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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: December 14, 1973

Project Title: Properties of Combustion Products from Building Fires

Project No: E-16-641

Principal Investigator: Dr. Ben T. Zinn

Sponsor: National Science Foundation

Agreement Period: From 10/1/73 Until 3/31/75*

Type Agreement: Grant No: GI-40782

Amount: $65,000 NSF Funds (E-16-641)
57,021 GIT Contrib. (E-16-536)
$122,021 TOTAL

Reports Required: Interim Technical Reports (at least Semi-Annually);
Final Summary Report

Sponsor Contact Person (s):

Technical Matters

Ralph H. Long
Program Mgr., Div. of Adavnced
Technology Applications
National Science Foundation
Washington, D. C. 20550

Administrative Matters

(Thru ORA)
Wilbur W. Bolton, Jr.
Grants Officer
NSF
Washington, D. C. 20550

*Proposed project period (12 mos.) ends Sept. 30, 1974; all committments to be met by grant expiration date unless formal extension is obtained in advance.

Assigned to: AE

COPIES TO:

- Principal Investigator
- School Director
- Dean of the College
- Director, Research Administration
- Director, Financial Affairs (2)
- Security-Reports-Property Office
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- Photographic Laboratory
- Project File
- Other

RA-3 (6-71)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: May 10, 1977

Project Title: "Investigation of the Properties of the Combustion Products Generated by Building Fires"

Project No: E-16-641

Project Director: Dr. B. T. Zinn

Sponsor: National Science Foundation

Effective Termination Date: March 31, 1977

Clearance of Accounting Charges: March 31, 1977

Grant/Contract Closeout Actions Remaining:

_ Final Invoice and Closing Documents
X Final Fiscal Report
_ Final Report of Inventions
_ Govt. Property Inventory & Related Certificate
_ Classified Material Certificate
_ Other _____

Assigned to: Aerospace Engineering (School/Laboratory)

COPIES TO:

Project Director
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Project Code (GTRI)
Other _____

CA–4 (3/76)

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET & FISCAL REPORT

Form Approved
Budget Bureau No. 99-R0013

Please read instructions on reverse side carefully before completing this form.

INSTITUTION AND ADDRESS	NSF PROGRAM	GRANT PERIOD
Georgia Institute of Technology Atlanta, Georgia	Disaster & Natural Hazards	from 10/1/73 to 3/31/77 REPORTING PERIOD from 10/1/73 to 8/26/77*

GRANT NUMBER	BUDGET DUR. (MOS.)	PRINCIPAL INVESTIGATOR(S)	GRANTEE ACCOUNT NUMBER
AEN73-03168 A02	12	Zinn	E-16-641

	NSF Funded Man Months			NSF AWARD BUDGET	CUMULATIVE GRANT EXPENDITURES *Do Not Round*
	Cal.	Acad.	Summ.		
A. SALARIES AND WAGES					
1. Senior Personnel					
a. 1 (Co)Principal Investigator(s)	2			$ 4,390	
b. 1 Faculty Associates	4			4,980	
Sub-Total				$ 9,370	$ 20,112.81
2. Other Personnel (Non-Faculty)					
a. 1 Research Associates—Postdoctoral	12			9,000	
b. 2 Non-Faculty Professionals	10			15,248	
c. 1 Graduate Students				7,125	
d. Pre-Baccalaureate Students					
e. 1 Secretarial—Clerical				720	
f. Technical, Shop, and Other					
TOTAL SALARIES AND WAGES				$ 41,463	$ 74,666.99
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				3,801	5,379.53
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				$ 45,264	$ 80,046.52
D. PERMANENT EQUIPMENT Infrared Analyzer $5,950 Spectrophotometer $6,050				12,000	77,405.61
E. EXPENDABLE EQUIPMENT AND SUPPLIES				4,600	19,209.92
F. TRAVEL 1. DOMESTIC (INCLUDING CANADA)				1,500	3,600.19
2. FOREIGN					1,529.46
G. PUBLICATION COSTS				400	594.51
H. COMPUTER COSTS IF CHARGED AS DIRECT COST					-
I. OTHER DIRECT COSTS					
Mass Spectra Computer Services $2,000 Advisory Board $1,530				3,530	435.75
J. TOTAL DIRECT COSTS (C through I)				$ 67,294	$ 182,821.96
K. INDIRECT COSTS					
65% of Salaries & Wages = $26,951 Amount Requested				25,707	50,078.04 **
L. TOTAL COSTS (J plus K)				$ 93,001	$ 232,900.00
M. AMOUNT OF THIS AWARD (ROUNDED)				$ 93,000	
N. CUMULATIVE GRANT AMOUNT				$ 232,900	
O. UNEXPENDED BALANCE (N. BUDGET MINUS L. EXPENDITURE)					$ 0.00

REMARKS: Use extra sheet if necessary

* No obligations were incurred outside the grant period of 10/1/73 through 3/31/77.

