

STRUCTURE-REACTIVITY RELATIONSHIPS FOR ORGANICS IN SUB- AND SUPERCRITICAL AQUEOUS MEDIA: DEVELOPMENT OF A KNOWLEDGE BASE.

Alan R. Katritzky^a, Michael Siskin^b and Daniel A. Nichols^a

^aCenter for Heterocyclic Compounds, Department of Chemistry, University of Florida, P. O. Box 117200, Gainesville, FL 32611

^bExxon Research and Engineering Co., Corporate Research Labs, Rt. 22E, Clinton Twp., Annandale, NJ 08801

Abstract: The products and reactions of diverse classes of organics with superheated water have been analyzed quantitatively by GCMS supplemented by QSPR-derived response factors.

Reaction types to be discussed include: (i) heterolytic carbon-heteroatom bond cleavages and formations catalyzed by water acting as an acid or base, (ii) oxidation-reductions and disproportionations, and (iii) heterolytic carbon-carbon bond formations and cleavages. The results (a) assist the rationalization of aspects of the diagenesis and catagenesis chemistries of kerogens, (b) help in the formulation of superior preparative procedures in which pure water is selected as a solvent, reagent, or catalyst and in special circumstances if it is optimal to add traces of specific reagents, and (c) offer potential solutions for chemical weapons disposal.

Keywords: water, supercritical, organic reactivity

The work carried out at the University of Florida was intended to complement the more applied studies underway at Exxon (see preceding paper) and to help build a knowledge base concerning the reactions undergone by carbon skeletons and typical functional groups found in naturally occurring feedstocks in superheated water. A supplemental objective was to explore the potential of aquathermolysis for chemical weapons disposal. A summary of the work has been published in *Accounts of Chemical Research*¹ and a more detailed overview is in preparation for *Chemical Reviews*.

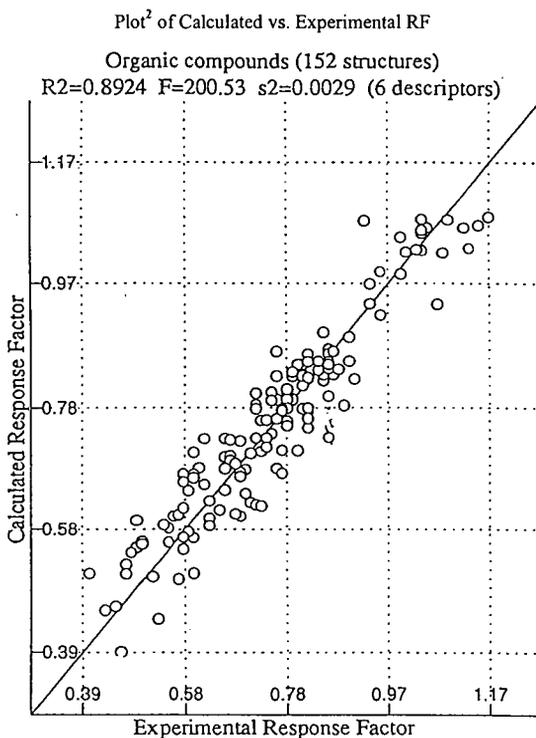
The methodology adopted was to heat known quantities of compounds in water (or water containing definite amounts of such additives as phosphoric acid, sodium hydroxide or formic acid) in small stainless steel bombs. Reactions were analyzed by GC/MS. From the fragmentation pattern and knowledge of the chemistry of the compounds in question at lower temperatures it was usually possible to deduce the structures of the products. This allowed a qualitative analysis. To turn from a qualitative into a quantitative analysis, it was necessary to know the response factors for all the products in the GC flame ionization detector. As it was impractical to measure these, a supplementary investigation was carried out and a quantitative structure property relationship established between chemical structures of a training set of 152 diverse compounds and their flame ionization response factors². It was found possible to correlate response factors with an R^2 value of 0.89 using six theoretical descriptors as shown in the Plot.

Heterolytic carbon-heteroatom bond cleavages and formations were found to be readily catalyzed by water acting as an acid or a base. Oxidation-reductions and disproportionations were also found to be common. Heterolytic carbon-carbon bond formations occurred frequently and sometimes such cleavage reactions were also uncovered.

