CATALYST DEVELOPMENT

Catalyst Forming Tests

Methanol catalyst is presently available in 3/16" Ø x 3/16" tablets for use in vapor phase synthesis systems. These tablets are not suitable for use in the liquid phase synthesis primarily because of mass transfer limitations which result in low effectiveness factors, and secondly, because high liquid fluidization velocities are required with this diameter particle.

For these reasons, some effort was spent in producing small catalyst particles via commercial means. Samples of commercial Catalyst A powder were obtained in both a pre- and post-calcined condition and used in these forming tests.

In the first series of tests, a commercial catalyst vendor tried extruding and spheroidizing (1/16" Ø) both powders with and without addition of a silicate binder. Inspection of this material indicated an unacceptably low crush strength, such that the extrudates did not warrant testing in the bench scale unit. Much later in the program, a second catalyst company worked on this approach. These efforts are described further on in this section.

The second series of tests used the commercial powder to produce 3/32" Ø x 3/32" tablets (mini tablets) in a variety of crush strengths and graphite (lubricant) addition levels. These materials were all physically acceptable showing no signs of attrition throughout their history of use in the bench scale unit.

Development of a Mini-Tablet

Table 4-9 lists the pertinent physical properties of the prepared 3/32"Ø X 3/32" tablets along with that of the 3/16" Ø X 3/16" commercial tablet. Allowing for the different size of the tablets, as well as the experimental procedure for testing crush strength, the 19.1 pound value

TABLE 4-9

PHYSICAL PROPERTIES OF CATALYST TABLET SAMPLES
PREPARED FROM CATALYST A CALCINED POWDER

TARGET STRENGTH (lbs)	% GRAPHITE	ACTUAL STRENGTH (lbs)	BULK DENSITY (gm/cc)	SURFACE AREA (M^2/gm)	PORE VOLUME (cc/gm)	PORE DIAMETER Å
		3/32" Ø x 3/32" TABLETS				
5	1.5	5.2	---	99	0.32	129
5	2.0	4.8	1.03	101	0.28	110
7	1.5	6.6	---	102	0.29	113
7	2.0	7.0	1.14	94	0.28	119
9	2.0	8.3	---	95	0.26	109
11	2.0	11.0	---	83	0.31	149
		COMMERCIAL 3/16" Ø x 3/16" TABLET				
--	2-3	10.1	---	99	0.27	109

for the 3/16" diameter tablet would be equivalent to a 6-8 pound value in the 3/32" diameter tablet

Samples of the different strength catalyst tablets were run in the bench scale reactor unit at 1000 psig and 230, 250, and 270°C at 2000, 3000, and 4000 VHSV. A synthesized Lurgi gas was used. This data can be found in Table 4-10. Figure 4-25 summarizes these results at the 230°C temperature level. Note that while the physical properties of the 11 pound crush strength tablets are significantly different from the other five samples, as well as the commercial preparation, the reaction results at all but the highest flow rates are well within the experimental scatter band of the other samples. The effect of graphite (used as a lubricant in the tabletting process) is seemingly ambiguous, resulting in sometimes higher and sometimes lower conversion levels. However, in retrospect, this is understandable since the average physical properties for the resulting particles are not all that different.

Later in the BSU development program tests were conducted with these mini-tablets in conjunction with a Koppers-Totzek feed gas. This work subsequently formed the basis for the second series of long-term activity tests conducted in both the BSU and PDU. The results for this process variable scan are presented in Table 4-11. The unit was operated on a continuous basis.

The initial activity level was established with a Lurgi type gas (50% H_2, 25% CO, 10% CO_2, 15% CH_4) at a pressure of 1000 psig, a temperature of 230°C and a gas feed rate of 2900 liters/hr-kg catalyst. The CO conversion level of 38-39 percent is typical for these conditions. After 33 hours of steady performance the feed gas composition was switched to Koppers-Totzek type gas (36% H_2, 56% CO, 2% CO_2, 6% Argon). Argon was used as an internal standard for flow calculations. For the next 90 hours a temperature and feed rate variable scan was performed operating at each run condition until at least 4 hours of steady performance had been attained. Three of the data points, 17-2, 3 and 6 were repeated during the scan, as 17-8, -9 and -10, respectively.

TABLE 4-10

SCREENING TESTS WITH MINI-TABLETS
(3/32 INCH BY 3/32 INCH TABLETS, WITCO 40 MINERAL OIL)

GAS COMPOSITION: 50% H_2, 25% CO, 10% CO_2, 15% CH_4

RUN NO.	TEMP. (°C)	PRESS (psig)	WHSV (Liter Gas/ Kg Cat-Hr)	VHSV (Liter Gas Liter Cat-Hr)	CO CONVERSION (%)
	SERIES 164 - 11 LB. AVERAGE CRUSH STRENGTH, 2% GRAPHITE				
1	230	1000	2040	2560	37.8
2	230	1000	2130	2675	39.1
3	230	1000	2150	2700	38.2
4	230	1000	2130	2675	37.8
5	230	1000	4095	5135	28.1
6	230	1000	2085	2620	37.2
7	230	1000	3965	4975	26.6
8	250	1000	3935	4940	27.7
9	250	1000	1975	2480	35.0
10	250	1000	4140	5195	26.1
11	270	1000	4075	5115	22.3
12	270	1000	2165	2720	27.7
	SERIES 165 - 5 LB. AVERAGE CRUSH STRENGTH, 1.5% GRAPHITE				
1	230	1000	4255	4250	34.6
2	230	1000	4070	4065	34.8
3	250	1000	3930	3975	33.4
4	250	1000	2010	2005	40.7
5	250	1000	4145	4140	32.5
6	270	1000	4105	4100	29.8
7	270	1000	2195	2190	31.6
	SERIES 166 - 9 LB. AVERAGE CRUSH STRENGTH. 2% GRAPHITE				
1	230	1000	4030	4540	30.7
2	230	1000	1675	1885	41.8
3	230	1000	3980	4485	30.8
4	250	1000	3970	4470	31.3
5	250	1000	2030	2285	37.8
6	270	1000	4045	4555	27.6
7	270	1000	1886	2125	32.2

