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Biodegradable Plastic from Starch

Prof. Gitanjali Pawar[1], Miss. Sanika Maharnawar[2], Miss. Kaveri Manchare[3], Miss. Kajal Kute[4], Mr. Ramahari Labde[5]
Prof. Computer Department [1]
Student, Information & Technology Engineering Department [2]
Student, AIDS Engineering Department [3]
Student, Information Technology Engineering Department [4]
Student, Civil Engineering Department[5]
Adsul's Technical Campus, Ahilyanagar, India [5]

Abstract: *The diversity and ubiquity of plastic products substantially testify to the versatility of the special class of engineering materials known as polymers. However, the non-biodegradability of these petrochemical-based materials has been a source of environmental concerns and hence, the driving force in the search for 'green' alternatives for which starch remains the frontliner. Starch is a natural biopolymer consisting predominantly of two polymer types of glucose namely amylose and amylopectin. The advantages of starch for plastic production include its renewability, good oxygen barrier in the dry state, abundance, low cost and biodegradability. The longstanding quest of developing starch-based biodegradable plastics has witnessed the use of different starches in many forms such as native granular starch, modified starch, plasticized starch and in blends with many synthetic polymers, both biodegradable and non-biodegradable, for the purpose of achieving cost effectiveness and biodegradation respectively. In this regard, starch has been used as fillers in starch-filled polymer blends, thermoplastic starch (TPS) (produced from the combination of starch, plasticizer and thermomechanical energy), in the production of foamed starch and biodegradable synthetic polymer like polylactic acid (PLA) with varying results. However, most starch-based composites exhibit poor material properties such as tensile strength, yield strength, stiffness and elongation at break, and also poor moisture stability. This therefore warranted scientific inquiries towards improving the properties of these promising starch-based biocomposites through starch modification, use of compatibilizers and reinforcements (both organic and inorganic), processing conditions, all in the hope of realizing renewable biodegradable substitutes for the conventional plastics.*

Keywords: Starch, biodegradable, material properties, composites, synthetic polymers

I. INTRODUCTION

The disposal problems associated with conventional oil-based plastics constitute grave environmental menace across the globe considering the amounts churned out as waste on a regular basis. Bearing in mind that some plastics (particularly thermosets) are not recyclable; the recycling option faces additional problems of high energy consumption and difficulties arising from contaminants and fiber reinforcements (Widmer, 2003). In addition, the option of recycling is becoming increasingly impractical with the production of complex multi-phased products. In 2005, the US alone generated about 28.9 million tons of plastic waste (11.8% of the total 245.7 million tons of municipal solid waste) with only a very small amount of about 1.7 million tons (5.7% of the total plastic waste) recovered for recycling while discarding the remaining 27.3 million tons (about 16.4% of the total municipal solid waste discards) to landfills (EPA, 2006). The container and packaging category constituted the highest tonnage. This is quite understandable since these products are mostly single-use items. Therefore, the current revolution taking place in the plastics industry is aimed at developing novel plastics possessing material properties comparable to their conventional counterparts coupled with the added advantage of biodegradability. Tremendous efforts are indeed underway towards building and perfecting this new generation of

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plastics tagged bioplastics or "green plastics" with renewable resources as the base materials. In addition, this class of plastics is capable of significantly reducing environmental impact such as energy consumption and greenhouse effect in certain applications (Bastioli, 2001). Patel (1999) reported that 0.8-3.2 tons of CO2 per ton of plastic could be saved using starch-based plastics. Needless to say, starch, an abundant naturally occurring biopolymer, remains at the core of this campaign. Starch consists predominantly of two types of polymers of glucose namely, amylose and amylopectin. Amylose is essentially a linear polymer of glucose linked together by α-1,4 bonds while amylopectin is a branched polymer consisting of both α-1,4 and α-1,6, glucosidic linkages, with the latter found at branch points (Gallant et al., 1992). The amylose/amylopectin ratio, which is a function of the starch source, is significant as it affects some physicochemical properties of starch which, in turn, influence its functionality and eventual applications. The advantages of starch for plastic production include its biodegradability, renewability, good oxygen barrier in the dry state, abundance and low cost (Thunwall et al., 2006). In this regard, starch has been used as fillers, thermoplastic starch (TPS), in the production of biodegradable synthetic polymer like polylactic acid (PLA), foamed starch and starch-synthetic polymer blends.

