CHAPTER 6

CONCLUSIONS

This Chapter summarises the significant contributions made towards interpreting the complex macroscopic behaviour of the granular bed motion in a horizontal rotating cylinder through a model based on DEM. Also, further work required to enhance our understanding and predictive capabilities of the model developed in this work is presented.

6.1 Conclusions

The motion of granular solids in the cross section of a horizontal rotating cylinder is simulated in this work by a theoretical model based on Discrete Element Method. The salient features of the present theoretical model are:

(a) There are no empirical parameters in the model
(b) There are no assumptions or any artificial boundary conditions are imposed at the boundaries as in the case with continuum models

The influence of the two important process variables namely; the fills fraction and rotational speed on the various regimes of granular solid bed motion is simulated in this work. The transition behaviour of the granular solids motion for the six different modes are predicted with the Froude Number as the basis and the results have been validated with the results reported by Mellmann [2001] and the agreement is found to be very good.

The criteria for the transition behaviour between slumping and rolling modes are quantified using the bed turn over time. The bed turn over time against
Conclusion

\[ \frac{1}{\omega} \], where \( \omega \) is the angular speed in rad/s of the rotating cylinder showed a linear relationship as predicted by Davidson et al. [2000].

The depth active layer obtained through simulation are compared with the results predicted by Van Puyvelde et al. [2000a] and the agreement is found to be very good. It has also been observed that the active layer depth does not depend on the particle size and cylinder diameter as observed by Van Puyvelde [2000a].

It has also been found that the active layer depth increases with rotational speed and decreases with degree of fill as predicted by Henein et al. [1983a, 1983b]. Increasing the percentage of fill signifies that although excess material goes into shearing, the amount of material sheared is distributed over a longer chord length and hence the smaller increment in thickness. This behaviour leads to results in the observed decrease in percent active layer depth. The decreasing active layer depth with increased percent fill is therefore related to geometrical constraints.

The surface velocity profiles computed from the simulation results of this work showed a parabolic nature and the maximum surface velocity increased with rotational speed in a linear manner as predicted by Yamane et al. [1998].

The simulation code has been used to study the mixing and segregation behaviour of the granular solids at the cross section of the horizontal rotating cylinder. The mixing behaviour has been quantified in terms of a mixing index and a rate coefficient of mixing. It is observed that the rate coefficient of mixing increases with the rotational speed and the mixing index decreases with fill fraction at a given rotational speed.
Conclusion

The segregation behaviour of granular solids is simulated for a

(a) Granular solid bed comprising of different sized particles with varying volume fraction of finer sized particles
(b) Granular solid bed comprising of equal sized particles but with varying density.

It is observed that the finer particles form an inner core and the predicted extent of the segregated core agrees with the experimental results reported by Henein [1983a]. Further denser particles formed an inner segregation core as observed by Ristow et al.,[1994].

The intensity of segregation intensity is quantified in terms of a percolation index. Other important conclusions are;

(a) A mathematical model for the granular solid bed dynamics based on first principles has developed and validated with the widely reported experimental results.
(b) It is found that fill fraction, rotational speed and particle size are the most sensitive parameters governing the flow behaviour.
(c) The depth of the active layer depth increases with increase in rotational speed. The coefficient of dynamic friction determines the dynamic angle of repose. The dynamic angle of repose increases with increase in the coefficient of dynamic friction up to a value of 0.5 and for higher values of friction coefficient, the dynamic angle of repose remains constant.
(d) The DEM model developed in this work is capable of quantitative predictions of concentration profiles of particles and the extent of segregation in the cross section of the rotating cylinder.
Finally it can be concluded that the present mathematical model is able to predict accurately particle concentration profile, velocity profiles, surface velocity profiles, active layer depth, individual particle trajectories, dynamic angle of repose, bed turn over time etc., thus providing a reliable and comprehensive model for the design, optimisation and interpretation of complex phenomena encounter in granular solids motion in horizontal cylinders.

6.2 Future Scope

1. The mathematical model should be extended to incorporate mass diffusion terms in the active layer, temperature effect due to heterogeneous reactions, so that it will enhance our knowledge on hot spots, product quality etc.

2. The simulation based on the mathematical model developed should be carried out in a more systematic way to study the effect of the following process variables directly relevant of scale up and real life problems involving rotary systems with granular solids

   i. Cylinder diameter
   ii. Continuous particle size distribution
   iii. Various particle shapes.