

CHAPTER 5.

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

(a) Characterization of Overloading at the Sinks

- This study has established clearly that the onset of rope discharge at the sinks represents the point at which the maximum spigot capacity of the dense medium cyclone is reached.
- A critical sinks ore concentration at which spigot overloading occurs has been observed. The quantity of the sinks ore concentration during roping observed in this study was generally between 43 and 54% (v/v), depending on the spigot diameter and particle size distribution of the medium particles. This equates to sinks medium-to-ore ratios ranging from 0.9 to 1.3 (v/v) (Fig. 5.1). These values are in good agreement with those reported in the literature of 40% (v/v) and higher. Further, $\%V_{MSU}$ values for classification cyclones, ranging from 39% to 68% (v/v), reported in the literature are also in good agreement with those obtained in the current study. It is thought that $\%V_{MSU}$ values of around 60% and higher were probably a consequence of increased short-circuiting of fines to the underflow.

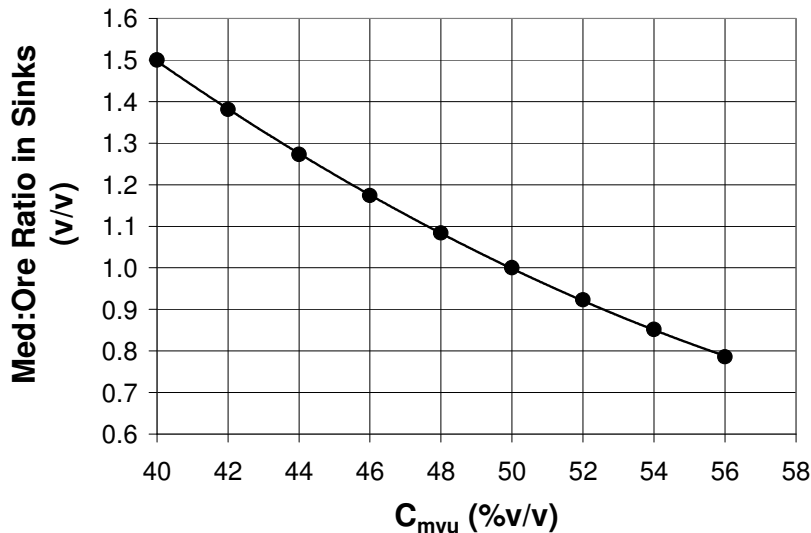


Figure 5.1. C_{mvu} expressed in terms of volumetric medium-to-ore ratio at the sinks.

- The sinks ore concentration during roping remained constant with further addition of ore into the cyclone with all the other variables unchanged. This is consistent with literature on both classification and dense medium cyclones. It has been established that the onset of spigot overloading can be predicted or anticipated by monitoring the volumetric underflow ore concentration.

- An argument that often arises with regard to anticipating the onset of roping is whether the feed ore concentration (or medium-to-ore ratio in the feed) could be used to predict the onset of roping. It is the author's opinion that the best (and simplest) indicator of the onset of roping is the volumetric sinks ore concentration. This can best be illustrated by considering an example of two hypothetical cyclones of the same dimensions, operating under the same conditions except that cyclone A is fed with silica only, and cyclone B with coal and silica. Assume that both cyclones are operating at a medium density above that of the coal and below that of the silica. If the two cyclones are allowed to reach the roping state the following is expected:
 - during roping the volumetric sinks ore concentration for both cyclones should be of similar quantities, however,
 - the feed concentration for cyclone A at the onset of roping would be less than that of cyclone B because of the coal present in the feed. Ideally all the coal should exit at the floats stream.
- During the onset of roping some of the sinks particles were indiscriminately misplaced to the floats stream. The same behaviour has previously been reported in the literature for both classification and dense medium cyclones. Moreover, there was no evidence of significant sinks particles misplacement to the float stream when a semi-rope discharge was prevalent at the spigot of both the 165mm and 350mm cyclones. Before roping commenced at the sinks, the cyclone still operated as a separation device, rather than a mass splitter, even close to the transition point from semi-rope to rope discharge. Further, the particle size distribution of the silica particles misplaced to the floats stream was exactly the same as that in the sinks stream. This behaviour was observed with both 165mm laboratory-scale and 350mm industrial-scale cyclones.
- Medium flow behaviour within the cyclone has been observed to govern the behaviour of various parameters of importance during the transition to roping, namely: the sinks ore concentration, slurry flow through the outlets, and the density differential. This was especially true at the onset of spigot overloading.

