BINDURA UNIVERSITY OF SCIENCE EDUCATION
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DEPARTMENT OF PHYSICS AND ENGINEERING

Designing of a Pellet Wood Pellet Making Machine

By

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A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF BACHELOR OF SCIENCE HONOURS DEGREE IN PHYSICS WITH SPECIALISATIONS (ENVRONMENTAL PHYSICS AND ENERGY SOURCES)

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APPROVAL FORM

The undersigned certify that they have supervised, have read and recommend to the University for acceptance and examination a research project entitled **DESIGNING OF WOOD PELLET MAKING MACHINE** submitted by **TINOTENDA SHOKO** in partial fulfilment of the requirements for the award of the degree of Bachelor of Science Honours Degree in Physics with Specialisations

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(Signature of the Chairperson) Date

DECLARATION

I, Tinotenda Shoko, hereby declare that this dissertation, "(of designing a wood pellet making machine*)*." is my own unaided work which has not been submitted before for any degree or examination at any other University. It is being submitted to the Bindura University of Science Education, in partial fulfilment of the requirements for the Bachelor of Science Honours Degree in Physics with Specialisations (Environmental Physics and Energy Sources). All figures, tables and panels, unless specifically acknowledged as being sourced from other persons. Where use has been made of the work of others, it is duly acknowledged.

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Acknowledgment

Firstly, I would like to appreciate God, that ‘I AM WHO AM’ for his sustained grace and strength to bring this work to accomplishment.

Secondly I would like to express my sincere gratitude to my project supervisor, Dr C Shonhiwa, for her motherly, unwavering efforts and patience in guiding this project.

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DEDICATION

To my parents, my brothers and sisters, my fellow friends and all other individuals who helped me with some knowledge.

ABSTRACT

Due to increase in energy crisis, increase of electricity prices load shading new technologies are implemented to make use of biomass waste. This study is mainly focusing on the designing of a wood pellet making machine which is used to produce pellets for biomass stover and simulate the data collected from pellets produced by the machine. To achieve this the researcher must design a model of a wood pellet making machine, calculate the dimensions for the parts of the model and simulates the data collected from the produced pellets. To get information about the model the researcher use some of the literature to design the model and simulate the data. The researcher also uses the Excel to calculate some equations and it also construct the graphs. A prototype of the pelleting machine was designed and developed for affordability. The machine was also tested to evaluate its performance. The machine consisted of a screw conveyor, die, barrel and hopper. It can be driven by an electric motor or a prime mover. The machine was tested with sawdust and at different levels of moisture content using 500, 750 and 1000 cm^3 each of water. The best pellets were formed using 750 cm^3. The average specific energy consumption when 750 cm^3 of starch binder was used was 0.69 kWh/kg while it was 0.93 kWh/kg when water was used as preconditioner. The density of the pellets varied between 0.7 and 1 g/cm^3. This machine can be manufactured at a local machine shop for small-scale especially in the communities where there is a lot of biomass in developing countries.

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Symbols

symbol	meaning	unit
P_x	Pelletizing pressure	N
P_{NO}	Pre-stressing term	N
μ	Sliding friction coefficient	– –
ν_{LR}	Poisson's ratio	– –
R	press channel radius	m
X	the length of the die channel	m
D	Normal screw	m
L	Length of the screw conveyor	m
ω_0	Material factor	– –
S	Pitch of the screw	– –
N	Maximum speed of screw	ms^{-1}
D	Solid shaft diameter	m
ψ	Loading efficiency	– –
μ_o	Friction factor of material	– –
β	Angle of inclination of screw to the horizontal	℃
P	Angle of inclination of screw to the horizontal	℃
η	Efficiency of gear reducer	– –
C	Factor of inclination,	– –
t_{max}	Tosinal shear stress	Nm^{-2}
r	Radius of the shafty	m
T	Torque or twisting moment	Nm^2
J	Second moment of area of area of the section about is axis	Nm^2
P	Power	W
q	Weight of the material	N
ϕ	Angle	℃

CHAPTER 1 INTRODUCTION

1.1 Introduction

In this chapter the researcher introduces the project. He outlined the background to the study, problem of statement, research questions, the objectives; significance of the study, limitations and delimitations as well as definition of terms.

1.2 Background of study

According to Makonese (2019) Zimbabwe has a sever energy crisis because its major sources of electricity are struggling to keep up with demand. This causes most people to resort to use of traditional energies like firewood and animal waste. Pellets from a pellet making machine can be used to improve the energy efficiency of the biomass which is used in the most places in especially in rural areas. Zimbabwe currently has a national electrification rate of 48%. Household electrification has reached 86 % of the urban households, and reached 28% of rural household (Anon., 200) .The consumption of electricity in Zimbabwe is very high this increases the load shading. The compaction of biomass into pellets is an old process which has been known for more than 10 years. The utilization of biomass pellets for heat and power production had its roots in the oil crisis during the early and late 1970s. Political upheavals in the Middle East caused an increasing oil price and delivery bottlenecks, which resulted in action to find alternative energy resources base on local resources. Zimbabwe has a vast of biomass waste which are not being used so far, if this biomass is utilised it can help the nation to grow its economy since the pellets can be used in place of coal to generate electricity. In Zimbabwe some of the sources used to generate electricity are fossil fuels. Fossil fuels causes climate change and the also causes air pollution. One of the major energy source is coal, it has its draw backs originates from its extraction and transportation. A lot of money is needed in using coal as a source of energy so pellets is ideal in place of coal. The researcher don't know any company so far which is producing wood pellets. He only knows about pellets for animal feedstock. Pellets are more efficient than heating ordinary biomass it produces a lot of heat and reduces smoke than heating biomass straight. Sawdust, branches, wood chips, straws, bamboo waste, bagasse, peanut shells, alfalfa waste papers all can be pressed into pellets.

1.3 Problem statement

Zimbabwe is facing energy crisis like most developing countries in the world. Only 40% of households in Zimbabwe are connected to the national grid (Chronicle .2020). In rural areas people are still using biomass straight from its traditional form and also in towns most people uses fire food because of load shading. In most parts of the country there is a lot of biomass waste which can be valorised to improve the biomass heating efficiency so that it can be used into biomass stoves to avoid cutting down of trees which may leads to deforestation. The biomass can be upgraded into different ways for example into pellets which can be used in the improved biomass stoves. We also have a lot of biomass in the form of sawmill dust in eastern highlands of the county for example in Manicaland at least 70,000 tonnes per annum of sawmill waste is produced and it is approximated that the timber industry is responsible for 50-80% of the waste in Manicaland only. Sawdust and shavings represent the most underutilized waste fractions, with heaps scattered all over the region, marring its aesthetic appeal and posing various ecological threats (V, et al., 2016). Farming activities in Zimbabwe have shown that a lot of waste is produce such as maze stock, tobacco, groundnuts (Stelte, 2011). If pellets are produced in enough quantities, they can substitute the use of fire wood because of improved biomass stove. However, at the moment there are no wood pellet making machines in the country. The only available pellet machine are the ones used for animal feeds. There is need to come up with a pellet machine for making improved biomass waste. To close this gap this project designed and a wood pelletiser.

1.4 Purpose of study

1.4.1 Aim

The aim of this study was to design a pelletiser for making for making pellets from biomass waste.

1.4.2 Objectives

In order to achieve this aim, the following objectives had to be made.

1. To describe and quantify the biomass waste available in the country
2. To investigate the types of the wood pelletizer which are available globally.
3. To design a pelletizer suitable for the type of most abundant waste
4. To simulate the performance of the pelletizer

1.5 Research question

In pursuit of research objectives different activities were explode on answering the following questions

1. What are the types and quantity of the biomass waste available in the country?
2. What are types of pelletizers available on the global market?
3. What is the design suitable for the type of most abundant waste?
4. How does the pelletizer perform?

1.6 Significance of the study

This study is important since it introduces a new way of making use of the unutilized waste biomass in pellets which are not being produced so far in Zimbabwe. Wood pellets can be used to replace firewood which reduces deforestation.

1.7 Scope of study

The research was done in Bindura between April and December 2022. It focused on designing a pelleting machine. Its manufacture was constrained by limited financial resources.

1.8 Limitations

- ❖ Financial constrains for the researcher to visit more places to gather information about biomass.
- ❖ Limited time since the researcher is a full time student and must also look for money during vacation.
- ❖ Limited time since courses and dissertation must be done at the same time.

1.9 Definitions of terms

Pellet making machine	It is a device used to make pellets (Stelte, et al., 2012)
Pellets	Are bio fuel made from compressed organic matter or biomass (Pandey, 2019)
Biomass	It is the amount of organic matter into either plants or animals (Shonhiwa , 2013)
Fossil fuels	natural fuel such as coal or gas, formed in the geological past from the remains of living organisms.
Crises	It is the time of intense difficult particularly in the shortage of power supply (Stern , 1992)
Biomass Stover	It is the device that burns compressed biofuel pellets to create a source of heat for residential spaces. (Pandey, 2019)
Tariffs	The amount of money framed by the supplier for the supply of electrical energy to consumers
National grid	The national grid is a network of power stations, power lines as well as electricity infrastructure that allows electricity to be generated, transported and used across the country

1.10 Summary

This chapter outlined the background of the study, problem of statement, purpose of the study. It further outlined the aim of the study, objectives, and research questions, significance of the study and definition of terms. The chapter further outlined the scope of the study, limitations, delimitations and the definition of key terms. Having introduced the project, the next chapter looks at the existing literature to give the research a full understanding of the area.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This literature review is focused on gathering the history of a pellet making machine which is used to make wood pellets for a wood pellet Stover.

