Production and Characterization of Sawdust Briquettes for Firewood Substitution

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Abstract. The possibility of substitution of firewood by sawdust briquettes was examined. Easy to operate and portable homemade briquetting machine was fabricated. Three internal diameters of molding cylinder/die diameters specifically 6, 8 and, 10 cm were used to examine the effect of pressure on the quality of sawdust briquettes. For all types of sawdust briquettes, the highest and lowest values of density, porosity index, volatile matter, ash content, fixed carbon, and calorific value are 218.2–322.6 kg/m^3, 34–312.4%, 70.2–90.6%, 2.3–7.3%, 6.7–24.3% and 14.5–18.4 MJ/kg respectively. The figured physical and chemical properties of sawdust briquettes were interesting. The density and porosity index of sawdust briquettes were extensively affected by molding cylinder diameter and waste paper percentage. An interesting quality of sawdust briquettes was attained at lower particle dimension, waste paper percentage and higher pressure. The optimum value of density, porosity index, percentage volatile content, percentage ash content and gross calorific value of 306.1 kg/m^3, 35.9%, 83.9%, 3.1% 17.1 MJ/kg respectively were acquired at a combination of die diameter of 6 cm and waste paper percentage of 25%. The capability of production of sawdust briquettes with good quality using only waste paper as a binder is an encouraging fact and the briquettes can be excellent augments to firewood.

Keywords: Sawdust · Briquette · Density · Calorific value

1 Introduction

Natural resources have a great role and impact on the functioning of an economic system of a country. Because of these, energy which, is usually obtained when all these natural resources are harnessed plays a vital role in the overall development planning of any nation. Energy has been the central cross-sectoral issue, which affects all human activities either directly or indirectly. It is a vital input to economic growth and development of any economic sector. Energy has been seen to be a crucial input in the process of economic, social and industrial development. Apart from the other three classical factors i.e. land, capital and labor, the role of energy cannot be underestimated when it comes to development (Kuti 2007).

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Energy resources are generally classified into two namely renewable and non-renewable. Renewable is thought to be a better option since the non-renewable has not a capability to be refilled. Renewable energy sources are more environmentally friendly and are thus better candidates for use in achieving some measures of technological development under a sustainable environment both in the developed and developing nations. The high cost of non-renewable energy sources has made people start deviating to the use of renewable energy sources for domestic cooking (Mahadeo and Dubey 2014). The renewable energy sources should be effectively utilized in order to meet the rapidly increasing energy demand. Biomass energy has greater prospective than the other form of energy (Rajaseenivasan and Srinivasan 2016).

The more comfortable human life is paid by excessive energy increase in all its forms. The reserves of not renewable energy sources (coal, crude oil, natural gas) are not limitless, they gradually get exhausted and their price continually increases (Brožek and Nováková 2012).

Materials, which originate through a conversion process like paper, cellulose, organic residues from wood industries and organic waste materials from industries and houses constitute a large part of the biomass. Wood is the largest potential source of biomass when compared to others. Most of this potential lies in wood processing by-products such as sawdust, spent paper pulping liquor, forest management by-products such as thinning and logging residues. Out of all the various kinds of wood wastes, sawdust is of high importance. Sawdust is always obtained from forest wastes or manufacturing wastes. As a result of growing worldwide concern regarding environmental impacts particularly climate change from the use of fossil fuels coupled with the volatile fossil fuel market and, the need for independent energy supply to sustain economic development, there is currently a great deal of interest in renewable energy in general and biomass energy in particular (Kuti 2007).

Apart from the problems of transportation, storage, and handling, the direct burning of loose biomass in conventional grates is associated with very low thermal efficiency and widespread air pollution. The conversion efficiencies are as low as 40% with particulate emissions in the flue gases in excess of 3000 mg/Nm^2. In addition, a large percentage of unburnt carbonaceous ash has to be disposed of (Maninder 2012). The utilization of biomass waste or residue as energy source could help alleviate dependence on imported energy and its use continues to be a topical issue (Carnaje and Talagon 2018). Briquetting involves the collection of combustible materials that are not usable as such because of their low density and compressing them into a solid fuel product of any convenient shape that can be burned like wood or charcoal. Thus, the material is compressed to form a product of higher bulk density, lower moisture content, and uniform size, shape and material properties. Briquettes are easier to package and store, cheaper to transport, more convenient to use, and their burning characteristics are better than those of the original organic waste material. Briquetting is undergoing renewals, principally due to the convergence of three critical factors. First, the recent developments in briquette processing and binding have dramatically changed the economics of using fuel briquettes as an energy resource. Secondly, a shortage of firewood has become increasingly severe in most of the developing countries. Finally, there has been a steady increase in environmental concerns to address the problem of domestic and urban waste disposal (Katimbo and Kiggundu 2014).

Briquettes made from materials that cost little or no money to obtain such as a newspaper or partially decomposed plant waste or sawdust can be an alternate source of domestic and industrial energy to charcoal, firewood, gas, coal, and electricity. Briquettes production thereby turns waste materials into a fuel source. This is therefore attractive because it is a sustainable process (Emerhi 2011). A sawdust briquette is one of the most preferred briquettes. This involving compressing and extruding sawdust to make a reconstituted log that can replace firewood. The production of briquettes from sawdust exemplifies the potential of appropriate technology for wood waste utilization. It save strees that can prevent soil erosion and desertification by providing an alternative to burning wood for domestic and industrial heating and cooking. Also, it substitutes saw milling waste for a valuable resource (Sivakumar 2011).

1.1 Statement of the Problem

The population of Ethiopia depends on biomass almost for all everyday energy needs. Forest resources in Ethiopia have experienced so much pressure due to the increasing need for wood and wood products. Almost all people in Ethiopia use wood for cuisine purposes and as a source of heat in cold seasons. Highly dependence on wood results in deforestation and environmental pollution. Sawdust is a byproduct of all wood processing activities. It is difficult to store and transport sawdust within a small volume because it is bulky. Due to the requirement of excess land to store and low thermal efficiency of direct burning of sawdust, wood processing industries are forced to dispose of sawdust in an open area far from their working areas. This exercise emanates profit reduction and environmental pollution. Starch is one of the staple foods of carbohydrates in human nourishment. In addition to this, starch is an excellent binder type in briquetting technologies. Even if starch is a well-known binder type, it has to be substituted by easily available, low cost, eco-friendly and non-food materials. Therefore, using waste paper as a binder is an interesting material to replace starch in briquette production activities. Sawdust briquettes can be a good substitution of firewood because sawdust is readily accessible in a considerable abundance. The provision of a choice of energy origin is a means to hand over the best living standard of the community in terms of energy cost and environmental security. Therefore, the production of sawdust briquettes is a better means to have an environmentally sound energy source for the substitution of firewood.

2 Materials and Experimental Methods

The experimental process of characterization of the raw sawdust and briquettes, except gross calorific value which was determined in laboratory of Alternative Energy Development and Promotion Directorate laboratory under Ministry of Water Irrigation and Electricity, Addis Ababa, was carried out in Bahir Dar Institute of Technology, Faculty of Chemical and Food Engineering, Chemical Research grade Laboratory, Bahir Dar. Waste paper (any available paper such as old newspaper, used up exercise book, etc.)

and sawdust of Cupressus Lusitanica were collected for the production of briquettes. The sawdust was sun-dried and of which part's of it was screened to the average particle size of 0.5 mm, 1.5 mm, 3 mm, 4.8 mm and 6.8 mm. Both sieved and raw sawdust were sampled, labeled and stored for briquetting purpose. Waste paper was used as a binder during briquetting of sawdust in different proportions (wt/wt), notably 25%, 30%, 35%, 40%, and 45%.as a binder during briquetting of sawdust in different proportions, notably 25%, 30%, 35%, 40%, and 45%.

2.1 Preparation of Materials

2.1.1 Sawdust

The feedstock (sawdust) was collected, sun-dried for two days to reduce the moisture content. The raw sawdust was characterized in terms of moisture content, density, volatile matter, and ash content. The dried sawdust was used to produce sawdust briquettes. A portion of the dried sawdust was screened by standard mesh sizes of 1 mm, 2 mm, 4 mm, 5.6 mm and 8 mm which were arranged vertically starting from the smallest to the widest sieve size and mounted in an electrical sieve shaker. The sieves were shacked for 10 min using the shaker and sorted based on their particle measurement as presented in Fig. 1.

