

Table of Contents

Certificate.....	ii
.....	iii
Declaration by the candidate.....	iii
Certificate by the supervisor	iii
Copyright transfer certificate	iv
Acknowledgment	v
Table of contents.....	viii
List of figure	xi
List of table	xv
List of symbols.....	xvi
Preface.....	xxii
Chapter 1 Introduction	1
Chapter 2 Literature Review And Objective	7
2.1. Literature survey for oil seed drying.....	7
2.2. Literature survey for deep bed rice drying.....	8
2.3. Literature survey for fluidized bed wheat drying.....	9
2.4. Literature survey for corn drying.....	10
2.5. Literature survey for kaolin drying.....	13
2.6. Outcome of literature review:	14
2.7. Objectives.....	15
Chapter 3 Basics Of Drying	17
3.1 basic principle of drying.....	17
3.2. Grain drying processes	18
3.2.1. Constant rate drying:	18
3.2.2. Falling rate drying	19
3.3. Equilibrium moisture content (emc)	21
3.4. Moisture content determination	22
3.5. Classification of dryers	23
3.6. Deep bed drying	25

3.6.1. Batch drying	25
3.6.2. Continuous drying	25
3.7 batch drying.....	26
3.7.1 batch in bin drying.....	26
3.7.2 recalculating batch drying	27
3.8 continuous drying:.....	29
3.9. Cross flow grain drying system:.....	30
3.10. Concurrent-flow dryers	31
3.11. Mixed-flow dryers.....	32
3.12. Counter current grain drying:.....	32
3.13. Advantages:	32
3.14. Disadvantages.....	33
3.15. Fluidized bed drying.....	33
3.16. Advantages of fluidized bed drying	36
3.17. Limitations of fluidized-bed drying	36
3.18. Kinds of fluidized-bed dryers.....	37
3.18.1. Batch dryers [geldart, 1986]	37
3.18.2. Continuous well-mixed dryers [geldart, 1986].....	38
3.18.3. Continuous plug flow dryers [geldart, 1986]	38
Chapter 4 Material Preparation And Experimental Procedure	41
Material preparation and experimental procedure	41
4.1. Steps in ceramic processing	42
4.2 experimental set-up	44
4.3. Experimental procedure	44
Chapter 5 Mathematical Modeling	47
5.1 assumptions:	47
5.2 governing equations for mathematical modeling.....	48
5.3. Discretization of bed	50
5.4 governing equations for each discretized element inside the bed.	51
5.5 discretization of particle	52
5.6 generation of diffusion equations using implicit method.....	53

5.7. Formulae used in intermediate computations for drying	55
5.8. Pressure drop in packed bed (deep bed) [rohsenow et al., 1998].....	60
5.9. Equilibrium moisture content [brooker et al., 1992].....	62
5.10. Drying efficiency.....	63
Chapter 6 Performance Analysis Of Deep Bed Drying Of Canola Seeds Using Numerical Technique.	65
6.1. Introduction	65
6.2. Numerical solution technique.....	65
6.3. Algorithm for solving the governing equation from node1 to node 2.	66
6.4. Results and discussions	70
6.5. Pressure drop in bed	77
6.6. Rating analysis of the drier.....	77
6.7. Conclusions	83
Chapter 7 A Sequential Numerical Technique For Efficient Utilization And Quality Improvement Of Rough Rice Using Multistage Deep Bed Drying With Tempering	85
7.1. Introduction	85
7.2. The detailed algorithm for computing the mathematical model from node 1 to node 2 is shown below.....	86
7.3. Results and discussions	90
7.3.1. Case-a	91
7.3.2. Case-b.....	97
7.4. Validation of results	104
7.5. Conclusion.....	105
Chapter 8 A Sequential Numerical Technique For Analysis Of Coupled Heat And Mass Transfer Phenomena During Fluidized Bed Drying Of Particulate Materials: Application To Wheat Drying	107
8.1. Introduction	107
8.2. Numerical solution technique.....	107
8.3. Detail algorithm for iterative scheme.....	108
8.4. Results and discussion.....	110
8.5 results without air recirculation.....	112
8.6. Results with air recirculation.....	115

