CHARACTERIZATION OF FUEL PELLETS BASED OF ALMOND SHELLS AND COTTON STALKS USING NATURAL GUM

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ABSTRACT: *The biomass materials have the potential to fulfil our energy needs. These materials are present in large amount in our agricultural based country. In order to make biomass materials to use as an alternative fuel, easy handling and proper feeding in the automatic feeding system of the combustion chamber, the biomass materials are processed in the form of pellets with the help of pelletization technology. In this article the procedure of increasing the density at room temperature and characteristics of fuel pellets based on the selected biomasses almond shells and cotton stalks with different concentration of the natural binder are discussed. The physical, mechanical, and heating values of the selected biomass almond shells and cotton stalks are studied. This article also discussed the effects of moisture contents in the form of concentration of the natural binder on the physical, mechanical, and heating values of pellets made of almond shells and cotton stalks. It was concluded from the study that both the materials almond shells and cotton stalks have potential to use as a boiler fuel with the varying amount of natural binder. It has been observed that binder impart specific characteristics like to enhance the binding strength of particles, bulk density, pellet density to the fuel pellets and also have significant impact on the heating values of the fuel.*

Keywords: Moisture contents, Bulk density, True density, Durability, Densification Biomass pellets, Heating Value.

1. INTRODUCTION

Presently, most of the energy needs are fulfilled from fossil fuel.it is considered to be the major source of energy in present world. Fossil fuel is consuming in tremendous amount in vehicles, airplanes and industries. Rate of consumption of fossil fuel is very high and it is predicted that the present reserves of fossil fuel will last only for next 40-50 years [1]. Furthermore the environmental damages like urban smoke acid rain and global warming are responsible by the production of emission from fossils fuels. Fossil fuel is the major source of contribution of the oxides of sulphur and nitrogen, carbon dioxides and Carbon mono oxide in the atmosphere. They are playing significant role in Air pollution on earth. Emission of SOx and NOx are the responsible of acid rain. Carbon dioxides are the responsible for global warming. Due to the present environmental damages, increasing prices and running short of fossil fuel the scientist and researchers are trying to find out alternative sources of energy like solar, wind, tidal, geothermal, biomass etc. [1, 2]. Due to abundantly availability of biomass, it is considered to be the best alternative source of energy. In the present world it is estimated that 10-15% of our energy need is fulfilled from biomass. Approximately 9-14% of energy demand is fulfilled by industries from biomass. In developed countries this amount is as high as one fifth to one third [3].

Steam system is very much important part of the industrial processes. In all process industries the energy is supplied to generate steam. This steam is used for different purposes like to concentrate and distil liquids, to heat processes, or is used directly as a feedstock. It is pointed out by the major industrial concern that steam system use considerable amount of fossil fuels. Food processing industries 57%, Paper& Pulp Industries 81% &chemicals 42%, Petroleum Refineries 23% and primary metals 10%.Since all the industrial systems are diverse but they have often major steam systems in common. For energy efficiency measure it makes very useful targets [4]. Saidur and Mekhilef [5] claim that in rubber producing industries in Malaysia 20% of the total energy is used.

Biomass is considered best renewable energy source with very specific properties. When compared with other renewable technologies such as solar or wind, biomass has very less problems with energy storage in other sense, biomass is stored energy. Moreover, biomass is a very versatile fuel that can be used to produce biogas, liquid fuels and electricity.it is considered as an earliest green source of energy. Biomass has become very vital source of renewable energy due to reduction of CO_2 emission in the atmosphere which is the burning question of this present world because of global warming. In combustion process biomass carbon reacts with oxygen of the air to form $CO_2$and released into the atmosphere. If fully combusted the amount of CO_2 produced is equal to the amount which was taken by the biomass from the atmosphere during the growing stage. Therefore in atmosphere net addition of CO_2 is zero and biomass can be considered as a carbon sink. A lot of other benefits by using biomass are economic, social and environmental benefits such as financial, conservation of fossil fuel resources, creation of jobs in industrial and agricultural sector and CO_2 and NO_x emissions reduction.

2. Materials and Methods

The Methodology of the whole process of pellet making consists on following three major steps.

2.1 Preparation of the Feed

2.1.1 Raw material Selection

Our country is an agricultural rich. Millions of tons of agricultural waste are generated throughout the country every year. The agricultural waste produced in Pakistan are Wheat Straw, Corn cobs, Bagasse, Cotton stalks almond shells Corn Stover etc. A significant amount of useful energy can be produced from these bio wastes materials after processing the biomass. The selection of the biomass material for pellets making depends upon the some of the features. The selected biomass should have High value of Carbon and volatile contents, Low ash contents, low sulphur. (For environmental friendliness) contents, cheap and abundantly availability throughout the year.

The Proximate and Ultimate analysis of almond shells and cotton stalks (Table 1 & Table 2) showed that both of the materials have high volatile matters content and elemental Carbon. It has low ash and sulphur contents. These silent features make it suitable choice for the selection of the biomass for pellets making. The stalks were obtained after removing the cotton bails and brought to the laboratory for washing.

