CERP

Casting Emission Reduction Program

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Process Optimization: Drying Emissions from Uncoated and Coated Phenolic Urethane Cores

Technikon # 1410-132 GK

September 2005
(revised for public distribution)

EPA United States Environmental Protection Agency

CISA

AFS

UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

USCAR

DAIMLERCHRYSLER Ford Motor Company GM General Motors

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Process Optimization:
Drying Emissions from Uncoated and Coated Phenolic Urethane Cores

Technikon Test # 1410-132 GK

This report has been reviewed for completeness and accuracy and approved for release by the following:

VP Measurement Technologies: *// Original Signed //*
Clifford Glowacki, CIH — Date

VP Operations: *// Original Signed //*
George Crandell — Date

The data contained in this report were developed to assess the relative emissions profile of the product or process being evaluated. You may not obtain the same results in your facility. Data were not collected to assess casting cost, or producibility.

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EXECUTIVE SUMMARY

This report contains the results of Test GK and compares the drying emissions from wet coated and dry uncoated phenolic urethane step cores. Previous tests have indicated that wet coated cores that have been forced air heated in a direct gas fired OSI drying oven exhibit lower pouring, cooling, and shakeout emissions than similar dry uncoated cores that have not passed through the heated drying process. This test was designed to estimate the VOCs and HAPs emitted from coated and uncoated cores during the core drying process.

The geometry of the heated air space in Technikon's core drying oven (OSI oven) does not lend itself to precise air flow measurement or total emission capture. In addition, since the oven is direct fired, the total air flow through the oven is so great that, even with the oven full of wet cores, the concentration of emissions in the oven exhaust was determined to be below instrument and method detection limits.

An enclosed stainless steel core holder that would provide the air flow rate over the surface of the test step core that was similar to that measured in the OSI oven was designed and fabricated for this test. The core holder was heated in an electrically powered AccuTherm oven to temperatures similar to those achieved in the OSI oven. Emission samples were collected from the exhaust of the enclosed core holder over a seventy-seven (77) minute period, including 45 minutes of heating, 10 minutes of radiant cooling, and 22 minutes of force ambient air cooling.

The emissions results are reported in both pounds per pound (Lbs/Lb) of binder and pounds per ton (Lbs/Tn) of cores.

Process and stack parameters were measured and include: the weights of the core, core binder, coating weight, coating water content; furnace and core temperatures; event timing; Loss on Ignition (LOI) values for the core prior to the test; stack temperature, pressure, volumetric flow rate, and moisture content. The process parameters were maintained within prescribed ranges in order to ensure the reproducibility of the test runs.

Emission samples were collected and analyzed for specific target VOCs and HAPs. All sampling procedures were based on US EPA Method 18. Continuous monitoring of the Total Gaseous Organic Concentration (TGOC) of the emissions was conducted according to US EPA Method 25A.

Mass emission rates for all target analytes were calculated using continuous monitoring data, laboratory analytical results, measured source data, and appropriate process data. Results are presented in summary in Section 3 of this report and in detail in Appendix B. Five emission indicators including TGOC as propane, Hydrocarbons (HC) as hexane, the Sum of target VOCs, the Sum of target HAPS, and the Sum of target polycyclic organic matter (POM) were calculated. Detailed descriptions of these indicators can be found in the Results section of this report.

Results for the emission indicators are shown in the following table reported as lbs/tn of core and lbs/lb of binder. The TGOC results appear to have a significant negative bias and have been invalidated. If the reason for this apparent negative bias is identified, and if the TGOC results can be corrected for the apparent bias, a revised report will be issued. The invalidated TGOC results are shown in red in Appendix B for the reader's review.

Table 1 Test Plan GK Average Emission Indicator Results

Test GK	Lb/Lb of Binder		Lb/Tn of Cores	
	Coated Cores	**Uncoated Cores**	**Coated Cores**	**Uncoated Cores**
TGOC as Propane	I	I	I	I
HC as Hexane	0.2682	0.5048	7.4140	13.9766
Sum of Target VOCs	0.0323	0.1141	0.9172	2.9811
Sum of Target HAPs	0.0205	0.0481	0.6080	1.3319
Sum of Target POMs	0.0056	0.0159	0.1965	0.4419

I: Invalidated

It must be noted that the testing performed is not suitable for use as emission factors or for purposes other than evaluating the relative emission reductions associated with the use of alternative materials, equipment, or processes. The emissions measurements are unique to the specific castings produced, materials used, and testing methodology associated with these tests, and should not be used as the basis for estimating emissions from actual commercial foundry applications.

1.0 INTRODUCTION

1.1. Background

Technikon LLC is a privately held contract research organization located in McClellan, California, a suburb of Sacramento. Technikon offers emissions research services to industrial and government clients specializing in the metal casting and mobile emissions areas. Technikon operates the Casting Emission Reduction Program (CERP). CERP is a cooperative initiative between the Department of Defense (US Army) and the United States Council for Automotive Research (USCAR). The parties to the CERP Cooperative Research and Development Agreement (CRADA) include The Environmental Research Consortium (ERC), a Michigan partnership of DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation; the U.S. Army Research, Development, and Engineering Command (RDECOM-ARDEC), a laboratory of the United States Army; the American Foundry Society; and the Casting Industry Suppliers Association. The US Environmental Protection Agency (US EPA) and the California Air Resources Board (CARB) also have been participants in the CERP program and rely on CERP published report for regulatory compliance data.

1.2. Technikon Objectives

The primary objective of Technikon is to evaluate materials, equipment, and processes used in the production of metal castings. Technikon's facility was designed to evaluate alternate materials and production processes designed to achieve significant air emission reductions. The facility's principal testing arena is designed to measure airborne emissions from individually poured molds. This testing arena has been specially designed to facilitate the repeatable collection and evaluation of airborne emissions and associated process data.

It must be noted that the reference and product testing performed is not suitable for use as emission factors or for purposes other than evaluating the relative emission reductions associated with the use of alternative materials, equipment, or processes. The emissions measurements are unique to the specific castings produced, materials used, and testing methodology associated with these tests, and should not be used as the basis for estimating emissions from actual commercial foundry applications.

1.3. Report Organization

This report has been designed to document the methodology and results of a specific test plan that was used to evaluate specific VOC and HAP emissions from core coating drying processes. Section 2 of this report includes a summary of the methodologies used for data collection and analysis, emission calculations, QA/QC procedures, and data management and reduction methods. Specific data collected during this test are summarized in Section 3 of this report, with detailed data included in Appendices B and C of this report. Section 4 of this report contains a discussion of the results.

The raw data for this test series is maintained at the Technikon facility.

1.4. Specific Test Plan and Objectives

Table 1-1 provides a summary of the test plan. A copy of the approved test plan is included in Appendix A. The goal of the test was to determine emissions from drying of coated cores.

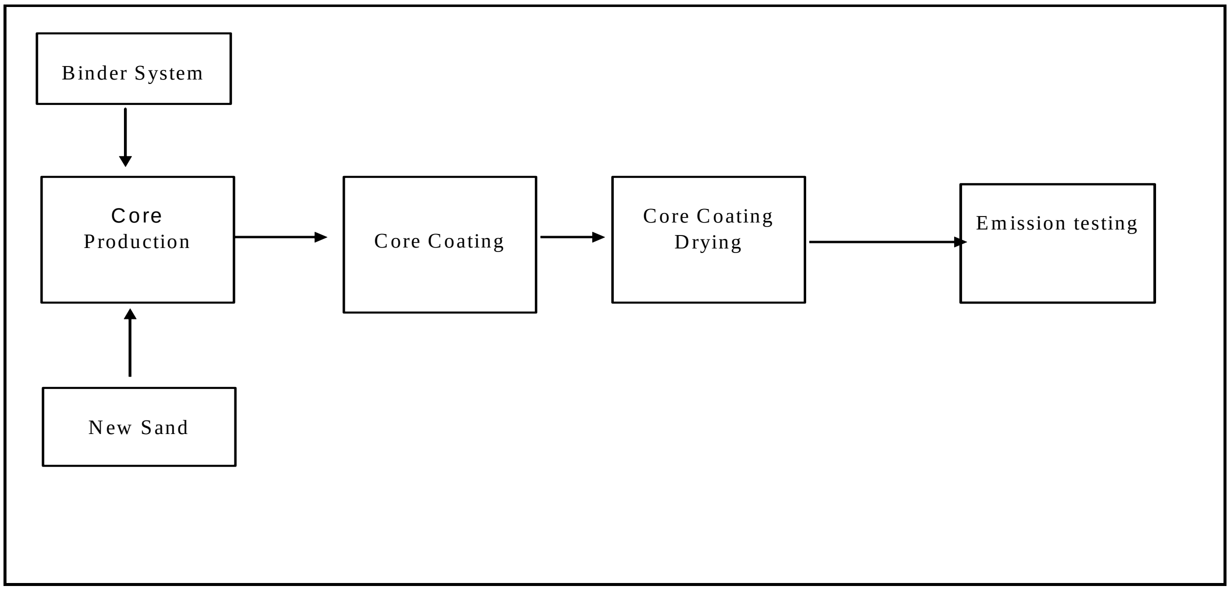
Table 1-1 Test Plan Summary

Test Plan Number	1410 132 GKa	1410 132 GKb
Type of Process Tested	Phenolic Urethane Uncoated Core Drying & Cooling	Phenolic Urethane Coated Core Drying & Cooling
Aggregate	Wedron 530 Silica Sand	Wedron 530 Silica Sand
Core Binder System	1.4% (BOS) Ashland ISOCURE® LF305/904GR TEA catalyzed	1.4% (BOS) Ashland ISOCURE® LF305/904GR TEA catalyzed
Metal Poured	None	None
Core type	Step	Step
Number of Cores	6	6
Test Dates	11/24/04 through 12/15/04	11/24/04 through 12/15/04
Emissions Measured	TGOC as Propane, HC as Hexane, 68 Target Analytes	TGOC as Propane, HC as Hexane, 68 Target Analytes
Process Parameters Measured	Total Core, and Binder Weights; core % LOI; Sand Temperature; Stack Temperature, Moisture Content, Pressure, and Volumetric Flow Rate	Total Core, Coating, and Binder Weights; core % LOI; Sand Temperature; Stack Temperature, Moisture Content, Pressure, and Volumetric Flow Rate

2.0 TEST METHODOLOGY

2.1. Description of Process and Testing Equipment

Figure 2-1 Research Foundry Core Making, Coating, and Drying Process Flowchart



2.2. Description of Testing Program

The process parameters not being evaluated were maintained within prescribed ranges in order to ensure the reproducibility of the tests. Emissions were continuously measured according to US EPA Method 25A, Total Gaseous Organic Concentration, calibrated with propane. Methods based on US EPA Method 18 and other selected NIOSH, OSHA, and US-EPA methods were used to collect and analyze samples for specific target VOCs and HAPs

The specific steps used in this testing program are summarized below:

1. **Test Plan Review and Approval:** The proposed test plan was reviewed and approved by the Technikon staff.

2. **<u>Core Preparation:</u>** The cores were prepared with 1.4% (BOS) Ashland ISOCURE® LF305/904GR phenolic urethane binder. The cores were blown in a Redford/Carver core blower using TEA catalyst. Relevant process data was collected and recorded. Sand and binder calibration weight were recorded on the Process Data Summary Sheet.

3. **<u>Core coating:</u>** The cores were dip coated with Ashland Velvaplast® CGW 9022 SL core coating at a standard temperature and viscosity. The relevant process parameters were recorded.

4. **<u>Preliminary Core Drying Evaluation:</u>** Cores were dried in the direct gas fired OSI oven used to produce cores for pouring, cooling, shakeout experiments to obtain time and/or temperature profile data on both dry uncoated cores and wet coated cores to enable accurate process modeling during the emissions collection testing. The OSI oven drying cycle consisted of 10 minutes on the entrance belt, 45 heated drying minutes at 275°F, 10 minutes of radiant cooling, and 25 minutes of ambient forced air cooling.

Figure 2-2 Redford/Carver Core Blower

Figure 2-3 Core Dipping

Figure 2-4 Preliminary Cores Drying in Direct Gas Fired OSI Oven

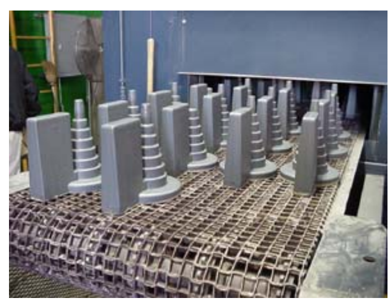


Figure 2-5 AccuTherm Furnace

5. **<u>Core Drying:</u>** The test was conducted with the core in a cone shaped emission collection chamber that was placed in the electrically heated AccuTherm furnace at 325°F. The higher oven temperature was chosen to best emulate the OSI oven thermal profile with the restrictions necessitated by the use of the emission collection cone.

6. **<u>Enclosed Core Holder</u>** The test cores were placed against locators in the preheated core holder and the enclosure was immediately closed and gasket sealed. The enclosure provided the same linear air flow rate over the core observed in the OSI furnace. Heated oven air entered an opening in the top of the enclosure, flowed over the core, and exited the bottom into the sample collection manifold. Dry and wet coated cores were instrumented with thermocouples to monitor the core temperature profile. The heat transfer from the air passing over the core in the collection cone was less effective than that demonstrated in the free flowing OSI production oven.

7. **<u>Oven operation</u>** The oven door was closed after the collection enclosure was sealed and remained so until it was reopened to emulate the radiant cooling period as cores passed from the heated to the forced cooling chambers of the OSI oven. Then, thermal insulation was placed between the collection cone and the radiant/shielded heat source of the AccuTherm oven. Finally a fan directed ambient air over and into the collection cone to emulate the forced air cooling.

Figure 2-6 Preheated Core Holder Enclosure

8. **<u>Test Plan Review and Approval:</u>** The proposed test plan was reviewed by the Technikon staff and the CERP Emissions and Test Design Committees, and approved. Table 2-1 lists the process parameters that were monitored during each test.

Table 2-1 Process Parameters Measured

Parameter	Analytical Equipment and Methods
Core Weight	Mettler SB12001 digital platform scale (Gravimetric)
Coating Weight	Mettler SB12001 digital platform scale (Gravimetric)
Binder Weight	Mettler SB12001 digital platform scale (Gravimetric)
LOI, % at Mold	Denver Instruments XE-100 (AFS procedure 5100-00-S)
Core Temperature	Recorder or Data Logger and J-Thermocouples
Core Coating Water Weight	Mettler SB12001 digital platform scale (Gravimetric)

9. **Airborne Emissions Analysis:** The specific sampling and analytical methods used in the test were based on the US EPA reference methods shown in Table 2-2. The details of the specific testing procedures and their variance from the reference methods are included in the Technikon Testing, Quality Control and Quality Assurance, and Data Validation Procedures Manual.

Table 2-2 Sampling and Analytical Methods

Measurement Parameter	Test Method*
Port Location	EPA Method 1
Number of Traverse Points	EPA Method 1
Gas Velocity and Temperature	EPA Method 2
Gas Density and Molecular Weight	EPA Method 3a
Gas Moisture	EPA Method 4, gravimetric
HAPs Concentration	EPA Method 18, TO 17, TO11, NIOSH 2002
Target Analytes Concentration	EPA Method 18, TO 17, TO11, NIOSH 2002, NIOSH 1500 (WCMA – MPTE)
TGOC as Propane	EPA Method 25A

*These methods were specifically modified to meet the testing objectives of the CERP Program.

10. **Data Reduction, Tabulation and Preliminary Report Preparation:** The analytical results, of the samples collected during each of the test runs, provides the mass of each analyte in each sample. The total mass of the analyte emitted is calculated by multiplying the mass of analyte in the sample times the ratio of total stack gas volume to sample volume. The total stack gas volume is calculated from the measured stack gas velocity and the duct diameter, and corrected to dry standard conditions using the measured stack pressures, temperatures, gas molecular weight, and moisture content. The total mass of analyte is then divided by the weight of the binder in the core and, separately, by the weight of the core to provide emissions data in pounds of analyte per pound of binder and pounds of analyte per ton of core, respectively. The results of each of the test runs are included in the appendices of this report. The average emissions results are shown in Tables 3-1 and 3-2.

11. **Report Preparation and Review:** The Preliminary Draft Report is reviewed by the Process Team and Emissions Team to ensure its completeness, consistency with the test plan, and adherence to the prescribed QA/QC procedures. Appropriate observations, conclusions and recommendations are added to the report to produce a Draft Report. The Draft Report is reviewed by the Manager-Process Engineering, the Vice President-Measurement Technologies, the Vice President-Operations, and the Technikon President. Comments are incorporated into a draft Final Report prior to final signature approval and distribution.

