

Project Title: Swedish/Norwegian PVC Incineration Project.

Objective of Project:

To carry out research demonstrating that incineration of PVC in municipal solid waste streams does not increase dioxin and furan emissions. Across Europe there continues to be a widespread perception that the presence of PVC in MSW is responsible for dioxin and furan emissions. Through our consultant, Dr. Richard S. Magee of NJIT, we are involved in the planning of Norwegian and Swedish laboratory studies which are intended to provide greater scientific rigour than previous investigations on the role of PVC in dioxin/furan emissions and consequently to gain greater acceptance for the incineration of PVC in the European community. These studies are being guided by a steering committee consisting of incineration experts from Belgium, Germany, and the USA (Dr. Magee).

Status Report:

The initial meeting of the steering committee was in Umea Sweden on October 30, 1990. The committee has met four more times (Oslo, Gottenberg, Umea, Karlsruhe), approximately once every six months. Progress has been painfully slow. A major difficulty for both groups has been the design, fabrication, and construction of the combustion reactors.

The most recent progress reports (Jan. 93) indicated that Umea spent zero time on the project, "this month we he had another big project to be concern about. However, next month we are back in the ECVm business again."

The SI report indicated that, as we suggested, they are unable to synthesize the radioactive labeled PVC and have suggested proceeding without labeled PVC. While I have agreed, any value of their research contribution has been significantly reduced. Further, recent test runs seem to indicate that the combustor performance is poorer than reported in December.

The next steering committee meeting is scheduled for April 29-30, 1993 in Brussels.

Recommended Actions & Future Programs:

Despite the extremely slow progress on this project it is very important that we continue our participation to ensure that the "good results" from the Pittsfield, MA study are not lost.

Meeting Agenda:

- 1) Are any decisions needed by the Technical Committee (Y/N)?.... N
- 2) Is a presentation and/or discussion needed (Y/N)?..... N
- 3) If yes to either #1 or #2, how much total meeting time should be scheduled for presentation, discussion and/or decision (Minutes)?..... _____

Prepared by: Richard S. Magee

Date: 2-22-93

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3/23/73

Appendix B

Add ① "publication rights" to RFP.

②

REQUEST FOR PROJECT TO EVALUATE COMPARATIVE ECONOMICS OF
MUNICIPAL SOLID WASTE AND HOSPITAL WASTE INCINERATION PROCESSES

I. BACKGROUND

Polyvinyl chloride (PVC) is the second largest thermoplastic material produced in the world today. The U.S. industry produced over 9.2 billion pounds in 1992. PVC, or vinyl, as it is sometimes called, is used to make a wide variety of industrial and household consumer products including water and sewer pipe, electrical conduit, wire and cable coatings, appliance housings and electronic products. Other major uses include wall coverings, home siding and window frames. Most of these are durable products which have long service lives and hence do not appear in the waste stream for many years.

However, over 500 million pounds per year of PVC are used in disposables such as product and food packaging, water bottles and food wrap and the majority of these items contribute to the waste stream.

II. ISSUES

Because the management of municipal solid waste (MSW) is a major societal problem, attention has been focused on minimizing the amounts of all disposable materials, including plastics, that are sent to incinerators or landfills. Among the strategies that are receiving the highest attention are source reduction, reuse and recycling.

In the case of polyvinyl chloride, programs have been undertaken by The Vinyl Institute and its individual member companies to develop technology to facilitate the recovery of vinyl containers and to encourage their recycling into second-generation products. While these recycling programs are technically feasible, several problems have been experienced, which limits their success. These include:

- Difficulty in having vinyl containers included in municipal recycling programs because they comprise less than 0.5% of the municipal waste stream.
- High capital costs for automatic sortation equipment needed to facilitate the separation of vinyl from other plastics.
- Unfavorable economics for recovery/recycling programs.

While plastics recycling programs will undoubtedly continue to receive emphasis and attention, incineration of the combustible portion of municipal solid waste with energy recovery has begun to receive greater attention.

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In the past, questions have been raised relating to the generation of toxic chlorinated dioxins and furans in the incineration of municipal solid waste (MSW) containing polyvinyl chloride. Studies carried out in the United States and abroad have demonstrated that incineration of MSW can be carried out safely, that the formation of dioxins/furans occurs as a result of any chlorinated materials being present in the MSW being incinerated and that dioxins/furans can be minimized by the use of proper incinerator operating conditions and state-of-the-art pollution control systems.

Incineration is also used to dispose of waste generated at hospitals including "red bag" waste containing pathogens as well as tubing, blood bags and bags used for administering parenteral solutions, some of which are PVC. Older hospital incinerators are generally not capable of operating at the higher temperatures (above 1500° F) necessary to minimize dioxin/furan formation.

However, incineration of either MSW or hospital waste does result in the generation of hydrogen chloride (HCl). This has been alleged to be a contributor to or cause of "acid rain."

III. CONFRONTING THE ISSUE

Since polyvinyl chloride contains 56.7% chlorine, its incineration results in the generation of 0.584 lbs. of hydrogen chloride per pound of PVC incinerated. State and federal environmental protection regulations require that this HCl be removed before incinerator off-gases can be discharged to the atmosphere.

Generally the removal of HCl can be accomplished by alkaline scrubbing using either caustic soda (aqueous) or lime (dry system).

While alkaline scrubbing (or some other economically viable method) would be required on any state-of-the-art MSW or hospital incinerator, little information is available on the economic impact of this air pollution control step. Particularly needed is an economic analysis of the impact of the presence (or absence) of polyvinyl chloride in MSW or hospital waste on the overall incineration cost.

IV. REQUEST FOR PROPOSAL

The Vinyl Institute has decided to seek proposals from a number of organizations to accomplish the following:

1. Development of current information on the PVC content of typical MSW and hospital waste.

2. Development of capital costs for incinerators for MSW and hospital waste that are representative of the sizes of incinerators that can be expected to be built in the future. Costs for three sizes, large, medium and small, should be prepared. The sizing of the scrubbers should be such that they are of the appropriate size dependent on whether or not PVC is contained in the waste being fed to the incinerator. Thus, a total of twelve capital costs are required, i.e. six (6) for MSW incinerators and six (6) for hospital incinerators (three sizes for each type of incinerator, with and without PVC in the incinerator waste feed).

3. Development of twelve (12) comparative economic analysis and costs (both capital and operating) of MSW and hospital incinerators under conditions where PVC is present in the incinerator waste feed and where PVC has been removed prior to incineration.

V. PROPOSAL CONTENT

The proposal should cover the following points:

1. Background of the submitting organization:

- Size
- Capabilities
- Relevant experience and/or special expertise
- Curriculum vitae of principal and supporting investigators.

2. General work plan to address elements in the Request For Proposal (See Section IV, pages 2 and 3.

3. Timetable:

- The Vinyl Institute has established a target date of six months for completion of this project.

- The proposal should therefore include mileposts to be met at agreed-upon dates in order to achieve completion by this target date.

4. Deliverables:

- The proposal should include the proposed contents of the final report that will be submitted at the conclusion of this project.

5. Cost:

- The proposal should include the cost as well as the payment schedule.

6. Date for Receipt of Proposals:

- Ten (10) copies of the proposals should be submitted by _____ to:

Mr. Robert H. Burnett
Executive Director
The Vinyl Institute
Wayne Interchange Plaza II
155 Route 46 West
Wayne, New Jersey 07470

7. Other

- Any additional information or suggestions that the responding organization believes will be useful in accomplishing the objectives of the Vinyl Institute in evaluating the submitted proposal.

VI. ORGANIZATIONS BEING INVITED TO SUBMIT PROPOSALS

The following organizations are receiving this Request for Proposal (RFP) and are being invited to submit proposals:

<u>Organization</u>	<u>Location</u>
- Battelle	Columbus, Ohio 43201-2693
- Ogden Martin Systems	Fairfield, New Jersey
- <i>Westinghouse</i>	
- <i>DeGusa</i>	
- <i>Jone Brown</i>	

Appendix D

To: Ron McCreedy, Dow USA

Interoffice
Communication

From: H. J. Hall
Date: March 4, 1993

Subject: Fire Science

VISTA

Objective of Project:

Monitor and promote scientific reasoning in the development of fire codes, standards and regulations that ensure a fair treatment for PVC products.

Status Report:

A. Corrosion

The Polyolefins Fire Performance Council continues to attempt to resurrect the ASTM E -5.21.70 radiant test which most closely resembles an acid gas test. At the February 23 meeting of the Electrical Materials and Products Subcommittee of the Coordinating Committee on Fire Safety (CCFS), a group representing Polyolefins, PVC and Fluoropolymers was formed to resolve the negatives on this protocol. It appears doubtful that the negatives can be resolved. All indications are that the present negatives on ASTM D9.21.04 should be answered and this protocol will be the U.S. test represented at IEC-89. This uses the cone calorimeter we favor.

We are continuing to monitor the formation of CSA and UL study groups on corrosion. Further information is needed before type and degree of VI participation can be determined.

