UNIVERSITY OF CAPE TOWN

DEPARTMENT OF CHEMICAL ENGINEERING

SOLID FLUID OPERATIONS
CHE329F

ASSIGNMENT 2

THE DESIGN AND SIZING OF A CENTRIFUGE FOR SAB

SAB

THE SOUTH AFRICAN BREWERIES LIMITED

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By: Kevin G. Dunn
Student N°: dnnkev003

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81%

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1. INTRODUCTION

It is the aim of this report to outline the design of a mini–plant to separate yeast cells from beer. Currently the "yeasty–beer" is produced by the plant in four batches of $100m^3$ per day. Ancillary equipment such as pumps, storage and surge tanks will also be specified in the design however the main component used in the separation will be a centrifuge whose design is the main criterion. All nomenclature used is defined in section 5.

2. TYPES OF CENTRIFUGES AND CENTRIFUGE SELECTION

When separating yeast from the beer produced we base our separation on the density difference between the beer liquid and the solid yeast cells. The following data has been given: $\rho_{beer} = 1020$ kg/m^3 and $\rho_{yeast} = 1075$ kg/m^3. [**1**, p 729] indicate in their table that in our case centrifugation or sedimentation would be best to achieve the separation. Since the yeast cells are suspended in the beer, it would possibly take very long to separate them based on gravity alone. Indeed it will be shown that the centrifuge produces a force many times that of gravity and allows faster separation.

Centrifuges can be broadly classified as sedimentation centrifuges where the liquid is of importance and filtration centrifuges where the solid is the desired product. For filtration centrifuges the centrifuge walls are porous allowing the liquid to pass and the deposited solid cake is collected and removed. [**3**, p 320]. Clearly it is the sedimentation type we are interested in and these we will now discuss.

2.1 Types of Sedimentation Centrifuges

There are three main types of sedimentation centrifuges that can be identified in the processing industry [classification according to **4**, p 622]. We will take a look at them and consider, based on the facts pertinent to our design, which would be the most appropriate for separating the yeast from the produced beer.

a) *Tubular Bowl Type*

The tubular bowl type centrifuge is generally used to separate two immiscible fluids or to separate fine solids from the liquid medium. It usually does not have an automatic solids removal system and hence needs to be operated batchwise and with a low solids content.

The device is mounted so that the axis of rotation is vertical. As seen in Figure 1 the bowl is supported on an upper bearing and drive assembly and is only loosely supported at the bottom. This is to allow the centrifuge to find its natural axis of rotation when the load becomes unbalanced when say the feed enters non–uniformly. The centrifuge may be operated at speeds of 15000 rpm industrially and at a force 13000 times that of gravity is often developed. Since such a high centrifugal force is developed, it is sound engineering sense to minimise the internal radius so as to minimise the wall stresses. This explains the large aspect ratios of the tubular bowl centrifuges of up to $\frac{L}{D} = 8$ with L a maximum of ≈ 1.5m.

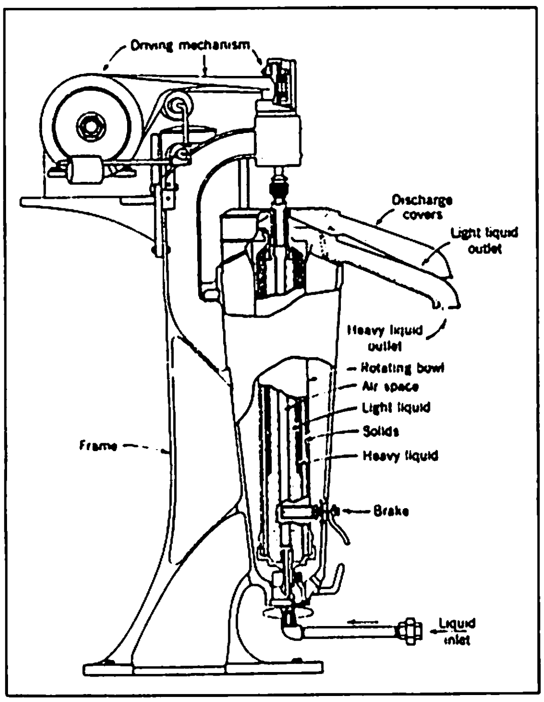

Figure 1

The feed enters at the bottom through a nozzle under pressure. Loose vanes inside the bowl accelerate the feed to the bowl speed. As this mixture moves up, the solids receive a greater centrifugal force than the fluid and are therefore thrown outward onto the bowl. If the mixture entering not only contains solids but also two fluids of different densities then these two fluids may also be separated. This is achieved by allowing two fluid outlets at different heights along the bowl.

