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Study on physical and chemical properties of crop residues briquettes for gasification

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Abstract: The selection of material was done on the basis of availability and need of the gasifier design. Moreover, agricultural production in the country is increasing day by day with the agricultural mechanization, providing tremendous volume of agricultural residue every year. The volatile matter of soybean briquette, pigeon pea briquette and mix briquette was found to be in the range of 77.07 - 79.14%. Highest volatile mater found in briquette of mix biomass. Regarding volatile matter content, soybean briquette, pigeon pea briquette and mix briquette materials include about 70% volatile probably due to their high moisture content. Taking into account both ash and volatile matter contents, soybean briquette, pigeon pea briquette and mix briquette seem to be the best material for pyrolysis and gasification. Bulk densities were in the range of 598-675 kg/m^3. The bulk density was found more with pigeon pea briquette. Highest ash fusion temperature was found to be 1210 °C, with pigeon pea briquette. The ash fusion temperatures indicate clinker formation. The Calorific values were found to be in the range of 4107-4520, cal/kg. The soybean briquette has higher calorific value than other briquette. Crop residues briquette can be used effectively as energy fuel for gasifier.

Keywords: Agricultural Crop Residues, Biomass, Biomass Briquette, Gasification, Physical Properties, Proximate Analysis, Pyrolysis

1. Introduction

A recent study showed that agricultural residues are the most potential considering their quantitative availability. In order to characterize the physical and chemical properties of crop residues briquette used as feedstock for energy conversion process. The selection of material was done on the basis of availability and need of the gasifier design. Moreover, agricultural production in the country is increasing day by day with the agricultural mechanization, providing tremendous volume of agricultural residue every year. Biomass fuels continue to representing the primary source of energy for more than 50% of the world population and amount to about 14% of the total energy global consumption [8]. On the other hand, biomass corresponds to the most common form of renewable energy, which becomes of increasingly interest since it is considered as playing an important role in mitigating global warming and securing fuel supply. During the past decade, interest in biomass came back on international stage since it is the most promising alternative to fossil fuels. Moreover, biomass is readily available in many countries worldwide, especially those of the developing world. This renewable energy resource could be sustainable when appropriately managed and assure locally fuel supply at competitive cost. Using biomass as fuel offers also environmental benefits. When correctly operated and controlled, the combustion of biomass produces significantly less nitrogen oxides and sulphur dioxide than that of solid fossil fuels such as coal or lignite, and is CO_2-neutral since the emitted carbon dioxide will serve for the biomass regrowth, and thus not to enhance global warming. Biomass is produced by green plants through photosynthesis using sunlight. Biomass contains organic matter which can be converted to energy. This energy can be replenished by human effort. Biomass today accounts for over one-third of all energy used in the developing countries. The estimated power generation potential from biomass in India is about 19000 MW. There are two methods to produce energy from biomass; gasification and combustion route. In combustion route, biomass is burnt to produce steam. The steam is used for power generation through turbines. In gasification process, biomass is converted into producer gas and the producer gas is used for thermal or electrical application. Biomass can be burnt in a boiler for production of high pressure superheated steam using conventional combustion technology that would generate power through steam.

In India, well-recognized as one of the first rank exporters of agricultural and food products, biomass has been the traditional energy source, especially in rural areas for decades. Various types of biomass are available in India mostly in the form of non plantation resources: (i) agricultural residues, (ii) residues from wood and furniture industry, (iii) animal manure, (iii) municipal solid wastes and landfill gas, and, (iv) wastewater. Policy Research for Renewable Energy Promotion and Energy Efficiency Improvement indicated that agricultural residues are the most potential considering their quantitative availability. Actually, agricultural residues, including residues from paddy (rice husk, rice straw), sugarcane (bagasse, leaves and trashiers), maize (corncob, stalk), cassava (stalk, sludge cake), and palm (empty fruit bunch, shell, fiber), annually amount a total of 98 million tons, and 41 million tons can be used as energy resource, but only 50% of the available quantity are currently used for energy purpose. For comparison, in China, available agricultural residues represent a total of 939 million tons annually, and 551 million tons can be used as an energy resource, but only 266 million tons are effectively used [3].