** 65% of $23,184.04 = $15,069.63
68% of $51,482.95 = $35,008.41
$74,666.99 $50,078.04

FOR NSF USE ONLY
Final Fiscal Report Accepted
Grant Closed _____ Remains Open _____
By _____ Date _____
Grants Administration Section, Area _____

SIGNATURE OF PRINCIPAL INVESTIGATOR	TYPED OR PRINTED NAME	DATE
	Ben T. Zinn	9/20/77

I CERTIFY THAT ALL EXPENDITURES REPORTED ARE FOR APPROPRIATE PURPOSES AND IN ACCORDANCE WITH THE AGREEMENTS SET FORTH IN THE APPLICATION AND AWARD DOCUMENTS

SIGNATURE OF AUTHORIZED OFFICIAL	TYPED OR PRINTED NAME & TITLE	DATE
	Evan Crosby, Associate Director of Financial Affairs	9/22/77

FOR NSF USE ONLY

Organ. Code	F.Y.	Fund ID	Prog. Code	Ob. Class	O/Dres.	Award No.	Amd.	Inst. Code	Unexpended Balance	Trans.	Lot
									$		

NSF Form 98, JULY 1971

SUPERSEDES ALL PREVIOUS EDITIONS

E-16-641

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

SUMMARY OF COMPLETED PROJECT

Form Approved
OMB No. 99R0013

Please read instructions on reverse carefully before completing this form.

1. INSTITUTION AND ADDRESS	2. NSF PROGRAM	3. GRANT PERIOD
School of Aerospace Engineering Georgia Institute of Technology Atlanta, GA 30332	Research Applied to National Needs	from 10/1/73 to 3/31/77

4. GRANT NUMBER	5. BUDGET DUR. (MOS)	6. PRINCIPAL INVESTIGATOR(S)	7. GRANTEE ACCOUNT NUMBER
AEN 73-03168 A02	42	Ben T. Zinn	E-16-641

8. SUMMARY (Attach list of publications to form)

The objective of the research program carried out under the subject grants is the determination of the physical and chemical properties of the particulate products (smoke) generated by burning polymeric materials under different environmental conditions simulating actual fire situations. In order to pursue this objective, the following facilities have been developed: (1) a small-scale, ventilated Combustion Products Test Chamber (CPTC); (2) an Aerosol (Smoke) Sampling System; (3) an Optical (Smoke) Aerosol Analysis System; and (4) a Chemical Analysis System. These facilities have been utilized for determining the dependence of the properties of smoke generated by the combustion of various materials on the temperature and composition of the chamber atmosphere, the type of burning, the radiant heat flux to the sample in nonflaming combustion, the orientation of the sample, and the amount of ventilation. The measured quantities are: (1) the smoke average particle size; (2) the smoke particle size distribution; (3) smoke particle concentration; (4) the index of refraction of the smoke particles; (5) rate of mass loss of the tested samples; and (6) the chemical composition of the smoke particles. A comprehensive research program dealing with wood, a rigid urethane foam and a rigid polyvinyl chloride (PVC) plastic tested in ventilation gases maintained at room temperature has been carried out. The results of this low temperature test program have provided important new information on the characteristics of smoke particulates generated by burning these materials under a wide variety of conditions. Furthermore, tests of the same wood and rigid PVC samples have been conducted at ventilation gas temperatures up to 300°C. Results have also been obtained for wood and PVC samples burned in different mounting orientations (vertical and horizontal). In addition, the effects of various commonly used additives on the properties of smoke produced by burning PVC have been studied. The Chemical Analysis System has been used to analyze smoke particulates collected during tests in the CPTC. These data provide information which is necessary in assessing the present physiological and toxicological hazards due to smoke produced in building fires. Finally, these data will be utilized in the development of the theoretical model for smoke production, which was initiated during this program. The application of the data in this manner will lead to a more fundamental understanding of smoke production; thereby enhancing the prospects for reduction of smoke hazards during fires.