2.2 Historical background of pellet making machine

The use of biomass pellet for energy dates back to the 1970s when alternatives to fossil fuels were sought in the wake of the energy crises of the decade. At this time, the technology used to produce animal feed pellets was modified to accommodate denser, woody materials (Eggeman, 2005). One of the industry's early movers was Sweden due to its prominent timber industry, desire for increased energy independence and its commitment to environmental conservation. Wood pellet production planning in Sweden started in the late 1970s with the decision to build a pellet plant in Mora. The plant started production in November 1982 and immediately ran into problems because costs were much higher than had been calculated. Equipment was developed for converting oil boilers to pellet fired boilers. In practically all cases, however, they were highly inefficient, not least because of the poor pellet quality. During this first year the raw material was usually bark. In 1987 the first plant for pelletizing dried material was built in Kil. It was designed for an output of 3,000 metric tons a year. This plant is still in operation and is the oldest commercial plant in Sweden. In the early 1990s the Swedish government came up with a proposal for taxation of mineral fuel. At this time, it also limited carbon dioxide emissions. In a short time period the prospect of burning fossil fuels became unprofitable with biofuels stepping in to fill the energy void. This marked a turning point and the use of wood pellets started to grow rapidly. Similarly, ambitious clean energy programs emerged elsewhere in Europe. As a result, Europe leads the world in biomass pellet consumption to this day. The level of sophistication has risen on the continent to such an extent that manufactured pellets can be delivered in bulk via tanker trucks and deposited directly in residential storage areas, similar to the way gas stations are restocked with gasoline. In addition to residential heating, European power plants increasingly use biomass pellets to generate electricity as well as for energy in other industrial applications. The wood pellet fuel industry became established in the mid-1980s with the introduction of the residential wood pellet stove. This appliance was capable of reducing particulate emissions well below the new requirements of the U.S.'s Environmental Protection Agency (EPA) for wood stoves and of providing consumers with a new level of automation and convenience for heating with wood. Sales of pellet stoves increased rapidly in the early 1990s, reaching a peak in 1994 before levelling off and declining somewhat due to competition with natural gas stoves. Pellet fuel sales followed the demand curve produced by residential pellet stoves. Residential use has accounted for approximately 95% of sales during this period, the balance being industrial use. In 1984 there were two pellet plants operating in the Pacific Northwest of the US. The majority of pellet plants are owned by small companies established specifically for that purpose. However, recently many large facilities have come online in response to rising demand in Europe, which has emerged as a key export destination for Canadian and American made pellets. The raw material used is commonly sawdust.

2.3 Energy situation in Zimbabwe

Power shortages are a common feature in Zimbabwe, negatively impacting on business and household needs. The current power supply in the country is inadequate, leading to load shedding in all sectors. This means that there is need for developing the local power industry, creating partnerships and building local capacities as key to resolving the problem. Such can be achieved if we increase the amount of energy we consume from renewable energy sources such as solar and biomass. The potential of renewable sources of energy such as biomass energy have not been fully realized in Zimbabwe. Improved use of renewable sources of energy and the local manufacturing of energy technologies by the private sector in Zimbabwe has the potential to create many green jobs and reduce poverty. The energy crisis can create investment opportunity in Zimbabwe.

The energy crisis in Zimbabwe affects many industries even many institutions like schools and hospitals. The load shedding is affecting the nation at large. In rural areas people are using fire wood for cooking and heating which increase the rate of deforestation. In town people are also using fire wood because of load shading.

2.4 Pellet Machine in Zimbabwe

In Zimbabwe so far the researcher doesn't know any other company which is producing wood pellet machine we only have pellet machine which are used to make feed stock.

2.5 Components of pellet making machine

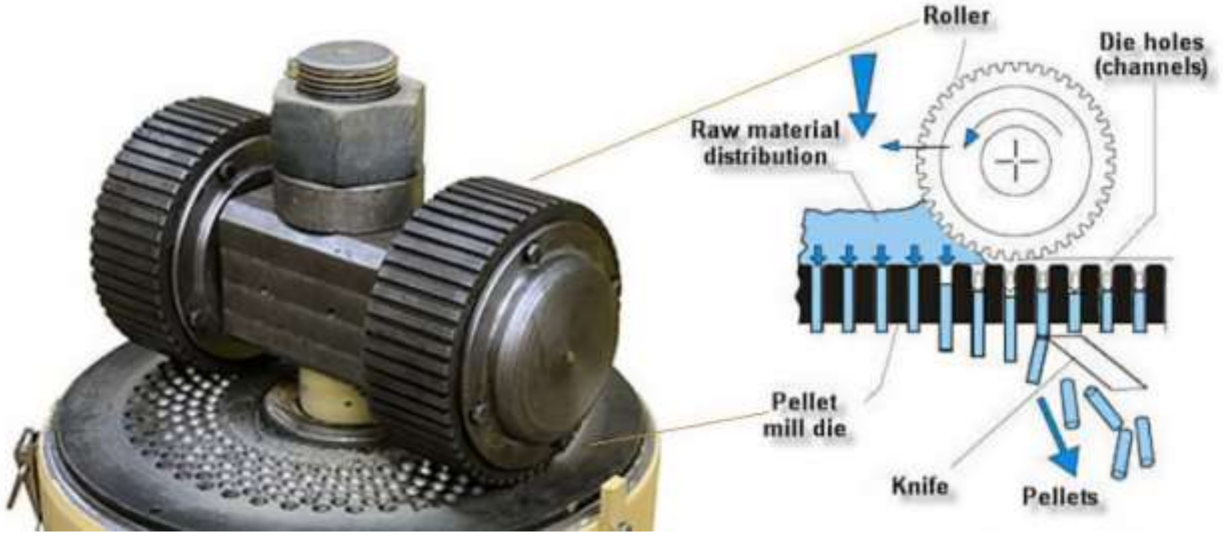

Figure 2. 1 Components of a pellet making machine

- Flate die is the core part for making pellets. It is pitted with many holes; whose diameter is from 2.5 mm to 10mm. It is made up of still alloy. When raw materials are fed into pellet making machine, they are pressed into these holes by roller, where they get formed into pellets. The depth and width of die holes depends on its purpose and raw materials. Formed biomass pellets come out through the holes like bullets, then a slicer cut them into certain length. Our flat die is made of superior alloy steel, which ensures long working time for users. The working duration of flat die is 800 hours. What's more, we've carried out a number of experiments to achieve the best compress ratio for over 30 kinds of materials. We can provide customized design according to your requirement.

- Gearbox the gearbox in TICO small pellet making machine adopts two-step gear transmission. Gears are made of superior alloy steel, whose surface is processed by the gearbox features stable transmission, low noise, high bearing capacity, low temperature and long service life.

Roler : The roller, flat die, main shaft and roller shaft have been processed by vacuum heat treatment, which improves their wear resistance, hardness, and life-span .The roller has large diameter, which allows higher production and forming rate. What's more, it helps produce uniform and high-hardness pellets. The working time of TICO roller lasts 1000 hours.
Bearing: The bearings in TICO pellet making machine are made of superior alloy steel. They are covered by full-sealed shell, which effectively prevent dusts from getting in, so as to improve the working condition of bearing, and prolong its working life. Main shaft adopts carburizing steel, with high wear-resistance. Its loading capacity is twice the former level.
Bevel gear drive: Bevel gear drive has higher transmission efficiency than belt and worm drive, as well as longer working time. Besides, without belt slippery, it features higher precision than belt drive (Javier & Jesús , 2019)

2.6 Biomass

Biomass is the energy derived from plants and animal waste. It contains chemical energy and this energy originates from sunlight through photosynthesis. This stored energy can be used in different ways like combustion, biochemical or thermal chemical process (Agbor et al., 2011; McKendry, 2002). The conversion of bio mass into (bio gas, bio fuel or heat) depend on end use purpose, for example converting biomass into bio fuel such as ethanol and butanol can be used motor vehicle fuels.

Bio mass is non-renewable source of energy it cannot be used up but can be constantly regenerated over time. Plants and animals are continuously growing on earth so biomass is also derived from them such as dead plants, animals, organic waste and agricultural crops. Bio mass can be alternative to fossil fuel. But the carbon emission on harnessing them is the same. One advantage of bio mass is that it does not add carbon dioxide to the atmosphere while fossil fuel does. Carbon dioxide produced buy bio mass is absorbed by plants during photosynthesis but the carbon dioxide from fossil fuel is trapped into the atmosphere and hence increasing the concentration of carbon dioxide leading to more heat trapping due to the warming of the atmosphere leading to global warming which pave a way to climate change. This makes bio mass more superior than conventional energy from environmental perspective.

Biomass accounts for about 1.5% of the energy used in the United States (U.S. Energy Information Administration, 2016) and around 10% (50 EJ) of world total primary energy supply today (International Energy Agency, 2017). Interest in biomass energy is increasing due to the increasing world energy demand, diminishing conventional energy sources, and increasing environmental problems. Biomass is readily available around the world and can help reduce the dependence on conventional energy since their major problem is pollution leading to global warming and climate change. Biomass is classified base on type (like vegetation and ecology) of biomass available in nature or on their applications. Broadly biomass can be classified as the following categories

2.6.1 Dedicated energy crops

These crops are planted explicitly for the purpose of using them as an energy feedstock's. They are planted on marginal lands where other food crops are not suitable. They can be further classified as herbaceous plants or woody biomass. Examples include herbaceous plants like switch grass, miscanthus, sorghum, and woody plants like bamboo, poplar, and willow

2.6.2 Agricultural crop

Corn, sugarcane, soybean and other oilseeds are the most prevalent examples under this category. Corn and sugarcane have been used widely for producing ethanol while soybean is used for producing biodiesel.

2.6.3 Agriculture crop residue

Crop residues are the leftovers of plants from the field production. They include leaves and stalks of the crops. Examples include corn Stover, wheat straw, and rice straw.

2.6.4 Forestry residue

They include the residues from the forest materials such as leaves, smaller branches, bark, and dead trees. A primary product called round wood is more valuable and used for pulp/paper or lumber. It also includes the vast sallmill dust in Manicaland

2.6.2 Aquatic plants

The aquatic plants include varieties of sources that originate in fresh water, ponds, lakes or sea water. Examples include water hyacinth, reeds, and rushes.

2.6.3 Biomass processing residue

Biomass processing residues originate from the wood industry, paper and pulp industry, and food processors. Sawdust from the wood processing plant and apple pomace from apple processing plants are some of the examples. These sources of biomass are generally inexpensive and are a useful on-site energy source, but are not plentiful enough for conversion to other fuels

.

2.6.4 Municipal waste

Municipal waste includes a significant amount of biomass that can be further processed to produce energy. Energy can be produced from wastes either by burning the wastes to generate heat or by decomposing them to get methane gas (Li et al., 2011). This organic matter includes sewage sludge and industrial wastes. Using these wastes as an energy source not only reduces their environmental impact but also the overall cost of such processing plants.

2.6.5 Animal waste

Animal waste can be used to produce energy through biogas process, this is done under anaerobic process.

