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CATALYST AND PROCESS DEVELOPMENT FOR HYDROGEN
PREPARATION FROM FUTURE FUEL CELL FEEDSTOCKS

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PREPARED BY

R. M. YARRINGTON

I. R. FEINS

H. S. HWANG

C. P. MAYER

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RESEARCH AND DEVELOPMENT DEPARTMENT
ENGELHARD INDUSTRIES DIVISION
ENGELHARD MINERALS AND CHEMICALS CORPORATION
MENLO PARK, EDISON, N.J. 08817

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CATALYST AND PROCESS DEVELOPMENT FOR HYDROGEN PREPARATION FROM
FUTURE FUEL CELL FEEDSTOCKS

ABSTRACT

Twelve steam reforming catalysts were evaluated using an autothermal reforming screening unit. Duplicate tests were run with two samples to determine test variability.

The samples tested contained either base metals, precious metals, or combinations of base and precious metals. The test was capable of distinguishing among samples where gross variations in composition is the main factor; for example, catalysts containing 2% by weight precious metals are more active than catalysts containing 15% by weight nickel.

The results show a decrease in hydrocarbon breakthrough as the weight of nickel charged to the constant volume reactor increases. A commercial nickel catalyst, G90C, appears slightly better than some Engelhard prepared samples of equal nickel concentrations due to the higher density of G90C.

Visual observation of the used catalysts show that samples containing only precious metals (Pt/Rh) did not coke during the run. The samples containing only base metals (nickel, cobalt) were coked and were magnetic. Samples containing 14.5% nickel by weight with 0.5% precious metals by weight added were not coked, were not magnetic, and had a blue colored core as compared to the black core of the virgin samples. Some speculation about deactivation mechanisms based on these observations are made.

REVIEW BY TASKSTask 4 - Catalyst Preparation (Engelhard Cost Contribution)

The catalysts submitted for screening are listed in Table I. The metals selected for evaluation include various base metals such as Ni, Co, La, precious metals such as Pt and Rh, and combinations of base metal and precious metals. The latter were made to extend our observation that rhodium is an excellent catalyst for its ability to lower the olefin content of the ATR product gas.

Task 5.1.B - Catalyst Screening Using an ATR Unit1. Experimental Details and Results

The catalysts prepared in Task 4 are being screened in the bench scale ATR test unit described in detail in the previous quarterly report. Figure 1 is a schematic drawing showing the location of thermocouples used to monitor temperatures. To date, 12 samples have been tested and two repeat runs have been made for a total of 14 test runs. In these tests a Pt/Pd monolithic catalyst is used in the CPO section. This was common to all the tests; fresh portions were used after about 3 tests mainly as a precaution. Deactivation of the CPO section was not observed.

The nominal test conditions used throughout this period were as follows:

Preheat Temperature	900°F
Pressure	Atmospheric
H ₂ O/C	2.7
O ₂ /C	0.43
Fuel	No. 2 Oil

During each run the temperatures were monitored to attempt to maintain run to run consistency. Referring to Figure 1, the thermocouples include one to measure the oil preheat temperature, which is located in the oil line but also approximates the resultant temperature of blending oil, steam, and air. At the bottom, one thermocouple above the catalyst bed measures

the temperature after the CPO section. Now this temperature is slightly influenced, via axial conduction, by the colder steam reforming bed temperatures. Three thermocouples are in the steam reforming bed and one is directly below the catalyst.

The temperature in the furnace adjacent to the steam reforming bed is held nearly constant from run to run. A furnace is required here to prevent excessive heat loss with this small, non-adiabatic unit. It is desirable to test catalysts under temperature conditions to be expected in the larger, adiabatic rigs. Therefore, heat is added using this furnace.

Figure 2 shows the temperature profile for two runs; run 7275 where an inactive catalyst was used and run 7271 where a highly active Ni/Rh catalyst was used. Assuming that the former run is typical of a run without catalyst, it is noted that heat is being lost in this section. The profile for run 7271 is a typical profile for an endothermic reaction in a reactor where heat is being supplied externally. This type of data can be used to augment the analytical data on product composition. An endothermic reaction temperature drop is calculated for several runs by subtracting the mid-bed temperature from the temperature directly below the CPO unit. In Figure 3, a crude relation is observed when hydrocarbon conversion is plotted versus this endothermic temperature drop. This figure indicates that about 80% of the feed hydrocarbon is converted in the CPO section under these test conditions.