9. SIGNATURE OF PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR	TYPED OR PRINTED NAME	DATE
	Ben T. Zinn	3/29/77

REPORTS AND PUBLICATIONS

1. "Annual Project Summary Report," in the proceedings of the NSF/RANN Conference on Fire Research, Georgia Institute of Technology, May 28-29, 1974, p. 167.

2. Bankston, C. P., Cassanova, R. A., Powell, E. A. and Zinn, B. T., "Properties of Smoke Produced by Burning Wood, Urethane and PVC Samples Under Different Conditions," presented at the Combustion Institute Meeting on Flammability and Burning Characteristics of Materials and Fuels, San Antonio, Texas, April 1975.

3. "Annual Project Summary Report," in the proceedings of the NSF/RANN Conference on Fire Research, Harvard University, June 25-27, 1975, p. 49.

4. Zinn, B. T., Cassanova, R. A., Bankston, C. P., Powell, E. A. and Tsoukalas, S. N., "Experimental Determination of the Physical and Chemical Properties of Smoke," presented at the Polymer Conference Series-Flammability of Materials, University of Utah, July 7-11, 1975.

5. Powell, E. A., Bankston, C. P., Cassanova, R. A., and Zinn, B. T., "Characterization of Smoke Produced by Burning Polymers Under Different Environmental Conditions," proceedings of the Second European Combustion Symposium, The Combustion Institute (French Section), 1975, p. 227.

6. Powell, E. A., Cassanova, R. A., Bankston, C. P., and Zinn, B. T., "Combustion Generated Smoke Diagnostics by Means of Optical Measurement Techniques," presented at the AIAA 14th Aerospace Sciences Meeting, Washington, D. C., January 26-28, 1976, AIAA Paper No. 76-67.

7. Zinn, B. T., Powell, E. A., Cassanova, R. A., Bankston, C. P., Tsoukalas, S. N. and Rhee, J. U., "Analysis of Smoke Produced During the Thermal Degradation of Natural and Synthetic Materials," presented at the International Symposium on Toxicity and Physiology of Combustion Products, University of Utah, March 22-26, 1976.

8. Bankston, C. P., "Determination of the Physical Characteristics of Smoke Particulates Generated by Burning Polymers," Ph.D. Thesis in the School of Aerospace Engineering, Georgia Institute of Technology, March 1976.

9. Bankston, C. P., Cassanova, R. A., Powell, E. A., and Zinn, B. T., "Initial Data on the Physical Properties of Smoke Produced by Burning Materials under Different Conditions," J. Fire and Flammability, Vol. 7, April 1976, p. 165.

10. "Annual Project Summary Report," in the proceedings of the NFPCA Annual Conference on Fire Research, Applied Physics Laboratory, Johns Hopkins University, July 14-16, 1976, p. 97.

11. Cassanova, R. A., Powell, E. A., Bankston, C. P. and Zinn, B. T., "The Effects of PVC Additives on the Properties of Smoke Produced During Non-flaming Combustion," presented at the Combustion Institute Meeting (Western Section) on Combustion Diagnostics and Fire Research, La Jolla, Ca., October 18-19, 1976.

12. Bankston, C. P., Powell, E. A., Cassanova, R. A. and Zinn, B. T., "Detailed Measurements of the Physical Characteristics of Smoke Particulates Generated by Flaming Materials," presented at the Combustion Institute Meeting (Eastern Section) on Chemical and Physical Processes in Combustion, Philadelphia, Pa. November 18-19, 1976 (Submitted for publication).

13. Zinn, B. T., Powell, E. A., Cassanova, R. A. and Bankston, C. P., "Investigation of Smoke Particulates Generated During the Thermal Degradation of Natural and Synthetic Materials," Fire Research, Vol. 1, March 1977, p. 23.