B. Toxicity

1. Toxicity

NYC has apparently adopted an "interim protocol" which is the U-Pitt test (NY State modified) with a cut off number of 19.7. NYC has not been generous on information on the why, how and when they did this. Rich Gottwald of the SPI was asked at the CCFS Executive February 24 Meeting to investigate the status of this action further. At this time, the only products affected are interior and floor finishes.

2. ASTM

No further information on ASTM E5.21 (NIST based method) from last meeting. Supposedly, a rewrite is underway to resolve eleven negatives.

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C. Defense Electronic Supply Center (DESC)

Marcelo Hischler obtained copies of two reports from Support Systems Associates, Inc. of San Antonio which as reported January caused PVC products to be placed on the Hazardous Materials Minimization (HMMIN) list. Marcelo has established contact with both the authors and the Air Force office that authorized the reports. Both B.F. Goodrich and Vista have copies of the report for review.

D. New Business

1. VSI Fire Test Program

The VSI is planning to conduct fire test on Type 3 and Type 4 non combustible construction. Plans are to establish a relationship between large and small scale tests. Work will be done at SWRI.

2. NFPA 90A Research Project

Recent statements by the Southern Building Code Congress (SBCC) on the total amount of combustibles in air handling plenums have prompted Panel 90A of the National Fire Protection Association (NFPA) to consider a research project on the amount and type of combustibles in plenums. The National Fire Protection Research Foundation (NFPRF) would conduct the research. Funding is being solicited now.

RECOMMENDED ACTIONS AND FUTURE PROGRAMS:**A. Corrosion**

Continue to monitor ASTM and IEC 89 actions. Promote the standardization of ASTM D9.21.04 as the most scientific useful corrosion protocol.

B. Toxicity

Support NIST activities on toxicity protocol development in ASTM. Monitor NYC through SPI and determine with other SPI Divisions a proper course of action.

C. Defense Electronic Supply Center (DESC)

Attempt a stealth approach with Marcelo alerting his contacts to the bad science involved. Both B.F. Goodrich and Vista will provide input for presentation.

D. Monitor developments on VSI and NFPA 90 A research.

Appendix E

PROJECT REPORT FOR VI TECHNICAL COMMITTEE MEETING

Date of Meeting: <u>March 23, 1993</u>	
Objective of Project: Develop a compendium of critical papers dealing with the combustion toxicity on fire hazard of PVC.	
Status Report: This project is on hold until the SWRI primate and rodent studies with HCl and PVC are published. Response to reviewers' comments are expected to be completed by the end of March, 1993.	
Recommended Action & Future Programs: Wait until April to restart activities. Compendium is expected to be completed and ready for publication by the end of 1993.	
Meeting Agenda:	
1) Are any decisions needed by the Technical Committee (Y/N) ?.....	<u>N</u>
2) Is a presentation and/or discussion needed (Y?N)?	<u>N</u>
3) If Yes to either #1 or #2, how much total meeting time should be scheduled for presentation, discussion and/or decision (Minutes)?	<u> </u>
The BFGoodrich Company Prepared by: <u>Robert K. Hinderer</u> Robert K. Hinderer, Ph.D. Director, Health, Toxicology and Product Safety Date: <u>03/22/93</u>	

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Appendix F

PROJECT REPORT FOR VI TECHNICAL COMMITTEE MEETING

Date of Meeting: March 23, 1993

Objective of Project:

To Prevent Solvent Cements from being regulated adversely by the Clean Air Act.

Status Report:

The present status quo is maintained. With no new regulations from SCAQMD, the next deadline is 1/1/98 at which time new cements would have to be developed to meet the 250 g/l VOC requirement.

Recommended Action & Future Programs:

The various air management districts in CA have different test methods, VOC level targets, product size exemptions, and timetables from South Coast, so that there is a need for harmonization between the districts. Because South Coast is the dominant player, we hope to use our results as the model for the other districts. We are also considering legislation in CA to direct all districts to accept laws based on the South Coast model.

Meeting Agenda:

- | | |
|--|---------|
| 1) Are any decisions needed by the Technical Committee? | N |
| 2) Is a presentation and/or discussion needed? | Y |
| 3) How much meeting time should be scheduled for presentation? | 10 min. |

Prepared by: Donald Goodman

Date: February 18, 1993

VI TECHNICAL COMMITTEE PROJECT PROPOSAL

Project Title:
Nature of Program: ☐ Continuation of Existing Project ☐ New Project
Objective of Program:
Description of Planned Activity:
Deliverables:
Relevance/Importance of Project to Vinyl Industry:
Timing: Project Starting Date: _____ Anticipated Completion Date: _____
Project Cost: Finances needed in FY '93-'94 \$ _____ Other Resources Needed _____ Will funding be needed in future years ? (Y/N) _____ If yes, how much? _____
Priority: ☐ Urgent - Highest priority ☐ Important - Include in program if finances permit. ☐ Can be delayed until next fiscal year.
Project Proposed by: _____ Date: _____
Technical Committee Action: ☐ Approved and Included in Technical Committee Program/Budget ☐ Postpone until next fiscal year ☐ Not approved. Date of Technical Committee Action: _____

VI TECHNICAL COMMITTEE PROJECT PROPOSAL

Project Title: Seminar Program for Vinyl Fabricators
Nature of Program: ☐ Continuation of Existing Project ☒ New Project
Objective of Program: To increase awareness of fabricators of vinyl products of environmental issues facing the PVC industry so they can become involved in grass-roots activity in their communities to refute anti-vinyl allegations by industry's critics.
Description of Planned Activity: A series of regional seminars (3 or 4 in different geographical areas) will be conducted with industry speaker covering the topics given in the attached letter to Ron Mc Creedy dated December 14, 1993. Appropriate take-home materials similar to those developed for the outreach "On the Firing Line" seminars would be provided to attendees.
Deliverables: Three or Four regional seminar programs and distribution of information for vinyl fabricators to use in defending vinyl products from attacks by industry's opponents.
Relevance/Importance of Project to Vinyl Industry: This program will help educate fabricators so they can become spokesmen in defense of the industry.
Timing: Project Starting Date: <u>After June 1, 1993</u> Anticipated Completion Date: <u>About 3-4 months after start</u>
Project Cost: Finances needed in FY '93-'94 \$ 12,000 - \$15,000 ^{\$25,000} Other Resources Needed: <u>VI Company personnel as speakers</u> Will funding be needed in future years? (Y/N) <u>Yes, for follow-up</u> If yes, how much? \$ <u>2,500 to \$ 3,000</u>
Priority: ☐ Urgent - Highest priority ☒ Important - Include in program if finances permit. ☐ Can be delayed until next fiscal year.
Project Proposed by: _____ Date: _____
Technical Committee Action: ☐ Approved and Included in Technical Committee Program/Budget ☐ Postpone until next fiscal year ☐ Not approved. Date of Technical Committee Action: _____

① Focus group(s) during seminar development (Edward Howard & Co.)



December 14, 1992

Mr. Ronald L. McCreedy
Dow Chemical Co.
2020 Willard H. Dow Center
Midland, Michigan 48674

Dear Ron:

You will recall that at the last Technical Committee Meeting on September 17, it was decided that you and I would work together to arrange and set up a seminar/meeting with vinyl fabricators of consumer products on environmental issues of interest to the industry. In anticipation of our next Technical Committee meeting on January 20, listed below are the general subject matters that I believe would be desirable and appropriate for such a seminar:

1. Overview of environmental issues affecting the industry.
2. Health and Safety Issues
 - a) Angiosarcoma/Unit Risk Factors
 - b) Fire/Combustion toxicity
3. Solid Waste Management Issues
 - a) Recycling including VI programs for sortation and reclaiming
 - b) Incineration including Dioxin generation
4. Life Cycle Analysis (LCAs) -- Review of current "state of the art" on PVC LCAs and proper use and application of LCAs.
5. Global Issues including the Greenpeace anti-chlorine activity, linkage with PVC and what industry is doing to counter this attack.
6. The role of the vinyl processor -- What can they do to assure the continued health and growth of the industry.

Let me have your thoughts on this and we can plan to discuss this at the next Technical Committee meeting. I will be leaving Florida on December 15 to spend the next few weeks in Rhode Island where our daughter is expecting her fourth child. If you have any project summary reports, please send them to me at the address below. I will put together a proposed agenda shortly thereafter and send it to you for your review and approval. If you have any new items you can also send them to me at the following address:

Dr. Roy T. Gottesman
c/o Dr. Cheryl S. Gottesman
293 Doyle Avenue
Providence, Rhode Island 02906

or call me at (401) 272-4683. Hope you and yours have a Merry Christmas and a Happy New Year.

