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Energy Efficient Biomass Gassifier Stove for Domestic Purpose

Khadija Sultan[1] Munir Ahmad[2]
1. Department of Energy Management in Agriculture, University of Agriculture Peshawar, Pakistan
2. Agricultural Engineering Division, Pakistan Agriculture Research Council, Islamabad, Pakistan

Abstract
Pakistan is facing issues with respect to sustainable energy and increasing of greenhouse gases, therefore, there is needed to take holistic approach to reduce energy crisis through the solution of renewable energy by natural resource management in the future. That is why this work has been carried out to develop and evaluate the performance of energy efficient biomass gasifier stove for domestic purposes as well as to compare its performance with improved cooking stove using locally available biomass fuels like wood chips. A biomass gasifier stove was developed and evaluated on wood chips fuel at National Agriculture Research Center (NARC), Islamabad. The design improvement of the stove focused on the following areas: provision of insulation around the chamber to reduce conduction heat loss across the walls of the chamber, incorporation of pot supporter as to minimize the smoke by direct contact to the fire and provision of sizable and adjustable air inlet to ensure the availability of sufficient air for the complete combustion of the fuel wood. The results obtained from this study showed that the gasifer wood stove has a maximum thermal efficiency of 30% as compared the thermal efficiency of improved stove of 18 %. Similarly, with a higher the useful heat energy output per kg of wood used was 1239.60 kJ/ kg than the useful heat energy output per kg of wood used by improved stove was 144.43 kJ/ kg. So, the performance of gasifier stove much better than improved stove.
Keywords: Energy, Biomass, Gasifier Stove, Cooking Stove and Gasifer Wood Stove

1. Introduction

Since the beginning of civilization, the cooking has been done by using the woody biomass. These woody biomasses are used in inefficient stoves by which there is wastage of wood and on other hand it caused health problems. For cooking electricity, gas or liquid fuels are preferred but these depend on having a suitable infrastructure and are expensive and often not available in the rural areas of developing countries (Bridgwater, 1995).

Modern agriculture is more energy intensive. Subsequently, the growths of green revolutions and high agricultural productivities have been made possible only by large amounts of energy inputs, especially those from fossil fuels. In most of developing countries, biomass fuels continue to play an important role both in the domestic and industrial sector. Among the biomass fuel wood is a widespread and flexible energy source, which provides a great deal of energy for the developing world. Many other forms of solar energy such as photovoltaic cells and wind turbines are only capable of providing useful energy when the sun shines or the wind blows. For the above reasons, wood has the potential to be an important renewable resource of energy (Abdul et al., 2011).

Pakistan is a developing country that consumes little energy compared to developed nations. Pakistan has a population of 170 million and ranks as the 6th most populous country and as well as among the South Asian region it also exhibits the highest growth rate (Pakistan Population Census, 2011). About forty nine percent of the population of the rural areas belongs to the low socioeconomic group; the energy that they use goes into cooking food over 50%. In Pakistan, the rural household's energy consumption is based on the biomass and animal dung. About 86% contribution of biomass fuel i.e; about 20.12 % of animal dung and 16.40 % agriculture residues as shown in Table 1.1 (Escorts Foundation, 1999).

The contribution of fuel wood in rural household energy consumption at 57.87% was significantly higher than in urban areas where the figure dropped to 37.94%. About 11.35% households used dung and 6.35% household's crop residues respectively in urban areas of Pakistan.

The Household Energy Strategy Study (HESS) was conducted by UNDP and World Bank during 1991-1993 which gave the different pictures among the rural and urban areas of Pakistan. The rural areas were consuming 95 % biomass fuel as compared to 56 % in urban areas. According to the survey report of HESS, the consumption pattern of biomass fuels in Pakistan's provinces showed that Balochistan consumed mostly the fire wood per household, however Punjab depends on the cow dung and crop residues due to large number of cattle in the province whereas Sindh province has the largest consumption of modern fuels like natural gad due to the reason of Karachi, the largest city in Sindh and Pakistan. (Escorts Foundation,1999).

Due to the energy crises with increase of prices and scarcity of the fuels in Pakistan, so the trend towards the alternative energy sources like solar, wind, geothermal, biomass etc. in all sectors. Similarly, in term of cooking condition the rural areas are mostly depending on the inefficient wood stoves like "Chula", the "Hiko", the "Maendeleo", etc, as cook badly and more heat dissipates not only waste wood but caused health problems also, and put more burden on forest. Electricity, gas or liquid fuels are preferred for cooking but are too expensive and unaffordable. Because of the problems of wood cooking, people often use charcoal for cooking. However, charcoal manufacturing process wastes energy and pollutes environment (Escorts Foundation, 1999).

To reach the holistic approach the wood stoves based on gasification principles may provide better solution to rural areas with control of health problems because of smokeless stove as well as to reduce the load on the forest trees. (Bhattachary et al. 2003).

The colder areas of Pakistan, the Chula-type stoves of U-shaped combustion boxes were used for both heating and cooking as the cow dung was the main fuel source. To reduce the levels of indoor air pollution in the home stoves were equipped with chimneys. Different types of stoves were emerged with the passage of time, having slightly different features from one another. So, Justa stove was a simple biomass stove, with elbow-shaped combustion chamber and insulated around it that provides more heat and clean combustion than an open fire stove which means that fuel consumption rate of fuel was less as compared to the three-rock stove. (Wood and Baldwin, 1985).

