

5.0 SUMMARY AND CONCLUSIONS

This study was performed to collect data to gain a better understanding of the impact of cooking on indoor air concentrations and personal exposures to air contaminants generated by cooking in residences. The objectives of the study were to:

- Characterize indoor air concentrations and emission rates and resultant indoor air concentrations and personal exposures for particulate matter (PM), carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO₂) produced by residential cooking under typical and realistic worst-case conditions.
- Characterize indoor air concentrations and emission rates and resultant indoor air concentrations for other cooking pollutants such as PAHs, elements, and other potential marker compounds.
- Measure the effectiveness of selected exposure reduction practices.

The study reported here represents the first large-scale study of cooking emissions and the resultant exposures in a residential setting under semi-controlled conditions. The study included thirty-two cooking tests with a variety of cooking methods and foods. It addressed various factors that may impact emissions from cooking and evaluated simple exposure reduction methods.

To meet the study objectives, a test house was rented in Rohnert Park, California. The house was a small single-story ranch style home constructed in the 1970s. The small size of the house (less than 1000 ft²) and the layout of the rooms, consisting of a kitchen, adjacent living room, and three bedrooms, resulted in good mixing in the house even though the house air handler was not operated during testing. The house had an attached garage where a laboratory was set up. The test house was instrumented with temperature and relative humidity sensors in the rooms and outdoors. Temperature sensors, a power transducer, and a dry gas meter were installed to collect data during cooking tests. Teflon® sampling lines were routed to the kitchen (K), living room (LR), master bedroom (MBR), and outdoors (OA) for collection of air contaminants. A second set of sampling lines was routed to the same rooms for collection of SF₆, the tracer gas measured to calculate air exchange rates. A laboratory was set up in the garage with pollutant monitoring instrumentation, a data acquisition system, and support hardware for instrument calibrations.

Following a pre-test and refinement of the study design and test protocols, a main study was performed that consisted of 32 cooking tests at the test house. The tests involved cooking with an electric range, gas range, and microwave oven. The microwave was used in three tests to compare emissions with the gas and electric ranges. The electric range was used for seven cooking tests. These same seven cooking activities were performed with the gas range for comparison. All other tests were performed with the gas range. Parameters measured during all tests included the following:

- CO, NO, and NO₂ with continuous pollutant monitors
- PM concentrations and size distributions (12 size fractions from 0.04 to 8.4 μm, aerodynamic mean diameter) with an electrical low pressure impactor (ELPI) that recorded data continuously

- PM_{2.5} and PM₁₀ mass, collected on Teflon® filters with size selective inlets
- Air exchange rates
- Temperature and relative humidity (RH) indoors and outdoors
- Range top burner and oven temperatures
- Gas or electric use during cooking

During selected tests, additional samples were collected for other air contaminants. These included samples for PAHs, elements, and aldehydes.

The 32 tests were designed to collect information on the following factors:

- Appliance type (gas, electric, and microwave)
- Cooking method (frying, baking, broiling, range-top burner, oven)
- Food type (variety of foods cooked)
- Cooking vessel (pan material, lids)
- Exposure reduction methods (exhaust fan, hood shields)

Realistic cooking activities were performed during the study. They involved cooking activities such as stovetop stir-frying on the range top burner, frying tortillas in oil, broiling fish in the oven, and baking a pre-packaged frozen lasagna in the oven. The amount of food cooked was larger than would be typical in a residential setting, and the duration of cooking was generally longer than typical in order to obtain sufficient pollutant mass for analysis.

PM_{2.5} and PM₁₀ were collected on Teflon® filters with size selective inlets both indoors and outdoors during all tests. The outdoor PM_{2.5} concentrations in Rohnert Park during February 2000 when the main study was performed were low, ranging from 0.6 to 13.6 µg/m³. PM₁₀ concentrations outdoors ranged from below the detection limit to 19.3 µg/m³. Cooking resulted in substantially increased indoor concentrations of PM_{2.5}. During the 32 cooking tests, PM_{2.5} concentrations ranged from below the detection limit to 3880 µg/m³, with the highest concentrations occurring during the self-cleaning of the gas oven. During that five-hour event, the average concentrations were above 2000 µg/m³ in the kitchen, living room, and bedroom, constituting a significant source of PM exposure in the house. The PM₁₀ concentrations were over 3500 µg/m³ in the kitchen during the gas oven self-cleaning test. Oven cleaning was also a significant source of PM for the electric oven, but the PM concentrations were less than half that measured during the gas oven self-cleaning test.