For each run, the dry gas from the ATR reactor was analyzed hourly using a Carle refinery gas chromatographic analyzer. These data are listed for each of the 14 runs in Tables 2A to Table 2N.

2. Discussion of Results

The experimental results for each test are summarized in Table III where the data after 3 hours on stream are listed and used to calculate hydrocarbon conversion and equivalent hydrogen. These are defined as follows:

$$\text{Hydrocarbon Conversion} = (\text{CO} + \text{CO}_2)/C_p$$

where C_p is the total carbon in the product gas

$$\text{Equivalent Hydrogen} = (\text{H}_2 + \text{CO})/C_f$$

where C_f = Carbon in the feed

The catalysts are rated on these two values, which are interrelated. In terms of hydrocarbon conversion the catalysts are rated from best to worst as follows:

<u>Catalyst</u>	<u>Active Metals</u>	<u>HC Conversion, %</u>
FP-1, FP-3	Pt/Rh	96.9 - 95.3
FP-7	Ni/Rh	93.5
FP-12	Ni/Pt/Rh	91.6
FP-19	Ni/Rh	91.3
G-90C	Ni	90.7 - 89.0
SF-3B	Ni	89.7
FP-5	Ni/Ru	88.2
FP-6	Ni	87.8
FP-8	Ni/Pt	87.3
FP-9	Ni	83.0
FP-4	Ni/Co	79.6

Based on the two duplicate runs the standard deviation of the test is $\pm 1.2\%$ hydrocarbon conversion. Based on this type of variation, it is concluded that the Pt/Rh sample is more active than either the base metal samples or the base metal plus precious metal combinations.

These latter samples were made with 14.5 wt % nickel plus 0.5 wt % precious metal. According to the ranking listed above, those nickel samples with rhodium added rank above the nickel samples with either Pt or Ru.

Of the nickel catalysts, the concentration of the nickel and the density of the catalysts vary. In Figure 4, hydrocarbon breakthrough is plotted versus the weight of nickel charged to the reactor (30 ml charge used in each test). The figure shows that both methane and ethylene breakthrough decline as the nickel content increases. G-90C contains 15% nickel by weight but is more dense than some of the Engelhard samples of similar nickel content.

The stability of the various catalysts can be compared by observing the hydrocarbon breakthrough versus run time. In Figure 5, the total hydrocarbon breakthrough as mole percent carbon (i.e. the summation of C_1 , C_2 , C_3 , etc) is plotted versus run time. Aging is occurring with all the catalysts shown. It is interesting to note that the combination catalyst falls midway between the nickel catalyst and the precious metal catalyst.

Task 5.2 - Analysis of Aged Catalysts

In Table IV, some visual observations concerning changes in the virgin versus used catalyst screened in the ATR unit are noted. Those catalysts containing only precious metals on alumina were not coked during the run nor was there any evidence of coke found in the reactor. There was no color change either from the virgin catalyst with a black shell and a white core.

In contrast, catalysts composed of base metal only on alumina were coked and could be separated from the alumina diluent by using a magnet. Again no color change; a uniformed black color throughout was observed.

Those samples containing 14.5 wt % nickel to which 0.5 wt % precious metal were added are quite different from the base metal only samples. The used samples containing no coke, are not magnetic and have a blue core as compared to the black core of the virgin samples. The blue color is indicative of nickel alumina spinel but must be confirmed by X-ray diffraction.

Based on the visually observed changes for the nickel and nickel-precious metal samples, nickel appears not to form spinel in the nickel-only system and may be deactivated by nickel sintering. The addition of a small amount of precious metal to a nickel catalyst appears to prevent nickel sintering but accelerates the formation of nickel alumina spinel. Perhaps the precious metal promotes the oxidation of nickel by steam (only NiO reacts with Al_2O_3 to form NiAl_2O_4). Attempts are now in progress to retard this NiAl_2O_4 interaction.

