Preliminary Investigation of Uncombusted Auto Fuel Vapor Dispersion within a Residential Garage Microenvironment

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PRELIMINARY INVESTIGATION OF UNCOMBUSTED AUTO FUEL VAPOR DISPERSION WITHIN A RESIDENTIAL GARAGE MICROENVIRONMENT

by

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ABSTRACT

Evaporative emissions from vehicles in an attached garage may represent a significant source of indoor pollution and human exposure. A pilot field study was undertaken to investigate potential in-house dispersion of evaporative emissions of uncombusted fuels from a vehicle parked inside an attached garage. In a set of experiments using sulfur hexafluoride (SF_6) tracer gas, the multizonal mass balance model, CONTAM88, was used to predict interzonal air flow rates and SF_6 concentration distributions within the garage and house. Several experiments were included to evaluate the effect of meteorology and mechanical mixing mechanisms on the dispersion of automobile fuel vapor. Measurements indicated that approximately three percent of the garage maximum concentration was measured in a room adjacent to the garage. The model successfully predicted garage concentrations under well mixed conditions, but underpredicted the measured concentrations within various rooms of the house, in which mixing was incomplete. Multizonal mass balance models such as CONTAM88 may be useful in approximating contaminant concentrations at various locations within the house.

Keyword index: Indoor air, multizonal models, mass balance models, methanol dispersion, attached garage.

INTRODUCTION

The introduction of oxygenated auto fuels and fuel additives (alcohols and ethers) into the U.S. motor vehicle fleet has served to reduce tailpipe emissions of carbon monoxide and total hydrocarbons[1]. Tailpipe emissions represent an obvious source of *ecological* pollution, however evaporative emissions from vehicles in attached garages may represent an important source of indoor (i.e. *microenvironmental*) pollution.

In-house and attached garage concentration of evaporated (uncombusted) fuel species from an automobile's fuel system may represent a significant component of total human exposure to these chemicals. The use of alcohol and ether additives increases the fuel vapor pressure, and hence the evaporation rate[2]. The magnitude of in-house concentration of a chemical species depends upon the emission rate of evaporating fuel, the concentration of the component species within the liquid fuel, and the air flow rates between garage and house. Measurement of these critical variables enables the development of predictive models useful in population exposure assessment.

This study examines the potential for dispersion of evaporative emissions from an auto fuel system into a residence from an attached garage. A series of field experiments were conducted to obtain estimates of in-house ambient concentration of fuel vapor components resulting from normal automobile use scenarios. A single family home with attached garage was selected as the test site. Air flow rates between the garage and various zones within the house were measured using SF_6 tracer gas. A multizonal mass balance model was used to predict the spatial and temporal contaminant dispersion within the house. Previous investigation has shown that multizonal mass balance models may be useful in designing field study monitoring strategies[3]. Modeling results were compared to SF_6 measurements in order to investigate the possibility of using the model to predict methanol and/or other

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alternative fuel dispersion in the garage and throughout the house. Methanol emissions and concentration distributions were examined in a later phase of this pilot study. Analyses of methanol concentration and supporting modeling results will be presented in subsequent report.

MATERIALS AND METHODS

RESIDENCE DESCRIPTION

During the summer of 1992, a house in Raleigh, North Carolina was chosen to study in-house dispersion of evaporative emissions of uncombusted automobile fuels from a vehicle parked inside an attached garage. This study determined quantitative flow rates between the garage (pollutant source) and selected rooms of the house. The first story of this two story house consisted of the master bedroom, a bathroom, a den, the kitchen and the dining room (Fig. 1); the second story of the house includes three bedrooms and a bathroom. One second story bedroom was located directly above the garage. The total volume of the garage was 95 m^3. The house physical characteristics were measured during the first day of the study. These measurements were subsequently used to model SF_6 concentration distribution in the garage and within the house. The SF_6 dispersion analysis was used to calculate interzonal air flows and to calculate contaminant concentrations in order to determine the rooms with significantly different concentrations.

MASS BALANCE MODEL

The multizonal mass balance model used in this investigation is the National Institute of Standards and Technology (NIST) model, NBSAVIS/CONTAM88[4] developed for the Environmental Protection Agency to simulate transient contaminant concentration distribution in buildings. The model is based on the element assembly approach, which assumes that a building can be represented as a combination of well-mixed zones linked by flow and kinetic elements (contaminant mass transport and decay). CONTAM88 solves a set of mass balance and flow equations. The mathematical formulation of the contaminant concentration is:

$$[\,W\,]\,\vec{C} + [\,M\,]\,\frac{d\vec{C}}{dt} = \vec{G} \qquad (1)$$

where:

C = Vector containing the discrete concentration values

[W] = System mass transport matrix which contains flow rate data

[M] = System matrix which contains mass (volume) data

G = System generation vector containing kinetics data.

