International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 05 | May 2021 www.irjet.net p-ISSN: 2395-0072

# PELLET MANUFACTURING AND TESTING USING VARIOUS BIOMASS COMPOSITIONS

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***Abstract-*** *Biomass Pellets are formed by combining different biomass compositions in different combinations after removing the moisture content. Biomass Pellets are recognized more and more by the world for modern day bioenergy. The energy generated by biomass pellet is very less compared to traditional sources. There are researches happening in world to increase its efficiency and energy generation. This paper is research to the same. Biomass can be made of many biomass materials in this paper shortlisting of some of the best materials is done. In this paper the combination of different composition have created samples which are tested for their properties like ultimate and proximate analysis and compared to existing pellets properties.*

***Key Words***: *Biomass pellet, Ultimate analysis, proximate analysis, Compositions combination and durability.*

## 1. INTRODUCTION

Biomass pellets are a well-liked sort of biomass fuel, generally made up of wood wastes, agricultural biomass, commercial grasses and forestry residues. In addition to savings in transportation and storage, pelletization of biomass facilitates easy and price effective handling. Dense cubes pellets have the flow ability characteristics almost like those of cereal grains. The even geometry and structure of biomass pellet helps in automatic feeding. Densely packed biomass pellets help in good durability in transport and storage. Pellets if densely packed and the moisture content is low the combustible properties can be increased.

Biomass pelletization may be a standard method for the assembly of high density, solid energy carriers from biomass. Pellets are manufactured in several types and grades as fuels for electrical power plants, homes, and other applications. Because of the availability of vast size, shape and type of machine biomass pellets can be made of different size, shape and with different bulk density.. Pellets have a cylindrical shape mostly and are about 6-25 mm in diameter with 3-50 mm in length also the particle size of<3.2mm is preferred according to norms. Pellet fuel are used in boilers and household purposes they are not used as electricity generator because of low energy to volume ratio compared to other sources which make biomass pellet uneconomical for electricity generation.

## 2. LITERATURE REVIEW

By comprehensive study of 24 existing paper, we have noted the important papers who's research help in shortlisting the best materials and to increase the properties of biomass pellet.

1. Carly Whittaker, Ian Shield et al[5] found that A high lignin content and optimum MC coupled with high pelleting temperature tends to improve biomass pellet durability. The coarser particle sizes, high extractive contents and high MCs results in reduce in the durability by reducing friction and disrupting binding.
2. Jaya Shankar Tumuluru et al [17] found that High moisture pelleting studies conducted using woody and herbaceous biomass samples indicate that pellet quality changes with composition and pellet die diameter. The 8mm diameter of the pellet die influenced the density and durability of the pellets produced. Wheat straw, sorghum, and lodge pole pine pellets are made using a 10 mm die which has a higher unit density and if we take corn Stover and pinion 8 mm die pellets are obtained, which resulted in higher unit density values. It stated that die size of 8mm to 10mm is preferred.
3. Niels Peter K. Nielsen, Douglas J. Gardner, Torben Poulsen, Claus Felby et al [20] found that very high moisture content in the biomass can act as a lubricant that allows chains to slide, which limits the binding phenomena, different techniques are used to bind more finely the grains on experimental basis.
4. Sriraam R. Chandrasekaran , Philip K. Hopke, Lisa Rector , George Allen , Lin Lin et al [24] found "carbon content effect in ash formation more the carbon content more ash is formed" .
5. Teresa Miranda, Irene Montero, Francisco José Sepúlveda, José Ignacio Arranz, Carmen Victoria Rojas and Sergio Nogales et al [2] observed Higher C percentages corresponded to higher HHV, and these parameters were similar for each couple of pellets in the group. Equally, higher bulk densities corresponded to low-durability pellets. Therefore, high bulk density did not imply proper durability. Pine sawdust material is only one which could give high

quality pellet with minimum ash content. The remaining woody biomass pellets, except for vine shoots, is used in industries as combustible properties are god.

6. Shyam Thapa et al [8] Performed multi-response process parameter for composite pellets made from agriculture waste it was found that MC of 13+-0.5% is preferred for good pellet by trial and error method. Analysis showed that significant impact in properties is in following manner binders > binder ratio > grind > feedstock.

