Wolkite University

College of Engineering and Technology

Department of Chemical Engineering

Production of Bio plastics from Corn Starch

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Declaration

We hereby declare that the thesis is based on our original work except for flotations and citations which have been duly acknowledged. We also declare that it has not been previously or currently submitted for any other schools at Wolkite University or other institutions.

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List of Acronyms

- **CSA:** Central Statistics Authority
- **DSC:** Differential scanning calorimeter
- **DNA**: Deoxyribonucleic acid
- **ICI:** Imperial Chemical Industry
- **IPP:** Isotactic polypropylene
- **IC:** Indirect cost
- **^{O}C:** Centigrade
- **L_{MTD}:** Logarithmic mean temperature difference
- **OL**: Operating labour
- **PEC:** Purchased equipment cost
- **PGA:** Polygloycolic
- **PHB:** Poly hydroxy butyrate
- **PHB:** Poly-β-hydroxybutyric acid
- **PLA:** Polylactide
- **PVC:** Polyvinyl chloride
- **SNNPR:** Southern nation nationality people region
- **TCA:** Tricarboxylic acid
- **TPC:** Total production cost
- **UK:** United Kingdom

Abstract

The aim of this study was to produce bio plastic from corn starch. Research samples were collected from Gubrie. The raw material was prepared and starch was extracted by using filter cloth and dried for two hours at 40°C.The experiment were carried out in 250ml. Frist,10gm of extracted starched and 60ml of distilled water were added to 250ml beaker. Then, 5ml of Vinegar and glycerine were added to the solution in all trials except trial number 5 and 6 respectively. Following this, Food colouring was added and stirred and next the solution was heated at 200°C, 200°C, 210°C, 210°C, 200°C, and 200°C for 10,12,10,12,10, &10 minutes respectively. The solution product was allowed to boil and to cool for a minute in all trials and the end product (plastics) was scooped out from the pot and spreaded out on the led plate and allowed to dry. The produced bio plastics were characterized by testing its soil burial biodegradation, water solubility, water absorption percentage and its Mechanical properties (tensile strength). The bio plastics produced in different condition were compared with each other by their character. The bio plastics produced at 200°C and mixed for 12minutes was best all bio plastic were more bio degradable than petro based plastic. Preliminary techno-economic feasibility analysis indicated that production of bio plastic is feasible with payback period 1.4years.

[1] **Keywords**

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[1] Bioplastic, Corn Starch, Vinegar and Glycerin

Chapter One: Introduction

1.1 Background.

Plastics can be classified as a group of artificial or natural organic materials that can be cast and hardened. Plastics are very common and useful nowadays and are used in almost every place such as; in packaging material, in bottles, cell phones, printers, even in pharmaceutical to automobiles industries. The reason why plastics are a useful option because their structures can be chemically treated with somestrength and shape to obtain higher molecular weights, low reactivity and long-lasting substances. In addition, they are durable and cost-effective. Nowadays, people are more aware about the harmful effectsof petrochemical derived plastic materials in the environment. Researchers have conducted many studiesfor managing plastic waste on Earth by finding eco-friendly alternatives to plastics. This eco-friendly alternative is bio plastics. Plastics derived from petroleum are made from synthetic polymers. However, polymer chains are also found in nature. These chains are common in cellulose, lignin, and starch. Cellulose is abundant in all plants, although some plants produce more than others. Lignin is typically found in wood, and starch is common in plants such as corn, potatoes, and wheat. Plants, wood, corn and potatoes are all raw materials that are renewable and readily available. The major difference between synthetic polymers and polymers found in nature is that the natural polymers contain oxygen and nitrogen. The oxygen and nitrogen in the polymer structure permit the polymer to biodegrade. Both corn starch and wood are inexpensive raw materials. At the current rate of production, the need for corn does not compete with the food supply. As production of natural resource polymers increases, there is speculation that the need for corn to make plastic will interfere with the food supply. An advantage of using corn is that because the corn is not directly consumed, waste corn can be used. [5]

Bio-plastics are a type of plastic that is made in whole or in part from polymers which are derived frombiological sources such as sugar cane, potato starch or cellulose from plants, straw and cotton, which when disposed in the environment, will easily degrade through the enzymatic actions of micro-organisms. Bio plastics are based on either bio-based, biodegradable, or both of bio-based and biodegradable properties. Bio-plastics are plastics derived from natural resources or biomass in some content such as sugar cane, corn or potato corn starch, cellulose and are not derived from petroleum resources. They may or may not be biodegradable but recyclable. Biodegradable property is added in bio plastics at the end of a products life. Biodegradation which depends on the chemical structure of the material does not rely on the sources of polymer.

Degradability is the process of disintegration of the polymers into smaller fragments by the action of abiotic factors such as UV radiation, oxygen attack, and biological attack. Most degradable plastics aremade from polyethylene and contain an additive to speed up the decomposition. They have to change significantly in their physical structure which leads to loss of structure properties.

A biodegradable plastic is able to make from renewable resources or fossil fuels. A biodegradable plasticmight be broken into smaller particles through the help of micro-organism activity, such as bacteria andfungi. Biodegradable refers to the biochemical processes in which microorganisms that occur naturallyin the environment, converted polymers into substances such as water, carbon dioxide and biomass. Depending on the composition and thickness of the material, some biodegradable plastics disintegrate quickly, whilst others take longer. [13]

1. 2 Statement of problem

Plastic is found to be the best packaging material because of its excellent long-life properties. Thus, its utilization is increasing every day. However, plastics cannot be degraded by natural processes in a short period of time and are left as plasticwaste, causing environmental problems.

In Ethiopia there are many industries which consume plastic products for different purposes such as packaging and storage. They simply import from foreign countries and expend large amount of money for plastic products. In addition to this, in this country different oil production industry produces oil from corn. However, they only use the germ part for the production while the part that contains starch is considered as waste, thus it is best to use this waste as raw material for starch production due to these reasons this study focuses on production of plastic from corn starch. For economic feasibility and not to compute with food consumption this project can be assembled with corn oil producers; oil producers use the germ of corn while rest part of corn will be waste or processed for animal food even though, it is not advisable because of acidification by SO_3 in the steeping process of oil production. So, it is better to be used as raw material for starch production.[9]

1.3. Objectives

1.3.1. General objective

- The general objective of this project was to produce bio plastic from corn starch.

1.3.2. Specific objectives

The specific objectives of the project were:

- To extract starch from corn.
- To analyze effect of temperatures on plastic production.
- To characterize bio plastic (compare biodegradability of bio plastic and petro based Plastic, test mechanical properties of the plastic (tensile strength) and analyze water Absorption properties of bio plastic).
- To analyze the effect of presence and absence of vinegar and glycerin on the quality of bio plastic to be produced.
- To perform the techno economic feasibility study of the project.

1.4. Significance of the project

The main significances of this project are: -

- To reduce dependency of our country on petro based plastics.
- To save foreign currency that is being used to buy plastics using millions of dollars per year. I.e. import substitution.
- To satisfy demand of plastic by substituting with bio plastics.
- To Increase the fertility of soil and reducing environmental pollution.
- To transfer technology.

Chapter Two: Literature Review

2.1. Plastics

Plastic is a word that originally meant “pliable and easily shaped.” It only recently became a name for a category of materials called polymers. The word polymer means “of many parts,” and polymers are made of long chains of molecules. Polymers abound in nature. Cellulose, the material that makes up the cell walls of plants, is a very common natural polymer. Over the last century and a half human have learned how to make synthetic polymers, sometimes Using natural substances like cellulose, but more often using the plentiful carbon atoms provided by petroleum and other fossil fuels. Synthetic polymers are made up of long chains of atoms, arranged in repeating units, often much longer than those found in nature. It is the length of these chains, and the patterns in which they are arrayed, that make polymers strong, light weight, and flexible. In other words, it’s what makes them so plastic. These properties make synthetic polymers exceptionally useful, and since we learned how to create and manipulate them, polymers have become an essential part of our lives. Especially over the last 50 years plastics have saturated our world and changed the way that we live. [2]

Plastics have proliferated so readily throughout the modern world because of their versatility. Plastics can be flexible or rigid, brittle or resilient, clear or colour, and have many other useful properties. Some plastics are electrically conductive while others are excellent insulators. It is widely divergent properties such as these that allow a plastic to perform almost any role. In general plastics have a high strength to weight ratio that allows products made of plastics to be lighter and less bulky. Plastics are also less costly alternatives to metals and wood for many applications, such as packaging. The ability to add pigments directly to plastics instead of applying paint is also a benefit. To summarize, plastics have not become popular because they are a superior material but rather that they are many superior materials. Plastics are a specific subset of polymers. Therefore, to understand plastics one must first understand polymers. A polymer is a molecule made up of a large number of small repeating subunits. A polymer subunit is called a monomer. Polymers come in three major varieties. [3]

Inorganic polymers are substances such as concrete or glass. DNA, proteins, and polysaccharides such as cellulose and glycogen are examples of natural organic biopolymers. The monomer units of DNA are nucleic acids. The monomer units of proteins are amino acids. The monomers of polysaccharides are sugars. A single protein often contains hundreds or even thousands of amino acid monomers, which are called residues. The final class of polymers is synthetic organic polymers. Most plastics are synthetic organic polymers. The word organic in this name means carbon based. The reaction by which monomers bond to form a polymer is called polymerization. Polyvinyl chloride or PVC as it is commonly known was the first synthetic organic polymer to be produced. It was polymerized accidentally in 1838 but at the time could not be made into a viable plastic.4 Polymers can form in three different ways. A polymer can be linear, branched, or cross-linked. A linear polymer simply has one chain of monomer units per molecule. A branched polymer has one chain that branches out into several side chains. A cross-linked polymer has several chains per molecule bonded together in multiple places. The main point to take from this is that all plastics are polymers but not all polymers are plastics. [17]

Plastics are a mouldable type of organic polymer. Most plastics in use today are petroleum based. Plastics can be made into fibres as well as solid continuous objects. Adding gas bubbles to plastics produces foams. Common plastics include nylon, rayon, Kevlar, PVC, lexan, polystyrene, polyethylene, and Plexiglas. Plastics can be broken down into two major classes; thermoplastics and thermo-set plastics. Plastics can also be grouped as commodity, engineering, and specialty plastics. Commodity plastics are low cost, easy to manufacture, and relatively weak. Engineering plastics are about two to three times more expensive than commodity plastics and have superior heat stability and strength. Specialty plastics are very high cost but have unique properties, which make them desirable, such as being able to withstand high temperatures. The raw form of a plastic is called a resin. [10] To summarize, plastics are differentiated from other polymers by a combination of their organic nature and their ability to be moulded or cast into a variety of shapes. [4]

2.2 Uses of plastic

Since its inception, plastic enabled countless advances in our industry and way of the life. Created to be light, durable, chemically resistant, non-reactive to outside influences, and easy to manufacture, plastic was a perfect building material for countless articles that are used not only by ordinary users in their daily affairs but also in aeronautics, construction industry, electronics, packaging, transportation, energy conservation, scientific components and other. [9]

A. In building and construction: from the moment famous Bakelite appeared in the first decade of 20th century, plastic became one of the most used building blocks of modern construction industry. This is only surpassed by packaging industry, which uses more plastic than construction industry. The most common uses for plastic in construction is in pipes, valves, bathroom units, flooring, siding, panels, insulation, plumbing fixtures, windows, doors, railings, glazing and gratings. They are used so much because of their awesome abilities to resist corrosion, natural elements and are also very light and easy to handle. [14]

B. Packaging: Versatile, durable, flexible, rigid, and light plastic was embraced by packaging industry with both hands. By employing various manufacturing techniques plastic can be shaped and moulded into any desirable form, have any colour, or any physical property. Plastic transport containers are not only used for household items such as shatterproof bottles and child resistant packages, but also in medicine (biohazard waste disposal, sensitive containers, transport moulds that hold their cargo in firm grip), research, and countless other fields. [8]

C. Transportation: Plastic is very popular material that is today part of all transport vehicles on the world. Because of its toughness, durability, lightness, and ease of colouring, plastic can be found in fenders, trunk lids, bumpers, housing for headlights and mirrors, hoods, doors, wheel covers, and many more other places. By introducing plastic, manufacturers were able to significantly reduce the weight of their cars, airplanes and other vehicles, enabling them to be much more power efficient and easier to service. Off course, smaller means of transportations such as bicycles, roller skates, kayaks, canoes, skateboards, snowboards, surfboards, motorcycles have managed to use all that plastic can offer us. In public transportation, plastic is used almost everywhere seats, handholds, carpeting, interior panels, and sometimes even polycarbonate windows. [9]

D. Electronic: Thermal and insulation properties of plastic made it ideal to become backbone of the electronic industry. Because modern plastic recipes will not change its form after they are heated, manufacturers use plastic regularly for circuit boards, chips, coffee makers, mixers, microwave ovens, hair dryers and even refrigerators. House utensils almost all equipment made up of plastic material such as plates, glasses, shoes, toys, barrels, electric wires, laptops. [15]

2.3 History of Bio plastic

Biodegradable plastics began being sparking interest during the oil crisis in the 1970's. As oil prices increased, so did the planning and creating of biodegradable materials. The 1980's brought items such as biodegradable films, sheets, and mould forming materials. Green materials (or Plant-based) have become increasingly more popular. This is due impart to the fact that they are a renewable resource that is much more economical then they were in the past [2].

