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A Review of Pellet Production from Biomass Residues as Domestic Fuel

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***Abstract*— *Burning fossil fuels and deforestation are the major contributors to anthropogenic climate change. As a result of climate change threat, the use of biomass and biomass residues have become extremely important to created a new industry focused on the production of clean energy through the use of renewable sources. However, factors such as low density, high moisture content, ease of handling, storage and transport are some disadvantage from the use of biomass. Pelletizing is a promising technology which converts it into a more useful form through densification in order to minimize these disadvantages. Between 2006 and 2012, pellet production worldwide grew from 7 to 19 million tons. However, the use of pellets is insignificant in developing countries. Many of the developing countries produce huge quantities of wood and agro residues with an interesting potential for biomass energy production, but they are used inefficiently causing extensive pollution to the environment. This paper presents a synthesis on what pellet is, the characteristic of pellet, the raw materials used for pellets production, biomass pelletizing process and description of a typical biomass pelletizing operation. Previous research that has been carried out on pellet production from biomass residues and application as domestic fuel has also been reviewed and cited in this paper.*

Keywords*— *Biomass residue, Pelletizing, Characteristics, Domestic fuel.

I. INTRODUCTION

It is known generally that burning fossil fuels and deforestation are the major contributors to anthropogenic climate change. The use of biomass as an alternative energy source provides substantial socio-economic and environmental benefits, compensating its localized nature for its high availability and carbon-neutral raw material for the production of energy.

However, bio-fuels have low bulk densities of 80–150 kg/m^3 for herbaceous and 150–200 kg/m^3 for woody biomass (Tumuluru *et al*. 2010). This limit their use to areas around their origin; plus, their heterogeneity is considered when it comes to moisture and loose nature, among others. These drawbacks are restrictive factors for their energy use (Arranz, 2011).

Many of the developing countries produce huge quantities of agro residues but they are used inefficiently causing extensive pollution to the environment. The major residues are rice husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks and cotton stalks. Sawdust, a milling residue is also available in huge quantity (Grover and Mishra 1996).

The least-expensive biomass resources are these residues from wood or agro-processing operations since they are basically considered as waste. These residues have been highly promoted to be used in various heating systems, during the past decades. Compared to fossil fuel, most biomass residues have higher moisture content and lower density, thus making them technically unsuitable for direct use due to combustion and handling problems. Nevertheless, densification of biomass minimizes these disadvantages being a process that compress these raw materials in order to obtain denser fuels, with homogeneous properties and size. It improves biomass handling characteristics, increases the volumetric calorific values, and reduces transportation, collection, and storage costs (Markson *et al*. 2013; Grover and Mishra 1996). Among the different techniques that are available, pelletizing is currently the most extended one (Poddar, 2014).

The global pellet production has considerably increased for the last few years. Between 2006 and 2012, pellet production worldwide grew from 7 to 19 million tons (Duca, 2014), with Europe and North America being responsible for, practically, the whole production and consumption of densified products. The use of pellets is insignificant in developing countries: The pellets market for Africa, Asia and South America combined production is

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only 0.3 million tons/year in 2009 (Pirraglia *et al.*, n.d. cited by Deepak, 2012).

The growth in pellet consumption has resulted in more diversity, when it comes to the use of raw materials for pellet manufacture. Consequently, the industry has started looking for products, such as wastes obtained from forestry, agriculture or a combination of the latter, currently obtaining a wide range of these products (Sepúlveda, 2014).

In spite of the huge raw materials, pelletizing technologies is yet to get a strong foothold in many developing countries because of the technical constraints involved and the lack of knowledge to adapt the use of these technologies to suit local conditions (Grover and Mishra 1996). Overcoming the many operational problems associated with this technologies and ensuring the quality of the raw material used are crucial factors in determining its commercial success for use as domestic fuels. In addition, the importance of these technologies lies in conserving wood - a commodity extensively used as domestic fuel in developing countries, leading to the widespread destruction of forests.

This research report aims to review pellet production from biomass residue and characterization for application as domestic fuel in developing countries. It is a key to the problem of environmental pollution caused by the inefficient use of biomass residues and long term solution to mitigate the problems of deforestation.

II. PREVIOUS RESEARCH

It is difficult to find information about the levels of pellet production and application in the developing countries. This is because the use of pellet is insignificant in developing countries. However, there is some global information on densified biomass fuels (DBFs) available, but most of the information does not separate between different kinds of DBFs. Hence, previous research on the production of pellets and application as domestic fuel will include both pellets and briquettes from wood and agricultural residue.

