

H-COAL FLUID DYNAMICS

STUDY OF EBULLATED BED FLUID DYNAMICS FOR H-COAL

FINAL PROGRESS REPORT  
AUGUST, 1977-DECEMBER, 1979

I. A. VASALOS, E. M. BILD, D. N. RUNDELL, D. F. TATTERSON

SUBMITTED: FEBRUARY, 1980

CONTRACT DE-AC05-77ET-10149

Date Published: April 16, 1980

Research and Development Department

Amoco Oil Company  
P. O. Box 400  
Naperville, Illinois  
60540

TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	1
OBJECTIVE AND SCOPE OF WORK	2
SUMMARY	2
Review of Prior Work	2
Data Collection and Analysis	3
Cold Flow Model	3
Data Analysis	4
Model Development	5
Recommendations	5
INTRODUCTION	5
CONSTRUCTION OF COLD FLOW UNIT AND DATA COLLECTION	11
Equipment	12
Physical Properties of Liquids and Solids	12
Unit Data	13
Pressure Drop Data	14
Gamma-Ray Scan Data	14
Tracer Data	14
Catalyst and Coal Fines Settling Data	15
Physical Properties of H-Coal Liquids	15
PDU Sampling Technique	15
Viscosity Measurements	15
Data Analysis	17
Fines Distribution	17
Liquid or Slurry Fluidization	17
Three-Phase Fluidization--Gamma-Ray	19
Three-Phase Fluidization--Tracer Data	20
Three-Phase Fluidization--Data Analysis	23
Catalyst and Coal Fines Settling--Data Analysis	24
Comparison of Experimental Results with HRI PDU Data	24
MODEL DEVELOPMENT	25
Three-Phase Holdup Model	25
Correlation of Wake Volume Ratio, $K_0$	26
Correlation of Bubble Terminal Velocity, $U_{tB}$	26
Correlation of Solids Holdup, $X_k$	27
Model Predictions	28
Gas Mixing Model	28
CONCLUSIONS AND RECOMMENDATIONS	29
ACKNOWLEDGMENTS	30

## TABLE OF CONTENTS

		<u>Page</u>
NOMENCLATURE		31
TABLE I	LIST OF PUBLICATIONS DURING THE PROGRAM	35
TABLE II	CORRELATIONS FOR THE EXPANSION OF LIQUID FLUIDIZED BEDS	37
TABLE III	EXPERIMENTAL CONDITIONS FOR BUBBLE COALESCENCE	39
TABLE IV	SUMMARY OF DATA FOR GAS/LIQUID/SOLID FLUIDIZATION	40
TABLE V	EMPIRICAL CORRELATIONS FOR THREE-PHASE BEDS	41
TABLE VI	BHATIA-EPSTEIN MODEL	42
TABLE VII	PHYSICAL PROPERTIES OF LIQUIDS USED IN COLD FLOW STUDIES	43
TABLE VIII	SUMMARY OF GAS/KEROSENE DATA	44
TABLE IX	VISCOSITIES OF COAL CHAR/KEROSENE SLURRIES	45
TABLE X	COMPARISON OF COAL CHAR WITH H-COAL REACTOR FINES	46
TABLE XI	CUMULATIVE SIZE DISTRIBUTION OF COAL CHAR	47
TABLE XII	PROPERTIES OF HDS-2A CATALYST	48
TABLE XIII	SUMMARY OF EXPERIMENTAL RUNS	49
TABLE XIV	DATA FOR PDU LIQUID SAMPLES	50
TABLE XV	COAL CHAR DISTRIBUTION ALONG THE REACTOR	51
TABLE XVI	PARTICLE SIZE DISTRIBUTION OF REACTOR COAL CHAR SAMPLES	52
TABLE XVII	VARIATION IN RICHARDSON-ZAKI INDEX	53
TABLE XVIII	FIRST AND SECOND MOMENTS CALCULATED BY TWO METHODS	54
TABLE XIX	CALCULATED GAS LINEAR VELOCITIES	55
TABLE XX	GAS HOLDUPS CALCULATED FROM GAS TRACER AND GAMMA-RAY TESTS	56
TABLE XXI	RESULTS OF GAMMA-RAY SCANS THROUGH CHORDS OF THE CROSS-SECTION	57
TABLE XXII	CALCULATION OF DISPERSION COEFFICIENT	58
TABLE XXIII	SOLUTION OF THE BHATIA-EPSTEIN MODEL	59
TABLE XXIV	BED SETTLING RATE	60

