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COLD-FLOW-MODEL STUDY OF REACTOR FLUID DYNAMICS, TASK III

HYDROCARBON RESEARCH, INC.
LAWRENCEVILLE, NJ

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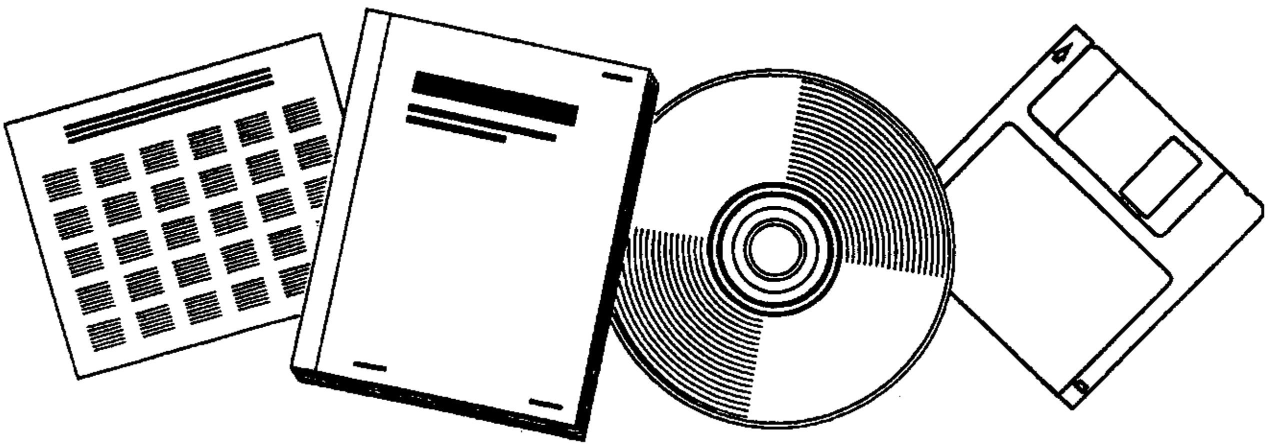

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COLD FLOW MODEL STUDY
OF
REACTOR FLUID DYNAMICS

TASK III

NOVEMBER 1982

TABLE OF CONTENTS

PAGE

SECTION I -
PROGRAM SUMMARY, ACHIEVEMENTS, CONCLUSIONS 1
SUMMARY 2
PROGRAM ACHIEVEMENTS AND CONCLUSIONS 3
EXTRUDATE CATALYST STUDY 3
SPHERICAL CATALYST STUDY 3
PLENUM STUDIES 4

SECTION II - OBJECTIVES AND SCOPE OF WORK
OBJECTIVES AND SCOPE OF WORK - Phase III 6
TASK III - COLD-FLOW MODEL STUDY OF REACTOR FLUID DYNAMICS 7
PROGRAM OBJECTIVES 7
SCOPE OF WORK 7

SECTION III - TECHNICAL PROGRAM RESULTS 9
6"-DIAMETER COLUMN EBULLATION STUDIES 10
GAS-LIQUID STUDY 10
EXTRUDATE CATALYST STUDY 14
Bed Expansion 14
Effect Of Liquid/Gas Velocities on Bed Expansion .. 14
Effect of Solids on Bed Expansion 14
Effect of Liquid Viscosity on Bed Expansion 15
Gas Holdup 15
Fines Segregation 16
CATALYST CARRYOVER 16
SPHERICAL CATALYST STUDY 29
Bed Expansion 29
Catalyst Carryover 30
Bed Stratification 30
Catalyst Suitability for H-Coal Application 30
5' - DIAMETER VESSEL PLENUM STUDIES 35
ORIGINAL PLENUM STUDY 35
Sight Glass Observations 35
GAS HOLDUP MEASUREMENTS CONFIRMED FLOW MALDISTRIBUTION WITH ORIGINAL PLENUM DESIGN 37
SECOND PLENUM STUDY 47
NEW PLENUM DESIGN IMPROVED FLOW DISTRIBUTION 48

