

**GAS-SOLIDS FLOWS IN DOWNERS:
HYDRODYNAMICS AND REACTOR MODELING**

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**DEPARTMENT OF CHEMICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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HYDRODYNAMICS AND REACTOR MODELING**

by

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DEPARTMENT OF CHEMICAL ENGINEERING

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CERTIFICATE

This is to certify that the thesis entitled '*Gas-Solids Flows in Downers: Hydrodynamics and Reactor Modeling*' being submitted by **Ms. Suryawanshi Vaishali Uttamrao** to the Indian Institute of Technology, Delhi for award of Doctor of Philosophy is a record of bonafide research work carried out by her under my guidance and supervision in conformity with the rules and regulations of Indian Institute of Technology, Delhi.

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

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ABSTRACT

Chemical engineers are pre-dominantly engaged in the design, scale-up and troubleshooting of process units for effecting potentially complex chemistries in a controlled environment. One such "reactor" that is being employed from several decades in various chemical and energy industries and in a number of applications of great economic value is the so called the circulating fluidized bed riser (CFBR). Employed in a variety of applications like fluid catalytic cracking (FCC) and partial oxidation of light paraffins, the CFBR loop usually consists of individual gas-solid contactors like fluidized beds, risers and downers. This thesis relates specifically to downers, though viewed in the general context of gas-solids dispersed flows, and in comparison to risers and fluidized beds.

In recent decades, developments in catalytic sciences, the drive for more profitable processes, as well as stringent environmental regulations demanding more efficient processes, have all motivated the search for the most optimal reactor for a certain chemical process. Certainly, with the development of fast acting catalysts and selective catalyst, the need of the hour is for having short contact time, narrow residence time and low back mixing reactors. The downer, which involves co-current downflow of fluid and solids, is a promising candidate as a short contact time reactor, since it closely follows this "wish-list".

This thesis specifically relates to computational fluid dynamic (CFD) models of downers. Euler-Euler modeling of downers has been presented and the developed models are validated against reliable experimental data. The model is optimized for closures that are robust and best describe the underlying flow phenomena and the dependencies between the key variables. Subsequently, this model has been extended to a reactor model for partial oxidation of n-butane to maleic anhydride. This reactor model is used to make comparative

predictions of downers and risers as reactors for partial oxidation (the use of risers being the current technology). Metrics by which downers may outperform risers as partial oxidation reactors are outlined.

In the final part of this thesis, Euler-Lagrange modeling of downers is presented in which each particle in the solids ensemble is tracked. This model is used to make various qualitative and quantitative predictions about flow features, fluctuating solids velocity and mesoscale, metastable structures that are formed in the flow field.

TABLE OF CONTENTS

CERTIFICATE	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iv
TABLE OF CONTENTS	vi
LIST OF FIGURES	xii
LIST OF TABLES	xxi
1. INTRODUCTION	1
1.1 Motivation	4
1.2 Objectives of the Research Work	6
1.3 Structure of the thesis	7
References	8
2. BACKGROUND	13
2.1 Introduction	13
2.2 General Background on Downers	16
2.3 Flow Patterns and Hydrodynamics of Downer	25
2.3.1 Axial Pressure Drop	25
2.3.2 Axial Solids Flow Structure (Solids Fraction and Solids Velocity)	30
2.3.3 Radial Flow Structure of Solids (Solids Fraction and Solids Velocity)	32

2.3.4	Gas and Solids Dispersion Studies	40
2.3.5	Slip velocity and Clustering	42
2.4	Heat Transfer	44
2.5	Mass Transfer	47
2.6	High Density Downers	48
2.7	Modeling of Gas-Solids Flow in Downer	50
2.7.1	1-D Models for Downer	52
2.7.2	2-D Models for Downer	53
2.7.3	Euler-Euler Models for Downer	55
2.7.4	Euler-Lagrange Models for Downer	57
2.8	Downer vs. Riser: Comparison as Gas-Solids Contactors	58
2.8.1	Hydrodynamic Characteristics	59
2.8.2	Heat transfer	71
2.9	Potential Applications of Downers	74
2.9.1	Downer as a FCC Unit	75
2.9.2	Other Potential Applications of Downer	85
2.10	Summary of Past Work	86
	Notation	90
	References	92
3.	EULER-EULER MODELING OF HYDRODYNAMICS IN DOWNERS	105
3.1	Background Literature on Euler-Euler Modeling of Gas Solids	106