Sincerely yours,

cc: Robert H. Burnett

Roy

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PROJECT REPORT FOR VI TECHNICAL COMMITTEE MEETING

Date of Meeting: <u>3-23-93</u>	
Objective of Project: Determine if membrane separation is technically feasible for recovering HCl from incineration and pyrolysis processes.	
Status Report: Contacted John Orr (Air Products 216-447-8877) and Pat O'Brian (Air Products/Permea 313-995-3499). Permea's Prism membranes are a variety of polyimides, and can tolerate less than 5 ppm HCl. A Japanese and a U.S. company make polyamide membranes which have similar tolerance. Per Tom Salpesio at W.R. Grace (410-531-4000), Grace's cellulose acetate membranes are prone to attack by wet HCl. Dry CO ₂ , SO ₂ , and N ₂ will permeate with dry HCl in all of the above membranes, as well as others like polysulfone. Pumping the gas stream to 100-200 PSIG has very poor process economics, plus poor separation (only 4 to 10 x concentration rise).	
Recommended Action & Future Programs: Follow "perstraction" in the literature. This involves a caustic solution on one side of an HCl tolerant membrane, with the gas stream or aqueous stream on the other side. See work by R. Klaasen of TNO-IMET in Apeldoorn, Netherlands, specific to HCl separation in flue gases with hybrid polysulfone membranes.	
Meeting Agenda: 1. Are any decisions needed by the Technical Committee (Y/N)? <u>No</u> 2. Is a presentation and/or discussion needed (Y/N)? <u>No</u> 3. If Yes to either #1 or #2, how much total meeting time should be scheduled for presentation, discussion and/or decision (Minutes)? <u> </u>	
Prepared by: <u>Alan J. [Signature]</u>	Date: <u>3/10/93</u>

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PROJECT REPORT FOR VI TECHNICAL COMMITTEE MEETING

Date of Meeting: <u>3-23-93</u>	
Objective of Project:	
Develop methodology with Fred Clarke and Bill Abbott (Battelle) for a "Corrosion Hazard Assessment."	
Status Report:	
Clarke reviewed the Battelle Proposal and SPI Polyofins Divisional Report. Clarke can do a hazard assessment comparing relative corrosivity per unit mass burned from the phase one Battelle work. Abbott agreed to substitute a larger corrosion chamber so combustion gases are sampled and collected from the entire burn. Greg Smith from Geon believes this approach would give credible results. DuPont (Jim Hoover) was informed of our plan, and DuPont is inclined to participate.	
Recommended Action & Future Programs:	
1. Inquire if DuPont will participate and loan an NBS Burner. 2. Proceed with Battelle Phase I and Clarke's Hazard Assessment. 3. Review attached revised budget and discussion.	
Meeting Agenda:	
1. Are any decisions needed by the Technical Committee (Y/N)?	<u>Yes</u>
2. Is a presentation and/or discussion needed (Y/N)?	<u>Yes</u>
3. If Yes to either #1 or #2, how much total meeting time should be scheduled for presentation, discussion and/or decision (Minutes)?	<u>30</u>
Prepared by: <u>Alan J. Olson</u>	Date: <u>3/10/93</u>

The BFGoodrich Company
Technical Center
P.O. Box 122
Avon Lake, Ohio 44012
216-933-0100

February 4, 1993

Dr. Fred Clarke III
President
Benjamin/Clarke Associates
10605 Concord St., Suite 501
Kensington, MD 20893

re: Vinyl Institute Smoke Corrosivity Project

Fred,

The Vinyl Institute is seeking to fund a study comparing relative corrosion risks from several type of polymers exposed to a fixed fire scenario. This risk assessment would entail modeling a fire scenario (such as a wastebasket fire in an office) and estimating the corrosion potential as a function of the material's fire properties and corrosivity of its combustion products. As a starting point, we would like to compare PE to nylon, PVC, acrylic, PPO/PS and a fluoropolymer.

As a follow-up to our telephone conversation, I am enclosing two background documents. The first is work published by the SPI Polyolefins Division regarding corrosivity of smokes from various plastics burned in three different combustion tests at UL. The second is a proposal from Battelle to verify that corrosion does occur from plastic materials burned in the NBS calorimeter, and to speciate major components of those firegases.

Please judge whether the SPI Polyolefins Div. data from UL would suffice for the risk assessment, or whether additional data would be required from Battelle. If you wish, please contact DuPont (one of your other clients) to determine if they might participate in this study.

If you have any questions or comments, please direct them to me at the above address. I can be reached by phone at 216-933-1958 and by Fax at 216-933-1655. Bud Hall from Vista Chemical (phone 512-331-2425) will also be working with me on this project.

Best Regards,



A.J. Olson

cc: Lou Maresca (BFG)
Chuck Daniels (BFG)
Bud Hall (Vista)
Ron McCreedy (Dow)
Bob Burnett (VI)

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The Society of the Plastics Industry, Inc.
POLYOLEFINS FIRE PERFORMANCE COUNCIL
1275 K Street N.W., #400 • Washington, DC 20005



Carl F. Tripp
Managing Director

TEL: 203-438-1754
FAX: 203-431-4375

November 23, 1992

Mr. Allen Olsen
B.F. Goodrich
6100 Oak Tree Blvd.
Cleveland, OH 44131

Dear Allen,

We're happy to supply, as you requested, Jim Bennett's paper presented at the recent FRCA Conference.

As I mentioned on the phone, if you have any questions after reading it, please give me a call.

Sincerely,

Carl F. Tripp

CT:s
Enclosure

R&S 144329

CORROSIVITY TEST METHODS FOR POLYMERIC MATERIALS PART 4-CONE CORROSIMETER TEST METHOD

JAMES G. BENNETT, JR.
GE Plastics

STEPHEN L. KESSEL
Quantum Chemical Corporation, USI Division

CHARLES E. ROGERS
Union Carbide Corporation

ABSTRACT

This is the fourth in a series of papers to investigate corrosivity test methods published by the Polyolefins Fire Performance Council, an operating unit of The Society of the Plastics Industry, Inc.

In the first paper, 24 polymeric materials were evaluated for smoke corrosivity following the test method proposed by ASTM E05.21.70 which uses a radiant combustion/exposure apparatus. The second paper discussed the evaluation of the same materials using the CNET corrosion test method under consideration by ISO TC61/SC4/WG2 and IEC TC89/WG3 and compared the CNET results with the ASTM E05.21.70 results. In the third paper, the 24 polymeric materials were evaluated using a modified DIN acid gas test method and the results were compared to both the previous ASTM E05.21.70 and CNET results. These commercially available polymeric materials cover a broad range of compositions used for wire and cable insulation and jacketing.

In this paper, the same polymeric materials were evaluated following the "Fire Response Standard For Determining the Corrosive Effect of Combustion Products Using a Cone Corrosimeter" proposed by ASTM D09.21.04. In this test method, a specimen is subjected to radiant heat at the recommended heat flux using a spark igniter to ignite combustible vapors. A portion of the products of decomposition or combustion are channeled in a dynamic mode through an exposure chamber in which corrosion targets are placed until the specimen has lost 70% of its total available mass loss. The mass loss is determined from previous experiments at the recommended heat flux. When the specimen has lost 70% of its mass loss, the exposure chamber is sealed and isolated. The corrosion of the target is determined by exposing the target to the now static combustion products

for one hour measured from the start of the test. The target is then placed in an environmental chamber at 75% relative humidity at 23°C for 24 hours. The test method measures the increase in electrical resistance of a metallic circuit. This increase is related to the decrease in conductive cross-sectional area resulting from metal loss due to corrosion. The increase in electrical resistance of each target is determined throughout the test and correlated to its metal loss. The 24 hour corrosion value is reported as metal loss in Angstroms.

In this study, heat fluxes of 25 and 50 kW/m² were used to simulate two different fire scenarios. All of the materials were run at 50kW/m² and 12 materials were run at 25 kW/m². Two targets, one with a span of 2,500 Å and the second with a span of 45,000 Å, were used during each test at each heat flux.

The results of this study indicate that the measured corrosivity of materials: (i) does not correlate consistent with the expectations based upon the known chemistry of their compositions (ii) varies numerically with the heat flux under which the tests are run and on the target used to obtain the corrosion data and (iii) although numerically different, loosely ranks the corrosive potentials of the materials in a consistent manner at both heat fluxes and with both targets.

The test protocol does not specify either the heat flux or the targets to be used recommending both in the Appendix. As corrosion values are numerically dependent on the conditions and target used to obtain the data, it is questionable how this test method can be used as a standard for determining and comparing the corrosion potentials of materials without requiring that both the specific heat flux and the target be specified in the test protocol as well as be reported with the results.

To complete the review of corrosion test methods, a comparison of the corrosive potentials of the 24 materials using the four test methods will be made and one test method recommended for use as a global standard.

INTRODUCTION

The effects of smoke and corrosive gases released in a fire are gaining increased attention due to the damage they cause to electronic equipment. While tests to determine smoke obscuration have been standardized and tests to determine toxicity are available, only recently have tests to measure smoke corrosivity been developed. Recent fire events have underscored the need for standardized tests that measure corrosivity, as corrosion is particularly important with fires in and around computer and telecommunications equipment.

