Casting Emission Reduction Program

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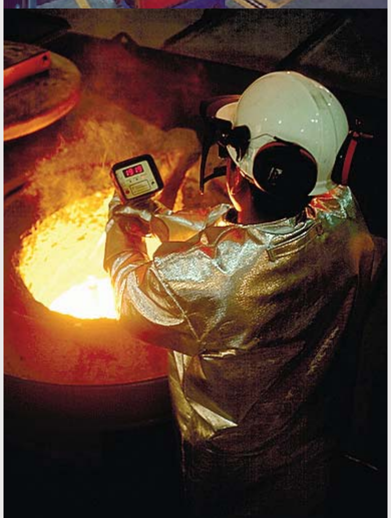

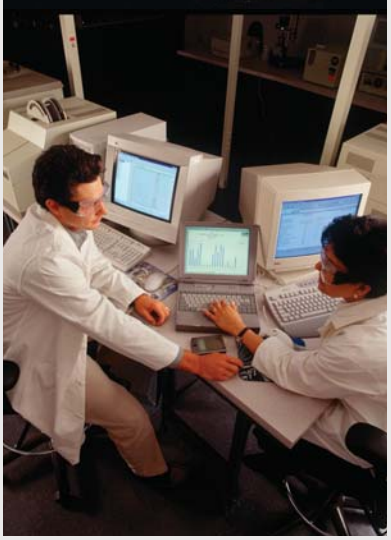

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Epoxy-Acrylic Cold Box Binder

1412-112 GX

May 2006

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Epoxy-Acrylic Cold Box Binder

1412-112 GX

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

Senior Scientist	*//Original Signed//* Sue Anne Sheya, PhD	Date
V.P. 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 cost or producability.

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EXECUTIVE SUMMARY

This report contains the results of emission testing to evaluate the pouring, cooling, and shakeout emissions from Test GX, an uncoated epoxy-acrylic cold box core in a greensand mold without seacoal. Test GX is compared to Test GY, a baseline using an uncoated phenolic urethane cold box core in a greensand mold without seacoal. The core binder for Test GX was activated with sulfur dioxide (SO_2), and the core binder for GY was activated with triethylamine (TEA). The emissions results are reported in both pounds of analyte per pound of binder (lb/lb) and pounds of analyte per ton of metal poured (lb/ton). The binder content of PCS baseline Test GY was nominally 1.4 % (BOS) and TEA activated whereas Test GX binder content was 1.20% and activated with SO_2. These differences need to be taken into consideration when comparing the emissions between the tests.

The testing performed involved the collection of continuous air samples over a seventy-five minute period, including the mold pouring, cooling, shakeout, and post shakeout periods for nine molds using a 4-on-step core pattern. Results comparing emission indicators for each test are summarized in Table 1.

Table 1 GY and GX Average Emissions Indicators Summary Table

	Lb/Tn Metal		Lb/Lb Binder	
Analyte Name	Test GY	Test GX	Test GY	Test GX
TGOC as Propane	1.0321	0.7994	0.1537	0.1422
HC as Hexane	0.5135	0.4013	0.0765	0.0708
Sum of Target VOCs	0.4969	0.2657	0.0662	0.0472
Sum of Target HAPs	0.4508	0.2098	0.0601	0.0369
Sum of Target POMs	0.1602	0.0087	0.0211	0.0015

Both process and stack parameters were monitored and recorded. Process measurements included the weights of the casting and mold sand, loss on ignition (LOI) values for the mold prior to the test, and relevant metallurgical data. Measured stack gas parameters included stack temperature, pressure, volumetric flow rate, and moisture content. All parameters were maintained within prescribed ranges to ensure the reproducibility of the test runs.

Adsorption tube samples were collected and analyzed for sixty-one (61) target compounds using procedures based on approved state and/or federal regulatory methods, including those of the US Environmental Protection Agency (EPA). Continuous on-line monitoring of Total Gaseous Organic Concentration (TGOC), carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen oxide (NOx) concentrations was conducted according to US EPA Methods 25A, 3A, 10, and 7E respectively.

Mass emission rates for all analytes were calculated using continuous monitoring or laboratory analytical results, measured source data and appropriate process data. Results are presented in detail in Appendix B. Individual analyte emissions were calculated in addition to five “Emission Indicators” which include TGOC as propane, hydrocarbons (HC) as hexane, the sum of target volatile organic compounds (VOCs), the sum of target hazardous air pollutants (HAPs), and the sum of target polycyclic organic matter (POM). Detailed descriptions of these indicators can be found in Section 3.0 of this report.

A photographic casting record was made of the twelve castings made with coated cores produced from the first three molds used as conditioning runs. These molds were poured prior to those molds poured for the generation of sampling emissions. The surface quality for each of the conditioning run castings was assessed relative to the others and to the benchmark castings from Test GY. Pictures of best, medium and worst casting quality are shown in Appendix C.

It must be noted that the reported TGOC results include the exempted compound methane. At present, the methane contribution to these results has neither been determined nor removed. In addition, results from the testing performed are 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. These measurements should not be used as the basis for estimating emissions from actual commercial foundry applications.

1.0 INTRODUCTION

1.1. CERP BACKGROUND AND OBJECTIVES

The Casting Emission Reduction Program (CERP) is a cooperative initiative between the Department of Defense (US Army) and the United States Council for Automotive Research (USCAR). The signers of the CERP Cooperative Research and Development Agreement (CRADA) include: the Environmental Research Consortium (ERC), a partnership of DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation; the U.S. Army Research, Development, and Engineering Command (RDECOM-ARDEC); the American Foundry Society (AFS); and the Casting Industry Suppliers Association (CISA). 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 reports for regulatory compliance data. All published reports are available on the CERP web site at www.cerp-us.org.

CERP's primary purpose 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 facilitates the repeatable collection and evaluation of airborne emissions and associated process data.

1.2. TEST OBJECTIVES

The objective of this test was to evaluate emissions from the pouring, cooling and shakeout of an uncoated epoxy-acrylic cold box core in a greensand mold without seacoal. These emissions are then compared to those from Test GY, an uncoated phenolic urethane cold box core in a greensand mold without seacoal.

1.3. TEST PLAN SUMMARY

Table 1-1 provides a summary of the test plan. The details of the approved test plan are included in Appendix A.

Table 1-1 Test Plan Summary

	Baseline Test GY	Comparison Test GX
Type of Process Tested	Phenolic Urethane Core, Greensand without Seacoal, Iron PCS Baseline	Acrylic Epoxy Core, SO_2 cured, Greensand without Seacoal, Iron PCS
Test Plan Number	1412-121-GY	1412-112-GX
Greensand System	Wexford W450 Lakesand, Western and Southern Bentonite, No Seacoal	Wexford W450 Lakesand, Western and Southern Bentonite, No Seacoal
Metal Poured	Iron	Iron
Casting Type	4-on Step Core	4-on Step Core
Core	1.4% Ashland ISOCURE® 305/904 Phenolic Urethane Binder System Wedron 530 Silica Sand	Step: 1.2% (BOS) HA International Bakelite 7181 GK01/02 in a 65/35 ratio SO2 activated. Wexford 465/463 sand.
Core Coating	Ashland VelvaPlast®CGW 9022 SL for conditioning runs only	HA International Technikoat 04-4900 for conditioning runs only
Number of Molds Poured	3 Conditioning and 9 Sampling	3 Conditioning and 9 Sampling
Test Dates	10/4/05 through 10/7/05	11/7/05 through 11/10/05
Emissions Measured	58 Analytes and TGOC as Propane, CO,CO_2,NOx	61 Analytes and TGOC as Propane, CO,CO_2,NOx
Process Parameters Measured	Total Casting, Mold, Binder Weights; Metallurgical data, % LOI; Stack Temperature, Moisture Content, Temperature, Pressure and Volumetric Flow Rate	Total Casting, Mold, Binder Weights; Metallurgical data, % LOI; Stack Temperature, Moisture Content, Temperature, Pressure, and Volumetric Flow Rate

1.4. REPORT ORGANIZATION

This report has been designed to document the methodology and results of a specific test plan that was used to evaluate the pouring, cooling and shakeout emissions from an epoxy-acrylic cold box cored greensand system without the addition of seacoal. Section 2.0 of this report includes a summary of the methodologies used for data collection and analysis, procedures for emission calculations, QA/QC procedures, and data management and reduction methods. Specific data collected during this test are summarized in Section 3.0 of this report, with detailed data included in the appendices of this report. Section 4.0 of this report contains a discussion of the results. The raw data for this test series are archived at the Technikon facility.

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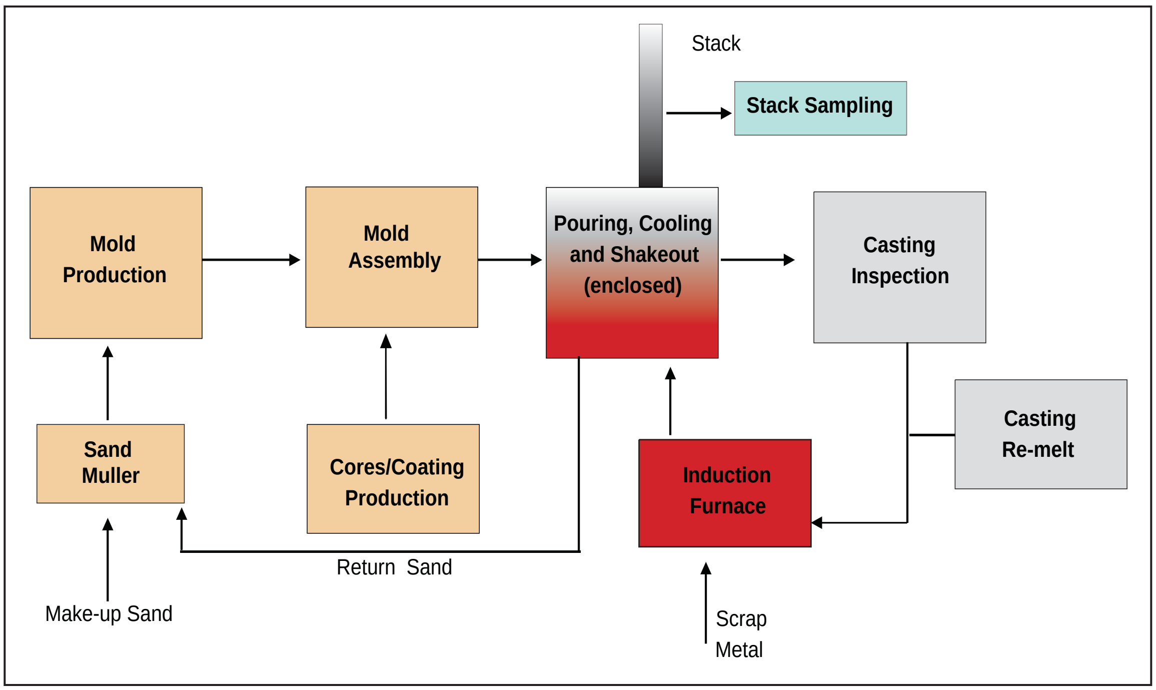
2.0 TEST METHODOLOGY

2.1. DESCRIPTION OF PROCESS AND TESTING EQUIPMENT

Figure 2-1 is a schematic diagram of the Research Foundry process used for this test.

Figure 2-1 Research Foundry Layout Diagram



2.2. DESCRIPTION OF TESTING PROGRAM

The specific steps used in this sampling program are summarized below.

2.2.1. Test Plan Review and Approval

The proposed test plan was reviewed and approved by the Technikon staff.

2.2.2. Mold, Core and Metal Preparation

The molds and cores were prepared (Figure 2-2) to a standard composition by the Technikon production team. Relevant process data was collected and recorded. Iron was melted in a 1000 lb.

Figure 2-2 Mold and Step Cores

Figure 2-3 Coated Step Cores

Figure 2-4 Pouring Metal into Mold in Total Enclosure Hood

Figure 2-5 Method 25A (TGOC) and Method 18 Sampling Train

Ajax induction furnace. The amount of metal melted was determined from the poured weight of the casting and the number of molds to be poured. The metal composition was Class-30 Gray Iron as prescribed by a metal composition worksheet. The weight of metal poured into each mold was recorded on the process data summary sheet.

The cores used in the conditioning runs were coated with the vendor supplied core coating and dried in an OSI core drying oven (Figure 2-3).

2.2.3. Individual Sampling Events:

Replicate runs were performed on nine (9) mold packages after the conclusion of three (3) conditioning cycles. Prior to pouring for each run, each mold package was placed into an enclosed test stand heated to approximately 85°F. The flow rate of the emission capture air was nominally 300 scfm. Iron was poured through an opening in the top of the emission enclosure, after which the opening was closed (Figure 2-4).

Continuous air samples were collected (Figure 2-5) during the forty-five minute pouring and cooling process, during the five minute shakeout of the mold, and for an additional twenty-five minute period following shakeout. The total sampling time was seventy-five minutes.

2.2.4. Process Parameter Measurements

Table 2-1 lists the process parameters that are monitored during each test. The analytical equipment and methods used are also listed.

2.2.5. Air Emissions Analysis:

The specific sampling and analytical methods used in the Research Foundry tests are based on federal regulatory 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 Standard Operating Procedures.

