E-ISSN: 2278–179X

JECET; December 12- February 2013; Vol.2.No.1, 160-172.

Journal of Environmental Science, Computer Science and Engineering & Technology

An International Peer Review E-3 Journal of Sciences and Technology

Available online at www.jecet.org

Environmental Science

Research Article

Briquetting Agricultural Waste as an Energy Source

Pallavi.H.V, Srikantaswamy.S*, Kiran B.M, Vyshnavi.D.R and Ashwin.C.A

Dept of Environmental Engineering, AIT, Chikmagalur, India

*Dept of Studies in Environmental Science, Manasagangothri, Mysore.

Received: 18 January 2013**; Revised:** 9 February 2013; **Accepted:** 14 February 2013

Abstract: This study aims at converting these agricultural wastes to char, by an eco-friendly, continuous batch process. The char thus obtained can be briquetted into a solid fuel form and later can be used as an efficient, clean source of fuel. Therefore, bagasse and coffee husk selected as a raw material for the carbonization that helps in mitigating both economic and environmental problems. Results obtained shows that the calorific value of briquettes produced from bagasse and coffee husk found to be 10439 KJ/Kg and 11389 KJ/Kg respectively. The briquette produced from the mixture of bagasse and coffee husk in the ratio 3:1 had a calorific value of 11126 KJ/Kg. Briquettes produced from coffee husk have greater calorific value. The calorific value of wood charcoal was found to be 8269 KJ/Kg, which is lesser, compared to the briquettes produced. Hence, briquettes have better physical properties and combustion rate than the initial waste. Production of briquette charcoal helps to ease the pressure on the forest cover, there by solving the deforestation problem.

Keywords: agricultural wastes, wood charcoal, briquette charcoal, calorific value, deforestation.

INTRODUCTION

Life is a continuous process of energy conversion and transformation. The accomplishment of civilization has largely been achieved through the increasingly efficient and extensive harnessing of various forms of energy to extend human capabilities and ingenuity. Thus, access to energy is necessary to sustain human life and to achieve overall economic, social and environmental aspects of human development.In India about 46% of total energy consumption is estimated to be met from various biomass resources, i.e., agricultural residues, animal dung, forest waste, firewood, etc. India produces nearly 350 million tons of agricultural wastes per year**.** A huge quantity of agricultural residues and a major part of it is consumed in traditional uses (such as fodder for cattle, domestic fuel for cooking, construction material for rural housing, industrial fuel for boilers, etc.). The direct burning of agricultural residues in domestic as well as industrial applications is very inefficient. Moreover, transportation, storage and handling problems are also associated with its use.The existing burden on biomass resources, the negative impacts on the environment and energy supply problems could be alleviated by undertaking comprehensive alternative energy technologies for decentralized applications. Thus, efficient biomass technologies used to extract biomass energy and convert it into a more useful form is required.

One of the approaches that are being actively pursued worldwide towards improved and efficient utilization of agricultural and other biomass residues is their densification in order to produce pellets or briquettes. Briquetting is the process of conversion of agricultural waste into uniformly shaped briquettes that are easy to use, transport and store. The briquetting of biomass improves its handling characteristics, increase the volumetric calorific value, reduces transportation costs and makes it available for a variety of application. Briquettes were discovered to be an important source of energy during the first and second world wars for heat and electricity production using simple technologies. Briquette charcoal is viewed as an advanced fuel because of its clean burning nature and the fact it can be stored for long periods of time without degradation. Hence this study focused on providing biomass as an alternative to wood charcoal using locally abundant agricultural wastes converted into charcoal briquettes on a small scale.

BRIQUETTING AND ITS TECHNOLOGIES

Use of agro-residues or waste paper in raw form is still limited because of a number of problems, such as low energy content per unit volume, low bulk density, high moisture content and high transportation cost. Transforming these loose biomasses into briquettes is an effective way to solve these problems, and to contribute towards alleviation energy shortage and environmental degradation. The biomass briquette is a fuel consisting of biomass, such as agricultural waste or waste paper, bound together and compressed into small pieces approximately 5 to 15cm. Briquette-making can serve as cottage industry in areas where the bio waste, wood waste and invasive shrubs are in abundance [1,2].