7. Rahul Dighe .,Prutviraj Vidhate , Vitthal Ghuge , Nitish Parab et al [4] research shows that The chemical composition of natural biomass system is simpler than that of solid fossil fuels; however, the semi-biomass system is sort of complicated as a results of incorporation of varied non-biomass materials during biomass processing. The biomass composition is different from that of coal is seen. The variations in the biomass compositions were found to be different than that of coal.

8. Phani K. Adapa , Lope G. Tabil , Greg J. Schoenau et al [13] analysis showed The pellet mill consumed the very best proportion of total specific energy followed by hammer mill, cooler and chopper for non-treated barley straw at 1.6 mm grind size. Proportion of energy by hammer mill can be observed by decrease in grain size to 0.8mm. It is preffered to develop the pellet which can be obtained from higher hammer mill screen sizes (>1.6 mm) to increase the net available specific energy for production of biofuels.

## 3. METHODOLOGY

### 3.1. Problem Definition

The recent advancement in technology and research had helped bioenergy to achieve new heights but still the gap between bioenergy efficiency and renewable energy source efficiency remain big. Consider coal which have kcal/kg value ranging between 4800-7000 and standard biomass pellet have kcal/kg from 3500 to 4200. The energy to volume ratio is also less as compared to coal. One of the major difficulties in using biomass pellet is transportation due to less durability nearly 10% of total biomass breakdown resulting in less efficiency. To avoid this we have used wax to cover it with thin wax so that durability is increased.


**Fig3.2.1.** Pellet materials

### 3.2. SHORTLISTED MATERIALS

1. Pine wood
2. Saw dust
3. Dried Sugarcane
4. Coconut Husk
5. Peanut Shell
6. Dried Cow dung
7. Waste Paper
8. Dried Leaves

### 3.3. MATERIAL PROPERTIES

**Pine Wood-** Pine wood pellets has high calorific value, about 21.32 MJ/kg. Low moisture content, less than 10%. Long burning time and high combustion efficiency. Amount of smoke release by pine is less. The post burning results by use of pine wood material as a main material in pellet result in 0.5% of less ash content and the waste product can also be used as fertiliser in garden. Also it can be used in thermal power plant. They have good heat value and also emission is less compared to coal.

**Coconut Husk(Coir)-** Coir is a natural, lignin rich, fiber that can be found between the hard internal shell and the outer coat of a coconut. There are multiple products but always significant amount of fibers accumulating remain utilized.. Coir fibers obtained from ripe (brown fibers) and unripe (white fibers) have a high lignin content about 41–42 wt% by weight, a low ash content. The produced pellets had high mechanical properties and were studied at laboratory scale. Dynamic mechanical thermal analysis showed that glass transition temperature of coir lignin at the applied conditions results in softening of lignin at about 120–130 °C is the usual temperature reached in an industrial scale pellet machine. This are some the reasons why coir is good raw material in biomass pellet. Also the high availability makes it easier to replace charcoal and wood and can help in reduction of deforestation.

**Dried Cow Dung-**

1. Low cost & high additional value-

With high calorific value and less cost cow dung can be used in biomass pellet. Also the ash after burning contains sodium, potassium and magnesium can be used as inorganic fertilizer.
2. High bulk density, convenient transportation-
The density of the biomass pellet can be increased by 0.8 to1.3. Because of fine particles the size is compact of biomass pellet and transportation can be easily done as bulk density increases..
3. Green energy, clean and environment protection-
Cow dung in pellet is a kind of green energy. The amount of smoke or harmful gas is less. The Sulphur and ash content are much less as compared to coal or oil. The cow dung fuel pellets are also called zero emission energy.
4. High efficiency & energy saving-
It is also high in carbon activity and volatile matter, ash content is only 1/20 of coal. The waste heat in ash is extremely low and the combustion ratio can reach up to more than 98%, which results in the burning time is longer.

