4.1.1.2 Effect of Iodide Concentration on the Ru/I/La Catalyst System

Prior to the initiation of this contract, it had been found that certain promoters, specifically certain lanthanide metal complexes, could enhance the activity and/or product selectivity of Ru/I$^-$ catalyst systems [1]. Since little was known about the characteristics of such promoted systems, studies were initiated to investigate the effects of several reaction variables.

The effect of the total iodide concentration on alcohols activity and C_2+ alcohols selectivity was studied in runs M-11 through 20, and 14752. In one set of experiments (11-15, 20), the iodide source was NaI and the solvent was N-methylpyrrolidone. Iodide concentrations ranged from 0.20 M to 0.53 M. The data are tabulated in Table 1 and displayed graphically in Figure 1. In a second set of experiments (16-19, 14752), the NaI level was varied from 0.13 M to 0.33 M in the presence of 0.067 M I_2. The solvent was N-methylpyrrolidone. These data are included in Table 1 and plotted in Figure 2. In both cases, the methanol rate decreased significantly with increasing iodide concentration while the ethanol and n-propanol rates remained relatively constant. In the presence of I_2, the ethanol rate actually begins to drop at the higher total iodide levels. Consequently, a large increase in C_2+ ROH selectivity was observed with increasing iodide levels. These results are opposite those observed previously using a Ru/I catalyst [2]. In the latter case, the methanol rate continuously increased with increasing iodide. The Ru/I studies were done in a different so vent (sulfolane) and at twice the pressure (12,500 psi) [2].

1. Dombek, B.D., U. S. Patent 4590216 (1986).
2. Dombek, B.D., *Adv. Catal.*, **32** (1983) 396.

Key to Tables 1, 2, and 3

SGHAM-M-#

—————————————

1	mmol Ru	Number of mmoles of Ru charged.
2	mmol I_2	Number of mmoles of I_2 charged.
3	mmol NaI	Number of mmoles of NaI charged.
4	mmol Total I	Total number of mmoles of I present.
5	Additive	Catalyst additive employed.
6	mmol	Number of mmoles of additive used.
7	Solvent	Reaction solvent used; 75 ml unless noted.
8	Pressure, psi	Reaction pressure, psig.
9	H_2/CO	Hydrogen:CO molar (volume) ratio.
10	Temp.,°C	Reaction temperature.
11	Uptake, psi	Gas uptake, psig.
12	Time, h	Reaction time in hours.

13	MeOH, M/h	Observed formation rates of individual products
14	EtOH, M/h	in moles/liter of catalyst solution/hr.
15	n-PrOH, M/h	
16	n-BuOH, M/h	
17	i-BuOH, M/h	
18	Other Ox., M/h	(Other oxygenates.)
19	Methane, M/h	
20	Tot. ROH, M/h	Total rate to alcohols in moles/l solution/hr.
21	C_2+ ROH, Wt.%	Wt. percentage of alcohols with a carbon number higher than 1 in the total alcohol fraction.

—————————————

Table 1. Effect of Total Iodide Concentration in the Ru System

SGHAM-M-#	11[a]	12	13	14
1 mmol Ru	6.00	6.00	6.00	6.00
2 mmol I_2	0.00	0.00	0.00	0.00
3 mmol NaI	15.00	15.00	19.00	25.00
4 mmol Total I	15.00	15.00	19.00	25.00
5 Additive	$LaCl_3$	$LaCl_3$	$LaCl_3$	$LaCl_3$
6 mmol	6.00	6.00	6.00	6.00
7 Solvent	NMP	NMP	NMP	NMP
8 Pressure, psi	6000	6000	6000	6000
9 H_2/CO	1.00	1.00	1.00	1.00
10 Temp.,°C	230	230	230	230
11 Uptake, psi	6000	6000	6000	6000
12 Time, h	0.52	1.70	1.62	1.82
13 MeOH, M/h	3.64	1.02	0.92	0.68
14 EtOH, M/h	0.24	0.41	0.42	0.44
15 n-PrOH, M/h	0.062	0.077	0.076	0.078
16 n-BuOH, M/h	0.002	0.009	0.009	0.010
17 i-BuOH, M/h	0.044	0.045	0.038	0.039
18 Other Ox., M/h	0.011	0.560	0.710	0.660
19 Methane, M/h	0.35	0.56	0.71	0.66
20 Tot. ROH M/h	3.99	1.57	1.46	1.25
21 C_2+ ROH, Wt.%	13.6	45.4	48.1	56.7

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 19.