A lot of different materials can be used for briquette-making, for example, agricultural residues like ground nut shells, straw, tree leaves, grass, rice and maize husks and banana leaves. It is also possible to use already processed materials such as paper, sawdust and charcoal fines [3]. The selection of raw material is usually most dependent on what is easily available in the surrounding areas where the briquettes are made. Another important criterion for the selection of the raw material is its ability to bond together when compressed. For this reason fibre-rich materials are good. When these materials soaked in water and partly decomposed, the fibres in the material are able to create strong bond. Biomass densification represents a set of technologies for the conversion of biomass into a fuel. The technology is also known as briquetting and it improves the handling characteristics of the materials for transport, storing etc. This technology can help in expanding the use of biomass in energy production, since densification improves the volumetric calorific value of a fuel, reduces the cost of transport and can help in improving the fuel situation in rural areas. Briquetting is one of several agglomeration techniques, which are broadly characterized as densification technologies. Agglomeration of residues is done with the purpose of making them denser for their use in energy production. Raw materials for briquetting include waste from wood industries, loose biomass and other combustible waste products[4]

Based on compaction, the briquetting technologies can be divided into:

(1)High pressure compaction; (2) Medium pressure compaction with a heating device and (3) Low pressure compaction with a binder

At present, there are two high-pressure technologies:

Piston press and screw extrusion machines used for briquetting. The briquetting produced by a piston press are completely solid while screw press briquettes have a concentric hole, which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogenous and do not disintegrate easily. Having a high combustion rate, these can substitute for coal in most applications and in boilers. Briquettes can be produced with a density of 1200Kg/m^3 from loose biomass of bulk density 100 to 200 Kg/m^3. A higher density gives the briquette a higher heat value (KJ/Kg), and makes the briquettes burn more slowly as compared to the raw materials from which the briquettes are made.

MATERIALS AND METHODOLOGY

Materials required for biomass briquetting;

(a) Agricultural wastes (b) Carbonizer or charcoal kiln (c) Hand mould (d) Binding material (starch)

Selection of Raw Material: The selection of raw material is most dependent on the easily available materials in surrounding areas where the briquettes made. Another important criterion for the selection of the raw material is its ability to bond together when compressed. Thus, fibre-rich materials are good. The main waste product of sugarcane production is a material known as bagasse. Bagasse is the fibrous residue that remains in large quantities upon the crushing of sugarcane to remove the sugar juices. For each tonne of sugarcane crushed, about 300 Kg of bagasse retrieved. Bagasse is a fibrous, low-density material with a very wide range of particle sizes and hence can serve, as a best alternative for the production of fuel. Coffee husk is one of the agro-industrial products that are available in large quantity. Thus coffee processing industries can provide sufficient amount of husks as by-products or wastes, which causes disposal problem, as well as have impacts on the environment if not properly managed. The impacts are production of undesired odour, emission of green-house gases to the atmosphere, air and water pollution, reduction of the aesthetic value of the area and increment of soil acidity thereby reduction of crop yield etc.Therefore, bagasse and coffee husk were selected as a raw material for the carbonization that helps in mitigating both economic and environmental problems. Converting these agricultural residues into economically useful and environment friendly form of energy enables us to overcome the problems and besides that it provides the coffee and sugarcane growing regions with renewable, clean and sustainable energy sources that can substitute fire wood and charcoal that was produced in traditional way.

(a) Coffee husk

(b) Bagasse

Fig. 1: Biomass used for carbonization

Carbonizer and Hand Mould: The carbonizer is a simple design that provides a means of creating low oxygen environment. The charring kiln or carbonizer is a portable cylindrical structure with an opening at the top for loading the dry biomass material. Carbonizer fabricated using a drum of about 88 cm height and 56 cm diameter made out by 16 gauge iron sheets. Seven fire ports were provided at the bottom of the drum for firing and removal of smoke. A metal plate with the handle was made to cover the opening of the drum. The briquettes moulder was fabricated using locally available materials at a local welding shop of diameter 5.8 cm. This is easier for adoption by a local community for small-scale production of briquettes.