To better define test methods that measure smoke corrosivity of polymeric materials and products used in the wire and cable industry, the Polyolefins Fire Performance Council (PFPC) initiated a program to compare corrosivity test methods under discussion around the world today. The specific goal of the program is to determine the suitability of proposed test methods for measuring corrosive potentials of polymeric materials. The Council has been an operating unit of The Society of the Plastics Industry, Inc. since 1989. It consists of the eight member companies listed in Table I.

Table I. Member Companies of the Polyolefins Fire Performance Council

Carl F. Tripp, Managing Director

BP Chemicals	J.M.Huber Corporation, Solem Division
Dow Chemical Company	Lonza Inc.
GE Plastics	Quantum Chemical Corporation, USI Division
Himont Inc.	Union Carbide Corporation

To accomplish this program goal, the PFPC decided to evaluate the four methods currently under consideration for global standardization: (i) the radiant combustion/exposure smoke corrosivity test method proposed by ASTM E05.21.70, (ii) the CNET combustion test method under review by ISO TC61/SC4/WG2 and IEC TC89/WG3, (iii) the DIN 57 472 acid gas standard test method which measures pH and aqueous conductivity changes and (iv) the cone calorimeter test method under review by ASTM D09.21.04 which uses a conical radiant heater system for generation of combustion gases.

The results using the ASTM E05.21.70 proposed "Standard Test Method For Measuring the Corrosive Effect of Smoke From the Burning or Decomposition of Materials and Products" with a radiant combustion/exposure apparatus were presented at the November 1991 International Wire and Cable Symposium (1). The data demonstrated that this test method did differentiate the corrosion potential of polymeric materials consistent with the expectations based on the known chemistry of their compositions.

The results of the CNET test method "Plastics - Smoke Generation - Determination of the Corrosivity of Fire Effluents (Static Method)" were presented at the Seventeenth International Conference on Fire Safety held in January 1992 (2). The CNET test method did not appear to measure an expected corrosion response for some materials, such as chlorinated polyolefins, fluoropolymers and polyethylenes with chlorinated and brominated additives. The information generated in the CNET test may be useful for some type of corrosive index where it is desired to take into account the presence of a flame to maintain combustion, but based on the incomplete sample weight loss, not for determining the corrosive potential of materials.

The results of the modified DIN test method "Testing of Cables, Wires and Flexible Cords; Corrosivity of Combustion Gases DIN 57 472 Part 813 Standard" were presented at the Fire Retardant Chemicals Association March 1992 meeting (3). The corrosive potentials of the 24 materials were differentiated as determined by solution conductivity and pH and correlated well with the results obtained from the ASTM E05.21.70 test method. The modified DIN results did not correlate with the % Corrosivity Factor "COR" obtained from the CNET test method.

The polymeric materials evaluated include a wide and balanced selection of wire and cable coating materials. The list contains non-halogenated filled polyolefins, polyolefins

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containing halogen flame retardants, halogenated polymers, high temperature thermoplastics, polyolefin and nylon base resins plus a Douglas fir reference material.

All of the cone calorimeter experiments were performed at the Underwriters Laboratory at Northbrook, Illinois under the direction of Dr. Pravinray Gandhi.

In a future publication, the corrosive potentials of these 24 polymeric materials determined using the four different corrosivity test methods will be compared. This will be the first time a direct comparison of the test methods using identical polymeric materials has been made. It is particularly important as corrosivity test methods are being standardized to determine and understand whether each test gives accurate results as well as relative results in terms of ranking materials by their corrosive potentials.

MATERIALS EVALUATED

Table II lists the 24 polymeric materials evaluated for smoke corrosivity. These resins and compounds represent a broad sampling of polymeric materials that are used in wire and cable jacketing and insulation applications. They are all commercially available.

The table covers polymeric materials that retard flame spread by several means. Some materials contain hydrated mineral fillers compounded with polyolefin resins or resin blends (Samples 1,4,10,11,12,13,14 and 15). They retard flame spread by endothermic release of water-of-hydration.

One material is an intumescent polypropylene compound containing a phosphorus flame retardant additive (Sample 8). This material retards flame spread by formation of a char barrier and its flaming characteristics are different from most of the others listed in the table.

There are two types of halogenated flame retardant materials included. Some contain halogenated additives (Samples 16 and 25) and others have halogen chemically bonded to the polymer backbones (Samples 2,3,17,18,19 and 20). The brominated and chlorinated materials deter flame spread by halogen release and subsequent formation of flame poisoning radicals. They act in the vapor phase to extinguish flame, often through the synergistic action of the halogenated species with antimony oxide. The fluoropolymers are halogenated materials that have a very high limiting oxygen index and retard flame spread by being difficult to ignite.

Included are three high temperature thermoplastic materials. Sample 5 is a polymer alloy containing a phosphorus flame retardant additive. Sample 6 is an unfilled PEI resin and Sample 7 is a PEI/siloxane copolymer that resists flame spread by the formation of a char barrier. Samples 6 and 7 are also difficult to ignite so they also retard flame spread by resisting ignition.

Also included are three unfilled base resins (Samples 21,23, and 24) from different suppliers so that a comparison of filled versus unfilled resins could be made.

Finally, Douglas fir (Sample 22) was included as a standard as it is widely used as a

control in the flame testing of materials for the building industry.

EXPERIMENTAL

SCOPE OF THE ASTM D09.21.04 TEST METHOD

This fire test response standard measures the corrosive effect, defined as the loss of metal, from exposure to combustion products of materials, components or products using a cone corrosimeter. A cone corrosimeter is defined as the equipment used to measure corrosion by metal loss using a conical radiant heater, a load cell, an exhaust system and a gas sampling system.

SUMMARY OF TEST METHOD

In this test method, a specimen is subjected to radiant heat at the recommended heat flux using a spark igniter to ignite combustible vapors. A portion of the products of decomposition or combustion are channeled through an exposure chamber in a dynamic mode in which the corrosion targets are placed until the specimen has lost 70% of its total mass loss, determined from previous experiments at the recommended heat flux. When the specimen has lost 70% mass loss, the exposure chamber is sealed and isolated. The corrosion on the target is determined by exposing the target to the now static combustion products for one hour measured from the start of the test, followed by 24 hour exposure of the target to 75% relative humidity at 23°C in an environmental chamber. The test method measures the increase in electrical resistance of a metallic circuit using a corrosometer, a modified Kelvin bridge type instrument that measures the change in resistance of targets. This increase in resistance is related to the decrease in conductive cross-sectional area resulting from metal loss due to corrosion. The increase in electrical resistance of each target is monitored throughout the test and correlated to its metal loss. The 24 hour corrosion value is reported as metal loss in Angstroms.

The test protocol does not specify either the heat flux or the targets to be used. Both are recommended in the Appendix. The Appendix however, is not part of the test method. In this study, heat fluxes of 25 and 50 kW/m² were used to simulate two different fire scenarios. Two targets were used during each test at each heat flux, Model 610 with a span of 2500 Å and Model 030788-S0.35-8061 with a span of 45,000 Å. The targets are available from Rohrback Cosasco Systems.

CONE CORROSIMETER APPARATUS

The test apparatus, shown in Figure 1, uses a Cone Corrosimeter or the Cone Calorimeter test equipment as described in ASTM E 1354-90 with the addition of a gas sampling system. The system consists of a conical heater, a temperature controller, an exhaust system, a load cell, a specimen holder, an ignition circuit, a gas sampling system and a corrosion target.

The gas sampling system consists of a conical funnel, stainless steel gas sampling tip, stainless steel tubing, electrical heating tape, silicone rubber tubing, flowmeter, exposure chamber, target support stand and pump. The exposure chamber is shown in Figure 2.

Table II. Polymeric Materials Evaluated

PFPC Number	Company	Product Designation	Material Description
1	BP	EXP 839	XL olefin elastomer with metal hydrate filler
2	DOW	5435-30-11	Blend of HDPE and chlorinated PE elastomer
3	DOW	5348-40-1	Chlorinated PE with fillers
4	EXXON	EX-FR-100	EVA polyolefin with ATH filler
5	GEP	NORYL®PX1766	Polyphenylene oxide/polystyrene blend
6	GEP	ULTEM®1000	Polyetherimide
7	GEP	SILTEM®STM1500	Polyetherimide/siloxane copolymer
8	HIMONT	EXP 127-32-6	Intumescent polypropylene
9	LONZA		Nylon with mineral filler
10	UCC	UNIGARD™RE DFDA-1736NT	Polyolefin copolymer with mineral filler
11	UCC	UNIGARD™RE HFDA-1393BK	XL polyolefin copolymer with mineral filler
12	QUANTUM	PETROTHENE® XL 7403	XL polyolefin copolymer with ATH filler
13	QUANTUM	PETROTHENE® YR 19535	XL polyolefin copolymer with ATH filler
14	QUANTUM	PETROTHENE® YR 19543	EVA polyolefin with mineral filler
15	UCC	UCARSIL® FR-7920NT	Polyolefin with mineral filler
16	BP	POLYCURE™798	XL polyethylene copolymer with chlorinated additive
17	COMMERCIAL SAMPLE		A polyvinylidene fluoride material
18	COMMERCIAL SAMPLE		A polytetrafluoroethylene material
19	COMMERCIAL SAMPLE		A PVC material
20	COMMERCIAL SAMPLE		A PVC building wire compound
21	UCC	DGDK-3364NT	Polyethylene homopolymer
22			Douglas fir
23	QUANTUM	ULTRATHENE® UE 631	EVA polyolefin copolymer®
24	NYLET	P50	Nylon 6,6
25	UCC	UNIGARD™HP HFDA-6522NT	XL polyethylene copolymer with brominated additive

