## 1.1 Object of the Work

The problem of separating solid particles from a fluid stream or their classification according to size or density arises in large number of industries and the usual method followed is settling by gravity. As the particles are ground smaller, they reach a size where the surface drag of the surrounding fluid almost neutralises the gravitational pull with the result that the particles require a very long time to separate out from the fluid medium. In many industrial operations this type of fine slime almost in colloidal range are to be encountered. The present trend is, therefore, to use centrifugal force which is many times greater than the gravity force. The separation rate can then be enhanced and controlled.

The objective of the present work is to study the motion of particles in suspension flowing through a horizontal rotating cylinder, to study the effect of centrifugal force on the separation of particles and compare the settling with that in the case of flow of suspension through stationary cylinder.

## 1.2 Classification in a Flowing Stream

The phenomenon of separation of particles from a flowing fluid stream has been used in many conventional classifiers. The literature contains a large number of excellent contributions in this field. Lapple and Shephard[1] have deduced equations for particle trajectory for two dimensional motion of particles in stationary fluid.

Investigations in hydraulic transport have led to valuable contribution in the field of settling from suspension flowing through pipeline. It has been found[2-4] that there are two definite velocities which are useful in slurry flow. One is called the minimum velocity below which the solids settle freely, and the other is defined as standard velocity where the entire mass of solid is carried out in a near homogeneous flow without any concentration gradient from top to the bottom of the pipe. In all intermediate velocities there is a concentration gradient. A correlation for standard velocity has been given by Spells[5] from a combination of Froude number and Reynold's number valid for particle size between 50 to 500 microns.

1.3 Use of Centrifugal Force for Separation of Phases

For the treatment of fine sizes of materials differing very little in specific gravity, the use of centrifugal force in solid-liquid mixtures dates back to as early as nineteenth century when de Laval, a Swedish physicist invented continuous centrifuge. Substantial progress has since been made in the design and performance of centrifugal classifiers and these have found extensive use in a large number of industries. Hebb and Smith[6], Lavanchy et al[7] give a comprehensive treatise on centrifuges and their mechanism of separation. Moyers[8], Morris[9] have dealt with the problem of selection of centrifuge for specific separation purposes. Danatos[10] has described the use of centrifugal classifiers for various applications in chemical industries. Koeber and Ruf[11] have dealt with centrifuge for continuous operation. A very interesting application of centrifugal force is in the field of centrifugal extractor[12]. For the separation of ion exchange materials into precise grain size fractions, centrifugal separation has been utilised by Verteshev[13]. Continuous centrifuges of large capacity are being used at present in many industries. Usually, a scraper is used in these cases for removal of deposited material.

Continuous separation into two streams has been possible by the development of hydrocyclone, where centrifugal force is imparted to the solids by tangential entry of the suspension under high pressure. Valuable informations on hydrocyclone can be obtained from the publications of Dahlstrom[14,15], Rietma[16,17], Lilge[18], Bradley[19], Fahlstrom[20] and a number of other workers[21-24]. Hydrocyclone has the advantage of simplicity and flexibility but as opposed to centrifuge it is more suitable for classifying rather than clarifying. The reason is to be found in the development of high shear stress in case of hydrocyclone which promotes suspension of particles and opposes flocculation of fines[16].

## 1.4 Trajectory of Particle and Mechanism of Separation by Centrifugal Force

The mechanism of separation has been studied by several workers particularly for the separation of very fine sizes. Neuzil and Neuzil[25] have derived an equation for the sedimentation time in a centrifugal field.

$$t = \left[ \frac{4.5\,\mu}{\pi^2 N^2 d_p^2 (\rho_S - \rho_L)} \right] (\ln R_2 - \ln R_1) \quad \text{for spherical particles.}$$

$$= \left[ \frac{2.93\,\mu}{\pi^2 N^2 d_p^2 (\rho_S - \rho_L)} \right] (\ln R_2 - \ln R_1) \quad \text{for cubic particles.}$$

Yoshiro Mori et al[26] have developed a theoretical correlation for the efficiency of recovery in a vertical centrifugal classifier. With the help of this equation, it is possible to correlate the positions of the particle at the entrance and at the exit end. The equation assumes the application of Stoke's law both in vertical and in radial direction.

Hauser and Lynn[27] have developed an equation for the trajectory of particle in laminar flow condition. The equation has been proposed to be used for the determination of particle size in the colloidal range. The equation is of the form

$$Z = \frac{18\ KQ\ \mu}{(R^2 - R_a^2)\ d_p^2\ \omega^2\ (\rho_S - \rho_L)} \left[ R^2 \ln \frac{R}{r_i} - \frac{R_a^2}{2} \left(\ln \frac{R}{r_i}\right)^2 + \frac{r_i^2 - R^2}{4} \right]$$

where

$$K = \frac{R^2 - R_a^2}{\frac{3}{4} R_a^4 + \frac{R^4}{2} - R_a^2\ R^2 - R_a^4 \ln \frac{R_a}{R}}$$

Svedberg[28], Beams[29] and McBain[30] have developed techniques for the estimation of particle size by using ultracentrifuge. R.D.Murley[31] has found methods to calculate particle size distribution in centrifugal separation.

In hydrocyclone the flow pattern has been the subject of study by different workers[32-37]. Kelsall[21], Bradley[19,38] and Lilge[18] studied the particle trajectory and have given relations to determine the position of particle in the hydrocyclone under different operating conditions and to predict the probability of particles escaping along with the overflow or underflow. The effect of hydrocyclone geometry has been the subject of investigations by different workers[14,15,17,19,23,39-41]. The separation efficiency can be predicted from equations developed by Dahlstrom[15], Tarjan[42] and other workers[18,19,23,43-45] in this field.

An interesting investigation has been reported by Ferrara[46]. He has calculated the sliding velocity of particles along the cylinder wall in axial direction when a suspension is flowing through a horizontal rotating cylinder. It has been shown by him that the sliding velocity will depend upon the flow rate of suspension, the RPM of the cylinder and particle characteristics. Conditions can be so chosen that the particles, depending upon their density and size, may not have any axial sliding velocity. Following this principle the author has claimed to have developed a method for separation of particles according to their size and density. The method proposed suffers from the drawbacks of conventional centrifuges in that the deposited particles will have to be intermittently scraped out and removed.

## 1.5 Scope of the Present Work

From the published literature it is found that although the use of centrifugal force for the separation of fine particles from a suspension has been widely used in industry, the relationships developed for particle motion are restricted mainly to very fine sizes. The investigations reported are limited to the Stoke's law range i.e. for ultrafine particle and for very low flow rates, and as such cannot be applied to the particles of size range usually encountered in industrial processes. Further, in majority of cases where centrifugal separation is adopted, the process is usually intermittent without simulataneous discharge of the two products. In the horizontal tube classifier proposed by Ferrara[46], the conditions are such that due to a difference in sliding velocity, only one product is discharged and the other is retained within the tube. In the case of hydrocyclone it is, however, possible to obtain two products continuously, but there is a limitation to the tangential force and for the separation of very fine sizes the capacity per cyclone has to be low requiring the use of a battery of cyclones.

The object of the present work is, therefore, to study the motion of particles suspended in a fluid stream flowing through a horizontal rotating cylinder and the possibility of developing a continuous separation-cum-classification device. The problem can, therefore, be divided into two parts (i) to study the trajectory of particles and its settling on the cylinder wall. (ii) The separation and discharge of particles into two streams, the coarser sliding along the cylinder wall and the finer flowing in suspension through a concentric tube introduced for the purpose.