TABLE I

Samples Submitted for ATR Screening

<u>FP-</u>	<u>Nominal Composition</u>	<u>Samples Tested</u>
1	1.4 wt% Pt - 0.6 wt% Rh	✓✓
2	15 wt% Ni	
3	1.4 wt% Pt - 0.6 wt% Rh	✓
4	7.5 wt% Ni - 7.5 wt% Co	✓
5	14.5 wt% Ni - 0.5 wt% Ru	✓
6	15 wt% Ni	✓
7	14.5 wt% Ni - 0.5 wt% Rh	✓
8	14.5 wt% Ni - 0.5 wt% Pt	✓
9	10.0 wt% Ni - 5.0 wt% La	✓
10	15 wt% Ni	
11	15 wt% Ni	
12	14.5 wt% Ni - 0.35 wt% Pt - 0.15 wt% Rh	✓
13 13	15 wt% Ni 2% Rh	
19	15 wt% Ni + 0.5 wt% Rh	✓
SF-3B	15 wt% Ni	✓
T2043	United Catalyst 15 wt% Ni (G90C Formulation on 1/8" Tableted α -Al ₂ O ₃)	✓✓

TABLE IIA

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using SF-3B (Ni)

(Run #7233; $H_2O/C = 2.61$; $O_2/C = 0.43$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄	C ₄ H ₆	C ₅ ⁺
1	853	32.48	11.10	11.63	0.10	42.54	1.86	0.04	-	-	0.23	0.02	-	-	-
2	855	32.63	11.63	11.29	0.09	42.22	1.83	0.04	-	-	0.25	0.02	-	-	-
3	855	32.08	12.00	11.00	0.10	42.59	1.87	0.04	-	-	0.31	0.02	-	-	-
4	857	31.76	12.18	10.81	0.10	42.78	1.93	0.05	-	-	0.38	0.03	-	-	-

TABLE IIB

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using FP-1 (Pt/Rh)

(Run #7238; $H_2O/C = 2.72$; $O_2/C = 0.44$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼	C ₄ H ₆	C ₅ ⁺
1	815	36.77	10.19	12.36	0.41	39.85	0.42	-	-	-	-	-	-	-	-
2	805	37.22	10.46	12.52	0.37	38.73	0.71	-	-	-	-	-	-	-	-
3	800	37.20	10.28	12.65	0.37	38.67	0.83	-	-	-	-	-	-	-	-
4	807	36.53	10.53	12.48	0.37	39.36	0.74	-	-	-	-	-	-	-	-
5	806	36.62	10.56	12.47	0.37	39.21	0.79	-	-	-	-	-	-	-	-
6	805	36.56	10.43	12.54	0.37	39.29	0.82	-	-	-	-	-	-	-	-
7	805	36.35	10.47	12.51	0.37	39.48	0.82	-	-	-	-	-	-	-	-

on Stream	Temp. (°C)	% DRY GAS COMPOSITION												
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ =	C ₄ H ₆
1	802	36.64	11.32	11.99	0.48	38.79	0.79	0.00	-	-	0.00	-	-	-
2	795	36.45	11.42	11.86	0.47	38.84	0.95	0.00	-	-	0.00	-	-	-
3	795	35.71	11.59	11.65	0.48	39.56	1.01	0.00	-	-	0.00	-	-	-
4	795	35.58	11.89	11.44	0.48	39.49	1.09	0.01	-	-	0.00	-	-	-
5	800	35.36	12.09	11.25	0.48	39.66	1.13	0.02	-	-	0.00	-	-	-
6	805	35.09	12.18	11.17	0.48	39.89	1.14	0.02	-	-	0.01	-	-	-
											0.03	0.01	-	-

TABLE IID

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using IP-6 (Ni)

(Run #7244; $H_2O/C = 2.63$; $O_2/C = 0.43$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼	C ₄ H ₆	C ₅ ⁺
1	845	33.51	10.74	12.18	0.0	41.57	1.55	0.07	-	-	0.34	0.04	-	-	-
2	850	33.49	10.70	12.22	0.0	41.36	1.87	0.06	-	-	0.29	0.03	-	-	-
3	847	32.81	10.82	12.04	0.0	41.95	1.93	0.07	-	-	0.36	0.04	-	-	-
4	845	32.55	10.84	11.96	0.0	42.11	1.94	0.11	-	-	0.44	0.04	-	-	-
5	842	32.11	10.89	11.87	0.0	42.63	1.98	0.08	-	-	0.42	0.05	-	-	-

TABLE IIE

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using FP-1 (Pt/Rh)

(Run #7251; $H_2O/C = 2.67$; $O_2/C = 0.41$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION												C ₄ ⁺	C ₅ ⁺
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼		
1	792	37.04	11.02	12.47	0.44	37.92	1.13	-	-	-	-	-	-	-	-
2	792	36.91	11.20	12.23	-	38.50	1.16	-	-	-	-	-	-	-	-
3	795	36.67	11.23	12.17	-	38.73	1.15	-	-	-	-	-	-	-	-
4	800	36.23	11.71	11.88	-	39.00	1.20	0.01	-	-	0.01	-	-	-	-
5	804	35.65	11.85	11.67	-	39.50	1.27	0.02	-	-	0.03	-	-	-	-

