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CPD No. 3237

Conceptual Process Design
Chemical Process Technology

Subject

Production of Coated Detergent Enzyme Granules

Authors	***Telephone***
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Enzyme, protease, fermentation, membrane separation, high shear granulation, fluidized bed drying, fluidized bed coating

Assignment issued : 1st April 1999
Report issued : 2nd July 1999
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TU Delft
Technische Universiteit Delft

Faculteit Technische Natuurwetenschappen
Scheikundige Technologie en Materiaalkunde

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Kick off :	April, 1st 1999
Report :	July, 2nd 1999

Authors:	C. P. Almeida-Rivera P. Du R. G. Padios R. Pitchumani J. B. Taboada
Mentor:	dr. ir. G. M. H. Meesters
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This report is the result of a design project in st493 " Conceptual Process Design " which is a part of our program in Master of Science in Chemical Engineering. We are a team composed of five students from four different countries. It has been a very interesting and challenging experience for us to combine the best of our knowledge (and certainly our respective cultures) to come-up with a profound design project.

We hope everybody who reads this report will find it interesting and that it gives new and comprehensible concepts about the topic. The authors have been trying their very best to make this report a useful tool in the future. In this regard, we would like to acknowledge and thank the following people who unselfishly helped us throughout the three months of work:

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Cristhian Almeida-Rivera	Ecuador
Peng Du	China
Ricardo G. Padios	Philippines
Ramanan Pitchumani	India
Jerome B. Taboada	Philippines

SUMMARY

In recent times, the use of enzymes has been more and more common. Several industries like the starch industry, the dairy industry, and the detergent industry, are already using enzymes. In the detergent industry, for example, all enzymes customary for detergent and cleaning purposes are processed into enzyme granules.

In this project, the objective is to process enzyme-coated granules. The design of the process has a capacity of 5,000 tons per year of enzyme granules with an activity of 2.3 x 10^6 units per gram of granules, density (bulk) of 1011.32 kg/m^3 and a desired particle size range from 250 µm to 1000 µm.

For the enzyme production, specific microorganisms like *Bacillus licheniformis* and *Bacillus amyloliquefaciens* and the corresponding complex medium which is mainly composed of glucose, ammonium source, trace elements, are charged in a designed batch bioreactor to produce the alkaline serine protease enzyme. After twenty hours (20 hrs) of batch fermentation time, 487.40 tons enzyme is taken out and purified using a membrane separator and concentrated to yield a concentrated enzyme solution with an activity of 500,000 units per gram enzyme. This concentrated enzyme solution containing 85.98% enzyme is used to produce the enzyme-coated granule. Whereas, 482.92 tons per batch of the by-product, mainly composed of biomass and unreacted substances from the reactor is sent to the appropriate waste-treatment plant, which is already outside the battery limit of the plant.

The Builder is sent through a Lödige Mixer granulator and is sprayed with the concentrated enzyme solution together with the Binder consisting of PEG 6000 and PVP 30K (Poly Ethylene Glycol and Polyvinyl Pyrrolidilone respectively). The throughput of the granulator is sent to the fluidized bed dryer, where excess moisture from the granule is removed. To meet the particle size specification, the granules are sieved. The over-sized particles are passed through a roll mill before sending it back to the granulator; while the fine particles are sent directly back to the granulator. Finally, the granules are coated with a Coating consisting of PEG 6000, TiO_2 and Magnesium Silicate, in the fluidized bed coating equipment to produce an enzyme-coated granule with an activity mentioned above

This report includes a detailed definition of the process, as well as the process options. For the process streams, process conditions like pressure, temperature and other stream properties are discussed. Also included are the properties and the value of the mass flow of components in the stream.

In chapter 3, all basic assumptions are stated. This includes the capacity of the plant, the location, the battery limit, and the definition of all in-and-out going streams/substances passing through the battery limits. For the plant capacity, the feedstock, the products, and the by-products are described.

Lastly, the economic potential of the designed project is evaluated.

TABLE OF CONTENTS

1 INTRODUCTION

Gross world sales for enzymes in 1987 was US $ 450 M. The following enzymes are currently produced commercially:

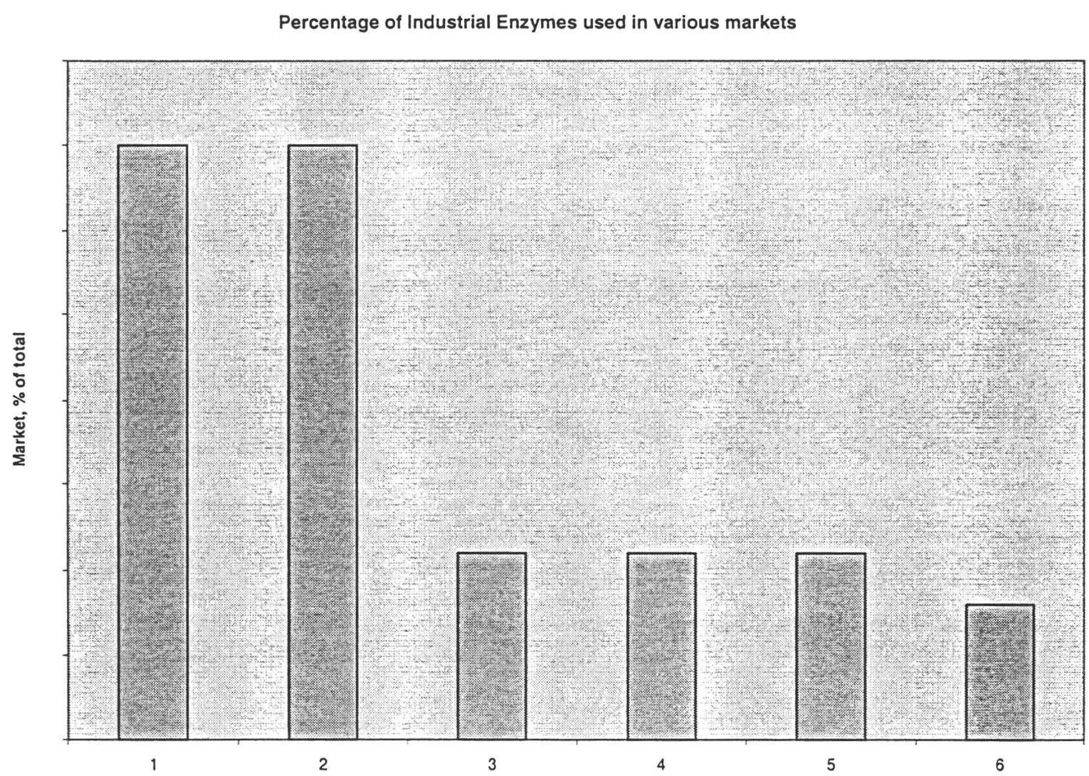
1. Enzymes used in industry such as, amylases, proteases, catalases, etc.
2. Enzymes for analytical purposes such as glucose oxidase, cholesterol oxidase, etc.
3. Enzymes used in medicine such as asparaginase, lipases, proteases, etc.

These areas of application require varying levels of quality and quantity. On the tonnage basis, the most important are the industrial enzymes. The United States and Western Europe produce about 40-45% of the world market, and nine firms account for 90% of the total market. Table 1 and Figure 1 show the production of industrial enzymes and percentage of industrial enzymes used in various markets

[1]*Table 1. Production of industrial enzymes*

Enzyme	Enzyme preparation Tons/year	Sales, % of total
Bacillus proteases	6200	45
Glucoamylases	4500	13
Bacillus amylase	4200	5
Glucose isomerase	1900	6
Rennin (microbial)	1500	10
Amylases (fungal)	800	4
Pectinases	100	3
Protease (fungal)	100	2
Others	-	12

[2]*Figure 1 Percentage of Industrial Enzymes used in various markets*



Legend				
	1	Detergent industry	5	Fruit and juice industry
	2	Starch industry	6	Brewing industry
	3	Dairy industry		
	4	Distilling industry		

Detergent enzymes are produced in large amounts (1300-1500 tons/year) and make up about 40% of the selling price (US $ 300 M) of industrial enzymes. By 1969, 80% of all laundry detergents contained enzymes. Today, 95% of the laundry detergents in Europe contain the enzyme protease although such detergents are much less widely used in the United States.
Other areas in which proteases are used include the pharmaceutical industry, the leather industry, the manufacture of protein hydrolysates, the food industry, the film industry, and waste processing.

The detergent enzymes are the alkaline serine protease Subtilisin Carlsberg formed by Bacillus licheniformis and protease Subtilisin NOVO by Bacillus amyloliquefaciens. They have a pH optimum of 8-11 and a temperature optimum of 80°C. In this design project, only B. licheniformis is mainly dealt with.

Bacillus licheniformis is a facultative aerobic bacterium used in the fermentation industry to produce exocellular enzymes, among which the alkaline serine protease is the most abundant. However, in spite of the industrial importance of the enzyme, published literature on the production using a complex medium is limited.

The media used in the cultivation of microorganisms must contain all elements in a form suitable for synthesis of cell substances and for the production of metabolic products. Although medium preparation seems to be a simple step, it is essential to consider that careless preparation of media may cause complete failure of the process productivity. In industrial fermentations, complex, almost undefinable substances are frequently used for economic reasons. Depending on the particular process, 25% to 75% of the total cost of fermentation may be due to the carbohydrates source. The typical complex media composition is found in Chapter 3.

The process options and selection for the production of enzyme-coated granules is fully described in Chapters 2 and 5. The batch fermentation process is preferred over the fed-batch due to a higher enzyme activity achieved, on the other hand, maintaining a sterile condition is difficult in a continuous process. For the primary separation of the products of the bioreactor, a continuous rotary vacuum drum filter is used for relatively simple operation compared to continuous centrifuge which operation involves too many operating variables. There are many available processes for the concentration of the enzyme product, ultrafiltration using a hollow fiber is the most economical and other equally important reasons are cited in the above-mentioned chapters.

For this design project, the Lödige high shear mixer has been chosen for granulating the enzyme. It is a batch granulation system which has an operating range of 300-2000 kg/h.

The granules from the granulator still contain high moisture due to the mixing of the ultra-filtrate. It is difficult to handle and transport. The fluidized bed dryer is excellent to use for removal of excess moisture. One major advantage of these types of dryers is the close control of conditions so that a predetermined amount of free moisture may be left with the solids to prevent dusting of the product during subsequent material handling operations.

The desired product should have a size range from 250 μm to 1000 μm. Industrial screens have to be used to classify the product into the desired size class. The oversize and undersize are re-processed to meet the product size range. This increases the throughput of the granulator and hence the feed has to be reduced depending on its own performance i.e. the amount of over size and under size produced.

Coating of enzyme granules is important in order to protect the enzyme from the environment. In this project a fluid bed coating system will be used to coat polyethylene glycol (PEG 6000) on the enzyme granules. Fluid bed equipment has been found to be useful for forming and coating granules particularly smaller granules which are difficult to handle by other methods. The dust is also controlled by placing a coating around the granules which binds fines to larger particles or prevents attrition of the granule.

Ecological and safety aspects are also important in this design project. Based on literature survey and pathogenity tests, the microorganism used is non-toxic. However, during the cultivation process, contamination tests are regularly performed and contact with the medium is avoided since the enzymes cause allergic reaction to humans. For handling of raw materials, products and wastes, the usual safety and disposal regulations hold true. More details on this matter are presented in Chapters 9 and 10.

The design project is also limited by the availability of data. Since most the processes are proprietary in nature, some data are not available for use in this design. But somehow, this limitation is abated by the use of the Super Pro 2.7 simulation package for the bioreactor design and initial design process of the whole plant, e.g. material and energy balances. Also, scaling-up to industrial scale processes successfully developed at the laboratory scale is not a simple procedure especially when dealing with biochemical reactions, this is not dealt with. In addition, the separation of the specific enzyme from the enzyme mixture is not within the scope of this design project and lastly, optimization of the process parameters (e.g. medium composition) are not dealt with. Detailed discussion of the process structure and description is presented in Chapter 5.

2 PROCESS OPTIONS AND SELECTION

The production of coated detergent enzyme granules is composed of the following operations:

2.1 ENZYME PRODUCTION

Proteases are one of the most important industrial enzymes currently in industrial production. Proteases, having molecular weights ranging from 25000 – 30000, are produced commercially both from bacteria and fungi and are stable up to a temperature of 65°C.

Screening of the microorganism should be done to assure its stability under alkaline conditions. Strains of B. licheniformis and B. subtilis showed optimal growth in the pH range 6-7, but the new genetically modified strains can grow at pH 8-11. Protein engineered Bacillus has improved properties such as substrate specificity, pH optimum, and stability to bleaching agents. At their optimum pH range, at least 90% of the maximal growth rate is attained.

The detergent enzymes are alkaline serine protease Subtilisin Carlsberg formed by *Bacillus licheniformis* and protease Subtilisin NOVO™ by *Bacillus amyloliquefaciens*. The proteases of this type have many features of value for use as detergent enzymes:

- stability at high temperature (maximum 60°C)
- stability in the alkaline range (pH 9-11)
- stability in association with chelating agents and perborates, however, their stability in the presence of surface-active agent is low, thus limiting their shelf life.

The cultivation with complex medium used in the industry are yielding protease activity of 0.5×10^9 U/kg_{cells}. The concentration of cells is 30 kg_{cells}/m^3_{liquid}.

The enzyme production can be carried out in three modalities:

2.1.1 Batch process

A batch fermentation is considered as a closed system. At t=0 sec., the sterilized nutrient solution in the fermenter is inoculated with the microorganisms and incubation proceeds under optimal physiological conditions. During the fermentation, only oxygen (air), an antifoam agent and acid or base to control pH are added. The composition of the culture medium, the biomass concentration, and the metabolite concentration generally change constantly as a result of the metabolism of the cells.

2.1.2 Fed-Batch process

The fed-batch process is the modification of the conventional batch process. In this process, the substrate is added in increments as the fermentation progresses. The formation of many secondary metabolites is subject to catabolic suppression by high concentrations of glucose, other carbohydrates, or nitrogen compounds. So, in the fed-batch system the critical elements of the nutrient solution are added in small concentrations at the start of the fermentation and are continuously added in small doses during the production phase. Experiments showed that the biosynthesis of the alkaline serine protease is dependent on the growth rate of the culture and concentration of nitrogen and carbon sources in the medium. Ammonium was reported to inhibit protease production. The experiments showed that in the fed-batch fermentation a constant low level of ammonium concentration should be maintained for optimum protease production. In a fed-batch procedure, production could be increased 4.6-fold in comparison to an uncontrolled batch process.

2.1.3 Continuous process

Continuous process is considered as an open system. Sterile nutrient solution is added to the bioreactor continuously and an equivalent amount of converted nutrient solution with microorganisms is withdrawn out of the system. The reactor could be a homogenously mixed bioreactor or a plug flow type. A homogenously mixed reactor is either a chemostat where the cell growth is controlled by adjusting the concentration of one substrate (limiting factor) or a turbistat, cell growth is maintained by using turbidity to monitor the biomass concentration and the rate of feed of the nutrient solution is properly adjusted.

The batch and the fed-batch processes are generally used in the fermentation process. The latter is employed to keep down the concentration of ammonium ions and amino acids, since these nitrogenous materials repress protease production. But on the other hand, the enzyme activity achieved in a fed-batch process is two times lower than in a batch process. Although continuous processes have been described, they are not commercially used. For this design project, the batch process will be used since many published data are available.

The following reactions take place in the bioreactor:

(1) $1.10\ C_6H_{12}O_6 + 1.2\ NH_3$	$\rightarrow$	$C_6H_{10.8}N_{1.2}O_{3.0} + 2.4\ H_2O + 0.6\ CO_2$	*enzyme formation*
(2) $1.03\ C_6H_{12}O_6 + 1.74\ NH_3$	$\rightarrow$	$C_6H_{9.48}N_{1.74}O_{2.04} + 0.18CO_2 + 3.78\ H_2O$	*biomass formation*
(3) $C_6H_{12}O_6 + 6O_2$	$\rightarrow$	$6\ CO_2 + 6\ H_2O$	
(4) $3.13\ C_6H_{12}O_6 + 2.94NH_3 + 6O_2$	$\rightarrow$	$C_6H_{10.8}N_{1.2}O_{3.0} + C_6H_{9.48}N_{1.74}O_{2.04} + 6.18\ H_2O + 6.78\ CO_2$	

Where $C_6H_{12}O_6$ is the glucose, $C_6H_{10.8}N_{1.2}O_{3.0}$ the protein and $C_6H_{9.48}N_{1.74}O_{2.04}$ the biomass.

2.2 SEPARATION

The first downstream step in a biological process is usually the removal of suspended cell mass and other particulate/colloidal debris from the suspending medium. The concentration of extra-cellular enzymes in typical biotechnological processes is 0.5-1% (w/w).

In the past, the preferred methods of cell harvesting were filtration or centrifugation. To be economical on an industrial scale, the method must be a continuous process. Continuous centrifuges, where the cells are removed by the action of high G forces, are expensive to buy, operate, and maintain. The production rate of a centrifuge is a function of many variables, among them the square of the particle diameter, the difference in density between the particles and the suspending medium, the G force and the viscosity of the suspending medium. The production rate and the cell recovery (yield) are strongly dependent on particle size and inversely proportional to each other. In addition, there may be substantial heat generation requiring complicated cooling system; there may be production of aerosols, and the capacity of most tubular centrifuges is limited and may require frequent teardowns and cleaning (Cheryan, 1998).

Filtration, on the other hand, is not limited in throughput by the particle size, and the separation rate does not go down as smaller microorganisms are harvested. The most common method is rotary drum filters, where a vacuum draws the broth to the drum surface. The microbial cells and other insoluble solids accumulate on the filter cloth and are scraped off with a knife.

2.3 CONCENTRATION

Many traditional cell-harvesting processes are being replaced by cross-flow membrane filtration. With proper selection of the membrane, the module, and operating parameters, 100% cell recovery can be obtained, and capacity can be increased by carefully adding more membrane area.

Over 130 materials have been used to manufacture membranes but only a few have achieved commercial status and fewer still have obtained regulatory approval for use in food, pharmaceutical, and kindred applications. The family of polysulfone membranes has been chosen in the concentration step of this process due principally to the following favorable characteristics:

- Wide temperature limits: typically, temperatures up to 75°C
- Wide pH tolerances: these membranes can be continuously exposed to pHs from 1 to 13
- Fairly good chlorine resistance: up to 200 ppm chlorine for cleaning and up to 50 ppm chlorine for short storage of the membrane
- Easy to fabricate membranes in a wide variety of configurations and modules
- Wide range of pore sizes available for ultrafiltration applications, ranging from 10A° (1000 MWCO) to 0.2μm in commercial-size modules.
- Good chemical resistance to aliphatic hydrocarbons, fully halogenated hydrocarbons, alcohols and acids.

Membrane technology presents six basic designs of equipment: (1) tubular, with inner channel diameters>4 mm; (2) hollow fibers, with inner diameters of 0.2-3 mm; (3) plate units; (4) spiral-wound modules; (5) pleated-sheet cartridges; and (6) rotary modules.

A hollow fiber design has been chosen due to the following characteristics:
- It is one of the more economical designs in terms of energy consumption because of combination of pressure drops and flow rates. Operating velocity of 0.5-2.5 m/s (Reynolds numbers of 500-3000) and pressure drops of typically 1.35-2.35 bara, depending on flow rate, fiber diameters and lengths.

- Hollow fibers have the highest surface area-to-volume ratio among the modules. Holdup volume is low.
- A big advantage with hollow fibers is its back-flushing capability, which improves its cleanability. This is possible because the fibers are self-supporting.

Though ultrafiltration is the most economical method for concentrating the filtrate, it cannot achieve very high concentrations (~99%) due to reduction in efficiency as the concentration gradient is very low and the osmotic pressure becomes low. More membrane systems are required in order to achieve such high concentrations.

Another possibility could be freeze concentration, which is done by freezing the ultra filtrate and then the ice formed on the surface of the liquid is scraped off. The refrigeration of the ultra filtrate is energy intensive compared to evaporation.

2.4 GRANULATION

The protease rich ultra filtrate can be spray dried and introduced into the detergent in powdered form (mean particle size 0.3 mm with considerable amount of small particles) (Kadam, 1991). The dust in the environment has high protease concentration and can cause allergenic reactions in workers handling these products. Hence the proteases are an environment hazard in the powdered form. In order to eliminate this hazard, the protease rich ultrafiltrate can be mixed with Builder and Binder and granulated using a granulator. In industry, granulators are bought as there are standard designs. For the present project, Lödige High Shear Mixer/Granulator has been chosen for granulating the enzyme. It is a batch granulation system where the Builder, Binder and Ultra filtrate are mixed under high shear conditions leading to the formation of granules

2.5 FLUIDIZED BED DRYING

The granule formed in the granulator has high moisture content due to the mixing of the ultra-filtrate. The wet granules are difficult during handling and transportation. Drying reduces the cohesive forces between the individual granules enabling ease in handling. The best and most widely used dryer in industry is the fluidized bed dryer. The reason being that heat transfer is very rapid due to the convection currents formed around each individual granule in the bed. Another major advantage of these type of dryers is the close control of conditions so that a predetermined amount of free moisture may be left with the solids to prevent dusting of the product during subsequent material handling operations.

2.6 SCREENING, CRUSHER AND RECYCLE

The product stream has a wide size distribution. The desired product should have a size range from 250 μm to 1000 μm. Industrial screens have to be used to classify the product into the desired size class. The over size i.e. the size above 1000 μm has to be crushed with a crusher and sent back to the granulator and the under size i.e the size class below 250 μm has to be sent directly to the granulator. This increases the throughput of the granulator and hence the feed to the granulator has to be reduced depending on its own performance i.e. the amount of over size and under size produced.

2.7 FLUIDIZED BED COATING

Coating of enzyme granules is important in order to protect the enzyme from the environment. The Coating is usually a mixture of polymer (PEG 6000) along with TiO_2 and Magnesium Silicate which effectively isolates the enzyme from the environment. One can also control the dust by placing a coating around the granules which binds fines to larger particles, or prevents attrition of the granule. In this project a fluid bed coating system will be used to coat the Coating on the enzyme granule. Fluid bed equipment has been found to be useful for forming and coating granules particularly smaller granules which are difficult to handle by other methods. They are designed to keep even small particles in the processing chamber where they may become coated.

2.8 SELECTED OPTION

2.8.1 Description of the process

For this project the components shown in all the process flow schemes and calculations consist of the following sub-components:

1) Ammonium phosphate (Di-ammonium hydrogen phosphate)
2) Biomass (inoculum or micro-organism which produces the enzyme)
3) Glucose

4) Inerts
   a) Cellulose
   b) Insoluble salts
   c) Antifoam Ke 211
5) Nutrients
   a) Magnesium sulfate heptahydrate
   b) Manganese sulfate monohydrate
   c) Di-sodium hydrogen phosphate dodecahydrate
   d) Potassium di-hydrogen phosphate
   e) Ferrous sulfate heptahydrate
6) Builder
   a) Cellulose powder
   b) Sodium sulphate (filler)
   c) Yellow dextrine
   d) Calcium acetate
   e) TiO_2
7) Binder
   a) PEG 6000 (Polyethylene Glycol, MW : 6000)
   b) PVP K30 (Polyvinyl Pyrolidone, MW : 30,000)
8) Coating
   a) PEG 6000 (Polyethylene Glycol, MW : 6000)
   b) TiO_2
   c) Magnesium silicate

The process starts with the 1 hour of filling of substrate and water in the blending tank (T-101). The mixing in the blending tank occurs for 5 hours. The contents of the blending tank are then discharged into the sterilizer (E-101) which takes about 30 minutes. The mixture is sterilized at 121°C for 15 minutes with steam. The sterilized stream is then cooled to cultivation temperature. The cooling process takes about 15 minutes. The mixture from the sterilizer is fed to the fermentor (R-101) along with another stream consisting of the biomass which runs for 20 hours. The end point of the process is when the maximum enzyme activity is reached which is usually after 20 hours of fermentation time, which is shown in Appendix. The oxygen for the fermentation is supplied using a compressor (K-101) which blows ambient air through an Air Filter (S-101) for the removal of impurities and the pure air (devoid of impurities like dust etc.) is sent through the fermenter. After the fermentation, the broth is cooled down to 5°C in the cooler (E-102) using Brine solution as a cooling agent and transferred to the separation and concentration units.

The separation unit consists of a rotary drum vacuum filter (S-102), where a vacuum draws the broth to the drum surface. The microbial cells and other insoluble suspended solids accumulate on the filter cloth and are scraped off with a knife. The filtrate from the rotary drum vacuum filter is sent to the Ultra Filter (S-104) for concentration.

A hollow fiber design has been chosen for the next operation and has the following characteristics

Table 2. Characteristics of the selected concentration equipment

PARAMETER	VALUE
Membrane design	Hollow fibers
Membrane material	Polysulfone
Pore Size [A°]	200
Fiber diameter [mm]	0.5
Fiber length [m]	0.1
Temperature and pressure rating	80°C – 1 atm
pH value	8-11
Manufacturer	A/G Technology

For the present project, Lödige High Shear Mixer (G-101) has been chosen for granulating the enzyme. It is a batch granulation system which consists of a cylindrical vessel having plow-shaped mixing tools mounted on a horizontal shaft rotating at very high speeds of 3000 rpm. At the bottom of the vessel, there are choppers which break the large granules into smaller sizes in order to maintain a narrow size distribution. At first the Builder is fed into the High Shear Mixer and then the Ultrafiltrate from the Ultrafilter along with Binder. The contents are mixed under high shear condition for 10 minutes and discharged to the fluidized bed dryer.

Afterwards, the granules are dried in fluidized bed dryer (D-101), because the heat transfer is very rapid due to the convection currents formed around each individual granule in the bed. Another major advantage of these type of dryers is the close control of conditions so that a predetermined amount of free moisture may be left with the solids to prevent dusting of the product during subsequent material handling operations. The drying process takes about 30 minutes. The dried granules have a wide size distribution and industrial screens (S-105) have to be used to classify the product into the desired size class (250 μm to 1000 μm). The over size (i.e. the size above 1000 μm) has to be crushed with a crusher (A-101) and sent back to the high shear mixer and the under size (i.e the size class below 250 μm) has to be sent directly to the high shear mixer.

In this project a fluid bed coating system will be used to coat PEG 6000 on the enzyme granule. Fluid bed equipment has been found to be useful for forming and coating granules particularly smaller granules which are difficult to handle by other methods.

2.8.2 Batch versus Continuous

The reactor will be operated in batch mode as the micro-organisms which produce the enzymes tend to change their DNA structure after every batch. So a new culture has to be introduced after every batch. This also involves sterilising the vessel and the substrate. The granulator and all subsequent downstream processing will be batch mode as control of particle size distribution and strength of the granules is extremely difficult in continuous mode.

3 BASIS OF DESIGN (BOD)

3.1 DESCRIPTION OF THE DESIGN

The objective of this project is to produce enzyme-coated granules. The design of the process is such that it has a capacity of 5,000 tons per year of enzyme granules with an activity of 2.34 x 10^6 units per gram granules, density (bulk) of 1011.32 kg/m^3 and a desired particle size range from 250 μm to 1000 μm.

For the enzyme production, specific microorganisms (*Bacillus licheniformis* and *Bacillus amyloliquefaciens*) and the complex medium are charged in a designed batch bioreactor to produce the enzyme. After twenty hours of batch fermentation time, the reactor products are sent for downstream processing. The first process is the separation of the fermentation broth from the solid materials using a vacuum drum filter. The broth is then concentrated using ultra-filtration to yield a concentrated enzyme solution with an activity of 8.97 x 10^6 units per gram enzyme. This concentrated enzyme solution is used to produce the enzyme-coated granules. 5071.898 tons per batch of wastes, mainly composed of the biomass, is sent to the appropriate waste-treatment plant for treatment, which is already outside the battery limit of the plant.

Sodium Sulfate (Na_2SO_4), which is used as a core granule, is sent through a Lodige mixer and is sprayed with the concentrated enzyme solution together with the binder and builder mixture composed of PEG 6000, PVP K30, cellulose powder, calcium acetate, TiO_2, and yellow dextrin. The discharge of the granulator is sent to the fluidized bed dryer, where excess moisture from the granule is removed. To meet the particle size specification, the granules are sieved. The over-sized particles are passed through a hammer mill before sending it back to the granulator; while the fine particles are sent directly back to the granulator. Finally, the granules are coated with the coating composed of polyethylene glycol (PEG 6000), magnesium silicate and TiO_2 in the fluidized bed coating equipment to produce 24.45 tons per batch of enzyme-coated granule with an activity mentioned above.

For the calculations, the following assumptions have been made:

1) conversion of the bio-reactor is 95%, i.e. 95% of the main reactants (corn starch, soy flour and corn steep liquor) are converted into products following the stoichiometric coefficients.
2) rotating drum filter separates the enzyme and water from the rest of the components present in the bio-reactor outlet stream.
3) efficiency of the hollow fiber membrane ultra-filter is 90%, i.e. 90% of the water present in the inlet stream is removed.
4) the activity of the enzyme is not affected by the processing conditions, e.g. pressure, temperature, etc.
5) no particle breakage during the coating process
6) hydrolyzed starch contains 90% starch, 10% inert
7) soy flour contains 74.0% carbohydrates, 12.0% protein, 14.0% inert
8) sodium-caseinate contains 95.0% protein (% min.), 5.0% inert
9) 80% of the glucose requirement is from hydrolyzed starch and 20% from the soy flour

3.2 PROCESS DEFINITION

3.2.1 Process Concepts chosen

In Chapter 2, some of the options of the processes for the enzyme production, downstream processing, granulation and coating of enzyme granules are presented and these will be briefly discussed here. Since there are many possible options, it was narrowed down to the most feasible for industrial application. The choice was based on technological insight, interdependence of the processes, common sense and insight from experts of this field.

3.2.1.1 Enzyme production

The production of the enzyme could be done in three modes, namely; batch, fed-batch, and continuous fermentation processes. Each of the processes has its inherent advantages and disadvantages, which is discussed profoundly in the preceding chapter.

