Organic Process Research & Development **2001**, *5,* 599–603

Technical Notes

Permanganate: A Green and Versatile Industrial Oxidant

Nirmal Singh and Donald G. Lee*

Carus Chemical Company, LaSalle, Illinois 61354, U.S.A., and Department of Chemistry, University of Regina, Regina, Saskatchewan, Canada S4S 0A2

Abstract:

The use of permanganate as an effective oxidant in organic chemistry has a long and extensive history. Industrial applications have recently become more attractive environmentally by the introduction of a process for recycling manganese dioxide, a coproduct of these reactions. This recycling approach has reduced the environmental impact of permanganate technology and made it sustainable as defined by the Brundtland Commission. Several current and potential industrial applications of permanganate oxidations are discussed along with a description of some emerging technologies.

Introduction

During the synthesis of complex organic compounds, oxidations are among the most important and widely used reactions. As a consequence, a large number of oxidants have been developed by researchers for specific purposes. One of these, permanganate, is a general, versatile, widely used and often cited reagent (Table 1).[1]

Early organic chemists used permanganate as a general oxidant and especially for the oxidation of compounds containing carbon–carbon double bonds. Over a century ago both Kekulé[2] and Wagner[3] described its use for the *cis*-dihydroxylation of compounds such as maleic and fumaric acids. Since then, conditions have been found under which permanganate can be used for a large number of oxidative transformations.[4]

In addition to its importance as a reagent on the researcher's bench, permanganate has been used industrially for the preparation of many organic compounds. Table 2 contains examples of compounds that are produced industrially using this oxidant. The following article describes some of the current uses of permanganate, summarizes recent research results, and presents the new "green" technology currently employed to mitigate adverse environmental impacts.

Table 1. **Frequency of oxidant citations in the recent literature**[a]

oxidant	no. of citations
hydrogen peroxide	1680
periodate	200
permanganate	136
nitric acid	127
hypochlorite	107
manganese dioxide	62
dichromate	62
m-chloroperbenzoic acid	49
chlorochromate	48
nitrous acid	35
NCS	33
NBS	30
chromic acid	24
manganate	21
perruthenate	19
selenium dioxide	17
osmium tetroxide	16
chromyl chloride	9
ruthenium tetroxide	8
ruthenate	6

[a] Obtained from a search of the abstracts contained in *Current Contents* for 1998 and 1999. Citations indicate the frequency that the name of each oxidant was used in conjunction with the word *oxidation*. The oxidants were selected from the list of oxidizing agents compiled by Smith.[1]

"Green" Oxidations

A major manufacturer of permanganate, the Carus Chemical Company, has announced that it is now able to recycle manganese dioxide, a coproduct produced when organic compounds are oxidized by permanganate. To understand how this can be done economically, it is helpful to note that permanganate is produced by the oxidation of manganese dioxide ore in a two-stage process.[5] It is first oxidized to potassium manganate(VI) by oxygen in a concentrated potassium hydroxide solution and then to potassium permanganate electrochemically as summarized in Scheme 1. Using a similar process, manganese dioxide produced from the reduction of permanganate can be converted back into permanganate[6] or used in other applications.[7] Currently, Carus is recycling about 90% (several million pounds annually) of the manganese dioxide produced from organic oxidations with their permanganate. The use of recovered

---

(1) Smith, M. B. *Organic Synthesis*; McGraw-Hill: New York, 1994; p 95.

(2) Kekule, A.; Anschuetz, R. *Ber. Dtsch. Chem. Ges.* **1881**, *14*, 714.

(3) Wagner, G. *J. Russ. Phys. Chem. Soc.* **1895**, *27*, 219.

(4) (a) Stewart, R. In *Oxidation in Organic Chemistry Part A*; Wiberg, K. B., Ed.; Academic Press: New York, 1965; Chapter 1. (b) Arndt, D. *Manganese Compounds as Oxidizing Agents in Organic Chemistry*; Open Court: La Salle, IL, 1981. (c) Lee, D. G. *The Oxidation of Organic Compounds by Permanganate Ion and Hexavalent Chromium*; Open Court: La Salle, IL, 1980. (d) Lee, D. G. *Oxidation*; Augustine, R. L., Ed.; Dekker: New York, 1969; Chapters 1 and 2. (e) Fatiadi, A. J. *Synthesis* **1987**, 85. (f) Lee, D. G. In *Oxidation in Organic Chemistry Part D*; Trahanovsky, W. S., Ed.; Academic Press: New York, 1982; Chapter 2.

