Potassium Chlorochromate on a Solid Support: A Convenient and Mild Reagent for the Oxidation of Alcohols

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The oxidation of primary and secondary alcohols by potassium chlorochromate supported on alumina or silica gel is reported. The results indicate that the yields in some cases depend on the support medium. Benzylic and secondary alcohols are oxidized in the best yields. The effect of solvent on the reaction is discussed and the conclusion is drawn that the best yields are obtained in non-polar solvents.

In a recent publication,[1] we reported the use of potassium chlorochromate, KCC, as a efficient reagent for the oxidation of alcohols. During a study of the effect of steric and electronic factors on the activity of Cr-reagents, we investigated the properties of KCC on solid-support materials. It has been previously found that Cr(VI) reagents supported on insoluble inorganic matrices are particularly convenient in organic syntheses. The main advantage associated with the use of a solid supported Cr-reagent is the ease of purification of the final product since both the initial Cr-reagent, which may be used in excess to help drive the reaction to completion, and its by-products are insoluble and can be separated from the organic products by simple filtration. However, the insoluble support can modify the reactivity and selectivity of the oxidizing agent.

A variety of chromium(VI) compounds on solid-support materials have appeared in the literature. Thus, Cheng *et al.*[2] observed that pyridinium chlorochromate on alumina is an efficient and selective oxidation agent for primary and secondary alcohols. Similarly, chromyl chloride on alumina[3] exhibited increased selectivity compared with the unbound reagent. Other reagents reported are chromium trioxide on graphite[4] or on a polymer support,[5] chromic acid on silica gel[6] or on ion-exchange resins,[7] pyridinium chlorochromate or pyridinium dichromate on a polymer support[8] or molecular sieves.[9]

We now report on the use of KCC on alumina or silica gel and describe the chemical properties of these reagents on the oxidation of a variety of alcohols.

Results and discussion

Solid-supported KCC reagents were prepared very easily by stirring a solution of KCC in acetone with alumina or silica gel. The reagents were isolated as yellow or light brown powders either by filtration or by evaporation of the solvent. Either of these procedures gave satisfactory results. The oxidation capacity of the reagent was easily determined by oxidation of either 1-phenylethanol to acetophenone or benzyl alcohol to benzaldehyde. The degree of conversion of the reaction was measured by GLC using an *n*-alkane as an internal standard. The oxidation capacities of the reagents containing typically 10 weight % of KCC were usually found to be in the range of 0.5–0.6 mmol of oxidizing agent, expressed as chlorochromate, per gram of dry reagent.

Oxidation capacity. The measured capacities were lower than predicted from the stoichiometries (85–95 % of the theoretical) and appear to depended on how well the support material and solvent were dried prior to preparation of the reagent. This may be due to the hydrolytic action of the water in the support materials resulting in the formation of potassium dichromate. Therefore, the best results were observed when the alumina or silica gel was carefully dried prior to use. The reagents are stable when kept dry. Thus, no changes in activities were detected after storage in closed containers for more than three years. Control experiments using potassium chromate on alumina show that this reagent does not oxidize alcohols under the standard reaction conditions employed for the KCC oxidations.

We have previously shown that KCC in solution can react violently with alcohols in a variety of organic solvents.[1] Its reactivity may conveniently be moderated by absorption onto alumina or silica gel. Indeed, we found that the supported reagents exhibited the expected decrease in reactivity.

Solvent effects. KCC on alumina or silica gel can be used in a variety of solvents. The results in Table 1 show the effect of solvents on the rate of oxidation of benzyl alcohol with an excess of KCC/alumina at room temperature in 5 ml of

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Table 1. Oxidation of benzyl alcohol with KCC/Al_2O_3:[a] influence of solvents on the reaction rate.

Solvent	Benzaldehyde yield / %
Carbon tetrachloride	82
Benzene	81
Dichloromethane	69
Ethyl Acetate	43
Acetone	36
N,N-Dimethylformamide	16

[a]Reaction of 0.5 mmol of alcohol with 2.0 g of KCC/alumina (10.2 %) and 50 mg of *n*-dodecane in 5 ml of solvent at room temperature for 2 h.

the solvent under nitrogen. The KCC-promoted oxidation proceeds readily in non-polar solvents such as benzene or carbon tetrachloride and is more sluggish in dichloromethane or ethyl acetate. The same trend has been observed by other workers in studies of polymer-supported chlorochromate[8a] and chromic acid.[7] Polar solvents such as acetone and *N,N*-dimethylformamide were found to be less suitable as a marked decrease in reactivity was observed and also because KCC itself is highly soluble in these solvents. KCC in the supported reagent is probably not chemically bound but rather deposited on the surface of the support agent. Therefore, by using polar solvents some of the general advantages of supported reagents are lost.

