

SOLIDS FLOW FROM FIXED & FLUIDIZED BEDS THROUGH INCLINED PIPES

by

MANTU SARKAR

Department of Chemical Engineering

*Thesis submitted
in fulfillment of the requirements for
the award of the degree of
DOCTOR OF PHILOSOPHY*



to the

INDIAN INSTITUTE OF TECHNOLOGY, DELHI


HAUZ KHAS, NEW DELHI-110016 INDIA

March, 1980

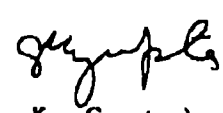
CERTIFICATE

This is to certify that the thesis entitled 'SOLIDS FLOW FROM FIXED & FLUIDIZED BEDS THROUGH INCLINED PIPES' being submitted by Mr. Mantu Sarkar to Indian Institute of Technology, Delhi, for the award of Doctor of Philosophy in Chemical Engineering, is a record of bonafide research work carried out by him. Mr. Mantu Sarkar has worked under our guidance and supervision and has fulfilled the requirements for the submission of thesis, which to our knowledge has reached the requisite standard.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.



(M. K. Sarkar)
Professor
Department of Chemical Engg.
Indian Institute of Technology
New Delhi - 110016, INDIA.



(S. K. Gupta)
Assistant Professor
Department of Chemical Engg.
Indian Institute of Technology
New Delhi - 110016, INDIA.

A C K N O W L E D G E M E N T

I express my deep sincere gratitude and heart-felt regards to Prof. M. K. Sarker and Dr. S. K. Gupta for their unflinching guidance and encouragement throughout the progress of this work.

It remains for me to record my special gratitude to Prof. D. Subba Rao for his constant encouragement, stimulating discussions, and valuable suggestions.

Acknowledgements are due to Prof. K. Vasudeva, Head, Dr. H. P. Mani, Dr.(Mrs.) K. Gadgil, Dr. B. K. Guha and all other faculty members of the Department for their help and co-operation.

I am indebted to Dr.(Mrs.) M. Ghosh Dastidar and Mr. I. Ghosh Dastidar for helping me in procuring sands.

My special thanks go to Prof. J. F. Davidson, Prof. T. M. Knowlton, and Dr. P. K. Agarwal for their thoughtful comments, and fruitful suggestions.

It is my great pleasure to acknowledge the co-operation received from A. Dey, A. Jana, A. K. Mukhopadhyay, C. Mukhopadhyay, S. Bhattacharya, R. Haldar, I. Talukdar, S. Bose, N. Panja, P. K. Dey, A. K. Gupta, A. K. Jain, Md. A. Aziz, Mr. A. Dutta, Mrs. N. Dutta, Miss. N. Mitra, Miss. S. Mohanty and many others.

I would like to thank Mr.R. D. Tiwari, Satish Kumar, Seva Ram, and all other supporting staff of the workshop, store, computer centre, and library for their necessary help.

My greatest debt is to my parents, brothers, sisters, 'BOUDI' (brother's wife) whose inspiration, encouragement, love, and affection helped me to work on the subject without tension.

Another source of my inspiration is the love of Rintu, Tinku, Mamuni, and other youngsters of our family.

I would like to thank Mr. R. Arora for helping in typing.

I am grateful to the Director, I.I.T. Delhi for providing me the scholarship to carry out the research work.

Mantu Sarkar
(MANTU SARKAR)

findings are qualitatively explained.

All the experimental results are summarized in ~100 tables in appendix - I. Some representative data are also reproduced in graphical form to show the dependence of individual variables on solid flow rates.

C O N T E N T

Page No.