Gasification of wood (or other biomass) offers the possibility of better controlled gas cooking that converts biomass into smokeless gases which are quite safe after being burnt due to the thermo-chemical processes as drying, pyrolysis, oxidation and reduction process. Therefore, it is possible to distinguish four separate zones in which converting the fuel to a combustible gas; generally contain combustible gases are produced; like Carbon monoxide (CO), Hydrogen (H2) and traces of Methane and non-useful products like tar and dust. The fuel was put into the combustion zone from the top, and the air was normally introduced from the bottom so the gases were come out from the top of reactor (Souza-Santos, 2004).

Gasification is a process in which the partial combustion of solid fuel (biomass) takes place under the temperatures of about 10000C. The reactor is called a gasifier. After the incomplete combustion of biomass, generally combustible gases are produced; like Carbon monoxide (CO), Hydrogen (H2) and traces of methane and nonuseful products like tar and dust. In designing the gassifier stove, the following conditions were the co-key factors such that (a) charcoal produced by biomass reduction and, (b) at high temperature charcoal was altered as to produce CO and H2. Similarly, if the same way if the combustion of biomass fuels was completed, then the production of carbon dioxide and water vapor, will not be harmful at all, whereas incomplete combustion release health damaging pollutants and GHG (CO, N2O, CH4) and polycyclic aromatic hydrocarbon etc. (Houmoller, 1997).

The principle of the Gasification technology was that organic material (e.g., wood/biomass) reacts with limited amount of O2 at high temperatures converts into combustible or syngas gases (CO + H2). (Panwar, 2009).

$$\text{Biomass + limited oxygen} \Longrightarrow \text{syngas + heat}$$

During this process with supply of a limited /controlled of air to a carbon (char) as to oxidize to form carbon dioxide (CO2) and to release heat. Similarly, Hydrogen (H) is oxidized with a limited/controlled supply of air to form water (H2O) and heat is released. In this process hot carbon (char) reacts with CO2 and converts it to carbon monoxide (CO). In the same way hot carbon also reacts with H2O, “reacting” an oxygen atom producing carbon monoxide and hydrogen gases. Some of the char (C) also bound with hydrogen to produce methane similarly carbon mono oxide reacts with hydrogen to form CH4 and H2O. (Panwar, 2009).

This study focused on the development of enclosed biomass gasifier stove specifically designed for large scale cooking. Therefore, it was believed that such type of technology should be acceptable and promoted. It would have offered advantages like easily affordable; efficiently work and safety measure like to reduce the health problems which would help its rapid adoption in commercial and institutional level and also modified and reduced size could be applicable in rural households across the country.

II Design Description, Analysis and Calculation

Design Description

The biomass gasifier stove was designed and developed at ABEI workshop, NARC, Islamabad in 2012 by using different tools and equipments. The front view of the developed gasifier is shown in Figure 3.1. The materials required for the fabrication of the biomass gasifier stove include mild steel sheet gauge #19, glass wool and mica sheet for insulation purposes, and mild steel flat to support the pot. The proposed design of gasification stove was operated for different fuels with natural draft of air.

The material selection was very important for the stove especially for the inner cylinder which was directly in contact with the very high fuel temperature. In some places GI sheet material can also be used but it needed extra care by using it because, it emits poisonous gases when the zinc coating oxidizes at high temperature. Secondly, the cost and the weight of the materials were also very important factors during the design of the stove. Thirdly, during the design of the stove thickness of the material was also to be considered as it increased the life span of the stove.

Design Analysis and Calculations

Design Specifications:

There were different types of design factors for the development of gasification stove. There was a need to give proper consideration during the designing procedure as to achieve its proper performance. The following the different factors for gasifier stove design were considered: height of the outer cylinder, Houter = 811 mm; height of the inner cylinder, Hinner= 741 mm; diameter of the outer cylinder, Dout = 230 mm; diameter of the inner cylinder, Dinner = 170 mm.

Reactor (Inner cylinder) was the component of the stove, where biomass fuels were fed and burned with limited amount of air, and it consisted of primary holes made on the bottom of the lid in the form of slots or small number of holes and 12 numbers of secondary holes of 3 mm diameter with equally spacing around the cylinder. Similarly, outer cylinder has 12 numbers of primary holes of 2.5 mm diameter with equally spacing. The 24 number of secondary holes were made with size of 3mm diameter. Its shape was cylindrical with mild steel sheet gauge #19 materials which were enclosed with outer cylinder of the same material as to minimize the heat loss. The outer cylinder having an annular space was tightened with mica sheet and with glass wool as to prolong the cooking duration as well as storing heat energy to improve the stove efficiency. The outer cylinder also contained a number of holes which are equally distributed for the intake air into the cylinder for combustion process. The numbers of holes were selected on the basis of air fuel requirement for the combustion of the fuel. The material used for the pot supporter was mild steel flat that hold the pot during cooking.

