EQUIPMENT DESIGN OF AN AIRLIFT BATCH FERMENTOR.

An Equipment Design Report

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# CHAPTER ONE

## 1.0 INTRODUCTION

A fermenter is a reactor that sustains and supports life for cells and tissue culture (Fogler, 2016). Fermentation is the breakdown of glucose by microorganisms to produce products such as organic acids, alcohol or gases (Jagani et al., 2010). Bioreactors use live cells or enzymes to perform biochemical transformations of feedstocks to desired products. Bioreactor operation is restricted to conditions at which these biological systems can function. Most plant and animal cells live at moderate temperatures and do not tolerate extremes of pH (Perry, 2008). The main purpose of a fermenter or bioreactor is to provide a suitable ambient in which microorganisms or ferments can live and produce the desired product. Fermentation is not what happens in the fermenter only but also the upstream activities, midstream activities and downstream activities (fermenter outlet). The design and mode of operation of a fermenter mainly depends on the production organism, the optimal operating condition required for target product formation, product value and scale of production (Jagani et al., 2010).

In a U.S. Department of Energy report published in 2004, succinic acid was identified as one of the top twelve building-block chemicals that could be produced from renewable feedstock. Currently, succinic acid uses a petroleum-derived maleic anhydride route for its production, which is both costly and environmentally unfriendly. As a result, there is a growing interest towards discovering a more economical and environmentally cleaner way for its production. 0One methodology that has been receiving increased attention is the use of bacterial microorganisms. This technology takes advantage of the fermentative capabilities of various microorganisms and utilizes a renewable substrate as a carbon source for acid formation (Vaswani, 2010). In the process under review, succinic acid is produced by microorganisms (*Mannheimia succiniciproducens*) using glucose as the fermentation feedstock (substrate).

## OBJECTIVES

## 1.1.1 Main Objectives

To design a fermenter to enable microorganisms (*Mannhemia succiniciproducens*) to feed on glucose (substrate) to produce succinic acid.

### 1.1.2 Specific Objectives

The main objective will be achieved with the specific objectives below.

* To carry out a detailed chemical engineering drawing of an air lift batch mode fermenter.
* To carry out a detailed mechanical engineering drawing of an airlift batch mode fermenter.
* To justify the equipment chosen.

# CHAPTER TWO

## 2.0 PROBLEM STATEMENT

The aim of this design is to make available an air-lift batch fermenter (bioreactor) unit which will be used to produce fermentation broth which will be sent for the separation of biomass from permeate which at the end of the day leads to the production of the desired product (succinic acid).

## 2.1 Fermenters

Regardless the type of fermentation, an established process may be divided into six basic component parts

1. The formulation of media to be used in culturing the process organism during the development of the inoculum and in the production fermenter.
2. The sterilization of the medium, fermenters and ancillary equipment
3. The production of an active, pure culture in sufficient quantity to inoculate the production vessel.
4. The growth of the organism in the production fermenter under optimum conditions for product formation. The extraction of the product and its purification.
5. The disposal of the effluents produced by the process (Stanbury et al., 1995).

## **2.2 Major Fermenter Categories**.

According to Katoh and Yoshida (2004) although there are many types of bioreactor, they can be categorized into the following major groups.

1. Mechanically stirred (agitated) tanks.
2. Pneumatic stirred – cylindrical vessels without mechanical agitation in which gas is bubbled through a liquid and their variations such as airlifts.
3. Loop reactors with pumps or jets for forced liquid circulation.
4. Packed-bed reactors (tubular reactors).
5. Membrane reactors uses semi-permeable membranes usually of sheet or hollow fiber-type.
6. Microreactors.
7. Miscellaneous types for example, rotating-disk, gas–liquid contactors and so on.

## 2.3 Types Based on Process Requirement

In terms of process requirements, they are of the following types.