For the batch process, the sterilized nutrient solution in the fermenter is inoculated with the microorganisms and incubation proceeds under optimal physiological conditions. During the fermentation, only oxygen (air), an antifoam agent and acid or base to control pH are added and the broth containing the products is withdrawn only at the end of each batch run. Fed-batch process is the modification of the conventional batch process. In this process, the critical elements of the nutrient solution are added in increments as the fermentation progress but the culture broth containing the metabolites (products) is taken only after each batch run. In a fed-batch procedure, production could be increased 4.6-fold in comparison to an uncontrolled batch process. Sterile nutrient solution is added to the bioreactor continuously and an equivalent amount of converted nutrient solution with microorganisms is withdrawn out of a continuous system. The continuous operation has been generally regarded as the most efficient one, but maintaining a high activity microorganism in the continuous culture is difficult to due to their genetic variations. Also, long-term continuation of pure culture is hard because of microbial contamination, so in reality, continuous process is hardly employed in industrial scale.

The batch and the fed-batch processes are generally used in the fermentation process. But the enzyme activity achieved in a fed-batch process is two times lower than in a batch process. Although continuous processes have been described, they are not commercially used, since maintaining a sterile condition for a long period of time is difficult. For this design project, the batch reactor will be used since many published data are available.

The fermentation process is distinguished by three characteristic phases; (1) glucose consumption alone (no protein consumption) with pH reduction, (2) consumption of sugar and protein with pH increase, maximum metabolic activity, maximum amino acid concentration and increase of cell mass, DNA, and protease concentration, (3) protease activity attained maximum and then its reduction with increase of pH, amino acids and NH_4^+ concentrations.

The following reactions take place in the bioreactor:

(1) $1.10\ C_6H_{12}O_6 + 1.2\ NH_3 \rightarrow C_6H_{10.8}N_{1.2}O_{3.0} + 2.4\ H_2O + CO_2$ *enzyme production*

(2) $1.03\ C_6H_{12}O_6 + 1.74\ NH_3 \rightarrow C_6H_{9.48}N_{1.74}O_{2.04} + 0.18CO_2 + 3.78\ H_2O$ *biomass production*

(3) $C_6H_{12}O_6 + 6O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

For simplicity the oxidized form of NAD has been omitted. In this design, the stoichiometric reactor model in the Super Pro 2.7 simulation tool is used.

3.2.1.2 Separation

The first downstream step in a biological process is usually the removal of suspended cell mass and other particulate/colloidal debris from the suspending medium. The concentration of extra-cellular enzymes in typical biotechnological processes is 0.5-1% (w/w).

Filtration and centrifugation are the most common methods use in biological separation. To be economical on an industrial scale, the method must be a continuous process. Continuous centrifuges are difficult to operate and maintain due to the many variables, e.g. the production rate and the cell recovery (yield) are strongly dependent on particle size and inversely proportional to each other. In addition, there may be substantial heat generation requiring complicated cooling system.

On the other hand, filtration is not limited in throughput by the particle size, and the separation rate does not go down as smaller microorganisms are harvested. The most common method is rotary drum filters which can efficiently operated as a batch process.

3.2.1.3 Concentration

After the product is recovered and isolated, it needs to be purified or concentrated further. The purification can be done by precipitation, freeze concentration and ultrafiltration. Precipitation causes denaturation of the product while freeze concentration is energy intensive. Therefore, cross-flow membrane filtration is chosen. With proper selection of the membrane, the module, and operating parameters, 100% cell recovery can be obtained, and capacity can be increased by carefully adding more membrane area.

3.2.1.4 Granulation

The proteases are an environment hazard in the powdered form. The dust in the environment with high protease concentration can cause allergenic reactions in workers handling these products. To avoid this problem, it has to be in granular form. In industry, granulators are bought as there are standard designs. For the present project, the Lodige mixer has been chosen for granulating the enzyme. It is a batch granulation system which has an operating range of 300-2000 kg/h. The machines are provided with lid for charging and inspection of the product.

3.2.1.5 Fluidized bed drying

The granule formed in the granulator has high moisture content due to the mixing of the ultra-filtrate which is difficult during handling and transportation. The best and most widely used dryer in industry is the fluidized bed dryer. The reason being that heat transfer is very rapid due to the convection currents formed around each individual granule in the bed. Another major advantage of these types of dryers is the close control of conditions so that a predetermined amount of free moisture may be left with the solids to prevent dusting of the product during subsequent material handling operations.

3.2.1.6 Screening, Crusher and Recycle

The product stream has a wide size distribution. The desired product should have a size range from 250 µm to 1000 µm. Industrial screens have to be used to classify the product into the desired size class. The over size i.e. the size above 1000 µm has to be crushed with a hammer mill and sent back to the granulator and the under size i.e. the size class below 250 µm has to be sent directly to the granulator. This increases the throughput of the granulator and hence the feed to the granulator has to be reduced depending on its own performance i.e. the amount of over size and under size produced.

3.2.1.7 Fluidized bed coating

Coating of enzyme granules is important in order to protect the enzyme from the environment. The barrier (coating) is usually a polymer (PEG 6000) which effectively isolates the enzyme from the environment. One can also control the dust by placing a coating around the granules which binds fines to larger particles, or prevents attrition of the granule. In this project a fluid bed coating system will be used to coat PEG 6000 on the enzyme granule. Fluid bed equipment has been found to be useful for forming and coating granules particularly smaller granules which are difficult to handle by other methods. They are designed to keep even small particles in the processing chamber where they may become coated.

3.2.2 Block Schemes

The block scheme is presented in the Appendix 3-1 at the end of this report.

3.2.3 Thermodynamics Properties

The thermodynamics properties of the components are tabulated in Chapter 4, section 4.3

3.2.4 Pure Components Properties

The following table shows the properties of the pure components present in the process

Table 3. List of pure components

NAME	STRUCTURAL FORMULA	MW	TEMPERATURE [°C]		DENSITY	LD_{50}
		[g/mol]	BOILING	MELTING	[kg/m3]	[mg/kg]
Glucose	$C_6H_{12}O_6$	180.0	83.0	120.0	1544.0	9000
Di-ammonium hydrogen phosphate	$(NH_4)_2HPO_4$	132.07	-	155.0	1619	-
Di-sodium hydrogen phosphate Dodecahydrate	$Na_2HPO_4\ (12H_2O)$	358.14			1679	17000
Potassium di-hydrogen phosphate	KH_2PO_4	136.09	-	256	2338	-
Manganese sulfate monohydrate	$MnSO_4(H_2O)$	168.99	850.00	700	3235	332
Ferrous sulfate heptahydrate	$FeSO_4\ (7H_2O)$	277.91	300.00	64.0	1899	319
Magnesium sulfate heptahydrate	$MgSO_4\ (7H_2O)$	246.38	-	70.0	2660	5344*
Oxygen	O_2	32.00	-182.96	-218.0	1.429**	-

* LDLo
** reported at 0°C
*** LCLo,ppm/5M
**** TCLo,mg/m^3/6h
***** TCLo,mg/kg/19w

Source: *Lewis, R., SAX's Dangerous Properties of Industrial Materials, New Yor, 8th ed., 1989*
Perry, R., Handbook of Chemical Engineering, New York, McGraw-Hill, 1982

Table 3. List of pure components (cont.)

NAME	STRUCTURAL FORMULA	MW	TEMPERATURE [°C]		DENSITY	LD_{50}
		[g/mol]	BOILING	MELTING	[kg/m3]	[mg/kg]
Nitrogen	N_2	28.00				-
Water (liquid)	H_2O	18.00	100.00	0.0	1000	-
Biomass	$(C_6H_{10.8}N_{1.2}O_{3.0})$	147.6	-	-	-	-
Protein	$(C_6H_{9.48}N_{1.74}O_{2.04})$	138.48	-	-	-	-
Carbon dioxide	CO_2	44.00	-78.5	-56.6	1.53	90000***
Sodium sulfate	Na_2SO_4	142.05		888.0	2671	5989
Calcium acetate	$Ca(CH_3COO)_2$	158.0	-	-	2500	52.0
Titanium dioxide	TiO_2	79.8	<3000	1640.0	4220	250****
Magnesium silicate	$Mg(SiO_4)$	278.91	2230.0	1710.0	2500	100*****

* LDLo

** reported at 0°C

*** LCLo,ppm/5M

**** TCLo,mg/m^3/6h

***** TCLo,mg/kg/19w

Source: *Lewis, R., SAX's Dangerous Properties of Industrial Materials, New Yor, 8th ed., 1989*
Perry, R., Handbook of Chemical Engineering, New York, McGraw-Hill, 1982

3.3 BASIC ASSUMPTIONS

3.3.1 Plant Capacity

The plant operates as batch process with a total output of 5000 tons of PEG 6000 coated enzyme granules per year having an activity of 2.34 x 10^6 U/g. There are 300 batches annually with a cycle time of 35.5 hours.

489.75 tons per batch of medium is mainly composed of glucose, ammonium source, trace elements, water and other growth factors. The waste streams amount to 482.92 tons per batch of liquid and solid liquid wastes and 681.59 tons per batch of gaseous wastes. The complete stream report is found in the appendices.

Based on normal operating hours of 7200 hrs per year, the plant operates at 300 days per year. The remainder number of days is used for maintenance and legal holidays. The plant life is assumed to be 15 years (including 1.5 years for construction) since the product is competitive in the market.

3.3.2 Location

The plant will be located in Pune, India. The country has an average ambient temperature of 25 °C throughout the year which is favorable for the fermenter as compared to Europe where low temperatures is prevalent which is unsuitable for fermentation. Since the road networks are favorable, transport of the raw materials and products is easy. The plant can be located in the outskirts of the city in order to avoid contamination of the surrounding air in case of accident or leaks. Also, the environmental regulations will not be a critical issue at present since no existing policies for this type of industries. But this should not be understood as taking advantage of the present situation.

3.3.3 Battery Limit

The design project includes the following important equipment inside the battery limit. The reference block diagram can be found in the Appendix of this report.

1) R-101 Aerated Stirred Tank Bioreactor with cooling jacket. The reactor is also equipped with baffles and mechanical foam separator. There are 2 units of this reactor with a total volume of 290.0 m^3 each and the construction material is SS316.

2) RV-101 Rotating Drum Vacuum Filter. The suspension is sucked through a filter cake on a rotating drum and the filter cake is removed with a blade. The filter cake is rinsed during the rotation. Three units of this filter with a filter area of 96.0 m^2 each.

3) UF-101 Hollow Fiber Membrane Ultra-filtration system. Two units having a membrane area of 446.0 m^2 per unit are used. The concentration factor (the ratio of feed to retentate) is 100.

4) G-101 Lodige mixer/granulator. It is a batch granulation system where the builder, binder and ultra filtrate are mixed under high shear conditions leading to the formation of granules

5) D-101 Fluidized Bed Dryer. One unit with a volume of 1.70 m^3, height is 6.0 m and a diameter of 0.6 m. The drying temperature is 40°C. Steam heated air is used in this equipment.

6) S-105 Screens (Industrial Sieves). These are of vibrating type since large capacity and high efficiency are required. The screening system classifies the particle in the range of 1,000 μm to 250μm.

7) A-101 Hammer mill. It used for pulverizing and disintegration at high speed. The rotor shaft is horizontal with T-shaped hammers. A cylindrical screen serves as an internal classifier. The size of the product can be controlled by changing the rotor speed, feed rate, or clearance between the hammers and grinding plates.

8) D-102 Fluidized Bed Spray Coating System.

9) E-101 Coolers. This is a plate and frame type with a heat transfer area of 79.8 m^2. NaCl brine is used as the cooling medium to cool down the reactor product to 5°C.

10) E-102 Coolers. This is also a plate and frame type with a heat transfer area of 0.05 m^2. NaCl brine is used as the cooling medium to cool down the enzyme granules product to 20°C.

11) S-101 & S-102 Air filters. The max throughput of the filters is 4.0 m^3/s.

12) T-101 Blending tank. It is used to homogenized the medium prior to fermentation. Two units which have a volume of 283.0 m^3 per tank. The agitation rate is 1.0 kW/m^3 for 6 hours. Chilled water is used as cooling agent.

13) P-101, 102, 103 & 104 Centrifugal Pumps. These are widely used in chemical industries for pumping liquids with very wide ranging properties and suspensions with high solids contents.

14) K-101, 102, & 103 Compressors. The compressors can carry a pressure change of 2 bars and have an efficiency of 70%.

15) E-101 Sterilizer. Three units of sterilizer are used with a diameter of 70cm and the holding tube length is 196.8 m. The heating medium used is steam at a temperature of 152.0 °C and a built cooler which uses a cooling water.

Other facilities available outside the battery limit:

1) Ion-exchanger for the process water used in the medium preparation and cleaning of interior and internals of bioreactor
2) Vessels for the cooling water, washwater, and other water requirement of the plant
3) Air receivers for the oxygen supply into the bio-reactor and other oxygen requirement.
4) Boilers for the low pressure steam requirement of the plant.
5) Tanks and other vessels for the storage of the raw materials.
6) Seed tank for the inoculum preparation.
7) Vessel for the NaCl brine container

3.3.4 Definition In- and Out-going streams

The values are valid at the battery limit.

Listed below are the compositions of the typical technical (complex) media for the production of the enzyme.

Table 4. Technical medium composition in tap water

COMPONENT	COMPOSITION [kg/m^3]
Hydrolysed starch	100.00
Sodium caseinate	27.00
Soy-flour	23.00
Corn steep	7.00
Di-ammonium hydrogen phosphate	0.50
Di-sodium hydrogen phosphate dodecahydrate	0.50
Potassium di-hydrogen phosphate	0.30
Manganese sulfate monohydrate	0.02
Ferrous sulfate heptahydrate	0.05
Magnesium sulfate heptahydrate	0.05
Antifoam agent Ke 211	4.00

Since this process is not available from literature or previous published works, it is not possible to mention commercial specifications for the streams. The design stream values are shown in tabulated form.

3.3.4.1 Feedstocks

Substrate (IN)

This stream is composed of complex or undefined substances listed above and the biomass. For simplicity, only the necessary constituents are found in the table below. These substances (for the medium) are taken from the storage and weighed to desired proportion. The inoculum is from the seed tank which is outside the BL.

Stream Name: 1		Substrate			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. note numbers)
Glucose			54.27	(1)	(1) hydrolyzed starch and soy flour are the source of the glucose, although some other hydrates are present, they are assumed to be reduced to glucose.
Biomass			1.49		
Ammonium phosphate			3.12	(2)	(2) source of nitrogen, also, amino acids from steep and casein are significant, they are not participating in the reaction based on stoich
Nutrients			0.92	(3)	(3) composed of hydrated salts of Mn, Mg, Fe, agents
Inert			40.20	(4)	(4) other components such as antifoam agent, insoluble cellulose substances
Total			100.00		
Temp.	°C		25.00		
Press.	bar_a		1.01		
Phase	V/L/S		L		
Price	US$/kg		1.0596		

Water (IN)

Process water can be defined as the water used in the bioreactor. It also includes the medium make-up, in association with direct liquid additions, and for cleaning of the vessel interior and internals. The process water is classified under the low-endotoxin water. It is from the water storage, which requires precautions against microbial proliferation. It is fed through a distribution system (e.g. hoses, pipes) which is regularly sterilized.

Stream Name:	2	**Water**			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Water			100		
Total			100.00		
Process Conditions and Price					
Temp.	^oC		25		
Press.	bar_a		1		
Phase	V/L/S		L		
Price	US$/kg		0.01		

Discharge T101

This stream is the homogenized mixture of the medium, inoculum, nutrients and water. This is done to ensure that the solids in suspension is adequately agitated when it is transferred to the fermentor.

Stream Name:	3	Discharge T101			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Ammonium phosphate			0.32		
Biomass			0.15		
Glucose			5.51		
Inert			4.08		
Nutrients			0.09		
Water			89.84		
Total			100.00		
Process Conditions and Price					
Temp.	^oC		25		
Press.	bar_a		1		
Phase	V/L/S		S+L		
Price	US$/kg		-		

Discharge E101

Sufficient steam sterilization is necessary to kill and remove included microbial contaminants. It is done using a plate-type sterilizer. The process conditions, e.g. time and temperature, should be monitored to eliminate the bacteria and ensure no severe alterations of the medium (due to chemical reaction).

Stream Name: 4		Discharge E101			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Ammonium phosphate			0.32	(1)	
Biomass			0.15		
Glucose			5.51		
Inert			4.08		
Nutrients			0.09		
Water			89.84		
Total			100.00		
Process Conditions and Price					
Temp.	°C		37		
Press.	Bar_a		1.01		
Phase	V/L/S		S+L		
Price	US$/kg		-		

Air for R101 (IN)

Process air is supplied to the bioreactor for aerating the culture medium. It is also used, in smaller quantity, for performing pressure transfers and breaking vacuum after steam sterilization. As a material that enters the process, it has the potential to contaminate the process. It should be free from atmospheric contaminants and contamination by the compression system itself. It is from the centralized site and distributed through pipelines. Air receivers are installed in the system to cope with peak loads and short-term drops in supply due to compressor change-over or start-up of additional units.

Stream Name: 5		**Process Air**			
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.0		
Oxygen			21.0		
Total			100.00		
Process Conditions and Price					
Temp.	°C		25.00		
Press.	Bar_a		1.01		
Phase	V/L/S		V		
Price	US$/kg		-		

Discharge K101

The sterile condition of the process air is maintained after compression.

Stream Name:	6			**Process Air**	
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.0	(1)	
Oxygen			21.0		
Total			100.00		
Process Conditions and Price					
Temp.	°C		40.00		
Press.	Bar_a		3.01		
Phase	V/L/S		V		
Price	US$/kg		-		

Discharge S101

Sterilization of air is done by filtration using fibrous or membrane filters since sterilization by heat is economically impractical and ineffective due to the low heat-transfer of air compared to liquids. Airborne particles are also removed from the air.

Stream Name:	7			Discharge S101	
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.0		
Oxygen			21.0		
Total			100.00		
Process Conditions and Price					
Temp.	°C		40.00		
Press.	Bar_a		3.01		
Phase	V/L/S		V		
Price	US$/kg		-		

Bottom R101

Stream Name: 10		Bottom R101			
Comp.	Units %wt	Specifications Available	Design	Notes	Additional information (also ref. Note numbers)
Ammonium phosphate			0.02		(1) may also contain several other enzymes and
Biomass			1.04		Inactive protein which has synergistic effects on
Enzyme			0.84	(1), (2)	Activity of enzymes
Glucose			2.13		(2) activity is 8.44×10^4 U/ml
Inert			4.10		
Nutrients			0.09		
Water			91.77		
Total			100.00		
Process Conditions and Price					
Temp.	°C		37		
Press.	bar_a		1.01		
Phase	V/L/S		L		
Price	US$/kg		-		

Discharge E102

Stream Name: 11		Discharge E102			
Comp.	Units %wt	Specifications Available	Design	Notes	Additional information (also ref. Note numbers)
Ammonium phosphate			0.02		(1) The temperature of the reactor products is
Biomass			1.04		Reduced to 5°C to avoid self-digestion of
Enzyme			0.84		
Glucose			2.13		
Inert			4.10		
Nutrients			0.094		
Water			91.77		
Total			100.00		
Process Conditions and Price					
Temp.	°C		5.00	(1)	
Press.	bar_a		1.01		
Phase	V/L/S		L		
Price	US$/kg		-		

Discharge S103

Stream Name: 14			Discharge S103		
Comp.	Units %wt	Specifications Available	Design	Notes	Additional information (also ref. Note numbers)
Ammonium phosphate			0.02		(1) activity is 8.97×10^4 U/ml
Enzyme			0.89	(1)	
Glucose			2.25		
Water			96.85		
Total			100.00		
Process Conditions and Price					
Temp.	°C		5.00		
Press.	bar_a		1.01		
Phase	V/L/S		L		
Price	US$/kg		-		

Discharge S104

Stream Name: 16			Discharge S104		
Comp.	Units %wt	Specifications Available	Design	Notes	Additional information (also ref. Note numbers)
Ammonium phosphate			0.01		(1) activity is 8.97×10^6 U/ml
Enzyme			31.79	(1)	
Glucose			38.66		
Water			29.54		
Total			100.00		
Process Conditions and Price					
Temp.	°C		7.00		
Press.	bar_a		1.01		
Phase	V/L/S		L		
Price	US$/kg		-		

Builder + Binder (IN)

This stream composed the main core of the granules. For ecological reasons, these raw materials should be as natural as possible. These agents improve the activity stability, dust forming behavior, and handling. For example, the addition of the cellulose powder prevents the adherence of the wet granulate mass on the walls of the granulator.

Stream Name: 17				Binder + Builder	
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Builder			88.24	(1)	(1) composed of 79.13% Na_2SO_4, 8.70% dextrin, 6.96% $Ca(OAc)_2$, 3.48% TiO_2, and 1.74% cellulose powder
Binder			11.76	(2)	(2) composed of 85.71% PEG 6000, 14.29% PVP K30
Total			100.00		
Process Conditions and Price					
Temp.	°C		25.00		
Press.	bar_a		1.01		
Phase	V/L/S		S		
Price	US$/kg		1.588		

Discharge G101

This is the product of the granulating equipment. Based on the performance of the equipment, 98.% of the product is within the desired particle size range (1,000 μm – 250 μm) and 2.0% goes to the oversize and undersize streams.

Stream Name: 18				Discharge G101	
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Enzyme			19.99		
Glucose			24.32		
Builder			32.74		
Binder			4.36		
Water			18.59		
Ammonium phosphate			Trace		
Total			100.00		
Process Conditions and Price					
Temp.	°C		18.10		
Press.	bar_a		1.01		
Phase	V/L/S		S+L		
Price	US$/kg		-		

Discharge D101

Stream Name: 19		Discharge D101			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Enzyme			20.02		
Glucose			24.36		
Builder			32.79		
Binder			4.37		
Water			18.45		
Total			100.00		
Process Conditions and Price					
Temp.	°C		18.1		
Press.	bar_a		1.01		
Phase	V/L/S		S		
Price	US$/kg		-		

Oversize S105

This stream is sent to the hammer mill for crushing before recycling it to the granulator. This stream is 1.0% of the output of the fluid bed dryer.

Stream Name: 20		Oversize S105			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Enzyme			20.02		
Glucose			24.36		
Builder			32.79		
Binder			4.37		
Water			18.45		
Total			100.00		
Process Conditions and Price					
Temp.	°C		18.10		
Press.	bar_a		1.01		
Phase	V/L/S		S		
Price	US$/kg		-		

Discharge A101

Stream Name: 21		Discharge A101			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Enzyme			20.02		
Glucose			24.36		
Builder			32.79		
Binder			4.37		
Water			18.45		
Total			100.00		
Process Conditions and Price					
Temp.	°C		18.10		
Press.	bar_a		1.01		
Phase	V/L/S		S		
Price	US$/kg		-		

Undersize S105

This stream is directly sent back to the granulating equipment. This stream is 1.0% of the fluid bed dryer output.

Stream Name: 22		Undersize S105			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Enzyme			20.02		
Glucose			24.36		
Builder			32.79		
Binder			4.37		
Water			18.45		
Total			100.00		
Process Conditions and Price					
Temp.	°C		18.10		
Press.	bar_a		1.01		
Phase	V/L/S		S		
Price	US$/kg		-		

Discharge S105

Stream Name: 26		Discharge S105			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Enzyme			20.02		
Glucose			24.36		
Builder			32.80		
Binder			4.37		
Water			18.45		
Total			100.00		
Process Conditions and Price					
Temp.	°C		40.00		
Press.	bar_a		1.01		
Phase	V/L/S		S+L		
Price	US$/kg		-		

PEG 6000 (IN)

After drying the granules, it can be coated with a protective coating. The coating can serve to color the granulate or for the protection of the enzyme, or can cause retardation of the release of the enzyme or enzyme mixture. The binder selected from water soluble polymers, especially PEG with molecular weights in the range of 1,500 to 10,000.

Stream Name: 27		PEG 6000			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Coating			32.00	(1)	(1) composed of 60.0% PEG 6000, 26.67% 13.33% $MgSiO_2$
Builder			48.00		
Water			20.00		
Total			100.00		
Process Conditions and Price					
Temp.	°C		60.00		
Press.	bar_a		1.01		
Phase	V/L/S		S+L		
Price	US$/kg		1.122		

Mixture for D101

Stream Name: 28				Mixture for D101	
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Enzyme			15.93		
Glucose			19.38		
Coating			6.54		
Builder			35.90		
Binder			3.48		
Water			18.77		
Ammonium phosphate			Trace		
Total			100.00		
Process Conditions and Price					
Temp.	°C		45.97		
Press.	bar_a		1.01		
Phase	V/L/S		S+L		
Price	US$/kg		-		

3.3.4.2 Product

Enzyme Granules

This is the final product, coated enzyme granules which has an of activity of 2.34×10^6 U/ml.

Stream Name: 33				**Enzyme Granules**	
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Enzyme			15.93		(1) as dry substance, amount with respect to the particles of the uncoated enzyme granulate
Glucose			19.38		
Coating		5.0 – 26.0*	6.54	(1)*	
Builder			35.90		
Binder			3.48		
Water			18.77		
Ammonium phosphate			Trace		
Total			100.00		
Process Conditions and Price					
Temp.	°C		20.00		
Press.	bar_a		1.01		
Phase	V/L/S		S		
Price	US$/kg		15.00		

3.3.4.3 Utilities

Air for D101

This stream is used for the fluidized bed dryer for the drying of the granules.

Stream Name:	23		Air for D101		
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.00		
Oxygen			21.00		
Total			100.00		
Process Conditions and Price					
Temp.	°C		25.00		
Press.	bar_a		1.01		
Phase	V/L/S		V		
Price	US$/kg		-		

Discharge K102

Stream Name:	24		Discharge K102		
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.00		
Oxygen			21.00		
Total			100.00		
Process Conditions and Price					
Temp.	°C		40.00		
Press.	bar_a		3.01		
Phase	V/L/S		V		
Price	US$/kg		-		

Air for D102

This is used for the fluidized bed for the coating of the granules.

Stream Name:	29		**Air for D102**		
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.00		
Oxygen			21.00		
Total			100.00		
Process Conditions and Price					
Temp.	°C		25.00		
Press.	Bar_a		1.01		
Phase	V/L/S		V		
			-		

Discharge K103

Stream Name:	30		Discharge K103		
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.00		
Oxygen			21.00		
Total			100.00		
Process Conditions and Price					
Temp.	°C		40.00		
Press.	Bar_a		3.01		
Phase	V/L/S		G		
Price	US$/kg		-		

Discharge E103

Stream Name: 31		Discharge E103			
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.00		
Oxygen			21.00		
Total			100.00		
Process Conditions and Price					
Temp.	°C		20.00		
Press.	Bar_a		1.03		
Phase	V/L/S		G		
Price	US$/kg		-		

NaCl Brine

This utility is used as a cooling agent of the coolers and ultrafilter.

Stream Name:		NaCl brine			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
NaCl Brine			100.00		
Total					
Process Conditions and Price					
Temp.	°C		-9.00		
Press.	Bar_a		1.01		
Phase	V/L/S		L		
Price	US$/kcal		$28.00/10^6$kcal		

Cooling water

Cooling water for the sterilizer and fermentor.

Stream Name:		Cooling Water			
Comp.	Units %wt	Specifications Available	Design	Notes	Additional information (also ref. Note numbers)
Water			100.00		
Total			100.00		
Process Conditions and Price					
Temp.	^oC		5.00		
Press.	Bar_a		1.01		
Phase	V/L/S		L		
Price	US$/kcal		$1.00/10^6$kcal		

Low Pressure Steam

Heating agents for Sterilizer and Fluidized bed dryer

Stream Name:					
Comp.	Units %wt	Specifications Available	Design	Notes	Additional information (also ref. Note numbers)
Water			100.00		
Total			100.00		
Process Conditions and Price					
Temp.	^oC		152.0		
Press.	Bar_a				
Phase	V/L/S		V		
Price	US$/kcal		$10.00/10^6$kcal		

Wash water

This is used for washing of the cake of the vacuum drum filter.

Stream Name:	12	**Wash Water**			
Comp.	Units %wt	Specifications Available	Specifications Design	Notes	Additional information (also ref. Note numbers)
Water			100.00		
Total			100.00		
Process Conditions and Price					
Temp.	°C		25.00		
Press.	Bar_a		1.01		
Phase	V/L/S		L		
Price	US$/kg		0.005		

3.3.4.4 Wastes

Gas R101

This is the exhaust gas of the fermentor which is mainly composed of air and CO_2 and possibly traces of fermentation product.

Stream Name:	8	Gas R101			
Comp.	Units %mol	Specifications Available	Specifications Design	Notes	Additional information (also ref. Note numbers)
Nitrogen			78.99		
Oxygen			20.23		
Carbon dioxide			0.77		
Total			100.00		
Process Conditions and Price					
Temp.	°C		37.00		
Press.	Bar_a		1.01		
Phase	V/L/S		V		
Price	US$/kg		-		

Discharge S102

Stream Name: 9		Discharge S102			
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			78.99		
Oxygen			20.23		
Carbon dioxide			0.77		
Total			100.00		
Process Conditions and Price					
Temp.	°C		37.00		
Press.	Bar_a		1.01		
Phase	V/L/S		V		
Price	US$/kg		-		

Solid Waste

This stream is sent to the appropriate treatment plant.

Stream Name: 13		**Solid waste**			
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Ammonium phosphate			0.01		
Biomass			10.96		
Glucose			1.01		
Inert			43.07		
Nutrients			0.99		
Enzymes			0.40		
Water			43.56		
Total			100.00		
Process Conditions and Price					
Temp.	°C		5.00		
Press.	Bar_a		1.01		
Phase	V/L/S		S/L		
Price	US$/kg		-		

Liquid Waste S104

This waste stream is sent to the wastewater treatment facility.

Stream Name: 15				Liquid waste	
Comp.	Units	Specifications			Additional information
	%wt	Available	Design	Notes	(also ref. Note numbers)
Glucose			1.21		
Water			98.77		
Ammonium phosphate			0.02		
Total			100.00		
Process Conditions and Price					
Temp.	°C		7.00		
Press.	Bar_a		1.01		
Phase	V/L/S		L		
Price	Nfl/kg		-		

Top D101

The exhaust gas of the fluidized bed dryer. This could contain particulates.

