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BIOLOGICAL AND AGRICULTURAL ENGINEERING

PHA Production: Making Bioplastic from Cheese Byproduct

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Introduction

Background: Since the 1950s, 8.5 billion metric tons of plastics have been produced, with half of that figure being from the past fifteen years alone. Of that, 91% goes unrecycled globally. When these plastics fail to get recycled, they end up disproportionately affecting the aquatic ecosystems in countries that lack recycling infrastructure [1].

Problem Statement: At every point in its life cycle, petroleum-based plastics emit greenhouse gases that contribute to global warming—greenhouse gas emissions from plastic production could reach 1.34 gigatons per year by 2030 if the current production rate persists [1]. Bio-based and biodegradable plastics can mitigate pollution. However, bioplastic production presents its own challenges, as production costs exceed that of traditional plastic by up to three to four times as much [2].

Existing Solutions: One viable bioplastic alternative, polyhydroxyalkanoate (PHA), is a naturally occurring, biodegradable polyester. As of 2017, PHAs only made up 3.3% of the global bioplastic market. This is likely because microbially-produced bioplastics require a feedstock, that can account for up to 40% of operational costs [3]. Because PHAs have a high market value of $6 per kilogram [4], selecting a low-cost feedstock will make PHA a more competitive option in the bioplastic market.

Figure 1: PHA fermentation cell broth, PHA pellet after initial centrifugation, and dry PHA powder

Goal & Deliverables

Goal: Develop an engineering design and cost-estimate for a pilot-scale (25lb/batch) PHA production system utilizing cheese byproduct as the low-cost feedstock.

Deliverables:
(1) Process flow diagram (PFD) of system
(2) Piping & instrumentation diagrams (P&IDs) of major unit operations
(3) Equipment and instrumentation list
(4) PHA production plant layout

Requirements, Constraints, & Evaluation Criteria

Design Requirements:
1) Output of 25 lb/batch dry PHA
2) Critical Materials Used:
   - Lactose
   - Lactase enzyme
   - *Haloferax mediterranei* (PHA producer)
3) Contain the Major Unit Operations (in order):
   - Hydrolysis > Fermentation > Centrifugation/Extraction > Drying
4) Monitor, measure, and control temperature, pH, dissolved oxygen and fermentation times
5) Within $5,000,000 budget

Design Constraints:
1) Safety: All equipment and operations must meet OSHA regulations
2) Environmental: Wastewater and emissions must meet EPA regulations

Design Criteria Evaluation:
1) Production rate of at least 25 lb/batch
2) Ease of implementation (layout, equipment, piping, scheduling)
3) Equipment and instrumentation costs < $5,000,000

Final Design Description

Process Flow Diagram (PFD)