[a] Anomalous result, not included in graphs.

Table 1. Effect of Total Iodide Concentration in the Ru System
            (Cont'd)

SGHAM-M-#	15	16	17	18
1 mmol Ru	6.00	6.00	6.00	6.00
2 mmol I_2	0.00	5.00	5.00	5.00
3 mmol NaI	29.00	10.00	15.00	20.00
4 mmol Total I	29.00	20.00	25.00	30.00
5 Additive	$LaCl_3$	$LaCl_3$	$LaCl_3$	$LaCl_3$
6 mmol	6.00	6.00	6.00	6.00
7 Solvent	NMP	NMP	NMP	NMP
8 Pressure, psi	6000	6000	6000	6000
9 H_2/CO	1.00	1.00	1.00	1.00
10 Temp.,°C	230	230	230	230
11 Uptake, psi	6000	6000	6000	6000
12 Time, h	1.58	1.63	1.90	1.88
13 MeOH, M/h	0.63	0.92	0.56	0.45
14 EtOH, M/h	0.46	0.45	0.45	0.44
15 n-PrOH, M/h	0.082	0.076	0.075	0.074
16 n-BuOH, M/h	0.013	0.010	0.011	0.011
17 i-BuOH, M/h	0.046	0.036	0.035	0.034
18 Other Ox., M/h	0.017	0.021	0.020	0.016
19 Methane, M/h	0.68	0.59	0.63	0.68
20 Tot. ROH, M/h	1.23	1.49	1.13	1.01
21 C_2+ ROH, Wt.%	60.1	49.2	61.5	65.8

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 19.

Table 1. Effect of Total Iodide Concentration in the Ru System
            (Cont'd)

SGHAM-M-#	19	20	14752
1 mmol Ru	6.00	6.00	6.00
2 mmol I_2	5.00	0.00	5.00
3 mmol NaI	25.00	40.00	15.00
4 mmol Total I	35.00	40.00	25.00
5 Additive	$LaCl_3$	$LaCl_3$	$LaCl_3$
6 mmol	6.00	6.00	6.00
7 Solvent	NMP	NMP	NMP
8 Pressure, psi	6000	6000	6000
9 H_2/CO	1.00	1.00	1.00
10 Temp.,°C	230	230	230
11 Uptake, psi	4810	6000	6000
12 Time, h	3.00	1.90	1.80
13 MeOH, M/h	0.09	0.40	0.62
14 EtOH, M/h	0.23	0.40	0.49
15 n-PrOH, M/h	0.043	0.072	0.080
16 n-BuOH, M/h	0.009	0.014	0.010
17 i-BuOH, M/h	0.021	0.040	0.040
18 Other Ox., M/h	0.015	0.013	0.019
19 Methane, M/h	0.37	0.50	0.82
20 Tot. ROH, M/h	0.39	0.94	1.24
21 C_2+ ROH, t.%	84.7	67.4	61.4

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 19.

