

Table 1

Gas Phase Tests

Catalyst (on Al ₂ O ₃)	Batch #	Composition (wt %)	Gas Phase Run #	Pressure (psig)	Temp. (°C)	GHSV (h ⁻¹)	Feed Usage CO/H ₂ (Δ CO/ Δ H ₂)	X _{CO+H₂}	X _{CO}	X _{H₂}	Bulk Activity, mol syngas kg cat/hr	Specific Activity mol CO/ mol metal/min
Co/Zr	7804-618- 191	Co 3.6 Zr 6.6	7977-3- 191	300	247	1124	1.0	0.47	512	33	69	0.25
Co/Zr	7804-720- 261	3.6 6.2	7977-8- 261	300	240	1223	1.0	0.55	42	29	54	0.25
Co/Zr	7804-82- 291	3.8 6.8	7977-14- 291	300	240	1244	1.0	0.54	50	35	65	0.27
Co/Zr	7804-1010- 371	3.8 6.8	7977-28- 371	300	240	986	1.0	0.59	56	42	71	0.26
Co/Zr	7804-912- 341	4.4 1.8	7977-16- 341	300	240	1031	1.1	0.61	53	41	66	0.31
Co/Mn/Zr	7804-914- 350	Co 3.4 Zr 6.6 Mn 1.6	7977-24- 356	300	240	1006	1.0	0.59	57	43	72	0.31
Ru/Zr	7804-115- 478	Ru 2.8 Zr 4.9	7977-32- 478	300	260	975	1.0	0.42	45	26	63	0.48
Co/Fe	7804-1019- 397	Co 1.4 Fe 0.51	7977-30- 397	300 300 300	260 260 240	879 897 897	1.9 0.9 0.9	0.35 0.54 0.72	20 27 32	56 50 44	19.8 24.2 23.8	0.40 0.40 0.48
Co/Fe/K	7804-1112- 517	Co 1.2 Fe 0.4 K 0.3	7977-34- 517	300 300	260 280	896 896	1.9 1.9	0.17 0.31	14 24	5 13	30 43	0.13 0.34

Table 1 (continued)

GAS PHASE TESTS

Catalyst (wt. Al ₂ O ₃)	Batch #	Composition (wt %)	Gas Phase Run #	Pressure (psig)	Temp. (°C)	GHSV (h ⁻¹)	Feed w/H ₂	Usage (dCO/dH ₂)	λ_{CO/H_2}	λ_{CO}	λ_{H_2}	Bulk Activity mol syngas/ kg cat/hr	Specific Activity mol CO/ mol metal/min
Co	7864-1026- 445	4.7	7977-36- 445	300	240	935	1.0	0.56	53%	38	68	36.2	0.25
Co/Ti	7864-1130- 589	Co 11 3.5 8.6	7977-37- 589	300	240	965	0.9	0.58	45%	35	55	21.6	0.23
Co/Zr	7864-0114- 691A	10% Co/Zn/Al	7977-41- 691A	300	240	1008	1.0	0.53	36%	26	46	18.8	N.D.
Co/Zn/Al	7864-0114- 691B	10% Co/Zn/Al	7977-43- 691B	300	240	841 806	1.0 1.9	0.66 0.35	44% 18%	35 7	54 39	21.6 8.5	N.D. N.D.
Co/Fe	7864-013- 677	Co 11 2.6 0.35	7977-34- 677	300	260	1008 978	1.0 1.9	0.65 0.62	60% 43%	48 26	71 75	43.5 30.3	0.49 0.34
Co/Fe/K	7864-0122- 707	Co 11 2.4 0.78 0.02	7977-45- 707	300	240	971	0.9	0.51	37%	26	47	26.3	0.27
Co/Zr	7864-1126- 567	Co 11 3.9 5.6	7977-46- 567	300	240	1911	1.0	0.55	52%	38	66	26.8	0.24
Co/Zr	7864-0305- 731	5.1 4.4	7977-48- 731	300	240	1099	1.1	0.64	59%	44	76	34.4	0.26

Table 1

Gas Phase Tests

Catalyst (on Al_2O_3)	Batch #	Composition (wt %)	Gas Phase Run #	Pressure (psig)	Temp. (°C)	GHSV (h^{-1})	Feed CO/H_2	Usage ($\Delta\text{CO}/\Delta\text{H}_2$)	$\text{X}_{\text{CO}+\text{H}_2}$	X_{CO}	X_{H_2}	Bulk Activity mol syngas/ kg cat/hr	Specific Activity mol CO/ mol metal/min
$\text{Co}(\text{NO})_2/\text{Zr}$	B466-2	$\frac{\text{Co}}{4.2} \frac{\text{Zr}}{7.1}$	7977-52-2 (syngas activation)	300	260	1110	0.98	0.60	35%	26	43	23.2	0.20
				300	280	1110	0.98	0.59	59%	44	73	39.5	0.33
$\text{Co}(\text{NO})_2/\text{Zr}$	B466-2	4.2 7.1	8413-1-2 (H_2 activation)	300	220	1100	1.0	0.47	13%	8	17	8.7	0.064
				300	240	1100	1.0	0.50	38%	26	51	26.2	0.20
Co/Zr	B466-4	4.0 6.4	8413-12-4 (syngas activation)	300	220	1002	1.1	0.48	14%	9	18	6.1	0.048
				300	240	1002	1.1	0.57	48%	35	62	21.5	0.16
				300	260	1002	1.1	0.56	73%	52	54	32.4	0.29
Co/Zr	B466-4	4.0 6.4	8413-20-4 (H_2 activation)	300	220	1157	1.1	0.49	26%	16	37	12.9	0.10
				300	240	1157	1.1	0.47	53%	33	76	26.4	0.21
				300	260	1157	1.1	0.53	69%	46	94	34.1	0.29

Table 1 (continued)

