EFFECTS OF FEED SOLIDS CONCENTRATION ON DUAL FUNCTIONALITY OF A HYDROCYCLONE.

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ABSTRACT

The dual functionality, i.e. thickening and classification of a 50.8mm diameter hydrocyclone has been investigated. A metallurgical slime consisting of a 50% mixture of quartz and petroleum coke was used in the tests. It was found that in order to achieve both thickening and classification at the same time, the pressure drop across the hydrocyclone, the underflow diameter and the feed solids content have to be subtly controlled.

1. INTRODUCTION

Solids dispersed in a continuous fluid can be removed by several complimentary methods which exploit different mechanisms for separations. Within the class of inertial separators or classifiers, the hydrocyclone is noteworthy because of its geometric and operational simplicity and its many diverse applications [1,2]. Athough there is a number of variants, an illustration of a typical hydrocyclone with the principal dimensional variables is shown in Fig.1. As shown in the plan view in Fig. 1, the feed slurry is introduced in the volute section of the hydrocyclone whereupon the fluid pressure creates rotational fluid motion and, as a consequence, vortex flow. This rotational motion results in an imposition of a centrifugal force which acts on the particles in the slurry. The settling characteristics of the particles under this force are generally assumed to obey Stoke's law. The settling velocity depends on particle mass and shape and, therefore, both particle size and density influence the settling behaviour. In the absence of any other forces, all particles would migrate, at different rates, to the outer wall of the hydrocyclone and subsequently flow down the wall and exit via the apex or spigot. The nature of the hydrocyclone geometry and the relative sizes of the orifice openings are such that most of the water entering the separator leaves through the vortex finder. The movement of the water towards the centre of the hydrocyclone results in a mechanical entrainment of those particles whose slip velocity is insufficient to result in a net outward motion.

Separation of solids from liquids is achieved efficiently with very dilute slurries, e.g. 0.2% v/v [2,3]. When the slurry is very dilute, the underflow discharges through the apex in a spray discharge, with the rotational motion of the slurry providing the force to sustain the annular geometry. An air core persists in the central region of the apex and maximum removal of solids from liquid can be achieved under this condition. As the feed solids content increases to some "critical" point, the underflow discharge changes from spray to roping, which can be seen as a rotating mass coming from the underflow.

Hydrocyclones can be used either for thickening (maximum removal of solids to the underflow) or classification (separation of solids according to their sizes) [1,2]. A variant of geometries exists for each specific duty and application. However, under certain operating conditions, hydrocyclones can be used to achieve, simultaneously, thickening and classification. So far information on the double function of the hydrocyclone is scanty [2,3].

In this work performance of the 50.8mm diameter hydrocyclone was investigated. Experiments were conducted for different feed solids concentrations, pressure drop, vortex finder and spigot diameters.

