

DESIGN OF BIOREACTOR FOR PRODUCTION OF METHANE BY RHODOSPIRILLUM

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ABSTRACT: The fermentation of slightly soluble gaseous substrates, such as H_2 and CO requires the transport of the substrate from gas phase, liquid phase, and solid phase for conversion purpose. These reactions are generally mass transport limited, and the bioreactor design must realize high mass transfer coefficients as well as high cell concentrations to reduce reactor volume. The immobilized cell systems are perfect for these fermentations with a high pressure facilitates gas solubility and faster mass transfer. This project gives the performance of a continuous stirred tank reactor for the conversion of CO and H_2 coal synthesis gas into methane using *R. rubrubacterium*,

1. INTRODUCTION:

Design is a creative process in which an innovative solution for a problem is conceived. A fashion designer creates clothes that will enhance the appeal of an individual. An automobile designer creates a car model that will provide transportation and a certain appeal to the consumer. The car's appeal may be because of its power, beauty, convenience, economy, size, operability, low maintenance, uniqueness, or gimmicks [1]. A process engineer designs a plant to produce a given substrate. In each of these instances a new thing is created or an old thing is created in a new way.

The reaction stage is the heart of a biological manufacturing process. In the reactor, the substrate is brought together under conditions which promotes the production of the desired product; invariably by-products and unwanted compounds will also be formed [2].

1.1 Anatomy of a Bio Process Industry

The basic components of a typical bio process are shown in (Fig.1) in which each block represents a stage in the overall process for producing a product from the substrate. Fig.1 represents a generalized process in which not all the stages will be needed for any particular process, and also the complexity of each stage will depend on the nature of the process. Bio-engineering design is mainly concerned with the selection and arrangement of the stages, and the selection, specification and design of the equipment are required to perform the stage functions.