NBSAVIS is a preprocessor to CONTAM88 which allows the idealization of a building through the generation of a file that describes the building configuration, including indoor and outdoor contaminant sources. Data input to NBSAVIS is facilitated by a series of data entry screens that allow the user to specify: interior and exterior wall types; interior and exterior doors, windows, open passageways; filters and fans; room descriptions; and heating, ventilation, and air conditioning (HVAC) system descriptions. NBSAVIS then calculates the interzonal air flow rates and system matrices. NBSAVIS was used to build an idealization of the house. The parameters that were measured in order to run NBSAVIS are:

- . The house physical dimensions (including all windows, doors and other openings).
- . The house HVAC system output as well as all the locations of the vents with air flow rates.
- . The contaminant source information (name, molecular weight, emission rate).
- . The location of the source (inside the garage).
- . The temperatures of the various rooms in the house.
- . The outdoor meteorological conditions (temperature, wind speed and wind direction).

EXPERIMENTAL DESIGN

Three experiments in which SF_6 was released in the garage and traced inside the garage and the house were designed and implemented. SF_6 was chosen because it is non-toxic, stable with respect to chemical reactions, its removal due to deposition is negligible and it can be measured in very low concentrations with high accuracy[5]. A diluted mixture of SF_6 in nitrogen (0.362g SF_6 / m^3) was prepared and used in all experiments. Samples were analyzed using gas chromatography/electron capture detection (GC/ECD), with a lower detection limit of 20 parts per trillion volume (ppt). Measurement accuracy was within 5%. Measurement precision (standard deviation) was within 5% of the measured concentration. During the entire study the outdoor temperature ranged between 19 C and 23 C, the wind speed did not exceed 0.5 m/s and the wind direction varied. The low wind speeds were mainly due to shielding of the house and property by trees.

The first experiment was designed to assess the percentage of contaminant that infiltrates in the house from the garage. A car was parked in the garage with the front of the car facing an interior wall of the garage. In this experiment five automated sequential syringe samplers[6] were used. Three samplers were placed in the house: one in the kitchen, one in the den and one in the bedroom above the garage. The remaining two samplers were located in the garage. One sampler was placed on the car roof, one was placed on the garage floor, next to the car. The garage door was closed during the experiment. SF_6 was released for 20 min at a rate of 1 liter per minute (l/min). The total mass of SF_6 released was 7.23 mg. The SF_6 source was located next to the gasoline tank on the passenger side of the car. A large box fan was used next to the source to create a well mixed condition. Samplers in the garage were started simultaneously with the SF_6 source. At the end of the SF_6 release (20 min), the three samplers inside the house were activated.

The second experiment was designed to investigate how quickly the concentration in the garage drops after the garage door is opened. In this experiment no car was in the garage. Air samples were taken at two vertical locations in the garage. The upper sample location was centered 2 feet from the garage ceiling while the lower sample location was centered 2 feet above the floor. The samples were analyzed in real time. SF_6 was released in the garage for 10 min at a rate of one l/min for a total mass released of 3.62 mg. The box fan was used to create a well mixed condition. At the end of the 10 min release time, the fan was turned off and the garage door was opened.

Experiment three was performed to test the well mixed garage assumption. Five syringe samplers were used in the garage, one on the car roof, one next to the driver's side, one next to the passenger side, one in front of the car (back wall location), and one in the back of the car (next to the garage door). No fan was used, and sampling time was set to 12 min intervals for all the samplers. SF_6 was released for 20 min at a rate of 1 l/min. The SF_6 source was located next to the gas tank on the passenger side of the car. The garage door was closed during the experiment.

RESULTS AND DISCUSSIONS

During the first experiment, CONTAM88 was used to simulate the dispersion of SF_6 in the garage and throughout the house. Good agreement was found between simulated and measured data (Fig. 2). Differences may be due to a lack of complete mixing in the garage. There were two samplers in the garage; the one on the passenger side (labeled LEFTGARAGE in Fig. 2) showed a sharp drop of concentration approximately 30 min after the experiment started. This sampler was located close to the kitchen door, therefore the drop in concentration may be due to local air exchange. The other sampler (labeled TOPGARAGE in Fig. 2) agrees better with the model, which assumes a well mixed condition.