Figure 1: Almond shells

Figure 2: Cotton Stalks

2.1.2 Washing

The raw materials Almond shells and Cotton stalks were taken in sufficient amount in a bucket for washing. Almonds shells and cotton stalks were washed with ordinary tab water to remove the all the unwanted dust particles mud and debris materials from the raw materials.

2.1.3 Atmosphere Drying

The washed raw materials were placed in the atmosphere for drying. Almonds shells were dried in the atmosphere under shelter for four days and the cotton stalks were dried under shelter for one week until constant weights. The dried constant weight biomass materials were packed in plastic polythene bags.

2.1.4 Size reduction

The size reduction is very important step of pellets making process. If the particles of the pellets are too Fine, they usually have tendency to accept more moisture from the atmosphere than large particles and, hence high level of conditioning need to be done. In the same way if the particles size is large; there are fissure points on the particles that may be the cause of cracks and fractures in pellets [14].

The recommended size by some researchers for pellets of fine quality is 0.5mm to 0.7mm [14].For size reduction the biomass materials cotton stalks and almond shells were grinded in locally made ultrafine grinder in the laboratory. The screen used in the ultrafine grinder was 2mm which gives the maximum grinded material of required mixed size that is 0.5mm to 0.7mm. The 2mm screen of the ultrafine grinders gave the 60%grinded Almond Shells material of our required size. The grinded cotton stalks and almond shells were again packed in the polythene bags to avoid the effects of moisture of the atmosphere.

2.1.5 Screen Analysis

In order to obtain the particles of desired size 0.5 to 0.7mm, Screening of the grinded raw materials were done by using different screens having opening diameters 1mm, 0.833mm, 0.71mm, 0.50mm, 0.355mm, and 0.212mm.Theresults of screen analysis of the two raw materials are listed below.

The result (Table 3) of the screen analysis of grinded Almond shells showed that about 33% retained on screen having sizes 0.5mm to 0.7mm which was our desire size range and approximately 67% of the materials were above or below our desire range. All the above and below the recommended size materials were wasted.

The above results (Table 4) of screen analysis of cotton stalks showed that 38% of the crushed biomass were found to be in our desired size and approximately 62% of the crushed material were above and below this recommended range and were wasted. Since no particles were retained on 0.8mm screen, therefore there was no particle having 0.8mm of size.

2.1.6 Sieving

Two locally made sieves 1mm and 0.5mm were used to obtain the particles of our desired size range for pellets making. The grinded Almond shells and cotton stalks were passed through the 1mm sieve and retained on the 0.5mm sieve were separated and collected in the polythene bags. This shows the particles that passed through 1mm sieve were undersized of 1mm particles size and retained on 0.5mm sieve means particles size were lies in desired size range 0.5mm to 0.7mm.Above screen analysis shows that there was no particles retained on the 0.833 screen and all the material passing through 1mm screen and retaining on 0.5mm were in our desire range.

2.2 Making of Pellet

The pellet making process consist of following six steps which are explained below.

- ➢ Preparation of solution of Natural Gum
- ➢ Mingling of biomass and binder
- ➢ Hydraulic Pelletizing Press
- ➢ Pelletizing die
- ➢ Pelletizing pressure and temperature
- ➢ Formation of pellets using die and hydraulic press

2.2.1 Preparation of solution of Natural Gum

Natural Gum (Gum Arabic) is complex mixture of glycoproteins and ploy saccharides. The natural gum was bought from the market. The 50:50 by weight solutions of natural gum and water were prepared in the laboratory. Took 100 gram of natural gum and 100 gram of water in a china dish and placed it for 24 hours until the proper homogeneity of the solution is achieved and all the gum turn into dark brown or black in colour.

Fig3. Dry Natural Gum.

Fig 4.Gum in water.

Fig 5.Brown colour after 24 hours

2.2.2 Mingling of biomass and binder in different concentrations

The grinded biomass was mixed with 50% concentrated solution of natural binder in different amounts in china dish and mixed thoroughly until the homogeneous mixture is achieved.

- 95% biomass and 5% gum
- 90% biomass and 10% gum
- 85% biomass and 15% gum

2.2.3 Hydraulic Pelletizing Press

For pellets making hydraulic pelletizing press was used to compress the mixture of grinded biomass and solution of natural binder. In Hydraulic press the hydraulic pressure is exerted by the oil. The maximum pressure exerted by hydraulic press is about 3200 psi with the help of compressing rod and Base made of Mild Steel in order to withstand at high pressure without being cracked.

2.2.4 Pelletizing Die

For pellet making of desired size and shape, a cylindrical die, compressing rod and small plug was fabricated locally against the desired specification. The Steel 1045 was the constructional material of the die. The detailed specification of the die is list below (Table 5).

2.2.5 Pelletizing Pressure and Temperature

All the pellets were made at room temperature in the laboratory. At the time of the pellets making the temperature of the room/laboratory was 20 degree centigrade. The pressure at which the raw material Almond Shells got pelletized was 1500 psi and the pressure of pelletizing of cotton stalks was 1200 psi.