2.3. Quality Assurance and Quality Control (QA/QC) Procedures

Detailed QA/QC and data validation procedures for the process parameters, stack measurements, and emissions data are included in the "Technikon Testing, Quality Control and Quality Assurance, and Data Validation Procedures Manual" In order to ensure the timely review of critical quality control parameters, the following procedures are followed:

Immediately following the individual runs performed for each test, specific process parameters are reviewed by the Manager-Process Engineering to ensure that the parameters are maintained within the prescribed control ranges. Where data are not within the prescribed ranges, the Manager-Process Engineering and the Vice President-Operations determine whether the individual test runs should be invalidated or flagged for further review.

The source (stack) parameters and analytical results are reviewed by the Emission Measurement team to confirm the validity of the data. The Vice President-Measurement Technologies reviews all recommendations that individual run data should be invalidated. If the recommendations are approved, the invalidated data are not used in subsequent calculations.

3.0 TEST RESULTS

A comparison of the average drying emission results from coated and uncoated cores is presented in Tables 3-1 and 3-2 in pounds per pound of binder and pounds per ton of cores, respectively. The tables include the individual target compounds that comprise at least 95% of the total target analytes measured, along with the corresponding Sum of Target VOCs, Sum of Target HAPs, and Sum of Target POMs. The tables also include TGOC as propane, and HC as hexane. Appendix B contains the detailed emissions data including the results for all analytes measured.

Compounds that are structural isomers have been grouped together and are reported as a single quantity. For example: ortho-, meta-, and para-xylene are the three structural isomers of dimethyl benzene and their sum is reported as o,m,p-xylene. Trimethylbenzenes and dimethylphenols are also treated and reported in a similar manner.

Two methods were employed to measure undifferentiated hydrocarbon emissions as emission indicators: TGOC as propane, performed in accordance with EPA Method 25A, and HC as hexane, performed in accordance with Wisconsin Cast Metals Association – Maximum Potential to Emit (WCMA – MPTE) Method revised 07-26-01. EPA Method 25A is weighted to the detection of the more volatile hydrocarbon species, beginning at C_1 (methane), with results calibrated against the three-carbon alkane (propane). The HC as Hexane method detects hydrocarbon compounds in the alkane range between C_6 and C_{16}, with results calibrated against the six-carbon alkane (hexane).

Other emissions indicators, in addition to TGOC as propane and HC as hexane, were calculated and are presented in these tables. The emissions indicator "Sum of Target VOCs" is the sum of all the individual target analytes detected and includes targeted HAPs and POMs, as well as other targeted VOCs (volatile organic compounds). By definition, HAPs are specific compounds listed in the Clean Air Act Amendments of 1990. The term POM defines not one compound, but a broad class of compounds based on chemical structure. POMs as a class are a listed HAP. A subset of the 188 listed EPA HAPs was targeted for collection and analysis. These individual target HAPs (which may also be POMs by nature of their chemical properties) detected in the samples are summed together and defined as the "Sum of Target HAPs," while the "Sum of Target POMs" only sums those HAPs that are also defined as POMs.

Figures 3-1 through 3-3 present the five emissions indicators and selected individual HAP and VOC emissions data from Table 3-1 in graphical form.

Figures 3-4 through 3-6 present the five emissions indicators and selected individual HAP and VOC emissions data from Table 3-2 in graphical form.

Table 3-3 includes the averages of the key process parameters. Detailed process data are presented in Appendix C. Charts showing core surface and internal temperature profiles during drying in both the OSI oven and in the enclosed core holder test apparatus are also shown in Appendix C

Method 25A charts for the tests are included in Appendix D of this report. The charts are presented to show the qualitative VOC profile of emissions for each test run.

Table 3-1 Average Emissions Results – Lb/Lb Binder

Analytes	Coated Core Drying Emissions Lb/Tn Cores	Uncoated Core Drying Emissions Lb/Tn Cores	% Difference Coated to Uncoated
Emissions Indicators			
TGOC as Propane	I	I	
HC as n-Hexane	7.4140	13.9766	-47
Sum of Target VOCs	1.0060	2.9192	-66
Sum of Target HAPs	0.6080	1.2640	-52
Sum of Target POMs	0.1965	0.3791	-48
Specific Target HAPs			
2,3,5-Trimethylnaphthalene	0.0010	0.0008	28
2-Butanone	0.0001	0.0005	-77
Acenaphthalene	0.0002	0.0008	-77
Acetaldehyde	0.0042	0.0130	-68
Acrolein	ND	ND	NA
Benzene	0.0004	0.0004	7
Biphenyl	0.0022	0.0054	-59
Cresols	0.0631	ND	NA
Dimethylnaphthalenes	0.0307	0.0575	-47
Ethylbenzene	0.0005	0.0006	-22
Formaldehyde	0.0146	0.0103	43
Hexane	0.0001	0.0017	-96
Methylnaphthalenes	0.1603	0.3820	-58
Naphthalene	0.0043	0.0017	148
Phenol	0.0318	0.2202	-86
Propionaldehyde	ND	ND	NA
Styrene	0.0005	0.0001	258
Toluene	0.0002	0.0008	-74
Triethylamine	0.2975	0.6669	-55
Xylenes	0.0015	0.0017	-8
Other Target VOCs			
Dimethylphenols	0.1771	0.9260	-81
Decane	0.0581	0.3421	-83
Trimethylbenzenes	0.0267	0.1940	-86
1,3-Diethylbenzene	0.0178	ND	NA
Ethyltoluenes	0.0140	0.0988	-86
Indene	0.0124	0.0055	128
Propylbenzene, n-	0.0061	0.0210	-71
Undecane	0.0058	0.0485	-88
Heptane	0.0055	0.0008	613
Tetradecane	0.0046	0.0095	-51
Butyraldehyde/Methacrolein	0.0027	ND	NA
Nonane	0.0011	0.0006	90
Pentanal	0.0008	0.0007	20
Crotonaldehyde	0.0008	ND	NA
Indan	0.0005	0.0070	-93
Octane	0.0004	0.0004	12
Hexaldehyde	0.0003	0.0004	-25
Cyclohexane	0.0002	0.0001	192
o,m,p-Tolualdehyde	ND	0.0001	NA
Dodecane	ND	ND	NA
Benzaldehyde	ND	ND	NA

Individual results constitute >95% of mass of all detected target analytes.
ND: Non Detected at the Reporting Limit of 0.0001 lb/lb binder; NA: Not Applicable
I: Invalidated

Table 3-2 Average Emissions Results – Lb/Tn Cores

Analytes	Coated Core Drying Emissions Lb/Lb Binder	Uncoated Core Drying Emissions Lb/Lb Binder	% Difference Coated to Uncoated
Emissions Indicators			
TGOC as Propane	I	I	
HC as n-Hexane	0.2682	0.5048	-47
Sum of Target VOCs	0.0347	0.1048	-67
Sum of Target HAPs	0.0182	0.0456	-60
Sum of Target POMs	0.0056	0.0137	-59
Specific Target HAPs			
2,3,5-Trimethylnaphthalene	ND	ND	NA
2-Butanone	ND	ND	NA
Acenaphthalene	ND	ND	NA
Acetaldehyde	0.0002	0.0005	-68
Acrolein	ND	ND	NA
Benzene	ND	ND	NA
Biphenyl	0.0001	0.0002	-59
Cresols	0.0023	ND	NA
Dimethylnaphthalenes	0.0011	0.0021	-46
Ethylbenzene	ND	ND	NA
Formaldehyde	0.0005	0.0004	43
Hexane	ND	0.0001	NA
Methylnaphthalenes	0.0051	0.0138	-63
Naphthalene	0.0002	0.0001	148
Phenol	0.0011	0.0080	-86
Propionaldehyde	ND	ND	NA
Styrene	ND	ND	NA
Toluene	ND	ND	NA
Triethylamine	0.0108	0.0241	-55
Xylenes	0.0001	0.0001	-8
Other Target VOCs			
Dimethylphenols	0.0064	0.0334	-81
Decane	0.0021	0.0123	-83
Trimethylbenzenes	0.0010	0.0077	-87
1,3-Diethylbenzene	0.0006	ND	NA
Ethyltoluenes	0.0005	0.0036	-86
Indene	0.0004	0.0002	128
Propylbenzene, n-	0.0002	0.0008	-71
Undecane	0.0002	0.0018	-88
Heptane	0.0002	ND	NA
Tetradecane	0.0002	0.0003	-51
Butyraldehyde/Methacrolein	0.0001	ND	NA
Nonane	ND	ND	NA
Pentanal	ND	ND	NA
Crotonaldehyde	ND	ND	NA
Indan	ND	0.0003	NA
Octane	ND	ND	NA
Hexaldehyde	ND	ND	NA
Cyclohexane	ND	ND	NA
Dodecane	ND	ND	NA
Benzaldehyde	ND	ND	NA
o,m,p-Tolualdehyde	ND	ND	NA

Individual results constitute >95% of mass of all detected target analytes.
ND: Non Detected at the Reporting Limit of 0.0001 lb/lb binder; NA: Not Applicable
I: Invalidated

Table 3-3 GK Summary of Process Parameters

GK Summary	Oven Drying Wet Coated Core Average	Oven Heating Previously Air Dried Coated Core	Oven Heating Uncoated Core Average
Test Date	17-21 Dec 04	22-Dec-04	16-17 Dec 04
Part I Binder Weight, gm	174.90	174.30	174.93
Part II Binder Weight, gm	143.50	143.30	143.00
Sand Weight, Lbs	50.00	50.00	50.00
% Binder (BOS)	1.40	1.40	1.40
% Binder (BOS)	1.38	1.38	1.38
Bare core dry weight, gm	1833.70	1806.10	1848.53
Binder Weight, gm	25.39	24.94	25.55
Core age, days	6.00	6.00	2.17
Coated core wet weight, gm	1920.95	1897.70	NA
Coated core dry weight, gm	1864.74	1843.50	NA
Coating dry weight, gm	34.42	37.40	NA
Coating water weight as dipped, gm	54.14	54.20	NA
Coating % solids	38.87	40.83	NA
Coating Baum	21.04	42.00	NA
Test duration, minutes	77.00	77.00	77.00
Oven Equilibrium Temperature, Deg F	323.17	330.00	317.33
Temporary Oven Temp @ core loading, Deg F	289.50	233.00	282.67
TGOC concentration during drying, ppm	1120.83	1351.00	1833.33
TGOC Conc. Normalized to binder weight ppm/gm	44.15	54.16	71.74