L-76-67

NATIONAL SCIENCE FOUNDATION

RESEARCH APPLIED TO NATIONAL NEEDS

GRANT NUMBER AEN 73-03168 A02

INVESTIGATION OF THE PROPERTIES OF THE COMBUSTION PRODUCTS GENERATED BY BUILDING FIRES

Final Summary Report

for the period

October 1, 1973 to March 31, 1977

Principal Investigator: Dr. B. T. Zinn, Regents' Professor

Other Personnel: Dr. R. A. Cassanova, Research Engineer

Dr. E. A. Powell, Assistant Professor

Dr. C. P. Bankston, Research Associate

Dr. J. U. Rhee, Assistant Research Engineer

Dr. S. N. Tsoukalas, Senior Research Scientist

School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, Georgia

FOREWORD

This Final Summary Report describes the efforts conducted under National Science Foundation Grants GI40782, ERT 73-03168 A01, and AEN 73-03168 A02 during the period October 1, 1973 to March 31, 1977. The subject grants entitled "Investigation of the Properties of the Combustion Products Generated by Building Fires," were conducted in the School of Aerospace Engineering at the Georgia Institute of Technology. The principal investigator was Dr. Ben T. Zinn, Regents' Professor. Contributing professional personnel were: Dr. R. A. Cassanova, Research Engineer; DR. E. A. Powell, Assistant Professor; Dr. C. P. Bankston, Research Associate; Dr. S. N. Tsoukalas, Sr. Research Scientist; and Dr. J. U. Rhee, Ass't. Research Engineer.

I PROJECT SUMMARY

A. Objectives

The objectives of this program were: (1) to develop and utilize facilities and experimental techniques required for the determination of particle size distributions and particulate mass concentrations, the chemical properties of both smoke and gaseous products, and the optical properties of smoke produced by burning various building materials; (2) determination of the dependence of the properties of smoke generated by the combustion of various materials on the temperature and composition of the chamber atmosphere, the type of burning, the radiant heat flux to the sample in non-flaming combustion, the orientation of the sample, and the amount of ventilation; (3) determination of the dependence of smoke and gaseous products generated by burning synthetic polymers on the type and amount of chemical additives found in those polymers; and (4) improve methodology for the utilization of small-scale test data to predict full-scale fire situations.

B. Research Plan

To pursue the objectives outlined above, the efforts of this research project can be divided into three major categories or tasks. Task I is concerned with the design, fabrication, installation, calibration and subsequent modifications to the experimental facilities needed for performing the research. Task II deals with the actual determination of the detailed characteristics of the products generated during the combustion of materials in a ventilated, small-scale Combustion Products Test Chamber under carefully controlled conditions. Finally, Task III, which has recently begun, is concerned with the theoretical modeling of smoke production from burning materials.

II RESEARCH RESULTS

A. Experimental Setup (Task I)

The following facilities have been developed under Task I for the determination of the properties of smoke particulates generated during fires.

1. Combustion Products Test Chamber (CPTC).

A ventilated combustion products test chamber (CPTC) has been developed to simulate a wide variety of environmental conditions that may be encountered in actual fire situations (Refs. 1, 2, 4, 7, 8, 9, 11, 13). Specifically, the design of the CPTC permits the easy selection and control of the following variables during the combustion of small samples of materials: (1) mode of combustion (i.e., flaming vs. smoldering combustion), (2) sample radiant heating up to 10 watts/cm^2, (3) continuous sample weight measurement during the test, (4) composition of the ventilating gas surrounding the sample, (5) temperature of the ventilation gas up to 650°C and (6) vertical and horizontal sample mounting. The CPTC consists of a cubical (4' x 4' x 4') solid stainless steel outer shell and a perforated stainless steel inner shell consisting of cylindrical and conical sections. The lower cylindrical section is 27 inches in diameter and the total height to the top of the conical section is 32 inches. The perforations in the inner shell allow the ventilating gas mixture, flowing from metering valves into the plenum between the shells, to slowly and uniformly flow into the immediate surroundings of the test sample. The flow of the ventilating gas through the perforated shell also prevents deposition of condensable vapors and solid particles on the surface of the inner shell, and it forces all combustion products to flow through a Sampling Section located immediately above the CPTC.

In a typical test, a small sample (3 inch square, 1/8 - 3/8 inch thick, depending upon the material) of the material to be tested is positioned within the inner shell. The sample holder is supported by a force transducer for continuous recording of sample weight. After the specified ventilation gas has begun

to flow through the chamber, a variable flux radiant heater is adjusted to radiate the face of the sample at a predetermined heating rate; and, for flaming tests, the sample face is also exposed to a propane-air flame. When the radiant heater has reached a steady state operation, a cover positioned over the sample is remotely withdrawn and the collection of data by the sampling system, the in situ optical measurement system, and the force transducer begins.