Biodegradable plastics can be made from many different sources and materials. One research group from Cornell is working with a number of fibres including those obtained from kenaf stems, pineapple and henequen leaves and banana stems. Their team is working with resins made from microorganisms and commercial resins as well as composites made from soybean protein and plant-based fibres. Australian Researchers are working plastics that are used from either starches or bacteria [4].

The development of new materials is constantly in progress. Researchers must balance many variables in order to make a suitable biodegradable material. Starch based plastics are mainly harvested from wheat, potatoes, rice, and corn. Of these four starches, corn is the most commonly used and is the least expensive starch. Most sales of starch come from the United States, which makes about $1.8 million annually. Being an extremely versatile product, about 20% of starch is used for non-food items. Starch is used for many non-food items such as making paper, cardboard, textile sizing, and adhesives. Starched based plastics have already been processed into eating utensils, plates, cups and other products [6].

The corn starch-based material has the, look, feel, and flexibility of conventional plastics and can be used for a range of items, from cellophane to plant pots and medical devices. When water is added, it completely disappears into the soil over a period of time. This is excellent for food packaging and farming. This corn starch blend of plastic is now cheap enough to compete with conventional plastic. There is a corn starch based organic waste bag now on the market. It is called the Bio bag and is 100% biodegradable and 100% compostable. The Bio bag is made up of corn starch, biodegradable and compostable polyester and vegetable oil. After 10-45 days, it is said to be completely biodegraded depending on the certain conditions and methods. The Bio bag is compliant with the FDA and EU requirements and can be printed using flexo printing. "Another feature of this Bio bag is that it breathes, and reduces the weight of its contents by up to 25% in five days [4].

There are many advantages to creating the biodegradable plastics. Starch-based plastics have been proved to be more environmentally friendly. Starch-based biodegradable plastics have been shown to degrade 10 to 20 times faster than traditional plastics. When traditional plastics are burned, they create toxic fumes which can be damaging to people's health and the environment. If any biodegradable films are burned, there is little, if any, toxic chemicals or fumes released into the air. Biodegradable plastics have been proved to improve soil quality. This process is performed as the microorganisms and bacteria in the soil decompose the material, and it actually makes the ground more fertile. [21]

2.4 Biodegradable Polymers versus Conventional Polymers

Biodegradable materials are beginning to be accepted in many countries. These materials are thought to help the environment by reducing waste issues. The two main reasons for using biodegradable materials, according to Mohanty are, "the growing problem of waste resulting in the shortage of landfill availability and the need for the environmentally responsible use of resources". As the government and many organizations are working to save the environment, there is a definite advantage to making biodegradable plastics more of a reality. Conventional plastics have widespread use in the packaging industry because biodegradable plastics are cost prohibitive. The key, bringing the costs down, is to have numerous companies buy a large sum of biodegradable materials. Laws of supply and demand state that increasing demand will drive costs down. Like conventional plastics, biodegradable plastics must have the same structural and functional qualities, in addition to re acting the same as conventional plastics when used by the consumer. The biodegradable plastics also must be inclined to, microbial and environmental degradation upon disposal, without any adverse environmental impact. [22]

2.5 Purpose and Needs of Biodegradable Materials

Annual expenditure on packaging has increased by more than 4% between 1994 and 1996 according to a report from Pira, the UK packaging consultancy. Plastic's share of the total packaging expenditure remained constant over the same period, at 29%. Since there is an abundant amount of waste in the world, there has been a lot of interest in research devoted to the creating of biodegradable materials. There are many advantages to creating the biodegradable plastics. Starch-based plastics have been proved to be more environmentally friendly. Starch-based biodegradable plastics have been shown to degrade 10 to 20 times faster than traditional plastics [6].

When traditional plastics are burned, they create toxic fumes which can be damaging to people's health and the environment. If any biodegradable films are burned, there is little, if any, toxic chemicals or fumes released into the air. Biodegradable plastics have been proved to improve soil quality. This process is performed as the microorganisms and bacteria in the soil decompose the material, and it actually makes the ground more fertile. With all of the advantages of biodegradable plastics, there are a number of disadvantages. Recycling helps the environment and it works well for many plastic containers such as bottles. Eventually there is a limit to how many times a piece of plastic can be recycled, so there will in the end there will be waste produced. The cost of recycling plastics, in terms of energy, can be significantly higher than virgin resin. Toxic gases can be releasing from burning waste plastics in order to harness the energy for production. Many plastics that appear to be biodegradable in reality break down into miniscule bits that can affect both the soil and animals. Unfortunately, as researchers try to improve the environment with these new plastics, in essence they may be creating risks, as well. [12]

2.6 Production of bio plastic

2.6.1. From Microorganisms

The occurrence of polyhydroxy alkanoic acids as storage polymers in prokaryotic cells is now known to be very widespread indeed. They are water-insoluble compounds. Many bacteria produce an intracellular carbon and energy storage compound - poly-β-hydroxybutyric acid (PHB) - in relatively large quantities. While this property is absent from enteric species, it is widely found in Pseudomonad and related species including the plant symbiotic Rhizobium and also in nitrogen-fixing Azotobacter spp. Accumulation is normally a response to unbalanced growth in the presence of excess carbon and energy source. Under appropriate conditions the polymer can amount to more than 50-80 per cent of cell dry weight. The storage product is found as granular inclusion bodies within the cytoplasm. [5]

However, many of these compounds represent in relatively small amounts or because of their short chain lengths or other properties are unsuitable as potential bio plastics. Among species synthesizing PHB and PHV are some Archae including Haloferax mediterranea. These halophytic bacteria might present advantages for production as their culture requirements of salinity and relatively high temperature provide little opportunity for growth of contaminants. In species such as Azotobacter vinelandii, simultaneous production of large amounts of exopoly saccharide diverts substrate to alternative products and makes recovery of PHB difficult. Development of high-yielding mutant strains resulted in conversion rates of 65 percent for PHB and eventual PHA yields of 71 per cent dry weight. [15]

2.6.2. From Plants

The major limitation associated with the production of bio plastics in bacteria is the high cost when compared to the petroleum-derived plastics. Potentially, in turn, the plant offers an alternative approach to synthesize these bulk commodity products at low cost. Whereas PHA production in bacteria and yeast requires costly fermentation process with an external energy source such as electricity, in plant systems it is considerably less expensive as it relies on water, soil nutrients, atmospheric CO2 and sunlight. In addition, a plant production system is much more environment friendly. While in bacteria PHB synthesis and its accumulation is limited in the cystol, in plants PHB can be produced in a number of sub cellular compartments like cystol, plastids, mitochondria and paroxysms. [13]

Arabidopsis thaliana was the first plant to be used for PHA production. In Arabodopsis, a small amount of PHB production was first demonstrated by expressing plastics cytoplasm two enzymes (acetoacetyl-CoA reductase and PHB syntheses) from the bacterium Ralstonia eutropha.The polymer produced was of high molecular weight and similar in structure and properties to PHB but the yield was low and plants were stunned in growth. The yield was later increased from 1% to 14% dry wt. The achievement was ground breaking, producing one transgenic plant with 14% dry wt. of PHB in its leaves. Later on, low amount of medium chain length PHA copolymers were synthesized in peroxysomes by polymerization of 3-hydroxyacyl-CoA intermediate generated by degradation of fatty acids in peroxisomes of Arabidopsis plant. After the success of synthesizing PHB in plants, PHB copolymers were produced in both A. Thaliana and seeds of Brassica napus (oilseed rape). [11]

Plastic is often used to improve the mechanical properties of fibre-based composites. In case of cotton, R. Eutrphapha genes when successfully expressed in the cystol of its fibres, the fibres from its transgenic plants contained 0.34% PHB, which was sufficient to improve the insulating properties of the fibre. Similarly, in stems of transgenic flax (Linnum usitatissimum), bio plastic has also been produced with an aim to improve the quality of fibre rather than providing a plant source of PHB for extraction. Interestingly, seed production as well as plant growth and morphology were found to be enhanced in these transgenic plants. At commercial level, the approach to convert plant sugar into plastic was first adopted by Cargil, an agricultural business giant, and Dow Chemicals in corn and other plants to produce a plastic called PLA (polylactide). Later on, other companies including ICI (Imperial Chemical Industry) developed ways to produce a second plastic, called PHA. Like PLA, it is made from plant sugar. Thus, researchers have turned toward plants as being a potentially cheaper and more convenient method of producing renewable, biodegradable plastics. [20]

2.6.3 Plastic production from Starch

Starch-based polymers can be thermally processed and can undergo extrusion, injection molding, compression, and film casting. Lui's group showed extensive work on processing techniques that can be used on starch-based materials as well as phase transitions during processing. They also tested processing properties of the starch-based polymers by observing effects of water, glycerol, citric acid and other plasticizers and additives. His group showed that after processing, there was some loss in mechanical function due to temperature changes during processing. The group also showed that processing needed to be controlled and mechanical function of the polymers was based largely on the processing technique and control of moisture within each stage, as an increase in moisture greatly affected the mechanical function in the end stage of processing. Several other studies also found difficulties in working with starch-based polymers and attribute it to difficulties with phase control and control of heat and moisture during processing. [23]

The thermal processing of starch-based polymers involves multiple chemical and physical reactions such as water diffusion, granule extension, gelatinization, decomposition, melting and crystallization. Between the various phase transitions, gelatinization is particularly important because it is closely related to the others, and it is the basis of the conversion of starch to a thermoplastic. Furthermore, the decomposition temperature of starch is higher than its melting temperature before gelatinization. The well-accepted concept of 'gelatinization' refers to the destruction of the crystalline structure in starch granules which is an irreversible process that includes, in a broad sense and in time sequence, granular swelling, native crystalline melting (loss of birefringence) and molecular solubilisation. Starch gelatinization is a multistage process that can be detected by DSC. [16]

Starch is also one of the least expensive biodegradable materials used for many non-food items such as in paper making, cardboard, textile sizing and adhesives. Recently, starch has been used as the main polymer in thermoplastic compositions and has been processed into eating utensils and as raw material for film production. Starch offers an interesting alternative for synthetic polymers where long-term durability is not needed and rapid degradation is an advantage. [14]

2.6.4 Process flow diagram of bio plastic production

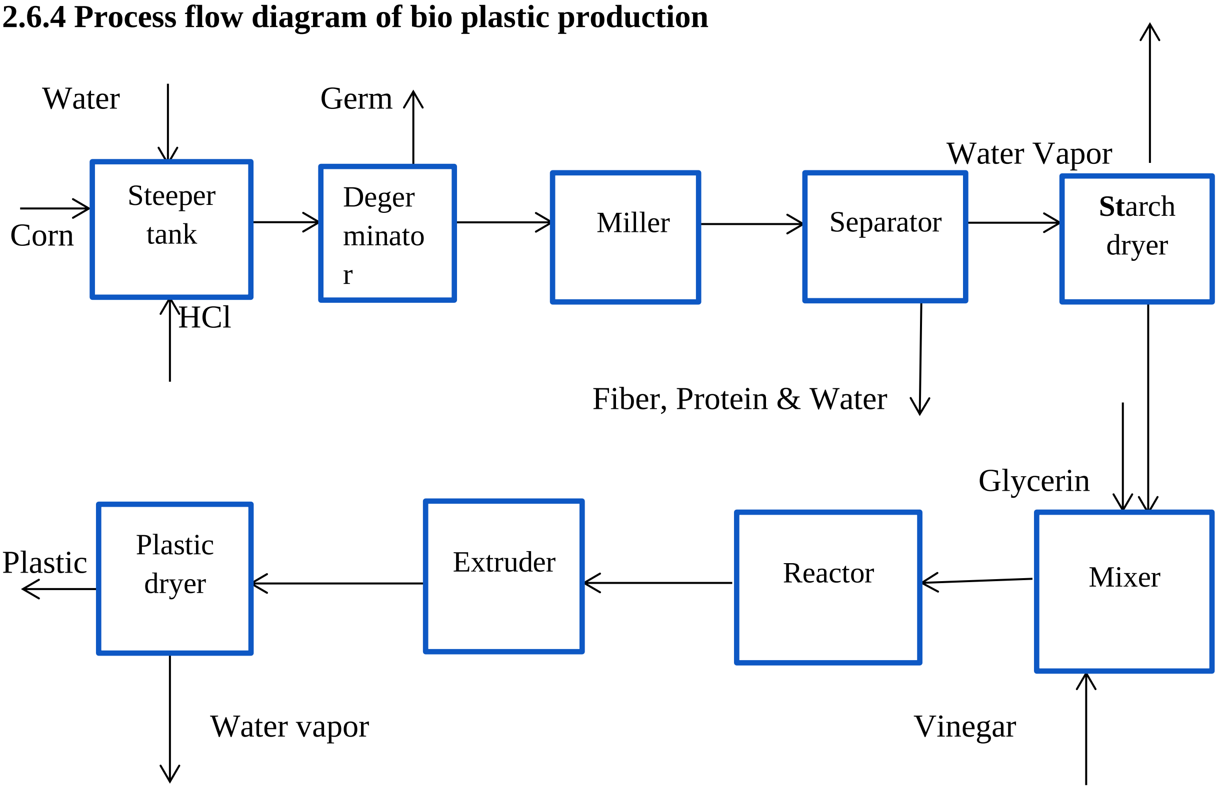


Figure 1 Block flow diagram of bio plastic production

2.6.5 Factors affecting plastic production from starch

A. Temperatures: - reaction temperature is the important factor that affects the yield of bio plastic. For example, higher reaction temperature increases the reaction rate and shortens the reaction time due to decreasing activation energy. Bio plastics produced at different temperature have different tensile strength; this tensile strength is characterising the type of bond created during mixing process. [14]

B. Type of process followed: -bio plastics produced using different methods have different chemical and physical characteristics. [18]

C. Type of raw material: -starch from different crops have different composition of amylose(linear) and amylopectin (branched) so, bio plastics from different raw material resulted to have different properties (tensile strength, biodegradability etc. properties).Also bio plastic can be produced from fibrous materials with different property.[19]

D. Heating duration: This has effect on chemical reaction of the bio plastic production during heating process.

2.7. Classification of Starch bio plastics

Starch, the storage polysaccharide of cereals, legumes and tubers is the key raw material for bio plastics. Flexibilisers (sorbitol) and plasticizers (glycerin) are added during the processing of bio plastics. For use as bio plastic, starch should attain adequate and required mechanical properties like high percentage elongation, tensile and flexural strength unless it is treated by either plasticization, blending with other materials, genetic or chemical modification or combinations of different approaches.[6]

2.7.1 Bio plastics from bio-based monomers

Polylactic acid is the polymer with the highest potential for a commercial production as bio plastic. However, a wide range of other bio polyesters can also be made by fermentation. Very high cost of the production of the monomers was the major restriction. The process changes the starch from a lactic acid monomer into a polymer chain called poly lacitide (PLA) or polygloycolic (PGA).