2.7 Biomass Composition

Biomass is composed of cellulose, hemicellulose, lignin and a small percentage of other proteins and extractives (Khurmi & Gupta, 2005). The percentage of each component varies with different plants. Cellulose is a homogeneous polymer of glucose (a hexose) while hemicelluloses are heterogeneous in nature and are a mixture of 5-carbon and 6-carbon sugars. Cellulose has a fibrous-like structure arranged in bundles called fibrils and hemicellulose is intertwined with cellulose. Lignin acts as a binding material in the cell wall and consists of phenylpropane units (Khurmi & Gupta, 2005). Lignin is particularly resistant to biodegradation and contributes to recalcitrance. Cellulose is of greater importance while it comes to biochemical conversion because it is composed entirely of glucose, which is most readily fermentable to more valuable products. The composition of major lignocellulosic materials are shown in Table 1 (Sun and Cheng, 2002)

Table 2. 1 Composition of some common biomass

Lignocellulosic materials	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Hardwood trees	40-55	25-40	18-25
Softwood trees	45-50	25-35	25-35
Corn cobs	45	35	15
Grasses	25-40	35-50	10-30
Paper	85-99	0	0-15
Wheat straw	30	50	15
Leaves	15-20	80-85	0
Cotton seed hairs	80-95	5-20	0
Newspaper	40-55	25-40	18-30
Waste papers from chemical pulps	60-70	10-20	5-10
Primary wastewater solids	8-15	-	24-29
Solid cattle manure	1.6-4.7	1.4-3.3	2.7-5.7
Coastal Bermuda grass	25	35.7	6.4
Switchgrass	45	31.4	12

2.8 Uses of Biomass

Biomass can be a valuable energy source to fulfil the increasing energy demands and overcome the dependence on traditional fossil fuels. It can be used in the production of fuels like ethanol, butanol, biodiesel or biogas. Ethanol and biodiesel can be blended with gasoline and petroleum diesel in certain ratios without any major modification in the engine parts. Biomass is also used in the production of biogas which can be used for generating heat and electricity. Biomass can also be combusted directly (sometimes in a mixture with coal or other fuels) to generate electricity or for heating purposes. Biomass can also be used to make pellets which can be used for heating purposes especially in rural areas where people are using fire wood in their traditional form.

2.9 Biomass in Zimbabwe

It is approximated that the timber industry is responsible for 50-80%of the waste in Manicaland. The percentage of round wood recovered is only 40-45%, resulting in more waste losses. This waste comprises approximately 10% bark, 5% sawdust, and 45% offcuts and chips (Shonhiwa , 2013). There is actually a lot unquantified waste left from harvesting, pruning or thinning of timber in the form of tree offcuts, lops and tops. Although a part of this waste is taken up by local communities for firewood, they do not always have a ready access to plantations for security reasons' Consequently, both plantation owners and communities cannot keep up with their rate of accumulation. When this waste is left lying on the ground, it can provide abundant fuel for a ground fire that could destroy a large area of the forest. This is an important fact in this nation, where vast tracks of forestry plantations have been lost through fires, most of them caused by acts of arson or inadvertently, by illegal settlers (miners and farmers). There need for large, systematic commercial uptake of the waste. Sawmilling, the largest sector of the timber industry has maintained an upward growth trend, while potential downstream pulp, paper and board industries have either ceased or been on the decline, due to the economic recession. Consequently, the demand for sawmill waste is less than the amount produced, depending on its form. Table 1 shows how various forms of timber waste are utilized, as obtained from the survey.

Table 2. 2 Utilization of various forms of sawmill waste in Manicaland

Form of wood waste	**Current utilization avenues**	**Comments**
Back	Bought by dealers for onward sale to tobacco farmers, who use it as good manure for the tobacco seedbed. Also used for horticulture (flowers).	A lot of bark is now being used given the growth of tobacco and horticultural activities
Shavings	Collected by middlemen or farmers who use it as bedding for poultry and animals.	Demand not so high. Shavings are the second most unutilized form, after sawdust
Offcuts	Most commercial sawmills send these to a chipper to produce chips that are used as boiler fuel	Not all offcuts get to be chipped, in some sawmills. A good fraction is taken up by communities for firewood, furniture, building or fencing.
Chips	All commercial sawmills with kiln driers utilize most of their chips.	Bush sawmills have no kiln driers; therefore, they heap sawmill wastes or burn them
Sawdust	In some commercial sawmills it is mixed with chips for boiler fuel; using sawdust alone would require specialized boiler designs which are still in development.	Still, 20-70% of the sawdust has to be disposed, usually by incineration, along with

some shavings and spilled chips

2.9.1 Evidence of biomass waste in Zimbabwe

Evidently, this is wood waste disposal which are available in Manicaland. This waste may end up causing a major environmental problem and hazard for this region unless there is a large scale utilization of this resource. (Shonhiwa , 2013)

Figure 2. 2 Sawmill waste scenes from Manicaland

2.10 Types of pellet making machines

- Flat and Die Pallet Making machine

Figure 2. 3 Flat and die pellet making machine

It is a kind of new type of pellet making machine that can be produced various kinds of granulated materials. It has the characteristics of simple structure, convenient operation and maintenance, low energy consumption, high efficiency and so on. In general; the flat die pellet machine consists of feeding device, main body, cutting device and electrical control system. the feeding device includes feeding device (which is the feeder), hopper and conveyor belt etc., it is used to put raw materials into the main body through the hopper after they are crushed by

Pros

1. The flat die pellet making machine features compact structure, simple operation and low energy consumption
2. It occupies less space than traditional roll press machines.
3. The noise of this machine is relatively low, which is suitable for use in residential areas.

Cons

1. The flat die mill is less efficient than other pellet mills because it does not have a water jacket around the rotor, which helps keep it cool. This means that you may have trouble getting high quality pellet products from this machine.
2. The flat die pellet mill also has less power than other types of pellet mills, which means that more time will be spent on each piece of wood than with other types of machines.
3. It is difficult to control the size of the pellet and its density. This makes it difficult to produce uniform sized pellets.

- Horizontal Die Pellet Making Machine

Figure 2. 4 Horizontal die pellet making machine

It is mainly used in the production of various kinds of pellets from biomass materials and other organic materials, such as animal feed pellets, seedling pellets, fish pellets and so on. The machine consists of affixed ring die, a moving ring die and a hydraulic system. The fixed ring die is located in the lower part of the machine and has multiple impression dies which are used to compress the biomass materials into pellets. The moving ring die is installed above the fixed one and also has multiple impression dies which can be adjusted according to customer requirements. A hydraulic system is used to derive these two rings to rotate at different speeds in order to squeeze out or extrude out materials from the impression dies by adjusting their relative positions during working process.

Pros

1. It requires less labour because it needs only one operator instead of two like other machines do.
2. It offers more control over particle size distribution.

3. The pellets are more consistent than those produced by other methods.
4. It produces fewer fines than other methods which means that there will be less waste material left over after producing your pellets.

Cons

1. The most notable disadvantage is that the machine is relatively expensive. This means that non-professional pellet makers may not be able to afford the horizontal Ring Die Pellet Making Machine.
2. Another disadvantage is that this machine requires a lot of space in order to function properly. If you don’t have enough room for this machine, then you need to find another place to store it or get rid of it altogether.
3. The last disadvantage of horizontal ring die pellet making machines is that it does not produce very high quality pellet. The quality of these pellets can vary greatly depending on the size of the ring die and how much pressure is applied during the pressing process.

- Vertical Ring Pellet Making Machine

Figure 2. 5Vertical ring pellet making machine

It is also called Vertical Ring Die Pellet Mill, which is a kind of advanced equipment for the pellet making process. The Vertical Ring Die Pellet Making Machine is widely used in the field of industrial pellet making, such as chemical industry, food processing, construction material, medicine and so on. The principle of Vertical Ring Die Pellet Making Machine is to compress the raw materials by ring dies and then extrude them into pellets by continuous extrusion presses has the characteristics of energy saving, high efficiency and low power consumption. The fuel consumption is about ¼ compared with other machines. It is suitable for processing large size raw materials into small size granular materials(pellets). (abc machinery, 2022)

Pros

1. High quality products: The pelletizing ring die can crush all kind of materials into small pieces and it has an excellent surface finish. The finished product will have good quality and on defects.
2. Low energy consumption; compared with other machines, Vertical Ring Die Pellet Making Machine requires less power during operation because it uses low-energy motors or electric motors instead of large-scale engines drive its equipment. This saves energy cost and improves profits for manufacturers.

3. Easy operation: Vertical Ring Pellet Making Machine has simple structure, easy operation and maintenance, which makes it suitable for use at home or in workshops where people don't have much experience in operating heavy equipment like mills and crushers

Cons

1. The main disadvantage of Vertical Ring Die Making Machine is that it is too expensive. The price ranges from $20000 to $60000 depending on the specifications of the machine and its features.
2. Vertical Die Pellet Making Machine is large in size and not portable, they don't have small capacity model, capacity at least 1000kg/h; and the power relatively higher than other smaller machine.
3. It requires large amount of space to operate in, which makes it difficult to install in small areas.

2.11 Pellet Processes

Mechanical densification of biomass is an established process technology that has been on the market for more than a century. The first patented biomass densification process was registered in 1880 by Mr. William Harold Smith in Chicago, Illinois8. It describes a process where saw dust is heated up to 150 °C, put in a strong mold and is compressed using a steam hammer. Biomass densification first became a commercial, large scale process in the second half of the last century, and was used to increase the handling properties of biomass both for energy production and animal feedstock. In North America, wood pellets came into existence in the 1970s with the primary purpose to resolve the energy crisis. They were mainly used by industrial, commercial and institutional sectors for heating. Residential consumers followed in 1983 when the first pellet stoves were introduced to the market. The European markets started later, with Sweden running at the forefront beginning about 1980 and then soon spread all over Europe. This development was initially driven by increasing prices for fossil fuels and good availability of residues from sawmills and pulp and paper industry. Political decisions aiming to reduce carbon dioxide emissions and a general environmental consciousness became important factors too Pelletizing processes consist of multiple steps as shown below.

Figure 2. 6 Pellet process

2.12 Process parameters and modelling

Pellets are produced in a pellet mill that generally consist of die with cylindrical press channel and roller that force the biomass to flow into and through the channels. A die with press channels and rollers are the basic parts of the pellet making machine as show on the figure below.

