Recent trends in the chemistry of pyridine N-oxides

Shaker Youssif

Department of Chemistry, Faculty of Science, Zagazig University, Zagazig, Egypt
(received 16 Mar 01; accepted 10 Dec 01; published on the web 18 Dec 01)

Abstract
This review describes the synthesis and reactions of pyridine N-oxides within the last ten years. The first part surveys the different synthetic methods which include ring transformation, classical oxidations using peracids, the use of metalloorganic oxidizing agents and cycloaddition reactions. The second part surveys the reactions of pyridine N-oxides including the deoxygenation, nucleophilic reaction and cycloaddition to N-O bond.

Keywords: Synthesis of pyridine N-oxides, reactions of pyridine N-oxides, cycloaddition reactions, metalloorganic oxidizing agents

Introduction
Spectroscopic properties
1 Synthesis of pyridine N-oxides
1.1 From the esters of N-hydroxy-2-thiopyridone
1.2 By ring transformation of isooxazoles.
1.3. By the oxidation of pyridine derivatives
   1.3.1 Using H2O2/ AcOH
   1.3.2 Using H2O2/ manganese tetrakis(2,6-dichlorophenyl)porphyrin
   1.3.3 Using H2O2/ methyltrioxorhenium (MTO)
   1.3.4 Using dimethyldioxirane (DMD)
   1.3.5 Using bis(trimethylsilyl)peroxide (BTSP)
   1.3.6 Using Caro’s acid
   1.3.7 Using m-chloroperoxybenzoic acid
   1.3.8 Using oxaziridines
1.4 Through cycloaddition reaction

2 Reactions of pyridine N-oxides
2.1 Deoxygenation
2.2 Rearrangement of allyloxypyridine N-oxide
2.3 Nucleophilic reactions
2.4 Metallation followed by electrophilic substitution
2.5 O- Alkylation.  
2.6 Nucleophilic substitution of 3-bromo-4-nitropyridine N-oxide.  
2.7 Cycloaddition to dipolar N-O  
3 Conclusion  

**Introduction**

The chemistry and applications of N-oxides have recently received much attention due to their usefulness as synthetic intermediates and their biological importance. Heterocyclic N-oxides are also useful as protecting groups, auxiliary agents, oxidants, ligands in metal complexes and catalysts.

The N-O moiety of pyridine N-oxides possesses a unique functionality which can act effectively as a push electron donor and as a pull electron acceptor group. This strong push-pull property has an essential chemical consequence; it accounts for the equally easy synthesis of 4-substituted derivatives of pyridine N-oxides with donor as well as acceptor groups. The contribution of the resonance forms I and II depends on the nature of the substituent at position 4. The strong electron-acceptor nitro group favors the charge transfer form II.

![Resonance structures of pyridine N-oxide]

**Spectroscopic properties**

For the single pyridine ring hydrogen atom of an isolated molecule three different vibrations are expected, e.g. =C-H stretch, in plane bend and out of plane deformation. The crystal data have shown that there are two different types of =C-H bonds in crystal. The =C-H stretch band is split into two components in the Raman spectrum, at 3066 and 3054 cm\(^{-1}\), while IR spectrum shows just one band at 3052 cm\(^{-1}\). The strongest band in the IR spectrum is observed at 1231 cm\(^{-1}\) together with adjacent absorptions at 1238 and 1250 cm\(^{-1}\); and the Raman band at 1252 cm\(^{-1}\) these are assigned to the N-O stretch, because this vibration is accompanied by a large change in dipole moment and polarizability. The blue shifted very strong IR band at 1258 cm\(^{-1}\) supports both the assignment to \(\nu(N-O)\) and existence of CH…O-N hydrogen bonding.
**UV spectra**
The electronic structures and spectra of heterocyclic amine N-oxides have been extensively studied by many researchers. In the case of pyridine N-oxide, the strong $\pi-\pi^*$ band was observed near 280 nm, in aprotic solvents. On going from pyridine N-oxide to 2,6-dimethylpyridine N-oxide this band shows a blue shift to 274 nm. The study of 3-halo-2,6-dimethylpyridine N-oxides has shown that apart from the strong 272-278 nm band, two or three more bands are observed in the regions 220-240 and 310-330 nm. The third, weak band is observed at 363.3 nm. It might originate from the n-$\pi^*$ transition, i.e. excitation from HOMO to either the LUMO or higher MO. This band is observed at a significantly higher energy (363.3 nm) for 4-chloro-2,6-dimethyl-3-iodopyridine N-oxide than for 3-iodo-2,6-dimethyl-pyridine N-oxide (329 nm).9-11