2. Combustion Products Sampling System.

The Sampling Section (above the CPTC) is designed to allow samples to be continuously withdrawn from the gases flowing from the CPTC during tests, while simultaneous optical aerosol measurements are also being made (Refs. 1, 2, 4, 7, 8, 9, 11, 13). Two stainless steel sampling probes are used to withdraw samples of the combustion products from the sampling section. The sample withdrawn by one of the probes (½" O.D.) leads to an Andersen Sampler (Model 21-000), which measures particle size distribution for the size range 0.43 to 11 microns. Part of the sample withdrawn by the second probe (¼" O.D.) goes to a Whitby Electrical Aerosol Analyzer (Thermal Systems, Inc., Model 3030) for particle size distribution determination in the range 0.01 to 1.0 micron. The remaining portion of the second sample is directed into a mass monitor (Thermal Systems, Inc., Model 3200B), which measures the smoke particulate mass per unit volume. The Whitby Analyzer provides size distribution measurements every 1.5 minutes during a test while the Andersen Sampler (Cascade Impactor) gives an integrated size distribution for an entire test. Samples of the solid and liquid particles accumulated in the stages of the Andersen Sampler are collected after each test, weighed and then stored for later chemical analysis. Smaller particles (less than 0.43 micron) not collected in the Andersen Sampler are trapped by an absolute filter (Gelman Type A, glass fiber) and are later recovered for further chemical analysis.

3. Optical Aerosol Analysis System.

The optical smoke analysis system (Refs. 1, 4, 5, 6, 7, 12, 13) provides a method of in situ size and concentration measurement which can be applied in situations where the accuracy of conventional sampling techniques is questionable. Measurements of scattered blue light at forward angles of 5^{o} and 15^{o} and measurements of transmitted monochromatic red and blue light give the average smoke particle size, smoke particle refractive index, and volume concentration of smoke particles. The red light source is a helium-neon laser operating at 632.8 nm while the blue light source is an argon-ion laser operating at 457.9 nm. The laser beams are combined and directed through the smoke emerging from the 11.4 cm diameter stack leading from the CPTC. Photomultiplier tubes detect the scattered and transmitted light intensities and diffractive scattering theory is employed to calculate time-resolved values of average particle size, refractive index and particle volume concentration. In addition, smoke optical density is calculated as a function of time.

4. The CPTC Heating System.

The capabilities of the CPTC were expanded midway through this program to include the ability to heat the CPTC ventilating gas flow to temperatures up to 650^{o}C. (Refs. 7, 11). This feature allows materials to be tested in the high temperature gases that may be present in actual fires. The inner perforated shell of the CPTC is heated by quartz infrared heater elements that are positioned around the back and sides of the inner shell. Incoming ventilation gases are then preheated by flowing over the heater element reflectors and adjacent insulation. The gases are heated to the final preselected operating temperature by flowing around and through the perforated inner shell. A thermocouple placed near the sample is used with temperature controllers to regulate the power input to the heaters.

5. Horizontal Sample Mounting.

The initial design of the CPTC provided for vertical sample mounting only. Subsequent modifications now provide for the horizontal mounting of samples (in addition to vertical mounting). This capability allows comparisons of smoke characteristics in different geometric configurations and permits tests of materials that tend to melt during combustion. Horizontally mounted samples are irradiated by two radiant panels positioned on stainless steel brackets above the sample.

6. Chemical Analysis System.

The chemical analysis of smoke particulates generated by burning various materials in the Combustion Products Test Chamber has been carried out using the following facilities (Refs. 1, 4, 7, 10):

(a). Gas Chromatograph/Mass Spectrometer/Data System - This coupled analytical system includes a Hewlett-Packard Model 5711A gas chromatograph equipped with dual columns and a flame ionization detector. The GC is interfaced with a Hewlett-Packard 5930A Mass Spectrometer for real-time analysis of gas chromatograms. The mass spectrometer is a quadrapole type with electron impact ionization. It is also equipped with ports for direct injection of solid and liquid samples. The entire GC/MS system may be controlled by the computer data system and all data obtained is stored on a disc cartridge for subsequent analysis. Identification of mass spectra is aided by computerized mass spectral search routines utilizing a 12000 spectra library.