(Continued)
TABLE 4-10

SCREENING TESTS WITH MINI-TABLETS
(3/32 INCH BY 3/32 INCH TABLETS, WITCO 40 MINERAL OIL)
Gas Composition: 50% H_2, 25% CO, 10% CO_2, 15% CH_4

RUN NO.	TEMP. (°C)	PRESS. (psig)	WHSV (Liter/Gas Kg Cat-Hr)	VHSV (Liter Gas Liter Cat-Hr)	CO CONVERSION (%)
	SERIES 167 - 7 LB. AVERAGE CRUSH STRENGTH, 2% GRAPHITE				
1	230	1000	3900	3810	33.3
2	230	1000	1875	1830	40.1
3	230	1000	3945	3850	31.9
4	250	1000	3970	3875	30.4
5	250	1000	1880	1835	37.5
6	250	1000	4265	4165	30.7
7	270	1000	4205	4105	29.7
8	270	1000	1885	1840	33.5
	SERIES 170 - 7 LB. AVERAGE CRUSH STRENGTH, 2% GRAPHITE				
1	230	1000	4070	4165	30.0
2	230	1000	2080	2130	37.7
3	250	1000	2160	2210	33.6
4	250	1000	3920	4015	26.7
5	230	1000	3920	4015	25.8
6	250	1000	3890	3980	24.7
7	270	1000	3885	3975	22.8
8	270	1000	1950	1975	27.8
9	270	1000	2185	2235	30.2
10	250	1000	2115	2165	35.1
11	230	1000	2070	2120	36.5
12	230	1000	4320	4420	33.2
13	250	1000	4400	4505	25.0
14	270	1000	4345	4450	21.4

(Continued)
TABLE 4-10

SCREENING TESTS WITH MINI-TABLETS
(3/32 INCH by 3/32 INCH TABLETS, WITCO 40 MINERAL OIL)
Gas Composition: 50% H_2, 25% CO, 10% CO_2, 15% CH_4

RUN NO.	TEMP. (°C)	PRESS. (psig)	WHSV (Liter Gas/ Kg Cat-Hr)	VHSV (Liter Gas Liter Cat-Hr)	CO CONVERSION (%)
	SERIES 171 - 5 LB. AVERAGE CRUSH STRENGTH, 2% GRAPHITE				
1	230	500	1810	1805	18.4
2	230	500	4225	4215	9.6
3	230	1000	1710	1705	37.5
4	230	1000	5070	5055	16.8
5	230	1000	2030	2025	24.7
6	270	1000	2015	2010	24.9
7	250	1000	2080	2075	25.6
8	250	500	2140	2135	8.4
9	230	500	2165	2160	8.1
10	230	500	2030	2023	8.3
11	230	500	1150	1145	12.1
12	250	500	1235	1230	10.5
13	250	1000	2060	2055	25.7
14	250	1000	1080	1075	32.3

FIGURE 4-26

EFFECT OF CRUSH STRENGTH

CATALYST A / WITCO 40 LURGI GAS

3/32" ϕ TABLETS 230°C 1000 PSIS

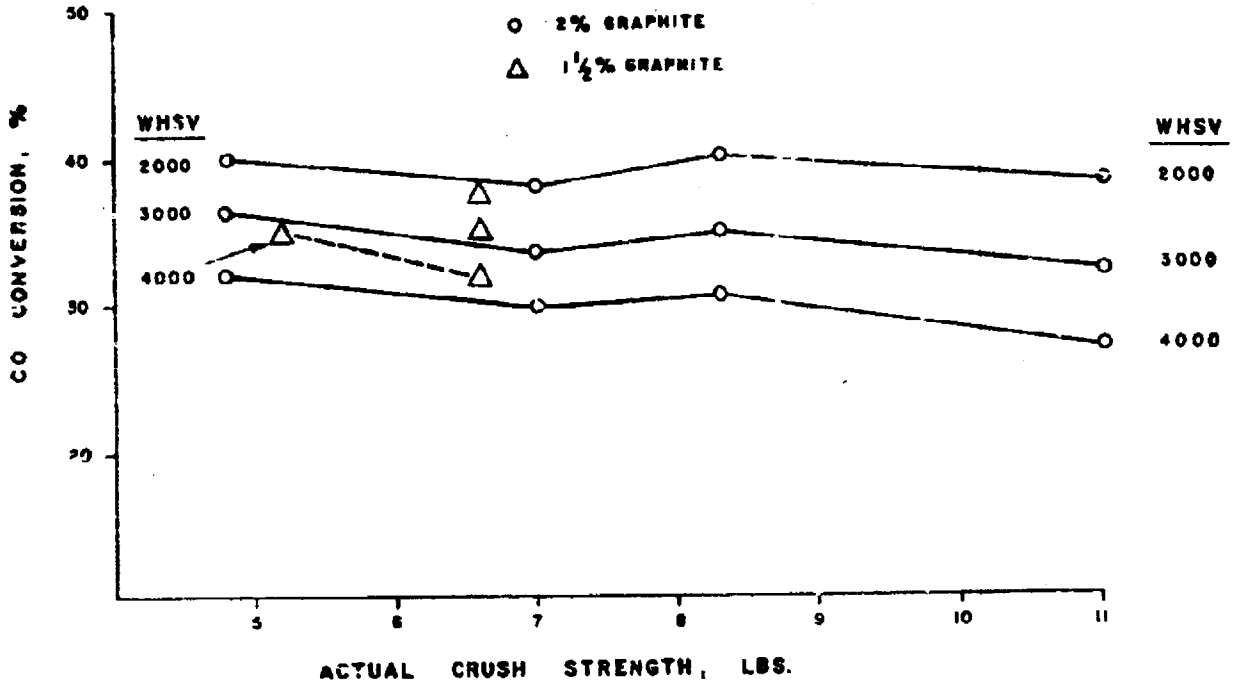


TABLE 4-11

BENCH SCALE UNIT PROCESS VARIABLE SCAN
KT Gas/Catalyst A*/Witco 40 mineral oil

Run	Gas	Pressure (psig)	Temperature (°C)	Feed Rate Liters Gas/ Hr-Kg Cat.	CO Conversion (%)
17-1	Lurgi	1,000	230	2,300	38.5
17-2	KT	1,000	230	2,100	20.2
17-3	KT	1,000	250	2,150	21.5
17-4	KT	1,000	220	1,800	16.0
17-5	KT	1,000	220	3,050	12.8
17-6	KT	1,000	250	3,100	16.6
17-7	KT	1,000	230	2,900	13.6
17-8	KT	1,000	230	1,950	16.4
17-9	KT	1,000	250	2,150	19.0
17-10	KT	1,000	250	3,100	15.4

* Catalyst A: 3/32" Ø X 3/32", 5 lb. crush strength.