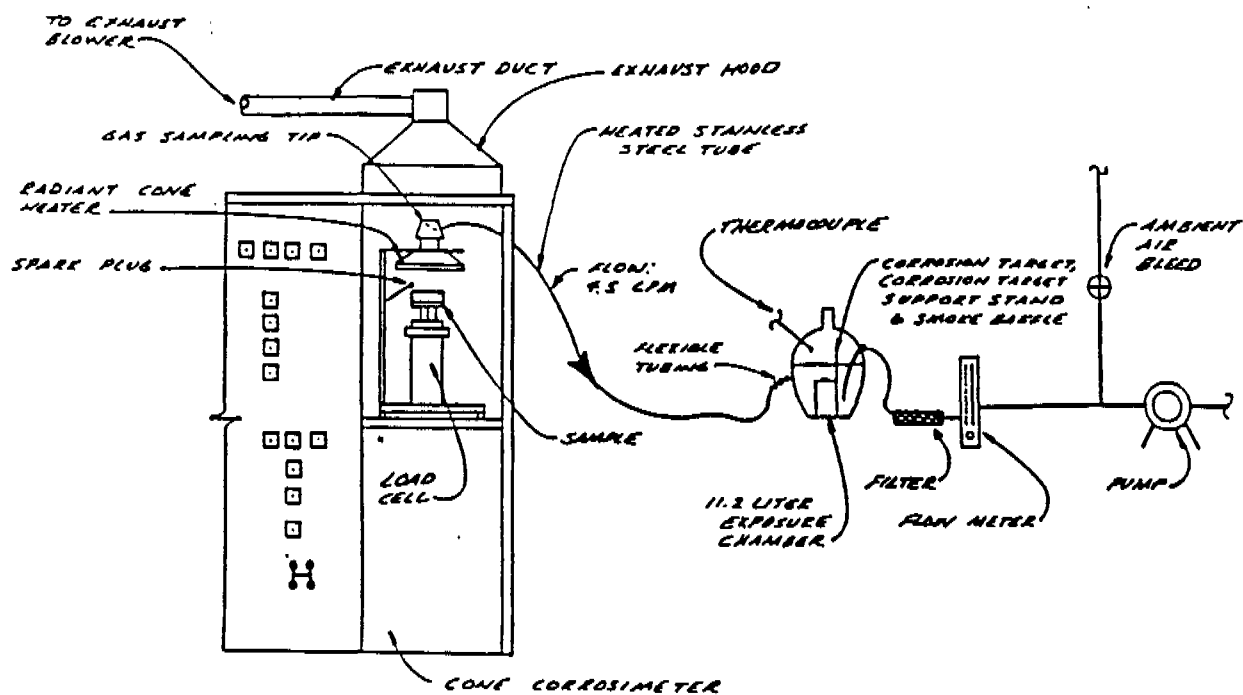


Figure 1 Equipment for Corrosion Testing

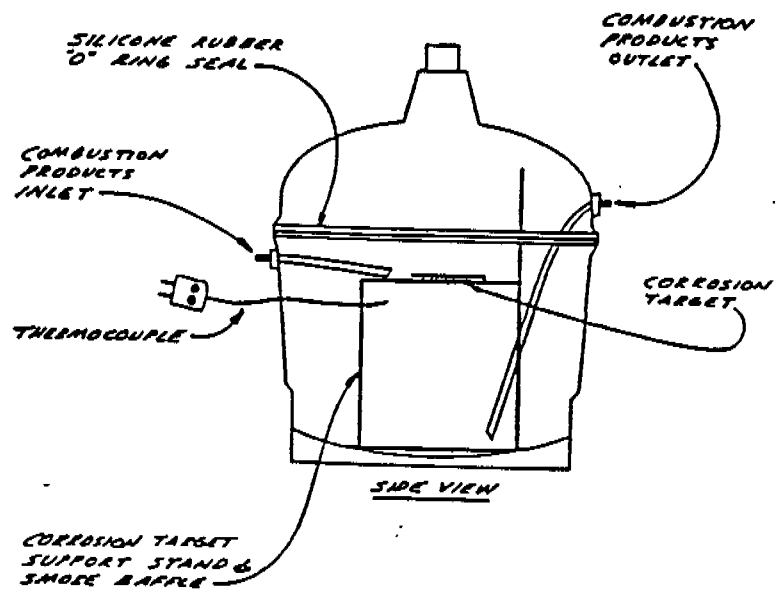


Figure 2 Exposure Chamber

SAMPLES

The test protocol states that the types of specimens permitted are materials in the form of a flat plaque, constituents of a product, or an end-use product. When the specimen is a material or a constituent of a product, the specimen size is 100 x 100 x 6.3 mm (4 x 4 x 0.25 inches). The specimens used for this study were molded plaques.

TEST PROCEDURE

After setting the exhaust flow rate to 0.024 m³/s, both the heater flux and the load cell are calibrated. The initial mass of the specimen is recorded. The specimen is wrapped in a single layer of aluminum foil and the foil cut along the open edges of the specimen so that the top of the specimen is exposed. The grid, used to prevent fouling of the spark igniter with samples that intumesce, is placed on top of the specimen and the assembly is placed in the specimen holder. The sampling system is checked for leaks by pinching off the flexible tubing with clamps and noting that the flow from the flowmeter drops to zero.

Prior to conducting corrosion tests, two mass loss determination tests were conducted, without corrosion gas sampling, on each material to establish the total mass loss at the designated heat flux. The data is reviewed to determine 70% mass loss using an average of the data from the two tests.

The test is started by placing the specimen, held in the sample holder, on the load cell and simultaneously starting the ignition timer and the data collection system. The spark plug is placed over the test specimen and the power turned on. Termination of the sampling flow occurs when the specimen has lost 70% of the total mass loss determined previously or 60 minutes have elapsed after the start of the test. The inlet and outlet lines of the exposure chamber are sealed with clamps and the combustion products are allowed to react with the corrosion targets for a total of 1 hour measured from the start of the test.

The targets are then placed in an environmental chamber with a dry bulb temperature of 23°C and 75% relative humidity for 24 hours. After 24 hours in the environmental chamber the resistance value of the corrosion target is recorded and the metal loss determined.

RECORDED DATA

The following information is recorded during the test: sample identification and composition, date, room temperature and relative humidity, specimen thickness and mass, radiant heat flux, corrosion target span and identification, volumetric sampling rate, time to sustained flaming, mass lost data, exposure chamber temperature, time of test start, sampling time and corrosometer values of the targets at the start of the test, at the end of the 1 hour combustion products exposure and at the end of the 24 hours of post-exposure in the environmental chamber.

FLAMMABILITY PARAMETERS

During the experiments to determine total available mass loss the following flammability data was obtained for the 24 materials and will be reported in a future publication: time to ignition, maximum heat release, total heat release, average heat of combustion and average specific extinction coefficient. This is an extremely valuable portion of the cone calorimeter test method as it provides a variety of flammability parameters on materials in addition to corrosion data.

SUMMARY OF CORROSION DATA

The corrosion results obtained at a heat flux of 25 kW/m² using both targets are shown in Table III with the results at 50 kW/m² shown in Table IV. For ease of comparison, the 25 kW/m² data is plotted in Figure 3 with Figure 3A illustrating the data from the 2,500 Å span target and the data from the 45,000 Å span target shown in Figure 3B. The 50 kW/m² data is shown similarly in Figure 4. A comparison of the two heat fluxes is plotted in Figures 5A and 5B.

DISCUSSION OF RESULTS

DRIPPING

During the testing, a problem occurred with the PTFE Sample 18, the PE homopolymer Sample 21 and the EVA homopolymer Sample 23. At both heat fluxes all of the specimens of these materials melted over the edges of the sample pan dripping off the load cell onto the bottom of the combustion chamber. When this occurred the determination of mass loss became invalid as did the corrosion results. This problem could be corrected by the use of a sample pan with higher walls or by placing the smaller sample pan in a second larger pan, as long as the irradiance level remains constant, so the sample materials do not fall off the load cell when this phenomenon occurs.

COMPARISON OF TARGETS

Several observations were made after reviewing the data. The first is the apparent severity of the test method. At 50 kW/m² with the 2,500 Å span target, most of the materials appear to be corrosive. This data is difficult to correlate with the compositions of the materials tested. It is not clear why Samples 1, 4 and 11 containing metal hydrate, ATH and mineral fillers respectively and unfilled nylon Sample 24 showed corrosive potentials greater than Sample 25 containing a brominated flame retardant additive. This raises serious questions regarding the accuracy and usefulness of this test method.