(a) Carbonizer

(b) Hand mould

Fig. 2: Carbonizer and Hand mould

Selection of Binder Material: The binder material used for strengthening the briquettes. The carbonized char powder mixed such that every particle of char is coated with binder. It will enhance charcoal adhesion and produce identical briquettes. Two types of binders may be employed, combustible and non-combustible. Combustible binders prepared from natural or synthetic resins, animal manures or treated, dewatered sewage sludge. Non-combustible binders include clay, cement and other adhesive minerals. Although, combustible binders are preferable, non-combustible binders may be suitable if used in sufficiently low concentrations. For example, if organic waste mixed with too much clay, the briquettes will not easily ignite or burn uniformly.

The binder can be commercial starch, rice powder, rice starch (rice boiled water), readily available and other cost effective materials like clay soil mixed in different proportions and shapes with the help of the briquetting machine. Suitable binders include starch (5 to 10%) or molasses (15 to 25%). Hence starch was selected as the binding material.

METHODOLOGY

Biomass collection: Bagasse and coffee husk selected as raw materials because of their availability. Bagasse collected from a local sugarcane crusher and coffee husk collected from a nearby coffee estate.

Drying: Bagasse and coffee husk were sun dried for a period of 10 days until its moisture content was found to be around 10-15%. Later their initial characteristic properties like calorific value, volatile matter and ash content were determined in three intervals. After noting the initial moisture content, the carbonization process carried out.

Carbonization: The dry biomass material (i.e., bagasse, coffee husk and the mixture of bagasse and coffee husk in three different trials) were loaded into the drum through the opening at the top. Papers and dry leaves used to light fire. The biomass inside the drum catches fire easily. Air enters the drum through the holes at the bottom and supports combustion of biomass. The biomass was allowed to burn for about 10 to 15 minutes.

After the smoke becomes clear, close the opening at the top as well as the holes at the bottom of the drum, so that air does not enter inside the drum. Then the drum made to rest on the ground. The sides of the drum resting on the ground covered by the soil. At the same time, top opening covered by the metal cover and sealed tightly using some soil. The drum was left undisturbed for two hours for the complete combustion of biomass (decompose) in the absence of air.

(a) **(b)** **(c)**

(a) Feeding of Biomass; (b) Metal plate covering the top opening;
(c) Carbonization process showing release of clean smoke

Fig 3: Steps in carbonization process

Char yield: After complete carbonization of biomass, water sprinkled over the carbonizer and resultant char was used for briquetting. The carbonization process produces about 40-45% char powder from the biomass. The char yield varies from one biomass to another (i .e, 12 Kg of bagasse yielded 2Kg of char, 13 Kg of coffee husk yielded 3.5Kg of char and the mixture of bagasse and coffee husk in the ratio of 3:1 yielded 3Kg of char). Finally, the obtained char crushed into fine powder using a crusher and sieved using a sieve of 250-micron meter for making the briquette charcoal.

Fig.4: Char yield

Binder preparation and mixing: The binder material used for strengthening the briquettes. Commercial starch was selected as the binder material and about 11grams of starch was carefully mixed with 100ml of distilled water in the beaker. It was then boiled to form a gelatinous material. About 40gram of char was added and mixed until a homogeneous mixture was obtained. The added binder material enhances charcoal adhesion and produce identical briquettes.

Fig.5: Binder preparation

Briquetting: Briquetting is one of the several compaction technologies to form a product of higher bulk density, lower moisture content, and uniform size, shape and material properties. The charcoal mixture was made into briquettes using hand moulds. The charcoal mixture was directly added into the mould to form uniform sized briquettes, which was later dried in oven at a temperature of 105^0C for a period of 5hrs or sun dried for a period of 7-8 days depending upon the raw material used.

Fig.6: Prepared briquettes

RESULTS AND DISCUSSIONS

Properties of Briquettes: The initial characteristic properties of bagasse and coffee husk were determined before carbonization and were tabulated in the **Table-1**. The quantity of char obtained from the carbonization of biomass was tabulated in the **Table-2.** The final characteristics of the prepared briquettes were tabulated in the **Table-3**. The comparison of properties of briquette charcoal and wood charcoal was tabulated in the table 4.4 and the graphs were plotted for the same.