GA₃ PHASE TESTS

Catalyst	Batch #	Composition (wt%)	Gas Phase Run #	Pressure (Pstg)	Temp. (°C)	GHSV (h ⁻¹)	Feed CO/H ₂	Usage (ΔCO/ΔH ₂)	X _{CO+H₂}	X _{CO}	X _{H₂}	Bulk Activity, mol syngas/ kg cat/hr	Specific Activity, mol CO/ mol metal/min
Co/Ir/Al ₂ O ₃	H466-9	Co 10.4 Ir 0.5	8413-25-9	300	220	1043	1.0	0.61	29%	22	37	17.6	0.06
				300	240	1043	1.0	0.63	65	49	42	39.2	0.14
				300	260	1043	1.0	0.70	72	54	48	43.7	0.16
Co/Ir/SiO ₂	H466-10	Co 3.5 Ir 0.6	8413-28-18	300	220	1000	0.94	0.55	28	20	35	31.3	0.31
				300	240	1000	0.94	0.50	49	33	63	55.4	0.51
				300	260	1000	0.94	0.43	65	40	88	73.6	0.62
Co/Fe/Ir/SiO ₂	8466-22	Co 3.7 Fe 0.72 Ir 1.3	8413-36-22	300	220	1002	1.0	0.36	18	9	26	18.2	0.10
				300	240	503	1.0	0.55	64	44	46	33.5	0.26
				300	240	1002	1.0	0.46	46	28	65	48.1	0.33
				300	240	1518	1.0	0.47	32	20	44	50.6	0.35
				300	260	1038	1.0	0.49	63	40	86	67.6	0.49

Table I

Gas Phase Tests

Catalyst	batch #	Composition wt.-%	Gas Phase Run #	Pressure (P.s.i.g.)	Temp. (°C.)	Gas Flow ($\frac{\text{ml.}}{\text{min.}}$)	Feed $\frac{\text{CO}+\text{H}_2}{\text{CO}+\text{H}_2+\text{N}_2}$	Usage ($\frac{\text{g. CO}+\text{H}_2}{\text{g. catalyst}}$)	$\frac{\text{CO}+\text{H}_2}{\text{CO}+\text{H}_2+\text{N}_2}$	$\frac{\text{CO}}{\text{CO}+\text{H}_2}$	$\frac{\text{H}_2}{\text{CO}+\text{H}_2}$	Bulk Activity, $\frac{\text{mol. synthesize}}{\text{g. catalyst}}$	Specific Activity, $\frac{\text{mol. CO}}{\text{mol. metal/mg.}}$
				400	220	1000	1.0	0.33	10	0	1	1.0	0.07
				400	240	1000	1.0	0.1	26	10	1	1.1	0.24
				300	240	1000	1.1	0.57	46	4	1	1.1	0.45
				340	220	1010	1.0	0.33	12	0	1	1.1	0.44
				300	240	1050	1.0	0.54	33	27	1	1.1	0.23
				300	260	1010	1.1	0.57	57	30	23	1.1	0.45
				300	220	1000	1.1	0.73	11	9	1	1.1	0.14
				300	240	1000	1.0	0.53	25	15	1	1.1	0.18
				300	260	1000	1.1	0.46	50	22	28	1.1	0.33
				400	240	1000	1.1	0.47	24	14	1	1.1	0.27
				300	220	1000	1.0	0.45	26	10	1	1.1	0.40
				300	240	1050	1.0	0.59	49	18	1	1.1	0.38
				300	260	1000	1.0	0.46	56	30	27	1.1	1.05
				300	220	1000	1.1	0.46	15	11	1	1.1	0.17
				300	240	1000	1.0	0.51	30	10	4	1.1	1.21
				300	260	1000	1.0	0.43	39	24	1	1.1	0.30

Table 1 (continued)

GAS PHASE TESTS

Catalyst	Batch #	Composition (wt%)	Gas Phase Run #	Pressure (psig)	Temp. (°C)	GHSV (hr ⁻¹)	Feed CO/H ₂	Usage (%CO/%H ₂)	X _{CO+H₂}	X _{CO}	X _{H₂}	Bulk Activity, mol syngas/ kg cat/hr	Specific Activity, mol/CO mol metal/min
Fe/Zr/SiO ₂	8466-40	Fe 2.4 Zr 7.3	8413-88-40	300	220	1000	1.0	1.0	2.2	2.2	2.2	N.D.	N.D.
				300	240	1000	1.0	1.0	1.7	1.7	1.7	N.D.	N.D.
				300	280	1000	1.0	1.0	5.6	5.6	5.6	N.D.	N.D.
Co/Zr/SiO ₂	8466-45	Co 4.0 Zr 4.6	8413-93-45	300	220	1000	1.0	0.43	18	11	25	22.2	0.16
				300	240	1000	1.0	0.42	49	29	69	61.3	0.44
				300	260	1000	1.0	0.42	66	39	92	82.7	0.60
Co/Zr/SiO ₂	8466-46	Co 4.4 Zr 2.3	8413-99-46	300	220	1000	1.0	0.37	10	5	15	14.0	0.08
				300	240	1000	1.0	0.43	33	20	46	46.5	0.32
				300	260	1000	1.0	0.49	56	37	75	78.9	0.58
Co/Zr/SiO ₂	8466-47	Co 4.6 Zr 0.7	7743-2-47	300	220	1000	1.0	0.18	7	2	11	9.4	0.03
				300	240	1000	1.0	0.35	25	13	38	36.1	0.20
				300	260	1000	1.0	0.61	69	53	86	98.5	0.79
Co/SiO ₂	8466-49	Co 4.2	7743-8-49	300	220	1000	1.0	0.03	4	0.2	8	6.2	0.004
				300	240	1000	1.0	0.33	16	8	24	24.0	0.14
				300	260	1000	1.0	0.35	22	12	32	32.8	0.20

Table 1 (continued)

GAS PHASE TFSTS

Catalyst	Batch #	Composition (wt%)	Gas Phase Run #	Pressure (PSIG)	Temp. (°C)	Gas ($\frac{m^3}{h}$)	Feed $\frac{CO/H_2}{CO/H_2}$	Usage $\frac{(\Delta CO/H_2)L}{(h \cdot CO/H_2)}$	$\frac{K_{CO/H_2}}{K_{CO/H_2}}$	$\frac{K_{H_2}}{K_{H_2}}$	Bulk Activity, $\frac{mol\ syngas/}{kg\ cat/hr}$	Specific Activity, $\frac{mol\ CO}{mol\ metal/min}$
Co/Zr/SiO ₂	B466-55	Co 4.1 Zr 6.8	7743-16-55	300	220	1000	1.0	0.44	33	20	21.0	0.16
				300	240	1000	1.0	0.44	67	42	42.5	0.31
				300	260	1000	1.1	0.61	74	53	49.9	0.45
				300	205	2000	0.75	0.49	11	13	13.5	0.11
				300	220	1500	0.53	0.48	25	23	23.7	0.18
Co/Zr/SiO ₂	B466-58	Co 11.0 Zr 7.4	7743-27-58	300	205	2000	0.35	0.42	25	28	38.9	0.10
				300	220	1500	0.52	0.42	64	56	79.1	0.21
				300	220	1000	1.0	0.47	52	33	43.4	0.12
				300	240	1000	1.0	0.45	68	43	54.2	0.15
				300	260	1000	1.0	0.58	76	56	64.3	0.21
Co/Zr/SiO ₂	B466-63	Co 14.4 Zr 10.2	7743-39-63	300	220	1050	1.0	0.51	39	26	20.8	0.05
				300	240	1050	1.0	0.54	56	38	29.8	0.07
				300	260	1050	1.0	0.56	67	48	36.0	0.09