- R_m was consistently higher than R_f at R_f and R_m values below 0.6 during spray and semi-rope discharges. However, during roping R_f and R_m values were consistently almost always equal.
- The density differential was diminished during the transition to roping; the density differential was close or equal to zero when the cyclone was operated in roping conditions. The exception, obviously, being when the cyclone was operated with coarse magnetite particles. The density differential could possibly be useful in detecting and/or avoiding overloading of the spigot. Furthermore, the floats and sinks medium densities were observed to equal the feed medium density during roping.

(b) Effect of Cyclone Geometry on Spigot Capacity

- D_u was found to be the variable that influenced Q_{USM} and Q_{UM} the most. The nature of the relationship between Q_{UM} and Q_{USM} , and D_u , especially for the data obtained with the 165mm cyclone operating with the cone A, was in good agreement with the literature. This applies to both classification and dense medium cyclones. Q_{UM} was, however, less sensitive to changes in D_u for the relationship that included data from both the 165mm and 350mm cyclones. The change in the sensitivity of Q_{UM} to D_u at larger cyclone diameters was also reported by Jull (1972), and Mular and Jull (1978). C_{mvu} was found to increase slightly with increasing D_u , although the correlation was poor.
- There are strong indications that the cyclone diameter has a significant and independent influence on Q_{UM} . Thus, for a scenario in which two cyclones have the same D_u but different D , the one with a larger D should have a larger Q_{UM} given that the operating conditions are the same. This has serious implications for the case in which a choice must be made between one large cyclone or two smaller ones. Due to the independent effect of D_u and D , the two parameters that influence Q_{UM} the most (eq. 4.5), larger cyclones are expected to have disproportionately higher spigot capacities as compared to a combination of smaller cyclones. This is illustrated in Table 5.1. N is the number of cyclones required to reach the spigot ore capacity of a 350mm cyclone when using a combination of smaller cyclones or those with same D and a smaller D_u .

Table 5.1. Number of cyclones required to reach the spigot ore capacity of a 350mm cyclone when using a combination of smaller cyclones or those with smaller D_u .

D (mm)	D_u (mm)	Q_{UM} (l/hr ore)	$\frac{Q_{UM(350mm)}}{Q_{UM(D)}}$	N
165	45	3016*	5.46	6
200	60	5290*	3.11	4
250	75	8570*	1.92	2
350	60	7298	2.26	3
350	75	11884	1.39	2
350	100	16461*	1	1

* Calculated through equation 4.5, with $H = 10D$ and $\rho_{med} = 1.5\text{kg/l}$.

- Spigot design was observed to have a significant effect on the spigot capacity. Q_{USM} and Q_{UM} values obtained with cone B were higher than those obtained with cone A by about 20% and 16%, respectively. Both cones have an angle of 20° , the main difference between cone A and B is that cone A is 115mm longer (which results in increased resistance to flow). DSM design provides the least resistance to flow, and therefore should give higher spigot capacities.
- Q_{USM} and Q_{UM} increased significantly with increasing D_i . The effect of D_i on Q_{USM} and Q_{UM} was due to the increase in Q with increasing D_i . S_R , C_{mvu} and R_m were observed to be independent of changes in D_i in this study.
- Q_{USM} and Q_{UM} decreased slightly with increasing D_o . This effect is thought to be a consequence of the influence of D_o on Q and S_R . No correlation was found between D_o and C_{mvu} in the current study. On the contrary, Fahlstrom (1963) and Heiskanen (2000) observed $\%V_{MSU}$ to increase slightly with increasing D_u/D_o ratio. The results obtained in the current study seem to suggest that the increase in $\%V_{MSU}$ with increasing D_u/D_o reported by Fahlstrom (1963) and Heiskanen (2000) was probably due to the effect of the spigot diameter only.
- Differences in the spigot design of the cones employed obscured the effect, if any, of the cone angle on the spigot capacity. The results obtained to determine the effect of cone angle on spigot capacity were inconclusive.