It must be noted that as soon as the fluid leaves the top of the bowl it is subjected to a high shear force and will also strike the casing of the bowl with a great speed. This causes the fluid to break up into finer droplets and if this is detrimental to the desired product, a centripetal pump or skimmer must be used to remove the liquid.

As mentioned before the tubular bowl centrifuge is run batchwise and the solids need to be removed once the quality of the clarification is insufficient. To aid in the cleaning, a layer of paper is usually placed inside the centrifuge so that the solids may be removed in a single package.

Typical maximum liquid flowrates to the centrifuge are 60 *l*/hour for removing bacteria and up to 4500 *l*/hour for oil purifying. The centrifuge can hold a maximum of 5kg solids and takes about 15 minutes to clean between each batch.

b) ***Disk–Bowl Type***

The disk–bowl centrifuge is mostly used to clarify liquid from a liquid-solid stream or may also be used to separate liquid-liquid or liquid-liquid-solid mixtures. Some types are operated batchwise and other types continuous, the continuous type having an outlet stream for the concentrated solids.

The disk–bowl centrifuge is mounted vertically and the mechanical drive at the bottom or the top, depending on manufacturer design as seen in figure 2. In the batch type the feed normally enters at the top and travels down through a series of truncated cones, that is cones whose top points have been cut off. This assembly is called the disk stack. Generally there are a hundred or more disks per stack at an angle of between 35 and 50° to the vertical. The purpose of the stack is to decrease the sedimentation distance, since once a particle is underneath a disk it is, in effect, separated. Once under the disk it will travel towards the centrifuge wall where it is collected. The fluid then passes along the disks and out the top.

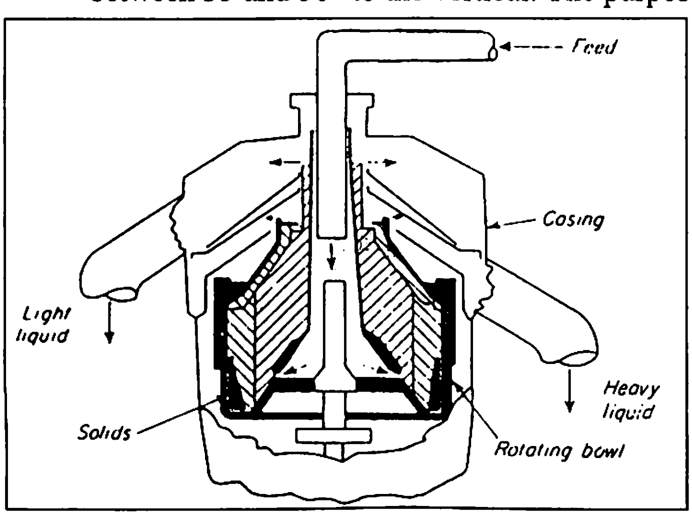

Figure 2

If two fluids of different densities are present with the solid, then the less dense fluid passes up, while the heavier fluid passes down with the solid. This principle is illustrated in figure 3 with dirt entrapped in an oil–water mixture.

In the continuous type the feed generally enters at the top as well the clarified effluent. The solids that have accumulated against the wall are removed by a nozzle discharge system whereby the solids leave, with some of the fluid, in a concentrated solid phase. The nozzle diameter is typically twice that of the maximum particle size and there maybe up to 24 nozzles around the bowl. The nozzles should be angled tangentially backward to take advantage of the kinetic energy and reduce power consumption.