Table 2

COMPARATIVE CATALYST TEST DATA

- SLURRY PHASE -

Catalyst/ Run No.	Composition, Wt %	P, psig	T, °C	SV, L/g/hr	Feed CO/H ₂	Usage CO/H ₂	% Conv.		Bulk Activity mol syngas/kg cat/hr	Specific Activity mol CO/mol metal/min	Hydrocarbon Selectivity, Wt %						
							H ₂ +CO	H ₂			C ₁ - C ₂ -C ₄	C ₅ -C ₁₁	C ₁₂ -C ₁₈	C ₁₉ -C ₂₃	C ₂₄ + C ₅ -C ₂₃		
1 Co ₂ (CO) ₈ / Zr(OPr) ₄ /Al ₂ O ₃ 7595-60-C48.4	Co 3.81 Zr 6.84	309	220.9	1.65	1.05	0.57	17.8	23.2	12.6	0.12	13.6	24.9	33.2	14.3	7.6	6.4	55.1
		305	250.8	1.64	1.57	0.67	25.3	38.9	16.6	0.19	11.5	10.4	29.2	15.3	12.5	21.1	57.0
		305	281.0	1.64	1.57	0.59	31.7	51.2	19.4	0.22	28.6	20.2	30.4	12.1	3.9	4.8	46.4
1 Ru ₃ (CO) ₁₂ / Zr(OPr) ₄ /Al ₂ O ₃ 7887-36-478	Ru 2.75 Zr 4.93	316	241.1	2.04	1.87	0.95	7.5	10.6	5.7	0.20	9.7	11.5	12.2	20.5	18.5	27.6	51.2
		601	281.6	2.04	1.77	0.67	25.4	45.4	14.2	0.51	14.6	13.6	37.1	20.1	9.3	5.3	66.5
		600	276.7	0.97	1.33	0.51	39.9	61.6	23.6	0.36	9.3	10.2	36.7	27.5	8.7	17.6	72.9
1 Co ₂ (CO) ₈ /Al ₂ O ₃ 7887-67-445	Co 4.71	300	239.4	2.06	1.50	0.67	16.7	25.1	11.1	0.13	9.6	11.5	23.7	22.7	15.3	17.2	61.7
		300	240.9	1.07	1.84	0.79	21.6	34.3	14.7	0.09	7.6	9.8	24.9	22.1	14.9	20.7	61.9
		300	230.7	2.07	2.00	0.88	14.7	23.4	10.3	0.13	7.9	9.4	20.6	25.0	19.4	18.7	64.0
1 FeCo ₃ (CO) ₁₂ / Al ₂ O ₃ 8385-22-677	Fe 0.85 Co 2.60	315	242.6	1.86	1.02	0.42	20.2	28.7	11.9	0.14	10.1	11.0	26.0	20.4	16.7	15.8	63.1
		320	261.1	1.09	2.14	0.40	17.5	39.0	7.4	0.07	13.8	15.7	33.5	21.2	10.0	5.8	64.7
		308	281.0	1.92	2.02	0.60	24.5	46.2	13.8	0.22	16.9	15.8	35.6	19.3	7.9	4.5	62.8
1 Co ₂ (CO) ₈ / Ti(OPr) ₄ /Al ₂ O ₃ 7888-1-589	Ti 8.65 Co 3.49	300	239	0.90	2.02	0.60	24.0	46.0	13.1	0.10	7.1	12.3	30.4	22.8	12.6	14.8	65.8
		600	258	1.07	1.57	0.46	26.2	42.5	14.4	0.20	15.4	15.5	34.3	18.8	7.9	8.1	61.0
		310	282	1.82	1.51	0.56	20.7	34.3	11.7	0.16	24.8	15.6	30.3	16.9	9.3	3.1	56.5
1 Co ₂ (CO) ₈ / Zr(OPr) ₄ /Al ₂ O ₃ 7888-33-731	Zr 4.39 Co 5.07	300	239	0.86	1.95	0.41	19.4	40.7	8.5	0.04	8.0	11.3	22.9	22.5	12.2	13.1	67.6
		305	262	0.86	1.95	0.51	32.3	63.0	16.5	0.08	7.7	9.6	29.2	24.1	12.9	16.5	66.2
		300	259	1.73	0.98	0.41	35.8	50.3	21.0	0.16	14.1	12.0	34.4	19.8	9.2	10.5	63.4

Table 2 (cont'd.)