(5) Reidies, A. H. In *Ullmann's Encyclopedia of Industrial Chemistry*; VCH: Weinheim, 1990; p 123.

10.1021/op010015x CCC: $20.00

Table 2. **Compounds that are produced industrially using permanganate oxidations**

compound	CAS no.
2-acetamidobenzoic acid	89-52-1
acipimox	51037-30-0
algestone acetophenide	24356-94-3
cetirizine	83881-51-0
chlormezanone	80-77-3
cicloxilic acid	57808-63-6
dinicotinic acid	499-81-0
finasteride	98319-26-7
flumazenil	78755-81-4
isocinchomeronic acid	100-26-5
isonicotinic acid	55-22-1
metolazone	17560-51-9
pyrazinamide	98-96-4
2,3-pyrazinedicarboxylic acid	89-01-0
pyrazinoic acid	98-97-5
2,6-pyridinedicarboxylic acid	499-83-2
sulbactam	69388-84-7
4-sulfobenzoic acid	636-78-2
trimethylpyruvic acid	815-17-8

Scheme 1. **Preparation of permanganate**

$$MnO_2 \xrightarrow[KOH]{O_2} K_2MnO_4 \xrightarrow[\text{(Electrochemical)}]{-e^-} KMnO_4$$

manganese dioxide, as compared to that of ore, also reduces the amount of solid waste produced during the preparation of permanganate by about 20%.

Prior to the decision by Carus to recycle manganese dioxide, the material was a waste product usually disposed of in landfills. However, the new approach is perpetually recyclable, thus promoting the universal benefits of sustainable development as defined by the Brundtland Commission.[8]

In conjunction with the Responsible Care initiative for product stewardship, Carus also offers customers the option of having the oxidation completed at their facilities. Both approaches, the recycling of MnO_2 and on-site oxidation, are currently in use and contributing to the worldwide objective of “greening industry”.[8b]

Collection of manganese dioxide from a manufacturing process may be difficult because, under certain circumstances, it is a gelatinous colloid difficult to filter. However, it has been found that adjustments to the conditions of the reaction can be used to control the physical nature of this product. It is usually possible to find conditions under which manganese dioxide is deposited as an easy-to-filter precipitate. The data in Table 3, for example, indicate the improvement in filtering time that can be achieved by varying a combination of temperature and agitation rate.[9]

Table 3. **Effect of temperature and stirring rates on the physical properties of manganese dioxide obtained from the reduction of permanganate by 2-picoline[9]**

temp (°C)	stirring rate (rpm)	yield (%)	filtration time (min)
70	180	59.5	7.5
70	220	68.0	13.8
90	180	69.7	1.6
90	220	69.7	3.3

Table 4. **Typical reactions of permanganate**

reductant	process	product
$RCH{=}CHR$	*cis*-dihydroxylation	$\overset{OH}{\overset{\vert}{RCH}}-\overset{OH}{\overset{\vert}{CHR}}$
$RCH{=}CHR$	oxidative cleavage	$\overset{O}{\overset{\Vert}{RCH}}$ or $\overset{O}{\overset{\Vert}{RC}}OI$
$RCH{=}CR_2$	ketol formation	$\overset{O}{\overset{\Vert}{RC}}-\overset{OH}{\overset{\vert}{CR_2}}$
$R_2C{=}CR_2$	oxidative cleavage	$R_2C{=}O$
$RC{\equiv}CR$	oxygen transfer	$\overset{O}{\overset{\Vert}{RC}}-\overset{O}{\overset{\Vert}{CR}}$
$\overset{OH}{\overset{\vert}{RCHR}}$	dehydrogenation	$\overset{O}{\overset{\Vert}{RCR}}$
RCH_2OH	dehydrogenation/oxidation	RCO_2H
$\overset{O}{\overset{\Vert}{RCH}}$	oxidation	RCO_2H
$ArCH_3$	oxidation	$ArCO_2H$
$ArCH_2R$	oxidation	$\overset{O}{\overset{\Vert}{ArCR}}$
$ArCHR_2$	oxidation	$\overset{OH}{\overset{\vert}{ArCR_2}}$
RSR	oxygen transfer	$\underset{\underset{O}{\Vert}}{\overset{\overset{O}{\Vert}}{RSR}}$
RSH	oxidative coupling	$RSSR$
$ArSH$	oxidation	$ArSO_3H$
R_2CHNH_2	oxidation	$R_2C{=}O$
$ArNH_2$	oxidative coupling	$ArN{=}NAr$

