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Environmental Chamber Determinations of VOC Emissions from Sources of Indoor Air Pollutants: Overview of Protocols, Applications, and Issues

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ABSTRACT

The use of environmental chambers to characterize VOC emissions from sources of indoor air pollutants has increased in recent years. Far greater commercial and research use is expected in the next few years. Results are used by manufacturers during product development to assess the potential strength and, in rare instances, the potential health effects of exposure to emissions from their products. Increasingly emissions test results are used to satisfy inquiries from potential customers including individual consumers as well as building design professionals who are selecting and specifying products.

Environmental chamber testing to determine VOC emissions rates is expensive, time consuming, and not always definitive. Advances in automation of sample collection, analysis, and compound identification/quantification may reduce personnel costs which constitute the major cost element. However, considerable investments in developing and acquiring such improvments will be necessary before reasonable cost levels can be attained by a significant number of laboratories.

Knowledge of health effects from exposure to most emissions is insufficient, especially at the low concentrations usually found in indoor air. Furthermore, the effects of exposure to complex mixtures is almost entirely lacking. Recent application of bioassay techniques to determine irritation and neurotoxicity of some sources of indoor air pollutants presents some promise for the increasing the knowledge base in the intermediate term future, but the use of such methods is still very limited due to their cost and the general lack of awareness of their utility.

Interpretation of data and comparison of results from testing performed on different product types or by different investigators is difficult because standardized test prtocols promulgated by either government or private organizations are lacking for most product and material types. Efforts to develop standards have been burdened by the large differences in the requirements for testing diverse types of products such as architectural coatings, adhesives, caulks, composite wood products, floor and wall coverings, insulations, and furnishings. Differences in the rates of drying, evaporation (off-gassing), curing, aging, or other terms and processes are significant giving rise to the need for different protocols. Assemblies such as floor covering systems, wall systems, furnishings, require special protocols to determine emissions from individual components as well as from assemblies that represent the products as they are used in buildings.

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ABSTRACT

Environmental chamber (EC) testing to characterize VOC emissions from indoor air pollutant sources has increased recently and is expected to increase further during the coming years. Manufacturers use results during product development and to respond to consumers' and building designers' inquiries. EC testing is expensive and time consuming. Reductions in personnel costs, the major cost element, may be achieved in the future through automation.

The lack of standardized test protocols makes data interpretation and comparison of test results difficult for most product types. Standards development efforts are burdened by large differences in requirements for testing diverse types of products. Differences in the rates of drying, evaporation (off-gassing), curing, aging, or other terms and processes are significant creating the need for different protocols. Material assemblies such as floor covering systems and others require special protocols to determine emissions from individual components as well as from assemblies that represent the products as they are used in buildings. Knowledge of health effects from exposure to most emissions including both individual chemicals and complex mixtures is insufficient, especially at the low concentrations usually found in indoor air. Application of bioassay techniques appears promising for increasing the available knowledge, especially for assemblies and composite products.

INTRODUCTION

The use of environmental chambers (EC) and other methods to characterize VOC emissions from sources of indoor air pollutants has increased in recent years. (See Table 1.) Manufacturers, consumers, building design professionals, indoor air quality consultants, and government officials have contributed to the growing interest and activity. Far greater commercial and research use is expected in the next few years as a result of increasing customer requests as well as manufacturer interest in liability and marketing implications of product emissions.[1]

Historically, testing emissions of formaldehyde from composite wood products commenced due to the very large number of indoor environment problems attributed to elevated formaldehyde concentrations. Standardized test methods were developed, and testing enabled manufacturers and consumers respectively to develop and obtain lower emitting products. Formaldehyde emissions today are roughly an order of magnitude lower than they were a decade ago for many building materials and other products.

EC test results are used by manufacturers during product development to determine the potential magnitude, composition, and, sometimes, the potential health effects of exposure to their products' emissions. The test results can lead to modification of product components, changes in manufacturing or assembly procedures, and conditioning of products before shipping. Manufacturers also develop information useful in their defense in the event of legal action alleging harm arising from the use of their product.

Emissions test results are increasingly used to satisfy inquiries from potential customers including concerned individual consumers as well as building design professionals (architects, engineers, interior designers) who are selecting and specifying products. Levin[2] first reported on the use of emissions testing for product selection during design of a large (155,000 m^2) office building. In 1988 emissions test results submissions were part of the pre-design study developed to be part of the bid documents for a new national headquarters facility for the U.S. Environmental Protection Agency. The State of Washington has included maximum emissions limits in bid documents for a series of new state office buildings now under development. Results of EC testing can also help designers and builders determine ventilation protocols during and after installation of materials in order to reduce air concentrations to suitable levels or to accelerate emission rate decay before initial occupancy in a curing process sometimes referred to as a "bake-out."

The U.S. Environmental Protection Agency has stimulated a current burst of interest through its so-called "carpet policy dialogue." Representatives of the carpet industry and other interested parties are developing guidelines for EC testing of emissions from carpets, carpet pads, and carpet adhesives. The dialogue is also intended to produce voluntary agreements for periodic testing and reporting of total VOC (TVOC) emissions from carpet and associated products.