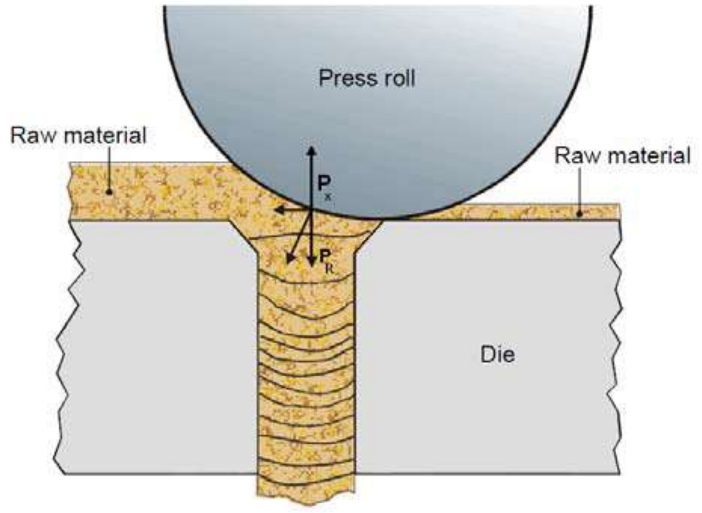

Figure 2. 7 How pellets are forced into the die

The produced pellets depend on the moisture, temperature, particle size and pressure

2.12.1 Moisture content

The moisture content of biomass affects the quality of pellets. The optimum moisture content of pelleting corn Stover was found to be 10% (wt.) (Javier & Jesús , 2019). Moisture content above the optimum level adversely affects the mechanical properties and density of the pellets. Nielsen et al. showed the increase in moisture content reduces the energy requirement for palletisation for pine and beech . (Korkmaz & Büyüksarı, 2019)

2.12.2 Temperature

Heat is generated during palletization due to friction between biomass and the press channels of the pellet mill. ticle Serrano et al. have studied the heat distribution by taking thermo graphic images of a pellet press and found out that the temperature of a die under operation at stable conditions is about 90 °C while the temperature of the biomass is just about 70 °C

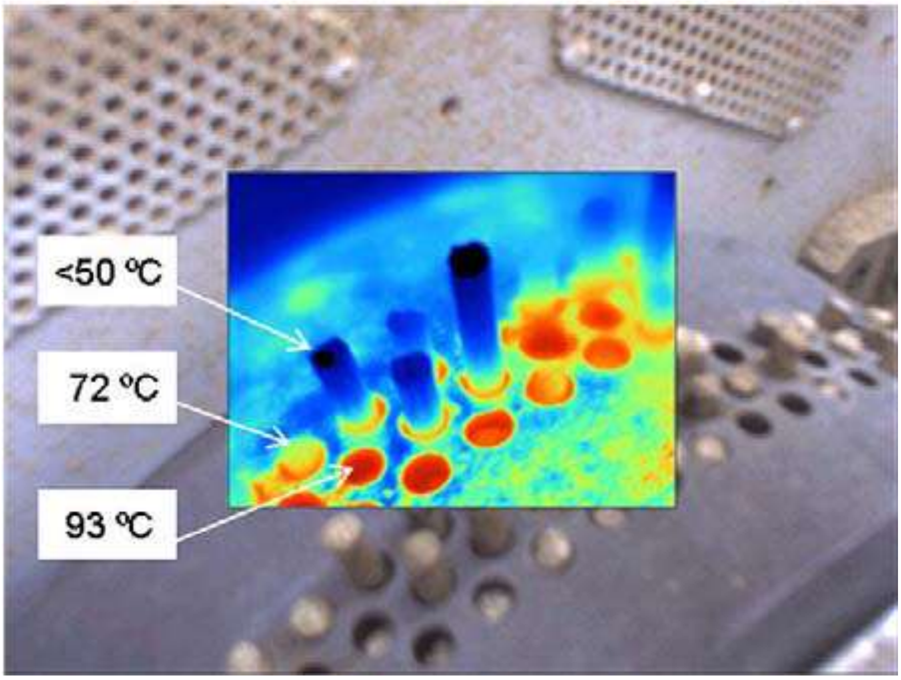

Figure 2. 8 Temperatures for heat generated during palletisation

2.12.3 Particle size

Kaliyan et al. (2010) also found the density of the pellets increased with a decrease in particle size, but Serrano et al. (2011) found just the opposite. The difference in the result is explained to be the use of an industrial pellet mill in the latter one and the laboratory scale single pellet press units in the former (Stelte et al., 2012). A broad variation in particle sizes, in general, is beneficial for good quality pellets. For pellets, particles with a size 0.5 mm diameter should not exceed 10-20% if no external binding agents are used (Stelte et al., 2012).

2.12.4 Pelletizing Pressure

The pressure applied during pelleting also influences pellet density, durability, and energy consumption (Stelte et al., 2012). Several studies have been done in this area (Carone et al., 2011; Gilbert et al., 2009; Kaliyan and Morey, 2010). It was found that the correlation between pressure and pellet density follows the saturation curve in which the maximum limit of pellet density to be equal to that of the plant cell wall of that particular biomass. The compressive strength and durability also increases with increase in pressure up to a certain limit, after which any further increase in pressure didn't give better quality pellets. The excess pressure results in heat production and loss (Stelte et al., 2012) .The effect of biomass constituents on the strength and durability of feed pellets have recently been reviewed by Kaliyan and Morey, who focused on the influence of starch, protein, fiber, fat and extractives on the biomass bonding properties. Although fuel pellets serve a different purpose and vary considerably in composition from pelletized fodder i.e. contain less starch, protein and fat, a lot of valuable information can be found in this study. Starch plasticizes in presence of heat and moisture in a process generally known as gelatinization which significantly increased the pellet durability. Proteins are, like starch, known to plasticize under heat and pressure and have been shown to increase the pellet strength. The fiber content of biomass has to be differentiated into water soluble and insoluble fibers. Soluble fibers generally increase the viscosity of the feed and have a positive effect on the pellet structure while insoluble fibers can entangle with each other. The stiffness and resilience of a fiber can be problematic during palletization. The presence of lipids in pellet feedstock results in a decrease of the pellet's mechanical properties, mainly due to inhibition of bonding properties of the water soluble compounds (hydrogen bonding). Results from those studies indicate the importance of thermal softening and plastic deformation, flow and subsequent hardening of biomass polymers during palletization. In the case of fuel pellets from biomass, it has been shown that high extractives contents lower the friction in the press channel of a pellet mill and that high concentrations of extractives on the biomass particle surface can reduce the mechanical strength of densified biomass products. Additives or binders may be added to improve the pellet's mechanical properties i.e. increase density and strength, improve the pelletizing process (throughput) or improve of moisture resistance. Other reasons for additive addition is to improve the combustion properties i.e. ash melting point, slagging and corrosion.

Many different aspects of biomass palletization have been the subject of mathematical models. There are several different general approaches to model the compression of (biomass) powders and these have been reviewed extensively by Leuenberger and Rohera. Kaliyan and Morey have reviewed that different constitutive and rheological models describing biomass densification processes and proposed a constitutive model for the densification of corn Stover. Their model is characterized the biomass thermos mechanical properties through five models parameters (elastic modulus, strength coefficient, strain hardening exponent, viscous coefficient and frictional loss factor). The models are affected by pressure, particle size, moisture content and temperature. Holm et al have developed a pellet production model.

$$P_x(x) = {}^{P_{NO}}\!/\!_{\nu_{LR}} \left(e^{2\mu\nu_{LR} x/r} - 1\right) \text{ (Khurmi \& Gupta, 2005)} \qquad (2.1)$$

	symbol	meaning	unit
where	P_{NO}	pressure	N
	ν_{LR}	Poisson's ratio	– –
	r	press channel radius	mm
	x	length of the die channel:	mm

However, Equation (2.1) contains three variable prameters (P_{NO}, μ) and ν_{LR} having only one equation, it is not possible to fit all parameters in a single step because of mutual correlations. Futhermore, values for μ and ν_{LR} are not available in the literature for all types of biomass and not available for temperature and moisture contents either. The material specific parameter P_{NO} can only be determined experimentally.

2.13 In the pelleting machine

The feed comes in through the hopper where it is conveyed forward by the worm screw. The worm screw is situated inside the conditioning chamber where mixing into uniform malt is achieved. Friction between the sawdust particles in the conditioning chamber produces heat which then starts to activate lignin, a natural binder found in sawdust. By the time the feed reaches the pelleting chamber it is well mixed which makes the pelleting process whole lot easier. The grinding of the rollers against the flat die generates heat which further activates lignin which holds the pellets in a compact form thus reducing fines.

2.14 In the Flat die-roller setup

The rollers are coupled to a roller frame with four arms and the frame itself is coupled to the rotating shaft. As the shaft rotates the rollers rotates in the same direction pressing and compacting the feed into the die holes thereby producing pellets. The rollers and the die are considered to be circular frictional plates. The die is considered to be a plain circular plate whilst the rollers are toothed circular plates. Rollers rotate inside scrapers whose job is to scrap off extra feed sticking on the rollers. If the feed is not scrapped it causes slipping on the roller-die contact.

2.15 The pellet machine drive

The pelleting chamber is powered by a 25kW electric motor mounted on base of the machine. From the electric motor transmission is through V belts with a velocity ratio of 2:1 to the bevel gear connection. The bevel gears are meeting at a right angle and the power is transmitted with a velocity ratio of 3:1.

2.16 The throughput capacity

$$T_{pc} = W_R / t \qquad (2.2)$$

where

Symbol	meaning	unit
W_R	recovered weight	kg
t	time	s

2.17 The machine efficiency (ε)

$$\varepsilon = W_R / W_F \qquad (2.3)$$

where

symbol	meaning	unit
W_R	recovered weight	N
W_F	Weight of feed fed	N

2.18 Pelletizing efficiency

$$\eta = W_P / W_R \qquad (2.4)$$

Where

symbol	Meaning	Unit
W_P	weight of the pelletized sample.	N
W_R	recovered weight	N

2.19 Throughput capacity

The throughput is the rate at which the feed sample fed into the machine is been recovered. This was obtained using equation (2.2). In this work, 3 kg of the homogenous feed mixture was fed into the machine and 2.2 kg of the feed was recovered at a time interval of 8 min. This gave a throughput capacity of 0.275 kg/min, which is approximately 17 kg/h.

