	4.09	28.5	7.18
61.54	34.69	18.02	4.47	29.3	7.26
64.6	37.57	19.72	4.83	30.5	7.48
67.66	38.76	20.91	5.36	30.9	7.92
72.42	42.67	22.86	5.75	31.6	7.94
48.6	**29.6**	**15**	**3.6**	**28.7**	**6.43**

Table 2: Mean Computed System thermal Energy and Losses for the 2nd stage

Q_1 (kJ/kg)	Q_2 (kJ/kg)	Q_3 (kJ/kg)	Q_{LT} (kJ/kg)	Q_{13} (%)	Q_{IL}(%)
72.93	52.87	25.02	5.83	34.3	7.99
78.03	56.78	27.8	6.2	35.6	7.95
82.45	59.67	29.16	6.43	35.4	7.80
87.55	63.91	31.2	6.53	35.6	7.46
89.94	68.68	34.17	6.82	38	7.58
93.5	72.25	36.53	6.98	39.1	7.47
98.77	75.65	39.19	7.21	39.7	7.30
103.7	79.05	41.48	7.39	40	7.13
107.6	82.62	44.2	7.59	41.1	7.05
117.3	89.7	48.08	7.9	41	6.73
106.08	93.84	44.88	7.8	42.3	7.35
94.35	**72.3**	**36.5**	**7.0**	**38.4**	**7.44**

Table 3: Mean Computed System thermal Energy and Losses for the 3rd stage

Q_1 (kJ/kg)	Q_2 (kJ/kg)	Q_3 (kJ/kg)	Q_{LT} (kJ/kg)	Q_{13} (%)	Q_{IL}(%)
122.4	85.17	42.84	7.74	35.0	6.32
125.97	89.25	45.39	7.76	36.0	6.16
130.05	91.29	48.71	8.16	37.5	6.27
134.64	93.33	51.26	8.34	38.1	6.19
137.7	97.92	53.81	8.54	39.1	6.20
140.25	99.96	55.85	8.66	39.8	6.17
141.78	102.51	59.16	8.79	41.7	6.20
145.86	104.04	61.71	8.99	42.3	6.16
152.22	106.59	64.77	9.2	42.6	6.04
155.04	108.63	67.07	9.38	43.3	6.05
138.6	**97.9**	**55.1**	**8.6**	**35.9**	**5.61**

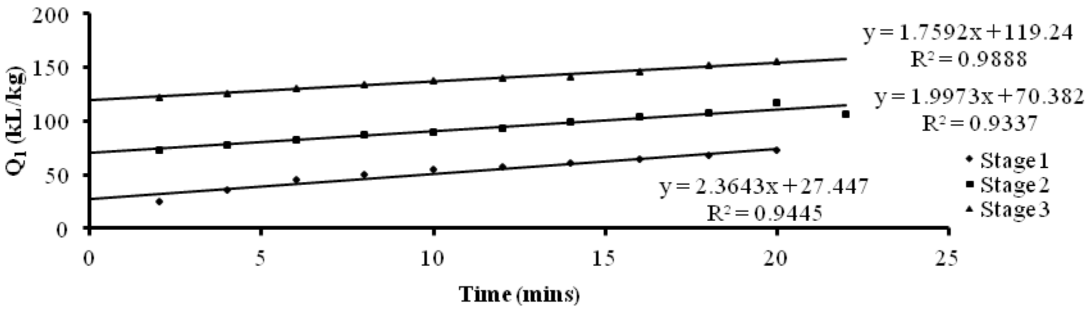


Fig. 2: Variation of thermal energy generated in the stove enclosure with time for the three stages.

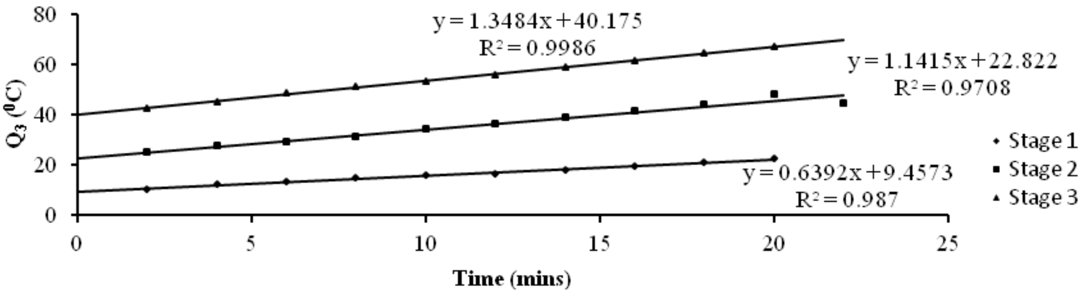


Fig. 3: Variation of thermal energy generated in the heat receiver with time for the three stages.