Selective Oxidations

When permanganate is used for water purification[10] or wastewater treatment,[11] it acts as a general oxidant, attacking all organic material present and often converting it into carbon dioxide and water. However, when it is used as an oxidant in organic synthesis, conditions must be defined under which permanganate can be used selectively for specific purposes. With this goal in mind, researchers have developed a variety of processes, and it is currently possible to carry out many reactions selectively as indicated by the summary in Table 4.

---

(6) To be recycled, the recovered manganese dioxide must meet the following specifications: 30% Mn minimum, 5% Na maximum, 5% TOC maximum, and 50% water maximum. A high concentration of KOH is beneficial to the recycling process. Customers receive credit for manganese dioxide, depending on the quality of the product. Manganese dioxide, shipped in 1000-kg supersacks, is currently being accepted from many counties. Recycling capabilities will soon be available at Carus’ recently acquired plant in Spain.

(7) Manganese dioxide can also be used as a mild oxidant and in catalysts, batteries, or pigments.

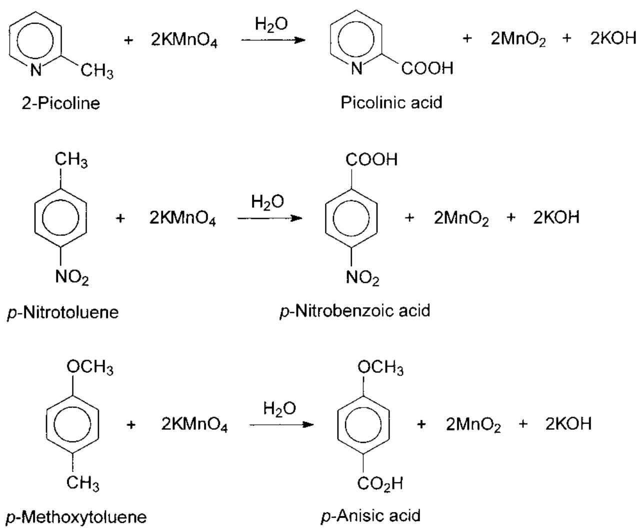
(8) (a) Brundtland, G. H. *Our Common Future*; World Commission on Environment and Development, Oxford University Press: London, 1987. (b) *Greening Industry*; A World Bank Policy Research Report; Oxford University Press: New York, 1999.

(9) DeBlois, R. E. Carus Chemical Company, Poster Presentation, Oxidation Conference, Southhampton, UK, 1999.

(10) Permanganate is used by thousands of municipalities for predisinfection/oxidation/organics removal. The American Water Works Association in Denver, CO, U.S.A., may be contacted for more information.

(11) Pope, R. J.; Weber, R. A. *Water Environment Federation, Operations Forum*; 1994; p 11.