Table 2-1 Process Equipment and Methods

Parameter	Test GY	Test GX
Mold Weight	Cardinal 748E Platform Scale (Gravimetric)	Cardinal 748E Platform Scale (Gravimetric)
Casting Weight	OHAUS MP2 Platform Scale (Gravimetric)	OHAUS MP2 Platform Scale (Gravimetric)
Muller Water Weight	OHAUS MP2 Platform Scale (Gravimetric)	OHAUS MP2 Platform Scale (Gravimetric)
Binder Weight	MyWeigh i2600	MyWeigh i2600
Core Weight	Mettler Toledo SB12001	Mettler Toledo SB12001
Volatiles	Mettler Toledo PB302	Mettler Toledo PB302
LOI, % at Mold	Denver Instruments XE-100 Analytical Scale (AFS Procedure 5100-00-S)	Denver Instruments XE-100 Analytical Scale (AFS Procedure 5100-00-S)
Metallurgical Parameters		
Pouring Temperature	Electro-Nite DT 260 (T/C Immersion Pyrometer)	Electro-Nite DT 260 (T/C Immersion Pyrometer)
Carbon/Silicon Fusion Temperature	Electro-Nite DataCast 2000 (Thermal Arrest)	Electro-Nite DataCast 2000 (Thermal Arrest)
Alloy Weights	Ohaus MP2 Scale	Ohaus MP2 Scale
Mold Compactability	Dietert 319A Sand Squeezer (AFS Procedure 2221-00-S)	Dietert 319A Sand Squeezer (AFS Procedure 2221-00-S)

2.2.6. Data Reduction, Tabulation and Preliminary Report Preparation

The analytical results of the emissions tests provide the mass of each analyte in the sample. The total mass of the analyte emitted is calculated by multiplying the mass of analyte in the sample by the ratio of total stack gas volume to sample volume. The total stack gas volume is calculated from the measured stack gas velocity and duct diameter and corrected to dry standard conditions using the measured stack pressures, temperatures, gas molecular weight

Table 2-2 Emission Sampling and Analytical Methods

Measurement Parameter	Test Method(s)*
Port Location	US EPA Method 1
Number of Traverse Points	US EPA Method 1
Gas Velocity and Temperature	US EPA Method 2
Gas Density and Molecular Weight	US EPA Method 3a
Gas Moisture	US EPA Method 4 (Gravimetric)
Target VOCs and HAPs	US EPA Methods: TO17, TO11; NIOSH Methods: 1500, 2002; OSHA Method 55
TGOC	US EPA Method 25A
CO	US EPA Method 10
CO_2	US EPA Method 3A
NO_x	US EPA Method 7E
SO_2	OSHA ID 200

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

and moisture content. The total mass of analyte is then divided by the weight of the casting poured or weight of binder to provide emissions data in pounds of analyte per ton of metal or pounds of analyte per pound of binder.

Individual results for each analyte for all sampling events are included in Appendix B of this report. Average results for each event are given in Tables 3-1a and 3-1b.

2.2.7. Report Preparation and Review

The Preliminary Draft Report is created and reviewed by Process Team and Emissions Team members 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 then reviewed by senior management and 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 laboratory analytical procedures are included in the "Technikon Emissions Testing and Analytical Testing Standard Operating Procedures" publication. In order to ensure the timely review of critical quality control parameters, the following procedures are followed:

- Immediately following the individual sampling events 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 of Process Engineering and the Vice President of Operations determine whether the individual test samples should be invalidated or flagged for further analysis following review of the laboratory data.

- The source (stack) and sampling parameters, analytical results and corresponding laboratory QA/QC data are reviewed by the Emissions Measurement Team to confirm the validity of the data. The Vice President of Measurement Technologies reviews and approves the recommendation, if any, that individual sample data should be invalidated. Invalidated data are not used in subsequent calculations.

3.0 TEST RESULTS

The average emission results in pounds per pound (lbs/lb) of binder and pounds per ton (lbs/ton) of metal for individual target analytes and emission indicators are presented in Tables 3-1a and 3-1b. In addition, these tables also include the percent change in emissions from Test GY (the baseline

Table 3-1a Summary of Top 95% of Emission Averages - Lb/Tn Metal

	Reference Test GY Average	GX Average	Pct Change
Emission Indicators			
TGOC as Propane	1.0321	0.7994	-23
HC as Hexane	0.5135	0.4013	-22
Sum of Target VOCs	0.4969	0.2657	-47
Sum of Target HAPs	0.4508	0.2098	-53
Sum of Target POMs	0.1602	0.0087	-95
Selected Target HAPs and POMs			
Phenol	0.1038	0.0368	-65
Benzene	0.0886	0.0654	-26
Methylnaphthalenes	0.0838	0.0017	-98
Naphthalene	0.0477	0.0068	-86
Cresols	0.0363	0.0096	-74
Aniline	0.0302	NT	NA
Dimethylnaphthalenes	0.0248	0.0002	-99
Toluene	0.0154	0.0203	32
Xylenes	0.0063	0.0073	17
Acetaldehyde	0.0054	0.0175	223
Styrene	0.0008	0.0035	336
Ethylbenzene	0.0006	0.0059	939
Propionaldehyde (Propanal)	0.0003	0.0085	2779
Acetophenone	NT	0.0090	NA
Cumene	NT	0.0153	NA
Additional Selected Target VOCs			
Trimethylbenzenes	0.0130	0.0036	-72
Dimethylphenols	0.0109	NA	NA
Octane	0.0074	NA	NA
Pentanal (Valeraldehyde)	0.0001	0.0033	2958
Hexaldehyde	<0.0001	0.0139	NA
1,6-Hexanediol diacrylate	NT	0.0128	NA
Trimethylol Propane Triacrylat	NT	0.0149	NA
Criteria Pollutants and Greenhouse Gases			
Carbon Dioxide	NA	3.7899	NA
Carbon Monoxide	1.8376	1.8916	3
Nitrogen Oxides	0.0087	0.0022	-75
Sulfur Dioxide	0.0084	0.0185	120

Selected results constitute >95% of mass of all detected target VOCs for GY/GX
Names in Italics are not included in top 95% of VOC mass for Reference Test GY.
Bold numbers=compounds whose calculated t-statistic is significant at alpha=0.05
<0.0001=less than reporting limit of 0.0001 lb/tn metal
NA=Not Applicable; Not Available
NT=Not Tested
Numbers are calculated with full precision to avoid rounding errors.

Table 3-1b Summary of Top 95% of Emission Averages – Lb/Lb Binder

	Reference Test GY Average	GX Average	Pct Change
Emission Indicators			
TGOC as Propane	0.1537	0.1422	-8
HC as Hexane	0.0765	0.0708	-7
Sum of Target VOCs	0.0662	0.0472	-29
Sum of Target HAPs	0.0601	0.0369	-38
Sum of Target POMs	0.0211	0.0015	-93
Selected Target HAPs and POMs			
Phenol	0.0137	0.0065	-53
Methylnaphthalenes	0.0124	0.0003	-98
Benzene	0.0117	0.0115	-2
Naphthalene	0.0063	0.0012	-81
Cresols	0.0054	0.0017	-69
Aniline	0.0045	NT	NA
Dimethylnaphthalenes	0.0037	<0.0001	NA
Toluene	0.0020	0.0036	76
Xylenes	0.0009	0.0013	39
Acetaldehyde	0.0008	0.0031	282
Styrene	0.0001	0.0006	485
Ethylbenzene	0.0001	0.0010	1287
Propionaldehyde (Propanal)	<0.0001	0.0015	NA
Acetophenone	NT	0.0016	NA
Cumene	NT	0.0027	NA
Additional Selected Target VOCs			
Trimethylbenzenes	0.0019	0.0006	-66
Dimethylphenols	0.0016	NA	NA
Hexaldehyde	<0.0001	0.0025	NA
1,6-Hexanediol diacrylate	NT	0.0027	NA
Trimethylol Propane Triacrylat	NT	0.0026	NA
Criteria Pollutants and Greenhouse Gases			
Carbon Monoxide	0.2739	0.3373	23
Nitrogen Oxides	0.0013	0.6753	-70
Sulfur Dioxide	0.0013	0.0004	165
Carbon Dioxide	NA	0.0033	NA

Selected results constitute >95% of mass of all detected target VOCs for GY/GX
Names in Italics are not included in top 95% of VOC mass for Reference Test GY.
Bold numbers=compounds whose calculated t-statistic is significant at alpha=0.05
<0.0001=less than reporting limit of 0.0001 lb/tn metal
NA=Not Applicable; Not Available
NT=Not Tested
Numbers are calculated with full precision to avoid rounding errors.

test) to test GX. These tables include the individual target compounds or isomer classes that comprise at least 95% of the total targeted VOCs measured for either test, as well as the "Sum of Target VOCs", the "Sum of Target HAPs", and the "Sum of Target POMs". These three analyte sums are part of a group termed "Emission Indicators". Two other combinations of hydrocarbon emissions included in this group and reported in the tables are TGOC as propane and HC as hexane. Additionally, average values for selected criteria and greenhouse gases such as carbon monoxide, carbon dioxide, sulfur dioxide and nitrogen oxides are given.

Compounds that are structural isomers have been grouped together and are reported as a single isomer class. For example: ortho-, meta-, and para-xylene are the three structural isomers of dimethyl benzene and their sum is reported as xylenes. All other isomers are 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 methane, the single carbon alkane (C_1), with results calibrated against propane, which is the three-carbon alkane (C_3). Results reported from this method therefore include methane, which is an exempted compound and whose contribution has not been determined. 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 (C_6).

The emissions indicator called the "Sum of Target VOCs" is the sum of all individual target VOCs detected and includes compounds which may also be defined as HAPs and POMs. 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 and boiling point. 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.

On December 19, 2005 the EPA amended the list of HAPs by removing methyl ethyl ketone (also known as MEK or 2-Butanone). Although this compound was removed from the federal list of hazardous air pollutants, it may still be regulated as such by individual states. Therefore, it is still reported as a HAP in the tables and appendices of this report as both a single analyte and as a contributor to the "Sum of HAPs" emission indicator.

Figures 3-1 to 3-3 present a graphical depiction comparing the five emissions indicators as well as selected individual HAP, VOC, and criteria pollutant and greenhouse gas emissions data from Test GY to Test GX given in Tables 3-1a and 3-1b.

Figure 3-1a Emissions Indicators Comparison, GX to GY, Average Results – Lb/Tn Metal

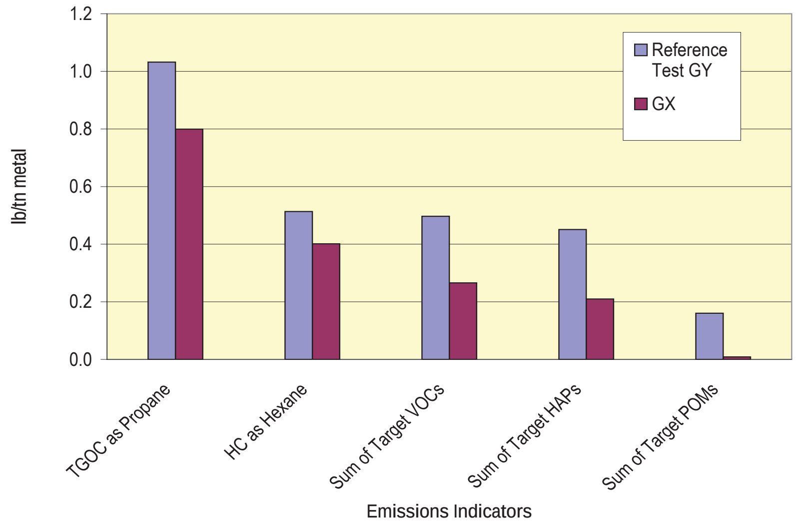


Figure 3-1b Emissions Indicators Comparison, GX to GY, Average Results – Lb/Lb Binder

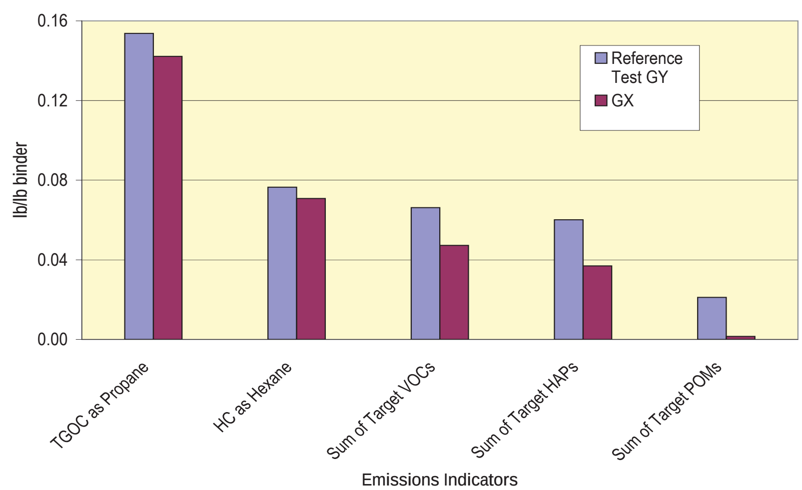


Figure 3-2a Selected HAP and VOC Emissions Comparison, GX to GY, Average Results – Lb/Tn Metal

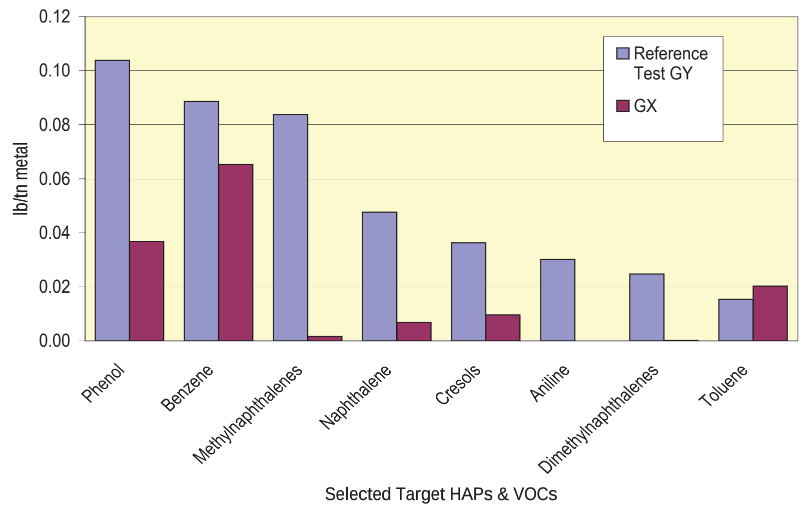


Figure 3-2b Selected HAP and VOC Emissions Comparison, GX to GY, Average Results – Lb/Lb Binder

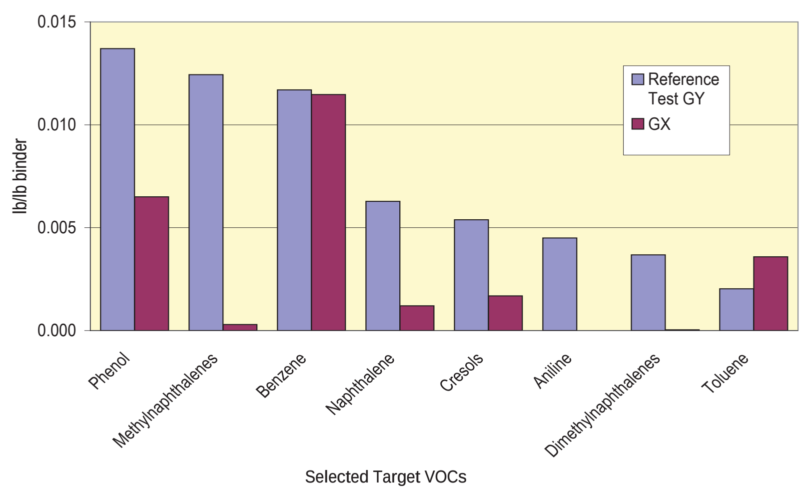


Figure 3-3a Criteria Pollutants and Greenhouse Gases Comparison, GX to GY, Average Results – Lb/Tn Metal