**Peanut shell-** Due to good density the combustion efficiency is good of peanut shell, sometimes the centre temperature may reach 1110 degree centigrade, heat value can reach 3700 ~ 4000 kcal / kg, ash content less than 8%. The peanut shell also has its own unique advantages different than coal or oil. High firepower and less ash. During burning, the pellet can keep shape, no distortion and fall apart. The pellet fuel ash can be used as the potash fertilizer to return into soil, Clean and environmental protection. The emission of only 40mg/m3 is done by peanut shell which is good for environment. So use the pellet fuel with peanut shell can improve air quality and avoid greenhouse effect. Convenient transportation and easy to store are the advantages.

**Saw Dust-** Sawdust is used mainly as a fuel for heating when it comes to overseas markets, especially in countries with very cold weather. Because the amount of heat generated by burning it is very high at around 4600 Kcal / kg compared to wood at only 2100 Kcal/kg, more than twice that. Saw dust are formed by tree chips or waste chips. Waste of wood processing industry. It is said that they are a product that makes use of waste products which have higher environmental protection value than any other burning material.

**Dried Sugarcane (Bagasse)-** Bagasse is a tree-free, renewable resource made from sugarcane fibre left after juice is extracted.
Chemical analysis on dried sugarcane or bagasse is:

Cellulose 45–55%
Hemicellulose 20–25%
Lignin 18–24%
Ash 1–4%
Waxes <1%

Sugarcane is a tree-free renewable resource, which makes it superior to other kind of fuels. Sugarcane bagasse pellets are with high calorific value of 3400 to 4200 kilocalorie and low ash. It's a wise choice as fuel energy.

**Waste Paper-** Paper pellets are made to meet the quality demands of the energy system. They are very dense, and the Btu content is similar to coal. The dry processing gives them extremely low moisture content.

**3.4. PROCESS**

**Pre-heating-** Pre-heating- In this process the raw materials to be used are kept in direct sunlight for the drying the material so that the MC can be decreased in the required amount. An estimated amount is taken for drying process as more drying could result in not so good binding. Some of the materials like bagasse are undergone heating to 125-140 Celsius. The moisture content in biomass are often considerably high and are usually up to 50% – 60% which should be reduced to 10 to fifteen. Rotary drum dryer is that the commonest equipment used for this purpose. Drying increases the efficiency of biomass and it produces almost no smoke on combustion as the biomass burns completely. It should be noted that the feedstock shouldn't be over dried, as a little amount of moisture helps in binding the biomass particles. The drying process takes almost 70% of total energy in production of pellets.

**Screening-** After the pre-heating is done this materials are screened for any possibilities of stones, waste materials or unnecessary particles which could result in improper pellet formation.

**Hammering-**Before feeding the biomass must be brought according to norms that are not more than 3.2 mm. If the pellet size is just too large or too small, it affects the standard of pellet and successively increases the energy consumption. Size reduction is done by hammering or grinding the particles to 3mm. If the feedstock is sort of large, it goes through a chipper before grinding.

**Pelletization-** The next most important step is pelletizing here is where the pellets are formed by rolling the materials over die late. Due to the high , frictional forces increase, resulting in a substantial rise in temperature. High temperature causes the lignin and resins present in biomass to melt which acts as a binding agent between the biomass fibers. This way the biomass particles fuse to make pellets.

**Cooling-** Due to the friction heat is generated which may result in breaking so cooling is done. The pellets may then be skilled a vibrating screen to get rid of fine materials. So that the mud is removed and pellets are clean.