* Aerobic
* Anaerobic
* Solid state
* Immobilized cell bioreactors (Ghasem, 2007)

## 2.4 Classifications of Bioreactors

### 2.4.1 On the Basis of Microorganisms Used

On the basis of the microorganisms used, bioreactors are grouped into the following two broad classes

1. Those based on living cells
2. Those employing enzymes (Yagani et al., 2010).

### 2.4.2 Classification Based on Phases in Contact

Classifying reactors according to the phases in contact (Silla, 2003)

These are:

1. gas-liquid
2. liquid-liquid
3. gas-solid
4. liquid-solid
5. gas-liquid-solid

### 2.4.3 Classification Based on Mode of Operation.

The modes of operation of a fermenter include (Shiego Katoh and Fumitake Yoshida)

1. Batch: In a batch reactor, the reactants are initially charged and after a certain reaction time, the products are recovered batchwise. The concentration of reactants and products change with time. Batch culture represents a closed system in which the medium, nutrients and inoculum are added to the bioreactor, mostly under aseptic conditions at the beginning of cultivation that is, the volume of the culture broth in the bioreactor is theoretically constant during cultivation. At the beginning of batch cultivation, a known number of viable cells are inoculated into the fermenter that is already filled with sterilized medium containing all nutrients.

Advantages of batch culture.

1. Easy to set up and maintain.
2. In case of contamination only one batch is affected.

Disadvantages of batch culture.

1. The growth rate is slower because nutrients level decline with time.
2. Batch cultures are less efficient as the fermenter is not in operation all the time (downtime is associated).
3. Variability in products/batch.
4. Fed-batch: In the fed-batch reactor, the reactants are fed continuously, and the products are recovered batch wise. The concentration of reactants and products change with time. In general, the fed-batch system does not deviate completely from the batch culture. Fed-batch culture represents a semi-open system in which one or more nutrients are aseptically and gradually added to the bioreactor.

According to Zhou et al., (2013) the process has plenty of applications and it can be utilized for a variety of products. The fermentation starts as a batch fermentation but at a determined point, one or more components is fed to the operation either continuously or intermittently. So the volume of the culture usually increases during the process unless concentrated substrate is used to keep the volume relatively constant. By feeding for example nutrients, carbon or inducers to the fermenter, one can manipulate the growing conditions during the process. The aim of it is for the concentrations of limiting substances to remain constant (steady-state) or for them to follow a predetermined profile. This leads to a maximized yield of the product. The products are harvested only at the end of the process. If the cells are still alive and productive, some of the culture broth may be left in the fermenter which serves as inoculum for the next run

Advantages of fed-batch cultivation

The main advantages of fed-batch over batch cultures are:

1. The possibility to prolong product synthesis
2. The ability to achieve higher cell densities and thus increase the amount of the product, which is usually proportional to the concentration of the biomass.
3. The capacity to enhance yield or productivity by controlled sequential addition of nutrients.

Disadvantages of fed-batch culture

1. It is expensive
2. Not easy to perform.
3. Everything about the microorganisms should be known

iii. Continuous stirred: the reactor contents are perfectly mixed and uniform throughout the reactor. Thus, the composition of the outlet flow is constant, and the same as that in the reactor. Continuous culture represents an open system in which nutrients are aseptically and continuously added to the bioreactor, and the culture broth (containing cells and metabolites) is removed at the same time that is, the volume of the culture broth is constant due to a constant feed-in and feed-out rate. In a continuous operation, one or more feed streams containing the necessary nutrients are fed continuously, while the effluent stream containing the cells, products and residuals is continuously removed. A steady state is established by maintaining an equal volumetric flow rate for the feed and effluent streams. In so doing, the culture volume is kept constant, and all nutrient concentrations remain at constant steady state values. Continuous reactor operations are common in chemical industries. With the exception of single-cell protein production, certain beer production, and municipal waste treatment processes, continuous cultures have not been adopted widely by industry. It is not a dominant mode of industrial operation primarily because of the difficulty in maintaining sterility (contamination by other organisms) (Henry C. Lim and Hwa Sung Shin). The main advantages of continuous culture (chemostat) over the batch mode are

1. The possibility to set up optimum conditions for maximum and long-term product synthesis,
2. The ability to achieve stable product quality (the steady state is characterized by a homogeneous cell culture
3. In spite of these advantages, there are also several problems that hamper the extensive utilization of continuous operation on a large scale. These include
4. Increased risk of contamination due to the pumping of the medium in and out of the bioreactor
5. The danger of genetic mutations in the production strain in a long-term operation,
6. Additional investments may be required for technical facilities.