- No correlation was found between Bl , and Q_{USM} and Q_{UM} . Further Q , S_R , C_{mvu} , and R_m were also found to be independent of changes in the barrel length.

(c) Effect of Operational Variables on Spigot Capacity

- Q_{USM} and Q_{UM} increased with increasing H , and the effect was relatively small. It is thought that the effect of H on Q_{USM} and Q_{UM} is a consequence of its influence on Q and S_R . No correlation was observed between H , and C_{mvu} .
- Q_{USM} and Q_{UM} decreased with increasing feed medium densities, and their sensitivity to ρ_{med} increased significantly at around $\rho_{med} \approx 1.5RD$. This behaviour was observed with data obtained with the 165mm cyclone (cone A only). Data obtained with the 350mm cyclone indicate that Q_{UM} to reach a maximum at around $\rho_{med} \approx 1.5RD$, beyond this medium density Q_{UM} decreased with increasing ρ_{med} . The density differential was also observed to reach a maximum and then decrease as ρ_{med} was increased. It is thought that the effect of ρ_{med} on Q_{USM} and Q_{UM} is related to changes in the medium rheology with increasing ρ_{med} .
- No correlation was found between medium grade and any of the following parameters: Q_{USM} , Q_{UM} , Q , S_R and R_m . Medium grade was, however, found to have a statistically significant effect on C_{mvu} at the 0.05 significance level, although the correlation was poor.
- There are indications that particle size has an influence on the spigot capacity and none on C_{mvu} , whilst the width of the particle size distribution has no influence on the spigot capacity but has an effect on C_{mvu} .

(d) Comparison with DSM

- Q_{UM} values obtained in this study were generally more than double those specified by DSM. A safety factor, defined as the difference between Q_{UM} values between the two investigations divided by the relevant Q_{UM} value from the current study, of about 60% was established. This factor was determined making use of data obtained from cyclones that were not geometrically similar, whilst DSM data was determined on geometrically

similar cyclones. It can, therefore, be concluded that there is large potential to increase the ‘spigot capacities’ specified by DSM. Especially considering that the cyclone still behaves as a separation device even close to the transition point from semi-rope to rope discharge. It is, however, not advisable to operate too close to this transition point because variations in the feed can easily lead to overloading.

- There are indications that DSM possibly defined their ‘spigot capacities’ as the maximum spigot loading that can be achieved before semi-rope commences. This notion is supported by the sinks ore concentrations (at the DSM specified ‘spigot capacities’), which were inferred from the DSM data and are consistent with semi-rope conditions. Further, the spigot loading (in l/hr ore) at the transition point from a spray to semi-rope discharge was about 40% of the maximum spigot capacity; this gave a safety factor of about 60%, which is consistent with that given above.
- Correction for the independent influence of cyclone diameter on Q_{UM} yielded a safety factor of about 50%, which is applicable to geometrically similar cyclone. Assuming that this safety factor of about 50% holds for all conditions, then the spigot ore capacities for the larger cyclones could be estimated as illustrated in Fig. 4.55 (repeated here for convenience). The extrapolated spigot ore capacities in Fig. 4.55 are at best estimates; experimental work is required to valid them.