Due to the significant feed gas composition change, the catalyst requires a certain period of time to establish a new stabilized activity level as evidenced by the shift of lower conversion levels for the later points. The stabilized levels are indicated in Figure 4-27. For Run 17-10 operating at the design conditions of 1000 psig and 3100 liters/hr-kg catalyst, the conversion level of 15.4 percent is nearly 20 percent greater than the target activity level for this feed gas composition.

These data were subsequently analyzed with respect to reaction modelling and is discussed in more detail in Section 8. It is interesting to note that product alcohol compositions are quite dependent on the feed gas composition used, as shown in Table 4-12. The Lurgi type gas gives a product very high in MeOH, with 2-3 percent H_2O, but very low in higher alcohols, less than 1 percent total. A K-T type gas product contains less than 1 percent water and more than 8 percent higher alcohols. This is discussed in more detail in Section 8.

Development of An Extrudate

As had been mentioned at the beginning of this section, an alternative approach to the use of mini-tablets (3/32" Ø x 3/32"), was the development of small, ≤ 1/16", spherical or extruded forms of catalyst. While initial experiments had been unsuccessful, a second catalyst manufacturer felt there was sufficient incentive to continue the effort. This work was internally funded, and unfortunately a subsequent change in corporate policy resulted in a premature cancellation of their program. Nevertheless, their work is detailed here in order to provide guidelines for future work in this area.

In order to prevent unnecessary experiments in the BSU the manufacturer screened the catalyst candidates in a fixed bed vapor phase reactor. In a parallel effort, several samples were also tested at Chem Systems laboratory. Quantitative data from the manufacturer were not always available when needed, thus there was some duplication of effort.

FIGURE 4-27

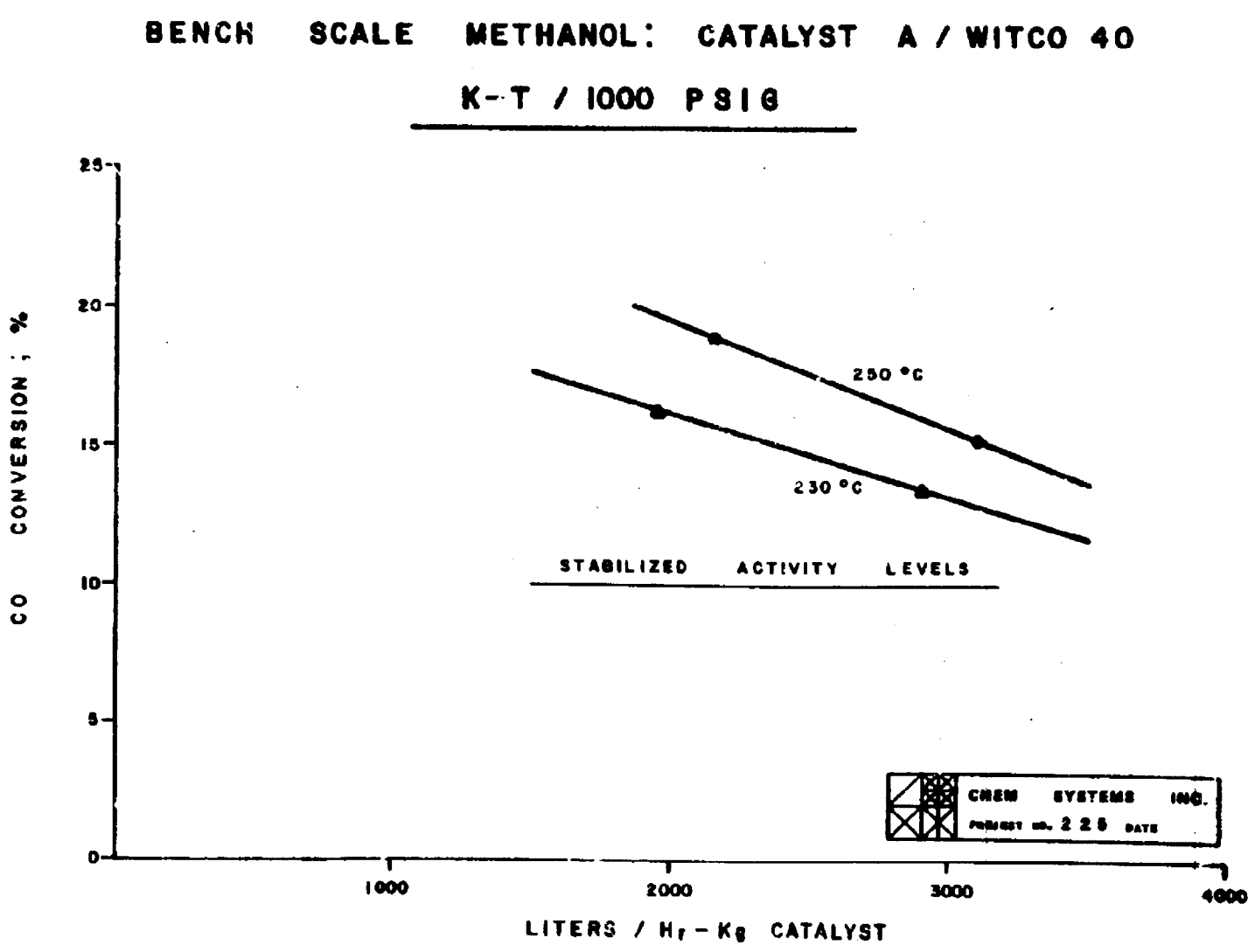

BENCH SCALE METHANOL: CATALYST A / WITCO 40
K-T / 1000 PSIG
CO CONVERSION ; %
25
20
15
10
5
0
250 °C
230 °C
STABILIZED ACTIVITY LEVELS
CHEM SYSTEMS INC.
1000
2000
3000
4000
LITERS / Hr - Kg CATALYST

TABLE 4-12

ALCOHOL PRODUCT ANALYSIS (1), WEIGHT BASIS

	Lurgi Gas BSU	Koppers-Totzek BSU
Methanol	96.16	91.44
Methyl Formate	0.17	0.24
Ethanol	0.32	2.55
i-Propanol	tr	tr
Methyl Acetate	0.07	0.78
n-Propanol	0.14	1.23
C_4 Alcohols	0.23	1.43
C_5 Alcohols	0.33	1.40
C_{6+} Alcohols	0.06	0.55
Water	2.71	0.51

(1) Oil-free basis, oil level is a function of composition (especially water concentration) and temperature.

