CHAPTER – 3
THEORETICAL ANALYSIS

3.1 INTRODUCTION

Centrifugation is a technique which utilizes the centripetal force with the help of centrifuge for the sedimentation of heterogeneous mixtures and is adapted in laboratory and industrial settings. This procedure is useful in the separation of two immiscible materials and it also helps to analyze macromolecules of its hydrodynamic properties. Denser particles of the mixture settle down at bottom and lighter particles move towards top in the capillary tube by centrifugation process. Researchers have studied precipitation of particles in a capillary tube by varying the gravitational power which is dependent on rotational speed [110].

A centrifuge is a motor driven piece of equipment that rotates an object around fixed axis by applying the perpendicular force to a fixed axis. The centrifuge follows the principle of sedimentation where substances are evenly distributed with centripetal acceleration i.e. according to their densities. There are many different types of centrifuges including those which have very specialized specific use. It can be utilized for feasible counts, when vibrating the culture e.g. yeasts that are suspended in a mixture. Centrifuges are instruments that spin samples at high speeds, tending the denser particles to settle at the bottom of tube. The most common use of centrifuge in clinical laboratory is to separate the cellular constituents of the blood from the plasma [111].

Centrifuges vary in speed capability, capacity and size. The model that is used for serum separation or urine analysis is named as clinical centrifuge [112-114]. The speed capacity of these models is in the range of 0-3000 RPM and they hold 5 to 50 ml of sample in tubes. A serofuge is a smaller form of centrifuge that is used to spin serological tubes in blood banking and serology.

Micro-fuges or Micro centrifuges are also predominantly used. The procedure adapted in these centrifuges involves a spinning of specialized micro tubes (0.5-1.5 µl capacity) at high speeds, normally up to 12,000-14,000 rpm. Micro hematocrit
centrifuge is a variated form of the micro-fuge where the capillary tubes are spun at a higher speed, so that measurement of the hematocrits can be done.

A high-speed refrigerated centrifuge is a type of centrifuge that has speed capabilities of 0-20,000 rpm and ultracentrifuges have speeds over 50,000 rpm.

3.2 TYPES OF CLINICAL CENTRIFUGES

The major types of centrifuge are:

- Laboratory centrifuge
- Preparative centrifuge or ultracentrifuge

Laboratory centrifuge

A laboratory centrifuge is a motor driven piece of laboratory equipment, in which samples of liquids are spun at a high speed. There are many varieties of centrifuges, depending on the sample capacity and size. Like any other centrifuges, laboratory centrifuges follow the principle of sedimentation, where separation of substances is done with the help of centripetal acceleration based on the density of substances.

Ultracentrifuge

The preparative centrifuge is another name for ultracentrifuge which spins at very high speed with the help of rotor capable of attaining acceleration up to 1000000 times g (approx. 9810 km/s²). Preparative centrifuge finds its importance in polymer science, biochemistry and molecular biology.

3.3 THE NEED OF LABORATORY CENTRIFUGES

Laboratory centrifuges find their usefulness when there is a small scale separation and classification. The range to handle liquid volumes by such devices is normally from 1 - 5000 ml. These centrifuge tubes are attached to rotating unit (rotor) in a systematic manner. There are two most widely used varieties of rotors, one is called swing-out rotor and another one is called fixed-angle rotor.
In a fixed-angle rotor centrifuges are arranged in a fixed method at an exact angle to the rotation axis. In swing-out rotors, the capillary tubes are held parallel to the rotation axis, while the rotor is at a standstill position. When the rotor is put into the action the capillary tubes are swung out in such a manner that they align themselves to the rotation axis perpendicularly.

The spinning of centrifuge tubes creates a stimulated gravitational force towards the direction that is outward relative to the rotation axis and this force the particles towards the bottom of the capillary tube. Normally the laboratory centrifuges range in the speeds of 1000 to 15000 RPM. The measurement magnitude of the gravitational force \((G)\) is estimated in terms of acceleration due to gravity \((g)\) value. The gravitational force is dependent on the speed of rotation as well as the style of the holding the centrifuge tubes by the rotor.

### 3.4 IMPORTANCE OF LABORATORY CENTRIFUGES

Centrifugal technique has been used in the proposed model for separation of blood components. Laboratory centrifuge follows the principles of sedimentation. Laboratory centrifuge is motor driven equipment that spins samples of liquid very swiftly. Centrifuges are categorized into various types based on sample capacity and size.