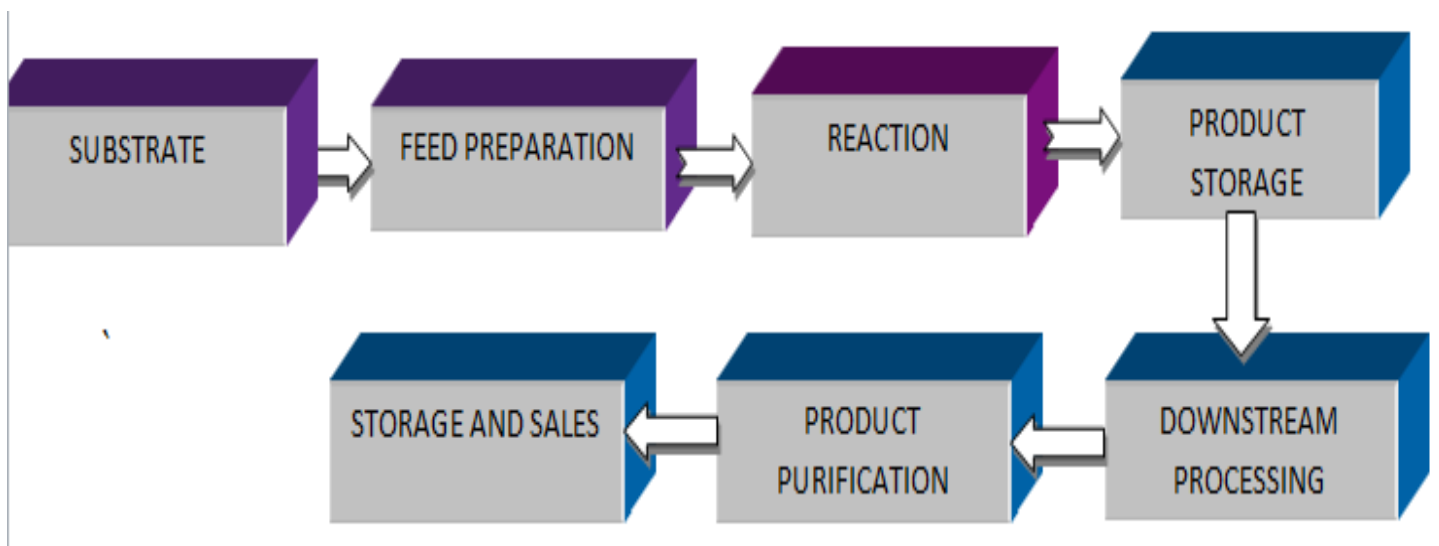


Figure.1. Block diagram of biological manufacturing process

1.2. Jacketed type Bioreactor:

In the process of fermentations with strict aseptic requirement, it is important to select materials that can withstand repeated steam sterilization cycles. The American Iron and Steel Institute (AISI) states that steels containing less than 4% chromium are classified as steel alloys and those containing more than 4% are classified as stainless steels [9]. The corrosion resistance of stainless steel is supposed to depend on the existence of a thin hydrous oxide film on the surface of the metal (Fig.2). The minimum amount of chromium needed to resist corrosion will depend on the corroding agent in a particular surrounding, such as, alkalis, acids, salt or fresh water.

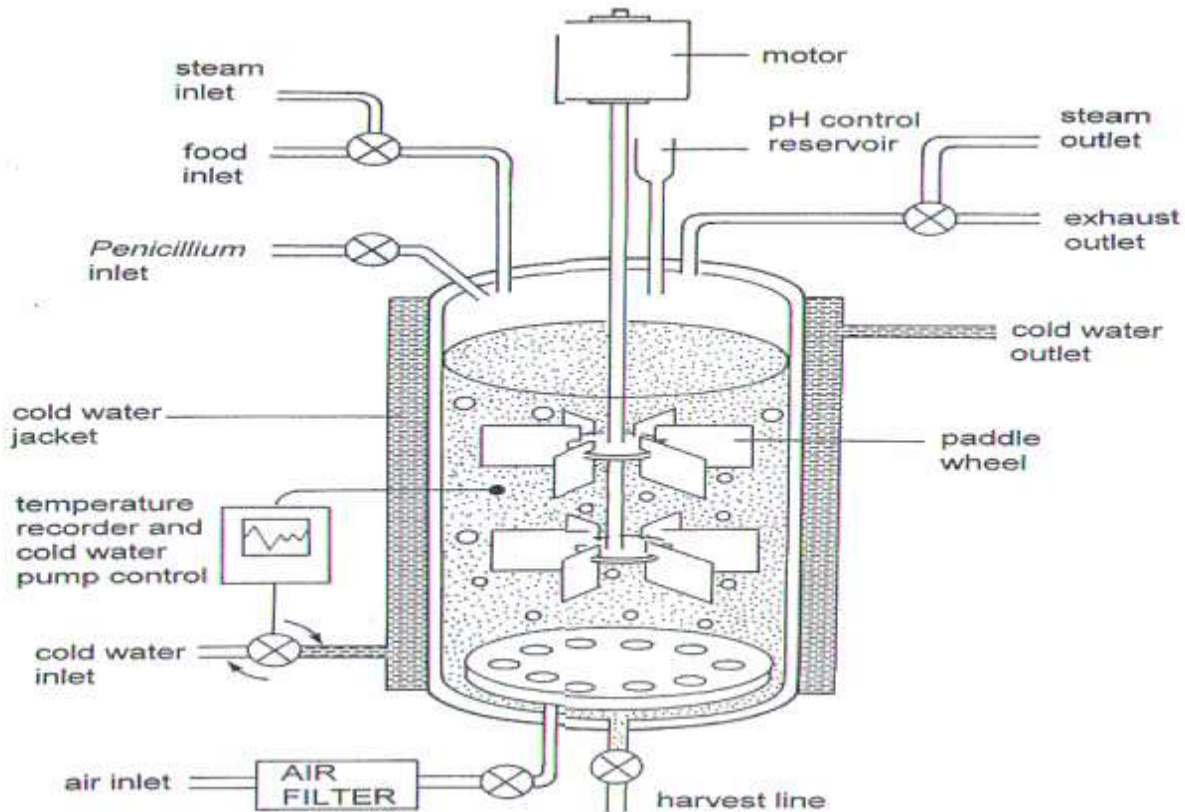


Figure. 2 Jacketed type Bioreactor [9]

On a small scale of about (1-30 dm³), it is possible to use stainless steel or glass. Glass is useful since it gives smooth surfaces, non-toxic, corrosion free, and it is usually easy to observe the interior of the vessel [10]. Basically, two types of fermenters are used. The increase in chromium content enhances the corrosion resistance whereas the grades of steel containing at least 10-13% chromium develop an effective film.