2.2.6 Formation of pellets using die and hydraulic press

The small plug was inserted inside through the hole at the bottom of the cylindrical die to make it a mould to give cylindrical shape to the pellets and placed cylindrical die and plug on the hydraulic press. 5 grams of the mixture of the crushed biomass and natural binder was taken into at the top of cylindrical die. Then compressing rod was inserted into the mould for the compressing the biomass inside the cylindrical die to give cylindrical shape. Compressive force was exerted by the moving plug of the hydraulic press on the compressing rod.

After the removal of the compressive force, the cylindrical die is taken out of the hydraulic press. For the pellet to be removed out of the cylindrical die hollow cylinder was placed on the inverted mould and compressing force is applied again on the hollow cylinder. The compressing rod at the bottom got inserted into the mould and forced the small plug with pellet to come out of the cylindrical die.

After the collection of the pellets were placed in the open atmosphere for drying in the laboratory and packed into the air tight polythene bags.

Figure6: Samples of pellet

3. Experimentation

The properties of the fuel pellets for the current study are given below

- Physical properties
- Mechanical properties
- Heating values

3.1 Physical Properties

Moisture content, sizes of pellet, bulk density of the pellet and pellet density or pellet true density are important physical properties of densified fuel pellets and were determined by the standard methods.

3.1.1Moisture contents

The standard method used to determine the moisture content of the fuel pellets is ASTM E871-82 (2006) [15]. According to this standard procedure the pellets were place in the electric driven oven for 18 hours at 103 ± ^{0}C to a constant weight. Randomly selected three pellets were used for the determination of the moisture contents of the pellets. The results were presented in table form as percentage moisture content of the pellet which is the average of three samples.

3.1.2Size of Pellet

For the determination of the size of the pellets, three randomly selected pellets were used to determine the diameter (mm) and length (mm) of the pellet by using the digital Vernier callipers [16,17] and determined the average of the values of the diameter and length of the three samples taken.

3.1.3Bulk density of Pellet

The pellet bulk density was determined by the standard method ASTM E873-82 (2006 [18]. This standard method is used to calculate the volume and mass of the pellets to determine the bulk density of the pellets. The above procedure was repeated three times to calculate the average values pellet bulk density.

3.1.4True Density of the Pellets

Pellet true density was measured according the standard procedure CEN/TS 15150:2005 [19]. The volume of the fuel pellet was calculated by Stereometric methods (by measuring the dimensions of the pellets like length, diameter) by using the formula $W/\pi r^2 L$ where W is the weight of the pellet and L is the length of the pellet and r the radius of the pellet [20, 21]. The above procedure is repeated for three times to find out the average value by taking three randomly chosen pellets.

3.2Mechanical Properties

The two significant mechanical properties were studied in this section. The water resistance and the impact resistance which are discussed below

3.2.1 Impact Resistance

The impact resistance (Drop Resistance) is the important characteristics of the pellets. The impact resistance test is the vital test to determine the resistance of the pellet against impact, break or shattering of the pellets during transportation, loading and unloading from trucks to ground, the handling and feeding the pellet to burning chamber.

The standard test to determine the impact resistance is ASTM. D440-07which is the drop shatter test made for coal [22].In this test the fuel pellet is allowed to drop at standard recommended height of 1.83m on a concrete floor[22] and IRI(Impact Resistance Index) was calculated according the standard method described by Richard. [24]

$$IRI=\frac{Average\ Numberof\ Drop \times 100}{Average\ Number\ of\ pieces}$$

If greater the value of IRI the greater will be the impact resistance of the pellets. The fines and small pieces of the broken pellets having weight less than five percent (5%) of the original weight should not be taken into account.

3.2.1 Water Resistance Test

The water resistance test is an important test because of the need for fuel pellet to be water resistant for its end use. Most of the fuel pellet manufactures sale their products in the market in proper packages to avoid the exposure of the pellets to rain. But some of manufactures of the industrial fuel pellets want their products should be water resistant or have water proofing property so that their product should not be damaged during transportation through wagons or trucks and outdoor stockpiling [22]. Almost all binders are water soluble binders and therefore the fuel pellets manufacture from this type of binders usually has no resistance to water and get damaged with contact with water.

The water resistant of the fuel pellets was determined by the S.R Richards [24], He calculated the water resistance and presented in the WRI form with following equation

WRI= 100- % water absorbed after 30 minutes immersion

The procedure used to determine the Water Resistant Index is “a weighed fuel is submerged in tap water and determine the tendency of the fuel pellet being disintegrated by the application of finger pressure at about 10 minute intervals. If the fuel pellets survives for 30 minutes immersion the pellet is withdrawn, pellet is wiped to remove surface moisture and again weighed. The results were presented in term of WRI.

4. Heating Values

Bomb calorimeter (ECO Isothermal Bomb Calorimeter CALK2K) was used to determine the Net heating values or Low Heating values (LHV) in the laboratory. The calorific values of three randomly selected pellets of each concentration were calculated using bomb calorimeter and the result presented in term of average values.