During six standard cooking tests that included stovetop stir-frying, frying bacon, frying tortillas, cooking French fries, broiling fish in the oven, and baking a pre-packaged lasagna in the oven, PM_{2.5} concentrations ranged from 195 to 1090 µg/m³ in the kitchen for the gas range tests and from 112 to 1270 µg/m³ with the electric range. The median concentrations were 524 and 294 µg/m³ in the kitchen for the comparable gas and electric tests. Although the PM_{2.5} concentrations were lower in the living room and master bedroom, they were very high relative to outdoors. Median concentrations during the six standard cooking tests with the gas range were 142 and 134 µg/m³ in the living room and bedroom, respectively. They were even higher

during the tests with the electric range. The median PM_{2.5} concentrations were 391 and 300 µg/m³ in the living room and bedroom, respectively.

PM₁₀ concentrations in the house were also substantially elevated due to cooking. Median concentrations in the kitchen, living room, and master bedroom during the six standard tests were 265, 216, and 274 for the tests with the gas range and 538, 407, and 402 µg/m³, respectively for the tests with the electric range.

The PM_{2.5} and PM₁₀ concentrations measured by the integrated sampling and gravimetric analysis method during the cooking tests were highly variable. Some of the variability was associated with poor precision of the sampling method. The relative standard deviation was greater than 25% for all duplicate samples of PM_{2.5}. The precision of the PM₁₀ gravimetric samples was better, with six of the eight pairs of samples having a relative standard deviation of less than the data indicator goal of ± 25%. The poor precision for the PEMs may have been related to poor stability of the pump flow rates over the duration of the sampling period. The impactors used in the study have not been validated for collection of cooking aerosols. The type of particulate matter, being predominantly oil droplets, may have adversely affected sampler performance.

The PM concentrations measured in replicate cooking tests using the same cooking method and type of food varied substantially. In three sets of duplicate cooking tests, the indoor concentrations of PM_{2.5} had a relative difference ranging from 2% (frying beef, bedroom sample) to 103% (baking lasagna, living room sample). The relative difference for the PM₁₀ concentrations ranged from 2% (frying beef, living room sample) to 155% (baking lasagna, bedroom sample). Although some of the variability may have been related to the poor precision of the PM measurements, analysis of the CO, NO, and NO₂ concentrations during the replicate tests showed that much of the variability was in the replication of the tests. Average CO concentrations during three replicate cooking tests differed by between 5 and 53%. NO concentrations differed by 3 to 64% during replicate tests. Similarly, average NO₂ concentrations differed by 4 to 52%, and peak concentrations differed by up to 59%.

The median and average concentrations of PM_{2.5} during these standard cooking events, which ranged from approximately 1.5 to 5 hours in duration, exceeded the NAAQS of 65 µg/m³ (24 hour average). The PM₁₀ concentrations exceeded the California 24 hour standard of 50 µg/m³ and the NAAQS of 150 µg/m³. The data indicate that cooking can be a significant source of exposure to PM.

Measurements with the ELPI, a real-time PM monitor, showed that the particles emitted during cooking were primarily less than 1 µm aerodynamic diameter. The instrument has the capability to measure particles down to 0.04 µm diameter, but peak particle sizes from natural gas flames are typically in the 0.01 µm range. Therefore, the ELPI did not detect the peak particle size except in tests during which bacon was cooked in a pan and tortillas were fried in oil in a pan on the electric range burner. In those tests, the peak particle sizes were at 0.21 and 0.13 µm. The small particle size has significant implications with respect to human exposure to these emissions.