COMPARATIVE CATALYST TEST DATA

- SLURRY PHASE -

Catalyst/ Run No.	Composition, wt %		P, psig	T, °C	SV, L/g/hr	Feed CO/H ₂	Usage CO/H ₂	Conv. % H ₂ +CO H ₂	Conv. % H ₂	Bulk Activity mol syngas/kg cat/hr	Specific Activity mol CO/mol metal/min	Hydrocarbon Selectivity, wt %								Fuels							
																				C ₁ -C ₄		C ₅ -C ₁₁	C ₁₂ -C ₁₈		C ₁₉ -C ₂₃	C ₂₄ -C ₂₉	
																				C ₁	C ₂ -C ₄	C ₅ -C ₁₁	C ₁₂ -C ₁₈	C ₁₉ -C ₂₃	C ₂₄ -C ₂₉	C ₃₀ -C ₃₅	
¹ FeCo ₃ (CO) ₁₂ / K/Al ₂ O ₃ 8385-60-707	Fe	Co	K	320	240	1.6	2.01	11.9	21.9	6.9	8.4	0.10	9.8	11.7	31.0	22.1	14.6	10.8	67.7								
				320	260	1.6	2.03	20.6	37.2	12.5	14.5	0.18	10.0	11.6	34.1	24.9	12.3	7.1	71.3								
				298	282	1.5	1.01	41.0	55.0	27.3	27.3	0.27	19.1	15.7	35.4	17.4	7.5	4.9	60.3								
² Co ₂ (CO) ₈ / Zr(OPr) ₄ /Al ₂ O ₃ 8523-1-4	Co	Zr		302	241	2.0	0.91	42.5	56.0	29.0	35.3	0.29	7.9	13.7	37.0	23.4	8.9	9.1	69.3								
				307	258	2.0	1.43	34.5	56.0	19.9	28.7	0.24	7.2	10.8	34.1	27.9	8.6	11.4	70.6								
				302	260	1.0	1.87	37.6	68.3	21.2	15.8	0.14	4.9	7.1	26.2	26.2	17.2	18.4	69.6								
Co(NO ₃) ₂ /Zr(OPr) ₄ / Al ₂ O ₃ 7888-85-2	Co	Zr		310	241	1.0	2.10	20.8	40.6	10.9	11.4	0.09	5.2	4.2	11.2	16.9	23.7	38.8	51.8								
				310	260	2.0	1.58	24.8	39.9	15.3	27.7	0.23	12.0	9.1	22.7	25.8	14.1	16.3	62.6								
				310	281	2.0	1.60	33.4	57.2	18.2	37.2	0.30	14.5	11.2	23.7	18.9	13.4	17.9	56.0								
Co ₂ (CO) ₈ /Zr(OPr) ₄ / Al ₂ O ₃ 8523-41-9	Co	Zr		303	239	2.0	1.00	32.7	45.7	19.7	30.7	0.07	7.7	15.0	22.0	22.6	13.9	18.8	58.5								
				310	239	2.0	2.00	14.5	30.3	6.7	13.5	0.03	8.3	13.8	22.2	21.0	15.7	19.0	58.9								
				310	260	1.0	1.00	45.9	61.3	30.4	21.5	0.06	15.0	14.0	27.4	20.0	9.8	13.8	57.2								
Co ₂ (CO) ₈ /Zr(OPr) ₄ / SiO ₂ 8670-11-18	Co	Zr		310	240	2.0	1.00	40.8	55.5	26.2	36.5	0.23	8.1	14.5	37.4	24.9	8.2	6.9	70.5								
				310	261	1.0	1.50	42.9	75.1	21.4	19.1	0.12	11.0	12.9	37.4	23.3	8.0	7.4	68.7								
				310	282	1.0	2.00	41.4	78.0	23.1	18.5	0.14	13.5	15.4	32.1	23.9	9.6	5.5	65.6								

Table 2 (cont'd.)

COMPARATIVE CATALYST TEST DATA

- SLURRY PHASE -

Catalyst/ Run No.	Composition, Mol %	P, psig	T, °C	SV, L/g/hr	Feed CO/H ₂	Usage CO/H ₂	% Conv.		Bulk Activity mol syngas/kg cat/hr	Specific Activity CO/mol metal/min	Hydrocarbon Selectivity, wt %							Fuels	
							H ₂ +CO	H ₂			C ₁ - C ₂ -C ₃	C ₄ - C ₅ -C ₆	C ₇ -C ₁₁	C ₁₂ -C ₁₈	C ₁₉ -C ₂₃	C ₂₄ + C ₂₅ -C ₂₉			
Co ₂ (CO) ₈ /Fe ₃ (CO) ₁₂ / Zr(OPr) ₄ /SiO ₂ 8670-12-23	Co 4.91 Fe 0.93 Zr 9.09	300	241	2.0	1.6	0.55	37.3	61.6	21.7	34.1	0.20	4.8	9.2	29.4	29.0	14.5	13.1	72.9	
		300	261	2.0	1.0	0.30	33.9	46.4	21.4	30.3	0.16	13.1	19.8	39.7	17.1	5.5	4.8	62.3	
		315	280	2.0	2.0	0.59	27.3	52.0	15.2	24.4	0.15	15.8	19.4	41.8	18.2	3.6	1.2	63.6	
Co ₂ (CO) ₈ /Zr(OPr) ₄ / MgO*3.6SiO ₂ 8670-60-25	Co 4.8 Zr 9.4	301	240	2.0	1.0	0.45	24.4	33.7	15.1	21.8	0.138	10.5	19.4	28.9	24.8	8.3	8.1	62.0	
		302	261	2.0	1.5	0.52	22.8	37.6	13.0	20.4	0.143	19.1	27.2	34.5	12.0	4.2	3.0	50.7	
		300	260	2.0	2.0	0.52	18.0	35.8	9.2	16.0	0.112	17.8	27.4	33.9	14.3	4.9	1.7	53.1	
Co ₂ (CO) ₈ /Ti (OPr) ₄ /SiO ₂ 8670-57-27	Co 5.2 Ti 4.8	298	240	2.0	1.0	0.32	20.0	30.2	9.8	17.9	0.083	12.6	26.5	37.1	16.4	5.2	2.2	58.7	
		300	261	2.0	1.0	0.58	33.0	41.8	24.2	29.5	0.206	15.3	13.7	29.6	21.3	10.6	9.6	61.5	
		300	282	2.0	1.0	0.54	41.1	53.3	28.8	36.7	0.245	23.5	17.3	34.3	15.2	6.0	3.7	55.5	
Co ₂ (CO) ₈ /Zr (OPr) ₄ /SiO ₂ Extended Test 8862-1-31	Co 5.3 Zr 10.2	300	242	1.8	0.52	0.49	65.8	67.1	63.2	52.9	0.323	20.6	26.7	38.0	10.7	2.5	1.4	51.2	
		300	260	2.0	1.0	0.53	53.9	70.4	37.4	48.1	0.312	13.2	14.4	41.7	18.9	7.5	4.2	68.1	
		300	260	2.0	1.0	0.55	23.6	30.4	16.8	21.1	0.140	45.3	27.4	23.3	3.3	0.5	0.3	27.1	
Ru ₃ (CO) ₁₂ /Zr (OPr) ₄ /SiO ₂ 8862-16-37	Ru 4.1 Zr 4.7	300	240	2.0	1.0	0.25	5.8	9.4	2.3	5.2	0.042	11.1	7.3	13.9	20.4	20.5	26.7	54.8	
		305	260	2.0	1.0	0.44	9.3	12.9	5.7	8.3	0.104	19.4	10.6	19.8	11.2	14.9	24.1	45.9	
		300	262	1.0	1.0	0.21	6.8	11.3	2.3	3.0	0.021	25.4	15.6	19.0	7.7	11.2	21.1	37.9	

Table 2 (cont'd.)