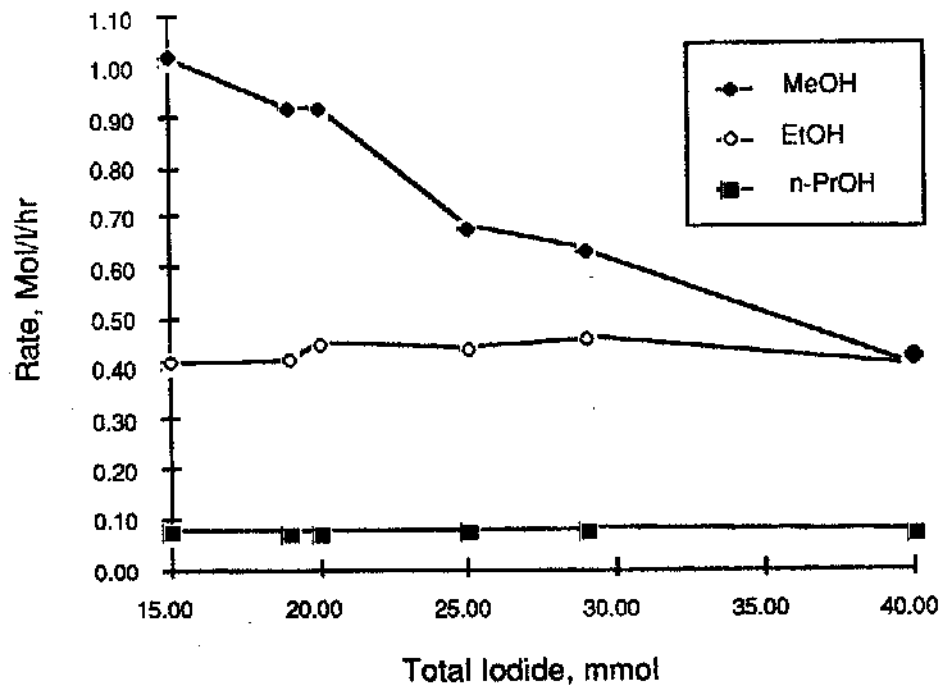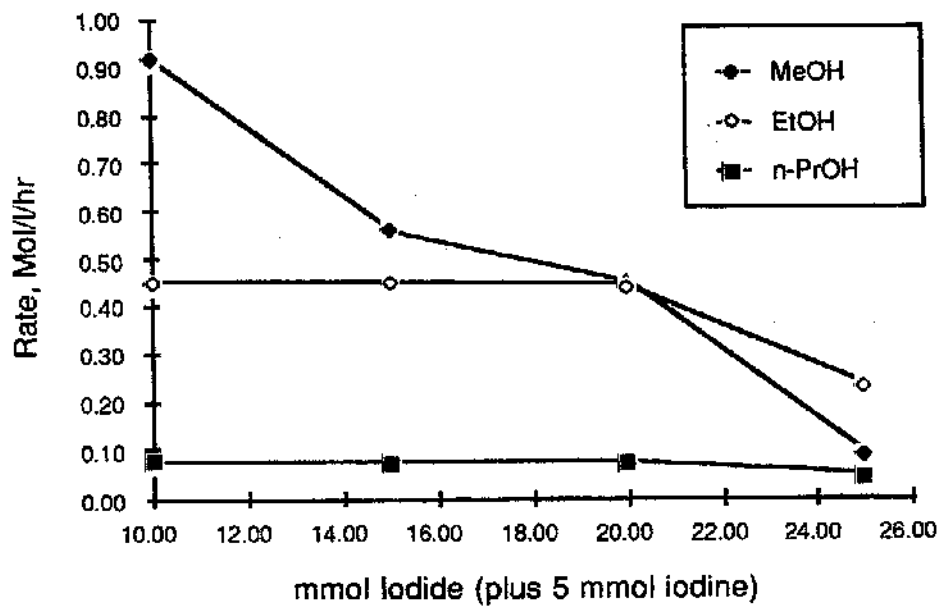Figure 1. Product Rates Versus Total Iodide

Figure 2. Product Rates Versus Iodide at Fixed Iodine Level

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4.1.1.3 Effect of Acidity on Ruthenium Catalyst Systems

Runs M-2 through 5, 10 through 12, and runs 14748 and 14752 were done to study the effect of acidity on alcohols activity and C_2^+ alcohols selectivity in the presence of a Ru/I/lanthanide catalyst. Both N-methylpyrrolidone and tri-n-propylphosphine oxide were used as solvents. The acidity was varied by using varying levels of iodine, which reacts with H_2 under reaction conditions to yield HI or its equivalent. A constant level of NaI was also added to all runs. The iodine level was varied from 0.027 M to 0.093 M while the NaI level was held constant at 0.20 M. The data are tabulated in Table 2 and are depicted graphically in Figures 3 and 4. With both solvents, the effect of increasing the acidity (i.e., increasing I_2) was to decrease the activity, primarily by decreasing the methanol rate. The rates to the higher alcohols increased slightly, then decreased slightly with the net result being an increase in C_2^+ ROH selectivity with increasing acidity.