**Fig3.4.1**. Pellet Machine

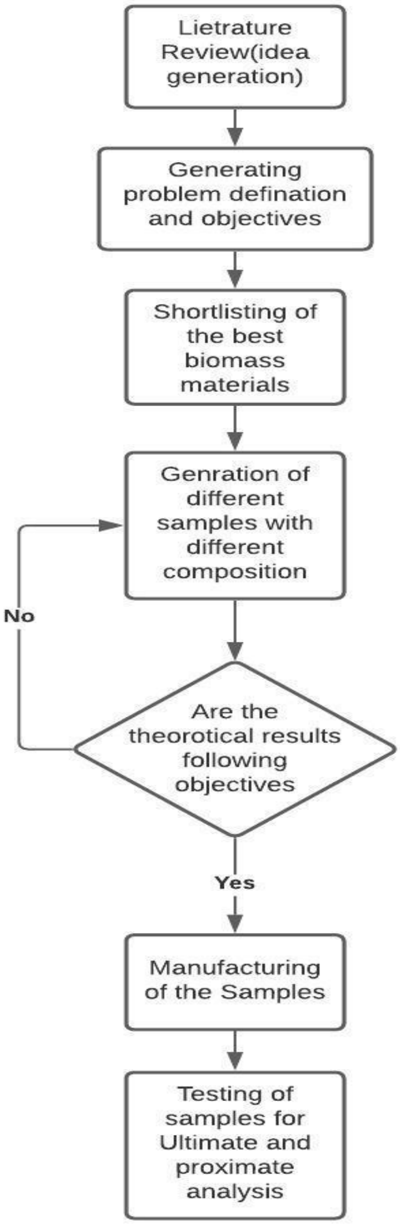


**Fig3.4.2.** Process flowchart

**3.5. BINDERS**

**3.5.1 Functions of binders in pellet production**

1. Binders are used in pellet production for better bonding, lubrication or to decrease combustion problems while igniting.
2. They are used in increasing the durability of the pellets their by reducing the fine dust and particles.
3. When pellet quality does not meet the demand binders can be used to increase the properties.
4. Increase the productivity by lubrication.
5. While manufacturing the pellets can make less energy consumption,

**3.5.2 Factors influences bonding effect**

During pellet production, what is going to influence the bonding effect and eventually influence the sturdiness of the pellets. Some of the main factors are listed below for your sake.

***Feedstock composition-*** The composition of the biomass material directly results in changes in bonding effect. Lignin is natural binder so high content helps in easy molding of material to pellet. Low lignin content biomass should have binders added to realize a far better bonding effect. Bonding effects vary with the materials.

***Particle size-*** When the feedstock is compacted, the distance between the particles is reduced and the intermolecular attractive forces play a role in the particle bonding. The attractive forces are increased as the particle size is decreased.

***Temperatures-***Due to the high temperature the constituents diffuse resulting in bonding when cooled.

***Moisture-***The proper moisture can help in bonding, the binders bond more firmly resulting in good durability and no slip. The pellet die holes gets block due to high moisture.

***Pelletizing pressure-***Mechanical pressure casted by pellets mills are one of the major factors that influence bonding effect. Bonding effect increase with increase in pressure. High quality pellet plant will make sure the pellet quality.

**3.5.3 Common binders in biomass pellet production**

Binders are often a liquid or solid forming a bridge, film, or matrix, or to cause a reaction imparting enhanced inter-particle bonding. Examples of possible bonding agents for wood pellets include starch, molasses, plant oil, lignin sulphate and synthetic binders. In the following paragraphs, some common binders are going to be discussed in details for your reference.

***Starch-***Bonding agents (from corn or rice) also can be wont to decrease abrasion. Small amount of starch, but 2 percent by mass, increase pellet strength. Corn and potatoes are most common starch derivaties. A cost benefit analysis must be performed to work out if, and the way much, starch should be used. This sort of addition is common in Austria, a number one country within the utilization of biomass pellets. However, numerous other factors determine the general level of abrasion.

***Lignin-***Lignin is a natural binder it helps in binding and molding of material. At higher temperature lignin softens which results in proper molding of materials into pellets. There is a threshold to the advantages of adding lignin, levels above 34% in wood tends to decrease durability.

***Sodium lignosulphonate-*** One of the best binding agents used tin palletisation process it gives best pellet properties with good ash content and good CV. It is mostly used by the European union. It gives best results but is costly which makes it of limited use.

### 3.6. ULTIMATE ANALYSIS AND PROXIMATE ANALYSIS

In ultimate analysis we calculate Carbon%, Sulphur %, Nitrogen %, hydrogen % and Oxygen %. Ultimate analyser is used to calculate.

**Carbon-** Total carbon in the ultimate analysis is the measured weight percent of carbon in a pellet, including the carbon in volatile matter. Method used is ASTM method D5373-08 (American Society for Testing and Materials, 2013, p. 628–636).