Stream Name: 25					Top D101
Comp.	Units	Specifications			Additional information
%mol		Available	Design	Notes	(also ref. Note numbers)
Water			69.44		
Nitrogen			24.15		
Oxygen			6.41		
Total			100.00		
Process Conditions and Price					
Temp.	°C		40.00		
Press.	bar_a		1.01		
Phase	V/L/S		V		
Price	US$/kg		-		

Top D102

This is the exhaust gas from the fluidized bed coating equipment. Particulates are possible contaminants of this stream.

Stream Name:	32		Top D102		
Comp.	Units	Specifications			Additional information
	%mol	Available	Design	Notes	(also ref. Note numbers)
Nitrogen			79.00		
Oxygen			21.00		
Water			Trace		
Total			100.00		
Process Conditions and Price					
Temp.	°C		20.00		
Press.	Bar_a		1.01		
Phase	V/L/S		V		
Price	US$/kg		-		

3.4 ECONOMIC MARGIN

Below is the tabulated data for the evaluation of economic margin (see Appendix 3-2):

Feed Stream Costs

TOTAL VALUE OF FEEDSTOCKS, PROCESS CHEMICALS IN

Stream --------->	Prices [US$/kg]	Units	1	2	5	12	17	23	27	29	Total Price US$
Ammonium phosphate	1.00	kg/day	1,550.00	-	-	-	-	-	-	-	1,550.00
Biomass	5.00	kg/day	740.00	-	-	-	-	-	-	-	3,700.00
Glucose	1.00	kg/day	27,000.00	-	-	-	-	-	-	-	27,000.00
Inerts	1.00	kg/day	20,000.00	-	-	-	-	-	-	-	20,000.00
Nutrients	1.00	kg/day	460.00	-	-	-	-	-	-	-	460.00
Coating	2.00	kg/day	-	-	-	-	-	-	1,600.00	-	3,200.00
Builder	1.00	kg/day	-	-	-	-	6,379.99	-	2,400.00	-	8,779.99
Binder	6.00	kg/day	-	-	-	-	850.00	-	-	-	5,100.00
Water	0.01	kg/day	-	440,000.00	-	24.00	-	-	1,000.00	-	3,307.68
Nitrogen	-	kg/day	-	-	521,053.82	-	-	16.84	-	22,135.80	-
Oxygen	-	kg/day	-	-	158,181.84	-	-	5.11	-	6,720.00	-
Carbon dioxide	-	kg/day	-	-	-	-	-	-	-	-	-
Total Mass rate		kg/day	49,750.00	440,000.00	679,235.66	24.00	7,229.99	21.95	5,000.00	28,855.80	-
										Total US$	**73,097.67**

TOTAL VALUE OF PRODUCTS OUT

Stream --------->	Prices [US$/kg]	Units	33	Total Price US$
Enzyme granules	12.00	kg/day	24,454.38	293,452.56
Total Mass rate		kg/day	24,454.38	
			Total US$	**293,452.56**

MARGIN = OUT-IN

MARGIN [US$/year] **66,106,467.00**

Margin = (293,452.56)-(73,097.67) = US$ 220,354.89 per day
= US$ 66 million per year

1) The above prices are approximation of the prices available on the internet.
2) The above cost analysis has been made considering that the biomass produced is worthless, when actually, it could be dried and incinerated to produce electricity.

Based on the table above, the design project is economically feasible. The estimated cost of feedstocks and other chemicals is US$ 73,097.67 while the product value is US$ 293,452.56 on a per day basis. This means a economic margin of US$ 220,354.89 per day or US$ 66 million annually. The cost of the raw materials could still be reduced if the medium composition is optimized.

4 THERMODYNAMIC PROPERTIES

Table 5. Technical medium composition in tap water

Component	Cp [kJ/kg-K]	ρ[kg/m³]	State	Source
Ammonium phosphate	0.90	1619	Solid	[1] Perry
Biomass	0.7	1050	Solid	[2]SPD
Glucose	1.22	1562	Solid	[2]SPD
Inerts	**1.33**	**1200**	**Liquid**	**Calculated**
Cellulose	1.31	1350	Solid	[1] Perry
Insoluble salts	4.184	2300	Solid	Assumed
Antifoam Ke 211	24.02	1000	Liquid	Assumed
Nutrients	**0.73**	**1000**	**Liquid**	**Assumed**
Builder	**1.22**	**1800**	**Solid**	**Calculated**
Cellulose powder	1.34	1350	Solid	[1] Perry
Sodium sulphate (filler)	137.24	2698	Solid	[1] Perry
Yellow dextrine	1.34	1038	Solid	Assumed
Calcium acetate	0.59	2500	Solid	Assumed
TiO_2	0.63	4220	Solid	[1] Perry
Binder	**1.34**	**1010**	**Liquid**	**Calculated**
PEG 6000 (Polyethylene Glycol, MW : 6000)	1.13	1100	Liquid	Assumed
PVP K30 (Polyvinyl Pyrolidone, MW : 30,000)	1.47	1000	Liquid	Assumed
Water	4.184	1000	Liquid	[1]Perry
Coating	**1.40**	**1100**	**Liquid**	**Calculated**
PEG 6000 (Polyethylene Glycol, MW : 6000)	1.53	1100	Liquid	Assumed
TiO_2	0.63	4220	Solid	[1] Perry
Magnesium silica	107.11	2500	Solid	Assumed
Water	4.184	1000	Liquid	[1]Perry

Source:
[1]Perry, R.H. and Green, D., Perry's Chemical Engineers' Handbook, 6 Ed. McGraw-Hill, 1984
[2] Super Pro Designer, version 2.7 – Simulation Software

4.1 Operating Window

Temperature range: 5°C [278 K] – 60°C [313 K]
Pressure rande: 1 bara – 3.01 bara

Densities and specific heats of all components have been assumed constant for the purpose of calculation throughout the rnge of the operating window.

4.2 Data Validation

4.3 Data Accuracy

5 PROCESS STRUCTURE AND DESCRIPTION

5.1 CRITERIA AND SELECTIONS

5.1.1 Enzyme production

Proteases are one of the most important industrial enzymes currently in industrial production. Proteases, having molecular weights ranging from 25000 – 30000, are produced commercially both from bacteria and fungi and are stable up to a temperature of 65°C.
The detergent enzymes are alkaline serine protease Subtilisin Carlsberg formed by *Bacillus licheniformis* and protease Subtilisin NOVO™ by *Bacillus amyloliquefaciens*.
The cultivation with complex medium used in the industry are yielding protease activity of 0.5×10^9 U/kg_{cells}. The concentration of cells is 30 kg_{cells}/m^3_{liq}.
The proteases of this type have many features of value for use as detergent enzymes:

- stability at high temperature
- stability in the alkaline range (pH 9-11)
- stability in association with chelating agents and perborates, however, their stability in the presence of surface-active agent is low, thus limiting their shelf life.

Screening of proteases should be done to assure its stability under alkaline conditions. Strains of *B. licheniformis* and *B. subtilis* showed optimal growth in the pH range 6-7, but the new genetically modified strains can grow at pH 8-11. Protein engineered Bacillus has improved properties such as substrate specificity, pH optimum, and stability to bleaching agents. At their optimum pH range, at least 90% of the maximal growth rate is attained.
The enzyme production can be carried out in three modalities:

Batch process: A batch fermentation is considered as a closed system. At t=0 sec., the sterilized nutrient solution in the fermenter is inoculated with the microorganisms and incubation proceeds under optimal physiological conditions. During the fermentation, only oxygen (air), an antifoam agent and acid or base to control pH are added. The composition of the culture medium, the biomass concentration, and the metabolite concentration generally change constantly as a result of the metabolism of the cells.

Fed-Batch process: The fed-batch process is the modification of the conventional batch process. In this process, the substrate is added in increments as the fermentation progresses. The formation of many secondary metabolites is subject to catabolite suppression by high concentrations of glucose, other carbohydrates, or nitrogen compounds. So, in the fed-batch system the critical elements of the nutrient solution are added in small concentrations at the start of the fermentation and are continuously added in small doses during the production phase. Experiments showed that the biosynthesis of the alkaline serine protease is dependent on the growth rate of the culture and concentration of nitrogen and carbon sources in the medium. Ammonium was reported to inhibit protease production. The experiments showed that in the fed-batch fermentation a constant low level of ammonium concentration should be maintained for optimum protease production. In a fed-batch procedure, production could be increased 4.6-fold in comparison to an uncontrolled batch process.

Continuous process: Continuous process is considered as an open system. Sterile nutrient solution is added to the bioreactor continuously and an equivalent amount of converted nutrient solution with microorganisms is withdrawn out of the system. The reactor could be a homogenously mixed bioreactor or a plug flow type. A homogenously mixed reactor is either a chemostat where the cell growth is controlled by adjusting the concentration of one substrate (limiting factor) or a turbistat, cell growth is maintained by using turbidity to monitor the biomass concentration and the rate of feed of the nutrient solution is properly adjusted.

The batch and the fed-batch processes are generally used in the fermentation process. The latter is employed to keep down the concentration of ammonium ions and amino acids, since these nitrogenous materials repress protease production. Although continuous processes have been described, they are not commercially used. For this design project, the batch reactor will be used since many published data are available.

The process starts with the sterilization of the seed and fermentation (with medium) tank at 121°C for 30 minutes with steam. The sterilized medium is then cooled to cultivation temperature. The inoculum will be fed to the seed tank (1-20 m^3) which runs from 20-70 hours depending on the volume and the microorganisms used. At this sterile conditions, the inoculant is transferred to the fermenter, which is typically between 40-100 m^3, for the fermentation process. The end point of the process is when the maximum enzyme activity is reached which is usually after 24-28 hours of fermentation time. After the fermentation, the broth is cooled down and transferred to the drop tank for further separation and concentration. The batch process will usually take a time range of 45 to 130 hours depending on the microorganisms, the type, amount and quality of the raw materials.

The following reactions take place in the bioreactor

(1)	$1.10\ C_6H_{12}O_6 + 1.2\ NH_3 \rightarrow C_6H_{10.8}N_{1.2}O_{3.0} + 2.4\ H_2O + CO_2$	*enzyme production*
(2)	$1.03\ C_6H_{12}O_6 + 1.74\ NH_3 \rightarrow C_6H_{9.48}N_{1.74}O_{2.04} + 0.18CO_2 + 3.78\ H_2O$	*biomass production*
(3)	$C_6H_{12}O_6 + 6O_2 \rightarrow 6\ CO_2 + 6\ H_2O$	

5.1.2 Separation

The first downstream step in a biological process is usually the removal of suspended cell mass and other particulate/colloidal debris from the suspending medium. The concentration of extra-cellular enzymes in typical biotechnological processes is 0.5-1% (w/w).

In the past, the preferred methods of cell harvesting were filtration or centrifugation. To be economical on an industrial scale, the method must be a continuous process. Continuous centrifuges, where the cells are removed by the action of high G forces, are expensive to buy, operate, and maintain. The production rate of a centrifuge is a function of many variables, among them the square of the particle diameter, the difference in density between the particles and the suspending medium, the G force and the viscosity of the suspending medium. The production rate and the cell recovery (yield) are strongly dependent on particle size and inversely proportional to each other. In addition, there may be substantial heat generation requiring complicated cooling system; there may be production of aerosols, and the capacity of most tubular centrifuges is limited and may require frequent teardowns and cleaning (Cheryan, 1998).
Filtration, on the other hand, is not limited in throughput by the particle size, and the separation rate does not go down as smaller microorganisms are harvested. The most common method is rotary drum filters, where a vacuum draws the broth to the drum surface.
The microbial cells and other insoluble solids accumulate on the filter cloth and are scraped off with a knife.

5.1.3 Concentration

Many traditional cell-harvesting processes are being replaced by cross-flow membrane filtration. With proper selection of the membrane, the module, and operating parameters, 100% cell recovery can be obtained, and capacity can be increased by merely adding more membrane area.
Over 130 materials have been used to manufacture membranes but only a few have achieved commercial status and fewer still have obtained regulatory approval for use in food, pharmaceutical, and kindred applications. The family of polysulfone membranes has been chosen in the concentration step of this process due principally to the following favorable characteristics:

- Wide temperature limits: typically, temperatures up to 75°C
- Wide pH tolerances: these membranes can be continuously exposed to pHs from 1 to 13
- Fairly good chlorine resistance: up to 200 ppm chlorine for cleaning and up to 50 ppm chlorine for short storage of the membrane
- Easy to fabricate membranes in a wide variety of configurations and modules
- Wide range of pore sizes available for ultrafiltration applications, ranging from 10A° (1000 MWCO) to 0.2μm in commercial-size modules.
- Good chemical resistance to aliphatic hydrocarbons, fully halogenated hydrocarbons, alcohols and acids.

Membrane technology presents six basic designs of equipment: (1) tubular, with inner channel diameters>4 mm; (2) hollow fibers, with inner diameters of 0.2-3 mm; (3) plate units; (4) spiral-wound modules; (5) pleated-sheet cartridges; and (6) rotary modules.
A hollow fiber design has been chosen due to the following characteristics:

- It is one of the more economical designs in terms of energy consumption because of combination of pressure drops and flow rates. Operating velocity of 0.5-2.5 m/s (Reynolds numbers of 500-3000) and pressure drops of typically 1.35-2.35 bara, depending on flow rate, fiber diameters and lengths.
- Hollow fibers have the highest surface area-to-volume ratio among the modules. Holdup volume is low.
- A big advantage with hollow fibers is its back-flushing capability, which improves its cleanability. This is possible because the fibers are self-supporting.

The hollow fiber design that suits the process requirement has the following characteristics:

Table 6. Characteristics of the selected concentration equipment

PARAMETER	VALUE
Membrane design	Hollow fibers
Membrane material	Polysulfone
Pore Size [A°]	200
Fiber diameter [mm]	0.5
Fiber length [m]	0.1
Temperature and pressure rating	80°C – 1 atm
PH value	8-11
Manufacturer	A/G Technology

Though ultrafiltration is the most economical method for concentrating the filtrate, it cannot achieve very high concentrations (~99%) due to reduction in efficiency as the concentration gradient is very low and the osmotic pressure becomes low. More membrane systems are required in order to achieve such high concentrations. In order to avoid this, an evaporator is used to concentrate the ultra-filtrate further. The enzymes begin to degenerate at temperatures beyond 330 K in water. Hence, the boiling point of the ultra filtrate has to be reduced by vacuum. Thus, the evaporator has to function under vacuum conditions.
Another possibility could be freeze concentration, which is done by freezing the ultra filtrate and then the ice formed on the surface of the liquid is scraped off. The refrigeration of the ultra filtrate is energy intensive compared to evaporation.

5.1.4 Granulation

The protease rich ultra filtrate can be spray dried and introduced into the detergent in powdered form (mean particle size 0.3 mm with considerable amount of small particles) (Kadam, 1991). The dust in the environment has high protease concentration and can cause allergenic reactions in workers handling these products. Hence the proteases are an environment hazard in the powdered form. In order to eliminate this hazard, the protease rich ultrafiltrate can be mixed with Builder and Binder and granulated using a granulator. In industry, granulators are bought as there are standard designs. For the present project, Lödige High Shear Mixer/Granulator has been chosen for granulating the enzyme. It is a batch granulation system where the Builder, Binder and Ultra filtrate are mixed under high shear conditions leading to the formation of granules.

5.1.5 Fluidized bed drying

The granule formed in the granulator has high moisture content due to the mixing of the ultra-filtrate and Binder, both of which are solutions. The wet granules are difficult during handling and transportation. Drying reduces the cohesive forces between the individual granules enabling ease in handling. The best and most widely used dryer in industry is the fluidized bed dryer. The reason being that heat transfer is very rapid due to the convection currents formed around each individual granule in the bed. Another major advantage of these type of dryers is the close control of conditions so that a predetermined amount of free moisture may be left with the solids to prevent dusting of the product during subsequent material handling operations.

5.1.6 Screening, Crusher and Recycle

The product stream has a wide size distribution. The desired product should have a size range from 250 μm to 1000 μm. Industrial screens have to be used to classify the product into the desired size class. The over size i.e. the size above 1000 μm has to be crushed with a crusher and sent back to the granulator and the under size i.e the size class below 250 μm has to be sent directly to the granulator. This increases the throughput of the granulator and hence the feed to the granulator has to be reduced depending on its own performance i.e. the amount of over size and under size produced.

5.1.7 Fluidized bed coating

Coating of enzyme granules is important in order to protect the enzyme from the environment. The Coating is usually a mixture of polymer (PEG 4000) along with TiO_2 and Magnesium Silicate which effectively isolates the enzyme from the environment. One can also control the dust by placing a coating around the granules which binds fines to larger particles, or prevents attrition of the granule. In this project a fluid bed coating system will be used to coat the Coating on the enzyme granule. Fluid bed equipment has been found to be useful for forming and coating granules particularly smaller granules which are difficult to handle by other methods. They are designed to keep even small particles in the processing chamber where they may become coated.

5.1.8 Batch/Continuous

The reactor will be operated in batch mode as the micro-organisms which produce the enzymes tend to change their DNA structure after every batch. So a new culture has to be introduced after every batch. This also involves sterilising the vessel and the substrate. The granulator and all subsequent downstream processing will be batch mode as control of particle size distribution and strength of the granules is extremely difficult in continuous mode.

5.1.9 Heat Integration

Energy saving plays an important role in the design process. Heat integration reduces the energy requirement of a certain process, thus making it more economically attractive. However, the inclusion of heat integration in this design project is not practically useful. The temperatures of the streams are not large enough because they are restricted by the allowable limit of the enzymes. This is usually the case of bioprocesses, they are working at a relatively low temperature. For this design project, the working temperature is 5°C and the highest is 121°C.

5.2 PROCESS FLOW SCHEME

The Process Flow Scheme diagram is shown in Appendix 5-1.

5.3 BATCH CYCLE DIAGRAM

The Batch Cycle diagram is shown in Appendix 5-2.

5.4 PROCESS STREAM SUMMARY

The Process Stream Summary is shown in Appendix 5-3.

5.5 UTILITIES

The details on the utilities is shown in Appendix 5-4.

5.6 PROCESS YIELDS

The process yields have been shown in Appendix 5-5.

6 PROCESS CONTROL

6.1 INTRODUCTION

The overall objective in any process -continuous or batch- is to convert certain raw materials into desired products in the most economical way. During production, the process must meet a number of requirements, such as safety, production specifications, environmental regulations, operating constraints and economics. All these requirements indicate the need for continuous monitoring and control of the operation of a process plant. This is accomplished through a rational arrangement of equipment (measuring devices, valves, controllers, computers) and human intervention (design and operating personnel) which together constitute the control system. The control loops of the detergent enzyme granules manufacturing process have been shown in the process flow scheme. The following sections will discuss in detail the control system of two major units, namely the fermenter and the fluid bed dryer/coater.

6.2 PHYSICAL CONTROL OF THE FERMENTATION

The growth of microorganisms is a process which is regulated by a complex interaction between the external physical, chemical and biological conditions of the liquid environment of the fermentation and the internal biochemical processes within the cells. The control objective therefore is to regulate the environment so that the correct conditions are obtained for cell growth and production. In this process the aerated stirred tank fermenter is supplyed with means of measuring temperature, pressure, pH, dissolved oxygen concentration and the agitator speed. Foaming is not depressed by the controlled addition of antifoam agent since excessive amount may have inhibiting effects on the growth of the microorganism. A sophisticated device "Fundafoam system" (Checap) mounted on to the agitator shaft is used to destroy the foam. The nutrient solution held in the foam flows back into the bioreactor, and the air released from the foam leaves the vessel.

6.2.1 Temperature

The temperature measuring instrument for the fermenter is the platinum resistance thermometer with standard Pt 100 probe. Heating is not necessary as the power input from the impeller is sufficient to heat up the vessel. All tanks are fitted with baffles which prevent a large central vortex being formed and improve mixing, and coolant passes through the baffle. As the fermentation is a batch process, the temperature control must be time-dependent. Therefore, full PID control using the control valve of straight-through cooling water is used.

6.2.2 Pressure

The fermenter is fitted with a mechanical pressure gauge with local read-out for safety. A manual needle valve can be used on the fermenter outlet to keep a back-pressure in the fermenter, but this will require much fiddling to keep the pressure constant. A pressure regulator gives a more constant back-pressure, but regulators on fermenters tend to block and are not of hygienic design. The best arrangement is a control loop consisting of a pressure transmitter, PID controller, and air-operated air flow control valve on the vessel exit line.

6.2.3 Agitation

Reliable and precise agitator speed control is not easily obtained. A precise method consists of a control loop with a frequency sensor reading the fermenter shaft speed and feedback control to the motor drive. Modern A.C. speed controllers and motors are now available. Adjustment of agitator speed is the easiest way to control dissolved oxygen tension in the fermenter. For this reason the motor speed controller has set-point input, sometimes called external or remote set-point control. This input can then be set by the output of the dissolved oxygen controller.

6.2.4 pH control

Measurement of pH is based on the absolute standard of the electrochemical properties of the standard hydrogen electrode. Control of pH is actually achieved by the controlled pulse modulated feeding of either acid or base. This operates such that when the pH measurement exceeds the set-point value, acid is fed to the reactor, and when the measured pH is less than the set-point, feeding of base occurs. The provision of either acid or base side of the set-point results in a two-sided discontinuous corrective feeding of either acid or base. A variable dead-band PI controller is used because it can be set up to allow the fermenter pH to drift natually within a defined band, with acid or base control being applied only outside the upper and lower limits of the dead-band.

6.2.5 Dissolved oxygen

The dissolved oxygen content of the fermentation broth is a very important fermentation parameter, affecting both cell growth and production formation. Three main methods, namely: (1) the tubing method, (2) the use of mass spectrometer probes, and (3) electrochemical detectors, may be used for the determination of dissolved oxygen concentration. All require a prior calibration procedure since they use membranes to separate the point of measurement from the broth. DOT control can be achieved via four controlled variables on the fermenter: air flow, pressure agitator speed, and oxygen/inert gas mixing. In this project a control combination of air flow and agitator speed is used, which is most common in practice. This works generally by the controller first regulating agitator speed and varying this up to a fixed maximum value. At this point, the controller the begins to increase gas flow rate. The combined control scheme is cascaded, such that the controller output signal is used to adjust the set-point of the agitator speed control, or the set-point of the gas flow rate controller.

6.3 PHYSICAL CONTROL OF THE FLUID BED DRYING AND COATING

The aim of any industrial drying processes is to produce a solid product of desired quality at minimum cost and maximum throughput and to maintain these consistently. The control of dryers is probably one of the least studied areas of process control because of the highly nonlinear dynamics of drying process. The most important manipulated inputs to a fluid bed dryer are inlet air temperature and air flow rate. The most desirable drying process output variable to control is the product moisture content, but this is generally difficult to measure directly. Often, the moisture content of the dried product can be inferred from the temperature and humidity of the exhaust gas, although care must be taken in applying appropriate mass and heat balances. Moreover, measuring the temperature of the exit gas is simple, accurate, reliable, cheap and has significant effects on the drying rate. Therefore, Among available control strategies, the control system based on exhaust air temperature as the control variable and inlet air temperature as the manipulated variable is found to be adequate for the fluid bed dryer. This control strategy performs quite satisfactory under any load changes because of the fluid bed capacity. Compared to the fluid bed dryer, one more manipulated input is available: the flow rate of the liquid. Therefore, we have two alternative basic types of control systems. Control system A features two quick-response control loops:

1. Control of exhaust air temperature by feed rate regulation.
2. Control of inlet air temperature by air heater regulate.
3. Control system B uses air heater regulation to compensate for any deviation from the desired outlet air temperature. This system also features manual regulation of the feed rate. Both system are commonly used in the industrial dryers. In this project, the control system B is preferred since wide variations in feed rate cannot be handled.
4 These control schemes are provided with safety systems that prevent any failure in the feed system in order to prevent the outlet air temperature rising above a specified safety level.

7 MASS AND HEAT BALANCES

7.1 PRACTICAL ASPECTS

The mass balance for the present process has been solved accurately with a difference of zero. However, the heat balance has not been solved to the same accuracy, but with a difference of 8 kW. The reason could be due to some discrepancies in the specific heats of the materials. The specific heats have been taken constant in the range of the operating window and this has led to the discrepancy. But since 8 kW is very small compared to the total power input and output, it can be neglected.

7.2 BALANCE FOR TOTAL STREAMS

The Balance for the total stream is shown in Appendix 7-1.

7.3 BALANCE FOR STREAM COMPONENTS

The Balance for the Stream Components is shown in Appendix 7-2.

8 PROCESS AND EQUIPMENT DESIGN

8.1 INTEGRATION BY PROCESS SIMULATION

For the production of enzyme-coated granules, the process can be divided into two parts: 1) the production of the enzymes; and 2) the granulation. To simulate the process, the group used the aide of the SuperPro Designer Version 2.7(hereafter referred to as SPD2.7). The SPD2.7 is one of the many simulation software for process simulation. However, what is distinctive of SPD2.7 is its capability of simulating a bioprocess.

The main problem encountered when simulating the whole process is the gap created by the granulation part of the process. SPD2.7 is not equipped with the simulation of granulation. So from the production of enzymes, the group treated the granulation part as a simple unit operation of mixing of the product enzyme and the binders used in granulation, and then proceeds to the rest of the unit operations (i.e. fluid bed drying, and fluid bed coating). By treating the granulation part as purely mixing, does not at all affects the mass balance assuming that nothing is lost during granulation.

The simulation modeling is given in Figure 2.

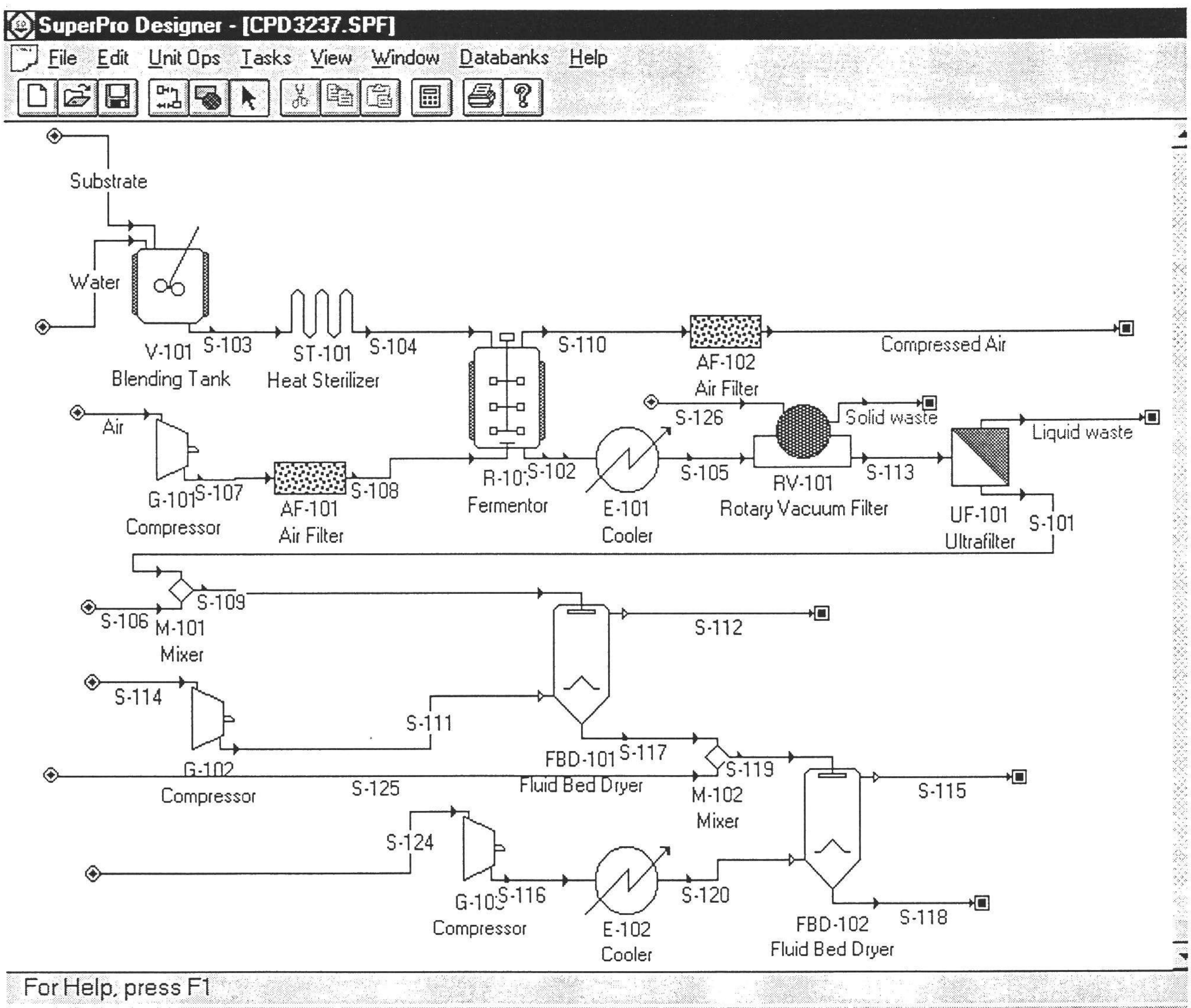


Figure 2. Process Simulation Model

8.2 EQUIPMENT SELECTION AND DESIGN

8.2.1 Blending tank

The volume of the tank is calculated as follows (for batch Operation)

(Liquid Volume) = (Total Liquid Volume Processed per Batch) / (Number of Cycles).

8.2.2 Sterilizer

The purpose of this model is to rigorously simulate the holding tube of a continuous sterilizer and to approximately estimate the cost of the entire system, including the holding tube along with its insulation, the heat exchangers for energy conservation, the pumps, etc. Continuous heat sterilization is simulated assuming logarithmic death rate of microorganisms and spores (Wang et al, 1979):

$$-\frac{dN}{dt} = k * N,$$

where N is the concentration of viable organisms in number/m^3, k is the specific death rate constant in sec-1, and t is time in minutes. At t = to, N = No.

The specific death rate (k) is related to sterilization temperature by an Arrhenius type equation:

$$k = A * e^{\left(-\frac{\Delta E}{RT}\right)},$$

where A is the frequency factor in sec-1, ΔE is the activation energy of death in J/mole, R is the gas constant in J/mole-K, and T is the absolute temperature in K.