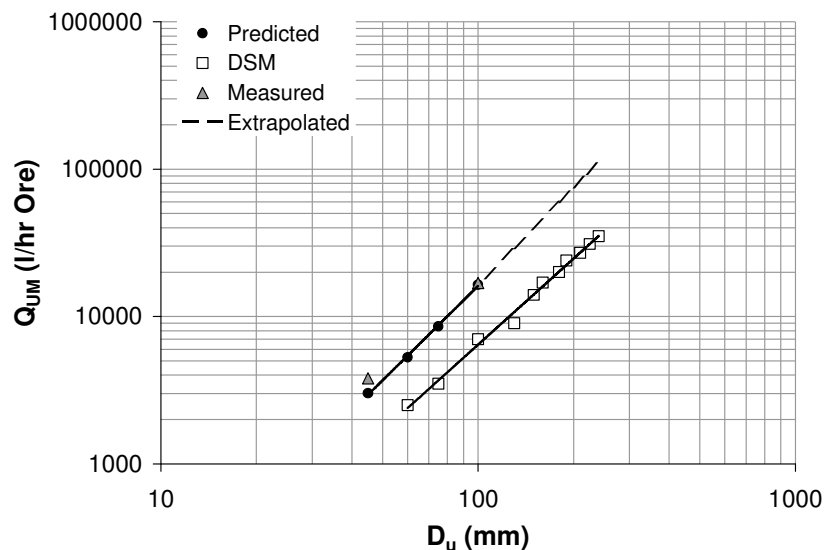


Figure 4.55. Comparison of Q_{UM} predicted from eq. 4.5 (to correct for effect of D) and those specified by DSM. Dashed line is extrapolation of eq. 4.11.

(e) Model

- The following empirical equations, based on a 165mm cyclone (cone A only), to predict spigot capacity (Q_{USM} and Q_{UM}) were developed in this investigation:

$$Q_{USM} = 0.394D_u^{2.09} D_o^{-0.14} D_i^{0.43} H^{0.36} \exp[-5.67(\rho_{med} - 1.45)^3] \quad (4.3)$$

$$Q_{UM} = 0.226D_u^{2.16} D_o^{-0.11} D_i^{0.38} H^{0.20} \exp[-7.59(\rho_{med} - 1.45)^3] \quad (4.4)$$

Only variables that were significant at the 95 percent confidence level were added to the regression equations. Inclusion of the data obtained with the 350mm dense medium cyclone into the regression analysis yielded the following expression:

$$Q_{UM} = 0.235D^{0.63} D_u^{1.53} H^{0.18} \exp[-1.58(\rho_{med} - 1.45)^2] \quad (4.5)$$

The quality of the fit was very good for these three expressions (Table 5.2).

Table 5.2. R^2 values for the various equations developed in the current study.

Equation No.	R^2
4.3	0.9805
4.4	0.9821
4.5	0.991
4.6	0.9446
4.7	0.9637
4.10	0.96

Furthermore, expressions to predict Q , S_R and R_m during roping were also developed:

$$Q = 64.72(D_u^2 + D_o^2)^{0.074} D_i^{0.90} H^{0.62} \rho_{med}^{0.18} \quad (4.6)$$

$$S_R = \frac{Q_{USM}}{Q_{OS}} = 10^{-4.52} D_u^{2.76} D_o^{-0.25} H^{-0.70} C_{vf}^{0.83} \quad (4.7)$$

$$R_m = 10^{-3.78} D_u^{1.96} D_o^{-0.25} H^{-0.17} C_{vf}^{0.52} \quad (4.10)$$

5.2. Recommendations

- Spigot overloading of a dense medium cyclone can be detected visually by observing the discharge type at the sinks and monitoring particle misplacement to the floats stream. The simplest and best indicator of possible spigot overloading is the sinks ore concentration, measurement of this parameter could, however, prove challenging on most industrial cyclones.
- It is important to consider the composition of the ore to be treated in the process of sizing and selection of dense medium cyclones. When the cyclone feed constitutes a high proportion of sinks particles there is a danger of overloading the spigot. It is the sinks ore concentration rather than feed concentration that is of importance in anticipating overloading at the sinks. The higher the proportion of sinks particles in cyclone feed the lower the feed ore concentration must be in order to avoid spigot overloading.
- There are essentially 5 ways in which the spigot capacity can be increased, and that is through D_u , D , D_i , H , and D_o .
 - D_u and D have the strongest influence on the spigot capacity. There is, however, a limitation on how much D_u can be increased; when D_u/D_o ratio is more than 85% the separation efficiency suffers according to DSM (1985).
 - D_i also presents a viable option to increase the capacity of a cyclone that is spigot constraint.
 - Spigot capacity can also be increased through H , although its influence is relatively weak.
 - Increasing the spigot capacity through D_o does not seem to be a reasonable option because this would be at the expense of the floats capacity and D_o 's influence on the spigot capacity is small. In cases where only a small portion of the ore in the feed exits through the floats stream, the use of D_o to increase the spigot capacity becomes an option because overloading at the floats would not be a concern any longer.
- There is strong case for the usage of large diameter cyclones because of the relatively strong, independent influence of D_u and D on the spigot capacity. The disproportionately

