AP42 Section:	9.13.3
Related	1
Title:	Further Development of Emission Test Methods and Development of Emission Factors for Various Commercial Cooking Operations Final Report SCAQMD University of California/Riverside JM Norbeck July 24, 1997

Tom,
Please coordinate a response to Bob McCrillis for EFIG.
DCM

cc: EFIG PM + O_3 Teams (w/o attachments)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
AIR POLLUTION PREVENTION AND CONTROL DIVISION
RESEARCH TRIANGLE PARK, NC 27711

January 15, 1998

OFFICE OF
RESEARCH AND DEVELOPMENT

MEMORANDUM

SUBJECT: Commercial Cooking Emissions Data

FROM: Robert C. McCrillis (MD-61) Bob
Emissions Characterization and Prevention Branch

THROUGH: Larry Jones (MD-61) Larry
Chief, Emissions Characterization and Prevention Branch

TO: David Misenheimer (MD-14)
Emissions, Monitoring, and Analysis Division, OAQPS/OAR

Attached is a copy of the detailed data report entitled Further Development of Emission Test Methods and Development of Emission Factors for Various Commercial Cooking Operations, submitted by the University of California/Riverside - Center for Environmental Research and Technology (CE-CERT) to South Coast AQMD. This report contains stage-by-stage particle size data. It also contains detailed aldehydes data and data on emission of reactive organic gases (ROG). I am passing this report by our QA people to get their reading on the data.

My own assessment is that the particle size data are usable quality. I am concerned, however, that CE-CERT (1) extracted the particle size samples from the stacks through a curved and heated probe and (2) that the impactor was heated. By extracting the sample through a curved probe, there is a good change the larger particles (>15 μm)were inertially separated and did not make it to the impactor at all. Heating the probe and impactor to stack temperature would have prevented condensation of some of the intermediate molecular weight organics, so they would have passed through the impactor as gases. My concern here is mitigated somewhat since stack temperatures during the reported tests ranged from a high of 136 °F for the charbroiled hamburger down to the high 70s °F for the deep fat frying operations. These stack temperatures were not high enough, except perhaps for the charbroiled hamburgers, to make any appreciable difference.

The curved probe could result in under reporting the larger particles, resulting in a greater fraction of small particles.

My preference would be to first duct the stack gases into a dilution tunnel. The unheated impactor would then be located directly in the tunnel with a straight nozzle. This arrangement would overcome my two concerns with the method used by CE-CERT.

I think the total particulates, aldehydes, and ROG data are all good quality.

I have proposed a FY98 project to determine particle size of commercial cooking emissions. Based on the work done so far, I think a few of the tests reported in the attached document (charbroiled hamburger, in particular) should be repeated using the preferred sampling approach for particle size. I would also like to do speciation of the material caught on the particle size filters from all of the tests if CE-CERT still has them archived. I would appreciate your feedback on these ideas. I want to be sure that the project, if funded, addresses your needs to the greatest possible extent.

Attachment

cc: Tom Pace (w/o attachment)

FURTHER DEVELOPMENT OF EMISSION TEST METHODS AND DEVELOPMENT OF EMISSION FACTORS FOR VARIOUS COMMERCIAL COOKING OPERATIONS

Final Report

for:

Applied Science and Technology Division
SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT
Contract No. 96027

July 24, 1997

Principal Investigator:
Joseph M. Norbeck

Prepared by:

William A. Welch
Principal Development Engineer

Report No: 97-AP-RT58-002-FR

Table of Contents

APPENDICES

APPENDIX A: Source Test Data and Calculations

A1 - ROG Method Verification Tests
A2 - Hamburger/Underfired Charbroiler
A3 - Whole Chicken/Underfired Charbroiler
A4 - Atlantic Salmon/Underfired Charbroiler
A5 - Shoestring Potatoes/Open. Deep Fat Fryer
A6 - Breaded Chicken/Open. Deep Fat Fryer
A7 - Breaded Fish/Open. Deep Fat Fryer
A8 - Hamburger/Flat Griddle
A9 - Skinless. Boneless Chicken Breast/Flat Griddle
A10 - Cod Fillets/Flat Griddle
A11 - Hamburger/Automated Charbroiler
A12 - Hamburger/Automated Charbroiler/Catalyst A
A13 - Hamburger/Automated Charbroiler/Catalyst B

APPENDIX B: Source Test Analytical Data

B1 - ROG Method Verification Tests
B2 - Hamburger/Underfired Charbroiler
B3 - Whole Chicken/Underfired Charbroiler
B4 - Atlantic Salmon/Underfired Charbroiler
B5 - Shoestring Potatoes/Open, Deep Fat Fryer
B6 - Breaded Chicken/Open. Deep Fat Fryer
B7 - Breaded Fish/Open. Deep Fat Fryer
B8 - Hamburger/Flat Griddle
B9 - Skinless, Boneless Chicken Breast/Flat Griddle
B10 - Cod Fillets/Flat Griddle
B11 - Hamburger/Automated Charbroiler
B12 - Hamburger/Automated Charbroiler/Catalyst A
B13 - Hamburger/Automated Charbroiler/Catalyst B

APPENDIX C: Food Product Fat Content Analytical Data

Background

The University of California, Riverside College of Engineering - Center for Environmental Research and Technology (CE-CERT) has conducted the following emissions testing and analyses:

Report No: 97-AP-RT58-002-FR

For: South Coast Air Quality Management District
Program Manager: Glenn Kasai (909) 396-2271

Contract No.: 96027

Principal Investigators: Joseph M. Norbeck, William A. Welch

Purpose: To develop process operations, sampling and analytical procedures for evaluating particulate matter and reactive organic gas emissions from commercial cooking operations. Additionally, to develop emission factors for several common cooking processes and investigate the efficiencies of possible control technologies.

Tested At: CE-CERT
University of California, Riverside

Test Dates: April 19, 1996 – March 31, 1997

Final Draft Report: December 6, 1996

Final Report: July 24, 1997

Project Staff:

William A. Welch, Principal Development Engineer
Sven P. Sodemann, Senior Development Engineer
Daniel Yap, Laboratory Assistant
C. Anthony Taliaferro. Development Technician V
Ethan Altman, Laboratory Assistant
David Cocker, Student Assistant

ACKNOWLEDGEMENTS

The University of California. Riverside Bourns College of Engineering - Center for Environmental Research and Technology would like to thank the following people for their participation on the Technical Advisory Committee. The comments and recommendations provided by committee members contributed significantly to the success of this program.

Joe Knapp	McDonald's Corporation
Don Fisher	Pacific Gas & Electric Company
Duane Crisp	Burger King Corporation
Michael Lo	Southern California Edison
Bob Whitely	Englehard Corporation
John Higuchi	South Coast Air Quality Management District
Glenn Kasai	South Coast Air Quality Management District

EXECUTIVE SUMMARY

The South Coast Air Quality Management District (SCAQMD) plans to promulgate new regulations affecting emissions of particulate matter (PM) and reactive organic gases (ROG) from restaurants operating in the South Coast Air Basin through development and implementation of Proposed Rule 1138. As part of the rule development process, the SCAQMD has evaluated the feasibility of using a standardized facility for certifying cooking and control equipment in lieu of source testing at actual field sites. The standardization process substantially reduces the cost of compliance for restaurant operators. As part of this program, testing has been conducted to determine the accuracy and reproducibility of the process, sampling, and analytical aspects of operating the standardized facility.

While the previous program successfully demonstrated the feasibility of the standardized facility concept, the information developed was narrow in scope. Further work was necessary to refine sampling and analytical protocols, to develop baseline emission factors from common commercial cooking processes, and to demonstrate the efficiencies from a selected number of control technologies.

Under contract with the SCAQMD, the University of California, Riverside College of Engineering - Center for Environmental Research and Technology (CE-CERT) has developed and demonstrated an alternative test procedure for determination of ROG emission factors from commercial cooking operations. In addition, CE-CERT modified the PM test procedures to include sampling and analyses for determination of particle size distribution. After development and demonstration, CE-CERT used the new procedures to conduct emissions testing for determination of baseline emission factors for various processes and a selected number of processes using control technologies.

The results documented in this report include method verification, emission factors and particle size distributions for eleven uncontrolled commercial cooking processes and three processes with emission control technologies.

1.0 INTRODUCTION

In 1994, the South Coast Air Quality Management District (SCAQMD) developed a document titled "Determination of Particulate and Reactive Organic Gaseous Emissions from Restaurant Operations - Interim Protocol."[1] The protocol utilizes traditional reference methods for determination of PM and ROG emission factors from commercial cooking operations. Results from field tests conducted under this protocol at restaurant sites have shown a high degree of variability. Under a previous contract with the SCAQMD, CE-CERT adapted the SCAQMD Interim Protocol for use in a test chamber with controlled process and environmental conditions in order to reduce variables associated with individual restaurant processes. The program involved the formation of a technical advisory committee, development of a test plan, preparation of the test chamber facility, operational checkout, and emissions testing using one common restaurant cooking process.

The main objective of CE-CERT's previous effort was the initial development of standardized procedures as well as the demonstration of the validity of those procedures for evaluating emissions from commercial cooking operations. A second objective was the investigation of surrogate methods for determination of several subset pollutants, including particulate matter with an aerodynamic diameter less than 10 microns (PM_{10}), speciated organic gases, ROG from a modified reference method, and total gaseous hydrocarbons using a continuous flame ionization detector (FID). Finally, CE-CERT investigated discrepancies found in the ROG measurement method through performance of several diagnostic test runs.

Under the current contract with the SCAQMD, CE-CERT refined methods for sampling and analysis of reactive organic gas (ROG) and particulate matter (PM) emissions from commercial cooking operations. The methods are adaptations of the reference methods detailed in the Interim Protocol. PM emissions were determined using a modified SCAQMD Method 5.1, which includes PM captured on a filter as well as condensed PM captured in impinger solutions. Particle size distributions (PSD) were determined using a cascade impaction system. ROG emissions were determined using a continuous flame ionization detector (FID) to measure total gaseous hydrocarbons and methane in a conditioned sample stream. A second sample was drawn from the gaseous stream to determine the fraction of effluent containing oxygenated compounds. By knowing the species, concentration, and FID response factors for oxygenated compounds, an overall weighted average response factor is applied to the average FID measured concentration to obtain an accurate total hydrocarbon concentration. CE-CERT verified that the surrogate ROG emissions measurement method was more consistent and precise than the accepted reference method.

CE-CERT used the refined procedures to determine emission factors for eleven uncontrolled cooking processes and three processes with emission control technology. During each test run, PM, PSD, and ROG samples were taken concurrently. Three consecutive runs were performed for each process tested. Results were statistically evaluated with regard to precision in determination of PM and ROG emissions from each cooking operation.

This report details the findings from a series of tests conducted in CE-CERT's stationary source emissions test chamber. The initial testing consisted of a series of six identical test runs performed for the alternative ROG method verification, followed by a seventh run using three separate FID analyzers for instrumental comparison. After review and evaluation of these results by the technical advisory committee, CE-CERT used the refined methods to develop PM and ROG emission factors and particle size distributions from effluents of eleven common commercial cooking processes and three processes using control technologies. This report details the process and environmental conditions under which the tests were performed, the sampling and analytical procedures used, and the resultant emissions data.

2.0 TEST CHAMBER AND EQUIPMENT SPECIFICATIONS

A test chamber equipped with natural gas, electricity, ventilation and fire suppression utilities was used to conduct the testing program. The dimensions of the chamber are 25' x 25' x 10'. Natural gas is provided inside the chamber through 1 1/4" pipe at 5 psig. 115 V single phase, 230 V single phase, 230 V three phase, and 480 V three phase electrical utilities are available inside the chamber. Exhaust ventilation is provided by a hood that is ducted to a centrifugal-type upblast blower located on the roof of the chamber. Make-up air is supplied by an evaporative cooler and blower through four penetrations and eight diffuser panels in the test chamber ceiling. Access to the sampling locations is provided by a stairway on the west end of the chamber. A schematic of the chamber is shown in Figure 1.

The cooking device used during the method verification portion of the test program was a Nieco Model 850 conveyorized charbroiler, fired with natural gas. The natural gas flow rate was measured with a calibrated dry gas meter. The heating value of the gas was measured with a Cutler-Hammer calorimeter.

Emissions generated during the cooking process were captured by a 4' x 4' Captive-Aire stainless steel wall canopy hood. Emissions captured by the hood were ducted horizontally across the roof of the test chamber to the upblast blower. The exhaust blower, equipped with a variable speed drive and controller, was adjusted for precise setting of the exhaust flow rate. Emissions samples were drawn from the horizontal section of the duct through access ports. The cooking and ventilation equipment configuration is shown in Figure 2.

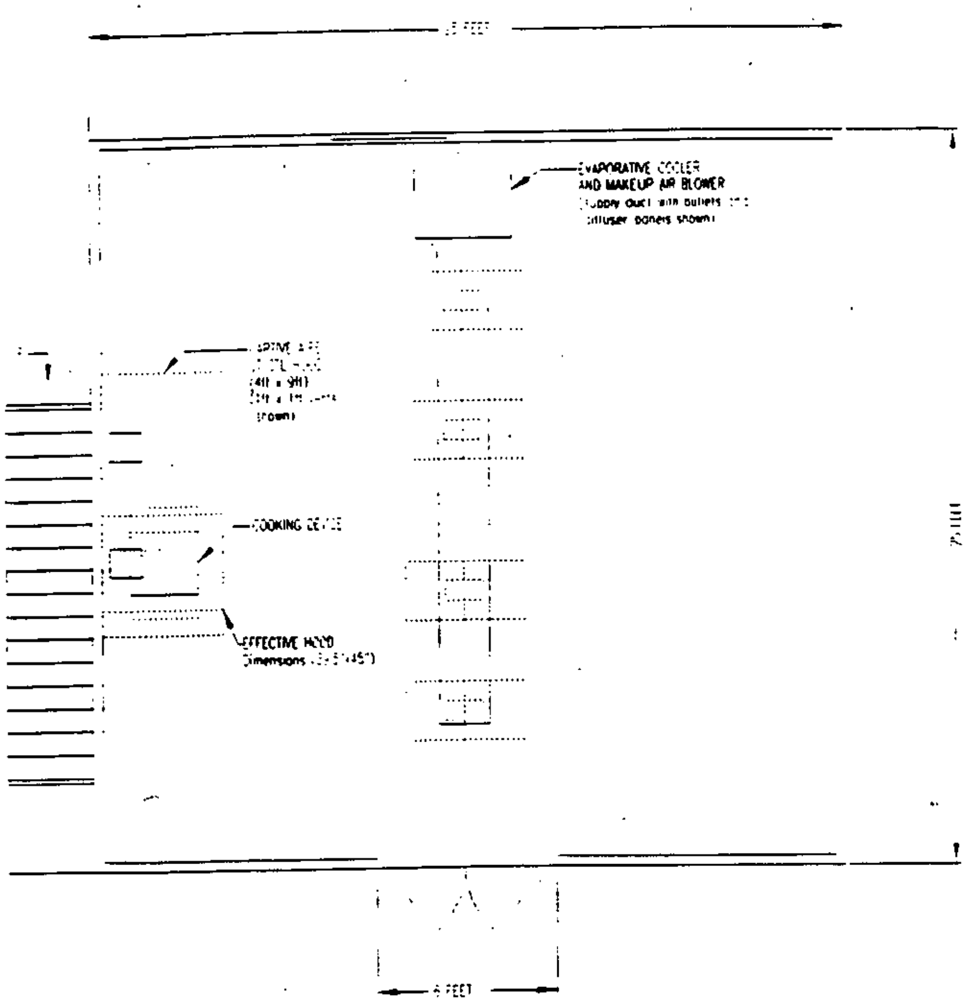


Figure 1

Test Chamber Schematic

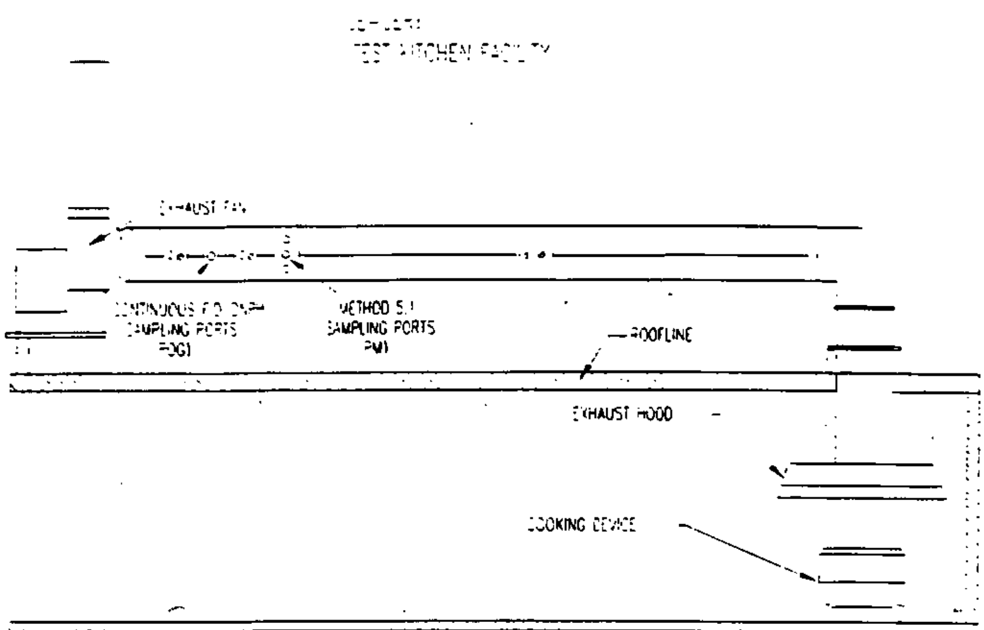


Figure 2

Cooking Equipment and Ventilation Configuration

3.0 SAMPLING AND ANALYTICAL PROCEDURES

3.1 Particulate Matter Method

For determination of total PM, the exhaust stream was sampled isokinetically following SCAQMD Method 5.1. An integrated sample for each test was acquired over a minimum of 72 minutes. Each sample was extracted from the exhaust duct through a stainless steel nozzle and probe, impingers immersed in an ice bath, and a 0.45 micron Gelman filter located downstream of the last impinger. An additional straight tube impinger (empty bubbler) was placed at the front of each sampling train (see Figure 3). Organic extraction and solid particulate matter analyses was performed on the probe, nozzle, filter, and impinger solutions using a modified SCAQMD Method 5.1. The modification involved using methylene chloride as a wash in addition to water. Samples not analyzed within a 48 hour period after acquisition were stored at 4 °C until analyses.

3.2 Particle Size Distribution

For determination of the particle size distribution by aerodynamic diameter, the exhaust stream was sampled isokinetically using a cascade impaction system. An integrated sample for each test was acquired over a minimum of 72 minutes. Each sample was extracted from the exhaust duct through a heated stainless steel nozzle and probe, ten-stage cascade impactor, and 0.45 micron Gelman filter located downstream of the last impactor substrate (see Figure 4). The entire system was contained in an insulated box and heated to the stack temperature for each test conducted. The mass of material collected on each stage was determined gravimetrically after a conditioning period of at least 24 hours in a temperature and humidity controlled environment.