A: Height of reactor

Height of the reactor was affected by the total operating time to produce gas as higher the reactor, the longer is the operating time. The height of the reactor can be computed by using the below formula (Belonio, 2005).

$$H = \frac{SGR \times T}{\rho}$$

Where;
H = height of reactor, m
SGR= specific gasification rate, kg/m2h
T = time of wood stove duration, h
ρ = wood density, kg/m3

B: Diameter of reactor

This represents the size of the cross-section of the cylinder where biomass to be burned. The diameter of the reactor can be calculated by using the formula given below:

$$V = \pi \times r2 \times h$$

Where;
V= cylinder volume, m3
r = cylinder radius, m
h= cylinder height, m

C: Air fuel rate (amount of air needed for gasification)

The amount of gas generated by the stove was mostly depending on the size and number of holes for primary air (drived the pyrolysis) as well as secondary air (helped in combustible gas to improve the combustion of the fuel) calculated by using the following formula (Belonio, 2005).

$$AFR = \frac{Vs}{4} \times D2$$

Where;
AFR = air flow rate, m3/sec
Vs = superficial air velocity of wood is 0- 0. 6, m/sec (Paul 2007)
D = diameter of reactor, m
OR

$$AFR = \frac{FCR \times SA \times €}{\partial}$$

Where,
AFR= air flow rate, m3/sec (Belonio 2005)
FCR = fuel consumption rate, kg/ h
SA = stoichiometry, actual air/fuel ratio, 5.53284 kg air/ kg fuel
∂ = density of air, kg /m

III Performance Testing of the Biomass Stove

Test Procedures Water Boiling Test

The performance parameters and comparison of gasifier stove with improved stove were measured at Quetta station. In these tests the stoves were checked in actual kitchen environment with water boiling test (WBT) was used to test the efficiency and performance of the biomass gasifier stove and improved stove for this study. A measured amount of fuel wood chips with the removal of the moisture content by using the oven of AZRC, Quetta laboratory at temperature of 700C as to keep for 24 hours of uniform moisture content 28% was weighed out for each stove i.e., 3.14 kg and 1.14 kg. Wood chips, were loaded into the both stoves from the top of the reactor. The pot was weighed, and then a measured amount of water by volume one lit and three liter were added to the pot and weighed again to determine the weight of the water. The test was five times repeated for each water test procedure. The already weighed fuel wood of sizing range was 25 mm to 50 mm to put into the reactor and initiated the wood chips by using a piece of paper. Then the pot was placed on the stove when the combustion gases were covered mostly area of the reactor. The initial temperature of water which was going to be tested was measured as 230C. The temperature of the water was recorded regularly until the water temperature reached to a boiling point as recorded in this test was 100oC. The same procedure was repeated five times as on average base the boiling time. The collections of char/ash produced from both stoves were also weighed.

- The moisture content (M.C) was obtained by using the following formula:

$$\mathbf{M.C} = \frac{\text{Fuel initial weight} - \text{Fuel final weight}}{\text{Fuel final weight}} \times 100$$

- Fuel consumption rate (FCR) was determined when the amount of fuel consumed during the stove was operating per unit time by formula (Belonio, 2005)

$$FCR = \frac{\text{Weight of wood chips fuel used (kg)}}{\text{Operating time (h)}}$$

- Sensible heat (SH) was computed when the amount of energy used to raise the initial temperature level until boiling of water in pot. It was calculated by using the formula (Belonio,2005)

$$SH = \frac{Mw \times Cp \times (Tf - Ti)}{WBt}$$

Where,
SH = sensible heat, kJ/ h
Mw = mass of water, kg (1kg)
Cp = specific heat of water, 0.239 kJ / kg 0C
Tf = final boiling temperature of water approx 100 0C
Ti = initial temperature of water before boiling, 0C
WBt= water boiling time (h)

- Latent heat (LH) was determined when the amount of energy required for evaporating the water in the pot during the test as to be computed by using the formula (Belonio, 2005).

$$LH = \frac{Ww \times LHw}{Ewt}$$

Where,
LH = latent heat, kJ/ h
Ww= weight of water evaporated, kg
LHw = latent heat of water, 129.18 kJ /kg
Ewt= water evaporation time, h

Thermal efficiency (ηT)will be computed by using the formula (Belonio,2005)

$$\eta T = \frac{SH + LH \times 100}{HHVf \times WFCR}$$

Where,
ηThermal = thermal efficiency, %
SH = sensible heat, kJ / h
LH = latent heat, kJ / h
HHVf = higher heating value of fuel, 802.63 kJ / kg
WFCR = fuel consumption rate, kg/ h

Energy input and output is the amount of energy released or utilized by the stove for cooking purposes by using the formula (Belonio, 2005)

$$Ein = FCR \times HHVf$$
$$Eout = FCR \times HHVf \times \eta T$$

Where,
Eout = energy output, kJ/ h
Ein = energy input, kJ / h

- The percentage of coal/ash production can be calculated as the ratio between the amounts of ash/ coal produced to the amount of biomass used. This can be computed by using the formula.

$$\text{Ash/ Coal production} = \frac{\text{Weight of ash produced (kg)}}{\text{Weight of wood used (kg)}} \times 100$$

1.1.1 Results

Test Results for Boiling of Water by Gasifier Stove and Improved Stove

To measure the performance of the stove it was necessary to remove the moisture content from the woodchips. The reason was that it was necessary for upper fuel layer to ignite the next lower layer. So, if the fuel was in dry form the fire was easily propagating to the next layer. To compare the performance of two stoves, it was necessary to feed the woodchips at same moisture content to both stoves. The moisture content of wood chips was 28% for both stoves (wood gasifier stove and improved stove) as showed in Figure 4.1

4.1 Analysis of the water boiling test (WBT) of gasifier stove

The analysis of the water boiling test of gasifier stove for one liter and three liter of water was tested. The one liter of water was boiled from 230C to 1000C in 6.6 minute by using 1.14 kg of wood fuel whereas the three liter of water was boiled in 26.1 minute by using 3.14 kg of wood fuel. Results analysis gasifier stove for one liter and three liter of water tabulated in table 4.1

The analysis of the water boiling test of improved stove for one liter and three liter of water was tested. The one liter of water was boiled from 230C to 1000C in 13.5 minute by using 1.14 kg of wood fuel whereas the three liter of water was boiled in 29.36 minute by using 3.14 kg of wood fuel. Results analysis improved stove for one liter and three liter of water tabulated in table 4.2

The ash and coal was collected from gasifier and improved stoves. The carbon percentage was tested in LRI's laboratory and the percentage of the carbon was 4.28 % in ash and 6.54 % in coal, Figure 4.2, Figure 4.3, Figure 4.4 and Figure 4.5.