## TABLE OF CONTENTS

		<u>Page</u>
Figure 1	H-COAL PDU REACTOR	61
Figure 2	DRIFT FLUX VS. GAS HOLDUP: DARTON AND HARRISON	62
Figure 3	SCHEMATIC DIAGRAM OF THE FLUID DYNAMICS UNIT	63
Figure 4	SCHEMATIC DIAGRAM OF EXPERIMENTAL UNIT FOR VISCOSITY MEASUREMENT	65
Figure 5	GAMMA-RAY SCAN	65
Figure 6	RADIOTRACER DETECTOR LOCATION	66
Figure 7	COAL FINES SETTLING RATE	67
Figure 8	DEFINITION OF BINGHAM FLUID	68
Figure 9	EFFECT OF TEMPERATURE ON VISCOSITY OF H-COAL SAMPLE	69
Figure 10	VARIATION IN BED EXPANSION WITH TEMPERATURE AND COAL FINES CONCENTRATION	70
Figure 11	EFFECT OF VISCOSITY ON BED EXPANSION--MINERAL OIL	71
Figure 12	BED EXPANSION WITH KEROSENE SLURRIES AND MINERAL OIL	72
Figure 13	EFFECT OF CATALYST PARTICLE PROPERTIES FOR BED EXPANSION	73
Figure 14	CORRELATION OF LIQUID/SOLID DATA	74
Figure 15	EFFECT OF OPERATING CONDITIONS ON BED EXPANSION	75
Figure 16	EFFECT OF TEMPERATURE ON BED EXPANSION	76
Figure 17	BED EXPANSION--COMPARISON OF VARIOUS LIQUIDS	77
Figure 18	EFFECT OF PARTICLE SIZE ON BED EXPANSION	78
Figure 19	BED EXPANSION--EFFECT OF GAS TYPE	79
Figure 20	BED EXPANSION--EFFECT OF GAS TYPE, MINERAL OIL	80
Figure 21	GAS HOLDUP--EFFECT OF COAL FINES	81
Figure 22	GAS HOLDUP--COMPARISON OF VARIOUS LIQUIDS	82
Figure 23	TRACER RESULTS WITH 0 VOL% COAL CHAR	83
Figure 24	TRACER RESULTS WITH 15.5 VOL% COAL CHAR	84
Figure 25	DRIFT FLUX--EFFECT OF OPERATING CONDITIONS	85
Figure 26	DRIFT FLUX--EFFECT OF LIQUID VISCOSITY	86
Figure 27	COMPARISON OF PDU WITH COAL CHAR/KEROSENE	87
Figure 28	VARIATION OF BUBBLE-INCLUDED ANGLE WITH LIQUID VISCOSITY	88
Figure 29	WAKE VOLUME--EFFECT OF COAL FINES	89
Figure 30	WAKE VOLUME--EFFECT OF LIQUID TYPE	90
Figure 31	BUBBLE TERMINAL VELOCITY--EFFECT OF COAL FINES	91
Figure 32	BUBBLE TERMINAL VELOCITY--EFFECT OF LIQUID TYPE	92
Figure 33	RELATIVE SOLIDS HOLDUP--EFFECT OF LIQUID TYPE	93
Figure 34	CATALYST HOLDUP--PREDICTED VS. ACTUAL KEROSENE AND 17.8 VOL% COAL CHAR	94
Figure 35	GAS HOLDUP--PREDICTED VS. ACTUAL KEROSENE AND 17.8 VOL% COAL CHAR	95
Figure 36	GAS MIXING MODEL	96
Figure 37	FITTING RESIDENCE TIME DISTRIBUTION--KEROSENE WITH NO FINES	97
REFERENCES		98

TABLE OF CONTENTS

-4-

	<u>Page</u>
APPENDIX A: EQUIPMENT DETAILS	105
APPENDIX B: EXPERIMENTAL DATA AND METHOD OF ANALYSIS	115
APPENDIX C: TRACER DATA ANALYSIS	215
APPENDIX D: VISCOSITY MEASUREMENTS OF H-COAL LIQUIDS	219
APPENDIX E: PREDICTIVE COMPUTER PROGRAM	227
APPENDIX F: CIRCULATION MODEL FOR GAS RESIDENCE TIME DISTRIBUTION IN THREE-PHASE FLUIDIZATION	261
APPENDIX G: MODEL DEVELOPMENT	283