	Downers	
3.2	Model Formulation: Two-Fluid CFD Model for Downers	110
3.2.1	Conservation Equations	111
3.2.2	Closures for Solids Fluctuations	113
3.2.3	Closures for Gas-Solids Drag	119
3.2.4	Closures for Gas Phase Turbulence	125
3.3	Results and Discussion	131
3.3.1	Base Case Simulation	132
3.3.2	Selection of “Best Suited” Drag Closure	143
3.3.3	Solids Phase Kinetic Energy	146
3.3.4	Effect of Gas-Phase Turbulence	149
3.3.5	Effect of Operating Conditions	151
3.3.6	Effect of Particle Diameter and Column Diameter	159
3.4	Summary and Conclusions	160
	Notation	166
	References	168
4.	POTENTIAL OF DOWNERS AS REACTORS FOR PARTIAL OXIDATION: REACTOR MODELING	177
4.1	Introduction	177
4.2	Kinetics of n-Butane Oxidation	180
4.3	Modeling: CFD and Reactor Model	191

4.3.1	Scalar Transport Simulation	193
4.3.2	Reactor Model for Downer	195
4.4	Results and Discussion: Reactor model	203
4.4.1	Lattice Oxygen Diffusion	203
4.4.2	Reactor Performance of Downer vs. Riser	209
4.5	Summary and Conclusions	223
	Notation	226
	References	227
5	DEM MODELING OF GAS SOLIDS DISPERSED FLOW	233
5.1	Introduction and Objectives	233
5.2	Euler-Euler (EEM) vs. Discrete Particle Modeling (DPM): Background	241
5.3	DPM Modeling: Background	245
5.3.1	Hard Sphere Approach	246
5.3.2	Direct Simulation Monte Carlo (DSMC)	253
5.3.3	Soft Sphere Approach (DEM)	254
5.4	Literature Survey: Past Studies in DPM Modeling for Fluidized Beds	256
5.4.1	Overview of DPM Modeling in ‘Batch’ Fluidized Beds	256
5.4.2	Overview of DPM modeling in ‘flow through’ fluidized systems	266
5.4.3	Key issues in the DEM Modeling: Literature Summary	275
5.5	Modeling with Soft Sphere (DEM) Approach: Present Work	278

5.5.1	Governing Equations	279
5.5.2	Co-ordinate System and Notation	281
5.5.3	Contact Force	282
5.5.4	Model Parameters for Contact Force	286
5.5.5	Drag force (particle motion; equation 5.28)	289
5.5.6	Gradient term of hydrodynamic pressure (particle motion: equation 5.28)	290
5.5.7	Interparticle van der Waals force (particle motion: equation 5.28)	291
5.5.8	Neighbor List and Cell List	292
5.5.9	Gas Phase Motion	293
5.5.10	Numerical Solution	295
5.5.11	Boundary Conditions	296
5.5.12	Two-way coupling of equations	297
5.5.13	Initialization of Simulation for ‘Flow Through’ System	302
5.6	Results and Discussion	304
5.6.1	Base Case Simulation	304
5.6.2	Analysis of Solids Fluctuational Velocity Component	313
5.6.3	Effect of Operating Conditions on Solids Fluctuations	316
5.6.4	Solids Mean Flow Profiles	324
5.6.5	Temporal Variations	329

5.7	Summary and Conclusions	335
	Notation	338
	References	340
6	THESIS SUMMARY, CONCLUSIONS AND OUTLOOK	362
6.1	Summary of the Thesis and Key Conclusions	362
6.2	Outlook	366
	Appendix A1	369
	Appendix A2	372
	Appendix A3	374
	Author's Biodata	392