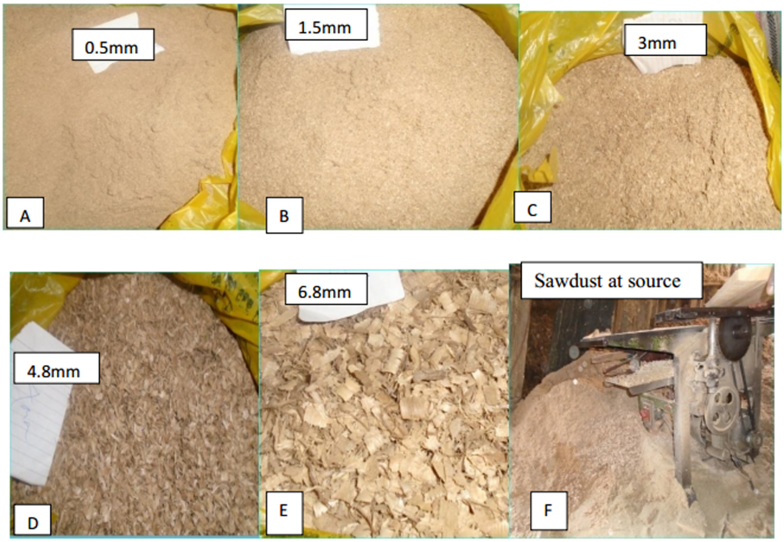

Fig. 1. Sawdust, A; passed through 1 mm, B; retained on 1 mm, C; retained on 2 mm, D; retained on 4 mm, E; retained on 5.6 mm, F; raw sawdust at the source.

2.1.2 Preparation of Binder

Briquetting of sawdust with rurally available cheap binding material will be best for power generation. The problem constituting the waste paper is enormous. How to dispose of this waste is becoming worrisome and it is generated every day. Mixing waste paper with sawdust briquettes could lead to better briquette performance and cost-effectiveness making this fuel more attractive to both producers and consumers (4).

The binder was prepared from waste paper. The waste paper (used up exercise books, newspapers, old books, and old exam papers) was collected, cut into small pieces, sampled and then soaked in water until it seems like porridge. Five levels of weight-weight percentages notably 25%, 30%, 35%, 40% and 45% on a dry basis, of each were considered.

2.2 Construction of Homemade Briquetting Press Machine

A homemade briquetting machine was constructed. It was constructed mainly from wood while some parts of it were made from metal. It was used to produce sawdust briquettes using waste paper as a binder at different proportions. It has five different parts which includes the main body/stand that supports the rest, four cylinders/molds connected each other by nails with supporting base, a plate base which covers the opening of the cylinders while pressing, the presser having four equal legs which are assembled with circular woods at their bottom ends to press down the well-mixed sample during briquette production and press arm, which is assembled on one side of the stand, to push down the presser by applying pressure on it (Fig. 2).

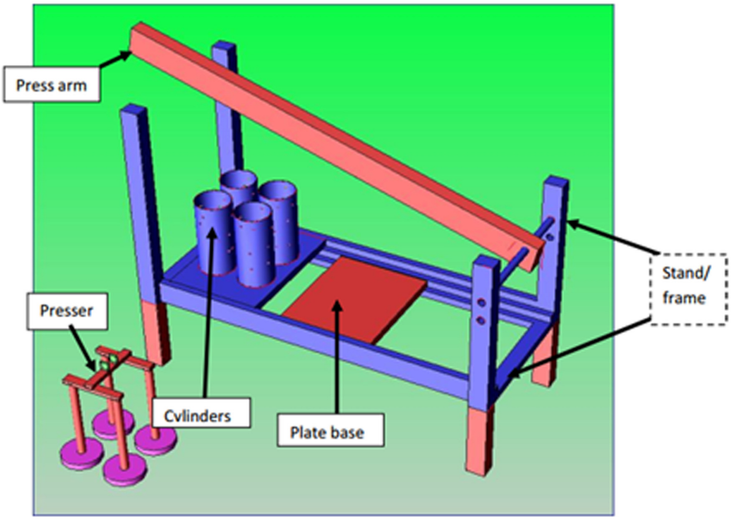

Fig. 2. Cad drawing of briquetting machine

The stand supports the rest parts having a press arm, is made from wood which is milled in size of 4 cm width, 5 cm length, and height of 61 cm on one side and 76 cm on another side. The two sides, 100 cm far from each other, are connected by wood using nails. There are two stages, having 2 cm width and height, on the stand to support and allow the movement of the base and cylinder supporter base to both ends of the briquetting machine. The press arm, which is used to push down the presser and having a dimension of 4 cm * 5 cm * 120 cm, is assembled at a height of 51 cm from the base. The cylinders, 10 cm in internal diameter and 20 cm in height, are made from metal sheets and are connected in a square arrangement. They are 2 cm far from each other and positioned vertically over the supporting base. They are drilled all around so that the water can escape when the feedstock is pressed. A flat wood base/plate which was placed on the first stage of the stand and which was free to move to both ends was used to cover the bottom end of molding- cylinder during compression and moved to one of the ends of the stand during ejection of the briquettes. The base and supporting base with the four cylinders are free to move to both sides of the stand on their own stage provided. The presser, its legs have a square arrangement, is made from pieces of metals. It is constructed in such a way that its legs with assembled circular wood can freely move up and down inside the cylinders during briquette production and ejection. The briquetting press machine is medium in size and all its five parts are not assembled permanently. During briquette production, all the parts are joined together temporarily but during the ejection of briquette, the base will be moved towards either of the two ends and the openings of the cylinders become free. Hence the briquettes will be free to leave out from the cylinders.

The briquetting press machine was constructed in such a way that first the main body/stand is constructed using different wood assembled each other permanently. Secondly, four cylinders were constructed and assembled to a wood base which has four holes to insert and support the cylinders. Thirdly four lids were constructed in such a way that they can move freely inside the cylinders while pushing the briquette downward. Finally, the presser is constructed which enables to press the feedstock inside the four cylinders simultaneously. All motions such as the vertical motion of presser in and out of the cylinders, the horizontal motion of base and supporting base with cylinders: up and down movement of arm press and the ejection of the briquettes are operated manually.

2.3 Determination of Physical and Combustion Properties of Sawdust Briquettes

2.3.1 Density

The mass and volume of briquettes were decided using digital balance and direct measurement of the dimensions of briquettes respectively. The density of briquettes was determined by taking the ratio of the mass of briquettes to their corresponding volume.

2.3.2 Porosity Index

A pre-weighed briquette was immersed in water for 30 s. Then the briquette was taken out of the water and reweighed to obtain the wet weight of briquette. The weight of water absorbed was the difference in the wet weight of the briquette and dry weight of the briquette. The porosity index was computed by dividing the mass of water absorbed into the mass of dry briquette.

2.3.3 Percentage Volatile Matter

A part of a briquette was kept in an oven in order to get the dry weight of the sample. The oven-dried sample was kept in the muffle furnace at a temperature of 550 for 10 min. After which the volatile matter in it has escaped, the crucible and its contents retrieved and cooled in a desiccators and weighed after cooling to obtain the weight of the volatile part of the sample i.e. the change in weight of the sample before and after transfer to the furnace. The analytical balance was used to weigh the weight of the sample. The percentage volatile matter is the ratio of the weight of volatile matter to the weight of the oven-dried sample.

2.3.4 Ash Content

A portion of a briquette was kept in an oven until it is free of moisture content. The oven-dried sample was then placed in a pre-weighed crucible. This was transferred into the furnace set at 900 and left for about 30 min. Then after, the crucible and its contents were transferred to desiccators and cooled. After cooling the crucible and its contents were reweighed to obtain the weight of the ash.

2.3.5 Heating/Calorific Value

The gross heating values of sawdust briquettes were determined using a standard Oxygen Bomb calorimeter (Parr 6200). A predetermined mass of each sample was burnt in the bomb calorimeter until complete combustion was obtained. The 6200 calorimeters will automatically make all of the calculations necessary to produce a gross heat of combustion for the sample.