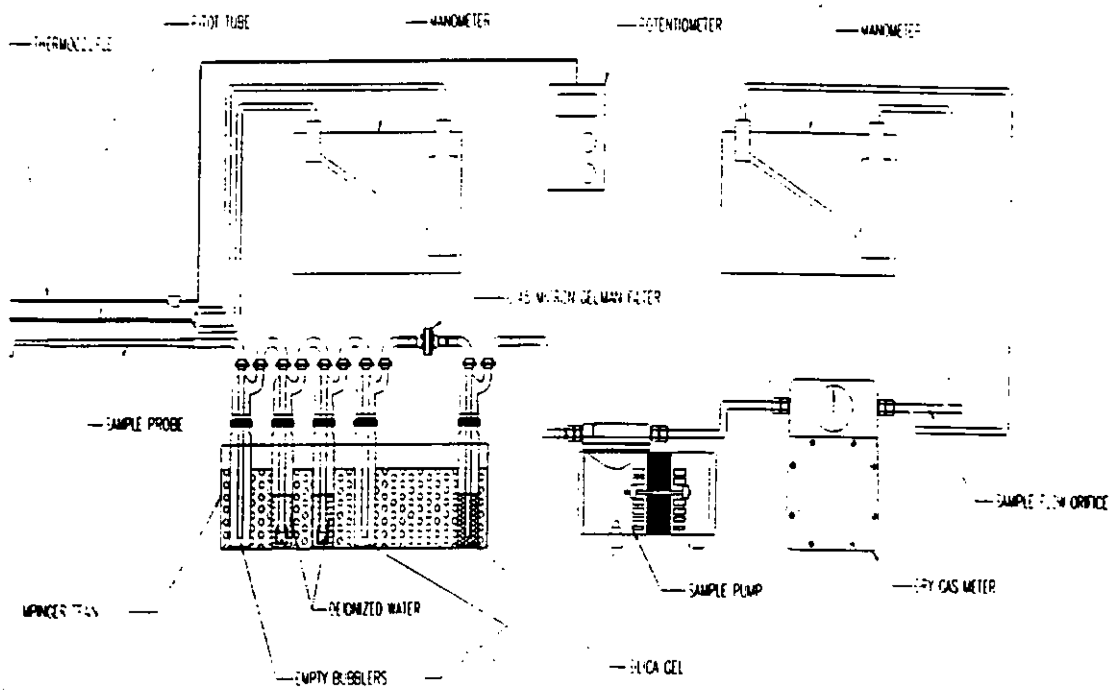


Figure 3

Particulate Matter Sampling System

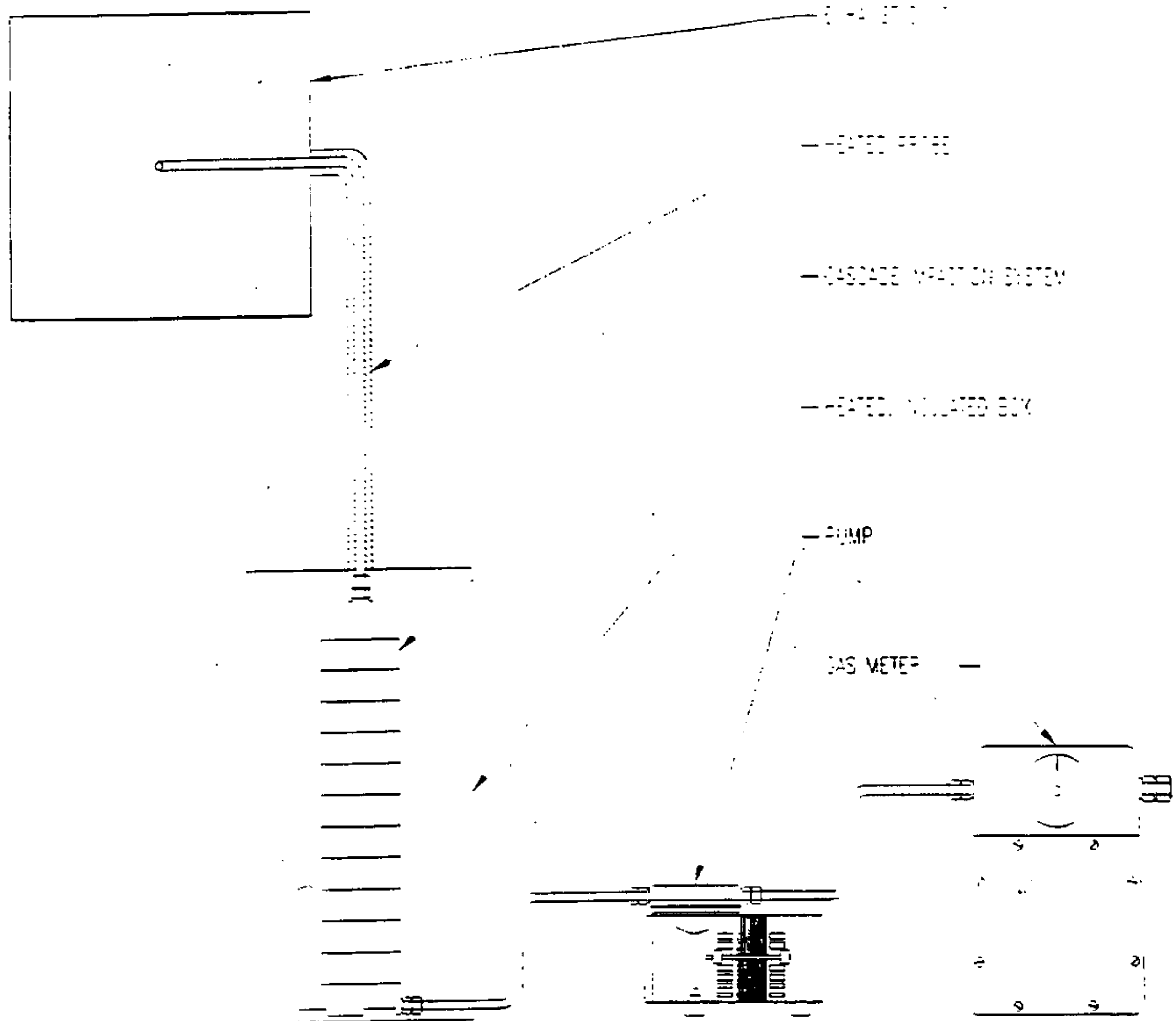


Figure 4

Particle Size Distribution Sampling System

3.3 Reactive Organic Gas Method (Continuous FID/Oxygenates)

Sampling was conducted according to procedures developed by CE-CERT and documented in a report titled "ROG Protocol Refinement," issued in November, 1995.[2] A continuous sample was extracted from the exhaust stream through a sample conditioning system. The conditioning system consisted of a SCAQMD Method 5.1 sampling train, including a single in-stack nozzle (facing downstream), a stainless steel probe, impingers in an ice bath, and a 0.45 micron Gelman filter. The sample stream was drawn through the conditioning system and manifold to an analyzer using a flame ionization detector (FID). The FID analyzer continuously measured the total gaseous hydrocarbon concentration (as CH_2). Methane was determined with either a dual-channel FID or a single-channel FID fitted with an activated carbon filter. In the latter case, an integrated sample was acquired in a Tedlar bag at the end of each test run over a minimum of 15 minutes. The sample was then immediately analyzed.

The FID analyzer was zeroed with pure nitrogen and calibrated with a known concentration of a gaseous hydrocarbon mixture prior to each test. The calibration procedure included checks for linearity and system bias. The analyzer was operated for the entire duration of each test. A post-test calibration check was performed with the zero nitrogen and span gas following each sampling period.

A second sample was drawn from the manifold through a series of three cartridges containing crystalline dinitrophenylhydrazine (DNPH). The sample flow rate was set to approximately 1 liter per minute and measured with a calibrated dry gas meter. The DNPH cartridges were analyzed for aldehydes and ketones using high performance liquid chromatography (HPLC). A comparison of concentrations of each species in the three cartridges was performed to determine the extent of breakthrough and for quality control to verify that all of the sample mass was captured. Mass emissions of individual carbonyl species were determined from analyzed concentrations, sample volume, and effluent volumetric flow rate. This data was used to determine a weighted average FID response. The ROG sampling and analytical system is illustrated in Figure 5.

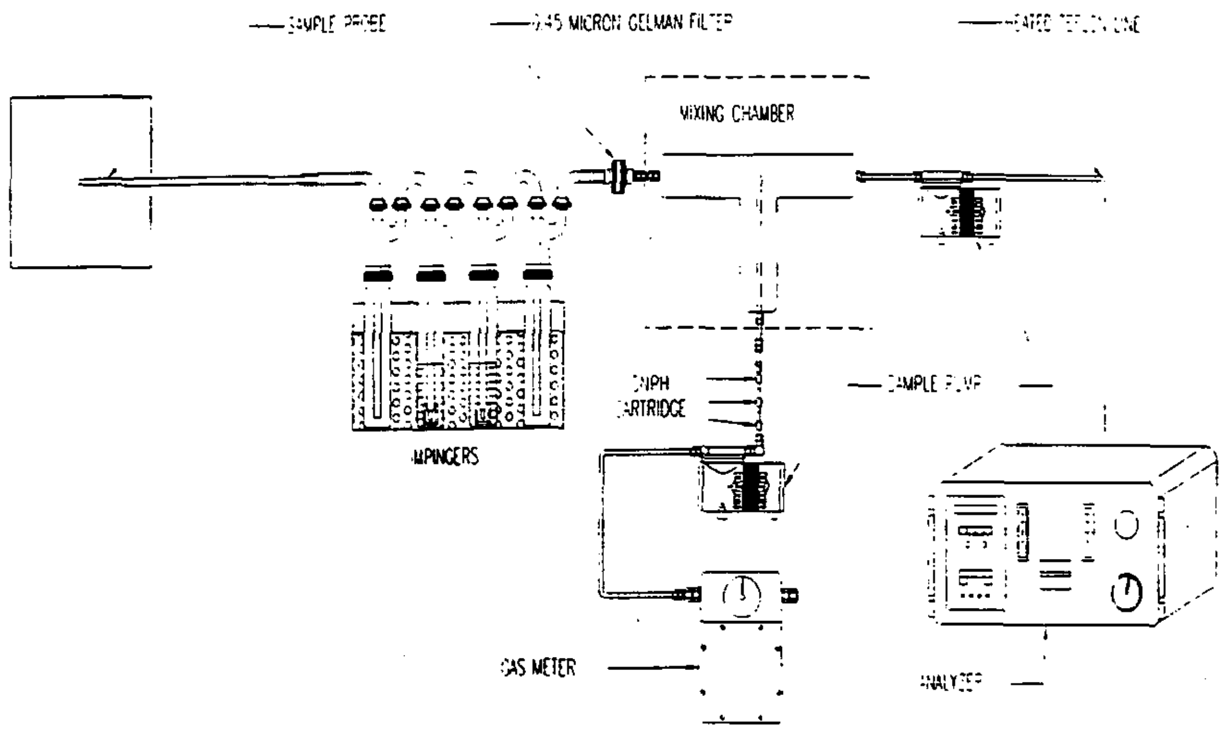


Figure 5

ROG Sampling System

For the method verification test runs, the method was compared with the reference method (modified SCAQMD Method 25.1) for determination of ROG. The reference sampling apparatus consisted of two evacuated twelve liter tanks, each equipped with flow controllers, condensate traps, vacuum gauges, and probes. The modification to the method involved conditioning of the sample stream prior to acquisition in the condensate traps and evacuated tanks. The conditioning system consisted of a single in-stack nozzle (facing downstream), a stainless steel probe, two miniature impingers in an ice bath, and a 0.45 micron Gelman filter. The two Method 25.1 probes were attached to the downstream side of the filter by means of a "tee," as shown in Figure 6. An integrated sample for each test was acquired over a 60 minute period. Samples were analyzed according to the SCAQMD Interim Protocol. Laboratory analyses data for ROG determination are presented in Appendix B.

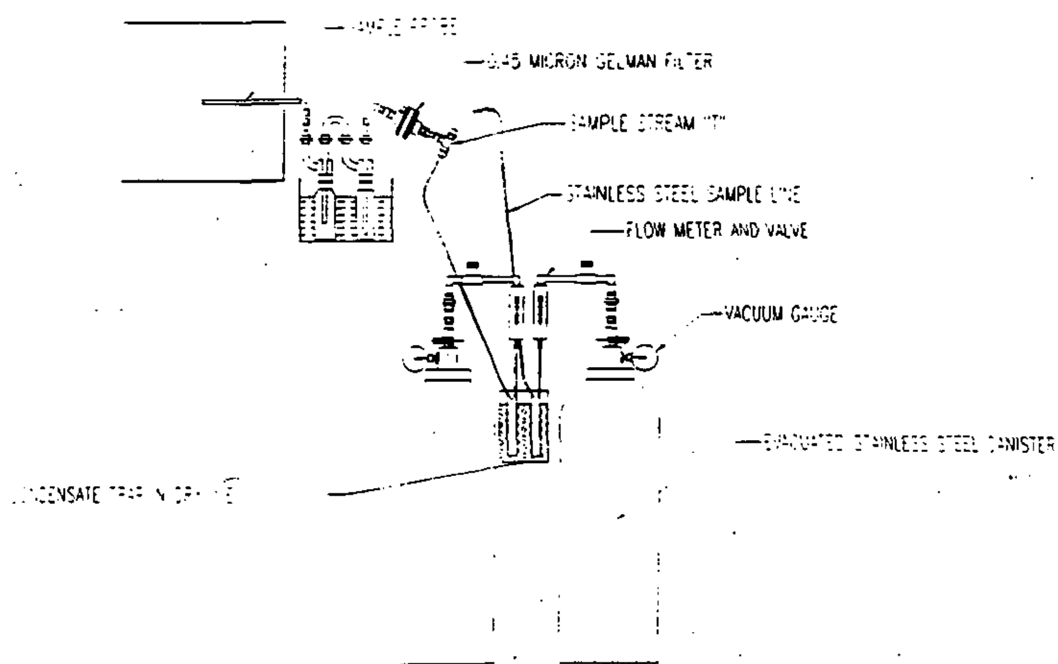


Figure 6

Reference ROG Sampling System

3.4 Fixed Gases, Moisture, and Flow Determination

Carbon monoxide and carbon dioxide concentrations were continuously monitored and recorded using a non-dispersive infrared detector. The sampling, conditioning, and analyses of CO and CO_2 followed SCAQMD Method 100.1. Flow rate in the exhaust duct was determined using SCAQMD Methods 1, 2 and 3. Moisture content in the effluent was determined using SCAQMD Method 4.

4.0 PROCESS DESCRIPTIONS

4.1 Hamburger Meat/Underfired Charbroiler Process

The cooking device used was a 36" Wolf underfired charbroiler, fired with natural gas. The natural gas flow rate was measured with a calibrated dry gas meter. The heating value of the gas was measured with a Cutler-Hammer calorimeter. The firing rate was set to operate within 5% of the manufacturer's specified input rate. In addition, the gas supply pressure was adjusted to within +/- 2.5% of the manufacturer's specified operating pressure. The broiler controls were set such that the broiling area achieved an average temperature of 600 ° F, as measured by a plate thermocouple. The grill surface temperature was measured at the center of each of location where hamburger patties were placed.

4.1.1 Process Conditions

Prior to testing, the hamburger patties were prepared by loading them onto sheet pans lined with freezer paper. The 1/3 pound meat patties specified were finished grind, pure beef hamburger, 25% fat by weight, 58-62% moisture, 5/8" thick, and 5" in diameter. The fat and moisture content of the patties were verified in accordance with recognized laboratory procedures (Association of Official Analytical Chemists (AOAC) Official Actions 960.39 and

950.46, respectively). One patty from the batch designated for each run was reserved for these analyses. Each pan was loaded with 24 patties. The pans were stacked in a refrigerator with spacers between each pan to provide for airflow. The internal refrigerator temperature was maintained at approximately 38 ° F. This temperature was continuously monitored with a thermocouple placed in a hamburger patty to ensure the pre-cooked condition of the meat.

The broiler grate was conditioned in accordance with the manufacturer's instructions. The underfired broiler controls were set to achieve maximum input (not exceeding 600 ° F grate temperature), and allowed to warm up for a minimum of one hour. The grill was loaded at 2/3 capacity. Therefore, 16 patties were sequentially loaded on the broiler grate over a 45 second time period (approximately one patty every three seconds). The patties were placed on the grill according to the pattern illustrated in Figure 7.

Patties were cooked for 4½ minutes on the first side, starting from the time the first hamburger patty was placed on the broiler grate. The patties were then turned in the same order they were loaded over a 45 second time interval. For the second side, patties were cooked for an additional three minutes (including the time to turn hamburger patties).

No mechanical pressing of the patties was performed, due to variability introduced through inconsistent application. Patties were removed in the order placed on the broiler over a 45 second time period. The cycle was repeated 30 seconds after the last patty was removed from the grill. During this 30-second period, the grill was scraped to remove any excess fat and charred material from the cooking surface.

Patties were cooked to an average internal temperature of 166 ° F +/- 5 °F, to confirm a medium-well condition. Internal meat temperature was determined with a stack of hamburger patties placed in a temperature measurement system. The system consisted of an insulated container with a thermocouple bundle attached to the lid (see Figure 8).

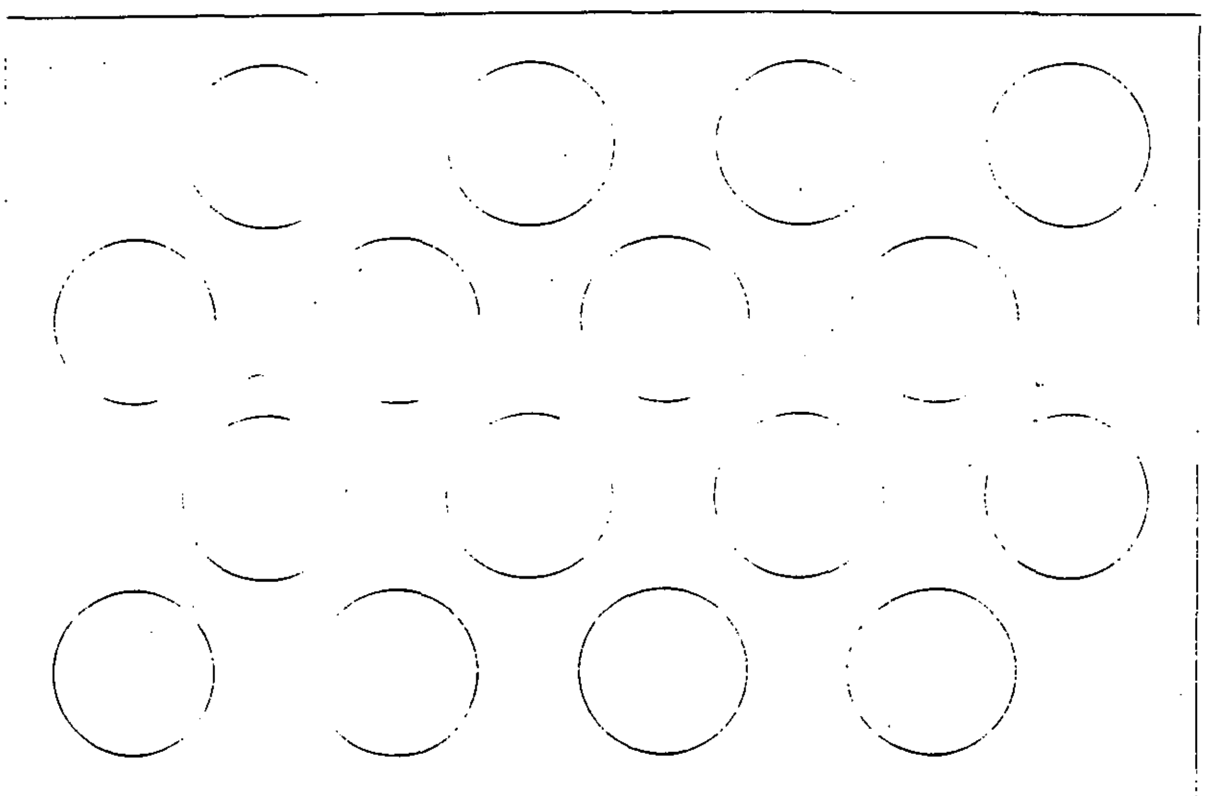


Figure 7

Cooking Pattern (2/3 Load)

(Hamburger, Chicken Breasts)

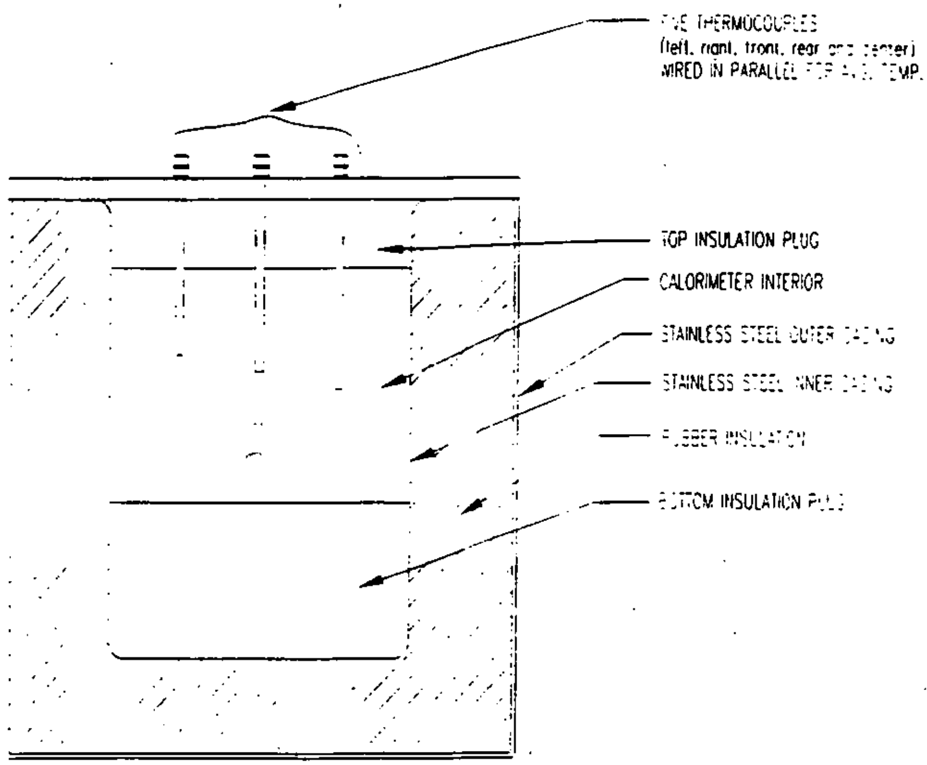


Figure 8

Internal Meat Temperature Measurement System

The five thermocouples were placed in different locations and depths in order to minimize the variability of the measurement.