higher spigot capacities of large diameter cyclones allows for the operation of cyclones at relatively high medium-to-ore ratios while simultaneously achieving high capacities.

- Manufacturing of dense medium cyclones with an adjustable geometry seems to be worth considering given that the spigot capacity is determined mainly by the cyclone geometry. The necessary changes to the cyclone geometry can therefore be made to accommodate the character of the ore being treated.

CHAPTER 6. REFERENCES

Abbott, J. 1967a. The use of Bretby hydrocyclones for the thickening and recovery of fines- Part 1. *Coal Preparation*. March/April, pp. 53-61.

Abbott, J. 1967b. The use of Bretby hydrocyclones for the thickening and recovery of fines- Conclusion. *Coal Preparation*. May/June, pp. 97-104.

Aplan, F.F. 1985. Heavy Media Separations, Chapter. 4 in *SME Mineral Processing Handbook, Vol. 1*, edited by Weiss N.L. New York. SME/AIME. pp. 4-3 – 4-27.

Asomah, A.K. and Napier-Munn, T.J. 1997. An empirical model of hydrocyclones, incorporating angle of cyclone inclination. *Minerals Engineering*. Vol. 10, No. 3, pp. 339-347.

Bosman, J. 2003a. Latest developments in cyclone technology. *Trans. Instn. Min. Metall. (Sect. C: Mineral Process. Extr. Metall.)*. Vol. 112, pp. C10-12.

Bosman, J. 2003b. *Mineral Processing 411-Class Notes*. Department of Materials Science and Metallurgical Engineering. University of Pretoria.

Bradley, D. 1965. *The Hydrocyclone*. Oxford. Pergamon Press.

Clarkson, C.J., and Wood, C.J. 1993. Model of a dense medium cyclone performance. *Coal Preparation*. Vol. 12, pp. 101-115.

Cohen, E. and Isherwood, R.J. 1960. Principles of dense media separation in hydrocyclones. *International Mineral Processing Congress*. London. Inst. Min. Met. pp. 573-591.

Collins, B., Napier-Munn, T.J. and Sciarone, M. 1974. The production, properties, and selection of ferrosilicon powders for heavy-medium separation. *J of S. Afr. Inst. Min. Metall.* Vol. 75, pp. 103-119.

Collins, D.N., Turnbull, T., Wright, B.A. and Ngan, W. 1983. Separation efficiency in dense medium cyclones. *Trans. Instn. Min. Metall. (Sect. C: Mineral Process. Extr. Metall.)*. Vol. 92, pp. C38-51.

Concha, F., Barrientos, A., Montero, J., and Sampaio, R. 1996. Air core and roping in hydrocyclones. *Int. J. Miner. Process.* Vol. 44-45, pp. 743-749.

Dahlstrom, D.A. 1949. Cyclone operating factors and capacities on coal and refuse slurries. *Trans. AIME*. Vol. 184, pp. 331-344.

Darby, R. 1986. Hydrodynamics of slurries and suspensions. *Encyclopaedia of Fluid Mechanics, Vol. 5: Slurry Flow Technology*. Edited by N.P. Chermisinoff. pp. 49-92.

Davidson, M.R. 1995. An adaptive method of predicting the air core diameter for numerical models of hydrocyclone flow. *International Journal of Mineral Processing*. Vol. 43, No. 3-4, pp. 167-177.