Figure 3-1 Summary of Emission Indicators – Lb/Tn Cores

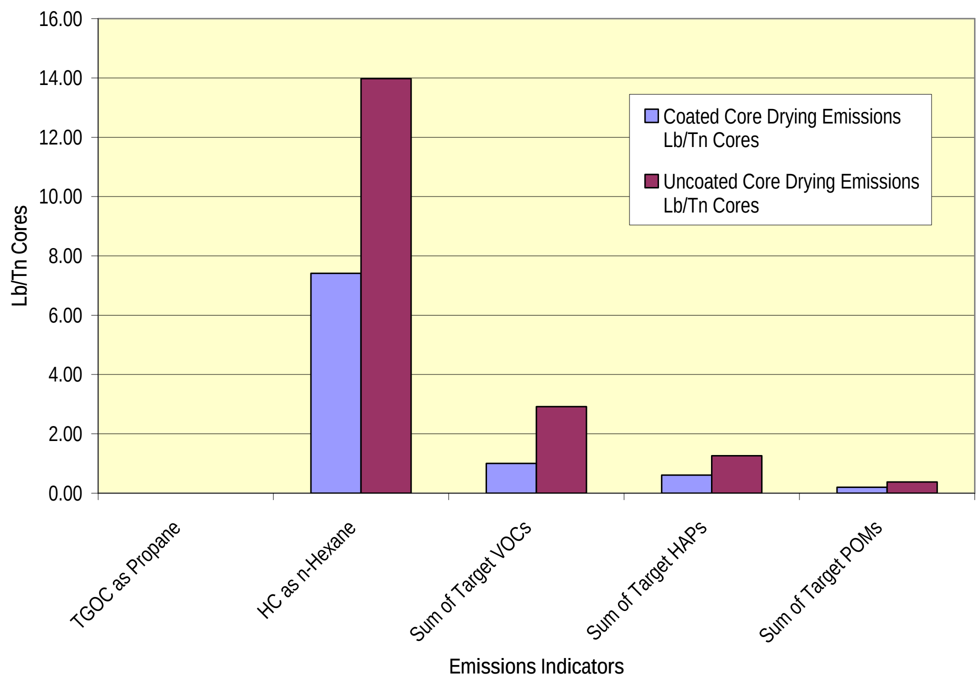


Figure 3-2 Summary of Selected HAPs - Lb/Tn Cores

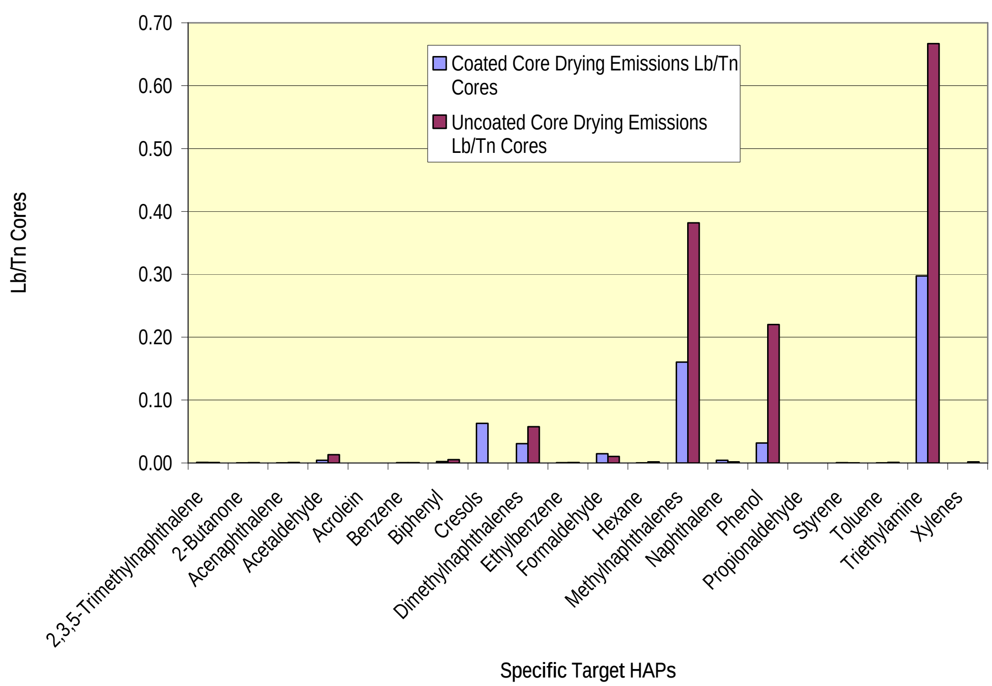


Figure 3-3 Summary of VOCs - Lb/Tn Cores

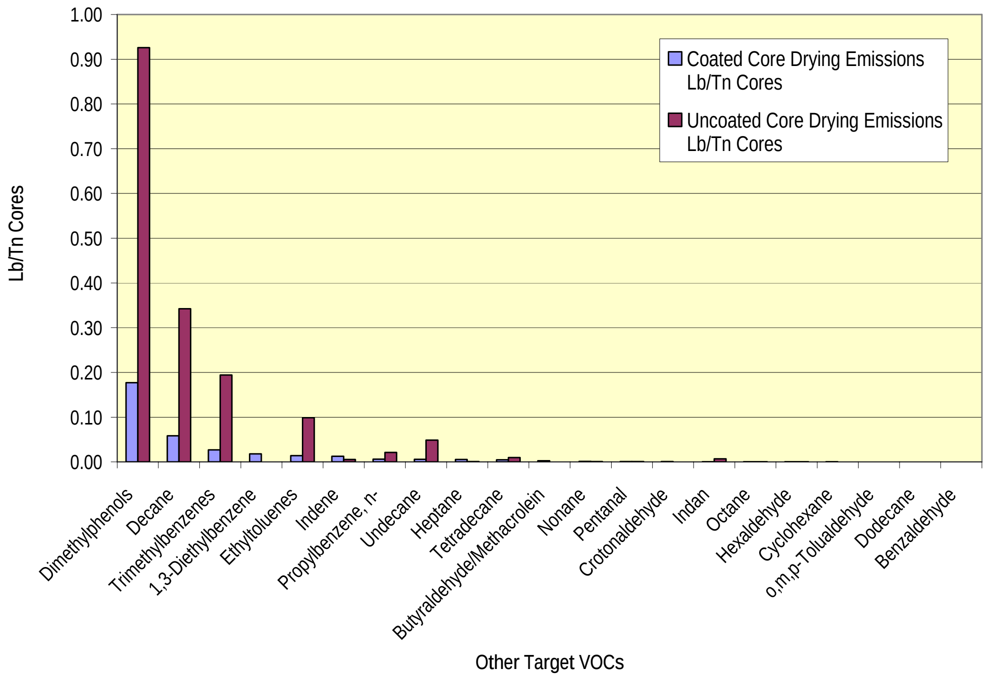


Figure 3-4 Summary of Emissions Indicators – Lb/Lb Binder

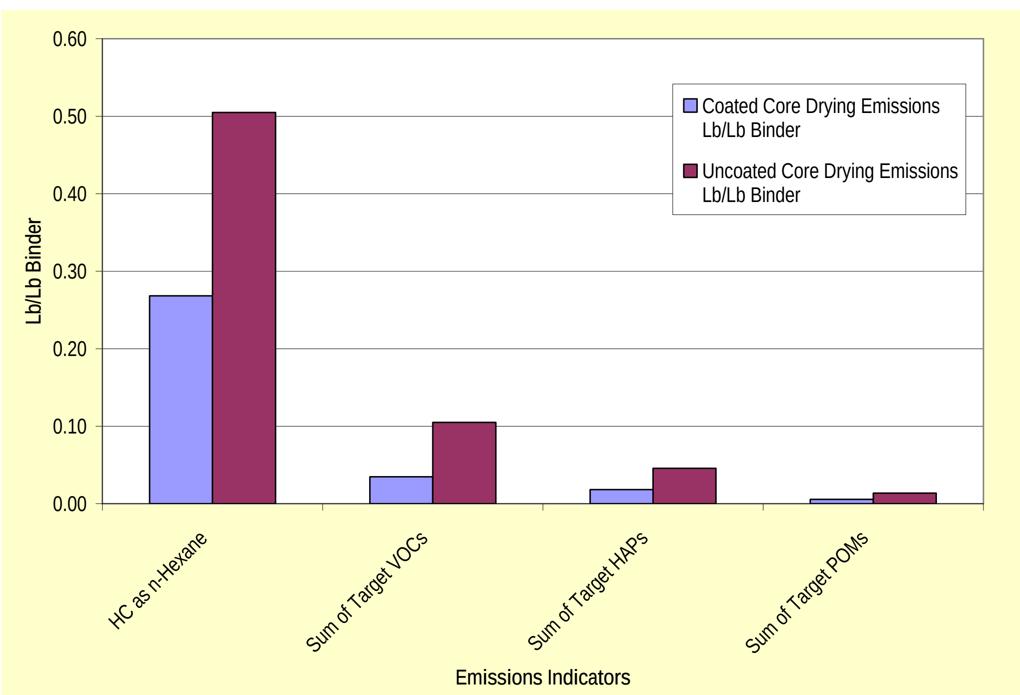


Figure 3-5 Summary of Selected HAPS - Lb/Lb Binder

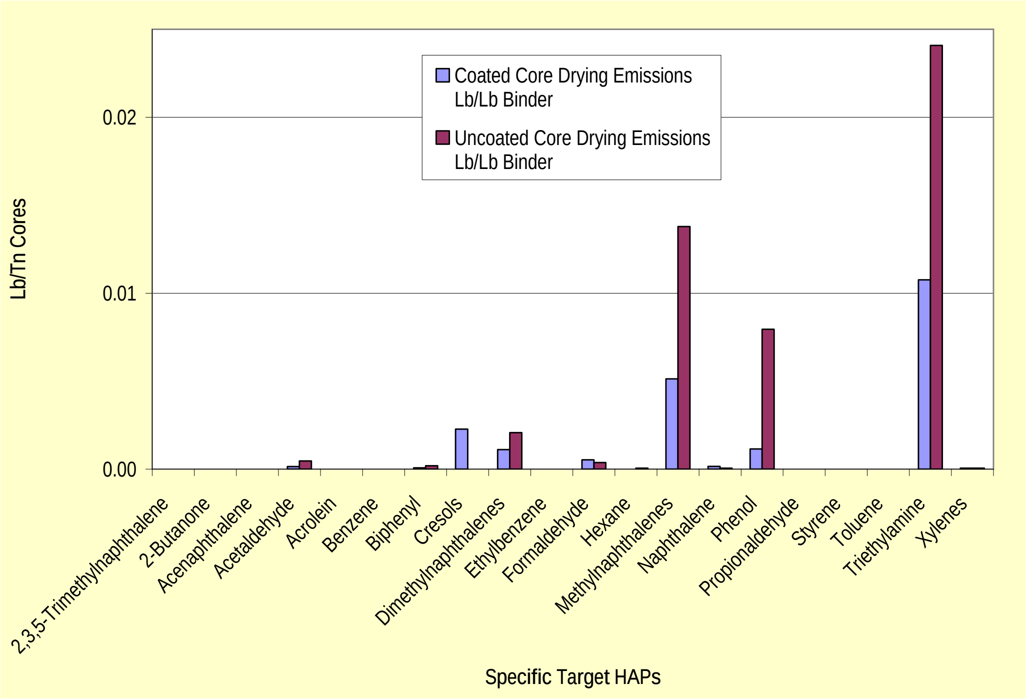
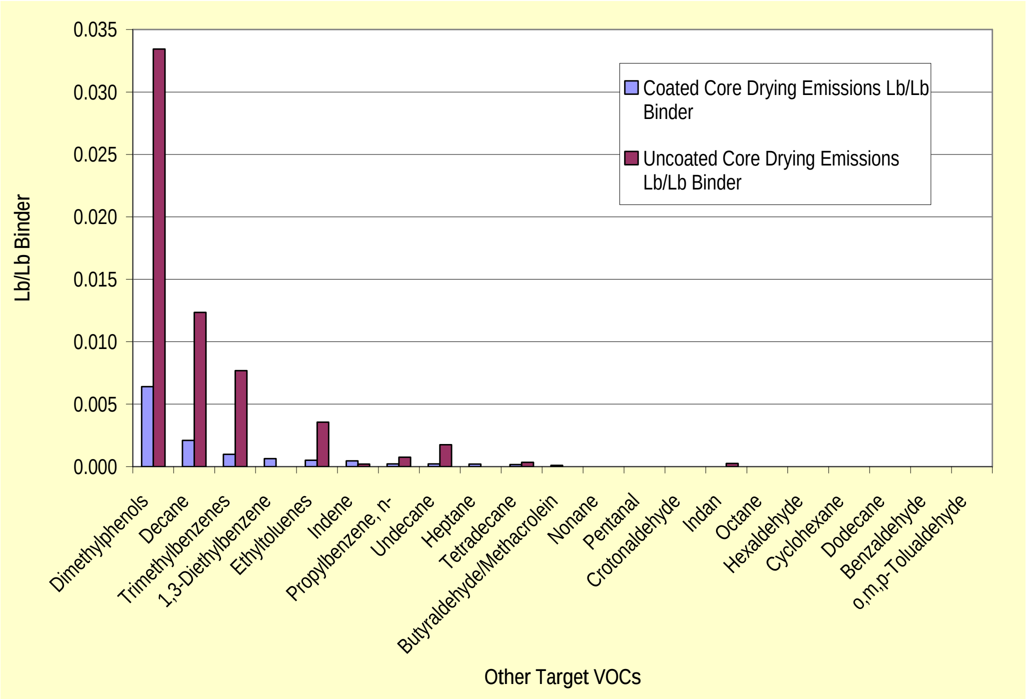


Figure 3-6 Summary of VOCs - Lb/Lb Binder



4.0 DISCUSSION OF RESULTS

This report contains the results of testing to measure the drying emissions from coated and uncoated phenolic urethane step cores. Previous tests have indicated that coated cores that have been dried in a forced air gas fired OSI drying oven exhibit lower pouring, cooling, and shakeout emissions than uncoated cores.

The total emissions reflect the emission summed over time. The emissions in this comparison of cores with the same manufacturing history are typical of Technikon's experience with other emission processes controlled by vapor pressure and diffusion. The emissions in this comparison were driven by the core surface temperature, as reflected by the surrounding air temperature in the oven, and the internal core temperature. Charts showing dry and coated core surface and internal temperature comparisons may be found in Appendix C.

The TGOC results for all of the test runs have been invalidated. The results show evidence of a significant systematic negative bias. A detailed review of the TGOC raw data and calculations failed to identify the cause of the apparent negative bias. A similar detailed review of the HC as hexane and other specific target analyte results found that these data are correct and that the relationships between the HC as Hexane, Sum of Target VOCs, Sum of Target HAPs, and Sum of Target POMS results are consistent with expectations.

Target analyte quantitation limits expressed in pounds per ton of core and pounds per pound of binder are shown in Appendix B.

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APPENDIX A APPROVED TEST, SAMPLING PLANS AND PROCESS INSTRUCTIONS FOR TEST GK

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Technikon Test Plan

♦ **CONTRACT NUMBER:**	1410	**TASK NUMBER**	1.3.2	**SERIES**	GK
♦ **SITE:**	Pre-production				
♦ **TEST TYPE:**	Process Optimization: Coated core emissions during coating drying in a gas fired oven				
♦ **METAL TYPE:**	None				
♦ **MOLD TYPE:**	None				
♦ **NUMBER OF MOLDS:**	None				
♦ **CORE TYPE:**	Coated Step: 1.4% Ashland Isocure ® Phenolic Urethane LF305 part I (55%), 904GR Part II (45%), amine cured. Bagged 1 hour after manufacture. Exposed for ten (10) minutes prior to insertion in the oven.				
♦ **CORE COATING:**	Ashland Velvaplast® CGW 9022 SL				
♦ **SAMPLE EVENTS:**	Six (6) individual uncoated cores and six (6) wet coated cores in the final test configuration.				
♦ **TEST DATE**	**START:**		11/22/04		
	FINISH:		12/17/04		

TEST OBJECTIVES:

1. Establish protocol for emulating the drying of the cores in the OSI heating and cooling cycles.
2. Measure the evaporative emissions from an emulation of drying individual coated cores in the OSI core drying oven.

VARIABLES:

The cores will be the step cores with the gating section removed so that the core is axially symmetric. The coated cores will be dipped in the core coating slurry of standard temperature and specific gravity to achieve a standard dry coated weight. The core will be air dried with ambient air for 10 minutes at 70-80^{o}F and 40-60% Rh, then passed through an emulation of the OSI oven at 275^{o}F for 45 minutes, 10 minutes of radiant cooling, and finally 25 minutes of forced ambient air cooling total 80 minutes. The core coating material, and weight or thickness, and application method will be by a method developed by Ashland Chemical. This core coating procedure is the standard for core coating product testing

BRIEF OVERVIEW:

Previous tests have indicated that dry uncoated cores and wet coated cores that have been forced air heated in our gas fired OSI drying oven exhibit less pouring, cooling, and shakeout emissions than those not passed through the heated drying process. Whether this is totally due to the heated evaporation in our OSI core drying oven or is in part due to the core coating itself is not known. This test is designed to make that distinction.

The heated air space in the OSI oven does not lend itself to precise air flow measurement or total emission capture. Furthermore the total air flow through the oven is too great to have enough cores of the same age be co-resident in the oven to have the emission concentration high enough for our instruments to detect. Therefore the oven's thermal and air flow conditions will be emulated.

A collection chamber has been developed to emulate the air volume flow rate over the test step core, a modified step core without its gating section, as if it were to be dried in the OSI oven. In the collection chamber, the annular space between the chamber and the core is so designed as to maintain a constant volume flow rate of air over all core step diameters. The annular space is small at the large diameter end and wide at the small end. The surface linear velocity will be allowed to vary from one end to the other. This is acceptable because a) the stepped geometry creates turbulent flow at each step and b) preliminary heat transfer calculations demonstrate that the heat transfer from the air to the core that drives evaporation is relatively insensitive to linear air velocity in the neighborhood of the air velocity typical of the OSI oven.

SPECIAL CONDITIONS:

The air volumetric flow rate will be consequent to the air pump only (i.e. minimal pressure drop across the core emission chamber). The air velocity over the core surface will be established by the vacuum created by the air pump, the annular orifice at the large end of the core. When temperature and pressure corrected the air viscosity characteristics should have no impact on the air volumetric flow rate.

The characteristic temperature profile of coated and uncoated cores passing through the OSI oven, have been measured. The test will be developed to emulate these profiles.

PRE-PRODUCTION GK - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
											Coated Core
RUN 1											
M-18	GK00101		1						**30**	1	Carbopak charcoal
M-18	GK00102				1				**0**		Carbopak charcoal
	Excess								**30**	2	Excess
	Excess								**30**	3	Excess
	Excess								**30**	4	Excess
NIOSH 2010	GK00103		1						**100**	5	100/50 mg Silica Gel (SKC 226-10)
NIOSH 2010	GK00104				1				**0**		100/50 mg Silica Gel (SKC 226-10)
	Excess								**100**	6	Excess
NIOSH 1500	GK00105		1						**40**	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GK00106				1				**0**		100/50 mg Charcoal (SKC 226-01)
	Excess								**40**	8	Excess
TO11	GK00107		1						**100**	9	DNPH Silica Gel (SKC 226-119)
TO11	GK00108				1				**0**		DNPH Silica Gel (SKC 226-119)
	Excess								**100**	10	Excess
	Excess								**900**	11	Excess
	THC	X							**1400**	12	TOTAL
	Excess								**7700**	13	Excess

PRE-PRODUCTION GK - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
											Coated Core
RUN 2											
M-18	GK00201		1						**30**	1	Carbopak charcoal
M-18	GK00202					1			**30**	1	Carbopak charcoal
	Excess								**30**	2	Excess
	Excess								**30**	3	Excess
	Excess								**30**	4	Excess
NIOSH 2010	GK00203		1						**100**	5	100/50 mg Silica Gel (SKC 226-10)
NIOSH 2010	GK00204					1			**100**	5	100/50 mg Silica Gel (SKC 226-10)
	Excess								**100**	6	Excess
NIOSH 1500	GK00205		1						**40**	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GK00206					1			**40**	7	100/50 mg Charcoal (SKC 226-01)
	Excess								**40**	8	Excess
TO11	GK00207		1						**100**	9	DNPH Silica Gel (SKC 226-119)
TO11	GK00208					1			**100**	9	DNPH Silica Gel (SKC 226-119)
	Excess								**100**	10	Excess
	Excess								**900**	11	Excess
	THC	X							**1400**	12	TOTAL
	Excess								**7700**	13	Excess

PRE-PRODUCTION GK - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
											Coated Core
RUN 3											
M-18	GK00301		1						**30**	1	Carbopak charcoal
M-18	GK00302					1			**30**	1	Carbopak charcoal
M-18	GK00303			1					**30**	2	Carbopak charcoal
M-18	GK00304					1			**30**	2	Carbopak charcoal
	Excess								**30**	3	Excess
	Excess								**30**	4	Excess
NIOSH 2010	GK00305		1						**100**	5	100/50 mg Silica Gel (SKC 226-10)
NIOSH 2010	GK00306					1			**100**	5	100/50 mg Silica Gel (SKC 226-10)
	Excess								**100**	6	Excess
NIOSH 1500	GK00307		1						**40**	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GK00308					1			**40**	7	100/50 mg Charcoal (SKC 226-01)
	Excess								**40**	8	Excess
TO11	GK00309		1						**100**	9	DNPH Silica Gel (SKC 226-119)
TO11	GK00310					1			**100**	9	DNPH Silica Gel (SKC 226-119)
	Excess								**100**	10	Excess
	Excess								**900**	11	Excess
	THC	X							**1400**	12	TOTAL
	Excess								**7700**	13	Excess