5. RESULTS DISCUSSION

5.1Physical Properties:

5.1.1Effect of moisture on size and density of Pellets:

The pellets of Almond shells and Cotton Stalks were in cylindrical form. The average diameter of almond shells pellets was about 20.09, 20.29 and 20.13mm, and the average length 15.35, 14.34.14.32mm (Table 8) and the average diameter of cotton stalks pellets was found to be 19.94, 20.01, 20.62mm and the average length was 18.91, 17.21, 23.64mm(Table 9).The moisture content in the form of natural binder in the fuel pellet is very much important physical property because it has direct effect on the heating value or calorific value of the fuel pellets. The greater the moisture content of the pellet the lower will be its calorific value.it also has effect on the combustion efficiency and combustion temperature [26]. On the other hand the moisture content of feed is also essential to pelletize the biomass. Without the appropriate level of moisture contents in the feed of almond shells, the Almond shells cannot be pelletized. The acceptable level of moisture contents in pellet should be less than 20% [14].The result shows the average value of the moisture contents within the acceptable limits for the good quality Pellets [25]. The result shows by increasing the binder concentration in the pellets for durability of the pellets the moisture contents also increases about 2% within the acceptable limits. The moisture contents of fuel pellets made of cotton stalks has same effects on the heating calorific values like almond shells. Although without binder concentration in the pellet of cotton stalks, it can be pelletized but required level of strength and durability cannot be achieved. The average values of the result show that by increasing the concentration of the binder the moisture content increases 3% and again it is with in the acceptable limits (20%) [25] of the fuel pellets which satisfied the both conditions affording in case of calorific values and strength and durability.

The result (Table 8) has shown that the change of dimension of the pellet by increasing the concentration of the binder and the moisture in the following pattern.

Diameter: 5% Binder > 10%Binder > 15% Binder

Length: 5% Binder < 10%Binder < 15% Binder

The result (Table 8) of almond shells pellet showed that the pellet with 15% binder concentration are more densified and compact with regular shape of fine durability and high impact resistance and bulk density and thus has high every density.

The result (Table 9) again showed that by increasing the binder concentration from 5% to 15% the length and diameter also varies in minute amount but even than the fuel pellets made of cotton stalks are considered in even and regular shape which is suitable for the automatic system of the combustion chamber. The pattern of the change is given in the following order

Diameter: 5% Binder < 10%Binder < 15% Binder

Length: 5% Binder > 10%Binder < 15% Binder

The result (Table 9) of cotton stalks pellet showed that the pellet with 15% binder concentration are more densified and compact with regular shape of fine durability and high impact resistance and bulk density and thus has high energy density.

The average values of Bulk density of the almond shells biomass grinds were700 kg/m^3,733 kg/m^3, and 763kg/m^3(Table 10) having moisture contents 10.06%,12.35% and 14.02%(Table 6). The average values of bulk density of cotton stalks biomass were found to be 233,239, and 246 kg/m3(Table 11) with moisture contents 8.72%, 12.31% and 15.52%(Table 7).The result showed that almond shells biomass grind had the highest bulk density value of 763 kg/m3 with a moisture content 14%. The bulk density values of biomass grinds obtained in this study were depending on particle size and moisture content (Lam et al., 2008; Mani et al., 2006b). The process of pelletization of biomass could significantly increase bulk density values in accordance with the results obtained with different biomasses by Kaliyan and Morey [14]. The true density of individual pellet or pellet density may be as high as 1000- 1400 Kg/m^3 and bulk density can be increased upto 700 Kg/m^3 shown by Sokahansanj et al., 1999 [17].In the present study, it had shown that the bulk density values of pellets of almond shell had increased 325 Kg/m^{3}with 5% binder concentration, 347 Kg/m^3 with 10% binder and 330 Kg/m^3 with 15% binder concentration and the bulk density of cotton stalks had found to be increased 616 Kg/m^3, with 5%binder, 595 Kg/m^3 increased with 10%binder and 829 Kg/m^3 increased with 15% binder concentration with the particles size range 0.7mm to 0.9mmafter pelleting.

The variation of the bulk density can be given in the following increasing order.

Bulk density of almond shells: 5% binder <10% binder < 15% binder

This again showed that the 15% binder concentration has the high bulk density and therefore most suitable concentration with in the acceptable limit for good quality pellets.

The variation of the bulk density can be given in the following increasing order.

Bulk density of Cotton Stalks: 5% binder <10% binder < 15% binder

This again showed that the 15% binder concentration has the high bulk density of cotton stalks and therefore most suitable concentration within the acceptable limit for good quality pellets and has high energy density.

It had also been shown by the present study that the True density values of biomass pellets, which were 1025 with 5% binder concentration, 1080 with 10% binder and 1093 kg/m^3 with 15%binder, 849 kg/m^3 with 5%, 834 kg/m^3 with 10% and 1075kg/m^3 with 15% binder concentration in case of almond shell and cotton stalks respectively were always higher than bulk density values because the volume of voids was excluded from the calculation. It had studied the effects of moisture content on physical characteristics of almond shell and cotton stalk pellets and found that bulk density of almond shell and cotton stalk pellets did not increase significantly as moisture content of the pellets increased.