3 Results and Discussions

Density, porosity index, volatile matter content, ash content and heating/calorific value of sawdust briquettes were examined. Waste paper percentage, molding cylinder/die diameter and particle measurement of raw sawdust were the agents used to estimate the features of sawdust briquettes.

3.1 Density

It is a substantial physical characteristic of briquettes. The maximum density of sawdust briquettes attained in this work was 322.62 kg/m^3. The highest value obtained in this experiment was lower than the lowest value obtained by M. Brožek (Brožek and Nováková 2012). This can be due to the difference in pressure applied resulted from the variation of the molding machine.

3.1.1 Effect of Particle Measurement

The outcome of particle measurement, at constant molding cylinder diameter of 10 cm, on the density of sawdust briquettes, is presented in Fig. 3.

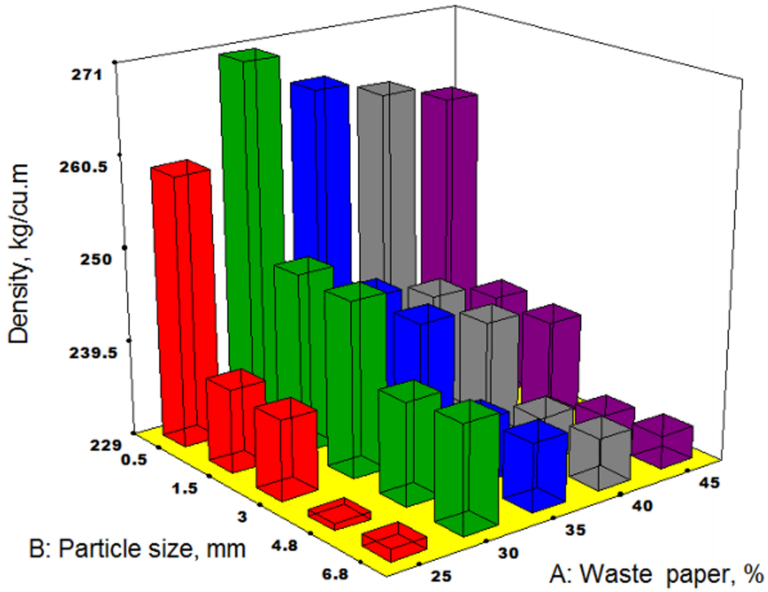

Fig. 3. Outcome of particle measurement of sawdust on density of briquettes.

The highest and lowest density of sawdust briquettes attained in this work was 280.78 kg/m^3 and 218.24 kg/m^3 at particle measurement of 0.5 mm and 4.8 mm respectively. The density of sawdust briquettes was decreased when the average particle size of sawdust increased for each waste paper percentage combinations. The smaller particle size is compact easily leading to a small number of pore spaces while the greater particles have a large number of pore spaces. As the number of pores increased, the void space within the briquette increases, the density will be decreased. That is why the density of briquettes was decreased when the average particle of sawdust was increased.

3.1.2 Effect of Waste Paper Percentage

Different levels of waste paper percentages were combined for each of sawdust of size of 0.5 mm, 1.5 mm, 3 mm, 4.8 mm and 6.8 mm at constant die diameter of 10 cm (Fig. 4).

The density of sawdust briquettes was increased as the percentage by weight of waste paper increased. Nevertheless, density was declined when the waste paper percentage transcended 30%. This implies the effect of waste paper percentage was not a significant factor; however, it has to be at the optimum percentage of 30% on the basis of density of briquettes since it could bring a change in the density of briquettes.

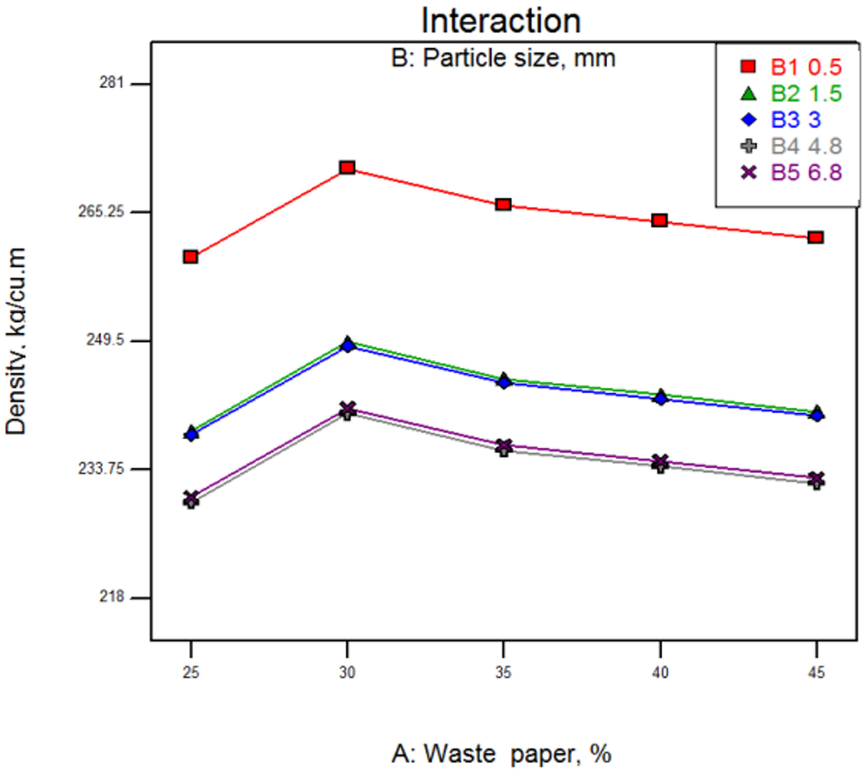

Fig. 4. The consequence of binder percentage on density of sawdust briquettes.

3.1.3 Effect of Molding Cylinder Diameter

The effect of pressure was considered by varying the diameter of the molding cylinders/die. The raw sawdust was sampled and combined with waste paper in different weight percentages. The same combination of sawdust and waste paper was briquettes using the three die-diameters. As can be seen from the Fig. 5, the maximum density (322.62 kg/m^3) was obtained for the die diameter of 6 cm and the least density (246.27 kg/m^3) from dying diameter of 10 cm. The density was decreased when the die diameter was increased. As the die geometry increases the contact area will also increase. Hence the applied pressure will be smaller and smaller because pressure and area have inverse relations.

Lower pressure allows a large number of pores hence the density will be lower. From the result obtained, it can be concluded that the molding cylinder diameter was the basic factor for briquetting and the optimum die diameter on the bases of density was attained at a smaller die diameter of 6 cm.

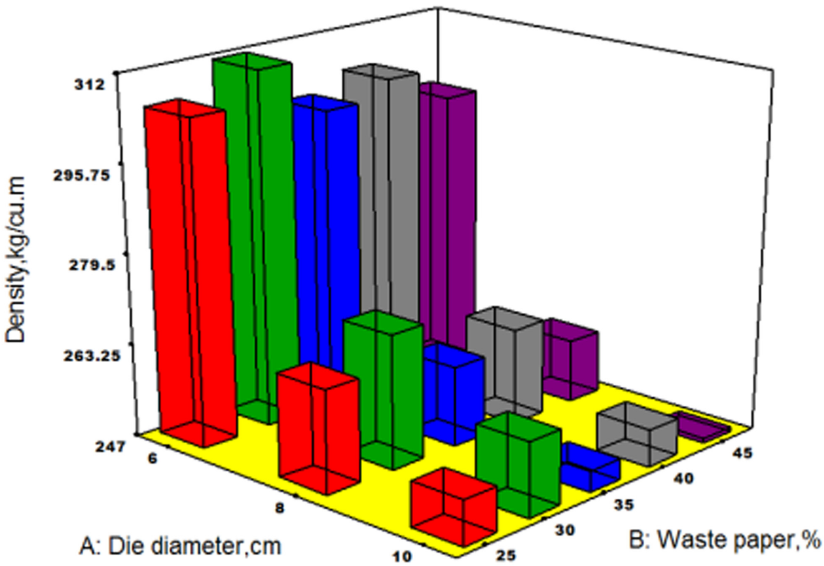

Fig. 5. Effect of molding cylinder diameter on density of sawdust briquettes

3.2 Porosity Index (Weight, %)

A briquette with a higher porosity index has lower water resistance capacity. Hence, briquettes having a low porosity index are desirable to storage and water resistance. The least porosity index (33.97%) was obtained from 0.5 mm particle size of sawdust while the highest (312.24%) was from sawdust of average particle size of 6.8 mm. At constant die diameter and waste paper (binder) percentage, the porosity of sawdust briquettes was raised when particle measurement getting larger and larger. This is due to increasing the average particle size introduces the number of pore space within the briquette by reducing the surface area thereby enhancing the penetration of water into the briquettes. The lower porosity index the higher resistance to water. If briquettes have a higher porosity index, it will absorb more water and will be disintegrated easily and also lowers the calorific value (Fig. 6).