Disadvantages of continuous culture

* Set up is more difficult, the maintenance of required growing conditions can be difficult to achieve.
* If contamination occurs, huge volumes of products will be lost.

1. Plug flow reactors: Plug flow is the idealized flow with a uniform fluid velocity across the entire flow channel and with no mixing in the axial and radial directions. The concentrations of both reactants and products in the plug flow reactor change along the flow direction, but are uniform in the direction perpendicular to flow and the PFR with no mixing in the flow direction.

## 2.5 Microorganism selection

Many different microorganisms have been screened and studied for succinic acid production from various carbon sources. The inoculum culture will pass through a number of phases. There is a period during which it appears that no growth takes place; this period is called lag phase and it’s considered as a time of adaptation. In a commercial process the period of lagging should be short as possible by using a suitable inoculum. The stage at which the cells grow at a constant, maximum rate is called exponential or log phase. The stage at which growth rate is equal to death rate is the stationary phase and the stage at which dead rate is greater than growth rate is called death phase.

Among them, *Anaerobiospirillum succiniciproducens* and *Actinobacillus succinogenes* have been most intensively studied due to their ability to produce a relatively large amount of succinic acid. More recently, a new succinic acid producing bacterium *Mannheimia succiniciproducens* MBEL55E was isolated from bovine rumen. Also, there has been much effort in developing recombinant Escherichia coli strains which are capable of enhanced succinic acid production under aerobic and anaerobic conditions.

### 2.5.1 Actinobacillus succinogenes

*Actinobacillus succinogenes* 130z was originally isolated from bovine ruminal contents and belongs to the family *Pasteurellaceae* based on its 16S rRNA sequence analysis. The phenotypic analysis showed that this organism is a facultative anaerobic, non-motile, pleomorphic, and Gram-negative rod or occasionally filamentous bacterium. A. succinogenes shows a distinctive ability to produce a relatively large amount of succinic acid from a broad range of carbon sources such as arabinose, cellobiose, fructose, galactose, glucose, lactose, maltose, mannitol, mannose, sorbitol, sucrose, xylose or salicin under anaerobic condition. Strain 130Z produced 66.4 g/ l of succinic acid by consuming 98.3 g /L of glucose after 84 h fermentation. The batch fermentation was performed in a 1 l fermenter with 15 g l/L of yeast extract and corn steep liquor. More recently, the continuous and repeat-batch biofilm fermentation of A. succinogenes allowed a significant increase in succinic acid productivity (8.8 g l/L/ h), while the yield of succinic acid was less than 50% (w/w), which is rather low for commercialization (Song and Lee, 2005).

### 2.5.2 Mannheimia succiniciproducens

Another promising succinic acid producing bacterium, *M. succiniciproducens* MBEL55E, was recently isolated from the bovine rumen. Phenotypic and phylogenetic studies suggest that *M. succiniciproducens* is a facultative, mesophilic, nonmotile and capnophilic Gram-negative bacterium. It produces succinic acid as a major product, acetic and formic acids as the second major ones from various carbon sources under 100% CO2 condition at pH of 6.0 to 7.5. The succinic acid productivity of as high as 3.9 g L−1 h−1 could be achieved, which is the highest value that has been reported so far (Song and Lee, 2005).

### 2.5.3 Anaerobiospirillum succiniciproducens

A. succiniciproducens was isolated from the throat and faeces of beagle dog and produces succinic and acetic acids as major fermentation products and ethanol and lactic acid as minor ones under strictly anaerobic condition. It belongs to the family *Succinivibrionaceae* and is a strictly anaerobic, motile, and Gram-negative bacterium. Like *A. succinogenes* and *M. succiniciproducens*, it also uses PEP (phosphoenol pyruvate) carboxylation pathway to form succinic acid.