1 Synthesis of pyridine N-oxides
   1.1 From the esters of N-hydroxy-2-thiopyridone

The reaction of diethyl azodicarboxylate (DAD) with a series of the esters of N-hydroxy-2-thiopyridone of general formula 1 afforded compounds (2a-e). The irradiation of compounds 2 in acetonitrile with a medium pressure mercury lamp at room temperature for 1-4 h led to the formation of the corresponding dimers 3 as well as the expected disulfides 4 as shown in (Scheme 1).12
5-Cyanomethyl-2-isoxazolines (5) were reported to react with catalytic amount of base, such as 1,5-diazabicyclo[5.4.0]undec-5-ene (DBU) in boiling xylene to form 6-substituted-2-aminopyridine N-oxides (6). The transformation should proceed through the cyclization of the reactive Z-vinylene-hydroxylamine spontaneously to give the final product 6.
R = -Me, -C₆H₅, -CH=CHC₆H₅

1.3 By the oxidation of pyridine derivatives

1.3.1 Using H₂O₂/ AcOH

Picolinic acid (7) was converted into 4-nitropicolinic acid N-oxide (8), which on treatment with hydrogen chloride in methanol afforded 4-chloropicolinic acid N-oxide (9)\(^{14}\).

(a) KOH. (b) H₂O₂/ AcOH. (c) HNO₃/H₂SO₄. (d) HCl.

On the other hand, the isonicotinanilide N-oxide (12) have been prepared from isonicotinic acid (10) via the anilide (11).\(^{15}\)
Oxidation of 2,6-diamino-3,5-dinitropyridine (13) with 30% aqueous hydrogen peroxide in acetic acid under reflux afforded 2,6-diamino-3,5-dinitropyridine N-oxide (14) in 80% yield.\textsuperscript{16,17}

1.3.2 Using H\textsubscript{2}O\textsubscript{2}/ manganese tetrakis(2,6-dichlorophenyl)porphyrin [Mn(TDCPP)Cl]

A variety of pyridine derivatives 15\textsubscript{a-d} were converted into their corresponding N-oxides 16\textsubscript{a-d} in good yields and high chemoselectivity in the presence of hydrogen peroxide as oxygen donor, catalytic amount of manganese tetrakis(2,6-dichlorophenyl) porphyrin [Mn(TDCPP)Cl] and ammonium acetate as cocatalyst in CH\textsubscript{2}Cl\textsubscript{2} / CH\textsubscript{3}CN.\textsuperscript{18} The pyridines bearing an alkyl substituents shows almost complete conversion to N-oxides rather than pyridines bearing chlorine substituent.
1.3.3 Using H$_2$O$_2$/ methyltrioxorhenium (MTO)

Pyridines 17a-c are oxidized in high yields to their N-oxides 18a-c by using 30% aqueous H$_2$O$_2$ in the presence of catalytic amounts of methyltrioxorhenium (MTO). It was noted that, 3- and 4-substituted pyridines, regardless of their electronic nature, gave high yields of the corresponding N-oxides on using only 0.2-0.5 mol% of MTO.

On the other hand, the most simple 2-substituted pyridines require high catalyst loading, typically 5 mol% to reach both full conversion and high yields. 19-28

1.3.4 Using dimethyldioxirane (DMD)

Addition of excess of dimethyldioxirane (DMD), to a solution of pyridines 15a and/or 19a-d in CH$_2$Cl$_2$ at 0°C led to rapid and quantitative conversion to the corresponding N-oxides 16a and 20a-d. 23-35

(a) $X = \text{CN (2-, 3-, 4-)}$. (b) $X = \text{CH}_3\text{CO (3-, 4-)}$. (c) $X = \text{F (2-)}$