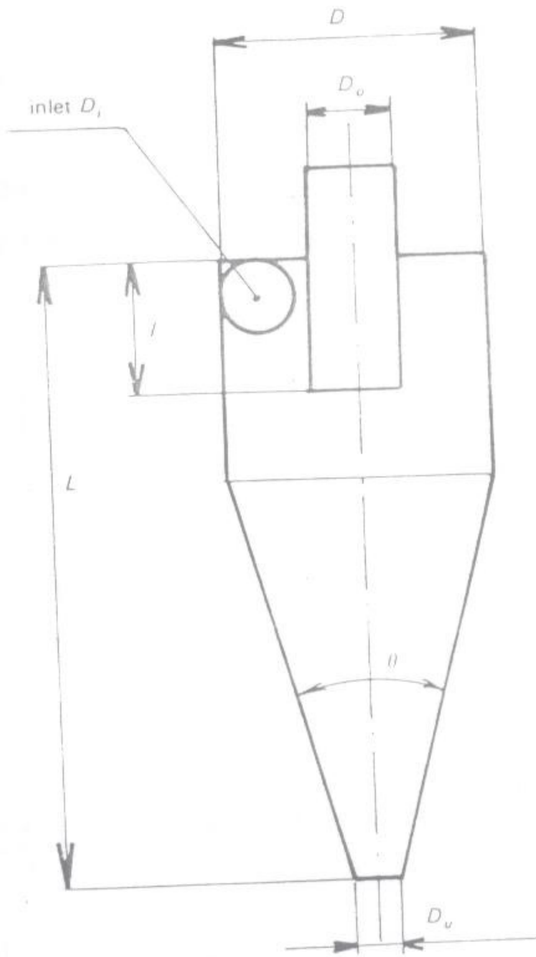

Fig.1: Typical hydrocyclone configuration

2. EXPERIMENTAL

2.1 *Apparutus*

A schematic diagram of the experimental test rig is shown in Fig.2. The feed slurry was introduced into the feed tank (2). Valves V1 and V2 were fully opened and valve V3 was opened so as to allow overflow product to return to the feed tank. A Mono pump (3) was used to pump the slurry through the circuit. By closing valve V1 partially, the desired pressure drop could be set (6). Overflow sample was collected in a bucket (4) while underflow sample was collected in small beakers. A Coulter Counter (Model TA II) was used to measure the particle size distribution of the overflow product.

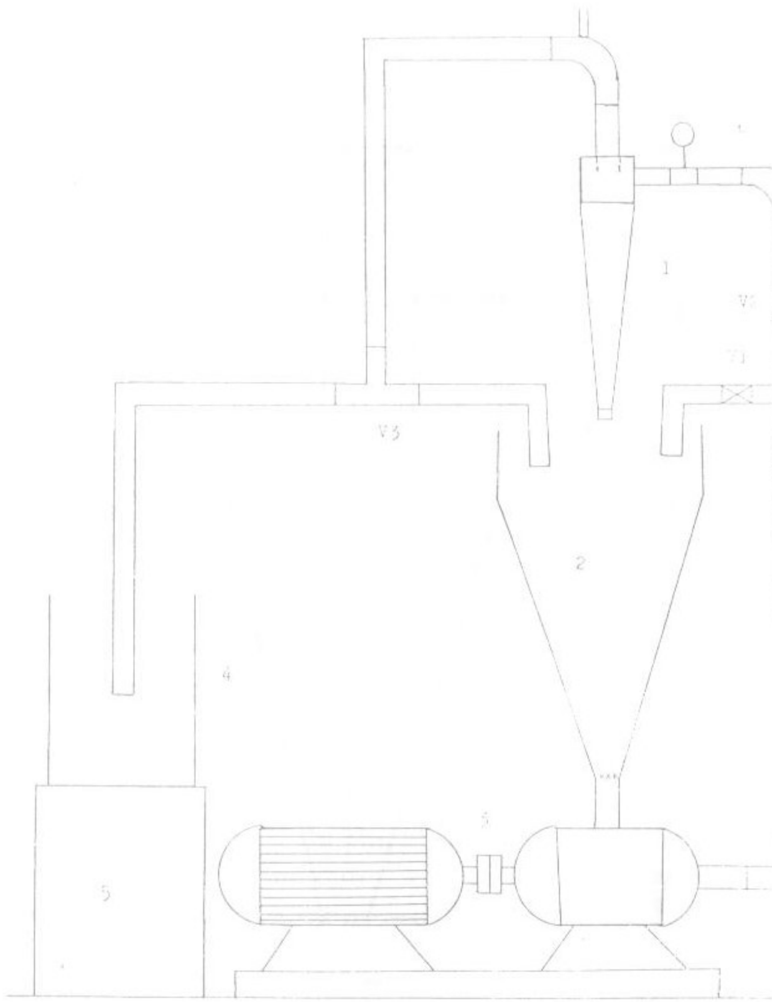

Fig.2: Test rig.

