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Casting Emission Reduction Program

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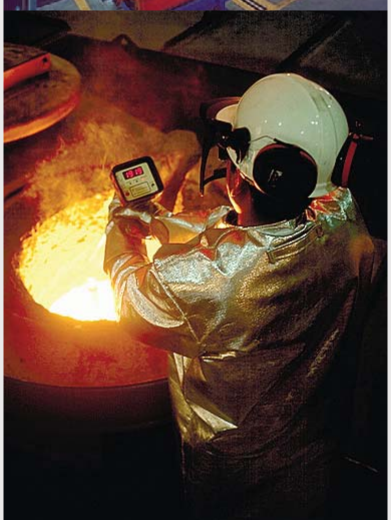

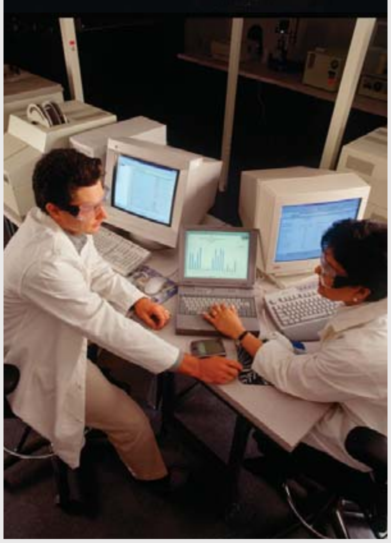

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Pouring, Cooling Shakeout Emissions from Digitally Printed Molds

1412-124 HRb

February 2008
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CASTING INDUSTRY SUPPLIERS ASSOCIATION

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Pouring, Cooling Shakeout Emissions from Digitally Printed Molds

1412-124 HRb

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

Director of Analytical Measurement Technologies	//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 casting quality, cost, or producibility.

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EXECUTIVE SUMMARY

This report contains the results of Test HRb, an evaluation of the airborne emissions released during the pouring, cooling and shakeout of 4-on gear molds made using a Pro Metal S-15 digital mold machine (The ExOne Company, Irwin, Pennsylvania). The mold binder was furfuryl alcohol based (ProMetal RCT™ Binder FB001) at a concentration of 1.5% Based on Sand (BOS). A toluenesulfonic acid activator (ProMetal RCT™ Activator FA001) was used at a concentration of 0.32% BOS.

Eight molds were poured with iron at 2630 ± 10°F. The pouring time of 23-41 seconds was followed by cooling for an elapsed pouring and cooling time of 45 minutes. This was followed by 15 minutes of shakeout, and a post shakeout cooling period of an additional 15 minutes. Emission samples were continuously collected for the total 75 minute testing period.

The emissions results were calculated in both pounds of analyte per pound of binder (lb/lb) and pounds of analyte per ton of metal poured (lb/ton). All emissions have been background subtracted to provide accurate reporting of results for the tested process only. The samples collected for target analyte identification using charcoal tubes under Method 18 were analyzed and quantitated using gas chromatography/mass spectrometry (GC/MS) instead of using gas chromatography/flame ionization detection (GC/FID). The GC/MS technique provides for positive compound identification and more accurate quantitative results than does GC/FID analysis.

Twenty-nine (29) of the 80 individual target analytes sampled by adsorption tube (excluding criteria pollutants and greenhouse gases) contributed to emissions above the practical quantitation limit (PQL), as did 18 of the 33 HAPs targeted for analysis. Phenol, benzene, toluene, mp-cresol, acetaldehyde, formaldehyde, mp-xylene, o-cresol, and naphthalene accounted for approximately 90% of the measured target analyte emissions. Phenol, benzene, and toluene contributed 65% to the measured emission concentration, but only 37% of the mass as determined by GC/MS peak area because of the limited number of speciated target analytes. Numerous additional compounds found through GC/MS analysis contributed higher emissions than the pre-selected targeted compounds. These additional compounds were not included in the sums in Table 1a and 1b.

Table 1a Average Emission Indicators Summary Table, Test HRb, lb/ton metal

Emissions Indicator	Average	Standard Deviation
THC as Propane	2.15E+00	8.07E-02
Non-Methane Hydrocarbons	1.57E+00	6.19E-02
Sum of Target Analytes	2.28E-01	2.70E-02
Sum of Target HAPs	2.18E-01	2.59E-02
Sum of Target POMs	6.90E-03	2.56E-03

Table 1b Average Emission Indicators Summary Table, Test HRb, lb/lb binder

Emissions Indicator	Average	Standard Deviation
THC as Propane	3.11E-02	4.80E-04
Non-Methane Hydrocarbons	2.28E-02	3.58E-04
Sum of Target Analytes	3.18E-03	3.48E-04
Sum of Target HAPs	3.00E-03	3.37E-04
Sum of Target POMs	9.49E-05	3.49E-05

Emission results from the testing performed and described herein 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. 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 point source 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 Leadership Council of USCAR, a Michigan 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.

1.2. CERP/Technikon Objectives

The primary objective of CERP is to evaluate materials, equipment, and processes used in the production of metal castings. Technikon's facility was developed to evaluate alternative 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 facility enables the repeatable collection and evaluation of airborne emissions and associated process data.

1.3. Report Organization

This report has been written to document the methodology and results of a specific test plan that was used to evaluate the pouring, cooling and shakeout airborne emissions generated from digitally produced molds using a furfuryl alcohol based binder and poured with iron.

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 and detailed data which include the variations appear in the appendices of this report. Section 3.1 of this report contains a discussion of the results.

The raw data for this test series are archived at the Technikon facility.

1.4. Specific Test Plan and Objectives

Test HRb was designed to evaluate airborne emissions generated from pouring, cooling and shakeout processes of 4-on irregular gear molds produced by a digital printing machine. The mold binder was a furfuryl alcohol-based binder (ProMetal RCT™ Binder FB001) at a concentration of 1.5% Based on Sand (BOS). The toluenesulfonic acid activator (ProMetal RCT™ Activator FA001) was used at a concentration of 0.32% BOS, and was mixed into the sand prior to the resin application.

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

Test Plan Number	1412-124-HRb
Type of Process Tested	PCS, printed
Metal Poured	Iron
Casting Type	4-on Irregular Gear
Sand System	Prometal RCT FS001-EU sand with 1.5% (BOS) Prometal RCT FB001-EU Binder and 0.32% (BOS) FC001-EU Activator
Number of Molds Poured	8 sampling
Test Dates	6/28/07-7/02/07
Process Parameters	Total casting and mold weights, metallurgical data, % LOI, stack temperature, moisture content, pressure, and volumetric flow rate

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2.0 TEST METHODS, ASSUMPTIONS AND PROCEDURES