A. Polylactic acid (PLA) plastics

PLA is a biodegradable, thermoplastic, aliphatic polyester derived from lactic acid which itself produced from the fermentation of agricultural by-products such as cornstarch or other starch-rich substances like maize, sugar or wheat. The ratio between the two mesoforms of the lactic acid monomer determines the properties of PLA. The use of 100% L-PLA results in a material with a very high melting point and high crystalline. On the other hand, a 90%/10% D/L co-polymers gives a material which can be polymerized in the melt and is easily process able meeting the requirements of bulk packaging.

B.Poly hydroxyl alkanoate (PHA) and poly hydroxyl butyrate (PHB)

PHA and PHB are the most common polyester produced by bacteria by processing glucose or starch. The properties of PHA are dependent and relates upon the composition of monomer unit, the microorganisms used in fermentation, as well as the nature of the carbon source used during the fermentation process. PHA has low water vapor permeability which more or less same to that of LDPE. Moreover, PHA has similar properties of polystyrene. PHB resembles isotactic polypropylene (iPP) in relation to melting temperature (175-180°C) and mechanical behaviour. The incorporation of 3HV or 4HB co-monomers in PHB produces remarkable changes in the mechanical properties. Stiffness and tensile strength decrease with increase of toughness with increasing fraction of the respective co-monomer. PHB is produced by bacteria, algae, and genetically modified plants requiring no extra polymerization step within the cell via a complex enzymatic process. The raw material for the biological synthesis is Acetyl-CoA; wh ich is p art of the tricarbox y lic acid (TCA) cycle. First, a β- ketothiolase catalyzes the production of acetoacetyl-CoA by condensing two molecules of acetyl-CoA together. Next, acetoacetyl-CoA reductase reduces the acetoacetyl-CoA producing β-hydroxybutyryl-CoA. The final step is carried out by PHB synthase, which catalyzes the polymerization of β- hydroxybutyryl-CoA to PHB. The PHB is present as cysts within the cytoplasm of the cell. The production of PHB requires bioreactors since microorganisms produce the polymer. [2]

2.8 Starch production from corn

2.8.1. Alkali extraction method

Several methods have been proposed and developed to extract starch from cereal flours using alkali treatment. The starch extraction method developed by Dimler for wheat flour was the most effective method so far to obtain starch in high yield and purity. They used 0.50-1.0% alkali solutions to extract starch from wheat flour. This method also was applied to corn flour to extract corn starch. However, the yield (maximum 67% on flour dry basis) and purity (0.5-1% protein content) of the starch extracted from corn flour was lower than that obtained from wheat starch. A modified alkali extraction process was developed that extracted starch from corn flour with higher yields and purity than those of the earlier alkali processes and then those from commercially obtained corn starch. This modified method uses lower alkali concentrations (<0.5%) than those used by Dimler.

Alkali has been used to produce modified starches and starch products having properties different from those of native corn starch. Several studies have been reported that investigated the behavior of starch when reacted with alkali solutions. Strong alkali solutions have varying effects on starch, such as granule swelling, increased viscosity, and gelatinization. The conditions for alkali extraction of starch are significantly different from those used for starch modifications. Conditions generally have shorter exposure times and lower alkali concentrations. No studies have been reported to investigate the properties and characteristics of starch resulting from alkali extraction. Alkali-extracted starches are characterize using the amyl graph, differential scanning calorimeter (DSC), the X-ray diffract meter, birefringence, vapour sorption isotherms, scanning electron microphotographs, and enzymatic hydrolysis and to study the effect of alkali extraction parameters (alkali concentration, extraction temperature, and extraction time) on starch characteristics.[13]

2.8.2. Commercial corn starch production method

If the starch produced by the corn wet milling process is simply dried, it is called a common, regular or unmodified corn starch. It is available in various physical forms: corn starches may be sold as fine or coarse powders, as flakes, as pearls or be agglomerated to larger particles Slight variations can be introduced into unmodified starch by adjusting pH, by mild heat treatment, or by adding small quantities of chemicals or adjuvant before or after drying. Such starches will then perform more effectively in specific applications. For example, common starch intended for enzyme conversion may be adjusted to a specific pH and small amounts of inorganic salts that facilitate enzyme action may be added. Starches for food use are also often pH adjusted. More unmodified corn starch is sold than any other type. It is used in the manufacture of corrugated board, coated and sized paper, paperboard, adhesives, salad dressings, beer, canned foods, dry food mixes (such as puddings, cakes, baking powder, etc.), moulding starch, laundry starch, etc.[8]

The chemical composition of starch highly oxygenated carbon compounds make starch an excellent product for use as a chemical feedstock. Many industrial products, which today are derived from petrochemical feedstock, are increasingly being synthesized from starch or cellulosic feedstock. Examples of current commercial products of this type include the use of corn starch in the production of biodegradable plastics. [22]

2.8.3 Composition of corn starch

Starch exists as a major carbohydrate storage product in all plants containing chlorophyll. In the process known as photosynthesis, green plants extract energy from sunlight to form glucose from carbon dioxide and water. Glucose fuels plant growth processes and is the primary building material for plant support structures such as cellulose and hemicelluloses. When the plant reaches maturity, the reproduction cycle begins, culminating in pollination and formation of the starch- and oil-rich seed embryo. Starch and oil exist in the corn kernel to supply energy to the germinating seed. Starch is a carbohydrate polymer made by the linking of glucose units end-to-end into very long chains. Newly-synthesized starch is layered around a helium nucleus within the plant cell, in structures called granules. [1]

Starch granules vary in size and shape, characteristic of specific plant sources. Starch molecules are oriented within granules in specific crystalline patterns. The highly structured nature of the starch granule is demonstrated by its great strength. Granule integrity also persists in both modified and derivative starches. Isolated starch is typically a dry, soft, white powder. It is insoluble in cold water, alcohol, ether and most organic solvents. Though starch granules are physically durable, they can be disrupted quite easily. If granules in water suspension are gradually heated, they begin to absorb water. The granules hydrate, increase in size and finally lose their structural integrity. This results in loss of characteristic birefringence and opacity, an increase in viscosity, and the eventual formation of a paste or gel. This process is referred to as starch pasting or gelatinization. [2]

Under well-defined conditions, starches can be classified using gelatinization temperature as a means for differentiation. The properties of the starch granule are dependent upon the arrangement of the bonds which link glucose units to one-another within the starch molecule itself. In most starches the alpha-1,4-linkage predominates, with only occasional 1,6-linkages. The 1,4-linkages yield straight chain starch molecules called amylose, while the 1,6-linkages serve as the branching point in branched chain starch molecules called amylopectin. The proportions of these two types of starch molecules are established genetically and are relatively constant for each species of starch. For example, corn starch contains 27% of the linear amylose polymer, potato starch 20%, and tapioca starch 17%. [24].

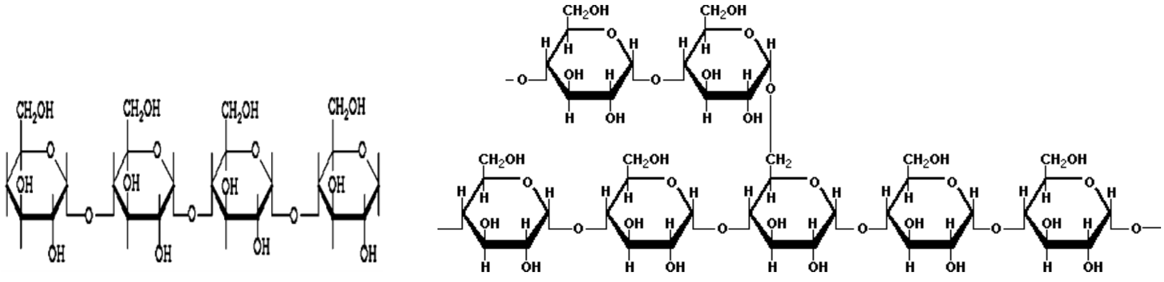


Figure 2 Structure of Amylase and amylopectin

2.8.4 Properties of starch

Starch is stored in plants as granules. The granules, which are isolated and sold in bulk by the wet milling industry, may vary in size from a few to 50 or more, depending on the source plant. Starch granules are hydrophilic since each starch monomer unit contains three free hydroxyl groups. Consequently, starch changes moisture content as relative humidity changes. Cornstarch granules retain about 6 % moisture at 0% relative humidity (RH) but contain 20 %moisture when in equilibrium with about 80 % RH. [2]

Starch solutions are unstable at low temperatures. On standing in dilute solutions, the linear amylose component crystallizes. Many branches of amylopectin may also crystallize. Rapid cooling of concentrated starch dispersions creates stiff gels which crystallize more slowly. Amylose, and to a lesser degree the outer branches of amylopectin, can assume helical conformations which have a hydrophobic core. Each turn of the helix comprises about six monomer units. Iodine, fatty acids, lipids, alcohols, and other materials may enter the core of the helix to form stable complexes with starch.

Starch molecules readily depolymerize into glucose sugar when heated in acid solutions or when treated with a variety of amylolytic enzymes. They are generally stable to alkaline conditions at moderate temperature. When heated with amines under alkaline conditions, they undergo complex Millard reactions to form brown colored products with Carmel like odors. [18]

Starch may also be modified by grafting synthetic polymer branches onto the starch backbone. Various initiators, such as ceric ammonium nitrate, create radical sites on the starch backbone. Addition of water-dispersible unsaturated monomers to the radicals gives rise to graft copolymers of synthetic polymers and starch. Granular starch may be compounded into plastics as biodegradable filler. Gelatinized starch, if dried during processing of the plastic composite, may also become particulate filler in plastics; offering the potential of reduced particle size of the filler through control of compounding. Alternatively, starch may be plasticized with low levels of water (5-20%) and compatibilized with the other polymers to become a part of the connective matrix of the plastic. This type of thermoplastic starch product is exemplified by the starchpoly(ethylene co-acrylicacid) alloy product extruded byotey and co-workers.