Previous studies showed that *A. succiniciproducens* can efficiently utilize glucose, glycerol, sucrose, maltose, lactose and fructose as carbon sources. The use of glycerol as a carbon source resulted in an increased succinic acid yield (133%, mol/mol) and much higher ratio of succinic acid to acetic acid (Gram ratio of25.8:1) than those obtained with glucose(Song and Lee, 2005).

### 2.5.4 Recombinant E. coli

A wild type E. coli primarily ferments glucose to ethanol, formic, acetic and lactic acids with only detectable amounts of succinic acid under anaerobic condition. The succinic acid yield on glucose typically obtainable is no more than 0.2 mol mol−1.

It has been known that E. coli utilizes six pathways to form succinic acid, and differently from three bacteria mentioned above, the PEP (phosphoenol pyruvate) carboxykinase plays a minor role. Nevertheless, metabolic flux analysis showed that the maximum achievable succinic acid molar yield in E. coli is 1.647. A number of metabolic engineering strategies have been developed to enhance succinic acid production by E. coli (Song and Lee, 2005).

# CHAPTER THREE

## 3.0 EQUIPMENT DESCRIPTION AND JUSTIFICATION

## 3.1 Process Description

In an airlift fermenter, mixing is accomplished without any mechanical agitation. Airlift bioreactors are used for tissue culture because the tissues are shear sensitive and normal mixing is not possible. In the usual form, air is fed into the bottom of a central draught tube through a sparger ring reducing the apparent density of the liquid in the tube relative to the annular space within the bioreactor. The flow passes up through the draught tube to the head space of the bioreactor, where the product and CO2 disengage. The degassed liquid then flows down the annular space outside the draft to the bottom of the bioreactor. Cooling can be provided by either making the draught tube an internal heat exchanger or with a heat exchanger in an external recirculation loop. Batch mode of operation was chosen over the other modes because it is less expensive, easy to set up and maintain, in case of contamination only one batch is affected and new product can always be formed.

The advantages of airlift bioreactor are:

1. In low shear, there is low mixing which means the bioreactor can be used for growing plant and animal cells.
2. Since there is no agitation, sterility is easily maintained. (Najafpour, 2007).

Yoshida et al. (1973) introduced the fed-batch system to describe batch cultures which are fed continuously with medium or substrate without the removal of culture fluid.

For the purpose of this project, the airlift batch type is chosen over the continuous and fed-batch processes of fermenting.

## 3.2 Mode of operation of a fermenter

The fermenter consists of various parts. It has an impeller mounted to a shaft through a bearing in the lid of the fermenter, driven by a motor. The impeller is fitted with impeller blades which when rotated at high speed, vigorous stirring which creates circular movements of the medium and agitation of the medium is achieved.

Baffles are attached to the sides of the fermenter walls which helps in proper mixing of the medium and microbial cells to prevent vertex formation. A sparger is located at the bottom of fermentation tank so the impeller disperses air from the sparger. The fermenter has sensors to monitor and control the fermentation process (Stanbury et al., 2010)

The performance of any fermenter depends on the following

1. Agitation rate
2. pH
3. Temperature
4. foam production
5. Foam

The problem often encounters in fermentation is foaming. Foam is produced during most microbial fermentation. Foaming may occur either due to a medium component such as protein present in the medium or some compound produced by the microorganism. Foam control is very important because when foaming becomes excessive, there is a danger of pressure build up in the fermenter and can lead to loss of medium.

Foam can be controlled with mechanical foam breaker or addition of surface active chemical agents, called anti foaming agents. (Jagani et al, 2010)

1. An ideal antifoam should have the following properties:
2. It should disperse rapidly and act on the existing foam.
3. It should be non-toxic.
4. It should not be used up of degraded by the organism.
5. It should not interfere with downstream processing (Jagani et al, 2010)
6. pH Control

Certain microorganisms grow in particular pH only. In fermentation it is very essential to control pH in order to grow the desired microorganisms for product formation. pH control sensors are used in fermenter for periodically checking of pH. In this project ammonia (base) and sulfuric acid are used in adjusting the pH of the system.