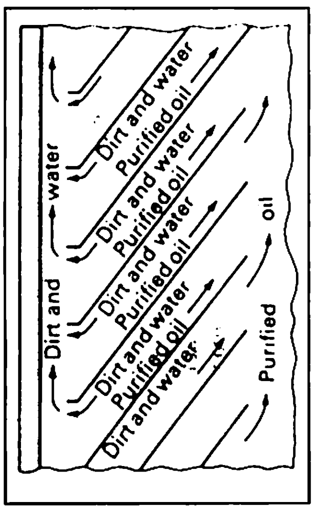

Figure 3

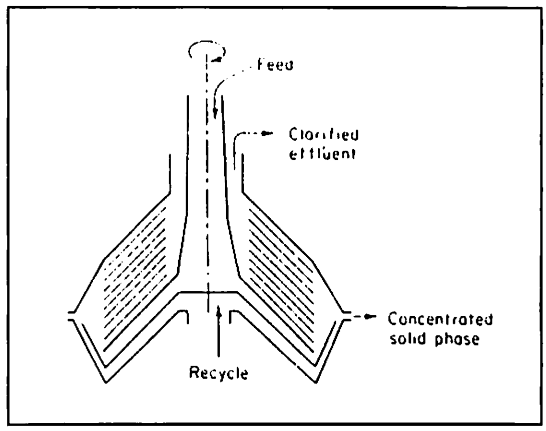

Figure 4

Often as shown in figure 4, a part of the solid phase is recycled back to ensure that there are always solids present at the nozzle so as to minimise the amount of desired liquid product being recycled. The recycle stream could be reintroduced in the feed, but this often reduces the clarification required by increasing the incoming solids concentration.

These types of centrifuges are operated at a far lower speed than the tubular bowl type since they have a greater internal surface area. Typical speeds are around 10000 rpm with forces of about 14000 that of gravity. The volumetric flowrate of feed of moderate solids concentration (±15% by volume) that can be treated is around 100 m^3/hour.

Their use is diverse and they are used in catalyst separation, separation of marine oils, as well as in the food processing industry to separate creams, refining fish oils and processing fruit juices, yeasts, starches and meats where aseptic operation is critical.

c) ***Solid Bowl Discharge***

The solid bowl centrifuge is applied in the same areas as the tubular bowl centrifuge but with the additional use that some sort of classification of the solids may take place. As shown in figure 5, the solid bowl centrifuge has a horizontal axis of rotation. The feed enters in one side into a cylindrical bowl. On the outer edge of the bowl is a screw conveyor that rotates with the bowl but at a few revolutions per minute lower. The solids that accumulate against the wall are thus removed with the screw conveyor. The typical speeds of rotation range between 1600 to 6000 rpm with a force of around 3000 times that of gravity.

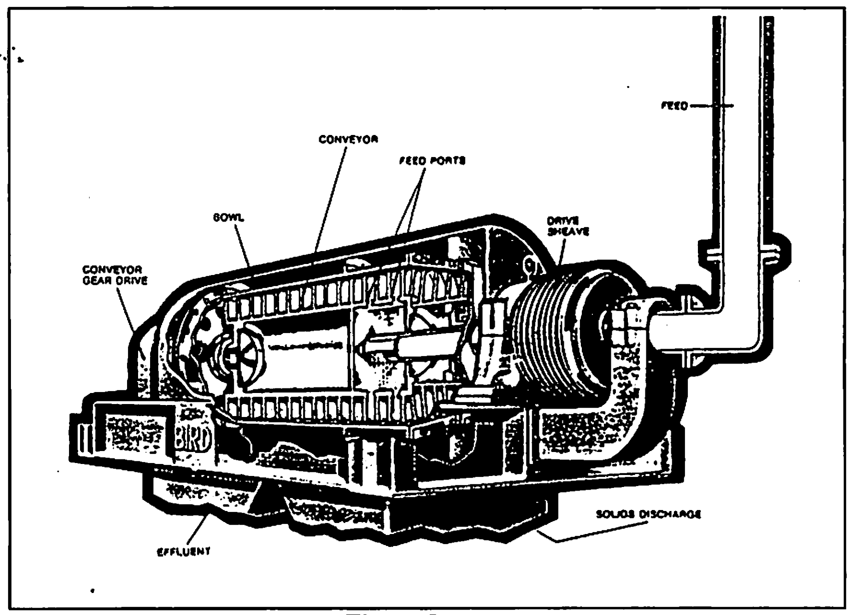

Figure 5

As mentioned, the bowl speed and feed rate may be adjusted so that the smallest particles leave with the fluid causing a very sharp separation. This may be required when say the coarser material needs to be reprocessed to get it finer, and the finer material continues with another process. A hydrocyclone should be considered as an alternative in such a case though.