However, to use biomass efficiently for energy production a detailed knowledge of its physical and chemical properties is required. These properties, more specifically average and variation in elemental compositions, are also essential for modeling and analysis of energy conversion processes [9]. Actually, information on concentration and speciation of some elements is useful both for energy and environmental issues, e.g. concentration and speciation of alkali will help to better design biomass power generation system or of heavy metal to assess the potential environmental impacts. Therefore, the investigation of chemical elemental characteristics of biomass fuels would help finding for them suitable and appropriate energy conversion technologies, but also for different existing conversion technologies to effectively use biomass feedstock. Extensive research to determine the physical and chemical properties of the indigenous available biomass resources has been conducted in several countries and international networks [14].

Gasification as a process for energy conversion has been used extensively for charcoal and woody biomass, but very little work has been reported for loose agro wastes except rice husk, at small power plant levels (about 1 MW). Current estimation of the net annual bio-residues availability for power generation in India stands at 100 million tones (t) per year amounting to about 15,000 MW capacities [2, 11]. Typical residues generated from agro industries are rice husk, coconut shell, corncobs, coir pith, tapioca waste, groundnut shells, coffee husk, etc. Bagasse from the sugar industry has a captive use for both heat and electricity. There are other wastes generated from industries where wood or woody like material is used as raw material; as in industries manufacturing paper, plywood, furniture, pencils, etc., where sawdust is available in abundance. Typically, 5– 20% of the feedstock remains as waste depending upon the industry. Some of these residues are used as fuel in combustion systems either for heat or power generation or a combination of both. The power generation is packaged with steam turbines in the capacity range of 4 MW and above. The concept of captive power generation using wastes generated in-house is common in industries such as sugar, paper, and rice mills. These industries require heat in addition to electricity for process application. In recent times, cogeneration has been promoted in several countries, leading to improvement in the overall energy efficiency. For instance in India, the sugar sector is adopting cogeneration packages where exporting electricity to the state grid is financially attractive under the rules of the state electricity regulatory commissions. Even though there are several case studies where captive power generation systems have been successfully implemented, there is also enough evidence that a large amount of these raw materials is being inefficiently utilized, thus contributing to pollution of the environment.

Among several kinds of biomass, agricultural residues have become one of most promising choices. They are easily available and environmentally friendly. Nevertheless, the majority of them are not suitable to be utilized as fuel without an appropriate process since they are bulky, uneven and have low energy density. These characteristics make this kind of waste for difficult in handling, storage transport and utilization. One of the promising solutions to overcome these problems is the briquetting technology. The technology may be defined as densification process for improving the handling characteristics of raw, material and enhancing the volumetric calorific value of the biomass. The biomass are available in different forms like rice husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks, cotton stalks, bamboo dust, caster seed, palm husk, soybean husk pigeon crop residues has traditionally been a handy and valuable source of heat energy all over the world in rural as well as the sub urban areas. In spite of rapid increase in the supply of, access to and use of fossil fuels, agri residue is likely to play an important role in developing countries in general and India in particular, in the foreseeable future. Thus, developing and promoting techno-economically viable technologies to utilize crop residue for power generation, remains a pursuit of high priority. The effective agro-residues utilization for gasification will impart the boost for utilization of the briquetting and gasification technology in our country. The outcome of the project will certainly enhance the spectrum of use of agro residues for gasification to generate the electricity on decentralized mode. The project will lead to provide the technology for generation of fuel, prepared from different agro residues for their application in a gasifier. Thus, the outcome will be highly useful for the gasifier users to attain the better gasification by using wide variety of agro residues. pea stalk and wheat straw etc. The use of biomass as a source of energy is of interest worldwide because of its environmental advantages. During recent decades, biomass use for energy production has been proposed increasingly as a substitute for fossil fuels. There is large variability in crop residues generation and their uses in different regions of country depending on the cropping intensity, productivity and crops grown [14]. They estimated total available crop residues in India as 523.4 Mt/year and surplus as 127.3 Mt/year. The annual surplus crop residues of cotton stalk, pigeon pea stalk, jute & mesta, groundnut shell, rapeseed & mustard, sunflower were 11.8, 9.0, 1.5, 5.0, 4.5, and 1.0 Mt/year, respectively. The residues of most of the cereal crops and 50% of pulses are used for fodder. Coconut shell, stalks of rapeseed and mustard, pigeon pea and jute & mesta, and sun flower are used as domestic fuel. Biomass as energy is gaining importance as a renewable source to strengthen the country's agriculture as a prime player in Indian economy. The use of biomass for thermal energy is ancient but the biomass as a renewable energy source implying clean combustion process is more recent. In the last three decades the Ministry of New and Renewable Energy (MNRE) of Govt. of India, has encouraged R&D in developing gasification systems in India. Therefore the objectives of this paper is used to find a clean and more efficient source of renewable energy from crop residues for this reason we must know their chemical and physical characteristics, in order to choose the best energetic conversion process.