Table-1: Initial Properties of Biomass

SL. NO	Initial properties of Biomass	Bagasse	Coffee husk	Mixture of Bagasse & Coffee husk(3:1)
1	Moisture content after sun dried (%)	8.5	9.3	9.2
2	Calorific value (KJ/Kg)	8542	9489	10441
3	Volatile matter (%)	86	75	83
4	Ash content (%)	5	8.6	6.8
5	Fixed carbon (%)	9	16.4	10.2

Table-2: Quantities of Char Obtained After Carbonization

SL. NO	Biomass	Mass of biomass carbonized (kg)	Mass of char obtained (kg)	Percentage of char obtained (%)
1	Bagasse	12	2	17
2	Coffee husk	13	3.5	27
3	Bagasse + Coffee husk	7+3	3	30

Table-3: Final Properties of Briquettes

SL. NO	Final properties of Briquette	Bagasse	Coffee husk	Mixture of Bagasse and Coffee husk (3:1)
1	Moisture content (%)	5.1	3.5	4.4
2	Calorific value (KJ/Kg)	10439	11389	11126
3	Volatile matter (%)	28.9	23	24
4	Ash content (%)	10.99	13.1	12
5	Fixed carbon (%)	60.11	63.9	64
6	Bulk density (Kg/m^3)	289	1088	455.2
7	Compressive strength (KN/m^2)	1.2	1.7	1.3

DISCUSSIONS

- The initial physical and chemical properties of bagasse and coffee husk were determined in order to ensure the suitability of the waste for the briquette production and were tabulated in the **Table1.**
- Moisture content is one of the important properties to be considered during the selection of raw material. The raw material with moisture content of 10 to 15 % is optimum for briquette production. Hence bagasse and coffee husk were sun dried for a period of ten days and moisture content was determined. From the table 4.1, the moisture content of bagasse was found to be 8.5% and that of coffee husk was 9.3%, which is within the required range.

- The initial calorific value of bagasse and coffee husk were determined to calculate the increase in the heating efficiency after briquetting. The initial calorific value was found to be 8542 KJ/Kg for bagasse and 9489 KJ/Kg for coffee husk.
- Fuels with high volatile matter have low heating values. The volatile matter was found to be 86% and 75% for bagasse and coffee husk respectively.
- From the **Table-.2**, percentage of char obtained by the carbonization of bagasse and coffee husk was found to be 17% and 27% respectively from the 12Kg of bagasse and 13Kg of coffee husk. When mixture of bagasse and coffee husk in the ratio 3:1 was carbonized about 30% char was obtained. Carbonization of coffee husk yields more char compared to bagasse whereas mixture yields comparatively more char than bagasse and coffee husk.
- The physical and chemical properties of prepared briquettes were determined and the values were tabulated in **Table-3**.
- The moisture content of briquettes produced from bagasse was found to be 5.1% and that of coffee husk is 3.5%. The briquette produced from the mixture of bagasse and coffee husk in the ratio 3:1 had a moisture content of 4.4%. A considerable decrease in the moisture content is observed after briquetting.
- The calorific value of briquettes produced from bagasse and coffee husk was found to be 10439 KJ/Kg and 11389 KJ/Kg respectively. Briquettes produced from coffee husk have greater calorific value. The briquette produced from the mixture of bagasse and coffee husk in the ratio 3:1 had a calorific value of 11126 KJ/Kg. The initial calorific value of bagasse, coffee husk and the mixture of bagasse and coffee husk had a value of 8542KJ/Kg, 9489KJ/Kg and 10441KJ/Kg respectively.
- The volatile matter and ash content of the briquettes produced from bagasse was found to be 28.9% and 10.99%. The briquettes produced from coffee husk had volatile matter of 23% and ash content of 13.1%. The briquette produced from the mixture of bagasse and coffee husk in the ratio 3:1 had a volatile matter and ash content of 24% and 12% respectively. It was found that after carbonization, there was a decrease in the volatile matter and increase in the ash content.