Scheme 2. Typical oxidation reactions in aqueous solutions



Solvent Selection

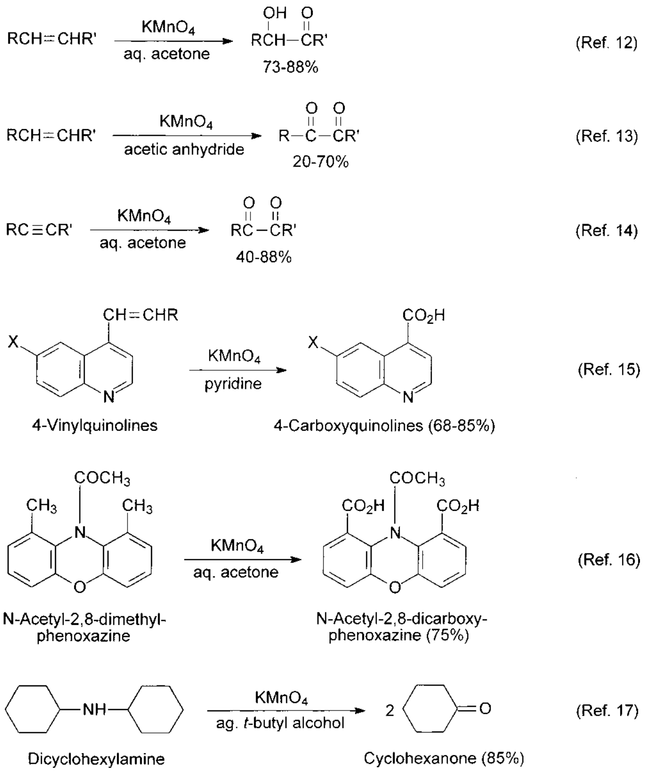
For a selective reaction to occur, it is necessary to find a solvent in which both the oxidant and the reductant are at least partly miscible. Since permanganate is readily soluble in water, aqueous solutions are preferred for industrial applications. LIQUOX, a 40% solution of sodium permanganate, offers many processing advantages over less concentrated potassium permanganate solutions. Because permanganate reactions in aqueous solutions are subject to both acid and base catalysis, it is usually easy to control reaction rates by adjustments of the pH. Examples of typical industrial processes that are carried out in aqueous solvents are summarized in Scheme 2.

Limitations observed when the organic compound is insoluble in aqueous solutions may be overcome by using a polar organic solvent such as acetone, pyridine, or *tert*-butyl alcohol in which both the oxidant and reductant are at least partly soluble. Other polar organic solvents such as ethanol and 2-propanol are less useful because they are capable of reducing permanganate at a rate that may compete with the intended reductant. Scheme 3 contains examples of reactions that have been carried out in polar organic solvents or in aqueous/organic solvent mixtures.

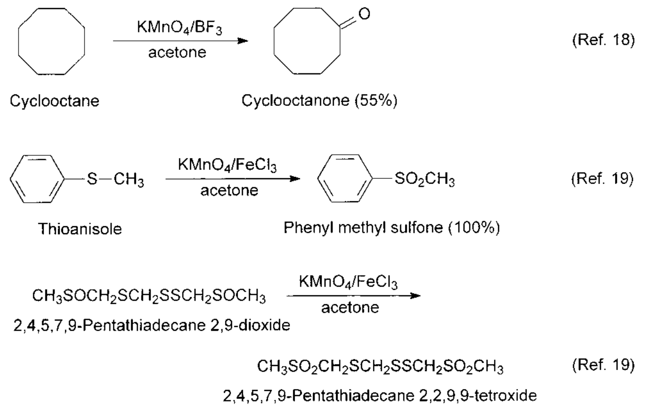
Recently it has been observed that permanganate oxidations in some polar organic solvents are catalyzed by Lewis acids such as ferric chloride, zinc chloride and boron trifluoride. Typical examples of reactions that have been carried out under these conditions are found in Scheme 4. Note that in the third example, the sulfoxide sulfurs are selectively oxidized to the exclusion of the sulfide and disulfide sulfurs.

If it is necessary to use a nonpolar organic solvent such as methylene chloride or toluene, soluble quaternary ammonium permanganates can be prepared by reacting quaternary ammonium halides with potassium permanganate. A large number of these compounds have been prepared, characterized,[20] and used for specific purposes.[21] Despite the apparent attractiveness of these reagents, their use has two limitations: (i) they have, under certain conditions, been known to decompose violently,[22] and (ii) the products from these reactions have to be separated from the quaternary ammonium salts.

Scheme 3. Typical oxidation procedures using polar organic solvents



Scheme 4. Typical Lewis acid-catalyzed permanganate oxidations



---

(12) Srinivasan, N. S.; Lee, D. G. *Synthesis* **1979**, 520.

(13) Jensen, H. P.; Sharpless, K. B *J. Org. Chem.* **1974**, *39*, 2314. Sharpless, K. B.; Lauer, R. F.; Repic, O.; Teranishi, A. Y.; Williams, D. R. *J. Am. Chem. Soc.* **1971**, *93*, 3303.