Davis, J.J. and Napier-Munn, T.J. 1987. The influence of medium viscosity on the performance of dense medium cyclones in coal preparation. *3rd Int. Conf. on Hydrocyclones*. Oxford. BHRA. Paper F3, pp. 155-165.

de Korte, J.G. 2000. *Index of South African Coal Preparation Plants*.
<http://www.sacoalprep.co.za/information.htm> (Visited Feb. 2007)

DME, 2005. *Operating and developing coal mines in the Republic of South Africa*. Directorate: Mineral Economics, Department of Minerals and Energy, Republic of South Africa.

DSM. The heavy medium cyclone washery for minerals and coal. Dutch State Mines (DSM) Handbook.

DSM. 1985. Guide to the calculation of h.m. cyclone and w.o cyclone plants. Stamicarbon bv, Netherlands.

Dyakowski, T. and Williams, R. A. 1995. Prediction of air-core size and shape in a hydrocyclone. *Int. J. Miner. Process.* Vol. 43, No. 1-2, pp. 1-14.

Fahlstrom, P.H. 1963. Studies of hydrocyclone as a classifier. *Proc 6th Intl Min Proc Congress, Cannes*, edited by Roberts, A. Pergamon Press. pp. 87-114.

Flintoff, B.C., Plitt, L.R. and Turak, A.A. 1987. Cyclone modelling: a review of present technology. *CIM Bulletin.* Vol. 80, No. 905, pp. 39-50.

Frankel, N.A., and Acrivos, A. 1967. On the viscosity of a concentrated suspension of solid spheres. *Chem. Eng. Sci.* Vol. 22, pp. 847-853.

Grobler, P.J. 2006. The production and application of ferrosilicon in the mining industry. *DMS and Gravity Concentration Operations and Technology in South Africa*, Edited by M. Dworzanowski. pp. 153-162.

Gutiérrez, J. A., Dyakowski, T., Beck, M. S. and Williams, R. A. 2000. Using electrical impedance tomography for controlling hydrocyclone underflow discharge *Powder Technology.* Vol. 108, Issues 2-3. pp. 180-184.

He, Y.B., and Laskowski, J.S. 1995a. Dense medium cyclone separation of fine particles. Part 1: The effect of medium split ratio on dense medium cyclone performance. *Coal Preparation.* Vol. 16, pp. 1-25.

He, Y.B., and Laskowski, J.S. 1995b. Dense medium cyclone separation of fine particles. Part 2: The effect of medium composition on dense medium cyclone performance. *Coal Preparation.* Vol. 16, pp. 27-49.

Heiskanen, K. 2000. Experimental hydrocyclone roping models. *Chem. Eng. J.* Vol. 80, pp. 289-293.

Jull, N.A. 1972. Parameters for cyclone selection. *Proc. Canadian Mineral Processors.* Ottawa.

Kelly, E. G. and Spottiswood, D.J. 1989. *Introduction to Mineral Processing*. Mineral Engineering Services, Denver. pp. 213-232.

Kelly, E.G. 1991. The significance of by-pass in mineral separators. *Minerals Engineering*. Vol. 4, No. 1, pp. 1-7.

King, R.P. and Juckes, A.H. 1984. Cleaning of fine coals by dense medium hydrocyclone. *Powder Technology*. Vol. 40, pp. 147-160.

Leonard, J.W. IV and Leonard, J.W. 1983. Using Tromp curves to diagnose performance problems in coal cleaning. In *Basic Mathematics and Computer Techniques for Coal Preparation and Mining*, edited by K.K. Humphreys and J.W. Leonard. New York, Marcel Dekker, INC. pp. 71-79.

Leva, M. 1959. *Fluidization*. New York. McGraw-Hill Book Company, Inc. pp. 54 – 56.

Lynch, A.J. and Napier-Munn, T.J. 1986. Dense medium separation research at the Julius Kruttschnitt Mineral Research Centre. *Trans. Instn. Min. Metall. (Sect. C: Mineral Process. Extr. Metall.)*. Vol. 95, pp. C221-225.