Research conducted by Pacific Gas & Electric Co. (PG&E Standard Test Method for the Performance of Underfired Broilers. 1995) has determined that the final internal temperature of cooked hamburger patties may be approximated by the percent weight loss incurred during cooking. For the hamburger patties specified in this test plan, an internal meat temperature of 165 ° F corresponds to a weight loss of approximately 30%. This correlation was confirmed using a minimum of three data points. The data points bracketed the target 165 ° F meat temperature. Thus, the percent weight loss was used to verify the "doneness" of the cooked patties. Using tongs, the patties were spread on a drip rack. After one minute, the patties were turned. After another minute the patties were transferred to a clean pan for weighing. If the average weight loss was not 30% +/- 2%, the total cooking time was adjusted to attain 30% +/- 2% weight loss. If the total cooking time required adjustment. even cooking on both sides of the hamburger patties was assured (approximately 60% of the total cook time was on the first side).

One patty from each run was reserved for moisture content analyses. These patties were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked patties was determined in accordance with American Organization of Analytical Chemists (AOAC) Official Action 950.46. The moisture loss during cooking was calculated based on the initial moisture content of the patties.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at 1600 fpm (with the charbroiler on). This velocity corresponds to a hood flow rate of

400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes, with the end of sampling corresponding with the end of a cooking cycle.

4.2 Whole Chickens/Underfired Charbroiler Process

The cooking device was a 36" Wolf underfired charbroiler, fired with natural gas. The natural gas flow rate was measured with a calibrated dry gas meter. The heating value of the gas was measured with a Cutler-Hammer calorimeter. The firing rate was set to operate within 5% of the manufacturer's specified input rate. In addition, the gas supply pressure was set within +/- 2.5% of the manufacturer's specified operating pressure. The broiler controls were set such that the average grill surface temperature achieved 450 °F, as measured by a flat plate thermocouple. The grill surface temperature was measured at the center of each location where fish was placed, with the remaining locations covered with metal plates. The burner controls on the broiler were adjusted until the average temperature measurement equaled 450 °F.

4.2.1 Process Conditions

Prior to testing, the chickens were prepared by loading them onto sheet pans lined with freezer paper. The chickens specified were whole with the skin on. The fat and moisture content of the chickens were verified in accordance with AOAC procedures. One sample chicken from the batch designated for each run was reserved for these analyses. The pans, loaded with uncooked chickens, were stacked in a refrigerator with spacers between each pan to provide for airflow. The internal refrigerator temperature was maintained at approximately 38 ° F. This temperature was continuously monitored with a thermocouple placed in a chicken to ensure the pre-cooked condition of the food product.

The broiler grate was conditioned in accordance with the manufacturer's instructions. The broiler grate was cleaned and sanitized. The broiler rods were sprayed generously with a no-stick formula, to prevent chicken from sticking to the rods and damaging the skin. The controls were set to medium, and the broiler was allowed to warm up for a minimum of one hour. The grill was loaded at 2/3 capacity. Therefore, 4 butterflied whole chickens were sequentially loaded on the broiler grate over a 30 second time period. The items were placed on the grill according to the pattern illustrated in Figure 9. For the first row, the chickens were placed cavity side down, with the legs to the front of the broiler. Chickens in the second row were placed cavity side down, with the legs to the back of the broiler.

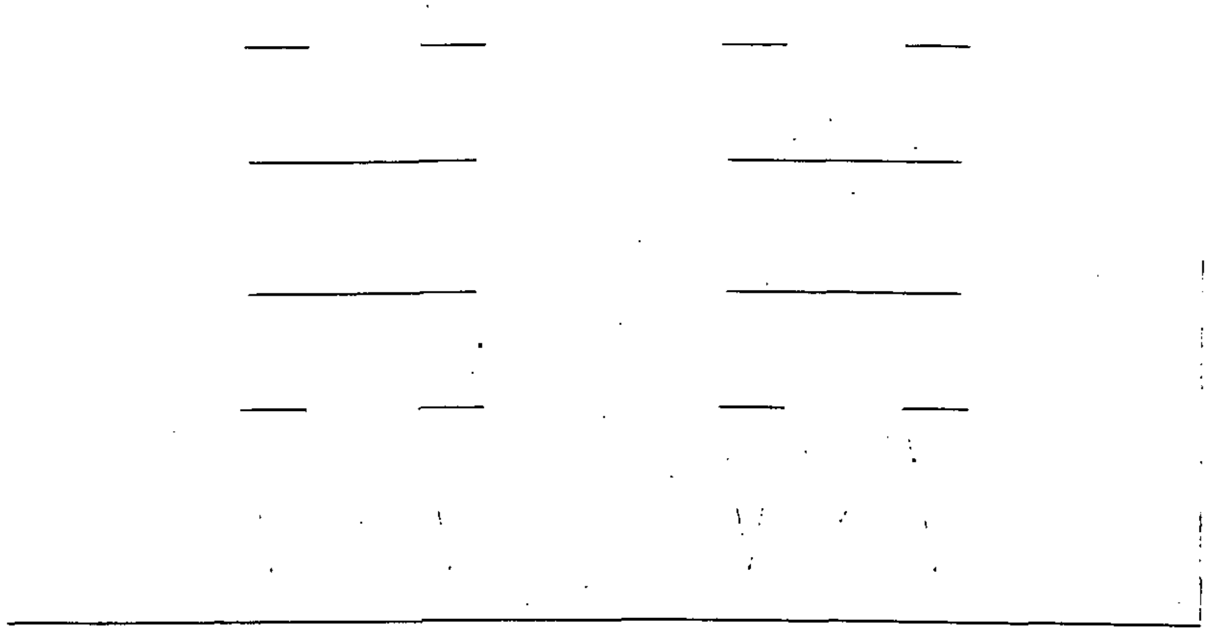


Figure 9

Whole Chicken Cooking Pattern

Chickens were cooked for approximately 20 to 25 minutes on the first side, starting from the time the first item was placed on the broiler grate. Visual indications for the time to turn the chicken were observed, such as a golden-brown ring around the cavity, dry and pasty skin, exposed breast meat turning from pink to white, and increasing rigidity.

The items were turned with a large fork to cradle the chickens without piercing the skin. In the back row, where the legs were facing towards the back of the broiler, the fork was positioned with one tine along the backbone and one tine along the cavity. The fork was moved inward until it cradled the chicken. The chicken was carefully lifted off the broiler, such that it did not drag on the broiler rods or touch other chickens. The chicken was then balanced on the fork and turned. In the front row, where the legs were facing the front of the broiler. the fork was positioned with one tine along the base of a thigh, and one along the underside. The fork was moved in until it cradled the chicken. lifted. balanced. and turned as above.

The items were turned (to cavity side up) in the same order they were loaded over a 30 second time interval. The chicken was cooked for approximately 15 to 20 minutes in this position, followed by a second run. A visual indication of the time for the second turn was the pooling of juices in the cavity.

The chickens were turned in the same manner as above. The chickens were cooked in this position (cavity side down) for approximately 10 to 12 minutes, followed by the third and final turn. Visual indications of the time for the third turn included an even golden-brown color in the cavity, a rigid chicken, and fully cooked wings. At this stage, the chickens were turned for the third time in the manner described above. The chickens were "finished" by cooking with the cavity side up for approximately 5 to 6 minutes. At the end of this stage, the skin was crisp, with an even golden-brown color. The chickens were removed in the order placed on the broiler over a 30 second time period. The fully cooked chickens were removed using 11" metal tongs, to avoid cross-contamination from the turning fork.

Total cooking time was approximately one hour. The cycle was repeated 30 seconds after the last item was removed from the grill. During this 30 second period, the grill was scraped to removed any excess fat and charred material from the cooking surface.

Occasionally during cooking, the juices inside the chicken boiled and escaped. When juices escaped, they dripped and landed on the radiants or burners under the broiler rods, causing flames to rise from the burner. When flare-ups occurred during broiling, it was necessary to lift the chicken that was causing the flare-ups to avoid burning the skin.

Chicken was cooked to an internal temperature of 182 °F +/- 8 °F. to confirm a medium-well condition. Internal meat temperature was determined with a thermocouple bundle inserted into the thickest part of the chicken breast and the thickest part of the thigh (see Figure 10). The five thermocouples were placed in different locations and depths in order to provide a stable average internal meat temperature.

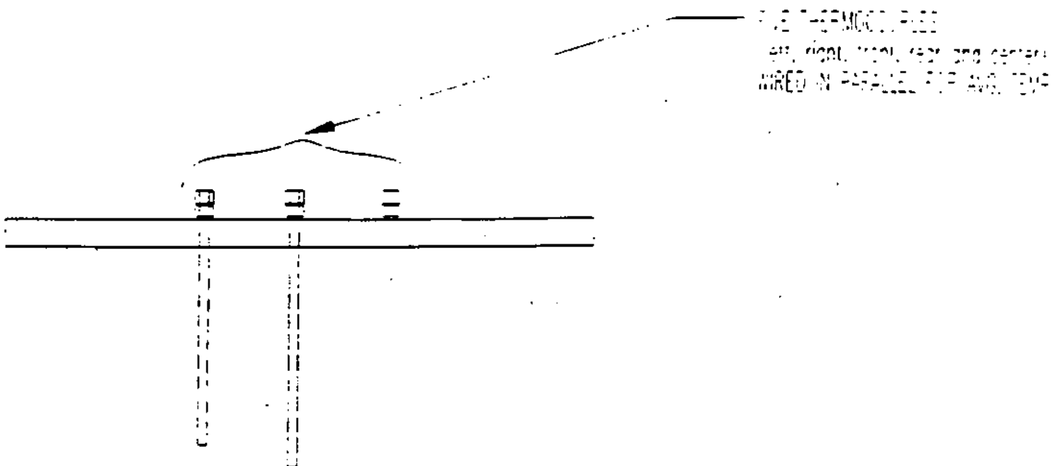


Figure 10

Internal Meat Temperature Measurement System

(Whole Chickens and Fish Fillets)

In addition, the chickens were evaluated for visual signs of doneness. Properly cooked chicken is rigid, firm, light, and has an even golden-brown color. The meat is firm, flakes into layers, is moist, and detaches from the bone. Undercooked chicken is soft and heavy, with a yellow or red color, with the meat fully attached to the bone. Overcooked chicken is very light, uneven, charred, and/or burned. The meat is dark brown and dry, and falls off the bone.

For the chicken specified for these tests, a correlation between internal meat temperature and weight loss was developed using a minimum of three data points. The data points bracketed the target internal food product temperature. The correlation showed that an internal meat temperature of 183 °F corresponded to a weight loss of 29%. The percent weight loss was used to verify the "doneness" of the cooked food products. Using tongs, the cooked products were spread on a drip rack. After one minute, the products were turned. After another minute the food products were transferred to a clean pan for weighing. The average weight loss was calculated for the chickens. If the average weight loss was not 29% +/- 2%, the total cooking time was adjusted to attain the proper weight loss developed from the correlation. If the total cooking time required adjustment, even cooking on both sides was assured by scaling each portion of the cooking cycle equally.

One sample food item from each run was reserved for moisture content analyses. These samples were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked food products was determined in accordance with recognized laboratory procedures (AOAC Official Action 950.46). The moisture loss during cooking was calculated based on the initial moisture content of the chicken.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at a minimum of 1600 fpm (with the charbroiler on). This velocity corresponds to a hood flow rate of 400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes, with the end of sampling corresponding with the end of a cooking cycle. For example, the chicken test runs required a minimum of 120 minutes to complete two cooking cycles.

4.3 Atlantic Salmon/Underfired Charbroiler Process

The cooking device used for these tests was a 36" Wolf underfired charbroiler, fired with natural gas. The natural gas flow rate was measured with a calibrated dry gas meter. The heating value of the gas was measured with a Cutler-Hammer calorimeter. The broiler controls were set such that the average grill surface temperature achieved 450 °F, as measured by a flat plate thermocouple. The grill surface temperature was measured at the center of each location where fish was placed, with the remaining locations covered with metal plates. The burner controls on the broiler were adjusted until the average temperature measurement equaled 450 °F.

4.3.1 Process Conditions

Prior to testing, the fish fillets were prepared by loading them onto sheet pans lined with freezer paper. The fish specified were 9 oz. Atlantic salmon fillets. The fat and moisture content of the fish were determined in accordance with AOAC procedures. One sample fish from the batch designated for each run was reserved for these analyses. The pans, loaded with uncooked fish, were stacked in a refrigerator with spacers between each pan to provide for airflow. The internal refrigerator temperature was maintained at approximately 38 °F. This temperature was continuously monitored with a thermocouple placed in a fish to ensure the pre-cooked condition of the food product. The pans were covered with plastic wrap to prevent the fish from drying out.

The broiler grate was conditioned in accordance with the manufacturer's instructions, and coated with a thin layer of cooking oil prior to each test run. The fish fillets were coated with liquid margarine, to prevent it from sticking to the rods during cooking. With the controls set according to the procedure described above, the broiler was allowed to warm up for a minimum of one hour. The grill was loaded at 2/3 capacity. Therefore, 16 salmon fillets were sequentially loaded on the broiler grate over a 45-second time period. The items were placed on the grill according to the pattern illustrated in Figure 11.

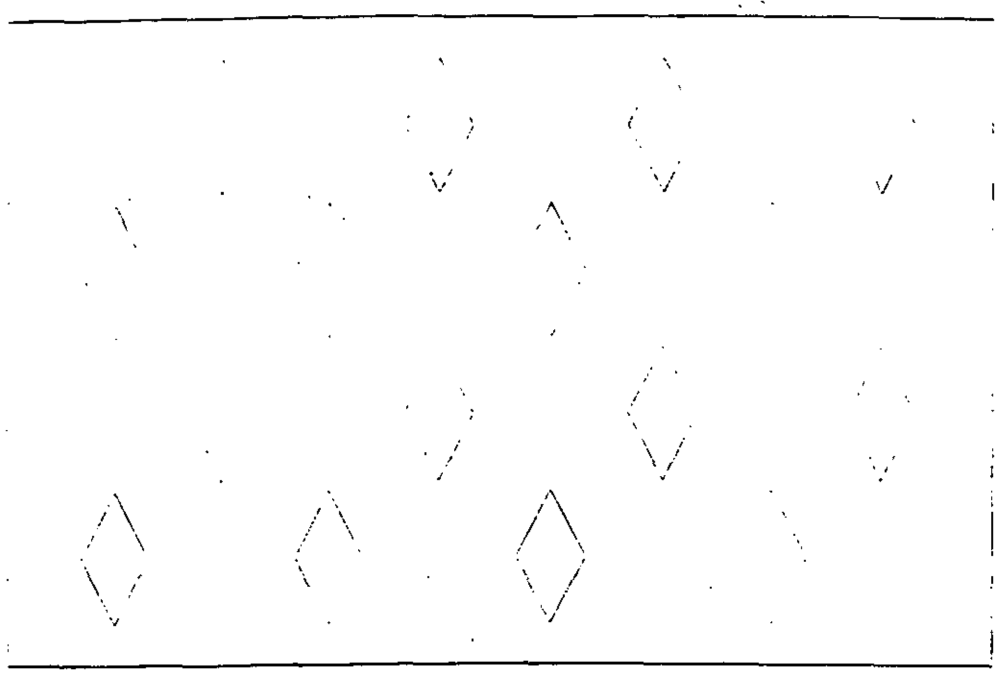


Figure 11

Salmon Cooking Pattern (2/3 Load)

Fish were cooked for approximately 5 minutes on the first side, starting from the time the first item was placed on the broiler grate. The fish were then turned with a spatula, in the same order they were loaded, over a 45-second interval. For the second side, the fish were cooked for an additional 5 minutes (including the time to turn the items). The fish were then removed in the order placed on the broiler over a 45-second time period.

The cycle was repeated 30 seconds after the last fish was removed from the grill. During this 30-second period, the grill was scraped to remove any excess fat and charred material from the cooking surface.

Fish were cooked to an internal temperature of 152 °F +/- 7 °F, to confirm a medium-well condition. Internal meat temperature was determined with a thermocouple bundle inserted into the thickest part of the fish fillet (see Figure 10). The five thermocouples were placed in different locations and depths in order to provide a stable average internal meat temperature.

For the fish specified for these tests, a correlation between internal meat temperature and weight loss was developed using a minimum of three data points. The data points bracketed the target internal food product temperature. The correlation showed that an internal meat temperature of 152 °F corresponded to a weight loss of 12.4%. The percent weight loss was used to verify the "doneness" of the cooked food products. Using tongs, the cooked products were spread on a drip rack. After one minute, the products were turned. After another minute the food products were transferred to a clean pan for weighing. The average weight loss was calculated for the chickens. If the average weight loss was not 12.4% +/- 2%, the total cooking time was adjusted to attain the proper weight loss developed from the correlation. If the total cooking time required adjustment, even cooking on both sides was assured (approximately 60% of the total cooking time was on the first side).

One sample food item from each run was reserved for moisture content analyses. These samples were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked food products was determined in accordance with recognized AOAC laboratory procedures. The moisture loss during cooking was calculated based on the initial moisture content of the fish.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at a minimum of 1600 fpm (with the charbroiler on). This velocity corresponds to a hood flow rate of 400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes. with the end of sampling corresponding with the end of a cooking cycle (e.g., minimum of 80 minutes for eight cooking cycles).

4.4 Shoestring Potatoes/Open Deep Fat Fryer Process

The cooking device used for this set of tests was a Frymaster FPH-50 Series, fired with natural gas. The fryer was installed according to the manufacturer's instructions under a 4-ft. deep canopy exhaust hood mounted against the wall with the lower edge of the hoop 6 ft., 6 in. from the floor. The fryer was positioned with the front edge of the frying medium inset 6 in. from the front edge of the hood at the manufacturer's recommended working height. The length of the exhaust hood and active filter area extended a minimum of 6 in. past the vertical plane of both sides of the fryer. In addition, both sides of the fryer were a minimum of 3ft. from any side wall, side partition, or any other appliance. A "drip" station was positioned next to the fryer. The equipment configuration is shown in Figure 12.

The fryer was connected to the natural gas supply line, downstream of a regulator and meter. The natural gas flow rate was measured with a calibrated dry gas meter. The heating value of the gas was measured with a Cutler-Hammer calorimeter. The gas supply pressure was adjusted (during maximum energy input) to within 2.5% of the operating manifold pressure specified by the manufacturer.

The fryer was cleaned by "boiling" with the manufacturer's recommended cleaning solution, followed by thorough rinsing. To prepare the fryer for temperature calibration, an immersion-type thermocouple was attached in the fry vat prior to testing.

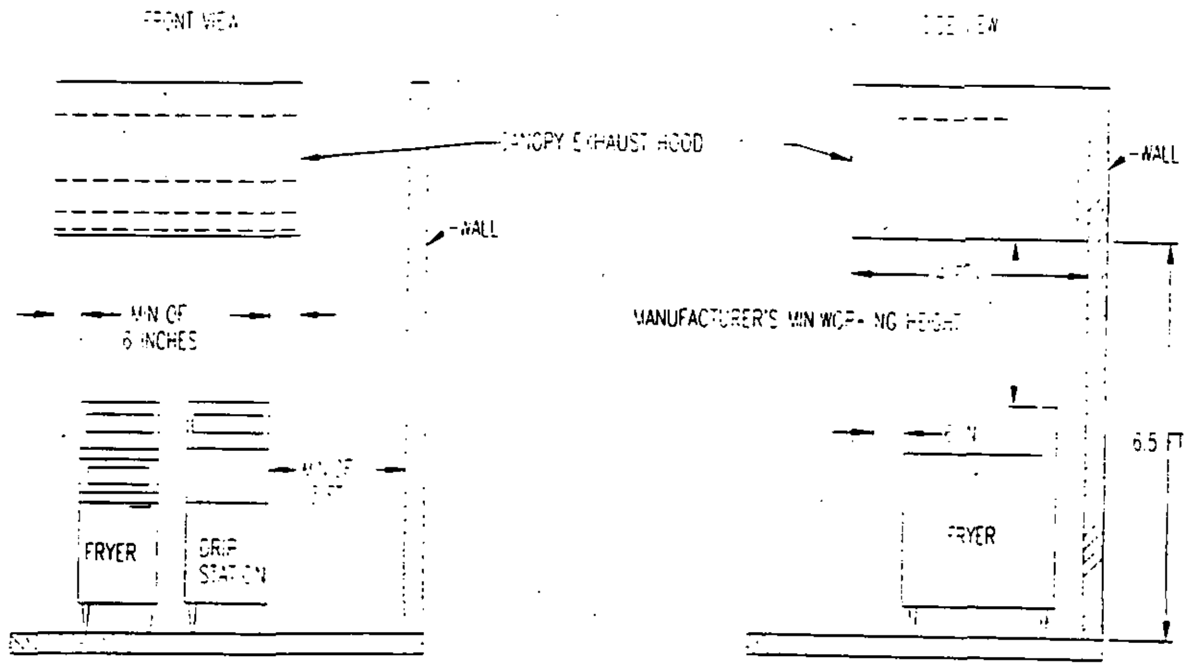


Figure 12

Open. Deep Fat Fryer Equipment Configuration

This thermocouple was located in the center of the vat, 1in. above the platform that supports the fry baskets (Figure 13).