Gravalos *et al. (*2010), conducted an experimental study on calorific energy values of biomass residue pellets for heating purposes. The fuel samples used, were biomass residues of agricultural (cotton, cardoon, etc.) and forest (pine, fir, beech, etc.) wastes. The experimental results obtained are encouraging and show that these materials can be used as alternative fuels.

Roos and Brackley (2012), examines the three major wood pellet markets in Asia: China, Japan, and South Korea. In contrast to the United States, where most wood pellets are used for residential heating with pellet stoves, a majority of the wood pellets in Asia are used for co-firing at coal-fired power plants. A consistent Factor in these nations is that their governments are promoting renewable energy, leading to policies that are driving demand for wood pellets. As these countries strive to meet their renewable energy targets, their wood pellet consumption is projected to grow.

Raju *et al.* (2014), in a work "Studies on development of fuel briquettes using locally available waste" stated that Briquettes of small size can be used in gasifies for power generation. If the plant sites are chosen properly for easy availability of raw material, the agricultural residues can be briquetted to reduce further transportation costs and associated pollution. This also improves the handling characteristics of biomass. The briquettes so obtained are very good fuels for local small scale industries and domestic purposes.

Trangkaprasith and Chavalparit, (2011) in a study "Heating value enhancement of fuel pellets from frond of oil palm" palm fronds were used as raw materials to produce pelletized fuel and waste glycerol as adhesive to reduce biodiesel production waste. The result from heating value analysis of frond is 17.25 MJ/kg. Therefore it is potential to make them to be useful by pelletizing. These pellets could be used for alternative energy in the industrial segment by mixing with glycerol to get higher heating value. The aim of the research was to find optimum ratio of ingredients (ratio of raw material, waste glycerol, and water) for producing fuel pellet from such materials.

In a study "Characterization and feasibility of biomass fuel pellets made of Colombian timber, coconut and oil palm residues regarding European standards", Carlos *et al.* (2012), assessed the main properties of Colombian timber industry residues, coconut shells and oil palm shells and compare the characteristics of pellets made from these raw materials with European standards. Pellets made from these feedstocks have an average density between 850 and $1025 kg \cdot m^{-3}$, low ash contents and heating values around $18000 kJ \cdot kg^{-1}$. Coconut shell pellets have low compression ratios and problems during pretreatment; whereas, sawdust, wood shavings and oil palm shell pellets proved to be an attractive opportunity for pellet industry development in Colombia.

Tokan *et al.* (2016), tested 9 samples of rice husk pellets; P_1 – P_9 using water boiling test, 100g of pellet sample P1, achieved 100^0C in 6 minutes to boil 500ml of water while 100g of pellet samples P6 and P7each achieved 100^0C each in 8 minutes to boil 500ml. Comparative studies of rice husk pellets and charcoal was also conducted, the results showed that 100g of pellets burns uniformly under free convection with pale yellow flame and very little smoke while 100g of charcoal burns irregularly and would require forced convection. With water boiling test, 100g of charcoal sample achieved 100^0C in 14 and 20 minutes to boil 500ml of water for C1 and C2 respectively. C3 did not achieve 100^0C. With calorific value ranging from 15.129 – 17.589 MJ/kg, and good physical and combustion characteristic of the rice husk pellet, it can conveniently substitute for charcoal as a domestic fuel.

Comparative thermal analysis of the properties of coal and corn cob briquettes was conducted by Ikelle and Chukwuma (2014). The work involved the production of smokeless briquettes of various compositions from coal and corn cob using CaSO4 and starch as binders, while Ca(OH) was used as desulphurizing agent. The briquettes were produced in the following ratio of coal and rice husk such as 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100 respectively. The proximate analyses of the raw coal sample yielded the following: ash content 12.56%, moisture content 7.03%, volatile matter 39.21%, fixed carbon 41.2% and calorific value 117.18 KJ/g. The corn cob gave the following values, ash content 12.56%, moisture content 7.03%, volatile matter 39.21%, fixed carbon 41.2% and calorific value 61.46 KJ/g. The prepared briquettes were sun dried for seven days, subjected to various tests to assess their fuel quality. Of the briquettes produced, the 80% coal: 20% corn cob briquettes produced using starch as binder had the following values; ash content 21.70%, fixed carbon 45.01%, moisture content 2.87%, density 0.482 g/cm 32, volatile matter 30.42%, porosity index 40.12%, calorific value 153.23 KJ/g, water boiling test 1.65 minutes, burning time 24.42 minutes, ignition time 41.22 seconds and sulphur content 6.05%. For briquettes produced with CaSO as binder, 80% coal: 20% corn cob had the following values; ash content 27.69 %, fixed carbon 41.63 %, moisture content 2.77 %, density 0.503 g/cm 43, volatile matter 27.91 %, porosity index 41.11 %, calorific value 134.46 KJ/g, water boiling test 1.71 mins, ignition time 41.40 secs, burning time 25.91 mins and sulphur content 7.42 %. The briquettes showed improved properties but with regards to combustible property, the briquettes made using starch as binder do have better qualities than those produced with CaSO as binder.

