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# Unprecedented Pyridine Ring C - C Bond Cleavages by Formic Acid#.

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**Abstract:** Formic acid at 350°C converts pyridine and 4-methylpyridine into products deriving from both αβ and βγ C-C bond cleavages of the pyridine ring.

Heterocyclic aromatics, including many pyridine derivatives, are minor but important components of coals, and major components of oil shales and liquids derived from these resources. Nitrogen-containing compounds in resource streams are detrimental for at least three major reasons: (i) they poison and deactivate catalysts used in further refining;[1] (ii) they form toxic nitrogen oxides upon combustion and (iii) they confer instability on the product fuel, causing discoloration and other detrimental reactions.[2-4] In addition, the denitrogenation of pyridine rings requires complete hydrogenation of the ring, which consumes excessive hydrogen, before denitrogenation can take place. The development of improved methods for nitrogen removal are needed, particularly from oil shale and heavy coal liquids.

Approaches which involve pyrolysis are not promising because aromatic C-N bonds are not broken preferentially as compared to C-C bonds, and pyrolysis of heavier feedstocks leads to excessive coking. The present studies originated from the belief that the hydrolytic cleavage of C-N bonds in pyrrole and pyridine ring systems has reasonable potential for success, especially at moderate temperatures (350°C) and high pressures (~3000 psi) in the presence of dilute acids.

Recently, our two research groups[5,6] have worked extensively in aqueous organic chemistry, including examining nitrogen removal from representative heterocyclic nitrogen model compounds. We found[5] that pyridine is unchanged over 3 days at 350°C in water alone and in the presence of montronite clay or aluminum-pillared clay and is little changed in aqueous 10% formic acid or 10% sulfuric acid. In the presence of calcium montmorillonite, it is 5% converted to give 2,2'-bipyridyl, 2,4'-bipyridyl, and other minor products in which the nitrogen ring is intact. Treatment with phosphoric acid gives almost 10% conversion, but the yield of denitrogenated (DN) products (toluene, ethylbenzene, and 3-ethyltoluene, etc.) remains low (1.7%). We now report studies of the treatment of pyridine and 4-methylpyridine with aqueous formic acid at 350°C which have led to surprising results.

Starting materials, used as obtained from commercial sources, were shown by GC to be of suitable purity (>99.5%). The reactions were conducted and the products analyzed by GC and identified by MS as previously described.[7] GC retention times and MS fragmentation patterns were also compared with authentic samples of alkyl piperidines. Details will be given in our full publication. The results are collected in the Table.

# Aqueous Organic Chemistry: Part 7. For Part 6 see M. Siskin, G. Brons, S.N. Vaughn, A.R. Katritzky, M. Balasubramanian, and J.V. Greenhill, Energy & Fuels, 1993 (in preparation).

Pyridine (1) on heating with aqueous 49% formic acid at 350°C, for 2 h underwent 16% conversion into 1-methyl- (2) (0.9%), 1-ethyl- (5) (2.3%), 1-propyl- (8) (3.6%), 1-pentyl- (10) (1.2%) and 1-formyl-piperidine (11) (8%). On heating in 100% $H^{13}CO_2H$ at 350°C for 2 h, pyridine showed 31.5% conversion to the same slate of products. Significantly, only the 1-methylpiperidine (3) (1.9%) and the 1-formylpiperidine (12) (19.2%) were labelled, and each contained just one $^{13}C$ label. The fact that the 1-ethyl- (5, 1.5%), 1-propyl- (8, 2.1%), and 1-pentyl-piperidine (10, 6.7%) produced simultaneously had no $^{13}C$ labeled carbons shows conclusively that the ethyl, propyl, and pentyl groups in 5, 8 and 10 are derived from pyridine and not from formic acid.

4-Methylpyridine (6) showed 59.6% conversion on heating in 49% formic acid at 350°C for 2 h into 1,4-dimethylpiperidine (4) (14.9%), 1-formyl-4-methylpiperidine (13) (36.5%), 4-methyl-1-(3-methylpentyl)piperidine (14) (5.1%), and a lesser amount of 1-ethyl-4-methylpiperidine (7). By analogy the ethyl, propyl and 3-methylpentyl groups required for the N-alkylation of 4-methylpiperidine were derived by fragmentation of 4-methylpyridine molecules (Scheme).