As can be also seen from the figure, sawdust at lower average particle size has a lower porosity index. Hence desirable briquettes can be produced with a relatively smaller particle size of sawdust.

3.2.1 Effect of Waste Paper Percentage

As can be seen from Fig. 7, the porosity index (%) was increased as a waste paper percentage was increased. However, the change was insignificant.

As the percentage of waste paper increased, the amount of water absorbed also increased. This is due to that paper has a higher water holding capacity than sawdust. Therefore, it is better to use lower waste paper percentage and smaller average particle size of sawdust to produce a desirable briquette.

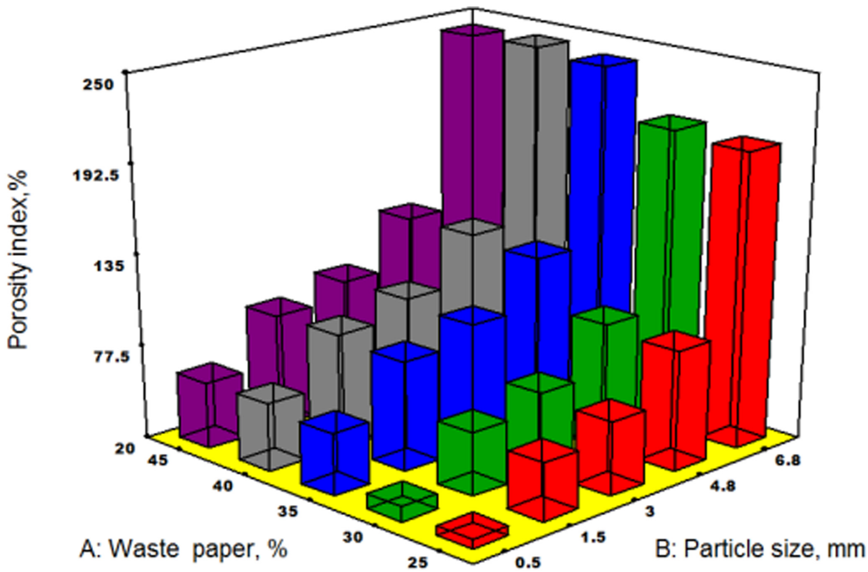

Fig. 6. Effect particle size of sawdust on porosity index of briquettes.

3.2.2 Effect of Die-Diameter

Results from the Fig. 8 shows that for increasing die diameter there was a corresponding increase in porosity index of briquettes.

This resulted from the variation of the pressure because pressure and die diameter have an inverse relationship. When the die diameter gets smaller and smaller, the pressure will become higher leading to fewer pores within the briquettes. Hence, the amount of water absorbed will be lower. This implies die geometry has a marked effect on the porosity index of briquettes. Therefore, briquettes with good quality can be produced at a lower die diameter of cylinders than higher diameters, other things being constant. At constant die diameter and waste paper percentage, the porosity index of briquettes produced from an average particle size of 1.5 mm was higher than that of briquettes produced from unscreened sawdust. This could be the consequence of the interlocking of particles due to the presence of different particle sizes. It can be concluded that it is better to use the raw sawdust instead of using very fine particle size of sawdust because it avoids the task of sieving.

3.3 Percentage Volatile Content

A briquette with a high percentage of volatile content is preferred. Because briquettes with lower percentage volatile content will release a high amount of smoke during burning which leads to environmental pollution.

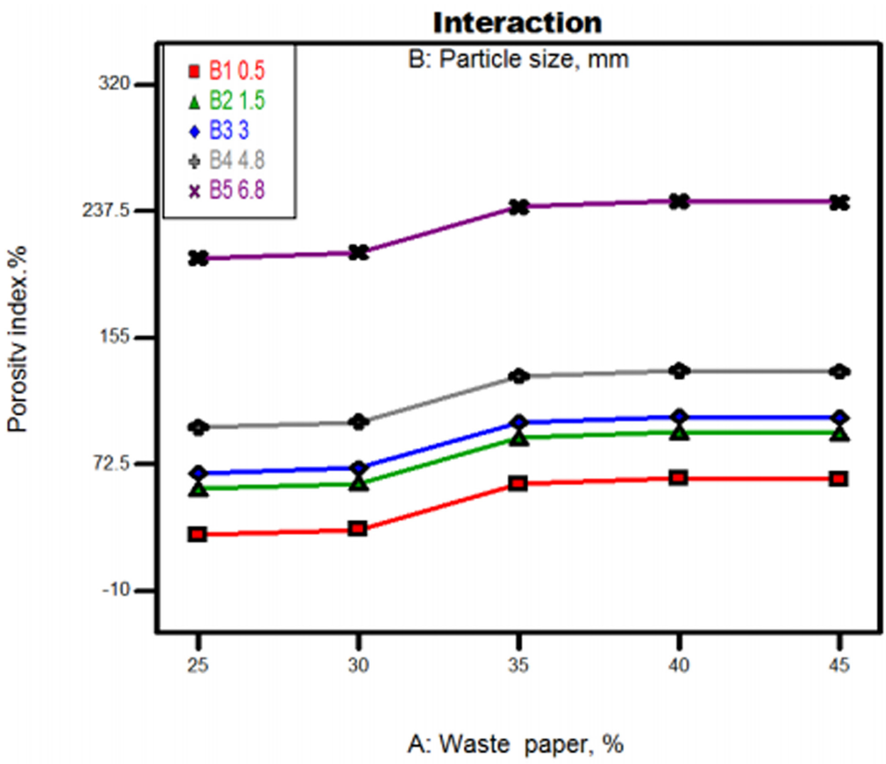

Fig. 7. Effect of waste paper percentage on porosity index of briquettes.

3.3.1 The Outcome of Particle Measurement of Sawdust

As can be seen from the figure, the highest and lowest percentage volatile content obtained was 90.56% and 70.46% respectively. As can be also observed from the figure, the volatile matter was generally increased with the direct proportion of particle size of sawdust. This could be the result of fine particles would be compacted easily compared to larger particles, other things being constant. If particles compacted well, the density will be higher leading to a low rate of mass transfer during the volatilizing phase hence the amount of volatile matter released will be reduced (Fig. 9).

However, it was decreased when the average particle measurement exceeded 3 mm. This can result from the size of individual particles of sawdust. As the average particle size of sawdust increases, the quantity of volatile content within it increases but the mass transfer rate within the particle itself is weak since the contact area is lower. The maximum value of volatile matter (90.56%) was obtained in the average particle size of sawdust of 3 mm. The result shows that briquetting of sawdust can give a better performance based on high volatile matter at 3 mm average particle size of sawdust.