Modeling results consistently underpredicted the concentration in all the rooms in the house (Fig. 3). The highest concentration was measured and modeled in the kitchen, followed by the den and then the bedroom above the garage. Overall, the model predicted a behavior similar to the data. However, the model underpredicted the kitchen and bedroom concentrations by approximately 30%, and the den concentrations by approximately 10%. The model assumption of well mixed zones was not satisfied in the house because of the absence of forced mixing. The model predicted that the maximum concentration attained in the kitchen would be 2% of the maximum concentration in the garage, while measurements showed that the maximum relative concentration was approximately 3%.

Following the completion of SF_6 injection, the concentration in the garage began to decrease, while the concentrations in the kitchen and the other rooms continued to rise. The time delay (phase lag) between the modeled maximum concentration in the garage and the kitchen was approximately 15 minutes; between the family room and the garage the time delay was approximately 30 minutes. In the bedroom the concentration was still rising 50 min after emission stopped (Fig. 3). The measured phase lag in concentrations between the various rooms of the house is also predicted by the model (Eq. 1). Conservation of mass (SF_6) - within the context of a box model - requires that a loss of mass from one box (e.g. the garage) be accounted for in a net increase of mass in the other boxes (e.g. other rooms of the house, the outdoors).

In the second experiment, CONTAM88 was used to simulate contaminant build up and decay after the garage door was open. Modeling results were in agreement with the measurements (Fig. 4). After the garage door was opened the SF_6 concentration decreased to less than 10% of the initial concentration in 3 minutes. Similar results were found using the decay from the modeling results. This decay rate corresponds to approximately 45 air changes per hour (ACH). During testing the wind speed was less than 0.2 m/s, therefore this high exchange rate is likely due to mechanical mixing that occurred when the garage door was opened. These results were supported by observations during smoke release experiments.

During the third experiment measurements were performed to test the well mixed box assumption. Model simulation was used to determine locations in the garage where the well mixed condition existed. Simulation results agreed with the data collected at the car roof, back of the garage, and the passenger side locations. The data collected near the garage door and driver side locations were approximately half of the model predictions. Total mixing occurred between 60 and 90 min after the SF_6 release stopped (Fig. 5). These results show that sampler locations cannot be assumed to measure average (well mixed) concentrations, particularly during the period of contaminant emission. However, for constant sources, a steady state regime may develop in the garage and house, resulting in quasi-mixed conditions.

CONCLUSIONS

Good agreement was found between modeling and experimental results in the garage when the well mixed assumption was verified (box fan on). In the rooms adjacent to the garage, the model underpredicted the concentration of SF_6. The model did help assess the broad trend of concentration distribution in those rooms. Approximately three percent of the maximum garage concentration was measured in the kitchen and 1.5 percent in the upstairs bedroom. These experiments were performed with the door between the kitchen and garage always closed. Higher in-house relative concentrations can be expected when this connecting door is opened.

When mixing was not forced (box fan off) within the garage, the well mixed assumption was not valid at locations next to the garage door and the kitchen door, but the other locations in the garage showed more thorough mixing. It took 60 to 90 min for total mixing to occur after the release of SF_6 stopped. Furthermore, the well mixed assumption did not hold during the contaminant release time.

Preliminary results showed that multizonal mass balance models such as CONTAM88 may be used to approximate contaminant concentrations within various locations of the house provided sampling time and location are chosen judiciously. These models may help identify the locations where mixing occurs and the time duration to attain well mixed conditions. The models may help choose sampler locations and sampling time during a field study. Locations of expected high concentration gradients (near locations of local air exchange, such as doors and windows) must be sampled more intensively than locations of low concentration gradients (remote from locations of local air exchange). Furthermore, CONTAM88 can be used to successfully model the dispersion of uncombusted fuel vapor inside a residence and its attached garage. For pollutant emissions in an attached garage, sampling locations should be next to the garage door and any connecting (interior) doors and windows, one sampler in another location in the garage is sufficient (car roof or back of garage, etc). Sampling time will be dependent on the contaminant source release period and the time the source takes to reach steady state.

The potential exists for in-house exposure to emissions (uncombusted fuel vapors and exhaust) from a vehicle in an attached garage. Therefore, the introduction of alternative fuels and fuel components into the U.S. automobile fleet will result in residential exposure to these chemicals and their combustion by-products. An exposure assessment project is ongoing to quantify potential human exposures. The models evaluated here are being incorporated into this project.