2. Material and Methods

Raw material of crop residues i.e. soybean and pigeon pea stalk available at energy and power division CIAE Bhopal, Briquettes were prepared using a briquetting machine based on piston-press technology in which soybean residues and pigeon pea residues are punched or pushed into a die of 60 mm by a reciprocating ram by high pressure. These briquettes are broken in the length of 60-100 mm manually. Open core downdraft gasifier used for its efficient operation. Following observations were recorded viz. Physical and Chemical properties of crop residues briquette are obviously the most vital parameter which decides the consistent and efficient operation of the gasifier. Following properties will be determined.

2.1. Physical Properties of Crop Residues Briquette

The physical properties such as moisture content, overall length and diameter, bulk density, tumbling resistance, and resistance to water penetration of crop residue briquettes were determined. The briquettes selected for determine physical and chemical properties of three type of briquette i.e. soybean briquette, pigeon pea briquette, Mix briquette of (soybean + pigeon pea). To measure the overall length and diameter of briquettes, scale and Vernier caliper was used.

2.1.1. Moisture Content

The moisture content of a solid is defined as the quantity of water per unit mass of the wet solid. The moisture content plays an important role in the formation of briquette and subsequently its combustion. Moisture content of biomass at the time of harvesting varies drastically. The moisture content of biomass was measured by oven dry method. Initially the sample with the known weight was kept in oven at 105°C for 24 hours. The oven dry sample is then weighed. The moisture content of sample was calculated by following formula. [1]

$$\text{M.C.} = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

Where,
W_1 = Weight of sample before drying, g
W_2 = Weight of sample after drying, g

2.1.2. Bulk Density

Water displacement method was used to measure the volume of individual briquette. The briquettes were coated with wax, in order to prevent any water absorption during merging process. Each briquette was weighed and then coated with wax. The wax-coated briquettes were weighed and then submerged into water in suspension position and weight of displaced water was measured and recorded as the volume of the wax briquettes. The volume of each briquette was calculated by subtracting the volume of coating wax from the volume of wax briquettes. The volume of coating wax was obtained by dividing its weight of the wax obtained by subtracting original weight of briquette from the weight of wax briquette by its volume. [13].

Volume of sample = Volume of waxed sample – Volume of wax

$$\text{Volume of sample} = V - \frac{W_3 - W_2}{\text{Density of wax}} \quad (2)$$

Where,
W_1 = Initial weight of sample, g
W_2 = Weight of sample + string, g
W_3 = Weight of waxed sample + string, g

2.1.3. Tumbling Resistance

The Tumbling test was conducted to find out percentage loss of weight of single briquette subjected to tumbling action. Each briquette was weighed and placed in the cuboids formed by angle iron frame having dimensions of 30×30×45 cm and fixed over hollow shaft diagonally was used to conduct the tumbling test. The sample of briquettes was put inside and cuboids is rotated for15 minute. After 15 minutes of tumbling action the briquette was taken out weighed and percent loss was calculated by using formula. [13]

$$\text{Weight loss }(\%) = \frac{W_1 - W_2}{W_1} \quad (3)$$

Where,
W_1 = Weight of briquette before tumbling, g
W_2 = Weight of briquette after tumbling, g

$$\text{Tumbling resistance }(\%) = 100 - \text{percent weight loss} \quad (4)$$

2.1.4. Resistance to Water Penetration

It is measure of percentage water absorbed by a briquette when immersed in water. Each briquette was immersed in 150 mm of water column at 27°C for 30 s. The percent water gain was calculated and recorded by using following formula. [13].