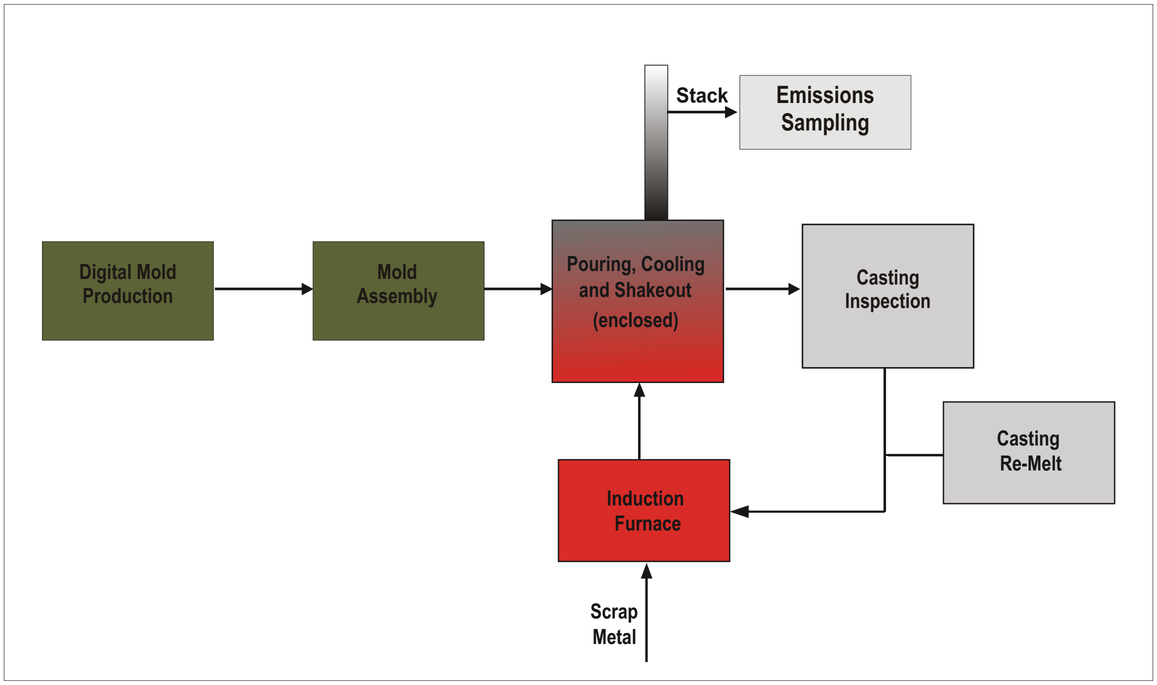
2.1. Description of Process and Testing Equipment

The Rapid Casting Technology (RCT) system from The ExOne Company was used to manufacture the 4-on gear molds used for Test HRb. Molds were constructed directly by the machine by depositing binder onto activator-primed sand for copes and drags of the 4-on irregular gear pattern. Binder deposition or "printing" is accomplished by means of digital information of the pattern from a CAD file conveyed directly from a process computer to a printhead. Information regarding the machine operation is also communicated through a computer process link. The RCT system uses conventional foundry sand, resin binder, and activator. Figure 2-1 shows the RCT system and peripheral equipment located in its dedicated 40' x 40' environmentally controlled room.

Figure** 2-1 **The RCT System

The digitally printed molds were then used for testing the pouring, cooling, and shakeout emissions from iron using the established Research Foundry testing process. Figure 2-2 is a diagram of the Research Foundry test process.

Figure 2-2 Mold/Core Making, Pouring, and Shakeout Process Diagram



2.2. Description of Testing Program

The testing program encompasses the foundry process and emissions testing, both of which are rigorously controlled. For digital printing, all relevant parameters are recorded by the process computer. They include: print resolution, material usage, layer time, recoating time, printing time, cleaning time, hardware dialog, idle time, cleaning completion time, error time, and printhead recovery time. The detail of the individual parameters under these headings, which is printed at the conclusion of the printing process, is included in this report in Appendix C. Parameters are monitored and recorded prior to and during the emission tests. Process measurements included the weights of the casting and mold sand, loss on ignition (LOI) values for the mold and core prior to the test, and relevant metallurgical data. Measured source 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.

Emission testing for hydrocarbons included several methods. Method 18 is one of the US Environmental Protection Agency's (EPA) promulgated reference methods for volatile organic compound (VOC) analysis. Method 18 is generally used to identify and/or measure as many compounds as possible in order to calculate actual VOC emissions from other measurements (e.g. US EPA Method 25 or 25A). The method is a guideline and a system of quality assurance (QA) checks for VOC analysis rather than a rigorous, explicit manual for sampling or analysis.

As described in the method, sampling can be conducted using a Volatile Organic Sampling Train (VOST), which was the technique used for sampling emissions during the tests described herein. A sample gas stream was extracted from the source and then routed using the train through tubes containing adsorbents, which are the collection materials upon which the organic analytes are deposited. Adsorption tube samples were collected and analyzed for eighty-one (81) target compounds using specific collection and analysis procedures based on approved federal methods, including those of the US EPA.

The samples collected for target analyte identification using charcoal tubes under Method 18 were analyzed and quantitated using gas chromatography/mass spectrometry (GC/MS) instead of using gas chromatography/flame ionization detection (GC/FID). The GC/MS technique provides for positive compound identification and more accurate quantitative results than does GC/FID analysis.

Individual component analysis for target compounds was done using sampling and analytical methods based on federal reference methods shown in Table 2-1. The details of the specific testing procedures and their variance from the reference methods are included in the Technikon Standard Operating Procedure.

Table 2-1 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 Analytes including HAPs and POMs	US EPA Methods TO17FID, TO17MS, TO11; NIOSH Methods 2002, 6010, S-347, 2529; OSHA ID 200, PV-2003
TGOC	US EPA Method 25A
CO	US EPA Method 10
CO2	US EPA Method 3A
NOx	US EPA Method 7E
SO2	OSHA ID 200
CH4	US EPA CTM 042

Some methods modified to meet specific CERP test objectives.

Two methods were employed to measure undifferentiated hydrocarbon emissions as Emission Indicators: TGOC as Propane, performed in accordance with US EPA Method 25A, and non-methane hydrocarbons as determined from methane results obtained in a manner similar to that prescribed in US EPA CTM-042.

Method 25A is an instrument based method in which the stack gas is introduced directly to a flame ionization detector (FID) without first separating the components. In Method 25A, sampling is accomplished by extracting a gas stream from the stack effluent and transferring it via heated non-reactive tubing to the FID analyzer under very controlled temperature and pressure conditions. The FID measures the quantity of carbon containing molecules, and is calibrated by a gas standard, which in this case is the three carbon alkane, propane (C_3H_8). The FID will give a response relative to the calibration standard and results are expressed in terms of the gas used for calibration. Because the FID responds to all carbon containing compounds, methane (CH_4) and other exempt compounds are included in the total hydrocarbon results.

Methane was analyzed by a separate FID equipped with an oxidizing catalyst (methane cutter) that removes all non-methane hydrocarbons (NMHC). The calibration gas for this FID was methane (CH_4). The two FIDs were run simultaneously, and collected data every second. Average results were calculated over the entire pouring, cooling and shakeout periods for each run. NMHC results were then determined by directly subtracting the detected methane from the total hydrocarbon value.

Continuous on-line monitoring of select criteria pollutant and greenhouse gases such as carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen oxide (NOx) was conducted according to US EPA Methods 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. Detailed emission results are presented in Appendix B. Individual analyte emissions were calculated in addition to five "Emission Indicators:" TGOC as Propane, NMHC, Sum of Target Analytes, Sum of Target Hazardous Air Pollutants (HAPs), and the Sum of Target Polycyclic Organic Matter (POMs). Full descriptions of these indicators can be found in Section 3.0 of this report.

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

2.2.1. Test Plan Review and Approval

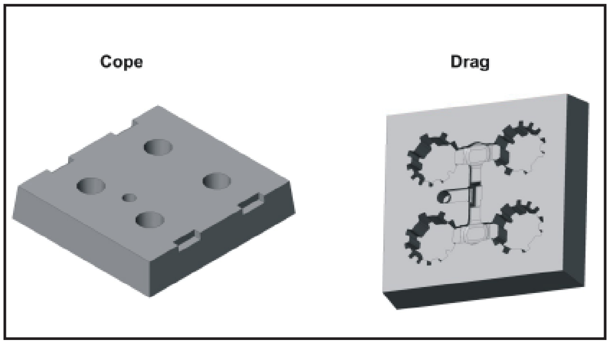
The proposed test plan was reviewed and approved by the Technikon staff and by CERP Working Group Chairs as appropriate.