Starch which has been extrusion cooked, typically at 15-25% moisture and 160-200°C, is largely amorphous in structure. The components of the extruded, gelatinized starch, amylose and amylopectin, appear to be mixed on a molecular scale. Extruded starch having, for example, approximately 15 % moisture has an initial tensile strength of 20-30 MPa and 10-15 % elongation [441. These are useful properties for some molded articles but are inadequate for film applications. The moisture content will also fluctuate with changing ambient humidity, leading to large changes in Tg and mechanical properties. In addition, extruded starch aged at constant temperature and moisture level shows a gradual decrease in elongation at break resulting in a more brittle material. This occurs over months to years at low (- 10%) moisture but over hours at higher (- 2 0 %) moisture levels. Differential scanning calorimetric (DSC) studies have shown that this phenomenon is due to structural relaxation of starch chains, leading to decreases in enthalpy and free volume with time. [1]

2.9 Availability of corn in Ethiopia

Corn is Ethiopia's largest cereal crop in terms of total production, area planted, and number of farm holdings. Corn accounts for 22 percent of the total area covered by cereal and around 30 percent of the total cereal production. In addition to the highest total production per annual and the highest per hectare yield. Corn is also the single most important crop in terms of number of farmers engaged in cultivation. During this reporting period, more than eight million small landholder farmers were involved in corn production. The lion’s share of corn production comes from three regions: the Oromia region (61%), Amhara (20%) and SNNPR (12%). Subsistence and small landholder farmers produce 95 percent of total corn production and commercial farms produce only around 5 percent. Corn productivity levels on commercial farms reach only 4 tons/ha, showing that there is still room for increasing productivity of small landholder farmers (about 2.5 tons/ha) when improved seed and fertilizer are used. Corn use survey data from the CSA shows that out of the total national production of corn, 80% was used for household consumption, 10% for sale, while the balance was used for seed, wages in kind, and animal feed. Because of lower prices compared to other grains, the per capita consumption of corn in the rural area is estimated to be 45 kg/year and 16 kg/year in urban areas. Most of the flour mills in the rural areas mix corn with wheat to lower the price of flour. This helps bakeries to lower the price of bread and to gain a better profit. [9]

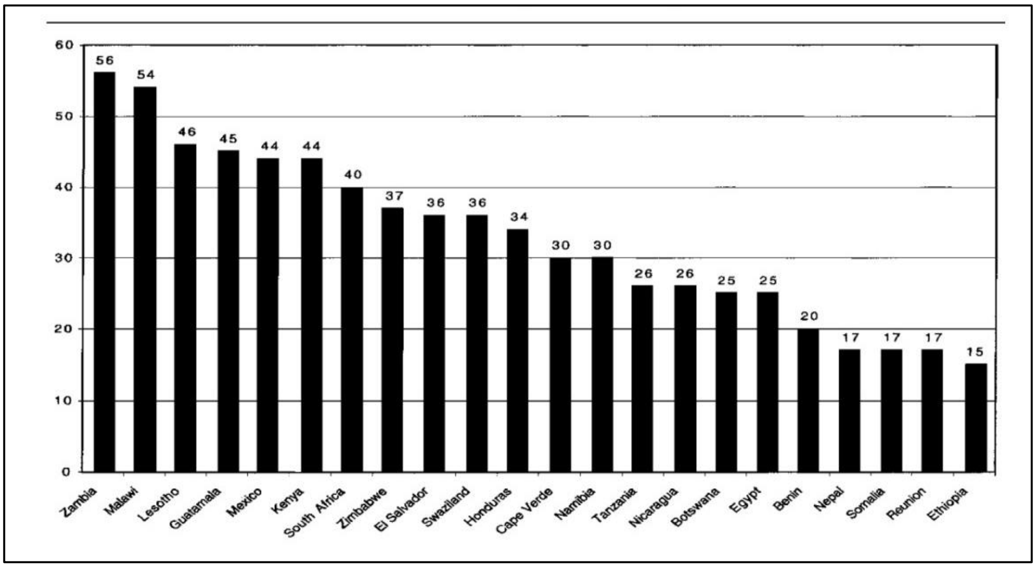


Figure 3 Corn consumption of African Countries

Source: www.African Countries corn Consumption.com

2.9.1 Composition of corn

The corn kernel varies in quality; typically, a standard analysis would yield the following:

Table 1 composition of corn

Substance	Composition (%)
Starch	67.6%
Protein/Gluten	4.6%
Oil	2.7%
Fiber	22.8%
Shrinkage	2.3%

Source: www.Composition of Corn Starch.com

2.10. Market and price of bio plastics

Worldwide bio plastics demand has grown tremendously over the past several years, albeit still representing a small fraction of global plastics demand. As of 2007 it was estimated that worldwide production of bio plastics amounted to approximately 360,000 metric tons (890,000 metric tons by 2012) and was projected to reach 1.5 to 4.4 million metric tons (Mt) by 2020.22 Another report by the European Bio plastics Association determined global bio plastic production reached 725,000 metric tons in 2010 and forecast production of 1.7

million metric tons by 2015.23 The Society of the Plastics Industry Bio plastics Council estimates the bio plastics industry will grow more than 20 percent annually through 201. According to European Bio-plastics Association, the global production capacity for bio plastics is projected to grow four times by 2020. The prices of any biopolymer are likely to be high when it is only produced on a small scale. The scale of production is likely to have a greater influence on the price than the costs of the raw material source and of the chemistry involved. According to EBA, Bio-plastics consumption is likely to reach two million tons by 2018. [9]

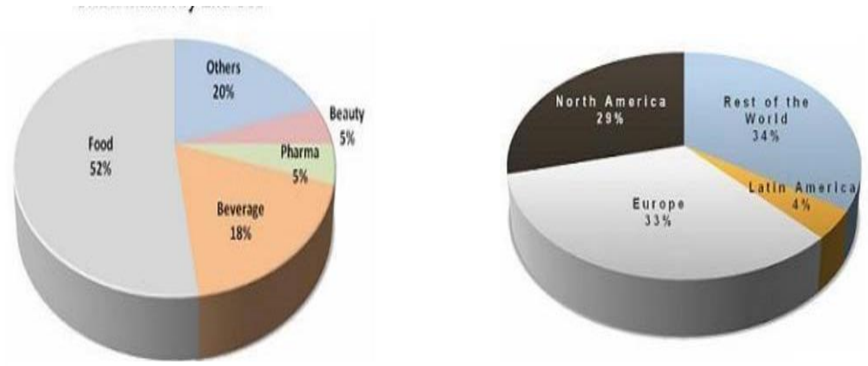


Figure 4 Global market of bio plastic end use and by geographical region.

As shown, Europe is the biggest market in terms of consumption of bio-plastics whereas Latin America the least. Also, Bio-plastics find more place in the food industry as compared to the other markets. According to global market watchers, global Poly Lactic Acid market is expected to reach US$2.6 billion by 2016 at a Compounded Annual Growth Rate (CAGR) of 28%. Region-wise analysis shows that Asia-Pacific is forecasted to record the highest growth rate of 29.3% during the analysis period 2011-2016. Europe follows Asia-Pacific with a CAGR of 28.9%. The Americas forecasts to drive the global market with a 27.3% increase. Volume based studies reveal that the maximum share of growth rate is expected from Asia Pacific region. Comparing the end-user industries, textiles and electronics are going to be the major supporters of this market. [11]

2.11 Advantages of Bio-plastics.

i. Reduced CO2 emissions: One metric ton of bio plastics generates between 0.8 and 3.2 fewer metric tons of carbon dioxide than one metric ton of petroleum-based plastics.

ii. Cheaper alternative: Bio-plastics are becoming more viable with volatility in oil prices.

iii. Waste: Bio-plastics reduce the amount of toxic runoff generated by the oil-based alternatives.

iv. Benefit to rural economy: Prices of crops, such as maize, have risen sharply in the wake of global interest in the production of bio-fuels and bio-plastics, as countries across the world look for alternatives to oil to safeguard the environment and for attaining energy security.

v. Reduced carbon footprint: Oil based plastics require fossil fuel as a key raw material. In addition, oil-based plastics require more energy during the plastic development process when compared with bio plastics. A Life Cycle Analysis for a typical oil-based plastics shows a carbon footprint of approximately 2.0 kg CO_2 equivalents per kg of plastic (from cradle to factory gate). These CO_2 emissions are 4 times higher than the CO_2emissions for Poly Lactic Acid (PLA) resin.

vi. Multiple end-of-life options: valuable raw materials can be reclaimed and recycled into new products, reducing the need for new virgin material and negative environmental impact of 'used' plastic products can be greatly reduced, if not, eliminated.In the future, bio-plastic products might be recycled in to bio-diesel.

- Reduce dependence on fossil fuel and foreign oil.
- Fully compostable.[20]

2.12 Disadvantages of bio plastics.

- Can compete with starch consumers.
- Some bio plastics have shorter life time than oil-based plastics.
- Not as tough as petro based plastics to hold mechanical loading.

Chapter Three: Materials and Methods

The experimental work was carried out in Wolkite University, department of Chemical Engineering, Chemical Engineering laboratory. The major methodologies that were used were laboratory work and data Analysis, which was done after laboratory work.

3.1. Laboratory Equipment

- Beaker, Stirrer
- Conical flask, Measuring cylinder, Filter cloth
- Oven, Stove, Thermometer
- Disc Miller, Weight balance

3.2. Raw materials and chemical agents

- Corn starch
- Glycerine
- Methyl red indicator
- Water
- HCl
- Corn
- Vinegar

Sample collection and identification

3 kg of corn was bought from the market, 1litre of distilled water was prepared, 100 ml of glycerine, 100 ml of vinegar and some food colorants were prepared.

3.3 Experimental Method

3.3.1 Corn starch extraction procedure.

The prepared corn was washed with cold water prior to soaking. The washed corn was soaked with 1 M HCl for 24 hours. Then, germ of the corn was removed out of the kernel, next the de germinated corn was grounded finely to disrupt the cells of endosperm and release the starch granules. After this the milled corn was allowed to dissolve in water; the protein dissolved completely in water whereas fibre and starch didn't then starch and fibres were separated by filter cloth. Finally, the extracted starch was allowed to dry in an oven for two hours at 40^{o}C.

Preparation of 0.1 M of HCl

$$\text{Molarities of HCl} = \frac{Purity\ in\ \%\times 10\times s.g}{molar\ mass}$$

$$= \frac{37\%\times 10\times 1.19}{36.5}$$

$$= 12.06\ \text{M}$$

Dilution equation

$$C_1V_1=C_2V_2$$

Where Ci =concentration Vi =volume

So, V_1=100 ml C_1= 0.1 M, C_2 =12.06 M and V_2=?

1000 ml×0.1 M = 12.06 M × V_2= V_2 = 83 ml

Step of 1 M HCl preparation.

Frist, 1litre distilled water and 83 ml of HCl were prepared. Then, 500 ml of distilled water and 83 ml were added volumetric flask. Following this 500 ml of distilled water was poured to the solution was added and mixed well.

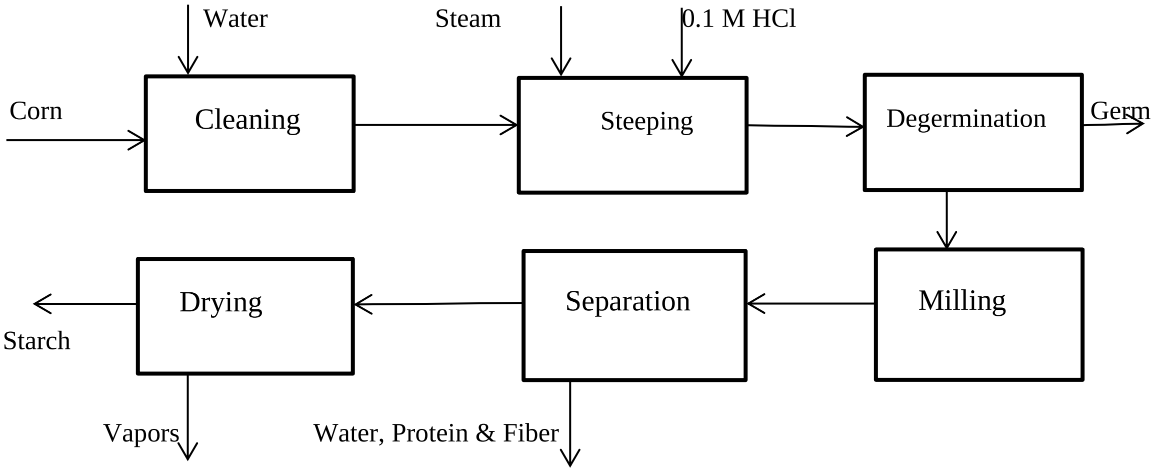


Figure 5 Block flow diagram of Corn starch production

3.3.2 Steps of bio plastics production from corn starch.

Frist, 10 gm of extracted starched and 60 ml of distilled water were added to 250 ml beaker. Then, a 5 ml of Vinegar and glycerine were added to the solution in all trials except trial number 5 and 6 respectively. Following this, Food colouring was added and stirred and next the solution was heated at 200°C, 200°C, 210°C and 210°C and the trials without glycerin and Vinegar for 10, 12, 10, 12, 10 and 10 minutes respectively. The solution product was allowed to boil and to cool for a minute in all trials and the end product (plastics) was scooped out from the pot and spreaded out on the led plate and allowed to dry for at least 24 hours.

Experimental Trials

Table 2 Laboratory trials production condition.

Type of Bio-plastic	Temperature (°c)	Starch to water ratio	Residence Time(min)
Bio plasic1	200	1 gm:6 ml	10
Bio plastic 2	200	1 gm:6 ml	12
Bio plastic 3	210	1 gm:6 ml	10
Bio plastic 4	210	1 gm:6 ml	12
No vinegar	200	1 gm:6 ml	10
No glycerine	200	1 gm:6 ml	10

3.4 Characterization of bio plastic

A. Water solubility

Test Procedure: Water solubility of the film samples was determined. All the bio plastic film samples were cut into 2 cm × 2 cm pieces dried at 60 °C for 2 hr and weighed. The dried pieces of films were immersed in 20 ml of distilled water in plate and kept at room temperature for 24 hour and the films were observed for solubility. The residues were dried at 110°C for an hour and then weighed to calculate the percentage of the solubility of the films.

Solubility % = $\frac{\boldsymbol{W0-Wf}}{\boldsymbol{W0}} * \mathbf{100\%}$

Where W_0 = initial dry weight, W_1 = final dry weight.

B. water absorption test

Test Procedure: All the bio plastic films were cut into 2 cm × 4 cm dimension and dried at 60°C in hot air oven for an hour. Initial mass of the films was measured noted. The films were immersed in the water for 24 hours. The mass after immersion was measured.

Water absorption % = $\frac{\boldsymbol{M0-M1}}{\boldsymbol{M0}} * \mathbf{100}\%$

Where M_0, M_1 = mass of the sample before and after immersion of the sample, respectively.