In a study "Using Agricultural Residues as a Biomass Briquetting: An Alternative Source of Energy", Maninder *et al*. (2012), showed that, raw material including rice husk, coffee husk, saw dust, ground nutshell and cotton stalks etc. were densified into briquettes at high temperature and pressure using different technologies. And also discuss the various advantages, factors affecting the biomass briquetting and comparison between coal and biomass briquetting. Maninder *et al*, (2012) concluded that apart from the transportation, storage and handling problems biomass briquetting have several advantages over coal, oil etc. so we have to use it for our domestic purposes like heating and cooking. Thus, biomass briquetting is an alternative source of energy.

In a work "Production and comparative study of pellets from maize cobs and groundnut shell as fuels for domestic use" Kyauta *et al*. (2015), handles the production and comparative study of solid fuels from agricultural waste (i.e. maize cobs and groundnut shell) that can serve as alternative energy sources for domestic use, using the densification process. The characteristics of the pellets determined were moisture content, ash content, combustion rate and calorific value. The result showed that groundnut shell pellets attained a higher temperature than maize cobs. The temperatures attained by 100g of each type of fuel were 756 0C and 600 0C for ground nut and maize cob pellets respectively. The result of the net calorific value test for maize cob was found to be 13.8MJ/kg while that of groundnut shell pellets was 13.9MJ/kg. These results showed that the pellets are capable of generating heat that is sufficient for domestic use if appropriate appliances are used.

Sánchez *et al*. (2014), presents the results of a project focused on the development of briquettes from the waste wood (sawdust) resulting from the main waste from timber companies located in the Piura Region of Peru. This waste wood currently lacks a useful purpose, and its indiscriminate burning generates CO and CO_2 emissions. Through a drying and compression process, sawdust briquettes were obtained with the following features: 19.8 MJ/kg, 10% of humidity, 894 kg/m3, 1.3% of ashes, 15,29% of fixed carbon, and 83.41% of volatile matter. The results achieved show that sawdust briquettes are a perfect substitute for the fuels coming from illegal logging of the dry forest reserve in Piura that are currently used in domestic stoves (e.g. charcoal, firewood) by 55.81% of families in the region. In order to investigate the acceptance of the substitute product, eleven communication and awareness workshops were conducted reaching over 600 families, in addition to product testing for 127 families in five low-income areas of the Piura region.

Production and characterization of rice husk pellet was investigated as an alternative source of energy by Japhet *et al*. (2015), Pellets were produced from rice husk at three (3) pressures of compaction of 28MPa, 31MPa and 34MPa and three (3) particles sizes of 212µm, 300µm and 425µm. The effects of compaction pressure on the properties of pellets were determined. The results showed that, the higher the compaction pressure the lower the porosity index and consequently the higher the bulk density. The fuel pellet's density affects its bulk thermal properties. This effect is seen, when 100g of each pellet sample were combusted. Increased burning time of pellets was observed as the bulk density increases. The result also showed that the maximum calorific value of 17.589MJ/kg was achieved with a compaction pressure of 34MPa and with particle size of 425µm. also the minimum calorific value of 15.129MJ/kg was achieved with a compaction pressure of 34MPa and with particle size of 212µm.

Golinski and Foltynowicz (2012), in a study "Pellet – a Key to Biomass Energy" state that Pellet production is a rapidly growing business in many European countries. This fact is strongly connected with increasing role of biomass as a resource of clean energy. Future of pellet market is influenced by different political, economical, environmental and social aspects which create complex relations between suppliers of raw material, pellet producers and consumers. That is why standardization and quality control is being introduced in many countries, that allows to deliver better product which can compete with other fuels in terms of efficiency and impact on environment.