Results obtained from the present study followed the same trend; bulk density of the two types of biomass pellets (Almond Shells, Cotton stalk) increased with an increase in moisture content on wet basis Fig. 7. In other words, pellets with relatively high moisture content had a low bulk density value (Table 10). Cotton stalk pellets had the highest moisture content and lowest bulk density (Table 11), whereas almond shells pellets had relatively lowest moisture content and highest bulk density. True density values of the biomass pellets also increased with an increase in moisture content because pellets increased in volume when they absorbed more moisture.(Fig.8). The true density of almond shell pellet also increased like Bulk density with increase in moisture contents but the true density of cotton stalks pellets increased significantly upto the values of true density of the almond shell pellet with 15% binder concentration with an increase in moisture content.The true density of the pellets increases from 5% concentration to 15% by increasing the binder concentration.

True density of almond shells: 5% binder < 10% binder < 15% binder

The true density of the cotton stalks increased in increasing order by increasing the concentration of the binder from 5% to 15%.

True density of Cotton Stalks: 5% binder < 10% binder < 15% binder

The results from present study showed that increase of true density of the almond shells is greater than the cotton stalks because of the material properties. The almond shells are the hard material while cotton stalks are fibrous material. When compressive force was applied on almond shells, the material was pelletized and when the compressive force was exerted on cotton stalks it expanded after the removal of force and thus volume increased due to the flexibility of the cotton stalks and therefore there was not much increase true density.