2.20 Machine efficiency

The machine efficiency is the ratio of the weight of the feed sample fed into the machine to the weight of the feed sample recovered after the pelletizing process. This was calculated using equation (2.3), which gave a machine efficiency of 73.33%. Hence the percentage loss in the pelletizing process is 26.67%. This loss is significant as a result of the clearance between the tip of the screw and the barrel.

2.21 Conclusion

This literature review outlines the historical background of pellet making machine in Zimbabwe and in the whole world. It also talks about the situation of energy in Zimbabwe. This chapter also describe the components of a pellet making machine as well as the biomass which is used to make pellets. This chapter talks about the condition needed to process pellet using pellet making machines. It also reveals the components of biomass and the biomass composition. Later on it talks about types of pellet making machines and lastly it reveals the pellet processes and gives the equation for through put, efficient of the machine and pelleting and pellet production model.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

In this chapter the researcher is going to give us steps on how he is going to design a model for a wood pellet machine.

3.2 Components Description

The researcher is going to use his literature to design the wood pellet making machine. The important components of a pelletizer are the hopper where powdered biomass is fed into the machine, the pellet chamber in the form of screw shafty which propel the powder biomass. The shaft is operated by pulley and the belt system that is powered by an electric motor. The output pellet was produce by compacting and forcing through a die opening via a mechanical process.

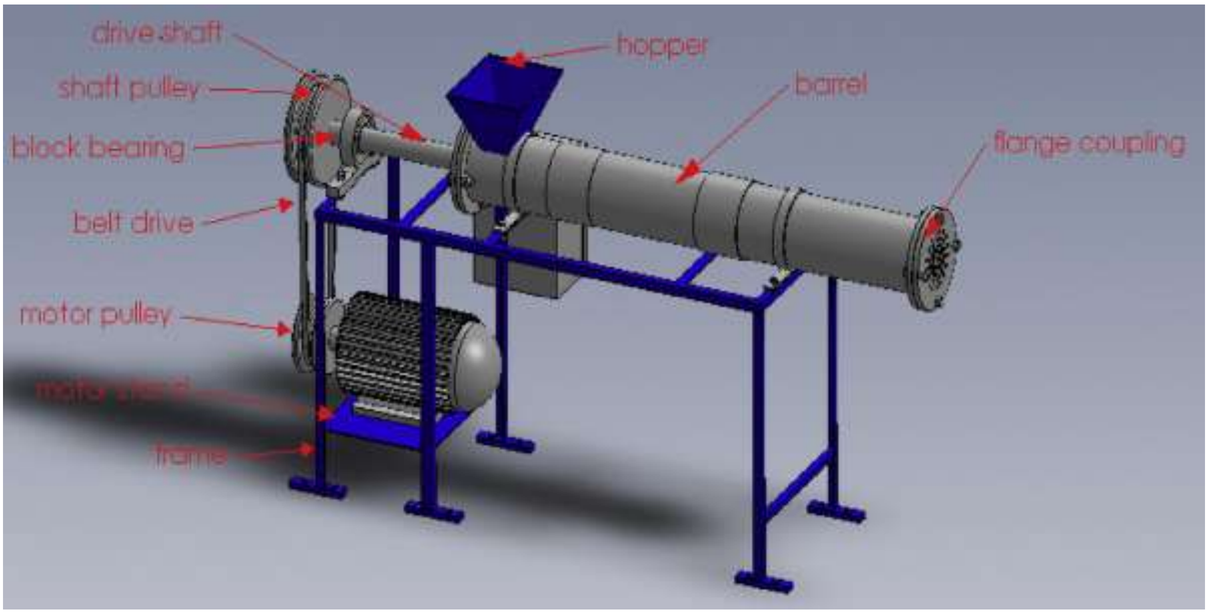

Figure 3. 1 Model for a wood pellet making machine

3.3 Machine design

3.3.1 Hopper design

The shape of the hopper is in the form of a truncated pyramid with an inclination angle of 60_ to enable conveying and storage of raw materials.

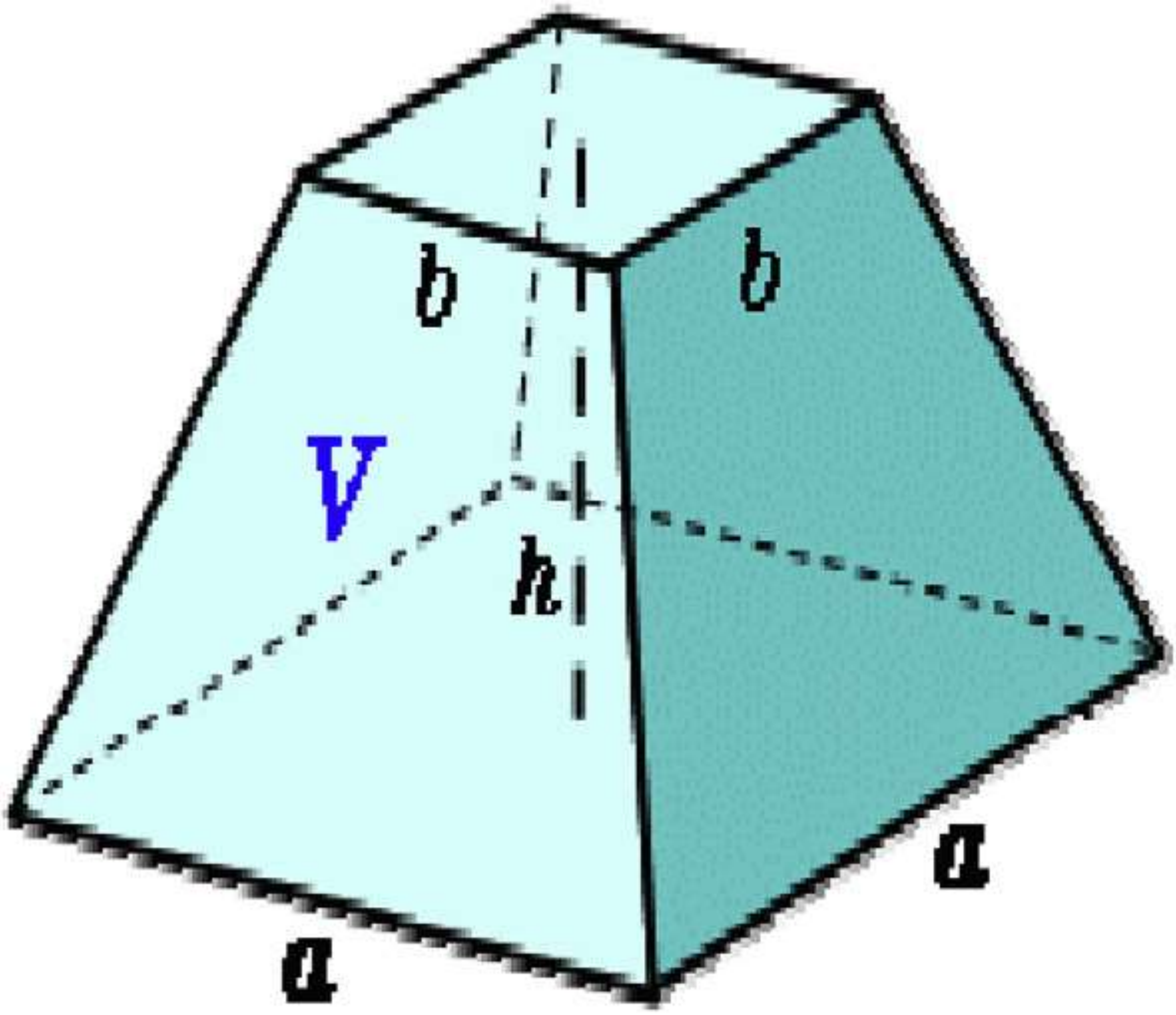

Figure 3. 2 the hopper

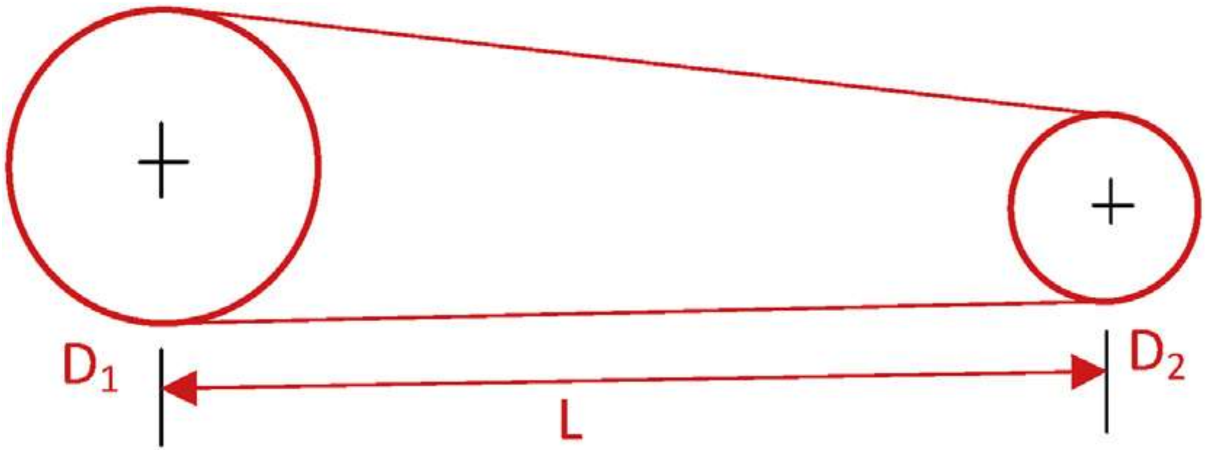

Figure 3. 3 Schematic diagram for belt and pulley design

Volume of the hopper =

$$(x^2 + y^2 + xy)\frac{h}{3} \text{ (Korkmaz \& Büyüksarı, 2019)} \qquad (3.1)$$

where

symbol	meaning	unit
x	length	mm
y	width	mm
h	height	mm

The mass flow through the hopper is =

$$p^o A\sqrt{\frac{Bg}{2(1+M)\tan\vartheta}} \text{ (Korkmaz \& Büyüksarı, 2019)} \qquad (3.2)$$

where

symbol	meaning	unit
p^o	bulk density of the material	kgm^{-3}
A	surface area of hopper	m^2
ϑ	hopper angle	°C
M	mass	kg
g	acceleration	ms^{-2}
B	symmetrical slot hopper	m