The effect of acidity on a Ru/I catalyst in tri-n-propylphosphine oxide solvent was studied by Dombek [1]. The trends observed for the Ru/I/lanthanide catalyst are quite similar to those observed for the Ru/I catalyst. According to Dombek, the acidity effect may be attributed to both solvent basicity as well as the oxidizing properties of HI. In order for catalytic activity to occur, the catalyst precursor, $Ru_3(CO)_{12}$, must be converted into $[HRu_3(CO)_{11}]^-$ and $[Ru(CO)_3I_3]^-$. The ratio of these two species is critical to the catalytic activity. The phosphine oxide solvent is sufficiently basic to promote reduction, by H_2, of $Ru_3(CO)_{12}$ to $[HRu_3(CO)_{11}]^-$, as shown in equation 1. The HI oxidizes part of the $[HRu_3(CO)_{11}]^-$ to $[Ru(CO)_3I_3]^-$. The $[R_3POH]^+$ ion may assist in the catalytic homologation of methanol to ethanol.

$$Ru_3(CO)_{12} + R_3PO + H_2 \longrightarrow [R_3POH]^+[HRu_3(CO)_{11}]^- \qquad (1)$$
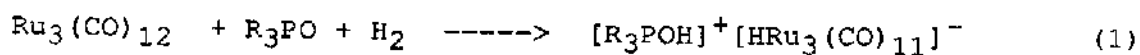
The effect of acidity in a Ru/I catalyzed process had not been reported for N-methylpyrrolidone solvent. Consequently, we ran these experiments (M-21 through 24 and 26) for comparison to the experiments done with the Ru/I/lanthanide catalyst. These data are tabulated in Table 2 and are plotted in Figure 5. Interestingly, the effect of acidity in this solvent was the opposite in the absence of the lanthanide and in its presence.

1. Dombek, B.D., *Adv. Catal.*, **32** (1983) 399.

Table 2. **Effect** of Acidity on Ru Catalyst Systems

SGHAM-M-#	2	3	4	5
1 mmol Ru	6.00	6.00	6.00	6.00
2 mmol I_2	2.00	2.00	7.00	7.00
3 mmol NaI	15.00	15.00	15.00	15.00
4 mmol Total I	19.00	19.00	29.00	29.00
5 Additive	$LaCl_3$	$LaCl_3$	$LaCl_3$	$LaCl_3$
6 mmol	6.00	6.00	6.00	6.00
7 Solvent	Pr_3PO	NMP	Pr_3PO	NMP
8 Pressure, psi	6000	6000	6000	6000
9 H_2/CO	1.00	1.00	1.00	1.00
10 Temp.,°C	230	230	230	230
11 Uptake, psi	6000	6000	6000	6000
12 Time, h	1.63	1.57	3.00	2.88
13 MeOH, M/h	0.69	0.87	0.09	0.19
14 EtOH, M/h	0.64	0.45	0.20	0.29
15 n-PrOH, M/h	0.072	0.078	0.046	0.046
16 n-BuOH, M/h	0.009	0.009	0.010	0.009
17 i-BuOH, M/h	0.015	0.042	0.022	0.020
18 Other Ox., M/h	0.020	0.010	0.010	0.018
19 Methane, M/h	0.56	0.66	0.32	0.43
20 Tot. ROH, M/h	1.43	1.45	0.34	0.56
21 C_2+ ROH, Wt.%	61.7	51.2	82.5	75.0

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 19.

Table 2. Effect of Acidity on Ru Catalyst Systems (Cont'd)

SGHAM-M-#	10	11[a]	12	21
1 mmol Ru	6.00	6.00	6.00	6.00
2 mmol I_2	0.00	0.00	0.00	12.50
3 mmol NaI	15.00	15.00	15.00	0.00
4 mmol Total I	15.00	15.00	15.00	25.00
5 Additive	$LaCl_3$	$LaCl_3$	$LaCl_3$	-
6 mmol	6.00	6.00	6.00	-
7 Solvent	Pr_3PO	NMP	NMP	NMP
8 Pressure, psi	6000	6000	6000	6000
9 H_2/CO	1.00	1.00	1.00	1.00
10 Temp.,°C	230	230	230	230
11 Uptake, psi	6000	6000	6000	6000
12 Time, h	2.07	0.52	1.70	1.85
13 MeOH, M/h	0.65	3.64	1.02	0.76
14 EtOH, M/h	0.38	0.24	0.41	0.20
15 n-PrOH, M/h	0.057	0.062	0.077	0.020
16 n-BuOH, M/h	0.009	0.002	0.009	0.002
17 i-BuOH, M/h	0.033	0.044	0.045	0.002
18 Other Ox., M/h	16.000	0.011	0.017	0.020
19 Methane, M/h	0.45	0.35	0.26	0.13
20 Tot. ROH, M/h	1.13	3.99	1.57	0.98
21 C_2+ ROH, Wt.%	53.8	13.6	45.4	30.4

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 19.

[a] Anomalous result, not included in graphs.