TABLE IIF

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using FP-12 (Ni/Pt/Rh)

(Run #7255; $H_2O/C = 2.65$; $O_2/C = 0.427$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼	C ₄ H ₆	C ₅ ⁺
1	824	35.88	9.62	12.95	-	39.76	1.71	0.04	-	-	0.04	-	-	-	-
2	830	35.83	9.87	12.78	-	39.69	1.74	0.04	-	-	0.06	-	-	-	-
3	828	35.26	9.75	12.77	-	40.31	1.79	0.05	-	-	0.09	-	-	-	-
4	827	34.73	9.58	12.82	-	40.75	1.87	0.07	-	-	0.15	0.03	-	-	-
5	829	34.20	9.76	12.67	-	41.17	1.91	0.07	-	-	0.19	0.04	-	-	-

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using FP-7 (Ni/Rh)

(Run #7271; $H_2O/C = 2.68$; $O_2/C = 0.42$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼	C ₄ H ₆	C ₅ ⁺
1		35.24	9.83	13.96	-	39.48	1.41	0.04	-		0.05	0.003			
2		34.87	9.74	15.00	-	38.57	1.38	0.41	-		0.05	0.003			
3		35.76	9.73	13.90	-	39.10	1.40	0.04	-		0.05	0.02			
4		34.45	9.75	15.75	-	38.62	1.35	0.03	-		0.05	-			
5		34.81	9.77	14.90	-	38.72	1.33	0.43	-		0.04	-			

TABLE II(I)

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using FP-4 (Co/Ni)

(Run #7275; $H_2O/C = 2.63$; $O_2/C = .42$)

Hours on Stream.	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼	C ₄ H ₆ •	C ₅ ⁺
1		27.60	9.62	12.32	-	45.89	2.97	0.09	-		1.43	0.09			
1 1/2		28.61	9.94	12.26	-	44.94	2.80	0.08	-		1.26	0.07			

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using FP-5 (Ni/Rh)

(Run #7277; $H_2O/C = 2.66$; $O_2/C = .42$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼	C ₄ H ₆	C ₅ ⁺
1		33.71	10.60	12.63	-	40.88	1.86	0.06	-		0.24	0.02			
2		33.17	10.49	12.57	-	41.43	1.90	0.06	-		0.34	0.03			
3		32.52	10.79	12.28	-	41.92	1.93	0.07	-		0.45	0.04			
4		32.11	10.80	12.18	-	42.35	1.95	0.06	-		0.51	0.04			

Composition for Autothermal Reaction of No. 2 Oil Using FP-8 (Ni/Pt)
 (Run #7283; $H_2O/C = 2.67$; $O_2/C = 0.43$)

2.67; $O_2/C = 0.43$)

5 TP-8 (Ni/Pt)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION												
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄	C ₄ H ₆
1		32.89	10.40	12.55	-	41.80	1.85	0.07	-	-	-	-	-	-
2		32.60	10.65	12.31	-	41.98	1.86	0.07	-	-	0.40	0.04	-	-
3		32.26	10.72	12.20	-	42.24	1.90	0.08	-	-	0.46	0.05	-	-
4		31.93	10.77	12.10	-	42.56	1.89	0.07	-	-	0.55	0.06	-	-
5		31.43	10.93	11.92	-	42.98	1.92	0.07	-	-	0.61	0.06	-	-
											0.69	0.07		

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TABLE II L

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using G90C (Ni)

(Run #7293; $H_2O/C = 2.66$; $O_2/C = 0.43$)

Hours on Stream	Temp.	% DRY GAS COMPOSITION													
	(°C)	H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼	C ₄ H ₆	C ₅ ⁺
1		32.85	12.95	10.78	-	41.66	1.37	0.05	-		0.30	0.04			
2		32.52	13.22	10.54	-	41.87	1.42	0.06	-		0.35	0.04			
4*		31.64	13.43	10.49	-	42.50	1.43	0.06	-		0.39	0.04			
5		32.06	13.40	10.39	-	42.21	1.45	0.06	-		0.39	0.04			
6		31.71	13.60	10.17	-	42.58	1.43	0.06	-		0.41	0.04			

* Missed third hour sample

TABLE II M

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using FP-19 (Ni/Rh)