2.2 Centrifuge Selection

Based on the above description, empirical tables have been drawn to facilitate centrifuge selection. An example of such a table, based on the settling velocity under gravity (Stokes' Terminal Settling Velocity – TSV) and the volumetric through–put required, appears below in figure 6.

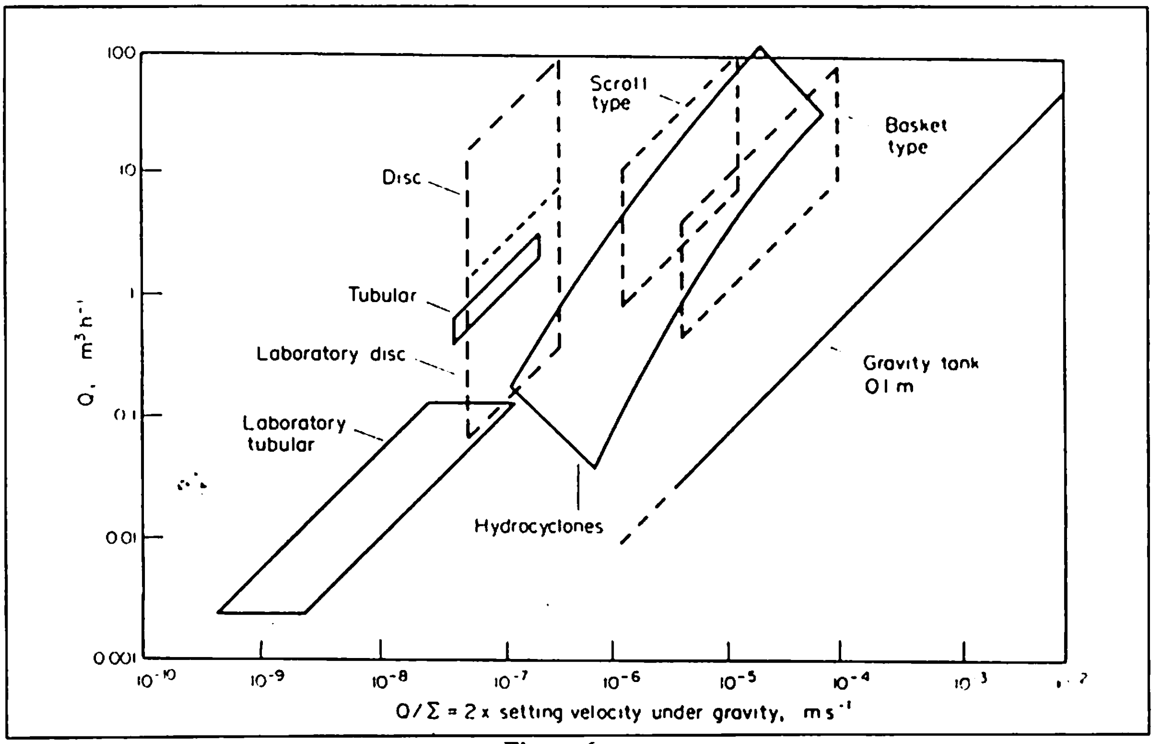

Figure 6

Based on the requirements for yeast separation from the produced beer, a disk–stack centrifuge appears to be the most appropriate. It provides aseptic operation and continuous removal of the yeast, which would also minimise contamination were it a batch process. It therefore provides ease of use and minimal operator supervision.

