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# ***Increasing the capacity of Australian raw sugar factory milling units***

Thesis submitted by

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in September 2003

for the degree of Doctor of Philosophy  
in the School of Engineering (Mechanical Engineering)  
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# ***Acknowledgements***

Firstly, the author wishes to thank the late Dr Rod Murry and Dr Vic Mason and Dr Ray Scott, both formerly of the Sugar Research Institute, for their encouragement to commence this investigation. The author also thanks Dr Terry Dixon and Dr Graeme Bullock of the Sugar Research Institute for their ongoing support throughout the investigation.

Secondly, Mr Rod Cullen, formerly of Bundaberg Sugar Limited, is acknowledged for suggesting the topic for this investigation.

Thirdly, the author sincerely thanks the Sugar Research and Development Corporation and the member mills of the Sugar Research Institute; in particular, CSR Limited, Mackay Sugar Co-operative Association Limited, Mulgrave Central Mill Company Limited, Tully Sugar Limited, Proserpine Co-operative Sugar Milling Association Limited, Maryborough Sugar Factory Limited, NSW Sugar Milling Co-operative Limited, Mossman Central Mill Company Limited and Isis Central Mill Company Limited; for their financial support of this project.

Fourthly, the author wishes to thank those who assisted in the experimental investigations that formed part of this investigation. Mr Neil McKenzie of the Sugar Research Institute, Dr Con Doolan, Mrs Linda Dixon-Kelso and Miss Lyn Forsell, formerly of the Sugar Research Institute and the staff of Mulgrave, South Johnstone, Invicta, Inkerman, Plane Creek and Isis factories are acknowledged for their assistance in the factory effectiveness survey. Mr Neil McKenzie, Mr John Williams and the late Mr Allan Connor of the Sugar Research Institute are acknowledged for their assistance in the permeability investigation. Mr Neil McKenzie and Mr John Williams of the Sugar Research Institute, Miss Kristine Strohfeldt and Mr Andrew Zammit formerly of the Sugar Research Institute and Mr Dave Kauppila and Mr Arasu Kannapiran of James

Cook University are acknowledged for their assistance with the two-roll mill experiment. Mr Neil McKenzie of the Sugar Research Institute, Miss Letitia Langens formerly of the Sugar Research Institute and Mr Kevin Wardrop, Mr Bob Watters, Mr Jeff King Koi and the staff of Mulgrave Central Mill Company Limited for their assistance with the factory mill experiment.

Fifthly, the author thanks his supervisors A/Prof Jeff Loughran of James Cook University and Dr Vic Mason formerly of the Sugar Research Institute, along with Dr Mac Kirby of CSIRO, Dr Floren Plaza and Dr Matt Schembri of the Sugar Research Institute, Dr Chris Downing formerly of the Sugar Research Institute, Dr Clayton Adam formerly of Queensland University of Technology and Mr Tom Davis, Mr John Sawyer and Mr John Li of Worley FEA for the fruitful discussions and advice received throughout this investigation.

Lastly, the author thanks his wife Karen and children Natasha and Christopher for their support and encouragement throughout this long investigation.

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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.

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# Contents

<b>Statement of access</b> .....	<b>ii</b>
<b>Electronic copy</b> .....	<b>iii</b>
<b>Statement of sources</b> .....	<b>iv</b>
<b>Acknowledgements</b> .....	<b>v</b>
<b>Abstract</b> .....	<b>vii</b>
<b>Contents</b> .....	<b>ix</b>
<b>Tables</b> .....	<b>xvi</b>
<b>Figures</b> .....	<b>xviii</b>
<b>Symbols</b> .....	<b>xxiv</b>
<b>1 Introduction</b> .....	<b>1</b>
1.1 Introductory remarks.....	1
1.2 Overview of the milling process and milling equipment.....	1
1.2.1 Description of sugarcane .....	1
1.2.2 Description of the milling process .....	3
1.2.3 Description of a milling unit.....	5
1.2.4 Definition of milling terms .....	7
1.3 The need to increase milling unit capacity.....	12
1.3.1 The Australian raw sugar industry.....	12
1.3.2 Maintaining industry viability .....	13
1.3.3 The path to processing larger crops .....	14
1.3.4 Increasing milling unit capacity.....	14
1.4 Overview of the thesis.....	14
1.5 Concluding remarks .....	16
<b>2 Mill throughput literature review</b> .....	<b>17</b>
2.1 Introductory remarks.....	17
2.2 Review of sugarcane milling unit throughput.....	17
2.2.1 Introductory remarks.....	17