Table 2. Effect of Acidity on Ru Catalyst Systems (Cont'd)

SGHAM-M-#	22	23[a]	24	26[a]
1 mmol Ru	6.00	6.00	6.00	6.00
2 mmol I_2	10.00	5.00	0.00	5.00
3 mmol NaI	5.00	15.00	25.00	15.00
4 mmol Total I	25.00	25.00	25.00	25.00
5 Additive	–	–	–	–
6 mmol	–	–	–	–
7 Solvent	NMP	NMP	NMP	NMP
8 Pressure, psi	6000	6000	6000	6000
9 H_2/CO	1.00	1.00	1.00	1.00
10 Temp.,°C	230	230	230	230
11 Uptake, psi	6000	6000	6320	6000
12 Time, h	2.13	2.32	4.22	2.73
13 MeOH, M/h	0.60	0.98	0.39	0.76
14 EtOH, M/h	0.17	0.29	0.13	0.26
15 n-PrOH, M/h	0.017	0.041	0.010	0.031
16 n-BuOH, M/h	0.002	0.003	0.000	0.001
17 i-BuOH, M/h	0.001	0.002	0.001	0.002
18 Other Ox., M/h	0.014	0.061	0.048	0.011
19 Methane, M/h	0.14	0.33	0.26	0.29
20 Tot. ROH, M/h	0.80	1.32	0.53	1.05
21 C_2+ ROH, Wt.%	32.5	34.7	35.7	36.9

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 19.

[a] Anomalous result, not included in graphs.

Table 2.   Effect of Acidity on Ru Catalyst Systems (Cont'd)

SGHAM-M-#	14748	14752
1 mmol Ru	6.00	6.00
2 mmol I_2	5.00	5.00
3 mmol NaI	15.00	15.00
4 mmol Total I	25.00	25.00
5 Additive	$LaCl_3$	$LaCl_3$
6 mmol	6.00	6.00
7 Solvent	Pr_3PO	NMP
8 Pressure, psi	6000	6000
9 H_2/CO	1.00	1.00
10 Temp.,°C	230	230
11 Uptake, psi	6000	6000
12 Time, h	2.92	1.80
13 MeOH, M/h	0.18	0.62
14 EtOH, M/h	0.38	0.49
15 n-PrOH, M/h	0.056	0.080
16 n-BuOH, M/h	0.006	0.010
17 i-BuOH, M/h	0.013	0.040
18 Other Ox., M/h	nd	0.019
19 Methane, M/h	0.61	0.82
20 Tot. ROH, M/h	0.64	1.24
21 C_2+ ROH, Wt.%	79.4	61.4

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 19.
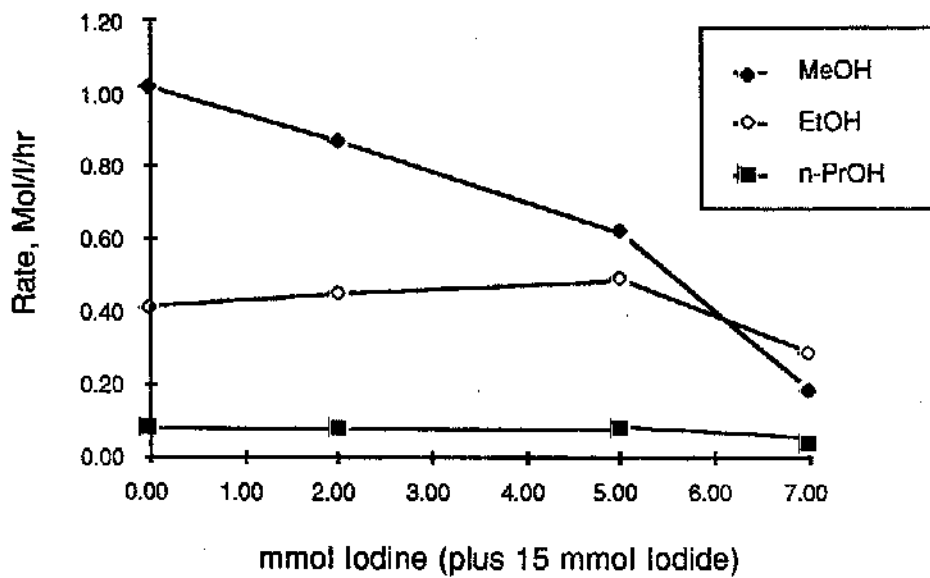
Figure 3. Product Rates Versus Iodine in NMP Solvent