COMPARATIVE CATALYST TEST DATA

- SLURRY PHASE -

Catalyst/ Run No.	Composition, wt %		P, psig	I, °C	SV, L/g/hr	Feed CO/H ₂	Usage CO/H ₂	% Conv.			Bulk Activity mol syngas/kg cat/hr	Specific Activity mol CO/mol metal/min	Hydrocarbon Selectivity, wt %								Fuels	
								H ₂ +CO	H ₂	CO			C ₁ - C ₂ -C ₃	C ₄ -C ₅ -C ₆	C ₇ -C ₈ -C ₉	C ₁₀ -C ₁₁ -C ₁₂	C ₁₃ -C ₁₄ -C ₁₅	C ₁₆ -C ₁₇ -C ₁₈	C ₁₉ -C ₂₀ -C ₂₁	C ₂₂ -C ₂₃ -C ₂₄		C ₂₅ -C ₂₆
Co ₂ (CO) ₈ /Zr (OPr) ₄ /SiO ₂ 8862-41-46	Co	Zr	305	241	2.0	1.0	0.56	20.5	26.8	14.5	18.3	0.134	13.3	13.2	42.5	15.8	8.2	7.0	66.5			
	4.8	2.7	295	262	2.0	0.96	0.45	39.8	53.7	25.2	35.5	0.223	15.5	11.6	36.0	19.5	8.7	8.7	64.2			
			300	260	1.0	1.0	0.54	40.1	52.3	28.0	17.9	0.128	15.3	13.8	35.6	17.8	8.8	8.8	62.2			
Co ₂ (CO) ₈ /SiO ₂ 8862-80-49	Co		300	241	2.0	1.1	0.53	8.6	11.6	5.8	7.7	0.053	14.7	16.7	38.6	21.5	7.9	0.5	68.0			
	4.9		300	260	2.0	1.0	0.48	24.4	33.0	15.8	21.8	0.141	17.5	14.5	37.0	21.3	6.4	3.2	64.7			
			290	260	1.0	1.0	0.52	23.3	37.2	19.4	12.6	0.087	11.0	16.5	39.7	18.0	4.9	10.0	62.6			
Co ₂ (CO) ₈ /Zr (OPr) ₄ /SiO ₂ 9093-10-58	Co	Zr	295	242	2.0	0.9	0.40	23.5	32.1	14.0	21.0	0.036	10.4	14.4	32.6	21.6	10.0	11.0	64.2			
	16.4	11.5	290	261	2.0	1.0	0.54	36.1	46.8	25.4	32.2	0.068	11.6	11.8	34.2	22.8	8.2	11.4	65.2			
			290	263	2.0	0.5	0.45	41.1	42.4	38.4	36.7	0.068	24.3	18.7	35.1	14.3	5.3	2.3	54.7			

1 Synthesis Gas Activation

2 H₂ Activation

*Last data point after 4,417 hours of operation.

Table 3

Basecase Slurry Test Summary

 $\text{CO}_2(\text{CO})_2/\text{Zr}(\text{OPr})_4/\text{Al}_2\text{O}_3$

7595-60-C48.4

Sample No.	Time on Stream h	P psig	T °C	Space Velocity L/g/hr	$\chi_{\text{CO}} + \text{H}_2$	χ_{CO}	χ_{H_2}	Feed, CO/H_2	Usage, $\Delta\text{CO}/\Delta\text{H}_2$	Bulk Activity mol-syn gas/kg cat/h	Specific Activity mol CO/mol metal/min	Selectivity Wt%					
												C_1	C_2-C_4	C_5-C_{11}	$\text{C}_{12}-\text{C}_{18}$	$\text{C}_{19}-\text{C}_{23}$	C_{24}
1	58.8	315	220.8	1.65	18.0	12.9	23.4	1.05	0.58	13.2	0.12	14.6	24.7	33.9	11.5	6.7	8.6
3	82.8	309	220.9	1.65	17.8	12.6	23.2	1.05	0.57	13.1	0.12	13.6	24.9	33.2	14.3	7.6	6.4
4	113.3	300	220.1	1.65	17.5	12.8	22.3	1.05	0.60	12.8	0.12	14.3	20.3	34.7	12.8	8.0	9.9
31	615.2	313	246.5	1.64	23.7	13.5	39.7	1.57	0.54	17.3	0.16	16.2	15.6	34.6	10.6	7.6	15.4
33	639.4	306	251.0	1.64	25.0	14.9	49.7	1.57	0.58	18.2	0.17	15.0	14.4	34.6	14.7	7.5	13.8
36	627.6	302	252.1	1.64	24.8	19.4	43.5	1.57	0.70	21.0	0.22	10.4	10.1	28.8	20.0	12.4	18.3
38	711.6	300	251.6	1.64	27.0	17.4	42.1	1.57	0.70	19.8	0.20	11.7	10.8	29.6	19.1	13.6	15.2
40	735.6	305	250.8	1.64	25.3	16.6	38.9	1.57	0.67	18.5	0.19	11.5	10.4	29.2	15.3	12.5	21.1
42	759.6	303	251.7	1.64	25.0	16.6	38.3	1.57	0.68	18.3	0.19	13.6	12.3	37.5	17.8	9.7	9.1
44	753.6	304	251.1	1.64	24.6	16.1	38.0	1.57	0.67	18.0	0.19	14.5	13.2	33.9	19.0	9.6	9.8
46	867.6	300	251.1	1.64	26.3	18.5	38.6	1.57	0.75	19.2	0.21	14.2	12.9	35.9	17.7	8.7	10.6
48	851.6	300	251.3	1.64	24.3	15.7	37.7	1.57	0.60	17.5	0.18	14.5	13.1	37.9	16.1	7.9	10.5
50	900.6	300	250.3	1.64	27.5	15.5	33.6	1.57	0.72	16.5	0.18	15.4	14.0	29.7	17.4	9.4	14.1
52	900.6	300	250.3	1.64	22.6	15.2	34.2	1.57	0.70	16.5	0.18	15.9	14.4	31.7	16.6	8.2	13.2
54	950.6	300	251.1	1.64	23.3	15.8	35.0	1.57	0.71	14.0	0.18	16.6	11.9	32.2	18.9	9.5	12.9
56	960.6	300	251.1	1.64	40.3	24.9	64.3	1.57	0.61	29.4	0.29	11.9	19.2	33.2	15.9	5.5	3.0
58	962.6	300	250.1	1.64	33.4	19.4	55.4	1.57	0.55	24.4	0.22	25.9	19.7	32.7	13.3	4.8	4.1
64	1111.6	300	251.1	1.64	14.4	21.2	55.0	1.57	0.61	25.1	0.24	25.7	19.8	34.1	12.6	4.4	3.2
66	1100.6	300	250.3	1.64	11.0	21.0	54.6	1.57	0.60	24.9	0.24	20.9	19.0	34.1	12.4	4.3	4.3
68	1100.6	300	251.1	1.64	10.9	17.8	51.4	1.57	0.54	22.6	0.20	21.5	19.7	31.7	13.1	4.2	3.6
70	1000.6	300	250.3	1.64	20.3	17.8	51.3	1.57	0.55	22.5	0.20	21.8	19.6	31.7	12.3	3.9	4.6
72	1000.6	300	250.3	1.64	11.0	18.2	51.0	1.57	0.56	22.6	0.21	22.9	19.6	30.6	11.8	3.9	4.8
74	1000.6	300	250.3	1.64	66.8	18.1	50.8	1.57	0.56	22.5	0.21	27.3	19.3	32.3	12.4	4.0	4.7
76	1000.6	300	250.3	1.64	11.7	19.4	51.2	1.57	0.59	23.2	0.22	20.4	20.2	30.3	12.1	3.9	4.8