The second observation is that the corrosion values varied numerically with the target used to obtain the data. The differentiation of the corrosive potentials using the 2,500 Å span target is limited by the large number of materials where the corrosion exceeded the capacity of the target driving them off-scale (Samples 3, 17 and 19 at 25 kW/m² and Samples 2, 3, 16, 17, 19 and 24 at 50 kW/m²).

The 45,000 Å span targets are less sensitive especially with materials having low corrosion. A distinct advantage of the higher span targets is that they provide a broader overall differentiated picture of corrosive potentials. The samples that went off-scale in Figure 4A are clearly differentiated in Figure 4B.

This data indicates that there is no one target available to determine, with equal sensitivity, the corrosivity of materials with both high and low corrosion potentials. The sputtered 2,500 Å span targets have thickness and surface morphology limitations inherent to the sputtering process and the 45,000 Å span targets, constructed from the thinnest copper film currently available, appear to exhibit a slower rate of corrosion than the sputtered target. Few field products use either technique raising the question of which target design is representative of end-use applications.

The test protocol does not specify the target to be used. The Appendix, a nonmandatory part of the test method, recommends the use of the 2,500 Å span target for materials with low corrosivity and the 45,000 Å span target for materials with high corrosivity. The protocol states that the corrosion values obtained using either target at either heat flux are numerically interchangeable and suitable for use in fire risk assessment. The data presented clearly shows this is not the case. The 2,500 Å span target yields corrosion values consistently higher than those obtained using the 45,000 Å span target except when the capacity of the lower span target is exceeded. As it is not known which results are accurate, the authors recommend that no attempt should be made to interchange the numerical corrosion values from the two model probes.

The third observation is that the corrosion results, although numerically different, loosely ranked the materials in a consistent manner with both targets at both heat fluxes. Additional testing would be required to determine if a correlation truly exists between the corrosion values obtained from the two targets.

COMPARISON OF HEAT FLUXES

A comparison of the two heat fluxes used in this study, 25 kW/m² and 50 kW/m², is shown in Figure 5. Four of the samples did not ignite at the lower flux. All of the samples ignited at the higher flux level. Figure 5A compares the corrosivity using the 2,500 Å span target. At the higher heat flux, the corrosivity of some materials increased (Samples 1, 6 and 12), some stayed the same (Sample 25) other than those that went off-scale and some decreased (Samples 8 and 11).

In Figure 5B with the 45,000 Å span target, no corrosion levels increased, some remained the same (Samples 1, 6, 8, 11 and 25) and some decreased (Samples 3, 17 and 19) at the higher flux. However, the same materials did not respond similarly at both heat fluxes and with both targets.

Lacking an understanding as to the reasons for these materials to behave differently, the conditions under which the corrosivity is determined must be specified in the test protocol as well as be reported with the results.

REPRODUCIBILITY OF THE TEST METHOD

To better define the reproducibility of the test method, 6 specimens of Sample 6 were run at 50 kW/m² so that a reasonable statistical treatment of the data could be performed. Previous papers used Sample 21 for reproducibility data but in this study Sample 21 dripped off the load cell invalidating the corrosion data so data from Sample 6 was used.

Table V. Standard Deviation Calculations For Sample 6

PFPC #	Time to Ignition (sec.)	Time to 70% Mass Loss (minutes)	24 hr Metal Loss 2,500 A Target (Angstroms)	24 hr Metal Loss 45,000 A Target (Angstroms)
6A	108	13	1546	360
6B	124	15	697	248
6C	138	13	126	0
6D	135	15	2305	473
6E	134	14	2004	608
6F	114	15	(2730)	653
AVERAGE	126	14	1568	390
STANDARD DEVIATION	12	1	992	244

The standard deviations of both corrosion values are considered high as they are 63% of the average, indicating a wide measure of dispersion in the data. This points out a needed improvement with this test method, especially if it is to be considered for use as a global standard. It is interesting to note that Samples 6A, B and C were run consecutively at one time and Samples 6D, E and F were run consecutively at a later date. A review of the data on Tables III and IV reveals many instances where one data point appears to be out of line, skewing the average. Additional runs are needed to provide sufficient data to determine whether such points can be statistically discarded. In this paper all data is presented with none discarded.

CONCLUSIONS AND RECOMMENDATIONS

1. THE CORROSIVITY OF SOME OF THE POLYMERIC MATERIALS EVALUATED USING THIS TEST METHOD DID NOT CORRELATE IN A MANNER CONSISTENT WITH EXPECTATIONS BASED UPON THE KNOWN CHEMISTRY OF THEIR COMPOSITIONS. THE TEST METHOD DID NOT APPEAR TO MEASURE AN EXPECTED CORROSION RESPONSE TO SOME MATERIALS, SUCH AS UNFILLED MATERIALS, MINERAL FILLED MATERIALS AND A MATERIAL CONTAINING A BROMINATED ADDITIVE.

2. THE NUMERICAL CORROSION VALUES OF THE MATERIALS VARIED INCONSISTENTLY WITH BOTH THE HEAT FLUX AND THE TARGET USED. IT IS RECOMMENDED (A) THAT THE NUMERICAL CORROSION VALUES NOT BE USED INTERCHANGEABLY AND (B) TO AVOID CONFUSION, BOTH THE HEAT FLUX AND TARGET SHOULD BE SPECIFIED IN THE TEST PROTOCOL AS WELL AS REPORTED WITH THE RESULTS.

3. THE 2,500 Å SPAN TARGETS YIELD CORROSION VALUES CONSISTENTLY HIGHER THAN RESULTS OBTAINED USING THE 45,000 Å SPAN TARGETS, GOING OFF-SCALE WITH MATERIALS WITH HIGH CORROSION.

4. THE TARGETS WITH 45,000 Å SPAN ARE LESS SENSITIVE RESULTING IN LOWER CORROSION VALUES THAN THOSE OBTAINED USING THE 2,500 Å SPAN TARGETS. THEY PROVIDE DIFFERENTIATION OF MATERIALS WITH BROADER CORROSIVE POTENTIALS, BUT WITH LESS RESOLUTION.

5. CORROSION OCCURRED EVEN WHEN THE SAMPLES DID NOT IGNITE.

6. SEVERAL MATERIALS BUBBLED OUT OF THE SAMPLE PAN DRIPPING OFF THE LOAD CELL. A CHANGE IN PAN DESIGN TO KEEP THIS MATERIAL ON THE LOAD CELL WOULD PREVENT LOSS OF DATA WHEN THIS PHENOMENON OCCURS.

7. THE REPRODUCIBILITY OF THE DATA USING THIS TEST METHOD IS POOR, POINTING OUT A FUTURE DEVELOPMENTAL NEED. AT THIS TIME IT IS NOT UNDERSTOOD WHETHER THE LACK OF REPRODUCIBILITY RESULTS FROM THE COMBUSTION METHOD, THE GAS SAMPLING TECHNIQUE OR THE TARGET MEASUREMENT SYSTEM.

ACKNOWLEDGMENTS

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Table III. Summary of Test Results at 25kW/m²

PFPC #	Time to Ignition (sec.)	Time to 70% Mass. Loss (minutes)	24 hr Metal Loss 2,500 A Target (Angstroms)	24 hr Metal Loss 45,000 A Target (Angstroms)
1A	418	24	592	0
1B	430	25	2151	1980
1C	412	26	1338	450
1 AVERAGE	410	25	1694	810
3A	160	17	(2675)*	7380
3B	163	16	(2675)*	6345
3C	175	17	(2675)*	2790
3 AVERAGE	166	17	(2675)*	5505
6A	DNI	15	284	135
6B	DNI	19	120	113
6C	DNI	14	266	158
6 AVERAGE	DNI	16	233	135
8A	114	29	1965	810
8b	111	31	1966	540
8c	122	25	2026	585
8 AVERAGE	116	28	1986	645
11A	389	23	(2675)*	495
11B	400	21	1934	608
11C	392	21	2342	810
11 AVERAGE	394	22	(2317)	638
12A	673	22	206	0
12B	690	22	96	0
12C	690	21	156	180
12 AVERAGE	684	22	153	60
17A	DNI	23	(2675)*	2790
17B	DNI	23	(2675)*	2340
17C	DNI	23	(2675)*	4455
17 AVERAGE	DNI	23	(2675)*	3195
18A	DNI	**	**	**
18B	DNI	**	**	**
18C	DNI	**	**	**
18 AVERAGE	DNI	**	**	**

* READING IN EXCESS OF TARGET SPAN

** SAMPLE DRIPPED; MASS LOSS / CORROSION DATA NOT VALID

*** SAMPLE NOT AVAILABLE AT TIME OF TESTING

() ASSUMES MAXIMUM TARGET SPAN

DNI = DID NOT IGNITE

NR = NOT RECORDED

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Table III. Summary of Test Results at 25kW/m² Continued