COMPARISON OF PHYSICAL AND CHEMICAL PROPERTIES OF BRIQUETTE CHARCOAL AND WOOD CHARCOAL

Table-4: comparison of briquette charcoal and wood charcoal

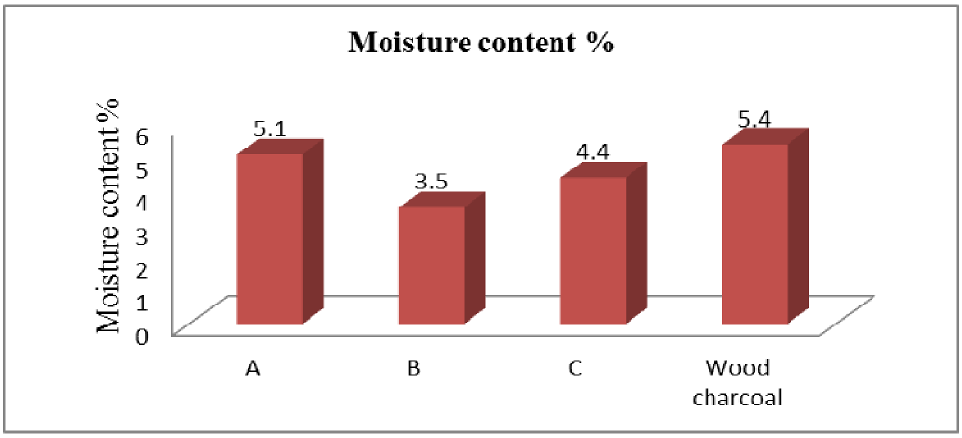
SL. NO	Briquette charcoal	Wood charcoal
1	Smokeless	Smoke
2	It exhibits faster heat release and greater heat value	Less heat release and smaller heat value
3	Low production cost when compared to purchase price of wood charcoal at local market	High production cost
4	Reduce impact of deforestation	Enhance deforestation impact
5	It can burn for long time (2-3 hours)	It can burn for short time (1-2 hours)

(Source "Education and source Journal" Vol. 5 No 1)

Table-4 shows the different properties of wood charcoal. The moisture content of wood charcoal is greater compared to the briquettes produced from bagasse, coffee husk and the mixture of briquettes produced bagasse and coffee husk in the ratio of 3:1. The calorific value, Ash content and fixed carbon, bulk density, compressive strength of wood charcoal is less compared to the briquettes produced from other species. Whereas the volatile matter of wood charcoal is greater than the briquette produced from different species.

Table-5: Comparison of physical and chemical properties of briquette charcoal and wood charcoal

SL. NO	Properties	Bagasse	Coffee husk	Mixture of Bagasse and Coffee husk (ratio 3:1)	Wood Charcoal
1	Moisture Content (%)	5.1	3.5	4.4	5.4
2	Calorific Value (KJ/kg)	10439	11389	11126	8269
3	Volatile Matter (%)	28.9	23	24	37.59
4	Ash Content (%)	10.99	13.1	12	9.8
5	Fixed Carbon (%)	60.11	63.9	64	52.61
6	Bulk Density (kg/m^3)	289	1088	455.2	349
7	Compressive Strength (KN/m^2)	1.2	1.7	1.3	0.8

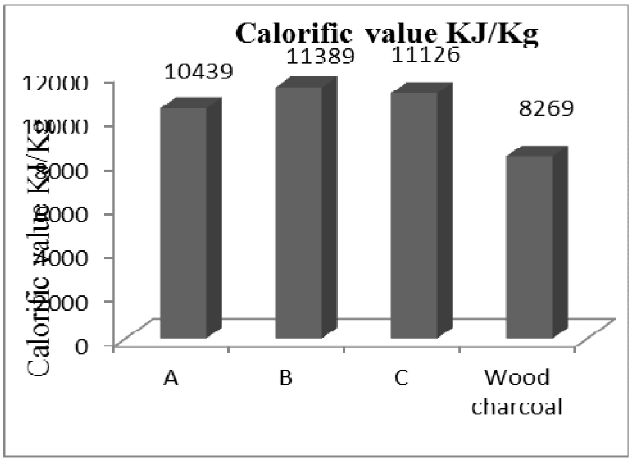


A Bagasse ; B Coffee husk; C Mixture of bagasse and coffee husk in the ratio of 3:1

Fig.7: Moisture contents of briquette charcoal and wood charcoal

The moisture content of briquettes produced from bagasse was found to be 5.1% and that of coffee husk is 3.5%. The briquette produced from the mixture of bagasse and coffee husk in the ratio 3:1 had a moisture content of 4.4%. Wood charcoal had a moisture content of 5.4% which was greater than the moisture content of the briquettes produced. A considerable decrease in the moisture content is observed after briquetting.