Thus, benzyl alcohol undergoes a wide variety of condensations to give benzyl benzyl alcohols and polybenzylated benzyl alcohols. Its hydroxy group can also be reduced into a methyl or oxidized into an aldehyde, and further transformations of both of these types of products occur to give a highly complex reaction palette, but one that is completely rationalizable in terms of expected chemical transformations. This research indicated that thermolysis of benzyl alcohol is in effect an aquathermolysis reaction significantly influenced by the water produced during the reaction; however, normal aquathermolysis reaction produces higher quantities of disproportionation products and less dibenzyl ether³.

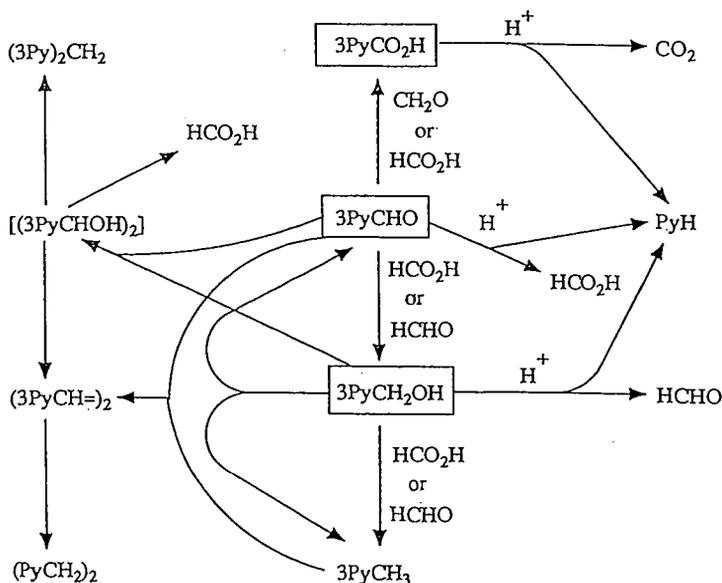
The behavior of hydroxymethyl, aldehyde and carboxyl groups attached to a pyridine ring were studied, and it was found that eventually all these compound types were converted into the parent pyridine together with the corresponding methyl pyridine by disproportionation and substituent cleavage reactions^{4,5}. The overall reaction pathways for pyridines substituted with a carboxyl, aldehyde or hydroxymethyl group in the 3-position⁴ as shown in Scheme 1. The patterns for the corresponding 2-⁶ and 4-⁵ substituted pyridines are still more complex.

In a system simulating water/carbon monoxide, it was found for a series of alkylpyridines that the ring can be cleaved by heating at 350 °C with 50% formic acid ($\text{HCOOH} \rightarrow \text{H}_2\text{O}/\text{CO}$). The products are a series of *N*-substituted piperidines where the *N*-substituent is derived from the fragmentation and C-C bond cleavage at the 3,4 positions of the pyridine ring of a second molecule of the starting pyridine⁷. This process shows considerable similarity to the formation of pyridines from one, two and three carbon building units in commercially well-known catalytic synthetic procedures.



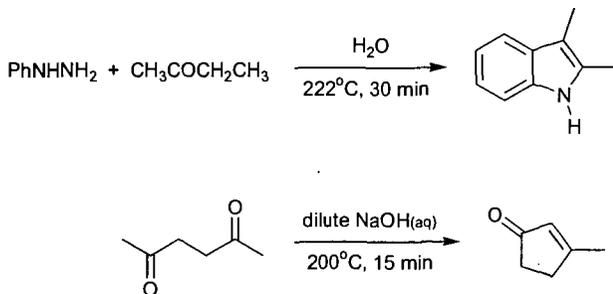
The applications of superheated water as a solvent for superior preparative procedures has been explored particularly by Strauss and his co-workers⁸. As depicted in Scheme 2, such

Scheme 1: Overall Reaction Pathways for 3-Substituted Pyridines⁶



reactions in pure water and in water containing traces of acid or base can have rate enhancements far exceeding those expected for such dilute systems. This is well illustrated by the one step Fisher indole synthesis of 2,3-dimethylindole from phenylhydrazine and butanone in neutral water at 222 °C in 67% yield in 30 minutes⁹. Additionally, although 2,5-hexanedione in neutral water failed to undergo ring closure at 250 °C in 1 hour¹⁰, Strauss found that 3-methylcyclopent-2-enone was formed in 81% yield within 15 minutes at 200 °C from the intramolecular aldol condensation in 0.05% aqueous sodium hydroxide⁸.

Scheme 2: Application of Superheated Water to Preparative Procedures^{8,9}



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