(Run #7298; $H_2O/C = 2.66$; $O_2/C = 0.42$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ ⁼	C ₄ H ₆	C ₅ ⁺
1		32.86	12.35	11.31	-	41.60	1.54	0.06	-		0.26	0.02			
2		32.93	12.60	11.18	-	41.44	1.52	0.06	-		0.26	0.03			
3		32.81	12.70	11.11	-	41.51	1.51	0.06	-		0.27	0.03			
4		32.51	12.79	11.02	-	41.81	1.50	0.06	-		0.29	0.03			
5		32.36	12.92	10.97	-	41.80	1.54	0.06	-		0.32	0.04			
6		32.03	13.10	10.84	-	42.08	1.53	0.06	-		0.33	0.04			

TABLE IIN

Dry Gas Composition for Autothermal Reaction of No. 2 Oil Using G90C (Ni)

(Run #7302; $H_2O/C = 2.63$; $O_2/C = 0.42$)

Hours on Stream	Temp. (°C)	% DRY GAS COMPOSITION													
		H ₂	CO	CO ₂	O ₂	N ₂	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₂ H ₄	C ₃ H ₆	C ₄ =	C ₄ H ₆	C ₅ ⁺
1		31.54	13.21	10.68	-	42.43	1.59	0.06	-		0.45	0.04			
2		31.43	13.38	10.52	-	42.54	1.57	0.06	-		0.46	0.04			
3		30.72	13.58	10.34	-	43.11	1.60	0.07	-		0.54	0.05			
4		30.23	13.73	10.18	-	43.51	1.62	0.07	-		0.59	0.06			
5		30.00	13.79	10.10	-	43.69	1.65	0.07	-		0.64	0.06			
6		29.55	14.01	9.91	-	44.05	1.67	0.07	-		0.69	0.06			

TABLE III

CATALYST SCREENING SUMMARY

Steam Reforming Catalysts in the ATR Mode

(CPO Catalyst = Pt/Pd/Monolith)

RUN NO.	#7238	#7251	#7242	#7233
SR CATALYST ACTIVE METAL(S)	FP-1 Pt/Rh	FP-1 Pt/Rh	FP-3 Pt/Rh	SF-3B Ni
CONDITIONS:				
H ₂ O/C	2.72	2.67	2.71	2.61
O ₂ /C	0.44	0.41	0.43	0.43
TEMPERATURES, °F				
OIL PREHEAT	895	892	900	885
AFTER CPO	1594	1620	1609	1643
SR BED TOP	1571	1587	1587	1634
" " MID	1483	1463	1468	1571
" " BOTTOM	1517	1504	1497	1585
BELOW SR BED	1535	1533	1511	1587
SR FURNACE	1391	1376	1378	1373
DRY GAS COMPOSITION, MOLE%				
H ₂	36.53	36.67	35.58	32.08
CO	10.53	11.23	11.89	12.00
CO ₂	12.48	12.17	11.42	11.00
N ₂	39.36	38.73	39.49	42.59
CH ₄	0.74	1.15	1.09	1.87
C ₂ H ₆	-	-	0.01	0.04
C ₂ H ₄	-	-	-	0.31
C ₃ H ₆	-	-	-	0.02
OTHER HC	-	-	-	-
HYDROCARBON CONV, %	96.9	95.3	95.5	89.7
EQUIVALENT HYDROGEN	1.99	1.91	1.94	1.67

TABLE III - Con't

CATALYST SCREENING SUMMARY

Steam Reforming Catalysts in the ATR Mode
(CPO Catalyst = Pt/Pd/Monolith)

RUN NO.	#7275	#7277		
SR CATALYST ACTIVE METAL(S)	FP-4 Co/Ni	FP-5 Ni/Ru		
CONDITIONS:				
H ₂ O/C	2.63	2.66		
O ₂ /C	≈0.42	0.42		
TEMPERATURES, °F				
OIL PREHEAT	866	890		
AFTER CPO	1674	1659		
SR BED TOP	1677	1652		
" " MID	1652	1571		
" " BOTTOM	1616	1530		
BELOW SR BED	NA	NA		
SR FURNACE	1363	1366		
DRY GAS COMPOSITION, MOLE%				
H ₂	28.61	32.52		
CO	9.94	10.79		
CO ₂	12.26	12.28		
N ₂	44.94	41.92		
CH ₄	2.80	1.93		
C ₂ H ₆	0.08	0.07		
C ₂ H ₄	1.26	0.45		
C ₃ H ₆	0.07	0.04		
OTHER HC				
HYDROCARBON CONV, %	79.6	88.2		
EQUIVALENT HYDROGEN	NA	1.62		