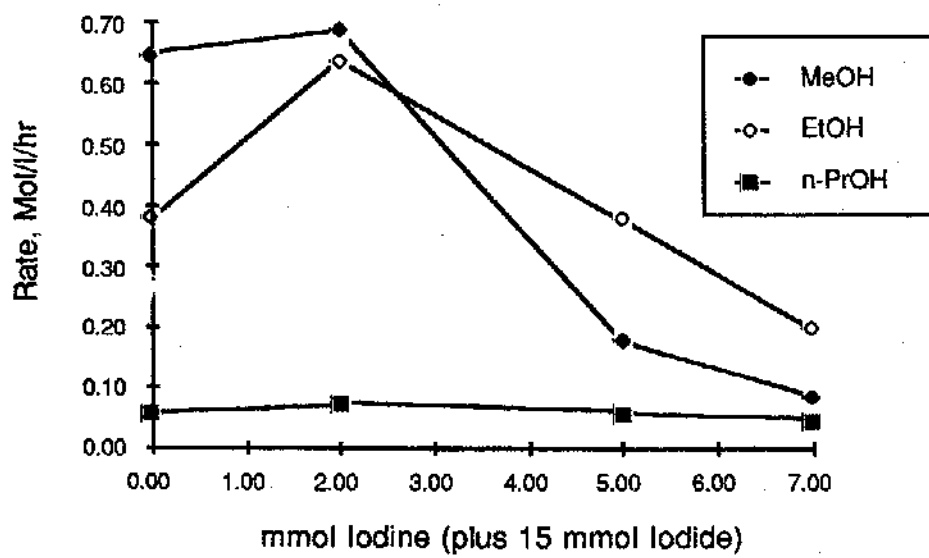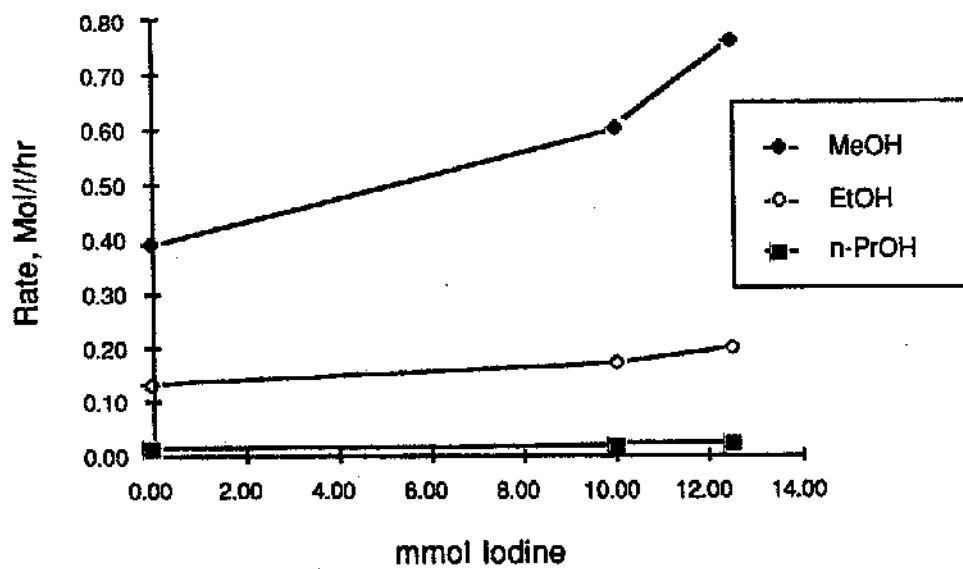Figure 4. Product Rates Versus Iodine in Pr_3PO Solvent

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Figure 5. Product Rates Versus Iodine in NMP Solvent With the Ru/I$^-$ Catalyst

4.1.1.4 Effect of Solvent Polarity in a Ru/I/Lanthanide Catalyst System

Experiment M-1 was done to test the effect of solvent polarity on the strength of the lanthanide effect in this system. We felt that the effect of the lanthanide complex on the catalytic activity might be enhanced in a less polar solvent. The solvent polarity was lowered by replacing the N-methylpyrrolidone solvent with a a 1:1 N-methylpyrrolidone:toluene solvent. The data are listed in Table 3. The activity was much lower in the less polar solvent. This result may be due to either decreased catalyst solubility or decreased catalyst activity; a polar environment appears to be necessary for CO hydrogenation to occur with these ruthenium catalysts.

