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Increasing the capacity of Australian raw sugar factory milling units

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Abstract

This thesis reports on an investigation to identify methods to increase the capacity or throughput of the six-roll roller mills used in Australia to extract sugar from sugarcane. The approach taken was to gain an understanding of the factors affecting mill throughput through the application of the computational milling model, developed in recent years at James Cook University. The computational milling model is based on general equations of force equilibrium and continuity and a general description of sugarcane material behaviour.

The development of the throughput model was conducted in stages. Firstly, an experiment was conducted on a laboratory two-roll mill to gain an understanding of the factors affecting throughput on this simple milling geometry. A two-roll computational model was constructed to predict the observed behaviour, accounting for all mechanisms identified from the experimental results. Secondly, a three-roll computational model was constructed which was sufficient to describe the throughput behaviour of the factory six-roll mill. An experiment was conducted on a factory six-roll mill to provide data to validate the model. The three-roll computational model was tested across the range of geometries and operating conditions known to exist in Australian factories and its throughput predictions were tested against throughput measurements.

The three-roll computational model was used to identify the main factors affecting mill throughput and was used to construct a data set across a wide range of parameter values. The data set was used in a multiple regression analysis to develop an empirical model that could readily be used to identify conditions for maximum throughput.

The computational and empirical models developed during this investigation were shown to predict throughput better than existing models. Conditions for maximum

throughput were identified and involved the openings between rolls, the speed of the rolls and the amount of water in the sugarcane material being processed.

As part of the investigation, further development of the computational milling model was undertaken in order to advance the model to a sufficient standard for this investigation. A material parameter was introduced to define the hardening rule for the plastic material model following established soil mechanics methodology. Darcy's law, describing fluid flow through porous media, was shown to adequately describe the flow of water through bagasse for a wide range of fluid velocities. Greater confidence in the measured magnitude of the permeability factor in Darcy's law was gained through improved experimental and parameter estimation procedures. One of the experimental and parameter estimation procedures was found to significantly reduce the time involved in measuring both the hardening rule for the plastic material model and the permeability for Darcy's law.

Contents

Tables

Figures

Symbols

A	Cross-sectional area
A_T	Total cross-sectional area
C_0	Compression ratio
D	Mean roll diameter
D'	Outside roll diameter
D_i	Inside diameter
D_p	Pressure feeder roll mean diameter
D_p'	Pressure feeder roll outside diameter
E	Effectiveness
F	Total frictional force
F	Yield surface
F_F	Tangential force component
F_H	Horizontal force component
F_N	Normal force component
F_V	Vertical force component
F_{b0}	Initial force at bottom of sample
F_c	Cap yield surface
F_s	Shear yield surface
F_{t0}	Initial force at top of sample
G	Plastic potential surface
$\hat{G}$	Shear modulus
G_c	Cap plastic potential surface
G_p	Pressure feeder torque
G_s	Shear plastic potential surface
G_u	Underfeed roll torque
H	Height of a strip of bagasse in the feed chute

H_1	Height of bagasse in the feed chute
H_2	Total height of feed chute
K	Bulk modulus
K_0	Ratio of transverse to axial pressure
L	Roll length
M	Slope of the critical state line
P	Pressure of fluid
P_a	Bagasse feed pressure
P_b	Pressure in bagasse
P_d	Bagasse pressure in feed chute
P_{dH1}	Bagasse pressure in feed chute at height H_1
P_{do}	Bagasse pressure at the feed chute exit
P_{sp}	Hydraulic pressure on pressure feeder drive
P_{su}	Hydraulic pressure on underfeed roll drive
p_t	Intercept of shear surface on p axis
p_t^e	Elastic tensile limit
$P_{v\theta}$	Vertical pressure in bagasse at an angle θ from the nip
Q	Total mass rate
Q_c	Cane rate
Q_{cf}	Cane fibre rate
Q_f	Fibre rate
Q_f^*	Theoretical maximum fibre rate for a pressure feeder
R	Cap eccentricity parameter
S	Roll surface speed (based on mean diameter)
S'	Roll surface speed (based on outside diameter)
S_F	Bagasse feed speed at entry plane
S_p	Top pressure feeder roll surface speed
S_p'	Top pressure feeder surface speed at outside diameter
U	Feed chute position offset
V	Volume
V_0	No-void volume

V_E	Escribed volume
V_g	Volume of solid
V_v	Volume of voids
W	Nip work opening
W_p	Pressure feeder nip work opening
W_s	Nip setting
W_{sp}	Pressure feeder nip setting
W_{su}	Underfeed nip setting
W_{su}^*	Underfeed nip setting for maximum throughput
W_{sua}	Underfeed nip setting relative to setting for maximum throughput
W_{sup}	Setting between underfeed roll and bottom pressure feeder roll
W_u	Underfeed nip work opening
Z	Level of cane preparation
a	Regression constant
b	Regression constant
c_i	Regression constants where i is a positive integer
d	Related to material cohesion
d_g	Roll groove depth
e	Void ratio
e_0	Void ratio at reference volume
f	Fibre fraction
f_c	Fibre fraction in cane
f_d	Fibre content of bagasse in feed chute (accounting for imbibition)
g	Acceleration due to gravity
h	Chute setting
h^*	Theoretical feed chute setting for maximum throughput of pressure feeder rolls
h_d	Feed chute setting
h_{do}	Feed chute exit setting
h_{do}^*	Feed chute exit setting for maximum throughput
h_{doa}	Feed chute exit setting relative to setting for maximum throughput
k	Intrinsic permeability

k_i, $i = 1, 2$	Permeability parameter
l	Length of bagasse mat
m	Mass
n	Porosity
n_R	Number of rolls in a milling train
p	Pressure stress
p_a	Pressure stress at maximum cap height
p_b	Hydrostatic compression yield strength
q	Deviator stress
r_M	Murry's feed speed ratio
t	Time
v_i, $i = x, y$ or z	Velocity component of fluid
w	Material coordinate
x	Cartesian coordinate
y	Cartesian coordinate
α	Contact angle (based on mean diameter)
α'	Contact angle (based on outside diameter)
α_{do}'	Contact angle between feed chute and rolls forming underfeed nip
β	Related to material angle of friction
ε_a	Axial strain component
ε_{ij}, $i, j = x, y$ or z	Strain component
ε_p	Volumetric strain
ε_q	Deviatoric strain
ε^e	Elastic strain
ε^p	Plastic strain
γ	Compaction
γ_α	Compaction of bagasse at entry plane
γ_d	Compaction in feed chute
γ_{do}	Compaction at the feed chute exit
η	Ratio of deviatoric to mean stress components

φ	Angle of nip
κ	Logarithmic bulk modulus
λ	Hardening rule size parameter
λ_1	Hardening rule size parameter
μ	Coefficient of friction
μ'	Ratio of tangential force to normal force
μ_v	Absolute or dynamic viscosity
ν	Poisson's ratio
θ	Angle
ρ	Bulk density
ρ_α	Bulk density at entry plane
ρ_f	Density of fibre
ρ_j	Density of juice
ρ_w	Density of fluid
σ_a	Axial stress component
σ_{ao}	Initial axial stress component
σ_{ij}, $i, j = x, y$ or z	Total stress component
σ'_{ij}, $i, j = x, y$ or z	Effective stress component
σ'_{zz0}	Initial axial effective stress component
ω	Roll angular velocity
ψ	Chute angle
z	Cartesian coordinate
z_0	Initial height