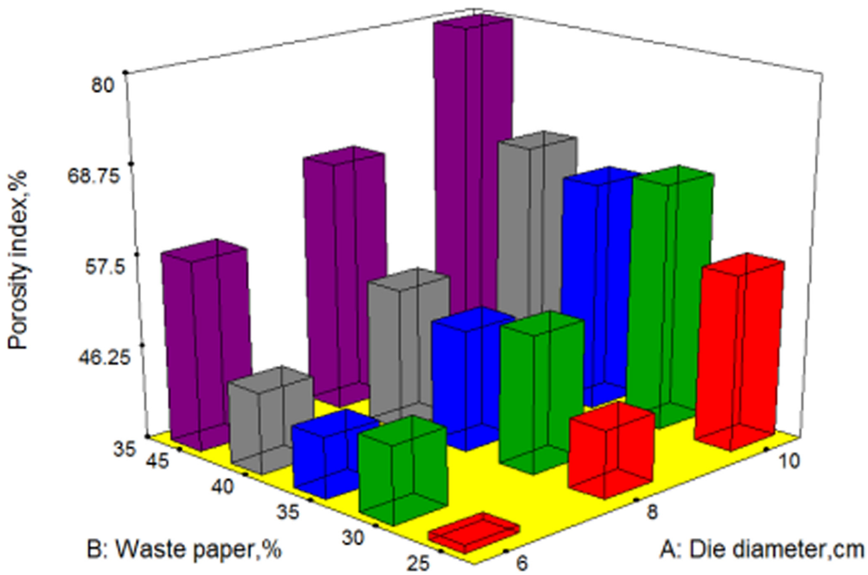

Fig. 8. Effect of die diameter on porosity index of briquettes.

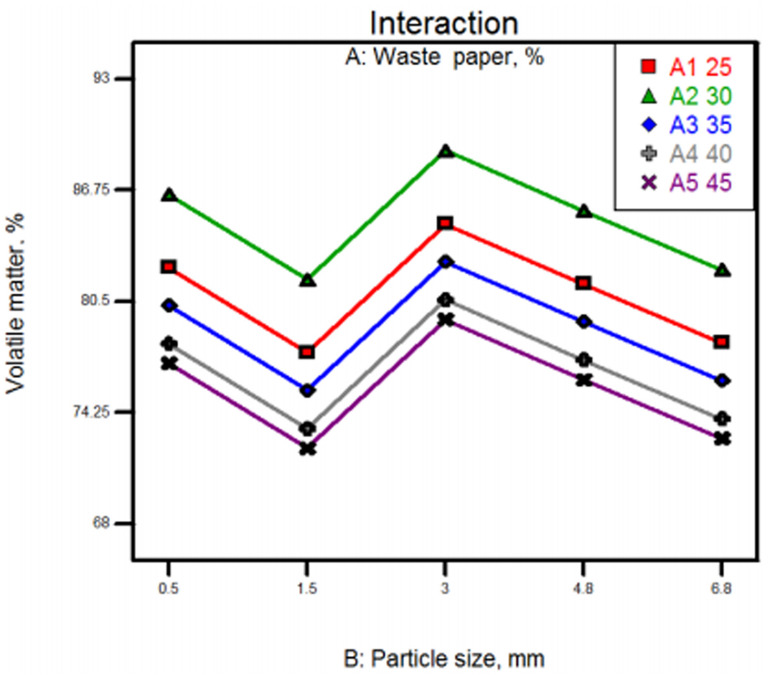

Fig. 9. The consequence of particle extent of sawdust on volatile matter of briquettes.

3.3.2 Effect of Die-Diameter

The raw sawdust was sampled and then bonded with soaked waste paper in five weight percentages notably 25, 30, 35, 40 and 45% at three die diameters.

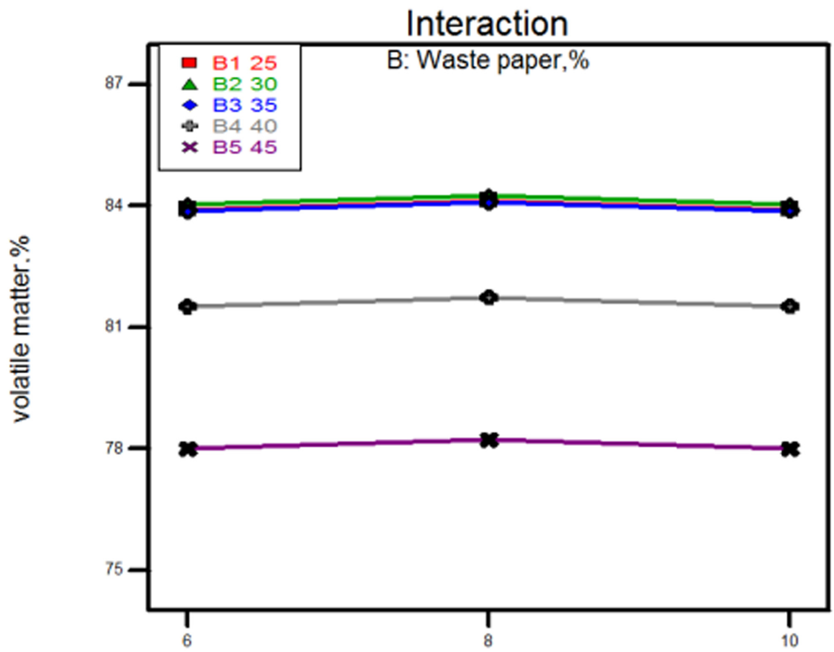

Fig. 10. The sequence of die diameter on percentage volatile content of sawdust briquettes.

As presented from Fig. 10, the volatile content of the briquettes was found to be the same in the three die diameters. The recorded result shows that the effect of die diameter has insignificant ($p = 0.3568$) effect on volatile matter of sawdust briquettes.

3.3.3 Effect of Waste Paper Percentage

The effect of binder percentage on the percentage of the volatile content of briquettes was displayed in Fig. 11. Generally, percentage volatile content of briquettes was increased when the waste paper percentage was increased from 25% to 30% but when the waste paper percentage was exceeded 30%, the volatile matter of briquettes was decreased. This could be either the waste paper has a lower volatile matter than sawdust or when the weight percentage of waste paper increases, the bond also increases. As a result, the mass transfer rate will be decreased i.e. the rate of volatilization will be hindered. That is why the volatile matter of the briquettes decreases when the weight percentage of waste paper increases.

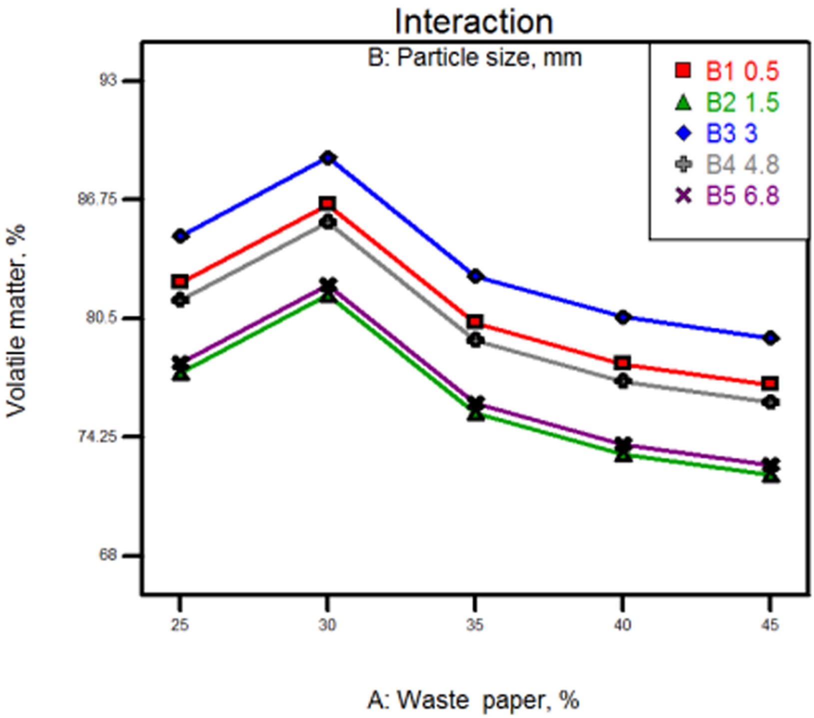

Fig. 11. Effect of waste paper percentage on volatile matter of briquettes.

3.4 Percentage Ash Content

Briquettes with lower ash content are preferred since they have higher calorific value and are suitable for cooking purposes.

3.4.1 Effect of Average Particle Size of Sawdust

The outcome of particle dimension on percentage ash content of briquettes was demonstrated in Fig. 12.