The vapor phase units were first put on-stream with the commercial Catalyst A tablets. This material had been previously tested and the run served both to check out the vapor phase units and provide a basis of comparison for the four new catalyst candidates.

The nominal reaction conditions in all cases were 500 psig and 225°C salt bath temperature. The feed gas* rate was equivalent to 2300-2500 liters gas/hr-kg catalyst.

The results for the commercial Catalyst A (3/16" Ø) tablets are shown in Figure 4-28. The initial CO conversion level of 19 percent at a 2200 Hr^{-1} VHSV level is consistent with the results obtained previously during the poisoning studies. There were two interruptions during the test: (1) the system was put on a N_2 purge and lowered to 180°C in order to reduce catalyst in the other reactor, and (2) the gas flow was temporarily lowered to about 1100 Hr^{-1} VHSV in order to conserve feed gas and maintain the unit on-stream when the feed gas cylinder delivery was late. In both cases, when normal operating conditions were re-established, the conversion level returned to its previous value. As in the previous run, there was a slight drop in conversion over the first 1000 hours on-stream. The product methanol stream was periodically analyzed during the run and a typical analysis is shown in Table 4-13.

With these results in hand three catalysts were tested. The catalyst compositions and properties are given in Table 4-14 and the reaction results are given in Figures 4-29, -30 and -31. The samples have varying ratios of Cu/Zn/Cr and there were no promoters used as the purpose of these runs was simply to zero in on the compositional region of interest. The G-1 (3/16" Ø x 1/16") and G-2 (3/16" Ø x 1/16") catalysts gave results quite similar to the commercial Catalyst A, while G-3 (3/16" Ø x 1/16") showed substantially lower activity. A review of the patent literature indicated that the G-2 catalyst is probably close in

*Nominal Composition: 50% H_2, 25% CO, 10% CO_2 and 15% CH_4.

