The First Example of Transition-Metal-Catalyzed Thioformylation of Acetylenes with Aromatic Thiols and Carbon Monoxide

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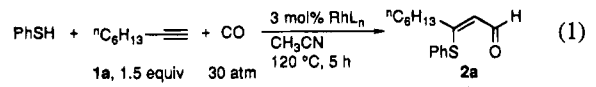
The first transition-metal-catalyzed thioformylation of terminal acetylenes with carbon monoxide and thiols has been revealed. While there are a considerable number of publications concerning hydroformylation and the related oxo analogue reactions,[1] there are no examples to date of the transition-metal-catalyzed reaction with carbon monoxide which permits simultaneous introduction of a formyl and a sulfide unit into carbon−carbon multiple bonds. Perhaps widespread prejudice that thiols are catalyst poisons has precluded investigation in this area. On the contrary, we have examined the reaction of acetylenes with thiols and carbon monoxide in the presence of a wide variety of transition-metal catalysts and ultimately have found that rhodium(I) complexes exhibit an excellent catalytic activity toward the desired thioformylation reaction of acetylenes.

Table 1 shows the results of the reaction of 1-octyne (**1a**) with benzenethiol using several rhodium catalysts under pressurized carbon monoxide. Among the catalysts employed, rhodium(I) complexes bearing phosphine ligands worked well as excellent catalysts for the desired thioformylation of **1a**. In particular, $RhH(CO)(PPh_3)_3$ was the most effective catalyst (entry 1): the reaction of **1a** with benzenethiol and carbon monoxide (30 atm) in the presence of 3 mol % of $RhH(CO)(PPh_3)_3$ at 120 °C for 5 h led to high-yield formation of the corresponding thioformylation product,[2,3] in which carbon monoxide was incorporated predominantly at the terminal carbon of the acetylene (eq 1). $RhCl(PPh_3)_3$ is also a good

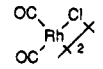
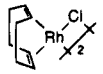


(1)

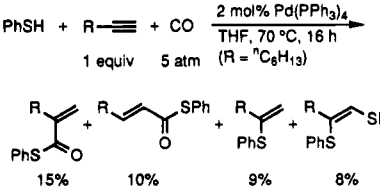
catalyst for the thioformylation, although prolonged reaction time is required (entry 2).[4] Rhodium complexes having no phosphine ligand were less effective for this transformation (entries 4−6).

In contrast to these rhodium catalysts, $Pd(OAc)_2$, which is effective for the Markovnikov-type addition of thiols to acetylenes,[5] exerted no effect on the carbonylation (in the presence of CO, only small amounts of the Markovnikov adducts were obtained with the recovery of the starting materials). Palladium complexes having phosphine ligands, like $Pd(PPh_3)_4$ and $PdCl_2(PPh_3)_2$, resulted in the formation of a complex mixture (eq 2). $NiCl_2(PPh_3)_2$, $IrCl(CO)(PPh_3)_2$, $RuCl_2(PPh_3)_3$, $Ru_3(CO)_{12}$, etc. exhibited no catalytic activity.

Table 1. Rhodium-Catalyzed Thioformylation of 1-Octyne

entry	catalyst	yield of **2a**
1	$RhH(CO)(PPh_3)_3$	82%
2	$RhCl(PPh_3)_3$	70%[a]
3	$RhCl(CO)(PPh_3)_2$	68%
4	$Rh_6(CO)_{16}$	16%[b]
5		19%
6		25%[b]

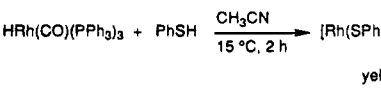
[a] 20 h. [b] 100 °C, 15 h.



