United States Environmental Protection Agency
Research and Development
National Risk Management Research Laboratory
Cincinnati, OH 45268
EPA/600/SR-98/080 August 1998

Project Summary

Indoor Air Emissions from Office Equipment: Test Method Development and Pollution Prevention Opportunities

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The report describes development and evaluation of a large chamber test method for measuring emissions from dry-process photocopiers. Application of the test method will lead to a better understanding of emissions from office equipment and to the development of lower emitting machines. Challenges and complications encountered in developing and implementing the test method include: heat generation, which can cause large increases in chamber temperature; finite paper supplies for photocopiers, which limit test duration; toner off-gassing between tests, or toner carryover if different types of toner are tested; varying power requirements that may require changes in chamber electrical supply; and remote starting of the machines, which is necessary to maintain chamber integrity.

The test method was evaluated in two phases. Phase I was a single laboratory evaluation at Research Triangle Institute (RTI) using four, mid-range, dry-process photocopiers. Phase I results indicate that the test method provides acceptable performance for characterizing emissions, adequately identifies differences in emissions between machines both in compounds emitted and their emission rates, and is capable of measuring both intra- and inter-machine variability in emissions. For Phase I, the compounds with the highest emission rates from the four different machines tested are: ethylbenzene (28,000 μg/hour), *m,p*-xylenes (29,000 μg/hour), *o*-xylene (17,000 μg/hour), 2-ethyl-1-hexanol (14,000 μg/hour), and styrene (12,000 μg/hour). Although many of the same compounds were detected in emissions from each of the four photocopiers, the relative contribution of individual compounds varied considerably between machines, with differences greater than an order of magnitude for some compounds. The toners appear to be the primary source of organic emissions from the photocopiers.

To investigate whether all chambers produce similar results, a four-laboratory, round-robin evaluation of the test method was performed in Phase II. A single, dry-process photocopier was shipped in turn to each of four laboratories along with supplies (i.e., toner and paper). Phase II results demonstrate that the test method was used successfully in the different chambers to measure emissions and that differences in chamber design and construction appear to have minimal effect.

This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Emissions from office equipment include: volatile organic compounds (VOCs), aldehydes/ketones, ozone, and particles. Exposure to these chemicals can contribute to health effects such as eye, nose, and respiratory system irritation, and several are listed as hazardous air pollutants under the Clean Air Act (e.g., styrene, ethylbenzene, *m,p*-xylene, *o*-xylene, toluene, and formaldehyde).

In March 1994, a group of technical advisors met to discuss research on pollution prevention approaches for reducing indoor air emissions from office equipment and to solicit input on technical priorities for the research. The technical advisors strongly recommended that a test method be developed that could be used to evaluate emissions from office equipment. It was felt that such a method is needed to evaluate different equipment types and to establish comparable baseline emission data that could be used as a starting point for the development of specific pollution prevention approaches. Concurrently with the technical advisors meeting, a literature search was conducted to identify and review published information on office equipment design; indoor air emissions of ozone, particulates, and organics; and potential pollution prevention approaches for reducing these emissions.

Based on the literature review and on input provided by the technical advisors, this research focused on development and evaluation of a large chamber test method for measuring emissions from dry-process photocopiers. EPA's objective in developing the test method is to promote emission testing of office equipment by manufacturers and others in order to increase understanding of emissions and encourage the development and manufacture of lower emitting equipment.

Overview of Test Method

Research Triangle Institute (RTI) and EPA's Air Pollution Prevention and Control Division collaborated with several office equipment manufacturers to develop the large chamber test method. It is based on the experience of RTI and EPA in product testing, a published American Society of Testing and Materials (ASTM) test method, and existing test methods used by the participating manufacturers of office equipment. The test method utilizes large, flow-through dynamic chambers because they are generally applicable to all types of equipment and can be used to mimic typical use conditions found in an office. Listed below are some unique considerations that are incorporated into the test method.

1. Chamber Size: The test chamber's linear dimensions must be a minimum of 1.4 times the dimensions of the equipment tested in accordance with typical industry testing procedures.
2. Heat Generation: To account for heat generation, a temperature range of 28.5 ± 2.5° C and an air exchange rate of 2 air changes per hour (ACH) are specified. Relative humidity (RH) within the chamber is to be maintained at 30-35%. (A RH of 35% at 31° C represents a mass of water equivalent to 50% RH at 23° C.)
3. Limited Paper Supply: A finite paper supply for copy machines limits test duration. For this study, a paper supply of 2000 sheets was used for each test.
4. Remote Starting: Remote starting of the machines from outside of the chamber is necessary to maintain chamber integrity.
5. Toner Carryover: When testing equipment that uses toner, a toner depletion and replenishment procedure is to be followed to avoid carryover of the previous toner between tests. Without the toner depletion/replenishment, toner from a new cartridge may be diluted by the toner still retained in the delivery system or the "old" toner may off-gas between tests, affecting emission results.