By using equation (3.1)

The Volume of the hopper: Where y= 150mm; x=450mm; h =350mm therefore;

$V=150^2 + 450^2 + (150+450)\frac{350}{3} = 34125000mm^3 = 0.0341m^3$

Surface area of hopper = $0.45\times0.45 = 0.2025m^2$

ϑ = hopper angle g = acceleration due to gravity=9.807 ms^{-2}

m = 0 (symmetrical slot hopper) B = w = 0.45m

Then by equation (3.2)

Therefore mass flow through the hopper $=1300X0,2025\sqrt{\frac{0.45x9.807}{2\tan 45}}$

$306{:}99996 kgs^{-1}$

3.3.2 Capacity design for a given electric motor

The design for motor output power allows appropriate selection of a motor with enough power to start and run the machine at full load.

$$P = F \times V \tag{3.3}$$

	Symbol	Meaning	Unit
Where	P	Power	W
	F	Rotational force acting on the shaft in Newton	N
	V	linear velocity of the shaft	m/s

But

$$F = ma \tag{3.4}$$

	Symbol	meaning	Unit
Where	m	mass of rotating shaft in kilogram	kg
	a	angular acceleration of the motor	$rads^{-2}$

$$a = \omega^2 r \tag{3.5}$$

	symbol	meaning	unit
where	ω	angular velocity of the motor in	$Rads^{-1}$
	r	radius of the motor disc	m

But

$$v = \omega r \tag{3.6}$$

By putting (3.3) in (3.2)

$$F = m\omega^2 r \tag{3.7}$$

By putting (3.5) in (3.10)

$$P = m\omega^2 r \times \omega r$$

$$P = m\omega^3 r^2 \tag{3.8}$$

But

$$\omega = {}^{2\pi N}\!/_{60} \tag{3.9}$$

so

$$P = 8m({}^{\pi N}\!/_{60})r^2 \tag{3.10}$$

	symbol	meaning	unit
where	m	mass	kg

N	Rotational speed of the shaft	rpm
r	radius	mm

3.3.3 Determination of screw conveyor diameter and power to drive conveyor

The diameter and power of the screw conveyor required for conveying material at a rate of 20 kg/h for the capacity of a continuous screw conveyors were calculated from

$$D^2 = 4Y/60\pi(Sn\psi pc) \quad \text{(Khurmi \& Gupta, 2005)} \qquad (3.11)$$

	symbol	meaning	unit
where	Y	capacity of screw conveyor	
	S	screw pitch	
	n	speed of convey	$Rads^{-1}$

$$Pr = QL(\omega_o + \sin\beta)/367 \quad \text{(Stelte W*, 2011)} \qquad (3.12)$$

	symbol	Meaning	Unit
where	L	Length of the conveyor	mm
	ω_o	Slow flowing abrasive material	– –
	Q	Capacity of screw	kg/hr
	β	Inclination angle of conveyor	°C

S = 0.8D; ϑ = 0.125 and c =1 for inclination angle β = 0:

The recommended minimum and maximum speed of conveyor are 200–490 rpm (Spivakovsky and Dyachkov, 1967)

$D^3 = 4x\,20/60\,x3.142x0.8x0.125x475x785$

$D = 0.105 = 105mm$

From equation (3.12)

$Pr = 9x20(4+0)/367$

$Pr = 1.96kw$

3.3.4 Length of screw

This is determined from the length to diameter ratio (L_S: D) of the screw. It is the ratio of the flight length of the screw to the original diameter. A ratio of 13:1 was selected for portability. This means that the flight length of the screw is 13D (where D= original diameter of the screw). The feed section, transition section and the metering section are in the ratios of 4D: 4D: 5D respectively.

3.3.5 The pitch screw

$$S = \pi x D x \tan\delta \quad \text{(Khurmi \& Gupta, 2005)} \qquad (3.13)$$

	symbol	meaning	Unit
where	D	Diameter of screw	mm
	δ	flight angle	℃

Feed section length $(Fl) = 4D = 4 \text{ x}105 = 420mm$

Feed section depth $(Fd) = 0.2D = 105x0.2 = 21mm$

Transition section length $(Tl) = 4D = 4x105 = 420mm$

Metering section length $(Ml) = 5D = 5x105 = 525mm$

Metering section depth $(Md) = 0.33Fd = 0.33x21 = 6.93mm$

For standard screw profile, the angle the flight makes with a line perpendicular to the shaft

(Flight angle)is 17.6568^0.

Flight width (screw thickness) $= 0.1D = 10.5mm$

Screw barrel clearance $= 0.17D = 17.85mm$

3.3.6 Design of drive system (Belt and pulley design)

The machine runs with a 1400 rpm motor which will produce a speed reduction of 70 rpm. This reduces the speed of the motor via a V – belt before it enters the shaft. The smaller pulley is adapted at the motor and connected to the bigger pulley on the shaft of the screw via a belt drive. The bigger pulley welded to the shaft of the screw which passes through two pillow bearing.

3.3.7 Determination of pulley diameter

The speed of driving pulley versus speed of driven pulley can be expressed in this form

$$D_1N_1 = D_2N_2 \text{ (Khurmi \& Gupta, 2005)} \qquad (3.14)$$

	Symbol	meaning	unit
where	D_1	diameter	mm
	N_1	speed of driving pulley	rpm
	D_2	diameter	mm
	N_2	speed of driving pulley	rpm

In other to get a speed of 112 rpm on the drive shaft using an electric motor of 1400 rpm, the diameter of the driven pulley is calculated thus using a pulley of 40 mm diameter for the driver.

$1400rpm \text{ x } 40mm = 112rpm \text{ x } D_2$

$D_2 = 1400 \text{ x } 40 = 70$

$D_2 = 500mm$

Therefore, for a driving pulley of 40 mm diameter, the driven pulley diameter was calculated from the above as 500 mm.

3.3.8 Determination of belt length

$$L = 2C + (D_2 - D_1 / 4C) + 1.57(D_2 + D_1) \text{ (Javier \& Jesús , 2019)} \qquad (3.15)$$

	symbol	meaning	unit
where	D	Pitch diameter	mm
	C	Center distance between shaft	mm

With known pitch diameters of pulleys $D_2 = 500$ mm , $D_1 = 40$ mm and center distance between motor/shaft pulley, $C = 340$ mm .The length of belt required is calculated using the equation(3.15).

$L = 2(340\ ) + [500 - 40 / 4x340] + 1.57(500 + 40)$

$L = 2027.77mm$

3.3.9 Determination of tension in the belt

Tension T_1 acting on the tight side of the belt and the tension T_2 acting on the slack side of the belt. The values of T_1 and T_2 are calculated using the

$$\frac{T_1 - mv^2}{T_2 - mv^2} = e^{\left(f\Phi / \sin 5.0\theta\right)} \quad \text{(Korkmaz \& Büyüksarı, 2019)} \qquad (3.16)$$

	symbol	meaning	unit
where	m	mass of a unit h of the belt	kg
	v	Linear velocity of belt	ms^{-1}
	ϕ	Angle of wrap on pulley	rad
	T_1	Tension in the tight side of belt	N
	T_2	Tension in the tight side of belt	N
	θ	Groove angle for $v-$ belt	°C

The maximum tension in the tight side of the belt depends on the allowable stress of the material. For a B section belt the following parameters are given

T_1 =allowable tension = 900 N

$\theta = 38 \pm 0.50P,\ f = 0.2$

The linear velocity is given by equation (3.17)

$V = 3.142 \text{ x } 0.04 \text{ x } 1400/60$

$V = 2.93ms^{-1}$

For small pulley

$\phi = \phi_1 = 161.7^0 (2.82 \text{ rad}) \text{using} \theta = 38.5^0 (0.672 \text{ rad})$

The small pulley with the highest value of 5.54 will be used as a basis for the design. Substituting the value of $T_1 = 900$ N , $m = 0.19$ and V into the equation(3.16). The tension T_2 on the slack side can be calculated as:

$900 - 0.19(2.93)^2 / T_2 - 0.19(2.93)^2 = 5.54$

$T_2 = (898.4 + 9.03)/5.54$

$T_2 = 163.8N$

The linear velocity

Is given by =

$$v = \pi DN/60 \qquad (3.17)$$

	symbol	Meaning	Unit
where	D	Diameter	mm
	N	Number of revolution per hour	N/hr

3.3.10 Design of the barrel

The barrel is designed to withstand a high temperature up to 400 ℃and to be a very good conductor of heat. The barrel is made of stainless steel which has a melting point of 1515 ℃ and a thermal conductivity of 50.2 W/m

Volume of the barrel = volume of cylinder =

$$\pi r^2 h \qquad (3.18)$$

The volume is calculated from equation (3.18)

V= $(114mm)^2$ x 3.142 x 860mm

V= $35116751.52mm^3$

3.3.11 Design of the frame

The base is designed to withstand the torque generated by the electric motor. The torque generated is calculated:

Torque =

$$9.549P/N \qquad \text{(Khurmi \& Gupta, 2005)} \qquad (3.19)$$

	symbol	meaning	unit
where	P	electric motor horse powers	W
	N	number of revolutions	

It is from the equation (3.19)

kg Torque $= 9.549x2/1400 = 0.00670Nm$

3.4 Machine designing parameters

A lot of parameters were considered during the designing of the machine.

Table 3. 1 The table showing list of input and output parameters.