TABLE 4

EFFECT OF STIRRER SPEED

(Slurry Run 7595-60-C48.4)

TEMP, °C	IMPELLER		BULK ACTIVITY, MOL SYNGAS/KG CAT/HR	HYDROCARBON SELECTIVITY, WT%					
	FEED CU/H ₂	SPEED, RPM		C1	C2+4	C5+11	C12+18	C19+23	C24+
220	1.05	1200	13.0	14.2	23.3	33.9	12.9	7.4	8.3
250	1.57	1200	19.0	13.0	12.3	31.4	15.9	10.7	16.8
250	1.57	1600	17.2	14.7	13.1	34.1	17.6	9.0	11.5
280	1.57	1600	24.8	25.8	19.4	33.7	12.8	4.5	3.9
280	1.57	1200	23.1	27.8	19.7	31.5	12.3	4.0	4.7

TABLE 5

EFFECT OF Co SOURCE ON ACTIVITY AND SELECTIVITY

4% Co ON Zr/Al₂O₃ -- SLURRY PHASE(CO/H₂ = 1.0, 2.0 NL/hr-g cat, 300 psig)

<u>COBALT SOURCE</u>	<u>CARBONYL</u>		<u>NITRATE</u>	
	<u>240°C</u>	<u>260°C</u>	<u>240°C</u>	<u>260°C</u>
BULK ACTIVITY, mol SYNGAS/kg cat/hr	35.3	38.5	15.8	29.9
SPECIFIC ACTIVITY, mol CO/mol Co/min	0.29	0.32	0.09	0.21
<u>SELECTIVITY, WT%</u>				
C ₁	7.9	10.4	10.9	16.5
C ₂₋₄	13.7	15.0	6.5	11.1
C ₅₋₁₁	37.0	44.5	12.9	26.5
C ₁₂₋₁₈	23.4	25.8	19.8	23.8
C ₁₉₋₂₃	8.9	2.0	21.9	10.6
C ₂₄₊	9.1	2.3	28.0	11.5
TOTAL FUELS C ₅₋₂₃	69.3	72.3	54.6	60.9

TABLE 6
 EFFECT OF SYNGAS VS. HYDROGEN ACTIVATION
 ON HYDROCARBON SELECTIVITY
 4% Co ON Zr/Al₂O₃ -- SLURRY PHASE

	SYNGAS	H ₂
SPACE VELOCITY, NL/g cat/hr.	1.6	2.0
CO/H ₂	1.6	1.5
PRESSURE, PSIG	300	300
TEMPERATURE, °C	250	258
<u>WT%</u>		
C ₁	11.5	7.2
C ₂₋₄	10.4	10.8
C ₅₋₁₁	29.2	34.1
C ₁₂₋₁₈	15.3	27.9
C ₁₉₋₂₃	12.5	8.6
C ₂₄₊	21.1	11.4
C ₅₋₂₃	57.0	70.6

Table I

ZIRCONIUM VS. TITANIUM AS SUPPORT MODIFIER IN
CO₂(CO)₂/Al₂O₃ OR SiO₂ CATALYSTS(1)

Catalyst No.	Support	Composition (Wt%)		% Conversion CO + H ₂	Bulk Activity (mol syngas/ kg cat/hr)	Specific Activity (mol CO/ mol Co/min)
		Co	Zr Ti			
7864 1010-371	Al ₂ O ₃	3.8	6.8 0	56	27.0	0.26
7864 1130-589	Al ₂ O ₃	3.5	0 8.6	45	21.6	0.23
8466 18	SiO ₂	3.5	6.6 0	49	55.4	0.51
8466 21	SiO ₂	4.4	0 3.9	26	33.1	0.24

(1) Both Zr and Ti were added as the H(OPr)₄. Tests were done in the gas phase at 240°C, CO/H₂ = 1.0, 300 psig and 1000 GHSV. Al₂O₃ catalysts were syngas activated; SiO₂ catalysts were H₂ activated.