$$\text{Water gain by briquettes }(\%) = \frac{(W_2 - W_1)}{W_1} x100 \quad (5)$$

Where,
W_1 = Initial weight of briquette, g
W_2 = Weight of wet briquette, g

Resistance to water penetration (%) = 100 – Water gain (%) (6)

2.2. Chemical Parameter of Crop Residues Briquette

Chemical properties are very important to determine the fuel quality. Study of proximate analysis of biomass was carried out for determination of volatile matter, fixed carbon, ash content, Ash fusion temperature and Calorific value, in the biomass. The ASTM D 3172, ASTM D 3177, ASTM D 3175, ASTM D 1875, ASTM D 3286 respectively was used for the study [1].

2.2.1. Volatile Matter

The same sample from previous determination of moisture content is used to determine the percentage of volatile matter. The sample in the covered crucible is then heated in the muffle furnace at temperature of 950 ± 20°C for 7 minutes. crucible was taken out the and first brought down its temperature to room temperature rapidly (to avoid oxidation of its contents) by placing in a cold iron plate and then transferred warm crucible to desiccators to bring it to room temperature. Take the final weight of crucible and contents. Percentage of volatile matter of the sample is determined by using the following formula. [1]

$$\text{volatile matter, \%} = \frac{b - c}{a} \times 100 \quad (7)$$

Where, a = initial weight of sample, 1g.
b = final weight of sample after cooling
(Heating temperature 107± 3 °C for 1 hour).
c = final weight of sample after cooling
(Heating temperature 950 ± 20 °C).

2.2.2. Fixed Carbon

The residue remaining after volatile matter release has been expelled, contains the mineral matter originally present and non volatile or fixed carbon. The fixed carbon was thus calculated as follows. [1]

$$\text{Fixed carbon }(\%) = 100 - (\%\text{ moisture} + \%\text{ Ash} + \%\text{ V.M}) \quad (8)$$

2.2.3. Ash Content

The same sample from previous determination of volatile matter content is used to determine the percentage of Ash content. The sample from in the crucible was then heated without lid in a muffle furnace at 700 ± 50°C for an hour. The crucible was then taken out, cooled first in air, then in desiccators and weighed. Heating, cooling and weighing is repeated till a constant weight is obtained. The residue was reported as ash on per cent basis. Percentage of ash is to be determined by using the following formula. [1]

$$Ash(\%) = \frac{Weight\ of\ ash\ left}{Weight\ of\ sample\ taken} \times 100 \quad (9)$$

2.2.4. Ash Fusion Temperature

The standard tests for fusibility of coal and coke ash are based on ASTM D-1875.[1] The biomass is dried, ground, and placed in the muffle furnace at 750°C in the atmosphere of air till constant weight is obtained. The residual ash is then finely ground a solution containing 10% dextrin, 0.1% salicylic acid and 89.9% H_2O by weight, is added to ash. To make it a plastic mass, the mass is moulded to a cone shape by pressing it into a suitable mould. These cones are taken out and allowed to dry. The dry cones placed on a refectory base are then inserted in a high temperature furnace and heated to 800 ^{0}C. After about 15 minutes interval the temperature of the sample is raised at an increment of 50°C during each interval the shape of the cone is observed. The temperature range at which the initial rounding off or bending of the apex of the cone is observed can be termed as 'ash deformation temperature'. As the temperature is further increased, the same sample has a tendency to fuse into a hemispherical lump. The temperature range during which the phenomenon is observed can be taken as 'ash fusion temperature.'

2.2.5. Calorific Value

A known mass of the given sample was taken in clean crucible. The crucible was then supported over the ring. A fine magnesium wire, touching the fuel sample, was then stretched across the electrodes. The bomb lid was tightly screwed and bomb filled with Oxygen 25 atmospheric pressure. The bomb was then lowered into copper calorimeter, containing a known mass of water. The stirrer was worked and initial temperature of the water was noted. The electrodes are then connected to 6-volt battery and circuit completed. The sample burns and heat was liberated. Uniform stirring of water was continued and the maximum temperature attained was recorded, the experimental setup for determination of calorific value using Bomb calorimeter. The calorific value of the different crop residues briquette was determined by using Bomb Calorimeter. The calorific value of the briquette was determined by using the following formula [6]

$$\text{Calorific value (kcal/kg)} = \frac{(W+w)\times(T_1-T_2)}{X} \quad (10)$$

Where,
W = weight of water in calorimeter (kg),
w = water equivalent of apparatus,
T_1 = initial temperature of water (^oC),
T_2 = final temperature of water (^oC),
X = weight of fuel sample taken (kg)