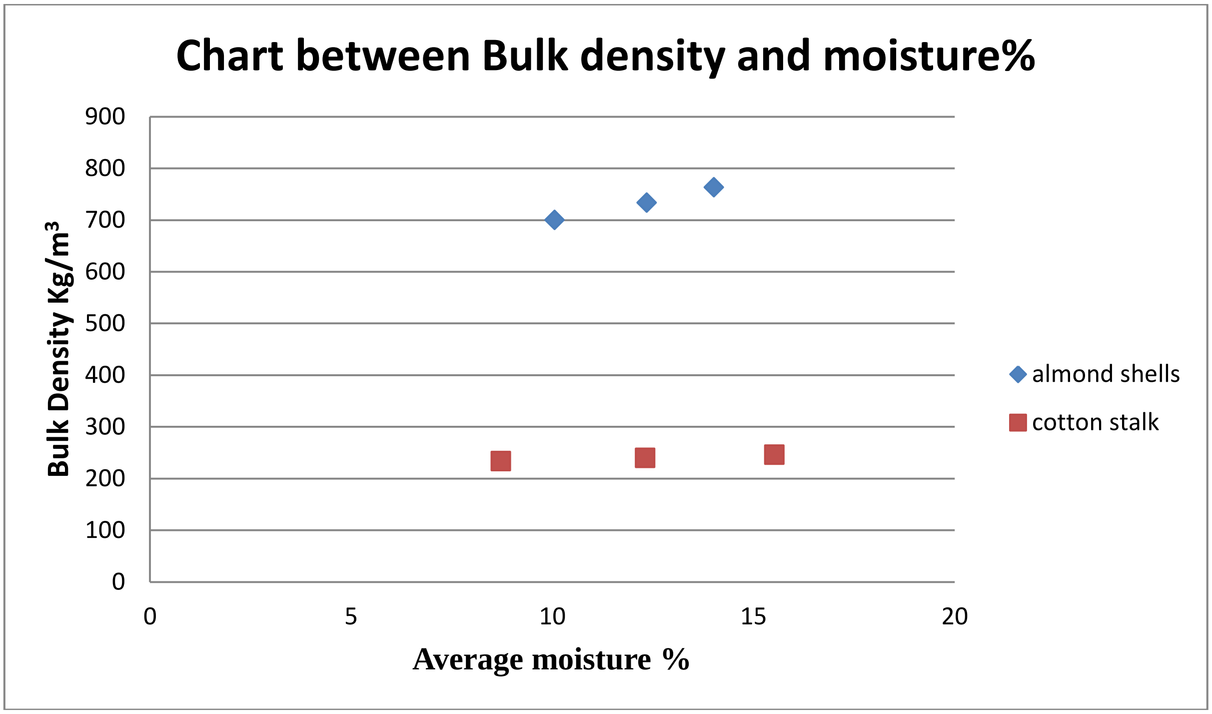

Fig.7: Bulked density and Average moisture % of almond shells and cotton stalks

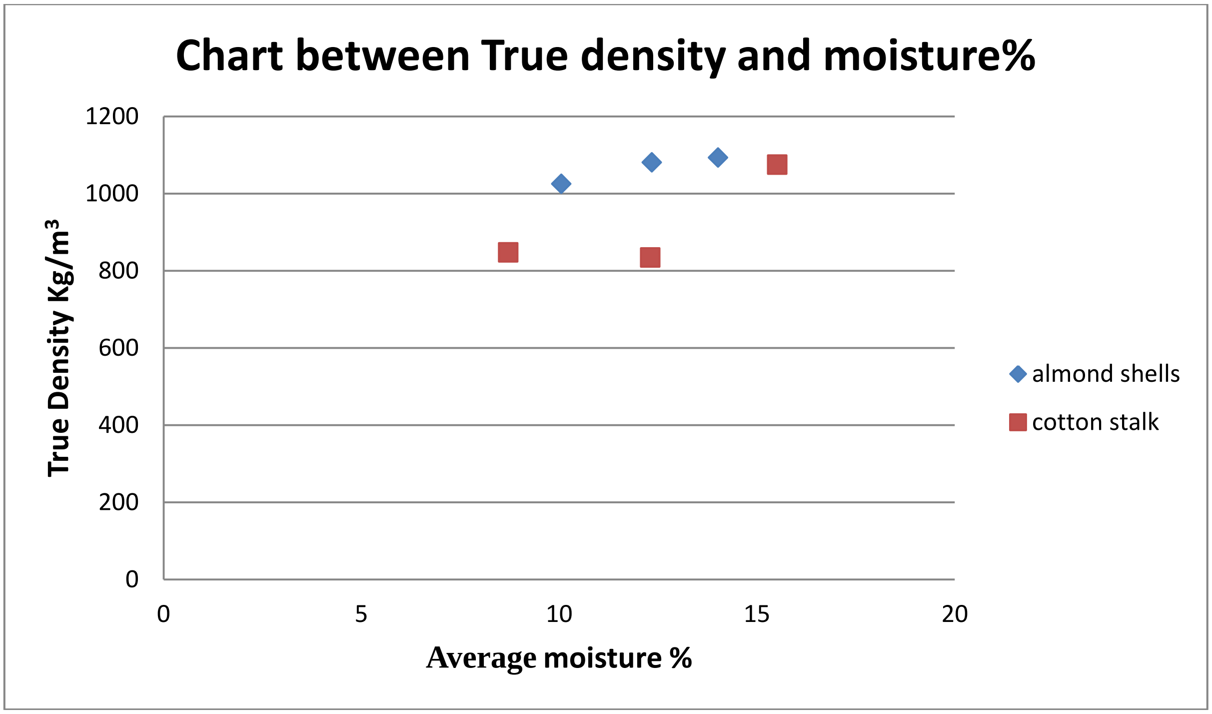

Fig.8: True density and Average moisture % of almond shells and cotton stalks

5.2 Mechanical Properties

5.2.1 Effect of moisture on durability of pellets

The process of densification of biomass by pelletization technology basically creates a very dense and durable product. Several works on pelletization have reported that the strength and durability of densified biomass increased with increasing moisture content until the level of optimum is reached (Kaliyan and Morey, 2009). It is reported by some researchers that the Optimum level of moisture contents of the biomass is required to produce strong and durable pellets. It is reported that optimum level of moisture content for biomass to be pelletized is usually in the range of 12–15%. Turner (1995)warned that pellet-mill dies would be choked when the level of moisture content of the conditioned feed biomass is found more than 16–18% (w.b.). During the pelletization process, high fiber feeds are not able to absorb moisture in the conditioning chamber so water remains on the surface of the particles, causing excess particle-to-particle lubrication. This condition causes the center of the pellet to extrude faster than the exterior, thus forming a ‘‘Christmas tree’’ shape of pellets, which would reduce the pellet durability Winowiski TS (1995). The effect of moisture content on the durability of biomass pellets in this study (Almond shells cotton stalks) is presented in (Table14). The present study had proved the same effect of moisture contents on the strength and durability of the biomass material of almond shells and cotton stalks. The maximum strength and durability of almond shells pellets obtained when moisture contents of the biomass is increased. In other words, an increase in moisture content from 10.02% (w.b.) to 14.02% (w.b.) and 8.72% (w.b.)to 15.52% (w.b.) had produced very much pellet durability. However, increasing the moisture content beyond 15% (w.b.) reduced pellet durability. This is in accordance with the results of Tabil (1996) who found that an increase in moisture content of the pellets from 6.3% (w.b) to 10% (w.b.) did not affect pellet durability, but pellet durability decreased as moisture content of the pellets increased beyond 12% to 14% (w.b.). The initial increase in durability with an increase in moisture was probably due to the binding forces of the water molecules that strengthened the bonds between individual particles in the pellets. Further increases in moisture resulted in swelling and disintegration of the pellets. No capillary force was present to maintain the pellet structure and thus left the pellets with cracks which made them susceptible to breakage (Singh, 2004; Fasina and Sokhansanj, 1996; Fasina, 2008).

The results **(**Table 14) were shown in term of impact resistance index (IRI) and equivalent to 50%. If the value of the impact resistance index is below 50 the result is considered as fail otherwise it is passed. The above results had shown that the IRI factor changes in increasing order as the concentration increases as the moisture contents increases.

IRI: 5%Binder < 10% binder < 15% binder

The results had proven that the almond shells pellets with 5% binder were broken easily in 2 to 3 drops and did not pass the impact resistance test and by increasing the binder concentration the pellets pass the test and shown the strength and durability. The pellets made of cotton stalks also behave in the same manner that is by increasing the binder concentration pellets gained the resistance again the impact force. The pellets with 15% binder concentrations showed great strength and durability in case of almond shells and cotton stalks.

5.2.2Water Resistance Test

For the present study the binder selected is water based binder. It is soluble in the water. In the water resistance test, 5 numbers of fuels pellets made of almond shells and cotton stalks were chosen randomly of each concentration. When they were dipped in the water they immediately absorbs the water and the binder get dissolved in water. All the pellets disintegrated instantly and showed no resistance against the water.

Figure 9: Almond shells water resistance test.

Figure 10: Almond shells water resistance test after 10 mints.

