Influence of Narrow Inclined Channels on Fine Particle Separations

A Thesis Submitted for the Degree of

Doctor of Philosophy

By

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Kelly Joel Walton

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Kevin P. Galvin

For
All those who didn't believe

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Abstract

The Reflux Classifier is an industrial technology that separates particles on the basis of size and / or density. It consists of a conventional vertical fluidised bed with a section of parallel inclined channels positioned above. The research described in this thesis is an examination of the effects of using “narrow” inclined channels (with widths as fine as 1.77 mm) on the performance of a Reflux Classifier.

The finest channels studied prior to this work were nominally 7 mm wide. The understanding of particle elutriation from these relatively wide inclined channels was developed by Laskovski *et al.* (2006). They noted that there was an increased preferential re-suspension of low density particles as the channel spacing narrowed. However, this re-suspension phenomenon was not fully investigated, thus, the mechanisms for this re-suspension were not fully understood or accounted for in their generalised correlation.

Experiments were performed in laboratory-scale vessels, with 1 m long channels, inclined at 70° to the horizontal. Channel widths from 18 mm down to 1.77 mm were investigated. Batch experiments were performed using well-defined feeds with particles of a single density (PVC, glass ballotini and ilmenite) and also using an industrial coal sample. It was found that: 1) relatively narrow channels produced a previously unobserved size suppression effect; and 2) the maximum particle size to channel width ratio for optimum performance was determined to be 0.33. A theoretical model, with no adjustable parameters, was developed which successfully predicted and explained the observed results. The main cause of the suppression of size effects is that when laminar

flow occurs in narrow channels, the effective fluid velocity experienced by the particles lying on the channel wall is proportional to their size.

Further experiments were performed in continuous mode with simultaneous feed addition, and underflow and overflow removal. A number of different industrial coal feeds were used. Comparing these results against those from the more traditional wider channelled Reflux Classifiers, it was demonstrated that the size suppression effect observed in batch narrow channel operations also occurred in continuous operations. The new narrow 5.5 mm channel Reflux Classifier was capable of processing an extended size range of - 2.0 mm + 0.25 mm while achieving a separation density of 1560 kg/m^3 and Ep of 0.062. Where Ep is a measure of how accurately the separation device performed, with an Ep of “0” being a perfect splitting of a stream over a point and an Ep of “1” showing that there was no preferential segregation in the splitting of the stream. The traditional wide 30 mm or 120 mm channel Reflux Classifier could only achieve for a similar separation density and feed size range of - 2.0 mm + 0.25 mm could only typically produce an Ep of 0.15 (55). While the narrow channels operate best at a capacity of 20 t/(m^{2}h), allowing significant separation down to 0.075 mm, increasing the processing rate of the classifier is possible, though at a diminished capacity. At 30 t/(m^{2}h) the narrow channel Reflux Classifier will competently process particles as fine as 0.125 mm and at throughputs of ~ 40 t/(m^{2}h) the channel Reflux Classifier would only be able to process a feed range of - 2 mm + 0.25 mm which is comparable to the maximum capacity of the more traditional wide channel Reflux Classifier.

A final set of continuous experiments were undertaken to investigate the performance of a two-stage operation in which a narrow 5.5 mm channel gravity Reflux Classifier performed an initial gravity separation and a second wider 12 mm channel Reflux Classifier performed a de-sliming step to remove the high ash content fines. It was concluded for the de-sliming vessel that a separation of less than 0.05 mm with a very low Ep (0.009), accounting for a variance of less than 0.02 mm between 25th and 75th pentiles of the curve, is achievable. It was discovered that: 1) the presence of a dense autogenuous bed seems to be detrimental to the operations of the de-sliming vessel; 2) without a bed present the superficial channel velocity is the primary controlling factor in particle elutriation; and 3) the processing area of the de-sliming vessel probably needs to be at least double that of its preceding continuous gravity Reflux Classifier.

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Nomenclature

Symbol	Description	Units
B	Depth of channel or vessel	m
C	Constant	$m^2.s^{-2}$
C_D	Coefficient of drag	-
C_{DNS}	Non-spherical Coefficient of drag	-
d	Diameter of a particle	m
d_{sph}	Diameter of a spherical particle	m
d_*	Non-spherical diameter	m
D	Dispersion Coefficient	-
D_h	The hydraulic width of channel, pipe or vessel	m
F	Throughput Advantage	-
F_G	Particles gravitational force	$m.s^2$
F_B	Particles buoyancy force	$m.s^2$
F_D	Particles drag force	$m.s^2$
F_f	Frictional force	$m.s^2$
g	Gravitational force	$m.s^2$
g_x	Gravitational force in the “x” direction	$m.s^2$
g_y	Gravitational force in the “y” direction	$m.s^2$
g_z	Gravitational force in the “z” direction	$m.s^2$
L	Length of the incline	m
L_f	Lift Force	N
n	Richard and Zaki constant	-

P	Pressure	$N.m^{-2}$
P_A	Particles acceleration	$m.s^2$
Re	Fluids Reynolds number	-
Re_P	Particles Reynolds number	-
Re_S	Shear Reynolds number	-
Re_{Sed}	Sedimentary Reynolds number	-
Re_{Sph}	Spherical Particle Reynolds number	-
Re_T	Particles velocity at terminal free settling Reynolds number	-
U_{CP}	Critical particle velocity	$m.s^{-1}$
U_C	Inclined channel velocity	$m.s^{-1}$
U_P	Particles velocity	$m.s^{-1}$
U'_P	Particles velocity in the inclined channel	$m.s^{-1}$
U_{HS}	Hindered settling particle velocity	$m.s^{-1}$
U_{seg}	Particle segregation velocity	$m.s^{-1}$
U_T	Particles velocity at terminal free settling	$m.s^{-1}$
U'_T	Particles terminal velocity in the inclined channel	$m.s^{-1}$
U_*	Non-spherical particle velocity	$m.s^{-1}$
U	Fluid velocity	$m.s^{-1}$
U'	Average Fluid Velocity	$m.s^{-1}$
U_I	Interstitial fluid velocity	$m.s^{-1}$
U_S	Fluid slip velocity	$m.s^{-1}$
U_x	Fluid velocity in the “x” direction	$m.s^{-1}$
U_y	Fluid velocity in the “y” direction	$m.s^{-1}$
U_z	Fluid velocity in the “z” direction	$m.s^{-1}$

V	Average fluid velocity	$m.s^{-1}$
x	Distance in the "x" direction	m
y	Distance in the "y" direction	m
z	Distance in the "z" direction	m
z'	Perpendicular distance between inclined channels	m

Greek Letters

Symbol	**Description**	**Units**
Δ	Change/difference	-
ϕ	Solids concentration	-
ϕ_{sph}	Sphericity of a particle	-
γ	Fluid shear rate	s^{-1}
η	Segregation Efficiency	-
μ	Viscosity	$N.s.m^{-2}$
μ_S	Suspension viscosity	$N.s.m^{-2}$
π	Pi	-
ρ_F	Fluid density	$kg.m^{-3}$
ρ_m	Fluidised medium density	$kg.m^{-3}$
ρ_P	Particle density	$kg.m^{-3}$
ρ_s	Suspension density	$kg.m^{-3}$
∂	Partial differential operator	-