Fig. 2.1. Different crop residue briquette produces at energy enclave CIAE, Bhopal

3. Results and Discussion

Properties of crop residues briquette suitable for gasification properties of soybean briquette, pigeon pea briquette, mixed biomass briquette were studied prior to use this fuel in the gasifier for power generation. The results such as overall length and diameter, moisture content, bulk density, volatile matter, ash content, fixed carbon, tumbling resistance, resistance to water penetration, ash fusion temperature and calorific value of crop residues briquette. (Fig.2.1)

3.1. Physical Properties of Briquette

3.1.1. Overall Length and Diameter

Analyzed for the briquette were produced from 60 mm and 30 mm diameter. The length of Soybean briquette, Pigeon pea briquette, mixed briquette were found to be 60-85, 65-90, 65-80, respectively. The diameter of briquette of soybean, pigeon pea and mix were varied from 59.9-60 mm. where as its diameter was found to be 60 mm, 30 mm and 60 mm. respectively. The gasification system is designed for selected sizes of briquette fuel were within the acceptable limit.

3.1.2. Moisture Content

Moisture content is of important interest since it corresponds to one of the main criteria for the selection of energy conversion process technology. Thermal conversion technology requires biomass fuels with low moisture content, while those with high moisture content are more appropriate moisture content of lesser than 15%, and hence more suitable to serve as feedstock for thermal conversion technologies. The ground biomass used to produce briquette were measured different properties shown in table 3.1. Moisture content of Soybean briquette, Pigeon pea briquette, mixed briquette were found to be 8.75, 9.12 and 8.9 per cent, respectively. The acceptable limit of moisture content in the fuel for efficient gasification should in the range of 6 – 10 per cent. The values of moisture content of fuel were found within the limit and as per the requirement of gasification process.

Table 3.1. Physical properties of different crop residues briquette

Type of briquette	Diameter (mm)	Length (mm)	Bulk density (kg/m^3)	True Density (kg/m^3)
Soybean	60	60-85	618	1130
Pigeon pea	60	70-95	625	1150
Pigeon pea	30	65-90	675	1125
Mix biomass	60	65-80	598	1120

3.1.3. Bulk Density

It has been stated that bulk density of biomass briquettes depends on density of the original biomass [5]. Bulk density play vital role in transportation and storage efficiency. bulk and true densities of the briquette are depicted in fig.3.1 where as bulk density varies between 598 to 675 kg/m^3.several researcher have reported that densification would result in bulk densities in the range of 450 to 700 kg/m^3 depending upon feedstock and densification condition [12]. True density of the briquette varies between 1120 to 1150 kg/m^3. Obviously, for all crop residues briquettes, Comparison between each briquette indicated that Pigeon pea briquette had the highest density followed by Soybean briquette and mixed briquette respectively. The bulk density of pigeon pea briquette was found more shown in (table 3.1). High densities of fuel represent high-energy value. Bulk density of all three fuels showed their suitability as a fuel in gasifier.

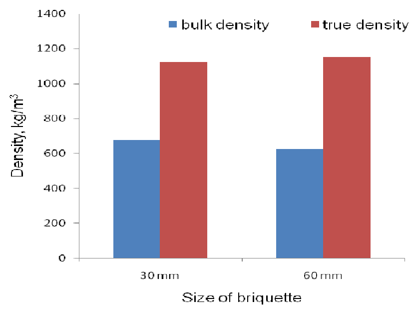

Fig 3.1. Effect of briquette size on bulk density and true density

3.1.4. Tumbling Resistance

Tumbling resistance test was performed for Soybean briquette, Pigeon pea briquette and Mix briquette. The average material loss from briquette was observed less than 4 percent during tumbling test for Soybean briquette, Pigeon pea briquette, and mixed briquette. The tumbling resistances of briquette were found to be 94.7 to 97.1 percent. The variation in tumbling resistance are given in (fig 3.2) above values indicated that the briquettes can be handled easily during transportation without any damage.