III. MATERIALS AND METHODS

3.1 What Is Pellet

Pellets are closely related to briquettes except that they have a smaller diameter and are more adapted to small scale use. Ashden (2011) refers to pellets as very small briquettes. There are a few different definitions of a pellet, but the one used in this study is as follows; *"A Wood briquette (pellet) is a mass of ground fuel stuff moulded or pressed into a convenient unit with or without the aid of a binder"* (written by Natividad, 1982 cited by Vinterbäck, 2000).

Pellets are a form of densified biomass with interesting opportunities for development of renewable energy. This solid fuel is mainly produced from wood residues but other biomass residues could be used. Pellets are an important renewable energy source that can easily be used in small-scale domestic systems. The dimensions of fuel pellets vary between 3 and 25 mm in diameter depending on the die block that is used in production. The length generally varies between 5 and 40 mm. If the product exceeds 25 mm in diameter it is called a briquette (Morten *et al*., 2009). Two major factors have promoted the growth of the pellet fuel market. The first is the instability in price and consistent rise in the cost of fossil fuels, and the second is the increasing attention given to the effect of climate change on the environment caused by the use of fossil fuels. Other factors supporting the use of pellets are that they are a fuel that can be produced locally, from local wood and biomass residues. The local production of pellet can produce an affordable fuel, while creating local jobs and mitigating the problem of deforestation in developing countries.

3.2 Characteristics of Pellet

The main purpose of pelletizing a raw material is to reduce the volume and thereby increase the energy density. When densification has taken place, there are two quality aspects that need to be considered. Firstly, the pellet has to remain solid until it has served its purpose (handling characteristics). Secondly, pellet has to perform well as a fuel (fuel characteristics). The energy characteristics are other important issues when describing and comparing pellets with other fuels (Karlhager, 2008).

3.3 Biomass Raw Materials for Pelletizing

Biomass raw material base for the production pellets (briquettes) has been thoroughly described by Hirsmark (2002). There are a number of biomass materials that can be used for pellet (briquette) production. Wood residues as saw dust, wood chips, planer shavings, recycled wood and pure wood can all be used after milling. Agricultural residues as straw, hemp or reed canary grass can be used. Short rotation coppice, e.g. Salix can also be used in pelletizing (briquetting) processes. Peat is another raw material suitable for pelletizing (briquetting) (Hirsmark 2002). There is no data of which raw material is the most important for briquette production (Karlhager, 2008). Hirsmark showed that saw dust and planer shavings are the two most common raw materials for pellet and briquette production though. In many developing countries which produce huge quantities of agro residues, the potential agro-residues which do not pose collection and drying problems, normally associated with biomass are rice husk, groundnut shells, coffee husk and coir waste (obtained by dry process). At present, loose rice husk, groundnut shells and other agro-residues are being used mostly by small scale boilers in process industries (Grover and Mishra 1996). "Fig." 1, shows some biomass sources for pelletizing.

Fig.1: Biomass sources for pelletizing (Kiss and Alexa, 2014).

3.4 Biomass Pelletizing Process

Pelletizing is the process of densification of biomass to produce homogeneous, uniformly sized solid pieces of high bulk density which can be conveniently used as a fuel. The densification of the biomass can be achieved by any one of the following methods: (i) Pyrolysed densification using a binder, (ii) Direct densification of biomass using binders and (iii) Binder-less briquetting (pelletizing) (Karaosmanoglu, 2000). Depending upon the type of biomass, three processes are generally required involving the following steps:

I. Sieving - Drying - Preheating - Densification - Cooling – Packing
II. Sieving - Crushing - Preheating - Densification - Cooling – Packing
III. Drying - Crushing - Preheating - Densification - Cooling – Packing

3.5 Description of a Typical Biomass Pelletizing Operation

A typical biomass pelletizing operations consisting of three major unit operations - drying, size reduction (grinding), and densification (pelletizing) is shown in "Fig." 2.

The biomass is dried to about 10% (wb) in the rotary drum dryer. Superheated Steam dryers, flash dryers, spouted bed dryers, and belt dryers are also common in European countries (Stahl *et al*., 2004; Thek and Obernberger, 2004) but they are not used in North America (to the knowledge of the authors).