(2)

Table 2 lists examples of the $RhH(CO)(PPh_3)_3$-catalyzed thioformylation of acetylenes. Arenethiols can be employed successfully for the thioformylation of acetylenes (entries 2 and 3), whereas the thioformylation with alkanethiols such as *n*-dodecanethiol required prolonged reaction time and was accompanied by the formation of thioester **3a'''** (entry 4). Aliphatic acetylenes underwent regioselective thioformylation successfully (entries 5, 6, 8, and 9). Likewise, the thioformylation of aromatic acetylenes proceeded regioselectively, although the Markovnikov adduct of thiols to acetylenes was formed as a byproduct (*e.g.*, 28% of α-(phenylthio)styrene was obtained in the case of phenylacetylene, entry 7).

To explore the mechanism of this thioformylation, stoichiometric reaction of the rhodium catalyst with an aromatic thiol was attempted: equimolar reaction of $RhH(CO)(PPh_3)_3$ with PhSH at 15 °C in acetonitrile under argon atmosphere afforded a yellow solid with the evolution of molecular hydrogen. ^1H NMR spectra indicated the disappearance of the signal at δ −9.71 assigned to the hydride of $RhH(CO)(PPh_3)_3$.[6] The IR spectra of the yellow solid showed that the CO absorption (1922 cm^{-1})[6] of $RhH(CO)(PPh_3)_3$ disappeared and a new carbonyl absorption appeared at 1969 cm^{-1}. There results and elemental analysis of the yellow solid suggest the formation of $Rh(SPh)(CO)(PPh_3)_2$ (eq 3).[7,8] A possible mechanism for this thioformylation may include the regioselective thiorhodation[5] of acetylenes by the rhodium sulfide complex formed *in situ*. However, elucidation of the precise mechanism requires further detailed investigation.



(3)

(1) (a) Falbe, J. *New Syntheses with Carbon Monoxide*", Springer-Verlag: Berlin, 1980; p 1. (b) Tkatchenko, I. In *Comprehensive Organometallic Chemistry*; Wilkinson, G., Ed.; Pergamon: Oxford, 1982; Vol. 8, p 115. (c) Stille, J. K. *Comprehensive Organic Synthesis*; Trost, B. M., Ed.; Pergamon: Oxford, 1991; Vol. 4, p 913.

(2) Representative procedure for the thioformylation of acetylenes with thiols and carbon monoxide: In a 50 mL stainless steel autoclave with a magnetic stirring bar under argon atmosphere were placed $RhH(CO)(PPh_3)_3$ (3 mol %), acetonitrile (5 mL), 1-octyne (7.5 mmol),[9] and benzenethiol (5 mmol). Carbon monoxide was purged three times and then charged at 30 atm. The reaction was conducted with magnetic stirring for 5 h[10] at 120 °C. After carbon monoxide was purged, the resulting mixture was filtered through Celite and concentrated *in vacuo*. Purification by MPLC (silica gel, 25−40 μm; length, 310 mm; 25 mm i.d., eluent, *n*-hexane:Et_2O = 4:1) provided 0.86 g (69%) of (*Z*)-3-(phenylthio)-2-nonenal ((*Z*)-**2a**) and 0.16 g (13%) of (*E*)-3-(phenylthio)-2-nonenal ((*E*)-**2a**).

(3) The stereochemistry of thioformylation products was determined unambiguously by NOE experiment: in the case of (*Z*)-**2a**, for example, irradiation of allylic methylene triplet resulted in a 14% enhancement of the vinylic doublet.

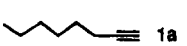
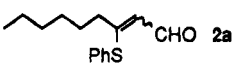
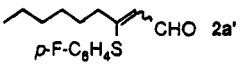
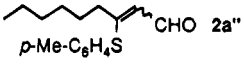
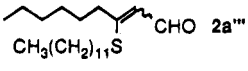
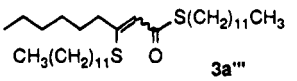
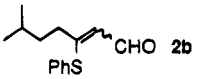
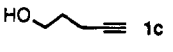
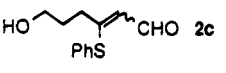
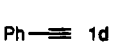
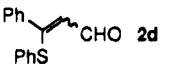
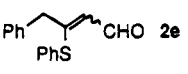
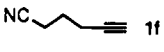
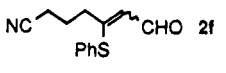
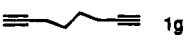
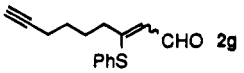
(4) When the $RhCl(PPh_3)_3$-catalyzed reaction of **1a** with CO and PhSH was conducted at 120 °C for 5 h, 46% of the thioformylation product **2a** was obtained with the recovery of the starting materials.

