# Effect of Particle Drag on Performance of a Conical Base Classifier

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**Abstract — Conical base classifier is designed, manufactured and installed to carry out the experimental study to evaluate the performance and study the effect of particle behavior and drag on performance of the classifier. Classifiers are used in mineral processing to sort out the valuable minerals and collect them for further processing. Several experiments conducted for different $d_{50}$ (50% probability of particle to move to underflow or overflow, vice versa) particle cut size and duty parameters. In this work sand (size range 75 microns to 500 microns) is used as a sorting material fed in the classifier at less than 10% concentration by volume in water, which is fed through the feed well provided at the classifier inlet. Newton's law is applied to find the terminal velocity of the particle, based on which teeter water flow rate is determined and maintained. Experimental results are tabulated and compared the partition coefficient with ideal theoretical partition coefficient. Also the observations are discussed in detail, to highlight the particle behavior and effect of drag on classifier performance.**

## I. INTRODUCTION

Classifier finds its applications in removal of clay fines from siliceous sands, particle size control in closed circuits with mills, fine control in taconite pellet washing, dewatering coal tailings prior to centrifugation, silica removal from iron ores, cement purification, etc. Thus, performance evaluation of classifier is most important in mineral processing, so that the classification can be done more effectively. The classification process in the classifier primarily depends on the terminal velocity of the particle and drag offered by the upward flow of teeter water. The drag offered by the upward fluid, makes higher size ($>d_{50}$) particle settle slowly in the underflow and lower size particles ($<d_{50}$) to flow along with teeter water and get collected in overflow tank. The particle equal to or almost equal to cut size will be suspension and have tendency to move to overflow or underflow tank. Based on the amount of particles of different sizes reported to underflow and overflow, classifier performance is calculated.

The most common method to represent the classifier performance is either by plotting a performance or a partition curve, which relates the mass fraction for each particle size going to the underflow to the size range of particles used. Cut size or separation size of the classifier is defined as the size for which there is 50% probability that the particles in the feed report to the underflow, i.e. particles of this size have an equal chance of going either with the overflow or underflow. Cut size point is represented as the d50 size.

In general, classifiers follow the rules that govern the motion of solid particles in a fluid environment. When a solid particle falls through a viscous medium, it experiences resistance in form of drag and buoyancy forces. When equilibrium is attained between the gravitational and these resistance forces, the solid particle starts falling with a constant velocity called terminal or settling velocity. The particle drag varies as the size varies for small particles due to their non-uniformity in the shape. This will have a considerable effect on the performance on the classifier when its tested in close range of particle sizes. There are two general models that are applied in classification process - Stokes' and Newton's models.

Stokes' model is applicable for low values of Reynolds's number where viscous forces dominate inertial forces. Hence, the drag force on a spherical particle is assumed to be entirely due to viscous resistance. Equating gravitational and viscous forces, we get:

$$v_s = \frac{gd^2(\rho_s - \rho_f)}{18\mu} \qquad (1)$$

Newton's model is applicable when Reynolds's number is high i.e. inertial forces dominate the viscous forces. Hence, the drag force is entirely related to turbulent resistance, and therefore:

$$v_s = \sqrt{\frac{4gd(\rho_s - \rho_f)}{3\rho_f C_d}} \qquad (2)$$

where $v_s$ is the terminal velocity, g is the acceleration due to gravity, d is particle size, $\rho$ is the phase density (solid, s, and fluid , f), $C_d$ is the drag coefficient and μ is the fluid viscosity.

Using the above mentioned model's the terminal velocity is calculated with respect to $d_{50}$ cut size and same is used to set the teeter water flow velocity so that sufficient drag is applied to the particles present in the slurry.

In the previous work on single column classifier [1] the theoretical calculation is performed on force balance on particle in fluid which is also applicable to current conical base classifier. Thus previous work is taken as a reference in this experimental work from which it is observed that Newton's law for free settling is applicable for low capacity classifiers.