Since actual plug flow through the holding tube of a continuous sterilizer is never achieved, an axial dispersion model is assumed to account for residence time distribution. Solving the material balance equation, we get:

$$\frac{N}{No} = \frac{4 * \delta * e^{\left(\frac{N_{pe}}{2}\right)}}{\left(1+\delta^2\right) * e^{\left(\frac{N_{pe}\delta}{2}\right)} - \left(1-\delta^2\right) * e^{\left(\frac{N_{pe}\delta}{2}\right)}},$$

where $\delta = \sqrt{1 + \frac{4N_R}{N_{pe}}}$, $N_R = \frac{kL}{U}$, $N_{pe} = \frac{UL}{D_z}$

U is the average medium velocity (m/sec), L is the length of the holding tube (m), Dz is the axial dispersion coefficient (m^2/sec). Dz is estimated as a function of the Reynolds number from the following equation:

$$\frac{D_z}{\mu / \rho} = 6.0936 * 10^5 - 1.2342 * 10^5 \ln(\text{Re}) + 6279.2[\ln(\text{Re})]^2,$$

where μ is the liquid viscosity (kg/m-s) and ρ is the liquid density (kg/m^3). This equation was derived by curve fitting experimental data (Figure 40, Levenspiel, 1972).

The tube diameter (dt) and the sterility level (N/N_0) are specified and the equations are solved iteratively to estimate the required tube length (L).

The size estimation of the heat exchangers that are used for energy conservation as well as the estimation of utilities are based on intermediate and final temperatures of various streams that are specified by the user.

8.2.3 Fermentor

The fermentor is modeled as a stoichiometric reactor. It can be used to simulate bio-transformations when the reaction kinetics are unknown or unimportant but the mass stoichiometry is known and the extent of reaction can be specified or calculated based on the concentration of a reference component. The extent of reaction is defined as the fractional conversion of the limiting component.

8.2.3.1 Reaction Initialization and Material Balances

The user provides the mass stoichiometric coefficients (Ai) of the various components for the overall reaction. Negative coefficients are used for reactants and positive for products. The sum of all stoichiometric coefficients must be equal to zero to guarantee mass conservation. The extent of reaction (x) is based on the limiting component and it is either specified by the user or calculated based on the specified concentration of a reference component. If the specified reference component concentration is not feasible, the user is warned and the algorithm assumes a reaction extent of 100% or 0% depending on whether the reference component is a product or reactant, respectively. The material balances are based on the following simple algorithm:

Case where the reaction extent is specified
First, the limiting component (k) is identified, based on the mass stoichiometry and the composition of the feed streams. Its outlet mass flowrate (Fout,k) as a function of its inlet mass flowrate (Fin,k) and the extent of reaction (x) is:

$Fout_k = Fin_k (1-x)$,

where,

$Fout_k$ is the mass flowrate of the limiting component after the reaction,

Fin_k is the mass flowrate of the limiting component before the reaction, and

x is the reaction extent.

Second, the outlet mass flowrate (Fouti) of component (i) as a function of its inlet mass flowrate (Fini), the extent of reaction (x), and the mass stoichiometric coefficients (A_i), is given by the following equation:

$Fout_i = Fin_i - Fin_k * x * (A_i/A_k)$,

where A_k is the coefficient of the limiting component.

Case where the concentration of a reference component is specified
The algorithm starts again with the identification of the limiting component (k). Next it checks whether the specified reference component concentration is feasible (it corresponds to a reaction extent between 0 and 100%). If the reference component concentration is feasible, the algorithm calculates the reaction extent that corresponds to the specified concentration using an iterative computational procedure. If the specified reference component concentration is not feasible, the user is warned and the algorithm assumes a reaction extent of 100% or 0% depending on whether the reference component is a product or reactant, respectively. After the calculation / selection of the extent of reaction, the reaction material balances are completed as in the previous case.

8.2.3.2 Vapor Effluent

Vapor-liquid equilibrium calculations in the fermentor are not carried out. To account for gas components exiting in the gas outlet stream, the user must specify the removal fraction (Percent in Gas Outlet) for each component. The calculation of the gas outlet stream composition is based on materials that are available in the vessel after the completion of the fermentation.

8.2.3.3 Intra/Extracellular Component Flowrate

You may also specify the extracellular percent (100% by default) of each of the reactions product components. This feature is useful when tracking of intracellular water is desired because it affects the performance of centrifugation, filtration, etc. further downstream. If the Extra-Cell % of certain reaction product components is less than 100 (or in other words a fraction of the component is intracellular) and the Primary Biomass and Water components are identified (through the component initialization dialog window), then the model automatically associates intracellular water with the intracellular reaction product components. Then, if a separator is used to remove intracellular components (i.e., removal of biomass by a centrifuge), the separation (removal %) of intracellular water will be the same as that of the intracellular component(s).

8.2.3.4 Vessel Sizing

The bioreactor volume (V) for continuous operation is estimated based on the overall feed volumetric flowrate (F) and the average dilution rate (D):

$V = F/D$

For batch operation, when the reactor volume is not specified by the user, it is set equal to the volume of the material that is processed during each cycle.

8.2.3.5 Aeration Rate

When the aeration rate is set by the user (in Volume of air under standard conditions per Volume of fermentation broth per Minute - VVM), the flowrate of the aeration stream is adjusted by the fermentor model. If the aeration stream has a source unit operation (e.g., a compressor), then the adjustment of its flowrate is recursively back - propagated till flowsheet feed streams are reached. At least one of the flowsheet feed streams that feed into the aeration stream must have non-zero flowrate. Only units with a single output stream can be part of the sequence of units that feed into an aeration stream. An exception to this rule is the Custom Mixer which is not allowed to be part of the sequence even though it has a single output stream.

8.2.3.6 Utility Calculation

The average agitation power is estimated by multiplying the unit power requirement (kW/m3 of broth) by the liquid volume of the fermentor. To estimate the overall heating or cooling requirement, the model considers the sensible heat of the inlet and outlet streams along with the heat of reaction. The calculation of the heat of reaction for aerobic systems is based on the oxygen uptake rate (Cooney et al., 1968):

$Q_f = 0.12\ Q_{O2}$,

where Q_f is heat release in J/m^3-s and Q_{O2} is the oxygen uptake rate in mol/m^3-s. A default value of -15690 kJ/(kg of oxygen utilized) is used based on the above model.

8.2.3.7 Equipment Purchase Cost

The equipment purchase cost includes the cost of the vessel along with the agitator cost. If the vessel is checked as an ASME Vessel (i.e., constucted according to standards published by the American Society of Mechanical Engineers) then it asssumed to withstand vacuum to 35 psig and its purchase cost is penalized by 20% over the base vessel cost. If the operating pressure of the vessel is set to a pressure higher than 3 atm, then the vessels purchase cost is penalized by an 80% increase over the base cost.

8.2.4 Compressor

Compressors operate in pressure ranges and with compression ratios that often require external cooling to prevent damage to sensitive seals and metal surfaces. This physical situation falls between the isentropic and isothermal extremes and is called polytropic compression. To calculate the power requirement for polytropic compression, the equations developed by Shultz (1962) are used:

$$Power = \frac{\gamma}{\gamma - 1} p_1 v_1 \left[\left(\frac{p_2}{p_1} \right)^{(\gamma-1)/\gamma} - 1 \right]$$

$$p_2 = p_1 \left(\frac{T_2}{T_1} \right)^{(\gamma-1)/\gamma}$$

where γ = ratio of specific heat of gas at constant pressure to specific heat of gas at constant volume, v_1 = specific volume of gas at intake conditions, T_1 = absolute temperature of gas at intake conditions, and T_2 = absolute temperature of gas at final delivery conditions.

8.2.5 Air Filter

This unit operation model calculates the size and number of units based on the actual throughput.

8.2.6 Rotary Drum

In biochemical processes, centrifugal filtration is mainly used for dewatering and washing of crystalline and fibrous solids. This method uses filtration driven by centrifugal force. The equipment consists of a rotor with a perforated cylindrical shell, lined with an appropriate filter medium, mounted on a bowl bottom, and surmounted by an annular lip ring to retain its contents.

The material balances around a basket centrifuge are determined by the Retention Coefficient of the various components specified by the user . The fractions of solvent and solutes that are retained on the cake are estimated based on the cake porosity.

In design mode, the user specifies the average filtrate flux and the model calculates the filter area, the drum diameter and the number of units. In rating mode, the user specifies the drum diameter and the number of units and the model calculates the average filtrate flux.

Averaged data from vendors were used to estimate the purchase cost of basket centrifuges.

8.2.7 Ultrafilter

Tangential flow ultrafiltration is used to concentrate protein solutions and separate proteins from low molecular weight solutes. Ultrafilter membranes are rated based on molecular weight cut-off of spherical proteins that cannot pass through the membrane. Membranes are available with MW cut-off ranging from 2,000 Daltons up to 1,000,000 Daltons.

The average life of ultrafiltration membranes strongly depends on the degree of utilization and the operating conditions and ranges approximately from 6 to 12 months (or 1000 to 2000 hours of operation time).

The modeling equations of the membrane ultrafilter are identical to those of the membrane microfilter.

8.2.7.1 Microfilter

The purpose of this model is to simulate a tangential flow membrane microfilter used for solid-liquid separation and to estimate its capital and operating cost.

In bioprocessing, tangential flow microfiltration is frequently used for cell harvesting, cell debris removal, and sterilization of cell culture media. In tangential microfiltration, cross flow parallel to the filter surface is used to enhance filtration rate. The pore sizes of microfilters usually range from 0.1 to 0.45 microns.

Two modes of filtration are modeled by the membrane microfilter:

Batch Concentration (Figure 3):

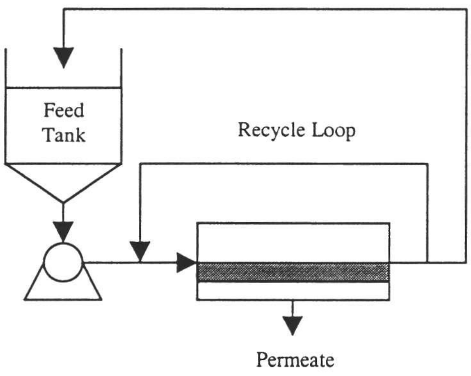


Figure 3. Ultrafiltration - Batch Concentration

A schematic of batch concentration is shown above. The retentate is returned to the feed tank for recycling through the module. This is the fastest method of concentrating a given amount of material and it requires the minimum membrane area. In batch concentration, the fraction (F_i) of a component (i) remaining in the retentate at the end of concentration is estimated by the following equation (McGregor, 1986):

$F_i = (CF)R_i\text{-}1$ Eq. 1

where CF is the concentration factor and is given by

(CF) = (Feed Volumetric Flowrate)/(Concentrate Volumetric Flowrate)and R_i is the rejection coefficient of component (i) and is defined by

$R_i = 1 - (C_{pri} / C_{ci})$

C_{pri} and C_{ci} are the concentrations of component (i) at the end of filtration in the permeate and concentrate streams, respectively.

For batch concentration, a simple algorithm is used to perform the material balances and estimate the size of equipment. The user always specifies the average permeate flux (J) and the rejection coefficients of the various particulate components. In large-scale operation, the filtrate flux of microfilters usually ranges between 10 and 80 liter/m2-h. In Rating Mode, the user also specifies the area (A) of the membrane and the number of identical units operating in paraller while in Design Mode the user specifies the concentration factor. A simple equation relates the average filtrate flux with the membrane area and the amount of material processed by the filter per cycle:

$J = V_{feed}$ (1 - 1/CF) / A / (Process Time) / (Number of microfilters)

V_{feed} is the volume of material fed to the microfilter per cycle. The process time is always specified by the user as part of the process scheduling initialization. In design mode (where the user specifies the concentration factor), the above equation is solved for A (the membrane area). If the calculated membrane area exceeds the maximum allowable membrane area per unit, the system assumes multiple identical units operating in parallel with a total membrane area equal to the calculated. In rating
mode (where the user specifies the area and the number of units), the above equation is solved for CF.

Having CF and R_i, Eq. 1 is used to calculate the fraction of each component retained in the concentrate and perform the material balances.

8.2.8 Cooler

8.2.8.1 Technical Description

The purpose of this model is to simulate a shell and tube surface condenser. Condensation is the process of converting a gas or vapor to liquid. Any gas can be reduced to a liquid by sufficiently lowering its temperature and/or increasing its
pressure.
The coolant runs in the tube side, while condensation takes place in the shell side. A constant overall heat transfer coefficient is assumed for this model (provided by the user).

The heat transfer for a surface condenser is governed by the following relationship:

$Q = U\, A_c\, \Delta T$,

Q is the total heat load, J /s.
U is the overall heat transfer coefficient, J / s -K - m^2 .
ΔT is the mean temperature difference driving force, K.
A_c is the surface area of the condenser, m^2.

Computational procedures to estimate the condensation efficiency are available for three different sets of specifications for the condenser model:

Operating pressure and temperature (isothermal condensation)
Operating pressure and percent of total condensation
Operating pressure and percent of condensation of a specific component

For each component the enters the condenser, the following material balance equation holds:

$F_m * z_i = V_m * y_i + L_m * x_i$

where F_m, V_m, L_m are the molar flowrates of the feed, vapor and liquid phase respectively and z_i, y_i, x_i are the mole fractions of component i in the three phases.

The mole fractions of component i in the vapor (y_i) and liquid (x_i) phase are related through the partition coefficient K:

$K = y_i/x_i$

The partition coefficients (K) are assumed to be independent of composition i.e. the model assumes ideal vapor and liquid phases (Antoine's equation is used to estimate the K value).
Since the design equation is a nonlinear equation an iterative numerical algorithm is used for its solution.

8.2.9 Granulation circuit

8.2.9.1 Technical Description

The granulator which is the heart of the granulation circuit is the Lödige Ploughshare®-Mixer Type FKM for Batch Operation. In this report it will be called the High Shear Mixer and shown in Fig. 1. It has a total volume of 30,000 l and is equipped with three ploughshare shovels attached to a rotating horizontal shaft and a side–mounted spinning chopper. The rotational speed of the ploughshares is variable and is set usually at 200 rpm. A hammer type chopper is used with fixed speed of 3000 rpm. The action of the chopper and the ploughshare is different as can be expected from their size and particularly from their tip speeds of about 5 m/s for the ploughshares and 25 m/s for the chopper. The ploughshares ensure mixing while the chopper provides impact forces on the granules. The residence time of the particles in the High shear mixer is around 10 minutes.

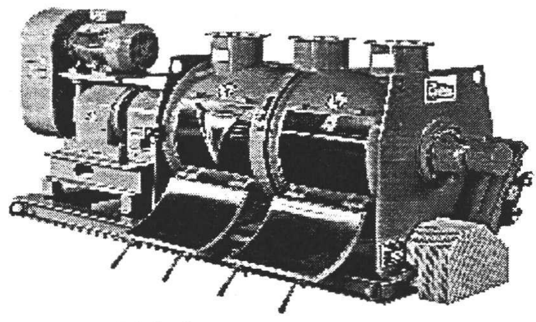


Figure 4. Lödige Ploughshare®-Mixer Type FKM

The second part of the granulation circuit is the Screens or Industrial sieves. They are placed after the Fluid Bed dryer in order to classify the granules within the size range of 250 µm to 1000 µm. There are two sieves/screens with 250 µm and 1000 µm sieve opening respectively.

The particles collected below the 250 µm sieve are either recycled or discarded as waste and the particles which are collected above the 1000 µm sieve are sent to the Crusher which the third part of the granulation circuit. The Crusher is a Hammer Mill which will break the particles in sizes smaller than 1000 µm and sent back into the High Shear Mixer for agglomeration. In this project 10% of fines (i.e. particle size <250 µm) and coarse (i.e. particle size > 1000 µm) are produced which will be sent back into the next batch for agglomeration.

8.2.10 Fluid Bed Dryer

8.2.10.1 Technical Description

In the fluid-bed dryer, the wet solids are fluidized by the drying gas. Mixing and heat transfer are very rapid. Wet feed is admitted to the top of the bed and dry product is taken out from the side near the bottom. The average time a particle stays in the dryer is typically 30 to 120 s.

A short-cut model is used to simulate the fluid-bed dryer. The user always specifies the drying temperature, the evaporation fraction of the solvent component(s), the specific heating requirement, the specific power requirement, the drying gas requirement, the height to diameter ratio and the average solids velocity.

The material balances are done based on the evaporation fraction of the solvent component(s). The average solids velocity is used to estimate the required height. In design mode, the user in addition specifies the solids residence time which along with
the average solids velocity is used to estimate the height of the vessel. Then, the height to diameter ratio is used to calculate the diameter and the volume of the dryer.

In rating mode, the user specifies the total dryer volume and the number of units and the program calculates the solids residence rate.

8.2.11 Granulation

There are some special issue with regards to the calculation of the size distribution obtained from the High Shear Mixer. There are batch data*• available on downscaled High Shear Mixers and from these a correlation was obtained between the operating conditions and the size distribution.

The particle size distribution of the granules should lie in the range of 250 µm and 1000 µm. Now according to batch data, the change in the size distribution is mainly caused due to change in amount of Builder, Binder and Ultra Filtrate. Using Rosin-Rammler Size distribution equation, the parameters were obtained from batch experimental data and correlated to the ratio of (Builder + Binder) and Ultra Filtrate. This correlation was obtained using non-linear regression. From the process design the ratio which is suitable to obtained a most optimum size distribution i.e. 10% above 1000 µm and 10% below 250 µm is 0.6.

• The references and the batch experimental data cannot be given as these are confidential.

8.3 Equipment Data Sheets

8.3.1 Equipment Summary Sheets

The Equipment Summary Sheets are shown in Appendix 8.1 to 8.6.

8.3.2 Equipment Specification Sheets

The Equipment Specification Sheets are shown in Appendix 8.7 to 8.22.

9 WASTES

This chapter is intended to make an in-depth review of all wastes produced during the production of enzyme granules and the methods of handling them. The management of wastes can be approached at the very start of the design process, e.g. during the selection of the processes and equipment. The emphasis of the new approach is prevention through basic design. The details of the waste treatment process will not be discussed in this design project.

9.1 INDIRECT WASTES

These wastes include all pollution occurring during the manufacturing of feedstocks and plant equipment or as a result of product usage. This category of wastes is not included in this design project.

9.2 DIRECT WASTES

The waste stream is characterized by organic solid and liquid wastes, contaminated exhaust gases, and particulates. These wastes do not contain toxic components which require specialized treatment and disposal systems. The available waste treatment technologies are applicable to reduce its impact to the environment at accepted level. The highly organic liquid and solid waste could be treated in an anaerobic wastewater system. Air filters are used to treat gaseous wastes. Below, these wastes are categorized and their effects are discussed.

Table 7. Characterization of wastes

Type (Quantity)	Stream #	Composition	Source	Effects
Exhaust gases (2.04×10^5 ton per year)	8	Mainly CO_2 , air , traces of gases (e.g. H_2S , CO , SO_x , NO_x which are products of possible side reactions)	Bioreactor	- SO_x causes sensory and respiratory irritation, vegetation damage, corrosion - CO reduces the oxygen-carrying capacity of blood
(8.67×10^3 ton per year)	24,25	Water , air , particulates	granulator, fluidized bed dryer, coating equipment	- causes allergic reactions to humans - particulates containing enzymes could be inhaled which will be [illegible]
Solid wastes (1.63×10^4 ton per year	13	Biomass, glucose, inert, nutrients, enzymes, (with water)	Wastes from the rotary drum vacuum filter	- high BOD reduces the dissolved oxygen of the lakes or streams to a certain level which is harmful to the marine life - also anaerobic
Liquid wastes (1.29×10^5 ton per year)	15	di-ammonium hydrogen phosphate, glucose, water	Ultrafilter	- same as solid waste
Others (cannot be quantified)			Packaging materials,	
(cannot be quantified)		Contains the solid and liquid wastes mentioned above	- Cleaning water of the bioreactor (interiors, internals) - Sanitary water, condensate	- Same as solid waste

Population Equivalent

The volume of organically contaminated industrial wastewater is often compared to that of domestic sewage in terms of the population equivalent (PE). The population equivalent is based on the amount of oxygen necessary to oxidize the domestic wastewater discharged by one person per day. Since the amount and concentration of organic pollutant vary per country, the quantitative definition of the PE varies nationally. The PE concept is used to calculate how much money industries must pay to the government in order to be allowed to discharge their wastewater in the public waters.

In the computation of the PE of the aqueous waste for this design project, we will use the American definition of a PE, that is, 76 BOD_5 /person/day and a BOD_5 of effluent water equal to 1,200 mg/liter. This value is typical in a process industry producing food products. It would be a good approximation since the nature of the wastewater is similar, the organic load is very large. The population equivalent of the wastewater produced is 6,780 people. This value is could affect the economic feasibility of the plant.

10 PROCESS SAFETY

In this chapter all the aspects of process safety of the designed process are discussed. A summary of the hazardous components is given and also a preliminary HAZOP-analysis of fluid bed spray coating is presented. Finally the DOW F&EI for the designed process is evaluated.

10.1 SAFETY

The fermentation process is internally not a very dangerous reaction. The energy produced by the dissimilation of glucose (2843kJ/mole glucose) is coupled with the anabolism of micro-organism. Power input of the agitator is the major heat source of the fermenter. Concerning the whole designed process, the most vulnerable part must be drying and coating. The statistics of industrial accidents also show that drying should be regarded as a potentially hazardous operation that has brought a number of reported incidents with serious results for personnel and equipment. Drying is particularly prone to fire and explosion hazards because it is a process in which External heat sources are applied. Most of the materials are combustible. All possible ignition sources may be present in dryers. In this designed process, the major hazard is the dust explosion. Combustible materials which can form an explosible dust cloud in a confined space will explode if: enough oxygen is present; the dust concentration falls within the explosive limits; and an ignition source of sufficient energy, either thermal or electrical, is present.

The minimum explosible concentration (MEC) for most dust clouds is in the range 0.01 to 0.06 kg/m3 and is in most cases above 0.04 kg/m3. The minimum oxygen concentration required to support a dust explosion varies from 3% to 15% v/v, depending on the chemical nature of the dust, its particle size, its moisture content and its temperature. The explosibility characteristics of some dusts are listed in the summary of hazardous components below. There are several methods available in dust explosion protection. The venting system will be applied to the designed process.

10.2 HEALTH

Enzymes are proteins an are no different from other proteins, such as pollen or animal dander, in their potential to be respiratory allergens. Inhalation of the enzyme can stimulate the body's immune system to produce antibodies. Antibodies can be generated at very low levels of exposure to an allergen. The exact level of exposure that stimulates allergen production varies from person to person and is allergen-dependent. A second potential health effect of enzymes on workers is skin irritation. Protease catalyzes breakdown of protein strains and is potential skin irritant. Another risk to the health of workers is the presence of the fine powders in the workplace. There are some standards on the concentration of dusts in air. In the designed process, the TWA(time-weighted average) limit of cellulose powder in workplace air is 10 mg/m3 (USA), and that of starch is 1 mg/m3(CSK).

10.3 SUMMARY OF HAZARDOUS COMPONENTS

Ammonium phosphate
Not flammable. Irritating to eyes, nose and throat. May be dangerous if it
enters water intakes.
Threshold limit value(toxicity): 25 ppm as ammonia. LD50: not available.
MAC: not available.
Calcium acatate
Flammable. Explosion danger. Irritating to eyes.
MAC: not available.

Cellulose
limits in workplace air(TWA): 10 mg/m3(USA). Limits in ambient air(annual):
10 mg/m3
Corn starch
MEC: 0.045 kg/m3, MIT 400 C(cloud), MIE: 0.040 J, MOC: 11%
Magnesium silicate (TALC)
Not flammable. Irritating to skin and eyes. Harmful if swallowed.
MAC: 2 mg/m3

PEG6000
No fire hazards at low temperature. Cleveland Open Cup flash point: 271 C.
No appreciable irritation to eyes. LD50(g/kg): >50 (male rats)

Sodium sulfate
not flammable. Irritating to eyes.
MAC: not available.

Soya flour
MEC: 0.045 kg/m3, MIT 530 C(cloud), 460 C(layer), MIE: 0.060 J, MOC: 15%

Titanium dioxide
Not flammable. Irritating to eyes.
MAC: 10 mg/m3

More data can be available in the Appendix.

10.1 HAZOP

Table 8.1 Risk Analysis of Fluid Bed Spray Coating D102

Guide Word	Deviation	Possible Causes	Consequences	Action Required
Not, No	No flow s27	1) P106 fails (motor fault, loss of drive, impeller corroded away, etc.)	Loss of feed of coating agent. Mechanical strength of final product decreased.	a)Install low level alarm on FC b)Ensure good communication with intermediate dryer operator c)Install kickback on P106
		2) Line blockage, valve closed in error	As for 1)	Covered by a) d)Institute regular patrolling and inspection of transfer line e) Install low level alarm on FC for air
		3) Line fracture	As for 1), Polymer solution discharged into area adjacent to pipeline	Covered by e), f) install relief valve on K103
	No flow s31	4)K103 fails (motor fault, impeller corroded away, etc.)	Loss of pressure overhead, No fluidization	
		5) line blockage, control valve closed in error	As for 4), overpressure on compressor K103	
More	More flow s27	6) FC fails open or FC bypass pen in error	high moisture content of coating, granules agglomerate	g) Install high level alarm on FC h) Institute locking off procedure for FC when not in use Covered by g),h) for FC on s31 i) Install wire mesh on air outlet
	More flow s31	7) FC for air fails open or bypass pen in error	Coating overdried, flooding, blow-off of granules	
	More pressure D102	8) Gas outlet blockage	Transfer line subjected to full pump delivery or surge pressure	covered by f) j) Install relief venting on D102
	More temperature D102	9) CV of cooling water E103 closed in error	Coating overdried, loss of enzyme activity	k) Check CV of cooling water regularly
Less	Less flow s27	10) Leaking flange or valve stub not blanked and leaking	Material loss adjacent to pipeline	Covered by d) l)Check line and flange ratings
	Less flow s31	11) Line fracture or flange leak	Inadequate mixing of granules with coating material. wide PSD	Covered by l) m) adjust the place of atomizer
	Less Temperature	12) CV of cooling water E103 fails open	High moisture content of coating, granules	Covered by k)

	D102	13) Winter conditions	agglomerate Polymer solution more viscous, smaller droplets, less spray formed by atomizer	n) K103 working continuously to keep D102 warm
As well as	Small size granules present	14) Sieve E105 fails	More dusts. Explosion risk	o) Spray of polymers before fluidization begins
Part of	High polymer concentration in s31	15) High polymer diversity of PEG6000	Polymer solution more viscous, smaller droplets, less spray formed by atomizer	Covered by n)

10.2 FEI

The calculation is based on the special form shown in Fig 9.2 of Coulson & Richardson's(1998).

Units: consider the total plant, no separate areas, but exclude the main storages.
The fluid bed dryer would have the greatst impact on the magnitude of any fire or explosion.

Material factor: sodium sulfate is the most abundant material in the builders. Others are minor and none of them has significant fire or explosion hazards.
Estimated material factor for sodium sulfate is: 2.0

General process hazards:
Base factor = 1.0
A. not applicable
B. not applicable
C. not applicable
D. not applicable
E. penalty = 0.35
F. adequate drainage would be provided, factor = 0.0

Special process hazards:
A. sodium sulfate is not toxic, MAC-value not available, factor = 0.2
B. not applicable
C. not applicable
D. dust explosion hazard, factor = 1.5
E. Operation Presure 3 atm = 3*14.7-14.7 = 29.4 psig. Set relief valve at 20% above the operating pressure = 35.6 psig.
F. not applicable
G. Not applicable
H. Stainless steel is the construction material, allow minimum factor = 0.1
I. Use minimum factor as full equipment details are not known at the flow-sheet stage, factor = 0.1
J. not applicable
K. not applicable
L. large compressors used, factor = 0.5

F1 = 1.35
F2 = 2.4
Unit hazard factor F3 = F1 * F2 = 3.24

Fire and Explosion Index FEI = MF *F3 = 6.5

The index works out at 6.5, classified as "mild". Sodium sulfate is normally not a dangerous material and non-toxic. The danger of dust-explosion is the main process hazard.

11ECONOMY

The purpose of this chapter is to present the economic evaluation of the project. From the estimated total capital investment and the total operating costs per year, the economic potential of the project is calculated. The detailed estimation of the total capital and the annual operating cost are shown in Appendix 3.2

11.1 INVESTMENT

Table 8 shows the estimation of the Capital requirements.

Table 8. Estimate of Capital requirements

	Total Cost
1. Manufacturing Capital	
Total Process Equipment	11,035,477.08
Total manufacturing capital based on (Lang)factor*	34209978.94
2. Nonmanufacturing Capital	
Proportionate share existing capital estimated at 15% manufacturing Capital"	5,131,496.84
3. Total Fixed Capital	
Sum of 1 and 2	39,341,475.78
4. Working Capital	
Raw Material	2192930.1
Store supplies and all other items at 5% gross sales"	1875000
Total Working Capital	4067930.1
5. Total Fixed and Working Capital	**43,409,405.88**

*Garrett, Donald E.: CHEMICAL ENGINEERING ECONOMICS. New York Van Nostrand Reinhold 1989.

"Douglas, James M.: Conceptual design of chemical processes. New York McGraw-Hill 1988.

11.2 OPERATING COSTS

Table 9 shows the Operating Cost .