PFPC #	Time to Ignition (sec.)	Time to 70% Mass Loss (minutes)	24 hr Metal Loss 2,500 A Target (Angstroms)	24 hr Metal Loss 45,000 A Target (Angstroms)
19A	DNI	14	(2675)*	17505
19B	DNI	14	(2675)*	20745
19C	DNI	14	(2675)*	23220
19 AVERAGE	DNI	14	(2675)*	20490
21A	227	**	**	**
21B	228	**	**	**
21C	234	**	**	**
21 AVERAGE	236	**	**	**
25A	516	12	1882	698
25B	514	12	1990	630
25C	492	11	1098	113
25 AVERAGE	507	12	1657	480

Table IV. Summary of Test Results at 50 kW/m²

PFPC #	Time to Ignition (sec.)	Time to 70% Mass Loss (minutes)	24 hr Metal Loss 2,500 A Target (Angstroms)	24 hr Metal Loss 45,000 A Target (Angstroms)
1A	91	16	(2675)*	606
1B	86	18	1568	450
1C	90	20	(2675)*	743
1 AVERAGE	89	18	(2305)	600
2A	54	11	(2675)*	4095
2B	49	11	(2675)*	4320
2C	50	11	(2675)*	5738
2 AVERAGE	51	11	(2675)*	4718
3A	38	9	(2675)*	4905
3B	38	NR	(2675)*	1350
3C	39	10	(2675)*	189
3 AVERAGE	38	10	(2675)*	2148
4A	86	14	2030	428
4B	88	NR	1949	450
4C	86	15	1398	315
4 AVERAGE	87	15	1792	398

Table IV. Summary of Test Results at 50 kW/m² Continued

PFPC #	Time to Ignition (sec.)	Time to 70% Mass Loss (minutes)	24 hr Metal Loss 2,500 A Target (Angstroms)	24 hr Metal Loss 45,000 A Target (Angstroms)
5A	55	5	(2675)*	405
5B	55	5	797	405
5C	55	5	1445	630
5 AVERAGE	55	5	(1639)	480
6A	108	13	1546	360
6B	124	15	697	248
6C	138	15	126	0
6 AVERAGE	123	14	790	203
7A	66	8	1755	585
7B	80	10	1511	653
7C	74	9	1394	383
7 AVERAGE	73	9	1553	540
8A	27	7	1715	653
8B	24	9	1883	585
8C	24	10	1418	383
8 AVERAGE	25	9	1672	540
9 ***				
10A	131	17	1926	608
10B	127	16	1440	563
10C	126	17	1899	675
10 AVERAGE	128	17	1755	615
11A	123	15	2009	583
11B	122	15	1935	473
11C	115	15	2036	810
11 AVERAGE	120	15	1993	622
12A	139	12	263	90
12B	138	12	380	0
12C	160	12	350	135
12 AVERAGE	146	12	331	75
13A	70	11	1386	518
13B	74	11	1621	653
13C	67	12	2386	765
13 AVERAGE	70	11	1798	645

Table IV. Summary of Test Results at 50 kW/m² Continued

PFPC #	Time to Ignition (sec.)	Time to 70% Mass Loss (minutes)	24 hr Metal Loss 2,500 A Target (Angstroms)	24 hr Metal Loss 45,000 A Target (Angstroms)
14A	65	7	1519	473
14B	45	7	(2675)*	495
14C	63	9	1962	518
14 AVERAGE	58	8	(2052)	495
15A	86	14	1901	630
15B	91	13	1736	450
15C	88	13	(2675)*	608
15 AVERAGE	88	13	(2104)	563
16A	83	7	(2675)*	1845
16B	61	6	(2675)*	1485
16C	75	6	(2675)*	2565
16 AVERAGE	73	6	(2675)*	1965
17A	766	12	(2675)*	2925
17B	891	12	(2675)*	2385
17C	803	13	(2675)*	2048
17 AVERAGE	820	12	(2675)*	2453
18A	204	**	**	**
18B	212	**	**	**
18C	NR	**	**	**
18 AVERAGE	208	**	**	**
19A	33	9	(2675)*	2903
19B	41	10	(2675)*	5760
19C	39	10	(2675)*	6953
19 AVERAGE	38	10	(2675)*	5205
20 ***				
21A	67	**	**	**
21B	61	**	**	**
21C	NR	**	**	**
21 AVERAGE	64	**	**	**
22A	29	13	1645	585
22B	27	NR	(2675)*	698
22C	29	13	1420	383
22 AVERAGE	28	13	1913	555

Table IV. Summary of Test Results at 50 kW/m² Continued

PFPC #	Time to Ignition (sec.)	Time to 70% Mass Loss (minutes)	24 hr Metal Loss 2,500 A Target (Angstroms)	24 hr Metal Loss 45,000 A Target (Angstroms)
23A	47	**	**	**
23B	49	**	**	**
23C	56	**	**	**
23 AVERAGE	51	**	**	**
24A	114	6	(2675)*	878
24B	70	5	(2675)*	878
24C	96	5	(2675)*	3375
24 AVERAGE	93	5	(2675)*	1710
25A	89	6	1893	450
25B	93	6	1654	315
25C	114	5	1522	540
25 AVERAGE	99	6	1700	435