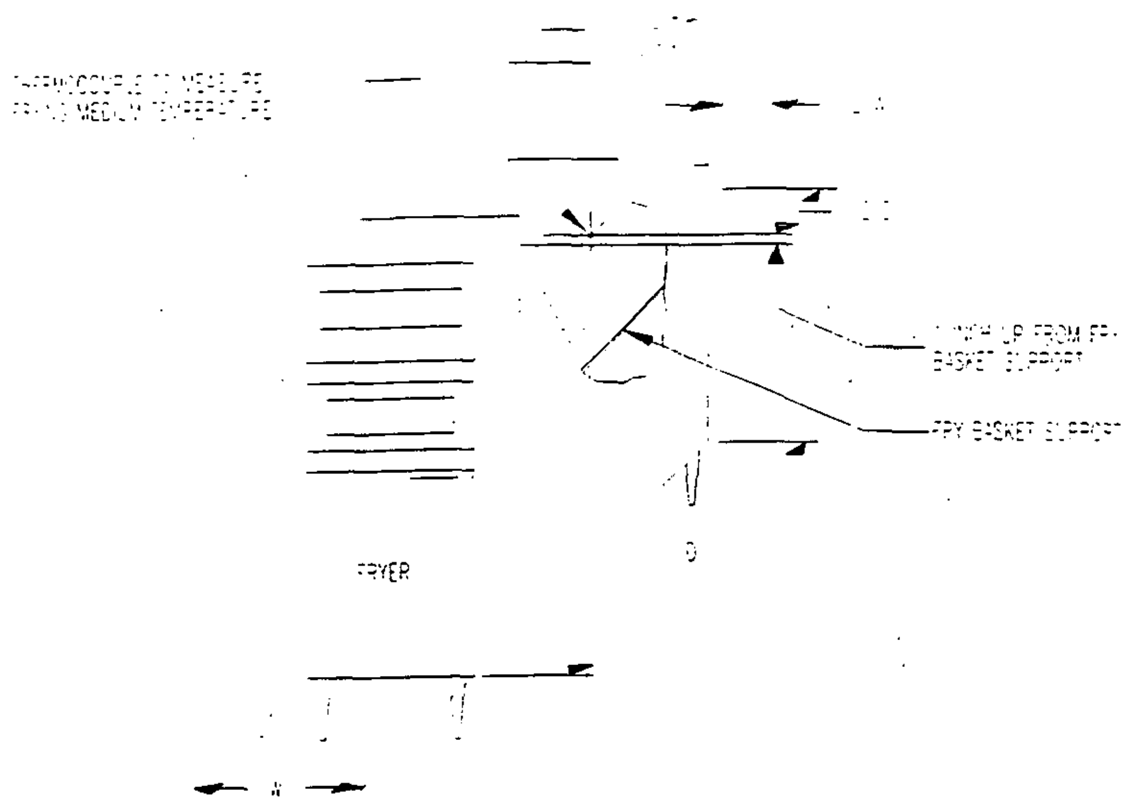


Figure 13

Thermocouple Placement

The energy input rate was determined with the temperature controls set to maximum. The fryer was loaded with water to the indicated fill line, and turned on. After a warm-up period of 15 min., the firing rate was determined by the time required for the fryer to burn 5 ft^3 of gas. The firing rate was adjusted (by adjusting the manifold gas pressure) until it was within 5% of the nameplate energy input rate.

Once the input rate was set, the fryer was drained, dried, and filled with partially hydrogenated, 100% pure vegetable oil to the indicated level. The fryer was turned on and allowed to warm up for 30 min. prior to the temperature calibration. The frying medium temperature was measured with the thermocouple positioned in the frying zone.

The average temperature of the frying medium was determined from the median temperature recorded over three complete thermostat cycles (periods between burner turning on and turning off). If necessary, the fryer temperature controls were adjusted to calibrate the fryer at an average frying medium temperature of 350 °F +/- 5 °F.

4.4.1 Process Conditions

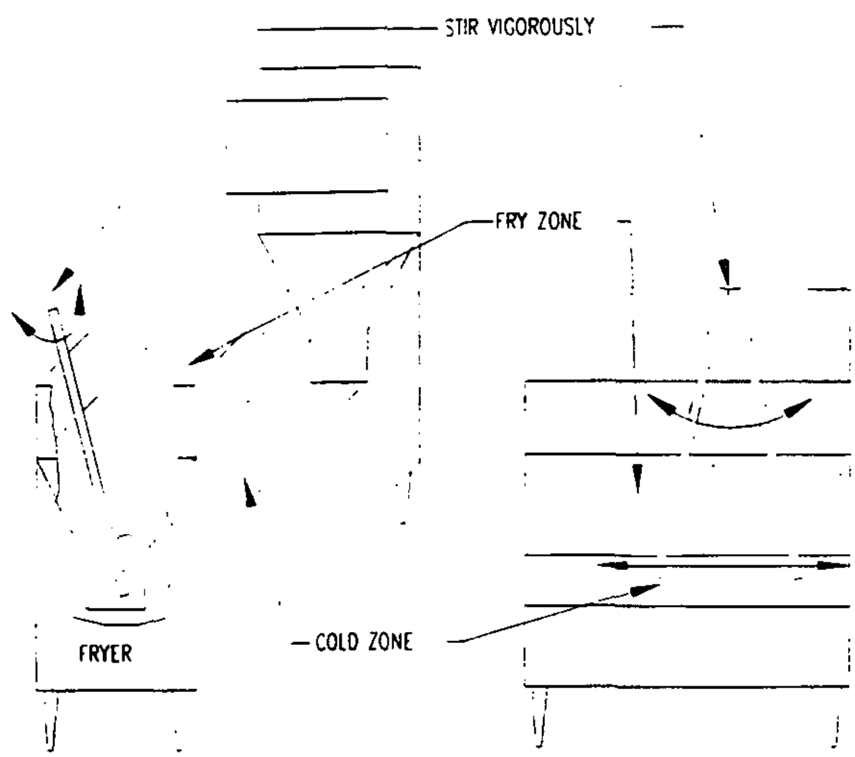
All cooking cycles were performed using blue ribbon product, par-cooked, frozen, ¼ in. shoestring potatoes. The fat and moisture content specified were 6 +/- 1% by weight and 66 +/- 2% by weight, respectively. Fat and moisture content of the uncooked product were verified using AOAC procedures. The french fries were prepared by weighing individual basket loads of 1.5 lb. +/- 0.01 lb. Each load was stored in a self-sealing plastic freezer bag, and the bags were placed in a freezer operating at -5 °F +/- 5 °F.

Cooking time for the shoestring potatoes was determined by the amount of time required to achieve a 30% +/- 1% weight loss of the product. Initially, a cooking time of 2 min. 45 sec. was assumed. Six consecutive loads of potatoes were cooked, and the average weight loss of the last five loads was determined, according to the following sequence.

1) Stabilization and stirring of the cold zone- Once the fryer had stabilized for 30 min. at the operating temperature, the cold zone (the oil in the lower valley of the vat) was stirred vigorously for 5 min. +/- 30 sec. to ensure uniform temperature (see Figure 14).

2) Six load stir up test- After the burners cycled off, the first load of potatoes (2 baskets, each with 1.5 lb. product) were placed into the fryer, and cooked for the estimated cooking time. Thirty sec. before removing the first load, the second load was removed from the freezer and placed in two baskets, ready for cooking. The first load was transferred at the designated time to the drip station and allowed to drain for two minutes.

The drip station was located in a position that prevented the dripping of oil back into the frying medium. The second load of product was placed in the fryer precisely 10 sec. after removing the first load or after the cook zone thermocouple indicated that the oil temperature had reached 340 °F. whichever was longer. This cycle was repeated until all six loads were cooked.



3) Cooki ... cold zone
stabili ... 6-load stir-up
test), ... ers cycled off,
the fir ... er, and cooked
for the ... the second load
was re ... The first load
was tr ... ain for two
minut ... sec. after
remov ... hat the oil
tempe ... peated until all
six loads were cooked. The weight loss was determined as the average weight loss of the last five loads of the six-load test. If the average weight loss was not 30% +/- 1%, the cooking time was adjusted, and the six-load cooking time determination test was repeated. Manual stirring of the cold zone and cold zone stabilization was not required if additional testing commenced within 10 min. of the last test.

Once the cooking time had been determined, emissions testing commenced. Sampling began as the first load of product was placed in the fryer. Each load consisted of one basket filled with 1.5 lb. of potatoes. Consecutive loads were cooked according to the procedure described above (cooking time determination) throughout the entire sampling period.

One sample food item from each run was reserved for moisture content analyses. These samples were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked food products was determined in accordance with recognized laboratory procedures (AOAC Official Action 950.46). The moisture loss during cooking was calculated based on the initial moisture content of the products.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at a minimum of 1600 fpm (with the fryer at operating temperature). This velocity corresponded to a hood flow rate of 400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes, with the end of sampling corresponding with the end of a cooking cycle.

4.5 Breaded Chicken, Breaded Fish/Open Deep Fat Fryer Process

Basic equipment specifications, including the cooking device, installation procedures, cleaning, start-up, temperature set point, and ventilation configuration followed the detailed description documented in Section 4.4 (Shoestring Potatoes/Open, Deep Fat Fryer).

4.5.1 Process Conditions

All breaded chicken cooking cycles were performed using 3 oz. Breaded chicken breast with rib meat. The fat content specified was 21% +/- 1%. All breaded fish cooking cycles were performed using 4 oz. Breaded cod fillets. The fat content specified was 1% +/- 0.5%. Fat and moisture content of the uncooked products were verified using AOAC procedures 984.23 and 984.25, respectively. The products were prepared by weighing individual basket loads of 1.5 lb. +/- 0.01 lb. Each load was stored in a self-sealing plastic freezer bag, and the bags were placed in a freezer operating at -5 °F +/- 5 °F.

Cooking time for the breaded chicken was determined by the amount of time required to achieve a 20% +/- 1% weight loss of the product. Cooking time for the breaded fish was determined by the amount of time required to achieve an 8% +/- 1% weight loss of the product. Initially, cooking times of 6 minutes for the chicken and 5 minutes for the fish were assumed. Six consecutive loads of each product were cooked, and the average weight loss of the last five loads was determined, according to the following sequence.

1) Stabilization and stirring of the cold zone- Once the fryer had stabilized for 30 min. at the operating temperature, the cold zone (the oil in the lower valley of the vat) was stirred vigorously for 5 min. +/- 30 sec. to ensure uniform temperature.

2) Six-load stir up test - After the burners cycled off, the first load of product (2 baskets, each with 1.5 lb. Loads) were placed into the fryer, and cooked for the estimated cooking time. Thirty sec. before removing the first load, the second load was removed from the freezer and placed in two baskets, ready for cooking. The first load was transferred at the designated time to the drip station and allowed to drain for two minutes. The drip station was located in a position that prevented the dripping of oil back into the frying medium. The second load of product was placed in the fryer precisely 10 sec. after removing the first load or after the cook zone thermocouple indicated that the oil temperature had reached 340 °F, whichever was longer. This cycle was repeated until all six loads were cooked.

3) Cooking time determination test- Ten min. +/- 1 min. after completing the cold zone stabilization test (stabilization and stirring of the cold zone followed by the 6 load stir-up test), the cooking time determination tests were conducted. After the burners cycled off, the first load of product (1 basket/ 1.5 lb. product) was placed into the fryer, and cooked for the estimated cooking time. Thirty sec. before removing the first load, the second load was removed from the freezer and placed in a basket, ready for cooking. The first load was transferred at the designated time to the drip station and allowed to drain for two minutes. The second load of product was placed in the fryer precisely 10 sec. after removing the first load, or after the cook zone thermocouple indicated that the oil temperature had reached 340 °F, whichever was longer. This cycle was repeated until all six loads were cooked. The weight loss was determined as the average weight loss of the last five loads of the six load test. If the average weight loss was not 20% +/- 1% for the breaded chicken product or 8% +/- 1% for the breaded fish product, the cooking time was adjusted, and the six load cooking time determination test was repeated. Manual stirring of the cold zone and cold zone stabilization was not required if additional testing commenced within 10 min. of the last test.

Once the cooking time had been determined, emissions testing commenced. Sampling began as the first load of product was placed in the fryer. Each load consisted of one basket filled with 1.5 lb. of product. Consecutive loads were cooked according to the procedure described above (cooking time determination) throughout the entire sampling period.

One sample food item from each run was reserved for moisture content analyses. These samples were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked food products was determined in accordance with recognized laboratory procedures (AOAC Official Action

950.46). The moisture loss during cooking was calculated based on the initial moisture content of the products.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at a minimum of 1600 fpm (with the fryer at operating temperature). This velocity corresponded to a hood flow rate of 400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes, with the end of sampling corresponding with the end of a cooking cycle.

4.6 Hamburger/Flat Griddle Process

The cooking device used was a 36" Taylor Model 69-23 flat electric griddle. The appliance was installed according to the manufacturer's instructions under a 4-foot-deep canopy exhaust hood. The griddle was positioned with the front edge of the cooking surface inset 6 in. from the front edge of the hood at the manufacturer's recommended working height. The length of the exhaust hood and active filter area extended a minimum of 6 in. past both sides of the griddle. In addition, both sides of the griddle were a minimum of 3 ft. from any side wall, side partition, or other appliance.

The supply voltage was measured and confirmed to be within 2.5% of the manufacturer's specified operating voltage. The voltage was monitored during each test. For each test run, the peak input rate was confirmed to be within 5% of the rated nameplate input.

The appliance was conditioned and the thermostats were set by the following procedures:

1) The thermostat controls on the griddle were set to 375 °F.

2) Once the griddle reached operating temperature, the entire surface was coated with a salt-free cooking oil. After five minutes, the oil residue was wiped off. The griddle was then allowed to stabilize for 60 min. at the set operating temperature.

3) Using a calibrated surface-type thermocouple, the griddle cooking surface temperature was measured at the center of each location where hamburger patties were placed. The surface temperature was monitored over several complete element cycles for each location. From this data, the average surface temperature was determined for each location. The measured temperatures were documented on a "map" of the griddle surface. The placement of the measurement points is shown in Figure 7.

4) Where required (as indicated by the average measured temperature at each location), the griddle temperature controls were adjusted to attain an actual average surface temperature of 375 °F +/- 5 °F. Step #3 was then repeated to confirm that the temperature of each sensing location was 375 °F +/- 5 °F. Once this requirement was met, the exact position of each thermostat control knob was marked.

4.6.1 Process Conditions

Prior to testing, the hamburger patties were prepared by loading them onto sheet pans lined with freezer paper. The ¼ pound meat patties specified were finished grind, pure beef hamburger, 24% fat by weight, 60-64% moisture, 3/8" thick with a nominal diameter of 5". The fat and moisture content of the patties were verified in accordance with recognized laboratory procedures (AOAC Official Actions 960.39 and 950.46, respectively). One patty from the batch designated for each run was reserved for these analyses. Each pan was loaded with 24 patties. The pans were stacked in a freezer with spacers between each pan to provide for airflow.

The internal freezer temperature was maintained at -5 °F +/- 5 °F. This temperature was continuously monitored with a thermocouple placed in the freezer to ensure the pre-cooked condition of the meat.

The griddle controls were set to the positions determined above, and allowed to warm up for a minimum of one hour. The griddle was loaded with 2/3 capacity. Therefore, 16 patties were sequentially loaded on the flat griddle over a 45 second time period (approximately one patty every three seconds). The patties were placed on the griddle according to the pattern illustrated in Figure 7. Patties were cooked for 3.5 minutes on the first side, starting from the time the first hamburger patty was placed on the griddle surface. The patties were then turned in the same order they were loaded over a 45 second time interval. For the second side, patties were cooked for an additional 2.5 minutes (including the time to turn hamburger patties).

No mechanical pressing of the patties were performed, due to variability introduced through inconsistent application. Patties were removed in the order placed on the griddle over a 45 second time period. The cycle was repeated 30 seconds after the last patty was removed from the griddle. During this 30-second period, the griddle was scraped to remove any excess fat and charred material from the cooking surface.

Patties were cooked to an internal temperature of 162 °F +/- 5 °F, to confirm a medium-well condition. Internal meat temperature was determined with a stack of hamburger patties placed in a temperature measurement system. The system consisted of an insulated container with a thermocouple bundle attached to the lid. The five thermocouples were placed in different locations and depths in order to minimize the variability of the measurement.

Based on the PG&E research of the hamburger patties specified in this section, an internal meat temperature of 163 °F corresponded to a weight loss of approximately 35%. This correlation was confirmed using a minimum of three data points. The data points bracketed the target 162 °F meat temperature. Once this correlation was confirmed, the percent weight loss was used to verify the "doneness" of the cooked patties. Using tongs, the patties were spread on a drip rack. After one minute, the patties were turned. After another minute, the patties were transferred to a clean pan for weighing. If the average weight loss was not 35% +/- 2%, the total cooking time was adjusted to attain 35% +/- 2% weight loss. If the total cooking time required adjustment, even cooking on both sides of the hamburger patties was assured (approximately 60% of the total cooking time was on the first side).

One patty from each run was reserved for moisture content analyses. These patties were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked patties was determined in accordance with recognized laboratory procedures (AOAC Official Action 950.46). The moisture loss during cooking was calculated based on the initial moisture content of the patties.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at 1600 fpm (with the griddle on). This velocity corresponded to a hood flow rate of 400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes, with the end of sampling corresponding with the end of a cooking cycle.

4.7 Boneless Chicken Breasts and Cod Fillets/Flat Griddle Process

Basic equipment specifications, including the cooking device, installation procedures, cleaning, start-up, temperature set point, and ventilation configuration followed the detailed description documented in Section 4.6 (Hamburger/Flat Griddle Process).

4.7.1 Process Conditions

All chicken breast cooking cycles were performed using 4 oz. boneless, skinless chicken breasts. The fat content specified was 3% +/- 1%. All cod fillet cooking cycles were performed using 6 oz. pieces. The fat content specified was 0.5% +/- 0.5%. Fat and moisture content of the uncooked products was verified using AOAC procedures 984.23 and 948.25, respectively. The products were prepared by loading them onto sheet plans lined with freezer paper. The pans were stacked in a freezer with spacers between each pan to allow for airflow.

The internal freezer temperature was maintained at -5 °F +/- 5 °F. This temperature was continuously monitored with a thermocouple placed in the freezer to ensure the pre-cooked condition of the meat.

Where required (as indicated by the average measured temperature at each location), the griddle temperature controls were adjusted to attain an actual average surface temperature of 350 °F +/- 5 °F. Once this requirement was met, the exact position of each thermostat control knob was marked.

Measurement of internal meat temperature for the chicken breasts and cod fillets was highly variable (+/- 50 °F), depending on the placement of the thermocouple probes in the food products. Therefore, weight loss was used for these two processes as the indication of doneness. Cooking time for the chicken breasts was determined by the amount of time required to achieve a 30% +/- 1% weight loss of the product. Cooking time for the cod fillets was determined by the amount of time required to achieve a 34% +/- 1% weight loss of the product. Initially, cooking times of 15 minutes for the chicken and 14 minutes for the fish were assumed.

The griddle controls were set to the positions determined above, and allowed to warm up for a minimum of one hour. The griddle was loaded at 2/3 capacity. Therefore, 16 chicken breasts or 12 cod fillets were sequentially loaded on the flat griddle over a 45-second time period (approximately one food item every three seconds). The chicken breasts were placed on the griddle according to the pattern illustrated in Figure 7. The cod fillets were placed on the griddle according to the pattern illustrated in Figure 15. The items were covered with stainless steel lids to trap steam. Each lid had dimensions of 21 in. x 13 in. x 3 in. The chicken breasts were cooked for 9.0 minutes on the first side, starting from the time the first chicken breast was placed on the griddle surface. The breasts were then turned in the same order they were loaded over a 45 second time interval, and the lids were replaced. For the second side, the breasts were cooked for an additional 6.0 minutes (including the time to turn the products). The cod fillets were cooked for 8.0 minutes on the first side, starting from the time the first fillet was placed on the griddle surface. The fillets were then turned in the same order they were loaded over a 45 second time interval, and the lids were replaced. For the second side, the fillets were cooked for an additional 5.0 minutes (including the time to turn the products).