2.2.2. Mold and Metal Preparation

For this test, castings were produced individually in discrete digitally manufactured mold packages in Technikon's Research foundry. The 4-on gear pattern designed to evaluate mold emissions was used for all runs. Four of the molds that were produced using an ExOne

Company digital printing machine (Pro Metal S-15) and used for this test were also used for emissions testing under 1412-124 Test HRa. The digitally produced molds are shown in Figure 2-3. Relevant process data during mold production and during pouring, cooling and shakeout testing were collected and recorded. The total amount of metal melted was determined from the expected poured weight of the castings and the number of molds to be poured. The weight of metal poured into each mold was recorded, as was the final casting weight.

Figure 2-3 Digital Molds



2.2.3. Individual Sampling Events

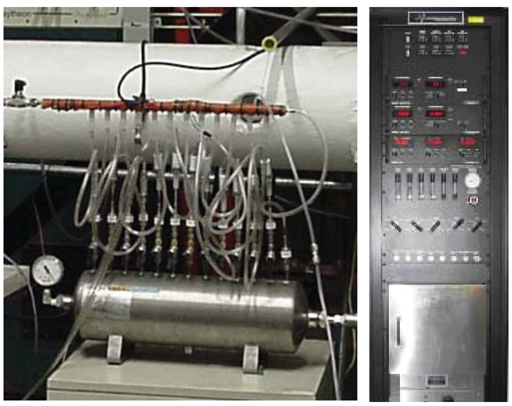
Test HRb was a test designed to evaluate emissions from molds produced using a digital printing machine and poured with iron. Prior to pouring and emission sampling for each run, a single mold package was placed onto a shake-out table contained within a hooded enclosure designed to meet the requirements of US EPA Method 204 for a total temporary enclosure. The enclosed test stand was pre-heated to 85° to 90°F. The flow rate of the emission capture air was nominally 600 scfm. Iron at approximately 2630°F was then poured through an opening in the top of the emission enclosure into the mold, after which the opening was closed (Figure 2-4).

Figure 2-4 Pouring Iron into Mold inside Total Enclosure Hood

The emissions generated were transported through an insulated six (6) inch duct or stack located at the top of the enclosure. Heated sample probes inserted into the stack at relevant locations, determined by US EPA Method 1, enabled collection of total emissions from all phases of the casting process. One probe provided gases for the VOST (Figure 2-5a). Another probe in the stack was used to continuously draw effluent samples and transport them via a forty-seven (47) ft heated sample line to the FID for methane measurement, and to an emissions console (Figure 2-5b) located in Technikon's laboratory. This console, or emissions bench, consists of a total hydrocarbon analyzer for TGOC analysis using a flame ionization detector, two infrared analyzers (for CO and CO_2) and a chemiluminescence analyzer for NOx.

Figure** 2-5* ***Stack Sampling Equipment

a) *b)*



Continuous air samples were collected during the forty-five (45) minute pouring and cooling phase, during the fifteen (15) minute shakeout of the mold, and for an additional fifteen (15) minute cooling period following shakeout. The total sampling time was seventy-five (75) minutes.

2.2.4. Process Parameter Measurements

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

Table 2-2 Process Equipment and Methods

Process Parameter	Equipment and Method(s)
Mold Weight	Cardinal 748E Platform Scale (Gravimetric)
Casting Weight	Ohaus MP2 Scale
LOI, % at Mold	Denver Instruments XE-100 Analytical Scale (AFS Procedure 5100-00-S)
Metallurgical Parameters	
Pouring Temperature	Electro-Nite DT 260 (T/C Immersion Pyrometer)
Carbon/Silicon Fusion Temperature	Electro-Nite DataCast 2000 (Thermal Arrest)
Alloy Weights	Ohaus MP2 Scale (Gravimetric)
Carbon Silicon Ratio	Electro-Nite DataCast 2000 (Thermal Arrest)

2.2.5. Data Reduction, Tabulation and Preliminary Report Preparation

Data calculations for determining emission concentrations resulting from the specific test plan outlined in Appendix A were based on process and emission parameters. The analytical results of the emissions sampling provided the mass of each analyte in the sample. The total mass of the analyte emitted was 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 was 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, 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 concentration and reporting limit results for each analyte for all sampling runs for all three tests are included in Appendix B of this report. Average results for all the runs in the tests are given in Section 3.0, Tables 3-1a and 3-1b.

2.2.6. Report Preparation and Review

The preliminary draft report was created and reviewed by Process Team and Emissions Team members to ensure its completeness, consistency with the test plan, and adherence to QA/QC procedures. Appropriate observations, conclusions, and recommendations were added to the report to produce a draft report. The draft report was then reviewed by senior management and comments were 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 were followed:

- Specific process parameters for this test were under constant surveillance by process engineers to ensure that the machine was operating properly and that all printing and mold parameters were maintained within the prescribed control ranges.

- The source (stack) and sampling parameters, analytical results and corresponding laboratory QA/QC data were reviewed by the Emissions Measurement Team to confirm the validity of the data. Senior management of Analytical Measurement Technologies reviewed recommendations regarding individual sample data that should be invalidated. Invalidated data were not used in subsequent calculations.

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3.0 Test Results

For Test HRb, stack samples were collected during the pouring, cooling and shakeout processes of eight (8) iron pours using digitally manufactured 4-on gear molds. The mold binder was a furfuryl alcohol-based binder (ProMetal RCT™ Binder FB001) at a concentration of 1.5% BOS. The toluenesulfonic acid activator (ProMetal RCT™ Activator FA001) was mixed with the sand prior to binder application at a concentration of 0.32% BOS. Average emissions results are presented in Tables 3-1a and 3-1b, as lb/ton metal and lb/lb binder, respectively.

Table 3-1a Average Emissions, Test HRb, lb/ton metal

Analyte Name	Average	Standard Deviation
Emission Indicators		
THC as Propane	2.15E+00	8.07E-02
Non-Methane Hydrocarbons	1.57E+00	6.19E-02
Sum of Target Analytes	2.28E-01	2.70E-02
Sum of Target HAPs	2.18E-01	2.59E-02
Sum of Target POMs	6.90E-03	2.56E-03
Selected Target HAPs and POMs		
Phenol	7.17E-02	7.76E-03
Benzene	4.83E-02	4.24E-02
Toluene	2.83E-02	3.99E-03
Cresol, mp-	1.62E-02	1.81E-03
Acetaldehyde	1.18E-02	1.34E-03
Formaldehyde	1.14E-02	1.90E-03
Xylene, mp-	9.22E-03	1.19E-03
Cresol, o-	6.11E-03	7.53E-04
Naphthalene	5.59E-03	4.45E-04
Ethylbenzene	2.03E-03	3.62E-04
Styrene	1.92E-03	3.58E-04
Xylene, o-	1.61E-03	2.34E-04
Biphenyl	9.66E-04	1.39E-04
Methylnaphthalene, 2-	8.94E-04	1.12E-04
Propionaldehyde (Propanal)	5.08E-04	8.47E-05
Methylnaphthalene, 1-	4.16E-04	5.58E-05
Acrolein	3.12E-04	8.94E-05
Hexane	3.02E-04	2.86E-05
Additional Selected Target Analytes		
Benzaldehyde	4.65E-03	7.96E-04
2-Butanone (MEK)	2.79E-03	1.57E-04
Indene	8.50E-04	1.51E-04
o,m,p-Tolualdehyde	8.32E-04	1.87E-04
Crotonaldehyde	6.22E-04	1.38E-04
Trimethylbenzene, 1,2,4-	5.97E-04	6.97E-05
Dimethylphenol, 2,4-	5.78E-04	1.89E-04
Pentanal (Valeraldehyde)	5.08E-04	5.37E-05
Ethyltoluene, 4-	4.39E-04	4.23E-05
Ethyltoluene, 3-	4.17E-04	4.50E-05
Butyraldehyde/Methacrolein	3.59E-04	4.03E-05
Additional Analytes		
Furan, 2-methyl-	3.12E-02	8.75E-03
Acetic acid	2.53E-02	9.99E-03
Phenol, 3-(1-methylethyl)-	9.77E-03	2.10E-03
Furan, 2,5-dimethyl-	6.80E-03	1.68E-03
Benzofuran	4.79E-03	1.51E-03
Dibenzofuran	7.95E-04	1.66E-04
Criteria Pollutants and Greenhouse Gases		
Carbon Dioxide	1.61E+01	2.66E+00
Carbon Monoxide	9.32E+00	7.12E-01
Sulfur Dioxide	8.22E-01	5.32E-02
Methane	5.73E-01	2.18E-02
Nitrogen Oxides	≤PQL	NA