If the gravitational field is increased in these equipments the precipitation at the bottom of capillary tube happens more swiftly and completely. The residual solution after the precipitation is known as supernatant. The supernatant solution is distilled from the tube or extracted using Pasteur pipette.

The rate of centrifugation is always dependent on applied acceleration on the sample, which is normally measured in RPM or RCF.

The settling velocity of the substances in the process of centrifugation is a function of their density, particle shape and size, solids present in the substance and the viscosity.
3.5 NOMOGRAM AND ITS SIGNIFICANCE

A Nomogram is a graph, which essentially contains three or more parallel scales graduated for different variables, so that when a straight line connects values of any two, the related value may be read directly from the third at the point of intersection. The nomogram can also be called nomograph which can also be defined to be graphical calculation tool. It is used by many engineers to solve the complex equations of graphical computations [121,122]. So a geometrical construction is made for the requirements of knowing or calculating the capillary tube diameter with known values of DC motor speed in rpm as well as known value of the centrifugal field. The nomogram arrangement gives the value of the capillary diameter requirement which is a way of finding unknown value from known two values.

In this research work nomogram as given in Fig 3.1 is used as cross verification tool which confirmed the values obtained from experimentation. Actually an experiment is conducted on optimization of capillary tube to determine the capillary tube diameter, DC motor speed and spinning time. This is described in chapter 4.2.

The diameter of capillary tubes used in centrifuges varies from 50mm to a few centimetres. This implies that in order to determine the RBC and WBC count values a large amount of blood sample is required. This is not acceptable from the medical science perspective especially if the blood sample of anaemic patient is to be tested. The sudden starting and stopping of motor of the centrifuge can result in disturbing the sedimentation of the substances in the blood sample.

This procedure tries to overcome these setbacks by utilizing a capillary centrifuge of 2mm diameter and by incorporating soft start and soft stop features for the drive to obtain accurate results. The examination of laboratory centrifuge and ultracentrifuge reveals that the laboratory centrifuge yields better results.

\[
G = \frac{r \omega^2}{g}
\]  
\[
\omega = 2\pi n
\]

Substituting for \(\omega\)

\[
G = r \left(2\pi n\right)^2/g
\]
\[ G = r \left[2 \times 3.14 \times \left(\frac{n}{60}\right)\right]^2 / 9.81 \]
\[ G = 1.12 \times 10^{-3} \times r \times n^2 \]
\[ G = 1.12 \times 10^{-3} \times r \times (\text{RPM})^2 \]  
(3)

Where

- \( r \) = distance from the axis of rotation or radius of the tube (m)
- \( \omega \) = angular velocity (radians/s)
- \( g \) = acceleration due to gravity (m/s^2)
- \( n \) = rotation speed, RPM

For the proposed design:

- Diameter = 2mm, Radius \( r = 1\text{mm} = .001 \text{ m} \)
- \( n = 10,000 \text{ RPM} \)

\[ G = 1.12 \times 10^{-3} \times 0.001 \times (10000)^2 \]
\[ G = 112 \text{ N} \]  
(4)

**Fig. 3.1** Nomogram to find out the relation between speed, RCF and radial distance

### 3.6 CHOPPER AND ITS ROLE

A DC chopper is a DC-DC converter. Similar to a Transformer, a DC chopper can function to step-up or step-down DC voltage. The DC choppers can be realized using any of the switching devices such as thyristors, MOSFETs (Metal Oxide
Semiconductor Field Effect Transistors), IGBT (Integrated Gate Bipolar Transistors), GTOs (Gate Turn-of Power Transistors).

Choppers are mainly used for traction-motor control in marine hoists, electric powered automobiles, forklift trucks, trolley cars and mine haulers. Choppers permit high efficiency, fast dynamic response and a smooth acceleration control [123].

Using constant voltage mains, DC choppers are employed to provide a variable voltage to a load. Turning ON and OFF of the switches will convert a constant DC voltage to a variable DC voltage. When a thyristor is used, it should have a firing unit to provide pulses at the gate and a turn-off mechanism (commutation) to make the thyristor off. Load should invariably have a freewheeling diode across it, so as to facilitate switching off of inductive loads without voltage spikes across the switch.