Lynch, A.J. and Rao, T.C. 1975. Modelling and scale-up of hydrocyclone classifiers. *11th International Mineral Processing Congress*. Cagliari, Sardinia. pp. 245-269.

Lynch, A.J. and Rao, T.C. 1968. Studies on the operating characteristics of hydrocyclone classifiers. *Indian Journal of Technology*. Vol. 6, pp. 106-114.

Moorhead, R.G. and Schutte, A. 2005. Operating guidelines for low density-density dense-medium cyclone separations. Paper presented at *SA Coal Preparation Conference and Exhibition*.

Mular, A.L. and Jull, N.A. 1978. The selection of cyclone classifiers, pumps and pump boxes for grinding circuits. *Ch. 17 in Mineral Processing Plant Design*. Ed. A.L Mular and R.B. Bhappu. New York. SME/AIME. pp. 376-403.

Narasimha, M., Brennan, M. and Holtham, P.N. 2007. Prediction of magnetite segregation in dense medium cyclone using computational fluid dynamics technique. *Int. J. Miner. Process.* Vol. 82, Issue 1, pp. 41-56.

Napier-Munn, T.J. 1986. Pressure drop in dense medium cyclones. *Int. J. Min. Process.* Vol. 16, pp. 209-230.

Napier-Munn, T.J. 1990. The effect of dense medium viscosity on separation efficiency. *Coal Preparation.* Vol. 8, pp. 145-165.

Napier-Munn, T.J., Morrell, S., Morrison, R.D., and Kojovic, T. 1999. *Mineral Comminution Circuits - Their Operation and Optimisation.* Queensland, Australia. Julius Kruttschnitt Mineral Research Centre.

Neesse, Th., Dallman, W. and Espig, D. 1984. Effect of turbulence on the efficiency of separation in hydrocyclones at high feed solids concentrations. *2nd Int. Conf. on Hydrocyclones.* Bath. BHRA. pp. 51-66.

Neesse, Th., Schneider, M., Golyk, V., and Tiefel, H. 2004a. Measuring the operating state of the hydrocyclone. *Minerals Engineering.* Vol. 17. pp. 697-703.

Neesse, Th., Schneider, M., Dueck, J., Golyk, V. Butenbach, S., and Tiefel, H. 2004b. Hydrocyclone operation at the transition point rope/spray discharge. *Minerals Engineering.* Vol. 17. pp. 733-737.

Neesse, Th., Golyk, V., Kaniut, P., and Reinsch, V. 2004c. Hydrocyclone control in grinding circuits. *Minerals Engineering.* Vol. 17. pp. 1237-1240.

Neesse, Th., Tiefel, H., and Kaniut, P. 2007. Volume split control of a hydrocyclone group. *Minerals Engineering.* Vol. 20. pp. 355 -360.

Peatfield, D. 2003. Coal and coal preparation in South Africa – A 2002 review. *J of S. Afr. Inst. Min. Metall.* Vol. 103, No. 6, pp. 355-369.

- Plitt, LR. 1976. A mathematical model of the hydrocyclone classifier. *CIM Bulletin*. Vol. 69, No. 776. pp. 114-123.
- Plitt, L.R., Flintoff, B.C. and Stuffco, T.J. 1987. Roping in hydrocyclones. *3rd Int. Conf. on Hydrocyclones*. Oxford. BHRA. Paper A3, pp. 21-34.
- Podd, F. J. W., Schlaberg, H. I. and Hoyle, B. S. 2000. Model-based parameterisation of a hydrocyclone air-core. *Ultrasonics*. Vol. 38, No. 1-8, pp. 804-808.
- Qian, L. and Ji Run, X. 1992. The effect of the air core on the flow field within hydrocyclones. *Hydrocyclones – Analysis and applications*. Edited by L. Svarovsky and M.T. Thew. London, Kluwer Academic Publishers. pp. 51 – 62.
- Reeves, R.A. 2002. Types and characteristics of heavy-media separators and flowsheets. *Mineral Processing Plant Design, Practice, and Control: Proceedings*. Edited by Mular, A.L., Halbe, D.N. and Barrat, D.J. SME, New York. Vol. 1, pp. 962-977.
- Restarick, C.J. and Krnic, Z. 1991. The effect of underflow/overflow ratio on dense medium cyclone operation. *Minerals Engineering*. Vol. 4, No. 3/4, pp. 263-270.
- Scott, I. A. and Napier-Munn, T.J. 1990. A dense medium cyclone model for simulation. Paper presented at the *4th Samancor Symposium on Dense Media Separation*. Cairns, Australia.
- Scott, I. A. and Napier-Munn, T.J. 1992. Dense-medium cyclone model based on the pivot phenomenon. *Trans. Instn. Min. Metall. (Sect. C: Mineral Process. Extr. Metall.)*. Vol. 101, pp. C61-76.
- Smith, M.R. 1989. Metal powders for use in mineral separation processes. *Powder Metallurgy*, vol 32, No. 1, pp. 41-45.
- Stas, M. 1957. The influence of the orifices on the washing characteristics of the hydrocyclone. *International Mineral Dressing Congress*. Stockholm. pp. 161-192.