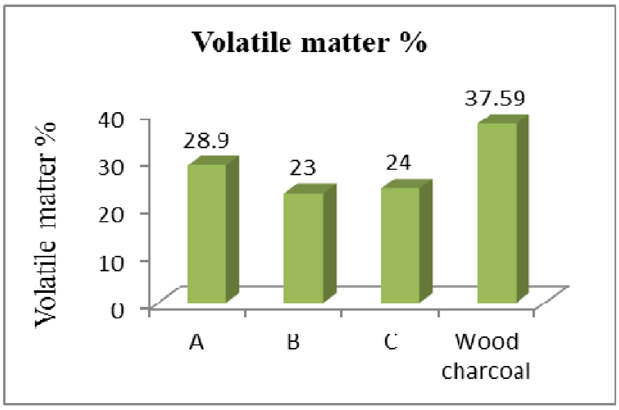
The high moisture content will lead to swelling and the disintegration of the briquette charcoal. Normally, the fresh charcoal from an opened kiln contains a very little moisture content, which is usually less than 1% but it can absorb the moisture content from the humidity of air itself rapidly with time, a gain of moisture even without any rain wetting and even the charcoal in well burned situation can take the moisture content about 5 to 10%. The quality specification of charcoal usually limits the moisture content between 5 to 15%, while the good quality of charcoal should have the moisture content is 10% maximum. On the other hand, there is some evidence concerned that charcoal with high moisture content at 10% or more than 10% tends to shatter when heated in the blast furnace.



A Bagasse ; B Coffee husk ; C Mixture of bagasse and coffee husk in the ratio of 3:1

Fig .8: Calorific values of briquette charcoal and wood charcoal

The calorific value of briquettes produced from bagasse and coffee husk was found to be 10439 KJ/Kg and 11389 KJ/Kg respectively. The briquette produced from the mixture of bagasse and coffee husk in the ratio 3:1 had a calorific value of 11126 KJ/Kg. The calorific value of wood charcoal was 8269KJ/Kg which is lesser compared to the briquettes produced from bagasse, coffee husk and the mixture of bagasse and coffee husk. Briquettes produced from coffee husk have greater calorific value.

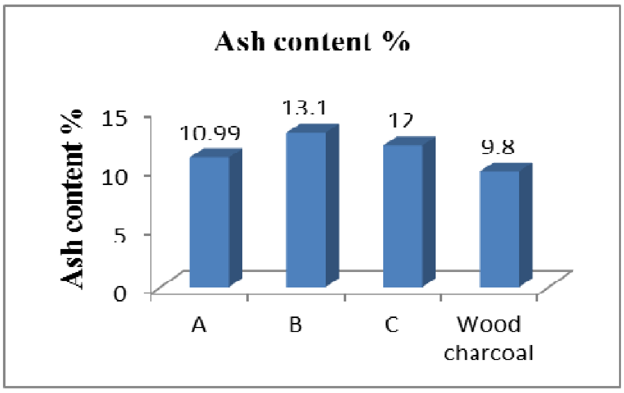


A Bagasse ; B Coffee husk ; C Mixture of bagasse and coffee husk in the ratio of 3:1

Fig.9: Volatile matters of briquette charcoal and wood charcoal

Fuels with high volatile matter have low heating values. The volatile matter of the briquettes produced from bagasse was found 28.9%. The briquettes produced from coffee husk had volatile matter of 23%. The briquettes produced from the mixture of bagasse and coffee husk in the ratio 3:1 had a volatile matter of 24% respectively. The lowest volatile matter was 23% and it was achieved by coffee husk and highest was 37.59%, achieved by wood charcoal.