1. Temperature control

The fermenter must have an adequate provision for temperature control. Microbial activity and agitation generate heat. If this heat generates a temperature that is optimum for the fermentation process, then heat removal or addition may not be required. But in most cases this may not be the case, either heating or removal of the excess heat would be required. (Jagani et al, 2010).

Available heating or cooling approaches are:

Welded to the outside Jacket

1. External coils
2. Pillow plate

Welded in the fermenter

1. Pillow plates
2. Tube coils
3. Thermo channels

Selection of Jacket: Jacketing provides the optimum method of heating and cooling process vessels in terms of control, efficiency and product quality.

It has many advantages which are given below:

1. All liquids can be used and velocity of heat transfer media can be accurately controlled.
2. Jacket is fabricated from less expensive metal than the reactor itself.
3. Contamination, cleaning and maintenance problems are eliminated.
4. Maximum efficiency, economy and flexibility are achieved.

There are three types of jackets available which are

1. Spiral baffle jacket
2. Half pipe coil jacket
3. Dimple jacket

Jacket selection

Factors to consider when selecting the type of jacket to use are listed below:

1. Cost
2. Heat transfer rate required
3. Pressure

Spiral baffle jacket is less expensive and gives low pressure drop than dimple and half pipe coil jacket.

## 3.3 Microbial Processes

Major characteristics of microbial processes are

1. The reaction medium is aqueous
2. The products are made in low concentration, rarely more than 5-10% for chemicals and much less for enzyme recovery.
3. Reaction temperatures with microorganisms or isolated enzymes are low, usually in the range of 10-60°C, but the optimum spread in individual cases may be 5°C or less.
4. With only a few exceptions, such as potable ethanol or glucose isomerate, the scale of commercial processes is modest, and for enzymes it is measured only in kilograms per day.
5. Batch processing is used preponderantly, but so many conditions must be regulated carefully that computer control is common (Walas, 1990)

## 3.4 Justification

Airlift fermenter operated in batch mode is chosen over all other types because since there is absence of an agitator sterility is assured and also the microorganism used is from animal source and this makes it shear sensitive. It has the least expensive operation cost and can be used with a variety of microbial species.

# CHAPTER FOUR

## 4.0 CHEMICAL ENGINEERING DESIGN

## 4.1 Scope of design.

The design of the fermenter will entail the following areas and parameters;

Material balance: calculate the amount of glucose, the amount of nutrients and CO2 entering the fermenter at a particular time in kg/hr.

Energy balance: calculate the amount of energy being added or removed and the quantity of steam added and removed in kg/hr.

Sectioning the fermenter: height of the column, diameter, volume of glucose at time, t, total volume of the medium

## 4.2 Summary of Material and Energy balance

### 4.2.1 Fermenter Sizing

For a batch system,

Accumulation = input – output + generation

Where;



FAO = Input

FA = output

GA = Generation

If all the system’s variables are uniform throughout the system,

GA = rAV

















CA = CAO (1-XA)



Where;

CAO, initial concentration.

CA, final concentration

XA, the conversion factor

k, rate constant.

t, residence time





t = 64 hours.

Where;

Calculating batch time.

tB = ' +'+ +'+' (Abulnanga, 2010)

= time taken for the entire batch operation.

'= time taken for filling.

= time taken for reaction.

’*=* time taken for emptying.

’= time taken for cooling.

’= time taken for heating

Assumptions.

1. Let cooling time be equal to heating time.
2. Let filling time be equal to emptying time.

Table 4.1

|  |  |
| --- | --- |
| Time | Hours |
|  | 64.0 |
| ' | 0.5 |
| ' | 1.0 |
| tC' | 0.5 |
| *'* | 1.0 |
|  | 67.0 |

Assumptions

* The fermentation reaction is a first order reaction.
* There is no spatial variation in concentration of the feed as well as its temperature.
* There is perfect mixing.
* The Reynolds number of the broth is greater than 10,000 (turbulent pattern of flow).