Reaction conditions. The preferred reaction conditions included a 1:2 mole ratio between substrate and oxidation agent at room temperature or in refluxing dichloromethane. The reactions were usually performed on a 10 mmol scale. An increase in temperature substantially increased the reaction rate without notable changes in the product composition. The products were usually formed in essentially quantitative yields (GLC) and were isolated after filtration and evaporation of the solvent followed by recrystallization or distillation.

Oxidation of saturated primary and secondary alcohols. Representative results for the oxidation of saturated primary and secondary alcohols are summarized in Table 2. Primary alcohols gave modest yields of the corresponding aldehydes as the only detected products. Despite the fact that the starting material was consumed and none of the expected carboxylic acid and ester by-products were detected, we did not succeed in increasing the yields. It is worth noting that supported KCC under the conditions used in this work gave aldehydes in constant, reasonable yields, contrary to those observed for KCC in solution.[1] However, even in the present modification the KCC reagent appears to be less useful for the oxidation of primary alcohols. Secondary alcohols were converted cleanly into ketones and in high yields.

Oxidation of benzylic alcohols. This class of alcohols was readily oxidized to the corresponding aldehydes or ketones. Selected examples are shown in Table 3. Formation of carboxylic acids or esters from primary benzylic alcohols was not detected. However, we have observed that under the prevailing reaction conditions, aldehydes are very prone to air oxidation to carboxylic acids. In this series of experiments a marked effect on the reaction rate was exerted by raising the temperature without changes in the product composition being observed.

Oxidation of cyclopropyl(aryl)methanols yielded ketones as the major products. This appears to exclude a possible radical mechanism.[10] We believe the ring-opened product shown in Table 3 arose due to an acid catalyzed ring-opening reaction on the cyclopropyl group – HCl is formed in during the course of the reaction. Acidic reaction conditions may also account for the formation of the ether and benzaldehyde.

Oxidation of unsaturated alcohols. As shown in Table 4, secondary allylic alcohols were oxidized to the corresponding ketones in high yields by any of the supported KCC reagents. Primary allylic alcohols were converted into aldehydes in moderate to good yields. Thus, geraniol yielded 72 % citral. The same product was also formed in moderate yield, 53 %, in an oxidative transposition reaction from the tertiary allylic alcohol, linalool. This result is in agreement with earlier results.[1]

The oxidation of cinnamyl alcohol with KCC on a solid support resulted in the formation of cinnamaldehyde to-

Table 2. Oxidation of saturated primary and secondary alcohols with KCC/Al_2O_3 or KCC/SiO_2.

Entry	Substrate	Support	Time/h	Product	Yield[a] / %
1	1-Hexanol	Al_2O_3	23	Hexanal	62
2	2-Octanol	Al_2O_3	40	2-Octanone	78
3	Menthol	Al_2O_3	73	Menthone	66
4	Borneol	SiO_2	80	Camphor	81
5	*endo*-Norborneol	SiO_2	80	2-Norbornanone	80

[a]Isolated yields after distillation or recrystallization. The yields are not optimized. All reactions were run at room temperature. Generally, 100 % conversion of the substrate was achieved prior to work-up.

Table 3. Oxidation of benzylic alcohols with KCC/Al_2O_3 or KCC/SiO_2.

Entry	Substrate	Support	Time/h	Product	Yield[a]/%
1	Benzyl alcohol	Al_2O_3	6	Benzaldehyde	77
2	4-Methoxybenzyl alcohol	Al_2O_3	3[c]	4-Methoxybenzaldehyde	79
3	4-Methylbenzyl alcohol	SiO_2	17	4-Methylbenzaldehyde	72
4	1-Phenylethanol	SiO_2	3[c]	Acetophenone	74
5	Benzoin	Al_2O_3	3[c]	Benzil	51
6	α-Cyclopropylbenzyl alcohol	Al_2O_3	50	Cyclopropyl phenyl ketone	85[b]
				Di(α-cyclopropylbenzyl) ether	2[b]
				4-Chloro-1-phenyl-1-butene	10
7	α-Cyclopropylbenzyl alcohol	SiO_2	5	Cyclopropyl phenyl ketone	31[b]
				Di(α-cyclopropylbenzyl) ether	39[b]
				4-Chloro-1-phenyl-1-butene	23[b]
				Benzaldehyde	2[b]

[a]Isolated yields after distillation. [b]Yields determined by GLC analysis. [c]Reflux of the reaction mixture.

Table 4. Oxidation of unsaturated alcohols with KCC/Al_2O_3 or KCC/SiO_2.