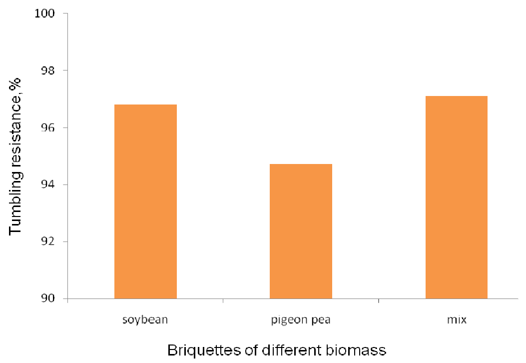

Fig 3.2. *Variation in tumbling resistance of different briquette*

3.1.5. Resistance to Water Penetration

This test was performed for Soybean briquette, Pigeon pea briquette and Mix briquette. It is observed that resistance to water penetration for given briquette was 58.4 to 71.4 and percent. Resistance to water penetration depends on the true density of material. As true density of Soybean briquette and Pigeon pea briquette was more shown in (fig 3.3) therefore, these briquettes are more resistant to water penetration. These briquettes can be stored for long duration without any adverse effect.

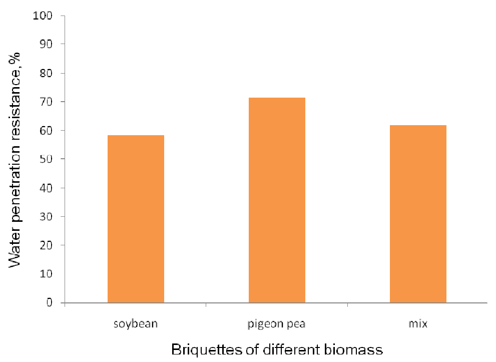

Fig 3.3. *Variation in resistance of water penetration of different briquette*

3.2. Proximate Analysis of Briquette

The proximate analysis of selected briquette were result obtained are given in (table 3.2) The volatile matter of soybean briquette, pigeon pea briquette and mix briquette was found to be 76.96, 77.07and 79.14 percent, respectively. Regarding volatile matter content, soybean briquette, pigeon pea briquette and mix briquette materials include about 70% volatile probably due to their high moisture content. Taking into account both ash and volatile matter contents, soybean briquette, pigeon pea briquette and mix briquette seem to be the best candidates for pyrolysis and gasification. The above analyses revealed that considerable amount of volatiles are available in the material of gasification.

Table 3.2. *Proximate analysis of briquette of different biomass*

Briquette	Volatile matter (%)	Fixed carbon (%)	Ash content (%)	Calorific value (kcal/kg)
Soybean	76.96	16.46	6.58	4520
Pigeon pea	77.07	15.88	7.05	4107
Mix biomass	79.14	13.52	7.34	4180

The ash content of Soybean briquette, Pigeon pea briquette and Mix briquette, were found to be 6.58, 7.05 and 7.34 percent, respectively. The ash content of biomass influences the expenses related to handling and processing to be included in the overall conversion cost. On the other hand, the chemical composition of the ash is a determinant parameter to consider for the operation of a thermal conversion unit, since it gives rise to problems of slagging, fouling, sintering and corrosion. It is desirable to use lower ash content fuel for gasification. This fuel was found suitable for gasification. For efficient gasification ash content of the fuel should be below 10 per cent [10]. High ash content fuel seriously interferes with the operation of gasifier and increase pressure drop.