## II. EXPERIMENTAL STUDY

Conical base classifier test setup is built as shown in fig:


Fig.1. Conical base classifier test setup

Test setup Specifications:

1. Classifier chamber c.s. area = 0.23*0.129 $m^2$
2. Teeter water pump flow rate range = 0 to 60 lpm
3. Teeter water pump head range = 0.5 to 6 m
4. Teeter water top up pump flow rate range = 0 to 20 lpm
5. Slurry water pump flow rate range = 0 to 20 lpm
6. Under flow tank capacity = 70 liters
7. Overflow tank capacity = 100 liters
8. Sand hopper capacity = 1 liter
9. Slurry water tank capacity = 100 liters
10. Orifice size in teeter water pipe = 6mm

Several experiments were conducted on the installed conical base classifier. Description of experiments and results are tabulated below:

### A. Experiment 1:

Description – $D_{50}$ cut size used is 106 microns (sand size range 0 – 106 microns) and teeter water flow rate is set to 35 lpm as calculated from Newton's law. Sand is fed directly into the classifier using conical flask at 0.076 lpm.

Table I. EXPERIMENT 1 RESULTS

| Sieve size greater than | Underflow (g) | Overflow (g) | Total mass(g) | Partition coefficient (%) | Theoretical partition coefficient (%) |
|---|---|---|---|---|---|
| 106 | 47.78 | 33.43 | 81.21 | 58.84 | 50 |
| 75 | 9.39 | 36.69 | 46.08 | 20.38 | 0 |
| < 75 | 10.13 | 79.48 | 89.61 | 11.3 | 0 |
| **Total** | 67.3 | 149.6 | 216.9 | | |

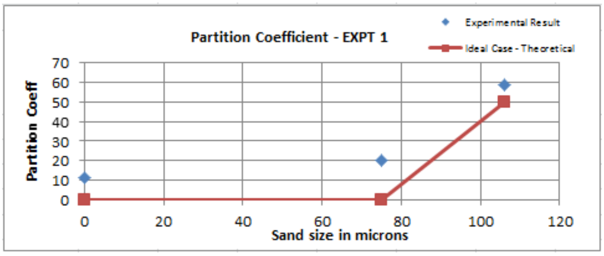


Fig. 1. Partition Coef vs Particle size – Expt 1

### B. Experiment 2:

Description - $D_{50}$ cut size used is 106 microns (sand size range 0 – 106 microns) and teeter water flow rate is set to 35 lpm as calculated from Newton's law. Slurry water flow rate 1.79 lpm, Sand is fed directly into the classifier using conical flask at 0.076 lpm.

Table II. EXPERIMENT 2 RESULTS

| Sieve Size greater than | Underflow (g) | Overflow (g) | Total(g) | Partition coefficient % | Theoretical Partition coefficient |
|---|---|---|---|---|---|
| 106 | 25.19 | 81.71 | 106.9 | 23.56 | 50 |
| 75 | 14.71 | 74.18 | 88.89 | 16.55 | 0 |
| < 75 | 6.71 | 25.44 | 32.15 | 20.87 | 0 |
| **Total** | 46.61 | 181.33 | 227.94 | | |

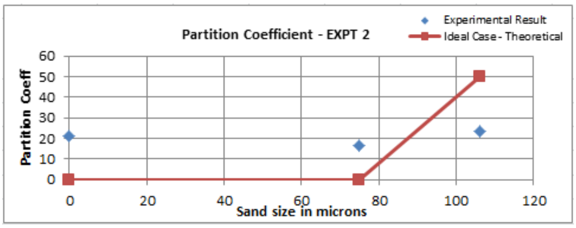


Fig. 2 Partition Coef vs Particle size – Expt 2

### C. Experiment 3:

Description - $D_{50}$ cut size used is 106 microns (sand size range 75 – 250 microns) and teeter water flow rate is set to 35 lpm as calculated from Newton's law. Slurry water flow rate 5.83 lpm, Sand is fed directly into the classifier using conical flask at 0.417 lpm.