NA= Not Applicable

≤PQL=Less than or equal to the Practical Quantitation Limit

Table 3-1b Average Emissions, Test HRb, lb/lb binder

Analyte Name	Average	Standard Deviation
Emission Indicators		
THC as Propane	3.11E-02	4.80E-04
Non-Methane Hydrocarbons	2.28E-02	3.58E-04
Sum of Target Analytes	3.18E-03	3.48E-04
Sum of Target HAPs	3.00E-03	3.37E-04
Sum of Target POMs	9.49E-05	3.49E-05
Selected Target HAPs and POMs		
Phenol	9.85E-04	9.88E-05
Benzene	6.68E-04	5.91E-04
Toluene	3.89E-04	5.50E-05
Cresol, mp-	2.23E-04	2.23E-05
Acetaldehyde	1.62E-04	1.87E-05
Formaldehyde	1.57E-04	2.64E-05
Xylene, mp-	1.27E-04	1.67E-05
Cresol, o-	8.41E-05	9.49E-06
Naphthalene	7.68E-05	5.43E-06
Ethylbenzene	2.79E-05	4.96E-06
Styrene	2.65E-05	4.83E-06
Xylene, o-	2.22E-05	3.21E-06
Biphenyl	1.33E-05	1.83E-06
Methylnaphthalene, 2-	1.23E-05	1.42E-06
Propionaldehyde (Propanal)	7.01E-06	1.18E-06
Methylnaphthalene, 1-	5.73E-06	7.03E-07
Acrolein	4.31E-06	1.21E-06
Hexane	4.25E-06	2.88E-07
Additional Selected Target Analytes		
Benzaldehyde	6.41E-05	1.09E-05
2-Butanone (MEK)	3.85E-05	2.11E-06
Indene	1.17E-05	1.96E-06
o,m,p-Tolualdehyde	1.15E-05	2.58E-06
Crotonaldehyde	8.57E-06	1.94E-06
Trimethylbenzene, 1,2,4-	8.22E-06	9.38E-07
Dimethylphenol, 2,4-	7.99E-06	2.50E-06
Pentanal (Valeraldehyde)	7.00E-06	7.34E-07
Ethyltoluene, 4-	6.05E-06	5.35E-07
Ethyltoluene, 3-	5.74E-06	5.83E-07
Butyraldehyde/Methacrolein	5.03E-06	5.06E-07
Additional Analytes		
Furan, 2-methyl-	4.33E-04	1.23E-04
Acetic acid	3.49E-04	1.39E-04
Phenol, 3-(1-methylethyl)-	1.35E-04	2.97E-05
Furan, 2,5-dimethyl-	9.37E-05	2.28E-05
Benzofuran	6.61E-05	2.10E-05
Dibenzofuran	1.10E-05	2.34E-06
Criteria Pollutants and Greenhouse Gases		
Carbon Dioxide	2.32E-01	3.29E-02
Carbon Monoxide	1.35E-01	8.52E-03
Sulfur Dioxide	1.13E-02	7.73E-04
Methane	8.30E-03	2.05E-04
Nitrogen Oxides	≤PQL	NA

NA= Not Applicable

≤PQL=Less than or equal to the Practical Quantitation Limit

Compounds that were chosen for analysis from pouring, cooling, shakeout (PCS) emissions that are based on chemical and operational parameters are termed "target analytes" (TA). The emissions indicator called the "Sum of Target Analytes" is the sum of the individual analytes that were targeted for collection and analysis, and detected at a level above the practical quantitation limit. For less complex samples with fewer individual analytes contributing to emissions, the target analyte sum would theoretically closely match the results for total hydrocarbons obtained by Method 25A, excluding exempt compounds such as methane, and including compounds such as formaldehyde, which are less responsive in the FID. For the results reported here, the Sum of Target Analytes plus methane averages approximately 37% of TGOC as Propane results that have been adjusted by addition of less responsive target compounds such as aldehydes and ketones.

The target analyte sum includes targeted compounds that 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 organic compounds from the current list of US 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 organic HAPs that are also defined as POMs.

Also included in the tables are the "Sum of Target Analytes," the "Sum of Target HAPs," and the "Sum of Target POMs." These three analyte sums are part of the group termed "Emission Indicators." Also included in this group and reported in the first section of the tables are "TGOC as Propane" as determined by Method 25A, and non-methane hydrocarbon (NMHC) as determined by CTM-042. The second section of the table includes average emission results for individual HAP and POM compounds selected as target analytes, while the third section contains results for additional speciated targeted compounds that are not HAPs or POMs but may be on the US EPA SARA 313 list of toxic chemicals, such as ammonia. The fourth section of the tables includes several analytes which were found from GC/MS analysis. These additional analytes were found in greater concentration than most of the pre-selected target analyte compounds, but were not included in any of the Emission Indicator sums. Average values for selected criteria and greenhouse gases including CO, CO_2, CH_4, SO_2, and NO_x are given in the last section of the tables.

Speciated results presented in the tables of this report, including those gases measured continuously on-line in real time at Technikon during Test HRb, have been background corrected. When sample measurements are made, the observed result includes the contribution of the analyte in the sample, plus a response due to the background contribution found from the blank. The net analyte sample concentration is therefore the amount of the analyte, if any, found in the blank subtracted from the amount of analyte found in the sample. Background correcting the data allows determination of the emissions resulting only from the specific materials tested, and not those that may be present in the ambient air of the research foundry during the testing period.

Emissions data that have been determined to be below the practical quantitation limit (PQL) after data validation and verification are substituted with the numerical value used for the PQL, rather than with the value of zero. If an analyte has calculated concentrations above the PQL for some runs, but values for other runs fall below the PQL, the PQL value is included when calculating analyte averages and sums. However, if an analyte has a concentration that is below the PQL for all runs in a test, the test average is indicated by ≤PQL (less than or equal to the PQL) in the Tables and Figures of this report, and no runs are included in any summations or averages. Omitting these less-than-reporting-limit analytes in calculations ensures that only those targeted compounds which contribute to emissions are included in emission sums.

Examination of measured process parameters indicated that Test HM was run within acceptable ranges and limits. The principal causes and secondary influences on emissions were fixed for each individual run, so that for pouring, cooling, and shakeout, the emissions reflect only the materials being tested.

3.1. Discussion of Results

3.1.1. Emissions

The individual chemical compounds targeted for collection and analyses from airborne emissions for this test were chosen based on the chemistry of the binder and activator used, as well as analytes historically targeted. Figures 3-1a to 3-4b graphically present the data from Tables 3-1a and 3-1b for Test HRb for the five emissions indicators, selected individual HAP, target analyte, and criteria pollutant and greenhouse gas emissions as both lb/ton of metal and lb/lb of binder.