A DC chopper is a technique that helps to convert DC to DC directly, which can also be called DC to DC converter and which can be considered as a DC equivalent of an AC converter which has a continuous variable turns ratio. Similar to a transformer a DC chopper can function to step-up or step-down source of DC voltage. DC choppers can be designed using thyristors, MOSFETs (Metal Oxide Semiconductor Field Effect Transistors), IGBT (Integrated Gate Bipolar Transistors) GTOs (Gate Turn-of Power Transistors) etc.

3.7 TYPES OF CHOPPERS

Choppers can be classified into two types [123,125,144] namely

I. Step-up chopper

II. Step-down chopper

**Step up chopper:** Step-up choppers or boost-converters are used to enhance the input voltage level of its output voltages. In step-up function output voltages is greater than input chopper voltages. This is achieved by fast switching of a semiconductor device. The increase in output voltage depends on the frequency of switching (depends on pulse given to the device). While switch is OFF, thyristors is open circuit, the output
voltage is almost same as input and when switch is ON, thyristors is assumed as short, hence current flow in a shortest path, so inductor gets energized and in continues flow to get output voltage greater than input.

**Step down chopper:** Step-down choppers or Buck converters are used to diminish the input voltage at the output. In step-down chopper output voltage is smaller than input chopper voltage. This is achieved by switching of a semiconductor device. The decrease in output voltage depends on the switch OFF and ON time of the thyristors. While device is OFF state it means there will not be any contact between load and the input. So, the output voltage will be zero. While device is ON state there will the output voltage and hence the loop continues.

Based upon quadrant of operation, choppers can be classified into five types and they are discribed below

**Class A Chopper**

The circuit of class A chopper is shown in Fig. 3.2. When chopper is ON, supply voltage \( V \) is connected across the load. When chopper is OFF, \( V_o = 0 \) and the load current continues to flow in the same direction through the forward diode (FWD). The average values of output voltage and current are always positive. Class A chopper is a first quadrant chopper. Class A chopper is a step-down chopper in which power always flows form source to load. It is used to control the speed of DC motor. The output current equations obtained in step down chopper with R-L load can be used to study the performance of class A Chopper.
**Class B Chopper**

Class B chopper is a step-up chopper which shown in Fig. 3.3. When chopper is ON, E drives a current through L and R in a direction opposite to \(i_0\) shown in figure. During the period when chopper is in ON state, the inductance L stores energy. When chopper is OFF, diode D conducts, and part of the energy stored in inductor L is returned to the supply. Here average output voltage is positive and average output current is negative. Therefore class B chopper operates in second quadrant. In this chopper, power flows from load to source. class B chopper is used for regenerative braking of DC motor.
Class C Chopper

Class C chopper is shown in Fig. 3.4. Class C chopper can be used as a step-up or step-down chopper. Class C chopper is a combination of class A and class B choppers. For first quadrant operation, CH₁ is ON or D₂ conducts. For second quadrant operation, CH₂ is ON or D₁ conducts. When CH₁ is ON, the load current is positive. The output voltage is equal to ‘V’ and the load receives power from the source. When CH₁ is turned OFF, energy stored in inductance L forces current to flow through the diode D₂ and the output voltage is zero. Current continues to flow in positive direction. When CH₂ is triggered, the voltage E forces current to flow in opposite direction through L and CH₂. The output voltage is zero. On turning OFF CH₂, the energy stored in the inductance drives current through diode D₁. When the supply output voltage is V, the input current becomes negative and power flows from load to source. Average output voltage is positive. Average output current can take both positive and negative values. Choppers CH₁ and CH₂ should not be turned ON simultaneously as it would result in short circuiting the supply. Class C chopper can be used both for DC motor control and regenerative braking of DC motors.
CH₁ = Thyristor1(Th₁), CH₂ = Thyristor2(Th₂), D₁ = Diode 1 and D₂ = Diode 2

Fig. 3.4 Class C Chopper

**Class D Chopper**

Class D chopper is a two quadrant chopper shown in Fig. 3.5. When both CH₁ and CH₂ are triggered simultaneously, the output voltage $v_0 = V$ and output current flows through the load. When CH₁ and CH₂ are turned OFF, the load current continues to flow in the same direction through $D_1$, load and $D_2$, due to the energy stored in the inductor L. Output voltage becomes $v_0 = -V$. Average load voltage is positive, if the duration of chopper in ON state ($t_{ON}$) is more than that in OFF state ($t_{OFF}$). Average output voltage becomes negative, if $t_{ON} < t_{OFF}$. Hence the direction of load current is always positive but load voltage can be positive or negative.
Class E Chopper