TABLE 8

EFFECT OF PROMOTER ON HYDROCARBON SELECTIVITY: ZR VS. TI

- GAS PHASE -

CATALYST	WT. % SELECTIVITY					
	C ₁	C ₂₋₄	C ₅₋₁₁	C ₁₂₋₁₈	C ₁₉₋₂₃	C ₂₄₊
Co/Zr/AL ₂ O ₃	9	12	28	29	15	7
Co/Ti/AL ₂ O ₃	14	19	38	17	7	5
Co/Zr/SiO ₂	10	15	39	25	8	3
Co/Ti/SiO ₂	18	30	40	10	2	<1

TABLE 9
 ENHANCED OLEFIN SELECTIVITY USING Ti PROMOTER

- GAS PHASE -

CATALYST	OLEFIN/ALKANE RATIO (C ₃₋₅)		WT% HYDROCARBON SELECTIVITY TO C ₃₋₅ OLEFINS	
	220°	240°	220°	240°
Co/Zr/SiO ₂	2.6	1.9	21	13
Co/Hf/SiO ₂	4.0	3.6	39	29

TABLE 10

ZIRCONIUM VS. TITANIUM AS PROMOTER IN

 $\text{CO}_2(\text{CO})_2/\text{SiO}_2$ CATALYSTS

- SLURRY PHASE - 1

CATALYST NO./ RUN NO.	REDUCED CATALYST COMPOSITION (WT%)			TEMPERATURE, °C	% CONV., CO + H ₂	BULK ACTIV., (MOLS SYNGAS/ KG CAT/HR)	SELECTIVITY, WT%		
	CO	ZR	Ti				C ₁₋₄	C ₅₋₂₃	C ₂₄₊
8466-18/				240	41	36	23	70	7
8670-11-18	4.9	9.3	0	260	50	45	33	61	6
8466-27/				240	20	18	39	59	2
8670-57-27	5.2	0	4.8	260	33	30	29	62	10

1 $\text{CO}/\text{H}_2 = 1.0$, $P = 300$ PSIG, $SV = 2.0$ L/G CAT/HR

TABLE 11
SUPPORT PROPERTIES

(1) SUPPORT	XRD Phases	B.E.T. Surface Area	PORE VOLUME		AVE. PORE Diameter	MEAN PARTICLE Diameter
			Macro.	Micro. ($<30\text{\AA}$)		
Catapal SB Alumina	$\gamma\text{-Al}_2\text{O}_3$ mostly amorphous	217 m^2/g	0.167 cc/g	0.879 cc/g	154 $\text{\AA}$ (Hg)	55.4 μm
Davison 952 silica gel	amorphous	339	1.25	1.22	153 (N_2) 251 (Hg)	57.3
Davison 952 Silica gel Calcined @ 900°C	N.D.	196	907	0.399	115 (Hg)	N.D.

(1) Supports were calcined at 500°C for 3 hours in static air.

TABLE 12

Ru CATALYST PERFORMANCE

CATALYST	FEED, CO/H ₂	SV	TEMP., °C	USAGE RATIO, ΔCO/ΔH ₂	BULK ACTIVITY, MOLS SYNGAS/ KG CAT/HR
— FIXED-BED REACTOR —					
Ru ₃ (CO) ₁₂ /Zr(OPr) ₄ /Al ₂ O ₃ (2.8% Ru, 4.9% Zr)	1.0	975 ^{cc} / _{cc-hr}	260	0.42	27
Ru ₃ (CO) ₁₂ /Zr(OPr) ₄ /SiO ₂ (4.0% Ru, 3.3% Zr)	1.0	1050	240	0.39	71
			260	0.46	81
— SLURRY REACTOR —					
Ru/Zr/Al ₂ O ₃	1.0	1.9 l/g/hr	240	0.90	8
	1.4	2.0	260	0.43	7
Ru/Zr/SiO ₂	1.0	2.0	240	0.25	5
	1.0	2.0	260	0.44	8

TABLE 13

ADDITION OF Cu/Zn/Al WATER - GAS SHIFT

CATALYST TO Co/Zr/Al₂O₃ F-T CATALYST

Catalyst ⁽¹⁾	CO/H ₂	Usage Ratio (CO/H ₂)	% Conversion, CO + H ₂	Bulk Activity, (mol syngas/kg cat/hr)
90% F-T + 10% SHIFT	1.0	0.53	36	18.8
90% F-T + 10% SHIFT	1.0	0.66	44	21.6
(Preactivated)	1.9	0.35	18	8.5
BASECASE F-T	1.0	0.59	56	27.0

⁽¹⁾ CONDITIONS: 240°C, 300 psig, 1000 GHSV

TABLE 14

ADDITION OF $\text{Fe}_3(\text{CO})_{12}$ TO $\text{Co}_2(\text{CO})_8$ / Zr/SiO_2 - FIXED-BED
($\text{CO}/\text{H}_2 = 1, 1000 \text{ hr}^{-1}, 300 \text{ psig}$)

CATALYST	TEMP., °C	USAGE RATIO, $\Delta\text{CO}/\Delta\text{H}_2$	BULK ACTIVITY, MOLS SYNGAS/ KG CAT/HR	WT.% SELECTIVITY $\text{C}_5\text{-C}_{23}$
$\text{Fe}_3(\text{CO})_{12}/\text{Co}_2(\text{CO})_8 /$ $\text{Zr}(\text{OPr})_4 / \text{SiO}_2$ (3.7% Co, 0.72% Fe)	260	0.49	68	60
$\text{FeCo}_3(\text{CO})_{12}/\text{Al}_2\text{O}_3$ (2.6% Co, 0.85% Fe)	260	0.66	44	71
BASECASE $\text{Co}_2(\text{CO})_8 /$ $\text{Zr}(\text{OPr})_4 / \text{SiO}_2$ (3.5% Co)	260	0.43	74	58
$\text{Fe}_3(\text{CO})_{12}/\text{Zr}(\text{OPr})_4 / \text{SiO}_2$ (2.4% Fe)	280	1.0	6	-

TABLE 15

CATALYST PROPERTIES

CATALYST	B.E.T.		METAL	
	SURFACE AREA	SURFACE AREA	SURFACE AREA	DISPERSION
3.5% Co/Zr/SiO ₂	316 m ² /g	1.9 m ² /g (a)		6%
4.0% Co/Zr/Al ₂ O ₃	209	0.3 (b)		1
4.1% Co/Zr/SiO ₂	210	1.9 (a)		7
11.0% Co/Zr/SiO ₂	302	8.1 (a)		12
10.8% Co/Zr/Al ₂ O ₃	N.D.	5.4 (a)		7
14.4% Co/Zr/SiO ₂	145	9.3 (a)		10
4.0% Ru/Zr/SiO ₂	325	1.6 (b)		8