1- 50.8mm hydrocyclone, 2- Feed Tank, 3- Mono Pump, 4- Bucket, 5- Stand, 6- Pressure gauge, 7- Breather, V1, V2, V3- Valves.

2.2 *Materials*

The feed material used was a mineralogical slime (100% - 600 μ m) consisting of an approximately 50% (dry basis) mixture of quartz and petroleum coke. Tap water was used to prepare the feed slurry and deionized water was used to prepare electrolyte solutions.

2.3 *Experimental Procedure*

Before slurry was introduced into the feed tank, the rig was cleaned to remove rust deposits which might have been formed. The desired vortex finder and spigot parts were fitted to the hydrocyclone. The pulp in the feed tank was circulated through the hydrocyclone at a high pressure for a sufficient length of time to ensure thorough dispersion of solids. The pulp density in the feed tank was measured with a "Marcy" specific gravity balance and was adjusted to the required range by addition of either more solids or water to the tank. The underflow and overflow rates were determined by taking samples for given time intervals. Samples collected were dried in an oven at 100°C. About 1g of the overflow product for each experimental run was dispersed in the electrolyte solution and analysed for particle size distribution with the Coulter Counter.

3.RESULTS AND DISCUSSION

Various ways of assessing the performance of the hydrocyclone exist [1,2]. In this paper the author has restricted himself to using the hydrocyclone capacity, total mass recovery to the underflow and particle size analysis of the overflow product as a way of assessing its performance.

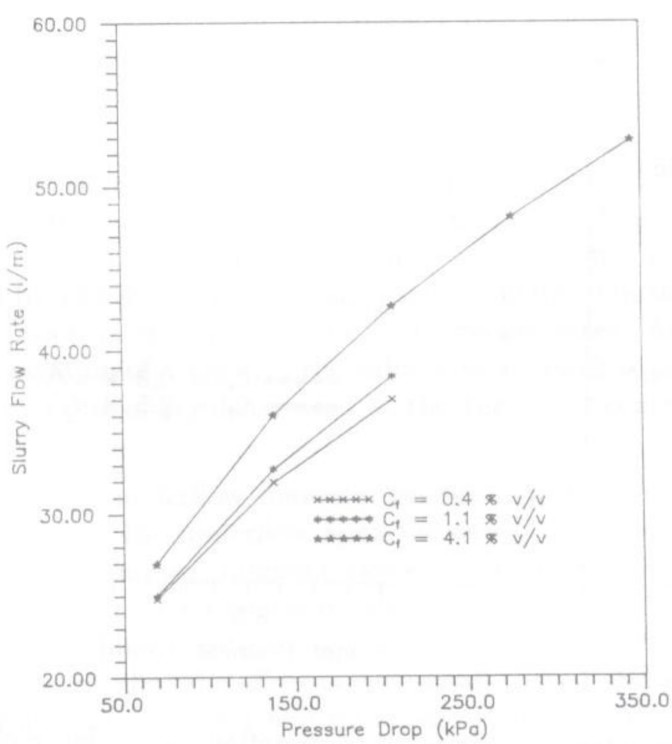

Fig. 3: Hydrocyclone Capacity as a function of pressure drop.

3.1 *Hydrocyclone capacity*

The hydrocyclone capacity Q_{fs} was calculated as the algebraic sum of the outgoing stream flow rates,

$$Q_{fs} = Q_{us} + Q_{os} \tag{1}$$

Fig.3 shows the hydrocyclone capacity as a function of pressure drop across the hydrocyclone. It can be seen that as the pressure drop increases the hydrocyclone capacity also increases non- linearly for any feed solids concentration. For comparison purposes, the hydrocyclone capacity for water alone is also plotted alongside that of sluries. It can be seen that the hydrocyclone capacity for slurries is greater than that for water alone at