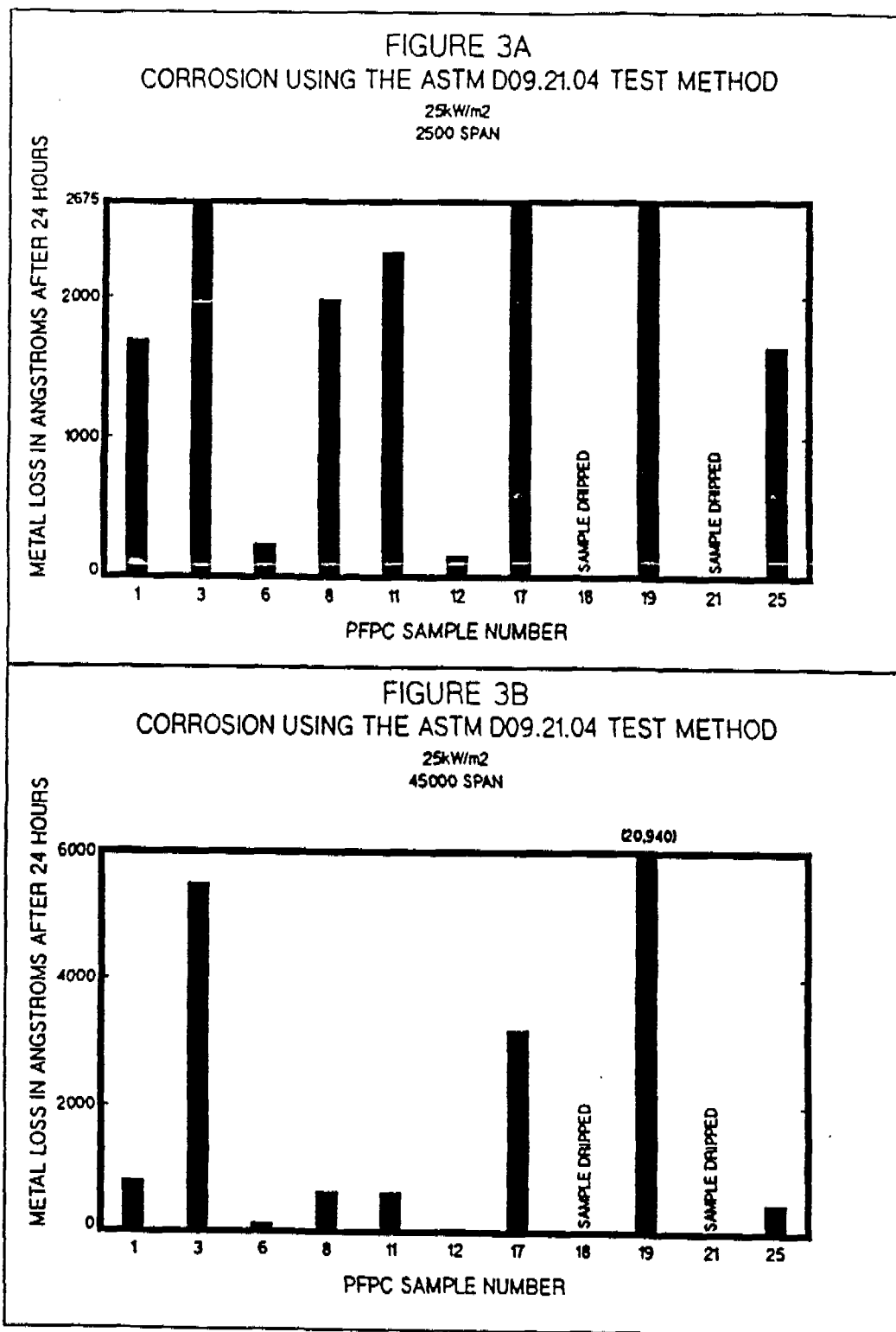


Figure 3 Comparison of Corrosivity Using Different Targets
at 25 kW/m²

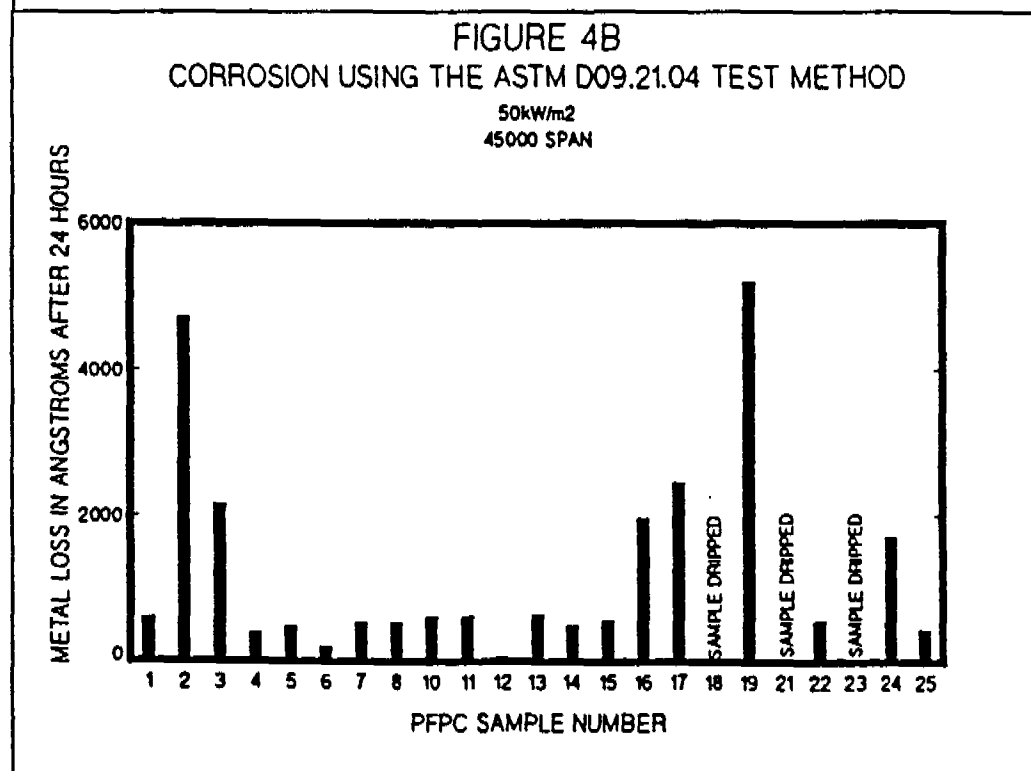
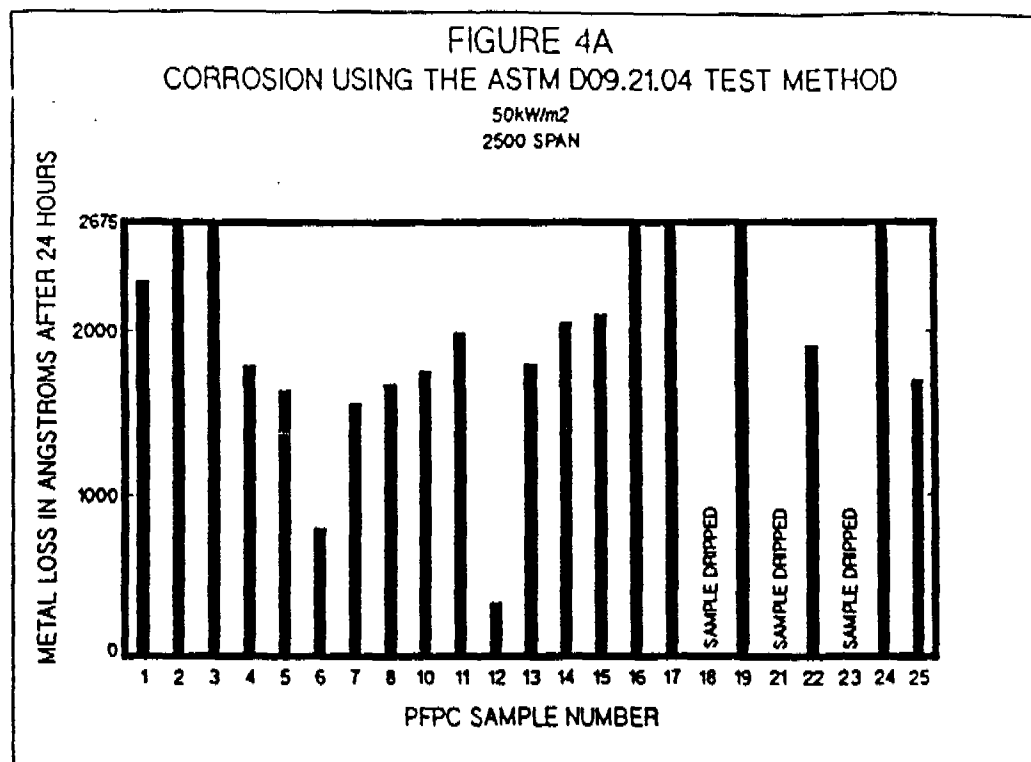


Figure 4 Comparison of Corrosivity Using Different Targets
at 50 kW/m²

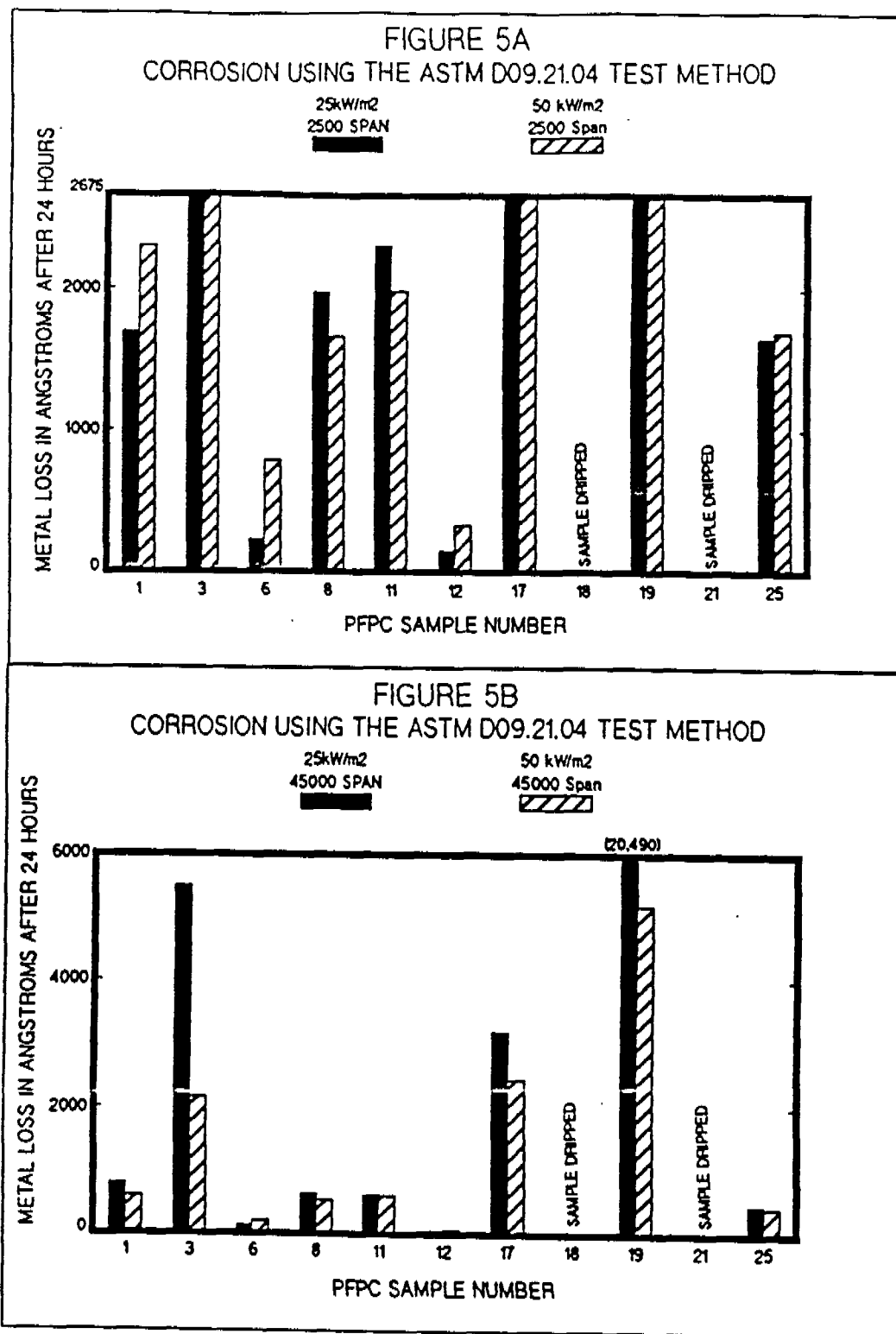


Figure 5 Comparison of Corrosivity at 25 kW/m² and 50 kW/m²
Using Targets With Different Spans