- Svarovsky, L. 1984. *Hydrocyclones*. Pennsylvania. Holt, Rinehart and Winston Ltd.
- Symonds, D.F. and Malbon, S. 2002. Sizing and selection of heavy media equipment: Design and layout. *Mineral Processing Plant Design, Practice, and Control: Proceedings*. Edited by Mular, A.L., Halbe, D.N. and Barrat, D.J. SME, New York. Vol. 1, pp. 1011-1033.
- Tarr, D.T. 1965. Practical application of liquid cyclone in mineral dressing problems. Preprint Fall Meeting AIME.
- Tarr, D.T. 1985. Hydrocyclones, Chapter. 3D in *SME Mineral Processing Handbook, Vol. 1*, edited by Weiss N.L. New York. SME/AIME, pp. 3D-10 – 3D-45.
- Trawinski, H. 1976. Theory, applications and practical operation of hydrocyclones. *Engineering and Mining Journal*. Vol. 177, No. 9, pp. 115-127.
- Upadrashta, K.R., and Venkateswarlu, D. 1982. Study of hydrocyclone as heavy media separator. *Journal of Powder and Bulk Solids Technology*. Vol. 6, No. 6, pp. 22-32.
- Van der Walt, P.J. 1950. Study of the operation of the cyclone washer and its application to Witbank fine coal. *J. Chem. Met. Min. Soc. S. Afr.* Vol. 51, pp. 19-103.
- Van Duijn, G. and Rietema, K. 1983. Performance of a large-cone angle hydrocyclone II: Separation properties. *Chemical Engineering Science*. Vol. 38, No. 10, pp. 1663-1673.
- Verghese, P.A., and Rao, T.C. 1994. Modelling of a 76mm diameter dense medium cyclone. *Coal Preparation*. Vol. 15, pp. 71-91.
- Williams, R.A., Ilyas, O.M., Dyakowski, T., Dickin, F.J., Guitierrez, J.A., Wang, M., Beck M.S., Shah, C., and Rushton, A., 1995. Air core imaging in cyclonic separators: implications for separator design and modelling. *Chem. Eng. J.* Vol. 56, pp.135-141.
- Wills, B. A. 1997. *Mineral Processing Technology: An introduction to the practical aspects of ore treatment and mineral recovery, Sixth Edition*. Butterworth-Heinemann, Oxford. pp. 192-213 and 237-257.

Wood, C.J., Davis, J.J., and Lyman, G. J. 1989. Towards a medium behaviour based performance model for coal-washing dense medium cyclones. *Coal Preparation*. Vol. 7, pp. 183-197.

Wood, C.J. 1990. *Coal-washing dense medium cyclones: A JKMRC Handbook for operators and plant designers*. JKMRC.

Yianatos, J.B., Lisboa, M.A., and Baeza, D.R. 2002. Grinding capacity enhancement by solid concentration control of hydrocyclone underflow. *Mineral Engineering*. Vol. 15, pp. 317-323.