C. Biodegradability test

Test procedure: The bio plastic films and petro based plastics were cut into small strips. The films were buried under the soil for assessing natural landfill degradation with time. Biodegradation of bio plastic films and petro based plastics were compared. The specimen was cut into pieces of 4.0 cm^2. Found near the roots of plants which are rich in nitrogenous bacteria, 500 gm of soil (having slight moisture content) was collected and stored in a container. One sample was buried inside the soil at a depth of 2 cm and another buried at a depth of 3 cm for 15 days under the conditions of the room. The weight of the specimen was measured before and after the testing. The biodegradability test was measured the following Equation.

Weight Loss (%) = $\frac{\boldsymbol{W0-W1}}{\boldsymbol{W0}} * \mathbf{100}\%$

Where W_o and W_1 are the weights of samples before and after the test.

D. Tensile strength test.

Test procedure: Computerized tens meter is not available to measure tensile strength of plastics. Therefore, we have used load method of tensile strength test. In this method the area of sample was calculated and known mass is applied until the hanged bio plastic is broken down. Then the Elongation (mm) and the force using the equation F = mg was calculated, if number of masses added to the sample.

$F = (m_1+m_2 .... m_n)\, g$

CHAPTER FOUR: Results and Discussion

4.1 Starch production

From the first extraction process 627 gm of starch out of 1,000 gm of corn, from the second extraction 632 gm of starch out of 1,000 gm of corn and from the third extraction 625 gm of starch out of 1,000 gm of corn were obtained. Totally 1,884 gm of Corn starch out of 3,000 gm of corn was obtained. Therefore; percent of extracted starch is:-

$$\%\text{ of extracted starch} = \frac{Weight\ of\ starch}{Weight\ of\ Corn} * 100\%$$

$$= \frac{632+627+625}{3000} * 100\%$$

$$\mathbf{= 62.8\%}$$

Comparison with the theoretical

The theoretical extraction of starch is 67.6% [18] and our result was 62.8% which nearly the same as the expected value.

Moisture content the of starch

The produced starch weighed after and before dying and the moisture content was calculated using the equation:-

$$\mathbf{M_n} = \frac{W1-W2}{W1} * \mathbf{100}\%$$

Where: $\mathbf{W_1}$ = Wet weight

$\mathbf{W_2}$ = Dry weight

$\mathbf{M_n}$ = Percentage moisture content of starch.

$$= \frac{\mathbf{2512-1884}}{\mathbf{2512}} * 100\%$$

$$\mathbf{= 25\%}$$

Theoretical moisture content of starch is 20% [18] and our result was 25% which nearly the same as the same.

Testing for the presence of starch

One table spoon of starch was added to 20 ml of methyl red indicator, after shaking sample from first trial gives no color change, but sample from second trial changes to blue black and then to yellow color. So, from theoretical point of view starch should be changed to yellow color by methyl red indicator. Therefore, the first sample was not starch and the second sample was starch.

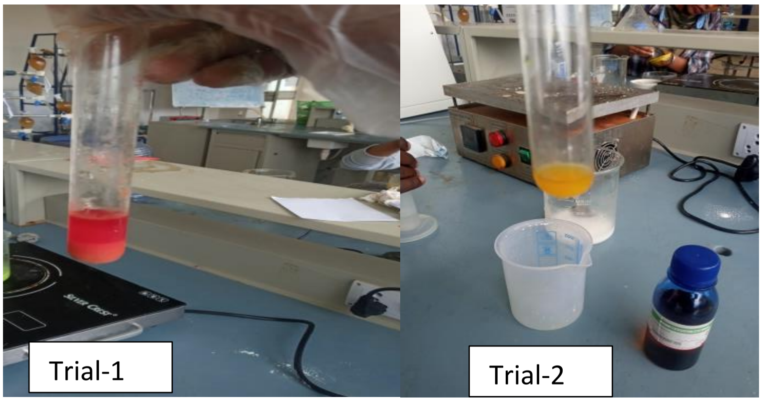


Figure 6 Starch test trials

4.1. Plastic production.

The production parameters were very important to produce both a good quality and quantity of bio plastic. As a result, to achieve these objectives different parameters with different levels were used during the extraction process. The parameters were temperature, residence time and absence and presence of glycerine and vinegar; i.e Bio plastic = f (vinegar, glycerin, water, Starch additives, temperature and residence time) change or replacing one item with another changes the characteristics of bio plastic. By using literature reviews [19] as spring point and taking into consideration the levels of temperature were 200 °C, and 210 °C, the second important factor and that was necessarily investigated was residence time and its duration were, 10min and 12min. The third parameter was the presence and absence of vinegar and glycerine. By considering those factors there were six runs. The laboratory experimental outputs in different variable with different levels were recorded.

The bio plastic produced at 200°C temperature heating for 12 minutes by mixing 10 gm of Corn Starch,60 ml of distilled water,5 ml of vinegar and 5 ml of glycerine was good showing good tensile strength with respect to other bio plastics and good bio degradability characters with respect to petro based Bio plastics. Whereas plastic produced at 200°C for 10 minutes by mixing 10 gm of Corn Starch,60 ml of distilled water,5 ml of vinegar and 5 ml of glycerine was not as good as the former one.

Vinegar:- Bio plastic without vinegar has showed the following characteristics Colorless, Easily breakable, Tiny cracks are present on its surface these information tells what vinegar is.Vinegar (acetic acid) liberates acetate ions and hydrogen ions in solution. This is important, because ions react with the starch polymers and make them be disordered more easily in the solution. Therefore, it facilitates the polymerization process by disordering the first polymer.

Glycerin:-The trial without glycerin hold less water, it was too hard and brittle from this observation; glycerin helps bio plastic to be flexible. Therefore, glycerol or plasticizer serves to reduce the stiffness and improve the flexibility of the plastics by increasing the mobility of the polymer bonding and improving the water holding capacity.

4.2. Characterization of produced plastics using different methods.

A. Water solubility

Table 3 Water Solubility of selected samples.

Temperature	Residence time(min)	Dry weight(gm)	Wet weight(gm)	Water Solubility (%)
200°c	10	2.8	3.3	15.9
200°c	12	2.9	3.3	9.5
210°c	10	1.6	1.8	12.7
210°c	12	2.7	2.78	12.1

The solubility of the films is an indicator of the presence of hydrophilic compounds in the film. The second bio plastic was less soluble because of high level of intermolecular attractions within the matrix and cross-linking bringing about lower capability to interact with water. The first bio plastic was most soluble because of lowest level of intermolecular attractions within the matrix and cross-linking bringing about higher capability to interact with water.

B. Water absorption percentage

Table 4 Water absorption percentages of Selected Samples

Temperature	Residence time(m)	Dry weight(g)	Wet weight(g)	Water absorption (%)
200^{o}c	10	2.8	3.3	17.86
200^{o}c	12	2.9	3.3	2.96
210^{o}c	10	1.6	1.8	12.5
210^{o}c	12	2.7	2.78	13.8

Table 4 presents the water absorption percentage of the bio plastics. The first bio plastic took up large amount of water content than the second. The crystalline nature of starch is destroyed in the presence of heat and excess water during melting process that makes the amylose and the branched chains of amylopectin to break and form hydrogen bonding. Additionally, there may be some exposed hydroxyl groups of amylose and amylopectin not involved in cross-linking with plasticizers, which react with water when exposed leading to swelling of the film. The second trial formed very strong interaction leaving little space for the film to take up water with least swelling. Heating causes the water molecules to move fast enough to penetrate and break up the starch granules, which then tangle together to form polymers. But beyond its optimum temperature heat have negative effect on cross linking with glycerine this is why the third and fourth trials absorbed more water than the second.

C. Soil burial biodegradation

Table 5 Comparison of bio degradability of bio plastic and Petro- plastics

Type of plastic	Initial mass(g)	Final mass(g)	Mass loss(g)	Time of disappearance (day)
Bio plastic	16.9	15.89	1.01	117.128
Petro based plastic	0.81	0.81	0.0	Above 30,000

Just like the rest of the products, bio plastics have a life cycle. However, due to the wide variety of bio plastics, the life cycle of each material differs, depending on the type of bio plastic. The degradability of bio-polymers is affected by the chemical and physical structure of the materials. As mentioned in [20] “degradability is a functional property or a disposal option at the end of the material’s life cycle”. The degradation process depends on a combination of abiotic (UV, temperature, moisture, pH) and biotic processes and parameters (microbial activity). The mass loss of plastics was calculated as follows.

Mass loss of Bio plastic = 16.9-15.89

= 1.01 gm

Assuming equal mass is lost per day.

Mass loss rate = 1.01 gm/7 days = 0.1442 gm/day

Maximum days needed to completely dis appear the 16.9 gm bio plastic are:-

Number of days = 16.9 gm/0.1442 gm/day = 117.128 days.

This is the approximate value because it considers 1.01gm bio plastic loss per week, but in reality this cannot happen due to the organisms around the bio plastic increases exponentially from day to day because the bio plastic is used as food .The relation of food (bio plastic) and number of organisms is inversely related, This means as the number of organisms increase exponentially the amount of food (bio plastic) decrease by same amount.

Therefore, the multiplication of bacteria is given by the equation

$Y = Y_o^{kt}$

Where: - Y = number of bacteria after time t

Y_o = the initial number of bacteria

T = time and K = constant

As the result shown above the bio plastic loss amass of 1.01 gm per week. To estimate the time to completely degrade the whole mass of the bio plastic use the equation $Y = Yo^{-KT}$

Where y = Final mass.

Y_o = Initial mass in gm.

T = The time needed to degrade an amount of mass.

K = Degradation constant

$$\ln 15.89 = \ln 16.9^{7k}$$

$$\ln 15.89 = 7k\ln 16.9$$

$$k = \frac{ln15.89}{7ln16.9} = 0.139$$

Now we can estimate how much time needed for bio plastic to reach at its minimum amount of mass by using the equation:-

$$\mathbf{Y = y_o^{-0.14t}}$$

The petro based plastic have no any change in a week. But it is impossible to say that petro based plastic is non-degradable. However, the degree of degradability of bio plastic is much higher than petro plastic.

D. Tensile strength test.

Table 6 Tensile strength data of selected bio plastics

Temperature (^{o}c)	Residence time(m)	A.mass (gm)	Li(cm)	Lf(cm)	Extension (cm)	Strain, ε= EXT/Li	load(N)	Stress δ= F/A(N / mm^2)
200	10	770.7	12.5	12.5	0	0	7.55	5.45
200	12	1970.8	12.1	13.06	1.5	0.124	19.31	14.86
210	10	1483.2	14.3	14.8	0.5	0.035	14.53	10.86
210	12	978.3	11.8	12.05	0.25	0.021	9.587	11.86

Tensile strength (TS) and elongation at break (EAB) show the ability of the bio plastic integrity. Tensile strength and elongation at break stress are important to determine their application. The tensile data of plastics is determined in an ideal temperature-controlled lab under short-term conditions, whereas real world operating environments apply loads over time with variable temperatures. The above table illustrates that the second bio plastics has a high plastic deformation characteristic (that is, a high elongation) with a high tensile strength as it fractures almost at the peak loading.

The above table 4.4 also shows the second has a high elongation in tension. These results demonstrate that the second bio plastics bag would be tougher than the others in mechanical loading.

Chapter Five: Material and Energy Balance

5.1 Mass balance across each unit during plastic production

Assumption: -from practical laboratory point of view for quality of plastic production the ratio of corn starch to water to be 20 gm/100 gm.

Production capacity = 926 kg/day.

The total working days = 270 days/yr.