4.2 Comparison between gasifier stove and improved stove for water boiling test (WBT)

The comparison graph (Figure 4.6a, 4.6b, 4.7a and 4.7b) between gasifier stove and improved stove for one liter and three liter of water indicated that the cooking duration of gasifier stove was lengthy as compared to improved stove with energy output of gasifier stove was higher than the output energy by improved stove. Subsequently, the thermal efficiency of gasifier stove was higher than the improved as well as the percentage of carbon in ash produced by gasifier stove was less than the improved, it means that the more fuel was utilized for heating purposes rather than converted into coal by which the cooking time was decreased as observed in case of improved stove. Similarly, the useful heat energy output per kg of wood used by gasifier stove was greater than the useful heat energy output per kg of wood used by improved stove.

4.3 operating performance of the gasifier stove and improved stove

Table 4.4 shows the data of the test result of operating performance of the gasifier stove and improved stove on accommodated of 3.14 kg of wood chips which was the total operating performance obtained from the star-up-time of the fuel loaded to the stoves until all the fuel was completely burned. The average initial weight of water in both cases was 15 kg.

4.4 Comparison result of operating performance between the gasifier and improved stove

Plot the graph Fig 4.8a and Fig 4.8b showed the comparison between gasifier stove and improved stove on the bases of operating performance between the two stoves. Against this data graph was plotted which indicated that the operating time of gasifier stove was 2.18 h whereas the operating time of improved stove was 1.46 h which concluded that the cooking duration of gasifier stove was more as compared to improved stove and energy output of gasifier stove was 344.32 kJ/ h but on the other hand the output energy by improved stove was 310.62 kJ/ h. Subsequently, the thermal efficiency of gasifier stove was higher than the improved stove as well as the percentage of carbon in ash produced by gasifier stove was less than the improved. It means that the more fuel was utilized for heating purposes rather than converted into coal due to which the cooking time was decreased as observed in case of improved stove. Similarly, the useful heat energy output per kg of wood used by gasifier stove was 239.60 kJ/ kg greater than the useful heat energy output per kg of wood used by improved stove was 144.43 kJ/ kg.

4.5 Cost analysis of wood gasifier stove

The Table 4.6 was the production cost of gasifier stove as PRs 6510.00 and its useful life was assumed four years as depending upon the materials used. Interest rate on average investment was computed as 12% according to the monitory policy statement 2012 by the state bank of Pakistan and straight line method was used to calculate depreciastion cost of gasifier stove. Repair and maintenance of gasifier was 10% of investment cost. Salvage values was 10 % of the total stove cost.

1.1.2 Discussion

Performance evaluation of the stoves i.e., gasifier stove and improved stove carried out on the basis of the one liter and three liter of water boiling test result as well as the operating performance of these two stoves.The operating time of gasifier stove for boiling 15 liter of water was 1.46 h and 2.73 h however the operating time of improved stove for boiling the one liter and three liter of water was 1.12 h and two hour respectively.It was concluded that the cooking duration of gasifier stove was prolonged as compared to improved stove. The input energy of improved stove was greater than gassifier stove for testing the one liter and three liter of water as 812.92 kJ/ h and 1260.13 kJ/ h, so the energy input of gasifier stove was 674.20 kJ/ h and 963.15 kJ/ h, respectively. But the energy output of gasifier stove was greater 269.68 kJ/ h and 346.73 kJ/ h than the improved stove as 134.15 kJ/ h and 214.22 kJ/ h, respectively. Similarly, the useful heat energy output per kg of wood used by one liter and three liter of water boiled by the gasifier stove was 321.72 kJ/ kg and 301.46 kJ/ kg greater than the useful heat energy output per kg of wood used of improved stove was 132.38 kJ/ kg and 136.44 kJ/ kg, respectively.

The operating performance of both stoves was also carried out on the basis of thermal efficiency energy input, energy output and useful energy out per kg of wood fuel used. The energy output of gasifier stove was 344.32 kJ/ h higher than the improved stove (310.62 kJ/ h), with less input energy of gasifier stove 1147.76 kJ/ h as compared to improved stove 1725.59 kJ/ h. Similarly, the useful heat energy output per kg of wood used by gasifier stove was 239.60 kJ/ kg greater than the useful heat energy output per kg of wood used of improved stove (144.43kJ/kg). So, the performance of gasifier stove was much better than improved stove.

The content in ash carbon was 4.28% was observed by gasifier stove which mean that all fuel was successfully converted into heat but on the other hand the coal's carbon percentage was 6.54 % by improved stove and more smoke was emitted, it means improved stove did not offer good control on boiling of water as well (Escort Foundation, 1999).

A number of factors control the performance of the stove. The first factor was an insulation material i.e., mica sheet and glass wool provided around the outer cylinder of the gasifier stove due to which the wall of the outer cylinder minimize the heat loss by conduction and convection and ensures that a good proportion of heat was utilized to the cooking purposes as showed shown by the data analysis. The second factor which was the availability of the limited amount of air for combustion purposes through the number of holes on the bases of air fuel ration. The third factor was the design of pot seat, which ensured that there was some distance between the port base and fuel as to bring about the maximum heat transfer to the pot and also avoid smoke, whereas the there was too much smoke emission by improved stove causing the irritation effects as it was so difficult to stand in the kitchen because of the pot seat position.