3. Centrifuge Theory and Calculations

In figure 6 we plotted the volumetric flowrate, Q, versus Stokes' TSV, u_O. Although the particles never really reach their true TSV in a centrifuge [**6**, p 19–95], we may assume they get very close to it. Stokes' Law equates the TSV as shown:

$$u_O = \frac{(\rho_{yeast} - \rho_{beer})gd^2}{18\mu}, \text{ where d = particle diameter, and } \mu = \text{fluid viscosity} \qquad (1)$$

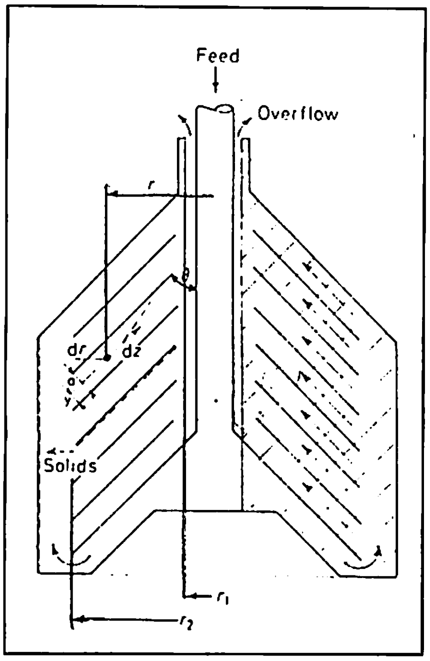

Figure 7

When discussing centrifuges it is useful to introduce the Σ concept. The units of Σ are m^2, and can be viewed as the equivalent size sedimentation tank required to affect the same separation. Σ is defined as $Q = 2u_O\Sigma$. (2)

For a disk–stack centrifuge, as shown in Figure 7, it can be shown that, from [**2**, p 373],

$$\Sigma = \frac{2\pi\omega^2(N-1)(r_2^3 - r_1^3)}{3g\tan\theta} \quad (3)$$

where ω = angular velocity in Hz (1Hz=9.549rpm) and θ is the half–angle of the disk stack.

In centrifugation we define a value called d_{max}. d_{max} is the maximum particle size diameter which will appear in the clarified liquid.

4. SIZING OF THE CENTRIFUGE TO SEPARATE YEAST FROM BEER

Firstly, we need to check that a disk–stack centrifuge is indeed appropriate for our design by ensuring that the solids concentration is not exceeded. In section 2.1 (b) it was indicated that a disk–stack centrifuge could handle up to 15% solids by volume. In the beer production 11.5 tonnes of yeast is suspended in $100m^3$ of beer, this then is a concentration of $\frac{\frac{11500kg}{1075kg}m^3}{100m^3} = 11\%$ by volume.

Since we produce $400m^3$ of beer per day we need only one centrifuge to cope with the volumetric flow of beer.

Our smallest particle size is 4μm, however to ensure that we obtain a totally clarified product we will choose d_{max} = 3μm. So then inserting this value of d_{max} into equation (1) and assuming the viscosity of beer to be similar to that of water, we have $u_O = 2.698\times10^{-7}$ m/s.

To reduce power consumption, we can run the centrifuge for only part of the day. This would require ideally an analysis of the equipment cost versus power cost. However, assuming that a slightly larger centrifuge's cost would be cheaper in the long term than the continuous power costs, we can run the feed rate at $60m^3$/hour, that is it operates for $6^2/_3$ hours per day. This will allow for adequate repair time during working hours if we place a surge tank in front of the centrifuge. The surge tank should be able to hold an entire day's production, ie $400m^3$, in the event that the centrifuge needs to be shut down for a while. Thus we have $Q = 60m^3/hr = 1/60\ m^3/s$ and figure 6 confirms that a disk–stack centrifuge would be appropriate. OK!

Now from equation (2) we can calculate that $\Sigma = 30\ 890m^2$. Now to design the centrifuge we want to approximate this value by selecting the variables in (3). However to aid us we have a few constraints, namely
$0 < \omega < 10000$ rpm; $35° < \theta < 50°$; $r_1 < r_2 < 1$meter; and N, where N is the number disks and is normally a figure around 50 to 150.

Various values were tried, and those that seem to most optimally satisfy the constraints are given below:

- r_2, the outside diameter of the disks = 0.25m
- r_1, the inner diameter of the disks = 0.1 m
- N = 50 disks
- $\theta = 45°$
- ω = 4500 rpm = 470 Hz
- z = 5660 G's, ie 5660 times the force of gravity is generated
- $\Sigma = 34000\ m^2$
- $d_{50} = 2.861\ \mu m$
- $d_{max} = 3\ \mu m$

We would also require a storage tank for the clarified beer and so a simplified flowsheet may be drawn up as shown in figure 8 on the following page.