Table 9. Operating Cost Summary

ESTIMATED PRODUCTION COST AT AN ENZYME-COATED GRANULATION PLANT
ENZYME-COATED GRANULE OUTPUT = 5,000 TONNES PER YEAR
PRODUCTION DELIVERED WITH 500,000 UNITS PER GRAM (ACTIVITY)
TOTAL MANUFACTURING CAPITAL = **34209978.94**
TOTAL FIXED AND WORKING CAPITAL = **43,409,405.88**

	UNIT	QUANTITY PER YEAR	UNIT PRICE ($/Unit)	COST PER YEAR ($/Year)
RAW MATERIALS				
Ammonium phosphate	**kg**	465000.00	1.00	465000.00
Biomass	**kg**	222000.00	5.00	1110000.00
Glucose	**kg**	8100000.00	1.00	8100000.00
Inerts	**kg**	6000000.00	1.00	6000000.00
Nutrients	**kg**	138000.00	1.00	138000.00
Coating	**kg**	480000.00	2.00	960000.00
Builder	**kg**	2633997.00	1.00	2633997.00
Binder	**kg**	255000.00	6.00	1530000.00
Water	**kg**	132307200.00	0.01	992304.00
			Subtotal :	**21929301.00**
DIRECT EXPENSE				
Operating Labor	**operators**	18	100,000.00	1800000
4.5 operators/shift; 4 shifts/day "				
Supervision				
10% of Operating labor "				180000
Plant Overhead				
50% of Operating labor "				900000
Steam	**10^6 kcal**	1022	10.00	10000
Electricity	**KWh**	20503136	0.10	2260923.76
Compressed Air				
Repaires@4%M.Cap."				1368399.16
Water-cooling	**10^6 kcal**	20325	1.00	509000
Chilled Water	**10^6 kcal**	736	35.00	26000
Water-process				
NaCl Brine	**10^6 kcal**	4365	28.00	124000
Factory Supplies &				684199.58
Laboratory@2% M. Cap."				
			Subtotal :	**7862522.497**
INDIRECT EXPENSE				
Depreciation (plant life: 15 years)				2280665.262
Taxes : *1% of M. Cap "*				342099.7894
Other indirect: *4% of M.Cap "*				1368399.157
			Subtotal :	**3991164.209**
			TOTAL :	**33782987.71**

"Douglas, James M.: Conceptual design of chemical processes. New York McGraw-Hill 1988.

11.3 INCOME

Quantity of Product per year	: 5 MKg of enzyme-coated granule per year
Price of Product	: US$ 12.00 per Kg
Sales of Product	: M US$ 60.00 per year

11.4 CASH FLOW

Total Operating Cost per year	: M US$ 34.00 per year
Net Income per year	: M US$ 26.00 per year

11.5 ECONOMIC CRITERIA

Rate of Return (ROR)	: 59.88%
Pay Out Time (POT)	: 1.67 Years
Discounted Cash Flow Rate of Return (DCFROR)	: 59.83%

11.6 COST REVIEW

In the Total Capital Investment, the total equipment costs and the installation costs tantamount to 79% of the total Investment. Majority of the investment is allotted to the installation cost, which is 3.1 times the equipment cost. This is based on the Lang factor for predominantly solids processing plant. From this assessment, it is suggested to better calculate/look for installation factor of each equipment, rather than using a more general lang factor; thereby placing the estimation of the capital investment in proximity to accuracy.

The price of the equipment is based from the Economic Evaluation Report of Super Pro Designer (software) from the simulation of the enzyme-coated granulation process. The prices are based on the year 1996, where the CE index is given at 381.7. To escalate the cost to the present date, the CE index of 389 as of may1999 is used. To have a more accurate estimation of the equipment costs, a vendor's quotation will give a much better if not best accuracy of the estimate.

12 CONCLUSIONS AND RECOMMENDATIONS

12.1 CONCLUSIONS

In this chapter, the most important results of this design project will be presented and conclusions will be made. For this design project entitled "Production of Coated Detergent Enzyme Granules", the following conclusions are drawn:

The demand for industrial enzymes for detergent has been increasing. In order to cope up with this, its productivity should be increased through efficient production processes at the same time preserving the enzyme activity. One area that should be looked into is the production of the enzymes. It has been found that the fermentation process to produce this enzyme is very dependent to various parameters like pH, oxygen concentration and the production of metabolites which repress the enzyme production. This exocellular enzyme, alkaline serine protease produce by Bacillus licheniformis, is repressed by high concentration of ammonia in the bioreactor. Several fermentation modes are available to minimize this repression namely, the batch, fed-batch and continuous operations. Fed-batch process is excellent in controlling the inhibitory effects of the critical elements but the activity of the enzyme produced is two times lower than the batch process. On the other hand, continuous process is considered as the most efficient, but maintaining a sterile condition for such a long time is a difficult condition to achieve in an industry. Thus, continuous process is hardly employed in industrial scale. For this design project, the batch process is chosen. Although the production is less compared to the other two, the activity of the enzyme is higher. The selection of the media for the cultivation of microorganism is also an important factor. It must contain all the necessary elements for synthesis of the cell substances and the production of metabolic products. For economic reasons, complex media are frequently used. In spite of its importance, there are only limited published literatures in this topic which has significantly affect the outcome of this design project.

The first downstream process employed is the separation of the solid mass from the fermentation broth. Vacuum drum filtration is chosen because of its simple operation compared to centrifugation which has too many operating variables. Cross-flow membrane filtration is used for the concentration of the enzyme concentrate. With proper selection of the membrane, 100% cell recovery can be obtained. The granulation of the enzyme is done using the Lodige High Shear Mixer/Granulator. It is a batch system where the builder, binder and enzyme concentrate are mixed under high shear conditions leading to the formation of granules. The drying of granules is performed in the fluidized bed dryer. This is preferred because a close control of conditions is possible allowing the predetermined moisture content to be met. Coating of enzymes is very necessary to protect them from the environment. A fluidized bed coating is chosen since it is found useful for forming and coating granules particularly smaller granules which are difficult to handle by other methods.

The above-mentioned processes are preferred for the preliminary plant design. Based on the results, the desired production rate of 5,000 tons of enzyme granules and activity of 2.34×10^6 U/ml are achieved. The amounts of solid and liquid wastes produced are 1.63×10^4 and 1.29×10^4 per year respectively and 2.13×10^5 tons per year of exhaust gases.

The whole production process is simulated using the Super Pro Designer 2.7 simulation package for bioprocesses. This software is very useful in simulating the preliminary process structure. Here, the simulation of the important equipment will be discussed briefly.

The fermentor is designed using the stoichiometric model. This is a simple model based on the stoichiometry of the reactions involved. There are more accurate but complicated options available in the software, but the availability of the kinetic data restricted our choice of the fermentor. The granulation and coating parts are simulated as mixing processes.

For the economic margin, the rate of return (ROR) is 59.88% and the pay out time (POT) is 1.67 years with the discounted cash flow rate of return (DCFROR) of 59.83%. The investment cost of the project is US $ **44 million** and the revenues is US $ **26 million**. This means that the project has very high economic potential.

12.2 RECOMMENDATIONS

This design project is limited by the availability of the published literature on the kinetics of the fermentor. It is therefore recommended to do more research in this area especially reaction involving a complex medium. These data greatly affect the result of the whole design project and make it more realistic. To the future teams who will be working in this area, more attention should be given in the optimization of the production parameters, e.g, the composition of the media to further reduce the quantity of raw materials which is economically advantageous.

LIST OF SYMBOLS

Symbol	Meaning	Unit
N	Concentration of viable organisms	[m^{-3}]
K	specific death rate constant	[s^{-1}]
t	time	[s^{-1}]
N_0	Initial Concentration of viable organisms	[m^{-3}]
A	frequency factor	[s^{-1}]
ΔE	Activation energy	[J mol^{-1}]
R	Gas constant	[J mol˙1 K^{-1}]
T	Temperature	[K]
U	Average medium velocity	[m s^{-1}]
L	Length of holding tube	[m]
Dz	Axial dispersion coefficient	[m^2 s^{-1}]
Re	Reynold's Number	[-]
μ	viscosity	[kg m^{-1} s^{-1}]
ρ	density	[kg m^{-3}]
dt	tube diameter	[m]
$Fout_k$	is the mass flowrate of the limiting component after the reaction	[kg s^{-1}]
Fin_k	is the mass flowrate of the limiting component before the reaction	[kg s^{-1}]
x	is the reaction extent	[-]
A_i	stoichiometric coefficients	[-]
V	volume	[m^3]
F	volumetric flow rate	[m^3 s^{-1}]
D	dilution rate	[s^{-1}]
Q_f	heat released	[J m^{-3} s^{-1}]
Q_{O2}	Oxygen uptake rate	[mol m^{-3} s^{-1}]
p	gas pressure	[Pa]
γ	ratio of specific heat of gas at constant pressure to specific heat of gas at constant volume	[-]
ν	specific volume of gas	[m^3 kg^{-1}]
F_i	fraction of component 'i'	[-]
CF	concentration factor	[-]
R_i	rejection coefficient of component 'i'	[-]
C_{pri}	concentration of component 'i' in permeate stream	[mol m^{-3}]
C_{ci}	concentration of component 'i' in concentrate stream	[mol m^{-3}]
J	permeate flux	[mol m^{-2} s^{-1}]
A	area of membrane	[m^2]
V_{feed}	volume of material fed to the ultrafilter per cycle	[m^3]
Q	Q is the total heat load	[J s^{-1}]
U	Overall heat transfer coefficient	[J m^{-2} s^{-1} K^{-1}]
ΔT	mean temperature difference driving force	[K]
A_c	surface area of the condenser	[m^2]
K	partition coefficient	[-]
x_i	mole fraction of component 'i' in liquid phase	[-]
y_i	mole fraction of component 'i' in vapour phase	[-]
z_i	mole fraction of component 'i' in feed	[-]
F_m	molar flow rate of feed	[mol s^{-1}]
V_m	molar flow rate of vapour phase	[mol s^{-1}]
L_m	molar flow rate of liquid phase	[mol s^{-1}]

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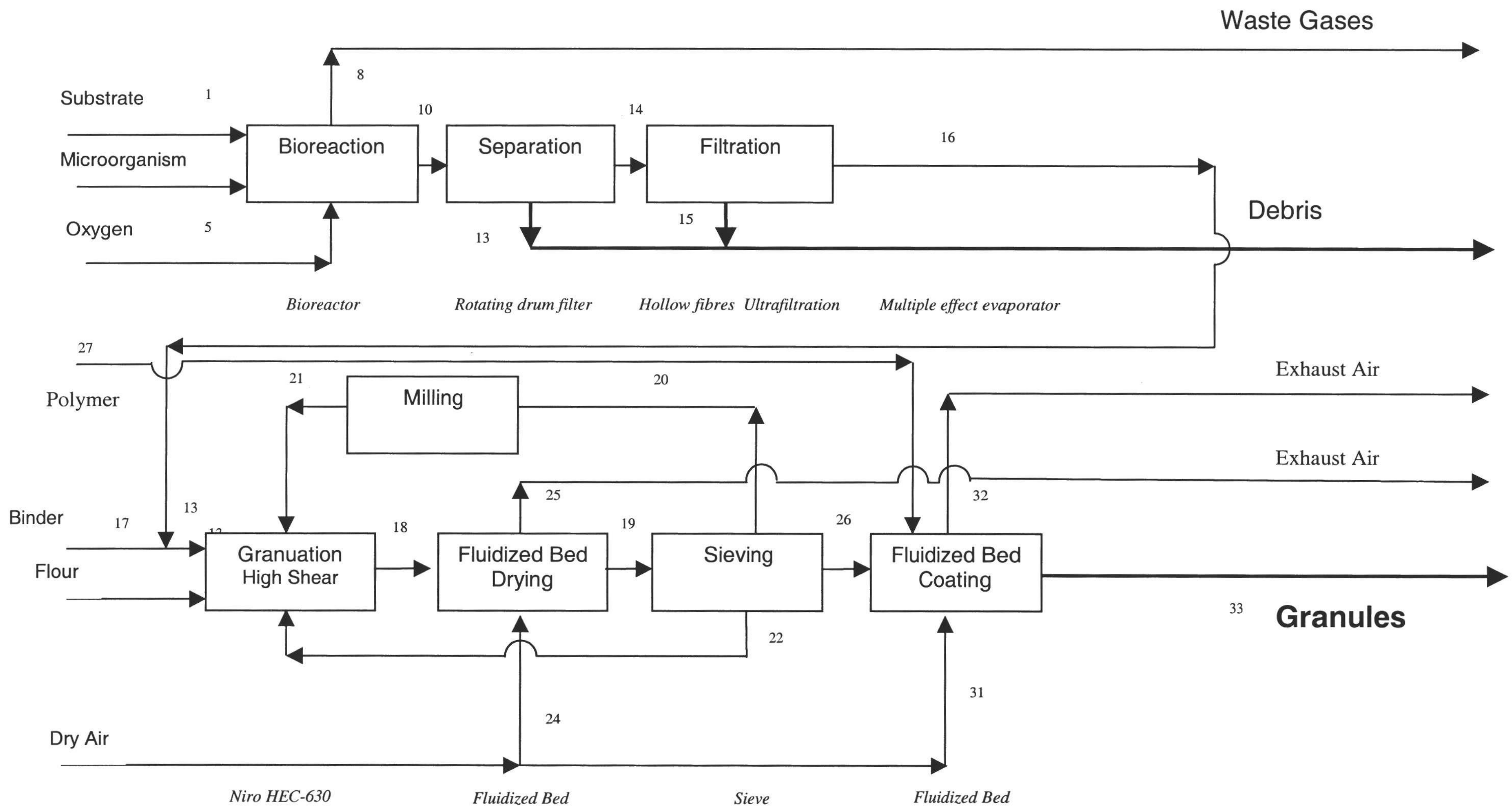
APPENDICES

APPENDIX 3.1

BLOCK SCHEME OF THE PROCESS "DETERGENT ENZYME GRANULE PRODUCTION PLANT"



APPENDIX 3.2
EQUIPMENT SCHEDULE

Item No.		Equipment name	Size	Number of Units	Unit Cost (US$) In SPD (1996)	Total Cost (US$) In SPD (1996)	CE index of 1996^	CE index of 1999^	Present Price (US$)
1	R101	Bioreactor (Stirred Tank)	289.16 m3	2	1,329,000.00	2,658,000.00	381.7	389	2708834.16
2	S103	Rotating Drum Vacuum Filter	97.16 m2	6	148,000.00	888,000.00	381.7	389	904982.97
3	S104	Hallow Fiber Membrane Filter	450.89 m2	4	161,000.00	644,000.00	381.7	389	656316.48
4	E102	Cooler	95.75 m2	5	16,000.00	80,000.00	381.7	389	81529.997
5	G101	Granulator (NIRO HEC 630)	30,000.00 L	1	-	-	-	-	800000.00
6	D101	Fluidized Bed Dryer	1.70 m3	1	9,000.00	9,000.00	381.7	389	9172.12
7	D102	Fluidized Bed Coating system	1.70 m3	1	9,000.00	9,000.00	381.7	389	9172.12
8	K101	Compressor	1315.27 kW	1	911,000.00	911,000.00	381.7	389	928422.85
9	K102	Compressor	0.17 kW	1	43,000.00	43,000.00	381.7	389	43822.37
10	K103	Compressor	50.80 kW	1	44,000.00	44,000.00	381.7	389	44841.50
11	S101	Air Filter	2.66 m3/s	2	22,000.00	22,000.00	381.7	389	22420.75
12	S102	Air Filter	2.67 m3/s	2	22,000.00	44,000.00	381.7	389	44841.50
13	T101	Blending Tank	282.35 m3	2	157,000.00	314,000.00	381.7	389	320005.24
14	E101	Heat Sterilizer	196.8 m (L)	3	857,000.00	2,571,000.00	381.7	389	2620170.29
15	E103	Cooler	6.60 m2	1	2,000.00	2,000.00	381.7	389	2038.25
16		Cost of unlisted Equipment at 20% of Total							1838906.47

Total Price (US$) : **11035477.08**

^ Chemical Engineering Journal , May 1999
SPD - SuperPro Designer

APPENDIX 3.2
MANUFACTURING CAPITAL

Item no.	Delivered Cost	Instalation Factor*	Total
R101	2,708,834.16	3.10	8397385.905
S103	904,982.97	3.10	2805447.21
S104	656,316.48	3.10	2034581.085
E102	81,530.00	3.10	252742.9919
G101	800000.00	3.10	2480000
D101	9172.12	3.10	28433.58659
D102	9172.12	3.10	28433.58659
K101	928,422.85	3.10	2878110.82
K102	43,822.37	3.10	135849.3581
K103	44,841.50	3.10	139008.6455
S101	22,420.75	3.10	69504.32277
S102	44,841.50	3.10	139008.6455
T101	320005.24	3.10	992016.2431
E101	2620170.29	3.10	8122527.901
E103	2038.25	3.10	6318.574797
Unlisted Equip	1838906.47	3.10	5700610.06
Total :	**11,035,477.08**	**Total :**	**34209978.94**

*Coulson's and Richardson's chemical engineering. Vol. 6.
An Introduction to chemical engineering design (SI units) / by R.K. Sinnott

APPENDIX 3.2
WORKING CAPITAL

	Cost
1. Raw Material *1 month supply @ 10% of Annual R.M.*	2192930.1
2. Other, at 5% Gross Sales *5,000,000*7.5*0.05*	1875000
total :	**4067930.1**

APPENDIX 3.2
ESTIMATE OF CAPITAL REQUIREMENTS

	Total Cost
1. Manufacturing Capital	
Total Process Equipment	11,035,477.08
Total manufacturing capital based on (Lang)factor*	34209978.94
2. Nonmanufacturing Capital	
Proportionate share existing capital estimated at 15% manufacturing Capital"	5,131,496.84
3. Total Fixed Capital	
Sum of 1 and 2	39,341,475.78
4. Working Capital	
Raw Material	2192930.1
Store supplies and all other items at 5% gross sales"	1875000
Total Working Capital	4067930.1
5. Total Fixed and Working Capital	**43,409,405.88**

*Garrett, Donald E.: CHEMICAL ENGINEERING ECONOMICS. New York Van Nostrand Reinhold 1989.
"Douglas, James M.: Conceptual design of chemical processes. New York McGraw-Hill 1988.

APPENDIX 3.2
UTILITIES SUMMARY

Utility	Item No.	Equipment name	Usage: Unit	Usage: Annual	Unit Price	Cost ($/yr)
1.Cooling Water			**Duty(kcal/h)**	**10^6 kcal**	**25US$/10^6 kcal**	
	R101	Bioreactor (Stirred Tank)	26211755.1	17125		428000
	K101	Compressor	373395.6	2661		67000
	E101	Heat Sterilizer	2935746.9	436		11000
	K102	Compressor	42	0		0
	K103	Compressor	14403.4	103		3000
					Subtotal ($/yr):	**509000**
2.Electricity			**Power (kW)**	**KWh**	**0.1US$/KWh**	
	R101	Bioreactor (Stirred Tank)	1440	9405666		941000
	S104	Hallow Fiber Membrane Filter	360.7	321283		32000
	G101	Granulator (NIRO HEC 630)	206.65	185985		18598.5
	D101	Fluidized Bed Dryer	0	15		1.5
	D102	Fluidized Bed Coating system	0	15		1.5
	K101	Compressor	1315.3	9371933		937000
	K102	Compressor	0.2	1228		123
	K103	Compressor	50.8	361950		36000
	T101	Blending Tank	480	855061		86000
		Unlisted Equipment		5% of Total		102536.225
		General Load		5% of Total		107663.036
					Subtotal (US$/yr)	**2260923.76**
3.Steam			**Duty (Kcal/h)**	**10^6 kcal**	**10US$/10^6 kcal**	
	D101	Fluidized Bed Dryer	11590.2	5		0
	E101	Heat Sterilizer	6850076	1017		10000
					Subtotal (US$/yr)	**10000**
4. Chilled Water			**Duty (Kcal/h)**	**10^6 kcal**	**35US$/10^6 kcal**	
	T101	Blending Tank	413010.1	736		26000
					Subtotal (US$/yr)	**26000**
5. NaCl Brine			**Duty (Kcal/h)**	**10^6 kcal**	**28US$/10^6 kcal**	
	S104	Hallow Fiber Membrane Filter	24111.2	21		1000
	E102	Cooler	14630664.3	4344		122000
	E103	Cooler	291362.3	43		1000
					Subtotal (US$/yr):	**124000**
					Total (US$/yr)	**2929923.76**

APPENDIX 3.2
OPERATING COST SUMMARY

ESTIMATED PRODUCTION COST AT AN ENZYME-COATED GRANULATION PLANT
ENZYME-COATED GRANULE OUTPUT = 5,000 TONNES PER YEAR
PRODUCTION DELIVERED WITH 500,000 UNITS PER GRAM (ACTIVITY)
TOTAL MANUFACTURING CAPITAL = **34209978.94**
TOTAL FIXED AND WORKING CAPITAL = **43,409,405.88**

	UNIT	QUANTITY PER YEAR	UNIT PRICE ($/Unit)	COST PER YEAR ($/Year)
RAW MATERIALS				
Ammonium phosphate	**kg**	465000.00	1.00	465000.00
Biomass	**kg**	222000.00	5.00	1110000.00
Glucose	**kg**	8100000.00	1.00	8100000.00
Inerts	**kg**	6000000.00	1.00	6000000.00
Nutrients	**kg**	138000.00	1.00	138000.00
Coating	**kg**	480000.00	2.00	960000.00
Builder	**kg**	2633997.00	1.00	2633997.00
Binder	**kg**	255000.00	6.00	1530000.00
Water	**kg**	132307200.00	0.01	992304.00
			Subtotal :	**21929301.00**
DIRECT EXPENSE				
Operating Labor	**operators**	18	100,000.00	1800000
4.5 operators/shift; 4 shifts/day "				
Supervision				
10% of Operating labor "				180000
Plant Overhead				
50% of Operating labor "				900000
Steam	**10^6 kcal**	1022	10.00	10000
Electricity	**KWh**	20503136	0.10	2260923.76
Compressed Air				
Repaires@4%M.Cap."				1368399.16
Water-cooling	**10^6 kcal**	20325	1.00	509000
Chilled Water	**10^6 kcal**	736	35.00	26000
water-process				
NaCl Brine	**10^6 kcal**	4365	28.00	124000
Factory Supplies &				684199.58
Laboratory@2% M. Cap."				
			Subtotal :	**7862522.497**
INDIRECT EXPENSE				
Depreciation (plant life: 15 years)				2280665.262
Taxes : *1% of M. Cap* "				342099.7894
Other indirect: *4% of M.Cap* "				1368399.157
			Subtotal :	**3991164.209**
			TOTAL :	**33782987.71**

"Douglas, James M.: Conceptual design of chemical processes. New York McGraw-Hill 1988.

APPENDIX 3.2
WORKING TABLE FOR DISCOUNTED CASH FLOW (DFC) CALCULATIONS

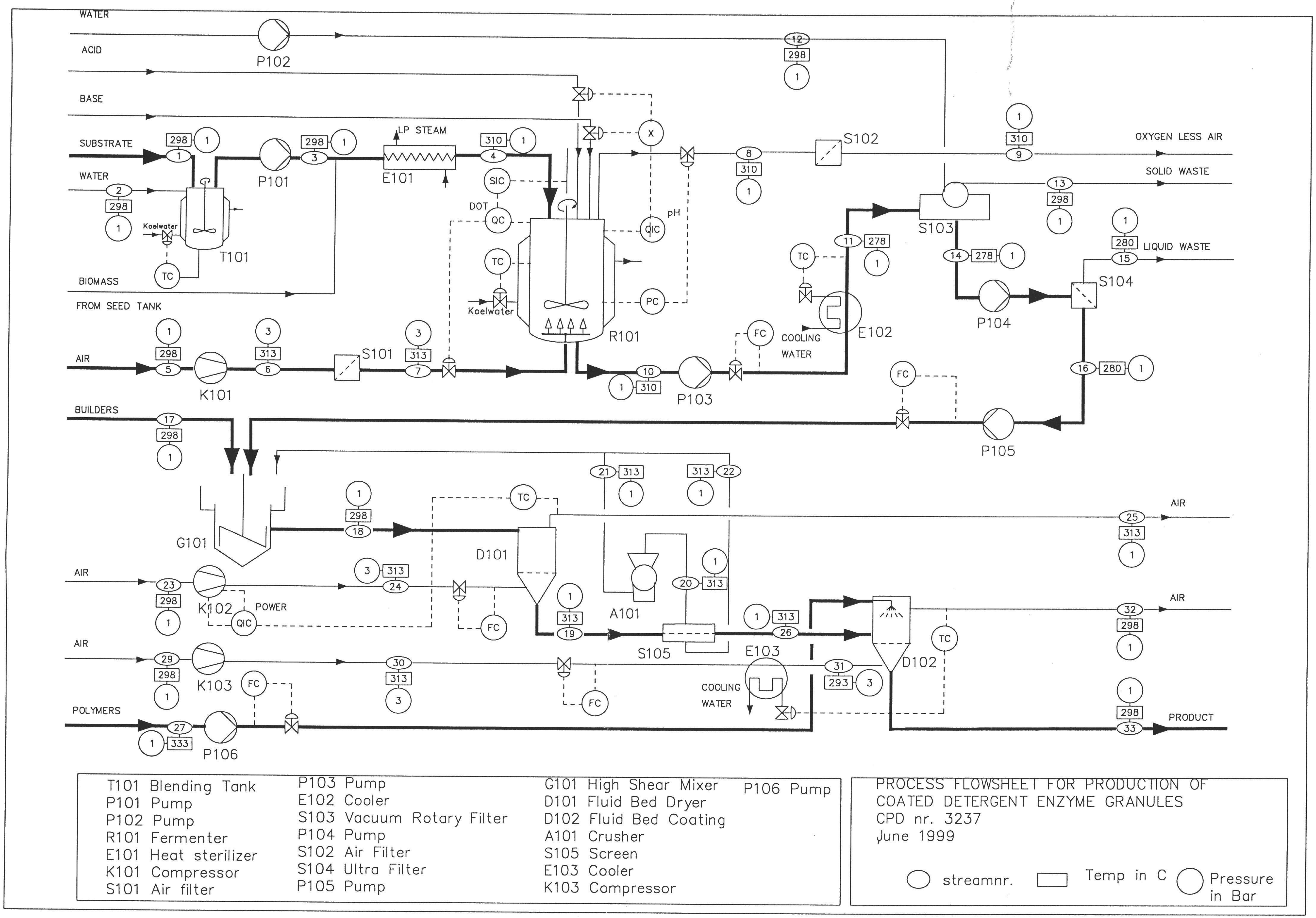
Year	Cash Flow (US$)		Cash Flow (US$)		Net Future Value	% Interest = 59.83	
	Cap. Cost(US$)	Accumulation	Cash Flow (US$)	Accumulation		Discount Factor	Present Value (US$)
0	43409405.88	43409405.88			-43409405.88	1.0000	-43409405.88
1			26,217,012.29	26,217,012.29	-17192393.58	0.6257	16403060.94
2			26,217,012.29	52434024.59	35241631	0.3915	10262817.33
3			26,217,012.29	78651036.88	113892667.9	0.2449	6421083.23
4			26,217,012.29	104868049.2	218760717.1	0.1532	4017445.56
5			26,217,012.29	131085061.5	349845778.5	0.0959	2513574.14
6			26,217,012.29	157302073.8	507147852.3	0.0600	1572654.79
7			26,217,012.29	183519086.1	690666938.3	0.0375	983954.69
8			26,217,012.29	209736098.3	900403036.7	0.0235	615625.79
9			26,217,012.29	235953110.6	1136356147	0.0147	385175.36
10			26,217,012.29	262170122.9	1398526270	0.0092	240990.66
						total net PV=	**6976.60**

Total Investment		US $44 million		
Total Operating cost per year		US $ 34 million		
Gross income per year	=	total amount of product per year*price of product		
	=	5,000,000kg/year * 12 US$/kg	=	US $ 60 million
Net Income	=	Gross Income - Operating Cost	=	US $ 26 million

Payout Period (years) : Total Investment/ Net Income = **1.655772419**

DCFROR (%) : **59.83**

Rate of Return (ROR) : 1/(POT) = **0.5988**



Appendix 5-1 Process Flow Sheet

APPENDIX 5.2
BATCH CYCLE DIAGRAM

APPENDIX 5.3

BATCH REMARKS AND CALCULTATION

COMPONENT	Cp [kJ/kgK]
Ammonium phosphate	0.900
Biomass	0.700
Enzyme	0.540
Glucose	1.220
Inerts	1.330
Nutrients	0.730
Coating	1.400
Builder	1.220
Binder	1.340
Water	4.184
Nitrogen	1.050
Oxygen	0.920
Carbon dioxide	0.940

Operation	Name	Time [h] Cycle	Turnaround	Remarks
Mixing T101	tx1	6.00	1.00	
Sterilization E101	ts	0.50	0.00	
Fermentation R101	tf	22.00	2.00	includes 1 hr filling, 20 hr reaction and 1 hr discharging
Blowing air K101	tca1	20.00	0.00	simultaneously with reaction time
Filtration air S101	tfa1	20.00	0.00	simultaneously with reaction time
Filtration gas S102	tfa2	20.00	0.00	simultaneously with reaction time
Cooling E101	tc1	1.00	0.00	
Filtration discharge E102	trd	3.00	1.00	
Ultrafilt. Discharge S103	tuf	3.00	1.00	simultaneously with trd
Granulation G101	tgr	2.67	1.00	
Screening S105	tsc	0.17	1.00	simultaneously with tgr
Crushing A101	tcr	0.17	1.00	simultaneously with tgr
Blowing air K102	tca2	0.50	0.00	simultaneously with tfb1
Drying D101	tfb1	1.50	1.00	includes 0.5 hr filling, 0.5 hr coating, 0.5 hr discharging
Compression K103	tca3	0.50	0.00	simultaneously with tfb2
Cooling E103	tc2	0.50	0.00	simultaneously with tfb2
Coating D102	tfb2	1.50	1.00	includes 0.5 hr filling, 0.5 hr coating, 0.5 hr discharging
Total	tt	35.50		

APPENDIX 5.3
BATCH PROCESS STREAM SUMMARY

STREAM Nr.		1,2-3			3-4		
Name:		Mixing substrate+water			Sterilization		
COMPONENT	MW	Cycle kg	Cycle kg/h	Process kg/h avg	Cycle kg	Cycle kg/h	Process kg/h avg
Ammonium phosphate	132.07	1550.00	258.33	43.66	1550.00	3100.00	43.66
Biomass	147.00	740.00	123.33	20.84	740.00	1480.00	20.84
Enzyme	138.48						
Glucose	180.00	27000.00	4500.00	760.49	27000.00	54000.00	760.49
Inerts	5000.00	20000.00	3333.33	563.33	20000.00	40000.00	563.33
Nutrients	229.03	460.00	76.67	12.96	460.00	920.00	12.96
Coating	6000.00						
Builder	142.05						
Binder	7000.00						
Water	18.00	440000.00	73333.33	12393.20	440000.00	880000.00	12393.20
Nitrogen	28.00						
Oxygen	32.00						
Carbon dioxide	44.00						
TOTAL		**489750.00**	**81625.00**	**13794.48**	**489750.00**	**979500.00**	**13794.48**
Enthalpy	MJ/MW/MW	0.000	0.000	0.000	22832.986	12.685	0.179
Phase			L			L	
Pressure	Bara		1.01			1.01	
Temperature	°C		25.00			37.00	
Cycle times	[h]						
Cycle & Process			6.00	35.50		0.50	35.50