Design professionals motivated by client and potential building occupant concerns about indoor air quality are seeking useful information to assist in product selection and specification. Comparison of products is difficult without test data or other useful information. Only limited data are available currently, either from EC testing or from other product evaluation methods. Even where test data are available, differing methodologies, testing of non-comparable specimens, or changes in product formulations decrease the data value for product selection. Uncertainties about the effects of exposure to the emitted VOC further limit the usefulness of test data.

METHODS FOR EVALUATING INDOOR AIR POLLUTANT SOURCE EMISSIONS

Environmental chamber tests are among several methods used to evaluate emissions from sources of indoor air pollutants. Other methods include reviews of manufacturer and published reports on product contents and emissions, other laboratory procedures, and human subject exposure and subjective evaluation studies. (See Table 2.)

Reviews, or "Paper" Studies

Reviews are "paper" studies to assess chemical content based on manufacturer-supplied Material Safety Data Sheets (MSDSs) or other, more complete listings of product contents. Designers request and sometimes receive listings that include more detail than is required by laws governing the preparation of MSDSs. Evaluation of such data includes determination of the volatility of the constituents as an indicator or the emissions potential, the nature of the product as an indicator of the probable emissions processes, and review of the toxicity, irritancy, or other health effects of exposure to the chemicals at the expected or plausible concentrations.

Extraction

Solvent extraction and vacuum extraction, sometimes under elevated temperature conditions, provide information on product/material contents and potential emissions. The South Coast Air Quality Management District (SCAQMD) limits the total VOC content in architectural coatings by measurement of the difference between pre- and post-evaporation mass (minus certain exempt compounds) according to a joint EPA-ASTM standard test method.

Human Exposure and Subjective Evaluation

Environmental chambers and special test apparatus have been employed to expose humans to controlled concentrations or emissions from products/materials. A widely publicized Danish system uses a rating system to quantify odor perception. Standardized diagnostic techniques have been used to determine effects on the human eye, performance of mental tasks, and respiratory function as well as other end points.

Animal Bioassays

Standardized test methods are used to measure mice respiratory rate depression which indicates irritancy of air constituents.[3] Emissions from products and materials provide the test atmospheres for these exposure studies. Results correlate well with TLVs based on irritation in humans. More sensitive species maybe used to evaluate low VOC concentrations. Or, a closed loop test system can be used to increase test atmosphere VOC concentrations. Other animal bioassay methods have been used to evaluate neurotoxicity.

Multiple Test Panels

Danish researchers[4,5] have combined most of the test methods mentioned above as well as chemical analysis from EC tests to evaluate emissions from various building material assemblies. Their results indicate reasonable agreement among the various test methods.

OVERVIEW OF ENVIRONMENTAL CHAMBER TESTING

A variety of chambers, other test apparatus, and protocols have been used to characterize VOC emissions as listed in Tables 3, 4 and 5.

Chamber Configuration and Size

Chamber interiors should be readily accessible for specimen loading and removal. In larger chambers, specimens may be prepared in-place to simulate installation procedures in buildings. Medium size chambers allow testing of uncut, full-size specimens so that surface-to-edge ratios are maximized and so that exposure of typically encapsulated components of a product does not occur. Air inlets and outlets should produce air flow patterns that create good mixing and realistic air velocities immediately above the specimen surface.

Chamber Construction

Environmental chamber construction is usually of smooth, non-adsorbent, non-reactive, easily cleanable surfaces in order to minimize "sink" effects (adsorption of airborne chemicals on chamber surfaces), contamination, and secondary emissions of adsorbed substances. Chamber interior surface materials often are polished or teflon-coated stainless steel or glass. Joint and gasket materials must also be carefully selected to avoid both adsorption as well as VOC emissions from the enclosure materials themselves. Minimal leakage area is necessary to avoid loss of chamber air or infiltration of room air into the chamber. Careful evaluation of chamber leakage is essential to ensuring accurate results.

Several investigators have reported satisfactory results using far less sophisticated and more economical test containers. Among these are cleaned "5 gallon" paint cans, glass water containers with their bottoms replaced by removable sections, and various laboratory containers. Dynamic headspace testing in small laboratory containers can be conducted with reasonably well controlled environmental conditions and may produce qualitative and quantitative or semi-quantitative emissions data of considerable value.

Chamber Environmental Conditions

Environmental chambers provide control of environmental parameters critical to test objectives and experimental design. These normally include temperature, relative humidity, air exchange rate, air movement pathways (complete mixing), and air flow velocity. Clean air must be supplied to the chamber. A system for generating clean air and delivering a specified quantity to the chamber is essential.

Test Parameters

Product loading ratios (specimen area to chamber volume) are often held close to those that occur in "real" conditions in buildings. Air exchange rates are also normally controlled to values representing actual building conditions, e.g., 0.5 - 5.0 ach. Product age and the exposure conditions between manufacture and testing must be known to interpret results for products of the same or different ages. Ideally age and conditioning subsequent to manufacturing are controlled by the investigator, although this not always the case. Test duration is a significant experimental variable that depends on the nature of the material being tested and the purpose of the testing. Tests as brief as 24 hours (for constant emission sources) and as long as several weeks (for slow decay rate sources) have been reported. Chamber time required for testing can contribute considerable expense if longer test periods are necessary. Alternatives include using other, less costly test containers for longer term testing.