Figure 3-1a Emissions Indicators, Test HRb, lb/ton metal

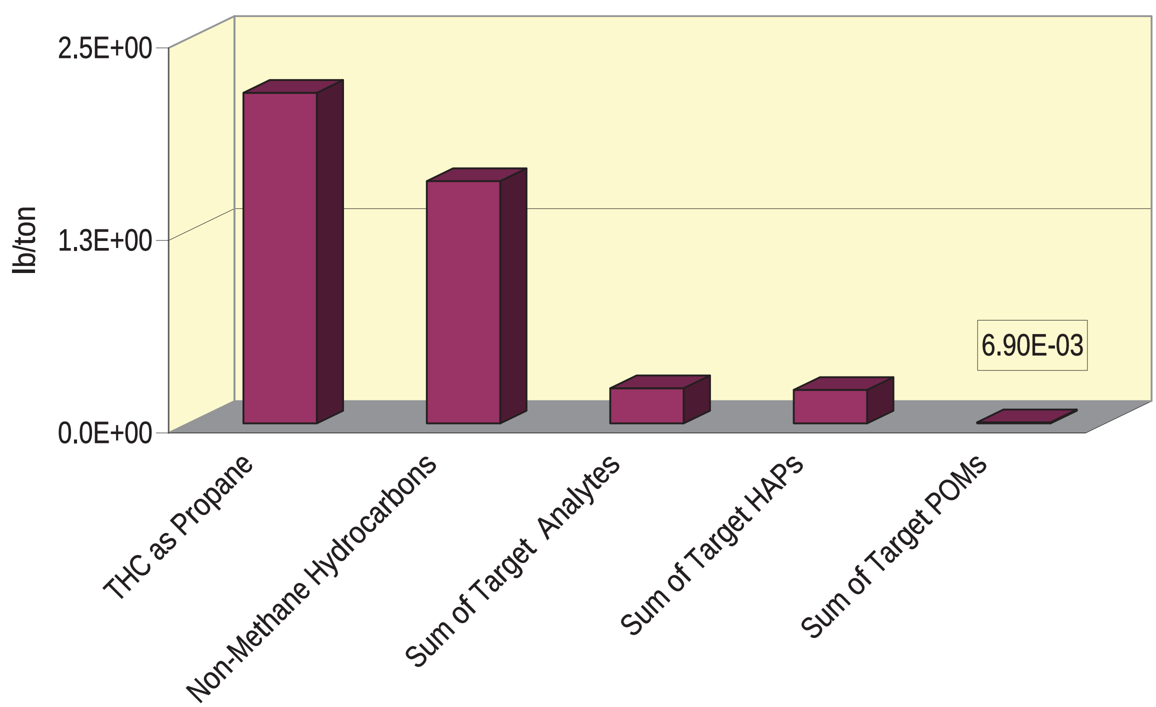


Figure 3-2a Selected HAP and POM Emissions, Test HRb, lb/ton metal

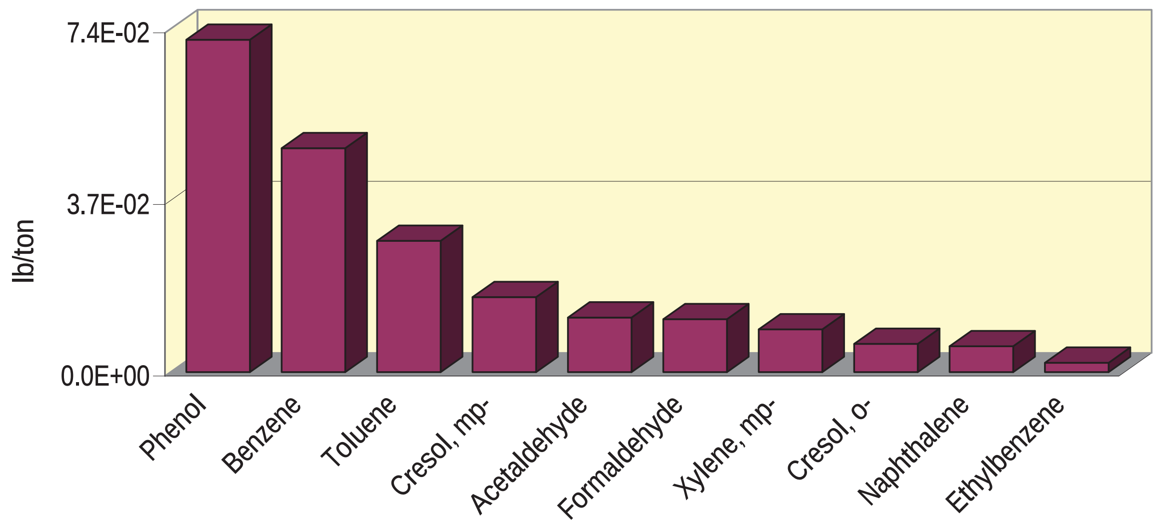


Figure 3-3a Selected Target Analyte Emissions, Test HRb, lb/ton metal

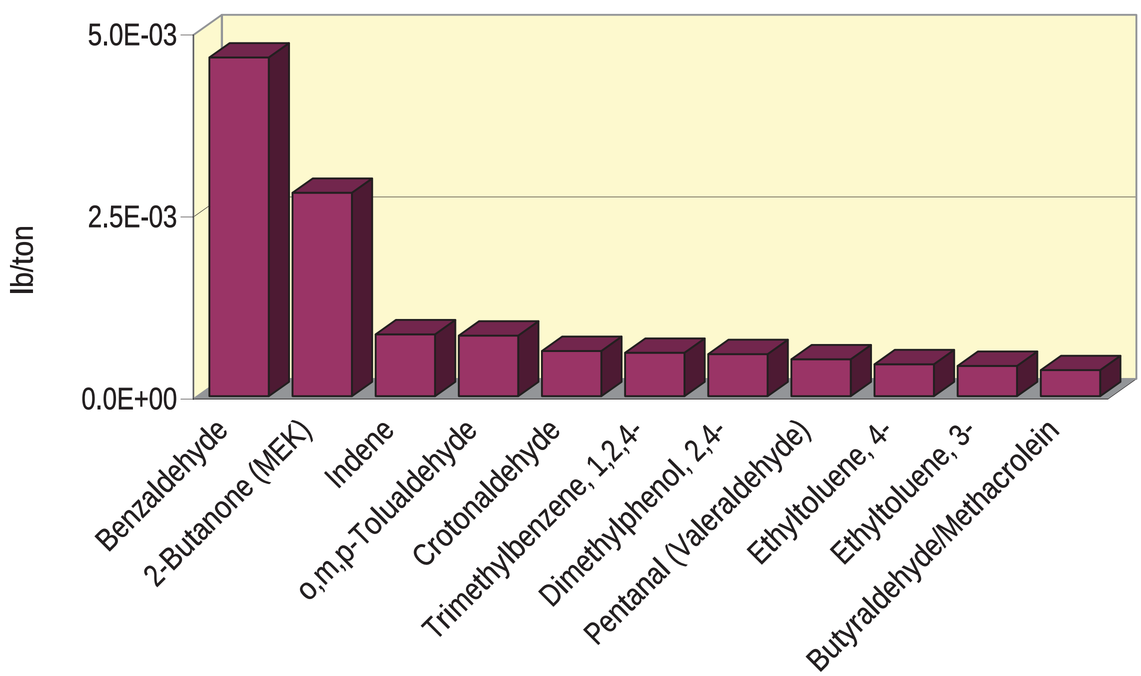


Figure 3-4a Criteria Pollutants and Greenhouse Gases, Test HRb, lb/ton metal

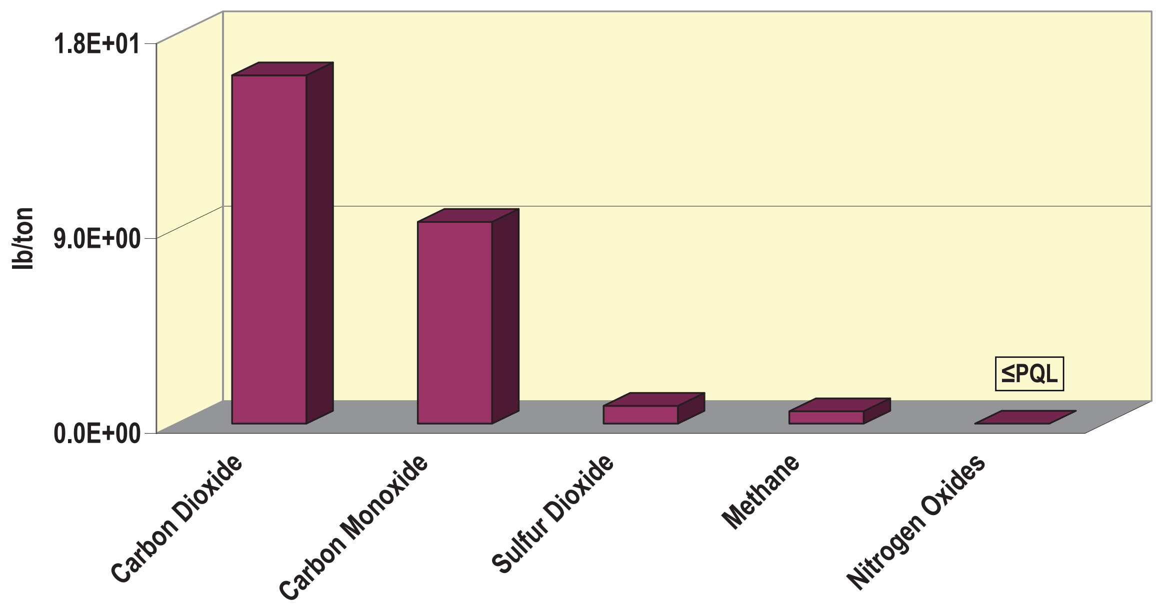


Figure 3-1b Emissions Indicators, Test HRb, lb/lb binder