Starch as Fillers:

Starch has been incorporated into conventional plastics in an attempt to impart some level of biodegradability on the resulting composites. Starch is a good biodegradable filler candidate because it possesses satisfactory thermal stability and causes minimum interference with meltflow properties of most materials used in the plastic industry unlike common cellulosic fillers such as woodflour and paper pulp that were found to interfere with flow properties. A remarkable success was recorded when starch was experimented with low-density polyethylene even during critical film extrusion process (Griffin, 1974). Since starch is hydrophilic, as opposed to plastics that are generally hydrophobic, there is therefore poor starch-polymer interfacial interaction with a resultant loss of mechanical properties (Albertsson and Karlsson, 1995) in starch-filled polymer composites. In other words, high surface energy between the hydrophobic polymer (say, polyethylene) and hydrophilic starch yields low degree of adhesion. In a perfect adhesion scenario, loading stresses would be transferred to the filler phase without any reduction in the effective surface area (Willet, 1994). However, a stronger interaction between the starch granules and the plastic matrix can be achieved with gelatinized or 'destructured' starches (Ellis et al., 1998). In addition, starch can also be used for this purpose in the chemically modified form (Takagi et al., 1994). Upon exposure to microbial activities, the composite structure is weakened as a result of the degradation of the starch component (Vallini et al., 1994), thus leading to a partial breakdown process referred to as biofragmentation. The granule size is an important factor in choosing the appropriate starch for composite use especially in the production of thin films (Lim et al., 1992). At constant filler content, modulus, tensile stress and yield stress decreased with increase in particle size. Nonetheless, Willett (1994) noted that adhesion played a greater role than particle size on starch-polyethylene composite tensile strength.

II. LITERATURE REVIEW

The growing environmental concerns associated with petroleum-based plastics have led to increased interest in biodegradable alternatives, particularly starch-based bioplastics. Several studies have explored the properties, processing techniques, and applications of starch-based bioplastics, highlighting their potential as a sustainable material. Starch as a Biopolymer: Starch, a naturally occurring polysaccharide found in plants, has been widely studied as a raw material for bioplastic production. According to Avérous and Halley (2009), starch is an abundant and renewable polymer capable of forming biodegradable films. However, native starch has poor mechanical properties and highwater sensitivity, which necessitates modifications through plasticization or blending with other biopolymers (Shah et al., 2015). Plasticization of Starch-Based Bioplastics: To improve the flexibility of starch bioplastics, plasticizers such as glycerol, sorbitol, or polyethylene glycol are commonly used. Research by Mali et al. (2006) found that glycerol effectively reduces starch film brittleness by increasing polymer chain mobility. However, an excess of plasticizer may weaken the material, making it overly soft and sticky (Krochta & De Mulder-Johnston, 1997). Influence of Acetic Acid on Bioplastic Properties: Acetic acid (vinegar) is often incorporated to break down starch granules and enhance gelatinization. Studies by Pelissari et al. (2012) indicate that acid modification improves starch dispersion, film transparency, and mechanical properties. However, excessive acid content may lead to excessive hydrolysis, weakening the bioplastic structure (Ma et al., 2008). Environmental Impact and Biodegradability: One of the major advantages of starch-based plastics is their biodegradability. Research by Thakur et al. (2014) demonstrated that starch bioplastics degrade within weeks to months, depending on environmental conditions. Unlike synthetic plastics, which persist for centuries, starch-based materials can be decomposed by microorganisms, making them a viable solution to plastic pollution (Narayan, 2010)

III. PRODUCT DESCRIPTION

A. Product Uses:

- There are various areas of applications of the PLA plastics pellets: 1. Some of the most common areas of application are the manufacture of plastic films, plastic bottles, plastic bags, etc.
- Secondly, a lot of biodegradable medical devices are made from the PLA plastic pellets (e.g. screws, pins, rods, and plates that are expected to biodegrade within 6-12 months).
- PLA constricts under heat and hence suitable for use as a shrink wrap material.
- The ease with which Polylactic Acid melts allows for some interesting applications in 3D printing.