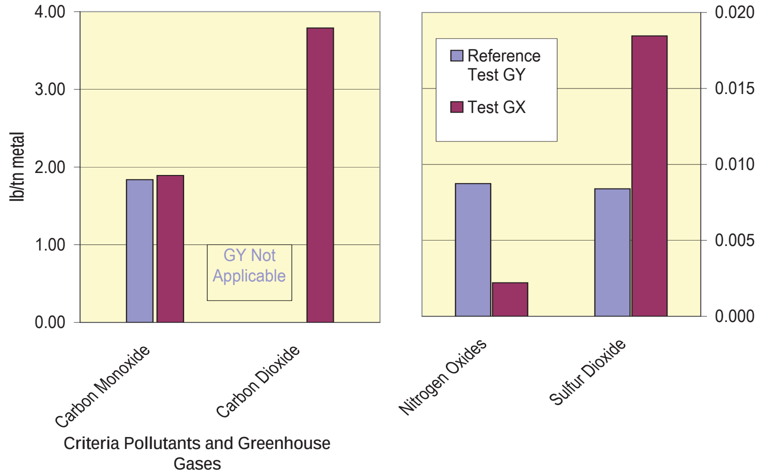


Figure 3-3b Criteria Pollutants and Greenhouse Gases Comparison, GX to GY, Average Results – Lb/Lb Binder

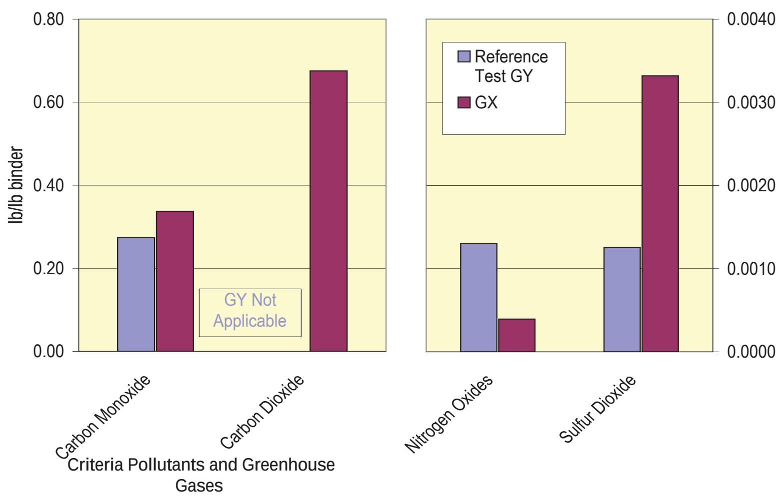


Table 3-2 includes the averages of the key process parameters.

Table 3-2 Summary of Test Plan Process Parameters

Greensand PCS with Epoxy Acrylic Cores	Baseline Test GY	Product Test GX
Test Dates	10/04/05-10/07/05	11/7/05-11/10/05
Cast Weight, Lbs.	116.3	119.2
Pouring Time, sec.	11	12
Pouring Temp ,°F	2633	2632
Pour Hood Process Air Temp at Start of Pour, °F	87	87
Mixer auto dispensed batch weight, Lbs	50.2	50.0
Dispensed core binder part I weight, g	175.4	177.3
Dispensed core binder part II weight, g	143.2	95.2
Total Dispensed core binder weight, g	318.6	272.4
% core binder (BOS)	1.40	1.20
% core binder actual	1.38	1.19
Total uncoated core weight in mold, Lbs	28.3	28.3
Total binder weight in mold, Lbs	0.390	0.335
Core LOI, %	1.12	1.31
Core dogbone tensile, psi	261.7	213.1
Core age, hrs.	68.9	1028.2
Muller Batch Weight, Lbs.	903	898
GS Mold Sand Weight, Lbs.	642	640
Mold compactability, %	56	56
Mold Temperature,°F	85	81
Average Green Compression , psi	22.6	20.0
GS Compactability, %	42	43
GS Moisture Content, %	2.01	1.86
GS MB Clay Content, %	7.2	6.9
MB Clay reagent, ml	37.4	35.2
1800°F LOI - Mold Sand, %	0.80	0.84
900°F Volatiles , %	0.41	0.34
Permeability index	229	216
Sand Temperature, °F	86	83

The comparative ranking of casting appearance for each casting made with coated cores used in the three conditioning runs for GX and GY is shown in Table 3-3. Each of the four castings from the molds of the three conditioning runs was assessed and compared relative to each other. Three benchmark visual casting quality rankings consisting of the best, the median, and the worst casting are assigned to three of the castings. The "best" designation means that a casting is the best appearing casting of the lot of twelve, and is given an in-series rank of "1". The "median" designation, given an in-series rank of "6", means that five castings are better in appearance and six are worse. The "worst" designation is assigned to that casting which is of the poorest quality, and is assigned an in-series rank of "12". The remaining castings are then compared to these three benchmarks. The three-benchmark castings from Test GY then were compared and collated to the benchmark castings from Test GX. Castings from the conditioning runs are used for surface finish quality comparisons only. No emissions from these runs were sampled and are therefore not included in the emission results reported here.

Table 3-3 Casting Quality Rank Order

Rank Order	Mold Number	Cavity Number	Baseline Test GY	Test GX
1	GYCR2	2	Best	
2	GXCR3	1		Best
3	GXCR2	1		
4	GXCR2	3		
5	GXCR3	2		
6	GYCR2	4	Median	
7	GXCR3	3		
8	GXCR3	4		Median
9	GXCR2	4		
10	GXCR2	2		
11	GXCR1	2		
12	GYCR3	2	Worst	
13	GXCR1	3		
14	GXCR1	4		
15	GXCR1	1		Worst

The four appendices in this report contain detailed information regarding testing and sampling, and data and results for each sampling event. Appendix A contains test plans, instructions and the sampling plan for Test GX. Appendix B contains detailed emissions data and average results for all targeted analytes. Target analyte reporting limits expressed in both pounds per pound of binder and pounds per ton of metal are also shown in Appendix B. These values are based on the practical quantitation limit which is related to the detection limitations of an analytical method and the capabilities of analytical instrumentation. Appendix C contains detailed process data and the pictorial casting record. Appendix D contains continuous monitor charts. The charts are presented to show time-dependent emissions profiles for TGOC, carbon monoxide, carbon dioxide, and oxides of nitrogen for each pour. Appendix E contains acronyms and abbreviations.

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4.0 DISCUSSION OF RESULTS

The chemical compounds targeted for collection and analysis were based on the chemistry of the binder and were identical for Test GX to those of baseline Test GY except for aniline and dimethyl-aniline in the binder used in Test GY, and the presence of trimethylol propane triacrylate, acetophenone, cumene, 1,6-hexanediol diacrylate and phenyl isopropyl alcohol in the binder used for Test GX. The binder content of PCS baseline Test GY was nominally 1.4 % (BOS) and TEA activated whereas Test GX binder content was 1.20% and activated with SO_2. These differences need to be taken into consideration when comparing the emissions between the tests.

A determination of whether the means of the baseline test and the current test were different was made by calculating a statistical T-test at a 95% significance level (α=0.05). Results at this significance level for the T-test indicate that there is a 95% probability that the mean values for GX are not equivalent to those of GY. Therefore, it may be said that the differences in the average emission values are real differences, and not due to test, sampling, or analysis methodologies.

The comparisons between Emissions Indictor results of the current test to the baseline test show reductions in emissions of 23% for TGOC as propane, 22% in HC as hexane, a 47% reduction in the Sum of Target VOCs, a 53% reduction in the Sum of Target HAPs, and a 95% reduction in the Sum of Target POMs when calculated as lb/ton metal. There was a general decrease in emissions in the targeted VOCs from GY to GX samples, although there were increases in some of the lesser contributing analytes, especially those near the reporting limit.

Seventeen (17) targeted analytes and isomer classes accounted for more than 95% of the concentration in lb/ton metal of all targeted VOCs detected from Test GX as can be seen in Table 3-1a. Benzene and phenol accounted for 25% and 14%, respectively, while the remaining 15 analytes contributed less than 8% each. Results for lb/lb binder can be found in Table 3-1b.

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APPENDIX A TEST & SAMPLE PLANS AND PROCESS INSTRUCTIONS

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TECHNIKON TEST PLAN

- **CONTRACT NUMBER:** 1412 **TASK NUMBER:** 1.1.2 **SERIES:** GX
- **SITE:** Research Foundry
- **TEST TYPE:** Pouring, cooling, shakeout: Uncoated Epoxy-Acrylic Cold Box Core in Greensand.
- **METAL TYPE:** Class 30, gray iron.
- **MOLD TYPE:** 4-on step-cored greensand with no seacoal.
- **NUMBER OF MOLDS:** 3 engineering/conditioning + 9 Sampling.
- **CORE TYPE:** Step: 1.2% (BOS) HA International Bakelite 7181 GK01/02 in a 65/35 ratio SO_2 activated. Wexford 465/463 sand.
- **CORE COATING:** HA International 04-4900 Technikoat for GXER1 to GXER3, none for production runs GX004-GX009.
- **SAMPLE EVENTS:** 9
- **ANALYTE LIST:** List G, CO/CO_2, NO_x, TGOC, Two other analytes from OSHA 55 which are Trimethylolpropane triacrylate and 1,6 Hexandiol diacrylate. Note that SO_2 is being routinely analyzed using OSHA ID200 method for all tests under the 1412 contract.
- **TEST DATE:** **START**: 07 Nov 2005
  FINISHED: 10 Nov 2005

TEST OBJECTIVES:

Measure selected PCS HAP & VOC emissions, CO, CO_2, NO_x, and TGOC from HA International Bakelite 7181 GK01/02 core binder activated with SO_2 in greensand with no seacoal.

VARIABLES:

The pattern will be the 4-on step core. The mold will be made with Wexford W450 sand, western and southern bentonite in a 5:2 ratio to yield 7.0 +/- 0.5% MB Clay, no seacoal, and tempered to 40-45% compactability, mechanically compacted. The molds will be maintained at 70-90^{o}F prior to pouring. The sand heap will be maintained at 900 pounds. Molds will be poured with iron at 2630 +/- 10^{o}F. Mold cooling will be 45 minutes followed by 15 minutes of shakeout, or until no more material remains to be shaken out, followed by 15 minutes additional sampling for a total of 75 minutes.

BRIEF OVERVIEW:

These greensand molds will be produced on mechanically assisted Osborne molding machines. (Ref. CERP test FH). The 4-on step-core standard mold is a 24 x 24 x 10/10 inch 4-on array of standard AFS drag only step core castings to compare to the cold box baseline GY. The cores will be manufactured at Technikon.

SPECIAL CONDITIONS:

The process will include rigorous maintenance of the size of sand heap and maintenance of the material and environmental testing temperatures to reduce seasonal and daily temperature dependent influence on the emissions. Initially a 1200 pound greensand heap will be created from a single muller batch. Nine hundred pounds will become the re-circulating heap. The balance will be used to makeup for attrition. Cores will be produced with Wexford 465/463 silica sand. The cores shall be bagged in plastic. The dipped and dried cores will be bagged in plastic as soon as sufficiently cooled. The cores will be approximately 8 weeks old when tested. The cores for the engineering runs GXCR1-3 will be dipped to provide 12 castings with an internal surface to be compared to the best, average, and worst of phenolic urethane baseline GY.

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
CONDITIONING - 1											
THC, CO, CO2 & Nox	GX CR-1	X									TOTAL

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
CONDITIONING - 2											
THC, CO, CO2 & Nox	GX CR-2	X									TOTAL

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
CONDITIONING - 3											
THC, CO, CO2 & Nox	GX CR-3	X									TOTAL