(a) HYDROGEN CHEMISORPTION PERFORMED AT 100°C

(b) HYDROGEN CHEMISORPTION PERFORMED AT 35°C

TABLE 16

Selected Kinetic Functionalities*

$$-r_{\text{CO} + \text{H}_2} = \frac{k C_{\text{H}_2}}{1 + k C_{\text{CO}_2} / C_{\text{CO}}} \quad (1)$$

$$-r_{\text{CO} + \text{H}_2} = \frac{k C_{\text{H}_2}}{1 + k C_{\text{H}_2\text{O}} / C_{\text{CO}}} \quad (2)$$

$$-r_{\text{CO} + \text{H}_2} = \frac{k C_{\text{H}_2}}{1 + k_1 C_{\text{CO}_2} / C_{\text{CO}} + k_2 C_{\text{H}_2\text{O}} / C_{\text{CO}}} \quad (3)$$

$$-r_{\text{CO} + \text{H}_2} = \frac{k C_{\text{H}_2}}{1 + k C_{\text{H}_2\text{O}} / (C_{\text{CO}} C_{\text{H}_2})} \quad (4)$$

$$-r_{\text{CO} + \text{H}_2} = k C_{\text{H}_2}^a C_{\text{CO}}^b \quad (5)$$

*To correlate the equations with reference 19: A = 2; B = 1; C = 3; D = 4

TABLE 17

Summary of Fitted Kinetic Parameters

Kinetic Functionality ¹	k^2	k^2	a	b	Average Error (%)
1	0.546	1.13	--	--	8.5
2	0.557	0.0939	--	--	9.3
4	0.664	4.24×10^{-6}	--	--	6.2
5	7.65×10^5	---	1.84	0.54	7.4

¹ Refer to Table 16

2 Units are consistent with: rate = mol/g. cat./sec.
concentration = mol/cc (slurry)

TABLE 18: Analysis of Slurry-Phase Fischer-Tropsch Synthetic Diesel Fuel

Reactor Conditions (both at 200 psig)		Slurry Phase Diesel Fuel Oil		ASTM Spec for	
		Sample BWB466-60	Sample BWB466-54	No. 1-D	Diesel Fuel Oil
		260°C, CO/H ₂ =1.0, SV=2.0 l/g cat/h.	240°C, CO/H ₂ =0.5, SV=1.8 l/g cat/hr		
Flash Point, PMCC	ASTM D93	116°F	118°F	100°F	(min.)
Visc./@100°F SUS	ASTM D88	35.1 sec	35.1 sec	34.4 sec	(max.)
Water & Sediment	ASTM D2709	trace	trace	0.05 vol. %	(max.)
Sulfur Content	ASTM D1552	0.03%	0.04%	0.5%	(max.)
Cloud Point	ASTM D2500	16°F	14°F	14°F	(max.)
Ash	ASTM D482	0.001%	0.002%	0.01%	(max.)
Car. Res. Con on 10%	ASTM D189	0.010%	0.020%	0.15%	(max.)
Corrosion 3 Hrs @ 212°F	ASTM D130	1A	1A	3	(max.)
Distillation:	ASTM D86				
Int. B. P.		385°F	400°F		
10% @		417°F	418°F		
50% @		465°F	461°F		
90% @		550°F	550°F	550°F	(max.)
End Point		580°F	576°F		
Recovery		98%	99%		
Cetane Index	ASTM D916	74.0	75.2	40	(min.)
Density @ 15°C	ASTM D1254	0.7695	0.7654		

TABLE 19

Detailed Requirements for Diesel Fuel Oils ^{A,H}

Grade of Diesel Fuel Oil	Flash Point °C (°F)	Cloud Point °C	Water and Sediment, vol %	Carbon Residue on 10% Residue, %	Ash weight %	Distillation Temperatures, °C (°F)		Viscosity				Sulfur weight %	Copper Strip Corrosion	Cetane Number ¹
								Kinematic, cSt ² at 40°C		Saybolt, SUS at 100°F				
						90% Point		Min	Max	Min	Max	Min	Max	
No. 1-D A volatile distillate fuel oil for engines in service requiring frequent speed and load changes	38 (100)	^a	0.05	0.15	0.01	282 (550)	338 (640)	13	24		344	0.50	No. 3	40 ³
No. 2-D A distillate fuel oil of lower volatility for engines in industrial and heavy mobile service	52 (125)	^a	0.05	0.35	0.01	282 (540)	338 (640)	19	41	32.6	40.1	0.50	No. 3	40 ³
No. 4-D A fuel oil for low and medium speed engines	55 (130)	^a	0.50		0.10			55	240	45.0	125.0	2.0		30 ³

^a To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller, and manufacturer.

^b It is unrealistic to specify low-temperature properties that will ensure satisfactory operation on a broad basis. Satisfactory operation should be achieved in most cases if the cloud point (or wax appearance point) is specified at 6°C above the tenth percentile minimum ambient temperature for the area in which the fuel will be used. The tenth percentile minimum ambient temperatures for the United States are shown in Appendix X2. This guidance is of a general nature; some equipment designs, use flow improver additives, if proper, or operations, or a combination thereof, may allow higher or require lower cloud point fuels. Appropriate low temperature operability properties should be agreed upon between the fuel supplier and purchaser for the intended use and expected ambient temperatures.

^c When cloud point less than -12°C (10°F) is specified, the minimum viscosity shall be 17 cSt (or mm²/s) and the 90% point shall be waived.

^d In countries outside the United States, other sulfur limits may apply.

^e Where cetane number by Method D613 is not available, Method D976 may be used as an approximation. Where there is disagreement, Method D613 shall be the reference method.

^f Low-atmospheric temperatures as well as engine operation at high altitudes may require use of fuels with higher cetane ratings.

^g 1 cSt = 1 mm²/s.

^h The values stated in SI units are to be regarded as the standard. The values in inch-pound units are for information only.

TABLE 20

ASTM Copper Strip Classifications

Classification	Designation	Description ^a
Freshly polished strip		
1	light tarnish	a. Light orange, almost the same as freshly polished strip b. Dark orange
2	moderate tarnish	a. Claret red b. Lavender c. Multicolored with lavender, blue or silver, or both overlaid on claret red d. Silvery e. Brassy or gold
3	dark tarnish	a. Maroon overlaid on brassy strip b. Multicolored with red and green showing (peacock), but no gray
4	corrosive	a. Transparent black, dark gray or brown with peacock green, barely showing b. Graphite or lusterless black c. Glossy or jet black

^a The ASTM Copper Strip Corrosion Standard is a colored reproduction of strips characteristic of these descriptions.

^b The freshly polished strip is included in the series only as an indication of the appearance of a properly polished strip before a test run. It is not possible to duplicate this appearance after a test even with a completely noncorrosive sample.