(b). High Pressure Liquid Chromatograph (HPLC) - The HPLC is manufactured by Waters Associates and is equipped with dual ultraviolet and differential refractometer detectors. The instrument is capable of operating at pressures of up to 3000 psi; and is currently utilized for separation and identification of high molecular weight compounds which cannot be readily separated by gas chromatographic techniques.

(c). Infrared Spectrophotometer - The infrared spectrophotometer is a Perkin-Elmer Model 257. This instrument aids in the identification of mixtures separated by gas and/or liquid chromatography.

B. Determination of the Characteristics of Smoke Particulates Generated by Burning Materials (Task II)

1. Low Temperature Studies of Vertically Mounted Wood, Urethane and PVC.

During the subject grant periods, a research program dealing with wood, a rigid urethane foam and a rigid PVC tested in ventilation gases maintained at room temperature has been completed. The results of this low temperature test program have provided important new information on the characteristics of smoke particulates generated by the burning of these materials. These low temperature data (Ref. 2, 4, 7, 8, 9, 12) show that the effects of changes in atmospheric composition on the characteristics of the generated smoke are relatively insignificant in both non-flaming and flaming combustion. However, qualitative and quantitative differences in smoke particulate characteristics were observed between non-flaming and flaming combustion of all three materials studied. In the case of non-flaming combustion both particle sizes and particulate mass concentrations were found to depend on the radiant heat flux received at the face of the sample. During flaming combustion, particle sizes are generally smaller and particulate mass concentrations are lower than those quantities measured

under non-flaming conditions at comparable weight loss rates.

2. High Temperature Studies.

Tests of the same (as in the low temperature studies) wood and rigid PVC plastic samples (mounted vertically) have been conducted at ventilation gas temperatures up to 300°C in the CPTC. These data indicate changes in particulate characteristics due to changes in ventilation gas temperature. Differences in particle size characteristics, smoke optical densities and sample weight loss are evident at different ventilation gas temperatures for flaming and non-flaming tests of both wood and PVC in air. The results of the high temperature studies will be formally presented during 1977.

3. Comparisons of Smoke Generated by Vertically and Horizontally Mounted Samples.

A limited number of wood and PVC samples were tested in two different mounting positions (vertical and horizontal) under nonflaming conditions to determine the effects of material orientation on smoke particulate properties. A comparison of the results indicates that different sample orientations can produce differing smoke properties even for samples that would not be expected to melt and flow out of a vertical mount during combustion (Ref. 11).

4. Tests of PVC with Different Additives.

Tests were conducted to determine the effects of various commonly used additives on the smoke properties of PVC. Additives in PVC were shown to have a noticeable effect on the weight loss rate and hence, the quantity of smoke particulates which are produced during smoldering combustion (Ref. 11). This program is continuing under the sponsorship of the National Bureau of Standards.

5. Chemical Analysis of Smoke Particulates.

Smoke particulates generated by burning PVC and urethane samples under nonflaming conditions have been analyzed using the Chemical Analysis System. These

efforts have concentrated on the development of improved methodology for separation of the high molecular weight compounds in the collected smoke particulate samples. Techniques which utilize the high pressure liquid chromatograph and preparative gas chromatography to provide initial separation of highly complex mixtures have been implemented. The samples which are simplified and collected by these techniques are then identified by use of the mass spectrometer, the infrared spectrophotometer, and if further separation is necessary, by the GC/MS system. Progress has been made in applying the new analytical techniques to the identification of smoke particulates from burning PVC. This program is continuing under National Bureau of Standards funding.

C. Theoretical Efforts (Task III)

Preliminary work was begun on the theoretical modeling of the smoke production during the burning of materials. Initially, efforts have been directed toward the modeling of the smoke produced from a smoldering sample of a synthetic polymer subjected to an incident radiant heat flux. The solid phase analysis is primarily concerned with the determination of the temperature distribution in this phase. The possible existence of different zones with different properties (e.g., a char layer) within the solid phase has been considered in the formulation of the model. The gas phase analysis is concerned with the transport of the volatile and condensable products of thermal degradation with allowances for particulate formation through the processes of nucleation, condensation and coagulation. This task is continuing under National Bureau of Standards funding.

III ACCOMPLISHMENTS

(1) Design, construction and checkout of the Combustion Products Test Chamber, the Combustion Products Sampling System, the Optical Aerosol Analysis System and the Chemical Analysis System.