**Hydrogen-** Weight percent method is used to find hydrogen in pellet in ultimate analysis.

**Oxygen-** The total oxygen content of a biomass pellet cannot be measured analytically, so it is determined through a calculation (ASTM method D3176-09; American Society for Testing and Materials, 2013, p. 510–513).

**Total oxygen weight % = 100 – (total carbon weight % + total hydrogen weight % + total nitrogen weight % + total sulphur weight % + total ash weight%)**

**Nitrogen-** Total nitrogen in the ultimate analysis is expressed as the measured weight per cent of nitrogen in the coal. ASTM method D5373-08 (American Society for Testing and Materials, 2013, p. 628–636) is used to find the results.

**Sulphur-** Total sulphur in the ultimate analysis is the measured weight percent of sulphur in the coal. It is determined by ASTM methods D5373-08, or D4239-02 (American Society for Testing and Materials, 2013, p. 628–636, 556–561, respectively). In the test, a biomass pellet sample is ground to a set size and weighed, then placed in a sulphur analyser. In the analyser, the sample is combusted at a temperature of 1,370°C in an oxygen atmosphere. The oxygen reacts with sulphur to form sulphur dioxide gas. The gas passes through an infrared absorption detector in the analyser, which measures the concentration of sulphur.

**Ash content-** With the help of Nabertherm furnace the ash content of samples is found out.

$$ASH\% = (x/g)*100$$

Here, g is the weight of sample and x is the weight of ash

**Moisture Content-** Moisture analyser can be used to calculated moisture content in biomass pellet. Theoretically it can be calculated by

$$MC\ \% = ((g-x)/g)*100$$

g is the Weight of sample, x is the Weight of dry matter and (g –x) is the Loss in weight.

### 3.7. TESTING GROSS CALORIFIC VALUE

DIN 51900-1 or ASTM D-240, determination of gross calorific value by bomb calorimeter is used for calculation of biomass pellet Gross Calorific Value.

$$Q = m.Cp.\Delta T$$

Q: heat absorbed (kJ)
m: Mass of water in the bomb calorimeter (g)
Cp: Specific heat 4.186 kJ / kg °C
ΔT: temperature difference (°C)

LHV and the HHV is calculated by the following equation:

$$LHV = (m*Cp*\Delta T)/m$$

The equation used to calculate HHV:

$$HHV = (T2 - T1 - TKP) \times (Cv\ (kJ / kg))$$

LHV = HHV – 3240 kJ / kg
Therefore, HHV = LHV + 3240 kJ / kg
T1 = temperature of the cooling water at bomb calorimeter before combustion (°C)
T2 = the temperature of the cooling water bomb calorimeter after burning (°C)
TKP = temperature rise caused by combustion wire
HHV = highest heating value (kJ / kg)
LHV = Lowest heating value (kJ / kg)

### 3.8. EXPERIMENT SETUP

For the testing purpose two samples are formed after study of shortlisted materials and mixing them in certain composition after going through Pre-heating, Hammering, Screening and pelletizing process.

**Sample 1- Pine wood 50% + Paper 20% + Dried Cow Dung 15% + Starch 15%**

**Sample 2- Coconut Husk 50% + Dried Sugarcane Waste 30% + Saw dust 10%+ sodium lignosulphonate 10%**

## 4. RESULTS AND DISCUSSION

The results found in Table4.1 are theoretical results found out by studying researches done on the materials. The Ash content and Moisture content are found by using the method "**MC %=((g-x)/g)*100**"," **ASH%= (x/g)*100**" by burning the sample in furnace.

| Sample | Raw Material | Binder | GCV Kcal/kg | ASH % | Sulphur % | Carbon % | Moisture Content % |
|---|---|---|---|---|---|---|---|
| **1** | Pine wood 50% + Paper 20% + Dried Cow Dung 15% | Starch 15% | 4620 | 3.12 | 0.12 | 28.87 | 5.75 |
| **2** | Coconut Husk 50% + Dried Sugarcane Waste 30% + Saw dust 10% | Sodium lignosulphonate 10% | 4750 | 4.6 | 0.171 | 29.35 | 4.2 |

**Table 4.1** Results

**Durability-** Sample 1 and sample 2 have more durability than the standard biomass pellet because of the wax coating. To check the durability is increase or not the 2kg of sample 1 and 2 and 2kg of standard biomass pellet was transported and the results obtained were 1 in 600 was damaged in Sample 1 and 2 while standard biomass pellet 1 in 100 were damaged. The result can be seen by observing the below figures of sample1 and 2 with standard biomass pellet after transportation.