TABLE OF CONTENTS

	PAGE
SECTION IV - MODEL DEVELOPMENT	52
DEVELOPMENT OF BED-EXPANSION CORRELATION	53
DEVELOPMENT OF IMPROVED INLET DISTRIBUTION SYSTEM	59
BACKGROUND	59
MODIFIED INLET DESIGN	60
APPENDIX A - CALCULATION PROCEDURES	64
CATALYST BED EXPANSION	65
VOLUMETRIC HOLDUPS	65
WEIGHT PERCENT FINES MEASUREMENT	67
PARTICLE SIZE ANALYZER	68
APPENDIX B - UNIT DESCRIPTIONS	69
EBULLATED CATALYST BED	70
SIX-INCH UNIT (176)	71
FIVE FOOT UNIT (UNIT 216) -	72

LIST OF FIGURES

FIGURE	TITLE	PAGE
1	Gas Holdup in Bubble Column	13
2	Effect of Fines Concentration on Bed Expansion	25
3	Effect of Liquid Viscosity on Bed Expansion ..	26
4	Gas Holdup in Kerosene-Nitrogen Catalyst System	27
5	Gas Holdup in Kerosene-Nitrogen-Catalyst 15% Fines System	28
6	Ebullation of Narrow Size Range Spherical Catalyst	33
7	Ebullation of Wide-Size Range Spherical Catalyst	34
8	Liquid Level Wave Frequency in Kerosene-Nitrogen System	40
9	Liquid Level In Kerosene-Nitrogen System	41
10	Liquid Level Wave Frequency in Kerosene-Nitrogen-Catalyst System	42
11	Liquid Level in Kerosene-Nitrogen-Catalyst System	43
12	Pressure Drop in Kerosene-Nitrogen System	44
13	Gas Holdup With Original Plenum Design	45
14	Pressure Drops in Kerosene-Nitrogen-Catalyst System	46
15	Pressure Drops in Kerosene-Nitrogen System (New Baffle)	50
16	Gas Holdup with Modified Plenum Design	51
17	Comparison of Predicted and Experimental Bed Expansions	58
18	Improved Inlet Plenum with New Difuser Pilot Plant Reactor	62
19	Modified Plenum Inlet Design	63
B-1	176 Unit Schematic Diagram	73
B-2	176 Unit Recycle Cup	74
B-3	176 Unit Bubble Cap	75
B-4	Cold Flow Model of Unit 216	76

LIST OF TABLES

TABLE	TITLE	PAGE
1	Gas Holdup In Bubble Column	12
2	System Characteristics	18
3	Bed Expansion Data For Kerosene/Nitrogen System	19
4	For Kerosene/Fines/Nitrogen System	20
5	For Circosol 304/Nitrogen System	21
6	For Circosol 306/Nitrogen System	22
7	Particle Size Distribution	23
8	Catalyst Carryover Into Recycle Cup At Spouting Conditions	24
9	Alumina Bead Physical Properties	31
10	Stratification Of The Wide-Distribution Catalyst During Ebullation	32
11	Gas Holdup Original Plenum Design	39
12	Gas Holdup Modified Plenum Design	49
13	Bed Expansion Data From PDU-10	57

SECTION I

PROGRAM SUMMARY, ACHIEVEMENTS, CONCLUSIONS

SUMMARY

Fluidization and elutriation characteristics of spent extrudate catalyst were investigated as directed in Contract DE-AC05-77ET-10152. Six systems involving liquids of different viscosities and slurries of various concentrations were studied using a 6"-diameter, cold-flow model. The cold-flow data have been used along with bed expansions measured in the HRI Process Development Unit reactor to develop a correlation for bed expansion. The predicted bed expansions were within 15% of the bed expansion measured in the Pilot Plant reactor.

The catalyst elutriation rates measured were small at typical H-Coal reactor flow conditions. Higher carryover rates were measured at spouting-bed conditions (high gas and low liquid velocity). The excessive catalyst carryover experienced at the Pilot Plant in 1980 was probably caused by flow channelling and the high viscosity of the reactor fluids during start-up.