8.7.comparison between computed and experimental results	120
8.8.conclusions	123
Chapter 9 Design Analysis Of Continuous Counter-Current Deep Bed Drying Of Corn Through Modelling And Simulation	125
9.1. Introduction	125
9.2. Input parameters taken for counter current grain drying.....	125
9.3. Results and discussion.....	127
9.4. Validation of programme	136
9.5. Conclusions	137
Chapter 10 Effect Of Environment Condition On Drying Performance Of Fluidized Bed Dryer During Kaolin Clay Drying: A Numerical And Experimental Study	139
10.1. Introduction	139
10.2. Results and discussion.....	139
10.3. Stresses distribution inside material.....	147
10.4. Validation of numerical model.....	150
10.5. Conclusion.....	151
Chapter 11 Overall Conclusion And Future Scope	153
Overall conclusion.....	153
Future work	154
References.....	157
Appendix.....	171

LIST OF FIGURE

Figure 1.1 Energy distribution in the grain production process	4
Figure 1.2. Energy distribution in ceramic production process [ciacco et al., 2017]	5
Figure 3.1 Constant rate drying falling rate drying	19
Figure 3.2 Different flow direction of air in the dryer [bakker-arkema et al., 1996]	26
Figure 3.3 Recalculating batch dryer [brooker et al., 1992].....	28
Figure 3.4.Continuous flow dryer [brooker et al., 1992]......	29

Figure 3.5 Region of fluidization [husain et al., 2007]	34
Figure 3.6. Fluidized bed dryer [wiriyaumpaiwong et al., 2001]	35
Figure 3.7. Schematic diagram of batch fluidized bed dryer [husain et al., 2007]	37
Figure 3.8. Continues plug flow fluidized bed dryer [geldart, 1986].....	39
Figure 4.1. Block diagram of key step of the ceramic processing.	41
Figure 4.2. Front views of the dryer.....	45
Figure 4.3. The sectional view of the dryer.	45
Figure 5.1. Discretization of counterflow deep bed into n elements with (n+1) nodes	50
Figure 5.2. Discretization of cross flow fluidized bed dryer along length.....	50
Figure 5.3. Discretization of grain along the radius.....	53
Figure 6.1. Variation of moisture content with radius inside the grain at different locations in the bed	70
Figure 6.2. Average moisture content of grain and material temperature vs. Length of the dryer	71
Figure 6.3. Air temperature and air outlet moisture vs. Height of the dryer.....	72
Figure 6.4. Material outlet temperature vs. Inlet air temperature	73
Figure 6.5. Material outlet moisture content vs. Inlet air temperature at different mass flow rate.....	74
Figure 6.6. Efficiency vs. Inlet air temperature at different mass flow rate.....	74
Figure 6.7. Efficiency of dryer vs. Inlet moisture content of the grain.....	75
Figure 6.8. Efficiency of dryer vs. Superficial velocity	76
Figure 6.9. Efficiency of dryer vs. Relative humidity of air	76
Figure 6.10. Pressure drop in dryer vs. Superficial velocity.....	77
Figure 6.11. Avg. Moisture content of the grain vs. Time at 50°C, rh 50%.].....	81
Figure 6.12. Avg. Moisture content of the grain vs. Time at 55°C, rh 50%	82
Figure 6.13. Avg. Moisture content of the grain vs. Time at 60°C, rh 50%	82
Figure 7.1. Average moisture content and temperature of grain vs. Depth of bed.	91
Figure 7.2. Specific humidity and temperature of air vs. Depth of bed.....	92