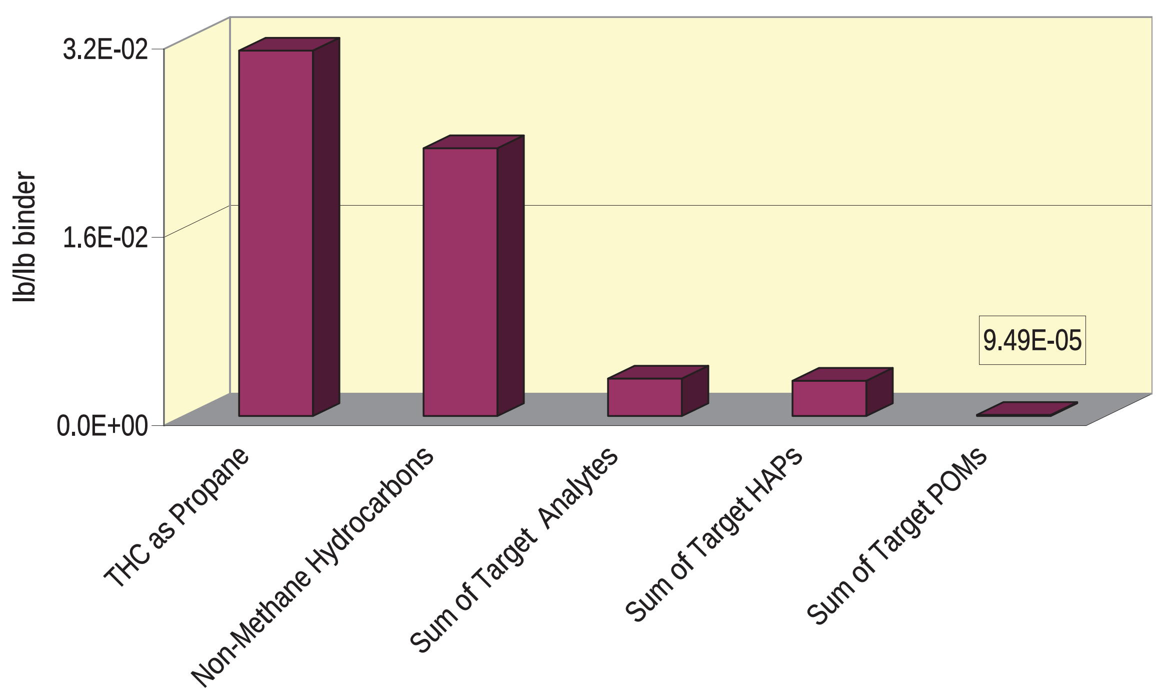


Figure 3-3b Selected Target Analyte Emissions, Test HRb, lb/lb binder

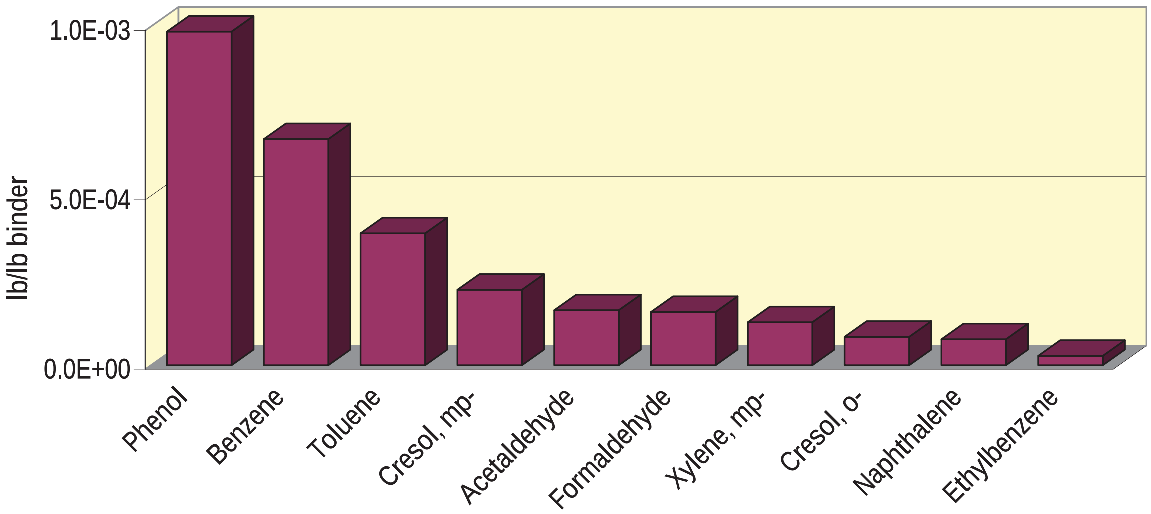


Figure 3-2b Selected HAP and POM Emissions, Test HRb, lb/lb binder

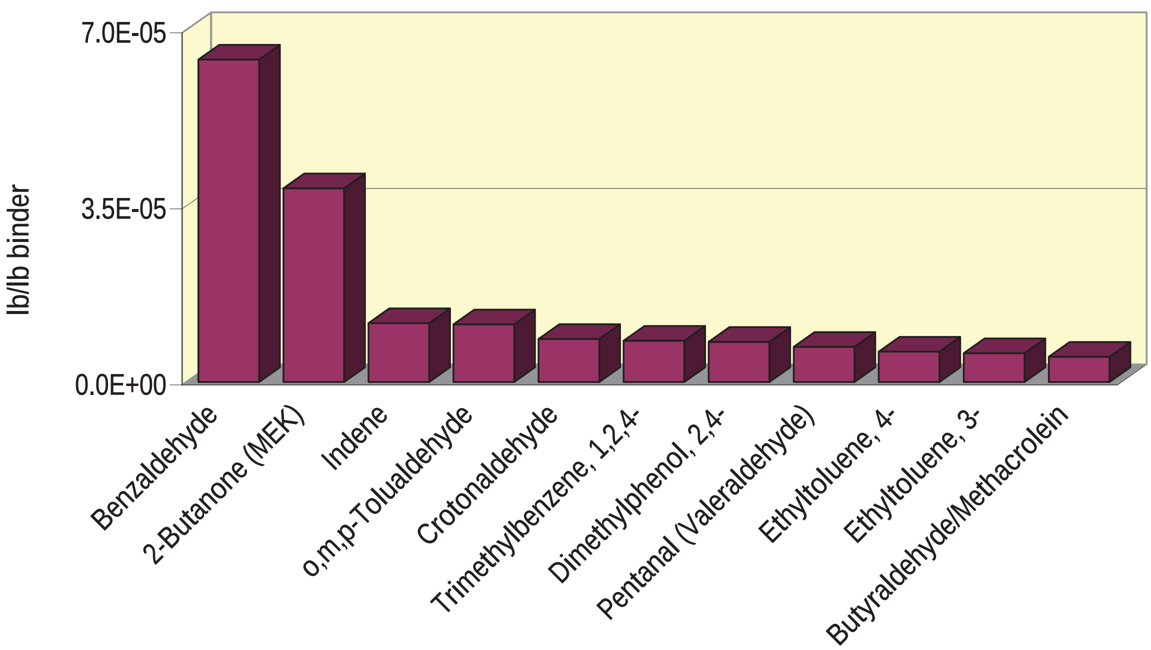
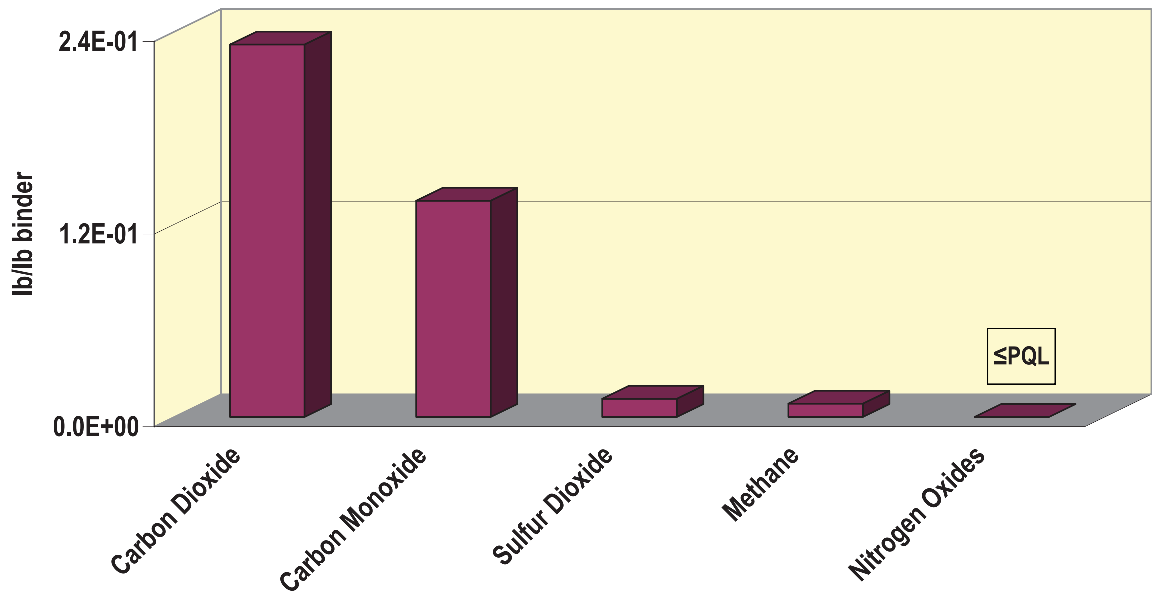
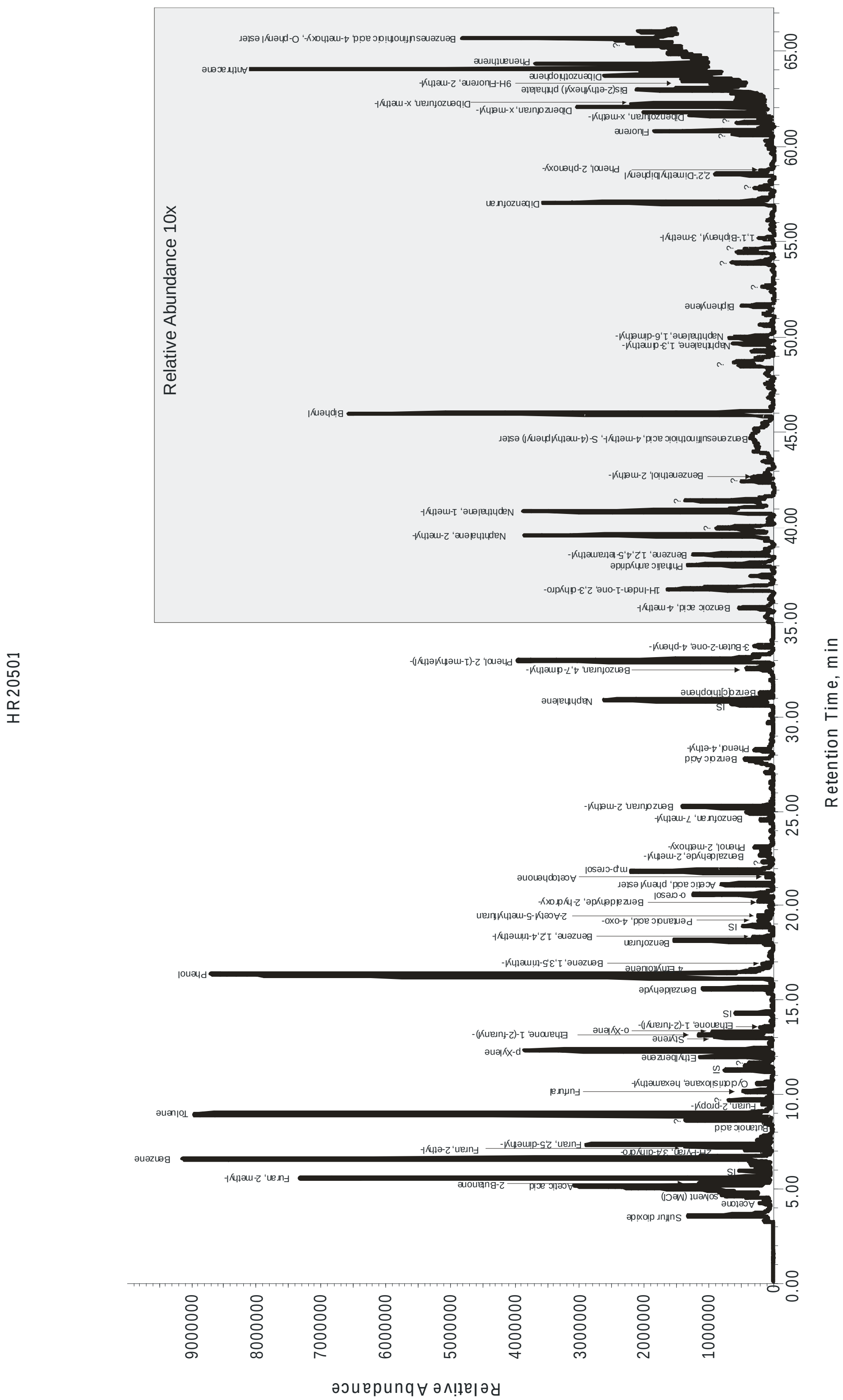


Figure 3-4b   Criteria Pollutants and Greenhouse Gases, Test HRb, lb/lb binder



A comprehensive review of the GC/MS analysis revealed a complex mixture for emissions as can be seen in Figure 3-5 using Run HRb20501 as an example. The main peaks identified consisted of many furan-based derivatives, although not as many as were found in the mold making emissions produced from manufacture of the digitally printing molds reported under Test HRa. Compounds traditionally targeted using charcoal tubes were not found in the mold making emissions from Test HRa, but were found in the pouring, cooling and shakeout process emissions from those same molds.