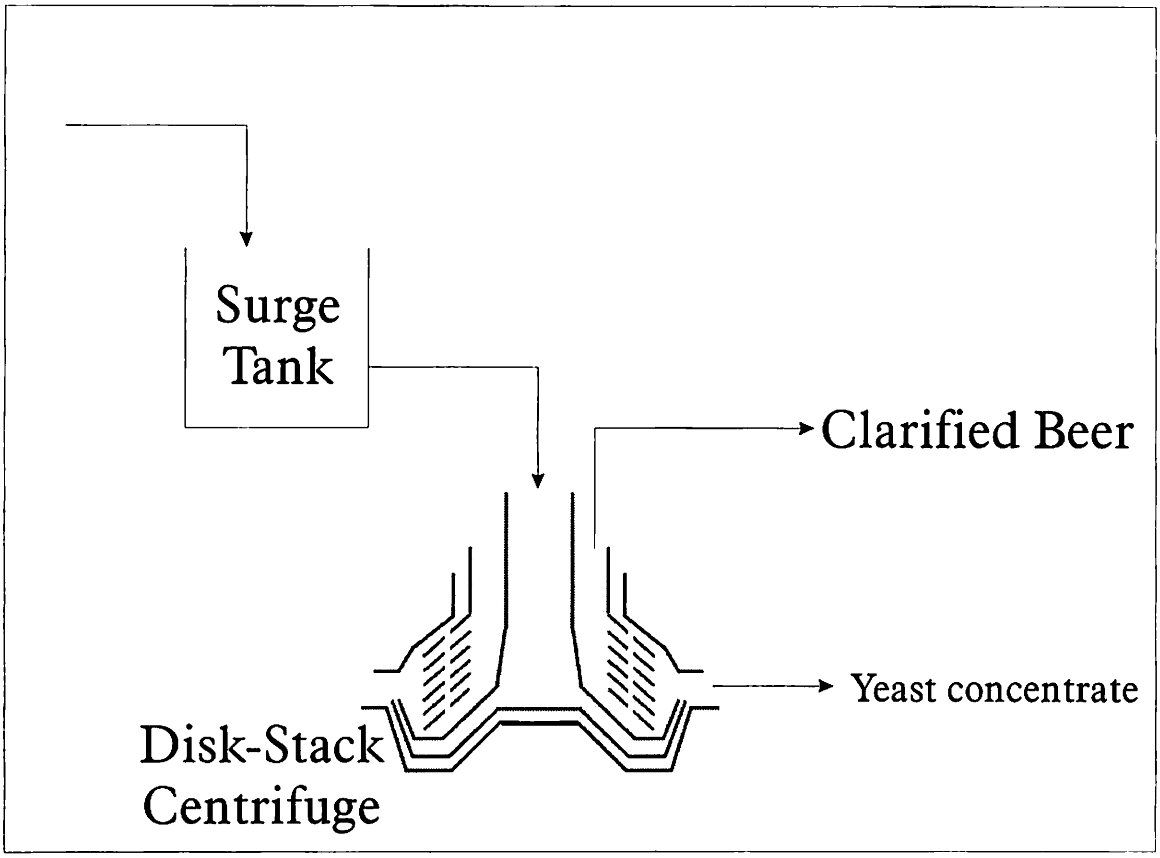

Figure 8

5. NOMENCLATURE

Symbol	Description	Units
D	Vessel diameter	m
d	Particle diameter	m
d_{50}	Particle cutsize	m
d_{max}	Diameter of largest particle in overflow	m
g	Gravitational Acceleration	$m.s^{-2}$
L	Vessel height	m
N	Number of disks	Dimensionless
Q	Volumetric flowrate	$m^3.s^{-1}$
r	Radius	m
u_O	Stokes' terminal settling velocity	$m.s^{-1}$
z	Force indication	Dimensionless
Σ	Sigma	m2
μ	Fluid viscosity	Pa.s
θ	Conical half–angle	radians
ρ	Density	$kg.m^{-3}$
ω	Angular velocity	rpm or s^{-1} (Hz)

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