2.2.2	Empirical models .....	18
2.2.3	The two-roll mill .....	19
2.2.4	Extending the two-roll mill theory to more complex milling geometry .....	25
2.2.5	The six-roll mill .....	26
2.2.6	Concluding remarks .....	29
2.3	Review of milling unit throughput research outside the sugarcane industry .....	29
2.3.1	Introductory remarks .....	29
2.3.2	Roller mill applications .....	30
2.3.3	Throughput models for roller mills .....	30
2.3.4	Concluding remarks .....	32
2.4	The milling computational model .....	32
2.5	Concluding remarks .....	33
<b>3</b>	<b>Evaluation of the Jenkins and Murry feeding model.....</b>	<b>34</b>
3.1	Introductory remarks .....	34
3.2	Measuring the effectiveness of factory milling units .....	35
3.3	Factory effectiveness measurements .....	37
3.4	Performance of the Jenkins and Murry model .....	38
3.5	Concluding remarks .....	41
<b>4</b>	<b>Foundations of a new feeding model.....</b>	<b>42</b>
4.1	Introductory remarks .....	42
4.2	Overview of the model .....	42
4.3	A porous media description for bagasse .....	43
4.4	Force equilibrium .....	44
4.5	Fluid continuity .....	46
4.6	Principle of effective stress .....	48
4.7	Constitutive behaviour of the solid phase .....	49
4.7.1	Introductory remarks .....	49
4.7.2	General description of a constitutive model .....	50
4.7.3	Elastic behaviour .....	52
4.7.4	Shape of the yield and plastic potential surfaces .....	53
4.7.5	Size of the yield and plastic potential surfaces .....	56

4.8	Constitutive behaviour of the fluid phase .....	60
4.9	Concluding remarks .....	61
<b>5</b>	<b>Determination of material parameters for the new feeding model.....</b>	<b>62</b>
5.1	Introductory remarks.....	62
5.2	Material parameters for the solid phase .....	63
5.2.1	Introductory remarks.....	63
5.2.2	Apparatus .....	64
5.2.3	Experimental method.....	67
5.2.4	The parameter estimation process.....	67
5.2.5	An example of the parameter estimation process .....	73
5.2.6	Concluding remarks .....	78
5.3	Material parameters for the fluid phase – steady state method.....	78
5.3.1	Introductory remarks.....	78
5.3.2	Apparatus .....	79
5.3.3	Experimental method.....	81
5.3.4	The parameter estimation process.....	81
5.3.5	An example of the parameter estimation process .....	83
5.3.6	Concluding remarks .....	86
5.4	Material parameters for the fluid phase – indirect method .....	87
5.4.1	Introductory remarks.....	87
5.4.2	Apparatus .....	87
5.4.3	Experimental method.....	88
5.4.4	The parameter estimation process.....	88
5.4.5	An example of the parameter estimation process .....	93
5.4.6	Concluding remarks .....	96
5.5	Effect of test method on permeability .....	97
5.5.1	Introductory remarks.....	97
5.5.2	Experimental materials .....	97
5.5.3	The steady state permeability measurement experiment .....	98
5.5.4	The transient permeability measurement experiment.....	100
5.5.5	Comparison of results .....	102
5.5.6	Concluding remarks .....	103
5.6	Concluding remarks .....	103