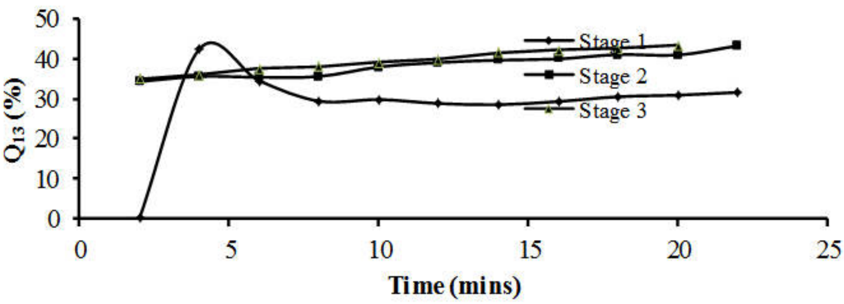


Fig. 4: Variation of the percentage of thermal energy generated in the stove enclosure that reaches the heat receiver with time for the 3 stages.

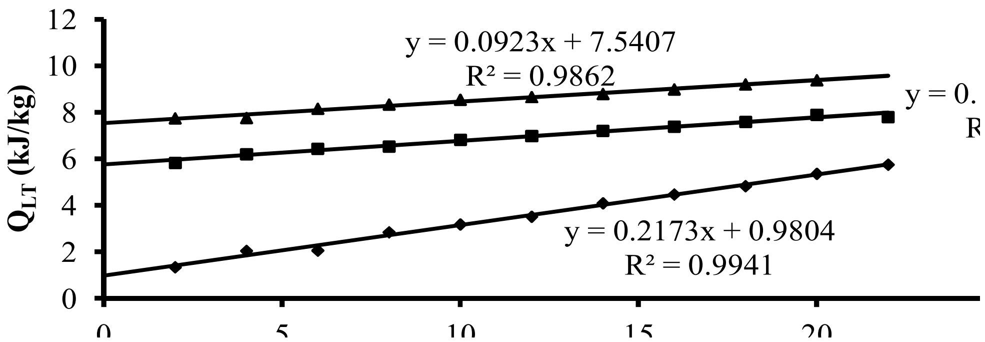


Fig. 5: Variation of Total Thermal Energy lost from the System with Time for the 3 stages.

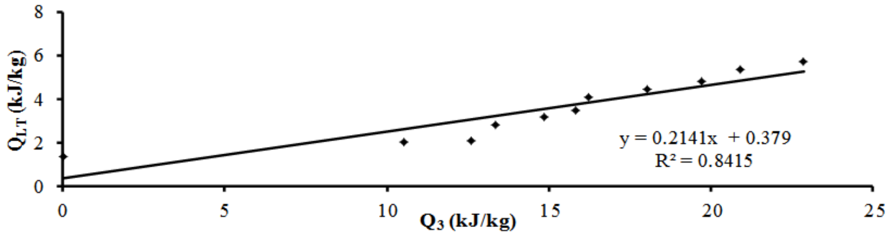


Fig. 6: Variation of Total Thermal Energy lost from the System with Thermal Energy in the Heat Receiver for stage 1.

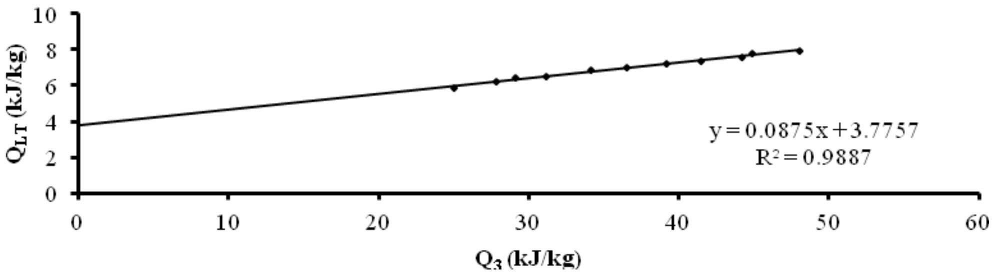


Fig. 7: Variation of Total Thermal Energy lost Thermal Energy in the Heat Receiver for stage 2.

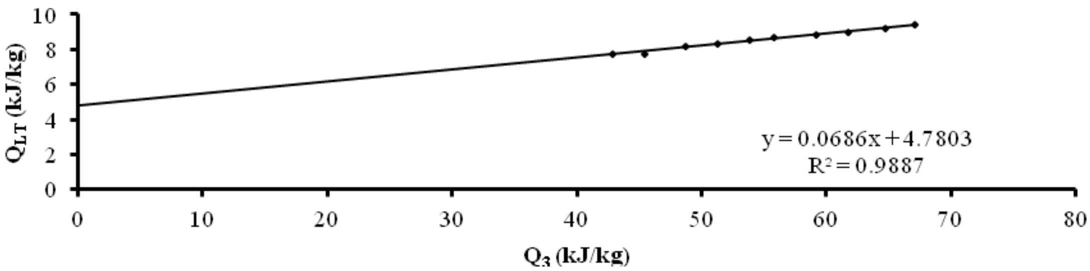


Fig. 8: Variation of Total Thermal Energy lost with Thermal Energy in the Heat Receiver for stage 3.