During trial and large scale, all fermenters are sterilized at appropriate position and any materials if being used will have to be assessed on their ability to withstand pressure sterilization, corrosion, potential toxicity and cost (Fig.3). These are normally constructed with stainless steel or at least have a stainless-steel cladding to limit or avoid corrosion.



Figure.3. Typical Industrial Bioreactor[10]

2. MATERIALS AND METHODS:

2.1 Methane Production from H₂ and CO₂

Methane may be produced by methanogenic bacteria from either acetate or Hydrogen and CO, and both has its origin from syngas components [3]. Acetate may be produced by several anaerobic bacteria, including *Peptostreptococcus* conversion of all CO and H₂ by *R. rubrum* which is essentially unaffected by CO partial pressures up to 2.0 atm. Therefore, as with products (H₂ and CO), the limiting factor in CO utilization by *R. rubrum* is the ability to maintain a high cell concentration and, consequently, a low dissolved CO tension in the liquid phase produces methane much faster than *M. barkeri*. However, in order to form a successful co-culture, *M. formicicum* must be able to tolerate low levels of dissolved CO [5].

2.2. Material balance:

Material balances are the basis of process design. A material balance which is taken over the

complete process will determine the produced products and quantities of substrate [4]. Balances over individual process units set the process stream flows and compositions. A good understanding of material balance calculations is essential in process design. Material balances are also useful tools for the study of plant operation and trouble shooting. They can be used to check performance against design; to extend the often-limited data available from the plant instrumentation; to check instrument calibrations; and to locate sources of material loss.

The general conservation equation for any process system can be written as:

Material out = Material in

In continuous culture, the exponential growth phase of organism may be prolonged by the addition of fresh medium to the vessel. The vessel should be designed in such a way that the added volume displaced an equal volume of culture from the vessel. If medium is fed to continuously to such vessel at a suitable rate, a steady state is achieved eventually. Steady state is formation of new biomass in the vessel is equivalent to the loss of cells from the vessel. The medium flow into the vessel is related to the total volume of the medium in the vessel expressed as dilution rate, D , which can be expressed in the form of mathematical equation,

$$D = F/V$$

Thus, under steady state conditions the specific growth rate is controlled by the dilution rate which is a controllable variable. An important objective of continuous culture operation is to control cell growth at a level at which productivity is optimum

2.2.1. Materials of construction

Many factors have to be considered when selecting engineering materials, but for bio process plant, the overriding consideration is usually the ability to resist corrosion. The process designer will be responsible for recommending materials that will be suitable for the process conditions. The material selected must have sufficient strength and be easily worked. The most economical material that satisfies both process and mechanical requirements should be selected; this will be the material that gives the lowest cost over the working life of the plant, allowing for maintenance and replacement [7]. Other factors, such as product contamination and process safety, must also be considered. In this project, stainless steel is been used and the material grade is used as ASTM A 312 TP 304.

3. Design Calculations

3.1. Reactor Sizing

Taking, Steady state operation

Temperature 30° C

Retention time =1 hrs

Production rate=500 mole/hr

Retention time=volume of the reactor/volumetric flow rate

$$1 = V/500$$

Volume of the reactor = 500mol

$$V = \pi/4 * D^2 * L$$

$$D^3 = 0.683$$

$$D = 0.863 \text{ M}$$

Size of the Reactor =863 mm

3.2. Thickness of the shell

$$\text{Thickness} = PD/2(SE+PY)$$

Design pressure=2 atm

Diameter of the vessel=0.87m

Allowable stress =16.7(from ASME B 31.3 TABLE A-1)

Joint efficiency=1 (from table 16 ASME B 31.3)