A cold-flow simulation was also completed of Pilot Plant reactor plenum performance using the 5-foot-diameter reactor model. The results confirmed that the initial inlet nozzle used in the Pilot Plant reactor resulted in flow maldistribution, and probably caused coke formation in the plenum and the reactor in earlier runs. A new inlet nozzle was tested, and the data showed marked improvement in flow uniformity at similar conditions. These cold-flow test results were consistent with Pilot Plant data obtained in Run No. 8, a 131-day operation on Illinois coal. A new inlet nozzle of similar design virtually eliminated flow maldistribution and reactor coking problems in that run.

Ebullation tests were made on two spherical catalyst samples with different size distributions. The results showed that the sample with a narrow size distribution gave uniform fluidization and negligible carryover at typical H-Coal reactor flow conditions. The catalyst appears suitable for H-Coal applications. However, the performance of the sample with a wide size distribution was unacceptable: non-uniform fluidization, poorly-defined bed interface, and excessive carryover rate.

PROGRAM ACHIEVEMENTS AND CONCLUSIONS

EXTRUDATE CATALYST STUDY

- A correlation for bed expansion with a standard error of estimate of 0.22 has been developed on the basis of cold-flow data obtained in this work and high-pressure, high-temperature data from PDU-10. The bed expansion predicted by this correlation agrees within 15% of that measured in the Pilot Plant reactor.

- No significant segregation of fines occurred when slurry was used for fluidization.

- Catalyst carryover rates were small at typical H-Coal reactor flow conditions but higher at spouting-bed conditions (high gas and low liquid velocity). All carryover rates were significantly lower than that observed during a startup of the Pilot Plant in 1980. The excessive carryover problem at the Pilot Plant was probably caused by flow channelling and the high viscosity of the reactor fluid during startup.

SPHERICAL CATALYST STUDY

- The narrow-size-distribution catalyst permitted a sharp catalyst bed interface and virtually no catalyst carryover in contrast to a less clearly defined interface and significant carryover when the wide-size-distribution catalyst was used. The former is more suitable for use in an ebullated-bed reactor.

PLENUM STUDIES

- Flow maldistribution was confirmed in both the plenum and the region immediately above the distributor grid of the 5'-diameter cold-flow model with the original plenum inlet design. Presumably then, a similar flow maldistribution exists in the Pilot Plant reactor with the original inlet design.

- The modified plenum inlet design greatly reduced flow maldistribution in the cold-flow model. This is consistent with the almost-coke-free, 131-day operation of Run No. 8 at the Pilot Plant in which a similar modified inlet design was used.

SECTION II

OBJECTIVES AND SCOPE OF WORK

OBJECTIVES AND SCOPE OF WORK

PHASE III PROGRAM OBJECTIVES

The overall objective of the HRI H-Coal Phase III laboratory program is to achieve maximum assurance of successful operations of the Catlettsburg, Kentucky H-Coal Pilot Plant. The specific objectives are:

1. Define preferred process conditions for Wyodak subbituminous coal which will provide improved process economics and system reliability.

2. Define preferred process conditions for Illinois No. 6. Explore conditions and process modifications which will improve process economics and process reliability.

3. Optimize the catalyst system with respect to catalyst selection, regeneration techniques, optimum replacement rate and compatibility with reactor operating conditions.

4. Study the preheater and its effect on the operating conditions of the ebullating bed reactor and the yield and quality of the resultant liquid fuels.

5. Analyze the mechanism of deposit formation in the reactor by means of cold flow studies. Provide means to correct these phenomena.

6. Conduct engineering support studies to identify areas of operation for improved process economics as a guide to the experimental program.

The work to be performed is divided into four tasks: PDU operation, bench-scale modification and operation, cold flow fluid dynamics studies, and process economic optimization and engineering studies.

TASK III

COLD-FLOW MODEL STUDY OF REACTOR FLUID DYNAMICS

PROGRAM OBJECTIVES

- Establish fluidization and elutriation characteristics of spent extrudate catalyst from bench scale or PDU experiments, including effects of gas/slurry velocities, liquid viscosity and fines concentration on fluidization.
- Simulate performance of the inlet distribution system of the Pilot Plant reactor and develop an improved design.
- Investigate ebullation characteristics of spherical catalysts.