Figure 11: Cotton Stalks water resistance test.

Figure 12: Cotton Stalks water resistance test after 1 minute.

Heading Values

The result (Table 15) of heating values or net calorific values have shown that the 5% almond shell pellets has the highest value of the calorific value even greater than the 5% value of the cotton stalks pellets. The heating value of the 15% almond shell has less calorific value due to the increase of 4 % more the moisture content than 5% almond shells but it has high durability due to increase of moisture with increase of the binder concentration than 5% binder pellets. In case of almond shell the moisture increases 4% more but the calorific value decreases 2.12 MJ/Kg but still it is positive result. While in case of cotton stalk the moisture content increases from 8.72% to 15.52%, the heater value decreases from 2.20 MJ/Kg and still it is acceptable to use binder.

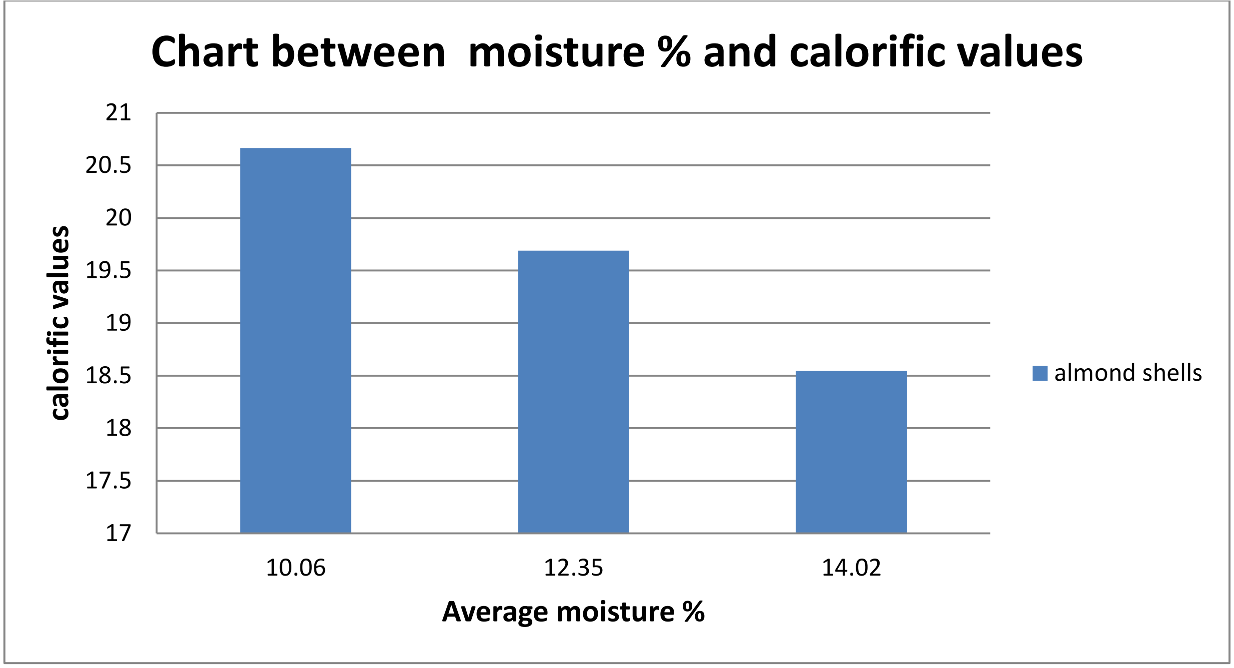

Fig.13: Graph between Calorific Values and Average Moisture% of almond shells

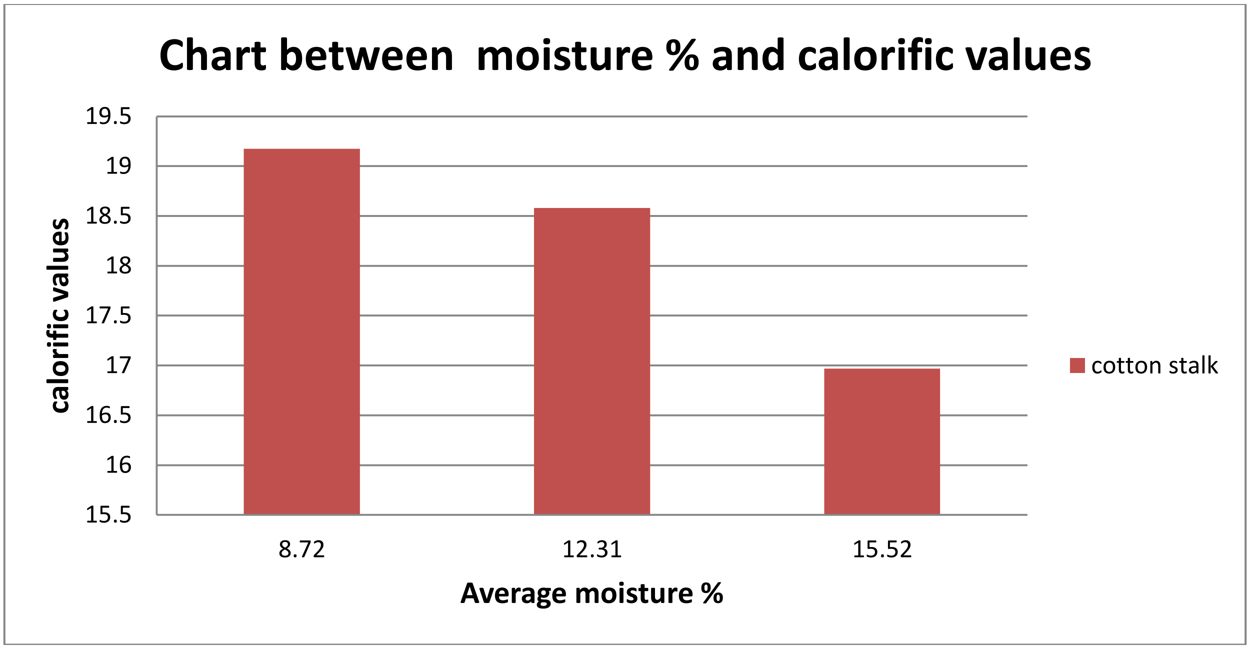

Fig.14: Graph between Calorific Values and Average Moisture% of cotton stalks

6.0 CONCLUSION

In this present study, data is obtained on the physical properties (i.e., Moisture Contents, Dimensions of the pellets, bulk density, and true density), Mechanical Properties (i.e. Impact Resistance, Water Resistance), and Heating Values of two varieties of biomass pellets (i.e., Almond Shells and Cotton Stalk). It is concluded that process of pelletization results in a significant increase in bulk density of these pellets, from 733–763 kg/m^3 to 1025–1093 kg/m^3 in case of almond shells and 233-246 kg/m^3 to 849–1075 kg/m^3 in case of cotton stalks. The strong, uniformed sized of biomass pellets with high bulk density makes the biomass easier to handle, transport and store. In addition, with the uniformity, regular shaped of the biomass, the amount of space required for biomass storage will be reduced because of the increase in bulk density. Some effects on their physical properties of the biomass due to the Moisture content of pellets had also been found. As the moisture content of pellets increased, bulk density and true density values increased because the pellets absorbed water contents. For pellets of almond shells, the increase in moisture content from 10% (w.b.) to 14% (w.b.) with binder concentration, did not affect durability. However, increasing the moisture content beyond 14% (w.b.) by increasing the binder reduced the durability of these pellets. For Cotton Stalks pellet, the increase in moisture content from 8.72% (w.b.) to 15.52% (w.b.) did not affect durability but the durability decreased as the moisture content increased beyond 15% (w.b.). For almond shells pellets, the durability value is zero with 5% binder concentration because of the low moisture contents of 10.06% and it fails the impact resistance index (IRI) and it has shown considerable durability with increase in moisture 12.35% and reached a maximum value of infinity at 10% (w.b.) to 14% (w.b.) moisture content. Therefore, it is clearly concluded from the present study that the determination of optimum level of moisture content of the pellets, which is found to be varied by biomass type, was required for production of stable and durable pellets and for the selection of suitable storage conditions for the biomass pellets.