Safe factor =0.4 (from table up to 700 F)

$$T = 202650 * 0.87 / 2(16.7 * 1000000 + 202650 * 0.4)$$

t=6 mm (corrosion allowance nil)

3.3. Outside diameter

$$D=(ID+2*t)$$

$$=863+2*6$$

Outside diameter of the reactor=875 mm

3.4. Thickness of head (hemispherical head)

The required thickness of a hemispherical head can be determined by Top Head [8]

$$t=(P*D/2S*E-0.2*P)$$

$$t=(202650*.87)/(16.7*1000000-.2*202650)$$

$$t=3 \text{ mm}$$

Bottom Head

Top head two times greater than bottom head can be used

So thickness of the top head = 6 mm

3.5. Agitator design

An important consideration in the design of agitated vessel is the power required to drive the impeller [6]. When the flow in the tank is turbulent the power requirement can be estimated from the flow rate and impeller kinetic energy. Dimensionless numbers are very important to estimate power

In agitation technology, there are a number of dimensionless units which are in common use. These include [7]:

Power Number, N_p

Reynolds Number, N_{Re}

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The value of $N_{Re} = D^2N\rho/\mu$, this number is proportional to the ratio of inertial to viscous forces. Though not used directly to calculate performance, virtually all other dimensionless numbers of design significance are functions of the Reynolds number. The Reynolds number defines the flow regime and level of turbulence. High Reynolds numbers (> 4000, for example) are characterized by mostly turbulent flow. Low Reynolds numbers (<2100) are principally in laminar flow. In between, there is a very broad transition range, which is often characterized by turbulent flow near the impeller and laminar flow near the tank wall.

$$N_{Re} = D^2N\rho/\mu$$

$$D = 0.33$$

$$N = 120\text{rpm}$$

$$\rho = 1000 \text{ Kg/m}^3$$

$$\mu = 1 \text{ Kg-m/s}$$

By substituting the values, the Reynolds number was found to be 12800, hence the flow can be characterized a turbulent flow near the impeller and laminar flow near the tank walls.

Power number, N_p

This is defined by $N_p = P/\rho N^3 D^5$

It is proportional to the ratio of power draw to liquid density and impeller parameters, including shaft speed. Its principal use is to calculate power draw. As such, it is used in all agitator designs. It is a function of impeller type, Reynolds number and various

$$N_p = P/\rho N^3 D^5$$

$$N_p = 5.5 \text{ (Refer table no.1)}$$

$$\rho = 1000 \text{ Kg/m}^3$$

$$N = 120 \text{ rpm}$$

$$D = 0.33 \text{ m}$$

By substituting the values we obtain power = 350 watts = 0.46 (the power is considered to be 1 Hp @ safety factor of 0.54)

Table-1

GEOMETRIC RATIOS FOR A STANDARD BIOREACTOR VESSEL							
Impeller type	D_i/D_t	H_t/D_t	L_i/D_i	W_i/D_i	H_b/D_i	W_b/D_t	No. Baffles
Flat blade turbine	0.33	1	0.25	0.2	1	0.1	4
Paddle impeller	0.33	1	0.25	0.25	1	0.1	4
Marine propeller	0.33	1	pitch=Di	-	1	0.1	4

4. Results and Discussion

Size of the Reactor 863 mm

Thickness of the shell: 6 mm

Thickness of the head: 3 mm

The power was found to be: 1 Hp

The traditional CSTR performed complete mixing and uniform concentrations throughout the reaction. For methane production the CO rate of mass transfer is increased by using the designed bioreactor. Diffusion of CO through Hydrogen increases by using flat bladed agitator vessel and also the productivity of methane increases per day.

5. CONCLUSION:

An experiment was performed in a continuous stirred-tank reactor to study the simultaneous conversion of CO and H2 directly to CH4 employing R.rubrum. Optimum temperatures, 30°C, was chosen for study. CSTR. The significant conversion of both CO and H2 occurred represents a methane yield from CO. and H2 of about 96 percent. The system was operated with a retention time of one hour and stable operation was monitored for several weeks.

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