<b>6</b>	<b>Mill feeding in a two-roll mill without juice expression.....</b>	<b>106</b>
6.1	Introductory remarks.....	106
6.2	Features of the two-roll mill.....	107
6.3	An experiment without juice expression.....	109
6.3.1	Introductory remarks.....	109
6.3.2	Apparatus.....	109
6.3.3	Experimental design.....	111
6.3.4	Procedure.....	111
6.3.5	Results.....	112
6.3.6	Discussion of feed speed results.....	124
6.3.7	Discussion of roll load results.....	132
6.3.8	Concluding remarks.....	133
6.4	Material parameters for modelling the experiment without juice expression.....	135
6.4.1	Introductory remarks.....	135
6.4.2	Material parameters for the solid phase.....	135
6.4.3	Material parameters for the fluid phase.....	141
6.4.4	Concluding remarks.....	144
6.5	Modelling the experiment without juice expression.....	145
6.5.1	Introductory remarks.....	145
6.5.2	Model details.....	146
6.5.3	Model results.....	152
6.5.4	Using the model to explore mill feeding behaviour.....	155
6.5.5	Concluding remarks.....	166
6.6	Concluding remarks.....	166
<b>7</b>	<b>Mill feeding in a two-roll mill with juice expression .....</b>	<b>168</b>
7.1	Introductory remarks.....	168
7.2	Review of Solomon’s experiments.....	169
7.2.1	Introductory remarks.....	169
7.2.2	Comments on experimental design.....	170
7.2.3	Analysis of results.....	171
7.2.4	Concluding remarks.....	179

7.3	Comparing Solomon’s results to the results of the experiment without juice expression.....	180
7.4	Modelling the two-roll mill with juice expression.....	181
7.5	Concluding remarks .....	182
<b>8</b>	<b>Modelling mill feeding in a factory milling unit .....</b>	<b>183</b>
8.1	Introductory remarks.....	183
8.2	Features of the factory milling unit.....	184
8.3	A computational feeding model.....	187
8.3.1	Introductory remarks.....	187
8.3.2	Geometry .....	187
8.3.3	Material parameters .....	189
8.3.4	Boundary and initial conditions.....	190
8.3.5	Feed speed calculation .....	191
8.3.6	Concluding remarks.....	191
8.4	Modelling Jenkins and Murry’s small-scale experiments.....	191
8.4.1	Introductory remarks.....	191
8.4.2	Analysis of results.....	192
8.4.3	Modelling Jenkins and Murry’s small-scale experiments .....	195
8.4.4	Concluding remarks.....	197
8.5	Modelling Jenkins and Murry’s factory experiment.....	198
8.5.1	Introductory remarks.....	198
8.5.2	Analysis of results.....	198
8.5.3	Modelling the experiment.....	199
8.5.4	Concluding remarks.....	200
8.6	Modelling a new factory experiment .....	201
8.6.1	Introductory remarks.....	201
8.6.2	Apparatus .....	201
8.6.3	Experimental design .....	206
8.6.4	Procedure .....	208
8.6.5	Results.....	209
8.6.6	Discussion of experimental results .....	213
8.6.7	Material parameters for modelling the factory experiment .....	214
8.6.8	Modelling the factory experiment.....	214

	8.6.9 Concluding remarks .....	216
	8.7 Concluding remarks .....	216
<b>9</b>	<b>Using the new feeding model .....</b>	<b>217</b>
	9.1 Introductory remarks .....	217
	9.2 Sensitivity analysis .....	217
	9.2.1 Introductory remarks .....	217
	9.2.2 Sensitivity to material parameters and initial and boundary conditions .....	218
	9.2.3 Sensitivity to geometry .....	220
	9.2.4 A final sensitivity analysis .....	222
	9.2.5 Concluding remarks .....	223
	9.3 Comparison with Jenkins and Murry model .....	224
	9.4 Concluding remarks .....	228
	9.5 Concluding remarks .....	229
<b>10</b>	<b>Avenues for increasing the capacity of Australian raw sugar factory milling units.....</b>	<b>230</b>
	10.1 Introductory remarks .....	230
	10.2 An empirical feeding model .....	231
	10.2.1 A data set for developing the new empirical feeding model .....	231
	10.2.2 The new empirical feeding model .....	232
	10.2.3 Testing the new empirical feeding model .....	233
	10.2.4 Concluding remarks .....	235
	10.3 Conditions for maximum throughput .....	236
	10.3.1 Introductory remarks .....	236
	10.3.2 Effect of underfeed nip setting on effectiveness .....	237
	10.3.3 Effect of underfeed roll speed on effectiveness .....	240
	10.3.4 Effect of fibre content on effectiveness .....	241
	10.3.5 Concluding remarks .....	242
	10.4 Understanding the conditions for maximum throughput .....	243
	10.4.1 Introductory remarks .....	243
	10.4.2 Comparing laboratory two-roll mill results to factory six-roll mill results .....	243
	10.4.3 The underfeed roll effect .....	246