DISCLAIMER

This paper has been reviewed in accordance with the U.S EPA's peer review and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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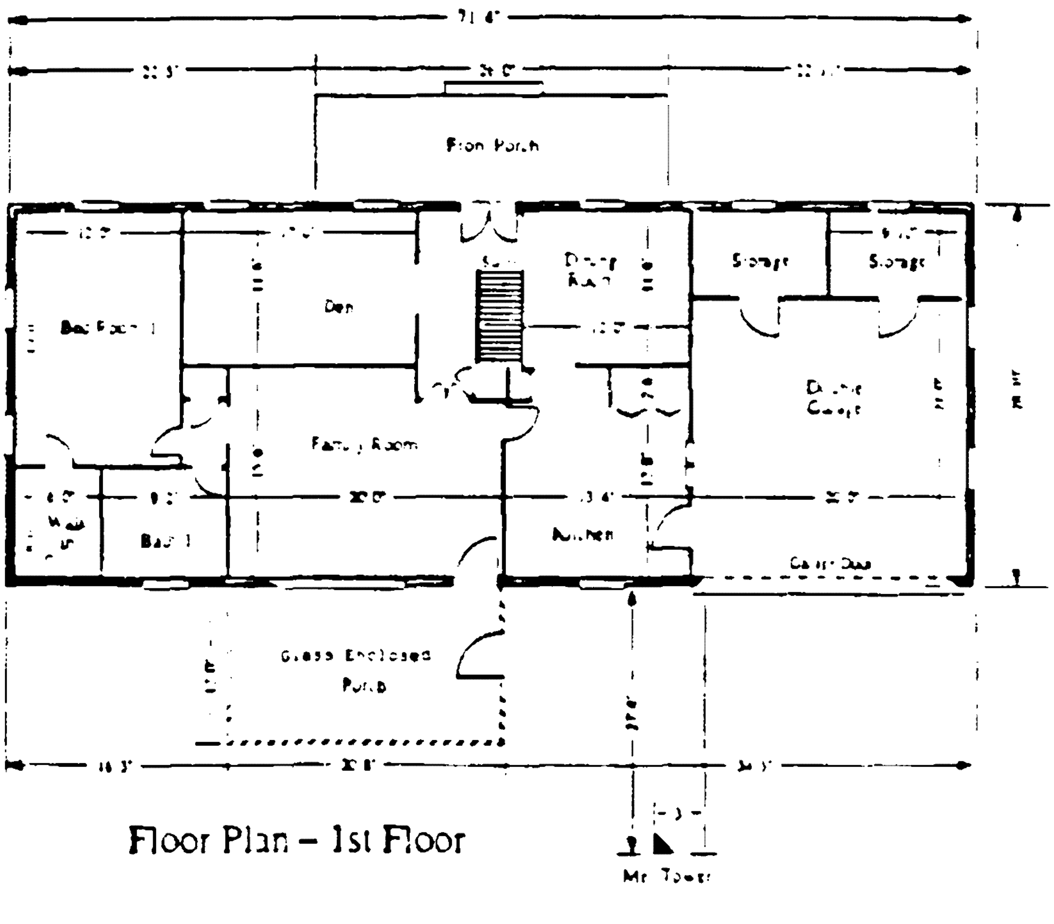

Figure 1. Residence floor plan. A second floor bedroom (not shown) was located directly above the garage.

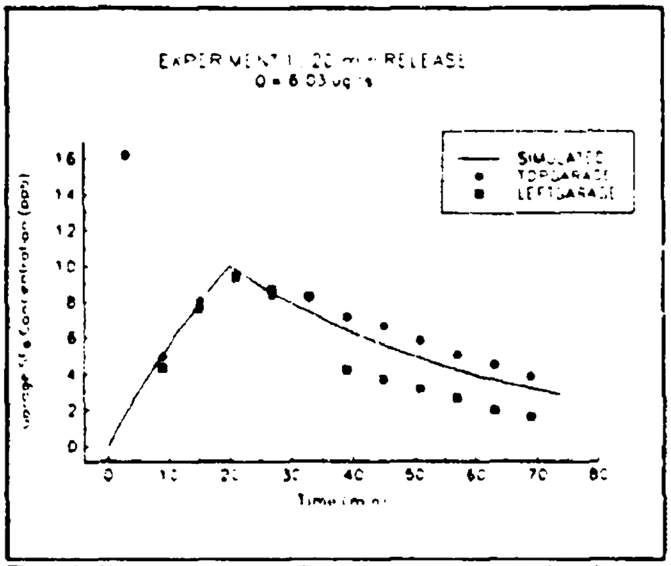

Figure 2. Simulated and measured garage transient concentrations during and after a 20 min SF6 emission