4.1.1.5 Effect of Added Methanol Hydroformylation Catalysts

One possible way to improve the selectivity to higher alcohols is to include a catalyst that would convert methanol to higher molecular weight oxygenates (preferably alcohols). As a preliminary test of this idea, we ran experiments M-6 and 7, in which a known methanol hydroformylation catalyst, A8 plus A9, was added to the Ru/I/lanthanide catalyst. The data are listed in Table 3. The alcohol activity was significantly suppressed.

Investigations were continued into the possibility of increasing the fraction of higher alcohols by adding another known methanol hydroformylation catalyst, $Co_2(CO)_8$, to the Ru/I system. Since significant amounts of methanol are formed, it is reasonable that the presence of such a catalyst would convert methanol to higher alcohols, leading to better selectivity. Three runs were made, one with no $LaCl_3$ and a LiI/I_2 iodide source, one with $LaCl_3$ and a LiI/I_2 iodide source, and one with $LaCl_3$ and a NaI/I_2 iodide source. The first gave a total alcohol rate of 1.18 M/h due primarily to an increased rate to methanol. The two runs with $LaCl_3$ included gave very similar total alcohol rates of 0.94 and 0.85 M/h with only minor differences in selectivity. Thus, surprisingly little effect on selectivity was observed upon addition of this potential cocatalyst.

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Table 3. Effects of Solvent Polarity and Addition of a Methanol
Hydroformylation Catalyst to the Ru System

SGHAM-M-#	1	6	7
1 mmol Ru	6.00	6.00	6.00
2 mmol I_2	5.00	5.00	5.00
3 mmol NaI	15.00	15.00	15.00
4 mmol Total I	25.00	25.00	25.00
5 Additive	$LaCl_3$	$LaCl_3$/A8	$LaCl_3$/A8/A9
6 mmol	6.00	6.0/4.0	6.0/4.0/4.0
7 Solvent	NMP/Toluene	NMP	NMP
8 Pressure, psi	6000	6000	6000
9 H_2/CO	1.00	1.00	1.00
10 Temp.,°C	230	230	230
11 Uptake, psi	6100	6000	1250
12 Time, h	3.00	2.62	3.00
13 MeOH, M/h	0.02	0.27	0.02
14 EtOH, M/h	0.08	0.46	0.08
15 n-PrOH, M/h	0.016	0.037	0.016
16 n-BuOH, M/h	0.002	0.004	0.003
17 i-BuOH, M/h	nd	0.003	0.001
18 Other Ox., M/h	nd	0.012	0.020
19 Methane, M/h	0.22	0.36	0.06
20 Tot. ROH, M/h	0.12	0.77	0.14
21 C_2+ ROH, t.%	88.5	73.0	89.7

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 19.

4.1.1.6 Product Distribution as a Function of H_2/CO Conversion

A better understanding of the mechanism of H_2/CO conversion by Ru/I/lanthanide catalysts should facilitate catalyst improvement. Two possible mechanisms for the conversion of H_2/CO into alcohols are: 1) methanol (alcohol) homologation; and 2) conversion of a common catalytic intermediate (e.g., a metallo-formyl) into methanol and ethanol via two separate, competing pathways. The approach taken to improve the catalyst could be quite different for the two mechanisms. In experiments M-27 through 30, 17, and 14752, we studied the changing product distribution as a function of H_2/CO conversion (i.e., run time). The data are tabulated in Table 4 and graphed in Figure 6.

In the early stages of the reaction, the primary product is methanol. As the reaction proceeds, ethanol and the higher alcohols build up, while methanol levels off. At longer run times, methanol production decreases dramatically and ethanol and higher alcohols begin to level off. These results are consistent with methanol homologation being the most significant pathway to ethanol, and subsequent homologation steps leading to higher alcohols. At longer run times, the catalyst activity for converting H_2/CO to methanol appears to decrease sharply. The reason for this change in activity is not entirely understood, but possibilities include a change in the catalytic species or a change in catalyst behavior due to changing solvent properties resulting from the accumulation of products.