Table III. EXPERIMENT 3 RESULTS

| Sieve Size greater than | Underflow (g) | Overflow (g) | Total(g) | Partition coefficient % | Theoretical Partition coefficient |
|---|---|---|---|---|---|
| 180 | 127.42 | 62.83 | 190.25 | 66.98 | 100 |
| 150 | 13.04 | 19.81 | 32.85 | 39.7 | 50 |
| 106 | 9.45 | 64.9 | 74.35 | 12.71 | 0 |
| 75 | 54.38 | 231.71 | 286.09 | 19.01 | 0 |
| <75 | 0 | 0 | 0 | 0 | 0 |
| **Total** | 204.29 | 379.25 | 583.54 | | |

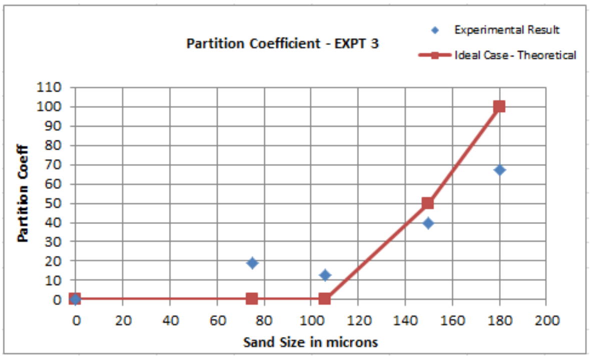


Fig. 3. Partition Coef vs Particle size – Expt 3

## D. Experiment 4:

Description - $D_{50}$ cut size used is 180 microns (sand size range 106 – 180 microns) and teeter water flow rate is set to 42.48 lpm as calculated from Newton's law. Slurry water flow rate 6.2 lpm, Sand is fed directly into the classifier using conical flask at 0.417 lpm.

Table IV. EXPERIMENT 4 RESULTS

| Sieve size greater than | Underflow (g) | Overflow (g) | Total(g) | Partition coefficient (%) | Theoretical Partition coefficient |
|---|---|---|---|---|---|
| 180 | 61.47 | 73.2 | 134.67 | 45.64491 | 50 |
| 150 | 43.24 | 43.98 | 87.22 | 49.575785 | 0 |
| 106 | 35.9 | 163.15 | 199.019 | 18.038479 | 0 |
| 75 | 12.1 | 46.93 | 59.029 | 20.498399 | 0 |
| <75 | 0 | 0 | 0 | 0 | 0 |
| **Total** | 65.38 | 327.26 | 479.938 | | |

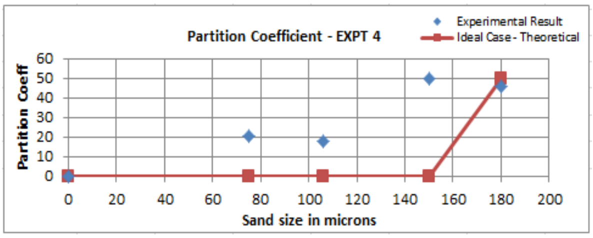


Fig. 4. Partition Coef vs Particle size – Expt 4

## E. Experiment 5:

Description - $D_{50}$ cut size used is 150 microns (sand size range 106 – 355 microns) and teeter water flow rate is set to 39.3 lpm as calculated from Newton's law. Slurry water flow rate 6.365 lpm, Sand is fed directly into the classifier using conical flask at 0.459 lpm.

Table V. EXPERIMENT 5 RESULTS

| Sieve size greater than | Underflow (g) | Overflow (g) | Total(g) | Partition coefficient (%) | Theoretical Partition coefficient |
|---|---|---|---|---|---|
| 355 | 323.59 | 33.46 | 357.05 | 90.63 | 100 |
| 250 | 14.78 | 3.84 | 18.62 | 79.38 | 100 |
| 180 | 13.42 | 9.45 | 22.87 | 58.68 | 100 |
| 150 | 198.23 | 233.16 | 431.39 | 45.95 | 50 |
| 106 | 120.82 | 203.8 | 324.62 | 37.22 | 0 |
| 75 | 3.02 | 14.68 | 17.7 | 17.06 | 0 |
| <75 | 0.12 | 0.61 | 0.73 | 16.44 | 0 |
| Total | 673.98 | 499 | 1172.98 | | |