15a, 16a) $R^1 = R^2 = R^3 = R^4 = \text{H}$
19a, 20a) $R^1 = R^4 = \text{H}, R^2 = R^3 = \text{CH}_3$
19b, 20b) $R^2 = R^3 = \text{H}, R^1 = R^4 = \text{CH}_3$
19c, 20c) $R^2 = \text{H}, R^1 = R^3 = R^4 = \text{CH}_3$
19d, 20d) $R^1 = R^2 = R^4 = \text{H}, R^3 = \text{4-}(\text{3-cyclohexenyl})$
1.3.5 Using bis(trimethylsilyl)peroxide (BTSP)

It was found that methyltrioxorhenium MTO can be replaced in the epoxidation process by cheaper and more readily available inorganic rhenium derivatives. Aqueous H₂O₂ is also replaced by bis(trimethylsilyl)peroxide (BTSP)³⁶. For example, when a mixture of methyl isonicotinate (21) and perrhenic acid in CH₂Cl₂ was treated with BTSP and stirred for 6h at 24°C afforded N-oxide 22.

1.3.6 Using Caro’s acid

The synthesis of aminopyridine N-oxides involved acylation of the amino group, oxidation of the ring nitrogen and deprotection has been reported¹. The use of Caro’s acid (peroxomonosulfuric acid, H₂SO₅) allows two useful variations: a) The reaction can be carried out over a wide pH range and b) The reaction can be carried out in water. It has been shown that, the reactions take place under neutral or basic conditions. When aminopyridines 23 were dissolved in KOH and Caro’s acid was added slowly at room temperature with stirring the corresponding N-oxides 24 were isolated.³⁷a

\[
\begin{align*}
\text{R}^1 & \quad \text{R}^2 & \quad \text{R}^3 & \quad \text{R}^4 & \quad \text{R}^5 \\
\text{NH}_2 & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} \\
\text{NH}_2 & \quad \text{H} & \quad \text{Me} & \quad \text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} & \quad \text{NMe}_2 & \quad \text{H} & \quad \text{H}
\end{align*}
\]
1.3.7 Using m-chloroperoxybenzoic acid (MCPBA)

Treatment of 3-trichloromethylpyridine (25) with m-chloroperoxybenzoic acid (m-CPBA) in dry chloroform gave 3-trichloromethyl-pyridine N-oxide (26).\(^{37b}\)

\[
\begin{align*}
\text{25} & \quad \text{26} \\
\end{align*}
\]

The oxidation of heterocyclic compounds by m-CPBA/HCl/DMF system has been reported.\(^{38-42}\) For example the N-oxidation of some pyridines with m-CPBA in DMF/MeOH in the presence of HF afforded their N-oxides in excellent yields\(^{43}\). The N-oxidation of 3,5-lutidine (27) and nicotinic acid (28) gave their N-oxides 29 and 30, respectively in excellent yields.

\[
\begin{align*}
\text{27} & \quad \text{29} \\
\text{28} & \quad \text{30} \\
\end{align*}
\]

The oxidation of 3-substituted pyridines (31) to their corresponding pyridine N-oxides 32 using (m-CPBA) gave the highest yield when compared to other oxidizing agents such as 30% H\(_2\)O\(_2\) in glacial acetic acid, sodium perborate monohydrate, potassium peroxymonosulfate and magnesium monoperoxy-phthalate.\(^{44-46}\)
1.3.8 Using oxaziridines

Perfluoro-(cis-2,3-dialklyloxaziridine) (33) proved to be versatile oxidizing agents, being powerful enough to give a clean oxyfunctionalization. So, the oxygenation of the heteroatom site of substrates **15a, 34b-c** to give N-oxides (**16a, 35b-c**) has been observed for all tested substrates and in some cases amination of the same site also occurred to give variable amounts of N-aminides (**36a-c**).

The formation of N-aminides (**36**) have been performed according to the following mechanism:
1.4 Through cycloaddition reactions

4-Nitroisoxazoles (37) substituted at position 5 easily undergo [2,4] cycloaddition reaction, leading to polynuclear heterocyclic systems. When compounds (37) were allowed to react with an equimolecular amount of 4-(1-cyclopenten-1-yl)morpholine (38) in alcohol at room temperature, the bicyclic pyridine N-oxide (39) were obtained in moderate yield.
The formation of (39) has been performed according to the following mechanism:
2 Reactions of pyridine N-oxides