FIGURE 4-28

CONVERSION VERSUS ON-STREAM TIME

CATALYST A; 3/16" T

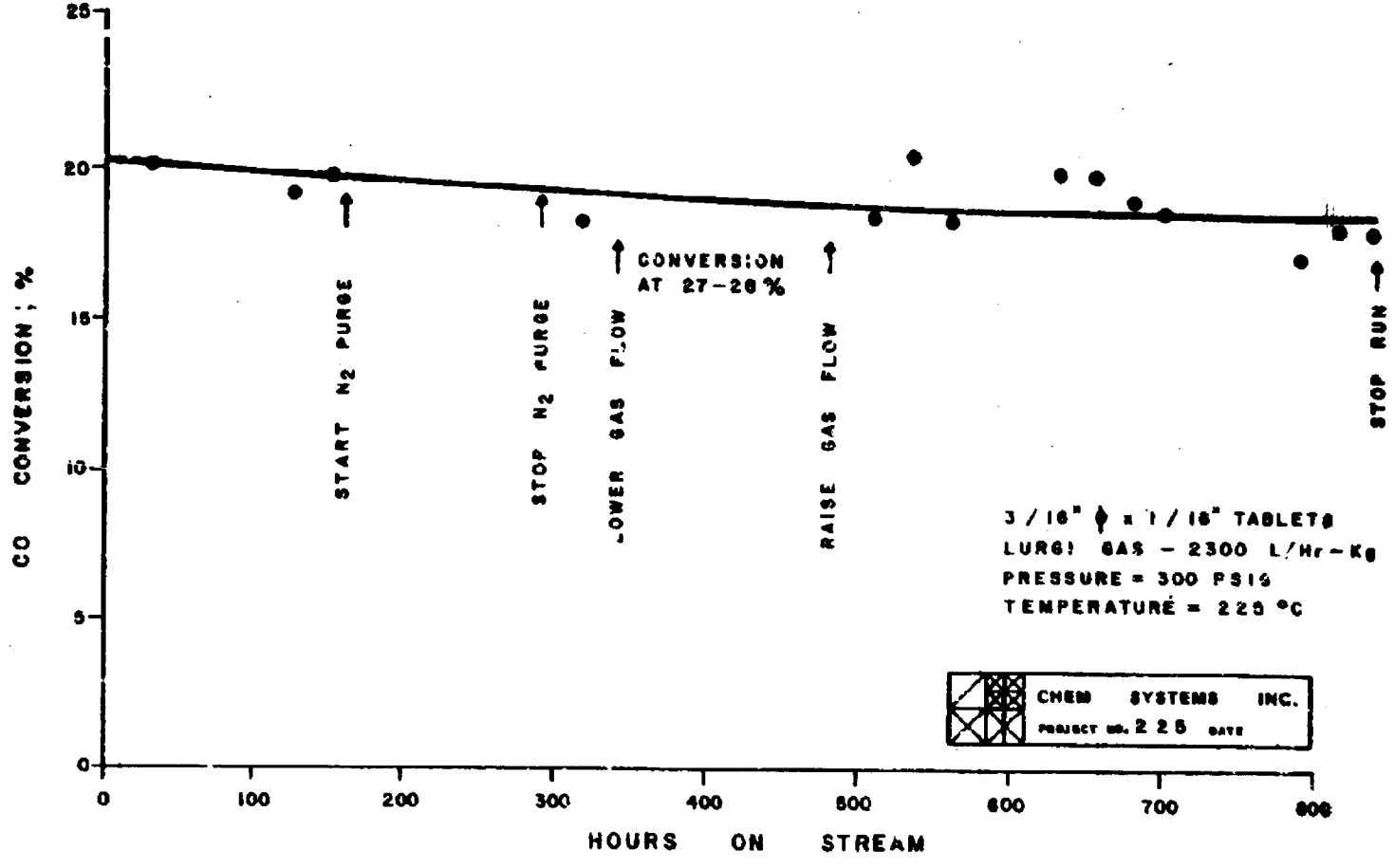


TABLE 4-13

ANALYSIS OF MeOH SAMPLES

Component	Catalyst A Tablet	W.R. Grace G-2 Tablet	W.R. Grace G-1 Tablet	W.R. Grace G-3 Tablet	W.R. Grace G-1 Extrudate
MeOH % By Difference	96.70	96.42	96.64	92.24	61.54
Methyl Formate	0.07	0.08	0.14	0.05	-
Ethanol	0.62	0.47	0.33	0.11	1.03
Isopropanol	0.01	0.01	≤ 0.01	≤ 0.01	0.13
Methyl Acetate	0.03	0.03	0.03	-	0.06
n-Propanol	0.23	0.16	0.11	0.07	0.44
t-Butanol	-	-	-	-	-
sec-Butanol	0.02	0.04	0.03	0.02	0.27
Isobutanol	0.07	0.04	0.03	≤ 0.01	0.19
n-Butanol	0.10	0.16	0.04	0.05	0.17
t-Amyl Alcohol	-	≤ 0.01	≤ 0.01	-	0.08
2- and 3-Pentanol	-	0.03	≤ 0.01	≤ 0.01	0.52
Isopentanol	0.03	0.04	≤ 0.01	0.02	4.00
1-Pentanol	0.02	0.06	≤ 0.01	≤ 0.01	-
C_6 and Higher Alcohols	0.07	0.05	-	-	0.27
Lights	0.06	0.03	≤ 0.01	-	-
Water, %	1.97	2.45	2.58	7.40	31.30
Oil, %	NA(1)	NA(1)	NA(1)	NA(1)	NA(1)
Others, %	-	≤ 0.01(2)	≤ 0.01	-	-
Total	100.00	100.00	100.00	100.00	100.00

(1) See Figure 8-14 for typical oil level.
(2) Unknown: May be methyl propionate.

TABLE 4-14

COMPOSITION AND PHYSICAL PROPERTIES OF METHANOL CATALYST PREPARATIONS

Sample	Composition Cu/Zn/Cr Atomic Ratio	Crush Strength lbs	Surface Area M^2/g	N_2 Pore Volume cm^3/g	Average Pore Diameter Å
G-1*	75/18/7	17.5	43	0.16	155
G-2*	60/30/10	17.3	120	0.50	166
G-3*	40/40/20	14.8	74	0.36	195
G-1**	75/18/7	NA	37	0.14	155

* Tablets were 3/16" Ø x 1/16".