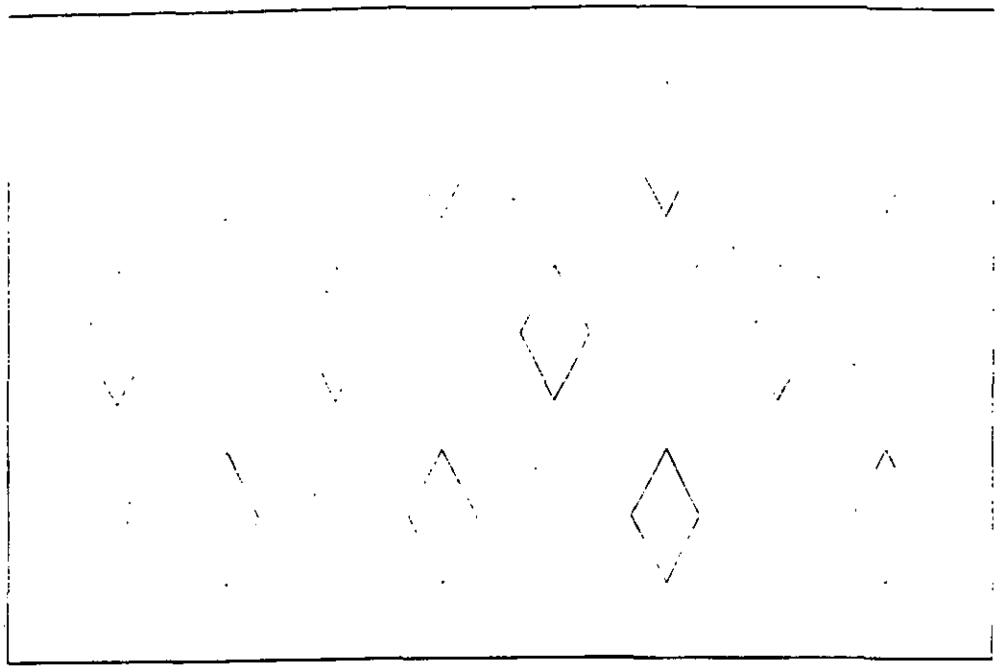


Figure 15

Cod Fillet Cooking Pattern (2/3 Load)

No mechanical pressing of the food products was performed, due to variability introduced through inconsistent application. Items were removed in the order placed on the griddle over a 45-second time period. The cycle was repeated 30 seconds after the last item was removed from the griddle. During this 30-second period, the griddle was scraped to remove any excess fat and charred material from the cooking surface.

Using tongs, the items were spread on a drip rack. After one minute, the items were turned. After another minute, the items were transferred to a clean pan for weighing. If the average weight loss was not 30% +/- 2% for the chicken breasts or 34% +/- 2% for the cod fillets, the total cooking time was adjusted to attain the proper weight loss. If the total cooking time required adjustment, even cooking on both sides of the food product was assured (approximately 60% of the total cook time on the first side).

One item from each run was reserved for moisture content analyses. These items were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked products was determined in accordance with recognized laboratory procedures (AOAC Official Action 950.46). The moisture loss during cooking was calculated based on the initial moisture content of the patties.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at 1600 fpm (with the griddle on). This velocity corresponded to a hood flow rate of 400 cfm for each linear foot of hood length. Testing conducted for a minimum of 72 minutes, with the end of sampling corresponding with the end of a cooking cycle.

4.8 Hamburger/Automated Charbroiler Process

The cooking device used for testing was a Nieco Model 960 conveyorized charbroiler, fired with natural gas. The natural gas flow rate was measured with a calibrated dry gas meter. The heating value of the gas was measured with a Cutler-Hammer calorimeter. The firing rate was set to operate within 5% of the manufacturer's specified input rate. In addition, the gas supply pressure was within +/- 2.5% of the manufacturer's specified operating pressure. The broiler controls, including the conveyor speed and thermostat, were set according to the manufacturer's specifications.

4.8.1 Process Conditions

Prior to testing, the hamburger patties were prepared by loading them onto sheet pans lined with freezer paper. The ¼ pound meat patties specified were finished grind, pure beef hamburger, 21% fat by weight, 58-62% moisture, 3/8" thick, and 5" in diameter. The fat and moisture content of the patties were verified in accordance with recognized laboratory procedures (AOAC Official Actions 960.39 and 950.46, respectively). One patty from the batch designated for each run was reserved for these analyses. Each pan was loaded with 24 patties. The pans were stacked in a freezer with spacers between each pan to provide for airflow. The internal freezer temperature was maintained at approximately -5 °F. This temperature was continuously monitored with a thermocouple placed in the freezer to ensure the pre-cooked condition of the meat.

The underfired broiler controls were set and the broiler was allowed to warm up for a minimum of one hour. The grill was loaded at 2/3 capacity. Therefore, 2 patties were sequentially loaded on the broiler grate every 30 seconds, corresponding to an input of 60 lbs./hr.

Patties were cooked to an internal temperature of 165 °F, to confirm a medium-well condition. Internal meat temperature was determined with a stack of hamburger patties placed in a temperature measurement system. The system consisted of an insulated container with a thermocouple bundle attached to the lid (see Figure 8). The five thermocouples were placed in different locations and depths in order to minimize the variability of the measurement.

For the hamburger patties specified in this section, an internal meat temperature of 165 °F corresponds to a weight loss of approximately 35%. This correlation was confirmed using a minimum of three data points. The data points bracketed the target 165 °F meat temperature. Once this correlation was confirmed, the percent weight loss was used to verify the "doneness" of the cooked patties. Using tongs, the patties were spread on a drip rack. After one minute, the patties were turned. After another minute the patties were transferred to a clean pan for weighing. If the average weight loss was not 35% +/- 2%, the total cooking time was adjusted (through adjustment of the conveyor speed) to attain 35% +/- 2% weight loss.

One patty from each run was reserved for moisture content analyses. These patties were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked patties was determined in accordance with recognized laboratory procedures (AOAC Official Action 950.46). The moisture loss during cooking was calculated based on the initial moisture content of the patties.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at 1600 fpm (with the charbroiler on). This velocity corresponded to a hood flow rate of 400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes.

4.9 Hamburger/Automated Charbroiler/Catalyst A and Catalyst B Processes

Basic equipment specifications, including the cooking device, installation procedures, cleaning, start-up, temperature set point, ventilation configuration, and process conditions followed the detailed description documented in Section 4.8 (Hamburger/Automated Charbroiler Process). For these tests, a catalytic control device and shroud was installed on top of the automated broiler. The control devices tested used the heat generated by the broiler to achieve operating temperature, and required no external utility.

Catalyst A consisted of a circular stainless steel shroud and support structure that contained a wound, corrugated steel material coated with a precious metal catalyst. This unit was new, and was supplied directly from the manufacturer. Catalyst B consisted of a rectangular stainless steel shroud and support structure that contained a honeycombed steel material coated with a precious metal catalyst. This unit had been used in the field at a high-volume restaurant for approximately 3½ years prior to testing at CE-CERT.

The hamburger specifications, loading rate, and doneness criteria were identical to those described in Section 4.8.

4.10 Hamburger/Double-Sided Flat Griddle Process

The cooking device used was a 36" Taylor Model 69-23 double-sided flat electric griddle. The appliance was installed according to the manufacturer's instructions under a 4-foot-deep canopy exhaust hood. The griddle was positioned with the front edge of the cooking surface inset 6 in. from the front edge of the hood at the manufacturer's recommended working height. The length of the exhaust hood and active filter area extended a minimum of 6 in. past both sides of the griddle. In addition, both sides of the griddle were a minimum of 3 ft. from any side wall, side partition, or other appliance.

The supply voltage was measured and confirmed to be within 2.5% of the manufacturer's specified operating voltage. The voltage was monitored during each test. For each test run, the peak input rate was confirmed to be within 5% of the rated nameplate input.

The appliance was conditioned and the thermostats were set by the following procedures:

1) The thermostat controls on the griddle were set to 375 °F.

2). Once the griddle reached operating temperature, all cooking surfaces (upper and lower) were coated with a salt-free cooking oil. After five minutes, the oil residue was wiped off. The griddle was then allowed to stabilize for 60 min. at the set operating temperature.

3) Using a calibrated surface-type thermocouple, the griddle cooking surface temperatures were measured at the center of each location where hamburger patties were placed. The surface temperatures were monitored over several complete thermostat cycles (power on/power off) for each location. From this data, the average surface temperature was determined for each location. The measured temperatures were documented on a "map" of the griddle surface. The placement of the measurement points is shown in Figure 7.

4) Where required (as indicated by the average measured temperature at each location), the griddle temperature controls were adjusted to attain an actual average surface temperature of 375 °F +/- 5 °F. Step #3 was then repeated to confirm that the temperature of each sensing location was 375 °F +/- 5 °F. Once this requirement was met, the exact position of each thermostat control knob was marked.

4.10.1 Process Conditions

Prior to testing, the hamburger patties were prepared by loading them onto sheet pans lined with freezer paper. The ¼ pound meat patties specified were finished grind, pure beef hamburger, 24% fat by weight, 60-64% moisture, 3/8" thick with a nominal diameter of 5". The fat and moisture content of the patties were verified in accordance with recognized laboratory procedures (AOAC Official Actions 960.39 and 950.46, respectively). One patty from the batch designated for each run was reserved for these analyses. Each pan was loaded with 24 patties. The pans were stacked in a freezer with spacers between each pan to provide for airflow.

The internal freezer temperature was maintained at -5 °F +/- 5 °F. This temperature was continuously monitored with a thermocouple placed in the freezer to ensure the pre-cooked condition of the meat.

The griddle controls were set to the positions determined above, and allowed to warm up for a minimum of one hour. The griddle was loaded with 2/3 capacity. Therefore, 16 patties were sequentially loaded on the flat griddle over a 45-second time period (approximately one patty every three seconds). The patties were placed on the griddle according to the pattern illustrated in Figure 7. The upper cooking surface was immediately pulled down to its locked position, contacting the patties. Patties were cooked for 1 minute and 43 seconds, starting from the time the upper cooking surface was closed and locked. At this time, the upper surface automatically opened and returned to its starting position.

Patties were removed in the order placed on the griddle over a 45-second time period. The cycle was repeated 30 seconds after the last patty was removed from the griddle. During this 30-second period, the griddle was scraped to remove any excess fat and charred material from the cooking surface.

Patties were cooked to an internal temperature of 167 °F +/- 2 °F, to confirm a medium-well condition. Internal meat temperature was determined with a stack of hamburger patties placed in a temperature measurement system. The system consisted of an insulated container with a thermocouple bundle attached to the lid. The five thermocouples were placed in different locations and depths in order to minimize the variability of the measurement.

For the hamburger patties specified in this section, an internal meat temperature of 167 °F corresponded to a weight loss of approximately 29%. This correlation was confirmed using a minimum of three data points. The data points bracketed the target 167 °F meat temperature.

Once this correlation was confirmed, the percent weight loss was used to verify the "doneness" of the cooked patties. Using tongs, the patties were spread on a drip rack. After one minute, the patties were turned. After another minute, the patties were transferred to a clean pan for weighing. If the average weight loss was not 29% +/- 2%, the total cooking time was adjusted to attain 29% +/- 2% weight loss.

One patty from each run was reserved for moisture content analyses. These patties were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked patties was determined in accordance with recognized laboratory procedures (AOAC Official Action 950.46). The moisture loss during cooking was calculated based on the initial moisture content of the patties.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at 1600 fpm (with the griddle on). This velocity corresponded to a hood flow rate of 400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes, with the end of sampling corresponding with the end of a cooking cycle.

4.11 Steak/Underfired Charbroiler Process

The cooking device used for this testing was a 36" Wolf underfired charbroiler, fired with natural gas. The natural gas flow rate was measured with a calibrated dry gas meter. The heating value of the gas was measured with a Cutler-Hammer calorimeter. The broiler controls were set such that the average grill surface temperature achieved 600 ^{o}F; as measured by a flat plate thermocouple. The grill surface temperature was measured at the center of each location where steaks were to be placed, with the remaining locations covered with metal plates. The burner controls on the broiler were adjusted until the average temperature measurement equaled 600 °F. Emissions generated during the cooking process were captured by a 4' x 4' Captive-Aire stainless steel wall canopy hood. Emissions captured by the hood were ducted horizontally across the roof of the test chamber to the upblast blower. The exhaust blower, equipped with a variable speed drive and controller, was adjusted for precise setting of the exhaust flow rate (minimum 1600 acfm). Emissions samples were drawn from the horizontal section of the duct through access ports.

4.11.1 Process Conditions

Prior to testing, the steaks were prepared by loading them onto sheet pans lined with freezer paper. The meat specified was 8 oz. New York steaks, 5/8" thick, 1/8" trim, middle choice, short shells with no tail. The fat and moisture content of the steaks were determined in accordance with recognized laboratory procedures (AOAC Official Actions 960.39 and 950.46, respectively). One sample steak from the batch designated for each run was reserved for these analyses. The pans, loaded with uncooked steak, were stacked in a refrigerator with spacers between each pan to provide for airflow. The internal refrigerator temperature was maintained at approximately 38 °F. This temperature was continuously monitored with a thermocouple placed in a steak to ensure the pre-cooked condition of the food product. The pans were covered with plastic wrap to prevent the steak from drying out.

The broiler grate was conditioned in accordance with the manufacturer's instructions. With the controls set according to the procedure described above, the broiler was allowed to warm up for a minimum of one hour. The grill was loaded at 2/3 capacity. Therefore, 8 steaks were sequentially loaded on the broiler grate over a 45-second time period. The items were placed on the grill according to the pattern illustrated in Figure 16.

The steaks were cooked for approximately 4 1/2 minutes on the first side, starting from the time the first item was placed on the broiler grate. The steaks were then turned, in the same order they were loaded over a 45 second time interval. For the second side, the steaks were cooked for an additional 4 1/2 minutes (including the time to turn the items). The steaks were then removed in the order placed on the broiler over a 45 second time period.

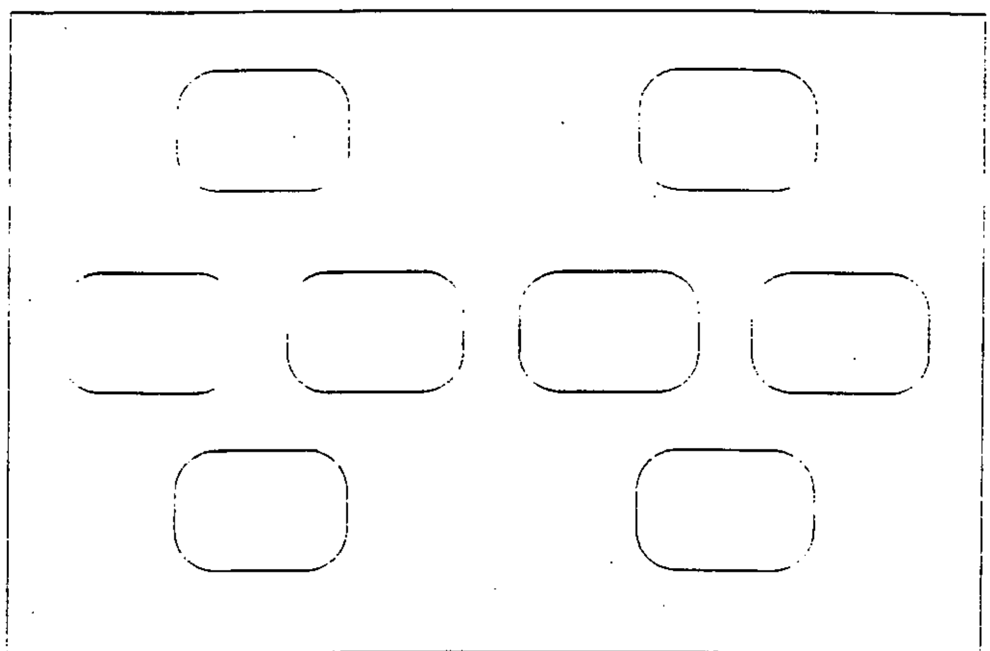


Figure 16
Steak Cooking Pattern

The cycle was repeated 30 seconds after the last steak was removed from the grill. During this 30-second period, the grill was scraped to remove any excess fat and charred material from the cooking surface.

Steaks were cooked to an internal temperature of 148 °F +/- 3 °F, to confirm a medium condition. Internal meat temperature was determined with a single thermocouple inserted into the middle of the steaks. Additional temperature measurements were made with a thermocouple bundle inserted into the centroid of the cooked steaks (see Figure 10). The five thermocouples were placed in different locations and depths in order to provide a stable average internal meat temperature.

For the steak specified in this test plan, a correlation was developed using a minimum of three data points. The data points bracketed the target internal food product temperature. The correlation showed that an internal meat temperature of 148 °F corresponds to a weight loss of 26.7%. Once this correlation was confirmed, the percent weight loss was used to verify the "doneness" of the cooked food products. Using tongs, the steaks were spread on a drip rack. After one minute, the steaks were turned. After another minute, the steaks were transferred to a clean pan for weighing. The average weight loss was calculated for the steak. If the average weight loss was not 26.7% +/- 3%, the total cooking time was adjusted to attain the proper weight loss developed from the correlations. If the total cooking time required adjustment, even cooking on both sides of the food products was assured (approximately 50% of the total cook time was on the first side).

One sample food item from each run was reserved for moisture content analyses. These samples were placed in a freezer inside self-sealing plastic bags unless the moisture content test was conducted immediately. The moisture content of the cooked food products was determined in accordance with recognized laboratory procedures (AOAC Official Action 950.46). The moisture loss during cooking was calculated based on the initial moisture content of the steak.

Clean grease baffles were installed in the hood prior to testing. The velocity in the duct was set at a minimum of 1600 fpm (with the charbroiler on). This velocity corresponded to a hood flow rate of 400 cfm for each linear foot of hood length. Testing was conducted for a minimum of 72 minutes, with the end of sampling corresponding with the end of a cooking cycle (e.g., minimum of 82 minutes for 8 cooking cycles). Ambient temperature, humidity, static pressure in the chamber, natural gas flow rate, heating value, and internal meat temperature were recorded during testing.

5.0 RESULTS

5.1 ROG Method Verification Testing

Six identical test runs were performed using the process described in Section 4.8. The alternative ROG sampling and analytical method was run concurrently with the reference method (modified SCAQMD M25.1) during all six runs. Table I summarizes the ROG results determined by the reference method. The large deviations in results from the reference method are consistent with previous research documented by CE-CERT.[3] Table II summarizes results determined by the alternative method for the same six runs. Results from testing performed using the alternative method demonstrate a significantly higher level of repeatability and precision compared with the reference method. Figure 15 illustrates the continuous total hydrocarbon concentrations for the six test runs as measured by the alternative method. A summary of process conditions and a direct comparison of the two methods are presented in Table III.