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
THC, CO, CO2 & Nox	GX001	X									TOTAL
M-18	GX00101		1						60	1	Carbopak charcoal
M-18	GX00102				1				0		Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
OSHA 55	GX00103		1						500	4	100/50 mg XAD-7 (SKC 226-95)
OSHA 55	GX00104				1				0		100/50 mg XAD-7 (SKC 226-95)
	Excess								500	5	Excess
OSHA ID200	GX00105		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
OSHA ID200	GX00106				1				0		100/50 mg Carbon Bead (SKC 226-80)
	Excess								1000	7	
NIOSH 1500	GX00107		1						1000	8	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GX00108				1				0		100/50 mg Charcoal (SKC 226-01)
	Excess								1000	9	Excess
TO11	GX00109		1						1000	10	DNPH Silica Gel (SKC 226-119)
TO11	GX00110				1				0		DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments:
THC, CO, CO2 & Nox	GX002	X									TOTAL
M-18	GX00201		1						60	1	Carbopak charcoal
M-18	GX00202			1					60	2	Carbopak charcoal
	Excess								60	3	Excess
OSHA 55	GX00203		1						500	4	100/50 mg XAD-7 (SKC 226-95)
OSHA 55	GX00204			1					500	5	100/50 mg XAD-7 (SKC 226-95)
OSHA ID200	GX00205		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
OSHA ID200	GX00206			1					1000	7	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 1500	GX00207		1						1000	8	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	GX00208			1					1000	9	100/50 mg Charcoal (SKC 226-01)
TO11	GX00209		1						1000	10	DNPH Silica Gel (SKC 226-119)
TO11	GX00210			1					1000	11	DNPH Silica Gel (SKC 226-119)
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
THC, CO, CO2 & Nox	GX003	X									TOTAL
M-18	GX00301		1						60	1	Carbopak charcoal
M-18 MS	GX00302		1						60	2	Carbopak charcoal
M-18 MS	GX00303			1					60	3	Carbopak charcoal
OSHA 55	GX00304		1						500	4	100/50 mg XAD-7 (SKC 226-95)
	Excess								500	5	Excess
OSHA ID200	GX00305		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
	Excess								1000	7	Excess
NIOSH 1500	GX00306		1						1000	8	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	9	Excess
TO11	GX00307		1						1000	10	DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments:
THC, CO, CO2 & Nox	GX004	X									TOTAL
M-18	GX00401		1						60	1	Carbopak charcoal
M-18	GX00402					1			60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
OSHA 55	GX00403		1						500	4	100/50 mg XAD-7 (SKC 226-95)
	Excess								500	5	Excess
OSHA ID200	GX00404		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
	Excess								1000	7	Excess
NIOSH 1500	GX00405		1						1000	8	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	9	Excess
TO11	GX00406		1						1000	10	DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
THC, CO, CO2 & Nox	GX005	X									TOTAL
M-18	GX00501		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
OSHA 55	GX00502		1						500	4	100/50 mg XAD-7 (SKC 226-95)
	Excess								500	5	Excess
OSHA ID200	GX00503		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
	Excess								1000	7	Excess
NIOSH 1500	GX00504		1						1000	8	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	9	Excess
TO11	GX00505		1						1000	10	DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
THC, CO, CO2 & Nox	GX006	X									TOTAL
M-18	GX00601		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
OSHA 55	GX00602		1						500	4	100/50 mg XAD-7 (SKC 226-95)
	Excess								500	5	Excess
OSHA ID200	GX00603		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
	Excess								1000	7	Excess
NIOSH 1500	GX00604		1						1000	8	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	9	Excess
TO11	GX00605		1						1000	10	DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
THC, CO, CO2 & Nox	GX007	X									TOTAL
M-18	GX00701		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
OSHA 55	GX00702		1						500	4	100/50 mg XAD-7 (SKC 226-95)
	Excess								500	5	Excess
OSHA ID200	GX00703		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
	Excess								1000	7	Excess
NIOSH 1500	GX00704		1						1000	8	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	9	Excess
TO11	GX00705		1						1000	10	DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments:
THC, CO, CO2 & Nox	GX008	X									TOTAL
M-18	GX00801		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
OSHA 55	GX00802		1						500	4	100/50 mg XAD-7 (SKC 226-95)
	Excess								500	5	Excess
OSHA ID200	GX00803		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
	Excess								1000	7	Excess
NIOSH 1500	GX00804		1						1000	8	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	9	Excess
TO11	GX00805		1						1000	10	DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

RESEARCH FOUNDRY GX - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments:
THC, CO, CO2 & Nox	GX009	X									TOTAL
M-18	GX00901		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
OSHA 55	GX00902		1						500	4	100/50 mg XAD-7 (SKC 226-95)
	Excess								500	5	Excess
OSHA ID200	GX00903		1						1000	6	100/50 mg Carbon Bead (SKC 226-80)
	Excess								1000	7	Excess
NIOSH 1500	GX00904		1						1000	8	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	9	Excess
TO11	GX00905		1						1000	10	DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

Series GX

PCS Greensand Uncoated Core with HA International Bakelite 7181 GK01/02 Cold Box Core Binder & Mechanized Molding

Process Instructions

A. Experiment:

1. Measure emissions from a greensand mold, with SO_2 cured HA International Bakelite 7181 GK01/02 cores, made with all virgin Wexford W450 sand, bonded with Western & Southern Bentonite in the ratio of 5:2 to yield 7.0 +/- 0.5% MB Clay, & no seacoal. The molds shall be tempered with potable water to 40-45% compactability, poured at constant weight, temperature, surface area, & shape factor. This test will recycle the same mold material, replacing burned clay with new materials after each casting cycle and providing clay for the retained core sand.

B. Materials:

1. Mold sand:

a. Virgin mix of Wexford W450 lake sand, western and southern bentonites in ratio of 5:2, and potable water per recipe.

2. Core:

a. Uncoated step core made with virgin Wexford 465/463 silica sand and 1.2% (BOS) HA International binder Bakelite 7181 GK01/02 in a 65/35 ratio, SO_2 cured.

3. Core coating:

a. Engineering/conditioning runs GXCR1-3 only, none for runs GX001-9. HA International Technikoat® 04-4900.

4. Metal:

a. Class 30, gray cast iron poured at 2630 +/- 10°F.

5. Pattern release:

a. Black Diamond, hand wiped.

b. 20 ppi 2 x 2 x 0.5 ceramic foam filter.

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 Pre-production operating and safety instruction manual.

D. Cold box one-piece Step Cores:

1. Cores were manufactured at Technikon LLC for Test GX.

- **a.** After manufacture the cores were sealed in polyethylene bags, numbered and dated to relate to manufacturing process parameters recorded at that time.
- **b.** Dog bones will be made from the same binder and sand as the cores and tensile tested at a 2 hour increment.
- **c.** The sand lab will sample one (1) core from each mold produced just prior to the emission test to represent the four (4) cores placed in that mold. Those cores sampled will be tested for LOI using the standard 1800°F core LOI test method and reported out associated with the test mold it is to represent.

2. Core coating for runs GXCR-1 to GXCR-3.

- **a.** Store the client supplied core coating at 70-80ºF for 24 hours prior to use.
- **b.** Vigorously stir the client supplied core coating.
- **c.** Sample at least 100 cc of coating in a graduated cylinder to determine the bulk density and record. (Or use a specific gravity hydrometer).
- **d.** Measure and record the coating temperature.
- **e.** Dip the core in the tip-down position to within ½ inch of the blow end.
  - **1)** The tip of an un-dipped core can be used as a substitute for the LOI test sample for the engineering runs.
- **f.** Allow the coating to stop running and begin dripping, then shake the core a couple of times and set it aside tip up.
- **g.** Dry the coated core at 230ºF for 2 hours. Measure and record un-dipped and dried dipped weight.

Note:
Do not put undipped cores for production runs GX001-9 in the drying oven, as uncaptured emissions will result.

- **h.** Re-bag the cores.

E. Sand preparation

1. Start up batch: make 1, GCER1.

- **a.** Thoroughly clean the pre-production muller elevator and molding hoppers.
- **b.** Weigh and add 1130 +/-10 pounds of new Wexford W450 lake sand, per the recipe, to the running pre-production muller to make a 1200 batch.
- **c.** Add 5 pounds of potable water to the muller to suppress dust distributing it across the sand. Allow to mix for 1 minute.
- **d.** Add the clays slowly to the muller to allow them to be distributed throughout the sand mass in proportion to the sand weight per the recipe for this test.
- **e.** Dry mull for about 3 minutes to allow distribution and some grinding of the clays to occur.

- **f.** Temper the sand-clay mixture slowly, with potable water, to allow for distribution.
- **g.** After about 2 gallons of water have been added allow 30 seconds of mixing then start taking compactability test samples.
- **h.** Based on each test add water incrementally to adjust the temper. Allow 1 minute of mixing. Retest. Repeat until the compactability, as would be measured at the mold, is in the range 40-45%.
- **i.** Discharge the sand into the mold station elevator.
- **j.** Grab sufficient sample after the final compactability test to fill a quart zip-lock bag. Label bag with the test series and sequence number, date, and time of day and deliver it immediately to the sand lab for analysis
- **k.** Record the total sand mixed in the batch, the total of each type of clay added to the batch, the amount of water added, the final compactability and sand temperature at discharge into the mold. The sand will be characterized for Methylene Blue Clay, AFS clay, Moisture content, Compactability, Green Compression strength, Permeability 1800°F loss on ignition (LOI), and 900°F volatiles. Each volatile test requires a separate 50 gram sample from the collected sand. Each LOI test requires 3 separate 30 gram samples from the collected sand.
- **l.** Empty the extra greensand from the mold hopper into a clean empty dump hopper whose tare weight is known. Set this sand aside to be used to maintain the recycled batch at 900+/-10 pounds

2. Re-mulling: GXCR2

- **a.** Add to the sand recovered from poured mold GXCR1 sufficient pre-blended sand so that the sand batch weight is 900 +/- 10 pounds. Record the sand weight.
- **b.** Return the sand to the muller and dry blend for about one minute.
- **c.** Add the clays, as directed by the process engineering staff, slowly to the muller to allow them to be distributed throughout the sand mass.
- **d.** Add 5 pounds of water to the muller to suppress dust distributing it across the sand. Allow to mix for 1 minute.
- **e.** Follow the above procedure beginning at E.1.f.

3. Re-mulling: GXCR3, GX001-GX009

- **a.** Add to the sand recovered from the previous poured mold, mold machine spill sand, the residual mold hopper sand and sufficient pre-blended sand to total 900 +/- 10 pounds.
- **b.** Return the sand to the muller and dry blend for about one minute.
- **c.** Add the clays, as directed by the process engineering staff, slowly to the muller to allow them to be distributed throughout the sand mass.
- **d.** Add 5 pounds of water to the muller to suppress dust distributing it across the sand. Allow to mix for 1 minute.
- **e.** Follow the above procedure beginning at E.1.f.

F. Molding: Step core pattern.

1. Pattern preparation:
   a. Inspect and tighten all loose pattern and gating pieces.
   b. Repair any damaged pattern or gating parts.

2. Making the green sand mold.
   a. Mount the drag pattern on one Osborne Whisper Ram molding machine and mount the cope pattern on the other Osborne machine.
   b. Lightly rub parting oil from a damp oil rag on the pattern particularly in the corners and recesses.

Caution:
Do not pour gross amounts of parting oil on the pattern to be blown off with air. This practice will leave sufficient oil at the parting line to be adsorbed by the sand weakening it and the burning oil will be detected by the emission samplers.

3. Use the overhead crane to place the pre-weighed drag/cope flask on the mold machine table, parting line surface down.
4. Locate a 24 x 24 x 4 inch deep wood upset on top of the flask.
5. Make the green sand mold cope or drag on the Osborn Whisper Ram Jolt-Squeeze mold machine.

WARNING
Only properly trained personnel may operate this machine.
Proper personal protective equipment must be worn at all times while operating this equipment, including safety glasses with side shields and a properly fitting hard hat. Industrial type boots are highly recommended.

WARNING
Stand clear of the mold machine table and swinging head during the following operation or serious injury or death could result.

   a. Open the air supply to the mold machine.

WARNING
The squeeze head may suddenly swing to the outboard side or forward. Do not stand in the outer corners of the molding enclosure.

   b. Turn the RAM-JOLT-SQUEEZE switch to ON.
   c. Turn the DRAW UP switch to AUTO.
   d. Set the PRE-JOLT timer to 4-5 seconds.
   e. Set the squeeze timer to 8 seconds.
   f. On the operator’s panel turn the POWER switch to ON

g. Set the crow-footed gagger on the support bar. Verify that it is at least ½ inch away from any pattern parts.
h. Manually spread one to two inches or so of sand over the pattern using a shovel. Source the sand from the overhead mold sand hopper by actuating the hopper gate valve with the lever located under the operators panel.
i. Fill the center potion of the flask.
j. Manually move sand from the center portion to the outboard areas and hand tuck the sand.
k. Finish filling the 24 x 24 x 10 inch flask and the upset with greensand from the overhead molding hopper.
l. Manually level the sand in the upset. By experience manually adjust the sand depth so that the resulting compacted mold is fractionally above the flask only height.
m. The operator will grab a sand sample for the Lab. The sand technician will quickly measure the sand temperature and compactability and record the results.
n. Initiate the settling of the sand in the flask by pressing the PRE-JOLT push button. Allow this cycle to stop before proceeding.
o. Remove the upset and set it aside.

WARNING
Failure to stand clear of the molding table and flasks in the following operations could result in serious injury as this equipment is about to move up and down with great force.

WARNING
Stand clear of the entire mold machine during the following operations.
Several of the machine parts will be moving.
Failure to stand clear could result in severe injury even death.

p. Using both hands initiate the automatic machine sequence by simultaneously pressing, holding for 2-3 seconds, and releasing the green push buttons on either side of the operators panel. The machine will squeeze and jolt the sand in the flask and then move the squeeze head to the side.

WARNING
Do no re-approach the machine until the squeeze head has stopped at the side of the machine.

q. Screed the bottom of the drag mold flat to the bottom of the flask if required.
r. Press and release the LOWER DRAW/STOP push button to separate the flask and mold from the pattern.
s. Use the overhead crane to lift the mold half and remove it from the machine. If the mold half is a drag, roll it parting line side up, set it on the floor, blow it out.
t. Finally, press and release the DRAW DOWN pushbutton to cause the draw frame to

return to the start position.

6. Set four (4) step cores that have been weighed and logged into the drag. Verify that the cores are fully set and flush with the parting line.
7. Place a 20 ppi filter into the mold.
8. Close the cope over the drag being careful not to crush anything.
9. Clamp the flask halves together.
10. Weigh and record the weight of the closed un-poured mold, the pre-weighed flask, the uncoated cores, and the sand weight by difference.
11. Measure and record the sand temperature.
12. Deliver the mold to the previously cleaned shakeout to be poured.
13. Cover the mold with the emission hood.

G. Pig molds

1. Each day make a 900 pound capacity pig mold for the following day's use.

H. Emission hood:

1. Loading.
   - **a.** Hoist the mold onto the shakeout deck within the emission hood.
   - **b.** Close, seal, and lock the emission hood.
   - **c.** Adjust the ambient air heater control so that the measured temperature of the blended air within the hood is 85-90°F at the start of the test run.

2. Shakeout.
   - **a.** After the 45 minute cooling time prescribed in the emission sample plan has elapsed turn on the shakeout unit and run for it the 15 minutes prescribed in the emission sample plan or until the sand has all fallen through the grating.
   - **b.** Turn off the shakeout.
   - **c.** Sample the emissions for 30 minutes after the start of shakeout, a total of 75 minutes.

3. When the emission sampling is completed remove the flask, with casting, and recover the sand from the hopper and surrounding floor.
   - **a.** Weigh and record the metal poured and the total sand weight recovered and rejoined with the left over mold sand from the molding hopper, spilled molding sand, and sand loosely adhered to the casting.
   - **b.** Add sufficient unused premixed sand to the recycled sand to return the sand heap to 900 +/- 10 pounds.