** Extrudate - 3/32" Ø.

FIGURE 4-29

CONVERSION VERSUS ON-STREAM TIME

W. R. GRACE CATALYST # 1

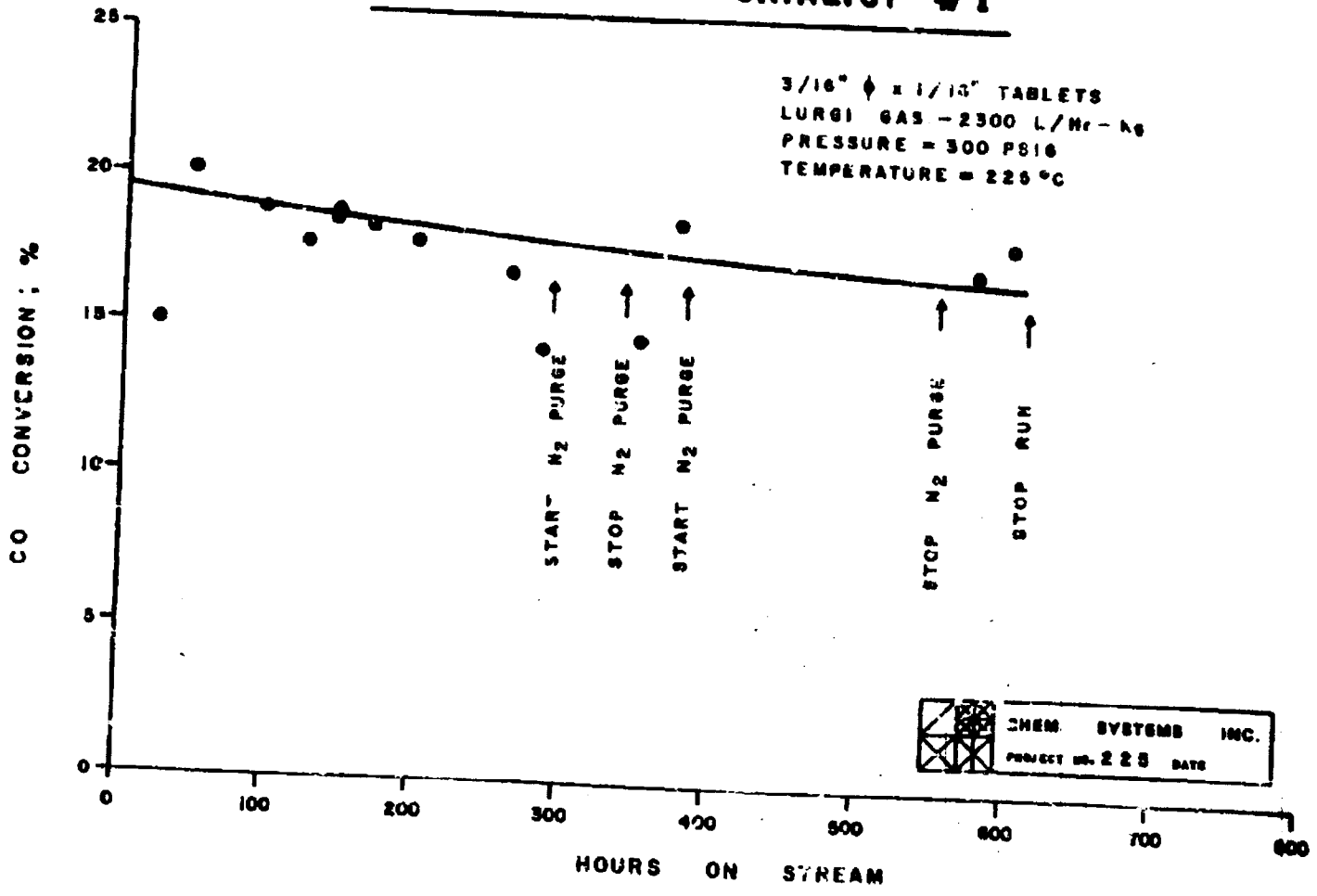


FIGURE 4-60

CONVERSION VERSUS ON-STREAM TIME

W. R. GRACE CATALYST #2

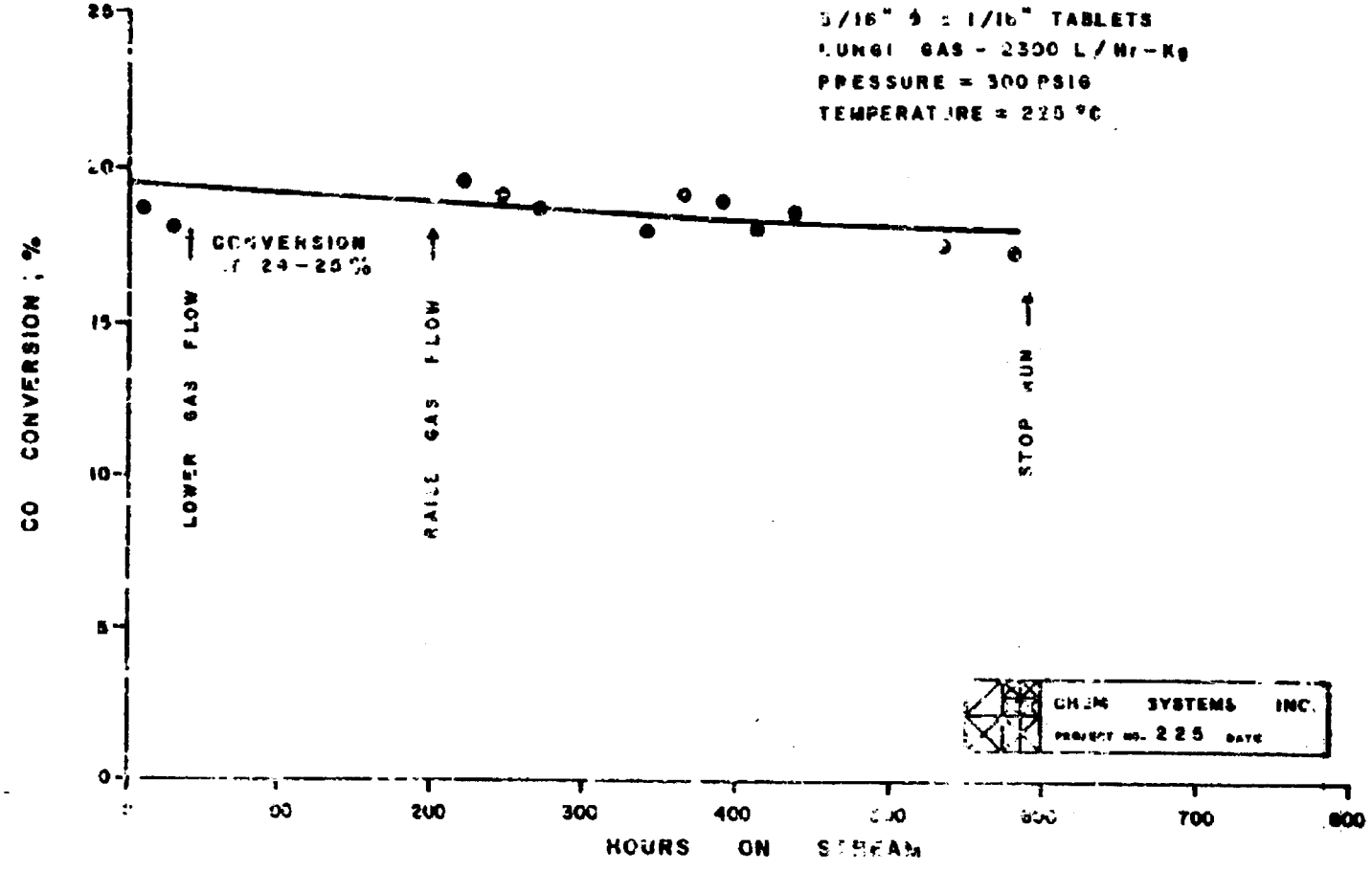
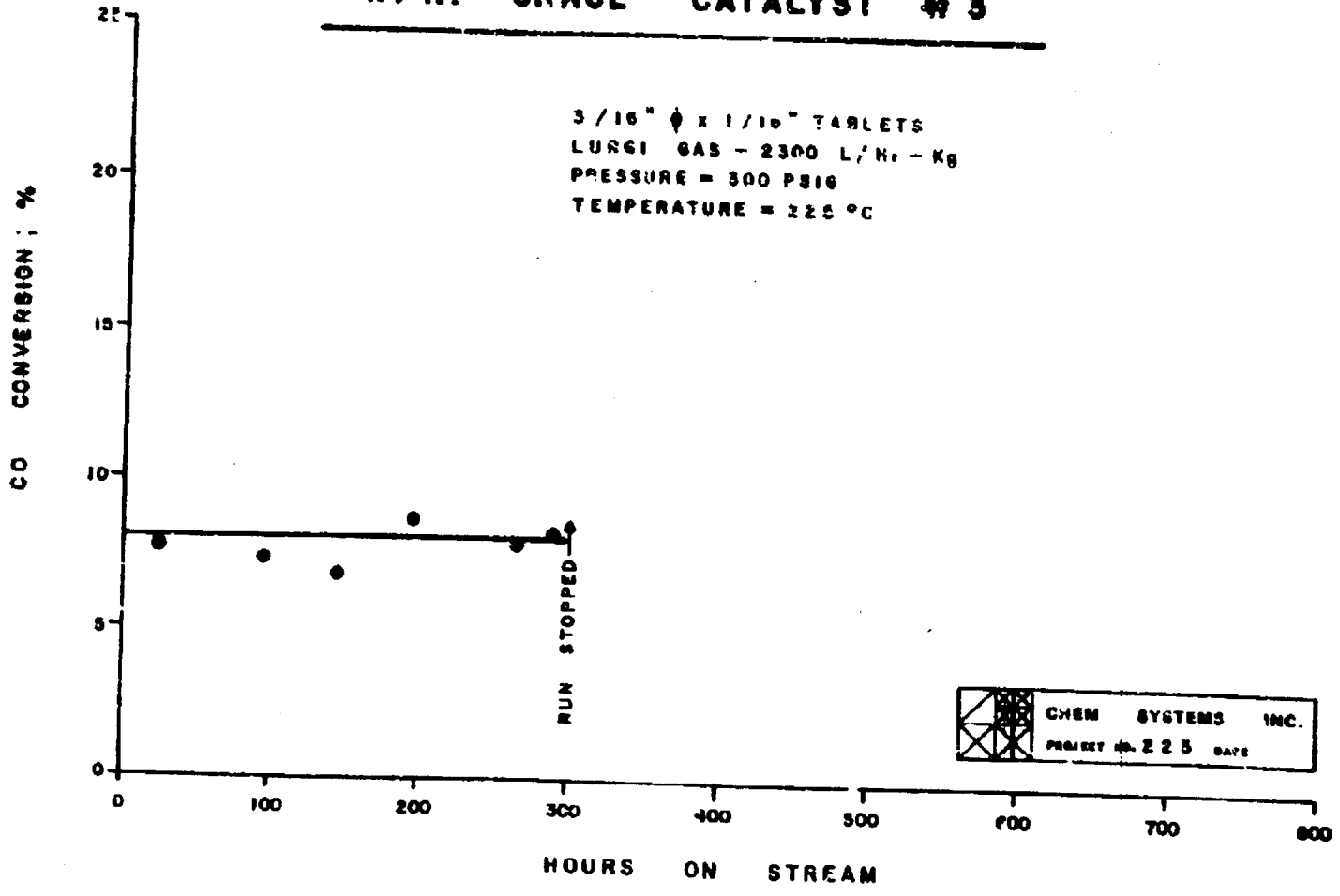