Sample Collection System

The sample collection system may include sorbents for low chamber concentrations and when the detection limits for the compounds of interest require a large sample volume. The sorbent chosen will depend on the compounds of interest, the desorption method, storage requirements, and other factors. Where analytical instrumentation and detection limits permit, samples may be collected by syringe or closed-loop connections and directly injected into the analytical instrument such as gas chromatograph (GC).

Analytical System

Various systems have been used depending on the purpose of the test and the compounds of interest. Most commonly, a GC with one of several detectors is employed for emissions testing. Detectors that are employed include flame ionization (FID), mass selective (MSD), and electron capture (ECD). Certain compounds such as low molecular weight aldehydes are separately analyzed by HPLC or wet chemical colorimetry.

COSTS OF EC TESTING

Environmental chamber testing to determine VOC emission rates is expensive and time consuming. The overwhelming majority of the costs are for personnel. (See Table 6.) Advances in automation of sample collection, analysis, and compound identification/quantification may reduce personnel costs in the future. This may be accomplished when libraries of compounds are assembled and computer programs are developed to assist in compound identification and confirmation. Additional savings can be achieved if automation can be developed to connect sampling and analytical equipment to multiple chambers for simultaneous testing. Substantial investments in developing such improvements are necessary before cost reductions can be attained.

INTERPRETING RESULTS FROM EC TESTING

Interpretation of data and comparison of results from testing performed on different product types or by different investigators is difficult because standardized test protocols promulgated by either government or private organizations are lacking for most product and material types. Efforts to develop standards have been burdened by the large differences in the requirements for testing diverse types of products such as architectural coatings, adhesives, caulks, composite wood products, floor and wall coverings, insulations, and furnishings. Differences in the rates of drying, evaporation (off-gassing), curing, aging, or other terms and processes are significant giving rise to the need for different protocols. Assemblies, e.g., floor covering systems, wall systems, and furnishings, require special protocols to determine emissions from individual components as well as from assemblies that represent the products as they are used in buildings.

Knowledge of human physiological and health effects from exposure to most products' VOC emissions is insufficient, especially for the low concentrations usually found in indoor air. Furthermore, understanding the effects of exposure to complex mixtures of such chemicals is almost entirely lacking. Application of bioassay techniques to determine irritation and neurotoxicity of some individual VOC and total VOC emissions from specific products presents promises to increase our understanding in the future.

THE FUTURE OF PRODUCT TESTING

The problems in standardizing test protocols are being addressed by ASTM. Standard test methods are being developed following an already adopted standard guide[6] on the subject. Major issues to be resolved include methods for standardizing measurements and reporting of total VOC; chamber air exchange and velocity conditions; product age, history, and conditioning; number and timing of samples required to determine emission factors; and, chamber size, construction, and calibration. Standardized testing of assemblies as well as their components (e.g., floor covering and adhesive) requires further methods development. Additional issues include determination of semi-volatile organic chemical emissions; possible usefulness of dynamic headspace or alternative vessels; and, interpretation of results for prediction of indoor air concentrations.

Because health effects data for VOC are so sparse, interpreting EC test results is difficult. Therefore, it is likely that test results will be used only to compare total emissions and identify known irritants and toxins for product selection. It is also likely that standardized test procedures will enable manufacturers to remove strong emitters from the marketplace and substitute particularly noxious constituents. The outcome will be improved indoor air quality in newly constructed or refurnished buildings. There will also be less uncertainty regarding potential problems and legal liability for all concerned. Ultimately, there will be increased pressure to improve our understanding of the health effects of exposure to indoor air contaminants.

REFERENCES

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1. H. Levin, "The evaluation of building materials and furnishings for a new office building," in Practical Control of Indoor Air Problems, Proceedings of the ASHRAE Conference IAQ 87, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, 1987, pp. 88-103.

2. H. Levin, "Building materials and indoor air quality," in J. Cone and M. Hodgson (Eds), Problem Buildings: Building Associated Illness and the Sick Building Syndrome, State of the Art Reviews in Occupational Medicine, Volume 4, Number 4, October-December 1989, Hanley & Belfus, Philadelphia.

3. ASTM E 981 - 84, "Standard Test Method for Estimating Sensory Irritancy of Airborne Chemicals," American Society for Testing and Materials, Philadelphia, 1984.

4. C.R. Johnsen et al, "Controlled human reactions: materials in climatic chambers. Part I: Performance and comfort". Indoor Air '90: Proceedings of the Fifth International Conference on Indoor Air Quality and Climate, Vol. 1, pp. 269-274. 1990.

5. P. Wolkopf et al, "Controlled human reactions to building materials in climatic chambers. Part II: VOC measurements, mice bioassay, and decipol evaluation," in Op.Cit., pp. 331-336. 1990.

6. ASTM D 5116-90, "Standard Guide for Small Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products," American Society for Testing and Materials, Philadelphia, 1990.