B. Raw Material Requirement:

The raw materials required for the production of PLA pellets are “Crops and Crop resides”. While the direct sources of the sugar and starch such as corn, wheat, rice, etc. are termed as the “First-Generation” raw material, the Crop residues are termed as the “Second-Generation” raw materials. The raw materials are fermented by the bacteria of the Lactobacillus genus such as Lactobacillus delbrueckii, L. amylophilus, L. bulgaricus and L. leichmanni. After the Polylactic acid has been prepared, it is mixed with a number of other substances depending on the purpose of the usage of the pellets. These include:

- Plasticizer such as Glycerol, Ethylene Glycol, Polyglycerol, etc. (2 – 30) %
- Flexibility agent like Urea, Citric Acid, Polyvinyl Alcohol. (10 – 40) %
- Binder such as Stearic acid, glycerol monostearate, montmorillonite, etc. (3 – 13) %
- Hydrophobic agent (0.1 – 5) % • Emulsifier (0.1 – 5) %

C. Manufacturing Process:

There are a number of steps for the formation of PLA which include 1) Direct Condensation Polymerization, 2) Azeotropic Dehydrative Condensation, and 3) polymerization through “lactic acid formation”. Currently, direct condensation and polymerization through lactic acid formation are the most used production techniques:

1. The process begins with the procuring of the raw materials from the agricultural fields. This can be sugarcane, corn, wheat, rice, or any other source of starch. If they are seeds then screened properly and then dried in the oven. They are then chopped into fine pieces or ground into fine particle in a Hammer mill for a higher surface area and better fermentation process. If they are juicy crops then they are crushed in the Milling machine.
2. The starch/ sugar present in the crops are then converted to simple sugar acids (lactic acid). The starch/ sugar of the crops is first converted to glucose by either Acidic or Enzyme hydrolysis. The glucose formed can either be “Crystallized” or used as the liquid concentrate for the conversion to the Lactic Acid.
3. The next step takes place in the Fermentation Tank. The pH and the temperature of the medium are kept in control. The pH ranges from 5.4 – 6.4, while the temperature ranges from 38 – 42 °C. This is an aerobic “Homofermentative reaction”, so the process takes in the presence of oxygen in fermentation tanks. In this process, 100 g of glucose produced can give rise to 90 g of Lactic Acid. Glycolysis is the first step in this conversion where the glucose is converted into different intermediates and then gets converted to Lactate. Lactic acid is the final product of the hydrolysis of glucose.

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4. After the formation of the Lactic acid, the resultant solution is then transferred from the Fermentation tank to the acidifying tank, where the solution is acidified and then it is filtered. The filtrate is then purified. The purification of lactic acid is a difficult process because of the low volatility and the high solubility is water. To overcome these problems, lactic acid is converted to its ester by reacting it with an alcohol to give the "Lactate Ester". The lactate ester is purified by distillation, and then hydrolyzed to obtain pure lactic acid.
5. Polymerization of the Lactic acid can be done by three steps as mentioned earlier at the start of this section. Out of those steps, Direct Polycondensation is the most opted step to carry out the conversation.
6. The process starts with the conversion of the Lactic acid to Oligo-Lactic Acid at 200 – 250 °C for a period of 6 – 8 hours, the Oligo-Lactic Acid is then converted to Lactide by the cyclization reaction. The lactide formed is purified by distillation and crystallization process to get pure Lactide. Finally the Lactide is converted to Polylactic acid at 200 – 250 °C after 48 hours and this takes place after being fed to a series of loop and plug-flow reactors. At temperatures above 260 °C, the cyclization reactions starts resulting in the formation of the "Lactide" while at temperatures lower than 200 °C, the amount of water formed is high and this can degrade the quality of the product formed, hence an optimum temperature is very important for the Polycondensation process. The water formed must be continuously removed with the help of a vacuum system.
7. After the formation of the PLA, the remaining volatile components in the medium are separated using the degassing the PLA melt.
8. After the separation, different components are mixed with the PLA melt that includes the plasticizers, binder, flexibility agent, emulsifying agents, and colorants in a static mixer.
9. The mixture is sent through to the Pelletizer to convert the melt into pellets. After they have been pelletized, the PLA pellets are extracted from the pelletizer and then allowed to solidify. They are then sent for the quality check to see if all the properties are okay. They are then filled in plastic bags as per the capacity required, weighed, and stored in the storage area.