FIGURE 4-31

CONVERSION VERSUS ON-STREAM TIME

W. R. GRACE CATALYST # 3



composition to the commercial preparation except that chromia is used instead of alumina. This is apparently not too important a difference since the methanol product compositions for the G-1 and G-2 catalysts are nearly the same as the Catalyst A product (see Table 4-13). The G-3 catalyst product has about four times the normal water level (7.4 percent instead of 2 percent) and a peculiar pale yellow color.

Based on these results, attempts were made to produce an extrudate form of both the G-1 and G-2 compositions. Unfortunately while composition G-1 formed perfect 1/16" ∅ and 3/32" ∅ extrudates, composition G-2 could not be processed to produce extrudates with any physical strength. More importantly, while the G-1 extrudates had the same chemical composition as the G-1 tablets, no more than 3 percent CO conversion was obtained when the extrudates were put on-stream (at the base conditions) following the standard reduction procedure. A repeat of this run with a new batch of catalyst gave the same results. In addition, as the analysis given in Table 4-13 indicates, the product made had a very different composition, containing substantial amounts of higher alcohols and water. At first it was thought that the processing might have produced a "thick-skinned" extrudate. Several "stronger" reduction procedures involving higher temperatures (up to 300°C, instead of 240°C), higher H_2 concentrations (up to 100 percent H_2, instead of 2 percent H_2) and higher pressures (up to 300 psig, instead of 0 psig) were tried. In all cases the conversion remained at a very low level. Subsequent chemical analysis of this catalyst revealed high levels of residual alkali metal as a result of incomplete washing of the alkali bicarbonate salts used in the precipitation step of the manufacturing process.

The manufacturer continued his development effort, ultimately producing several viable candidates for testing in the BSU. Table 4-15 presents the test data for these catalysts, including the mini-tablet version of Catalyst A. Based on these and in-house results, catalysts R-11076, R-11078 and R-11080 were tested. The pure Catalyst A (R-11075) was tested as a base case. The Catalyst A/25% α-alumina (R-11078) blend was

TABLE 4-15

VAPOR PHASE SCREENING TESTS - EFFECT OF COMPOSITION AND PHYSICAL FORM: MANUFACTURERS DATA

Sample	Description	% Conversion	Activity[2] Ratio
R-11081	60-30-10[1] composition, 3/32" pills	21.5	0.92
R-11082	60-30-10 composition, @ 25% Al_2O_3 3/32" pills	20.5	0.88
R-11076	Catalyst A composition, 3/32" pills	23.3	1.00
R-11078	Catalyst A composition, @ 25% Al_2O_3 3/32" pills	23.9	1.03
R-11080	60-30-10 composition, @ 50% Al_2O_3, 1/16" ext.	15.0	0.64
R-11079	60-30-10 composition, @ 50% Al_2O_3, 3/32" ext.	14.7	0.63

Nominal operating conditions: 230°C, 300 psig with a feed gas rate of 2,100 l/kg-hr (53.3% H_2, 26.7% CO, 20.2% CO_2).

(1) Cu/Zn/Cr atomic ratios

(2) (Conversion with catalyst R-xxxxx/Conversion with catalyst R-11076)

tested because the manufacturer recognized that the addition of α-alumina was necessary in order to be able to produce physically acceptable extrudates. Lastly, the high alumina blend catalyst (R-11080) was tested because: (1) it was the only compositional blend that the manufacturer had been able to form physically acceptable extrudates from and (2) at the time it was believed there was substantial promise of activity improvement with this material.

The results for the pure Catalyst A tablets (R-11076) are presented in Tables 4-16 and 4-17. As a basis for comparison, in the most recent tests with the same catalyst/liquid pair, the initial conversion levels at 230°C and 1000 psig were:

- 40 percent at 2000 liters/hr-kg cat
- 36 percent at 3000 liters/hr-kg cat
- 32 percent at 4000 liters/hr-kg cat

It can be seen that the results are well within the expected ranges.

There was some question during the Run 12 series of experiments arising out of the presence of a substantial quantity of material eluting during chromatography at the same time as the C_4 alcohols. This material was subsequently identified as cyclohexane, which had been used to clean the unit before operating.