STREAM Nr.		4,7-8,10			10-11		
Name:		Fermentation			Cooling		
COMPONENT	MW	Cycle kg	Cycle kg/h	Process kg/h avg	Cycle kg	Cycle kg/h	Process kg/h avg
Ammonium phosphate	132.07	1550.00	70.45	43.66	77.50	77.50	2.18
Biomass	147.00	740.00	33.64	20.84	5088.56	5088.56	143.33
Enzyme	138.48				4079.87	4079.87	114.92
Glucose	180.00	27000.00	1227.27	760.49	10401.23	10401.23	292.96
Inerts	5000.00	20000.00	909.09	563.33	20000.00	20000.00	563.33
Nutrients	229.03	460.00	20.91	12.96	460.00	460.00	12.96
Coating	6000.00					0.00	0.00
Builder	142.05					0.00	0.00
Binder	7000.00					0.00	0.00
Water	18.00	440000.00	20000.00	12393.20	447288.26	447288.26	12598.49
Nitrogen	28.00	521053.82	23684.26	14676.19		0.00	0.00
Oxygen	32.00	158181.84	7190.08	4455.41		0.00	0.00
Carbon dioxide	44.00					0.00	0.00
TOTAL		**1168985.66**	**53135.71**	**32926.08**	**487395.41**	**487395.41**	**13728.16**
Enthalpy	MJ/MW/MW	31144.591	0.393	0.244	-38338.285	-10.650	-0.300
Phase			L+S+G			L	
Pressure	Bara		1.01/6.01			1.01	
Temperature	°C		37.00			5.00	
Cycle times	[h]						
Cycle & Process			22.00	35.50		1.00	35.50

STREAM Nr.		16,17,21,22-19			18,24-19,25		
Name:		Granulation Circuit			Drying		
COMPONENT	MW	Cycle kg	Cycle kg/h	Process kg/h avg	Cycle kg	Cycle kg/h	Process kg/h avg
Ammonium phosphate	132.07	0.64	0.24	0.02	0.64	0.43	0.02
Biomass	147.00						
Enzyme	138.48	3975.11	1488.80	111.96	3975.11	2650.07	111.96
Glucose	180.00	4835.20	1810.94	136.19	4835.20	3223.47	136.19
Inerts	5000.00						
Nutrients	229.03						
Coating	6000.00						
Builder	142.05	6510.19	2438.27	183.37	6510.19	4340.13	183.37
Binder	7000.00	867.35	324.85	24.43	867.35	578.23	24.43
Water	18.00	3694.05	1383.54	104.05	3694.05	2462.70	104.05
Nitrogen	28.00				16.84	11.23	0.47
Oxygen	32.00				5.11	3.41	0.14
Carbon dioxide	44.00						
TOTAL		**19882.54**	**7446.64**	**560.02**	**19904.49**	**13269.66**	**560.64**
Enthalpy	MJ/MW/MW	-224.986	-0.023	-0.002	489.436	0.091	0.999
Phase			L			L	
Pressure	Bara		1.01			1.01	
Temperature	°C		18.10			40.00	
Cycle times	[h]						
Cycle & Process			2.67	35.50		1.50	35.50

APPENDIX 5.3
BATCH PROCESS STREAM SUMMARY

STREAM Nr.		26,27-28			28,31-32-33		
Name:		Mixing for Coating			Coating		
COMPONENT	MW	Cycle kg	Cycle kg/h	Process kg/h avg	Cycle kg	Cycle kg/h	Process kg/h avg
Ammonium phosphate	132.07	0.63	1.26	0.02	0.63	1.26	0.02
Biomass	147.00						
Enzyme	138.48	3895.60	7791.20	109.72	3895.60	7791.20	109.72
Glucose	180.00	4738.50	9477.00	133.47	4738.50	9477.00	133.47
Inerts	5000.00						
Nutrients	229.03						
Coating	6000.00	1600.00	3200.00	45.07	1600.00	3200.00	45.07
Builder	142.05	8779.99	17559.98	247.30	8779.99	17559.98	247.30
Binder	7000.00	850.00	1700.00	23.94	850.00	1700.00	23.94
Water	18.00	4589.66	9179.32	129.27	4589.66	9179.32	129.27
Nitrogen	28.00				22135.80	44271.60	623.49
Oxygen	32.00				6720.00	13440.00	189.28
Carbon dioxide	44.00						
TOTAL		**24454.38**	**48908.76**	**688.79**	**53310.18**	**106620.36**	**1501.55**
Enthalpy	MJ/MW/MW	863.521	0.480	0.007	-353.019	-0.196	-0.003
Phase			L+S			L+S	
Pressure	Bara		1.01			1.01	
Temperature	°C		45.97			20.00	
Cycle times	[h]						
Cycle & Process			0.50	35.50		0.50	35.50

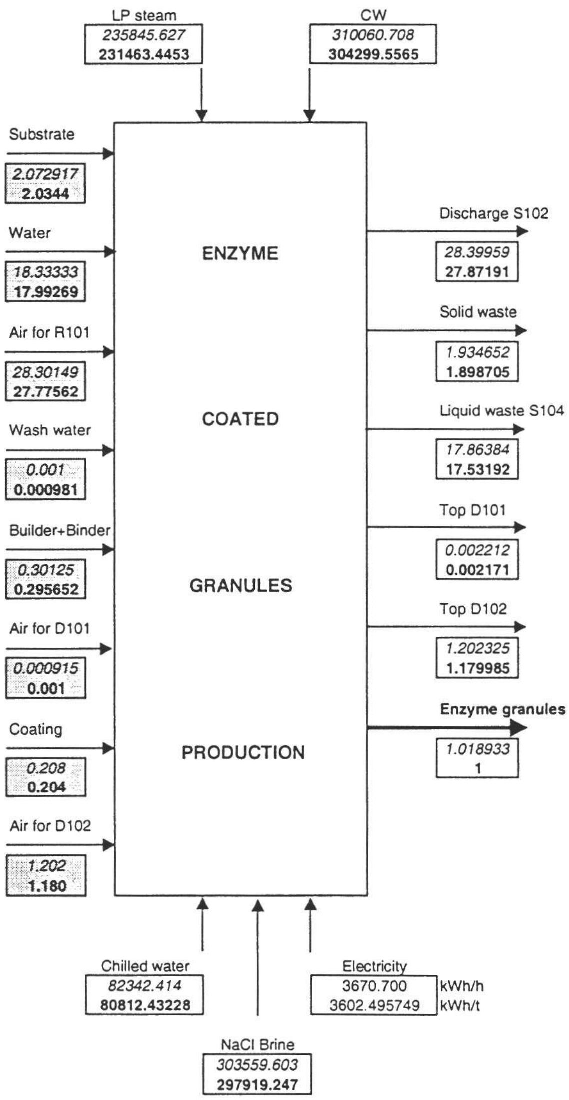
APPENDIX 5.4
SUMMARY OF UTILITIES

EQUIPMENT		HEATING		COOLING				POWER		REMARKS
		Load	Consumption	Load	Consumption [t/h]					
Nr.	Name	[kW]	LP steam [t/h]	[kW]	Cooling Water	NaCl brine	Chilled Water	Actual load [kW]	Electr. [kWh/h]	
T101	Blending tank	480.00					82342.41			Chilled water: Tin = 5°C; Tout = 10°C; Cp = 4.2 J/kg/K
E101	Sterilizer		235416.19		155480.00					Pressure = 1 bara, T superh. = 190°C; T condens. = 133.5°C; Cp = 2 J/kg/K
R101	Fermentor	1440.00			135253.33					Cooling water: Tin = 20°C; Tout = 40°C; Cp = 4.2 J/kg/K
K101	Compressor	1315.30			18607.52					Tin = 5°C; Tout = 10°C; Cp = 4.2 J/kg/K
S101	Air filter									
S102	Air filter									
E102	Cooler					270035.11				
S103	Rotary Vacuum Filter									
S104	Ultrafilter	177.90				1258.82				NaCl brine : Tin = -9°C; Tout = 0°C; Cp = 4.2 J/kg/K
G101	Granulator	149.20								
S105	Screens	20.00								
A101	Crusher	37.30								
K102	Compressor	0.20			2.09					
D101	Fluid Bed Dryer		429.43							
K103	Compressor	50.80			717.77					
E103	Cooler					32265.68				
D102	Fluid Bed Dryer									
TOTAL		**3670.70**	**235845.63**	**0.00**	**310060.71**	**303559.60**	**82342.41**	**0.00**	**0.00**	

APPENDIX 5.5
PROCESS YIELDS

Name	Ref. Name	kg/day IN	kg/day OUT	t/h IN	t/h OUT	t/t granul. IN	t/t granul. OUT
Substrate	<1>	49750.000		2.073		2.034	
Water	<2>	440000.000		18.333		17.993	
Air for R101	<5>	679235.662		28.301		27.776	
Wash water	<12>	24.000		0.001		0.001	
Builder+Binder	<17>	7229.990		0.301		0.296	
Air for D101	<23>	21.954		0.001		0.001	
Coating	<27>	5000.000		0.208		0.204	
Air for D102	<29>	28855.800		1.202		1.180	
Discharge S102	<9>		681590.248		28.400		27.872
Solid waste	<13>		46431.660		1.935		1.899
Liquid waste S104	<15>		428732.232		17.864		17.532
Top D101	<25>		53.090		0.002		0.002
Top D102	<32>		28855.800		1.202		1.180
Enzyme granules	**<33>**		**24454.380**		**1.019**		**1.000**
TOTAL		1210117.405	1210117.410	50.422	50.422	49.485	49.485

Name	Ref. Name	t/h	kW	t/t granul.	kWhh/ t granul.
LP steam	-	235845.627		231463.445	
NaCl Brine		303559.603		297919.247	
CW	-	310060.708		304299.557	
Chilled water	-	82342.414		80812.432	
Electricity	-		3670.700		3602.496



Figures in italics: t/h
Figures in bold font: t/ton granules

APPENDIX 7.1
MASS & HEAT BALANCE TOTAL STREAMS

IN						OUT				
Plant		EQUIPMENT			EQUIPM. IDENTIF.	EQUIPMENT			Plant	
Mass kg/day	Heat kW	Mass kg/day	Heat kW	Stream Nr.		Stream Nr.	Mass kg/day	Heat kW	Mass kg/day	Heat kW
49750.00	0.00	49750.00	0.00	<1>	T101	<3>	489750.00	0.00		
440000.00	0.00	440000.00	0.00	<2>						
	480.00		480.00		Operation					
					Duty			480.33		480.33
		489750.00	480.00		Total		489750.00	480.33		
		489750.00	0.00	<3>	E101	<4>	489750.00	264.27		
					Operation					
	7268.84		7268.84		Duty			3995.77		3995.77
		489750.00	7268.84		Total		489750.00	4260.04		
679235.66	0.00	679235.66	0.00	<5>	K101	<6>	679235.66	120.25		
	1315.30		1315.30		Operation					
					Duty			434.26		434.26
		679235.66	1315.30		Total		679235.66			
		679235.66	120.25	<6>	S101	<7>	679235.66	120.25		
					Operation					
					Duty					
		679235.66	120.25		Total		679235.66	120.25		
		489750.00	264.27	<4>	R101	<8>	681590.25	96.52		
		679235.66	120.25	<7>		<10>	487395.41	266.24		
	1440.00		1440.00		Operation					
					Duty			3155.91		3155.91
		1168985.66	1824.52		Total		1168985.66	3518.67		
		681590.25	96.52	<8>	S102	<9>	681590.25	96.52	681590.25	96.52
					Operation					
					Duty					
		681590.25	96.52		Total		681590.25	96.52		
		487395.41	266.24	<10>	E102	<11>	487395.41	-443.73		
					Operation					
					Duty			2835.91		2835.91
		487395.41	266.24		Total		487395.41	2392.18		
		487395.41	-443.73	<11>	S103	<13>	46431.66	-26.80	46431.66	-26.80
24.00	0.00	24.00	0.00	<12>		<14>	440987.75	-416.95		
					Operation					
					Duty					
		487419.41	-443.73		Total		487419.41	-443.75		
		440987.75	-416.95	<14>	S104	<15>	428732.23	-370.45	428732.23	-370.45
						<16>	12255.52	-4.80		
	177.90		177.90		Operation					
					Duty			13.22		13.22
		440987.75	-239.05		Total		440987.75	-362.04		
		12255.52	-4.80	<16>	G101	<18>	19882.54	-2.60		
7229.99	0.00	7229.99	0.00	<17>						
		198.51	0.06	<21>						
		198.51	0.06	<22>						
	149.20		149.20		Operation					
					Duty					
		19882.54	144.51		Total		19882.54	-2.60		
		19851.41	5.64	<19>	S105	<26>	19454.38	5.53		
						<20>	198.51	0.06		
						<22>	198.51	0.06		
	20.00		20.00		Operation					
					Duty					
		19851.41	25.64		Total		19851.41	5.64		
		198.51	0.06	<20>	A101	<21>	198.51	0.06		
	37.30		37.30		Operation					
					Duty					
		198.51	37.36		Total		198.51	0.06		
21.95	0.00	21.95	0.00	<23>	K102	<24>	21.95	0.00		
	0.20		0.20		Operation					
					Duty			0.05		0.05
		21.95	0.20		Total		21.95	0.05		
		19882.54	-2.60	<18>	D101	<25>	53.09	0.03	53.09	0.03
		21.95	0.00	<24>		<19>	19851.41	5.64		
					Operation					
	13.48		13.48		Duty					
		19904.49	10.88		Total		19904.50	5.66		
28855.80	0.00	28855.80	0.00	<29>	K103	<30>	28855.80			
	50.80		50.80		Operation					
					Duty			16.75		16.75
		28855.80	50.80		Total		28855.80	16.75		
		28855.80	5.11	<30>	E103	<31>	28855.80	-1.70		
					Operation					
					Duty			338.85		338.85
		28855.80	5.11		Total		28855.80	337.15		
		19851.41	5.64	<26>	D102	<32>	28855.80	-1.70	28855.80	-1.70
5000.00	3.79	5000.00	3.79	<27>		<33>	24454.38	-2.38	24454.38	-2.38
		28855.80	-1.70	<31>						
					Operation					
					Duty					
		53707.21	7.72		Total		53310.18	-4.09		
1210117.41	10956.81								1210117.41	10966.26

OUT-IN	0.00	9.45

APPENDIX 7.2
PROCESS STREAM SUMMARY

STREAM Nr.		1	*IN*	2	*IN*	3 *=1+2*		4 *=3*	
Name:		Substrate+Biomass		Water		Discharge T101		Discharge E101	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	1550.00	11.74	0.00	0.00	1550.00	11.74	1550.00	11.74
Biomass	147.60	740.00	5.01	0.00	0.00	740.00	5.01	740.00	5.01
Enzyme	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glucose	180.00	27000.00	150.00	0.00	0.00	27000.00	150.00	27000.00	150.00
Inerts	600.00	20000.00	33.33	0.00	0.00	20000.00	33.33	20000.00	33.33
Nutrients	229.03	460.00	2.01	0.00	0.00	460.00	2.01	460.00	2.01
Coating	2434.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Builder	1080.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Binder	9428.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	18.00	0.00	0.00	440000.00	24444.44	440000.00	24444.44	440000.00	24444.44
Nitrogen	28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	32.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon dioxide	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		**49750.00**	**202.09**	**440000.00**	**24444.44**	**489750.00**	**24646.54**	**489750.00**	**24646.54**
Enthalpy	kW	0.000		0.000		0.000		264.271	
Phase		L		L		L		L	
Pressure	Bara	1.01		1.01		1.01		1.01	
Temperature	°C	25.00		25.00		25.00		37.00	
Activity	U/ml	0		0		0		0	

STREAM Nr.		5	*IN*	6 *=5*		7 *=6*		8	*Calc*
Name:		Air for R101		Discharge K101		Discharge S101		Gas R101	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enzyme	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glucose	180.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inerts	600.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nutrients	229.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coating	2434.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Builder	1080.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Binder	9428.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	28.00	521053.82	18609.06	521053.82	18609.06	521053.82	18609.06	521053.82	18609.06
Oxygen	32.00	158181.84	4943.18	158181.84	4943.18	158181.84	4943.18	152525.18	4766.41
Carbon dioxide	44.00	0.00	0.00	0.00	0.00	0.00	0.00	8011.25	182.07
TOTAL		**679235.66**	**23552.25**	**679235.66**	**23552.25**	**679235.66**	**23552.25**	**681590.25**	**23557.55**
Enthalpy	kW	0.000		120.249		120.249		96.522	
Phase		G		G		G		G	
Pressure	Bara	1.01		3.01		3.01		1.01	
Temperature	°C	25.00		40.00		40.00		37.00	
Activity	U/ml	0		0		0		0	

STREAM Nr.		9 *=8*		10	*Calc*	11 *=10*		12	*IN*
Name:		Discharge S102		Bottom R101		Discharge E102		Wash water	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	0.00	0.00	77.50	0.59	77.50	0.59	0.00	0.00
Biomass	147.60	0.00	0.00	5088.56	34.48	5088.56	34.48	0.00	0.00
Enzyme	147.60	0.00	0.00	4079.87	27.64	4079.87	27.64	0.00	0.00
Glucose	180.00	0.00	0.00	10401.23	57.78	10401.23	57.78	0.00	0.00
Inerts	600.00	0.00	0.00	20000.00	33.33	20000.00	33.33	0.00	0.00
Nutrients	229.03	0.00	0.00	460.00	2.01	460.00	2.01	0.00	0.00
Coating	2434.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Builder	1080.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Binder	9428.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	18.00	0.00	0.00	447288.26	24849.35	447288.26	24849.35	24.00	1.33
Nitrogen	28.00	521053.82	18609.06	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	32.00	152525.18	4766.41	0.00	0.00	0.00	0.00	0.00	0.00
Carbon dioxide	44.00	8011.25	182.07	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		**681590.25**	**23557.55**	**487395.41**	**25005.18**	**487395.41**	**25005.18**	**24.00**	**1.33**
Enthalpy	kW	96.522		266.238		-443.730		0.000	
Phase		G		L		L		L	
Pressure	Bara	1.01		1.01		1.01		1.01	
Temperature	°C	37.00		37.00		5.00		25.00	
Activity	U/ml	0		84430.7		84430.7		0	

APPENDIX 7.2
PROCESS STREAM SUMMARY

STREAM Nr.		13	OUT	14 =11+12-13		15	OUT	16 =14-15	
Name:		Solid waste		Discharge S103		Liquid waste S104		Discharge S104	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	3.50	0.03	74.00	0.56	73.37	0.56	0.63	0.00
Biomass	147.60	5088.56	34.48	0.00	0.00	0.00	0.00	0.00	0.00
Enzyme	147.60	184.26	1.25	3895.60	26.39	0.00	0.00	3895.60	26.39
Glucose	180.00	469.75	2.61	9931.48	55.17	5192.98	28.85	4738.50	26.32
Inerts	600.00	20000.00	33.33	0.00	0.00	0.00	0.00	0.00	0.00
Nutrients	229.03	460.00	2.01	0.00	0.00	0.00	0.00	0.00	0.00
Coating	2434.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Builder	1080.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Binder	9428.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	18.00	20225.58	1123.64	427086.67	23727.04	423465.88	23525.88	3620.79	201.16
Nitrogen	28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	32.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon dioxide	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		**46431.66**	**1197.35**	**440987.75**	**23809.17**	**428732.23**	**23555.29**	**12255.52**	**253.88**
Enthalpy	kW	-26.805		-416.948		-370.455		-4.799	
Phase		L		L		L		L	
Pressure	Bara	1.01		1.01		1.01		1.01	
Temperature	°C	5.00		5.00		7.00		7.00	
Activity	U/ml	40643.5		89713.3		0		8971333.5	

STREAM Nr.		17	IN	18 =16+17+21+22		19 =20+22+26		20	Calc
Name:		Builder+Binder		Discharge G101		Bottom D101		Oversize S105	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	0.00	0.00	0.64	0.00	0.64	0.00	0.01	0.00
Biomass	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enzyme	147.60	0.00	0.00	3975.11	26.93	3975.10	26.93	39.75	0.27
Glucose	180.00	0.00	0.00	4835.20	26.86	4835.20	26.86	48.35	0.27
Inerts	600.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nutrients	229.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coating	2434.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Builder	1080.00	6379.99	5.91	6510.19	6.03	6510.19	6.03	65.10	0.06
Binder	9428.00	850.00	0.09	867.35	0.09	867.35	0.09	8.67	0.00
Water	18.00	0.00	0.00	3694.05	205.22	3662.92	203.50	36.63	2.03
Nitrogen	28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	32.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon dioxide	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		**7229.99**	**6.00**	**19882.54**	**265.14**	**19851.41**	**263.41**	**198.51**	**2.63**
Enthalpy	kW	0.000		-2.604		5.638		0.056	
Phase		S		S+L		S+L		S+L	
Pressure	Bara	1.01		1.01		1.01		1.01	
Temperature	°C	25.00		18.10		40.00		40.00	
Activity	U/ml	0		3351524		3351524		3351524	

STREAM Nr.		21	Calc	22	Calc	23	IN	24 =23	
Name:		Discharge A101		Undersize S105		Air for D101		Discharge K102	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Biomass	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enzyme	147.60	39.75	0.27	39.75	0.27	0.00	0.00	0.00	0.00
Glucose	180.00	48.35	0.27	48.35	0.27	0.00	0.00	0.00	0.00
Inerts	600.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nutrients	229.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coating	2434.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Builder	1080.00	65.10	0.06	65.10	0.06	0.00	0.00	0.00	0.00
Binder	9428.00	8.67	0.00	8.67	0.00	0.00	0.00	0.00	0.00
Water	18.00	36.63	2.03	36.63	2.03	0.00	0.00	0.00	0.00
Nitrogen	28.00	0.00	0.00	0.00	0.00	16.84	0.60	16.84	0.60
Oxygen	32.00	0.00	0.00	0.00	0.00	5.11	0.16	5.11	0.16
Carbon dioxide	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		**198.51**	**2.63**	**198.51**	**2.63**	**21.95**	**0.76**	**21.95**	**0.76**
Enthalpy	kW	0.056		0.056		0.000		0.004	
Phase		S+L		S+L		G		G	
Pressure	Bara	1.01		1.01		1.01		3.01	
Temperature	°C	40.00		40.00		25.00		40.00	
Activity	U/ml	3351524		3351524		0		0	

APPENDIX 7.2
PROCESS STREAM SUMMARY

STREAM Nr.		25	OUT	26 =16+17+23-26		27	IN	28 =26+27	
Name:		Top D101		Discharge S105		Coating		Mixture for D102	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	0.00	0.00	0.63	0.00	0.00	0.00	0.63	0.00
Biomass	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enzyme	147.60	0.00	0.00	3895.60	26.39	0.00	0.00	3895.60	26.39
Glucose	180.00	0.00	0.00	4738.50	26.33	0.00	0.00	4738.50	26.33
Inerts	600.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nutrients	229.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coating	2434.00	0.00	0.00	0.00	0.00	1600.00	0.66	1600.00	0.66
Builder	1080.00	0.00	0.00	6379.99	5.91	2400.00	2.22	8779.99	8.13
Binder	9428.00	0.00	0.00	850.00	0.09	0.00	0.00	850.00	0.09
Water	18.00	31.14	1.73	3589.66	199.43	1000.00	55.56	4589.66	254.98
Nitrogen	28.00	16.84	0.60	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	32.00	5.11	0.16	0.00	0.00	0.00	0.00	0.00	0.00
Carbon dioxide	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		53.09	2.49	19454.38	258.15	5000.00	58.44	24454.38	316.58
Enthalpy	kW	0.027		5.526		3.788		9.994	
Phase		G		S+L		L+S		L+S	
Pressure	Bara	1.01		1.01		1.01		1.01	
Temperature	°C	40.00		40.00		60.00		45.97	
Activity	U/ml	0		3360590.1		0		2342886.4	

STREAM Nr.		29	IN	30 =29		31 =30		32	OUT
Name:		Air for D102		Discharge K103		Discharge E103		Top D102	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enzyme	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glucose	180.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inerts	600.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nutrients	229.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coating	2434.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Builder	1080.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Binder	9428.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	28.00	22135.80	790.56	22135.80	790.56	22135.80	790.56	22135.80	790.56
Oxygen	32.00	6720.00	210.00	6720.00	210.00	6720.00	210.00	6720.00	210.00
Carbon dioxide	44.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		28855.80	1000.56	28855.80	1000.56	28855.80	1000.56	28855.80	1000.56
Enthalpy	kW	0.000		5.109		-1.703		-1.703	
Phase		G		G		G		G	
Pressure	Bara	1.01		3.01		3.01		1.01	
Temperature	°C	25.00		40.00		20.00		20.00	
Activity	U/ml	0		0		0		0	

				OVERALL COMPONENT MASS BALANCE					
STREAM Nr.		33	OUT	1+2+5+12+17+23+27+29		9+13+15+25+32+33		OUT-IN	
Name:		Enzyme granules		TOTAL IN		TOTAL OUT		Total Plant	
COMPONENT	MW	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day	kg/day	kmol/day
Ammonium phosphate	132.07	0.63	0.00	1550.00	11.74	77.50	0.59	-1472.50	-11.15
Biomass	147.60	0.00	0.00	740.00	5.01	5088.56	34.48	4348.56	29.46
Enzyme	147.60	3895.60	26.39	0.00	0.00	4079.86	27.64	4079.86	27.64
Glucose	180.00	4738.50	26.33	27000.00	150.00	10401.23	57.78	-16598.77	-92.22
Inerts	600.00	0.00	0.00	20000.00	33.33	20000.00	33.33	0.00	0.00
Nutrients	229.03	0.00	0.00	460.00	2.01	460.00	2.01	0.00	0.00
Coating	2434.00	1600.00	0.66	1600.00	0.66	1600.00	0.66	0.00	0.00
Builder	1080.00	8779.99	8.13	8779.99	8.13	8779.99	8.13	0.00	0.00
Binder	9428.00	850.00	0.09	850.00	0.09	850.00	0.09	0.00	0.00
Water	18.00	4589.66	254.98	441024.00	24501.33	448312.26	24906.24	7288.26	404.90
Nitrogen	28.00	0.00	0.00	543206.46	19400.23	543206.46	19400.23	0.00	0.00
Oxygen	32.00	0.00	0.00	164906.96	5153.34	159250.29	4976.57	-5656.67	-176.77
Carbon dioxide	44.00	0.00	0.00	0.00	0.00	8011.25	182.07	8011.25	182.07
TOTAL		24454.38	316.58	1210117.41	49265.88	1210117.41	49629.82	0.00	363.94
Enthalpy	kW	-2.383							
Phase		L							
Pressure	Bara	1.01							
Temperature	°C	20.00							
Activity	U/ml	2342886.4							

APPENDIX 8

EQUIPMENT SUMMARY AND SPECIFICATIONS

REACTORS AND VESSELS – SUMMARY

EQUIPMENT NR : NAME :	R101 Bioreactor	T101 Blending Tank			
Number of Units :	2	2			
Pressure [bara] :	1.50	1.50			
Temperature [°C] :	37.0	25.0			
Volume [m^3] : Diameter [m] : H [m] :	289.15 5.28 13.20	282.35 5.24 13.10			
Materials of Construction *(2)* :	SS316	SS304			
Other :					
Remarks: SS – Stainless Steel					

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

FILTERS - SUMMARY

EQUIPMENT NR : NAME :	S101 Air Filter	S102 Air Filter	S103 Rotary Vacuum Filter	S104 Ultrafilter	
Number of Units :	3	2	6	4	
Throughput $[m^3/s]$:	4.00	4.00			
Average Filter Flux $[L/m^2.h]$: Filter Area $[m^2]$: Cake Porosity [v/v]:			250.00 97.16 0.45	80.00	
Membrane Area $[m^2]$: Power [kW] :				450.89 360.7	
Materials of Construction *(2)* :	SS316	SS316	CS	SS316	
Other :					

Remarks:
SS – Stainless Steel
CS – Carbon Steel

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

FLUIDIZED BED – SUMMARY

EQUIPMENT NR : NAME :	D101 Fluid Bed Dryer	D102 Fluid Bed Coater			
Number of Units :	1	1			
Drying Temperature [°C] :	40.00	20.00			
Volume [m^3] : Diameter [m] : H [m] :	1.70 0.60 6.00	1.70 0.60 6.00			
Power [kW] :	0.00	0.00			
Materials of Construction *(2)* :	SS 316	SS 316			
Other :					

Remarks:

SS – Stainless Steel

Designers:			Project ID-Number	: CPD 3237
	C.Almeida	P. Du	Date	: July 1999
	R.Padios	R.Pitchumani		
	J.Taboada			

GRANULATION – SUMMARY

EQUIPMENT NR : NAME :	G101 Granulator	S105 Screens	A101 Crusher		
Number of Units :	1	1	1		
Pressure [bara] :	1	1	1		
Temperature [°C] :	20	20	20		
Volume [m^3] : Diameter [m] : H [m] :	30	 2	20		
Number - Series : - Parallel :					
Materials of Construction *(2)* :	SS316	SS316	SS316		
Other :					

Remarks:
SS – Stainless Steel

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

COOLERS and STERILIZER – SUMMARY

EQUIPMENT NR : NAME :	E101 Sterilizer	E102 Cooler	E103 Cooler		
Number of Units :	3	5	1		
Sterilization Criterion ln(No/N) :	41.00				
Temperature [°C] Sterilization : Preheat outlet : Final Exit :	 121.00 100.00 37.00	 5.00	 20.00		
Volume [m^3] : Diameter [m] : H [m] :					
Heat Transfer Area [m^2] :		95.75	6.60		
Holding tube length [m] : Holding tube Diameter [m] : Throughput [m^3/h] :	 196.80 70.00 320.00				
Materials of Construction *(2)* :	SS 316	CS	CS		
Other :					
Remarks SS – Stainless Steel CS – Carbon Steel					