Figure 7.3. Intra-kernel moisture distributions.....	93
Figure 7.4. Power and pressure in the dryer at different velocities	97
Figure 7.5. Average moisture content vs superficial velocity of air.figure 7.6. Average moisture content vs temperature of air at different material flow rate.....	98
Figure 7.7. Intra-kernel moisture distributions.....	99
Figure 7.8. Intra-kernel moisture for different tempering duration.....	99
Figure 7.9. Moisture content gradient vs tempering time (minutes).	101
Figure 7.10. Variation of moisture content of paddy in two-stage drying	104
Figure 7.11. Avg. Moisture content of the grain vs. Time at 55°C, rh 50%. And 43°C, rh 50%. At air velocity 1 m/sec.....	105
Figure 8.1. X_{out} versus neb for different values of nep	113
Figure 8.2. Variation of x and t_m with dryer length	113
Figure 8.3. Moisture distribution at different radius of grain along dryer length.....	114
Figure 8.4. X_{out} versus rr at different w_m	116
Figure 8.5. Efficiency versus rr at different w_m	117
Figure 8.6. Average moisture content and air outlet temperature variation with time at $t_{ain}=60^{\circ}c$ and $x_{in}=27.5\%$	122
Figure 8.7. Average moisture content and outlet air temperature variation with time at $t_{ain} =50^{\circ}c$ and x_{in} = 25.4%	122
Figure 9.1. Variation of moisture content of grain, x and humidity of air, y along bed.....	127
Figure 9.2. Variation of air temperature, t_a and material temperature, t_m along bed	128
Figure 9.3. Variation of moisture content within grain, x_m at various nodes in bed	129
Figure 9.4. Variation of t_{mout} and t_{aout} with the mass flow rate of air, g_a	130
Figure 9.5.variation of x_{out} and y_{out} with the mass flow rate of air, g_a	130
Figure 9.6. Variation of t_{mout} and t_{aout} with material mass flow rate, g_m	131
Figure 9.7. Variation of x_{out} and y_{out} with the material mass flow rate, g_m	131

Figure 9.8. Variation of x_{out} and y_{out} with the inlet air relative humidity	132
Figure 9.9. Variation of efficiency of the dryer with the inlet air relative humidity.....	133
Figure 9.10. Variation of efficiency of the dryer with the mass flow rate of air, g_a	133
Figure 9.11. Variation of efficiency with the mass flow rate of material, g_m	134
Figure 9.12. Variation of efficiency of dryer and t_{aout} with t_{ain}	135
Figure 9.13. Variation of moisture content with time at t_{ain} 60 deg c and $g_a=1800\text{kg/hr}$	136
Figure 10.1. Variation of moisture content of kaolin, x and material temperature, tm with time at t_{ain} 50deg c in different drying conditions	142
Figure 10.2. Variation of moisture content of kaolin, x and material temperature, tm with time at t_{ain} 60deg c in different drying conditions	143
Figure 10.3. Variation of moisture content of kaolin, x and material temperature, tm with time at t_{ain} 70deg c in different drying conditions.	144
Figure 10.4. Moisture content gradient inside material in different drying condition with time.....	147
Figure 10.5. Sem image of different cracked kaolin ball with high moisture content gradient (improper drying).....	148
Figure 10.6. Sem image of different kaolin ball with no crack having low moisture content gradient (controlled drying)	149
Figure 10.7. Experimental and theoretical value of moisture content in different ambient condition at 70 deg c	150

LIST OF TABLES

Table 3.0.1 Classification of dryers	24
Table 6.0.1 Input parameters used for computation	68
Table 6.0.2 Range of operating variables used for rating analysis.....	68
Table 6.0.3 Design set of operating data:	69
Table 7.0.1 Constant values for rough rice:.....	89
Table 7.0.2 Performance comparison for a given y_{in}	95
Table 7.0.3 Performance comparison for varying y_{in}	96
Table 7.0.4 Relation of moisture gradient (% d.b./mm) and fissured kernel (%).....	101
Table 7.0.5 Quality of paddy at different tempering period.	102
Table 7.0.6 Performance comparison in two stage of drying.	103
Table 8.0.1 Effect of recirculation ratio on output parameters	115
Table 8.0.2 Dryer performance at off-design conditions.....	120
Table 10.0.1 Value constants for gab equation.....	140
Table 10.2 Value of atmospheric temperature and humidity in different climate.....	141