The operation cost of gasifier stove per day was calculated PRs 36.77 however improved stove's total cost of production was PRs 32.67. If the Gi Sheet gauge # 18 will be used, the cost of the gasifier stove from 6500 PRs to 4000 PRs will be reduced because GI sheet is cheaper than the M.steel sheet gauge # 19.It was concluded that improved stove was slightly cheaper than gasifier stove but the efficiency of gasifier stove was better than improved one.

Conclusions

The gasifer wood stove has a maximum thermal efficiency of 30% and the useful heat energy output per kg of wood used by gassifier stove was 239.60 kJ/kg as greater than the useful heat energy output per kg of wood used by improved stove was 144.46 kJ/kg, respectively. So, the performance of gasifier stove is much better than improved stove. It was observed that virtually all the flue is successfully converted into heat has utilized by boiling water in case of gasifier stove because the percentage of carbon in coal from improved stove is 4.28 % whereas the presence of carbon in coal from improved stove was 6.54 %. Thus gasifier stove technology can be sustained using local available resources such as woodchips fuel should be permitted in rural area so that we can conserve forest trees in the rural area.

The enhance performance can be attributed to a number of factors i.e., an insulation material i.e., mica sheet and glass wool provided around the outer cylinder of the gasifier stove, likely due to increased distance of the pot bottom from the flame also gave the good result in gasifier stove case as compared to improved stove. The operating cost was predicted as Rs 36.77 which is reasonably low.

References

Abdul, W. B., A. B. Aqeel and Z. Gholamreza. 2011. Greener energy: Issues and challenges for Pakistan—Biomass energy prospective. Department of Chemical Engineering, Dawood College of Engineering & Technology, Karachi, Pakistan.

Belonio, A. T. 2005. Gas stove using rice hulls as a fuel, Glow. Yogyakarta, Indonisia.Vol:35.

Bhattacharya, S.C.,S. Kumar, L. M. Augustous and A. M. Khaing. 2003. Design Performance of a Natural Draft

Cross-Flow Gasifier Stove for Institutional and Industrial Applications. Proceedings of the International Seminar on Appropriate Technology for Biomass Derived Fuel Production. Yogyakarta, Indonesia. pp. 129-138.
Bridgwater, A.V. 1995.Technical and economic feasibility of biomass gasification for Belonio. 2005. Rice husk Gas Stove hand Book. Philippine. 98-101.
Escorts Foundation. 1999. Fuel Efficient Smokeless Stoves. Pakistan.J. Asia.Pakistan-1.p1.
Houmoller.1997.Fluid bed pyrolysis and biomass gasification. Published by Wikipedia on Answers.com. (http://www.cresard.com/gasifierblog/gasifierblog.htm).
Pakistan Population Census. 2011. Population census organization government of Pakistan. www.census.gov.pk
Panwar, N. L. 2009. Design and performance evaluation of energy efficient biomass gasified based cook stove on multi fuels, Springer Science and Business Media.
Souza-Santos, M. L. D. 2004. Solid fuels combustion and gasification: modeling, simulation, and operation of equipment. Marcel Dekker, New York, USA.
Wood, T. S. and S. Baldwin. 1985. Fuel wood and charcoal use in developing countries. J. Envir. Resource.vol.10:407-429.

Table 1.1 Different fuels consumption by the urban and rural population of Pakistan

Fuels consumption	Urban %	Rural %	Pakistan %
Firewood	37.94	57.87	53.22
Dung	11.35	20.12	18.08
Crop Residues	6.35	16.4	14.09
Charcoal	0.38	0.66	0.6
Subtotal biomass fuels	**56.04**	**95.04**	**85.98**
Natural Gas	30.16	0	7.08
Electricity	10.55	2.44	4.26
Kerosene	2	2.29	2.11
LPG	1.27	0.23	0.46
Subtotal Modern	*43.98*	*4.96*	*14.02*
Total	**100**	**100**	**100**

Source: Escorts Foundation 1999

Table 4.1 Results analysis gasifier stove for one liter and three liter of water

Stove	Parameters	Results	
		One Liter of water	Three Liter of water
	Initial mass of water in pan	1 kg	3 kg
	Final mass of water in pan	0.801 kg	2.2 kg
	Weight of water evaporated from Pan	0.117 kg	0.863 kg
Gasifier stove	Boiling Time of water	6.6 min	26.1 min
	Weight of Fuel used	1.14 kg	3.14 kg
	Fuel consumption rate (FCR)	0.84 kg/ h	1.2 kg/ h
	Sensible heat	134.13 kJ / h	93.16 kJ/ h
	Latent heat	137.70 kJ / h	256.29 kJ/ h
	Energy Input	674.210 kJ/ h	963.15 kJ/ h
	Energy output	269.68 kJ / h	346.73 kJ/ h
	Thermal efficiency (ηT)	40%	36%
	Char/Ash production	4.40%	28%
	Coal percentage in Ash/char	2.20%	4.28%
	Useful heat energy output per kg of woof used	321.72 kJ/ kg	301.46 kJ/ kg

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Table 4.2 Results analysis improved stove for one liter and three liter of water