As expected, the concentrations of combustion pollutants, CO, NO, and NO₂, increased substantially in the house during cooking tests with the gas range. The highest concentrations of CO occurred during the self-cleaning test with the gas oven, averaging approximately 14 ppm in the kitchen, living room, and bedroom during the five-hour test. The self-cleaning test with the electric oven resulted in CO concentrations of approximately 8 ppm in the three rooms. During the six standard cooking tests, the CO concentrations in the house averaged less than 4 ppm except in the test during which fish was broiled in the gas oven. NO concentrations were high during oven cleaning tests with both the gas and electric ovens, with average concentrations of approximately 400 ppb for the gas range and 140 ppb for the electric range. During oven cleaning with the gas range, the California 1-hour standard for NO₂ of 250 ppb was exceeded. During the six standard cooking tests, the concentrations of NO and NO₂ were elevated in the house only for the tests with the gas range. The NO₂ concentrations in the house during four of the six standard cooking tests with the gas range exceeded the NAAQS annual mean standard of 53 ppb.

PAHs were measured during a subset of tests. Because of the short test durations, it was difficult to collect sufficient mass for analysis. The number of compounds detected in the samples was low. The low amount of mass collected resulted in a high level of analytical uncertainty in the measurement results. However, the emission rates were low, less than 11.1 ng/g of food, for all compounds except naphthalene. Although PAHs were measurable in cooking oils used for the study, there was not a clear relationship between the presence of PAHs in the oils and in emissions during cooking. The data are not adequate for estimating exposure to PAHs due to cooking, nor to evaluate the impact on emissions of variables such as the type of cooking oil. However, despite the low concentrations and analytical uncertainty, the data suggest that cooking may impact indoor concentrations and exposures. The data suggest that additional testing and analysis are warranted to more fully evaluate the impact of cooking as a source of PAH exposure in residences. Alternative technical approaches will be required in future studies to ensure that sufficient mass can be collected during cooking tests in order to reduce the analytical uncertainty.

Element concentrations were measured in PM₁₀ mass collected during a subset of tests. Indoor concentrations during the cooking tests exceeded outdoor concentrations for most elements. Of particular significance were elevated concentrations of chromium, titanium, nickel, and zinc during the oven self-cleaning tests. The element measurements suffered the same limitation as the PAH measurements, having a high level of analytical uncertainty due to the small amount of mass that could be collected during the short cooking tests.

Aldehydes were measured in a subset of six tests to obtain preliminary data to evaluate the impact of cooking on aldehyde exposures in the home. Formaldehyde and acetaldehyde, Toxic Air Contaminants identified by the ARB, were measured in oven cleaning, broiling fish, and baking pork roast tests. During the 5-hr oven cleaning tests, the formaldehyde concentrations of 417 and 224 µg/m³ with the gas and electric ranges, respectively, substantially exceeded the 0.1 ppm (124 µg/m³) action level identified by the ARB. During the broiling fish test, the formaldehyde concentration of 129 µg/m³ also exceeded the action level.

Acetaldehyde concentrations were also elevated during the tests, with concentrations of 434 and 92 µg/m³ measured during oven cleaning and fish broiling tests with the gas range.

Although the aldehyde measurements were limited in scope, they indicated that cooking may have a significant impact on aldehyde exposures.

A number of tests were performed to evaluate the impact of various factors on emissions of air pollutants during cooking. Emissions were compared for gas and electric ranges. PM concentrations in the house were always higher during use of the gas oven than during use of the electric oven. This included both self-cleaning oven tests and the cooking tests. When cooking was performed on the range top burners, the PM emissions were higher during tests with the electric range that involved deep fat frying of French fries and tortillas.

Of the six standard cooking tests performed with both the gas and electric range, the highest emissions of PM_{2.5} occurred during frying of tortillas in oil on the electric range and baking a frozen lasagna in the gas oven. Broiling fish also produced high PM emissions.

In worst-case tests that involved realistic activities such as heating cooking oils too hot or slightly burning food, indoor air concentrations and emission rates were generally higher than in the standard tests. With the exception of the oven-cleaning tests, the highest PM concentrations were measured during the worst-case stovetop stir-frying test.

In general, the impact of variables such as type of cooking method, type of food, or pan material could not be determined precisely from the limited number of samples in this study. The concentrations of the air pollutants measured in the rooms and the emission rates calculated with the mass balance model were too variable to determine the significance of differences between different cooking activities.

Tests with the microwave demonstrated that emissions of PM and combustion pollutants were low with this cooking method. It was the most effective exposure reduction method evaluated in the study. Four tests with the range hood exhaust and range hood side shields resulted in lower concentrations of some of the air contaminants, but there was not a dramatic reduction in indoor air pollutant concentrations. Additional tests in a large number of homes with range hood exhaust systems of different age and design should be performed to determine the magnitude of the impact of range hoods on indoor pollutant concentrations under realistic conditions of use.