10.4.4	Concluding remarks .....	248
10.5	Concluding remarks .....	249
<b>11</b>	<b>General discussion and conclusions .....</b>	<b>251</b>
11.1	Introductory remarks .....	251
11.2	Aim of the research .....	251
11.3	Summary and conclusions of the research .....	251
11.3.1	Previous throughput models .....	251
11.3.2	The new feeding model.....	252
11.3.3	Testing the new feeding model.....	255
11.3.4	Insights into the feeding process.....	256
11.3.5	Increasing milling unit capacity.....	258
11.4	Significance of the research .....	259
11.4.1	Introductory remarks.....	259
11.4.2	Extraction benefits .....	259
11.4.3	Deferral of capital expenditure .....	260
11.5	Recommendations for future research .....	260
11.6	Concluding remarks .....	261
	<b>References.....</b>	<b>263</b>
	<b>Appendix A Jenkins and Murry’s factory measurements of effectiveness .....</b>	<b>270</b>
	<b>Appendix B 1997 factory measurements of effectiveness .....</b>	<b>274</b>
	<b>Appendix C Permeability measurements for comparing measurement techniques</b> <b>.....</b>	<b>277</b>
	<b>Appendix D A two-roll mill experiment at underfeed nip conditions.....</b>	<b>280</b>
	<b>Appendix E Results of Solomon’s two-roll mill feeding experiments.....</b>	<b>285</b>
	<b>Appendix F Results of Jenkins and Murry’s feeding experiments.....</b>	<b>296</b>
	<b>Appendix G A factory mill experiment.....</b>	<b>303</b>
	<b>Appendix H Data set used for the development of the new empirical feeding model</b> <b>.....</b>	<b>310</b>



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# Tables

Table 3.1	Comparison of Jenkins and Murry model results from Figure 3.3 .....	40
Table 5.1	Results of the parameter estimation process for the two assumed values of coefficient of friction.....	75
Table 5.2	Estimated parameters from the steady state permeability experiment.....	99
Table 5.3	Estimated parameters from the transient permeability experiment.....	101
Table 6.1	Roll dimensions for the two-roll mill experiments .....	110
Table 6.2	Levels of each factor explored in the two-roll mill experiment.....	111
Table 6.3	Analysis of variance of Murry's feed speed ratio for the two-roll mill experiment.....	113
Table 6.4	Analysis of variance of Murry's feed speed ratio for the two-roll mill experiment treating results from tests 3, 13 and 19 as missing values ..	118
Table 6.5	Analysis of variance of Murry's feed speed ratio for the 40° contact angle tests from the two-roll mill experiment.....	119
Table 6.6	Analysis of variance of Murry's feed speed ratio for the 120 mm nip setting tests from the two-roll mill experiment.....	121
Table 6.7	Results of the solid phase material parameter estimation process .....	136
Table 6.8	Analysis of variance of the four estimated solid phase material parameters .....	137
Table 6.9	Solid phase material parameters selected to be representative of the prepared cane used in the two-roll mill experiment.....	141
Table 6.10	Results of the permeability parameter estimation process.....	143
Table 6.11	Main effect of each experimental factor on Murry's feed speed ratio...	154
Table 7.1	Range of values for $\cos \alpha$ in Solomon's experiments .....	170
Table 7.2	Analysis of variance of Murry's feed speed ratio for Solomon's factorial experiment.....	175
Table 8.1	Roll dimensions for Mulgrave's #5 mill .....	202
Table 8.2	Factors and factor levels explored in the experiment.....	207