Input parameters			Output parameters		
parameters	symbol	unit	parameters	symbol	unit
Acceleration due to gravity	G	ms^{-2}	Angular velocity of the motor	Ω	rad
Angle of warap	Α	rad	Screw barrel clearance	Sbc	Mm
Bulk density	p^{o}	kg/m^3	Angular acceleration of the motor	Α	rad/s^2
Capacity of screw	Q	kg / hr	Rotational force acting on the shaft	F	N
Coeffient of friction between the belt and the pulley	Μ	– –	Feed section length	Fl	Mm
Convey speed	N	rmp	Length of belt	L	Mm
Diameter of driven pulley	D_2	mm	Power required to drive the conveyor	Pr	kw
Diameter of driving pulley	D_1	mm	Flight width	Fw	Mm
Flight angle	Δ	℃	Metering section depth	Md	Mm
Groove angle	θ	℃	Feed section depth	Fd	Mm
Hopper angel	β	℃	Volume of hopper	V	m^3
Hopper height	H	mm	Tension on the tight and slack side of the belt	T_1 and T_2	N
Hopper inlet width	A	mm	Mass flow rate	M	kg / s
Hopper outlet width	B	mm	Power of the electric motor screw length	P	kw
Loading factor	C	– –	Screw diameter	D	Mm
Radius of the shaft	R	mm	Screw pitch	S	Mm
Rotational speed of shaft	N	rpm	Transition section length	Tl	Mm

Speed of the electric motor	N_1	rpm	Screw length	L_s	Mm
Speed of driven pulley	N_2	rpm	Metering section length	Ml	Mm

3.5 Summary

This chapter outlined the research methodology used to design the model. It gives a detailed equations needed to design the model. In the next chapter, the results will be presented and analyzed.

Chapter 4 Data representation and analysis

4.1 Introduction

In this chapter the researcher is going to analyse and then give a detailed discussion of the findings of the study. The purpose of the study is to design and simulate the performance of a wood pellet machine. The data is presented and analysed as per the objectives of the research. The researcher will add a short paragraph and analysing the presented data after table. The data will be presented in graphs and tables.

4.2 Results for calculated components of the model

4.2.1 Hopper design

dimension	Value	units
Volume	0.0341	m^3
Surface area of hopper	0.2025	m^2
mass flow	306.99996	Kgs^{-1}

4.2.2 Determination of screw conveyor diameter and power to drive conveyor

dimension	value	unit
inclination angle	0	℃
diameter	0.105	mm
power	1.9	kw

4.2.3 Length of screw

dimension	value	unit
Feed section length	420	mm
Feed section depth	21	mm
Transition section length	420	mm
Metering section length	525	mm
Metering section depth	6.92	mm
Flight angle	17.6568	℃
Flight width	10.5	mm
Screw barrel	17.85	mm

4.2.4 Calculation of the pulley diameter

dimension	value	unit
diameter	500	mm

4.2.5 Calculation of the belt length

dimension	value	unit
length	20277.77	mm

4.2.6 Calculation of the tension in the belt

dimension	value	unit
tension	900	N
linear velocity	2.93	ms^{-1}

4.2.7 Design of the barrel

dimension	value	unit

volume	35116751.52	mm^3

4.2.8 Design of the frame

Dimension	Value	Unit
torque	0.00670	Nm

4.3 The full pelleting machine

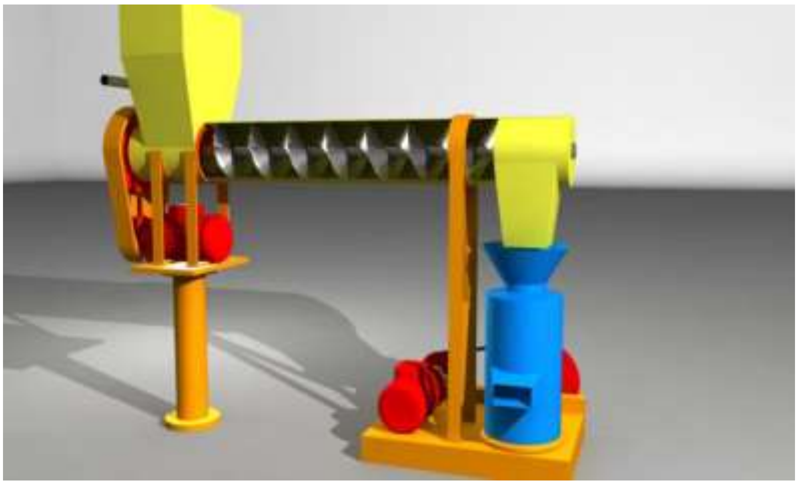

Figure 4. 1 The full pelleting machine

4.4 Flat die-roller setup

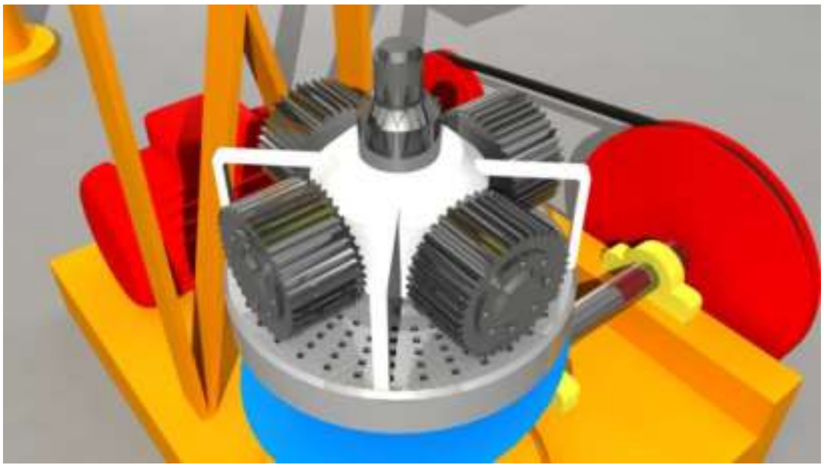

Figure 4. 2 Flat die-roller setup

4.5 the pellet machine drive

Figure 4. 3 The pellet machine drive

4.6 Performance tests and asimilation

A series of test was carried out to determine the throughput capacity, machine efficiency, pelletizing efficiency and dryness of the feed. The homogeneous feed was weighed and fed into the pelletizer to obtain the dry pelletized feed. The time taken for complete pelletizing was taken, the pelletized sample was weighed, and the dry feed was collected for the test. The throughput capacity, machine efficiency, and pelletizing efficiency was calculated using.

4.6.1 Procedure to obtain wood pellets

The procedure was the following around 250g of wood waste was fed through the hopper (1kg in total, so that the thickness of the sample on hopper was less than 1cm. several test was made with different drying air velocities (v = 0.8, 1.2, and 1.6ms^{-1}) and temperature (T = 30, 40 and 50 ℃)

4.7 Results and discussions

4.7.1 Pelletizing efficiency

The pelletizing efficiency was obtained using equation (2.4). This was used to determine the effectiveness of the machine in producing the pellets. The ratio of the weight of the pellets to the weight of the recovered feed gives the pelletizing efficiency. The weight of the pellets (W_P) was determined by weighing the pellets, which was manually separated from the recovered feed. The separated pellets weighed 2.0 kg. Hence the separating efficiency was obtained to be 90.90%. However, the mechanical damage obtained was 9.10% which arose from poor kneading as the feed conveys along the barrel.

Table 4. 1 Average dimension of mass, density of samples of pellets produced by wood pellet machine.

		Average length (mm)	***Average Diameter (mm)***	***Mass of 10 samples (g)***	***Average mass (g)***	***Average density (g/cm3)***	***Length to diameter ratio***
Wood Pellets With	*500 cm3 of starch*	24.935	6.604	6.70	0.670	0.78	3.8
	750 cm3 of starch	16.580	6.435	5.10	0.510	0.95	2.6
	1000 cm3 of starch	12.485	5.715	4.95	0.495	1.55	2.2
	500 cm3 of water	23.200	6.105	4.40	0.440	0.65	3.8
	750 cm3 of water	17.105	6.440	3.85	0.385	0.69	2.7
	1000 cm3 of water			No pellets formed			

Table 4. 2 Energy used during pelletizing process

Assay	**M_R(kgh^{-1})**	**M(%wb)**	**M_p(kgh^{-1})**	**EF(%)**	**E_p(kWh)**	**e_p(kWkg^{-1})**
1	28.58	18.26	26.80	94	5.06	0.19
2	29.62	21.11	26.60	90	5.80	0.22
3	36.10	19.94	33.40	93	5.26	0.16
4	41.80	15.85	39.60	95	6.34	0.16
5	42.41	17.06	40.40	95	6.37	0.16
6	49.85	15.65	44.76	90	6.82	0.15
7	58.82	15.49	56.20	96	7.00	0.12

4.7.2 The yield stress of confined sawdust

Table 4. 3 Data corresponding to the yield stress of confined sawdust and the main stress

Yield stress	Main stress
5	2
10	3
20	4
44	12
100	8
140	30

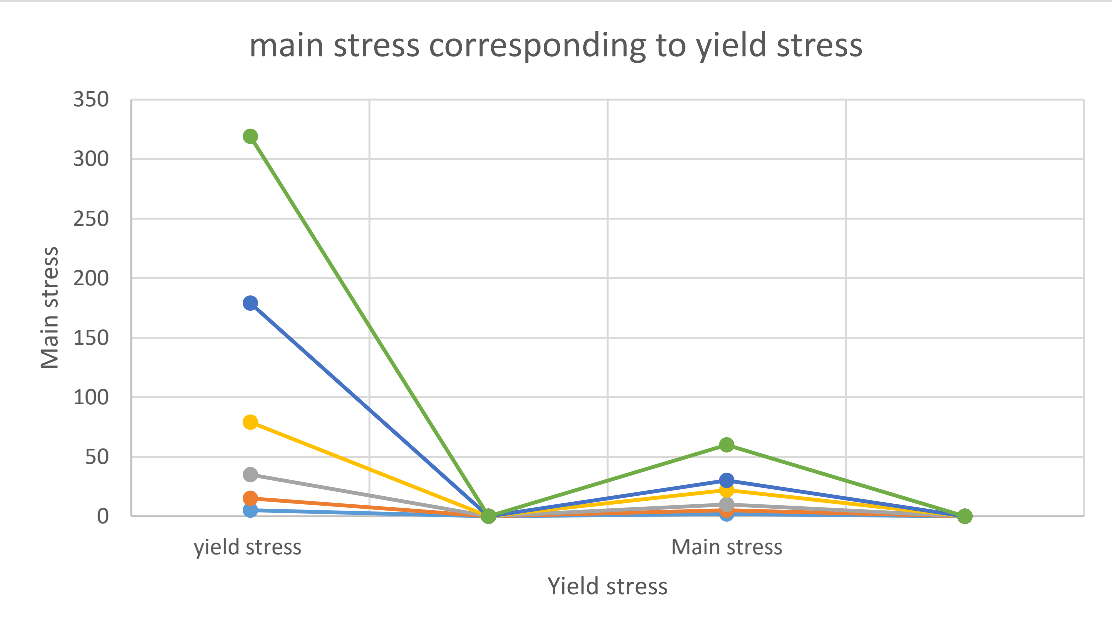

Figure 4. 4 The yield stress of confined sawdust and the main stress

4.8 The results properties of pellets from different biomass types

A study on the physical properties of peanut hull pellets and found that pellets durability increased initially with moisture content, reached a maximum value of 90.3% at 9.1% moisture and decreased as the moisture content increased beyond 9.1% (Fasina, 2008). Among other variations, Miranda et. al. studied the influence of moisture content (M) and bulk density (BD) on the durability (DU) of pellets obtained from 10 types of biomass: pyrenean oak (PO), pyrenean sylvestris (PS), cork powder (CP), pine sawdust (SW), vine shoots (VS), olive branches (OB), barley straw (BS), wheat straw (WS), olive pomace (OP) and grapepomace (GP) (Mohd, et al., 2022)