Key to Table 4

SGHAM-M-#

1	mmol Ru	Number of mmoles of Ru charged.
2	mmol I_2	Number of mmoles of I_2 charged.
3	mmol NaI	Number of mmoles of NaI charged.
4	mmol Total I	Total number of mmoles of I present.
5	Additive	Catalyst additive employed.
6	mmol	Number of mmoles of additive used.
7	Solvent	Reaction solvent used; 75 ml unless noted.
8	Pressure, psi	Reaction pressure, psig.
9	H_2/CO	Hydrogen:CO molar (volume) ratio.
10	Temp.,°C	Reaction temperature.
11	Uptake, psi	Gas uptake, psig.
12	Time, h	Reaction time in hours.

13	MeOH, g	Amounts of products formed, grams
14	EtOH, g	
15	n-PrOH, g	
16	n-BuOH, g	
17	i-BuOH, g	
18	MeOH, M/h	Observed formation rates of individual products
19	EtOH, M/h	in moles/liter of catalyst solution/hr.
20	n-PrOH, M/h	
21	n-BuOH, M/h	
22	i-BuOH, /h	
23	Other Ox., M/h	(Other oxygenates.)
24	Methane, M/h	
25	Tot. ROH, M/h	Total rate to alcohols in moles/1 solution/hr.
26	C_2+ ROH, Wt.%	Wt. percentage of alcohols with a carbon number higher than 1 in the total alcohol fraction.

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Table 4. Product Distribution as a Function of Syngas Conversion

SGHAM-M-#	17	27	28	29
1 mmol Ru	6.00	6.00	6.00	6.00
2 mmol I_2	5.00	5.00	5.00	5.00
3 mmol NaI	15.00	15.00	15.00	15.00
4 mmol Total I	25.00	25.00	25.00	25.00
5 Additive	$LaCl_3$	$LaCl_3$	$LaCl_3$	$LaCl_3$
6 mmol	6.00	6.00	6.00	6.00
7 Solvent	NMP	NMP	NMP	NMP
8 Pressure, psi	6000	6000	6000	6000
9 H_2/CO	1.00	1.00	1.00	1.00
10 Temp.,°C	230	230	230	230
11 Uptake, psi	6000	2000	4000	8000
12 Time, h	1.90	1.38	1.97	5.08
13 MeOH, g	2.57	1.49	1.99	1.63
14 EtOH, g	2.98	0.86	1.89	3.78
15 n-PrOH, g	0.64	0.16	0.40	0.71
16 n-BuOH, g	0.12	0.02	0.09	0.14
17 i-BuOH, g	0.36	0.09	0.29	0.26
18 MeOH, M/h	0.56	0.45	0.42	0.13
19 EtOH, M/h	0.45	0.18	0.28	0.22
20 n-PrOH, M/h	0.075	0.025	0.046	0.031
21 n-BuOH, M/h	0.011	0.002	0.008	0.005
22 i-BuOH, M/h	0.035	0.011	0.026	0.009
23 Other Ox., M/h	0.020	0.014	0.020	0.010
24 Methane, M/h	0.63	0.22	0.41	0.36
25 Tot. ROH, M/h	1.13	0.67	0.78	0.40
26 C_2+ ROH, Wt.%	61.5	40.0	57.3	75.0

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 36.

Table 4. Product Distribution as a Function of Syngas Conversion
(Cont'd)

SGHAM-M-#	30	14752
1 mmol Ru	6.00	6.00
2 mmol I_2	5.00	5.00
3 mmol NaI	15.00	15.00
4 mmol Total I	25.00	25.00
5 Additive	$LaCl_3$	$LaCl_3$
6 mmol	6.00	6.00
7 Solvent	NMP	NMP
8 Pressure, psi	6000	6000
9 H_2/CO	1.00	1.00
10 Temp.,°C	230	230
11 Uptake, psi	8860	6000
12 Time, h	7.00	1.80
13 MeOH, g	1.36	2.66
14 EtOH, g	3.79	3.01
15 n-PrOH, g	0.74	0.63
16 n-BuOH, g	0.15	0.13
17 i-BuOH, g	0.26	0.37
18 MeOH, M/h	0.08	0.62
19 EtOH, M/h	0.16	0.49
20 n-PrOH, M/h	0.024	0.080
21 n-BuOH, M/h	0.004	0.010
22 i-BuOH, /h	0.007	0.040
23 Other Ox., M/h	0.001	0.019
24 Methane, M/h	0.28	0.82
25 Tot. ROH, M/h	0.28	1.24
26 C_2+ ROH, Wt.%	78.4	61.4

Experimental procedure: B(1); Analytical procedure: C(1); Key on page 36.

Figure 6. Product Composition vs. Syngas Conversion