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999	

COMPRESSORS – SUMMARY

EQUIPMENT NR : NAME :	G101 Compressor	G102 Compressor	G103 Compressor		
Number of Units :					
Overall Efficiency % :	70	70	70		
Power [kW] :	1315.3	0.20	50.8		
Pressure Change [bara] :	2.00	1.00	2.00		
<u>Number</u> - Series : - Parallel :					
Materials of Construction *(2)* :	CS	CS	CS		
Other :					

Remarks:

CS – Carbon Steel

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999	

BLENDING TANK – SPECIFICATION SHEET

EQUIPMENT NUMBER	: T101
NAME	: Blending Tank
Service :	
Type :	
Number :	
Operating Conditions	
Operating Pressure [bara]	: 1.00
Exit Temperature [°C]	: 25.00
Agitation Rate [kW/m^3]	: 1.00
Equipment Design	
Height [m]	: 13.10
Diameter [m]	: 5.24
Total Volume [m^3]	: 282.35
Power [kW]	: 480.0
Heating [kcal/h]	: 0.0
Cooling [kcal/h]	: 413010.0
Heat Transfer Agent	
Medium	: Chilled Water
Inlet Temperature [°C]	: 5.0
Outlet Temperature [°C]	: 10.0
Remarks:	

Designers:	C.Almeida	P. Du	Project ID-Number	: CPD 3237
	R.Padios	R.Pitchumani	Date	: July 1999
	J.Taboada			

BLENDING TANK – SPECIFICATION SHEET

EQUIPMENT NUMBER		: T102
NAME		: Blending Tank
Service	:	
Type	:	
Number	:	
Operating Conditions		
Operating Pressure	[bara]	: 1.00
Exit Temperature	[°C]	: 25.00
Agitation Rate	[kW/m^3]	: 1.00
Equipment Design		
Height	[m]	: 13.10
Diameter	[m]	: 5.24
Total Volume	[m^3]	: 282.35
Power	[kW]	: 480.0
Heating	[kcal/h]	: 0.0
Cooling	[kcal/h]	: 413010.0
Heat Transfer Agent		
Medium		: Chilled Water
Inlet Temperature	[°C]	: 5.0
Outlet Temperature	[°C]	: 10.0
Remarks:		

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

HEAT STERILIZER - SPECIFICATION SHEET

EQUIPMENT NUMBER : E101
NAME : Heat Sterilizer

Service :
Type :
Number :

Operating Conditions

Sterilization Temperature	[°C]	: 121.00
Preheat Outlet Temperature	[°C]	: 100.00
Final Exit Temperature	[°C]	: 37.00

Design Criteria :
Sterilization Criterion {ln(No/N)} : 41

Equipment Design

Holding tube Diameter	[m]	: 0.70
Holding tube Length	[m]	: 196.80

Process Conditions

Reynolds Number		: 164965.36
Peclet Number		: 1218.54
Damkohler Number		: 42.38
Dispersion Coeff.	[m^2/s]	: 0.0373
Specific Death Rate	[1/s]	: 0.05
Throughput	[m3/h]	: 320.00
Linear Velocity	[m/s]	: 0.23
Heating	[kcal/h]	: 6850076.0
Cooling	[kcal/h]	: 2935746.9

Heat Transfer Agent

Heating Medium	: Steam	Cooling Medium	: Cooling Water
In temp. [°C]	: 152.00	In temp. [°C]	: 25.00
Out temp. [°C]	: 152.00	Out temp. [°C]	: 30.00

Remarks:

Designers:	C.Almeida	P. Du	Project ID-Number	: CPD 3237
	R.Padios	R.Pitchumani	Date	: July 1999
	J.Taboada			

FERMENTOR – SPECIFICATION SHEET

EQUIPMENT NUMBER	: R101		
NAME	: Fermentor		
Service :			
Type :			
Number :			
Operating Conditions			
Operating Pressure [bara]	: 1.00		
Fermentation Temperature [°C]	: 25.00		
Agitation Rate [kW/m³]	: 1.00		
Reaction Mass Data			
Component	Mass Stoich.	Extra-cell %	% To Gas Outlet
Ammonium phosph	-49.980	100.00	0.00
Binder	0.00	100.00	0.00
Biomass	147.60	0.00	0.00
Builder	0.00	100.00	0.00
Carb. Dioxide	271.92	0.00	100.00
Coating	0.00	100.00	0.00
Glucose	-563.40	20.00	0.00
Inert	0.00	0.00	0.00
Nitrogen	0.00	100.00	100.00
Nutrients	0.00	100.00	0.00
Oxygen	-192.00	0.00	100.00
Proteins	138.48	100.00	0.00
Water	247.38	100.00	0.00
Equipment Design			
Height [m]	: 13.20		
Diameter [m]	: 5.28		
Total Volume [m³]	: 289.16		
Power [kW]	: 1440.0		
Heating [kcal/h]	: 0.0		
Cooling [kcal/h]	: 2621755.00		
Heat Transfer Agent			
Medium	: Cooling Water		
Inlet Temperature [°C]	: 25.0		
Outlet Temperature [°C]	: 30.0		
Remarks:			

Designers:	C.Almeida	P. Du	Project ID-Number	: CPD 3237
	R.Padios	R.Pitchumani	Date	: July 1999
	J.Taboada			

COOLER – SPECIFICATION SHEET

EQUIPMENT NUMBER		: E102
NAME		: Cooler
Service :		
Type :		
Number :		
Operating Conditions		
Heat Transfer Coeff.	[kcal/m^2.h.^{o}C]	: 1290.66
Duty	[kcal/h]	: -14630664.00
Exit Temperature	[^{o}C]	: 5.00
Equipment Design		
Heat Transfer Area	[m^2]	: 95.75
Exchanger type		: Plate and Frame
Heat Transfer Agent		
Medium		: NaCl Brine
Inlet Temperature	[^{o}C]	: -9.01
Outlet Temperature	[^{o}C]	: -0.01
Remarks:		

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

COOLER – SPECIFICATION SHEET

EQUIPMENT NUMBER		: E103
NAME		: Cooler
Service		:
Type		:
Number		:
Operating Conditions		
Heat Transfer Coeff.	[kcal/m^2.h.°C]	: 1290.66
Duty	[kcal/h]	: -291362.3
Exit Temperature	[°C]	: 20.00
Equipment Design		
Heat Transfer Area	[m^2]	: 6.60
Exchanger type		: Plate and Frame
Heat Transfer Agent		
Medium		: NaCl Brine
Inlet Temperature	[°C]	: -9.01
Outlet Temperature	[°C]	: -0.01
Remarks:		

Designers:	C.Almeida	P. Du	Project ID-Number	: CPD 3237
	R.Padios	R.Pitchumani	Date	: July 1999
	J.Taboada			

ROTARY VACUUM FILTER – SPECIFICATION SHEET

EQUIPMENT NUMBER : S103
NAME : Rotary Vacuum Filter

Service :
Type :
Number :

Process Conditions

Retention Coefficients (RC) for Solids :

Component	**RC (%)**
Ammonium phosph	0.00
Binder	0.00
Biomass	100.00
Builder	0.00
Carb. Dioxide	0.00
Coating	0.00
Glucose	0.00
Inert	100.00
Oxygen	0.00
Proteins	0.00
Nitrogen	0.00
Nutrients	100.00
Water	0.00

Operating Condition

Average Filtrate Flux [L/m^2.h] : 250.00

Equipment Design

Filter Area [m^2] : 97.16
Cake Porosity [v/v] : 0.45

Remarks:

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

ULTRAFILTER – SPECIFICATION SHEET

EQUIPMENT NUMBER : S104
NAME : Ultrafilter

Service :
Type :
Number :

Operating Condition

Filtration Mode		: Batch Concentration
Exit Temperature	[°C]	: 7.00
Average Filtrate Flux	[$L/m^2.h$]	: 80.00
Max. Solids Conc. In Retentate	[g/L]	: 1200.00
Rejection Coefficient (RC)		: Set Proteins at 100.00% RC

Rest of components are set at 0% RC

Other Data

Unit Power Consumption	[W/m^2]	: 200.00
Membrane Repl. Frequency	[oper.h]	: 2000.00
Power	[kW]	: 360.70
Heating	[kcal/h]	: 0.00
Cooling	[kcal/h]	: 24111.2

Equipment Design

Membrane Area[m^2] : 450.89

Heat Transfer Agent

Medium		: NaCl Brine
Inlet Temperature	[°C]	: -9.01
Outlet Temperature	[°C]	: -0.00

Remarks:

Designers:	C.Almeida	P. Du	Project ID-Number	: CPD 3237
	R.Padios	R.Pitchumani	Date	: July 1999
	J.Taboada			

FLUID BED DRYER – SPECIFICATION SHEET

EQUIPMENT NUMBER		: D101
NAME		: Fluid Bed Dryer
Service :		
Type :		
Number :		
Operating Condition		
Drying Temperature	[°C]	: 40.00
Ave. Solids Residence Time	[s]	: 60.00
Ave. Solids velocity	[m/s]	: 0.10
Power	[kW]	: 0.00
Heating	[kcal/h]	: 11590.2
Evaporation Data		
Water is set at 5% Evaporated		
Rest of the components do not evaporate		
Other Data		
Drying Gas Required	[kg dry gas/kg evap]	: 5.00
Specific Power	[kW/ m^3 dryer vol.]	: 0.02
Specific Heating	[kJ/ kg evap]	: 2230.00
Equipment Design		
Volume	[m^3]	: 1.70
Diameter	[m]	: 0.60
Height	[m]	: 6.00
Heat Transfer Agent		
Medium		: Steam
Inlet Temperature	[°C]	: 152.00
Outlet Temperature	[°C]	: 152.00
Remarks:		

Designers:	C.Almeida	P. Du	Project ID-Number	: CPD 3237
	R.Padios	R.Pitchumani	Date	: July 1999
	J.Taboada			

FLUID BED DRYER – SPECIFICATION SHEET

EQUIPMENT NUMBER		: D102	
NAME		: Fluid Bed Dryer	
Service :			
Type :			
Number :			
Operating Condition			
Drying Temperature	[°C]	: 20	
Ave. Solids Residence Time	[s]	: 60.00	
Ave. Solids velocity	[m/s]	: 0.10	
Power	[kW]	: 0.00	
Heating	[kcal/h]	: 0.00	
Other Data			
Drying Gas Required	[kg dry gas/kg evap]	: 5.00	
Specific Power	[kW/ m^3 dryer vol.]	: 0.02	
Specific Heating	[kJ/ kg evap]	: 2230.00	
Equipment Design			
Volume	[m^3]	: 1.70	
Diameter	[m]	: 0.60	
Height	[m]	: 6.00	
Heat Transfer Agent			
Medium		: Steam	
Inlet Temperature	[°C]	: 152.00	
Outlet Temperature	[°C]	: 152.00	
Remarks:			

Designers: C.Almeida P. Du R.Padios R.Pitchumani J.Taboada	Project ID-Number : CPD 3237 Date : July 1999

GRANULATOR – SPECIFICATION SHEET

EQUIPMENT NUMBER	: G101
NAME	: Granulator

Service :
Type :
Number :

Operating Condition

Flow rate: 700 kg/h
Ploughshare rpm : 200
Chopper rpm : 3000

Other Data

Equipment Design

Volume : 30 m^3

Heat Transfer Agent

Remarks:

Designers:	C.Almeida	P. Du	Project ID-Number	: CPD 3237
R.Padios	R.Pitchumani		Date	: July 1999
J.Taboada				

CRUSHER – SPECIFICATION SHEET

EQUIPMENT NUMBER	: A101
NAME	: Crusher
Service :	
Type :	
Number :	
Operating Condition	
Flow rate : 700 kg/h	
Other Data	
Equipment Design	
Volume : 20m^3	
Heat Transfer Agent	
Remarks:	

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

SCREENS – SPECIFICATION SHEET

EQUIPMENT NUMBER	: S105
NAME	: Screens
Service	:
Type	:
Number	:
Operating Condition	
Other Data	
Equipment Design	
Diameter : 2 m Top Sieve opening : 1000 μm Bottom Sieve opening : 250 μm	
Heat Transfer Agent	
Remarks:	

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

COMPRESSOR – SPECIFICATION SHEET

EQUIPMENT NUMBER		: K101
NAME		: Air Compressor
Service :		
Type :		
Number :		
Operating Condition		
Pressure Change	[bara]	: 2.00
Power	[kW]	: 1315.3
Cooling	[kcal/h]	: 373395
Other Data		
Overall Efficiency	[%]	: 70.00
Heat Transfer Agent		
Medium		: Cooling Water
Inlet Temperature	[°C]	: 25.0
Outlet Temperature	[°C]	: 30.00
Remarks:		

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

COMPRESSOR – SPECIFICATION SHEET

EQUIPMENT NUMBER		: K102
NAME		: Air Compressor
Service :		
Type :		
Number :		
Operating Condition		
Pressure Change	[bara]	: 1.00
Power	[kW]	: 0.20
Cooling	[kcal/h]	: 42.00
Other Data		
Overall Efficiency	[%]	: 70.00
Heat Transfer Agent		
Medium		: Cooling Water
Inlet Temperature	[°C]	: 25.0
Outlet Temperature	[°C]	: 30.00
Remarks:		

Designers:	C.Almeida	P. Du	Project ID-Number	: CPD 3237
	R.Padios	R.Pitchumani	Date	: July 1999
	J.Taboada			

COMPRESSOR – SPECIFICATION SHEET

EQUIPMENT NUMBER		: K103
NAME		: Air Compressor
Service :		
Type :		
Number :		
Operating Condition		
Pressure Change	[bara]	: 2.00
Power	[kW]	: 50.80
Cooling	[kcal/h]	: 14403.4
Other Data		
Overall Efficiency	[%]	: 70.00
Heat Transfer Agent		
Medium		: Cooling Water
Inlet Temperature	[°C]	: 25.0
Outlet Temperature	[°C]	: 30.00
Remarks:		

Designers:	C.Almeida R.Padios J.Taboada	P. Du R.Pitchumani	Project ID-Number Date	: CPD 3237 : July 1999

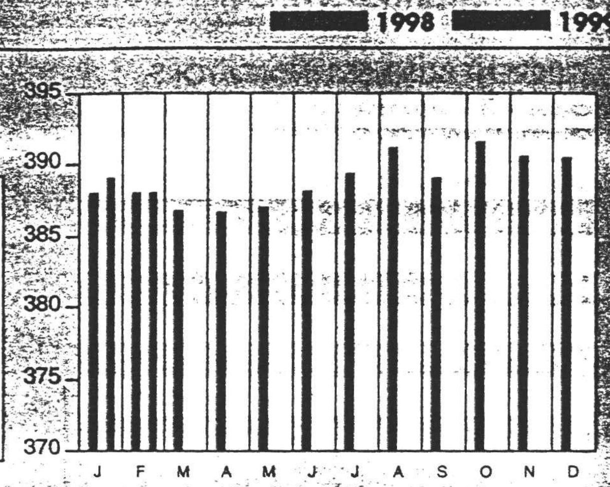
CHEMICAL ENGINEERING PLANT COST INDEX

(1957-59 = 100)

	Feb. '99 Prelim.	Jan. '99 Final	Feb. '98 Final
CE INDEX	**388.0**	**389.0**	**384.0**
Equipment	434.1	435.2	435.6
Heat exchangers & tanks	372.6	373.6	385.7
Process machinery	431.0	432.0	428.4
Pipe, valves & fittings	533.5	536.4	535.1
Process instruments	360.6	361.1	368.0
Pumps & compressors	658.1	662.6	644.3
Electrical equipment	334.7	335.1	332.1
Structural supports & misc.	411.2	407.6	384.6
Construction labor	285.7	287.5	281.6
Buildings	375.6	375.4	373.3
Engineering & supervision	340.2	340.4	341.8

Annual Index

1992 = 358.2
1993 = 359.2
1994 = 368.1
1995 = 381.1
1996 = 381.7
1997 = 386.5
1998 = 389.5



For an explanation and additional information call: 212-904-6931

VATAVUK AIR POLLUTION CONTROL COST INDEXES (VAPCCI)

(1st Quarter 1994 = 100.0)[1]

CONTROL DEVICE	1996 (Avg.)[2]	1997 (Avg.)[2]	1st Q. '98	2nd Q. '98	3rd Q '98	4th Q '98[3]	1st Q '99[3]
Carbon adsorbers	106.4	104.7	104.6	103.9	103.2	102.6	101.5
Catalytic incinerators	107.0	107.7	106.6	108.2	107.0	104.2	103.5
Electrostatic precipitators	108.0	108.8	109.0	109.7	110.5	107.3	103.2
Fabric filters[3]	104.5	106.2	107.9	108.7	110.4	110.9	111.5
Flares	104.9	105.8	104.4	104.3	103.6	102.3	99.4
Gas absorbers	107.8	107.6	108.9	109.4	110.0	110.0	111.0
Mechanical collectors[3]	103.3	103.9	106.0	107.3	114.3	115.4	117.9
Refrigeration systems	104.4	106.1	107.6	107.9	107.8	107.2	106.1
Regenerative thermal oxidizers	106.3	107.9	108.4	108.8	109.2	109.1	108.5
Thermal incinerators	108.2	109.4	109.9	110.6	110.9	110.5	109.1
Wet scrubbers	109.8	109.0	109.4	109.7	109.7	109.9	110.2

[1] Index values have been rounded to the nearest tenth.

[2] Each annual average is the arithmetic mean of the quarterly indexes for that year.

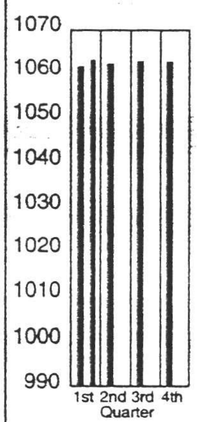
[3] All fourth quarter 1998 and first quarter 1999 indexes are preliminary.

[4] For fabric filters and mechanical collectors, each quarterly value shown is the average of the Producer Price Indexes (PPIs) for the three months in question, divided by the average of the PPIs for January, February, and March 1994 (i.e., first quarter 1994).

Note: For a detailed explanation of the development and use of the VAPCCI, see *Chem. Eng.*, December 1995, pp. 88-95.

MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)



	1st Q 1999	4th Q 1998	1st Q 1998
M & S INDEX	1,062.7	1,062.3	1,061.2
Process industries, average	1,078.8	1,076.6	1,074.6
Cement	1,067.8	1,066.8	1,065.3
Chemical	1,062.0	1,059.5	1,056.7
Clay products	1,063.7	1,063.0	1,062.7
Glass	989.6	988.9	989.1
Paint	1,079.7	1,078.3	1,078.1
Paper	1,027.8	1,026.5	1,027.2
Petroleum products	1,126.0	1,123.4	1,120.6
Rubber	1,153.0	1,150.9	1,149.3
Related industries			
Electrical power	963.7	966.6	966.8
Mining, milling	1,099.0	1,096.6	1,097.1
Refrigerating	1,266.2	1,264.2	1,262.7
Steam Power	1,037.6	1,037.5	1,036.7

Annual Index

1993 = 964.2
1994 = 993.4
1995 = 1,027.5
1996 = 1,039.2
1997 = 1,056.8
1998 = 1,061.9

CONSTRUCTION SPOTLIGHT

COMPANY	PROJECT	LOCATION	COST, CAPACITY	STATUS
Enron Corp. (Houston, Tex.)	Gas-fired power plant	New Albany, Miss.	$70 million	Bidding and construction schedules not yet determined; contract method undetermined; further information within 60–90 days
Husky Oil Ltd. (Calgary, Alta.)	Heavy-oil production unit	Lloydminster, Sask.	$50 million	Design drawings to be started soon; target completion set for March 2001
Constellation Power (Baltimore, Md.)	Power plant	Brevard County, Fla.	$30 million	Site acquired; further action pending various approvals; construction targeted to begin early 2000, with commercial operation commencing in 2001
El Paso Energy Corp. (Houston, Tex.)	Cogeneration plant	Windsor Locks, Conn.	$15-25 million	Construction scheduled to begin October 1999
Mobil Oil Corp. (St. Louis, Mo.)	Cogeneration plant	Beaumont, Tex.	$10-15 million	Preliminary plans in progress; contract method undetermined; construction schedules not yet determined; further information within 30–60 days
Town of Beauceville (Beauceville, Que.)	Filtration plant	Beauceville, Que.	$5.5 million	Architect selected; construction schedule undetermined; further information pending funding

This partial list of upcoming projects in the chemical process industries is from DataLine, an online-retrieval service of The McGraw-Hill Companies' F.W. Dodge division. Call 800-221-0088 for more information. The jobs selected are in the pre-planning stage, generally prior to finalization of the engineering design or selection of the general contractor

Economic Indicators

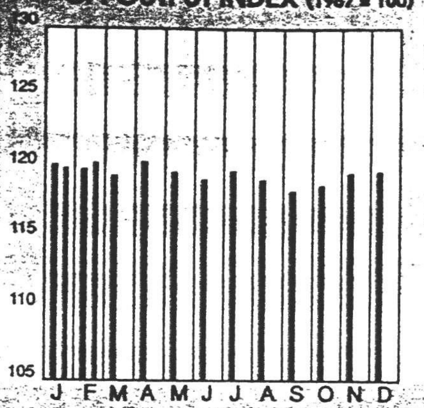
1998 1999

CURRENT BUSINESS INDICATORS

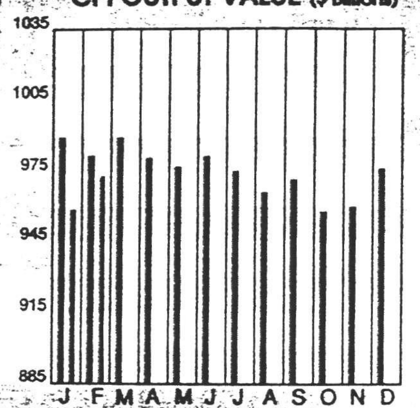
CURRENT BUSINESS INDICATORS	LATEST	PREVIOUS		YEAR AGO
CPI output index (1992 = 100)*	Feb. '99 = 120.4	Jan. '99 = 120.0	Dec. '98 = 119.9	Feb. '98 = 119.9
CPI value of output, $ billions†	Feb. '99 = 973.1	Jan. '99 = 958.6	Dec. '98 = 975.9	Feb. '98 = 981.8
CPI operating rate, %	Mar. '99 = 82.1	Feb. '99 = 82.1	Jan. '99 = 82.0	Mar. '98 = 83.4
Construction cost index (1967 = 100)	Apr. '99 = 569.3	Mar. '99 = 567.2	Feb. '99 = 567.8	Apr. '98 = 547.7
Producer prices, industrial chemicals (1982 = 100)	Mar. '99 = 117.4	Feb. '99 = 118.0	Jan. '99 = 118.9	Mar. '98 = 123.1
Index of industrial activity (1992 = 100)	Apr. 3, '99 = 142.9	Mar. 27, '99 = 142.8	Mar. 20, '99 = 142.7	Apr. 4, '98 = 135.2
Hourly earnings index, chemical & allied products (1992* = 100)	Mar. '99 = 118.7	Feb. '99 = 118.6	Jan. '99 = 118.9	Mar. '98 = 117.0
Productivity index, chemicals & allied products (1987 = 100)**	Mar. '99 = 112.8	Feb. '99 = 112.3	Jan. '99 = 111.0	Mar. '98 = 112.7

*See article CE, April, p. 58

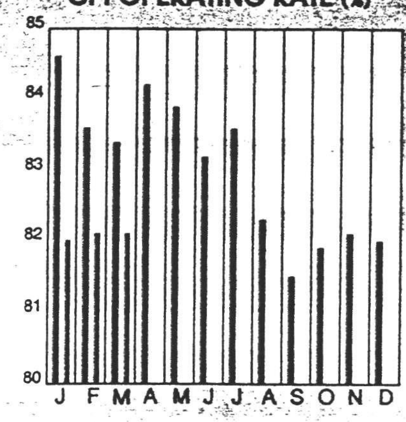
CPI OUTPUT INDEX (1987 = 100)



CPI OUTPUT VALUE ($ Billions)

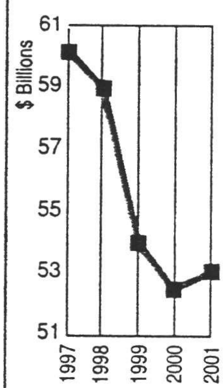


CPI OPERATING RATE (%)



*To convert to 1987 = 100 base, divide by 91.302 and multiply by 100. †Revised as of Jan. 1987 — multiply values from Jan. 1982 to Jan. 1987 by 0.9586 to convert to values starting with Jan. 1987.
**To convert to 1977 = 100 base, multiply by 1.478; P = Preliminary; R = Revised. For an explanation and additional information call: 212-904-6931.

CPI CAPITAL SPENDING INDEX



1997	60.22
1998	59.02
1999	54.03
2000	52.50
2001	53.09

The CE Capital Spending Index is derived from econometric forecasts of the U.S. economy produced by Standard & Poor's DRI, updated quarterly. DRI data are further refined by CE to reflect those portions of U.S. manufacturing that constitute the chemical process industries (CPI). The CPI include chemicals (SIC 28), pulp and paper (SIC 26), petroleum refining (SIC 29), food processing (SIC 20) and 14 other industry sectors.

All dollars are nominal (uninflated). For more information, call 212-904-6931

ISO UPDATE, MAY 1999

Company	(Standard)	Headquarters	Certified for:
Advanced Polymer Alloys	9002	Wilmington, Del.	Manufacture of Melt-Processible Rubber (MPR)
Von Roll America, Inc.	14001	East Liverpool, Ohio	Providing environmentally advanced incineration services
Chicago White Metal Casting	14001	Bensenville, Ill.	Manufacture of custom die casters
Degussa-Hüls	9002	Ridgefield Park, N.J.	Production of feed additives, peroxygenation chemicals and sodium cyanide
Conam Inspection Inc.	9002	Glendale Heights, Ill.	Providing nondestructive testing (NDT), metallurgical examination, chemical analysis, mechanical testing, training services and lubricant- and fluid-analysis services

Coming soon: News on new plants and capacity-expansion construction

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FOR MORE ECONOMIC INDICATORS, SEE NEXT PAGE

[illegible]'s Data Book 2nd ed. G. Weiss. Noyes Data Corp 1986

AMMONIUM PHOSPHATE

APP

Common Synonyms	Solid	White	Weak ammonia odor
Monoammonium orthophosphate Ammonium phosphate, dibasic Secondary ammonium phosphate Diammonium hydrogen phosphate Diammonium orthophosphate	Sinks and mixes with water.		

Stop discharge if possible. Keep people away.
Avoid contact with solid and dust.
Isolate and remove discharged material.
Notify local health and pollution control agencies.

Fire	Not flammable. Irritating gases may be produced when heated.
Exposure	CALL FOR MEDICAL AID. DUST Irritating to eyes, nose and throat. If inhaled will cause coughing or difficult breathing. If in eyes, hold eyelids open and flush with plenty of water. If breathing has stopped, give artificial respiration. If breathing is difficult, give oxygen. SOLID Irritating to skin and eyes. Harmful if swallowed. Remove contaminated clothing and shoes. Flush affected areas with plenty of water. IF IN EYES, hold eyelids open and flush with plenty of water. IF SWALLOWED and victim is CONSCIOUS, have victim drink water or milk. IF SWALLOWED and victim is UNCONSCIOUS OR HAVING CONVULSIONS, do nothing except keep victim warm.
Water Pollution	Effect of low concentrations on aquatic life is unknown. May be dangerous if it enters water intakes. Notify local health and wildlife officials. Notify operators of nearby water intakes.

1. RESPONSE TO DISCHARGE

(See Response Methods Handbook)

Disperse and flush

2. LABEL

2.1 **Category:** None
2.2 **Class:** Not pertinent

3. CHEMICAL DESIGNATIONS

3.1 **CG Compatibility Class:** Not listed
3.2 **Formula:** $NH_4H_2PO_4$ and $(NH_4)_2HPO_4$
3.3 **IMO/UN Designation:** Not listed
3.4 **DOT ID No.:** Data not available
3.5 **CAS Registry No.:** 7783-28-0

4. OBSERVABLE CHARACTERISTICS

4.1 **Physical State (as shipped):** Solid
4.2 **Color:** White
4.3 **Odor:** Diammonium-faint ammonia
Monoammonium-faint acid

5. HEALTH HAZARDS

5.1 **Personal Protective Equipment:** Dust mask, protective gloves, and goggles. When diammonium phosphate is stored in closed area, self-contained breathing apparatus is required to protect against ammonia fumes.
5.2 **Symptoms Following Exposure:** Inhalation of monoammonium form causes irritation of mucous membranes; with diammonium form, ammonia vapors in closed area can cause pulmonary edema and asphyxia. Contact with solid or with ammonia gas causes irritation of eyes and skin.
5.3 **Treatment of Exposure:** INHALATION: if exposed to ammonia fumes from diammonium phosphate, give artificial respiration and oxygen if needed; enforce rest. EYES: flush with water for at least 15 min.; if irritation persists, get medical attention. SKIN: flush with water.
5.4 **Threshold Limit Value:** 25 ppm as ammonia
5.5 **Short Term Inhalation Limits:** Data not available
5.6 **Toxicity by Ingestion:** Data not available
5.7 **Late Toxicity:** Data not available
5.8 **Vapor (Gas) Irritant Characteristics:** Data not available
5.9 **Liquid or Solid Irritant Characteristics:** Data not available
5.10 **Odor Threshold:** Odorless
5.11 **IDLH Value:** 500 ppm as ammonia

6. FIRE HAZARDS

6.1 **Flash Point:** Not flammable
6.2 **Flammable Limits in Air:** Not flammable
6.3 **Fire Extinguishing Agents:** Not pertinent
6.4 **Fire Extinguishing Agents Not to be Used:** Not pertinent
6.5 **Special Hazards of Combustion Products:** Toxic and irritating fumes of ammonia and oxides of nitrogen may form in fires.
6.6 **Behavior in Fire:** Data not available
6.7 **Ignition Temperature:** Not pertinent
6.8 **Electrical Hazard:** Not pertinent
6.9 **Burning Rate:** Not pertinent
6.10 **Adiabatic Flame Temperature:** Not pertinent
6.11 **Stoichiometric Air to Fuel Ratio:** Not pertinent
6.12 **Flame Temperature:** Not pertinent

7. CHEMICAL REACTIVITY

7.1 **Reactivity With Water:** No reaction
7.2 **Reactivity with Common Materials:** Data not available
7.3 **Stability During Transport:** Stable
7.4 **Neutralizing Agents for Acids and Caustics:** Not pertinent
7.5 **Polymerization:** Not pertinent
7.6 **Inhibitor of Polymerization:** Not pertinent
7.7 **Molar Ratio (Reactant to Product):** Data not available
7.8 **Reactivity Group:** Data not available

8. WATER POLLUTION

8.1 **Aquatic Toxicity:**
155 ppm/96 hr/fathead minnow/LC_{50}
8.2 **Waterfowl Toxicity:** Data not available
8.3 **Biological Oxygen Demand (BOD):** Data not available
8.4 **Food Chain Concentration Potential:** None

9. SHIPPING INFORMATION

9.1 **Grades of Purity:** Reagent; Technical
9.2 **Storage Temperature:** Ambient
9.3 **Inert Atmosphere:** Ventilated (forced)
9.4 **Venting:** Open

10. HAZARD ASSESSMENT CODE

(See Hazard Assessment Handbook)

SS

11. HAZARD CLASSIFICATIONS

11.1 **Code of Federal Regulations:** Not listed
11.2 **NAS Hazard Rating for Bulk Water Transportation:** Not listed
11.3 **NFPA Hazard Classification:** Not listed

12. PHYSICAL AND CHEMICAL PROPERTIES

12.1 **Physical State at 15°C and 1 atm:** Solid
12.2 **Molecular Weight:** Monoammonium: 115 Diammonium: 132
12.3 **Boiling Point at 1 atm:** Not pertinent (begins to decompose at 100°C)
12.4 **Freezing Point:** Not pertinent (begins to decompose at 100°C)
12.5 **Critical Temperature:** Not pertinent
12.6 **Critical Pressure:** Not pertinent
12.7 **Specific Gravity:**
Diammonium: 1.8 at 20°C (solid)
Monoammonium: 1.6 at 20°C (solid)
12.8 **Liquid Surface Tension:** Not pertinent
12.9 **Liquid Water Interfacial Tension:** Not pertinent
12.10 **Vapor (Gas) Specific Gravity:** Not pertinent
12.11 **Ratio of Specific Heats of Vapor (Gas):** Not pertinent
12.12 **Latent Heat of Vaporization:** Not pertinent
12.13 **Heat of Combustion:** Not pertinent
12.14 **Heat of Decomposition:** Not pertinent
12.15 **Heat of Solution:**
42 Btu/lb = 23 cal/g
= 0.97×10^5 J/kg
12.16 **Heat of Polymerization:** Not pertinent
12.25 **Heat of Fusion:** Data not available
12.26 **Limiting Value:** Data not available
12.27 **Reid Vapor Pressure:** Data not available

NOTES

NITROGEN

NXX

Common Synonyms Liquid nitrogen	Gas — Colorless — Odorless Floats and boils on water.