Table 8.3	Analysis of variance of Murry’s feed speed ratio for the factory mill experiment using the direct measure of feed speed .....	210
Table 8.4	Analysis of variance of Murry’s feed speed ratio for the factory mill experiment using the indirect measure of feed speed .....	210
Table 8.5	Results of the material parameter estimation process .....	214
Table 9.1	Comparison of model results from Figure 9.5 .....	228
Table 10.1	Comparison of model results from Figure 10.3 .....	235

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# Figures

Figure 1.1	Cross-section of a cane stem (after Payne 1968) .....	2
Figure 1.2	Typical layout of a milling train with four milling units (from Neill, McKinnon & Garson 1996) .....	5
Figure 1.3	Typical layout of a milling unit (from Neill, McKinnon & Garson 1996)	6
Figure 1.4	Roll dimensions.....	8
Figure 1.5	Nip and chute settings and contact angles.....	9
Figure 2.1	Two-roll mill geometry .....	20
Figure 2.2	Forces acting on a strip of bagasse in a two-roll mill .....	23
Figure 3.1	Feed chute dimensions .....	36
Figure 3.2	Comparison of the Jenkins and Murry and 1997 effectiveness measurements with Jenkins and Murry model predictions .....	39
Figure 3.3	Comparison of the difference in effectiveness of pairs of milling units with the predicted difference using the Jenkins and Murry model .....	40
Figure 4.1	Stresses acting on an elemental volume.....	44
Figure 4.2	Fluid flowing through the elemental volume .....	46
Figure 4.3	The yield surface for the simplified Drucker-Prager cap material model	54
Figure 4.4	A comparison of constant $\lambda$ and constant $\lambda_1$ hardening rules for modelling uniaxial compression.....	58
Figure 5.1	Uniaxial compression test cell used to provide experimental data for material parameter determination .....	65
Figure 5.2	Uniaxial compression test cell used to provide experimental data for material parameter determination (second configuration) .....	66
Figure 5.3	Typical experimental and model results for uniaxial compression tests obtained from parameter estimation process for solid phase material parameters .....	74

Figure 5.4	Results of sensitivity analysis for solid phase material parameters showing the relative change in the objective function for a change in the material parameters .....	77
Figure 5.5	Steady state permeability test apparatus (Downing 1999).....	80
Figure 5.6	Typical experimental results for the steady state permeability tests.....	84
Figure 5.7	Regression fit to determine the permeability parameters for typical experimental results for the steady state permeability tests.....	86
Figure 5.8	Typical experimental and model results for indirect permeability tests obtained from parameter estimation process for fluid phase material parameters .....	94
Figure 5.9	Results of sensitivity analysis for permeability parameters showing the relative change in the objective function for a change in material parameters .....	96
Figure 5.10	Results from the steady state permeability experiment.....	99
Figure 5.11	Void ratio and permeability relationships from the transient permeability experiment.....	101
Figure 5.12	Comparing permeability measurements between steady state (black curves) and transient (red curves) testing methods .....	102
Figure 6.1	Two-roll mill layout .....	108
Figure 6.2	Mean values of Murry's feed speed ratio for each level of each factor for the two-roll mill experiment with all results included .....	114
Figure 6.3	Significant interactions identified in the analysis of variance of Murry's feed speed ratio for the two-roll mill experiment.....	115
Figure 6.4	Mean values of Murry's feed speed ratio for the two-roll mill experiment with tests 3, 13 and 19 removed.....	116
Figure 6.5	Mean values of Murry's feed speed ratio for each level of each factor for the 40° contact angle tests from two-roll mill experiment .....	120
Figure 6.6	Mean values of Murry's feed speed ratio for each level of each factor for the 120 mm nip setting tests from two-roll mill experiment.....	122
Figure 6.7	Roll load history for the two-roll mill experiment's test 6.....	123
Figure 6.8	More realistic flow path for the surface of the bagasse mat .....	125
Figure 6.9	Forces acting on a strip of bagasse in a two-roll mill under conditions of forward slip .....	127