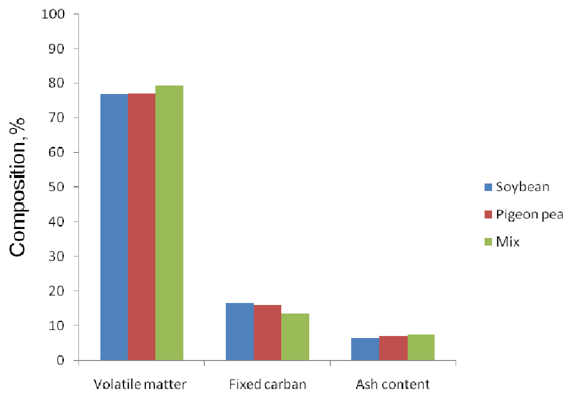

Fig 3.4. *Proximate analysis of different crop residues briquette*

Whereas fixed carbon content in Soybean briquette, Pigeon pea briquette and Mix briquette were found to be 16.46, 15.88 and 13.52 percent, respectively. It was found maximum in soybean briquette. Proximate analysis of different biomass briquette were volatile matter76.9-79.2, fixed carbon 13.5-16.5, which is comparable with woody biomass, (Prosopis juliflora) and (Leucaena leucocephala)in given (table 3.3) whose performance was already known. Meanwhile biomass briquette is suitable for gasification [7].

Table 3.3. *Proximate analysis of different woody biomass*

Woody biomass	Volatile matter (%)	Fixed carbon (%)	Ash content (%)
Prosopis juliflora	83.05	15.94	1.7
Leucaena leucocephala	82.17	16.94	1.47

3.3. Ash Fusion Temperature

The parameters that decide ash fusion are temperature and the residence time the particles are subjected to. The temperature in the oxidation zone can vary between 1,473 and 1,673 K and hence most of the agro residue ash can fuse in this zone if the char reaches such temperatures. The problem becomes serious if there are any traces of foreign matter like sand and mud. In order to determine the ash fusion conditions that are related to the operating flux conditions inside the reactor simple experiments were performed. The experimental setup consists of an inverted downdraft gasification stove with air being supplied in a controlled manner with the help of a blower and flow measuring device [4] Ash fusion temperature of Soybean briquette, Pigeon pea briquette and Mix briquette was found to be 1147 °C, 1210 °C and 1183 °C respectively(fig.3.5)

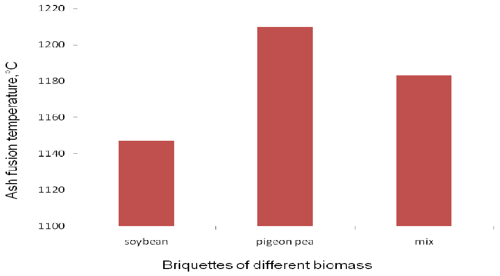

Fig 3.5. Variation in ash fusion temperature of different briquette

3.4. Calorific Value

Calorific value of different crop residues briquette are given in (table 3.2).Lower Heating Values indicate energy effectively released by the biomass fuels, and so the necessary quantity to feed in the energy conversion unit. Our results showed that among all analyzed samples, Soybean briquette has the highest calorific value, followed by Pigeon pea briquette and Mix biomass briquette.

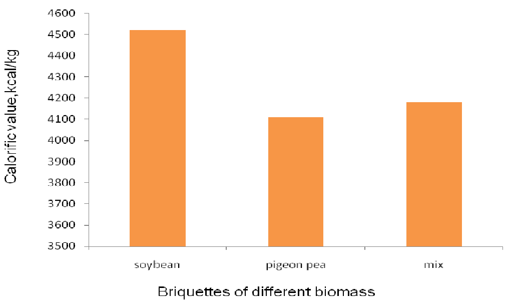

Fig 3.6. Variation in calorific value of different briquette

4. Conclusion

In order to characterize the physical and chemical properties of crop residues briquette used as feedstock for energy conversion process. The volatile matter of soybean briquette, pigeon pea briquette and mix briquette was found to be in the range of 77.07 - 79.14%. highest volatile found in briquette of mix biomass, Regarding volatile matter content, soybean briquette, pigeon pea briquette and mix briquette materials include about 70% volatile probably due to their high moisture content. Taking into account both ash and volatile matter contents, soybean briquette, pigeon pea briquette and mix briquette seem to be the best candidates for pyrolysis and gasification. Bulk densities were in the range of 598-675 kg/m^3. The bulk density was found more with pigeon pea briquette. The highest ash fusion temperature was found to be 1210°C, with pigeon pea briquette. The ash fusion temperature indicates clinker formation. The Calorific values were found to be in range of 4107-4520, kcal/kg. The soybean briquette has higher calorific value than other briquette. Crop residues briquette i.e. Soybean briquette, pigeon pea briquette and mix briquette can be used effectively as energy fuel for gasifier.

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