Quantity of distilled water required to produce solution= 926 kg/day

Density of corn starch = 1792 kg/m^3

Density of glycerine =103 kg/m^3

Density of vinegar =1002 kg/m^3

Quantity of HCl required for Corn steeping 30.9 *litres/day*

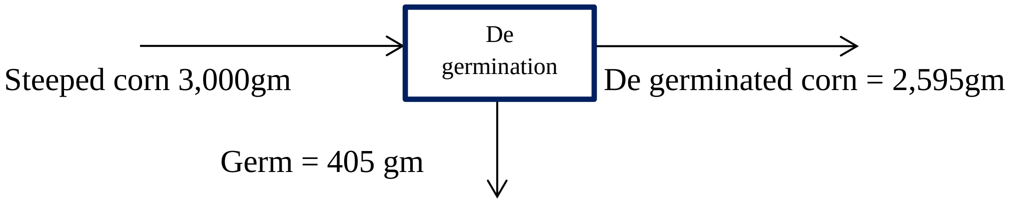
5.1 Material Balance

5.1.1 Mass Balance on laboratory scale.

Input+ generation – accumulation - consumption = out put

Assuming process is steady state process, the generation, accumulation and consumption become zero. Therefore, input =output

Mass balance on de germination

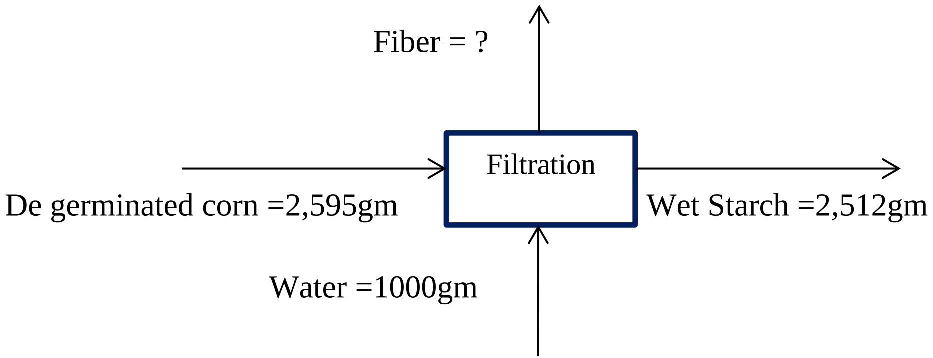


Input =output

Germ = 3,000-2,595

= 405 gm

Mass balance on Filtration

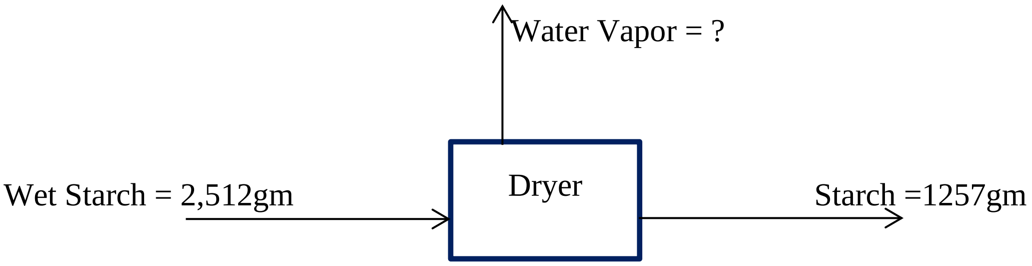


Input = output

Fiber = 2,595+1,000-2,512

=1,083 gm

Mass balance on Drying

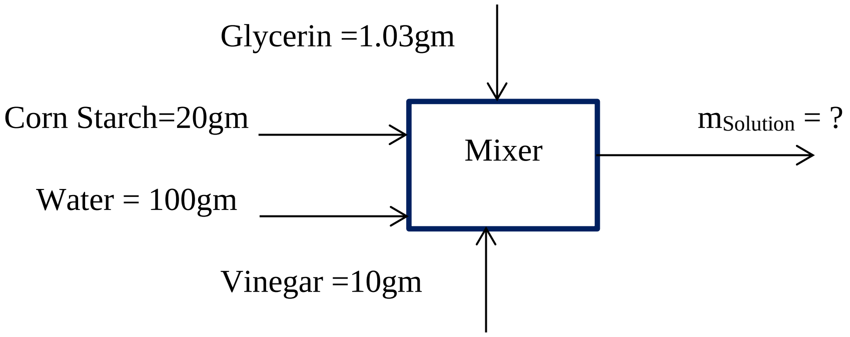


Input = output

Water Vapor = 2512-1884

= 628gm

Mass balance on Mixing

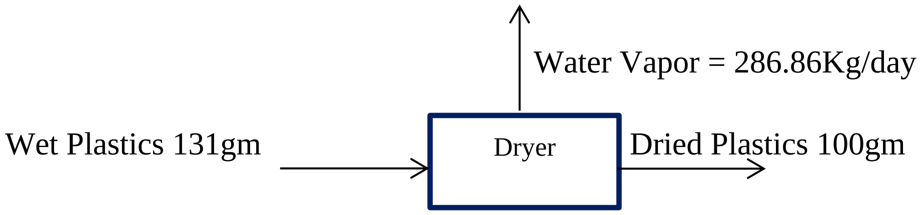


Input = output

$$m_{solution} = 100 + 20 + 10 + 1.03$$

$$= 131.03\text{gm}$$

Mass Balance on Drying



Input = output

Dried plastic = Wet Plastic –Water vapour

= 131-31 = 100 gm

After drying we have got 100gm of plastic

$$\text{Percentage water evaporated} = \frac{131-100}{131} * 100\% = 23.7\%$$

5.1.2 Industrial scale material balance

In industrial scale it is wanted to cover 5% the plastic consumption of Ethiopia. Plastic consumption of Ethiopia per year is 5,000 ton/year = 5,000,000 kg/year

Bio plastic to be produced = 926 kg/day

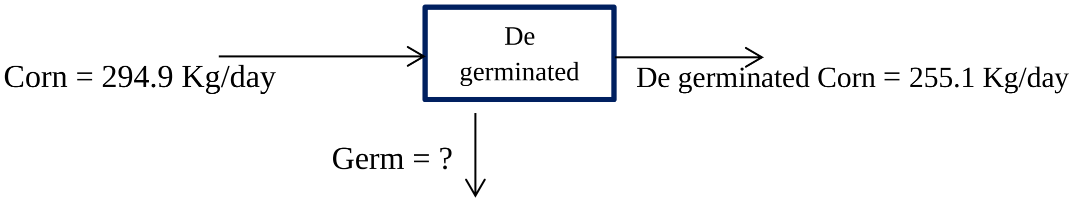
Corn = 294.9 Kg/day

Distilled Water = 926 Kg/day

Glycerine=9.26 Kg/day

Vinegar = 92.6 Kg/day

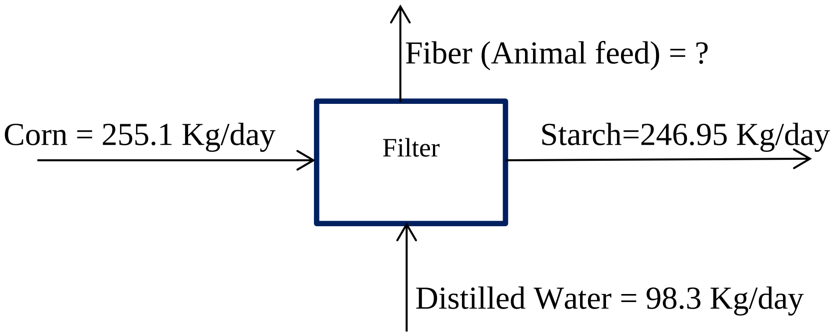
Mass balance on de germination



Input = output

Germ = 294.9-255.1= 39.8 Kg/day

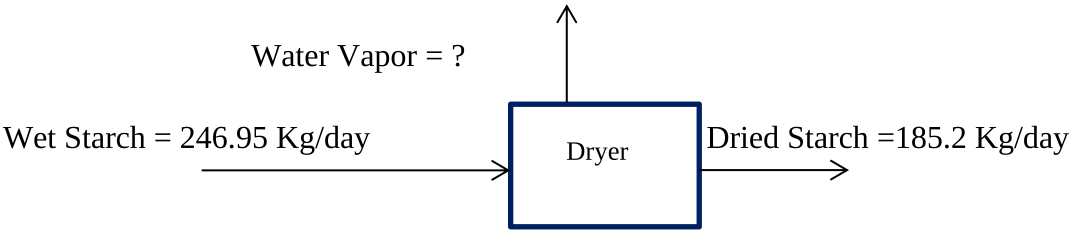
Mass Balance on Filtration



Input = output

Fiber = 255.1+98.3-246.95 = 106 Kg/day

Mass balance on Drying

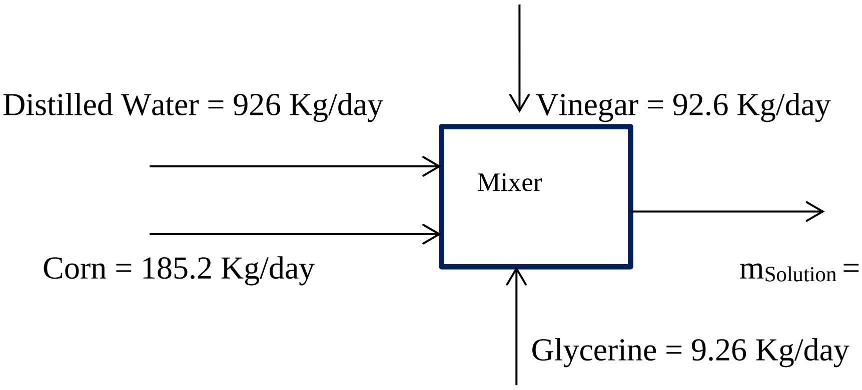


Input = output

Water Vapor = 246.95-185.2 = 61.75 Kg/day

According to Industrial scale 185.2 kg/day of dried Starch will be obtained.

Mass Balance on Mixer

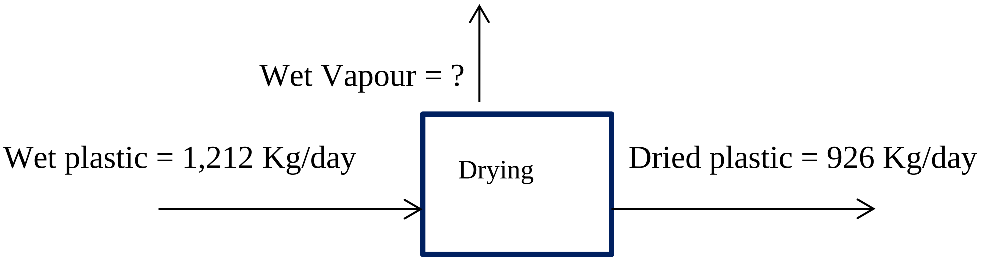


Input = output

$m_{Solution}$ = 185.2+926+9.26+92.6

=1,212.86 Kg/day

Mass balance on Drying



Input = output

Wet Vapour = 1,212.86-926

= 286.86 Kg/day

5.2 Energy balance

5.2.1. Energy balance on Dryer

Initial moisture content of Wet Starch (Y_1) = 35%

Final moisture content to be (Y_2) = 10%

Inlet temperature of Wet Starch = 25°c

Out let temperature bio plastic = 40°c

Wet starch flow rate to dryer (Gs) =246.95 kg/day

Inlet gas temperature =110°c

Gas outlet temperature =90°c

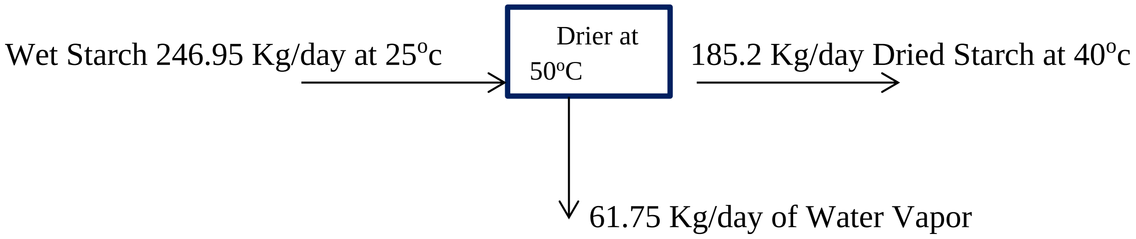
Inlet gas moisture content(X_1) =1.5%

Out let moisture content(X_2) =4.3%

Cp of gas at T=50°c=1010J/K°c

Cp of starch at T=50°c=0.8J/K°c

U-of dryer under good condition is =60W/m^2



From Conservation of energy

Energy in + Energy generation = Energy out + Energy Consumption + Energy Accumulation

But energy generation, energy Consumption and energy accumulation are zero. Therefore,

Energy in = Energy out

$$Q_{input} + Q_{supply} - Q_{vapour} - Q_{output} = 0$$

$$Q_{suppt} = mscp(Tin\text{-}Tout) + mv\lambda - mscp(Tin\text{-}Tout)$$

Where λ=2257KJ/kg

$$Qs = 926\ kg/day \times 235.9 J/kg\ (40-25)$$

$$= 3,276,651W$$

$$Qv = 61.75kg/day \times 2257KJ/kg = 139,369.75W$$

$$Qg = 12280kg/hr \times 1010J/kg^{o}C(110-90)$$

$$= 248,056,000W$$

$$Qs = Qs + Qv - Qg$$

$$Qs = 3,276,651\ W + 139,369.75\ W + 248,056,000\ W$$

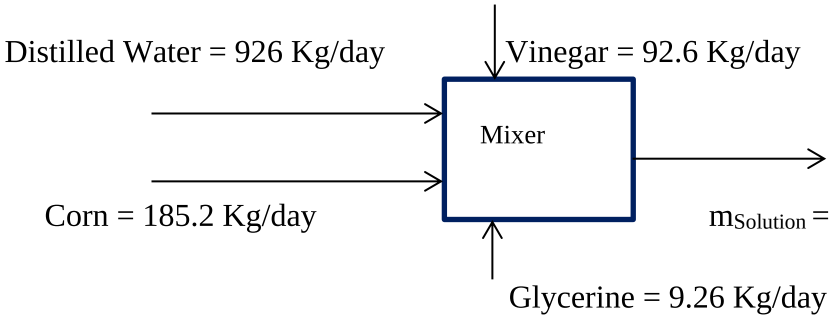
$$= 251,472,020.8\ W$$

Table 7 Physical properties of substances

Substance	Chem. formula	Mw(kg/kmol)	Input Temp(°c)	Cp (kJ/kg.k)	Mass(kg/hr)	Mass fraction
Corn Starch	$C_{27}H_{48}O_{20}$	692	25	0.8	278.3	0.298
Vinegar	CH_3CO_2H	60	25	2166.6	139.432	0.149
Glycerin	$C_3H_8O_3$	92	25	2227.2	14.3328	0.015
Water	$H2o$	18	25	4185.5	361.8	0.387
HCl solution	HCl	36.5	25	1.32	141.5	0.15
Total					1,074.5	1

5.2.2 Energy balance on reactor (Heater)

Source: www.cornstarch-raw-materials-properties.com



Heat supply + heat of reaction + input material energy- energy with output material = 0

$Qsup = Mplastic\sum^{n}_{i=1}yiCp$

QSup = (0.1526*0.8*25) + (0.7633*4,185.5*25) + (0.0076*2,227.5*25) + (0.076*2166.6*25)

Q_{sup} = 84,412.62 W

CW (cooling water) inlet temp T= 25°C

CG (corn starch) inlet T = 25°C

CG outlet, T = 90°C ………………….. Temperature of corn starch from water-bath

CW outlet T = 60°C ……………………………………………water from jacket

Reactor temperature T = 200°C

Approaches minimum temperature differences of the cooling jacket and the reactor

$\Delta T1=110 – 80= 30^oC =303^oK$

ΔT2= 110 – 25= 85 ^oC = 385^{o}K

$$\text{LMTD} = \frac{\Delta T1 - \Delta T2}{ln\,[\Delta T1\,/\Delta T2]} = 329.730$$

Heat of Reaction

Heat Removable by Jacket

UD = 550 W/ m2.^{0} K…………………………. Design Overall Coefficient

Q = ΔH r = 1.1 x 10^6 kJ/hr……..…..minimum amount of energy needed for

Reaction

Qj = UD x A x LMTD

= 550 W/ m2.^{0}K *0.58 m^2 *329.73^{0}K

=32511.4J/hr =32.5kJ/hr

Since heat of reaction (1.1 x 10^6 kJ/hr) > heat removable by jacket (721.034 kJ/hr) our design for a cooling jacket is justified in comparison with a cooling coil.