Stove	Parameters	Results	
		One Liter of water	Three Liter of water
Improved stove	Initial mass of water in pan	1 kg	3 kg
	Final mass of water in pan	0.87 kg	2.5 kg
	Weight of water evaporated from Pan	0.12 kg	0.50 kg
	Boiling Time of water	13.5 min	29.36 min
	Weight of Fuel used	1.14 kg	3.14 kg
	Fuel consumption rate (FCR)	1.03 kg/ h	1.57 kg/ h
	Sensible heat	65.49 kJ/ h	81.88 kJ/h
	Latent heat	68.89 kJ/ h	132.05 kJ/h
	Energy Input	16.25%	1260.13 kJ/h
	Energy output	312.92 kJ/ h	214.22 kJ/h
	Thermal efficiency (ηT)	134.15 kJ/ h	17%
	Char/Ash production	8.72%	32%
	Coal percentage in Ash/char	3.50%	6.54%
	Useful heat energy output per kg of woof used	132.38 kJ/ h	136.44 kJ/h

Table 4.3 Comparison between gasifier and improved stoves for one liter and three liter of water

Parameters	Units	Gasifier stove		Improved stove	
		1 Liter	3 Liter	1 Liter	3 Liter
Total operating time of stove	h	1.366	2.73	1.12	2
Sensible heat	kJ/ h	134.13	93.16	65.49	81.88
Latent heat	kJ/ h	137.4	256.29	68.89	132.05
Energy input	kJ/ h	674.21	963.15	812.92	1260.13
Energy output	kJ/ h	269.68	346.73	134.15	214.22
Thermal efficacy	%	40	36.28	16.25	17
Char production percentage	%	4.4	28	11	32
Carbon percentage in Char	%	2.2	4.28	3.5	6.54
Useful heat energy output per kg of wood used	kJ/ kg	321.72	301.46	132.38	136.44

Table 4.4Test result of operating performance of gassifier stove

S.No	Parameters	Results	
		Gasifier stove	Improved Stove
1	Initial mass of water in pan	15 kg	15 kg
2	Final mass of water in pan	10.82 kg	6.61* kg
3	Weight of water evaporated from Pan	4.16 kg	2.59 kg
4	Boiling Time of water	131.23 min	87.11** min
5	Weight of Fuel used	3.14 kg	3.14 kg
6	Fuel consumption rate (FCR)	1.43 kg/ h	2.15 kg/ h
7	Sensible heat	90.66 kJ/ h	73.19 kJ/ h
8	Latent heat	248.02 kJ/ h	230.45 kJ/ h
9	Energy Input	1147.76 kJ/ h	1725.59 kJ/ h
10	Energy output	344.32 kJ/ h	310.62 kJ/ h
11	Thermal efficiency (ηT)	30%	18%
12	Char/Ash production	28%	32%
13	Coal percentage in Ash/char	4.28%	6.54%
14	Useful heat energy output per kg of woof used	239.60 kJ/ kg	144.43 kJ/ kg

Note*: Final mass of water in pan 6.61 kg was less than gasifier stove the reason is that the temperature was not stopped increasing after three readings of calculations.** Boiling Time of water had been taken by improved stove was less than gasifier stove cause the fuel after three readings were not in working condition.

Table 4.5 Comparison between gasifier and improved stoves

Parameters	Units	Gasifier Stove	Improved Stove
Total operating time of stove	h	2.18	1.46
Sensible heat	kJ/ h	90.66	73.19
Latent heat	kJ/ h	248.02	230.45
EnergyiInput	kJ/ h	1147.76	1725.59
Energy output	kJ/ h	344.32	310.62
Thermal efficacy	%	30	18
Char production percentage	%	28	32
Carbon percentage in Char	%	4.28	6.54
Useful heat energy output per kg of wood used	kJ/ kg	239.6	144.43

Table 4.6 Fixed and variable cost of gasifire stove

S.No	Particulars	Units	PRs-Gasifier stove
1	Total cost gasifier stove	Rs	6510
2	Useful life	Years	4
3	Salvage Value @ 10 %	Rs	651
	Fixed Cost Parameters		
1	Depreciation cost	Rs	1,464.75
2	Interest on average investment (as per monitory policy of State Bank, 2012 was12%,)	Rs	429.66
3	Repair and maintenance cost 1%	Rs	65.1
4	Total annual fixed cost	Rs	1,959.51
	Total daily fixed cost	Rs	5.37
	Variable cost parameters		
1	Fuel cost per kg	Rs	10
2	Fuel cost 3.14kg	Rs	31.4
3	Total daily variable cost	Rs	31.4
4	Total daily cost(fixed +variable cost)	Rs	36.77