2.1 Deoxygenation

The deoxygenation of aromatic N-oxides, which are important in the syntheses of nitrogenous aromatic heterocycles have been reported.52-60 The reaction of 2,6-dimethylpyridine N-oxide hydrochloride (40) with phosphorus oxychloride in the presence of potassium carbonate led to the formation a mixture of 41 and 42. Treatment of the mixture with triethylamine converted the more reactive 41 to quaternary salt 43 which upon treatment with water gave 42 in (61%) yield.61

\[
\begin{align*}
\text{H}_3\text{C} & \quad \text{N}^+ & \quad \text{CH}_3\text{Cl} \\
\text{N}^- & \quad \text{CH}_3\text{HCl} & \quad \text{H}_3\text{C} & \quad \text{N}^- & \quad \text{CH}_3\text{Cl} \\
\text{O}^- & \quad 1) \text{POCl}_3 & \quad \text{41} & \quad \text{42} \\
\text{2) K}_2\text{CO}_3 & \quad \text{43} \\
\text{H}_3\text{C} & \quad \text{N}^+ & \quad \text{CH}_2\text{N}\text{C}_2\text{H}_5\text{Cl} \\
\text{43} & \quad \text{CH}_2\text{N}\text{C}_2\text{H}_5\text{Cl} & \quad \text{H}_3\text{C} & \quad \text{N}^+ & \quad \text{CH}_2\text{N}\text{C}_2\text{H}_5\text{Cl} \\
\text{43} & \quad \text{43} & \quad \text{43} & \quad \text{43} & \quad \text{43} \\
\text{43} & \quad \text{43} & \quad \text{43} & \quad \text{43} & \quad \text{43} \\
\end{align*}
\]

The addition of trifluoroacetic acid anhydride to a suspension solution of 4-cyanopyridine N-oxide (44) and NaI in CH\text{3}CN afforded the formation of 4-cyanopyridine (45).62-63

\[
\begin{align*}
\text{CN} & \quad \text{CF}_3\text{CO}_2\text{O} & \quad \text{CH}_3\text{CN} \\
\text{44} & \quad \text{44} & \quad \text{44} \\
\text{CN} & \quad \text{CF}_3\text{CO}_2\text{O} & \quad \text{CH}_3\text{CN} \\
\text{44} & \quad \text{44} & \quad \text{44} \\
\text{CN} & \quad \text{CF}_3\text{CO}_2\text{O} & \quad \text{CH}_3\text{CN} \\
\text{44} & \quad \text{44} & \quad \text{44} \\
\text{CN} & \quad \text{CF}_3\text{CO}_2\text{O} & \quad \text{CH}_3\text{CN} \\
\text{44} & \quad \text{44} & \quad \text{44} \\
\end{align*}
\]

It was found that aluminum iodide can be used as an economic and convenient reagent for the reductive cleavage of N-O bond in heterocycles. The reaction of aluminum iodide with pyridine N-oxides 16a and 46 afforded products 15a and 47, respectively in high yields.64-65
In some cases the resulting N-oxide efficiently decomposes the dioxirane with liberation of oxygen gas and regeneration of heteroarene. The deoxygenation of N-oxides by dioxirane proceeds by an $S_N^2$ attack of the nucleophilic N-oxide oxygen atom on the dioxirane peroxide bond as shown below. 4-N,N-Dimethylaminopyridine N-oxide (24c) was partially deoxygenated by dimethyldioxirane (DMD) to the corresponding amine (23c).\(^{29}\)

The best results were reported for the deoxygenation of pyridine N-oxides, when the reaction of compound 48 was carried out using zinc (4.5 eq.)\(^{66}\) gave 49.

The reduction products of p-nitropyridine N-oxide (50) depends on the concentration of reducing agent. Thus, the reduction of 50 with 3 molar equivalents of TiCl$_4$/SnCl$_2$ affords the azocompound (51) in almost quantitative yield. When 2 molar equivalents of the reagent were used, the reaction afforded 4,4’-azopyridine 1,1’-dioxide (52) as the exclusive product. The increasing of SnCl$_2$ amount in the reagent (TiCl$_4$/SnCl$_2$ ratio = 1:2, reagent : N-oxide ratio = 3:1) results in the formation of 4-pyridinamine (53) in high yield.\(^{67-69}\)
2.2 Rearrangement of allyloxypyridine N-oxide

Thermal rearrangement of 2-allyloxypyridine N-oxide (54) yields N-allyloxy-2-pyridones (55) and 3-allyl-N-hydroxy-2-pyridones (56). These transformations are shown to be regiospecific and the reactions involve concerted [1,4] and [3,3] sigmatropic rearrangements.