I. Melting:

1. Initial iron charge:
   - **a.** Charge the furnace according to the heat recipe.
   - **b.** Place part of the steel scrap on the bottom, followed by carbon alloys, and the balance

of the steel.
- **c.** Place a pig on top of the other materials.
- **d.** Bring the furnace contents to the point of beginning to melt over a period of 1 hour at reduced power.
- **e.** Add the balance of the metallics under full power until all is melted and the temperature has reached 2600 to 2700°F.
- **f.** Slag the furnace and add the balance of the alloys.
- **g.** Raise the temperature of the melt to 2700°F and take a DataCast 2000 sample. The temperature of the primary liquidus (TPL) must be in the range of 2200-2350°F.
- **h.** Hold the furnace at 2500-2550°F until near ready to tap.
- **i.** When ready to tap raise the temperature to 2700°F and slag the furnace.
- **j.** Record all metallic and alloy additions to the furnace, tap temperature, and pour temperature. Record all furnace activities with an associated time.

2. Back charging.
- **a.** Back charge the furnace according to the heat recipe.
- **b.** Charge a few pieces of steel first to make a splash barrier, followed by the carbon alloys.
- **c.** Follow the above steps beginning with I.1.e

3. Emptying the furnace.
- **a.** Pig the extra metal only after the last emission measurement is complete to avoid contaminating the air sample.
- **b.** Cover the empty furnace with ceramic blanket to cool.

J. Pouring:

1. Preheat the ladle.
- **a.** Tap 400 pounds more or less of 2700°F iron into the cold ladle.
- **b.** Carefully pour the metal back into the furnace.
- **c.** Cover the ladle.
- **d.** Reheat the metal to 2780 +/- 20°F.
- **e.** Tap 450 pounds of iron into the ladle while pouring inoculating alloys onto the metal stream near its base.
- **f.** Cover the ladle to conserve heat.
- **g.** Move the ladle to the pour position and wait until the metal temperature reaches 2630 +/- 10°F.
- **h.** Commence pouring keeping the sprue full.
- **i.** Upon completion, return the extra metal to the furnace and cover the ladle.
- **j.** Record the pour temperature and pour time on the heat log.

K. Rank order evaluation.

1. The supervisor shall select a group of up to five persons to make a collective subjective judgment of the casting relative surface appearance.

2. The rank order evaluation for cored castings shall be done on casting from the Engineering/ conditioning runs GXCR1-3, with coated cores, only.
3. Review the general appearance of the interior of the castings and select specific casting features to compare.
4. For each cavity 1-4:
   a. Place each casting in sequential mold number order.
   b. Beginning with the casting from mold GXCR1, compare it to castings from mold GXCR2.
   c. Place the better appearing casting in the first position and the lesser appearing casting in the second position.
   d. Repeat this procedure with GXCR1 to its nearest neighbors until all castings closer to the beginning of the line are better appearing than GXCR1 and the next casting farther down the line is inferior.
   e. Repeat this comparison to next neighbors for each casting number.
   f. When all casting numbers have been compared, go to the beginning of the line and begin again comparing each casting to its nearest neighbor. Move the castings so that each casting is inferior to the next one closer to the beginning of the line and superior to the one next toward the tail of the line.
   g. Repeat this comparison until all concur with the ranking order.

5. Record mold number by rank-order series for this cavity.
6. Compare GXCR1-3 all cavities to those in test GY.

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Project Engineer

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APPENDIX B DETAILED EMISSION RESULTS AND QUANTITATION LIMITS

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Detailed Emission Results - Lb/Tn Metal

VOC	POM	HAP		GX001	GX002	GX003	GX004	GX005	GX006	GX007	GX008	GX009	Average	Standard Deviation
				8-Nov-05	8-Nov-05	8-Nov-05	9-Nov-05	9-Nov-05	9-Nov-05	10-Nov-05	10-Nov-05	10-Nov-05	—	—
			Emission Indicators											
			TGOC as Propane	7.81E-01	7.99E-01	7.17E-01	7.90E-01	8.38E-01	8.20E-01	8.78E-01	7.41E-01	8.31E-01	7.99E-01	4.95E-02
			HC as Hexane	3.67E-01	4.05E-01	I	3.91E-01	4.16E-01	4.16E-01	3.94E-01	I	4.21E-01	4.01E-01	1.90E-02
			Sum of Target VOCs	2.91E-01	2.38E-01	1.73E-01	2.49E-01	3.16E-01	2.66E-01	2.43E-01	2.75E-01	2.42E-01	2.66E-01	4.00E-02
			Sum of Target HAPs	2.29E-01	1.83E-01	1.27E-01	2.05E-01	2.57E-01	2.06E-01	1.87E-01	2.25E-01	1.97E-01	2.10E-01	3.62E-02
			Sum of Target POMs	8.67E-03	7.71E-03	7.80E-03	8.39E-03	9.76E-03	9.76E-03	8.58E-03	8.32E-03	9.14E-03	8.68E-03	7.50E-04
			Selected Target HAPs and POMs											
V		H	Benzene	9.55E-02	5.07E-02	I	6.27E-02	9.51E-02	4.53E-02	4.30E-02	8.58E-02	4.47E-02	6.54E-02	2.32E-02
V		H	Phenol	3.18E-02	3.29E-02	3.31E-02	3.17E-02	4.56E-02	4.56E-02	3.26E-02	3.76E-02	4.05E-02	3.68E-02	5.76E-03
V		H	Toluene	1.92E-02	1.91E-02	1.82E-02	2.06E-02	2.04E-02	2.04E-02	2.41E-02	1.89E-02	2.21E-02	2.03E-02	1.82E-03
V		H	Acetaldehyde	1.76E-02	1.67E-02	1.62E-02	2.03E-02	1.78E-02	1.78E-02	1.71E-02	1.67E-02	1.69E-02	1.75E-02	1.17E-03
V		H	Cumene	1.38E-02	1.40E-02	1.29E-02	1.72E-02	1.56E-02	1.56E-02	1.72E-02	1.44E-02	1.67E-02	1.53E-02	1.59E-03
V		H	Acetophenone	5.38E-03	7.57E-03	6.69E-03	8.02E-03	1.21E-02	1.21E-02	8.34E-03	9.04E-03	1.15E-02	8.98E-03	2.44E-03
V		H	Propionaldehyde (Propanal)	8.87E-03	8.50E-03	7.80E-03	9.41E-03	8.02E-03	8.02E-03	8.88E-03	8.56E-03	8.03E-03	8.46E-03	5.33E-04
V		H	Cresol, o-	6.15E-03	6.35E-03	6.73E-03	6.16E-03	8.78E-03	8.63E-03	4.66E-03	5.95E-03	8.43E-03	6.87E-03	1.43E-03
V	P	H	Naphthalene	6.73E-03	6.04E-03	6.18E-03	6.62E-03	7.61E-03	7.61E-03	6.77E-03	6.62E-03	7.24E-03	6.82E-03	5.60E-04
V		H	Xylene, mp-	5.54E-03	5.38E-03	5.22E-03	5.88E-03	6.49E-03	6.49E-03	7.05E-03	5.78E-03	6.72E-03	6.06E-03	6.46E-04
V		H	Ethylbenzene	5.46E-03	5.22E-03	5.30E-03	5.93E-03	6.15E-03	6.15E-03	6.44E-03	5.78E-03	6.50E-03	5.88E-03	4.74E-04
V		H	Styrene	3.32E-03	3.30E-03	3.10E-03	3.60E-03	3.71E-03	3.71E-03	3.83E-03	3.14E-03	I	3.46E-03	2.86E-04
V		H	Cresol, mp-	2.35E-03	2.71E-03	2.48E-03	2.24E-03	3.67E-03	3.45E-03	1.89E-03	2.38E-03	3.37E-03	2.73E-03	6.24E-04
V		H	Xylene, o-	1.14E-03	1.14E-03	1.14E-03	1.34E-03	1.29E-03	1.29E-03	1.48E-03	1.35E-03	1.39E-03	1.29E-03	1.21E-04
V		H	Hexane	2.57E-03	8.15E-04	I	8.78E-04	7.16E-04	7.16E-04	8.45E-04	7.18E-04	I	1.04E-03	6.80E-04
V	P	H	Methylnaphthalene, 2-	8.80E-04	7.50E-04	7.16E-04	8.04E-04	9.45E-04	9.45E-04	8.34E-04	8.58E-04	8.49E-04	8.42E-04	7.80E-05
V	P	H	Methylnaphthalene, 1-	8.22E-04	7.20E-04	7.05E-04	7.64E-04	9.51E-04	9.51E-04	7.67E-04	8.36E-04	8.38E-04	8.17E-04	8.92E-05
V		H	Formaldehyde	4.69E-04	6.39E-04	6.40E-04	3.88E-04	5.25E-04	5.25E-04	4.79E-04	3.30E-04	3.76E-04	4.86E-04	1.10E-04
V		H	Biphenyl	6.44E-04	6.57E-04	ND	ND	8.61E-04	8.23E-04	ND	6.45E-04	7.35E-04	4.85E-04	3.72E-04
V	P	H	Dimethylnaphthalene, 1,3-	2.36E-04	2.00E-04	1.95E-04	2.00E-04	2.60E-04	2.60E-04	2.05E-04	ND	2.20E-04	1.97E-04	7.82E-05
V		H	2-Butanone (MEK)	1.04E-03	ND	ND	ND	ND	ND	ND	ND	2.08E-04	1.39E-04	3.45E-04
V	P	H	Acenaphthalene	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 1,2-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 1,5-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 1,6-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 1,8-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 2,3-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 2,6-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 2,7-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Trimethylnaphthalene, 2,3,5-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V		H	Acrolein	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA

NT= Not Tested
ND= Not Detected
NA= Not Applicable
I=Invalidated Data

Detailed Emission Results - Lb/Tn Metal

VOC	POM	HAP		GX001	GX002	GX003	GX004	GX005	GX006	GX007	GX008	GX009	Average	Standard Deviation
				8-Nov-05	8-Nov-05	8-Nov-05	9-Nov-05	9-Nov-05	9-Nov-05	10-Nov-05	10-Nov-05	10-Nov-05	—	—
			Additional Selected Target VOCs											
V			Trimethylol Propane Triacrylate	1.71E-02	1.40E-02	1.33E-02	1.72E-02	1.64E-02	1.64E-02	1.23E-02	1.29E-02	1.46E-02	1.49E-02	1.90E-03
V			Hexaldehyde	1.45E-02	1.57E-02	1.00E-02	I	1.45E-02	1.45E-02	1.50E-02	1.34E-02	1.37E-02	1.39E-02	1.73E-03
V			1,6-Hexanediol diacrylate	1.63E-02	1.11E-02	1.04E-02	1.36E-02	1.33E-02	1.33E-02	1.35E-02	1.12E-02	I	1.28E-02	1.89E-03
V			Trimethylbenzene, 1,2,4-	3.96E-03	3.56E-03	3.79E-03	4.10E-03	4.41E-03	4.41E-03	4.24E-03	ND	4.21E-03	3.63E-03	1.39E-03
V			Pentanal (Valeraldehyde)	3.13E-03	3.13E-03	3.57E-03	3.56E-03	2.86E-03	2.86E-03	3.16E-03	4.05E-03	3.69E-03	3.34E-03	4.04E-04
V			Phenyl Isopropyl Alcohol	1.63E-03	2.11E-03	1.78E-03	2.20E-03	2.83E-03	2.83E-03	2.12E-03	2.25E-03	2.43E-03	2.24E-03	4.09E-04
V			Indene	2.27E-03	2.05E-03	2.08E-03	2.10E-03	2.45E-03	2.45E-03	2.17E-03	1.99E-03	2.39E-03	2.22E-03	1.77E-04
V			Benzaldehyde	1.12E-03	1.15E-03	ND	1.25E-03	7.73E-04	7.73E-04	1.02E-03	1.26E-03	1.34E-03	9.65E-04	4.15E-04
V			o,m,p-Tolualdehyde	8.47E-04	9.10E-04	6.30E-04	I	8.89E-04	8.89E-04	1.24E-03	7.78E-04	7.74E-04	8.69E-04	1.75E-04
V			Ethyltoluene, 3-	ND	ND	5.96E-04	7.07E-04	7.16E-04	7.16E-04	7.28E-04	6.62E-04	6.67E-04	5.32E-04	3.05E-04
V			Butyraldehyde/Methacrolein	7.93E-04	8.47E-04	ND	ND	4.10E-04	4.10E-04	7.04E-04	8.17E-04	7.24E-04	5.23E-04	3.37E-04
V			Crotonaldehyde	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Cyclohexane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Decane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Diethylbenzene, 1,3-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Dimethylphenol, 2,4-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Dimethylphenol, 2,6-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Dodecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Ethyltoluene, 2-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Heptane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Indan	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Nonane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Octane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Propylbenzene, n-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Tetradecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Trimethylbenzene, 1,2,3-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Trimethylbenzene, 1,3,5-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Undecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
			Criteria Pollutants and Greenhouse Gases											
			Carbon Dioxide	4.05E+00	2.76E+00	4.02E+00	4.13E+00	3.75E+00	4.03E+00	NT	NT	NT	3.79E+00	5.23E-01
			Carbon Monoxide	1.87E+00	1.79E+00	1.80E+00	2.05E+00	1.89E+00	1.95E+00	NT	NT	NT	1.89E+00	9.69E-02
			Sulfur Dioxide	1.82E-02	1.75E-02	1.71E-02	1.73E-02	1.81E-02	1.81E-02	1.72E-02	2.28E-02	1.97E-02	1.85E-02	1.80E-03
			Nitrogen Oxides	2.65E-03	1.98E-03	2.51E-03	2.32E-03	1.72E-03	2.06E-03	NT	NT	NT	2.21E-03	3.49E-04