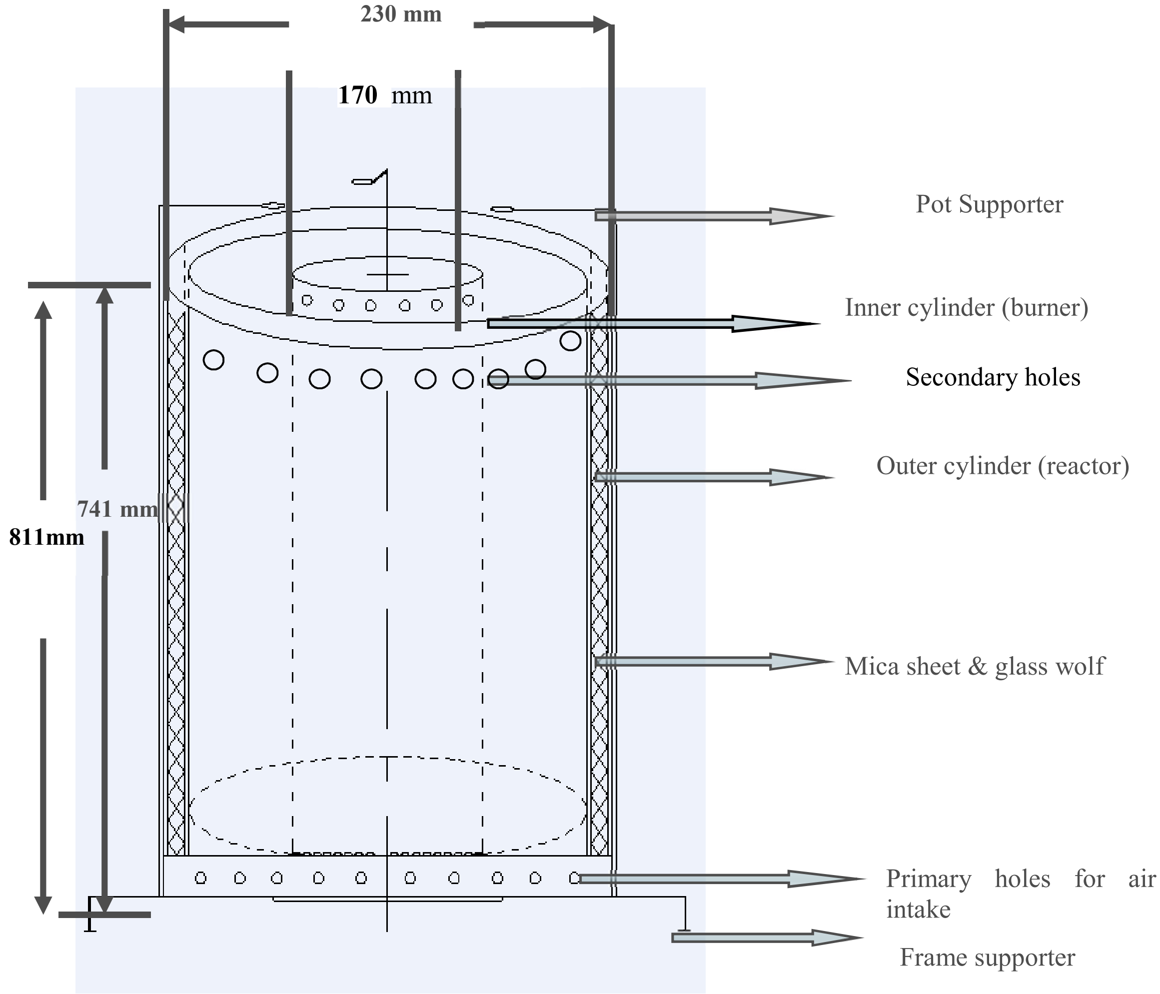

Fig. 3.1 Engineering drawing of developed gasifier stove

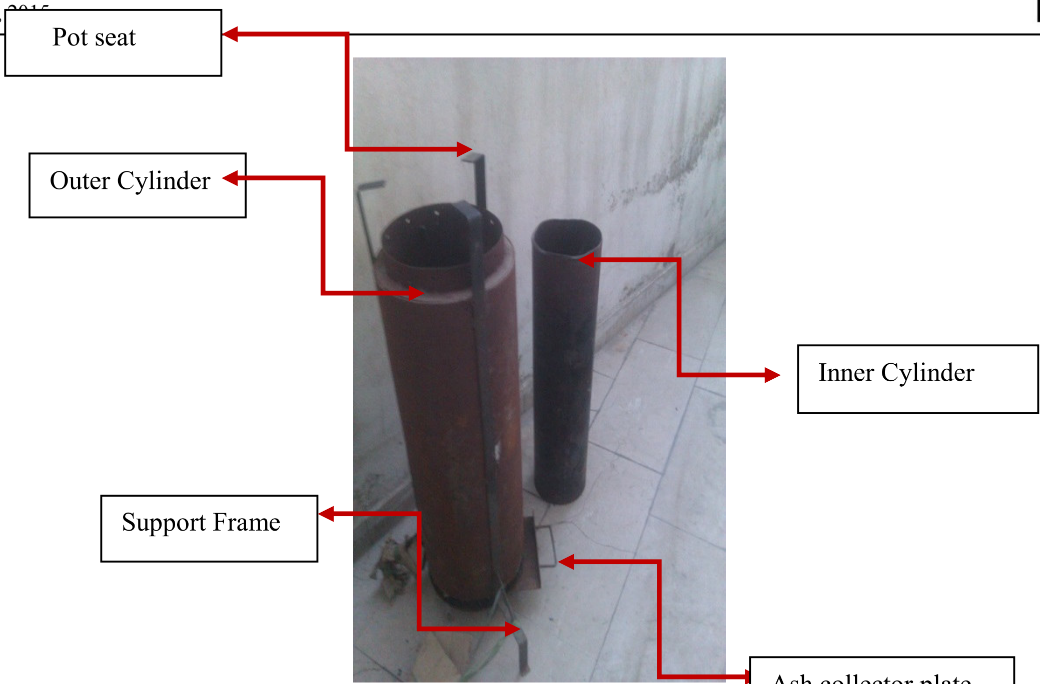

Fig. 3.2 Pictorial View of the Gasifier Stove

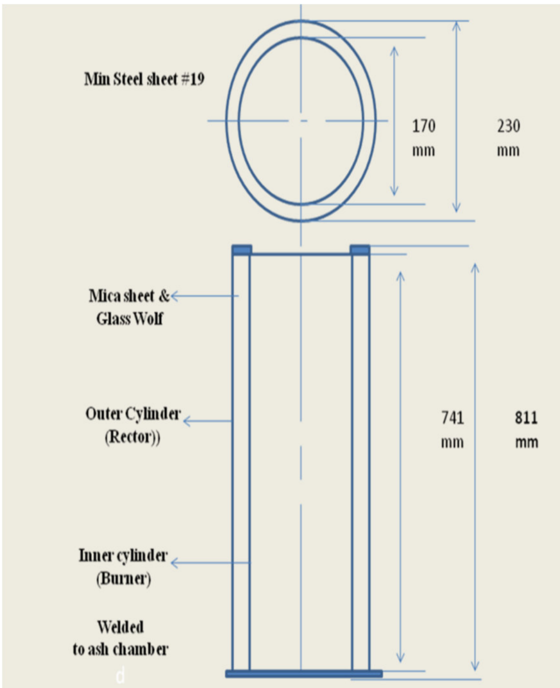

Fig. 3.3 cross sectional drawing of developed gasifier stove

Figure 4.1 Woodchips used in test

Figure 4.2 Biomass gasifier stove

Figure 4.3 Ash produced by gasifire stove

Figure 4.4 Imprroved stove

Figure 4.5 Coal produced by improved stove

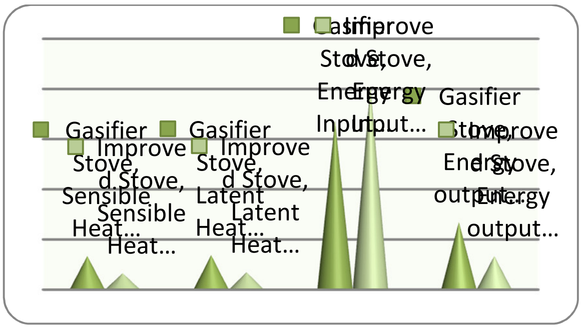

Figure 4.6 a Comparison between gasifier stove and improved stoves for one liter of water