2.3 Nucleophilic reactions

The reaction of 2-amino-3-ethoxycarbonyl-5-(4-pyridyl)pyridine N-oxide (57) with ethylmalonylchloride (58) in methylene chloride at room temperature affords the corresponding 2-ethoxycarbonyl-acetamidopyridine N-oxide (59) and the oxadiazole derivative (60).
3,5-Difluoropyridine (61) was converted into its N-oxide 62 in order to activate the system to electrophilic attack. Nitration of 62 gave the 4-nitro derivative 63 as the major isomer, together with the 2-nitro isomer 64. Treatment of 63 and 64 with ammonia gave the amino derivatives 65, 66 and 67. Thus, the synthetic value of this reaction was demonstrated when the reaction was carried out with 3,5-dichloropyridine (68), which upon nitration gave the nitro compound 69. Treatment of 69 with ammonia resulted in the formation amino derivative 70 as shown in Scheme 2.

(i) $\text{H}_2\text{O}_2$ / AcOH. (ii) Fuming $\text{H}_2\text{SO}_4$. HNO$_3$. (iii) $\text{NH}_3$ / CH$_3$CN.

Scheme 2
Displacement of chlorine in 4-chloropyridine N-oxide (71) to give the quaternary salt (72), could be achieved upon treatment with pyridine (15a) in tetracyanoethylene (TCNE). 75

\[
\begin{align*}
\text{Cl} & \quad + \quad \text{TCNE} \\
71 & \quad \rightarrow & \quad 72
\end{align*}
\]

The reaction of 3-trichloromethylpyridine N-oxide (26) with 1.5 eq of sodium methoxide in tetrahydrofuran (THF) afforded a mixture of 73a and 73b. When 4.5 eq of sodium methoxide was reacted with 31, a mixture of 73a, 73b and 73c was obtained. Similarly, the reaction with methyl thioglycolate or 2-mercaptoethanol in triethylamine at room temperature afforded 73d and 73e. 37b

\[
\begin{align*}
73a & \quad R^1 = -\text{OMe}, \quad R^2 = -\text{CH(OMe)}_2 \\
73b & \quad R^1 = -\text{OMe}, \quad R^2 = -\text{CHCl}_2 \\
73c & \quad R^1 = -\text{OMe}, \quad R^2 = -\text{C(OMe)}_3 \\
73d & \quad R^1 = -\text{SCH}_2\text{COOMe}, \quad R^2 = -\text{CHCl}_2 \\
73e & \quad R^1 = -\text{SCH}_2\text{CH}_2\text{OH}, \quad R^2 = \text{CHCl}_2
\end{align*}
\]

2.4 Metallation followed by electrophilic substitution

Lithiation of 2-N,N-diisopropylcarboxamidopyridine N-oxide (74a) and 2-pivaloylaminoipyridine N-oxides (74b) and (74c) with lithium diisopropylamide (LDA) in tetrahydrofuran (THF) at -75°C resulted in the formation of 75. Carboxamides and pivaloylamino groups are known to be ortho-directing groups under other conditions. 76-77 Reaction of various electrophiles namely, benzaldehyde, iodine, carbon dioxide and deuterated ethanol with the intermediate lithio species provided the corresponding compounds 75.
It has been reported that the reaction of butyl lithium with 3,4-dimethoxypyridine N-oxide (76) undergoes a regioselective metallation at C-2. Compound 76 was lithiated with 2.2 eq of butyl lithium in THF at 0°C for 45 min. to give an intermediate lithio species which on reaction with various electrophiles afforded the corresponding 2-,6- or 2,6-functionalized products 77, 78, and 79 respectively.78

When compound 14 was treated with hydroxylamine hydrochloride in aqueous KOH, it afforded compound (80) in 39% yield.16 The process of amination took place by indirect nucleophilic substitution, since the amino group was introduced from hydroxylamine or 4-amino-1,2,4-triazole.79 Nitration of 3,5-dimethoxypyridine N-oxide (81) gave 3,5-dimethoxy-2,6-dinitropyridine N-oxide (82). Aminolysis of 82 gave 84, rather than the expected 3,5-diamino-2,6-dinitropyridine N-oxide (83).
2-Nitroaminopyridine N-oxides (85) were converted to 2-amino-5-nitro-pyridine N-oxides (86) in the presence of sulfuric acid at 80°C.