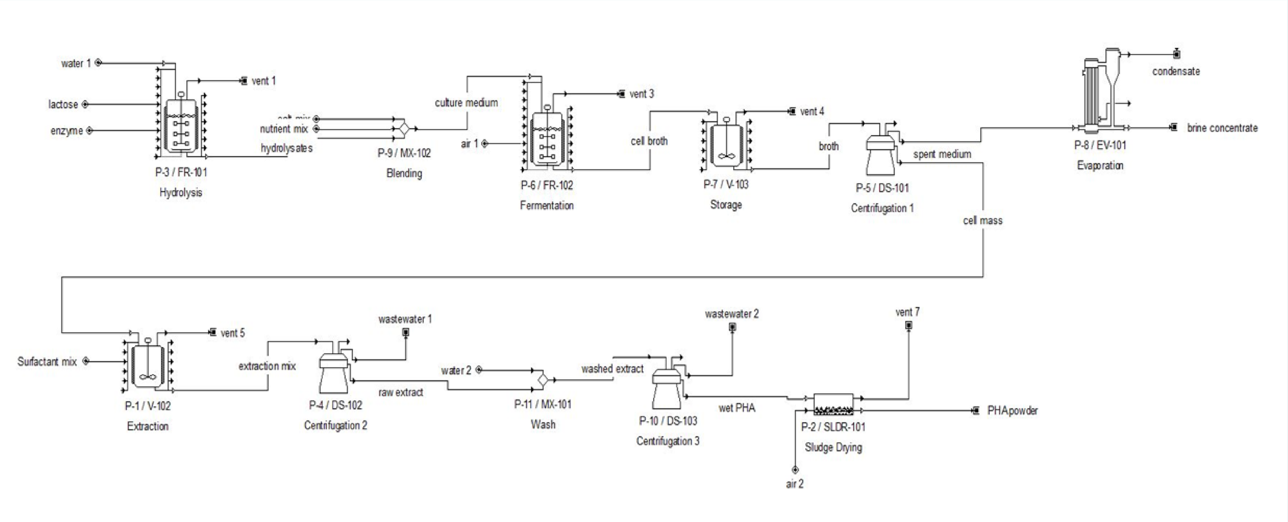

Figure 2: Process flow diagram of the PHA production process in SuperPro

Major Inputs	Mass Flow Rate (kg/batch)
Water	183.39
Lactose	78.41
Enzyme	1.42
TOTAL	263.22

Major Outputs	Mass Flow Rate (kg/batch)
Hydrolysates (from hydrolysis)	263.22
Cell broth (from fermentation)	255.19
PHA powder(from drying)	11.34 (25 lb/batch)
TOTAL	529.75

Table 1: Major inputs and outputs for the PHA production process

- Recipe batch time = 154.4 hours (120 hours fermentation)
- 58 batch/year
- Annual output = 657.72 kg
- Addition of an evaporator results in 81% salt and 64% water savings if 75% and 25% of water from spent medium goes to condensate and brine concentrate, respectively

Plant Layout

Figure 4 provides an idea of the expected space constraints in a facility.
- All major unit operations are positioned to allow the shortest runway for piping to plant utilities and exhaust vents
- Dryer and evaporator are positioned to allow for common venting of heat/emissions and to minimize the safety hazard of the excess heat they produce