Average density ( slurry)







= 1108.87 kg/m3

Volume of slurry, Vslurry



Vslurry = 5.6839 m3/hr

### 4.2.2 Calculating the volume of the fermenter

**



VF = 881.1m3

Where,

VF = volume of the fermenter.

ṁ = mass flowrate.

ρ = density.

Assuming 75% working space of the fermenter.

Since 75% is the working volume,

If 75% = 881.1 m3

Then 100% = x

Where x is the volume of the fermenter with 25% volume left.

x = m3

Since the volume of the reactor is large and will give us huge dimensions, it is advisable that the volume is divided. 10 of 117.4 m3 fermenters can make up for approximately the total volume of the reactor.

### 4.2.3 Dimensioning of Fermenter.

(Sinnott, 2005)

H = 2D

V = 

D = 4.2 m

H = 2×D = 2×4.2 = 8.4 m

According to (Sunggyu Lee, 2006)



  








Allowance between the sparger and the draft

Dd – Ds = 3.0 – 2.3 = 0.7 m



Therefore the distance between the sparger and draft is 0.33 m.

Where,

Hv = height of the vessel.

Hd = height of the draft.

Dd = diameter of the draft.

Ds= diameter of the sparger.

Orifice diameter is between 2 to 10mm (Encyclopaedia)

Hence the number of orifice on the sparger is



### 4.2.4 Viscosity of the Mixture

(Abulnaga, 2002)

µs = the viscosity of slurry (mixture formed)



µL = viscosity of water = 1cp = 10-3 Pa.s

= 0.001(1+ 2.5(0.127+10.05 (0.127+ 0.00273 exp (16.67(0.127))

= 1.50227×10-3 Pa.s

### 4.2.5 Power Required

For slurries, power required, P

(Walas,1990)  
but 171.4 m3= 24810.047 gal



P = 248.10047 hp

## Table 4.2: Summary of chemical design calculations on an airlift fermenter (batch mode).

|  |  |
| --- | --- |
| **Parameters** | **Specification** |
| **Vessel features** | |
| **Volume** | **117.4 m3** |
| **Aspect ratio** | **2.00** |
| **Diameter** | **4.2 m** |
| **Height** | **8.4 m** |
| **Temperature** | **37 oC** |
| **Pressure** | **192 kPa** |
| **Draft features** | |
| **Height** | **6.7 m** |
| **Allowance between draft and sparger** | **0.35 m** |
| **Number of orifice** | **288** |
| **Sparger features** | |
| **Diameter** | **2.3 m** |
| **Number of orifice** | **263.75** |
| **Diameter of orifice** | **0.008 m** |
| **Type** | **Ring sparger** |

# CHAPTER FIVE

## 5.0 MECHANICAL ENGINEERING DESIGN

A vessel must be designed to withstand the maximum pressure to which it is likely to be subjected in operation. For vessels under internal pressure, the design pressure is normally taken to be 5 to 10 per cent above the normal working pressure. The hydrostatic pressure in the base of the column is added to the operating pressure to determine the design pressure. (Sinnott, 2005)

## 5.1 Choice of Material

The vessel will be made from 316 stainless steel (16Cr, 12Ni, 2 Mo). Grade 316 is the standard molybdenum-bearing grade, second in importance to 304 amongst the austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to pitting and crevice corrosion in chloride environments. It has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts for applications in the industrial, food processing, pharmaceutical processing, architectural, and transportation fields. Grade 316 also has outstanding welding characteristics. Post-weld annealing is not required when welding thin sections.