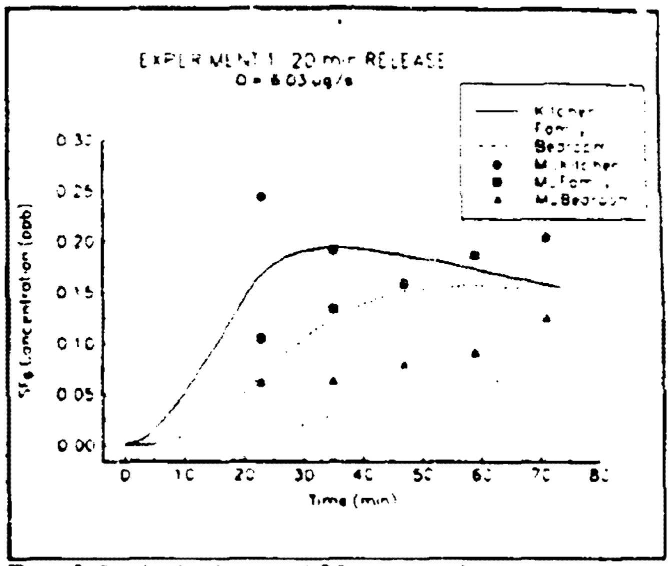

Figure 3. Simulated and measured (M) transient in house concentrations during and after a 20 min SF6 emission

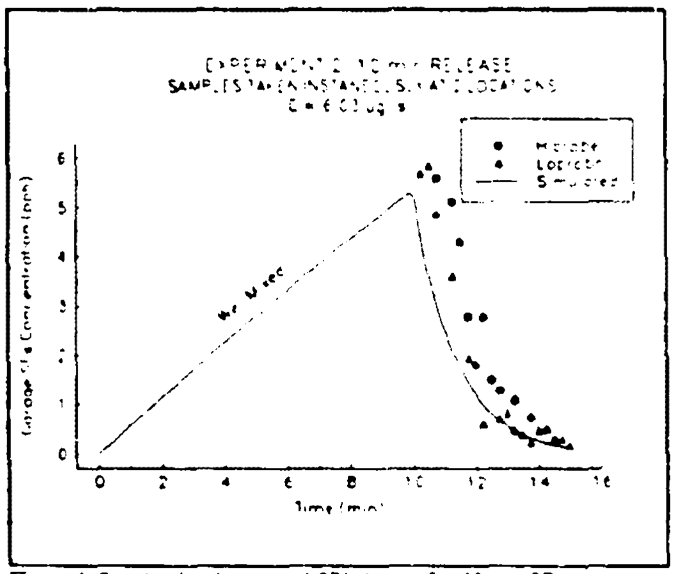

Figure 4. Simulated and measured SF6 decay after 10 min SF6 emission and after the garage door is opened

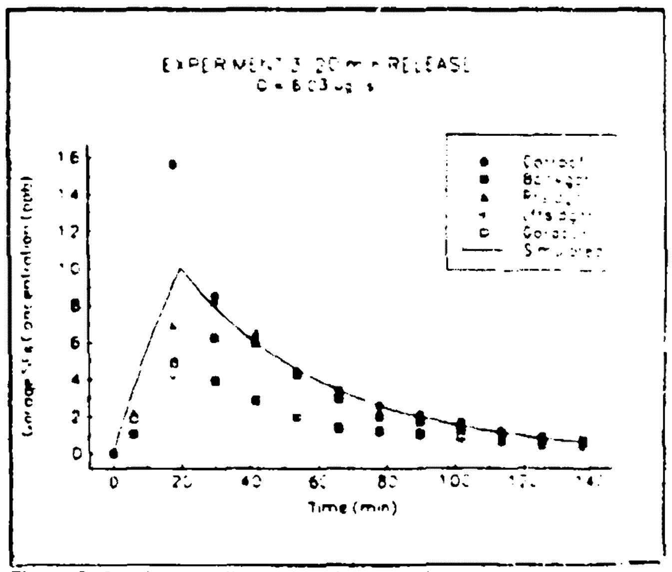

Figure 5. Simulated (well mixed) and measured transient concentrations at various locations in the garage.