Table 4. 4 Durability and moisture

Property	PO	PS	CP	SW	VS	OB	BS	WS	OP	GP
M(%)	6	10	8	9	11	7	7	9	7	7
BD(kg/m3)	95	97	97	98	99	98	96	94	91	86

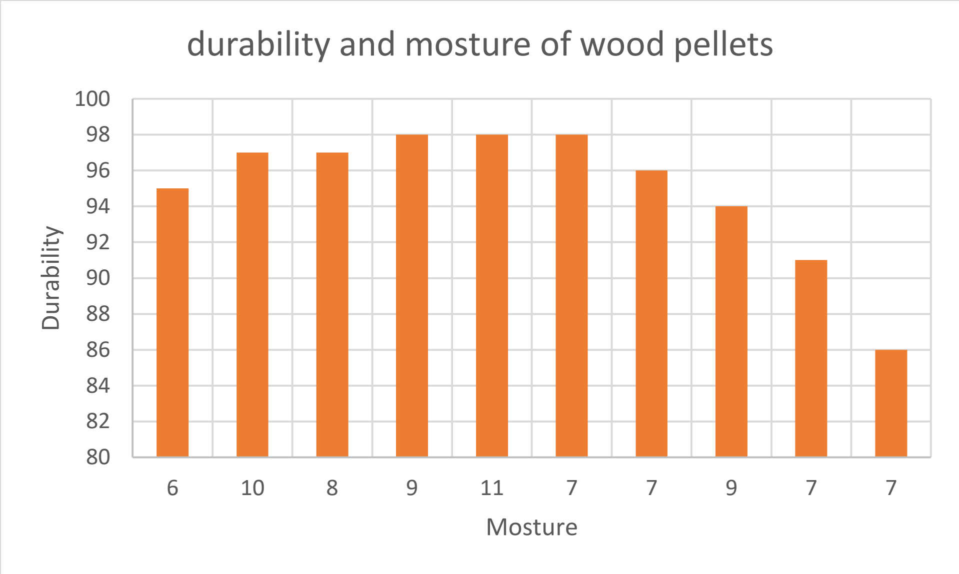

Figure 4. 5 Durability and moisture

Table 4. 5 Durability and bulk density

BD(kg/m^3	678	675	697	650	700	582	644	620	780	824
DU(%)	95	97	97	98	99	98	96	94	91	86
Property	PO	PS	CP	SW	VS	OB	BS	WS	OP	GP

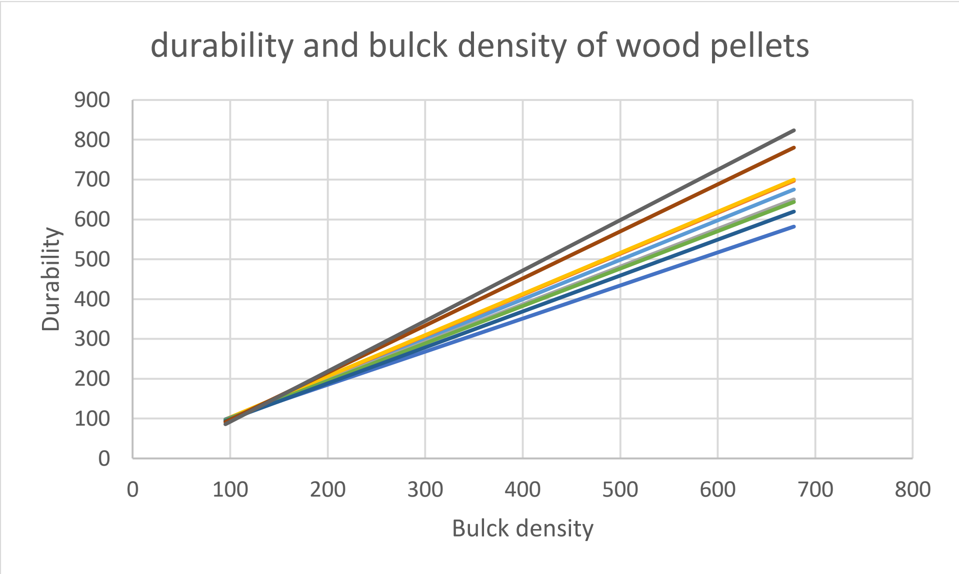

Figure 4. 6 Durability and bulk density

4.9 Feed dryness test

Feed dryness test was conducted by varying the temperature of the heater on the barrel (at a constant time) and the moisture of the feed was determined. Also, at a constant temperature, time is varied to know the effect of it on the feed. The results of the test are shown in table (4.3).

Table 4. 6 Dryness of feed at a varying temperature.

S/N	1	2	3	4	5
Temperature(°C)	125	175	200	250	300
Dryness(%)	55	60	67	80	89

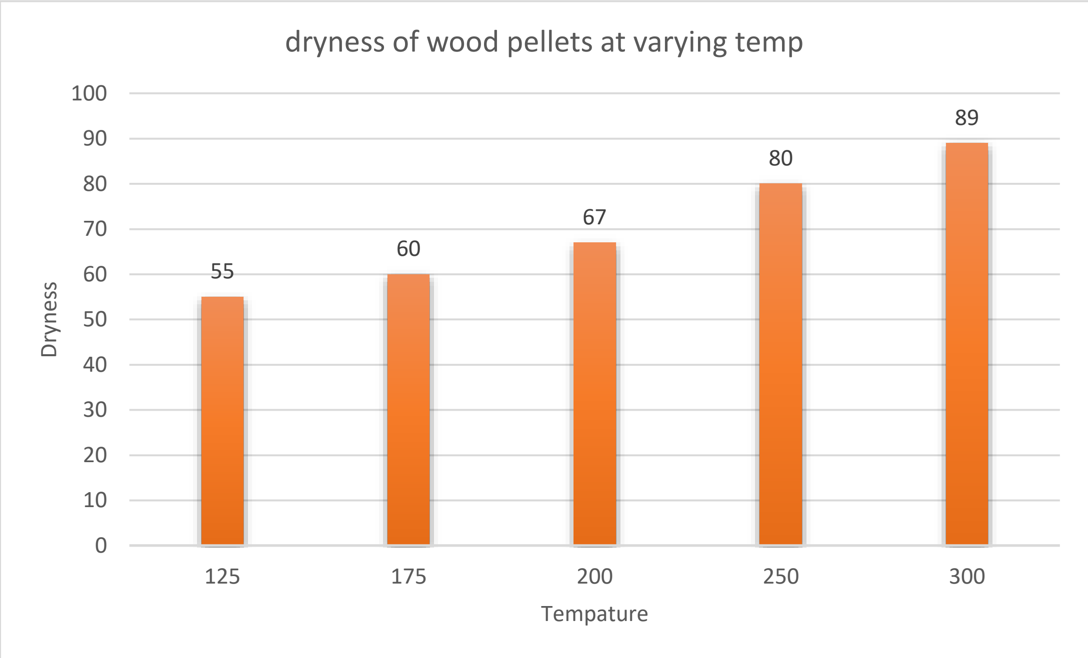

Figure 4. 7 Graph of dryness against temperature.

4.9.1 Dryness of feed at a varying time.

For all the cases with greater speed and higher temperatures of the drying air, shorter drying times were obtained. The effects of increasing air speed were more marked at low temperatures. Thus for T 30°C, drying time were 17% and 48% shorter when compared to the lower flow, however for T 50°C, drying times shortened 8% and 12% as air flow increased. This shows that for high drying temperature, the increase in air speed did not cause any substantial reduction in drying times.

Table 4. 7 Dryness of wood pellets at a varying time.

S/N	1	2	3	4	5
Time (s)	5	15	20	40	55
Dryness(%)	53	57	65	76	81

Figure 4. 8 Graph of dryness against time

4.10 Conclusion

This work successfully designed a pelletizing machine for wood pellets. Effective design and adequate material selection criteria were employed in the course of production of the machine. It was designed to be driven by a 1.5 HP, three phase electric motor. The performance test was carried out to determine the throughput capacity, machine efficiency and pelletizing efficiency which gave a value of 17 kg/h, 73.33% and 90.90% respectively. However, low mechanical damage of 9.10% was obtained. The cylindrical pellets size produced by the pelletizer was in the range of 2–8 mm diameter, depending on the size of die used for the pelletizing. Therefore, the machine is suitable for small and medium scale business.

CHAPTER 5 Conclusion and Recommendation

This chapter focus mainly on research summary, research conclusion that can be deducted from the findings and recommendations for further studies. Research conclusions will be drawn from the performance of the model.

5.1 Summary

This research is focused on designing a model for pellet making machine and simulating the data collected from pellets produced during testing the pellet making machine. Met lab was used to simulate the obtained and the Microsoft Excel was used to perform calculation for the components of the designed model. The research shows that it is economically advantage to have wood pellet making machine since it produces wood pellets which can be used in rural areas as an advanced use of biomass for cooking and heating and it can also be used in place of coal to generate electricity.

5.2 Conclusion

Basing on the calculations made, the production rate, energy consumption and all the calculations for the component of the model and also the simulated data from the collected data produced from the pellets. The results show the model can be made

5.3 Recommendations

Since this research is focused on designing of the wood pellet machine and simulate the data of the produced pellets and also the performance of the machine. Also, the process needs financial and economic analysis to get an insight on the economic and financial performance of the model. This will help the nation to inverts into it.

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