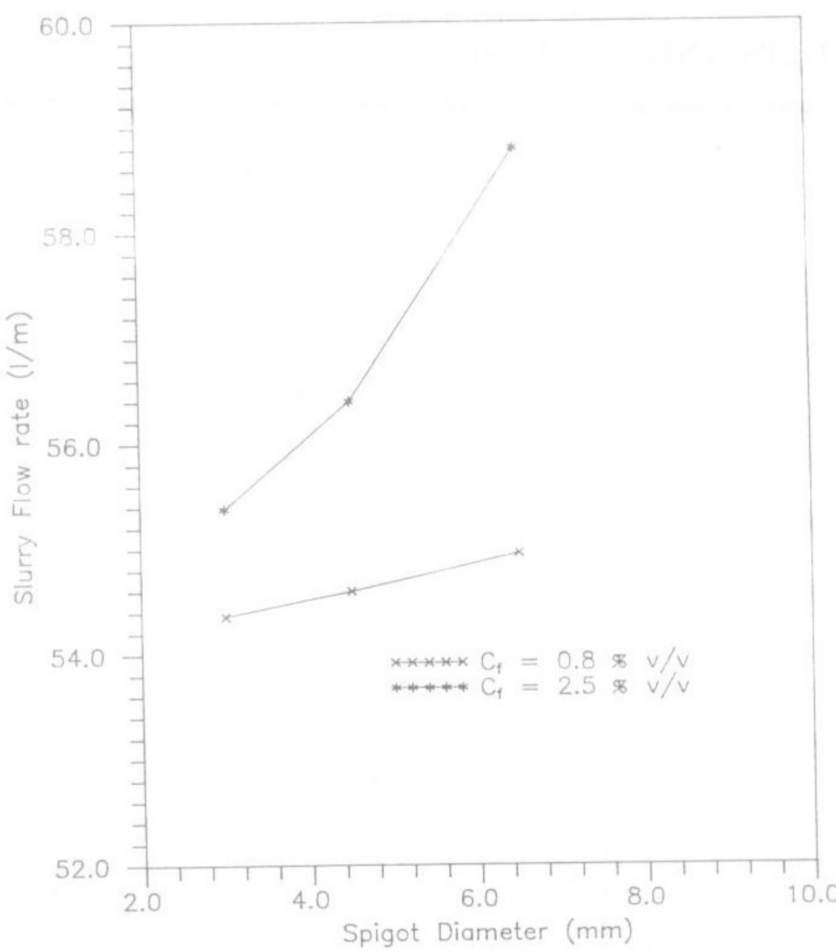

Fig. 4: Hydrocyclone Capacity as a function of spigot diameter.

any given pressure drop. This is in agreement with results of other authors [4,5].It can also be noted in Fig.3 that the hydrocyclone capacity increases with increasing feed solids content for the same pressure drop. The experimental results shown in Fig.3 were fitted to the following equation,

$$Q_{fs} = K_s(\Delta P)^x \tag{2}$$

The values of K_s and x calculated by the least square technique, are shown in Table 1. As can be seen in Table 1, the values of x lie within the range given by Bradley [1], i.e. 0.38 to 0.5. Theoretically, the value of x should be 0.5 [6,7], but as can be seen, the obtained values are lower than 0.5. This is probably due to friction losses occuring within the hydrocyclone. The values of K_s differ from one hydrocyclone to another and on the units of Q_{fs} and ΔP used. Lynch et al [4], who used the same units of Q_{fs} and ΔP as in this work, obtained values of K_s equal to 23.8 for a hydrocyclone of size 102mm and 115.8 for a hydrocyclone of size 254mm. He has also given correlations for the hydrocyclone capacity from which it can be deduced that the values of K_s decreases as the feed solids content increases. This shows agreement with values obtained. It should be said that lack of theoretical understanding of the hydrodynamics within the hydrocyclone has defied attempts to fully correlate K_s with both design and operating variables.