Catalyst A/25% α-alumina blend (R-11070) test results are tabulated in Table 4-18. While the initial activity levels for the pure Catalyst A were about 10 percent lower (relative) the composite catalyst appeared to equilibrate more rapidly, so that by the fourth day the activity levels were essentially the same (see Table 4-19).

The last series of experiments in this catalyst development task were performed with the composite 60Cu/30Zn/10Cr/ α-alumina extrudates (R-11080) The results are presented in Table 4-20. Run Series 15

TABLE 4-16

BSU PROCESS VARIABLE SCAN:
COMMERCIAL CATALYST A (3/32" Ø x 3/32")(1)/WITCO 40 MINERAL OIL

Run No.	Temperature; °C	Pressure psig	WHSV;(2) liters/hr-kg cat	CO Conversion; %
12-1a	230	1,000	3,515	35.6
12-1b	230	1,000	4,610	29.5
12-1c	250	1,000	4,260	29.4
12-1d	250	1,000	3,440	32.3
12-2a	230	1,000	3,380	32.3
12-2b	220	1,000	3,330	30.8
12-2c	210	1,000	3,210	26.2
12-2d	230	500	2,040	18.6
12-3a	230	1,000	2,080	37.9
12-3b	230	1,000	4,480	24.8
12-3c	230	1,000	3,305	29.5
12-3d	230	500	2,420	14.1
12-3e	230	500	1,705	18.5
12-4a	230	1,000	3,360	28.1
12-4b	230	1,000	2,210	34.9
12-4c	230	1,000	2,000	35.5
12-4d	230	1,000	4,555	22.5
12-4e	230	500	2,394	14.3
12-5a	200	1,000	3,325	18.4
12-5b	230	1,000	3,430	26.8
12-5c	250	1,000	3,425	26.4
12-5d	270	1,000	3,460	25.5
12-5e	230	1,000	3,520	25.8
12-6a	230	1,000	3,395	25.4
12-6b	230	1,000	2,720	33.7
12-6c	230	1,000	4,655	20.2
12-6d	230	1,000	2,670	27.0

(1) R-11076: Average crush strength - 5#, 2% graphite.
(2) Feed gas composition: 50% H_2, 25% CO, 10% CO_2 and 15% CH_4.

TABLE 4-17

3SU PROCESS VARIABLE SCAN:
COMMERCIAL CATALYST A (3/32" Ø x 3/32")[1]/WITCO 40 MINERAL OIL

Run No.	Temperature; °C	Pressure psig	WHSV;[2] liters/hr-kg cat	CO Conversion; %
13-1a	230	1,000	2,360	42.1
13-1b	230	1,000	3,505	34.2
13-1c	230	1,000	4,850	28.4
13-1d	230	1,000	2,205	41.9
13-2a	230	1,000	2,670	35.2
13-2b	230	1,000	3,490	32.2
13-2c	230	1,000	4,730	27.2
13-2d	230	1,000	2,265	30.4

(1) R-11076: Average crush strength - 5#, 2% graphite.
(2) Feed gas composition: 50% H_2, 25% CO, 10% CO_2 and 15% CH_4.

TABLE 4-18

PROCESS VARIABLE SCAN - BENCH SCALE UNIT
COMMERCIAL CATALYST A/α-ALUMINA (3/32" Ø x 3/32")(1)/WITCO 40 MINERAL OIL

Run No.	Temperature; °C	Pressure psig	WHSV;(2) liters/hr-kg cat	CO Conversion; %
14-1a	230	1,000	3,465	31.3
14-1b	230	1,000	4,180	28.5
14-2a	230	1,000	3,420	27.9
14-2b	230	1,000	4,130	25.7
14-2c	230	1,000	2,060	32.9
14-2d	250	1,000	2,165	31.0
14-3a	250	1,000	3,460	26.6
14-3b	230	1,000	3,495	25.5
14-3c	200	1,000	3.430	15.3
14-3d	270	1,000	3,490	22.6
14-3e	230	1,000	3,480	26.6
14-4a	230	1,000	2,130	34.6
14-4b	230	1,000	4,090	25.9
14-4c	230	1,000	4,840	24.1
14-4d	230	1,000	3,430	25.6

(1) R-11078: Composite catalyst consisting of 75% by weight Catalyst A and 25% by weight α-alumina. Average crush strength-5#, with 2% graphite.

(2) Feed gas composition: 50% H_2, 25% CO, 10% CO_2 and 15% CH_4.

TABLE 4-19

COMPARISON OF VAPOR PHASE AND LIQUID PHASE SCREENING TESTS

Catalyst	Activity Ratio(1) Vapor Phase	Liquid Phase
R-11076		
Catalyst A Tablets (3/32" Ø x 3/32")	1.00	1.00
R-11078		
Catalyst A @ 25% α-Alumina Tablets (3/32" Ø x 3/32")	1.03	1.0
R-11080		
60Cu/30Zn/10Cr @ 50% α-Alumina Extrudates (1/16" Ø)	0.64	0.7-0.8

(1) (Conversion with catalyst R-xxxxx/Conversion with catalyst R-11076).

TABLE 4-20

PROCESS VARIABLE SCAN - BENCH SCALE UNIT
60Cu/30Zn/10Cr @ 50% ALUMINA (1/16" EXTRUDATES) (1)/WITCO 40 MINERAL OIL

Run No.	Temperature; °C	Pressure psig	WHSV;(2) liters/hr-kg cat	CO Conversion; %
15-1a	230	500	2,300	12.8
15-1b	250	500	2,300	14.5
15-2a	230	500	2,300	9.5
15-2b	265	500	2,300	9.3
15-2c	265	500	3,450	8.1
16-1a	230	500	2,540	16.5
16-1b	230	500	3,420	13.0
16-1c	250	500	3,280	12.8
16-2a	230	500	2,310	14.7
16-2b	250	500	2,400	16.1
16-2c	250	500	3,480	12.8

(1) R-11080: Composite catalyst containing 50% by weight a 60Cu/30Zn/10Cr blend and 50% by weight α-alumina.

(2) Lurgi feed gas composition: 50% H_2, 25% CO, 10% CO_2, and 15% CH_4.