(14) Srinivasan, N. S.; Lee, D. G. *J. Org. Chem.* **1979**, *44*, 1574.

(15) Shroff, A. P.; Jaleel, H.; Miller, F. M. *J. Pharm. Sci.* **1966**, *55*, 844.

(16) Hazard, R.; Cheymol, J.; Chabrier, P.; Sekera, A.; De Antoni, J. *Comput. Rendu* **1961**, *252*, 4166.

(17) Rawalay, S. S.; Shechter, H. *J. Org. Chem.* **1967**, *32*, 3129.

(18) Lau, T.-C.; Wu, Z.-B.; Bai, Z.-L.; Mak, C.-K. *J. Chem. Soc., Dalton Trans.* **1995**, 695.

(19) Block, E.; DeOrazio, R.; Thiruvazhi, M. *J. Org. Chem.* **1994**, *59*, 2273. Xie, N.; Binsted, R. A.; Block, E.; Chandler, W. D.; Lee, D. G.; Meyer, T. J.; Thiruvazhi, M. *J. Org. Chem.* **2000**, *65*, 1008.

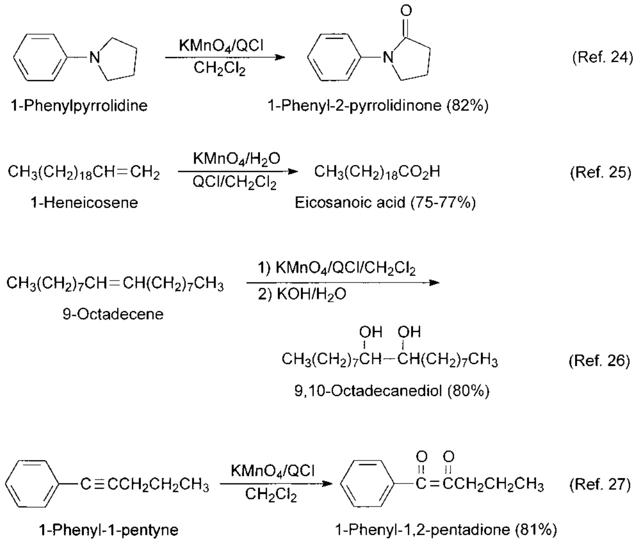
(20) Karaman, H.; Barton, R. J.; Robertson, B. E.; Lee, D. G. *J. Org. Chem.* **1984**, *49*, 4509.

(21) Holba, V.; Kosicka, R.; Lath, D. *J. Chem. Res. (S)* **1998**, 780. Okimoto, T.; Swern, D. *J. Am. Oil Chem. Soc.* **1977**, *54*, 862A. Sangaiah, R.; Krishna Rao, G. S. *Synthesis* **1980**, 1018. Scholz, D. *Monatsh. Chem.* **1979**, *110*, 1471.

Table 5. **Products from typical heterogeneous permanganate oxidations**

reductant	solid support	product	yield (%)	ref
4,4′-dimethoxystilbene	alumina	*p*-anisaldehyde	90−92	37
tetralin	cation exchange resin	tetralone	90	33
diphenylacetylene	copper sulfate	benzil	97	39
phthalan	copper sulfate	phthalide	95	35
cumene	zeolite	2-phenyl-2-propanol	82−84	32
borneol	copper sulfate	camphor	98	40
2,6-dimethyl-2-hydroxy-2-heptene	copper sulfate	2,2-dimethylbutyrolactone	76	41
butanethiol	copper sulfate	dibutyl disulfide	98	42
dibutyl sulfide	copper sulfate	dibutyl sulfone	100	43
cycloheptylamine	copper sulfate	cycloheptanone	95	44
aniline	copper sulfate	azobenzene	100	44

Scheme 5. **Typical phase-transfer assisted permanganate oxidations**



A more useful approach employs quaternary ammonium halides (QX) as phase-transfer catalysts.[4f] If a small amount of QX is dissolved in an organic solvent in contact with $KMnO_4$, a catalytic amount of the quaternary ammonium ion pair ($Q^+MnO_4^-$) will migrate into the organic solvent where it can react with the reductant.[23] Some typical ways in which phase-transfer catalysts have been used to assist permanganate oxidations are summarized by the reactions in Scheme 5. It may be noted that permanganate can be transferred from either a solid or an aqueous phase.[25]