Table 1: Values of x and K_s in equation (5):

C_f [% v/v]	x	K_s	Regime
0.4	0.364	5.31	Spray
1.1	0.391	4.77	Spray
4.1	0.419	4.57	Rope

The values of x and K_s corresponding to water alone were also calculated and found to be 0.418 and 3.82 respectively. It can be seen in Table 1 that introduction of even a small amount of solids in water causes the values of x and K_s to differ from that for water alone. For example, when the concentration of the feed slurry was 0.4% (v/v), the value of x was decreased by 12.9% and K_s was increased by 39.0%. On the other hand, as the feed solids concentration increases, the value of x also increases. At the condition of roping, i.e. feed concentration of 4.1% v/v, the value x was almost equal to that for water alone. In contrast, the value of K_s deacreased as the the solids content of the feed slurry was increased.

The influence of the underflow diameter on the hydrocyclone capacity can be seen in Fig.4. As the size of the underflow apex increases, the hydrocyclone capacity also increases. There are, however, different views on this issue. Lynch et al [4] working with sand (sp.gr.= 2.65) and feed concentration of up to 55% w/w, reported an increase in the hydrocyclone capacity with increasing underflow diameter. Svarovsky [2], on the other hand, contends that the effect is very small indeed and gives many correlations in which the variable D_u does not feature at all. Similarly, Mozley [8], gives plots of the hydrocyclone capacity as a function of pressure drop and vortex finder diameter D_o only. However, the authors [2,8], did not give the range of solids concentration with which they worked.

3.2 *Total mass recovery*

The total mass recovery, also called the reduced efficiency, is given by the equation,

$$E'_T = 100\frac{Q_{us}}{Q_{fs}}\left(\frac{C_u}{C_f - 1}\right) \times \frac{1}{\left(1 - \frac{Q_{us}}{Q_{fs}}\right)} \tag{3}$$

Equation (3) takes into account of fine particles which might be entrained [2] with water discharging to the underflow. Equation (3) also satisfies the basic requirement of an efficiency defition in that it becomes zero when no separation takes place ($C_u = C_f$) or unity for complete separation.

Fig.5 shows the total mass recovery as a function of pressure drop. It can be seen that, for any feed solids content, the total mass recovery increases with increasing pressure drop. It can also be noted in Fig.5 that, provided that the underflow discharge is spray , the total mass recovery increases with increasing feed solids content. When the underflow discharge regime changes from spray to rope, the total mass recovery drops significantly. This is due to, firstly, the air core collapses and secondly, the underflow apex fails to discharge all solids eligible for discharging to the underflow. At this condition, some of coarse particles exit via the overflow stream. The phenomenon of roping is a complex function of slurry rheology, hydrocyclone geometry, operating conditions and feed particle characteristics, and therefore has eluded any comprehensive mathematical description. In this work for example, roping was observed at different underflow concentrations depending on vortex finder and spigot combinations and feed solids concentration as shown in Table 2.

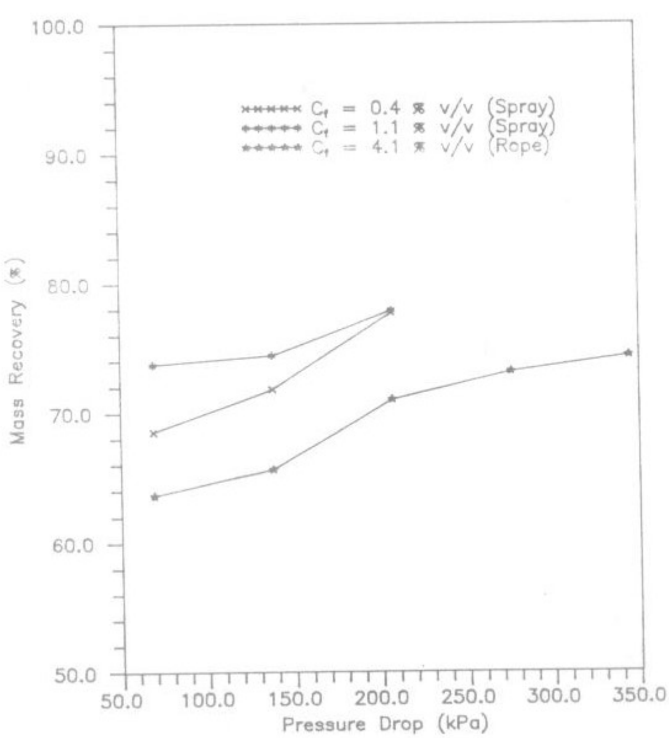

Fig. 5: Mass Recovery as a function of pressure drop.