NT= Not Tested
ND= Not Detected
NA= Not Applicable
I=Invalidated Data

Detailed Emission Results - Lb/Lb Binder

VOC	POM	HAP		GX001	GX002	GX003	GX004	GX005	GX006	GX007	GX008	GX009	Average	Standard Deviation
				8-Nov-05	8-Nov-05	8-Nov-05	9-Nov-05	9-Nov-05	9-Nov-05	10-Nov-05	10-Nov-05	10-Nov-05	—	—
			Emission Indicators											
			TGOC as Propane	1.38E-01	1.46E-01	1.31E-01	1.40E-01	1.50E-01	1.41E-01	1.57E-01	1.32E-01	1.44E-01	1.42E-01	8.43E-03
			HC as Hexane	6.38E-02	7.48E-02	I	6.86E-02	7.33E-02	7.33E-02	6.98E-02	I	7.20E-02	7.08E-02	3.77E-03
			Sum of Target VOCs	5.06E-02	4.40E-02	3.11E-02	4.38E-02	5.57E-02	4.65E-02	4.30E-02	4.81E-02	4.73E-02	4.72E-02	6.73E-03
			Sum of Target HAPs	3.99E-02	3.39E-02	2.28E-02	3.59E-02	4.53E-02	3.60E-02	3.31E-02	3.95E-02	3.37E-02	3.69E-02	6.17E-03
			Sum of Target POMs	1.51E-03	1.43E-03	1.40E-03	1.47E-03	1.72E-03	1.72E-03	1.52E-03	1.46E-03	1.56E-03	1.53E-03	1.19E-04
			Selected Target HAPs and POMs											
V		H	Benzene	1.66E-02	9.37E-03	I	1.10E-02	1.68E-02	7.72E-03	7.63E-03	1.50E-02	7.64E-03	1.15E-02	4.06E-03
V		H	Phenol	5.53E-03	6.08E-03	5.93E-03	5.55E-03	8.04E-03	8.04E-03	5.78E-03	6.59E-03	6.92E-03	6.50E-03	9.86E-04
V		H	Toluene	3.34E-03	3.53E-03	3.25E-03	3.61E-03	3.59E-03	3.59E-03	4.26E-03	3.31E-03	3.77E-03	3.58E-03	3.05E-04
V		H	Acetaldehyde	3.05E-03	3.09E-03	2.91E-03	3.55E-03	3.13E-03	3.13E-03	3.04E-03	2.93E-03	2.89E-03	3.08E-03	2.01E-04
V		H	Cumene	2.40E-03	2.58E-03	2.30E-03	3.02E-03	2.76E-03	2.76E-03	3.05E-03	2.52E-03	2.86E-03	2.69E-03	2.62E-04
V		H	Acetophenone	9.36E-04	1.40E-03	1.20E-03	1.41E-03	2.14E-03	2.14E-03	1.48E-03	1.58E-03	1.96E-03	1.58E-03	4.20E-04
V		H	Propionaldehyde (Propanal)	1.54E-03	1.57E-03	1.40E-03	1.65E-03	1.42E-03	1.42E-03	1.57E-03	1.50E-03	1.37E-03	1.49E-03	9.76E-05
V		H	Cresol, o-	1.07E-03	1.17E-03	1.20E-03	1.08E-03	1.55E-03	1.47E-03	8.25E-04	1.04E-03	1.44E-03	1.21E-03	2.37E-04
V	P	H	Naphthalene	1.17E-03	1.12E-03	1.11E-03	1.16E-03	1.34E-03	1.34E-03	1.20E-03	1.16E-03	1.24E-03	1.20E-03	8.73E-05
V		H	Xylene, mp-	9.63E-04	9.94E-04	9.35E-04	1.03E-03	1.14E-03	1.14E-03	1.25E-03	1.01E-03	1.15E-03	1.07E-03	1.06E-04
V		H	Ethylbenzene	9.50E-04	9.64E-04	9.50E-04	1.04E-03	1.09E-03	1.09E-03	1.14E-03	1.01E-03	1.11E-03	1.04E-03	7.23E-05
V		H	Styrene	5.77E-04	6.09E-04	5.54E-04	6.31E-04	6.55E-04	6.55E-04	6.79E-04	5.49E-04	I	6.14E-04	4.94E-05
V		H	Cresol, mp-	4.08E-04	5.01E-04	4.44E-04	3.92E-04	6.48E-04	5.88E-04	3.34E-04	4.17E-04	5.76E-04	4.79E-04	1.06E-04
V		H	Xylene, o-	1.99E-04	2.11E-04	2.05E-04	2.35E-04	2.28E-04	2.28E-04	2.62E-04	2.36E-04	2.38E-04	2.27E-04	1.94E-05
V		H	Hexane	4.47E-04	1.51E-04	I	1.54E-04	1.26E-04	1.26E-04	1.50E-04	1.26E-04	I	1.83E-04	1.17E-04
V	P	H	Methylnaphthalene, 2-	1.53E-04	1.39E-04	1.28E-04	1.41E-04	1.67E-04	1.67E-04	1.48E-04	1.50E-04	1.45E-04	1.49E-04	1.26E-05
V	P	H	Methylnaphthalene, 1-	1.43E-04	1.33E-04	1.26E-04	1.34E-04	1.68E-04	1.68E-04	1.36E-04	1.46E-04	1.43E-04	1.44E-04	1.47E-05
V		H	Formaldehyde	8.16E-05	1.18E-04	1.15E-04	6.81E-05	9.26E-05	9.26E-05	8.49E-05	5.78E-05	6.43E-05	8.61E-05	2.11E-05
V		H	Biphenyl	1.12E-04	1.21E-04	ND	ND	1.52E-04	1.40E-04	ND	1.13E-04	1.26E-04	8.49E-05	6.49E-05
V	P	H	Dimethylnaphthalene, 1,3-	4.10E-05	3.69E-05	3.50E-05	3.51E-05	4.59E-05	4.59E-05	3.64E-05	ND	3.76E-05	3.49E-05	1.37E-05
V		H	2-Butanone (MEK)	1.81E-04	ND	ND	ND	ND	ND	ND	ND	3.56E-05	2.41E-05	6.00E-05
V	P	H	Acenaphthalene	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 1,2-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 1,5-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 1,6-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 1,8-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 2,3-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 2,6-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Dimethylnaphthalene, 2,7-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V	P	H	Trimethylnaphthalene, 2,3,5-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V		H	Acrolein	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA

NT= Not Tested
ND= Not Detected
NA= Not Applicable
I=Invalidated Data

Detailed Emission Results - Lb/Lb Binder

VOC	POM	HAP		GX001	GX002	GX003	GX004	GX005	GX006	GX007	GX008	GX009	Average	Standard Deviation
				8-Nov-05	8-Nov-05	8-Nov-05	9-Nov-05	9-Nov-05	9-Nov-05	10-Nov-05	10-Nov-05	10-Nov-05	—	—
			Additional Selected Target VOCs											
V			1,6-Hexanediol diacrylate	2.84E-03	2.06E-03	1.86E-03	2.39E-03	2.34E-03	2.34E-03	2.39E-03	1.96E-03	5.94E-03	2.68E-03	1.25E-03
V			Trimethylol Propane Triacrylate	2.98E-03	2.60E-03	2.38E-03	3.02E-03	2.88E-03	2.88E-03	2.17E-03	2.25E-03	2.50E-03	2.63E-03	3.22E-04
V			Hexaldehyde	2.53E-03	2.90E-03	1.79E-03	I	2.56E-03	2.56E-03	2.65E-03	2.35E-03	2.34E-03	2.46E-03	3.24E-04
V			Trimethylbenzene, 1,2,4-	6.89E-04	6.58E-04	6.79E-04	7.19E-04	7.77E-04	7.77E-04	7.52E-04	ND	7.20E-04	6.41E-04	2.44E-04
V			Pentanal (Valeraldehyde)	5.45E-04	5.79E-04	6.39E-04	6.25E-04	5.04E-04	5.04E-04	5.60E-04	7.09E-04	6.31E-04	5.88E-04	6.82E-05
V			Phenyl Isopropyl Alcohol	2.84E-04	3.90E-04	3.19E-04	3.87E-04	4.99E-04	4.99E-04	3.75E-04	3.93E-04	4.16E-04	3.96E-04	7.11E-05
V			Indene	3.95E-04	3.80E-04	3.73E-04	3.69E-04	4.32E-04	4.32E-04	3.84E-04	3.49E-04	4.08E-04	3.91E-04	2.84E-05
V			Benzaldehyde	1.95E-04	2.13E-04	ND	2.20E-04	1.36E-04	1.36E-04	1.80E-04	2.20E-04	2.29E-04	1.70E-04	7.26E-05
V			o,m,p-Tolualdehyde	1.47E-04	1.68E-04	1.13E-04	I	1.57E-04	1.57E-04	2.19E-04	1.36E-04	1.32E-04	1.54E-04	3.17E-05
V			Ethyltoluene, 3-	ND	ND	1.07E-04	1.24E-04	1.26E-04	1.26E-04	1.29E-04	1.16E-04	1.14E-04	9.36E-05	5.35E-05
V			Butyraldehyde/Methacrolein	1.38E-04	1.56E-04	ND	ND	7.23E-05	7.23E-05	1.25E-04	1.43E-04	1.24E-04	9.23E-05	5.98E-05
V			Crotonaldehyde	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Cyclohexane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Decane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Diethylbenzene, 1,3-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Dimethylphenol, 2,4-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Dimethylphenol, 2,6-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Dodecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Ethyltoluene, 2-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Heptane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Indan	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Nonane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Octane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Propylbenzene, n-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Tetradecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Trimethylbenzene, 1,2,3-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Trimethylbenzene, 1,3,5-	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
V			Undecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA
			Criteria Pollutants and Greenhouse Gases											
			Sulfur Dioxide	3.17E-03	3.23E-03	3.07E-03	3.04E-03	3.20E-03	3.20E-03	3.05E-03	3.99E-03	3.36E-03	3.32E-03	3.26E-04
			Carbon Monoxide	3.29E-01	3.26E-01	3.28E-01	3.65E-01	3.40E-01	3.36E-01	NT	NT	NT	3.37E-01	1.43E-02
			Carbon Dioxide	7.14E-01	I	7.33E-01	7.35E-01	6.73E-01	6.95E-01	NT	NT	NT	6.75E-01	8.79E-02
			Nitrogen Oxides	4.67E-04	3.62E-04	4.58E-04	4.12E-04	3.09E-04	3.55E-04	NT	NT	NT	3.94E-04	6.25E-05

NT= Not Tested
ND= Not Detected
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I=Invalidated Data

Practical Reporting Limit - Lb/Tn Metal

Analyte	Lb/Tn Metal	Analyte	Lb/Tn Metal
Carbon Monoxide	2.77E-02	Ethyltoluene, 2-	1.79E-04
Carbon Dioxide	4.35E-02	Ethyltoluene, 3-	8.96E-04
Nitrogen Oxides	2.97E-02	Formaldehyde	1.72E-04
1,6-hexanediol diacrylate	3.09E-03	Heptane	8.96E-04
2-Butanone (MEK)	1.72E-04	Hexaldehyde	4.59E-04
Acenaphthalene	8.96E-04	Hexane	1.79E-04
Acetaldehyde	1.72E-04	Indan	8.96E-04
Acetone	1.72E-04	Indene	8.96E-04
Acetophenone	1.07E-03	Methylnaphthalene, 1-	1.79E-04
Acrolein	1.72E-04	Methylnaphthalene, 2-	1.79E-04
Benzaldehyde	2.87E-04	Naphthalene	1.79E-04
Benzene	1.79E-04	Nonane	8.96E-04
Biphenyl	8.96E-04	o,m,p-Tolualdehyde	1.72E-04
Butyraldehyde/Methacrolein	1.72E-04	Octane	8.96E-04
Cresol, mp-	8.96E-04	Pentanal (Valeraldehyde)	1.72E-04
Cresol, o-	8.96E-04	Phenol	8.96E-04
Crotonaldehyde	1.72E-04	Phenyl Isopropyl Alcohol	5.33E-03
Cumene	1.07E-03	Propionaldehyde (Propanal)	1.72E-04
Cyclohexane	8.96E-04	Propylbenzene, n-	8.96E-04
Decane	8.96E-04	Styrene	1.79E-04
Diethylbenzene, 1,3-	8.96E-04	Sulfur Dioxide	4.05E-03
Dimethylnaphthalene, 1,2-	8.96E-04	Tetradecane	8.96E-04
Dimethylnaphthalene, 1,3-	1.79E-04	THC as Undecane	8.96E-04
Dimethylnaphthalene, 1,5-	8.96E-04	THCs as n-Hexane	5.33E-03
Dimethylnaphthalene, 1,6-	8.96E-04	Toluene	1.79E-04
Dimethylnaphthalene, 1,8-	8.96E-04	Trimethylbenzene, 1,2,3-	1.79E-04
Dimethylnaphthalene, 2,3-	8.96E-04	Trimethylbenzene, 1,2,4-	1.79E-04
Dimethylnaphthalene, 2,6-	8.96E-04	Trimethylbenzene, 1,3,5-	1.79E-04
Dimethylnaphthalene, 2,7-	8.96E-04	Trimethylnaphthalene, 2,3,5-	8.96E-04
Dimethylphenol, 2,4-	8.96E-04	Trimethylol Propane Triacrylate	3.09E-03
Dimethylphenol, 2,6-	8.96E-04	Undecane	1.79E-04
Dodecane	8.96E-04	Xylene, mp-	1.79E-04
Ethylbenzene	1.79E-04	Xylene, o-	1.79E-04

Practical Reporting Limit - Lb/Lb Binder

Analyte	Lb/Lb Binder	Analyte	Lb/Lb Binder
Carbon Monoxide	4.85E-03	Ethyltoluene, 2-	2.01E-05
Carbon Dioxide	7.62E-03	Ethyltoluene, 3-	1.00E-04
Nitrogen Oxides	5.20E-03	Formaldehyde	1.93E-05
1,6-hexanediol diacrylate	3.46E-04	Heptane	1.00E-04
2-Butanone (MEK)	1.93E-05	Hexaldehyde	5.14E-05
Acenaphthalene	1.00E-04	Hexane	2.01E-05
Acetaldehyde	1.93E-05	Indan	1.00E-04
Acetone	1.93E-05	Indene	1.00E-04
Acetophenone	1.19E-04	Methylnaphthalene, 1-	2.01E-05
Acrolein	1.93E-05	Methylnaphthalene, 2-	2.01E-05
Benzaldehyde	3.21E-05	Naphthalene	2.01E-05
Benzene	2.01E-05	Nonane	1.00E-04
Biphenyl	1.00E-04	o,m,p-Tolualdehyde	1.93E-05
Butyraldehyde/Methacrolein	1.93E-05	Octane	1.00E-04
Cresol, mp-	1.00E-04	Pentanal (Valeraldehyde)	1.93E-05
Cresol, o-	1.00E-04	Phenol	1.00E-04
Crotonaldehyde	1.93E-05	Phenyl Isopropyl Alcohol	5.97E-04
Cumene	1.19E-04	Propionaldehyde (Propanal)	1.93E-05
Cyclohexane	1.00E-04	Propylbenzene, n-	1.00E-04
Decane	1.00E-04	Styrene	2.01E-05
Diethylbenzene, 1,3-	1.00E-04	Sulfur Dioxide	4.55E-04
Dimethylnaphthalene, 1,2-	1.00E-04	Tetradecane	1.00E-04
Dimethylnaphthalene, 1,3-	2.01E-05	THC as Undecane	1.00E-04
Dimethylnaphthalene, 1,5-	1.00E-04	THCs as n-Hexane	5.97E-04
Dimethylnaphthalene, 1,6-	1.00E-04	Toluene	2.01E-05
Dimethylnaphthalene, 1,8-	1.00E-04	Trimethylbenzene, 1,2,3-	2.01E-05
Dimethylnaphthalene, 2,3-	1.00E-04	Trimethylbenzene, 1,2,4-	2.01E-05
Dimethylnaphthalene, 2,6-	1.00E-04	Trimethylbenzene, 1,3,5-	2.01E-05
Dimethylnaphthalene, 2,7-	1.00E-04	Trimethylnaphthalene, 2,3,5-	1.00E-04
Dimethylphenol, 2,4-	1.00E-04	Trimethylol Propane Triacrylate	3.46E-04
Dimethylphenol, 2,6-	1.00E-04	Undecane	2.01E-05
Dodecane	1.00E-04	Xylene, mp-	2.01E-05
Ethylbenzene	2.01E-05	Xylene, o-	2.01E-05