The results (Table 14) from the Mechanical testing showed that the pellets with 10% and 15% binder concentration have more impact resistance. It is also concluded that the (15% binder) Almond shells pellets and (15% binder) cotton stalks have acceptable level of strength and durability to withstand in atmosphere, during transportation loading and storing. The pellets made from almond shells and cotton stalks with binder concentration less than 15% are not durable enough to be used hence we can conclude that 15% binder concentration is considered to be optimum level.

The results (Fig 13, 14) from bomb calorimeter for Heating values has shown that the calorific values of pellets made of almond shells with 5% conc. of the binder has highest calorific value of 20.664 MJ/Kg and the pellets of cotton stalk also has the highest value of heating of 19.173 MJ/Kg. while the heating value of almond shells with 15% binder concentration is 18.544 MJ/Kg and the heating value of cotton stalks with 15% binder concentration is found 16.667 MJ/Kg. the pattern of the graph showed that in almond shells pellets with increase of moisture contents from 10.06% to14.02% the decrease in heating value is 2.12 MJ/Kg and in case of cotton stalks with the increase of moisture contents from 8.72% to 15.52% the decrease in heating value is 2.20 MJ/Kg.it is concluded that we have to compromise with the decrease in calorific value if we want to avoid the wastage of the biomass material due to irregular shapes and sizes during transportation, handling and storage.

6.2 Recommendation

For the proper recommendation of the fuel on commercial level, some more tests are needed to be elaborated like Scanning Electron Microscopy (**SEM**), Fourier transform infrared spectroscopy (**FTIR**), Compressive Resistance, Tumbling Durability, Burning rate etc., as an alternate fuel. A suitable arrangement of gauges of temperature and pressure should be equipped to study the variation in the process of pelletization so that detailed study can be done. As shown in the result of water resistance test, new binder needs to be discovered in order to have water resistance property of the fuel pellets as well as require level of strength and durability. Using different biomass or mixture of biomasses which are abundantly available in our country to check their potential as fuel. A large amount of abundantly available biomass material or mixtures of biomass with coal should be tested as a fuel pellets to check their potential as an alternative source of energy

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