Table 2: Underflow concentration observed at roping condition:

D_o/D_u	C_f	ΔP	C_u
[mm/mm]	[% v/v]	[KPa]	[% v/v]
11/3	4.1	68.9	28.4
14/3	2.5	137.8	31.0
14/4.5	6.6	206.7	31.0

Other authors [8,9] give the underflow concentration, at which roping may be expected to occur as ranging from 24.0% to 47.3% v/v [8] and 45% to 60% v/v [9].

3.3 *Effect of operating variables on the purity of the classified overflow product*

The mass flows of the individual particles was calculated using the relation.

$$M_o(d_p) = 0.017Q_{os}C_of_o(d_p) \tag{4}$$

Fig.6 and 7 give a comparison of the mass flow rates of individual particles between the condition of spraying and roping respectively. It can be seen in Fig.6 that a particle whose diameter is below 12μm, for example, is more enhanced (in terms of recovery to the overflow) as the pressure drop increases than a particle with a diameter greater than 12μm. Table 3 gives an illustration of fine particle enhancement for a particle of diameter 3.24μm, as an example.

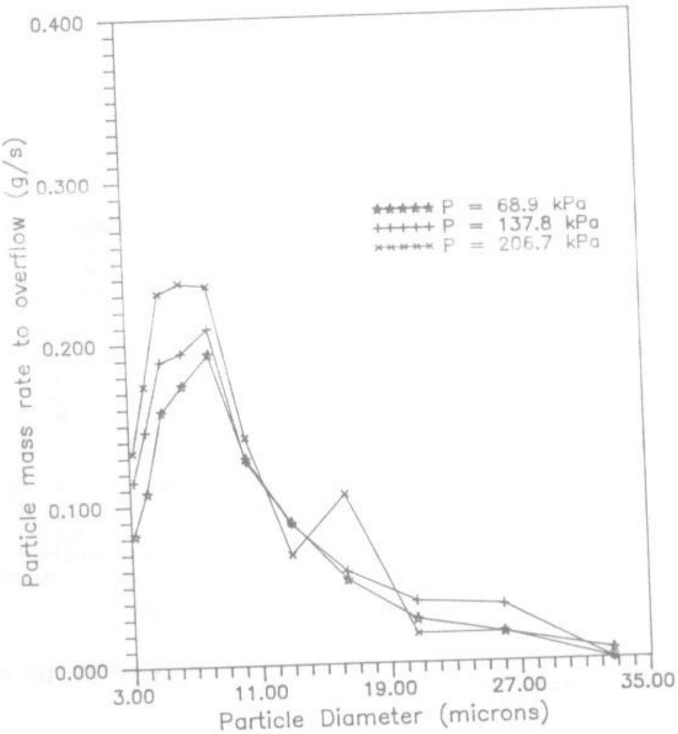

Fig.6: Mass flow rate of individual particles to overflow.

Table 3: Fine particles enhancement (data from Fig.6):

d_p	ΔP	$M_o(d_p)$	Increase
[μm]	[KPa]	[g/s]	[%]
3.24	68.9	0.082	-
3.24	137.8	0.115	40.0
3.24	206.7	0.133	60.0

Under the condition of roping, Fig.7, particles with diameters between 12μm and 24μm were equally enhanced as those below 12μm. The inability of the underflow apex to discharge all particles (at roping condition) causes some of the coarse particles to report to the overflow. Under this condition, it is not possible to obtain a relatively pure component lying below 12μm, for example,since it will be contaminated with coarse particles, e.g. 20μm particles. In the light of this, it can be said that, if the objective is to separate a mineral component confined in a given size range and it is further required that this component be less contaminated with particles greater than the desired size, high feed concentrations are undesired.