The highest percentage ash content (7.26%) was observed at an average particle size of 6.8 mm while the least (2.33%) was from sawdust of average particle size of 3 mm. Generally, as can be seen from the figure, the percentage ash content of briquettes was decreased when the average particle size of sawdust was increased. This could result from the presence of different pore spaces within the briquette. As the particle size increase, the number of pore space within the briquette will be higher. The smaller particles are less course, compacted easily, a small number of pore spaces leading to incomplete combustion. As the size of particles increases, the number of pore space within the sample will be greater allowing oxygen to flow easily within the sample. Therefore, briquettes with larger particles will be burn completely and the ash content will be smaller.

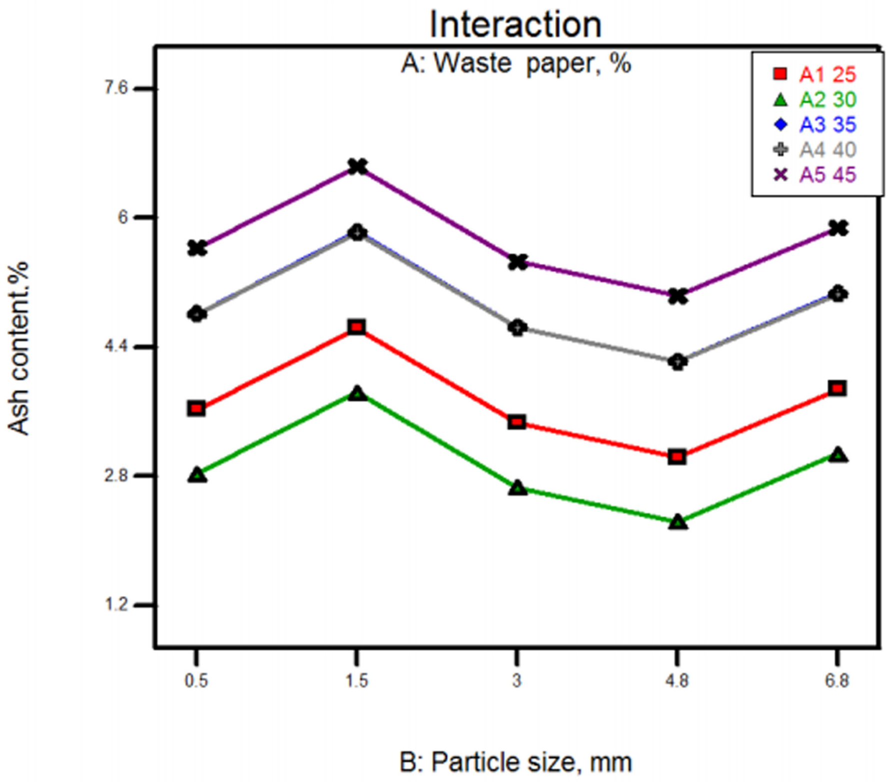

Fig. 12. The outcome of particle dimension on percentage ash content of briquettes.

3.4.2 Effect of Waste Paper Percentage

The highest percentage ash content (7.26%) was observed in 40% of the weight percentage of waste paper while the least value (2.33%) was from 30% waste paper. From Fig. 13, it can be observed that the quality of sawdust briquettes was increased when a percentage of waste paper was increased from 25% to 30%. This is because of the diminishment of the ash content. However, it was increased when the percentage of waste paper was exceeded by 30%. Hence for optimal performance waste paper at 30% could be added to sawdust briquettes.

This could be either waste paper has higher ash content than sawdust or as the percentage waste paper increase, the interparticle bond increases which can reduce the mass transfer rate within the briquette which can hinder the flow of oxygen. Therefore, it is better to use waste paper as a binder at the optimum weight percentage to produce briquettes with low ash content.

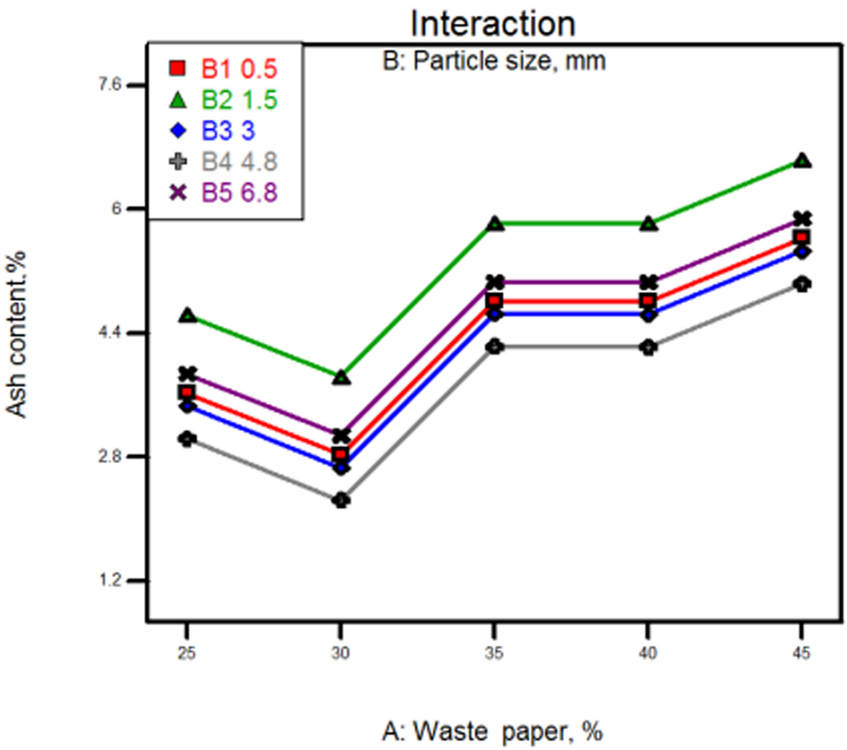

Fig. 13. Effect of percentage of waste paper on the ash content of briquettes.

3.4.3 Effect of Die-Diameter

The briquettes were produced from the raw sawdust using three different die diameters at a constant weight percentage of waste paper. The effect of die diameter on the ash content of briquettes was presented in Fig. 14.

The percentage ash content of briquettes produced at different die diameters shows almost similar values. From this result, it can be concluded that the effect of die diameter on the ash content of sawdust briquettes has an insignificant effect.

3.5 Percentage Fixed Carbon

Fixed carbon percentage is one of the consequential characteristics of briquettes. Briquettes with a smaller quantity of fixed carbon are chosen because they are effortless to burn. The percentage fixed carbon of sawdust briquettes obtained was ranged between 6.63% and 24.26%. The highest fixed carbon was observed in briquettes formed from sawdust of average particle size of 1.5 mm and waste paper percentage of 35%.

3.5.1 Effect of Average Particle Dimensions

The consequence of particle dimension on percentage fixed carbon of sawdust briquettes was presented in Fig. 15.