CERTIFICATE		i
ACKNOWLEDGEMENT		ii
ABSTRACT		iv
LIST OF TABLES		xi
LIST OF FIGURES		xv
NOMENCLATURE		xviii
CHAPTER - I	INTRODUCTION	1
CHAPTER - II	DEFINITIONS, PROPERTIES, CALIBRATIONS	
2.1	Definitions	3
2.2	Physical Properties of Solids	5
2.2.1	Minimum fluidization velocity, U_{mf}	6
2.2.2	Density of material	11
2.2.2.1	Bulk density of material, ρ_b	11
2.2.2.2	Particle density of the material, ρ_p	12
2.2.2.3	Bulk density at minimum fluidization	13
2.2.2.4	Relation among ρ_p, ρ_b and voidage	13
2.2.3	Particle Size	14
2.2.4	Shape of the particle	21
2.2.5	Angle of Repose	22
2.2.6	Classification of Powders	24
2.3	Calibration of Gas Flow Meters	24

	Page No
CHAPTER III	SOLID FLOW FROM FIXED BED
3.1	Literature survey 26
3.1.1	Effect of different variables on solid flow from hopper 52
3.1.1.1	Bed height 52
3.1.1.2	Bed or hopper diameter 53
3.1.1.3	Orifice and particle diameter 53
3.1.1.4	Density of material 55
3.1.1.5	Orifice shape 56
3.1.1.6	Hopper wall inclination 58
3.1.1.7	Angle of repose and sphericity 58
3.1.1.8	Length of the pipe 59
3.1.1.9	Inclination of pipe/orifice 60
3.2	Aim of work 62
3.3	Experimental 64
3.3.1	Experimental set-up 64
3.3.2	Experimental technique 67
3.3.2.1	Solid flow from fixed bed to atmosphere 67
3.3.2.2	Solid flow from fixed bed to vessel 67
3.4	Results and Discussion 69
3.4.1	Solid flow from packed bed to atmosphere 69
3.4.1.1	Effect of different variables 70
3.4.1.1.1	Entry shape 70
3.4.1.1.2	Pipe inclination & angle of repose 74
3.4.1.1.3	Pipe length 77

	Page	No.
3.4.1.1.4	Sphericity of the particle	80
3.4.1.2	Comparison of present correlations with that of others	82
3.4.2	Solid flow from packed bed to vessel	86
3.4.2.1	Development of correlation	86
3.4.2.2	Explanation of air flow rate with solid	89
3.5	Conclusion	93
 CHAPTER - IV SOLID FLOW FROM FLUIDIZED BED		
4.1	Literature Survey	94
4.2	Aim of Work	105
4.3	Experimental Procedure	106
4.3.1	Pipe outlet open to atmosphere	106
4.3.2	Measurement of gas flow rate through pipe	106
4.4	Analysis of the Experimental results	107
4.4.1	Standpipe outlet is open to atmosphere	108
4.4.1.1	Effect of fluidization velocity	108
4.4.1.2	Effect of area factor	111
4.4.1.3	Effect of pipe length	113
4.4.1.4	Effect of pipe inclination	117
4.4.1.5	Development of correlation	119
4.4.2	Pipe outlet kept on top of a vessel	126
4.4.2.1	Effect of gas flow rate	126
4.4.2.2	Development of correlation	129
4.5	Conclusion	133
4.6	Note	134

	Page No	
6.4	Results and Discussion	163
6.4.1	Effect of aeration in the pipe	163
6.4.2	Effect of fluidization velocity in different beds	166
6.4.3	Effect of bed height	166
6.4.4	Effect of internals inside the pipe	171
6.4.5	Effect of back pressure	171
6.4.6	Summary of results	173
6.5	Conclusion	175
 CHAPTER - VII OVERALL SUMMARY AND CONCLUSION		 176
CHAPTER - VIII FURTHER SCOPE		178
REFERENCES		179
 APPENDIX - I EXPERIMENTAL RESULTS IN TABULAR FORM		 196
APPENDIX - II A SAMPLE PROGRAM FOR CALCULATION		300
APPENDIX - III CALIBRATION CHARTS FOR GAS FLOW METERS		304
APPENDIX - IV ABOUT THE AUTHOR		308