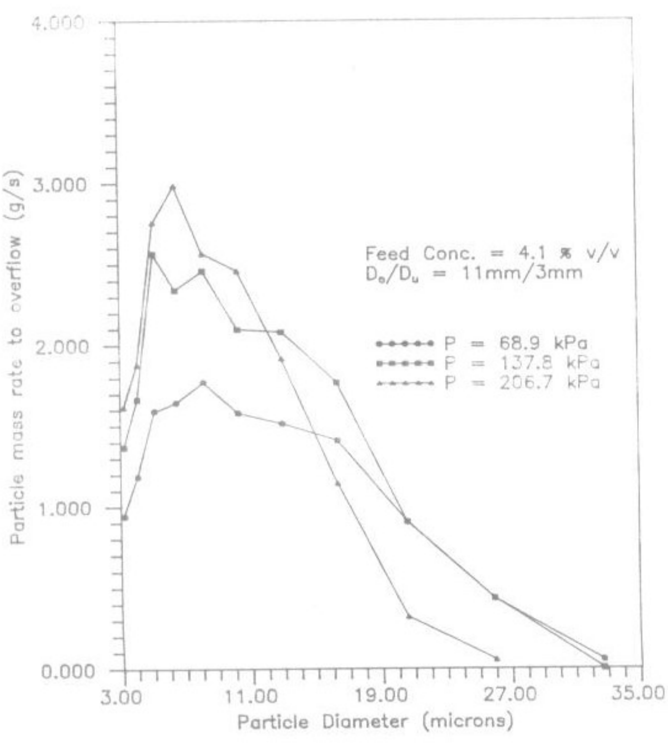

Fig.7: Mass flow rate of individual particles to overflow.

Fig.8 shows the effect of the size of the underflow diameter on fine particles recovery. It can be noted that there was substantial loss of particles between 8μm and 16μm. The percentage loss of 8.18μm and 10.3μm particles as the underflow diameters was changed from 3mm to 6.5mm is shown in Table 4.