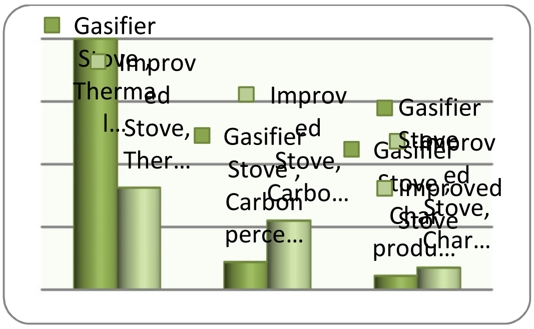

Figure 4.6 b Comparison between gasifier stoveand improved stoves for one liter of water

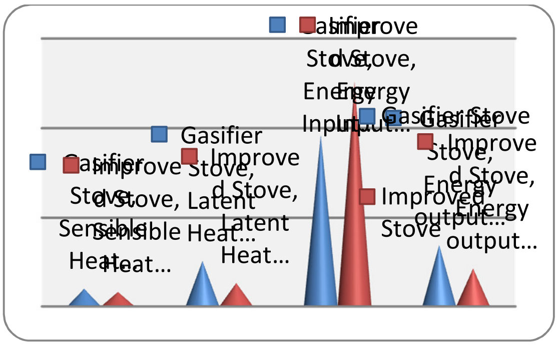

Figure 4.7 a Comparison between gasifier and improved stove for three liter of water

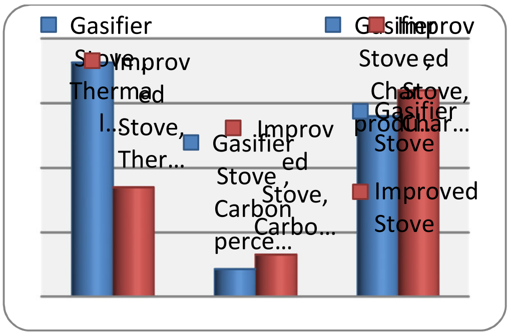

Figure 4.7b Comparison between gasifiere and improved stoves for three liter of water

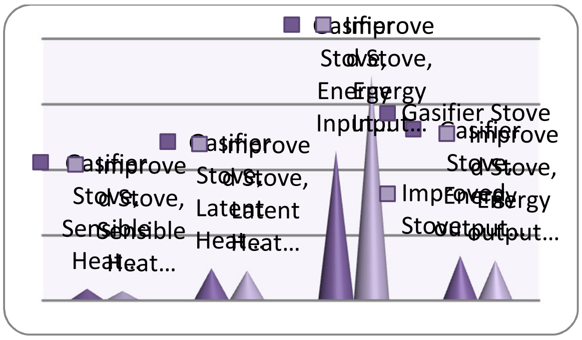

Fig 4.8 a Comparison between Gasifier and improved stoves for operating performance.

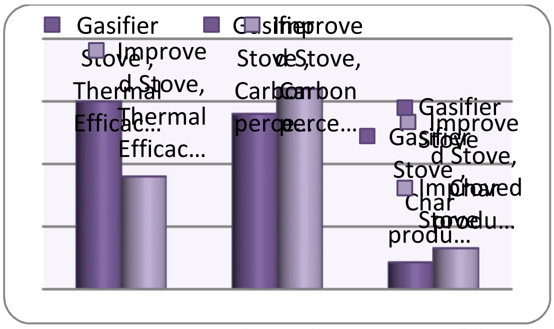

Fig 4.8 b Comparison between Gssifier and improved stoves for operating performance