Figure 6.10	The effect of the angle from the nip on the function of the angle in equation ( 6.3 ) .....	128
Figure 6.11	Mean values of estimated material parameters for each level of each factor from the material parameter estimation process .....	138
Figure 6.12	Significant interactions identified in the analysis of variance of the estimated material parameters.....	139
Figure 6.13	Results of sensitivity analysis showing the relative change in the objective function for a change in the elastic material parameters for cane variety Q117 prepared at a shredder speed of 1200 r/min .....	140
Figure 6.14	Permeability relationships for each cane variety and level of preparation using the estimated parameters .....	144
Figure 6.15	Typical unconfined uniaxial compression loading path.....	147
Figure 6.16	Mean values of Murry’s feed speed ratio for the two-roll mill numerical experiment.....	153
Figure 6.17	Murry’s feed speed ratio compared between the two-roll mill model and the two-roll mill experiment.....	155
Figure 6.18	Model blanket deformation for 40° and 16° model runs .....	156
Figure 6.19	Comparing the contact angle effect to the feed speed ratio effect .....	157
Figure 6.20	Speed of the selected node for 40° and 16° model runs.....	158
Figure 6.21	Difference in Murry’s feed speed ratio between models using coefficient of friction between prepared cane mat and roll surface of 0.36 and 1.00 .....	160
Figure 6.22	Effect of contact angle on the ratio of tangential stress to normal stress	161
Figure 6.23	The effect of nip setting, feed pressure and roll speed on model blanket deformation .....	163
Figure 6.24	The effect of nip setting, feed pressure and roll speed on model blanket speed.....	164
Figure 6.25	Air pressure differences due to surface speed changes (Pa) .....	165
Figure 7.1	Mean values of $\cos \alpha$ for each level of each factor for the factorial experiment.....	171
Figure 7.2	Mean values of Murry’s feed speed ratio for each level of compression ratio for Solomon’s initial test series .....	172

Figure 7.3	Mean values of Murry’s feed speed ratio for each level of compression ratio for Solomon’s compression ratio test series .....	173
Figure 7.4	Mean values of Murry’s feed speed ratio for each level of compression ratio for Solomon’s photographic measurement series .....	173
Figure 7.5	Mean values of Murry’s feed speed ratio for each level of each factor for Solomon’s factorial experiment series .....	176
Figure 7.6	Significant interactions identified in the analysis of variance of Murry’s feed speed ratio for Solomon’s factorial experiment series .....	177
Figure 7.7	Factors from Solomon's factorial experiment that affect work opening	178
Figure 8.1	Three-roll pressure feeder layout .....	185
Figure 8.2	Example model geometry .....	188
Figure 8.3	Typical relationship between void ratio and permeability $\left(\frac{k}{\mu_v}\right)$ .....	190
Figure 8.4	Quality of fit for regression equation ( 8.3 ) .....	193
Figure 8.5	Quality of fit for regression equation ( 8.4 ) .....	194
Figure 8.6	Experimental and model results for Murry’s feed speed ratio from the first model tests of Jenkins and Murry (1981).....	195
Figure 8.7	Experimental and model results for Murry’s feed speed ratio from the second model tests of Jenkins and Murry (1981).....	197
Figure 8.8	Quality of fit for regression equation ( 8.5 ) .....	199
Figure 8.9	Experimental and model results for Murry’s feed speed ratio from the Marian mill tests of Jenkins and Murry (1981).....	200
Figure 8.10	The underfeed roll support bracket allowing the underfeed nip setting to be easily adjusted .....	203
Figure 8.11	The three pneumatic cylinders allowing the feed chute setting and position to be adjusted.....	203
Figure 8.12	Mean levels of Murry’s feed speed ratio using directly measured feed speed results .....	211
Figure 8.13	Mean levels of Murry’s feed speed ratio using indirectly measured feed speed results .....	212
Figure 8.14	Murry’s feed speed ratio compared between the values calculated from directly and indirectly measured feed speed results.....	213