Emerging Technologies

Recent oxidation procedures that are still in the developmental stages involve the use of $KMnO_4$ adsorbed on a solid support as a heterogeneous reagent or under solvent-free conditions. In the first reported example of this technology, aqueous $KMnO_4$ was added to molecular sieves and stirred until homogeneous, and excess water was evaporated. The permanganate-coated molecular sieves were then placed in benzene and used heterogeneously to oxidize organic reductants present in the solvent.[28] When the reaction was complete, the molecular sieves, now coated with manganese dioxide, were separated from the product by a simple filtration procedure. Other solid supports such as alumina,[29,30] silica,[31] zeolites,[32] and cation-exchange resins[33] have also been used effectively as solid supports. Interestingly, a number of hydrated salts of transition metals have also been found to work very well as promoters of heterogeneous permanganate oxidations. Of these, the most effective and most often used is copper sulfate pentahydrate.[34,35] Some typical reactions that have been achieved by the use of permanganate under heterogeneous conditions are summarized in Table 5. It has been observed that the reactivity and selectivity of these reagents can be attenuated by changes to the nature of the solid support. For example, alkenes are not oxidized when a mild, neutral solid support such as copper sulfate is used;[36] however, when acidic alumina is used as the solid support, cleavage of carbon−carbon double bonds occurs readily.[37] In addition, when copper sulfate is modified by introduction of an *omega* phase,[38] ketols and epoxides are produced.[39] The use of copper sulfate also has the advantage that it can be easily recovered from the coproducts by aqueous (5% H_2SO_4) extraction. The manganese dioxide could then be recycled as previously described.

An application that has the potential for becoming an important approach to the control of stereochemistry is the epoxidation of Δ^5 steroids (Scheme 6). Contrary to the products obtained from the use of most other oxidants, the epoxide forms on the *more* hindered side of the molecule.

---

(22) Morris, J. A.; Mills, D. C. *Chem. Ind. (London)* **1978**, 446. Jager, J.; Lutolf, J.; Meyer, M. W. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 786. Schmidt, H. J.; Schafer, H. J. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 787.

(23) Lee, D. G.; Lee, E. J.; Brown, K. C. In *Phase Transfer Catalysis*; Starks, C. M., Ed.; ACS Symposium Series 326; Americal Chemical Society: Washington, 1985; Chapter 8.

(24) Markgraf, J. H.; Stickney, C. A. *J. Heterocycl. Chem.* **2000**, *37*, 109.

(25) Lee, D. G.; Lamb, S. E.; Chang, V. S. *Org. Synth.* **1981**, *60*, 11.

(26) Ogino, T.; Mochizuki, K. *Chem. Lett.* **1979**, 443.

(27) Lee, D. G.; Chang, V. S. *J. Org. Chem.* **1979**, *44*, 2726.

(28) Regen, S. L.; Koteel, C. *J. Am. Chem. Soc.* **1977**, *99*, 3837.

(29) Quici, S.; Regen, S. L. *J. Org. Chem.* **1979**, *44*, 3437.

(30) Zhao, D.; Lee, D. G. *Synthesis* **1994**, 915.

(31) Ferreira, J. T. B.; Cruz, W. O.; Vieira, P. C.; Yonashiro, J. *J. Org. Chem.* **1987**, *52*, 3698.

(32) Streekumar, R.; Padmakumar, R. *Tetrahedron Lett.* **1997**, *38*, 5143.

(33) Joshi, P. L.; Hazra, B. G. *J. Chem. Res. (S)* **2000**, 38.

(34) Menger, F. M.; Lee, C. *J. Org. Chem.* **1979**, *44*, 3446.

(35) Noureldin, N. A.; Zhao, D.; Lee, D. G. *J. Org. Chem.* **1997**, *62*, 8767.