PRE-PRODUCTION GK - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
											Coated Core
RUN 4											
M-18	GK00401		1						**30**	1	Carbopak charcoal
M-18	GK00402					1			**30**	1	Carbopak charcoal
M-18 MS	GK00403		1						**30**	2	Carbopak charcoal
M-18 MS	GK00404					1			**30**	2	Carbopak charcoal
M-18 MS	GK00405			1					**30**	3	Carbopak charcoal
M-18 MS	GK00406					1			**30**	3	Carbopak charcoal
	Excess								**30**	4	Excess
NIOSH 2010	GK00407		1						**100**	5	100/50 mg Silica Gel (SKC 226-10)
NIOSH 2010	GK00408					1			**100**	5	100/50 mg Silica Gel (SKC 226-10)
NIOSH 2010	GK00409			1					**100**	6	100/50 mg Silica Gel (SKC 226-10)
NIOSH 2010	GK00410					1			**100**	6	100/50 mg Silica Gel (SKC 226-10)
NIOSH 1500	GK00411		1						**40**	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GK00412					1			**40**	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GK00413			1					**40**	8	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GK00414					1			**40**	8	100/50 mg Charcoal (SKC 226-01)
TO11	GK00415		1						**100**	9	DNPH Silica Gel (SKC 226-119)
TO11	GK00416					1			**100**	9	DNPH Silica Gel (SKC 226-119)
TO11	GK00417			1					**100**	10	DNPH Silica Gel (SKC 226-119)
TO11	GK00418					1			**100**	10	DNPH Silica Gel (SKC 226-119)
	Excess								**900**	11	Excess
	THC	X							**1400**	12	TOTAL
	Excess								**7700**	13	Excess

PRE-PRODUCTION GK - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
											Coated Core
RUN 5											
M-18	GK00501		1						**30**	1	Carbopak charcoal
M-18	GK00502					1			**30**	1	Carbopak charcoal
	Excess								**30**	2	Excess
	Excess								**30**	3	Excess
	Excess								**30**	4	Excess
NIOSH 2010	GK00503		1						**100**	5	100/50 mg Silica Gel (SKC 226-10)
NIOSH 2010	GK00504					1			**100**	5	100/50 mg Silica Gel (SKC 226-10)
	Excess								**100**	6	Excess
NIOSH 1500	GK00505		1						**40**	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GK00506					1			**40**	7	100/50 mg Charcoal (SKC 226-01)
	Excess								**40**	8	Excess
TO11	GK00507		1						**100**	9	DNPH Silica Gel (SKC 226-119)
TO11	GK00508					1			**100**	9	DNPH Silica Gel (SKC 226-119)
	Excess								**100**	10	Excess
	Excess								**900**	11	Excess
	THC	X							**1400**	12	TOTAL
	Excess								**7700**	13	Excess

PRE-PRODUCTION GK - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
											Coated Core
RUN 6											
M-18	GK00601		1						**30**	1	Carbopak charcoal
M-18	GK00602					1			**30**	1	Carbopak charcoal
	Excess								**30**	2	Excess
	Excess								**30**	3	Excess
	Excess								**30**	4	Excess
NIOSH 2010	GK00603		1						**100**	5	100/50 mg Silica Gel (SKC 226-10)
NIOSH 2010	GK00604					1			**100**	5	100/50 mg Silica Gel (SKC 226-10)
	Excess								**100**	6	Excess
NIOSH 1500	GK00605		1						**40**	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GK00606					1			**40**	7	100/50 mg Charcoal (SKC 226-01)
	Excess								**40**	8	Excess
TO11	GK00607		1						**100**	9	DNPH Silica Gel (SKC 226-119)
TO11	GK00608					1			**100**	9	DNPH Silica Gel (SKC 226-119)
	Excess								**100**	10	Excess
	Excess								**900**	11	Excess
	THC	X							**1400**	12	TOTAL
	Excess								**7700**	13	Excess

Series GK

Evaporative Emissions from Ashland 305/904 cores coated with Velvaplast® During Forced Air Drying

Process Instructions

A. Experiment:

1. Measure the evaporative emissions from drying uncoated & coated Phenolic Urethane cores in the OSI core drying oven. The design of the OSI oven does not lend itself to defining air flow over the core surface or totally capturing emissions, therefore based on measured general oven air flow and core temperature profiles obtained from cores passing through the OSI oven an emulation will be done on individual cores in heated individual emission collection chambers in a AccuTherm electrically heated oven.

B. Materials:

1. Core:
   - **a.** Step core made with virgin Wedron 530 silica sand and 1.4 % Ashland Isocure ® LF305/52-904GR regular phenolic urethane binder in a 55/45 ratio, TEA catalyzed.
2. Core coating:
   - **a.** Ashland Velvaplast® CGW 9022 SL

C. Briefing:

1. The Process Engineer, Emissions Engineer, and the area Supervisor will brief the operating personnel on the requirements of the test at least one (1) day prior to the test.

Caution: Observe all safety precautions attendant to these operations as delineated in the Preproduction operating and safety instruction manual.

D. ISOCURE® regular Step Cores:

1. Make at least twelve (12) step cores according to the following procedures:
   - **a.** Allow the cores to age 60 minutes to emulate the customary time between manufacture and core coating then place them in sealed polyethylene bags.
   - **b.** Ten (10) minutes prior to beginning emulation remove a test core from a bag, weigh the core on the Mettler 12000B scale, and record the weight. For six cores coat the cores by the methods indicated below, reweigh the coated core, and record the wet coated core weight.

2. Klein vibratory core sand mixer.
   - **a.** The binder components should be 75-85^{o}F.
   - **b.** Calibrate the Klein mixer sand batch size.
     - **1)** Remove the mixing bowl skirt to gain access to the bottom side of the batch hopper outlet gate. Install a skirt on the back half of the mixing bowl

2) Calibrate sand.
   a) Turn the AUTO/MAN switch to MANUAL on main control panel.
   b) Place one bucket of preheated raw sand, of at least fifty-two (52) pounds net weight, into the sand hopper and manually fill batch hopper using max. and min. proximity switches.
   c) Discharge the sand from the batch hopper using the single cycle push button. Catch the sand as it leaves the batch hopper and record the net weight and the dispensing time.
   d) Repeat 3 times to determine the weight variation. The sand should be 75-85^{o}F.

c. Pre-weigh 1.4% (BOS) of the two part binder into two non-absorbing containers for addition to the mixer. 55% Part I shall be in one container, 45% Part II in the other.
d. Turn on the mixer and turn the AUTO/MAN switch to AUTO.
e. Press the SINGLE CYCLE push button on the operator's station to make a batch of sand. As soon as the sand enters the mixer chamber pour the pre-weighed binder through the open top front half of the mixing chamber.
f. Make three (3) batches to start the Redford Carver core machine.
g. Make a batch of sand for every 7 core machine cycles when using the step core. About two (2) batches will be retained in the core machine sand magazine.
h. Clean the mixer bowl when done.

Caution: Do not make more sand than sand magazine will hold plus one (1) batch. If too much sand is made the sand will be exposed to captured TEA and significantly shorten the sand bench life

3. Redford/Carver core machine
   a. Mount the Step-Core core box on the Carver/Redford core machine.
   b. Start the core machine auxiliary equipment per the Production Foundry OSI for that equipment.
   c. Set up the core machine in the cold box mode with gassing and working pressures and gas and purge time according to the core recipe sheet.
   d. Core process setup
      1) Set the TEA to a nominal 5 grams per blow (gas time 0.75 sec (R/C), flow .019 lbs/sec (Luber).
      2) Set the blow pressure to 30+/-2 psi for 3 seconds (R/C).
      3) Set the max purge pressure to 45 psi on the Luber gas generator.
      4) Purge for 20 seconds(R/C) with a 10 second rise time (Luber).
      5) Total cycle time approximately 1 minute.

   e. Run the core machine for three (3) cycles and discard the cores. When the cores appear good begin test core manufacture. Twelve (12) good cores are required.
   f. Set the ores aside for one hour then bag the cores
   g. After the cores are prepared for the test runs run the balance of the sand out of the magazine and empty the machine.

- **h.** The sand lab will sample, at the time of manufacture, one (1) core. Those cores will be tested for LOI using the standard 1800°F core LOI test method and reported out associated with the test runs they represent.

4. Core coating.

- **a.** Ashland Velvaplast® CGW 9022 SL core coating material will be used to dip-coat the cores. Prepare the coating before making the cores. The specific gravity shall be 1.340 +/-0.013 @ 77°F. Adjust with distilled water or an absorbing brick to correct.
- **b.** Normalize the core coating temperature to 70-80°F.
- **c.** Ten minutes before the beginning of an emulation run remove a test core from a bag, weigh the uncoated core, and log the weight.
- **d.** Coat the entire core up to ½ inch from the invest side.
- **e.** Dip the core into the core wash and hold for a count of two (2).
- **f.** Shake the core vertically until the coating ceases to drip.
- **g.** Weigh the wet core and log the weight.
- **h.** Place the core invest side down and wait for en (10) minutes.
- **i.** Dry the core according to the drying emulation procedure.

E. Core Drying.

- **1.** A protocol will have to be developed to emulate the OSI air flow rate and the core temperature profile through each of the four (4) OSI oven zones: ambient air staging immediately after dipping 10 minutes, 275°F forced air heating 45 minutes, ambient air convective-cooling 10 minutes, and ambient air forced air cooling 25 minutes.
- **2.** Set the OSI oven temperature to 275°F and allow stabilizing.
- **3.** Measure the air velocity above and below the OSI oven drying belt in the heated chamber.
- **4.** Measure the mean heated air velocity through the oven.
- **5.** Place two thermocouples axially in the centerline of an uncoated core, one at the 2 inch diameter and the second at the 3.5 inch diameter. Place a third thermocouple at the core surface against the core print. Fill any holes thus created with a sand/Corefix 8 mixture. Continuously record the three temperatures and the ambient temperature as the core passes through OSI oven.
- **6.** Reuse the same core and the implanted thermocouples when cooled to ambient temperature. Dip the core in core coating as described in section D.3 above. Send through the OSI oven a second time and record the same temperature data. This data will form the core temperature profile that is to be emulated.

F. Core drying emulation test protocol

1. Design an emission collection chamber to be place in the AccuTherm oven as follows:

- **a.** Assume that the core temperature and air velocity are the primary emission driving parameters.
- **b.** The collected air space will be limited to the air volume in the immediate proximity of the core being tested.
- **c.** The annular space between the core and the collection chamber shall cause the air volume around the various steps of the core to be constant and have a velocity closely emulating the air velocity in the OSI oven.

   d. The core will be located centered in the collection volume.

2. Collect TGOC data to validate the assumption in F.1.a
3. Conduct a series of drying tests to determine which AccuTherm oven temperature cycle and period will most nearly cause the core's temperature response to be most nearly like the thermal cycle and period for the OSI oven.

G. Core drying test.

1. Preheat the AccuTherm oven with all the emission containment collection hardware in the oven and the oven fan running.
2. Quickly open the oven door, set the core in the collection chamber, close & seal the chamber, and close the oven door.
3. Heat the core with the oven door closed for the period of time prescribed in the developed protocol to emulate the heating in the OSI drying system.
4. Open the door and turn off the power the when the cooling portion of the protocol prescribes.
5. Add thermal shields between the collection chamber and the oven and apply external fans as the protocol prescribes to emulate the forced cooling of the OSI drying system.

Steven M. Knight
Mgr. Process Engineering

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APPENDIX B DETAILED EMISSIONS DATA FOR TEST GK

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Test Plan GK Individual Emissions Results – Lb/Lb Binder

Uncoated Core Drying Emissions

HAPs	POMs	COMPOUND/RUN NUMBER	GK011	GK012	GK013	GK014	GK015	GK016	Average	STDEV
		Test Dates	12/16/04	12/16/04	12/16/04	12/16/04	12/17/04	12/17/04		
		TGOC as Propane (See Note 1)	1.03E-01	1.02E-01	9.75E-02	1.01E-01	9.67E-02	9.46E-02	9.91E-02	3.32E-03
		HC as n-Hexane	5.70E-01	4.82E-01	4.98E-01	4.88E-01	4.97E-01	4.96E-01	5.05E-01	3.23E-02
		Sum of Target VOCs	1.21E-01	9.40E-02	1.10E-01	1.16E-01	I	1.30E-01	1.14E-01	1.35E-02
		Sum of Target HAPs	5.41E-02	4.87E-02	4.11E-02	5.16E-02	I	4.49E-02	4.81E-02	5.20E-03
		Sum of Target POMs	1.47E-02	1.31E-02	1.67E-02	2.00E-02	I	1.53E-02	1.59E-02	2.62E-03
		Specific Target HAPs								
x		Triethylamine	2.97E-02	2.40E-02	2.33E-02	2.28E-02	2.17E-02	2.31E-02	2.41E-02	2.83E-03
x	z	1-Methylnaphthalene	1.20E-02	1.07E-02	1.35E-02	1.35E-02	I	1.29E-02	1.25E-02	1.19E-03
x		Phenol	8.59E-03	1.02E-02	I	7.54E-03	7.43E-03	6.08E-03	7.96E-03	1.52E-03
x	z	2-Methylnaphthalene	1.13E-03	9.70E-04	1.61E-03	1.64E-03	I	1.09E-03	1.29E-03	3.15E-04
x	z	1,6-Dimethylnaphthalene	1.00E-03	7.12E-04	9.93E-04	1.80E-03	1.13E-03	8.65E-04	1.08E-03	3.80E-04
x		Acetaldehyde	5.31E-04	4.62E-04	4.23E-04	4.86E-04	9.15E-04	ND	4.70E-04	2.92E-04
x		Formaldehyde	3.59E-04	3.60E-04	3.72E-04	4.25E-04	7.10E-04	ND	3.71E-04	2.26E-04
x	z	1,5-Dimethylnaphthalene	2.18E-04	1.59E-04	2.97E-04	7.16E-04	4.51E-04	1.87E-04	3.38E-04	2.13E-04
x	z	1,3-Dimethylnaphthalene	5.48E-05	1.28E-04	6.67E-05	1.61E-03	1.15E-04	5.36E-05	3.37E-04	6.22E-04
x	z	1,2-Dimethylnaphthalene	1.62E-04	1.27E-04	1.49E-04	3.20E-04	2.82E-04	1.27E-04	1.94E-04	8.44E-05
x		Biphenyl	1.61E-04	3.30E-04	9.70E-05	2.32E-04	1.96E-04	1.45E-04	1.94E-04	8.11E-05
x	z	1,8-Dimethylnaphthalene	8.76E-05	4.91E-05	8.59E-05	2.92E-04	1.39E-04	7.60E-05	1.22E-04	8.83E-05
x	z	Naphthalene	ND	2.11E-04	ND	ND	1.64E-04	0.00E+00	6.25E-05	9.80E-05
x		Hexane	ND	1.22E-04	6.19E-05	ND	4.46E-05	1.40E-04	6.14E-05	5.94E-05
x		m,p-Xylene	4.47E-05	5.65E-05	4.03E-05	3.29E-05	3.03E-05	2.60E-05	3.84E-05	1.11E-05
x		Toluene	1.98E-05	4.68E-05	3.83E-05	1.53E-05	3.09E-05	2.81E-05	2.99E-05	1.16E-05
x	z	Acenaphthalene	ND	2.31E-05	ND	1.19E-04	3.03E-05	ND	2.87E-05	4.61E-05
x	z	2,3,5-Trimethylnaphthalene	3.33E-05	1.80E-05	3.45E-05	2.56E-05	4.87E-05	9.33E-06	2.82E-05	1.38E-05
x		Ethylbenzene	3.42E-05	2.06E-05	1.12E-05	1.13E-05	1.77E-05	3.89E-05	2.23E-05	1.17E-05
x		o-Xylene	2.53E-05	2.62E-05	1.81E-05	2.06E-05	1.89E-05	1.90E-05	2.14E-05	3.53E-06
x		2-Butanone	1.59E-05	1.72E-05	1.57E-05	1.81E-05	3.72E-05	ND	1.74E-05	1.18E-05
x		Benzene	5.75E-06	4.65E-05	5.04E-06	8.53E-06	1.40E-05	9.79E-06	1.49E-05	1.58E-05
x		Styrene	4.02E-06	5.90E-06	4.09E-06	4.10E-06	5.50E-06	5.21E-06	4.80E-06	8.32E-07
x		m,p-Cresol	ND	ND	ND	ND	ND	ND	NA	NA
x		o-Cresol	ND	ND	ND	ND	ND	ND	NA	NA
x	z	2,3-Dimethylnaphthalene	ND	ND	ND	ND	ND	ND	NA	NA
x	z	2,6-Dimethylnaphthalene	ND	ND	ND	ND	ND	ND	NA	NA
x	z	2,7-Dimethylnaphthalene	ND	ND	ND	ND	ND	ND	NA	NA
x		Acrolein	ND	ND	ND	ND	ND	ND	NA	NA
x		Propionaldehyde	ND	ND	ND	ND	ND	ND	NA	NA
		Other Target VOCs								
		2,4-Dimethylphenol	3.51E-02	2.07E-02	3.97E-02	3.02E-02	1.03E-02	5.88E-02	3.25E-02	1.67E-02
		Decane	1.49E-02	1.08E-02	1.32E-02	1.57E-02	8.30E-03	1.12E-02	1.23E-02	2.78E-03
		1,2,3-Trimethylbenzene	5.39E-03	3.71E-03	6.30E-03	5.63E-03	I	5.72E-03	5.35E-03	9.78E-04
		2-Ethyltoluene	4.42E-03	2.99E-03	3.41E-03	4.64E-03	3.36E-03	2.57E-03	3.57E-03	8.11E-04
		1,3,5-Trimethylbenzene	2.28E-03	1.70E-03	2.45E-03	2.22E-03	3.01E-03	3.04E-03	2.45E-03	5.12E-04
		Undecane	1.90E-03	2.32E-03	1.32E-03	2.25E-03	1.10E-03	1.62E-03	1.75E-03	4.94E-04
		2,6-Dimethylphenol	1.37E-03	1.11E-03	9.41E-04	1.02E-03	6.00E-04	7.26E-04	9.61E-04	2.76E-04
		Propylbenzene, n-	9.52E-04	7.97E-04	6.44E-04	7.69E-04	7.14E-04	6.73E-04	7.58E-04	1.11E-04
		Tetradecane	2.51E-04	3.11E-04	3.42E-04	7.00E-04	1.72E-04	2.79E-04	3.43E-04	1.84E-04