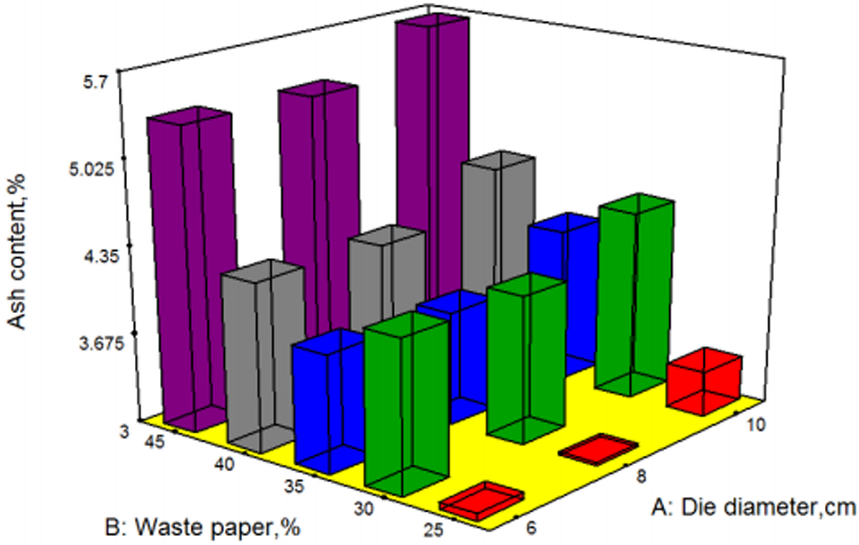

Fig. 14. Effect of die diameter on percentage ash content of briquettes

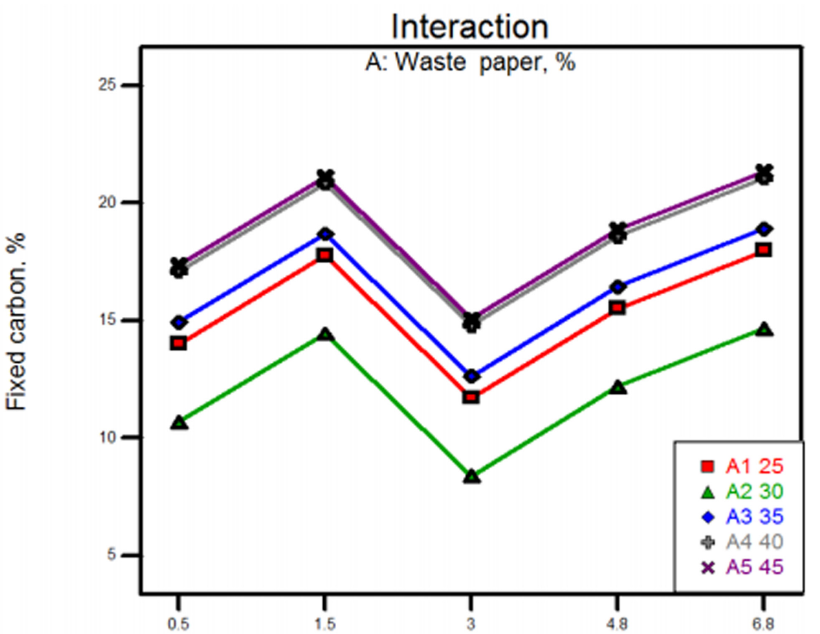

Fig. 15. Effect average particle size of sawdust on percentage fixed carbon of briquettes.

Generally, from the figure, it can be observed that the percentage fixed carbon of sawdust briquettes was increased as the particle dimension was increased. However, the change was not significant. A briquette with a high volatile matter was found to have a lower fixed carbon. Due to this fact the graph of volatile matter and fixed carbon, the effect of average particle size of sawdust, were found to be inverse of each other. The least fixed carbon percentage of briquettes obtained was at 3 mm average particle size of sawdust. Therefore, on the basis of the percentage fixed carbon of briquettes, it is better to use sawdust of average particle size of 3 mm.

3.5.2 Effect of Waste Paper Percentage

Generally, though there was no significant change, the fixed carbon percentage of briquettes was increased when the percentage of waste paper was increased. In the previous section, it was recorded that waste paper percentage and percentage volatile matter show inverse relations. If the volatile matter of the briquette is lower, the fixed carbon will be higher. So as waste paper percentage increases, the fixed carbon percentage also increases (Fig. 16).

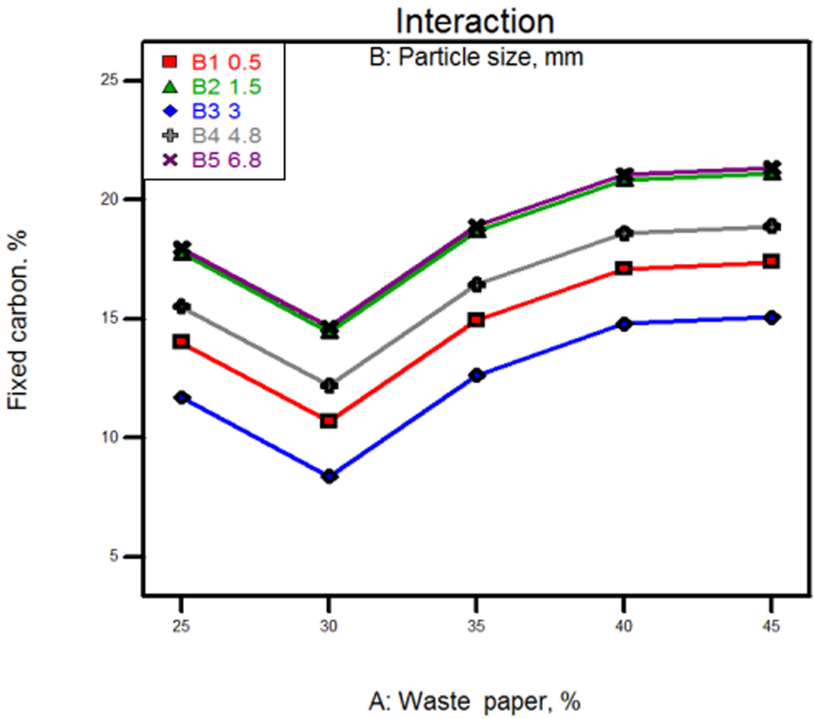

Fig. 16. Outcome of percentage waste paper on fixed carbon of briquettes.

3.5.3 Effect of Die-Diameter

Almost the same values, for each of dying diameters, were recorded for all types of briquettes briquette at different molding cylinder diameters. The effect of molding cylinder/die diameter on fixed carbon of briquettes was insignificant. Therefore, die diameter has not a meaningful effect on the chemical characteristics of briquettes based on the results attained (Fig. 17).

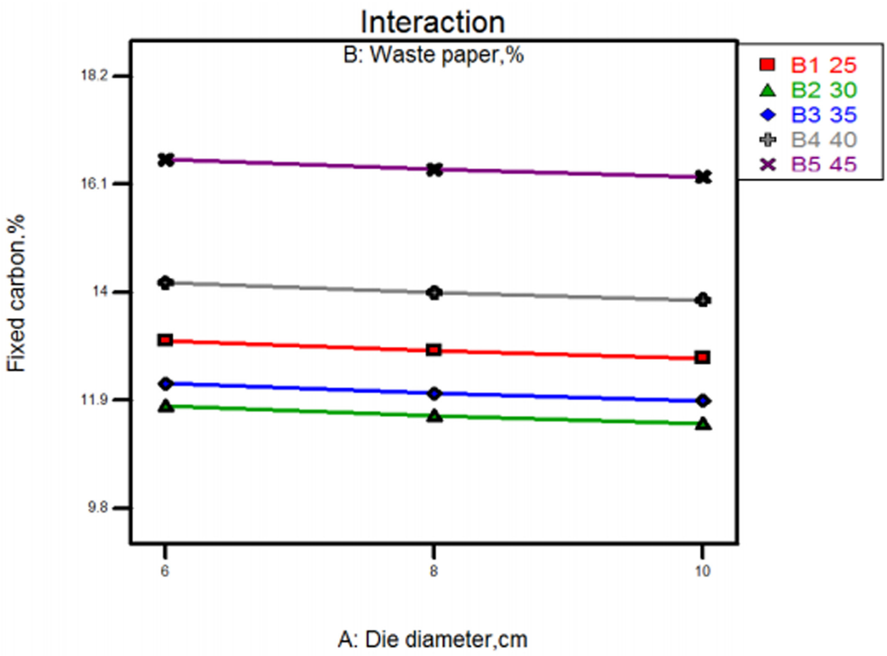

Fig. 17. Consequence of die diameter on percentage fixed carbon of briquettes.

3.6 Calorific Value

Calorific value is the most significant characteristic of briquettes. It is the measure of the amount of energy, in the form of heat, released during the burning of a unit mass of briquettes. Therefore, briquettes with higher calorific value are recommended to use for fuel application.

3.6.1 Effect of Average Particle Dimension of Sawdust

Figure 18 presents the difference in energy content of sawdust briquettes according to the average particle size of sawdust.