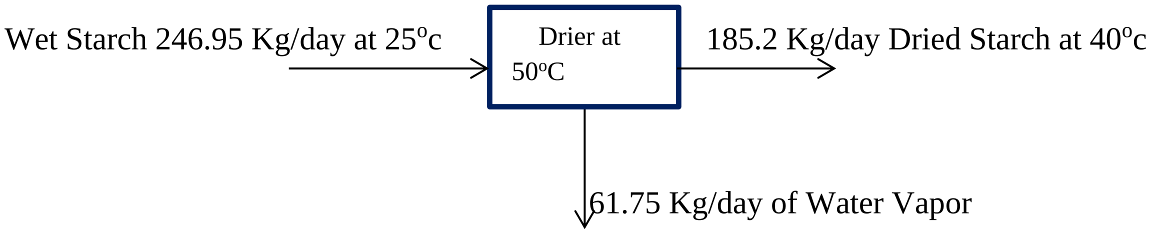
Now Cooling water Flow rate can be calculated as:

Heat to be removed from reactor = 1.1 x 10^6 kJ/hr.

$$\text{Mass flow rate of water} = \frac{Q}{Cp\Delta TLMTD}$$

$$= \frac{1.1\ x\ 106\ kJ/hr}{4.2kJ/kg0\ K * 329.730K} = \ 794.3\ \text{kg/hr.}$$

5.2.2 Energy balance on Dryer



Initial moisture content of Wet Starch (Y_1) = 35%

Final moisture content to be (Y_2) = 10%

Inlet temperature of Wet Starch = 80^{o}c

Out let temperature bio plastic = 100^{o}c

Wet plastic flow rate to dryer (Gs) =1,212.86 kg/day

Inlet gas temperature = 110^{o}c

Gas outlet temperature = 90^{o}c

Inlet gas flow rate to dryer = 12,280 kg/hr

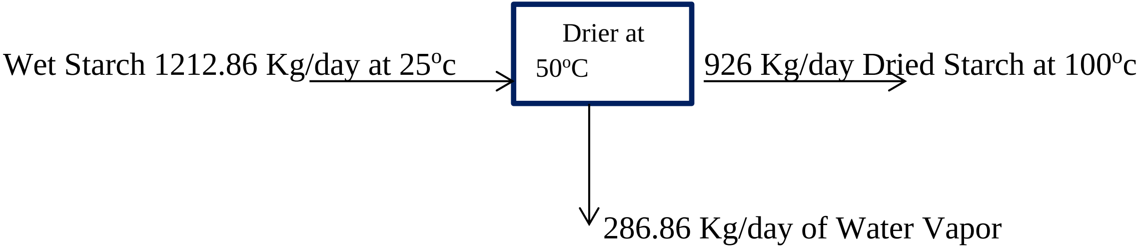
Inlet gas moisture content(X_1) = 1.5%

Out let moisture content(X_2) = 4.3%

Cp of gas at T = 50^{o}c = 1,010 J/K°C

Cp of starch at T = 50^{o}c = 0.8 J/K°C

U-of dryer under good condition is = 60 W/m^2



Ein=Eout

$$Q_{input} + Q_{supply} - Q_{vapour} - Q_{output} = 0$$

$$Q_{supply} = Q_{vapour} + Q_{output} - Q_{input}$$

$$Q_{suppt} = mscp(Tin\text{-}Tout) + mv\lambda - mscp(Ti\text{-}Tout)$$

Where λ=2257 KJ/kg

$$Qs = 926\ kg/day \times 235.9\ J/kg\ (100-80)$$

$$= 4{,}368{,}868\ W$$

$$Qv = 286.86\ kg/day \times 2257\ KJ/kg$$

$$= 647{,}443.02\ W$$

$$Qg = 12{,}280\ kg/day \times 1010\ J/kg^{o}C(110-90)$$

$$= 248{,}056{,}000\ W$$

$$Qs = Qs + Qv - Qg$$

$$= 4{,}368{,}868\ W + 647{,}443.02\ W + 248{,}056{,}000\ W$$

$$Q_S = 253{,}072{,}311\ W$$

Over all material balance

GS (Y1 – Y2) = Mg (X1 – X2)

1074.5(0.67-0.35) = Mg (0.043-0.015)

The air flow rate should Mg=12,280 kg/hr

5.3 Equipment sizing

5.3.1. Reactor Sizing

The following parameters are taken from the stirrer design.

Space between jacket and reactor vessel depend on the size of the vessel which typically range from 50 mm for small vessel to 300 mm for large vessel.

A gap 75 mm is selected as space between the two.

Diameter of jacket D_J =2.64 m

Diameter of vessel D_V = 2.5 m

Cooling fluid used = Cooling Water.

Cooling Jacket area available (A) = $\frac{\pi}{4}(D_J^2 - D_V^2)$

$$= \frac{\pi}{4}(2.643^2 - 2.5^2)$$

$$= 0.58\ m^2$$

Since the reactor is cylindrical

$$V = \left(\frac{DV}{2}\right)^2 * H \text{ but, } H/D = 1.5 \text{ and } H = 2.5 \times 1.5 \quad \text{thus, } H = 3.75 \text{ m}$$

$$V = \left(\frac{2.5}{2}\right)^2 * 1.5 * 2.5$$

$$= 18.4 \text{ m}^3 \text{ and } 10\% \text{ allowance}$$

$$= 20.24 \text{ m}^3$$

$$= 5{,}283.4 \text{ galon}$$

Wall thickness of the reactor

Working Pressure of Vessel (P) = 200 kPa

Density of the material (ρ) = 1,200 kg/m^3

Joint Efficiency, Ej = 0.80

Material of Construction = Carbon Steel

Maximum allowable pressure=1,795.8 kpa

$$\text{Static Pressure (P)} = \frac{\rho * g * H}{1{,}000}$$

$$= \frac{1{,}200 * 9.81 * 2.053}{1{,}000}$$

$$= 24.14 \text{ kpa}$$

$$\text{Total Pressure (Ps)} = \text{Pst} + \text{P} = 224 \text{ kpa}$$

$$\text{Maximum allowable pressure} = 1.25 * 224$$

$$= 280.2 \text{ kpa}$$

$$= 2.802 \text{ bar}$$

$$\text{Thickness (t)} = \frac{(Pi * Di)}{(2f * j) - Pi}$$

$$= \frac{(286 * 2.5)}{(2 * 0.8 * 1795) - 286}$$

$$= 31 \text{ mm}$$

Corrosion allowance = 2 mm

Therefore, wall thickness = 31 + Cc

= 31 + 2

= 33 mm

There are three types of heads:

1. Ellipsoidal head
2. Tori spherical head
3. Hemi spherical head

Ellipsoidal head and hemi Spherical head are used for pressure greater than 10 bar and are expensive; but for pressure less than 10bar we use tori spherical heads.

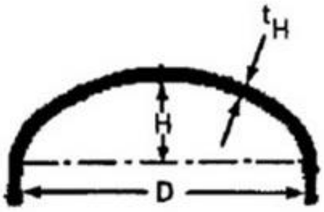


Figure 7 Tori spherical head

Thickness of the head.

$$t = \frac{0.885 * Pi * Rc}{(SE) - (0.1 * Pi)}$$

$$t = \frac{(0.885 * 280 * 2.5)}{(0.8 * 1795) - (0.1 * 280)}$$

t = 16mm

With corrosion allowance t =18mm

5.3.2. Dryer sizing

A = Q ÷ [U × {T – (t1 + t0)/2}]

A = 202,016.97 W ÷ [60W/m^{2o}C (110-20)**]**

$= 37.41\ m^2$ with 10% allowance

$= 41.15\ m^2$

$= 49.3\ yard^2$

The dryer is next to the reactor so, in order to carry the product it must be greater than or equal to the reactor in volume.

V = 5,283.4 galon

Storage tank

Storage tank can accommodate products that are produced over a month

Density of bio plastic...1,300 kg/m^3 [22]

Production per day...926 kg

Production per month..27,780 kg

$V = 27,780/1,300$

$V = 21.4\ m^3$ and 10% allowance

$= 23.54\ m^3$

Chapter Six: Site Selection and Financial Evaluation.

6.1. Financial Evaluation Assumptions

- The plant works 24 hour per day and contains 3 shift per day and 5 days per week.
- Construction period 1 year
- Plant operates 270 days/yr.
- Tax rate based on our country rule and regulation = 25%
- The service life of the plant estimated to be 20 yrs and required land is 600 m^2

From statically data on for $100m^2$ of land = 90,000 birr is required; i.e 540,000 birr is invested for land purchasing. The financial analysis of our plastic production plant project is based on the current raw material cost tabulated & the diagrammatic relationship of different costs will be correlated as follows.

Table 8 Man power requirement and their monthly and annually salary.

#	Description	Quantity	Monthly Salary ($)	Annual Salary ($)
1	Plant manager	1	600	7,200
2	Quality Control Service Head	1	500	6,000
3	Executive secretary	1	400	4,800
4	Planning and programming	1	450	5,400
5	Telephone operator	1	200	2,400
6	Administration Department	1	700	8,400
7	Production and sales head	1	650	7,800
9	Purchase head	1	400	4,800
10	Nurse	1	310.9	3730.07
11	Cleaners	2	250	6,000
12	Operators	3	500	18,000
13	Guards	2	300	7,200
14	Drivers	1	700	8,400
Total		17	14,750	90,130.07

Source: www.maches./equipment

6.1.1 Estimation of total capital investment cost.

Direct cost

Table 9 List of direct costs of the project

Direct Cost	Cost in $
Purchased equipment cost (PEC)	54,918
Installation (47%) of PEC	25,811
Instrumentation and controls (18%) of PEC	9,885
Buildings (including services) (18%) PEC	9,885
Service facility and yard 70% PEC	38,442
Land 6% PEC	3,295
Total Direct Cost	145,608.9

Indirect Cost (IC)

Table 10 List indirect costs of project.

Indirect Cost (IC**)**	Cost in $
Engineering and supervision	90,000
Construction expenses	5,000
Total indirect cost(IC)	***160,000***

Fixed capital investment cost (FCI) = DC+IC

= *$145,608.9+$160,000*

= $305,608.9

Contingency 10% (FCI) =$17921

6.1.2 Estimation of total production cost

Operating labor cost 10% of TPC (OL) = $ 157680

$$\text{TPC} = \frac{157680}{0.1}$$

TPC = $1,576,800

Fixed charge cost (FCC)

Table 11 List of Fixed charge costs.

Fixed charge cost (FCC)	Cost in $
Depreciation (10% of FCI)	17,921
Local taxes (4% of FCI)	7,168
Insurance (0.8% of FCI)	1,433
Total fixed charge cost	26,522

Direct production cost

Table 12 List of direct production costs.