Test Plan GK Individual Emissions Results – Lb/Lb Binder

Uncoated Core Drying Emissions

HAPs	POMs	COMPOUND/RUN NUMBER	GK011	GK012	GK013	GK014	GK015	GK016	Average	STDEV
		Indan	ND	ND	ND	9.59E-04	0.00E+00	5.56E-04	2.53E-04	4.12E-04
		Indene	ND	8.57E-04	ND	ND	3.28E-04	ND	1.98E-04	3.49E-04
		Heptane	ND	3.59E-05	1.30E-04	ND	ND	ND	2.76E-05	5.20E-05
		Pentanal	2.09E-05	2.08E-05	2.52E-05	2.88E-05	4.93E-05	ND	2.42E-05	1.59E-05
		Nonane	2.87E-05	3.03E-05	1.96E-05	1.91E-05	1.51E-05	1.16E-05	2.07E-05	7.40E-06
		Hexaldehyde	1.69E-05	1.51E-05	1.52E-05	1.70E-05	3.10E-05	ND	1.59E-05	9.83E-06
		Octane	1.38E-05	1.11E-05	8.30E-06	1.13E-05	2.18E-05	1.46E-05	1.35E-05	4.64E-06
		o,m,p-Tolualdehyde	ND	ND	ND	ND	2.21E-05	ND	3.68E-06	9.01E-06
		Cyclohexane	ND	1.32E-05	ND	ND	ND	ND	2.19E-06	5.37E-06
		1,3-Diethylbenzene	ND	ND	ND	ND	ND	ND	NA	NA
		Dodecane	ND	ND	ND	ND	ND	ND	NA	NA
		3-Ethyltoluene	ND	ND	ND	ND	ND	ND	NA	NA
		1,2,4-Trimethylbenzene	ND	ND	ND	ND	ND	ND	NA	NA
		Benzaldehyde	ND	ND	ND	ND	ND	ND	NA	NA
		Butyraldehyde/Methacrolein	ND	ND	ND	ND	ND	ND	NA	NA
		Crotonaldehyde	ND	ND	ND	ND	ND	ND	NA	NA

ND: Below the Quantitation limit shown in the tables at the end of this appendix.
NA: Not Applicable
I: Invalidated
Note 1: TGOC results **shown in red**. These data appear to have significant negative bias. The cause of this apparent bias is unknown.

Test Plan GK Individual Emissions Results – Lb/Lb Binder

Coated Core Drying Emissions

HAPs	POMs	COMPOUND/RUN NUMBER	GK001	GK002	GK003	GK004	GK005	GK006	Average	STDEV
		Test Dates	12/17/04	12/20/04	12/20/04	12/21/04	12/21/04	12/21/04		
		TGOC as Propane (See Note 1)	7.24E-02	5.84E-02	5.69E-02	5.55E-02	6.36E-02	5.77E-02	6.08E-02	6.34E-03
		HC as n-Hexane	1.43E-01	3.46E-01	3.34E-01	3.34E-01	3.66E-01	8.61E-02	2.68E-01	1.21E-01
		Sum of Target VOCs	3.95E-02	3.15E-02	2.73E-02	3.49E-02	3.18E-02	2.89E-02	3.23E-02	4.40E-03
		Sum of Target HAPs	2.80E-02	1.86E-02	1.66E-02	1.96E-02	1.89E-02	2.12E-02	2.05E-02	3.98E-03
		Sum of Target POMs	8.11E-03	5.00E-03	6.94E-03	5.49E-03	1.56E-03	6.40E-03	5.58E-03	2.25E-03
		Specific Target HAPs								
x		Triethylamine	1.67E-02	9.85E-03	6.51E-03	9.58E-03	1.14E-02	1.05E-02	1.08E-02	3.35E-03
x	z	1-Methylnaphthalene	5.69E-03	3.87E-03	3.38E-03	3.45E-03	7.52E-03	3.84E-03	4.63E-03	1.65E-03
x		m,p-Cresol	2.20E-03	1.84E-03	1.26E-03	1.89E-03	2.70E-03	2.24E-03	2.02E-03	4.83E-04
x	z	2-Methylnaphthalene	1.10E-03	9.36E-04	1.01E-03	1.43E-03	1.61E-03	9.51E-04	1.17E-03	2.81E-04
x		Phenol	I	7.05E-04	9.37E-04	1.37E-03	1.87E-03	8.64E-04	1.15E-03	4.72E-04
x		Formaldehyde	4.86E-04	5.93E-04	5.25E-04	4.66E-04	6.15E-04	4.93E-04	5.30E-04	6.11E-05
x	z	1,6-Dimethylnaphthalene	6.35E-04	2.62E-05	2.37E-04	ND	8.50E-04	2.11E-04	3.26E-04	3.43E-04
x		o-Cresol	2.83E-04	2.38E-04	1.39E-04	3.31E-04	2.79E-04	2.98E-04	2.61E-04	6.70E-05
x	z	1,8-Dimethylnaphthalene	1.55E-04	ND	1.72E-04	4.95E-04	2.02E-04	1.41E-04	1.94E-04	1.63E-04
x	z	1,3-Dimethylnaphthalene	2.06E-05	6.53E-06	4.44E-04	ND	3.19E-05	4.68E-04	1.62E-04	2.28E-04
x	z	Naphthalene	ND	1.59E-04	7.72E-04	ND	ND	ND	1.55E-04	3.09E-04
x		Acetaldehyde	1.53E-04	1.56E-04	1.10E-04	1.37E-04	1.93E-04	1.61E-04	1.52E-04	2.74E-05
x	z	2,7-Dimethylnaphthalene	ND	ND	4.48E-04	ND	ND	4.07E-04	1.42E-04	2.21E-04
x	z	1,5-Dimethylnaphthalene	3.50E-04	ND	ND	ND	2.85E-04	ND	1.06E-04	1.65E-04
x	z	2,3-Dimethylnaphthalene	ND	ND	3.44E-04	ND	ND	2.79E-04	1.04E-04	1.62E-04
x		Biphenyl	7.36E-05	2.78E-05	1.03E-04	6.84E-05	1.44E-04	6.25E-05	8.00E-05	3.97E-05
x	z	1,2-Dimethylnaphthalene	1.17E-04	ND	1.01E-04	ND	1.54E-04	8.71E-05	7.64E-05	6.32E-05
x		m,p-Xylene	ND	1.15E-05	2.44E-06	1.04E-04	7.83E-05	5.35E-05	4.16E-05	4.36E-05
x	z	2,3,5-Trimethylnaphthalene	2.36E-05	ND	1.88E-05	1.23E-04	3.19E-05	1.96E-05	3.62E-05	4.38E-05
x		Ethylbenzene	ND	6.67E-05	1.04E-05	9.38E-06	1.02E-05	7.60E-06	1.74E-05	2.45E-05
x		Styrene	ND	7.47E-05	2.05E-06	ND	2.05E-06	2.44E-05	1.72E-05	2.97E-05
x		Benzene	ND	ND	1.23E-05	8.33E-05	ND	ND	1.59E-05	3.34E-05
x		o-Xylene	ND	1.62E-05	4.94E-06	1.53E-05	1.49E-05	2.90E-05	1.34E-05	1.01E-05
x		Toluene	ND	ND	ND	1.02E-05	2.21E-05	1.50E-05	7.88E-06	9.42E-06
x	z	Acenaphthalene	1.57E-05	ND	1.56E-05	ND	8.79E-06	ND	6.68E-06	7.74E-06
x		2-Butanone	0.00E+00	0.00E+00	0.00E+00	6.83E-06	9.41E-06	7.26E-06	3.92E-06	4.38E-06
x		Hexane	ND	ND	1.59E-05	ND	ND	ND	2.65E-06	6.49E-06
x	z	2,6-Dimethylnaphthalene	ND	ND	ND	ND	ND	ND	NA	NA
x		Acrolein	ND	ND	ND	ND	ND	ND	NA	NA
x		Propionaldehyde	ND	ND	ND	ND	ND	ND	NA	NA
		Other Target VOCs								
		2,6-Dimethylphenol	7.82E-03	6.13E-03	4.57E-03	4.88E-03	7.52E-03	3.72E-03	5.77E-03	1.66E-03
		Decane	2.37E-03	1.98E-03	1.13E-03	2.66E-03	2.97E-03	1.50E-03	2.10E-03	7.00E-04
		1,3,5-Trimethylbenzene	ND	9.78E-04	7.80E-04	1.93E-03	4.06E-04	3.18E-04	7.35E-04	6.79E-04
		1,3-Diethylbenzene	5.52E-04	7.66E-04	3.93E-04	7.91E-04	5.82E-04	7.76E-04	6.43E-04	1.61E-04
		2,4-Dimethylphenol	3.66E-04	7.34E-04	5.05E-04	1.01E-03	7.04E-04	4.70E-04	6.32E-04	2.33E-04
		Indene	ND	3.06E-04	5.63E-04	1.83E-03	0.00E+00	ND	4.50E-04	7.14E-04
		3-Ethyltoluene	ND	ND	1.30E-03	6.07E-04	0.00E+00	3.39E-04	3.75E-04	5.18E-04
		Propylbenzene, n-	ND	2.69E-04	4.57E-04	3.52E-04	7.54E-05	1.82E-04	2.22E-04	1.71E-04
		Undecane	ND	1.25E-03	ND	ND	ND	ND	2.09E-04	5.11E-04

Test Plan GK Individual Emissions Results – Lb/Lb Binder

Coated Core Drying Emissions

HAPs	POMs	COMPOUND/RUN NUMBER	GK001	GK002	GK003	GK004	GK005	GK006	Average	STDEV
		Heptane	ND	ND	5.11E-05	3.99E-04	6.64E-04	7.04E-05	1.97E-04	2.73E-04
		Tetradecane	1.30E-05	2.73E-05	4.81E-04	5.19E-05	4.86E-05	3.83E-04	1.67E-04	2.08E-04
		2-Ethyltoluene	ND	2.02E-04	ND	5.85E-04	ND	ND	1.31E-04	2.37E-04
		1,2,3-Trimethylbenzene	8.50E-05	4.28E-05	3.52E-05	ND	4.43E-04	1.30E-04	1.23E-04	1.63E-04
		1,2,4-Trimethylbenzene	ND	5.18E-05	2.35E-04	ND	ND	3.54E-04	1.07E-04	1.52E-04
		Butyraldehyde/Methacrolein	1.24E-04	8.64E-05	8.38E-05	7.80E-05	1.13E-04	1.03E-04	9.81E-05	1.83E-05
		Nonane	ND	ND	2.47E-05	7.49E-05	4.84E-05	8.79E-05	3.93E-05	3.74E-05
		Pentanal	2.49E-05	3.29E-05	2.42E-05	2.94E-05	3.54E-05	2.76E-05	2.91E-05	4.44E-06
		Crotonaldehyde	3.01E-05	2.48E-05	1.83E-05	2.67E-05	3.50E-05	3.43E-05	2.82E-05	6.29E-06
		Indan	1.02E-04	ND	ND	ND	ND	ND	1.70E-05	4.18E-05
		Octane	ND	0.00E+00	1.87E-05	1.49E-05	1.97E-05	3.75E-05	1.51E-05	1.41E-05
		Hexaldehyde	9.36E-06	1.59E-05	1.21E-05	1.15E-05	1.25E-05	1.01E-05	1.19E-05	2.28E-06
		Cyclohexane	ND	ND	ND	ND	3.84E-05	ND	6.41E-06	1.57E-05
		Dodecane	ND	ND	ND	ND	ND	ND	NA	NA
		Benzaldehyde	ND	ND	ND	ND	ND	ND	NA	NA
		o,m,p-Tolualdehyde	ND	ND	ND	ND	ND	ND	NA	NA

ND: Below the Quantitation limit shown in the tables at the end of this appendix.
NA: Not Applicable
I: Invalidated
Note 1: TGOC results **shown in red**. These data appear to have significant negative bias. The cause of this apparent bias is unknown.

Test Plan GK Individual Emissions Results – Lb/Tn Core

Uncoated Core Drying Emissions

HAPs	POMs	COMPOUND/RUM NUMBER	GK011	GK012	GK013	GK014	GK015	GK016	Average	STDEV
		Test Dates	12/16/04	12/16/04	12/16/04	12/16/04	12/17/04	12/17/04		
		TGOC as Propane (See Note 1)	2.85E+00	2.81E+00	2.70E+00	2.79E+00	2.67E+00	2.62E+00	2.74E+00	9.05E-02
		HC as n-Hexane	1.58E+01	1.33E+01	1.38E+01	1.35E+01	1.37E+01	1.37E+01	1.40E+01	8.89E-01
		Sum of Target VOCs	3.10E+00	2.32E+00	3.04E+00	3.01E+00	I	3.43E+00	2.98E+00	4.05E-01
		Sum of Target HAPs	1.50E+00	1.35E+00	1.14E+00	1.43E+00	I	1.24E+00	1.33E+00	1.44E-01
		Sum of Target POMs	4.06E-01	3.62E-01	4.64E-01	5.56E-01	I	4.22E-01	4.42E-01	7.34E-02
		Specific Target HAPs								
x		Triethylamine	8.20E-01	6.63E-01	6.47E-01	6.34E-01	5.98E-01	6.38E-01	6.67E-01	7.82E-02
x	z	1-Methylnaphthalene	3.32E-01	2.95E-01	3.74E-01	3.74E-01	I	3.55E-01	3.46E-01	3.34E-02
x		Phenol	2.38E-01	2.81E-01	I	2.09E-01	2.05E-01	1.68E-01	2.20E-01	4.20E-02
x	z	2-Methylnaphthalene	3.13E-02	2.68E-02	4.49E-02	4.57E-02	I	3.02E-02	3.58E-02	8.82E-03
x	z	1,6-Dimethylnaphthalene	2.78E-02	1.97E-02	2.76E-02	5.01E-02	3.12E-02	2.39E-02	3.00E-02	1.06E-02
x		Acetaldehyde	1.47E-02	1.28E-02	1.18E-02	1.35E-02	2.53E-02	ND	1.30E-02	8.05E-03
x		Formaldehyde	9.94E-03	9.96E-03	1.03E-02	1.18E-02	1.96E-02	ND	1.03E-02	6.25E-03
x	z	1,5-Dimethylnaphthalene	6.02E-03	4.39E-03	8.25E-03	1.99E-02	1.25E-02	5.18E-03	9.37E-03	5.92E-03
x	z	1,3-Dimethylnaphthalene	1.51E-03	3.54E-03	1.85E-03	4.46E-02	3.18E-03	1.48E-03	9.36E-03	1.73E-02
x	z	1,2-Dimethylnaphthalene	4.47E-03	3.52E-03	4.14E-03	8.88E-03	7.79E-03	3.51E-03	5.38E-03	2.34E-03
x		Biphenyl	4.45E-03	9.13E-03	2.70E-03	6.45E-03	5.41E-03	4.02E-03	5.36E-03	2.24E-03
x	z	1,8-Dimethylnaphthalene	2.42E-03	1.36E-03	2.39E-03	8.10E-03	3.84E-03	2.10E-03	3.37E-03	2.45E-03
x	z	Naphthalene	ND	5.85E-03	ND	ND	4.52E-03	ND	1.73E-03	2.71E-03
x		Hexane	ND	3.37E-03	1.72E-03	ND	1.23E-03	3.87E-03	1.70E-03	1.64E-03
x		m,p-Xylene	1.24E-03	1.56E-03	1.12E-03	9.14E-04	8.36E-04	7.19E-04	1.06E-03	3.08E-04
x		Toluene	5.48E-04	1.30E-03	1.06E-03	4.25E-04	8.53E-04	7.76E-04	8.27E-04	3.22E-04
x	z	Acenaphthalene	ND	6.39E-04	ND	3.30E-03	8.36E-04	ND	7.96E-04	1.28E-03
x	z	2,3,5-Trimethylnaphthalene	9.22E-04	4.99E-04	9.59E-04	7.11E-04	1.35E-03	2.58E-04	7.82E-04	3.82E-04
x		Ethylbenzene	9.46E-04	5.70E-04	3.11E-04	3.15E-04	4.88E-04	1.07E-03	6.17E-04	3.23E-04
x		o-Xylene	7.01E-04	7.26E-04	5.04E-04	5.73E-04	5.22E-04	5.24E-04	5.92E-04	9.74E-05
x		2-Butanone	4.40E-04	4.75E-04	4.37E-04	5.02E-04	1.03E-03	ND	4.81E-04	3.27E-04
x		Benzene	1.59E-04	1.29E-03	1.40E-04	2.37E-04	3.86E-04	2.71E-04	4.13E-04	4.37E-04
x		Styrene	1.11E-04	1.63E-04	1.14E-04	1.14E-04	1.52E-04	1.44E-04	1.33E-04	2.28E-05
x		m,p-Cresol	ND	ND	ND	ND	ND	ND	NA	NA
x		o-Cresol	ND	ND	ND	ND	ND	ND	NA	NA
x	z	2,3-Dimethylnaphthalene	ND	ND	ND	ND	ND	ND	NA	NA
x	z	2,6-Dimethylnaphthalene	ND	ND	ND	ND	ND	ND	NA	NA
x	z	2,7-Dimethylnaphthalene	ND	ND	ND	ND	ND	ND	NA	NA
x		Acrolein	ND	ND	ND	ND	ND	ND	NA	NA
x		Propionaldehyde	ND	ND	ND	ND	ND	ND	NA	NA