(5) (a) Kuniyasu, H.; Ogawa, A.; Sato, K.; Ryu, I.; Kambe, N.; Sonoda, N. *J. Am. Chem. Soc.* **1992**, *114*, 5902. (b) Bäckvall, J.; Ericsson, A. *J. Org. Chem.* **1994**, *59*, 5850.

(6) (a) Bath, S. S.; Vaska, L. *J. Am. Chem. Soc.* **1963**, *85*, 3500. (b) Evans, D.; Yagupsky, G.; Wilkinson, G. *J. Chem. Soc. (A)* **1968**, 2660.

0002-7863/95/1517-7564$09.00/0

Table 2. Rhodium-Catalyzed Thioformylation of Acetylenes with Thiols and CO[a]

entry	acetylene	thiol	product	yield, %[b]	*E/Z*
1	 **1a**	PhSH	 **2a**	82	13/87
2		*p*-F-C_6H_4SH	 **2a'**	76	24/76
3		*p*-Me-C_6H_4SH	 **2a"**	72	31/69
4[c]		$CH_3(CH_2)_{11}SH$	 **2a'"**	27	41/59
			 **3a'"**	23	41/59
5	 **1b**	PhSH	 **2b**	80	14/86
6	 **1c**	PhSH	 **2c**	76	86/14
7[d]	 **1d**	PhSH	 **2d**	52	16/84
8	 **1e**	PhSH	 **2e**	63	54/46
9	 **1f**	PhSH	 **2f**	61	23/77
10	 **1g**	PhSH	 **2g**	58	1/99

[a] Reactions were conducted under the condition of 7.5 mmol of acetylene, 5.0 mmol of ArSH, and CO (30 atm) in the presence of 3 mol % of catalyst at 120 °C for 5 h in acetonitrile (5 mL). [b] Isolated yield. [c] 17 h. [d] α-(Phenylthio)styrene was also formed in 28% yield.

In summary, we have developed a highly selective thioformylation of acetylenes catalyzed by rhodium(I) complexes. The results mentioned in this paper suggest that the novel combination of organic sulfur compounds and transition-metal catalysts is synthetically very useful. We are currently examining the application of this methodology to different classes of substrates.

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Supporting Information Available: Analytical data on the compounds prepared (IR, ^1H NMR, ^{13}C NMR, and mass spectra and elemental analyses) (6 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, can be ordered from the ACS, and can be downloaded from the Internet; see any current masthead page for ordering information and Internet access instructions.

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(7) $Rh(SPh)(CO)(PPh_3)_2$ is known in the literature, see: (a) Bolton, E. S.; Havlin, R.; Knox, G. R. *J. Organomet. Chem.* **1969**, *18*, 153. (b) Vaska, L.; Jun, J. P. *J. Chem. Soc., Chem. Commun.* **1971**, 418. (c) Schiavon, G.; Zecchin, S.; Pilloni, G.; Martell, M. *J. Inorg. Nucl. Chem.* **1977**, *39*, 115.

(8) The results of elemental analysis are in fair agreement with the calculated values for the monohydrate of $Rh(SPh)(CO)(PPh_3)_2$. Anal. Calcd for $C_{43}H_{37}O_2P_2RhS$: C, 65.99; H, 4.76; S, 4.10. Found: C, 65.80; H, 4.69; S, 4.10.

(9) When equimolar amounts of 1-octyne and PhSH were used, the yield of thioformylation product (**2a**) was slightly reduced (57%, *E/Z* = 30/70).

(10) Prolonged reaction time (15 h) caused the *Z* to *E* isomerization to give a stereoisomeric mixture of **2a** (*E/Z* = 67/33).