The study successfully provided data necessary to obtain a better understanding of the impact of cooking on indoor air pollutant concentrations and exposure. The results indicate that cooking is a significant, although highly variable, source of indoor PM exposure, depending on the amount of cooking that is done and the duration of time spent in the home following cooking. With a gas range, exposure to NO₂ and CO is also increased substantially. Indoor formaldehyde concentrations can increase substantially when either an electric or gas oven is used.

The results of the study cannot be used to precisely assess the impact of different types of cooking methods, different foods, or other parameters related to cooking methods and utensils due to the high variability in the emissions. To evaluate the impact of these parameters, a much larger number of tests would need to be performed. These tests could be performed under highly controlled conditions in environment test chambers or in field studies under realistic cooking conditions.

6.0 RECOMMENDATIONS

This study has provided important information on the impact of cooking on indoor air concentrations and exposure. The data provide a better understanding of the magnitude and variability of emissions from cooking. Additional work in this area is recommended to obtain more precise data that can be used to estimate the impact of cooking on exposure to air contaminants. The following work would more fully address the ARB objectives with respect to cooking as a source of exposure to air contaminants in the home:

- Personal monitoring and area monitoring should be performed in field studies to obtain more comprehensive data on exposures to PM, PAHs, and combustion pollutants under realistic conditions in residences. If there is an opportunity to perform additional data collection in on-going or planned studies, survey questionnaires should address cooking as a source. Diaries that document cooking activities should also be considered. For new studies, data could be collected either in randomly sampled populations or in studies utilizing scripted protocol methods. In the latter studies, participants would be recruited into the study to meet a defined set of selection criteria developed to obtain a study sample that is reasonably representative of the California population with regard to home and cooking characteristics. Home occupants would perform normal cooking activities, but according to a protocol that would ensure that two or three meals were cooked during a 24-hour monitoring period. Diaries and cooking records should be maintained during the monitoring period. Monitoring and sample collection should be performed over 12 or 24-hour periods to obtain exposure estimates. Tests should be performed to measure the collection efficiency of PM samplers for aerosols representative of emissions during cooking. The impact of flow rate and sampler design on collection efficiency should be evaluated. The impact of high water vapor concentrations during sample collection should also be determined. Testing should be performed to determine the losses of VOCs and SVOCs during collection of cooking aerosols by gravimetric sampling methods. In future studies of cooking emissions, researchers should consider use of methods that incorporate collection of PM and SVOCS with sampling systems configured with denuders, filter packs, and sorbents. Such systems are currently being used to measure SVOCs and PM in source studies, and they can be configured to measure SVOCs lost from the particles during the sampling period.
- Prior to performing additional work to measure personal exposure to PM due to cooking, methods development and validation testing should be performed to document the performance of available PM samplers. The inlets used for personal sampling are currently validated for solid particles. Emissions from cooking result in a much different type of aerosol, consisting of grease droplets, often in the presence of high water vapor concentrations. Tests should be performed to measure the collection efficiency of PM samplers for aerosols representative of emissions during cooking. The impact of flow rate and sampler design on collection efficiency should be evaluated. The impact of high water vapor concentrations during sample collection should also be determined. Testing should be performed to determine the losses of VOCs and SVOCs during collection of cooking aerosols by both sampling artifacts and gravimetric sampling methods currently in use. In future studies of cooking emissions, researchers should consider use of methods that incorporate collection of PM and SVOCS with sampling systems

configured with denuders, filter packs, and sorbents. Such systems are currently being used to measure SVOCs and PM, and they can also be configured to measure SVOCs lost from the particles during the sampling period.

- Additional work should be performed to characterize the emissions from cooking. Emission rates are needed to predict exposure to PM and gas phase contaminants generated during cooking. This data can most easily and accurately be obtained by performing tests in controlled environment chambers. This work should include tests to determine the sink effect and deposition velocities specific to the aerosols generated during cooking.
- The impact of cooking in residences on exposures to aldehydes and PAHs should be further evaluated. Results of this study suggest that cooking may greatly impact exposures to these Toxic Air Contaminants.