## 5. CONCLUSION

### 5.1 CONCLUSION

The two samples created are when compared to standard biomass pellets the results show that the energy generation by the samples were greater than the standard biomass pellets by 30-40%. The ash content is also less. But by observing the cost of samples with the standard biomass pellets the cost is 3 -4 Rupees higher. But the energy generated is more compared to standard biomass pellet. The durability of the biomass pellet was increased nearly by 50% because of the coating. The film thickness if increase affects the initial combustion. So a thin wax coating is preferred. The biomass pellets can be used in industry or household to replace gas though the biomass pellets are not on the mark to replace the coal, which is still 20-30% higher energy. The use of sodium lignosuphonate have good results, like it increased durability, Increase the sulphur content which helps in continuous burning with oxygen without effecting the energy generation of pellet.

### 5.2 FUTURE SCOPE

The future scope of this project is vast and endless as it is in the starting phase. Some of the future scopes are mentioned below-

1. The more precise can be obtained by testing it on machines like ultimate and proximate analyser which could help in more precise result finding and other contents like oxygen, nitrogen can also be found.
2. The cost reduction can be done by mass production.
3. The Combination of more or different biomass materials or changing the binders can be done to increase the energy generation as advancements are done in this field.

## 6. REFRENCES

[1]. **"Elemental Analysis of Wood Fuels"** New York State Energy Research and Development Authority. Albany, N.Y. Sandra Meier, Ph.D. Senior Project Manager. Mass. Lisa R. Rector, Prof. Philip K. Hopke, Sriraam R. Chandrasekaran, Lin Lin.
[2]. **"A Review of Pellets from Different Sources"** Teresa Miranda , Irene Montero, Francisco José Sepúlveda, José Ignacio Arranz, Carmen Victoria Rojas and Sergio Nogales.
[3]. **"Influence of pellet diameter and length on the quality of pellets and performance, nutrient utilization and digestive tract development of broilers fed on wheat-based diets"** M.R. Abdollahi, V. Ravindran, T.J.

Wester, G. Ravindran & D.V. Thomas, British Poultry Science · May 2013.

[4]. **"Formation of pellets using efficient composition of biomass"** This research is done by Rahul Dighe .,Prutviraj Vidhate , Vitthal Ghuge , Nitish Parab from Department Of Mechanical Engineering,Bharti Vidyapeeth College Of Engineering, Navi Mumbai. It focuses on composition change of same biomass material used cuurently to increase efficiency, 2020.

[5]. **"Factors affecting wood, energy grass and straw pellet durability – A review"** Carly Whittaker , Ian Shield Department of Agro-Ecology, Rothamsted Research, Harpenden, Hertfordshire AL5 2JQ, UK, Elsevier, Renewable and sustainable energy review 71, 2017.

[6]. "NDMI Renewable Energy PVT LTD" Its an renewable energy producing industry. This company is expert in making pellets.

[7]. https://www.balanceenergy.co.in/ "Balance energy pvt ltd." Agro fuel hub this industry is one of the largest exporter of wooden pellets in India.

[8]. **"Manufacturing and optimization of pellet machine"** Sushant Ambre, Kirti Bhagat, Roshan Chawan and Akshay Gaikwad from Bharati vidyapeeth college of engineering, navi mumbai. This research is of optimizing the pellet machine, 2018.

[9]. **"recent development in biomass pellet"** Wolfgang Stelte, Anand R. Sanadi, Lei Shang, Jens K. Holm, Jesper Ahrenfeldt, and Ulrik B. Henriksen, bio resources , PEER-REVIEWED-REVIEW-ARTICLE.

[10] **"Investigation of Heat Generation from Biomass Fuels"** Naoharu Murasawa and Hiroshi Koseki, Energies 2015, 8, 5143-5158; doi:10.3390/en8065143, June 2015.