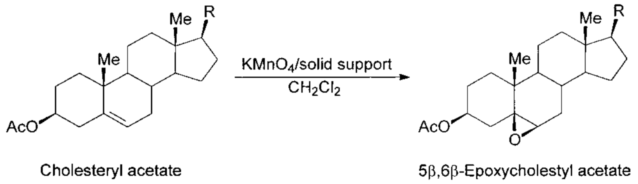
(36) Lee, D. G.; Noureldin, N. A. *J. Am. Chem. Soc.* **1983**, *105*, 3188.

(37) Lee, D. G.; Chen, T.; Wang, Z. *J. Org. Chem.* **1993**, *58*, 2918.

(38) The omega phase is formed by addition of small amounts of water and *tert*-butyl alcohol to the solid support. The properties of the solid support are thereby modified, possibly through formation of a thin coat on its surface.

(39) Baskaran, S.; Das, J.; Chandrasekaran, S. *J. Org. Chem.* **1989**, *54*, 5182.

Scheme 6. **Epoxidation of Δ5 steroids**



This provides a direct one-step route to compounds that can normally be obtained only by more involved procedures.[45]

An approach that is in the initial stages of development, but which has potential for industrial use, is the oxidation of organic compounds under solvent-free conditions. To achieve good results using this procedure, the oxidant must first be prepared by mixing potassium permanganate with copper sulfate pentahydrate and alumina. To this solid is added neat reductant, drop by drop, with stirring. The reaction is usually rapid, and the yields are nearly quantitative. When the reaction is complete, as indicated by the use of thin-layer chromatography, the product is extracted from the reduced oxidant by washing with an appropriate solvent such as methylene chloride or hexane.[46]

Table 6. **Typical solvent free permanganate oxidations**

reductant	product	yield (%)
benzyl phenyl sulfide	benzyl phenyl sulfone	85
methoxymethyl phenyl sulfide	methoxymethyl phenyl sulfone	90
dibutyl sulfide	dibutyl sulfone	90
ethyl benzene	acetophenone	95
indan	indanone	90
isochroman	1-isochromanone	95
2-ethylthiophene	2-acetylthiophene	90
4-heptanol	4-heptanone	90
benzyl alcohol	benzaldehyde	90
1-heptanol	heptanal	85
tetrahydrofuran	γ-butyrolactone	70

Several examples of reactions that have been completed using this procedure are summarized in Table 6.

Conclusions

As a result of its proven effectiveness as an oxidant in organic chemistry for over a century, permanganate continues to be used in new, advanced processes. Industrial applications that consume thousands of tons of potassium permanganate annually are now being carried out without adverse environmental impact. The use of recycling technology has made these processes environmentally friendly and sustainable. Existing and emerging technologies associated with the use of this reagent indicate that it will likely continue to be an important industrial oxidant for many more years to come.

Received for review February 13, 2001.

OP010015X

---

(40) Noureldin, N. A.; Lee, D. G. *J. Org. Chem.* **1982**, *47*, 2790.

(41) Baskaran, S.; Islam, I.; Vankar, P. S.; Chandrasekaran, S. *J. Chem. Soc., Chem. Commun.* **1990**, 1670.

(42) Noureldin, N. A.; Caldwell, M.; Hendry, J.; Lee, D. G. *Synthesis* **1998**, 1587.

(43) Noureldin, N. A.; McConnell, W. B.; Lee, D. G. *Can. J. Chem.* **1984**, *62*, 2113.

(44) Noureldin, N. A.; Bellegarde, J. W. *Synthesis* **1999**, 939.

(45) (a) Parish, E. J.; Li, S. *J. Chem. Res. (S)* **1996**, 288. (b) Salvador, J. A. R.; Sae Melo, M. L.; Campos Neves, A. S. *Tetrahedron Lett.* **1996**, *37*, 687. (c) Parish, E. J.; Li, H.; Li, S. *Synth. Commun.* **1995**, *25*, 927. (d) Hanson, J. R.; Hitchcock, P. B.; Liman, M. D.; Nagaratnam, S.; Manickavasager, R. *J. Chem. Res. (S)* **1995**, 220. (e) Syamala, M. S.; Das, J.; Baskaran, S.; Chandrasekaran, S. *J. Org. Chem.* **1992**, *57*, 1928.

(46) Shaabani, A.; Lee, D. G. *Tetrahedron Lett.* **2001**, *42*, 5833.