Direct production cost	Cost in $ Per year
Raw material cost (11% of TPC)	173,448
Direct supervisor and clerical labor (12% of OL)	18,921
Operating labor (OL) (10% of TPC)	157,680.
Utilities (13% of TPC)	204,984.
Maintenance and repair (3% of FCI)	5,376
Operating supplies (0.5% of FCI)	896
Laboratory charge (11% of OL)	17,344
Patent and royalties (2% of TPC)	31,536
Total	610,185

Plant overhead cost (POC)

POC (60% of OL) --= $94608

Indirect Production Cost = Fixed Charge + Plant Overhead

IPC = FCC + POC

= $94,608+$26,522

= $121,130

Manufacturing cost = direct product cost + indirect production cost

MC = $2,142,236+$3,236,980

=$5,379,216

General expense

Administrative cost (AC)

Administrative cost (AC) -- = $63072

Distribution and selling (DS) (8% of TPC) ------------------------------- = $30,000

Research and development cost (RDC) (5% of TPC) ------------------ = $25,276.93

Total general expense = Administrative cost (AC) + Distribution and Selling cost (DSC) + Research and development (RDC)

= $63,072+$30,000+$25,276.93

= $ 118,348.93

Total cost (TC) or working capital = Manufacturing cost + General expense

= $90,130.07+$118348.93

= $208,479

Total capital investment (TCI) = FCI + TC

= $5,179,216+$3,647,272

Table 13 Products and their prices

Product or By product/s	Price per Kg in $	Annual sell income in $
Bio plastic	1.58	395,031.5/yr
Fiber	0.5	14,310/yr
Germ	2	21,492/yr
	Total	430,219.6

Gross profit = total income – total product cost

GP = \$430,219.6/yr - \$90,130.07/yr

= \$340,088.9/yr

Annual tax = 35% total annual income

= 0.35×\$340,088.9/yr

= \$119,031.115/yr

Net profit = Gross profit - Annual tax

=\$340088.9/yr - \$119031.115/yr

= \$221,057.8/Yr

Rate of return on investment (RRI)

Assume minimum acceptable rate of return (mar) = 15% and assuming a 15 years' service life, Net profit average =

$$\text{RRI} = \frac{net\ profit\ average}{total\ capital\ investment} * 100$$

$$= \frac{\$221{,}057.8/Yr}{\$514{,}087.9/yr} * 100$$

$$= 43\%$$

Payback period

Payback period = total capital investment-working capital/ (net profit/yr + Depression/yr)

$$= \frac{total\ capital\ investment - working\ capital}{net\ profit/yr + Depression/yr}$$

$$= \frac{\$514{,}087.9/yr - \$208{,}479/yr}{\$221{,}057.8/yr + \$8{,}723.3/yr}$$

$$= 1.4\text{yrs}$$

Since the payback period is less than 5 years the project is feasible and acceptable. [20]

6.2. Site selection

It is obvious that plastic is a highly demandable goods and services in the whole part of Ethiopia. To select proper locations and sites, certain key requirements or criteria should be set, that would allow the assessment of a number of potential locations, and the rejection of those not fulfilling those requirements. The remaining alternatives are subject to a more in-depth qualitative and quantitative analysis of technical and financial criteria, including social, environmental and economic aspects of location and site selection. The selection of this site is based on the following conditions.

1. The selected site is near to raw material source, so that the transportation cost to the site is the minimum.

2. The cost of transporting finished goods, advertising and distribution is reduced since it is located near to the capital Addis Ababa.

3. Labor cost is an important item of the total production in manufacturing and in the selected site labor is highly available and the cost of labor is very cheap.

Depending on those reasons, Sebata was selected for the production of bio plastic plant. This location has additional benefit in reducing waste from handling and deterioration from changes during long transportation after processing.

Plant lay out for bio plastic production.

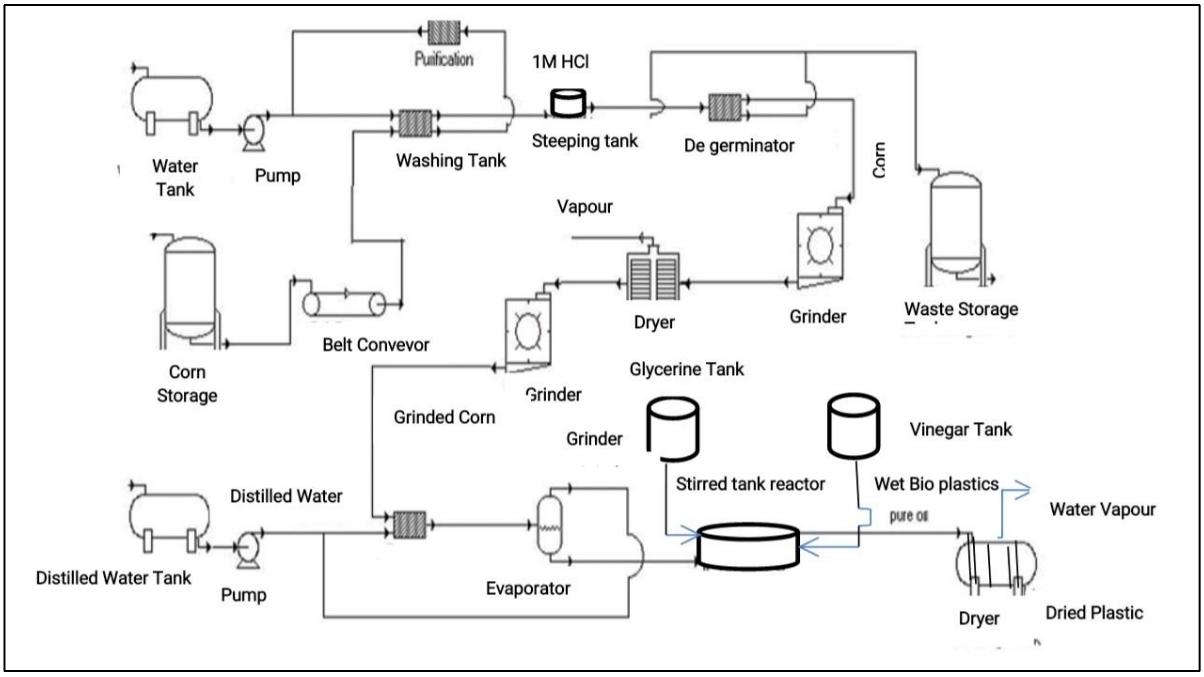


Figure 8 Plant lay out of Bio plastic production.

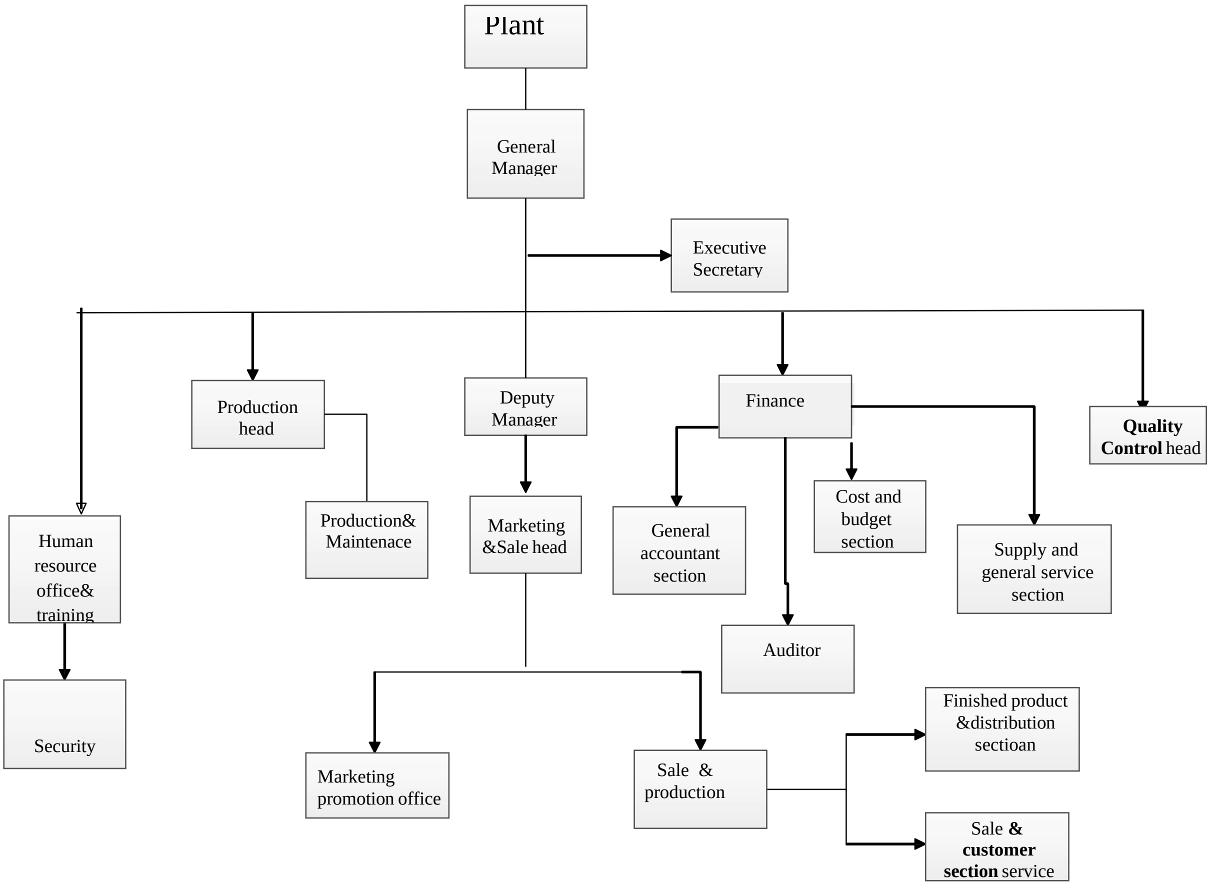


Figure 9 Overall Organization

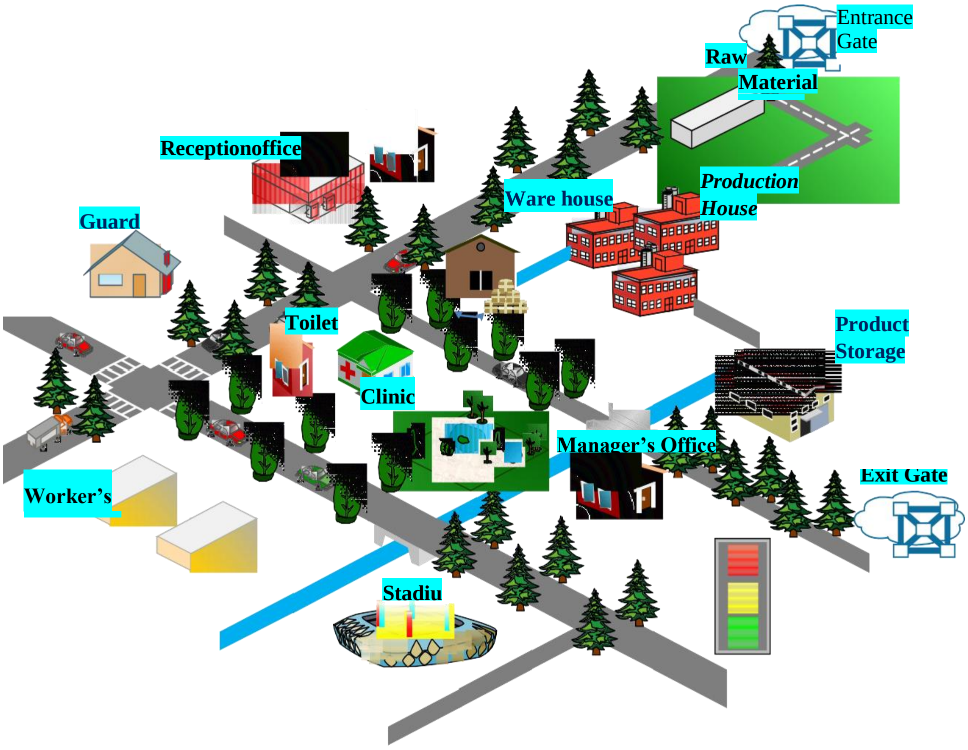


Figure 10 Bio plastic production Factory.

Chapter Seven: Conclusion and Recommendation

7.1 Conclusion

Generally, it can be concluded that bio plastics can be successfully produced from corn starch, glycerin, Vinegar and Distilled Water. Temperature and duration time were the considered parameters for investigation. Under this investigation temperature range; 200°C-210°C, heating time were considered.

From the experimentation it was found that optimum bio plastic production was obtained at temperature 200°C by thoroughly mixing and heating for 12minutes. This final year project is feasible from the economic point view in that its rate of return on investment (ROI) is 43%, which is greater than the minimum acceptable of return (MAR) value, and the payback period (PBP) is 1.4years, which is less than five years.

Finally, it can be concluded that the industrial utilization of corn starch for production of bio plastic would not only solve the problem of waste disposal but also save valuable foreign exchange by reducing the plastic imports and by using the general factorial analysis and reduce environmental pollution.

7.2 Recommendation

Further researches are recommended to improve the production of high quality and quantity of bio plastics by further characterizing the variety of Corn to be used to extract the starch of the corn.

Produced plastics were characterized only by tensile strength test, Soil degradation test, Heat resistance test and water absorption test it is recommended to use other methods of characterization such as Fourier transform infrared spectroscopy analysis, Thermo gravimetric Analysis, Scanning electron microscope analysis for good characterization results.

Here in the experimental work, effect of different compositions with different ratios of raw materials (i.e. compositions and ratios of Glycerine, Vinegar, Water and starch to each other) were not tested, for further information and detail knowledge these should be studied.

The time scope of this project was too short, as a result of this it was difficult to deeply and accurately characterize the produced plastics; more extended time scope is recommended for accurate and good characterizations.

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Appendix

Table 14 Appendix, A: Bio plastic raw materials properties

Substance	Chem. formula	Mw (kg/kmol)	Cp (kJ/kg.k)
Corn Starch	$C_{27}H_{48}O_{20}$	692	0.8
Vinegar	CH_3CO_2H	60	2166.6
Glycerin	$C_3H_8O_3$	92	2227.2
Water	H_2O	18	4185.5
HCl solution	HCl	36.5	1.32