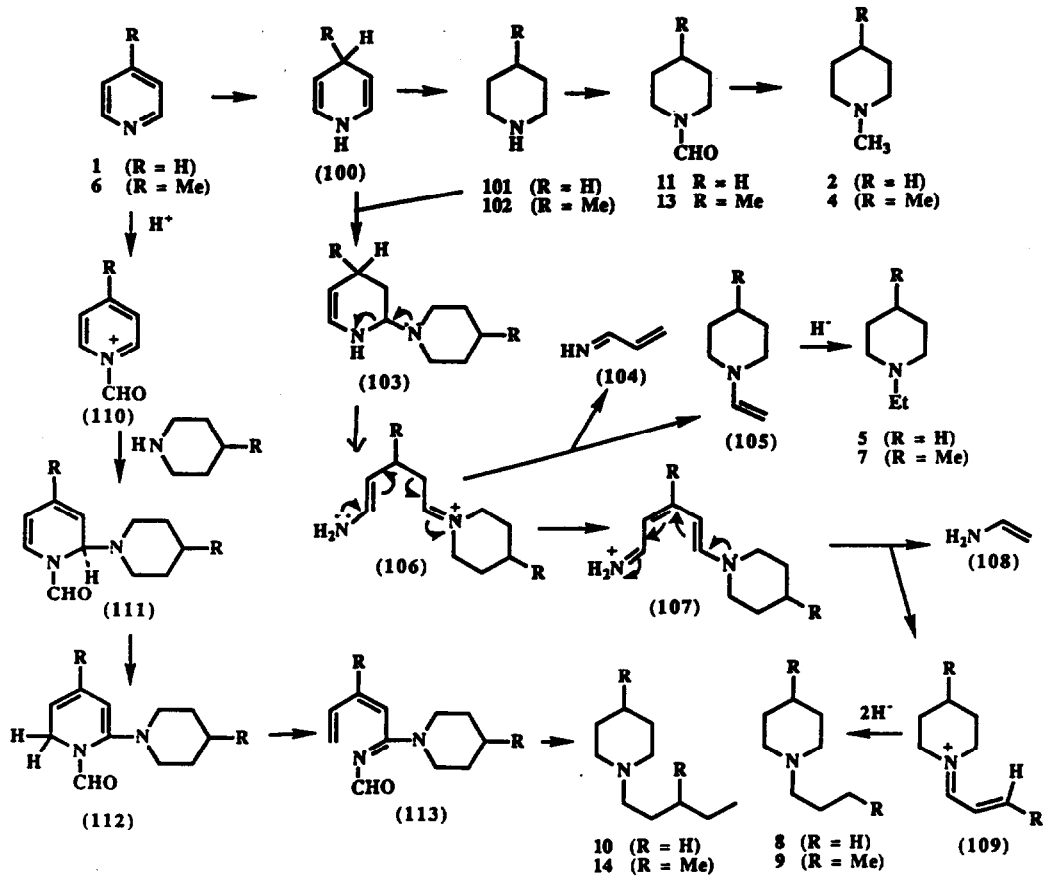
**Table. Products Obtained from Pyridine (1) and 4-Methylpyridine (6) at 350°C.**

| | | Pyridine | | 4-Methylpyridine |
|---|---|---|---|---|
| | **Time (h)** | **2** | **2** | **2** |
| **No.** | **Structure** | * | # | * |
| 1 | pyridine | 84.0 | 68.5 | - |
| 2 | 1-methylpiperidine | 0.9 | - | - |
| 3 | 1-($^{13}C$)-methylpiperidine | - | 1.9 | - |
| 4 | 1,4-dimethylpiperidine | - | - | 14.9 |
| 5 | 1-ethylpiperidine | 2.3 | 1.5 | - |
| 6 | 4-methylpyridine | - | - | 40.4 |
| 7 | 1-ethyl-4-methylpiperidine | - | - | 1.4 |
| 8 | 1-propylpiperidine | 3.6 | 2.1 | - |
| 9 | 1-butyl-4-methylpiperidine | - | - | 1.6 |
| 10 | 1-pentylpiperidine | 1.2 | 6.7 | - |
| 11 | 1-formylpiperidine | 8.0 | - | - |
| 12 | 1-($^{13}C$)-formylpiperidine | - | 19.2 | - |
| 13 | 1-formyl-4-methylpiperidine | - | - | 36.5 |
| 14 | 4-methyl-1-(3-methylpentyl)piperidine | - | - | 5.1 |

* in aq. 49% HCOOH; # in 100% $H^{13}COOH$

Formic acid reductions of quaternary salts of pyridine and of 1-methylpyridinium cation to the corresponding fully hydrogenated products, viz., piperidine and 1-methylpiperidine are well

documented.[8-12] The mechanistic pathway[13-15] to these compounds involves formic acid (or formate anion) donating hydride ion to C-4 of the pyridinium cation, resulting in 1,4-dihydropyridine. Further successive protonations and attacks of hydride ion at C-2 and C-6 yield piperidine (**101**). Piperidine underwent formylation to 1-formylpiperidine (**11**), which was reduced to 1-methylpiperidine (**2**) in the presence of formic acid as shown in the Scheme. In the same manner, 4-methylpiperidine (**102**), formed from 4-methylpyridine (**6**), is converted successively into 1-formyl-4-methylpiperidine (**13**) and 1,4-dimethylpiperidine (**4**).




**Scheme (Numbers ≥ 100 indicate uncharacterized intermediates)**

The reductive C-C bond cleavage of a pyridine ring to our knowledge is unprecedented. We suggest that the products are formed as shown in the Scheme; by the following mechanisms:

(i) Compounds **2, 4, 11** and **13** are expected from the earlier work quoted above.

(ii) The structures of **5** and **8** from pyridine and analogs **7** and **9** from 4-methylpyridine are well explained by bis-aza-retro-Aldol-fragmentations of the ring-opened isomers **106** of the addition products **103** of the piperidines **101** and **102** to the 1,4-dihydropyridines (**100**). Such direct fragmentation of **103** leads to **104** and **105**: the N-vinylpiperidines **105** are obvious precursors of **5** and **7**. Easy proton transfer in **106** leads to **107** which now fragments in the opposite sense into **108** and **109**, again **109** is the obvious precursor for **8** and **9**.

(iii) Compounds **10** and **14** could arise from electrocyclic ring opening of **112** to give **113**. Intermediate **112** is formed by 1,5-H-shift of the addition product **111** from cation **110**. Four hydride donations will fully saturate **113** to form **10** and **14**.

These results have important implications for heterocyclic ring formation (for example, in the important commercial preparations of pyridines from 1, 2, and 3 carbon fragments) as well as cleavage reactions. Extensive further work, which *inter alia* demonstrates that piperidines undergo similar cleavages, will be discussed in our full paper.

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