Test Plan GK Individual Emissions Results – Lb/Tn Core

Uncoated Core Drying Emissions

HAPs	POMs	COMPOUND/RUM NUMBER	GK011	GK012	GK013	GK014	GK015	GK016	Average	STDEV
		Other Target VOCs								
		2,4-Dimethylphenol	9.71E-01	5.72E-01	1.10E+00	8.40E-01	2.84E-01	1.63E+00	8.99E-01	4.61E-01
		Decane	4.13E-01	2.98E-01	3.66E-01	4.36E-01	2.29E-01	3.11E-01	3.42E-01	7.77E-02
		1,2,3-Trimethylbenzene	1.49E-01	1.03E-01	1.75E-01	1.56E-01	1.61E-02	1.58E-01	1.26E-01	5.92E-02
		2-Ethyltoluene	1.22E-01	8.26E-02	9.48E-02	1.29E-01	9.27E-02	7.10E-02	9.88E-02	2.26E-02
		1,3,5-Trimethylbenzene	6.30E-02	4.69E-02	6.80E-02	6.18E-02	8.32E-02	8.39E-02	6.78E-02	1.41E-02
		Undecane	5.27E-02	6.41E-02	3.67E-02	6.25E-02	3.03E-02	4.48E-02	4.85E-02	1.37E-02
		2,6-Dimethylphenol	3.80E-02	3.06E-02	2.61E-02	2.83E-02	1.66E-02	2.01E-02	2.66E-02	7.64E-03
		Propylbenzene, n-	2.63E-02	2.21E-02	1.79E-02	2.14E-02	1.97E-02	1.86E-02	2.10E-02	3.06E-03
		Tetradecane	6.94E-03	8.61E-03	9.51E-03	1.94E-02	4.75E-03	7.71E-03	9.49E-03	5.13E-03
		Indan	ND	ND	ND	2.66E-02	ND	1.54E-02	7.00E-03	1.14E-02
		Indene	ND	2.37E-02	ND	ND	9.06E-03	ND	5.46E-03	9.65E-03
		Heptane	ND	9.95E-04	3.60E-03	ND	ND	ND	7.66E-04	1.44E-03
		Pentanal	5.77E-04	5.75E-04	6.99E-04	7.99E-04	1.36E-03	ND	6.69E-04	4.39E-04
		Nonane	7.93E-04	8.39E-04	5.43E-04	5.31E-04	4.16E-04	3.21E-04	5.74E-04	2.05E-04
		Hexaldehyde	4.68E-04	4.17E-04	4.23E-04	4.72E-04	8.55E-04	ND	4.39E-04	2.72E-04
		Octane	3.81E-04	3.08E-04	2.30E-04	3.15E-04	6.03E-04	4.04E-04	3.73E-04	1.28E-04
		o,m,p-Tolualdehyde	ND	ND	ND	ND	6.10E-04	ND	1.02E-04	2.49E-04
		Cyclohexane	ND	3.64E-04	ND	ND	ND	ND	6.07E-05	1.49E-04
		1,3-Diethylbenzene	ND	ND	ND	ND	ND	ND	NA	NA
		Dodecane	ND	ND	ND	ND	ND	ND	NA	NA
		3-Ethyltoluene	ND	ND	ND	ND	ND	ND	NA	NA
		1,2,4-Trimethylbenzene	ND	ND	ND	ND	ND	ND	NA	NA
		Benzaldehyde	ND	ND	ND	ND	ND	ND	NA	NA
		Butyraldehyde/Methacrolein	ND	ND	ND	ND	ND	ND	NA	NA
		Crotonaldehyde	ND	ND	ND	ND	ND	ND	NA	NA

ND: Below the Quantitation limit shown in the tables at the end of this appendix.
NA: Not Applicable
I: Invalidated
Note 1: TGOC results **shown in red**. These data appear to have significant negative bias. The cause of this apparent bias is unknown.

Test Plan GK Individual Emissions Results – Lb/Tn Core

Coated Core Drying Emissions

HAPs	POMs	COMPOUND/RUM NUMBER	GK001	GK002	GK003	GK004	GK005	GK006	Average	STDEV
		Test Dates	12/17/04	12/20/04	12/20/04	12/21/04	12/21/04	12/21/04		
		TGOC as Propane (See Note 1)	2.00E+00	1.62E+00	1.58E+00	1.54E+00	1.76E+00	1.59E+00	1.68E+00	1.74E-01
		HC as n-Hexane	3.95E+00	9.56E+00	9.24E+00	9.24E+00	1.01E+01	2.38E+00	7.41E+00	3.34E+00
		Sum of Target VOCs	1.09E+00	8.51E-01	7.28E-01	9.27E-01	1.10E+00	7.99E-01	9.17E-01	1.55E-01
		Sum of Target HAPs	7.74E-01	5.14E-01	4.58E-01	5.41E-01	7.76E-01	5.86E-01	6.08E-01	1.36E-01
		Sum of Target POMs	2.24E-01	1.38E-01	1.92E-01	1.52E-01	2.96E-01	1.77E-01	1.97E-01	5.73E-02
		Specific Target HAPs								
x		Triethylamine	4.61E-01	2.72E-01	1.80E-01	2.65E-01	3.16E-01	2.91E-01	2.98E-01	9.25E-02
x	z	1-Methylnaphthalene	1.57E-01	1.07E-01	9.34E-02	9.53E-02	2.08E-01	1.06E-01	1.28E-01	4.57E-02
x		m,p-Cresol	6.07E-02	5.09E-02	3.48E-02	5.23E-02	7.47E-02	6.20E-02	5.59E-02	1.34E-02
x	z	2-Methylnaphthalene	3.03E-02	2.59E-02	2.80E-02	3.95E-02	4.46E-02	2.63E-02	3.24E-02	7.77E-03
x		Phenol	I	1.95E-02	2.59E-02	3.77E-02	5.17E-02	2.39E-02	3.18E-02	1.31E-02
x		Formaldehyde	1.34E-02	1.64E-02	1.45E-02	1.29E-02	1.70E-02	1.36E-02	1.46E-02	1.69E-03
x	z	1,6-Dimethylnaphthalene	1.75E-02	7.25E-04	6.55E-03	0.00E+00	2.35E-02	5.83E-03	9.03E-03	9.48E-03
x		o-Cresol	7.82E-03	6.58E-03	3.85E-03	9.16E-03	7.71E-03	8.26E-03	7.23E-03	1.85E-03
x	z	1,8-Dimethylnaphthalene	4.28E-03	ND	4.74E-03	1.37E-02	5.58E-03	3.89E-03	6.44E-03	4.10E-03
x	z	1,3-Dimethylnaphthalene	5.70E-04	1.80E-04	1.23E-02	0.00E+00	8.81E-04	1.29E-02	4.47E-03	6.31E-03
x	z	Naphthalene	ND	4.40E-03	2.13E-02	0.00E+00	ND	vvvv	8.58E-03	1.13E-02
x		Acetaldehyde	4.24E-03	4.31E-03	3.03E-03	3.77E-03	5.33E-03	4.46E-03	4.19E-03	7.61E-04
x	z	2,7-Dimethylnaphthalene	ND	ND	1.24E-02	0.00E+00	ND	1.13E-02	7.87E-03	6.84E-03
x	z	1,5-Dimethylnaphthalene	9.69E-03	ND	ND	ND	7.87E-03	ND	8.78E-03	1.28E-03
x	z	2,3-Dimethylnaphthalene	ND	ND	9.51E-03	0.00E+00	ND	7.73E-03	5.75E-03	5.05E-03
x		Biphenyl	2.03E-03	7.67E-04	2.86E-03	1.89E-03	3.99E-03	1.73E-03	2.21E-03	1.10E-03
x	z	1,2-Dimethylnaphthalene	3.22E-03	0.00E+00	2.80E-03	ND	4.25E-03	2.41E-03	2.54E-03	1.58E-03
x		m,p-Xylene	ND	3.19E-04	6.73E-05	2.86E-03	2.17E-03	1.48E-03	1.38E-03	1.19E-03
x	z	2,3,5-Trimethylnaphthalene	6.53E-04	ND	5.20E-04	3.40E-03	8.83E-04	5.42E-04	1.20E-03	1.24E-03
x		Ethylbenzene	ND	1.84E-03	2.88E-04	2.59E-04	2.82E-04	2.10E-04	5.77E-04	7.09E-04
x		Styrene	ND	2.06E-03	5.66E-05	ND	5.66E-05	6.76E-04	7.13E-04	9.47E-04
x		Benzene	ND	ND	3.40E-04	2.30E-03	ND	ND	1.32E-03	1.39E-03
x		o-Xylene	ND	4.46E-04	1.37E-04	4.23E-04	4.13E-04	8.04E-04	4.45E-04	2.37E-04
x		Toluene	ND	ND	ND	2.82E-04	6.11E-04	4.14E-04	4.36E-04	1.66E-04
x	z	Acenaphthalene	4.34E-04	ND	4.31E-04	ND	2.43E-04	ND	3.70E-04	1.09E-04
x		2-Butanone	ND	ND	ND	1.89E-04	2.60E-04	2.01E-04	2.17E-04	3.83E-05
x		Hexane	ND	ND	4.39E-04	ND	ND	ND	4.39E-04	NA
x	z	2,6-Dimethylnaphthalene	ND	ND	ND	ND	ND	ND	NA	NA
x		Acrolein	ND	ND	ND	ND	ND	ND	NA	NA
x		Propionaldehyde	ND	ND	ND	ND	ND	ND	NA	NA

Test Plan GK Individual Emissions Results – Lb/Tn Core

Coated Core Drying Emissions

HAPs	POMs	COMPOUND/RUM NUMBER	GK001	GK002	GK003	GK004	GK005	GK006	Average	STDEV
Other Target VOCs										
		2,6-Dimethylphenol	2.16E-01	1.70E-01	1.26E-01	1.35E-01	2.08E-01	1.03E-01	1.60E-01	4.60E-02
		Decane	6.55E-02	5.47E-02	3.13E-02	7.34E-02	8.22E-02	4.16E-02	5.81E-02	1.93E-02
		1,3,5-Trimethylbenzene	ND	2.70E-02	2.15E-02	5.33E-02	1.12E-02	8.80E-03	2.44E-02	1.78E-02
		1,3-Diethylbenzene	1.53E-02	2.12E-02	1.09E-02	2.19E-02	1.61E-02	2.15E-02	1.78E-02	4.45E-03
		2,4-Dimethylphenol	1.01E-02	2.03E-02	1.40E-02	2.79E-02	1.95E-02	1.30E-02	1.75E-02	6.44E-03
		Indene	ND	8.45E-03	1.56E-02	5.06E-02	ND	ND	2.49E-02	2.26E-02
		3-Ethyltoluene	ND	ND	3.60E-02	1.68E-02	ND	9.38E-03	2.07E-02	1.38E-02
		Propylbenzene, n-	ND	7.44E-03	1.26E-02	9.73E-03	2.09E-03	5.03E-03	7.38E-03	4.08E-03
		Undecane	ND	3.46E-02	ND	ND	ND	ND	3.46E-02	NA
		Heptane	ND	ND	1.41E-03	1.10E-02	1.84E-02	1.95E-03	8.19E-03	8.09E-03
		Tetradecane	3.60E-04	7.55E-04	1.33E-02	1.44E-03	1.35E-03	1.06E-02	4.63E-03	5.74E-03
		2-Ethyltoluene	ND	5.57E-03	0.00E+00	1.62E-02	ND	ND	7.25E-03	8.22E-03
		1,2,3-Trimethylbenzene	2.35E-03	1.18E-03	9.72E-04	ND	1.23E-02	3.59E-03	4.07E-03	4.70E-03
		1,2,4-Trimethylbenzene	ND	1.43E-03	6.50E-03	ND	ND	9.81E-03	5.92E-03	4.22E-03
		Butyraldehyde/Methacrolein	3.43E-03	2.39E-03	2.32E-03	2.16E-03	3.14E-03	2.85E-03	2.71E-03	5.06E-04
		Nonane	ND	ND	6.84E-04	2.07E-03	1.34E-03	2.43E-03	1.63E-03	7.78E-04
		Pentanal	6.88E-04	9.09E-04	6.70E-04	8.12E-04	9.81E-04	7.63E-04	8.04E-04	1.23E-04
		Crotonaldehyde	8.31E-04	6.86E-04	5.06E-04	7.37E-04	9.68E-04	9.49E-04	7.80E-04	1.74E-04
		Indan	2.83E-03	ND	ND	ND	ND	ND	2.83E-03	NA
		Octane	ND	ND	5.16E-04	4.11E-04	5.44E-04	1.04E-03	6.27E-04	2.79E-04
		Hexaldehyde	2.59E-04	4.38E-04	3.34E-04	3.17E-04	3.45E-04	2.79E-04	3.29E-04	6.31E-05
		Cyclohexane	ND	ND	ND	ND	1.06E-03	ND	1.06E-03	NA
		Dodecane	ND	ND	ND	ND	ND	ND	NA	NA
		Benzaldehyde	ND	ND	ND	ND	ND	ND	NA	NA
		o,m,p-Tolualdehyde	ND	ND	ND	ND	ND	ND	NA	NA

ND: Below the Quantitation limit shown in the tables at the end of this appendix.
NA: Not Applicable
I: Invalidated
Note 1: TGOC results **shown in red.** These data appear to have significant negative bias. The cause of this apparent bias is unknown.