(2) Subsequent modifications to the CPTC provide for high temperature ventilation gases and horizontal sample mounting.

(3) A series of low temperature smoke tests with wood, a rigid urethane foam, and a rigid PVC plastic under flaming and non-flaming conditions, in several atmospheric compositions were carried out. Smoke particulate characteristics were found to be highly dependent upon burning conditions, although atmospheric composition was found to have little effect on the measured smoke properties.

(4) High temperature smoke tests of wood and a rigid PVC plastic in air were conducted and results show variations in smoke characteristics as ventilation gas temperatures are increased.

(5) Comparison of smoke particulate characteristics for non-melting samples burned in vertical and horizontal mounting configurations show that different sample orientations can produce different smoke properties during nonflaming combustion in a ventilated test chamber.

(6) Results of tests designed to determine the effects of various additives on the smoke properties from burning PVC indicate that smoke characteristics are directly influenced by the presence of some chemical additives.

(7) Analytical techniques have been developed for enhanced separation and identification of the complex mixtures of compounds found in smoke particulates.

IV REPORTS AND PUBLICATIONS

1. "Annual Project Summary Report," in the proceedings of the NSF/RANN Conference on Fire Research, Georgia Institute of Technology, May 28-29, 1974, p. 167.

2. Bankston, C. P., Cassanova, R. A., Powell, E. A. and Zinn, B. T., "Properties of Smoke Produced by Burning Wood, Urethane and PVC Samples Under Different Conditions," presented at the Combustion Institute Meeting on Flammability and Burning Characteristics of Materials and Fuels, San Antonio, Texas, April 1975.

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5. Powell, E. A., Bankston, C. P., Cassanova, R. A., and Zinn, B. T., "Characterization of Smoke Produced by Burning Polymers Under Different Environmental Conditions," proceedings of the Second European Combustion Symposium, The Combustion Institute (French Section), 1975, p. 227.

6. Powell, E. A., Cassanova, R. A., Bankston, C. P., and Zinn, B. T., "Combustion Generated Smoke Diagnostics by Means of Optical Measurement Techniques," presented at the AIAA 14th Aerospace Sciences Meeting, Washington, D. C., January 26-28, 1976, AIAA Paper No. 76-67.

7. Zinn, B. T., Powell, E. A., Cassanova, R. A., Bankston, C. P., Tsoukalas, S. N. and Rhee, J. U., "Analysis of Smoke Produced During the Thermal Degradation of Natural and Synthetic Materials," presented at the International Symposium on Toxicity and Physiology of Combustion Products, University of Utah, March 22-26, 1976.

8. Bankston, C. P., "Determination of the Physical Characteristics of Smoke Particulates Generated by Burning Polymers," Ph.D. Thesis in the School of Aerospace Engineering, Georgia Institute of Technology, March 1976.

9. Bankston, C. P., Cassanova, R. A., Powell, E. A., and Zinn, B. T., "Initial Data on the Physical Properties of Smoke Produced by Burning Materials under Different Conditions," J. Fire and Flammability, Vol. 7, April 1976, p. 165.

10. "Annual Project Summary Report," in the proceedings of the NFPCA Annual Conference on Fire Research, Applied Physics Laboratory, Johns Hopkins University, July 14-16, 1976, p. 97.

11. Cassanova, R. A., Powell, E. A., Bankston, C. P. and Zinn, B. T., "The Effects of PVC Additives on the Properties of Smoke Produced During Non-flaming Combustion," presented at the Combustion Institute Meeting (Western Section) on Combustion Diagnostics and Fire Research, La Jolla, Ca., October 18-19, 1976.

12. Bankston, C. P., Powell, E. A., Cassanova, R. A. and Zinn, B. T., "Detailed Measurements of the Physical Characteristics of Smoke Particulates Generated by Flaming Materials," presented at the Combustion Institute Meeting (Eastern Section) on Chemical and Physical Processes in Combustion, Philadelphia, Pa. November 18-19, 1976 (Submitted for publication).

13. Zinn, B. T., Powell, E. A., Cassanova, R. A. and Bankston, C. P., "Investigation of Smoke Particulates Generated During the Thermal Degradation of Natural and Synthetic Materials," Fire Research, Vol. 1, March 1977, p. 23.