[11].**"Biomass pellets for power generation in India: a techno-economic evaluation"** Pallav Purohit & Vaibhav Chaturvedi, Environmental Science and Pollution Research (2018) 25:29614–29632.

[12].**"Research on Effect of Spruce Sawdust with Added Starch on Flowability and Pelletization of the Material"** Lucie Jezerskaa, Ondrej Zajonca , Jiri Rozbroja , Jan Vyletěleka , Jiri Zegzulka, Science direct, IERI Procedia 8 ( 2014 ) 154 – 163.

[13]**"Factors affecting the quality of biomass pellet for biofuel and energy analysis of pelleting process"** Phani K. Adapal, Lope G. Tabil , Greg J. Schoenau. Int J Agric & Biol Eng, Vol. 6 No.2, June 2013.

[14]**"Effect of Additives on Wood Pellet Physical and Thermal Characteristics: A Review"** Dmitry Tarasov, Chander Shahi, and Mathew Leitch are Faculty of Natural Resources Management, Lakehead University, 955 Oliver Road, Thunder Bay, ON, Canada, Hindawi Publishing Corporation, Volume 2013, Article ID 876939, 6 pages.

[15]. **"Agro-Pellets from Oil Palm Residues/Pine Sawdust Mixtures: Relationships of Their Physical, Mechanical and Energetic Properties, with the Raw Material Chemical Structure"** Artemio Carrillo-Parra , Juan Carlos Contreras-Trejo , Marín Pompa-García , Miguel Ángel Pulgarín-Gámiz, José Guadalupe Rutiaga-Quiñones , Gerardo Pámanes-Carrasco 1and Maginot Ngangyo-Heya, Applied sciences journal, 13 September 2020.

[16].**"Influence of pellet diameter and length on the quality of pellets and performance, nutrient utilisation and digestive tract development of broilers fed on wheat-based diets"** M.R. ABDOLLAHI, V. RAVINDRAN, T.J. WESTER, G. RAVINDRAN AND D.V. THOMAS of Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Palmerston North, New Zealand, British Poultry Science Vol. 54, No. 3, 337–345,, May 2013.

[17].**"Effect of pellet die diameter on density and durability of pellets made from high moisture woody and herbaceous biomass"** Jaya Shankar Tumuluru, Carbon Resources Conversion, carbon resource conversion 1 (2018) 44-54.

[18]. **"Analysis of paper sludge pellets for energy utilization"** Nosek, R., Holubcik, M., Jandacka, J., and Radacovska, BioRes. 12(4), 7032-7040. NV State University,2017.

[19].**"Effect of pellet made of waste material from paper industry"** Valesca B. San Martin, Pablo Undurraga, Celerino Quezada, José E. Celis, and Marco A. Sandoval. Chilean J. Agric. Res. vol.76 no.3 Chillán set. 2016.

[20].**"Importance of temperature ,moisture and species for conversion process of wood residue to fuel pellet"** Niels Peter K. Nielsen , Douglas J. Gardner, Torben Poulsen , Claus Felby, Wood and Fiber Science, 41(4), 2009, pp. 414–425 # 2009 by the Society of Wood Science and Technology.

[21].**"Physical and Compression Properties of Pellets Manufactured with the Biomass of Five Woody Tropical Species of Costa Rica Torrefied at Different Temperatures and Times"** Johanna Gaitán-Alvarez , Roger Moya, Allen Puente-Urbina and Ana Rodriguez-Zuñiga. Energies MPDI, 14 August 2017

[22].**"Investigation of Heat Generation from Biomass Fuels"** Naoharu Murasawa and Hiroshi Koseki, Chiba Institute of Science, 3 Shiomi-cho, Choshi Chiba 288-0025, Japan, Energies 2015, 8, 5143-5158; doi:10.3390/en8065143,2 June 2015.

[23].**"Binding material used in making pellets and briquettes"** G. R. YOHE, INDUSTRIAL MINERALS NOTES • No. 19, November, 1964.

[24].**" Chemical Composition of Wood Chips and Wood Pellets"** Sriraam R. Chandrasekaran , Philip K. Hopke, Lisa Rector, George Allen, Lin Lin. "Supplemental Material" NESCAUM, Boston, MA 02111.