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APPENDIX C DETAILED PROCESS DATA AND CASTING QUALITY PHOTOS

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Detailed Process Data

GX - Greensand PCS													
Test Dates	11/7/2005	11/7/2005	11/7/2005	11/8/2005	11/8/2005	11/8/2005	11/9/2005	11/9/2005	11/9/2005	11/10/2005	11/10/2005	11/10/2005	Averages
Emissions Sample #	GXCR1	GXCR2	GXCR3	GX001	GX002	GX003	GX004	GX005	GX006	GX007	GX008	GX009	
Production Sample #	GX001	GX002	GX003	GX004	GX005	GX006	GX007	GX008	GX009	GX010	GX011	GX012	
Cast weight, lbs.	117.05	119.40	116.95	118.30	121.95	121.75	119.30	119.95	115.85	120.50	119.10	116.20	119.2
Pouring time, sec.	13	11	14	12	13	12	12	11	12	13	13	13	12
Pouring temp ,°F	2631	2635	2640	2637	2628	2639	2620	2639	2635	2620	2632	2636	2632
Pour hood process air temp at start of pour, °F	86	88	88	88	87	88	85	88	88	87	87	88	87
Mixer auto dispensed sand weight, Lbs	50.02	50.02	50.02	50.02	50.02	50.02	50.02	50.02	50.02	50.02	50.02	50.02	50.0
Core binder part I weight, g	177.5	177.8	177.8	178.0	176.7	176.9	177.3	176.6	177.5	177.8	177.1	177.4	177.3
Core binder part II weight, g	96.3	95.9	96.2	95.6	95.5	94.8	95.5	95.0	95.2	95.5	94.7	94.7	95.2
Total core binder weight, g	273.8	273.7	274.0	273.6	272.2	271.7	272.8	271.6	272.7	273.3	271.8	272.1	272.4
% core binder (BOS)	1.21	1.21	1.21	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
% core binder	1.19	1.19	1.19	1.19	1.18	1.18	1.19	1.18	1.19	1.19	1.18	1.18	1.19
Total core weight in mold, lbs.	28.26	28.44	28.51	28.19	28.24	28.28	28.24	28.25	28.32	28.31	28.26	28.29	28.3
Total binder weight in mold, lbs.	0.34	0.34	0.34	0.34	0.33	0.33	0.34	0.33	0.34	0.34	0.33	0.33	0.3
Core LOI, %	1.34	1.29	1.29	1.29	1.31	1.30	1.30	1.33	1.33	1.32	1.31	1.30	1.3
Core dogbone tensile, psi	213	213	213	213	213	213	213	213	213	213	213	213	213
Core age, hrs.	1271	1274	1291	1294	1297	0	1318	1320	1339	1341	1344	0	1028
Muller batch weight, lbs.	1000	900	890	900	890	900	890	900	900	900	900	900	898
GS mold sand weight, lbs.	648	650	660	642	642	639	643	632	642	641	643	636	640
Mold compactability, %	60	55	53	52	59	54	57	58	55	55	55	55	56
Mold temperature, °F	72	75	80	87	82	75	70	80	84	91	80	83	81
Average green compression , psi	17.66	17.73	17.75	18.61	20.32	18.69	19.78	20.40	19.37	21.53	19.68	21.44	19.98
GS compactability, %	55	50	36	39	40	40	46	50	44	40	45	45	43
GS moisture content, %	2.20	1.98	1.62	1.70	1.66	1.80	1.98	1.82	1.82	1.76	1.96	2.20	1.86
GS MB clay content, %	6.89	6.89	6.89	7.38	7.28	7.08	7.08	6.89	6.69	6.69	6.49	6.69	6.92
MB clay reagent, ml	35.0	35.0	35.0	37.5	37.0	36.0	36.0	35.0	34.0	34.0	33.0	34.0	35.2
1800°F LOI - mold sand, %	0.84	0.88	0.85	0.87	0.92	0.83	0.86	0.85	0.82	0.81	0.82	0.81	0.84
900°F volatiles , %	0.32	0.30	0.30	0.34	0.34	0.28	0.34	0.36	0.38	0.30	0.36	0.32	0.34
Permeability index	250	235	219	239	230	220	221	223	202	205	202	202	216
Sand temperature, °F	82	84	82	90	81	83	73	81	84	77	87	87	83

Casting Surface Quality Comparison Photos

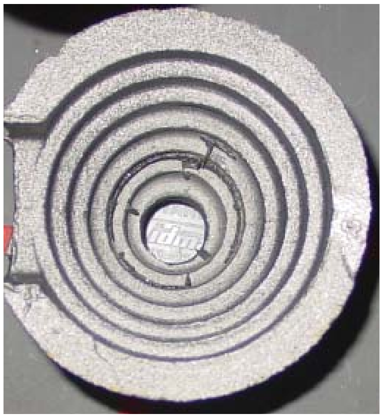
Best

GYCR2 Cavity 2

GXCR3 Cavity 1

Median

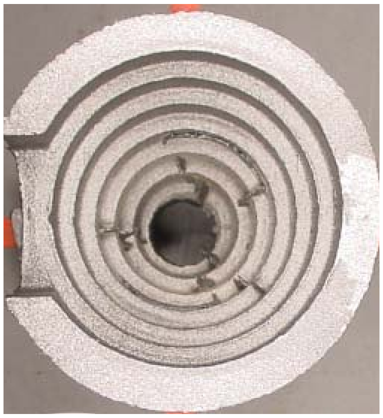
GYCR2 Cavity 4



GXCR3 Cavity 4

Worst

GYCR3 Cavity 2



GXCR1 Cavity 1

APPENDIX D CONTINUOUS EMISSION CHARTS

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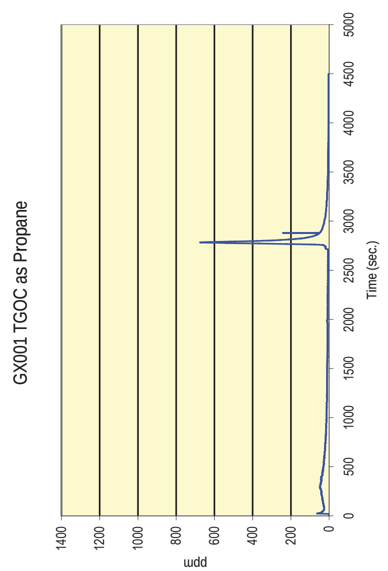
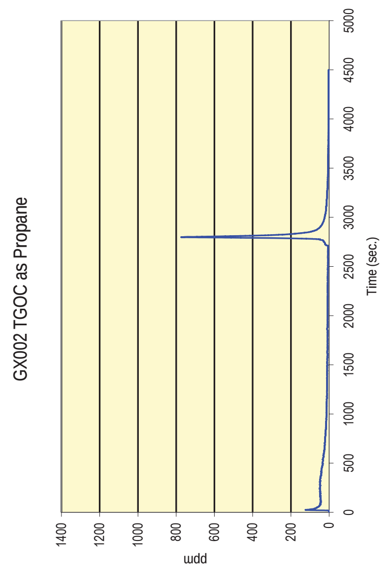
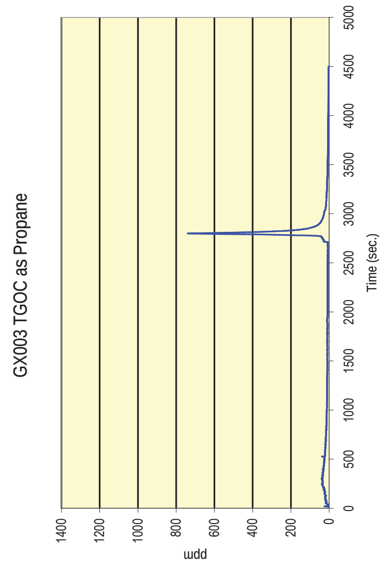
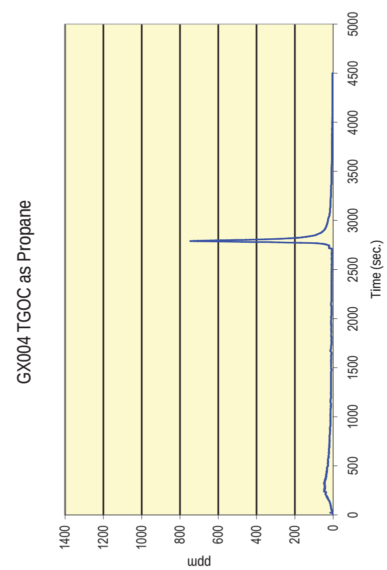
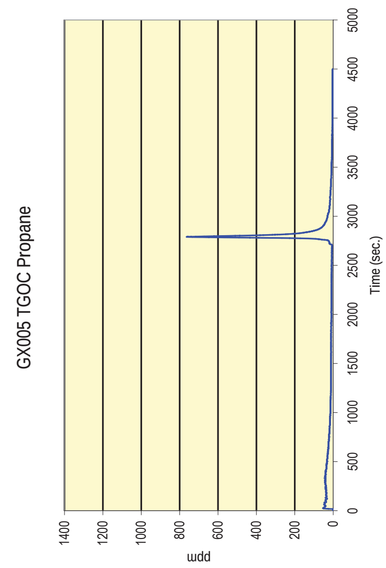
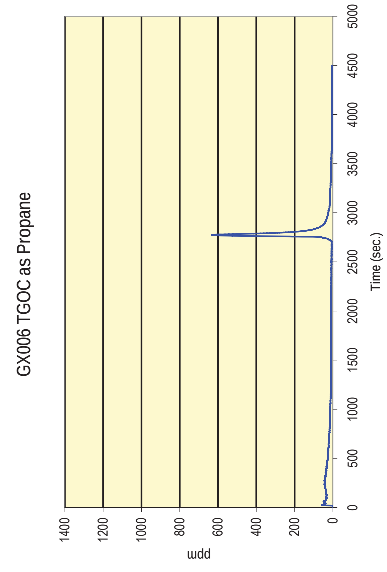

GX001 TGOC as Propane
ppm
Time (sec.)

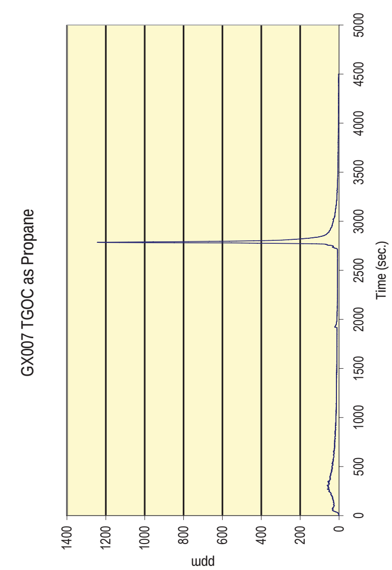

GX002 TGOC as Propane
ppm
Time (sec.)

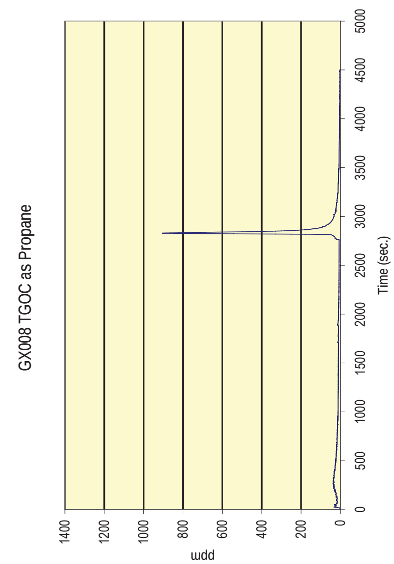

GX003 TGOC as Propane
ppm
Time (sec.)

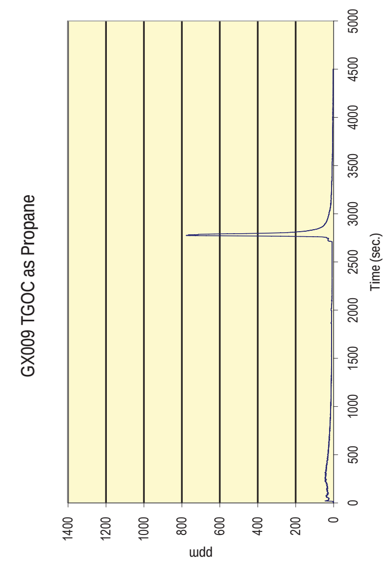

GX004 TGOC as Propane
ppm
Time (sec.)

