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Numerical simulation of particulate-flow in spiral separators: Part I. Low solids concentration (0.3% & 3% solids)

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ABSTRACT

The aim of the present study is the simulation of the particulate flow in spiral separators. The study is based on Eulerian approach and turbulence modeling. The results focus on particulate-flow characteristics such as the velocity, the distribution, and concentration of particulates on the spiral trough. The predicted results are compared with the experimental findings from *LD9* coal spiral. The comparison shows good agreement and indicates that the most accurate turbulence model is *RNG* K–ε.

1. Introduction

The spiral concentrator is considered as one of the most efficient and simple operating units for processing of minerals and coals. Because of its relative simplicity and high efficiency, it is widely used under a variety of circuit configurations. Since, their first-introduction by Humphreys in the 1940s, spirals have proved to be a cost effective and an efficient means of concentrating a variety of ores. Spirals are environment friendly, rugged, compact and cost effective. Most of the publications concerning spirals focused on their design and operation. Wills [1] presented a comprehensive review of such papers within the period from 1940s until the mid 1980s. It is clear that most spiral designs were evolved through empirical analysis. Many empirical models, which are based on experimental data, are stated. The drawback of these empirical models is that if the type of spiral, the minerals or the particle-size range are changed, new experimental data must be collected to modify the coefficients or even to change the mathematical model itself.

A fluid-flow mechanistic model is based on fluid mechanics equations. A mechanistic model incorporates the geometry of the device in the model. These models were started by Burch [2] when he assumed the pulp to be a liquid of uniform viscosity. He also assumed that the secondary flow would not affect the primary flow. Wang and Andrews [3] introduced a first step in the development of a mechanistic model of the spiral operation. The model determines the flow fields for simplified rectangular spiral sections. Jancar et al. [4,5] investigated the fluid flow on *LD9* spiral using their developed code. All these models were developed with time to be more reliable. Mathews et al. [6,7] presented *CFD* modeling of the fluid flow on a

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Nomenclature

C_1, C_2, P_m, P_{kk}, C_m, C_{kk} constants and parameters of *RSM* turbulence model
$C_{1\varepsilon}$, $C_{2\varepsilon}$, C_μ constants of k–ε turbulence model
C_{ij} convection term, *RSM*
C_D drag coefficient, (*dimensionless*)
$C_{fr,ls}$ coefficient of friction between solid phase particles
$D_{T,ij}$ turbulent diffusion term, *RSM*
$D_{L,ij}$ molecular diffusion term, *RSM*
d_s diameter of particles of phase (m)
e_{ls} the coefficient of restitution.
e_{ss} the coefficient of restitution for particle, (*dimensionless*)
F_{lift} lift force (N)
f different exchange coefficient models (*dimensionless*)
G_k generation of turbulence kinetic energy
G_ω generation of ω
$\vec{g}$ gravitational acceleration
H spiral height (m)
h height loss (m)
$\tilde{k}_c$ turbulent kinetic energy of continuous phase
L spiral separator length (m)
$L(r)$ mainstream distance (m)
L_c characteristic length (m)
m_p, m_q masses of particles p & q (kg)
n number of turns of spiral separator
n_p, n_q number of particles
P_{ij} stress production term, *RSM*
Q_{water} water flow rate (m^3/hr)
R angular distance in the mainstream direction from the spiral inlet (m)
Re Reynolds number (*dimensionless*)
R_{ls}, R_{sl} interaction force between phases
R_ε mean rate of strain, *RNG* k–ε model
r radial distance from centerline axis (m)
r_i inner radius (m)
r_o outer radius (m)
S modulus of the mean rate of strain tensor, *RNG* k–ε model
t_s time per a single iteration (S)
$t*$ non-dimensional time = $\left(t^* = \frac{U_{in} t_s}{L_c}\right)$
T_i turbulence intensity
U_{in} inlet velocity (m/s)
u spiral separator pitch (m)
$(-\rho\overline{u_i'u_j'})$ Reynolds stresses
$\vec{v}$ velocity vector
W trough width = $(r_o - r_i)$ (m)
x mainstream direction
x-velocity primary velocity (m/s)
Y_k and Y_ω dissipation of k and ω due to turbulence, *SST* k–ω model
y cross-stream direction.
y-velocity secondary velocity (m/s)
z depth-wise direction

Greek
α volume fraction
$\alpha(r)$ spiral separator descent angle (°)
$\alpha*$, a_1, σ_k, σ_ω *SST* k–ω model constants.
δ_{ij} Kronecker delta
ε=e kinetic energy dissipation rate
ε_{ij} dissipation term, *RSM*
θ_s granular temperature (K)
ϕ_{ij} pressure strain term, *RSM*
$\phi_{ij,w}$ wall-reflection term, *RSM*