The sequence of operations below was performed for the testing. Appendix B of the report presents a complete description of the test method.

1. Check out copier (by service representative);
2. Perform toner depletion/replenishment;
3. Collect background air samples from empty chamber;
4. Place copier in chamber;
5. Power up copier, load paper, and test remote start;
6. Equilibrate copier in chamber overnight in idle mode (i.e., powered but not copying);
7. Collect integrated chamber air sample for the copier in the idle mode for a total of the estimated copying time plus a time period equal to 4 air changes (i.e., for a chamber operating at 2 ACH, the total idle period sample collection time is the copying time plus 120 minutes);
8. Collect integrated chamber air sample during full copier operation and continue for a post-copying time period equal to 4 air changes (i.e., for a chamber operating at 2 ACH, the total sample collection time is the copying time plus 120 minutes); and
9. Determine air exchange rate using pulse injection of a tracer gas (e.g., carbon monoxide) during the test.

In this study, toner recommended by the manufacturer and the same type of paper (containing 25% recycled materials) were used. A standard image, representing about 15% coverage of the paper, was used to represent a typical maximum image for copying. For the copiers evaluated in this study, 2000 copies were produced for each test. Copying time for the 2000 sheets ranged, depending on the machine, from 20 to 40 minutes, for a total sample collection time of 140 to 160 minutes. Chamber air concentrations of VOCs were determined using multisorbent tubes analyzed by a gas chromatograph/mass spectrometer (GC/MS). Aldehyde/ketone samples were collected on 2,4-dinitrophenylhydrazine (DNPH)-coated silica gel cartridges and analyzed by high performance liquid chromatography. At RTI, ozone was monitored continuously using a DASIBI monitor. Limited particle measurements were made using a LAS-X optical particle counter.

Evaluation of the Test Method

The test method was evaluated in two phases: I) four, dry-process photocopiers were evaluated in RTI's chamber; and II) a round-robin evaluation of one dry-process photocopier was done in four different laboratories (including RTI). Results of triplicate measurements made in Phase I show that the test method provides acceptable performance for characterizing emissions from copiers. Percent recovery for calculated emission rates for standard materials released into the chamber at known rates was greater than 85%. Precision of replicate tests using both standard emitters and copiers was good, with less than 10% Relative Standard Deviation (RSD).

The data were also analyzed to determine differences in emissions between the four copiers (Table 1). Emissions of VOCs were consistently lower for Copier 3, which used a mono-component toner, than for the three machines that used dual-component toners (Copiers 1, 2, and 4). However, emission rates for many of the aldehydes and ketones were higher for Copier 3. Also, ozone levels for Copier 3 were higher than for the other three machines. The data show that, although the same compounds were emitted from all four machines, the emission rates of these compounds varied considerably between machines. For example, the emission rate for ethylbenzene was 28,000 µg/h for Copier 1 and <50 µg/h for Copier 3. Limited particulate data were collected for two of the four machines tested. Results show that operation of one of the machines increased particulate levels to 30 times chamber background levels for particles smaller than 0.2 :m in diameter.

Table 1. Estimated VOC, Aldehyde/Ketone, and Ozone Emission Rates from Four Copiers. (µg/h • copier)

Chemical	Copier 1	Copier 2	Copier 3	Copier 4
ethylbenzene	28,000	2,400	<50	360
m,p-xylene	29,000	6,100	100	510
styrene	9,900	12,000	300	3,000
o-xylene	17,000	4,500	<50	850
propylbenzene	790	2,100	<50	460
2-ethyl-1-hexanol	230	14,000	130	5,600
n-nonanal	1,100	3,600	2,000	3,900
formaldehyde	<500	2,600	2,200	<500
acetaldehyde	710	960	1,200	<500
acetone	2,000	<500	2,800	<100
benzaldehyde	1,800	2,600	<100	3,800
ozone	3,000	4,700	7,900	1,300

To investigate whether all chambers produce similar results (results may vary due to differences in sink effects, for example), a round-robin evaluation of the test method was performed in four U.S. laboratories during Phase II. To establish a common basis for comparison, a single, dry-process photocopier was shipped to each laboratory in turn along with supplies (i.e., toner and paper). The tests followed the same methodology used in Phase I with one exception: a procedure for toner depletion/replenishment was developed for the copier in the round-robin testing. As discussed above, without the depletion/replenishment process, off-gassing from a toner cartridge left in the copier for an extended time period prior to testing (at least 1 month for these tests) would affect emissions during subsequent testing.