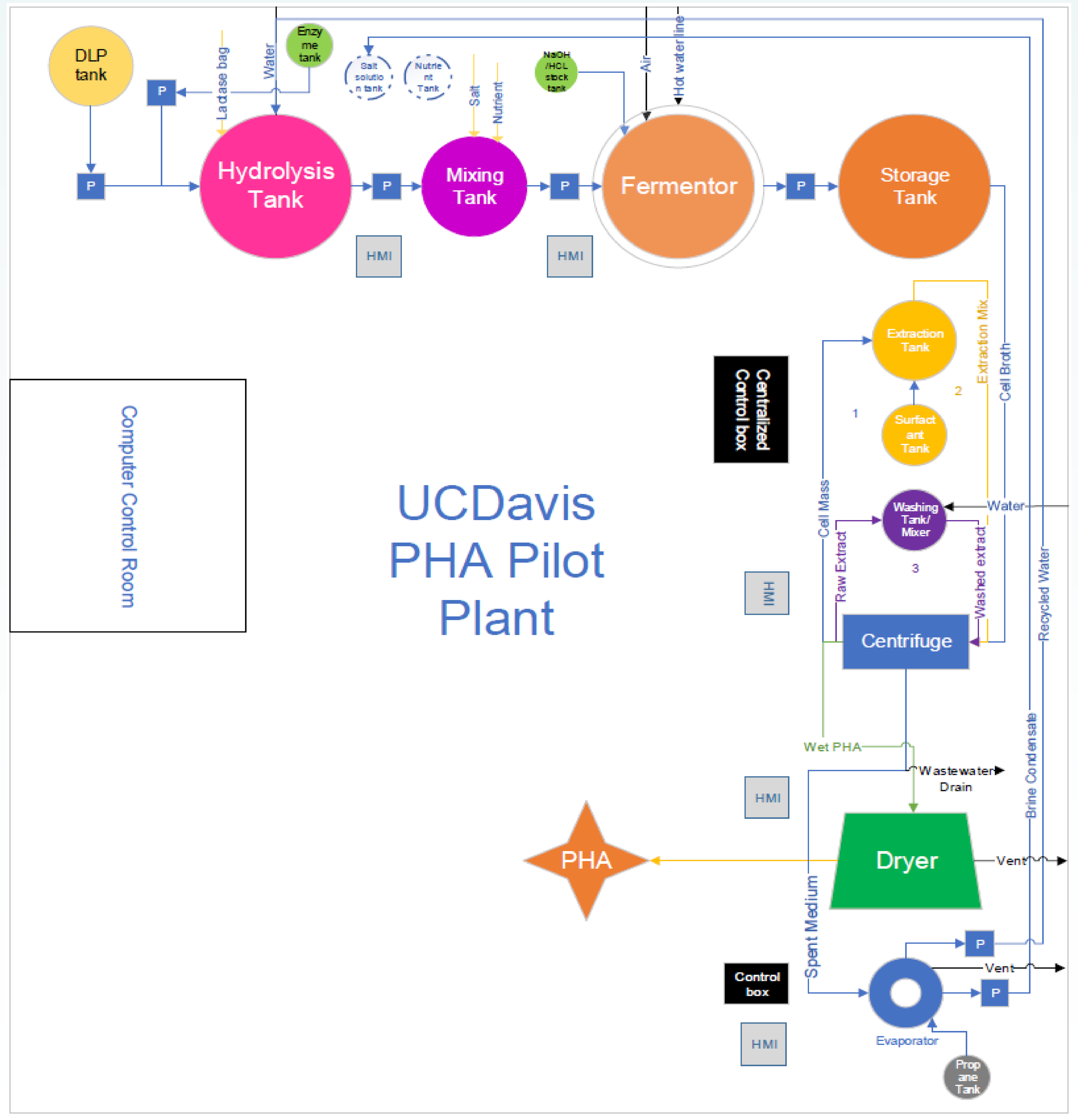

Figure 4: PHA Pilot Plant layout

Piping & Instrumentation Diagrams (P&IDs)