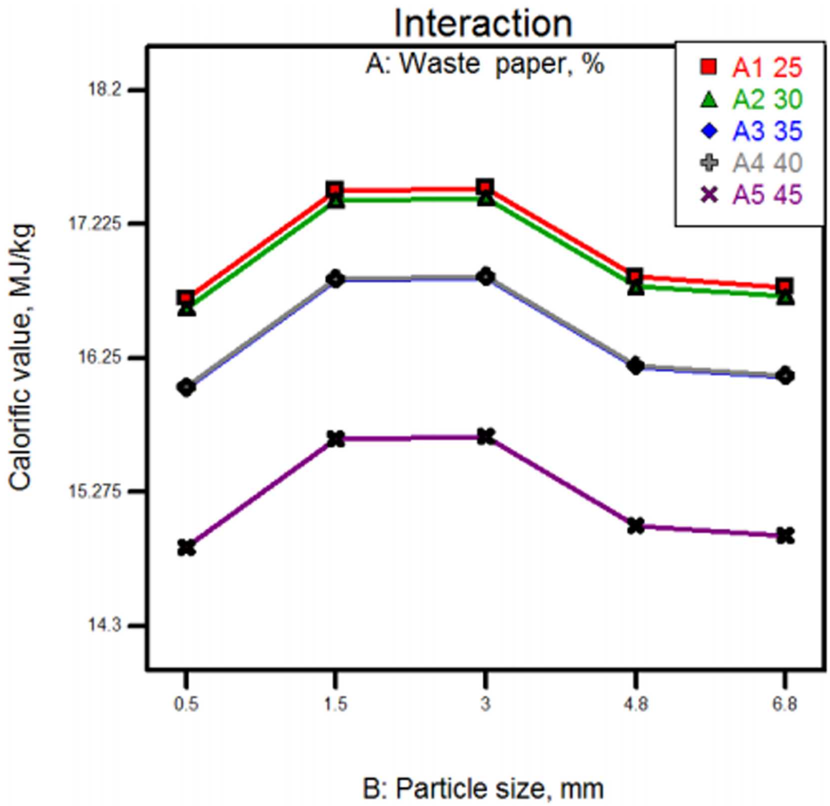

Fig. 18. Effect of average particle measurement on calorific value of briquettes.

The average particle dimension was found to be insignificant on the combustion characteristics of sawdust briquettes. The computed calorific value for all types of sawdust briquettes ranges from 14.5019 to 18.1332 MJ/kg. Therefore, sawdust briquettes are an excellent substituent for firewood for domestic cooking.

3.6.2 Effect of Waste Paper Percentage

As can be observed from the figure, for increasing waste paper percentage, there was a corresponding decrease in the calorific value of briquettes. This shows that the waste paper has to be added as small as possible to get briquettes with high energy content. As presented by Fig. 19, the calorific value of sawdust briquettes was significantly affected by percentage waste paper. Briquettes with low waste paper percentage produce higher

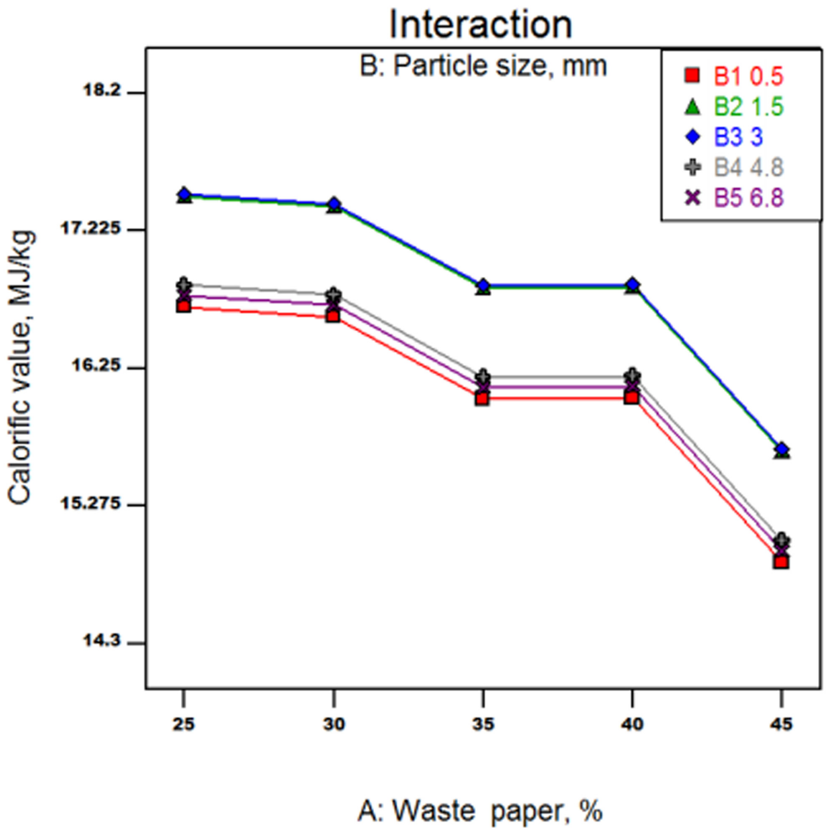

Fig. 19. Outcome of waste paper percentage on combustion characteristics of briquettes.

calorific value than briquettes with high waste paper percentages. It can be concluded that waste paper percentage is a significant factor in briquette production and the increase of waste paper percentage has reduced the calorific value of the briquettes.

3.6.3 Effect of Die-Diameter

The highest and the lowest calorific value of briquettes produced by using the three die diameters was 18.5832 MJ/kg and 15.1165 MJ/kg respectively. The calorific values of briquettes produced in different die diameters were almost constant it was discovered that the diameter of the molding cylinder/die has an insignificant effect (Fig. 20).

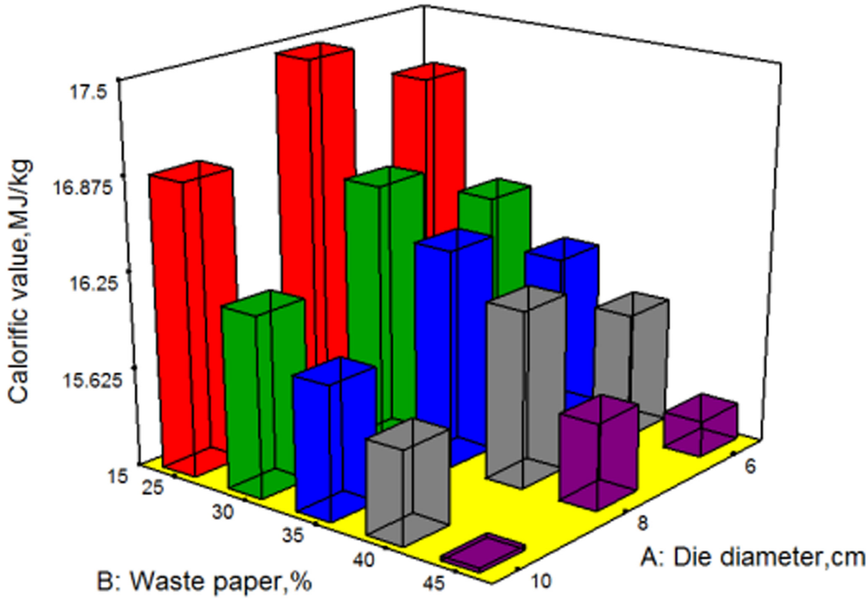

Fig. 20. Effect of die diameter on the calorific value of sawdust briquettes.

4 Conclusion

The paper focused on the very important physical and chemical characteristics of sawdust briquettes. For all types of sawdust briquettes, the highest and lowest values of density, porosity index, volatile matter, ash content, fixed carbon, and calorific value are 218.2–322.6 kg/m^3, 34–312.4%, 70.2–90.6%, 2.3–7.3%, 6.7–24.3% and 14.5–18.4 MJ/kg respectively. The figured physical and chemical properties of sawdust briquettes were interesting. The density and porosity index of sawdust briquettes were extensively affected by molding cylinder diameter and waste paper percentage. A considerable effect of particle size was observed on density, porosity index, and percentage volatile content of sawdust briquettes. The capability of the production of sawdust briquettes with good quality using only waste paper as a binder is an encouraging fact. Sawdust briquettes produced by using waste paper as a binder could be excellent augments to firewood for domestic cooking because it can be easily transported, stored, and used simply. Therefore, the production and utilization of sawdust briquettes using waste paper is sound and enhance environmental security.

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