Test Plan GK Quantitation Limits – Lb/Lb Binder

Analytes	Lb/Lb Binder
1,2,3-Trimethylbenzene	2.52E-07
1,2,4-Trimethylbenzene	2.52E-07
1,3,5-Trimethylbenzene	2.52E-07
1,3-Dimethylnaphthalene	2.52E-07
1-Methylnaphthalene	2.52E-07
2-Ethyltoluene	2.52E-07
2-Methylnaphthalene	2.52E-07
Benzene	2.52E-07
Ethylbenzene	2.52E-07
Hexane	2.52E-07
m,p-Xylene	2.52E-07
Naphthalene	2.52E-07
o-Xylene	2.52E-07
Styrene	2.52E-07
Toluene	2.52E-07
Undecane	2.52E-07
1,2-Dimethylnaphthalene	1.26E-06
1,3-Diethylbenzene	1.26E-06
1,5-Dimethylnaphthalene	1.26E-06
1,6-Dimethylnaphthalene	1.26E-06
1,8-Dimethylnaphthalene	1.26E-06

Analytes	Lb/Lb Binder
2,3,5-Trimethylnaphthalene	1.26E-06
2,3-Dimethylnaphthalene	1.26E-06
2,4-Dimethylphenol	1.26E-06
2,6-Dimethylnaphthalene	1.26E-06
2,6-Dimethylphenol	1.26E-06
2,7- Dimethylnaphthalene	1.26E-06
3-Ethyltoluene	1.26E-06
Acenaphthalene	1.26E-06
Biphenyl	1.26E-06
Cyclohexane	1.26E-06
Decane	1.26E-06
Dodecane	1.26E-06
Heptane	1.26E-06
Indan	1.26E-06
Indene	1.26E-06
m,p-Cresol	1.26E-06
Nonane	1.26E-06
o-Cresol	1.26E-06
Octane	1.26E-06
Phenol	1.26E-06
Propylbenzene	1.26E-06

Analytes	Lb/Lb Binder
Tetradecane	1.26E-06
HC as Hexane	3.83E-05
2-Butanone (MEK)	1.27E-07
Acetaldehyde	1.27E-07
Acetone	1.27E-07
Acrolein	1.27E-07
Benzaldehyde	1.27E-07
Butyraldehyde	1.27E-07
Crotonaldehyde	1.27E-07
Formaldehyde	1.27E-07
Hexaldehyde	1.27E-07
Butyraldehyde/Methacrolein	2.11E-07
o,m,p-Tolualdehyde	3.38E-07
Pentanal (Valeraldehyde)	1.27E-07
Propionaldehyde (Propanal)	1.27E-07
Triethylamine	4.52E-07
TGOC	5.40E-05

Test Plan GK Quantitation Limits – Lb/Tn Core

Analytes	Lb/Tn Metal
1,2,3-Trimethylbenzene	6.96E-06
1,2,4-Trimethylbenzene	6.96E-06
1,3,5-Trimethylbenzene	6.96E-06
1,3-Dimethylnaphthalene	6.96E-06
1-Methylnaphthalene	6.96E-06
2-Ethyltoluene	6.96E-06
2-Methylnaphthalene	6.96E-06
Benzene	6.96E-06
Ethylbenzene	6.96E-06
Hexane	6.96E-06
m,p-Xylene	6.96E-06
Naphthalene	6.96E-06
o-Xylene	6.96E-06
Styrene	6.96E-06
Toluene	6.96E-06
Undecane	6.96E-06
1,2-Dimethylnaphthalene	3.48E-05
1,3-Diethylbenzene	3.48E-05
1,5-Dimethylnaphthalene	3.48E-05
1,6-Dimethylnaphthalene	3.48E-05
1,8-Dimethylnaphthalene	3.48E-05

Analytes	Lb/Tn Metal
2,3,5-Trimethylnaphthalene	3.48E-05
2,3-Dimethylnaphthalene	3.48E-05
2,4-Dimethylphenol	3.48E-05
2,6-Dimethylnaphthalene	3.48E-05
2,6-Dimethylphenol	3.48E-05
2,7- Dimethylnaphthalene	3.48E-05
3-Ethyltoluene	3.48E-05
Acenaphthalene	3.48E-05
Biphenyl	3.48E-05
Cyclohexane	3.48E-05
Decane	3.48E-05
Dodecane	3.48E-05
Heptane	3.48E-05
Indan	3.48E-05
Indene	3.48E-05
m,p-Cresol	3.48E-05
Nonane	3.48E-05
o-Cresol	3.48E-05
Octane	3.48E-05
Phenol	3.48E-05
Propylbenzene	3.48E-05

Analytes	Lb/Tn Metal
Tetradecane	3.48E-05
HC as Hexane	3.48E-03
2-Butanone (MEK)	1.04E-04
Acetaldehyde	1.04E-04
Acetone	1.04E-04
Acrolein	1.04E-04
Benzaldehyde	1.04E-04
Butyraldehyde	1.04E-04
Crotonaldehyde	1.04E-04
Formaldehyde	1.04E-04
Hexaldehyde	1.04E-04
Butyraldehyde/Methacrolein	1.74E-04
o,m,p-Tolualdehyde	2.78E-04
Pentanal (Valeraldehyde)	1.04E-04
Propionaldehyde (Propanal)	1.04E-04
Triethylamine	3.48E-04
TGOC	1.49E-03

APPENDIX C DETAILED PROCESS DATA FOR TEST GK

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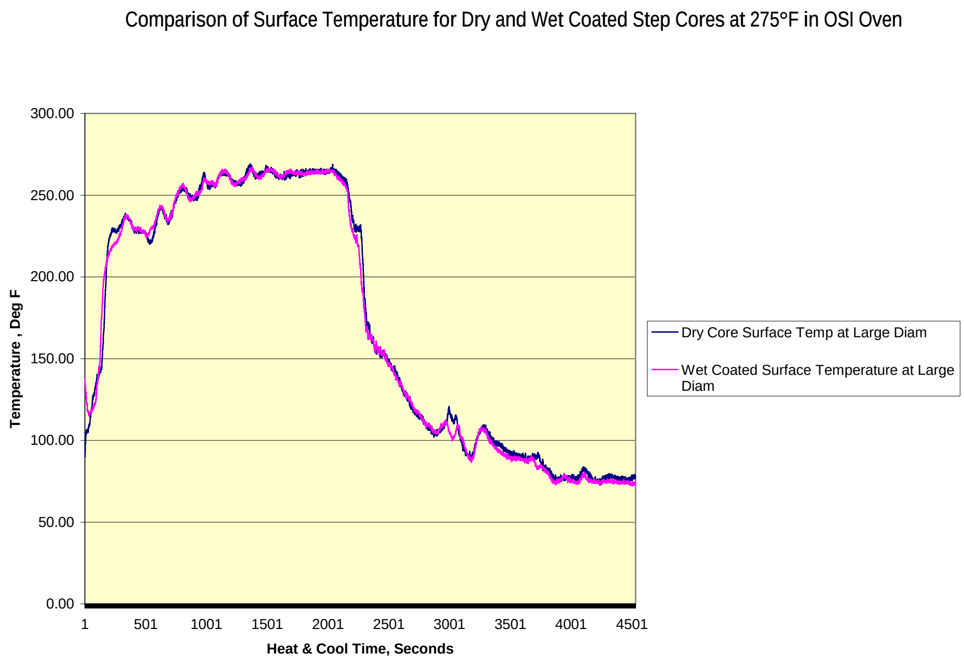
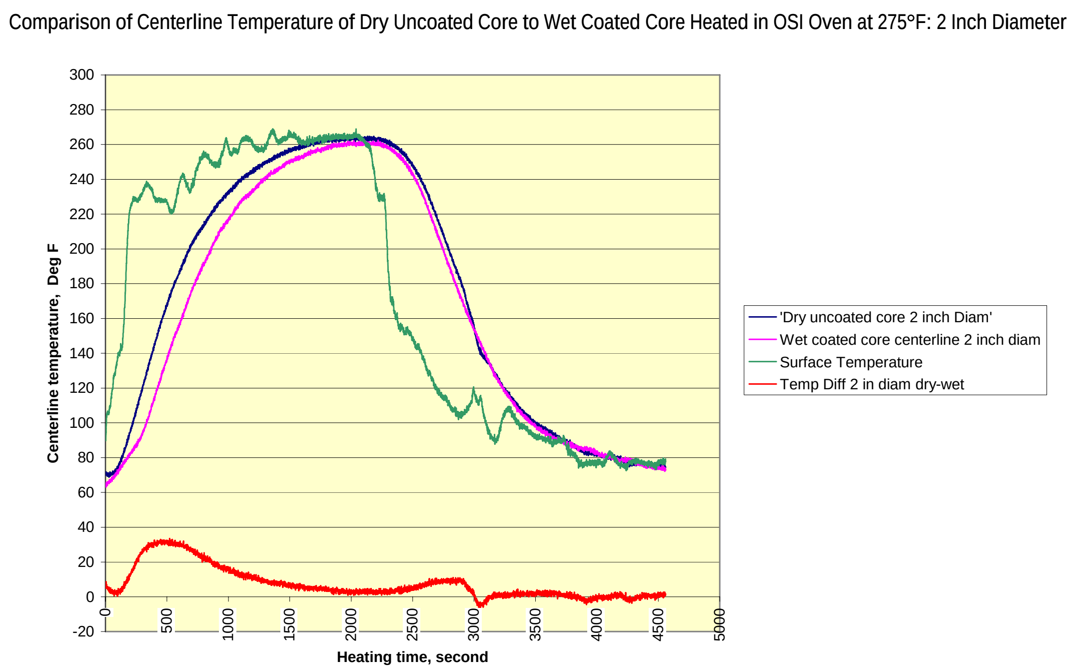
Test Series GK Detailed Process Data

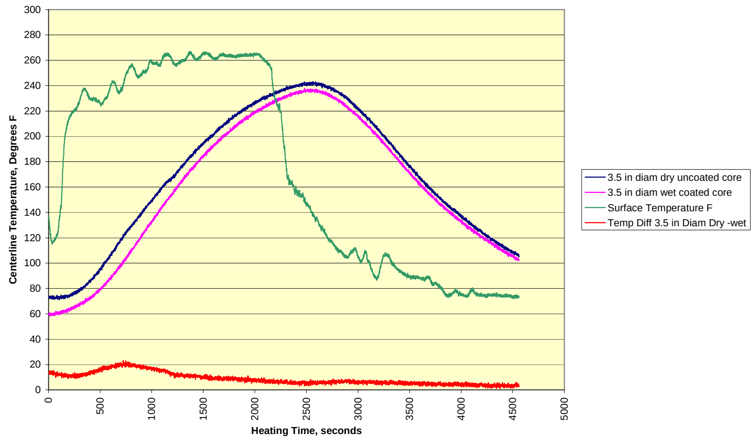
	Wet Coated Core Dried						Oven Drying Wet Coated Core Average	Uncoated Core						Oven Drying Uncoated Core Average	Oven Drying Wet Coated Core	Oven Redrying Air Dried Coated Core
	GK001	GK002	GK003	GK004	GK005	GK006		GK011	GK012	GK013	GK014	GK015	GK016		122204-1	122204-2
Test Date	17-Dec-04	20-Dec-04	20-Dec-04	21-Dec-04	21-Dec-04	21-Dec-04		16-Dec-04	16-Dec-04	16-Dec-04	16-Dec-04	17-Dec-04	17-Dec-04		22-Dec-04	22-Dec-04
Part I Binder Weight, gm	175.3	175.3	175.1	175.1	174.3	174.3	174.9	175	175	174.7	174.7	175.1	175.1	174.9	174.3	174.3
Part II Binder Weight, gm	142.9	142.9	144.3	144.3	143.3	143.3	143.5	142.8	142.8	143.1	143.1	143.1	143.1	143.0	143.3	143.3
Sand Weight, Lbs	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
% Binder (BOS)	1.40	1.40	1.41	1.41	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
% Binder	1.38	1.38	1.39	1.39	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
Bare core dry weight, gm	1850.6	1845.9	1850.4	1818.0	1817.2	1820.1	1833.7	1834.4	1833.6	1857.2	1843.8	1862.1	1860.1	1848.5	1806.5	1806.1
Binder Weight, gm	25.60	25.54	25.70	25.25	25.10	25.14	25.39	25.35	25.34	25.66	25.48	25.76	25.74	25.55	24.95	24.94
Core age, days	3	6	6	7	7	7	6	2	2	2	2	2	3	2	6	6
Coated core wet weight, gm	1931.3	1943.7	1941.7	1902	1901.7	1905.3	1921.0	NA	NA	NA	NA	NA	NA	NA	1908.2	1897.7
Coated core dry weight, gm	ND	1883.3	1886.8	1850.5	1849.4	1853.7	1864.7	NA	NA	NA	NA	NA	NA	NA	1845.7	1843.5
Coating dry weight, gm	NA	37.4	36.4	32.5	32.2	33.6	34.4	NA	NA	NA	NA	NA	NA	NA	39.2	37.4
Coating water weight as dipped, gm	NA	60.4	54.9	51.5	52.3	51.6	54.1	NA	NA	NA	NA	NA	NA	NA	62.5	54.2
Coating % solids	NA	38.2	39.9	38.7	38.1	39.4	38.9	NA	NA	NA	NA	NA	NA	NA	38.5	40.8
Coating Baume	32	23.10	21.89	19.93	19.93	20.35	21.04	NA	NA	NA	NA	NA	NA	NA	42	42
Test duration, minutes	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77
Oven Equilibrium Temperature, Deg F	323	331	330	316	322	317	323	323	324	324	322	328	283	317	324	330
Temporary Oven Temp @ core loading, Deg F	284	299	289	282	293	290	290	238	277	290	269	332	290	283	182	233
TGOC ave. concentration during drying, ppm	1346	1080	1062	1018	1164	1055	1121	1894	1863	1820	1867	1794	1762	1833	1013	1351
TGOC Normalized to binder weight ppm/gm	52.57	42.29	41.33	40.32	46.38	41.97	44.15	74.72	73.53	70.92	73.28	69.63	68.46	71.74	40.60	54.16

	OSI DRY	OSI WET	Accutherm Emulation		
Run #	102704-1	102804-1	121504-2	121504-3	101504-1
Oven set point temperature	275	275	300	325	350
Oven mean equilibriumt temperature	275	275	315	331	359
2.0 inch centerline peak temperature	262	262	255	265	311
2.0 inch centerline average temperature second by second	173	164	187	194	241
3.5 inch centerline peak temparature	240	237	203	213	263
3.5 inch centerline average temperature second by second	168	155	158	167	197
Average of 2.0 & 3.5 in centerline temperature second by second	170.5	160	173	180.5	219
Air Max temperature at tip	281	281	309	323	352
Air ave temperature at tip second by second	275	275	193	199	265
Air Maximum temperature at large diameter base	269	267	276	289	324
Air average temperature at large diameter base second by second	171	172	195	205	257
Air ave temperatrue at mid point second by second	223	224	194	202	261
Core average median temperature second by second	196.75	192	183	191	240

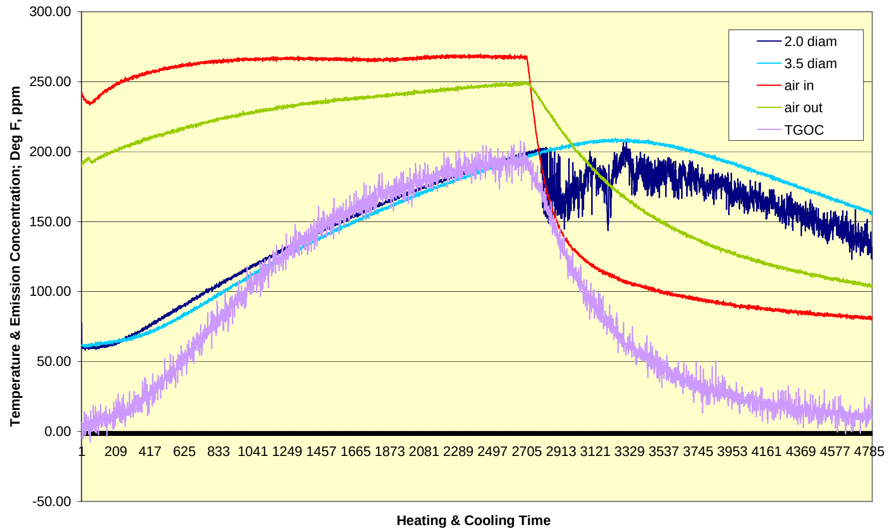

Comparison of Surface Temperature for Dry and Wet Coated Step Cores at 275°F in OSI Oven
Temperature , Deg F
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1
501
1001
1501
2001
2501
3001
3501
4001
4501
Heat & Cool Time, Seconds
Dry Core Surface Temp at Large Diam
Wet Coated Surface Temperature at Large Diam


Comparison of Centerline Temperature of Dry Uncoated Core to Wet Coated Core Heated in OSI Oven at 275°F: 2 Inch Diameter
Centerline temperature, Deg F
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Heating time, second
'Dry uncoated core 2 inch Diam'
Wet coated core centerline 2 inch diam
Surface Temperature
Temp Diff 2 in diam dry-wet

Comparison of Centerline Temperature of Wet Coated Core to Dry Uncoated Core Heated in OSI Drying Oven at 275°F: 3.5 Inch Diameter