Class E chopper is a four quadrant chopper shown in Fig. 3.6. When CH₁ and CH₄ are triggered, output current iₒ flows in positive direction through CH₁ and CH₄, with output voltage vₒ = V. This gives the first quadrant operation. When both CH₁ and CH₄ are OFF, the energy stored in the inductor L drives iₒ through D₂ and D₃ in the same direction, but output voltage vₒ = -V. Therefore the chopper operates in the fourth quadrant. When CH₂ and CH₃ are triggered, the load current iₒ flows in opposite direction and output voltage vₒ = -V. Since both iₒ and vₒ are negative, the chopper operates in third quadrant. When both CH₂ and CH₃ are OFF, the load current iₒ continues to flow in the same direction through D₁ and D₄. The output voltage vₒ = V. Therefore the chopper operates in second quadrant as vₒ is positive but iₒ is negative.
CH1 = Thyristor1 (Th1), CH2 = Thyristor2 (Th2), CH3 = Thyristor3 (Th3), CH4 = Thyristor4 (Th4), D1 = Diode 1, D2 = Diode 2, D3 = Diode 3 and D4 = Diode 4

Fig. 3.6 Class E Chopper

3.7 MORGAN CHOPPER

The thyristor (Th) with an LC combination is connected for commutation purpose as shown in Fig. 3.7. The load is connected in series with the thyristor. An anti-parallel diode D1 is placed across Thyristor (Th) and a freewheeling diode D2 across the load as shown in Fig. 3.8.

Fig. 3.7 Principle of commutation of Morgan chopper
Fig: 3.8 Power circuit of Morgan chopper

When the supply voltage (E) is switched ON in the chopper circuit, the capacitor (C) charges to supply voltage with the upper plate of the capacitor becoming positive through load. When thyristor(Th) is switched ON, steady state is obtained and D₂ conducts. D₂ does not conduct if the chopper circuit is started or is in the discontinuous state of conduction. thyristor(Th) starts conducting the load current and it takes over from D₂. If D₁ has been conducting, the current builds up from zero. Simultaneously, capacitor C discharges through Th and L, the discharge current being sinusoidal. The capacitor voltage swings to negative and becomes negative voltage across Thyristor(Th) and while conducting causes a negative voltage drop across D₁. Even though the capacitor voltage has a polarity, making its lower plate positive, D₁ does not conduct until current is zero. The current slowly transfers to D₁, which while conducting causes a reverse voltage across thyristor till it regains its forward blocking capability, so that even though the capacitor voltage reverse, thyristor does not conduct. The current transfers to D₂ and freewheels. The thyristor is fired again after the period of chopper is complete.

Morgan chopper for the proposed application is used saturable reactor as shown in Fig. 3.8. The ON-time of the thyristor depends on the value of L and C. A saturable reactor is placed such that under unsaturated conditions it offers a high inductance, making the ON-time larger. If it is saturated, its inductance is small, thereby making the ON-time also small. ON-times can be controlled without changing the values of C. The ON period of the chopper ends when the capacitor voltage reverses and by that
time the reactor flux also gets reversed. The reversing of capacitor voltage turns off Thyristor(Th). The ON period of the thyristor is the time period from the instant of providing a control pulse to $T_1$ to the instant when the reactor flux becomes positive or the capacitor changes its polarity. Thus the saturable reactor offers advantages over linear one by having high inductance during ON period and low inductance during OFF period. The output voltage control is accomplished by changing duty cycle. The low values of duty cycle gives low voltages. By increasing the frequency, the voltage may be increased. Morgan chopper has the simple operation of circuit and it is of low cost.

3.7 SUMMARY

This chapter covered the theoretical aspects related to various centrifuges, importance of centrifugation, Nomograms, DC choppers and highlighting the features of Morgan chopper. The centrifugation is a technique that uses centripetal forces to sediment heterogeneous mixtures. Centrifuge is a piece of equipment that uses a motor to achieve the required speed to drive the load. Then different types of centrifugation like laboratory centrifuge and ultracentrifuge are discussed. The findings of experimentation to optimize the capillary tube (diameter) and the operation (speed and spinning time) are cross verified with Nomograms. To achieve soft start and stop, Morgan chopper is used and it acts like a switch to the load. The design of optimization of capillary tube and Morgan chopper are described in the next chapter.