Volatile matter in charcoal can vary from a high value of 40±5%. Good quality charcoal should have volatile matter range from 20 to 25 %. Charcoal produced at high temperature will have lower value of volatile matter than charcoal produced at low temperature. In addition, the high value of volatile charcoal tends to be stronger, heavier, harder and easier for the ignition than low volatile charcoal. Therefore, high volatile charcoal is easier to ignite but may burn with smoky flame while low volatile charcoal is difficult to ignite and burns with less smoke.

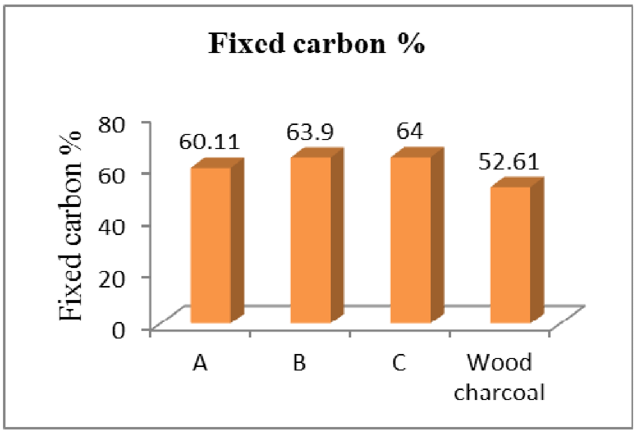


A Bagasse ; B Coffee husk ; C Mixture of bagasse and coffee husk in the ratio of 3:1

Fig.10: Ash contents of briquette charcoal and wood charcoal

The Briquette produced from bagasse had an ash content of 10.99%. And the ash content of briquette produced from coffee husk and mixture of coffee husk and bagasse was found to be 8.6% and 6.8% as shown in table 4.3. The briquette produced from coffee husk had a higher ash content of 13.1%. Lowest ash content was 9.8% and it was achieved by wood charcoal.

The good quality charcoal should have typically the ash content ranged from 3 to 4%. In the process of charcoal production if material less than 4 mm is screened out and only the particles of size greater than 4mm retains, then the charcoal produced may have an ash content of approximately 5 to 10%. Briquettes produced from bagasse, coffee husk and mixture of bagasse and coffee husk contains the highest ash content compared to wood charcoal.

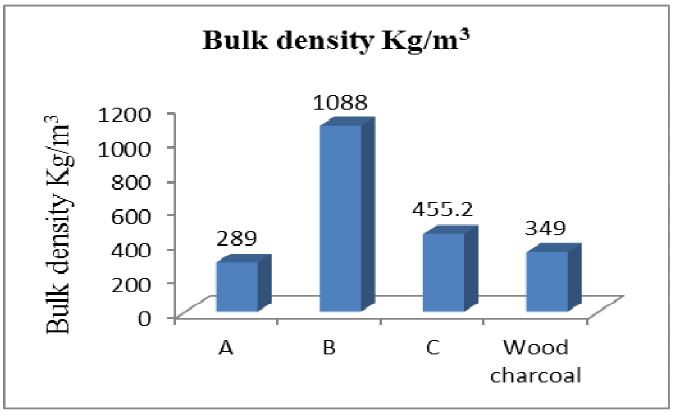


A Bagasse ; B Coffee husk ; C Mixture of bagasse and coffee husk in the ratio of 3:1

Fig.11: Fixed carbons of briquette charcoal and wood charcoal

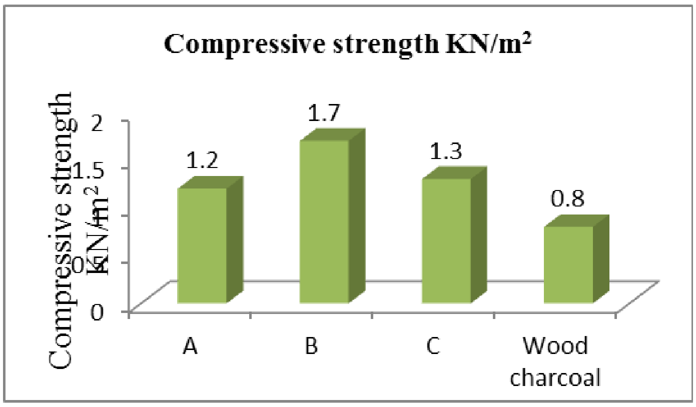
The briquette produced from bagasse, coffee husk and mixture of bagasse and coffee husk had a fixed carbon of 60.11%, 63.9%, and 64% respectively as shown in Fig 4.5. The briquette produced from coffee husk had a highest fixed carbon of 63.9% and lowest fixed carbon of 52.61% was achieved by wood charcoal.