Figure 8.15	Experimental and model results for Murry's feed speed ratio from the Mulgrave mill tests.....	215
Figure 9.1	Results of the sensitivity analysis of the material parameters and the initial and boundary conditions.....	219
Figure 9.2	Results of the sensitivity analysis of the geometrical parameters.....	221
Figure 9.3	Results of the sensitivity analysis of the most influential parameters ...	223
Figure 9.4	Comparison of Jenkins and Murry (1981) empirical model and new computational model predictions of effectiveness against measurements of Jenkins and Murry (1981) and Kent (1998).....	226
Figure 9.5	Comparison of effectiveness differences using the Jenkins and Murry (1981) empirical model and new computational model predictions of effectiveness against measured effectiveness differences from Jenkins and Murry (1981) and 1997 measurements .....	227
Figure 10.1	Comparison of new empirical model predictions with computational model values.....	233
Figure 10.2	Comparison of new empirical model predictions against measurements of Jenkins and Murry (1981) and 1997 measurements .....	234
Figure 10.3	Comparison of effectiveness differences using new empirical model predictions against measured effectiveness differences of Jenkins and Murry (1981) and Kent (1998).....	235
Figure 10.4	Effect of model parameters on the optimum underfeed nip setting (new empirical feeding model) .....	238
Figure 10.5	Effect of model parameters on the optimum underfeed nip setting (Jenkins and Murry model) .....	239
Figure 10.6	Effect of model parameters on the optimum ratio of underfeed roll speed to pressure feeder roll speed (new empirical model) .....	241
Figure 10.7	Typical effect of fibre content on Murry's feed speed ratio (new empirical model) .....	242
Figure 10.8	Stresses in the feed direction for a typical pressure feeder (in Pa) .....	244
Figure 10.9	Stresses in the feed direction for a pressure feeder without a bottom pressure feeder roll (in Pa) .....	245
Figure 10.10	The effect of the ratio of the underfeed roll speed to the pressure feeder speed on Murry's feed speed ratio .....	247

Figure 10.11 The ratio of the tangential pressure to the normal pressure on the underfeed roll for different ratios of the underfeed roll speed to the pressure feeder speed ..... 248



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# 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
$P_{dH_1}$	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 $\theta$ 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
$v_i, i = x, y \text{ or } z$	Velocity component of fluid
$w$	Material coordinate
$x$	Cartesian coordinate
$y$	Cartesian coordinate
$\alpha$	Contact angle (based on mean diameter)
$\alpha'$	Contact angle (based on outside diameter)
$\alpha_{do}'$	Contact angle between feed chute and rolls forming underfeed nip
$\beta$	Related to material angle of friction
$\epsilon_a$	Axial strain component
$\epsilon_{ij}, i, j = x, y \text{ or } z$	Strain component
$\epsilon_p$	Volumetric strain
$\epsilon_q$	Deviatoric strain
$\epsilon^e$	Elastic strain
$\epsilon^p$	Plastic strain
$\gamma$	Compaction
$\gamma_\alpha$	Compaction of bagasse at entry plane
$\gamma_d$	Compaction in feed chute
$\gamma_{do}$	Compaction at the feed chute exit
$\eta$	Ratio of deviatoric to mean stress components

$\varphi$	Angle of nip
$\kappa$	Logarithmic bulk modulus
$\lambda$	Hardening rule size parameter
$\lambda_1$	Hardening rule size parameter
$\mu$	Coefficient of friction
$\mu'$	Ratio of tangential force to normal force
$\mu_v$	Absolute or dynamic viscosity
$\nu$	Poisson's ratio
$\theta$	Angle
$\rho$	Bulk density
$\rho_\alpha$	Bulk density at entry plane
$\rho_f$	Density of fibre
$\rho_j$	Density of juice
$\rho_w$	Density of fluid
$\sigma_a$	Axial stress component
$\sigma_{a0}$	Initial axial stress component
$\sigma_{ij}, i, j = x, y \text{ or } z$	Total stress component
$\sigma'_{ij}, i, j = x, y \text{ or } z$	Effective stress component
$\sigma'_{zz0}$	Initial axial effective stress component
$\omega$	Roll angular velocity
$\psi$	Chute angle
$z$	Cartesian coordinate
$z_0$	Initial height