R = H, 3-Me, 4-Me, 6-Me

2.5 O- Alkylation

The alkylation of pyridine N-oxides 87 with alkyl halides 88 in acetonitrile at 25°C afforded the N-alkyloxypyrindinium halides 89. 81-82
\[ R^1 = \text{Me, MeO, Me}_2\text{N}; R^2 = \text{H, Me, Ph, PhCO}; X = \text{I, Br} \]

### 2.6 Nucleophilic substitution of 3-bromo-4-nitropyridine N-oxide

Heating of 3-bromo-4-nitropyridine N-oxide (90) with potassium salt of 3-hydroxypyridines (91) in anhydrous DMF at room temperature, afforded 4-nitro-3,3'-oxybispyridine N-oxide (92). Repeating the above experiment in methanol gave 3-bromo-4-methoxypyridine N-oxide (93).\(^{83}\)

\[ R = \text{Me, CH}_2\text{Ph, CH}_2\text{Ph-4-CF}_3 \]

When 3-iodo-2,6-dimethyl-4-nitropyridine N-oxide (94) was treated with acetyl chloride at 50\(^{\circ}\)C for 30 min. afforded 4-chloro-3-iodo-2,6-dimethylpyridine N-oxide (95)\(^{84-85}\) in 89% yield.
2.7 Cycloaddition to dipolar N-O

The cycloaddition of pyridine N-oxides $^{96a,b}$ to nitrilium salts $^{97a,b}$ in methylene chloride at 0-23°C for 20-45min. afforded the salts $^{99a-d}$ in good yield through a reactive intermediate $^{98}$ (through 1,5-sigmatropic rearrangement).

The strained 3,3,6,6-tetramethyl-1-thia-4-cycloheptyne (100) reacts at room temperature with pyridine N-oxide (16a) to yield the unstable intermediate 101 which rearranged to the spiro 3H-azepine derivative 103 in 54% yield via the azanorcaradiene (102).
Treatment of pyridine N-oxides 16a and 50 with 2-chloroalkyl- trichlorophosphonium hexachlorophosphorates (104) yields pyridines 15a, 105 and 2-chloroalkylphosphonic dichlorides (106).\textsuperscript{88}

\[
\begin{align*}
X &= H, NO_2; \quad R = C_6H_5, OC_2H_5 \\
R &= OC_4H_9
\end{align*}
\]

The reaction of tetracyanoethylene (107) with pyridine (15a) even in anhydrous solvents resulted in the formation of pyridinium pentacyano-propenoide (108).\textsuperscript{89}
Based on the above finding, it was expected that the reaction of pyridine N-oxides with tetracyanoethylene in dry benzene corresponds to salts derived from N-oxides and pentacyanopropene.

When pyridine N-oxides (109) was allowed to react with tetracyano-ethylene (107) in dry benzene, a solid begins to precipitate in 1-20 min, and the reaction is completed in 1-2 h afforded the ion charge transfer compound (110). It was found that the best results were obtained when the reaction was carried out in an ether-ethanol mixture.\(^9^0\)

\[
\begin{align*}
\text{NR}_2^+ & \quad \text{N}^\text{O}_- \\
& \quad \text{NC} \quad \text{CN} \\
\text{R} = 4-\text{CH}_2\text{Ph}, 4-\text{CH}_3 \\
\end{align*}
\]

The dissolution of the solid products in dioxane, methylene chloride, chloroform, or acetonitrile resulted in the formation of yellow solutions with absorption maxima at 400 and 420 nm. This was attributed to the formation of the charge-transfer band.\(^9^1-9^2\)

**Conclusions**

Hydrogen peroxide and acetic acid have been used previously for the oxidation of pyridines. This review summarizes the unusual oxidizing agents in quantitative conversion and high chemoselectivity. These reagents (e.g. dimethyldioxirane, oxaziridines) act as oxygen source for the oxidation of pyridine. Also, the use of pyridine N-oxides for the formation of ion charge transfer compounds which is very important in most of the chemical reaction and cycloaddition
of N-O bond with nitrilium salts was studied.

References