TABLE I
Reactive Organic Gas Results
(Modified SCAQMD Method 25.1)

RUN #	ROG 1 (ppm)	ROG 2 (ppm)	AVG. ROG (ppm)	FACTOR (lb/Mlb)
1	89	60	74.5	3.22
2	67	103	85	3.67
3	80	25	52.5	2.29
4	17	31	24	1.04
5	53	61	57	2.46
6	102	18	60	2.64
AVERAGE	**68.00**	**49.67**	**58.83**	**2.55**
SD	**30.23**	**31.75**	**20.92**	**0.90**

TABLE II

Reactive Organic Gas Results (VIG Dual-Channel Hydrocarbon Analyzer)

RUN #	AVG. TOTAL HC (ppm as CH_2)	AVG. CH_4 (ppm)	AVG. ROG as CH_2 (total - CH_4)	UNCORRECTED FACTOR (lb/Mlb)	CORRECTED FACTOR (lb/Mlb)
1	246.4	37.6	208.8	9.02	9.07
2	245.6	37.3	208.3	8.99	9.04
3	294.6	45	249.6	10.87	10.92
4	322.8	49	273.8	11.82	11.87
5	247.7	38	209.7	9.06	9.11
6	266.8	41 1	225.7	9.90	9.95
AVERAGE	**270.65**	**41.33**	**229.32**	**9.94**	**9.99**
SD	**31.78**	**4.77**	**27.02**	**1.18**	**1.18**

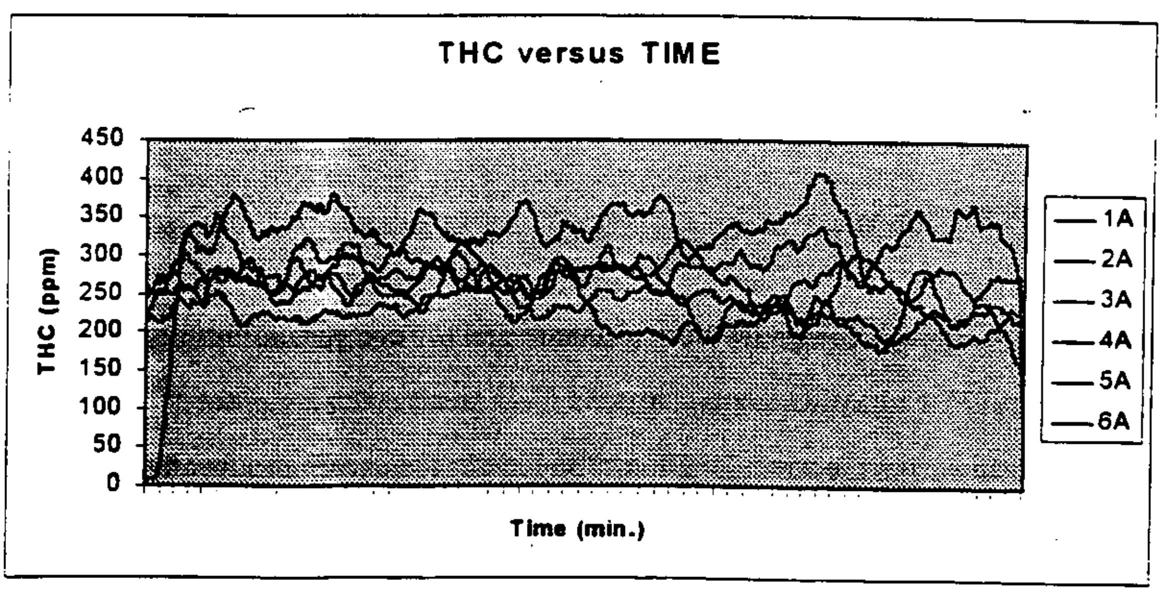


Figure 17

Continuous Total Hydrocarbon Concentrations

(Method Verification Testing)

TABLE III
Process Data and Emission Factor Comparison

RUN #	CORRECTED DELTA P ("H_2O)	DUCT TEMP. (°F)	FLOW RATE (dscfm)	METHOD 25.1 FACTOR (lb/Mlb)	CE-CERT METHOD FACTOR (lb/Mlb)
1	0.150	148.8	1170	3.22	9.07
2	0.150	149.0	1169	3.67	9.04
3	0.154	153.8	1179	2.29	10.92
4	0.151	152.8	1169	1.04	11.87
5	0.149	147.9	1170	2.46	9.11
6	0.155	151.1	1188	2.64	9.95
AVERAGE	0.15	150.57	1174.17	2.55	9.99
SD	0.00	2.38	7.78	0.90	1.18

The average ROG emission factor determined by the reference method was 2.55 lb/1000 lbs. of meat cooked, with a standard deviation of 0.9. The ROG emission factor determined by the alternative method was 9.99 lb/1000 lbs. of meat cooked, with a standard deviation of 1.18.

A seventh test run was performed with the same process to compare results obtained using three different FID total hydrocarbon analyzers. The analyzers were operated simultaneously during the test run. Figure 18 illustrates the continuous measurements of the three analyzers. The concentration measurements of one of the analyzers continually fell during the course of the test period. It was determined that inadequate sample flow to the analyzer was the cause. The sample flow was restricted due to filter loading over time, and the pump supplied with the analyzer was unable to compensate for the restriction.

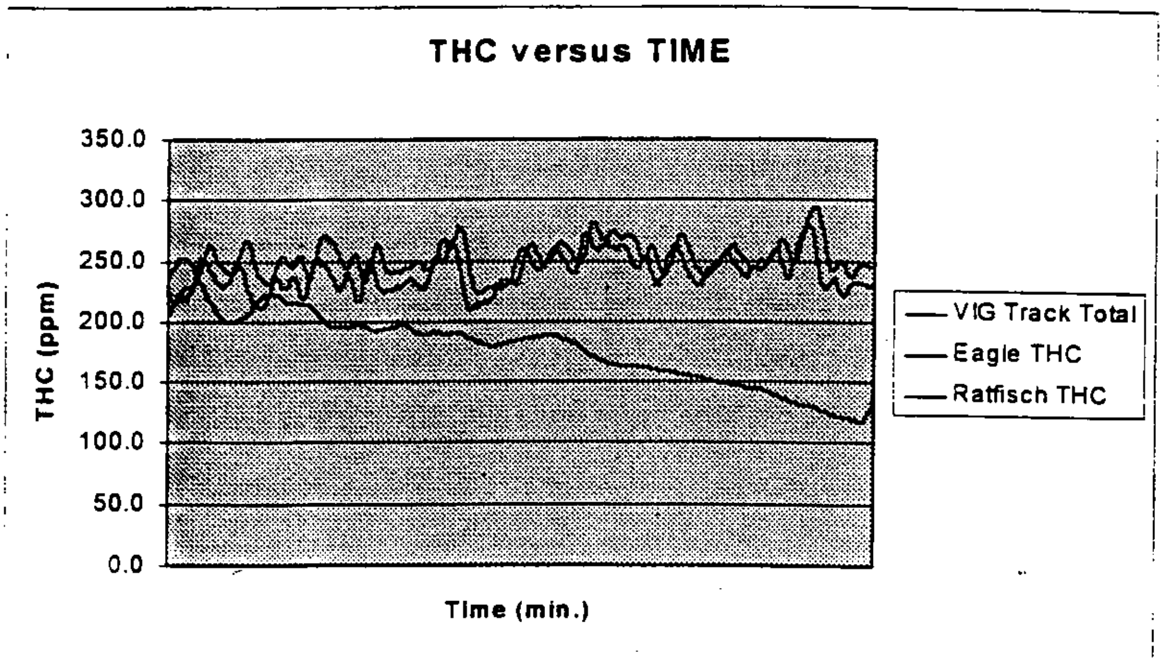
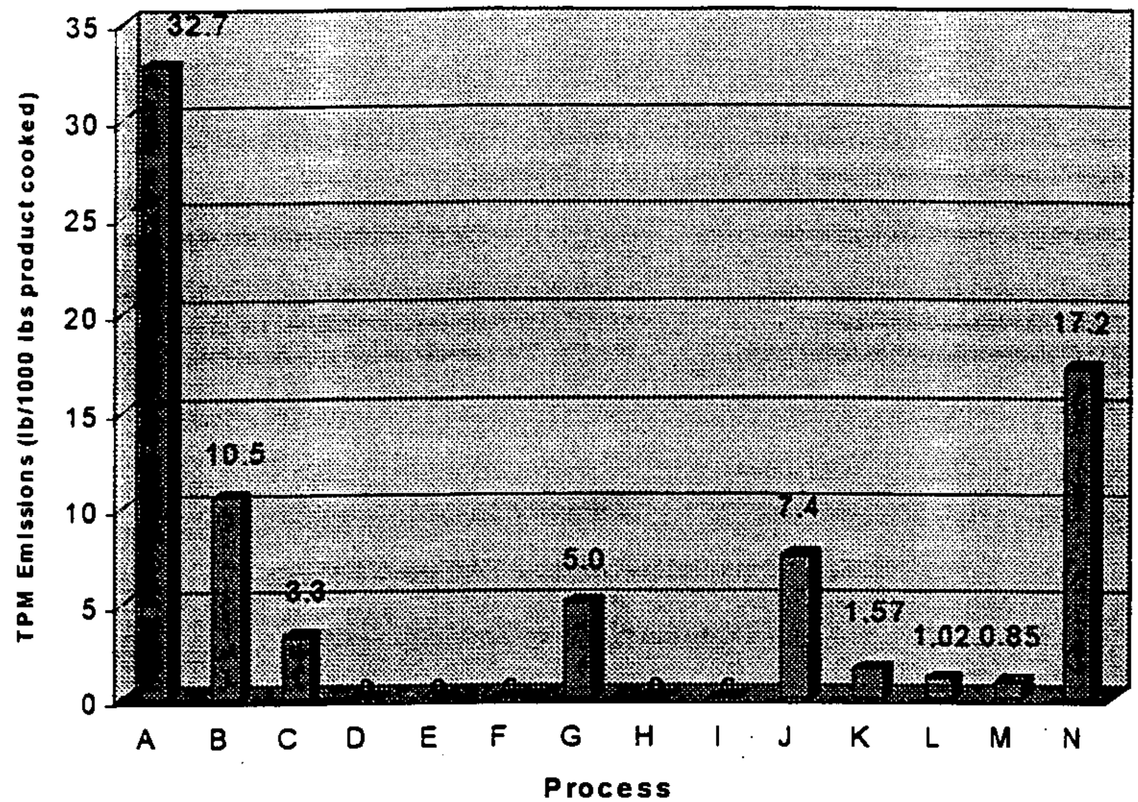


Figure 18

Comparison of Three FID Analyzers

5.2 Emission Factor Testing

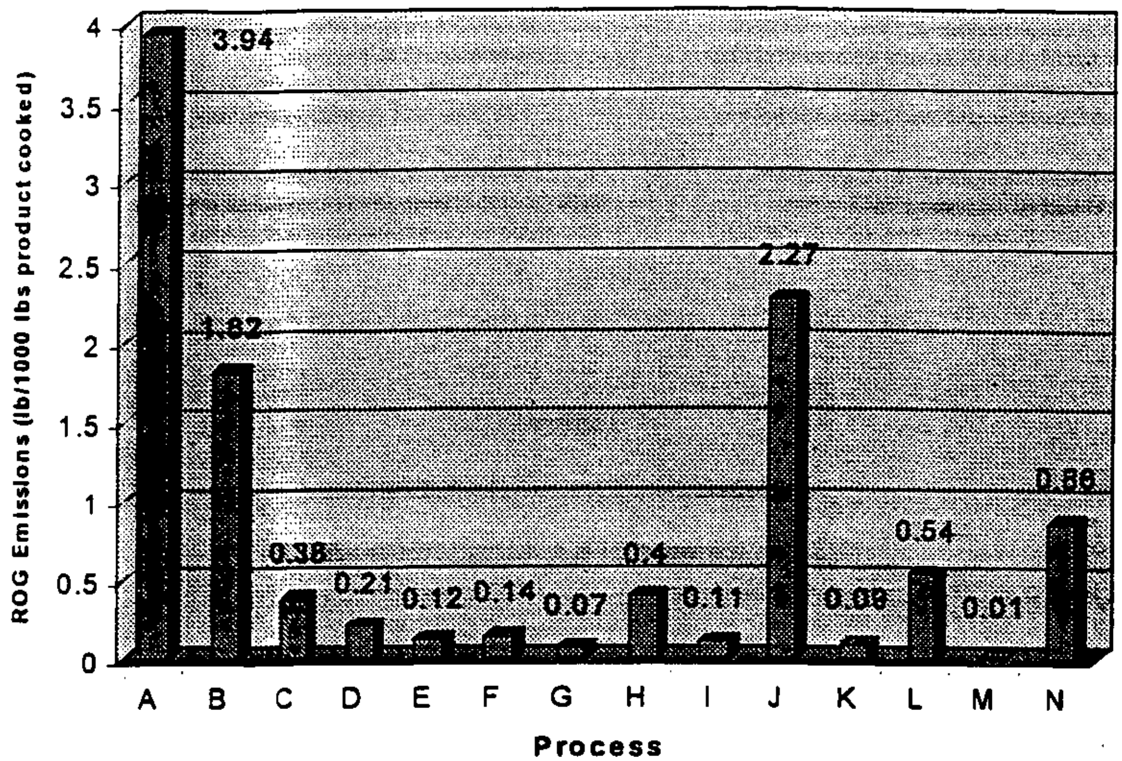
The following Tables and Figures summarize the results of the commercial cooking operation testing. Figure 19 and Figure 20 present the average particulate matter and reactive organic gas results in lb/1000 lbs. of product cooked, respectively. Additional tables present the specific results for each process; including firing rate, loading rate, final internal meat temperature, percent weight loss during cooking, percent fat content of the uncooked food products, and the PM and ROG emission factors. The additional figures illustrate the average particle size distribution of each cooking process effluent.


35
30
25
20
15
10
5
0
TPM Emissions (lb/1000 lbs product cooked)
32.7
10.5
3.3
5.0
7.4
1.57
1.02
0.85
17.2
A
B
C
D
E
F
G
H
I
J
K
L
M
N
Process

A - 25% fat hamburger/underfired charbroiler
B - butterflied chicken/underfired charbroiler
C - Atlantic salmon/underfired charbroiler
D - shoestring potatoes/open, deep fat fryer A
E - breaded chicken/open, deep fat fryer
F - breaded fish/open, deep fat fryer
G - 24% fat hamburger/electric flat griddle
H - boneless chicken breast/electric flat griddle
I - cod fillets/electric flat griddle
J - 21% fat hamburger/automated charbroiler
K - 21% fat hamburger/automated charbroiler/catalyst A
L - 21% fat hamburger/automated charbroiler/catalyst B
M - 24% fat hamburger/double-sided griddle
N - New York steak/underfired charbroiler

Figure 19

Total Particulate Matter Emission Factors from Commercial Cooking Operations


ROG Emissions (lb/1000 lbs product cooked)
4
3.5
3
2.5
2
1.5
1
0.5
0
3.94
1.82
0.38
0.21
0.12
0.14
0.07
0.4
0.11
2.27
0.08
0.54
0.01
0.88
A
B
C
D
E
F
G
H
I
J
K
L
M
N
Process

A - 25% fat hamburger/underfired charbroiler
B - butterflied chicken/underfired charbroiler
C - Atlantic salmon/underfired charbroiler
D - shoestring potatoes/open, deep fat fryer
A
E - breaded chicken/open, deep fat fryer
F - breaded fish/open, deep fat fryer
G - 24% fat hamburger/electric flat griddle
H - boneless chicken breast/electric flat griddle
I - cod fillets/electric flat griddle
J - 21% fat hamburger/automated charbroiler
K - 21% fat hamburger/automated charbroiler/catalyst
L - 21% fat hamburger/automated charbroiler/catalyst B
M - 24% fat hamburger/double-sided griddle
N - New York steak/underfired charbroiler

Figure 20

Reactive Organic Gas Emissions

from Commercial Cooking Operations

TABLE IV
Hamburger Meat/Underfired Charbroiler Results
(firing rate: 84,684 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960417-1	50.8	163.8	32.8	24.5	33.0	4.06
960419-2	51.3	169.0	36.6	25.1	32.2	4.72
960425-1	51.8	165.7	35.1	25.9	32.8	3.05
AVERAGE	**51.3**	**166.2**	**34.8**	**25.2**	**32.67**	**3.94**
SD	**0.50**	**2.63**	**1.91**	**0.70**	**0.42**	**0.84**

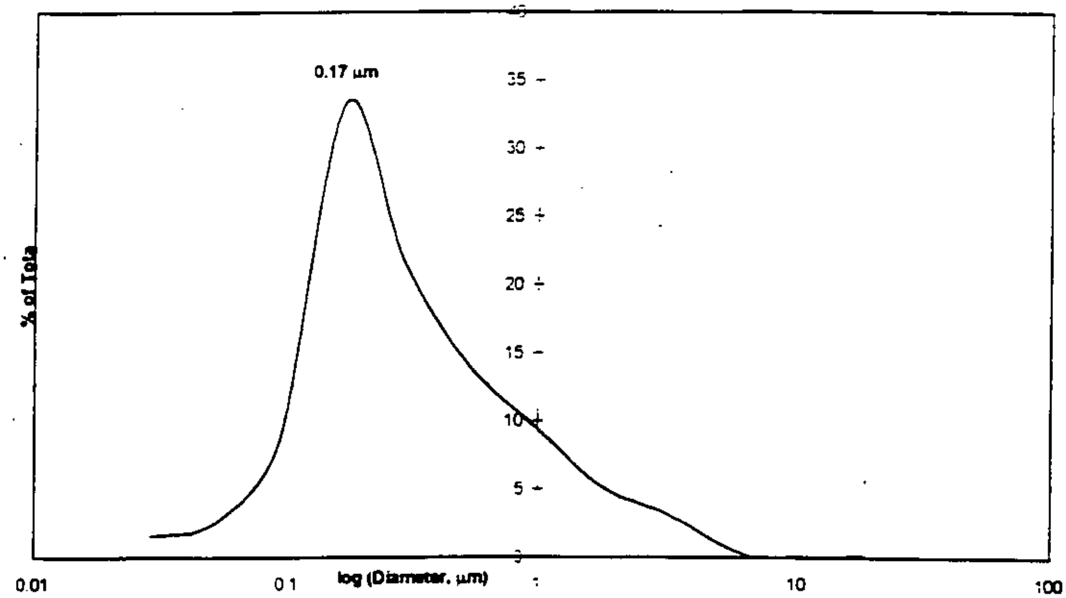


Figure 19

Particle Size Distribution

(hamburger meat/underfired charbroiler)

TABLE V
Whole Chicken/Underfired Charbroiler Results
(firing rate: 34,749 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960509-2	11.2	185.1	28.1	9.9	9.1	1.99
960510-1	12.7	182.1	28.5	9.3	10.8	1.84
960513-1	11.5	181.3	29.1	10.5	11.5	1.64
AVERAGE	**11.8**	**182.8**	**28.6**	**9.9**	**10.47**	**1.82**
SD	**0.79**	**2.00**	**0.50**	**0.60**	**1.23**	**0.18**

Figure 20

Particle Size Distribution

(whole chickens/underfired charbroiler)

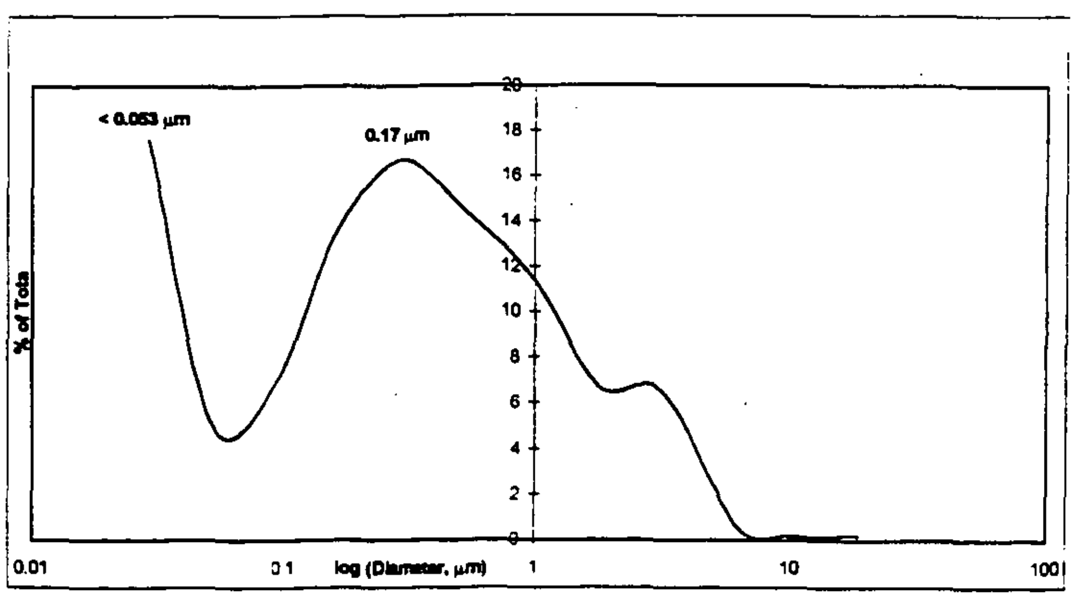


TABLE VI
Atlantic Salmon/Underfired Charbroiler Results
(firing rate: 47.654 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960522-1	32.8	149.2	11.7	2.5	3.5	0.32
960523-1	33.0	152.6	14.2	4.9	2.6	0.45
960524-1	33.8	154.8	11.2	5.2	3.7	0.37
AVERAGE	**33.2**	**152.2**	**12.4**	**4.2**	**3.27**	**0.38**
SD	**0.53**	**2.82**	**1.61**	**1.48**	**0.59**	**0.07**