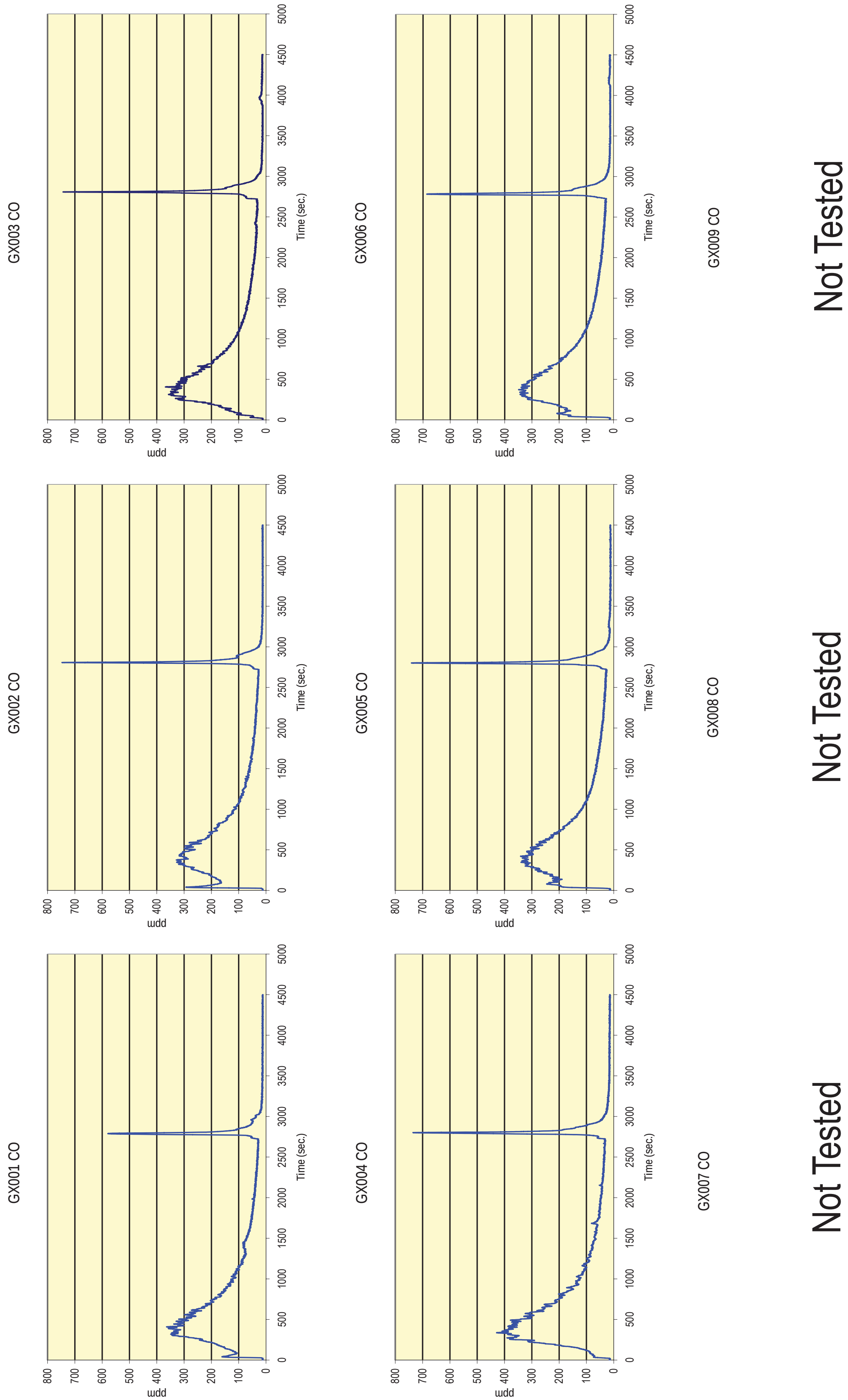

GX005 TGOC Propane
ppm
Time (sec.)

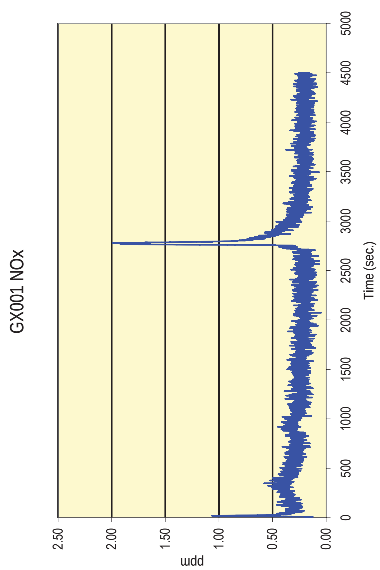

GX006 TGOC as Propane
ppm
Time (sec.)

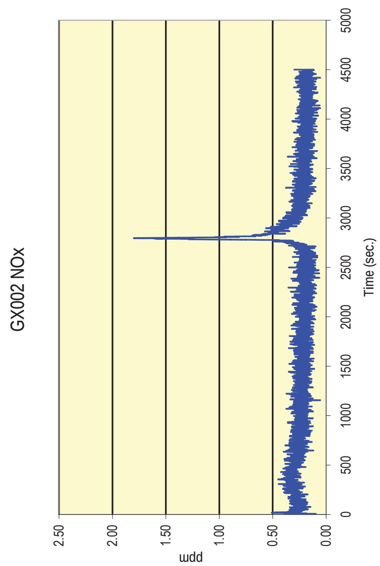

GX007 TGOC as Propane
ppm
Time (sec.)

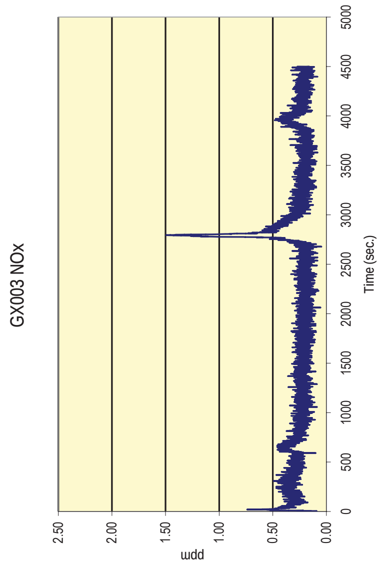

GX008 TGOC as Propane
ppm
Time (sec.)

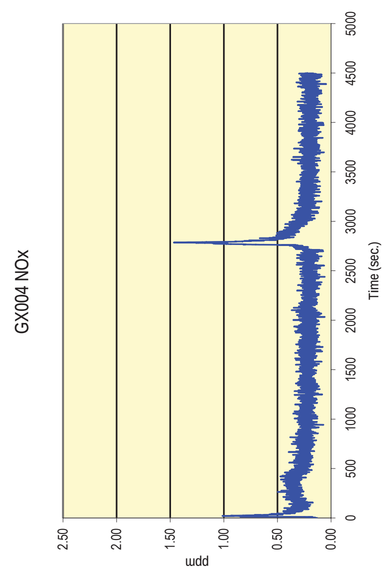

GX009 TGOC as Propane
ppm
Time (sec.)

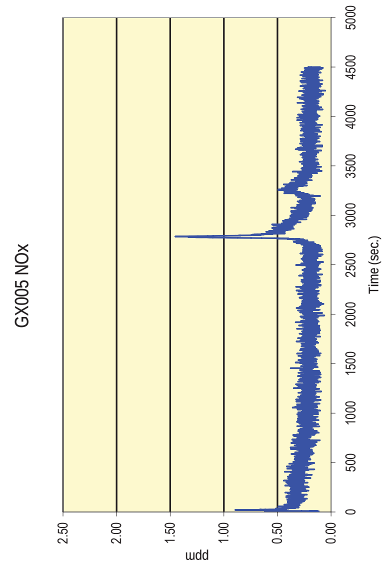

GX001 CO
GX002 CO
GX003 CO
GX004 CO
GX005 CO
GX006 CO
GX007 CO
GX008 CO
GX009 CO
ppm
Time (sec.)
0
100
200
300
400
500
600
700
800
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Not Tested
Not Tested
Not Tested

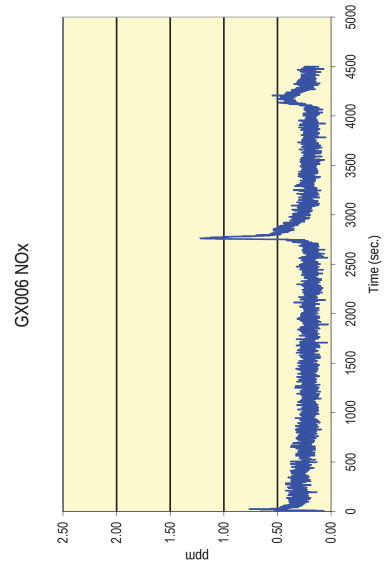












GX007 NOx

Not Tested

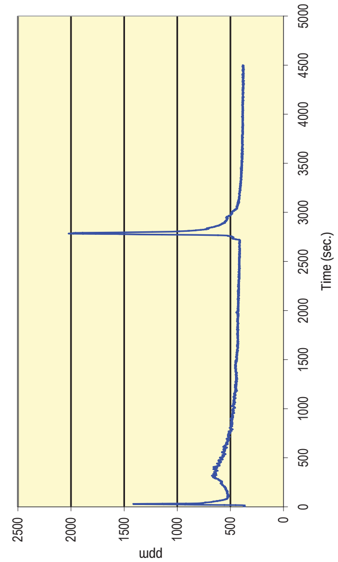
GX008 NOx

Not Tested

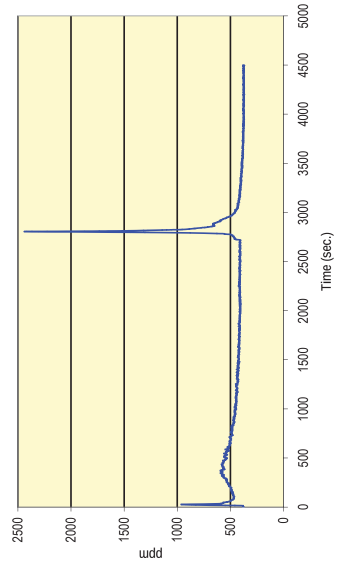
GX009 NOx

Not Tested

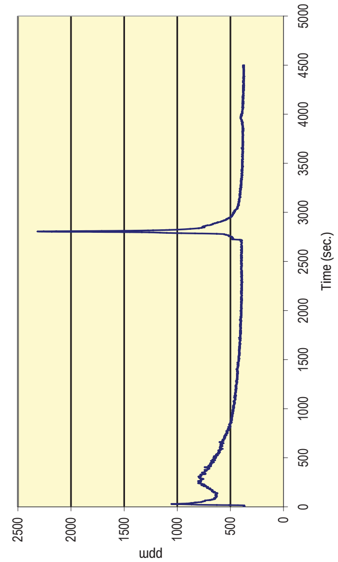
GX001 CO_2



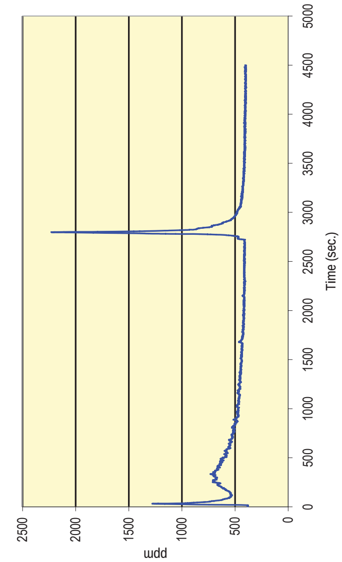
GX002 CO_2



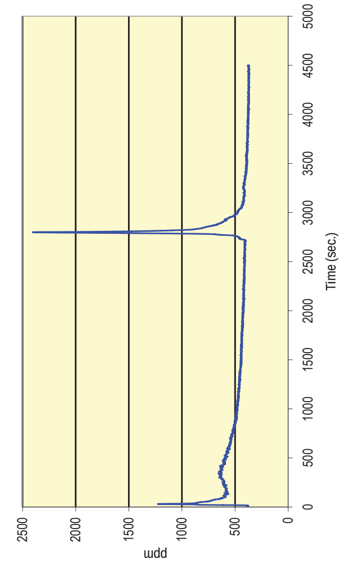
GX003 CO_2



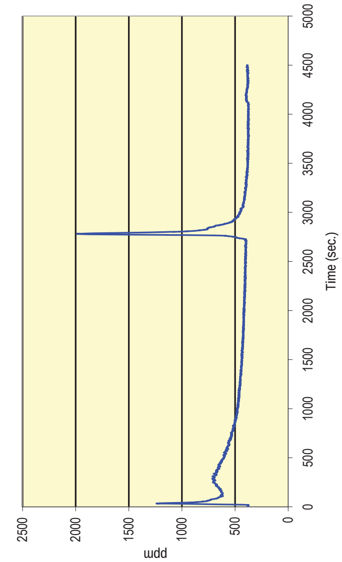
GX004 CO_2



GX005 CO_2



GX006 CO_2



GX007 CO_2

Not Tested

GX008 CO_2

Not Tested

GX009 CO_2

Not Tested

APPENDIX E ACRONYMS AND ABBREVIATIONS

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ACRONYMS & ABBREVIATIONS

AFS	American Foundry Society
ARDEC	(US) Army Armament Research, Development and Engineering Center
ATCAP	Armament Titanium Casting Advancement Program
BO	Based on ( ).
BOS	Based on Sand.
CAAA	Clean Air Act Amendments of 1990
CARB	California Air Resources Board
CEMS	Continuous Emissions Monitoring Systems
CERP	Casting Emission Reduction Program
CISA	Casting Industry Suppliers Association
CO	Carbon Monoxide
CRADA	Cooperative Research and Development Agreement
DOD	Department of Defense
DOE	Department of Energy
EEF	Established Emission Factors
EPA	Environmental Protection Agency
ERC	Environmental Research Consortium
FID	Flame Ionization Detector
GC	Gas Chromatography
GS	Greensand
HAP	Hazardous Air Pollutant defined by the 1990 Clean Air Act Amendment
HC as Hexane	The quantity of undifferentiated hydrocarbons determined by Wisconsin Cast Metals Association – maximum potential to emit method, revised 07/26/01.
I	Invalidated Data
Lb/Lb	Pound per pound of binder used
Lb/Tn	Pound per ton of metal poured
LOI	Loss on ignition
MACT	Maximum Achievable Control Technology
NA	Not Applicable; Not Available
ND	Non-Detect; Not Detected

NT	Not Tested - Lab testing was not done
PCS	Pouring, Cooling, Shakeout
POM	Polycyclic Organic Matter
PTE	Potential to Emit
QA/QC	Quality Assurance/Quality Control
TEA	Triethylamine
TGOC	Total Gaseous Organic Concentration
TGOC as Propane	Quantity of undifferentiated hydrocarbons including methane determined by EPA Method 25A.
THC	Total Hydrocarbon Concentration
TTE	Temporary Total Enclosure
US EPA	United States Environmental Protection Agency
USCAR	United States Council for Automotive Research
VOC	Volatile Organic Compound
WBS	Work Breakdown Structure