In grade 316 alloy, molybdenum is added to improve the corrosion resistance in reducing conditions, such as in dilute sulfuric acid and, in particular, to solutions containing chlorides (Sinnott, 1999)

## Table 5.1 Mechanical properties of AISI 306 stainless steel (16Cr, 12Ni, 2 Mo).

|  |  |
| --- | --- |
| Grade | 316 |
| Tensile strength(Mpa) min | 515 |
| Yield strength 0.2 offset, Mpa | 205 |
| Elongation ( in 50mm) min | 40.0 |
| Hardness  Max Brinell RB | 217 95 |

## Table 5.2: Calculating the average density of the fermenter medium.

|  |  |  |  |
| --- | --- | --- | --- |
| Mixture component | Mass fraction | Density , | ρavg, kg/m-3 |
| Glucose | 0.12 | 1540 | 184.80 |
| Cellulose | 0.06 | 1559 | 93.54 |
| Water | 0.8 | 1000 | 800 |
| Hemicellulose | 0.2 | 1520 | 30.4 |
| Dextrin | 6-3 | 400 | 2.4 |
| Alpha amylase | 0.0110-4 | 1250 | 0.125 |
| Glucoamylase | 0.0110-4 | 1892.9 | 0.18926 |
|  |  |  | Total= 1111.45kg/m-3 |

## 5.2 Vessel Thickness

There will be a minimum wall thickness required to ensure that any vessel is sufficiently rigid to withstand its own weight, and any incidental loads.

𝜌 = density of mixture = 1111.45 kg/m3

H= height of tank = 8.4 m

Internal pressure, = hydrostatic head + atmospheric pressure

g = acceleration due to gravity = 9.81 m/s2

Atmospheric pressure = 101325 N/m2 (Pa).

The pressure due to head = Hg = 1111.45×8.4 × 9.81 = 91587.9 Pa.

= 91587.9 + 101325

= 192912 Pa

Design pressure, Pd = internal pressure + (10% 0f the internal pressure)

Design pressure, = 1.1

= 1.1 × 192912

Design pressure, = 212204.9 Pa = 212.2 kPa.

The design stress of stainless steel 316 at 0 to 50 is 17 5 N/mm2 = 175000 kPa

The reactor is modelled a cylinder. The minimum thickness of a cylinder shell is



This is the form of the equation given in the British Standard PD 5500.



From (Sinnott, 2005) corrosion allowance of 2mm to 4mm should be added hence the minimum thickness is 6.54 mm.

For torispherical heads, the thickness of the head can be given by the equation

  
= stress concentration factor for torispherical heads = (3+ )

= crown radius,

= knuckle radius

The ratio of the knuckle to crown radii should not be less than 0.06, to avoid buckling; and the crown radius should not be greater than the diameter of the cylindrical section.

For formed heads (no joints in the head) the joint factor J is taken as 1*.0.*

= 4.2 m

= 0.06



= 3+ = 1.77 m





## 5.3 Dead Weight of Vessel (Wv)



Where: Wv = total weight of the shell, excluding internal fittings,

Cv = 1.08 (for vessels with only a few internal fittings to account for the weight of nozzles, internal supports, etc.)

H = height of the vessel = 8.4 m

t = wall thickness = 0.00654 mm

Dm = mean diameter of vessel = (D + t ×m = (4.2+6.54× = 4.21 m

240×1.08×4.2(8.4+0.8×4.2) 0.00654 = 83.7277 N

## 5.4 Wind Loading/ Bending Moment,



Where:

w = Loading per unit length due to wind pressure

x = Height of vessel = 8.4 m

For preliminary design we assume dynamic wind pressure (Pw) to be 1280 Pa

w = Pw × Dm (Sinnott, 2005)

w = 1280 × 4.213 = 5376 Nm



## 5.5 Primary Stresses

The primary stresses are longitudinal and circumferential stresses due to pressure.

### 5.5.1 Longitudinal Stress,



Where, = design pressure = 212204.9 Pa

D = internal diameter of vessel = 4.2 m

t = shell thickness = 0.00654 m



### 5.5.2 Circumferential stress,



### 5.5.3 Dead Weight Stress,



### 5.5.4 Bending Stress ()

Where,

= total bending moment

= Second moment area of the vessel

t = thickness of the vessel



The resultant longitudinal stress () is given as:

=

For upwind conditions,

*=*

For downwind conditions, the principal stress will be

=

=

The principal stresses will be and

The maximum difference between the principal stresses will be:

The maximum allowable design stress is

() Pa = 36172561.61 Pa

This is well below the maximum allowable design stress of 175000KPa.