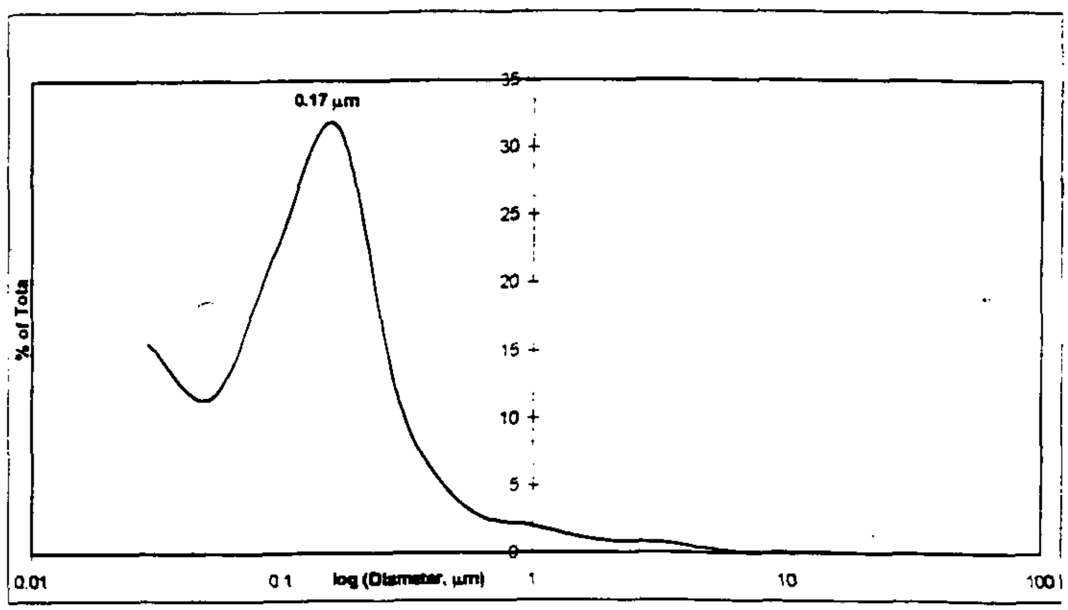


Figure 21

Particle Size Distribution

(Atlantic salmon/underfired charbroiler)

TABLE VII
Shoestring Potatoes/Open, Deep Fat Fryer Results
(firing rate: 42,938 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960603-1	35.4	N/A	30.8	5.4	BDL	0.22
960604-1	36.5	N/A	30.8	5.3	BDL	0.18
960605-1	36.6	N/A	31.1	5.3	BDL	0.23
AVERAGE	**36.2**	**N/A**	**30.9**	**5.3**	**BDL**	**0.21**
SD	**0.67**	**N/A**	**0.17**	**0.06**	**N/A**	**0.03**

N/A - Not Applicable
BDL - Below Detectable Limit

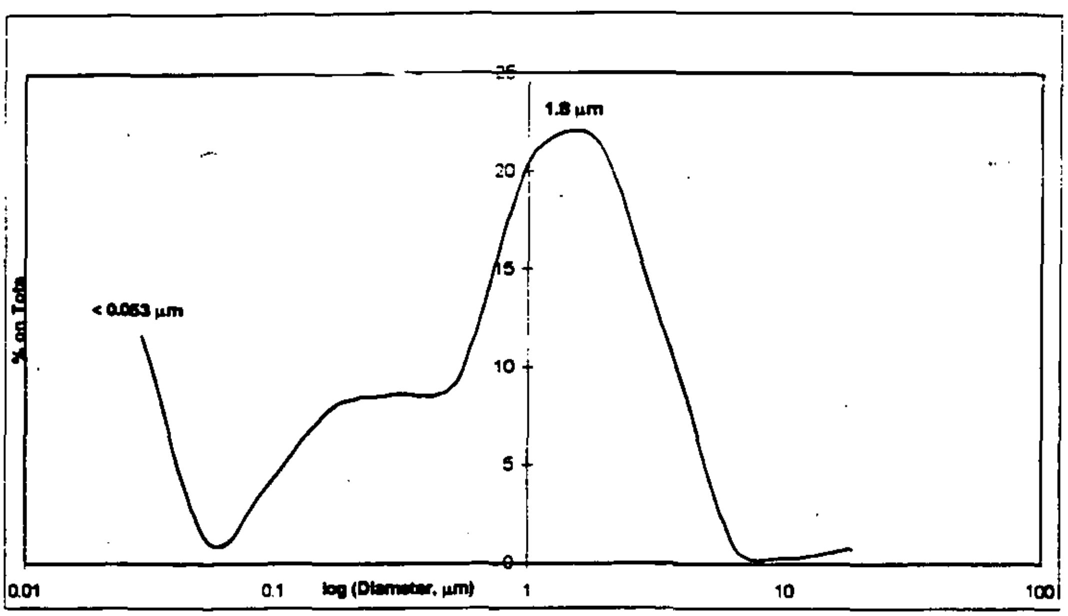


Figure 22

Particle Size Distribution

(shoestring potatoes/open, deep fat fryer)

TABLE VIII
Breaded Chicken/Open, Deep Fat Fryer Results
(firing rate: 22,302 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960606-1	16.7	N/A	18.7	16.5	BDL	0.20
960606-2	16.1	N/A	18.3	16.9	BDL	0.15
960607-1	16.8	N/A	21.6	15.8	BDL	0.02
AVERAGE	**16.5**	**N/A**	**19.5**	**16.4**	**BDL**	**0.12**
SD	**0.38**	**N/A**	**1.80**	**0.56**	**N/A**	**0.09**

N/A - Not Applicable
BDL - Below Detectable Limit

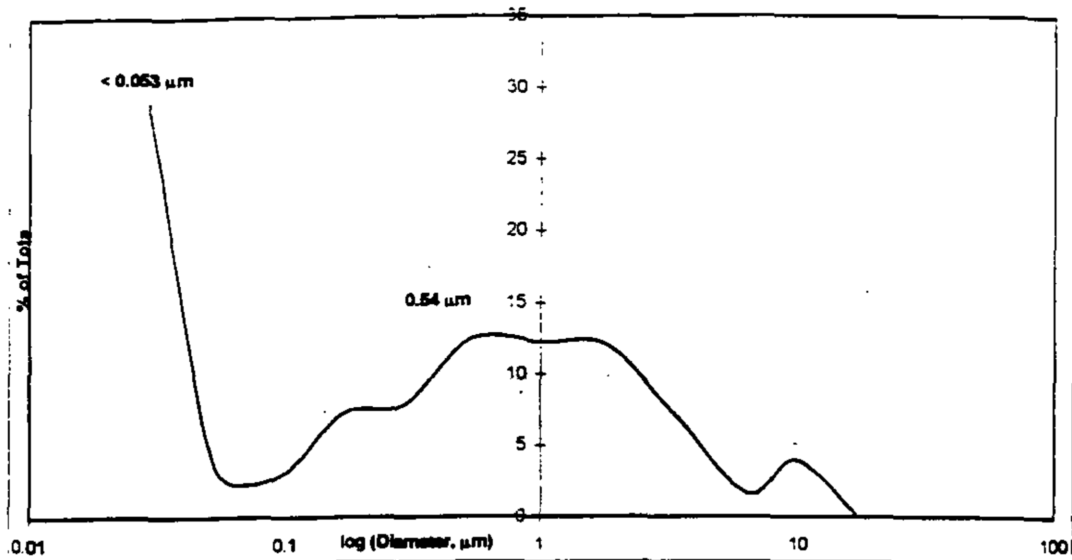


Figure 23

Particle Size Distribution

(breaded chicken/open, deep fat fryer)

TABLE IX
Breaded Fish/Open, Deep Fat Fryer Process
(firing rate: 22,312 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960610-1	14.6	N/A	6.6	1.2	BDL	0.00
960610-2	14.6	N/A	7.4	0.9	BDL	0.00
960611-1	14.8	N/A	4.8	0.9	BDL	0.42
AVERAGE	**14.7**	**N/A**	**6.3**	**1.0**	**BDL**	**0.14**
SD	**0.12**	**N/A**	**1.33**	**0.17**	**N/A**	**0.24**

N/A - Not Applicable
BDL - Below Detectable Limit

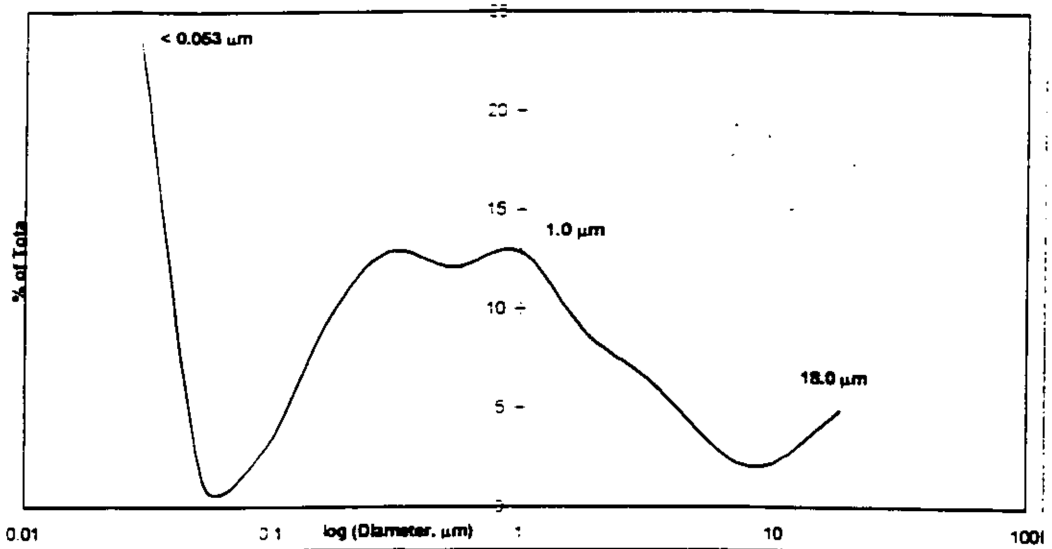


Figure 24

Particle Size Distribution

(breaded fish/open, deep fat fryer)

TABLE X
Hamburger/Flat Griddle Results
(rated input: 13.3 kW)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960712-1	31.9	160.4	32.1	24.1	5.9	0.07
960715-1	31.9	164.2	32.3	24.1	4.8	0.02
960716-1	31.8	160.3	32.3	24.4	4.3	0.12
AVERAGE	**31.9**	**161.6**	**32.2**	**24.2**	**5.00**	**0.07**
SD	**0.06**	**2.22**	**0.12**	**0.17**	**0.82**	**0.05**

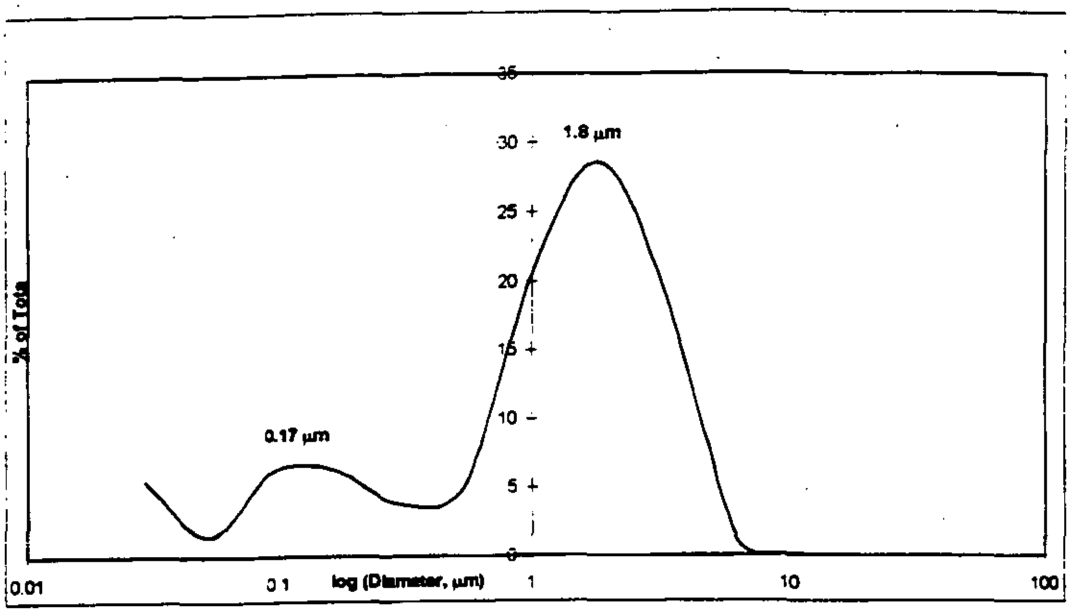


Figure 25

Particle Size Distribution

(hamburger/flat griddle)

TABLE XI
Skinless, Boneless Chicken Breast/Flat Griddle Results
(rated input: 13.3 kW)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960731-1	14.7	N/A	30.6	3.8	BDL	0.56
960731-2	15.4	N/A	31.6	2.2	BDL	0.34
960801-1	15.4	N/A	30.5	3.1	BDL	0.29
AVERAGE	**15.2**	**N/A**	**30.9**	**3.0**	**BDL**	**0.40**
SD	**0.40**	**N/A**	**0.61**	**0.80**	**N/A**	**0.14**

N/A - Not Applicable
BDL - Below Detectable Limit

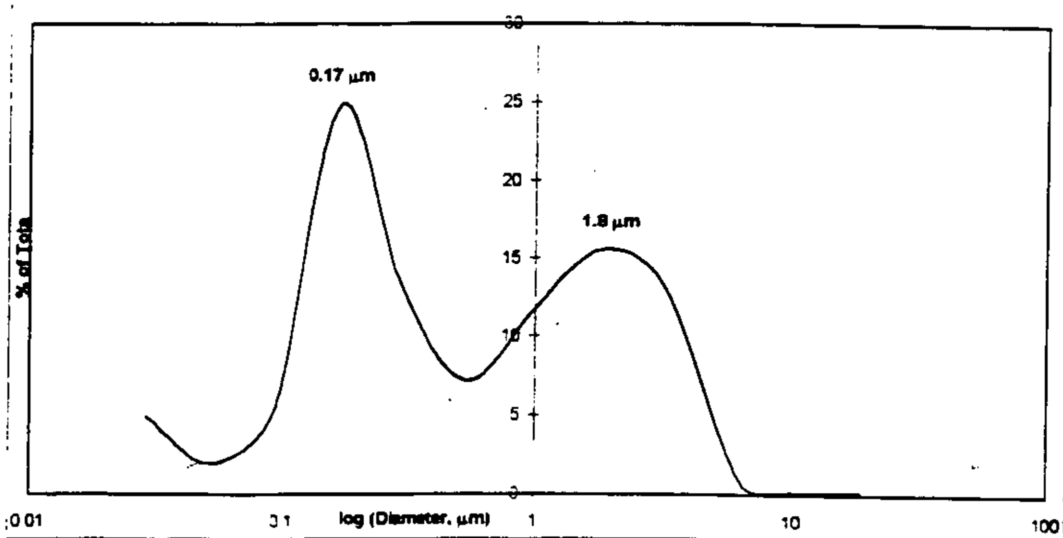


Figure 26

Particle Size Distribution

(skinless, boneless chicken breasts/flat griddle)

TABLE XII
Cod Fillets/Flat Griddle Results
(rated input: 13.3 kW)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960805-1	21.7	N/A	33.8	BDL	BDL	0.13
960805-2	24.5	N/A	32.6	BDL	BDL	0.12
960806-1	21.3	N/A	36.1	BDL	BDL	0.07
AVERAGE	**22.5**	**N/A**	**34.2**	**BDL**	**BDL**	**0.11**
SD	**1.74**	**N/A**	**1.78**	**N/A**	**N/A**	**0.03**

N/A - Not Applicable
BDL - Below Detectable Limit

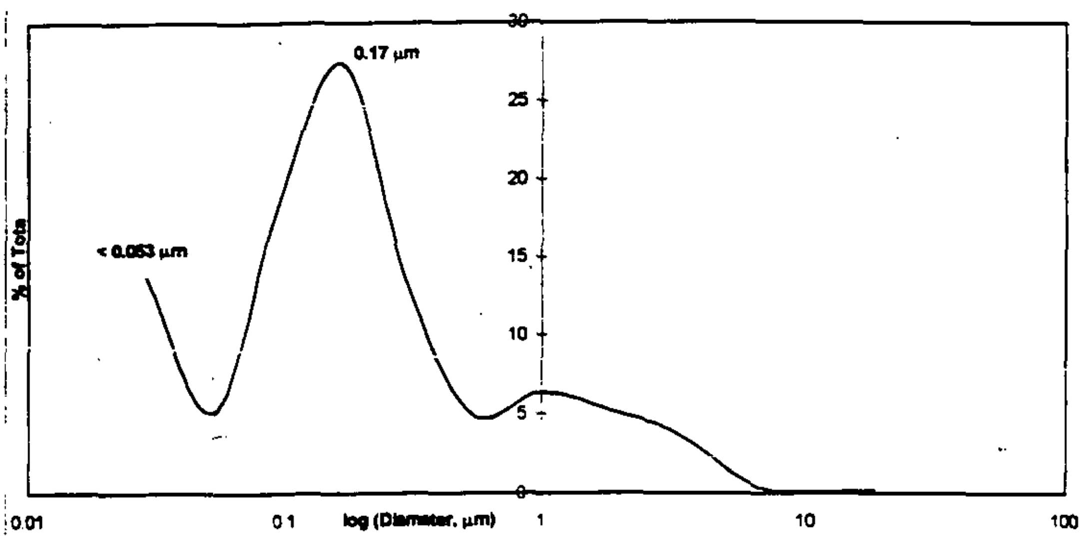


Figure 27

Particle Size Distribution

(cod fillets/flat griddle)

TABLE XIII
Hamburger/Automated Charbroiler Results

(firing rate: 77667 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960618-1	60.4	166.8	31.9	N/A	7.2	2.70
960620-1	60.0	161.0	28.4	N/A	7.9	1.85
960626-1	56.2	166.2	28.0	21.7	7.1	2.27
AVERAGE	**58.9**	**164.7**	**29.4**	**21.7**	**7.40**	**2.27**
SD	**2.32**	**3.19**	**2.15**	**N/A**	**0.44**	**0.43**

N/A - Not Available

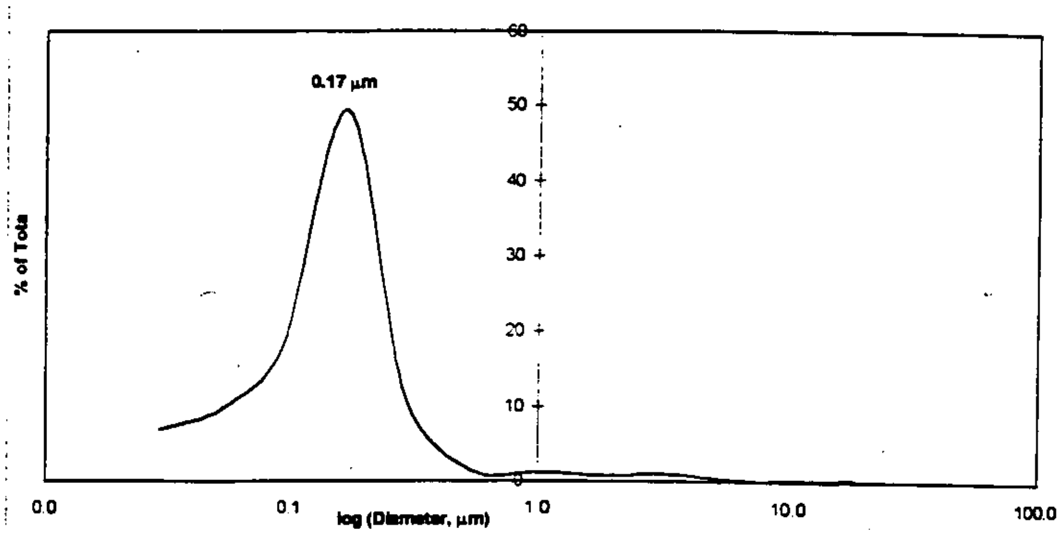


Figure 28

Particle Size Distribution

(hamburger/automated charbroiler)

TABLE XIV
Hamburger/Automated Charbroiler/Catalyst A Results
(firing rate: 72,077 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960708-1	60.9	162.4	32.7	N/A	1.5	0.03
960709-1	59.7	171.9	35.2	22.4	1.7	0.08
960709-2	59.9	170.6	37.6	N/A	1.5	0.17
AVERAGE	**60.2**	**168.3**	**35.2**	**22.4**	**1.57**	**0.09**
SD	**0.64**	**5.15**	**2.45**	**N/A**	**0.12**	**0.07**