Fig 5a. Hydrolysis tank

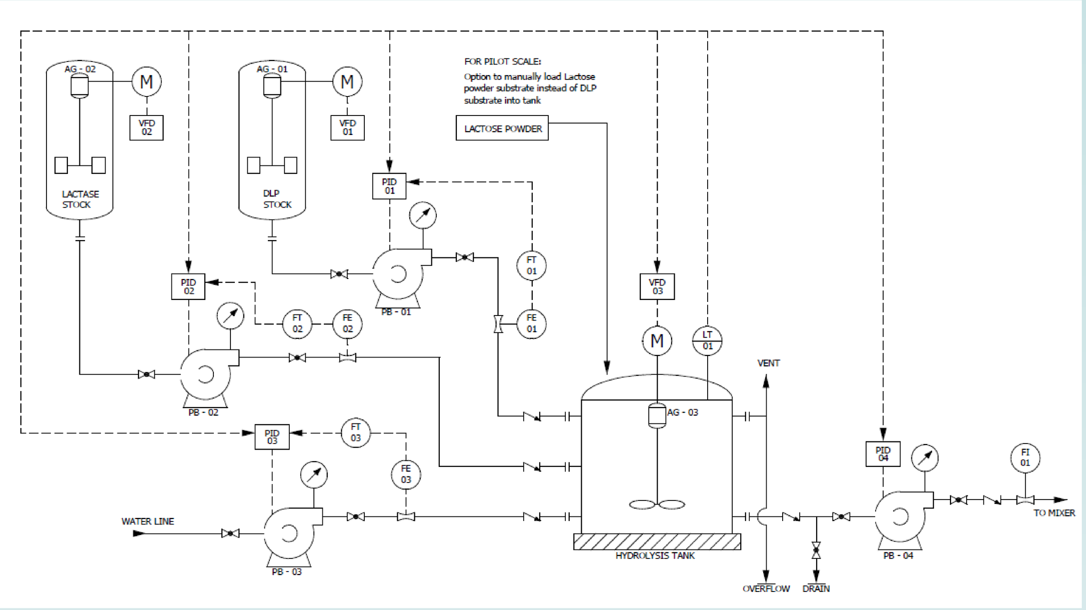

Fig 5b. Fermentation tank

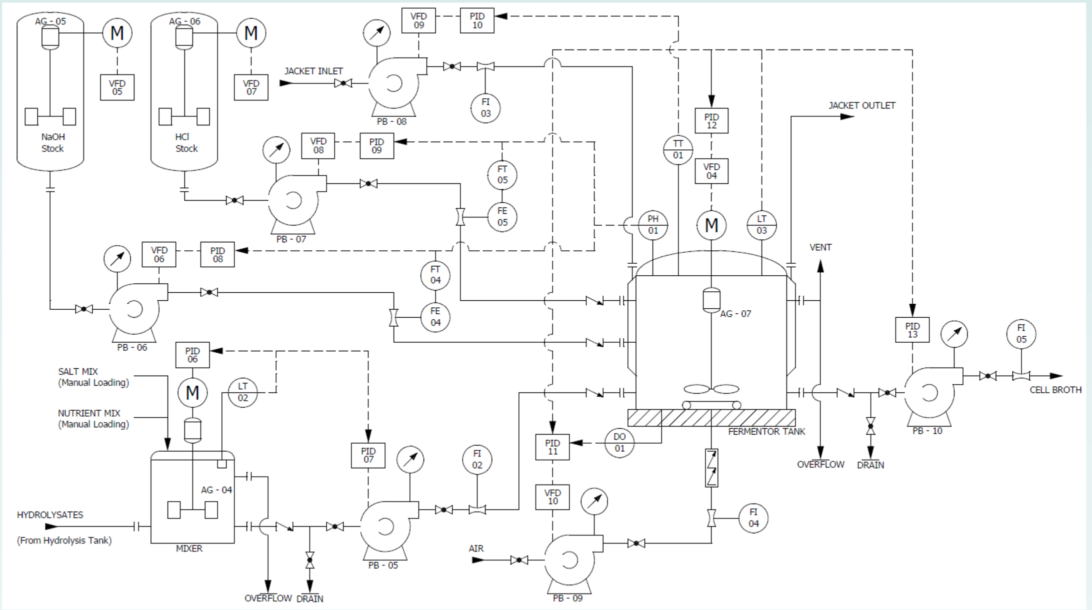

Fig 5c. Centrifugation/Extraction

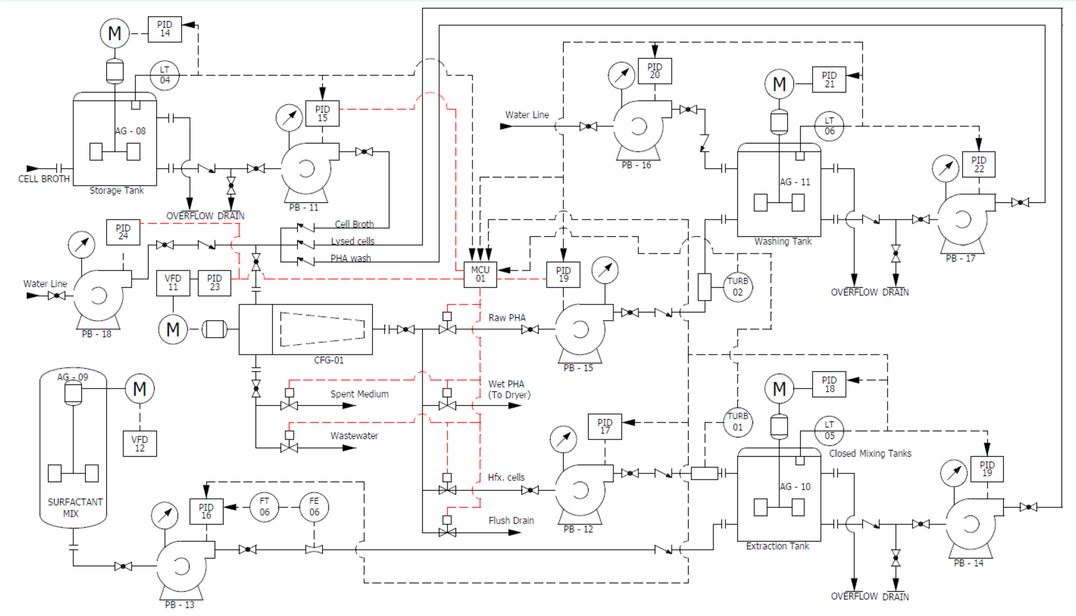

Fig 5d. Drying

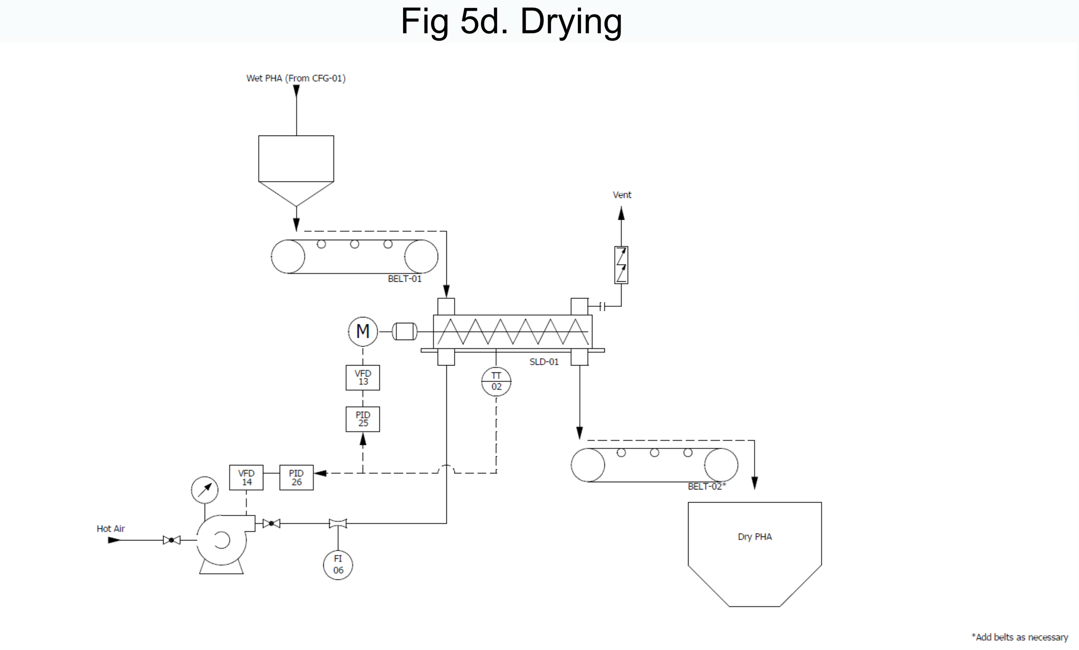

Figure 5: P&IDs in SolidWorks for a) hydrolysis tank, b) fermentation tank, c) centrifugation/extraction, d) drying

Design Evaluation

Equipment Cost Estimate from GEA

Unit Operation	Model	Size/ Capacity	Quote	Justification
Hydrolysis and Fermentation	Custom	350L WV / 500L	$1,880,000	All in one package (complex control system, all sensors and instrumentation, Cleaning system, installation, includes complete Hydrolysis and Fermentation unit operations in one skid)
Centrifugation and Extraction	P&W 50	~35 gal/hour	$140,000	All in one package (complex control system, all sensors and instrumentation, piping and installation)
Drying	Mobile Minor	0.5 – 6 kg/hr (water evaporation capacity)	$300,000	All in one package (complex control system, all sensors and instrumentation, piping and installation)
		Total	$2,320,000	**Within $5,000,000 budget**

Table 2: Equipment list and costs

Evaluation

Design requirements:
All design requirements met

Design Constraints:
1) Safety constraints: Pilot-plant facility and GEA will be responsible for ensuring safety constraints are met
2) Environmental constraint: Pilot-plant facility is responsible for meeting EPA regulations

Design Criteria Evaluation:
1) Production rate: 25 lb/batch (*Table 1*)
2) Ease of implementation (*Figure 4, Table 2*)
3) Equipment and instrumentation costs < $5,000,000 (*Table 2*)

Conclusions & Future Work

Conclusions:
Our team accomplished the following:
- Designed a 25lb/batch pilot-scale process flow diagram to produce PHA from cheese byproduct
- Created P&IDs for the major unit operations of pilot-scale model
- Generated a plant layout for the pilot-scale model
- Evaluated vendors to build and implement the pilot-scale model

The pilot-scale model is within budget and is ready for implementation upon finalizing contract execution details with GEA.

Future Work:
- Testing deflagration and viscosity properties of wet and dry PHA to confirm that the system is safe for operation during the drying process
- Economic analysis for scaled-up process

Acknowledgements

We would like to thank Dr. Ruihong Zhang, Dr. Stavros Vougioukas, Alexander Hobby, Ke Wang, Abdolhossein Edalati, and Kevin Hudnall for the resources and assistance necessary to complete this project.

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