Avoid contact with liquid.

Fire	Not flammable.
Exposure	CALL FOR MEDICAL AID. **VAPOR** Not harmful. In high concentrations may cause dizziness, difficult breathing, or loss of consciousness. **LIQUID** Will cause frostbite. Flush affected areas with plenty of water. DO NOT RUB AFFECTED AREAS.
Water Pollution	Not harmful to aquatic life.

1. RESPONSE TO DISCHARGE
(See Response Methods Handbook)

Restrict access

2. LABEL
2.1 **Category:** Nonflammable gas
2.2 **Class:** 2

3. CHEMICAL DESIGNATIONS
3.1 **CG Compatibility Class:** Not listed
3.2 **Formula:** N_2
3.3 **IMO/UN Designation:** 2/1977
3.4 **DOT ID No.:** 1977
3.5 **CAS Registry No.:** 7727-37-9

4. OBSERVABLE CHARACTERISTICS
4.1 **Physical State (as shipped):** Liquefied gas
4.2 **Color:** Colorless to faint yellow
4.3 **Odor:** None

5. HEALTH HAZARDS
5.1 **Personal Protective Equipment:** Safety glasses or face shield; insulated gloves; long sleeves; trousers worn outside boots or over high-top shoes to shed spilled liquid; self-contained breathing apparatus where insufficient air is present.
5.2 **Symptoms Following Exposure:** Inhalation can cause asphyxiation, if atmosphere does not contain oxygen; dizziness, unconsciousness, or even death can result. Contact of liquid with skin or eyes causes frostbite burns.
5.3 **Treatment of Exposure:** INHALATION: remove to fresh air; apply artificial respiration if breathing has stopped; call physician. EYES: treat for frostbite burns caused by liquid. SKIN: treat for frostbite; soak in lukewarm water.
5.4 **Threshold Limit Value:** Non-toxic
5.5 **Short Term Inhalation Limits:** Not pertinent
5.6 **Toxicity by Ingestion:** Not pertinent
5.7 **Late Toxicity:** None
5.8 **Vapor (Gas) Irritant Characteristics:** None
5.9 **Liquid or Solid Irritant Characteristics:** Frostbite
5.10 **Odor Threshold:** Not pertinent
5.11 **IDLH Value:** Data not available

6. FIRE HAZARDS
6.1 **Flash Point:** Not pertinent (nonflammable compressed gas)
6.2 **Flammable Limits in Air:** Not pertinent
6.3 **Fire Extinguishing Agents:** Not pertinent
6.4 **Fire Extinguishing Agents Not to be Used:** Not pertinent
6.5 **Special Hazards of Combustion Products:** Not pertinent
6.6 **Behavior in Fire:** Containers may explode when heated.
6.7 **Ignition Temperature:** Not pertinent
6.8 **Electrical Hazard:** Not pertinent
6.9 **Burning Rate:** Not pertinent
6.10 **Adiabatic Flame Temperature:** Data not available
6.11 **Stoichiometric Air to Fuel Ratio:** Data not available
6.12 **Flame Temperature:** Data not available

7. CHEMICAL REACTIVITY
7.1 **Reactivity With Water:** Heat of water will vigorously vaporize liquid nitrogen.
7.2 **Reactivity with Common Materials:** No chemical reaction. Low temperature may cause brittleness in rubber and plastics.
7.3 **Stability During Transport:** Stable
7.4 **Neutralizing Agents for Acids and Caustics:** Not pertinent
7.5 **Polymerization:** Not pertinent
7.6 **Inhibitor of Polymerization:** Not pertinent
7.7 **Molar Ratio (Reactant to Product):** Data not available
7.8 **Reactivity Group:** Data not available

8. WATER POLLUTION
8.1 **Aquatic Toxicity:** None
8.2 **Waterfowl Toxicity:** None
8.3 **Biological Oxygen Demand (BOD):** None
8.4 **Food Chain Concentration Potential:** None

9. SHIPPING INFORMATION
9.1 **Grades of Purity:** 99.5+%
9.2 **Storage Temperature:** —320°F
9.3 **Inert Atmosphere:** No requirement
9.4 **Venting:** Open

10. HAZARD ASSESSMENT CODE
(See Hazard Assessment Handbook)

A-C-D-F-G

11. HAZARD CLASSIFICATIONS
11.1 **Code of Federal Regulations:** Nonflammable gas
11.2 **NAS Hazard Rating for Bulk Water Transportation:** Not listed
11.3 **NFPA Hazard Classification:**

Category	Classification
Health Hazard (Blue)	3
Flammability (Red)	0
Reactivity (Yellow)	0

12. PHYSICAL AND CHEMICAL PROPERTIES
12.1 **Physical State at 15°C and 1 atm:** Gas
12.2 **Molecular Weight:** 28.0
12.3 **Boiling Point at 1 atm:** —320.1°F = —195.6°C = 77.6°K
12.4 **Freezing Point:** —354°F = —215°C = 58°K
12.5 **Critical Temperature:** —232.6°F = —147.0°C = 126.2°K
12.6 **Critical Pressure:** 493 psia = 33.5 atm = 3.40 MN/m²
12.7 **Specific Gravity:** 0.807 at —195.5°C (liquid)
12.8 **Liquid Surface Tension:** 8.3 dynes/cm = 0.083 N/m at —193°C
12.9 **Liquid Water Interfacial Tension:** Not pertinent
12.10 **Vapor (Gas) Specific Gravity:** 0.965
12.11 **Ratio of Specific Heats of Vapor (Gas):** 1.3962
12.12 **Latent Heat of Vaporization:** 95 Btu/lb = 53 cal/g = 2.2×10^5 J/kg
12.13 **Heat of Combustion:** Not pertinent
12.14 **Heat of Decomposition:** Not pertinent
12.15 **Heat of Solution:** Not pertinent
12.16 **Heat of Polymerization:** Not pertinent
12.25 **Heat of Fusion:** 6.15 cal/g
12.26 **Limiting Value:** Data not available
12.27 **Reid Vapor Pressure:** Data not available

NOTES

OXYGEN

OXY

Common Synonyms
Liquid oxygen
LOX

Gas | Light blue | Odorless

Sinks and boils in water.

Avoid contact with liquid. Keep people away.
Wear rubber overclothing (including gloves).
Stop discharge if possible.

Fire

Not flammable.
Containers may explode in fire.
Cool exposed containers with water.

Exposure

CALL FOR MEDICAL AID.

VAPOR
If inhaled will cause dizziness, or difficult breathing.

LIQUID
Will cause frostbite.
Flush affected areas with plenty of water.
DO NOT RUB AFFECTED AREAS.

Water Pollution

Not harmful to aquatic life.

1. RESPONSE TO DISCHARGE
(See Response Methods Handbook)
Restrict access

2. LABEL
2.1 **Category:** Oxidizer
2.2 **Class:** 5

3. CHEMICAL DESIGNATIONS
3.1 **CG Compatibility Class:** Not listed
3.2 **Formula:** O_2
3.3 **IMO/UN Designation:** 2/1073
3.4 **DOT ID No.:** 1073
3.5 **CAS Registry No.:** 7782-44-7

4. OBSERVABLE CHARACTERISTICS
4.1 **Physical State (as shipped):** Liquefied gas
4.2 **Color:** Light blue
4.3 **Odor:** None

5. HEALTH HAZARDS
5.1 **Personal Protective Equipment:** Safety goggles or face shield; insulated gloves; long sleeves; trousers worn outside boots or over high-top shoes to shed spilled liquid.
5.2 **Symptoms Following Exposure:** Inhalation of 100% oxygen can cause nausea, dizziness, irritation of lungs, pulmonary edema, pneumonia, and collapse. Liquid may cause frostbite of eyes and skin.
5.3 **Treatment of Exposure:** INHALATION: in all but the most severe cases (pneumonia), recovery is rapid after reduction of oxygen pressure; supportive treatment should include immediate sedation, anticonvulsive therapy if needed, and rest. EYES: treat frostbite burns. SKIN: treat frostbite; soak in lukewarm water.
5.4 **Threshold Limit Value:** Data not available
5.5 **Short Term Inhalation Limits:** Not pertinent
5.6 **Toxicity by Ingestion:** Not pertinent
5.7 **Late Toxicity:** Not pertinent
5.8 **Vapor (Gas) Irritant Characteristics:** Data not available
5.9 **Liquid or Solid Irritant Characteristics:** Data not available
5.10 **Odor Threshold:** Not pertinent
5.11 **IDLH Value:** Data not available

6. FIRE HAZARDS
6.1 **Flash Point:** Not flammable but supports combustion
6.2 **Flammable Limits in Air:** Not flammable
6.3 **Fire Extinguishing Agents:** Not pertinent
6.4 **Fire Extinguishing Agents Not to be Used:** Not pertinent
6.5 **Special Hazards of Combustion Products:** Not pertinent
6.6 **Behavior in Fire:** Increases intensity of any fire. Mixtures of liquid oxygen and any fuel are highly explosive.
6.7 **Ignition Temperature:** Not pertinent
6.8 **Electrical Hazard:** Not pertinent
6.9 **Burning Rate:** Not pertinent
6.10 **Adiabatic Flame Temperature:** Data not available
6.11 **Stoichiometric Air to Fuel Ratio:** Data not available
6.12 **Flame Temperature:** Data not available

7. CHEMICAL REACTIVITY
7.1 **Reactivity With Water:** Heat of water will vigorously vaporize liquid oxygen.
7.2 **Reactivity with Common Materials:** Avoid organic and combustible materials, such as oil, grease, coal dust, etc. If ignited, such mixtures can explode. The low temperature may cause brittleness in some materials.
7.3 **Stability During Transport:** Stable
7.4 **Neutralizing Agents for Acids and Caustics:** Not pertinent
7.5 **Polymerization:** Not pertinent
7.6 **Inhibitor of Polymerization:** Not pertinent
7.7 **Molar Ratio (Reactant to Product):** Data not available
7.8 **Reactivity Group:** Data not available

8. WATER POLLUTION
8.1 **Aquatic Toxicity:** None
8.2 **Waterfowl Toxicity:** None
8.3 **Biological Oxygen Demand (BOD):** None
8.4 **Food Chain Concentration Potential:** None

9. SHIPPING INFORMATION
9.1 **Grades of Purity:** 99.5+%
9.2 **Storage Temperature:** −183°C
9.3 **Inert Atmosphere:** No requirement
9.4 **Venting:** Safety relief

10. HAZARD ASSESSMENT CODE
(See Hazard Assessment Handbook)
A-I

11. HAZARD CLASSIFICATIONS
11.1 **Code of Federal Regulations:** Nonflammable gas
11.2 **NAS Hazard Rating for Bulk Water Transportation:** Not listed
11.3 **NFPA Hazard Classification:**

Category	Classification
Health Hazard (Blue)	3
Flammability (Red)	0
Reactivity (Yellow)	0

oxy

12. PHYSICAL AND CHEMICAL PROPERTIES
12.1 **Physical State at 15°C and 1 atm:** Gas
12.2 **Molecular Weight:** 32.0
12.3 **Boiling Point at 1 atm:** −297.3°F = −182.9°C = 90.3°K
12.1 **Freezing Point:** −361°F = −218°C = 55°K
12.5 **Critical Temperature:** −180°F = −118°C = 155°K
12.6 **Critical Pressure:** 738 psia = 50.1 atm = 5.09 MN/m²
12.7 **Specific Gravity:** 1.14 at −183°C (liquid)
12.8 **Liquid Surface Tension:** 13.47 dynes/cm = 0.01347 N/m at -183°C
12.9 **Liquid Water Interfacial Tension:** Not pertinent
12.10 **Vapor (Gas) Specific Gravity:** 1.1
12.11 **Ratio of Specific Heats of Vapor (Gas):** 1.3962
12.12 **Latent Heat of Vaporization:** 91.6 Btu/lb = 50.9 cal/g = 2.13 X 10^5 J/kg
12.13 **Heat of Combustion:** Not pertinent
12.14 **Heat of Decomposition:** Not pertinent
12.15 **Heat of Solution:** Not pertinent
12.16 **Heat of Polymerization:** Not pertinent
12.25 **Heat of Fusion:** Data not available
12.26 **Limiting Value:** Data not available
12.27 **Reid Vapor Pressure:** Very high

NOTES

NATRIUMSULFAAT WATERVRIJ

FYSISCHE EIGENSCHAPPEN		BELANGRIJKE GEGEVENS
Kookpunt, °C	> 1700	**WITTE HYGROSCOPISCHE KRISTALLEN OF POEDER** Bij sterke verhitting ontstaan prikkelende dampen.
Smeltpunt, °C	884	
Relatieve dichtheid (water = 1)	2,7	MAC-waarde niet vastgesteld
Oplosbaarheid in water, g/100 ml bij 20°C	16,2	
Log P octanol/water (berekend)	-3,0	**Wijze van opname/inademingsrisico:** De stof kan worden opgenomen in het lichaam door inslikken. **Directe gevolgen:** De stof werkt irriterend op de ogen. **Gevolgen bij langdurige, herhaalde blootstelling:** Contact met de huid kan een eczeemachtige huidaandoening veroorzaken op basis van een overgevoeligheidsreactie.[1]
Brutoformule:	Na_2O_4S	
Relatieve molecuulmassa	142	

DIRECTE GEVAREN	PREVENTIE	BLUSSTOFFEN
Brand: niet brandbaar.		bij brand in directe omgeving: alle blusstoffen toegestaan.

SYMPTOMEN	PREVENTIE	EERSTE HULP
Inademen:	ventilatie (indien niet in poedervorm), plaatselijke afzuiging of ademhalingsbescherming (filtertype P2).	
Huid:	handschoenen (butylrubber, PVC).	
Ogen: roodheid, pijn.	stofbril.	minimaal 15 minuten spoelen met water (evt. contactlenzen verwijderen), dan naar (oog)arts brengen.

NOODSITUATIE / OPRUIMING / OPSLAG	ETIKETTERING
Opruimen gemorst produkt: Draag handschoenen, laarzen, filtermasker met filtertype P2 en stofbril. *Gemorst produkt* zorgvuldig opzuigen/opscheppen en eventueel hergebruiken. *Restant* verwijderen met water. *Spoelwater* afvoeren naar riool. Vaten etiketteren en afvoeren volgens BAGA/KCA regels.	**Afleveringsetiket:** vraag leverancier **KCA** : 05/12

OPMERKINGEN

[1] Iemand die overgevoeligheidsverschijnselen heeft gekregen door blootstelling aan natriumsulfaat dient in de toekomst elke blootstelling aan deze stof te vermijden.
Natriumsulfaat.$10H_2O$ is glauberzout.

UN-nummer: VRIJ (RC)

CAS-nummer: [62-54-4][1)] $Ca(CH_3COO)_2$

CALCIUMACETAAT

FYSISCHE EIGENSCHAPPEN		BELANGRIJKE GEGEVENS
Ontleedt beneden het smeltpunt, °C	160	**WITTE, GRIJZE OF BRUINE HYGROSCOPISCHE KRISTALLEN of POEDER** De stof ontleedt bij verhitting boven 160°C of bij contact met sterke zuren onder vorming van bijtende dampen (o.a. *azijnzuur*, zie aldaar). Reageert heftig met oxidatiemiddelen.
Zelfontbrandingstemperatuur, °C	680	
Relatieve dichtheid (water = 1)	1.5	
Oplosbaarheid in water, g/100 ml bij 0°C	37	MAC-waarde: niet vastgesteld
		Wijze van opname/inademingsrisico: De stof kan worden opgenomen in het lichaam door inademing van stofdeeltjes en door inslikken. Deze stof verdampt bij 20°C praktisch niet; bij stuiven kan echter snel een voor de gezondheid gevaarlijke concentratie in de lucht worden bereikt. **Directe gevolgen:** De stof werkt irriterend op de ogen, de huid en de ademhalingsorganen.
Brutoformule:	$C_4H_6CaO_4$	
Relatieve molecuulmassa	158.2	

DIRECTE GEVAREN	PREVENTIE	BLUSSTOFFEN
Brand: brandbaar.		sproeistraal water, poeder.
Explosie: kans op explosie door ontstane ontledingsprodukten bij verhitting.		

SYMPTOMEN	PREVENTIE	EERSTE HULP
Inademen: hoesten.	ventilatie (indien niet in poedervorm), plaatselijke afzuiging of ademhalingsbescherming (filtertype P2).	
Huid:	handschoenen (butylrubber).	
Ogen: roodheid en pijn, slecht zien.	stofbril.	minimaal 15 minuten spoelen met water (evt. contactlenzen verwijderen), dan naar (oog)arts brengen.
Inslikken: obstipatie, buikpijn.		mond laten spoelen en arts raadplegen.

NOODSITUATIE / OPRUIMING / OPSLAG	ETIKETTERING
Opruimen gemorst produkt: Draag handschoenen, laarzen, filtermasker met filtertype P2 en stofbril. *Gemorst produkt* zorgvuldig opzuigen/opscheppen en eventueel hergebruiken. *Restant* verwijderen met water. *Spoelwater* afvoeren naar riool. *Vaten* etiketteren en afvoeren volgens BAGA/KCA regels. **Opslag:** Gescheiden van oxidatiemiddelen en zuren, droog.	**Afleveringsetiket:** vraag leverancier **BAGA:** D.6 **KCA** : 03

OPMERKINGEN

[1)] Het CAS-nr. van de gehydrateerde vorm is [5743-26-0].
Calciumacetaat komt ook voor in de gehydrateerde vorm: $Ca(C_3COO)_2.H_2O$.

UN-nummer: VRIJ (RC)

TALK

FYSISCHE EIGENSCHAPPEN	BELANGRIJKE GEGEVENS
Relatieve dichtheid (water = 1) 2,8 Oplosbaarheid in water niet	**WIT TOT GRIJSWIT POEDER**
	MAC-waarde[1)] (als respirabel stof) 2 mg/m^3
	Wijze van opname/inademingsrisico: Opwaaiend fijn stof kan worden ingeademd. Idem bij het leegschudden van een talkbus. Deze stof verdampt bij 20°C praktisch niet; als poeder kan bij verstuiven echter snel een irriterende concentratie in de lucht ontstaan.
Brutoformule: $Mg_3O_{11}Si_4.H_2O$ Relatieve molecuulmassa 379,3	

DIRECTE GEVAREN	PREVENTIE	BLUSSTOFFEN
Brand: niet brandbaar.		bij brand in directe omgeving: alle blusstoffen toegestaan.

SYMPTOMEN	PREVENTIE	EERSTE HULP
Inademen: benauwdheid, lichte prikkelhoest.	plaatselijke afzuiging of ademhalingsbescherming (filtertype P2).	
Ogen: roodheid.	stofbril.	
Inslikken: hoesten, keelirritatie.		

NOODSITUATIE / OPRUIMING / OPSLAG	ETIKETTERING
Opruimen gemorst produkt: Draag handschoenen, laarzen, filtermasker met filtertype P2 en stofbril. *Gemorst produkt* afdekken, vervolgens zorgvuldig opzuigen en eventueel hergebruiken. *Eventuele laatste resten* verwijderen met water. *Spoelwater* afvoeren naar riool. Vaten etiketteren en afvoeren volgens BAGA/KCA regels.	**Afleveringsetiket:** vraag leverancier **KCA** : 05/12

OPMERKINGEN

[1)] De MAC-waarde geldt voor stof zonder asbestvezels. Industriële talksoorten, met name vezelhoudende, kunnen soms asbestvezels bevatten. Aandoeningen aan de longen ten gevolge van inademing zijn dan mogelijk. In dat geval moeten de regelingen aangaande *asbest* (zie aldaar) worden toegepast. Voor zuivere talk zijn geen bijzondere voorzorgmaatregelen nodig.

CAS-nummer: [13463-67-7]
anataas
rutiel
titaanwit

TITAANDIOXIDE

FYSISCHE EIGENSCHAPPEN		BELANGRIJKE GEGEVENS
Kookpunt, °C	2500-3000	**WIT POEDER**[1]
Smeltpunt, °C	1840	
Relatieve dichtheid (water = 1)	4,3	MAC-waarde 10 mg/m^3
Oplosbaarheid in water	niet	**Wijze van opname/inademingsrisico:** De stof kan worden opgenomen in het lichaam door inademing en inslikken. Deze stof verdampt bij 20°C praktisch niet; bij verstuiven kan een hinderlijke concentratie in de lucht ontstaan. **Directe gevolgen:** De stof werkt irriterend op de ademhalingsorganen.
Brutoformule:	O_2Ti	
Relatieve molecuulmassa	79,9	

DIRECTE GEVAREN	PREVENTIE	BLUSSTOFFEN
Brand: niet brandbaar.		bij brand in directe omgeving: alle blusstoffen toegestaan.

SYMPTOMEN	PREVENTIE	EERSTE HULP
Inademen: hoesten.	plaatselijke afzuiging of ademhalingsbescherming (filtertype P2).	frisse lucht, rust.
Ogen: roodheid.	stofbril.	minimaal 15 minuten spoelen met water (evt. contactlenzen verwijderen), dan naar (oog)arts brengen.

NOODSITUATIE / OPRUIMING / OPSLAG	ETIKETTERING
Opruimen gemorst produkt: Draag filtermasker met filtertype P2 en stofbril. *Gemorst produkt* afdekken, vervolgens zorgvuldig opzuigen en eventueel hergebruiken. *Eventuele laatste resten* verwijderen met water of stoom. *Spoelwater* afvoeren naar riool. Vaten etiketteren en afvoeren volgens BAGA/KCA regels.	**Afleveringsetiket:** vraag leverancier **KCA** : 05/12

OPMERKINGEN

[1] De voornaamste typen zijn anataas en rutiel.

UN-nummer: VRIJ (RC)

Limits in Water (ug/l)
No Standards Set

Limits in Soil (Permissible Cleanup Levels) (mg/kg or ppm)
No Standards Set

CELLULOSE

CAS 9004-34-6 RTECS FJ5691460

$(C_6H_{10}O_5)_7$

Raw Material for Cellulose Esters, Paper

Carcinogen: No Data

Limits in Workplace Air (mg/m³)

Location	TWA	STEL	Notes	Reference
Respirable Dust:				
CHE	6	—	—	(1)
FRA	10	—	—	(1)
GBR	5	—	—	(34)
USA (NIOSH/OSHA)	5	—	—	(1)
Total Inhalable Dust:				
AUS				
BEL	10	—	—	(1)
CIS (SUN)	10	—	—	(1)
GBR	—	2	—	(37)
ISR	10	20	—	(34)
USA (ACGIH)	10	—	—	(35)
USA (NIOSH/OSHA)	10	—	—	(25)
	15	—	—	(1)

Limits in Ambient Air (ug/m³)

Location	0.5 hr	8.0 hr	24 hr	Annual	References
ND	—	100	—	—	(9)
TX	100	—	—	10	(9,20)

Limits in Water (ug/l)
No Standards Set

Limits in Soil (Permissible Cleanup Levels) (mg/kg or ppm)
No Standards Set

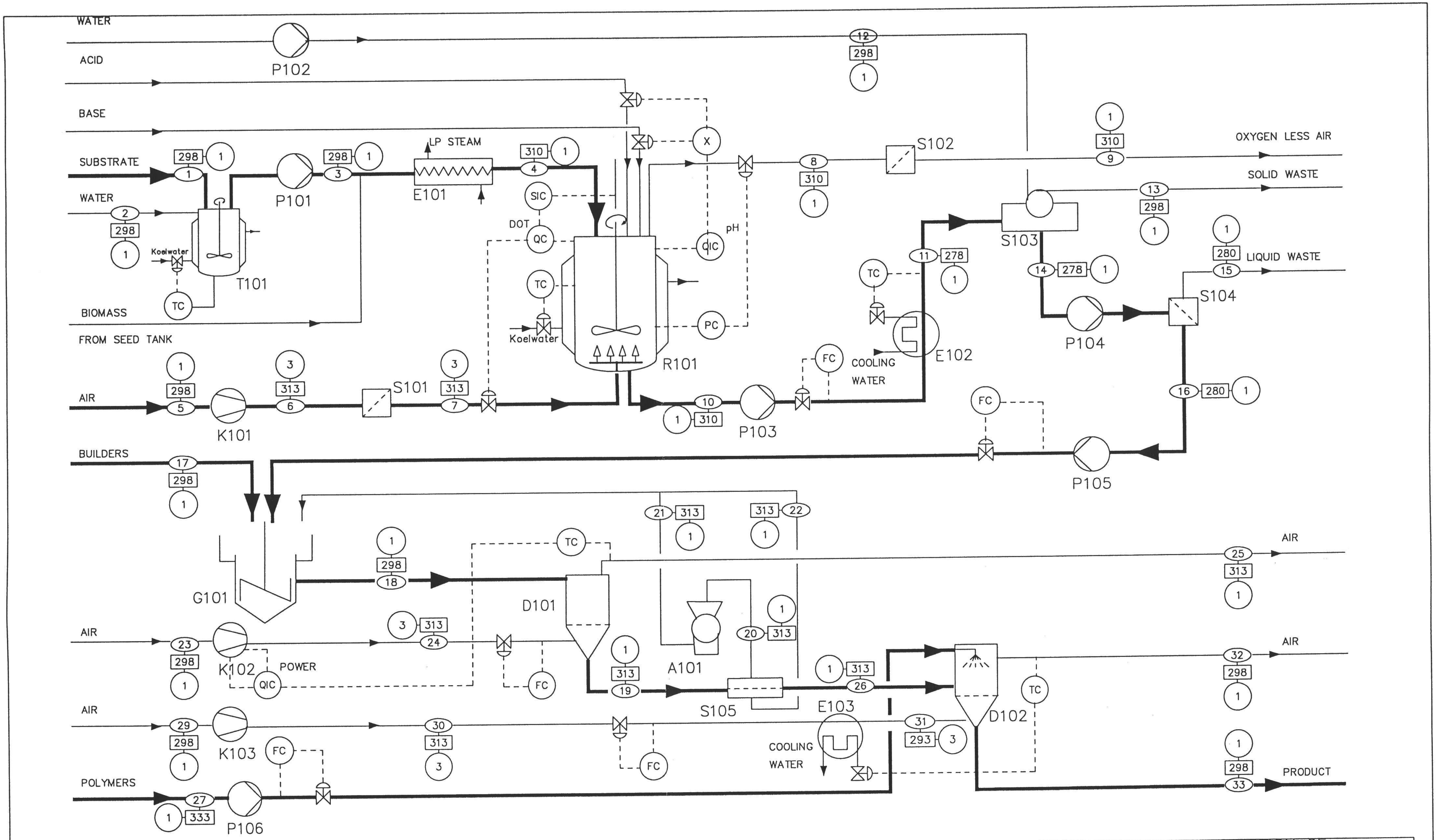
CEMENT (PORTLAND CEMENT)

CAS 65997-15-1 RTECS VA8770000

$(CaO)(SiO_2)(Al_2O_3)$

Construction Material

Carcinogen: No Data



T101 Blending Tank	P103 Pump	G101 High Shear Mixer	P106 Pump
P101 Pump	E102 Cooler	D101 Fluid Bed Dryer	
P102 Pump	S103 Vacuum Rotary Filter	D102 Fluid Bed Coating	
R101 Fermenter	P104 Pump	A101 Crusher	
E101 Heat sterilizer	S102 Air Filter	S105 Screen	
K101 Compressor	S104 Ultra Filter	E103 Cooler	
S101 Air filter	P105 Pump	K103 Compressor	

PROCESS FLOWSHEET FOR PRODUCTION OF COATED DETERGENT ENZYME GRANULES
CPD nr. 3237
June 1999

streamnr. | Temp in C | Pressure in Bar