TABLE III - Con't

CATALYST SCREENING SUMMARY

 Steam Reforming Catalysts in the ATR Mode
 (CPO Catalyst = Pt/Pd/Monolith)

RUN NO.	#7244	#7255	#7266	#7271
SR CATALYST	FP-6	FP-12	FP-9	FP-7
ACTIVE METAL(S)	Ni	Ni/Pt/Rh	Ni	Ni/Rh
CONDITIONS:				
H ₂ O/C	2.63	2.65	= 2.70	2.68
O ₂ /C	0.43	0.43	= 0.43	0.42
TEMPERATURES, °F				
OIL PREHEAT	904	865	870	880
AFTER CPO	1627	1634	1632	1652
SR BED TOP	1625	1630	1607	1638
" " MID	1553	1521	1539	1535
" " BOTTOM	1551	1537	1544	1535
BELOW SR BED	1551	NA	NA	NA
SR FURNACE	1384	1384	1495	1364
DRY GAS COMPOSITION, MOLE%				
H ₂	32.55	35.26	31.60	35.76
CO	10.84	9.75	9.48	9.73
CO ₂	11.96	12.77	12.68	13.90
N ₂	42.11	40.31	42.74	39.10
CH ₄	1.94	1.79	2.48	1.40
C ₂ H ₆	0.11	0.05	0.15	0.04
C ₂ H ₄	0.44	0.09	0.76	0.05
C ₃ H ₆	0.04	-	0.08	0.02
OTHER HC				
HYDROCARBON CONV, %	87.8	91.6	83.0	93.5
EQUIVALENT HYDROGEN	1.65	1.79	NA	1.83

TABLE III - Con't

CATALYST SCREENING SUMMARY

 Steam Reforming Catalysts in the ATR Mode
 (CPO Catalyst = Pt/Pd/Monolith)

RUN NO.	7283	7293	7298	7302
SR CATALYST	FP-8	G-90C	FP-19	G-90C
ACTIVE METAL(S)	Ni/Pt	Ni	Ni/Rh	Ni
CONDITIONS:				
H ₂ O/C	2.67	2.66	2.66	2.63
O ₂ /C	0.43	0.43	0.42	0.42
TEMPERATURES, °F				
OIL PREHEAT	890	882	880	895
AFTER CPO	1648	1594	1605	1612
SR BED TOP	1634	1584	1598	1609
" " MID	1549	1553	1551	1562
" " BOTTOM	1535	1555	1549	1555
BELOW SR BED	NA	NA	NA	NA
SR FURNACE	1373	1360	1382	1403
DRY GAS COMPOSITION, MOLE%				
H ₂	32.26	31.64	32.81	30.72
CO	10.72	13.43	12.70	13.58
CO ₂	12.20	10.49	11.11	10.34
N ₂	42.24	42.50	41.51	43.11
CH ₄	1.90	1.43	1.51	1.60
C ₂ H ₆	0.08	0.06	0.06	0.07
C ₂ H ₄	0.55	0.39	0.27	0.54
C ₃ H ₆	0.06	0.04	0.03	0.05
OTHER HC				
HYDROCARBON CONV, %	87.3	90.7	91.3	89.0
EQUIVALENT HYDROGEN	1.64	1.73	1.74	1.59

TABLE IV

Observed Changes in Catalysts After
ATR Screening Runs

(A) Precious Metal Catalysts

1. Are not coked
2. No visible changes

(B) Base Metal Catalysts

1. Contain much coke
2. No visible color change
3. Are highly magnetic

(C) Mixed Precious Metal - Base Metal Catalysts

1. Are not coked
2. Core changes from black to blue
3. Remain non-magnetic

FIGURE 1

ATR TEST UNIT THERMOCOUPLE LOCATIONS

FIGURE 2

ATR TEST UNIT

EFFECT OF CATALYST ACTIVITY ON REACTOR TEMPERATURE PROFILE

FIGURE 3

RELATIONSHIP BETWEEN
HYDROCARBON CONVERSION
AND TEMPERATURE DROP

RMG
12/7/79

FIGURE 4

HYDROCARBON BREAKTHROUGH FROM THE ATR SCREENING UNIT
VS. WEIGHT NICKEL IN REACTOR

Ir-1
1/23/00

ENGELHARD
INDUSTRIES

FIGURE 5
EFFECT OF AGING ON HYDROCARBON BREAKTHROUGH

1/18/87