The round-robin evaluation demonstrated that differences in chamber design and construction had minimal effect on results. Excluding problems with suspected analytical bias observed from one of the laboratories, measurement agreement between laboratories is excellent for VOCs, with RSDs of less than 10% in most cases. More variability was observed between laboratories for aldehydes/ketones (RSD of 20% for formaldehyde). Ozone emission rates between three of the laboratories were consistent (RSD of 15%), but emission rates measured at the fourth laboratory were much higher. Particle measurements were not a focus of the study because of the complexity of generating known masses of particles (which would be required for method evaluation).

Conclusions and Recommendations

Conclusions and recommendations are included for both Phase I and Phase II.

Phase I

Results of Phase I testing provided valuable information on the performance of the test method and the emissions characteristics of dry-process photocopiers.

The large chamber test method developed as part of this project provides acceptable performance for characterizing emissions from dry-process photocopy machines. In general, precision was much better for the emission rate measurements in the print mode than in the idle mode, where measured emission rates had much lower values.

A standard test method for measuring indoor air emissions from office equipment can present numerous challenges and complications. Specific considerations identified and addressed during this study are: heat generation, limited paper supply, power requirements, remote starting, and toner depletion and replenishment.

Although many of the same compounds tended to be detected in emissions from each of the four photocopiers, the relative contribution of individual compounds varied considerably between machines, with differences greater than an order of magnitude for some compounds. The variation in compounds is most likely due to different toner formulations and/or toner manufacturing processes.

Many of the compounds detected in this study (benzaldehyde, ethylbenzene, nonanal, ozone, styrene, and xylenes) are consistent with compounds identified in the literature from photoimaging equipment. Again, any variation in compounds is most likely due to the different toner formulations used for different machines.

The integrated sampling approach for generating emission rate data was determined to be acceptable. Time-point samples were evaluated for two machines. However, it is more labor-intensive and costly; thus, the need for collecting time-point samples should be evaluated on a case-by-case basis.

Toner headspace testing indicates that increased temperatures result in increased organic concentrations in the headspace gas. Results from the toner headspace analysis also indicate that there may be some correlation between toner headspace analysis and copier emissions; however, more testing of this relationship is required before any conclusions can be drawn.

Toner lot, manufacturing process, and age (as measured by the amount of time that a cartridge has been opened) have a significant impact on organic emissions during both headspace tests and copier operation. Therefore, any organization planning to conduct photocopier emission tests or analyze emissions data needs to consider and control for this variable.

Phase II

Results obtained from different chamber facilities are comparable. The VOCs reported to have the highest emission rates by all of the participating laboratories are ethylbenzene, *o*-, *m*-, *p*-xylenes, and styrene. These are also the compounds with the highest emission rates reported from Phase I testing.

Excluding problems with analytical bias as seen from one laboratory, agreement between laboratories for VOC measurements is excellent (RSD of less than 10% in many cases). Aldehyde/ketone and ozone emission rates are more variable.

Differences in chamber design and construction at the different laboratories seemed to have little effect on test results. However, an analytical bias was identified at one of the laboratories based on the analysis of duplicates at RTI.

Potential Pollution Prevention Opportunities

Potential opportunities for reduced emissions from office equipment, specifically, dry-process photocopiers, were identified from the literature, discussions with manufacturers, and tests conducted as part of this research.

The use of charged roller systems decreases ozone emissions; however, the charged roller system presently has copy rate limitations. Therefore, it is recommended that future research focus on investigating the application of this design change to higher throughput machines.

Both the literature and laboratory testing indicate that the greatest level of organic emissions from dry-process photocopiers comes from the toner during the operating mode. As a corollary, higher temperatures were shown to result in higher organic emissions during toner headspace tests. Therefore, additional pollution prevention research should focus on the relationship between toner formulation and the fusing process. Specifically, this could include:

- investigating the relationship between fusing temperature and time in contact with the fusing rollers;
- testing of designs that use only pressure fusing;
- evaluating specific differences between mono- versus dual-component toners and the resulting differences in emissions;
- evaluating the effect of toner particle size on toner transfer efficiency and particulate emissions;
- investigating methods for increasing the life of the photosensitive drum that would result in better transfer efficiency;
- identifying options for toner reformulation and the use of high purity raw materials; and
- evaluating other toner/fuser combinations, such as ultraviolet (UV)-curing technologies, that are being used by other sectors of the printing industry.

This research indicates that emissions can vary depending on the specific toner manufacturing process. The extrusion process for manufacturing toner should be investigated further. As one measure for ensuring that multimedia pollution prevention is being achieved, specifications should be refined to ensure consistent and "clean" raw materials for the toner manufacturing process.

Photocopier emissions have been shown to increase between routine maintenance cycles. Therefore, development of new equipment designs that require less (or even no) maintenance but are still able to operate with the lowest possible emission rates could result in pollution prevention benefits over the life of a copier.

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The complete report, entitled "Indoor Air Emissions from Office Equipment: Test Method Development and Pollution Prevention Opportunities," (Order No. PB98-165137; Cost: $36.00, subject to change) will be available only from
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