The fixed carbon of charcoal ranges from a low of approximately 50% to a high of around 95%. The charcoal for domestic use is recommended that it should contain 80.5% of fixed carbon, while the industrial charcoal is recommended to have 86.7% of fixed carbon. On the other hand, the quality smokeless domestic wood charcoal has been specified to consist 75% of fixed carbon or more than this while the industrial wood charcoal has been specified to contain not less than 85% of fixed carbon. The proportion of fixed carbon can be controlled through maximum temperature and its residence time during the carbonization process and the charcoal produced from high temperature will be higher in fixed carbon than the charcoal produced at lower temperature. In addition, the charcoal having high volatile matter has lower fixed carbon, which low fixed carbon tends to be harder, heavier, stronger and easier to ignite than charcoal containing high fixed carbon.
The bulk density of briquette produced from bagasse, coffee husk and mixture of bagasse and coffee husk was found to be 289Kg/m^3, 1088Kg/m^3, and 455.2Kg/m^3 respectively as shown in Table 4.3. The Briquette produced from coffee husk had a highest bulk density of 1088Kg/m^3 and wood charcoal had a lowest bulk density of 349Kg/m^3. The Briquette produced from coffee husk had a highest bulk density hence it can be stored and transported easily compared to other briquettes.



A Bagasse ; B Coffee husk ; C Mixture of bagasse and coffee husk in the ratio of 3:1

Fig.12: Bulk densities of briquette charcoal and wood charcoal



A Bagasse ; B Coffee husk ; C Mixture of bagasse and coffee husk in the ratio of 3:1

Fig.13: Compressive strengths of briquette charcoal and wood charcoal

The compressive strength of Briquette produced from bagasse, coffee husk and mixture of bagasse and coffee husk was 1.2 KN/m^2, 1.7 KN/m^2, and 1.3 KN/m^2 respectively as shown in Table 4.3. And compressive strength of wood charcoal was 0.8 KN/m^2. The Briquette produced from coffee husk had a highest compressive strength compared to briquettes produced from bagasse, mixture of bagasse and coffee husk in the ratio of 3:1 and wood charcoal. The Briquette having highest compressive strength can be easily transported and stored.

CONCLUSIONS

This project involves conversion of agricultural wastes to char, by an environment friendly, continuous batch process and briquetting of the char into a solid fuel form and to use of an efficient, clean and user friendly fuel. The calorific value of briquettes produced from bagasse, coffee husk and the mixture of bagasse and coffee husk in the ratio 3:1 are found to be 10439 KJ/Kg and 11389 KJ/Kg and 11126 KJ/Kg respectively. Briquettes produced from coffee husk have greater calorific value hence it is more suitable for briquetting. The briquette produced from coffee husk also has greater bulk density, compressive strength compared to briquettes produced from bagasse and wood charcoal. The briquettes produced from bagasse, coffee husk and mixture of bagasse and coffee husk in the ratio of 3:1 is a quality charcoal in terms of high gross calorific value and fixed carbon. Conversely, it has low volatile matter, low moisture and ash content respectively, compared to the wood charcoal. The calorific value of wood charcoal was found to be 8269KJ/Kg which is lesser compared to the briquettes produced hence we can say that briquettes are more efficient then wood charcoal. The manufacturing technologies involved in each step are easy to implement in rural areas, and therefore it is also provides new income generating opportunities in rural areas. The technology has a great potential for converting waste biomass into a superior fuel for household use, in an affordable, efficient and environment friendly manner.

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***Corresponding Author: Pallavi.H.V,**

Dept of Environmental Engineering, AIT, Chikmagalur, India