Entry	Substrate	Support	Time/h	Product[e]	Yield[a]/%
1	Geraniol	Al_2O_3	24	Citral[d]	72
2	Nerol	SiO_2	5[f]	Citral[d]	51
3	Linalool	Al_2O_3	49	Citral[d]	53
4	Verbenol	Al_2O_3	2[f]	Verbenone	76
5	Citronellol	SiO_2	73	Citronellal	50[b]
				Pulegone	50[b]
6	Citronellol	Al_2O_3[c]	19	Citronellal	12[b]
				Pulegone	75[b]
7	Cinnamyl alcohol	SiO_2	10	Cinnamaldehyde	64[b]
				Benzaldehyde	36[b]
8	Cinnamyl alcohol	Al_2O_3	1[f]	Cinnamaldehyde	75[b]
				Benzaldehyde	19[b]
9	3,7,11-Trimethyl-10-dodecen-5-ol	Al_2O_3	18	3,7,11-Trimethyl-10-dodecen-5-one	63
10	*endo*-5-Hydroxydicyclopentadiene	SiO_2	18	Dicyclopentadien-5-one	89

[a]Isolated yields after distillation. Except where otherwise noted, reactions were run at room temperature. [b]Yields were determined by GLC analysis. [c]Substrate to reagent ratio, 1:6. [d]Mixture of *cis–trans* isomers. [e]Products were identical in all respects with authentic samples. [f]The reaction was performed at refluxing temperature.

gether with the bond-cleavage product, benzaldehyde. The mechanism for this transformation has still not been established. Interestingly, the composition of the reaction mixture appeared to depend on the reaction conditions and the type of support material.

Alcohols with remote C–C unsaturation were converted into the corresponding aldehydes or ketones. As observed previously by other workers for the oxidation of citronellol by pyridinium chlorochromate,[11] KCC/alumina yielded citral together with varying amounts of pulegone, entries 5 and 6. The content of this by-product appeared to depend on reaction conditions, such as the KCC/substrate ratio and the type of support material.

Conclusion. KCC/Al_2O_3 and KCC/SiO_2 are useful reagents for the oxidation of secondary alcohols to ketones. They can also be used for the oxidation of primary alcohols, though less conveniently, as aldehydes were obtained in moderate yields only. However, primary benzylic alcohols gave aldehydes in high yields. The reactions were best performed at refluxing solvent temperature.

Experimental

General. ^1H NMR spectra were recorded on a Varian EM-390 or a JEOL FX-100 NMR spectrometer. IR spectra were obtained from a Perkin-Elmer 257 grating spectrometer or a Nicolet SXC-20 FT-IR spectrometer coupled to a Carlo Erba HRGC 5160 capillary gas chromatograph. Mass spectra were recorded on an AEI-MS-902 spectrometer at 70 eV. GLC analyses were performed with a Varian 3700 gas chromatograph, equipped with a BP-1 capillary column (25 m) or a 5 % packed OV-17 column (1.6 m).

Potassium chlorochromate, KCC, was prepared from potassium dichromate and 6 M hydrochloric acid according to the procedure described by Herzog *et al.*[12]

Preparation of potassium chlorochromate on alumina, KCC/Al_2O_3. To a solution containing 11 g of potassium chlorochromate in 200 ml of dry acetone were added 100 g of dried alumina. The resulting mixture was stirred or shaken for approximately 10 min and then the solvent was evaporated under reduced pressure, to leave the desired reagent as a free-flowing yellow or light brown powder which is stable when stored in a closed container. The reagent contains ca. 10 % available KCC. The acetone used for the preparation was dried by passing it through a short column of activated alumina. The alumina used for the reagent was dried prior to use by heating it in an oven at 250 °C for 12 h.

Preparation of potassium chlorochromate on silica gel, KCC/SiO_2. This reagent was prepared as described in the above for KCC/Al_2O_3.

Determination of oxidation capacity. The content of active Cr-species in the reagent was determined by stirring a solution of an excess (10 mmol) of 1-phenylethanol in 15 ml of dichloromethane together with the KCC-reagent (ca. 5 mmol) and an internal standard (*n*-dodecane, 300–400 mg) at room temperature under nitrogen for 24 h. The conversion into acetophenone was determined by GLC. The capacity determined in this way was usually in the range 85–95 % of the stoichiometric value.

Oxidation of alcohols with KCC/Al_2O_3. General procedure. To a slurry containing 20 mmol, (35 g) of 10 % KCC/alumina in dichloromethane (50 ml) was added the alcohol (10 mmol) and the reaction mixture was stirred until all of the alcohol had been consumed. The reaction was monitored by GLC. When the reaction was complete, the mixture was filtered, and the residue was washed with small amounts of dichloromethane or diethyl ether. After evaporation of the solvent, the yield of crude product was usually better than 90 %. The crude product was further subjected to molecular distillation or recrystallization.

Oxidation of alcohols with KCC/SiO_2. The procedure as described for the KCC/Al_2O_3-promoted reaction was applied.

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