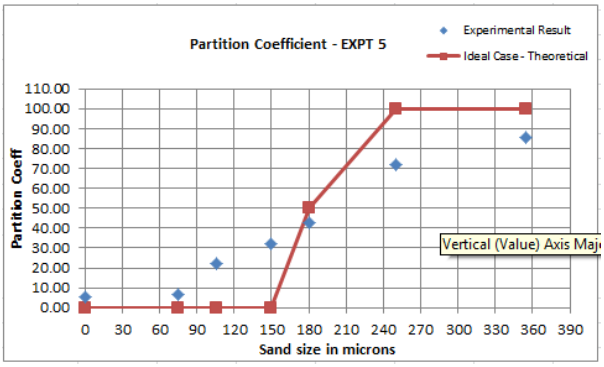


Fig. 5. Partition Coef vs Particle size – Expt 5

## F. Experiment 6:

Description - $D_{50}$ cut size used is 180 microns (sand size range 75 – 355 microns) and teeter water flow rate is set to 43.185 lpm as calculated from Newton's law. Slurry water flow rate 6.381 lpm, Sand is fed directly into the classifier using conical flask at 0.459 lpm.

Table VI. EXPERIMENT 6 RESULTS

| Sieve size greater than | Underflow (g) | Overflow (g) | Total(g) | Partition coefficient (%) | Theoretical Partition coefficient |
|---|---|---|---|---|---|
| 355 | 79.74 | 13.13 | 92.87 | 85.86 | 100 |
| 250 | 2.95 | 1.14 | 4.12 | 71.60 | 100 |
| 180 | 9.8 | 13.24 | 23.04 | 42.53 | 50 |
| 150 | 192.45 | 402.85 | 595.3 | 32.33 | 0 |
| 106 | 32.33 | 112.16 | 144.49 | 22.38 | 0 |
| 75 | 5.55 | 78.59 | 84.14 | 6.60 | 0 |
| <75 | 0.46 | 8.27 | 8.73 | 5.27 | 0 |
| Total | 323.28 | 629.38 | 952.69 | | |

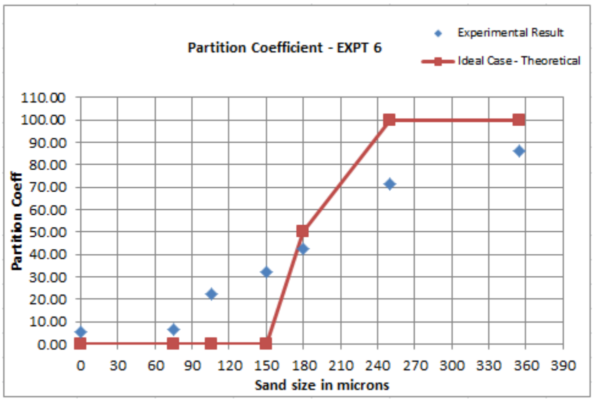


Fig. 6. Partition Coef vs Particle size – Expt 6

G. Experiment 7:

Description - $D_{50}$ cut size used is 180 microns (sand size range 75 – 355 microns) and teeter water flow rate is set to 40.85 lpm as calculated from Newton's law. Slurry water flow rate 3.38 lpm, Sand is fed directly into the classifier using conical flask at 0.459 lpm.