## 5.6 Vessel Support

Vessel support depends on size, shape, weight, vessel location and arrangement, design pressure and temperature (Sunggyu Lee, 2006)

### 5.6.1 Skirt Support Design

Skirt supports are used for tall, vertical columns. A skirt support consists of a cylindrical or conical shell welded to the base of the vessel. The supports must be designed to carry the weight of the vessel and contents, and any superimposed loads, such as wind loads. Supports will impose localized loads on the vessel wall, and the design must be checked to ensure that the resulting stress concentrations are below the maximum allowable design stress. Supports should be designed to allow easy access to the vessel and fittings for inspection and maintenance (Sinnott, 2005).

#### 5.6.1.1 Skirt Thickness

The skirt thickness must be sufficient to withstand the dead-weight loads and bending moments imposed on it by the vessel. (Sinnott, 2005)

The bending stress in the skirt is given by:

Where:

= Maximum bending moment evaluated at the base of the skirt

= Inside diameter of skirt at the base = outer diameter of vessel = 4.213 m

= Skirt thickness = 6.54 mm

According to Sinnot el at., (2005) skirt thickness must be sufficient to withstand the dead-weight loads and bending moments imposed on it by the vessel; it will not be under the vessel pressure. The minimum thickness should be not less than 6 mm.

Hence assuming thickness of 20 mm.

According to Pope (1997) skirt height should be within the range of 0.5 – 1.5 m.

Taking the height of skirt to be 0.8 m

= diameter of the skirt = (as outer diameter of vessel) + allowance (0.05)

= 4.213 + 4.213(0.05) = 4.424 m

5.6.1.

2 Dead Weight Stress,

## 5.7 Gaskets

Gaskets are used to make a leak-tight joint between two surfaces. It is impractical to machine flanges to the degree of surface finish that would be required to make a satisfactory seal under pressure without a gasket. Gaskets are made from "semi-plastic" materials; which will deform and flow under load to fill the surface irregularities between the flange faces, yet retain sufficient elasticity to take up the changes in the flange alignment that occur under load.

The following factors must be considered when selecting a gasket material:

1. The process conditions: pressure, temperature, corrosive nature of the process fluid.

2. Whether repeated assembly and disassembly of the joint is required.

3. The type of flange and flange face. (Sinnott, 2005)

The corrugated metal, asbestos inserted (soft steel) gasket is selected.

## 5.8 Base Ring and Anchor Bolt Design

A variety of base ring designs is used with skirt supports. The simplest types suitable for small vessels are the rolled angle and plain flange rings. (Sinnott, 2005)

## 5.9 Heat Transfer Area of Jacket

Water inlet temperature, T1 = 25oC

Water outlet temperature, T2 = 40oC



Reaction temperature, Trxn = 37oC

Overall heat transfer coefficient, U = 900.74 W/m2K

Heat of reaction, ∆H = -72309.08 W



Heat transfer area, A

A=

∆T = Trxn - Tave = 40 – 25 = 15oC

Table 6.1 Summary of Mechanical Engineering Calculation of an Airlift Batch Fermenter

|  |  |  |
| --- | --- | --- |
| Parameter | Value | Unit |
| Design pressure | 212204.9 | Pa |
| Cylindrical shell thickness | 6.54 | Mm |
| Torispherical head thickness | 4.5 | Mm |
| Bending moment/wind loading | 189665.28 | N/m |
| Dead weight | 83.7277 | N |
| Longitudinal stress | 68139188.07 | Pa |
| Circumferential stress | 34069594.04 | Pa |
| Dead weight stress |  | Pa |
| Skirt support properties | | |
| Bending stress |  |  |
| Dead weight stress |  |  |
| Diameter | 4.424 | m |
| Thickness | 20 | mm |
| Height | 0.8 | m |
| Cooling jacket properties | | |
| Heat transfer area | 110.84 |  |
| Heat of reaction | 72309.08 | W |
| Overall heat transfer coefficient | 900 | W/m2K |

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