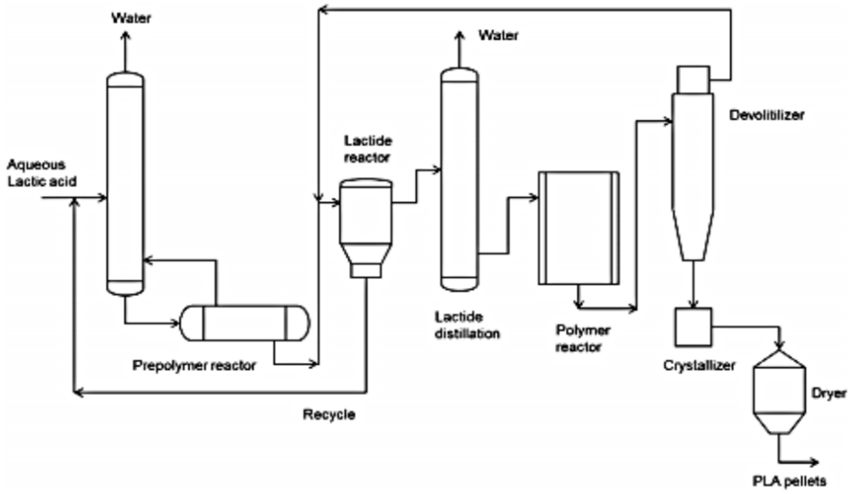

Fig. 1: Schematic diagram of the manufacturing process

D. Yield of Product/ Production Ratio:

The annual production capacity of this Biodegradable Plastic Pellet Plant is something between 1000 Tonne – 500, 000 Tonne per year depending upon the capacity of the machines used. This project is prepared based upon the new manufacturing startup with a production capacity of 1000-1500 Tonne plastic pellets per annum.

IV. METHODOLOGY

This study aims to develop biodegradable plastic using starch, an abundant and renewable biopolymer. The methodology involves formulation, processing, and characterization of starch-based bioplastic using natural ingredients such as cornstarch, water, glycerol, and vinegar.

Fig. 2: Potato Starch

Selection of Raw Materials: Starch (potato starch) serves as the primary polymer, water acts as a solvent to dissolve and gelatinize the starch, glycerol functions as a plasticizer, enhancing flexibility. Vinegar modifies the starch structure for better consistency.

Preparation of Bioplastic Formulation: The starch is mixed with water in specific proportions to create a homogeneous solution. Plasticizer (glycerol) and vinegar are added to alter the mechanical properties.

Heating and Gelatinization Process: The mixture is heated on a hot plate while being stirred continuously. The heating process enables gelatinization, where starch granules swell and form a thick, paste-like structure.

Casting and Molding: The thickened mixture is poured onto a mold or a flat surface to achieve the desired shape. The material is spread evenly to maintain uniform thickness.

Drying and Solidification: The bioplastic film is left to dry at room temperature for 24–48 hours. The drying process allows water evaporation, solidifying the material into a flexible, plastic-like sheet. This methodology provides a systematic approach to producing biodegradable plastic, demonstrating a sustainable alternative to conventional petroleum-based plastics.

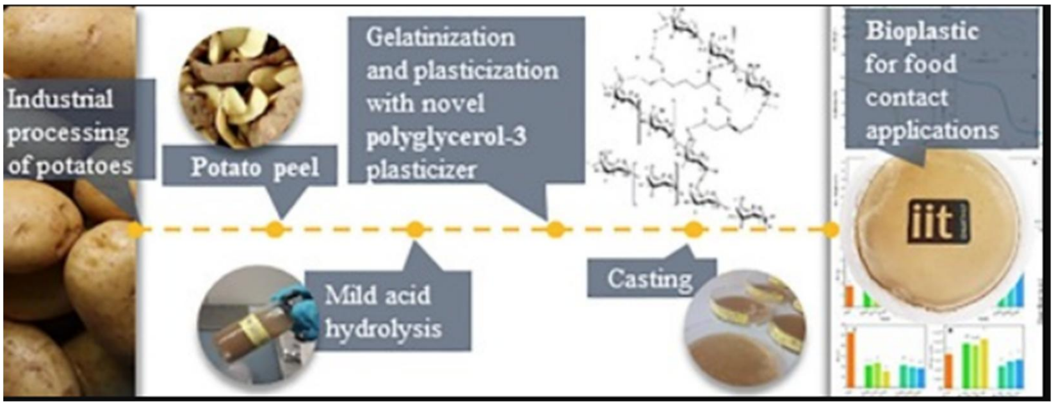

Fig. 3: Process

V. RESULT & DISCUSSION

Result:

Biodegradability: The starch-based plastic samples decomposed significantly faster than conventional plastic when exposed to natural conditions such as soil and water. Within a few weeks, visible degradation was observed, confirming their biodegradability. Mechanical Properties: The tensile strength and flexibility of the starch-based plastic were lower compared to traditional petroleum-based plastics. However, blending starch with plasticizers like glycerol improved flexibility. Production Feasibility: The plastic was successfully synthesized using simple and cost-effective methods, making it a viable option for small-scale and industrial production. Environmental Impact: The material showed no toxic effects during degradation, confirming its eco- friendliness.

Discussion

Sustainability and Eco-Friendliness: The results confirm that starch-based bioplastics are a sustainable alternative to conventional plastics. Since starch is biodegradable and derived from renewable sources, it offers a reduced carbon footprint. Challenges and Improvements: While the material showed promise, its mechanical strength and water resistance remain key challenges. Future improvements can focus on blending starch with other biodegradable polymers (such as PLA or PHA) and optimizing plasticizer concentrations. Industrial and Commercial Potential: The ease of production and availability of raw materials make starch-based plastics a strong candidate for replacing conventional plastics in packaging, disposable cutlery, and agricultural applications. However, large-scale production requires cost-effective modifications to enhance durability. Future Prospects: With continuous research and technological advancements, starch-based bioplastics can be further developed to meet industrial standards. Government policies and consumer awareness will play a crucial role in promoting their adoption

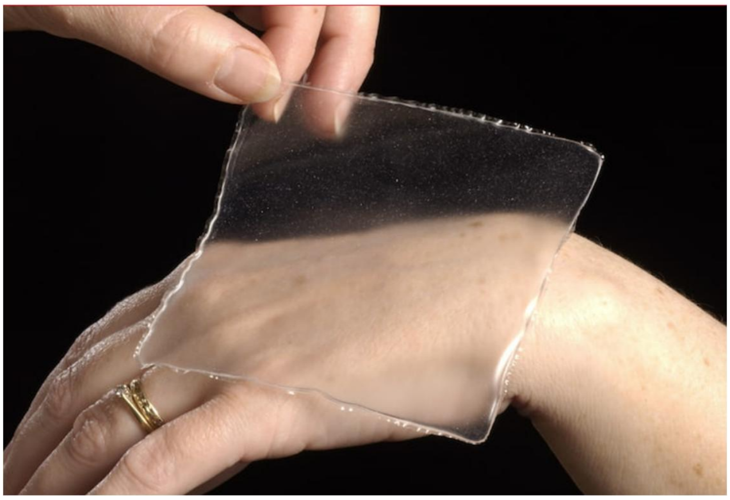

Fig. 1: Image of biodegradable plastic

VI. CONCLUSION

Biodegradable plastics made from starch offer a sustainable alternative to conventional plastics, reducing environmental pollution and dependence on fossil fuels. Starch-based bioplastics are biodegradable, renewable, and can be produced from agricultural sources like corn, potatoes, and cassava. While they have limitations such as lower durability and water resistance, these challenges can be addressed by blending starch with other biodegradable polymers and additives. With advancements in technology and increased adoption, starch-based addressed through further research and innovation. With increasing awareness, government regulations, and technological advancements, starch-based bioplastics have the potential to revolutionize packaging, agriculture, and various industries, ultimately leading to a cleaner and greener planet. bioplastics have the potential toto significantly reduce plastic waste and contribute to a more sustainable future. Starch-based biodegradable plastics present a promising solution to the global plastic pollution crisis. As a renewable, eco-friendly alternative, they can help reduce reliance on petroleum-based plastics while promoting sustainability. These materials decompose naturally, minimizing environmental harm and supporting a circular economy. However, challenges such as mechanical strength, water resistance, and cost-effective.

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