Characteristic Oven and Centerline Core Temperatures and TGOC Emissions



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APPENDIX D METHOD 25A CHARTS

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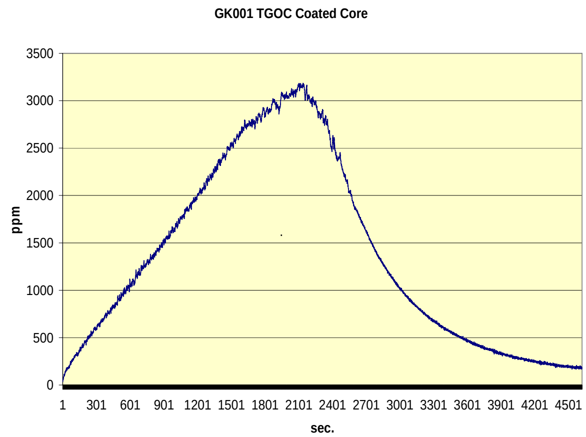
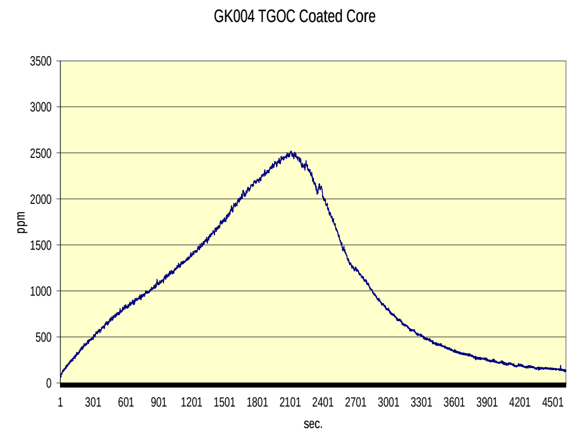
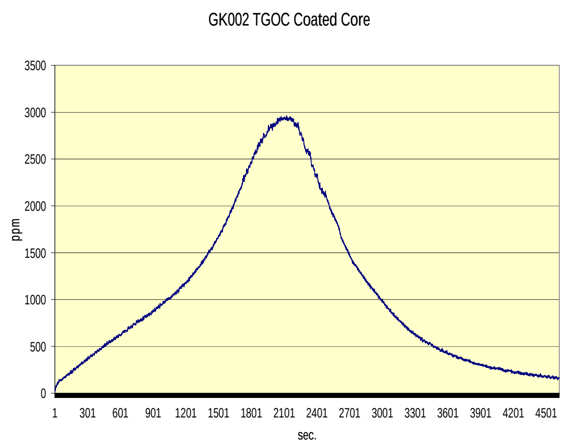
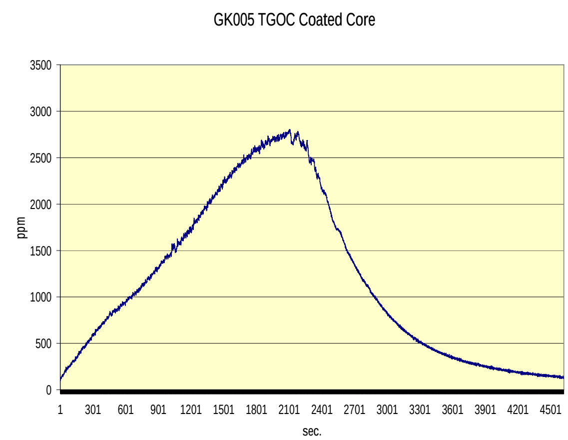

GK001 TGOC Coated Core
3500
3000
2500
2000
1500
1000
500
0
ppm
1 301 601 901 1201 1501 1801 2101 2401 2701 3001 3301 3601 3901 4201 4501
sec.


GK004 TGOC Coated Core
3500
3000
2500
2000
1500
1000
500
0
ppm
1 301 601 901 1201 1501 1801 2101 2401 2701 3001 3301 3601 3901 4201 4501
sec.


GK002 TGOC Coated Core
3500
3000
2500
2000
1500
1000
500
0
ppm
1 301 601 901 1201 1501 1801 2101 2401 2701 3001 3301 3601 3901 4201 4501
sec.


GK005 TGOC Coated Core
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3000
2500
2000
1500
1000
500
0
ppm
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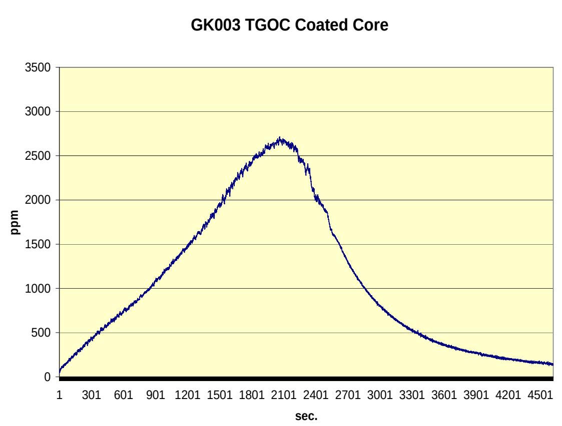
sec.


GK003 TGOC Coated Core
3500
3000
2500
2000
1500
1000
500
0
ppm
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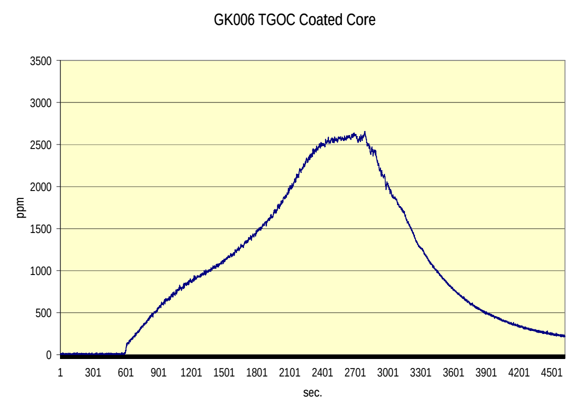
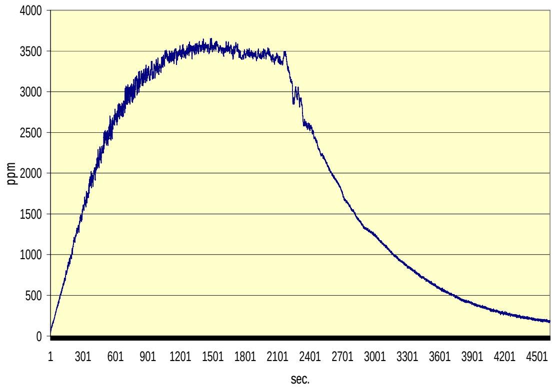
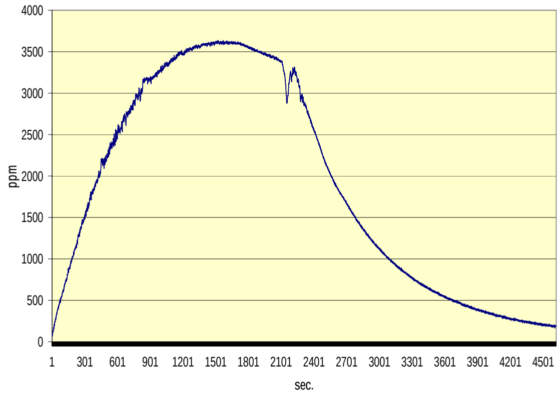
sec.


GK006 TGOC Coated Core
3500
3000
2500
2000
1500
1000
500
0
ppm
1 301 601 901 1201 1501 1801 2101 2401 2701 3001 3301 3601 3901 4201 4501
sec.

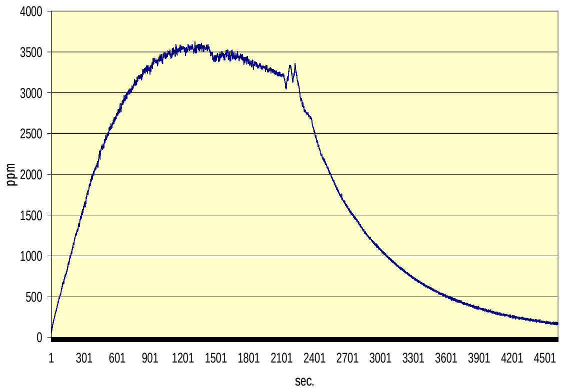
GK011 TGOC Uncoated core



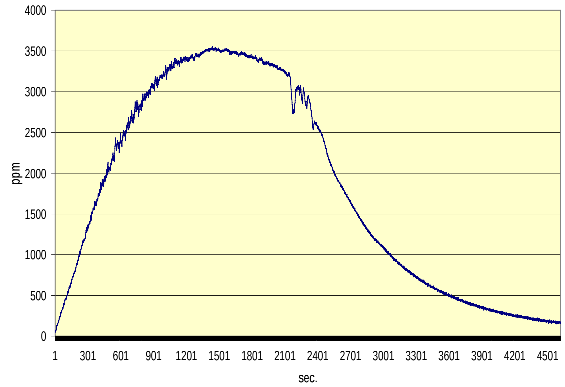
GK014 TGOC Uncoated core



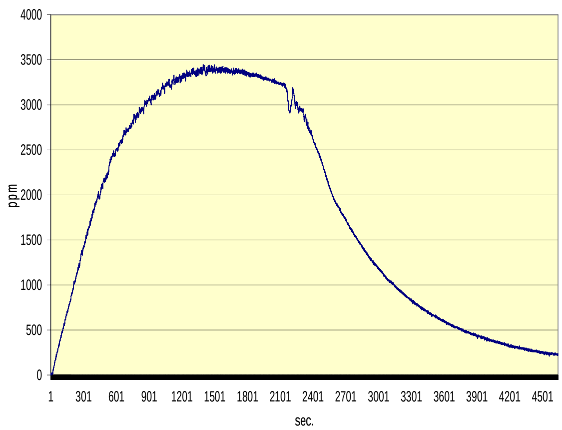
GK012 TGOC Uncoated Core



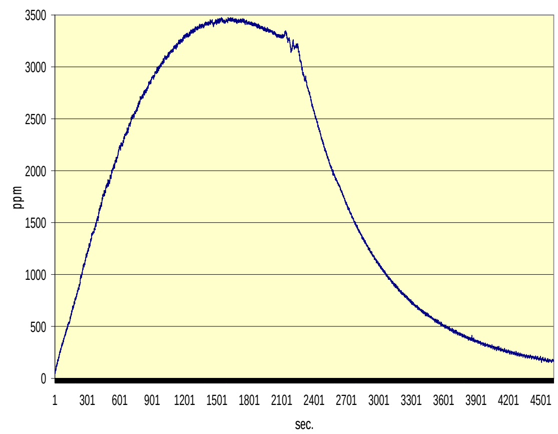
GK015 TGOC Uncoated Core



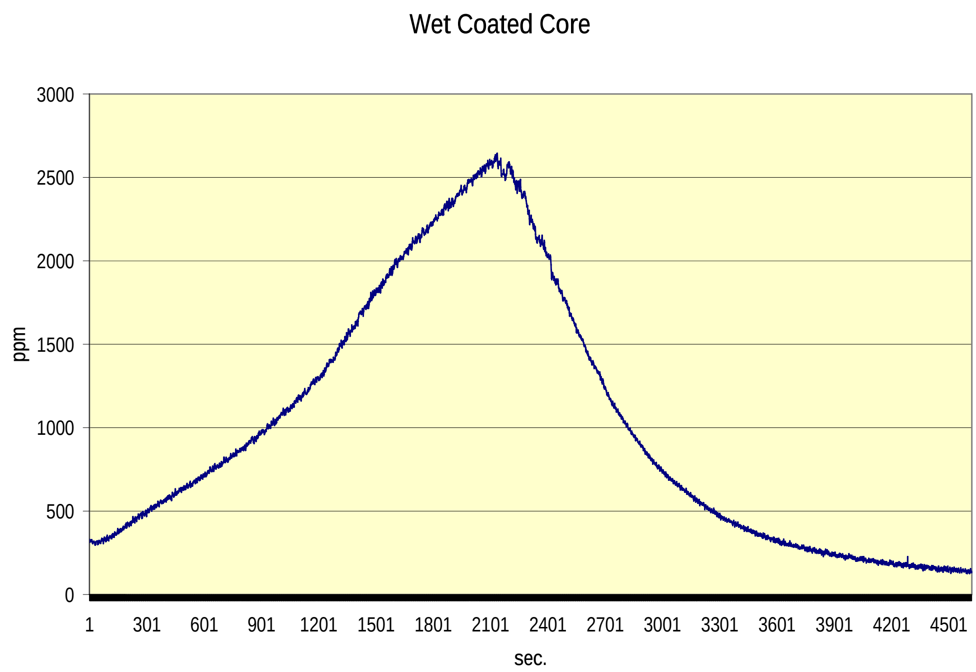
GK013 Uncoated Core

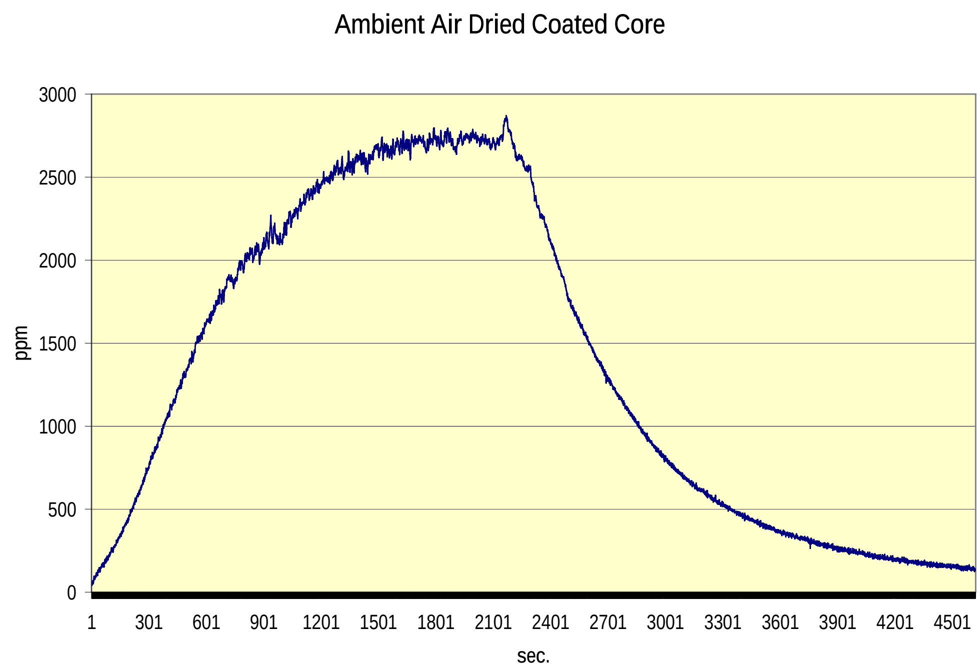


GK016 TGOC Uncoated Core



Comparison of oven heating wet coated cores and coated cores previously ambient air dried (85 degrees F)





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APPENDIX E ACRONYMS AND ABBREVIATIONS

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Acronyms and Abbreviations

ACFM	Actual Cubic Feet Per Minute
BO	Based on ( ).
BOA	Based on Aggregate
BOS	Based on Sand.
FPM	Feet Per Minute
HAP	Hazardous Air Pollutant defined by the 1990 Clean Air Act Amendment
HC as Hexane	Calculated by the summation of all area between elution of Hexane through the elution of Hexadecane. The quantification of HC is performed against a five-point calibration curve of Hexane by dividing the total area count from C6 through C16 to the area of Hexane from the initial calibration curve and multiplying by the hexane mass per unit area derived from the calibration cure.
I	Invalid, Data rejected based on data validation considerations
MPTE	Maximum Potential to Emit
NA	Not Applicable, Not Available
ND	Non-Detect
NT	Not Tested, Lab testing was not done
POM	Polycyclic Organic Matter (POM) including Naphthalene and other compounds that contain more than one benzene ring and have a boiling point greater than or equal to 100 degrees Celsius.
PPMV (PPM)	Parts Per Million by Volume
SCFM	Standard Cubic Feet per Minute
TGOC	Total Gaseous Organic Concentration (US-EPA Method 25A)
TGOC as Propane	Weighted to the detection of more volatile hydrocarbon species, beginning at C1 (methane), with results calibrated against a three-carbon alkane (propane).
VOC	Volatile Organic Compound
WCMA	Wisconsin Cast Metals Association