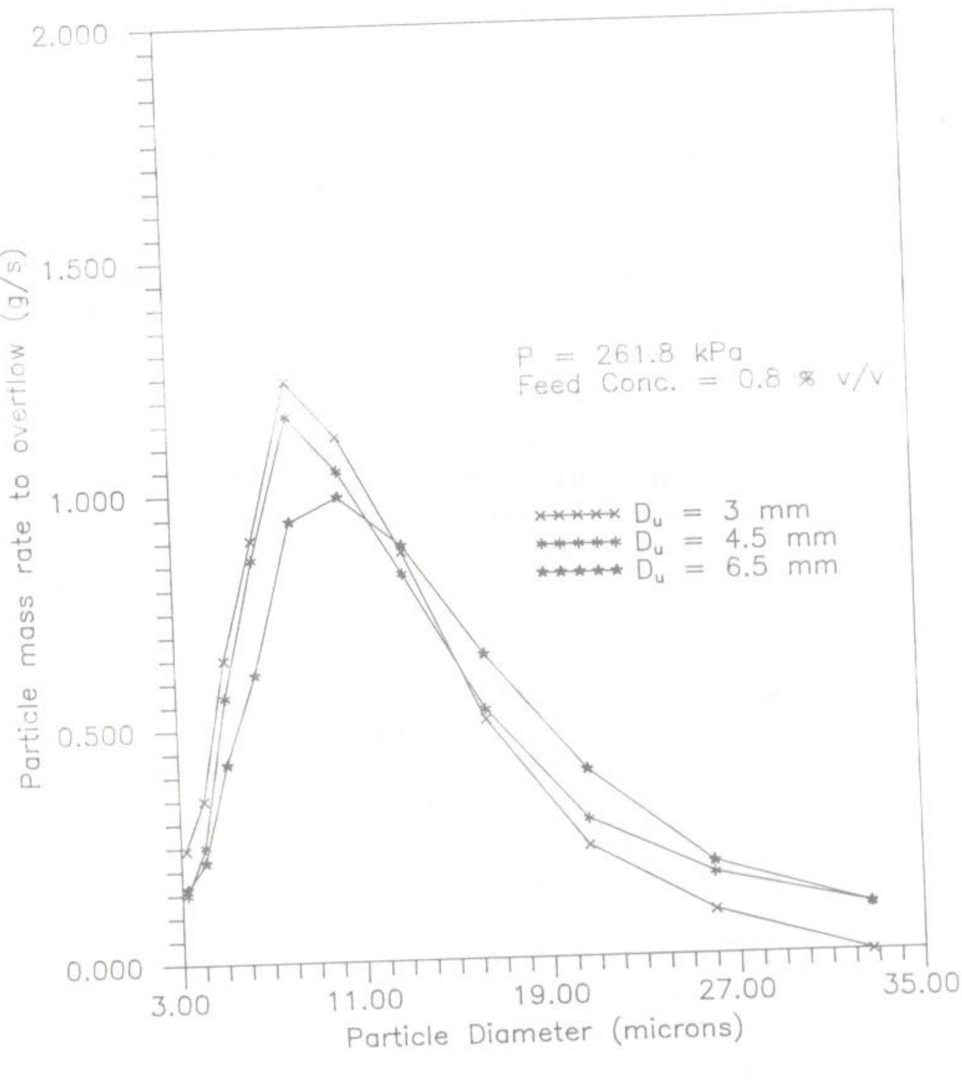

Fig.8: Mass flow rate of individual particles to overflow.

Table 4: Loss of fine particles to the underflow (data from Fig.8)

d_p [mum]	D_u [mm]	$M_o(d_p)$ [g/s]	Loss [%]
8.18	3.0	1.24	-
8.18	4.5	1.16	6.4
8.18	6.5	0.94	24.2
10.3	3.0	1.12	-
10.3	4.5	1.04	7.0
10.3	6.5	0.94	11.6

The data in Table 4 confirmed that, provided the feed solids content is not high, e.g less than 1%, fine particles recovery is high with small underflow diameters.

4.CONCLUSIONS

From the above discussion, the following conclusions were drawn.

For any given pressure drop, the hydrocyclone capacity was found to increase with feed solids concentration. Increasing the pressure drop, for the same concetration of the feed slurry, was also found to increase the hydrocyclone capacity.

The thickening capacity or total mass recovery of the hydrocyclone, was found to increase with pressure drop, for dilute feed slurries. Total mass recovery was also found to increase with feed slurry concentration, provided that the underflow discharge remained spray. At roping condition, the total mass recovery was found to drop.

Dilute feed slurries and small spigots gave better fine particles recovery to the overflow. High feed solids content which induced roping, caused the fine particles to be contaminated with large or coarse particles. Large spigots gave substantial loss of fine particles to the underflow due to water entrainment.

NOMENCLATURE

C_f, C_o, C_u	Solids concentration of feed, overflow, and underflow streams respectively, g/l
D_o, D_u	Vortex finder and Spigot diameters, m
d_p	Particle diameter, μm
E'_T	Total mass recovery, %
$f_o(d_p)$	Relative frequency of particles with diameter d_p in the overflow stream, %
K_s	A proportionality constant
$M_o(d_p)$	Flow rate of particles with diameter d_p in the overflow stream, g/s
ΔP	Pressure drop across the hydrocyclone, KPa
Q_{fs}, Q_{os}, Q_{us}	Flow rates of the feed, overflow and underflow streams, l/m
x	An index in eqn.2

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