N/A - Not Available

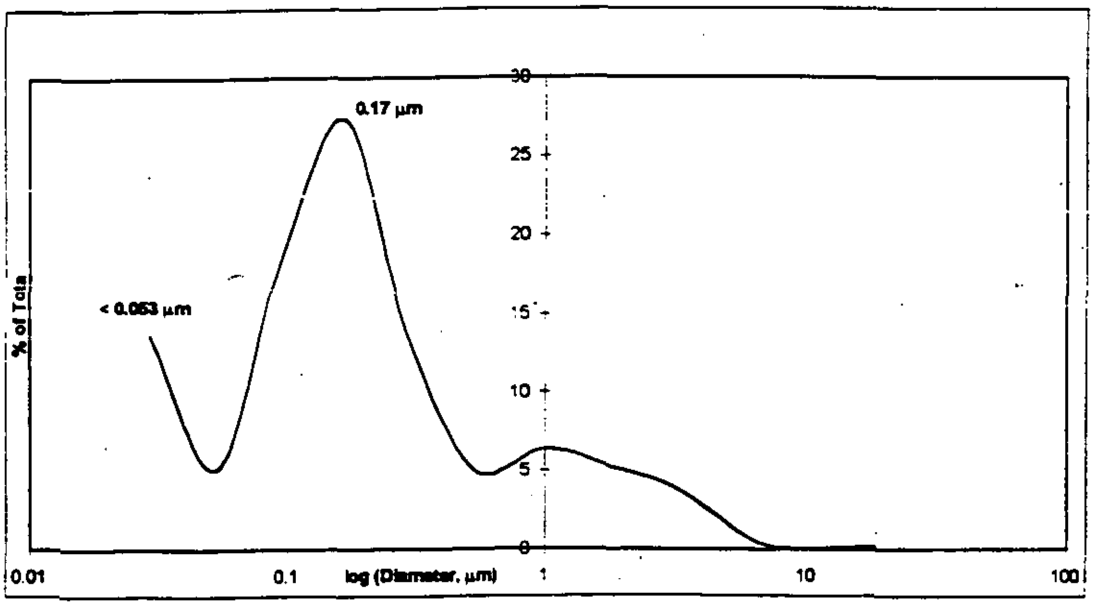


Figure 29

Particle Size Distribution

(hamburger/automated charbroiler/catalyst A)

TABLE XV
Hamburger/Automated Charbroiler/Catalyst B Results
(firing rate: 75,271 Btu/hr)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
960722-1	59.9	179.4	39.2	N/A	1.15	0.70
960722-2	59.9	165.4	31.8	21.0	0.95	0.60
960723-1	60.0	162.3	30.4	N/A	0.95	0.33
AVERAGE	**59.9**	**169.0**	**33.8**	**21.0**	**1.02**	**0.54**
SD	**0.06**	**9.11**	**4.73**	**N/A**	**0.12**	**0.19**

N/A - Not Available

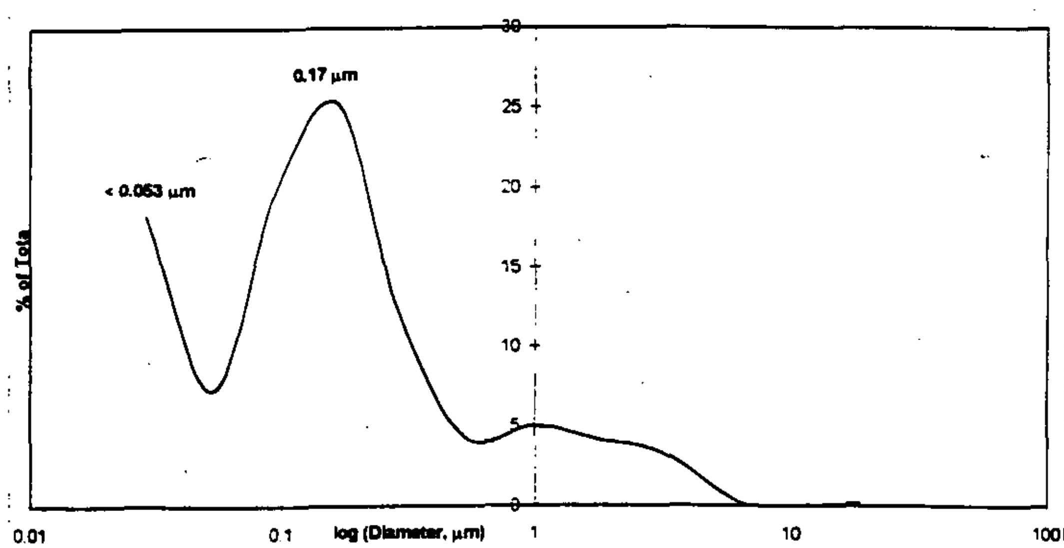


Figure 30

Particle Size Distribution

(hamburger/automated charbroiler/catalyst B)

TABLE XVI
Hamburger/Double-Sided Flat Griddle Process
(rated input: 13.3 kW)

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
970204-1	69.4	166.8	30.3	24.6	0.67	0.01
970205-1	67.3	167.8	28.1	24.2	0.75	0.01
970210-1	67.9	166.9	28.0	N/A	1.13	0.02
AVERAGE	**68.2**	**167.2**	**28.8**	**24.4**	**0.85**	**0.01**
SD	**1.08**	**0.55**	**1.30**	**0.28**	**0.25**	**0.01**

N/A - Not Available

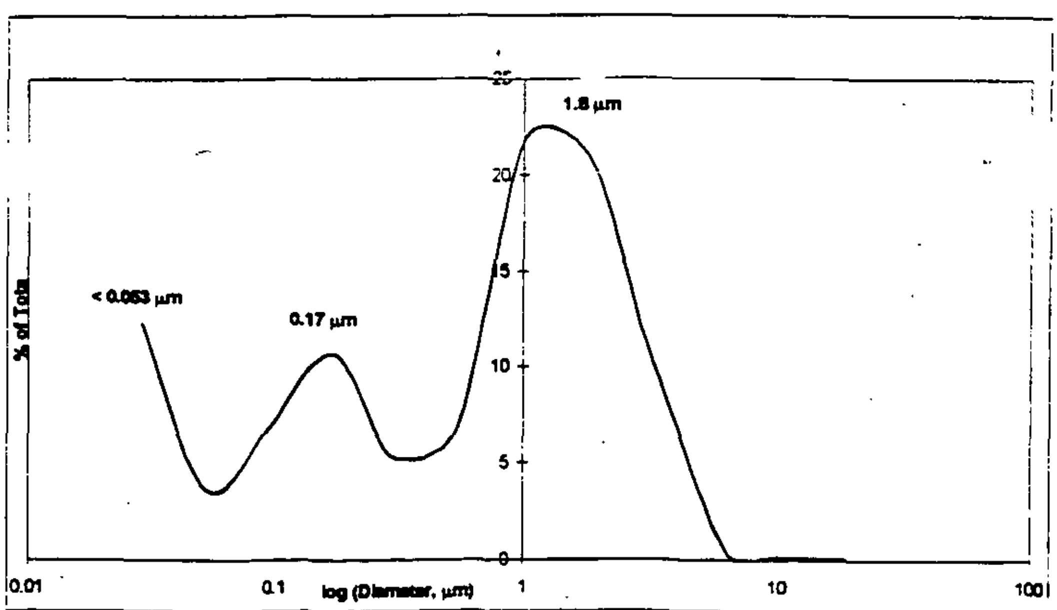


Figure 31

Particle Size Distribution

(hamburger/double-sided flat griddle)

TABLE XVII
Steak/Underfired Charbroiler Process
(firing rate: 57,206 Btu/hr)

N/A - Not Available

Test #	Loading (lb/hr)	Product Temp (°F)	% Weight Loss	% Fat Content	PM (lb/1000 lb)	ROG (lb/1000 lb)
970508-1	21.6	145.2	23.7	N/A	15.3	1.43
970508-2	22.6	149.0	27.9	N/A	17.7	0.51
970509-1	19.9	150.5	28.4	N/A	18.6	0.63
AVERAGE	**21.4**	**148.2**	**26.7**	**N/A**	**17.20**	**0.86**
SD	**1.37**	**2.57**	**2.58**	**N/A**	**1.71**	**0.50**

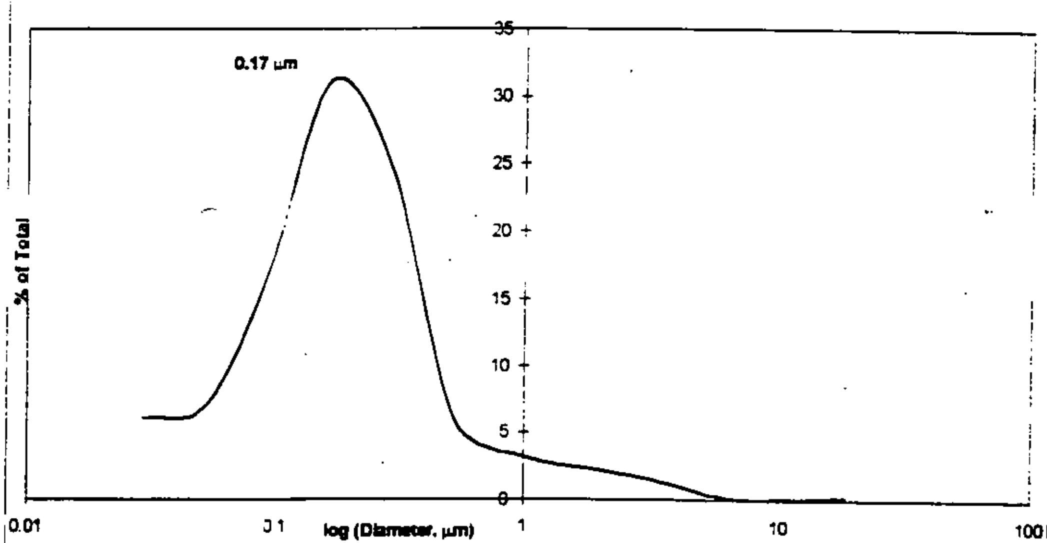


Figure 32

Particle Size Distribution

(steak/underfired charbroiler)

6.0 CONCLUSIONS

Results from the current commercial cooking emissions study indicate that measurement and control of process parameters in a laboratory setting can dramatically improve the consistency and repeatability of results compared with those obtained from field testing.[4,5,6,7] These process parameters include the fat content of the food product, energy input rate of the cooking device, loading rate of the food product, the cooking surface temperature, and the pre-cooked temperature of the food product. The variability of emission factors determined in the field are likely due to inconsistencies in one or more of these process parameters between test runs. By controlling these parameters within specified limits, CE-CERT was able to obtain consistent and repeatable results. Furthermore, the protocols developed during the study were successfully applied to a variety of cooking processes using an underfired charbroiler, a flat griddle, and a deep fat fryer.

Particulate matter emission factors determined during the test program range from 32.7 lbs/1000 lbs. meat cooked for the 25% fat hamburger/underfired charbroiler process to below detectable limits for the deep fat fryer processes. Particle size distributions determined for each of the processes indicate that the majority of particles present are less than 2.5 µm in diameter.

The refined ROG sampling and analytical protocol developed at CE-CERT in November, 1995 was successfully verified in a series of side-by-side tests with the SCAQMD reference method and a triplicate test using three separate sampling systems. The refined method provides a high degree of precision and repeatability for measurement of ROG emissions from commercial cooking effluents.

6.1 Process Conditions

Food product testing conducted during the test program included determinations of internal meat temperature, percentage weight loss during cooking, fat content of the uncooked food products, and moisture content of the uncooked and cooked food products. It appears from the testing that the percentage weight loss during cooking is the best indicator of "doneness," as the internal product temperature can vary depending on the placement of the thermocouple probes. This is readily apparent in non-homogeneous food products such as chicken and fish. For example, higher temperatures were found closer to the bones and in the leg/thigh meat in the whole chickens than those measured away from the bones or in the breast meat. The percentage weight loss during cooking for these processes was, in contrast, very consistent.

The measured fat content of the food products tested provided valuable information for quality control purposes between runs. It is apparent, however, that the restaurant industry uses a wide variety of meats. For example, the three types of hamburger meat tested in this program ranged in fat content from 20% to 25%. Results from testing indicate that emission rates may increase with increasing fat content of food products.

6.2 Particulate Matter

PM emission factors for five of the processes tested were greater than 4.0 lbs. per 1000 lbs. of meat cooked: the underfired charbroiler cooking hamburger, whole chicken and steak; the flat griddle cooking hamburger, and the automated charbroiler cooking hamburger. The hamburger emission factors correlate with those obtained in a previous studies at CE-CERT[2] and CalTech,[4] with the exception of the flat griddle/hamburger process. The emission factor determined at CE-CERT for this process was several times higher than the factor determined in the CalTech. The difference may be explained by the unique particle size distribution in the effluent of the flat griddle/hamburger process.

Particle size distributions for each process were determined using a cascade impaction system. Each cooking combination tested exhibited a peak at 0.17 μm, which is typical of combustion/condensation processes. The charbroiled chicken process, the charbroiled salmon process, and the automated charbroiler/catalyst processes exhibited a second peak at the afterfilter (< 0.053 μm). The flat griddle/hamburger process showed a second, large, broad peak around 2.0 μm. The existence of this 2.0 um peak may help explain the differences in the PM emission factor between the CalTech study and CE-CERT's study. The CalTech study focused only on submicron PM. As the charbroiling processes emit mainly submicron PM, the two studies correlate well. For the flat griddle/hamburger process, however, the CalTech study determined an emission factor of 0.6 lbs/1000 lbs. of meat cooked (vs. 4.1 lbs/1000 lbs. determined at CE-CERT). In this case, the CalTech study did not quantify the broad peak above 1 μm.

For all processes tested, the particle size distribution indicated the vast majority of PM was less than 2.5 μm in aerodynamic diameter. Recent studies have shown $PM_{2.5}$ to be a health effects and visibility concern.[8,9]

6.3 Reactive Organic Gases

Results from the method verification test runs showed that the surrogate ROG method developed for this project was more precise than the reference method for determination of emissions from commercial cooking operations. In addition, consistent performance was demonstrated by three different FID analyzers operated simultaneously.

The ROG emission factors determined in the current study were most significant for processes using high temperatures and high fat content meats. These processes included hamburger, chicken, and steak cooked on the underfired charbroiler, and hamburger cooked on the automated charbroiler. All other processes tested in this study emitted levels of ROG that were indistinguishable from background levels. As background ambient concentration levels are typically between 3 ppm and 8 ppm, CE-CERT defines "indistinguishable" as any average total hydrocarbon level below 10 ppm.

The correction of total hydrocarbon readings due to low response factors for oxygenated compounds averaged 15%, and were based on individual species and concentrations determined from HPLC analyses.

During the initial verification tests, total hydrocarbon concentrations measured in the effluent of the automated charbroiler/hamburger process averaged 271 ppm. During emission factor testing conducted later, the average measured total hydrocarbon concentration was 53 ppm. It is believed that the difference in measurements was due to different meat cooked during the method verification runs. While fat content analyses were not performed on the verification test meat, it is believed that the fat content was significantly higher than the 21% +/- 2% fat content specified in the cooking protocol. This is an illustration of the sensitivity of emissions to the fat content of the food product.

6.4 Control Technologies

Emissions reductions were successfully demonstrated for two catalytic control technologies with the automated charbroiler process, and for the double-sided flat griddle process. Catalyst A was a new, circular catalyst and ventilation shroud fitted to the top of the automated charbroiler. Catalyst B was a rectangular catalyst and shroud that had been in use at a busy fast food location for about 3 1/2 years. For PM, the units demonstrated control efficiencies of 79% and 86%, respectively. For ROG, the units demonstrated control efficiencies of 96% and 76%, respectively. The double-sided flat griddle process reduced PM emissions by 83% and ROG emissions by 86% compared with the traditional flat griddle process.

The particle size distribution curves for the controlled processes exhibited an afterfilter peak (< 0.053 µm) that was not present in the uncontrolled process. Inspection of the individual catches, however, reveals that the emission factors for every size distribution range are reduced when compared with the uncontrolled process.

While catalytic control technologies are effective in reducing emissions from the automated charbroiling process, there is difficulty in finding cost-effective emission reduction technologies for the underfired charbroiler and flat griddle cooking processes. Afterburners, scrubbers and electrostatic precipitators are all effective techniques for treating commercial cooking emissions, but are cost-prohibitive due to operational expenses.

7.0 REFERENCES

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Memo

To: Tom Pace
From: Roy H. Huntley
Subject: Review of Report Entitled, *Further Development of Emission Test Methods and Development of Emission Factors for Various Commercial Cooking Operations*, July 24, 1997
Date: January 30, 1998

Tom, this report was submitted by the University of California/Riverside - Center for Environmental Research and Technology (CE-CERT) to South Coast Air Quality Management District in California. I wanted to summarize this report for the team and provide my comments to you.

Purpose of Report

Two reasons. First, to improve emissions data from commercial cooking precesses. Some previous field testing had shown a lot of variability, so this testing was done in a test chambers under very precise conditions, in an effort to remove as many variables as possible. And second, to develop standardized procedures. Some modification of some of the standard methods was done.

Details of Test

All tests were conducted in a controlled 25' by 25' by 10' test chamber. The charbroiler and the deep fryer were fired by natural gas. The flat griddle was electric. Emissions were captured by a hood and ducted up out of the chamber, horizontally across the roof of the test chamber through a 1 foot square duct to a blower, and then out to the atmosphere through a vertical stack. Sample test ports were located upstream of the blower. Two control devices (identified as catalyst A and B) were tested. Both catalysts were positioned above the broiler in the hood. Their principal of operation was not stated, but they are heated by the broiler operation and my guess is that they burn the unburned hydrocarbons.

Pollutants tested were:

1. aldehydes and ketones,
2. total gaseous hydrocarbons,
3. methane,
4. total PM (plus condensibles),
5. PM 2.5, and
6. PM particle size distribution.

Cooking Processes tested were:

1. Hamburger meat/underfired charbroiler process

over

2. Whole chickens/underfired charbroiler
3. Atlantic salmon/underfired charbroiler
4. Shoestring potatoes/open, deep fat fryer process
5. Breaded chicken and fish/open deep fat fryer
6. Hamburger/flat griddle process
7. Boneless chicken breasts and cod fillets/flat griddle process
8. Hamburger/automated charbroiler process
9. Hamburger/automated charbroiler/catalyst A and catalyst B processes
10. Hamburger/double-sided flat griddle process
11. Steak/underfired charbroiler process

Tests Methods

The methods used in this tests were SCAQMD methods, and are not exactly like EPA's methods, but I believe that they do not differ significantly. However, it is important to understand the differences in the test methods in order to interpret the data properly.

For total PM, the testers used SCAQMD method 5.1. I am not familiar with that method and the description in the test report is skimpy. The sampling train diagram indicates that the filter is positioned behind the impingers, which would indicate that in-stack PM is not determined separately. On the other hand, the results indicates to me that a filter was used, so that point would need to be clarified. They also modified the SCAQMD method 5.1 to include a methylene chloride extraction of the impinger catch, which coincides with the EPA method 202 protocol.

The particle size distribution was done by a cascade impactor. I agree with Bob McCrillis's conclusion regarding the cascade impactor data, that is he said that he has some concerns but the data is usable. The main problem is the 90° end in the probe. There will be some particulate deposition there, probably biased toward the big stuff, meaning that the larger particle are more likely to impact the probe walls and stay there than the smaller particles. I recommend that we ask for the results of the probe wash. This will give us some idea of the size of the unwanted PM deposition in the probe. We could use the data without this, but this information would improve our confidence in the data and may be readily available.

Bob's other concern involved the heated probe and impactor. Apparently the probe and impactor (which is located out of stack) was heated to stack temperature. This is ok, and I am not concerned about it, but note that the impactor doesn't measure condensible emissions. Therefore I would look at how the PM2.5 emissions are calculated. Are the condensibles accounted for? We know that condensibles are all less than 1 μm, so we would want to make sure that the condensibles were included where appropriate.

For the organics, I would look carefully at the methods here as well. They did what amounts to an EPA Method 25 and Method 25A. They also measured separately methane ketones and aldehydes. They modified the Method 25A results by subtracting out the methane and adjusting to account for total aldehyde and ketone results. Good idea, in my opinion, but I would just give this a second look as it is not a typical procedures. They also did what looks like our method 25, and compared those results to the modified total hydrocarbon results.

Results

One of the primary variables in PM emissions seem to be the fat content of the meat. Emissions seem to increase with high fat content. Another important variable was the process. The underfired charbroilers were the big emitters, and the double sided flat griddle were the smallest emitters.

The catalysts did well, reducing PM emissions by 79% and 86%, and ROG emissions by 96% and 76%.

All of the emissions are PM10, and most of the emissions were PM2.5. The authors conclude from the particle size distribution that most of the emissions are condensible.

Interestingly, for the organics, the method 25 results were about ¼ of the modified THC method. No comment was made other than that this corresponded well to previously obtained data.

There was very little methane emitted, and the aldehyde/ketone adjustment to the total hydrocarbon number averaged 15%.

potato chip

VOC

.020 lb/ton of product

.~~4~~ ~~76~~

.42 lb/ ton of what ?

PM