PROGRESS REPORT ON FIRE TOXICITY AND CHEMISTRY RESEARCH IN THE UNITED STATES

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Deaths, injuries, and losses due to fires continue to be major problems in the United States which still holds the dubious distinction of having the highest death rate per capita in the industrialized world. Interest in the fire problem was indicated by a major week-long symposium entitled "Fire and Polymers" which was sponsored by the American Chemical Society in Dallas, Texas in April, 1989. One day of that symposium was devoted to combustion product toxicity and the rest of the sessions were devoted to the chemistry. The proceedings of that meeting are in the process of being published.

The research efforts in toxicity and chemistry, which at one time were pursued individually, are now starting to meld into a common endeavor. There are a number of issues which continue to drive the direction of this research:

1. The development of a proper small-scale toxicity test apparatus which will qualitatively and quantitatively simulate the combustion atmospheres found in large-scale fire tests and provide data that can be used in the prediction of fire hazard and regulation of materials and products.

2. The implementation of state-of-the-art analytical tools for identification and quantitation of toxic agents in fire atmospheres.

3. The development of a simplified gas model which can be used to predict the toxic potency of complex gas mixtures found in fire atmospheres and to provide data for hazard assessment.

4. The development of a bioanalytical screening test to determine whether the combustion products from materials are extremely toxic or unusually toxic.

5. The development of an incapacitation model that can be used in a hazard assessment analysis to predict the escape potential of people in fires.

6. The characterization of the smoke components from smoldering combustion and increased understanding of smoldering phenomena.

7. The prediction of carbon monoxide generation from various fuels and under various fire conditions.

8. The chemistry of soot formation and destruction in diffusion flames.

There are at least three laboratories [National Institute of Standards and Technology (NIST), Southwest Research Institute (SwRI), and University of Pittsburgh (UPITT)] which are currently working individually and cooperatively on perfecting small-scale toxicity test apparatus. This work is continuing even though the State of New York has passed a regulation that electrical conduit and electrical wire insulation; pipe, duct or thermal insulation; and interior finishes or interior floor finishes need to be tested by the University of Pittsburgh's toxicity test before being used in buildings or factory manufactured homes [1][1]. All of the current test methods consist of three main components - the combustion system, the analytical system and the animal exposure system. The main thrust of this effort is the improvement of the combustion system in order to assure that the combustion products are similar to those found in real fires. Both the National Institute of Building Sciences (NIBS) and NIST have been exploring different toxicity test protocols using a radiant heat combustor designed by Southwest Research Institute [2]. The UPITT is testing a procedure which combines the NIST cone calorimeter and the University of Pittsburgh's animal exposure chamber.

With regard to the implementation of state-of-the-art analytical tools for identification and quantitation of toxic agents in fire atmospheres, NIST is implementing the use of Fourier Transform Infrared Spectroscopy for the continuous on-line measurement of multiple fire gases [3], ion chromatography for the measurement of acid gases such as $HC\ell$, HBr and HCN [4], and chemiluminescence for NO_x [5].

NIST has developed a simplified gas model (the N-Gas Model) to predict the toxic potency of complex gas mixtures found in fire atmospheres [6-9]. This empirical mathematical model predicts the acute lethality of rats during short term exposures and the 24 hour post-exposure period and is currently based on the toxic interactions of 4 gases - CO, CO_2, HCN and reduced O_2. Work at SwRI is progressing towards the inclusion of $HC\ell$ and HBr into this model [10]. In an effort to include NO_2 into the N-Gas model, NIST has just completed a series of tests that demonstrated the synergism of NO_2 and CO_2 [5]. At the end of this year, we hope to have a seven gas model which predicts both within and post-exposure deaths. The current approach has been incorporated into a computer hazard assessment methodology entitled <u>HAZARD I</u> [11].

<u>HAZARD I</u>, which was developed by NIST, is now available to the public [11]. This computer-based methodology allows one to define a specific fire scenario, calculate the development of hazardous conditions over time, determine the escape time needed by building occupants and estimate the resulting loss of life based on predicted occupant behavior and toxic gas and heat tenability criteria.

A bioanalytical screening test has been developed at NIST to determine whether the combustion products from materials are extremely toxic (i.e., low concentrations produce toxic effect) or unusually toxic (i.e., the toxicity of the combined major fire gases is not sufficient to account for the observed toxicity) [12]. This test is based on the N-Gas Model and is designed to minimize the use of animals.

Modeling of incapacitation from fire smoke continues to be a difficult problem primarily because the degree of incapacitation can range from incorrect decision making to inability to physically move. Many people have tried to deal with this problem in the past. Most recently, the University of

[1]Numbers in brackets refer to references listed at the end of this paper.

Pittsburgh has published both a running mouse and guinea pig model [13,14]. The Navy is also conducting some studies with humans who are exposed to various oxygen concentrations. In these experiments, the ability to perform mathematical calculations while undergoing different levels of work (stationary bicycle riding) is being measured [15]. Incapacitation as used in Hazard I [11] is based on physical incapacitation (inability to move) and the individual toxic gas data from the non-human primate work of D. Purser [16].

Work is continuing on the characterization of the smoke components and controlling factors in smoldering combustion [17,18]. Current work at NIST has been concerned with self-sustained smoldering of solid wood under controlled air supply conditions. Transition to flaming and extinction depends on the air flow rates. During stable smoldering, 3 to 4 mole-percent of the exhaust gases is carbon monoxide. Other smoldering combustion gases have also been characterized. This work has led to an increased understanding of smoldering propagation and flaming transition phenomena.

The research necessary to model and predict carbon monoxide generation from various fuels in enclosure fires both in large and small-scale test conditions is another area of study at NIST [19].

The effects of the molecular structure on flammability properties are being examined at NIST and Factory Mutual Research Corporation. In particular, these two groups are studying the effects of thermal stability and melt viscosity of the material on piloted ignition [20], flame spread [21], non-flaming gasification rate and heat release rate [22]. Engineering correlations for heat of combustion, its convective and radiative components, yields of CO and particulates as functions of molecular weight and aromatic, saturated and unsaturated bonds of the material structure have been suggested [23].

Work continues on the long-term study of the chemistry of soot formation at NIST, Pennsylvania State University and George Washington University [24-26]. Through the use of laser techniques (such as absorption, fluorescence, multiphoton ionization) and mass spectrometric methods, the production and destruction rates of intermediate hydrocarbons and radical pool species are being examined. Recently, the first quantitative radical measurements in hydrocarbon diffusion flames have been reported [25]. Carbon monoxide formation and oxidation in a methane/air flame and the relationship between soot and CO formation is being studied.

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