Table VII. EXPERIMENT 7 RESULTS

| Sieve size greater than | Underflow (g) | Overflow (g) | Total(g) | Partition coefficient (%) | Theoretical Partition coefficient |
|---|---|---|---|---|---|
| 355 | 47.5 | 2 | 49.5 | 95.96 | 100 |
| 250 | 2.42 | 0.6 | 3.02 | 80.13 | 100 |
| 180 | 201.78 | 58.75 | 260.53 | 77.45 | 50 |
| 150 | 54.18 | 41.76 | 95.94 | 56.47 | 0 |
| 106 | 7.5 | 10.23 | 17.73 | 42.30 | 0 |
| 75 | 4.94 | 35.39 | 40.33 | 12.25 | 0 |
| 0 | 0.45 | 3.5 | 3.95 | 11.39 | 0 |
| Total | 318.77 | 152.23 | 471 | | |

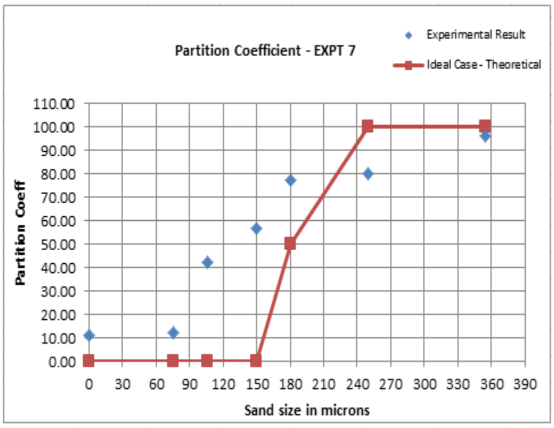


Fig. 7. Partition Coef vs Particle size – Expt 6

## III. RESULTS & DISCUSSION

Experiments are conducted on low capacity conical base classifier using sand slurry and performance is evaluated. From the results it is observed that the variation in performance is high when compared to theoretical curve. In experiment 1, 4, 5 and 6 teeter bed was prominent and in experiment 2 & 3 the teeter bed was unstable. From the previous work and present experiments it observed that sand particles were settling at free settling velocity rather than hindered settling velocity. This concludes that smaller size particle has negligible effect of particle to particle momentum loss. Thus Newton's law for turbulence flow for particle settling is much more in line with experimental results and which is been used (equation 2) to calculate the free settling velocity of particle. Based on $D_{50}$ cut size particle free settling velocity is calculated and in turn teeter water flow rate is set to suspend the particles so as to get the teeter bed formation. During this course of action it is been found that coefficient of drag for sand particles lies between 2.0 to 2.8 for size range 75 to 355 microns. For smaller size particle the drag coefficient is low thus teeter water flow rate required to suspend small size particle is high, as the particle size is increased the teeter water flow rate requirement is increases but at lower rate as drag coefficient is increased. For 75 to 106 microns sand size drag coefficient is found to be 2.0, for 150 to 180 microns size is found to 2.1 to 2.25, for 250 it is found to be 2.5 and for 355 it found to be 2.8. Thus using different sand size in sand slurry the experiments were conducted and results are plotted. Due to variation of drag coefficient for sand particles the classifier performance is not up to the mark. Thus variation of drag coefficient is primary factor which created inefficiency performance of classifier when tested for close range of particle sizes. Following are the some more parameters which affect the classifier performance:

- Improper settling and fluctuations of teeter water flow rate
- Improper slurry distribution.
- Due to sand cohesive force its particles stick together and fall like lumps, due to which the low size particles are carried along to underflow
- Shutting down of setup before proper particle settling could occur.
- Improper mixing of sand and water in feed well.
- Improper sieving of sand particles.

It is also observed that particle of size range 0 <75<106 has very less affinity to diffuse in the water upward water current which affected the higher size particle and suspension in as well as flow towards underflow. Thus it can be concluded from the results that due to all parameters mentioned above have brought down the efficiency of the classifier to 70%. Further work can be done to eliminate the above mentioned parameters and also using different slurry to study the particle behavior and evaluate the classifier performance.

## IV. NOMENCLATURE

V = volume of particle, $m^3$

$\rho_s$ = density of solid particle, $kg/m^3$

$\rho_f$ = density of fluid, $kg/m^3$

A = cross section area of particle, $m^2$

d = diameter of particle, m

g = acceleration due to gravity, $m/sec^2$

$v_s$ = settling velocity, m/sec

$C_d$ = Coefficient of drag

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