After drying, a hammer mill equipped with a screen size of 3.2 to 6.4 mm reduces the dried biomass to a particle size suitable for pelletizing. The ground biomass is compacted in the press mill to form pellets. The individual pellet density ranges from 1000 to 1200 kg/m^3. The bulk density of pellets ranges from 550 to 700 kg/m^3 depending on size of pellets. Pellet density and durability are influenced by physical and chemical properties of the feedstock, temperature and applied pressure during the pelletizing process (Mani *et al*., 2003). In some operations, the ground material is treated with super-heated steam at temperatures above 100°C before compaction. The superheated steam increases moisture and temperature of the mash causing the release and activation of the natural binders present in the biomass. Moisture also acts as a binder and lubricator (Robinson, 1984).

In some operations, binders or stabilizing agents are used to reduce the pellet springiness and to increase the pellet density and durability. Most widely used binders for pelletizing of animal feeds are calcium lignosulfonate, colloids, bentonite, starches, proteins and calcium hydroxide (Pfost, 1964; Tabil And Sokhansanj, 1996). Pfost and Young (1974) Reported that there was a significant increase in pellet durability when using colloids and calcium lingo-sulphonate as additives in the range of 2.6% by weight. Biomass from woody plants contains higher percentages of resins and lignin compared to agricultural crop residues (straw and stover). When lignin-rich biomass is compacted under high pressure and temperature, lignin becomes soft exhibiting thermosetting properties (van Dam *et al*., 2004). The softened lignin acts as glue.

The temperature of pellets coming out of the pellet mill ranges from 70°C to 90°C. The elevated temperature is due to the frictional heat generated during extrusion and material pre-heating. Pellets are cooled to within 5°C of the ambient temperature in a cooler. The hardened cooled pellets are conveyed from the cooler to storage areas using mechanical or pneumatic conveying systems. Pellets may be passed over a screen to have fines removed and were weighed before being stored in enclosed storage areas (Mani *et al*., 2006).

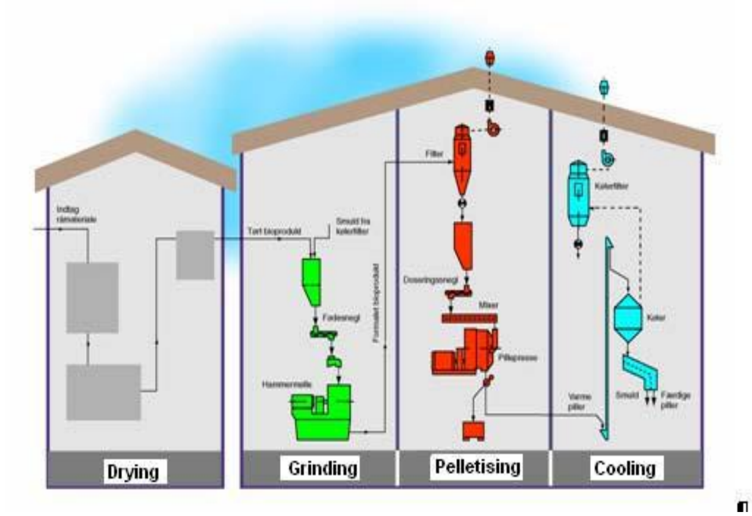

Fig.2: Flow diagram of the pelletizing process (Morten et al, 2009)

IV. DISCUSSION

Biomass residues – wood and agricultural waste, have high potential to contribute to the energy needs of developing countries, but factors such as low density and high moisture content are some drawbacks, making them technically unsuitable for direct use. Densification technologies provide practical options for overcoming some of the inherent drawbacks of biomass (moisture content and low energy density being the most important). Pelletizing can be regarded as one of the well established densification procedure, gaining increasing popularity and acceptance in recent years in the developed countries. Which are mainly due to pellets dimensions (appropriate for automatic feeding and for application in small domestic appliances). In this paper, the characteristics of pellets, biomass raw materials for pelletizing, biomass pelletizing process and description of a typical biomass pelletizing operation were described.

From previous research, it was shown that pellets with good handling and fuel characteristics could be produced from wood and agricultural waste. This will provide other alternatives for reducing problems caused by burning fossil fuels and deforestation which are the major contributors to anthropogenic climate change.

V. CONCLUSIONS

Massive production of fuel pellets from wood and agricultural waste, for application as domestic fuel could give a positive development to developing countries, where there are a lot of these resources and yet lack a sustainable source of biomass fuel supply.

Therefore, more research on different alternatives - combination of raw materials for the production of pellet from wood and agricultural waste, on analysis of their characteristics and their behavior on combustion, and on the appropriate appliance for their application, should be performed, to encourage the use of pellet as domestic fuel in developing countries.

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