SCOPE OF WORK

To meet these objectives, the scope of work included:

- Ebullation runs using the 6"-diameter column to determine the bed expansion and carryover of extrudate catalysts using various combinations of liquid and gas velocities in six systems involving kerosene with or without fines, Circosol 304 and Circosol 306.
- Installation of three additional pressure-drop taps in the catalyst bed region of the 5'-diameter vessel to detect flow maldistribution, and installation of eighteen 300 psig sight glasses in the vessel wall for visual observation of the flow pattern.
- Ebullation runs using the 5'-diameter vessel to study the flow pattern and ebullation characteristics of an extrudate catalyst in kerosene/nitrogen using various combinations of liquid and gas velocities.

- Modifications of the plenum inlet design in the 5'-diameter vessel to correct flow maldistribution.
- Ebullation runs repeated to check the modified plenum inlet design.
- Ebullation runs using two samples of spherical alumina beads in kerosene/nitrogen in the 6"-diameter model with various combinations of liquid and gas velocities.

SECTION III

TECHNICAL PROGRAM RESULTS

6"-DIAMETER COLUMN EBULLATION STUDIES

Fluid dynamics studies of a three-phase fluidized bed using extrudate and spherical catalysts were carried out in a Plexiglas column six inches in diameter (Unit 176). A description of this unit is given in Appendix B.

GAS-LIQUID STUDY

Shakedown of the 6-inch-diameter column was accomplished by studying the gas holdups in the kerosene/nitrogen system. Gas holdups in the 6-inch diameter column were obtained by pressure-drop measurements and by measuring the volume occupied by the gas in the bubble column. To obtain the gas volume, gas and liquid flows to the unit were shut off simultaneously, and the static liquid level was measured after the liquid degassed (in about 10 minutes). The difference between the bubble column height and the static liquid level is directly related to the gas volume in the bubble column. Gas holdups measured by these two methods were within ± 10% of each other.

Test results were compared with the prediction from the Hughmark[1] -Mashelkar[2] correlations (EQ.1), which were modified to take into consideration variations in the bubble rise velocity because of different bubble sizes observed. At gas velocities below 0.2 ft/sec, uniform bubble swarms of about 1/4" in diameter were observed. Slightly smaller bubbles (3/16" diameter) were observed at gas velocities ranging from 0.2-0.3 ft/sec.

Modified Hughmark-Mashelkar Correlation:

$$\epsilon_g = \left(\frac{V_g}{V_s + 2V_g}\right) \left(\frac{\delta}{72}\right)^{1/3} \left(\frac{1}{\rho_L}\right) \times 100 \qquad (1)$$

$V_s = 0.71\ (g\ D_B)^{1/2}$ (Nicklin[3] Correlation) where:

ε_g = gas holdup - vol %
V_g = superficial gas velocity, cm/sec
σ = liquid surface tension, dynes/cm
ρ_L = liquid density, g/cm^3
V_s = bubble rise velocity, cm/sec
D_b = bubble diameter, cm
g = 980 cm/gec^2

As shown in Table 1 and Figure 1, the measured gas holdups agree well with the literature correlation, indicating that the gas holdup measurement techniques are satisfactory.

(1) G. A. Hughmark, I&EC Proc. Des. and Devel., 6, 218 (1967)
(2) R. A. Mashelkar, British Chem. Eng., 15, 1297, 1970
(3) D. J. Nicklin, CES, 17, 693, 1962.

TABLE 1

GAS HOLDUP IN BUBBLE COLUMN

SYSTEM: N_2 - Kerosene

COLUMN DIAMETER: 6 Inches

LIQUID VELOCITIES: 0.01-0.15 ft/sec

GAS VELOCITY (ft/sec)	ESTIMATED BUBBLE SIZE (inches)	GAS HOLDUP MODIFIED CORRELATION*	GAS HOLDUP THIS WORK
0.06	1/4	0.08	0.08
0.10	1/4	0.12	0.13
0.12	1/4	0.14	0.13
0.16	1/4	0.17	0 15
0.21	3/16	0.21	0.24
0.32	3/16	0.26	0.28

*HUGHMARK-MASHELKAR

FIGURE 1

GAS HOLDUP IN BUBBLE COLUMN
(KEROSENE - N_2)

LIQUID VELOCITY: 0.01 - 0.15 FT/SEC