Figure 3-5 GC/MS Chromatogram, Test HRb



GC/MS analysis showed well over 100 different compounds (as represented by individual peaks in the chromatogram). Only 37% of the hydrocarbon mass (as determined by peak area) was for phenol, benzene, and toluene, although these three compounds contributed 65% to the measured emission concentration because of the limited number of pre-selected speciated target analytes. Numerous additional compounds found through GC/MS analysis contributed higher emissions than the historically targeted compounds. Six of these compounds, including four furan derivatives, are quantified in Tables 3-1a and 3-1b and Appendix B and are graphed in Figures 3-6a and 3-6b along with several of the target analytes for comparison.

Figure 3-6a Selected Target and Additional Analyte Emissions, Test HRb, lb/ton metal

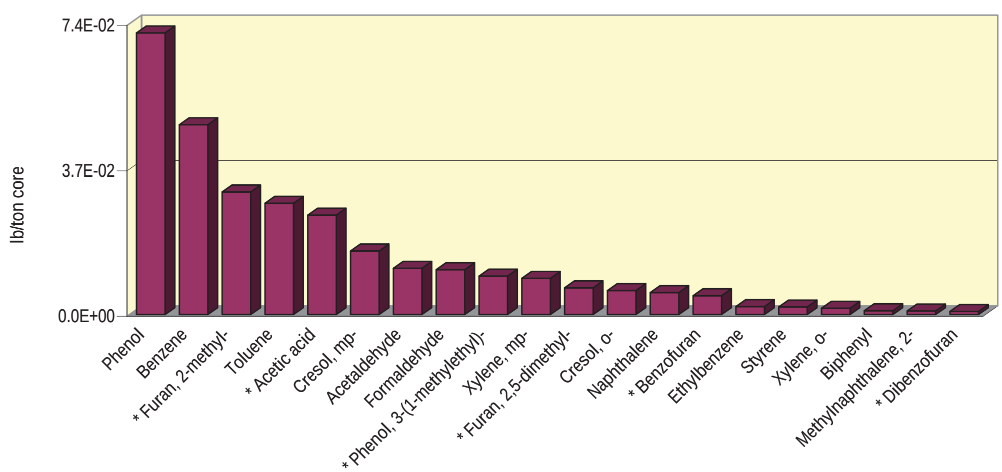
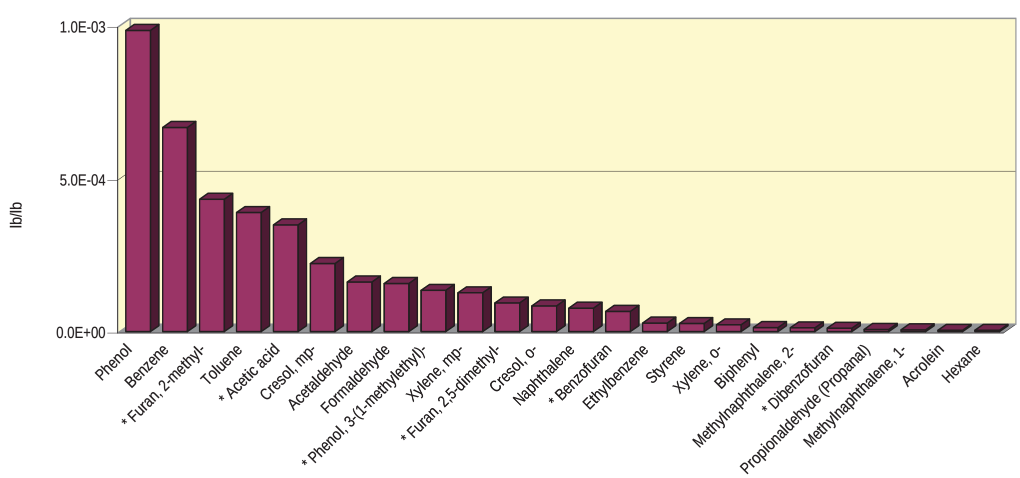


Figure 3-6b Selected Target and Additional Analyte Emissions, Test HRb, lb/lb binder



Forty-five (45) compounds found in the GC/MS chromatogram accounted for 90% of the peak area (concentration). The compounds are listed in decreasing order of peak area in Table 3-2. Twenty-nine (29) of the compounds on the list were in addition to those pre-selected for collection and analysis, and included ten (10) furan derivatives, one additional HAP (dibenzofuran), and one additional POM (phenanthrene).

Table 3-2 Compounds Accounting for 90% of Emissions of Test HRb

Phenol	Benzofuran, 4,7-dimethyl-
Benzene	Furan, 2-ethyl-
Toluene	2-Butanone
Phenol, 3-(1-methylethyl)-	Benzofuran, 7-methyl-
Acetic acid	**Naphthalene, 2-methyl-**
Furan, 2-methyl-	**Dibenzofuran**
m,p-Xylene	**Naphthalene, 2-methyl-**
m,p-cresol	1,3-Cyclopentadiene
Naphthalene	Pentanoic acid, 4-oxo-
Benzofuran, 2-methyl-	Ethanone, 1-(2-furanyl)-
Furan, 2,5-dimethyl-	Unknown
Benzofuran	3-Furaldehyde
o-cresol	3-Buten-2-one, 4-phenyl-
Sulfur dioxide	Phenol, 4-ethyl-
Benzoic Acid	1H-Inden-1-one, 2,3-dihydro-
Benzaldehyde	2-Cyclopentene-1,4-dione
Ethanone, 1-(2-furanyl)-	**Benzene, 1,2,3-trimethyl-**
Biphenyl	*Phenanthrene*
Acetic acid, phenyl ester	Benzaldehyde, 2-methyl-
Ethylbenzene	Phenol, 2-methoxy-
Furan, 2-ethyl-5-methyl-	Benzaldehyde, 2-hydroxy-
Styrene	Benzene, 1-ethyl-2-methyl-
o-Xylene	

(listed left column then right column in decreasing order)

Bold=HAP or criteria pollutant

Italic=POM

Of the 80 individual target analytes sampled by adsorption tube from Test HRb (excluding criteria pollutants and greenhouse gases), only 29 contributed to emissions above the PQL. Of the 33 HAPs targeted for analysis, 18 contributed to emissions above the PQL. Phenol, benzene, toluene, mp-cresol, acetaldehyde, formaldehyde, mp-xylene, o-cresol, and naphthalene accounted for approximately 90% of the measured target analyte emissions. The remaining compounds contributed less than 1% each to total emissions.

Eleven (11) non-HAP target analytes contributed to emissions above the PQL. The highest non-HAP target analyte emitters for Test HRb were benzaldehyde at 2% and 2-butanone at 1%. All remaining non-HAP target compounds contributed less than 1% to total emissions.

3.1.2. Process

The average process parameters measured and recorded for Test HRb are reported in Table 3-3.

Table 3-3 Summary of Test Plan Average Process Parameters

Printed Mold PCS with Iron

Test 1412-124-HRb	
Cast weight, lbs.	120.25
Pouring time, sec.	30
Pouring temp ,°F	2633
Pour hood process air temp at start of pour, °F	87.9
Mold activator %, BOR	0.32
Mold binder %, BOS (programmed)	1.5
Mold binder % , actual (programmed)	1.5
Mold weight, Lbs.	281.4
Binder weight in mold, lbs.	4.2
Mold 1800 LOI, %	1.79
Mold age when poured, days	5.1
Mold temperature, °F	79.3

Castings were selected from Test HRb for surface quality comparison purposes. Eight castings, one each from cavity 3 of each mold, were chosen. The comparison consisted initially of a visual examination of major and minor surface defects such as burn-in and veining. Castings were first ranked according to those defects. To further differentiate surface quality among castings, the finish was tested by touch for smoothness. The smoothest casting with the fewest visual surface defects received the highest ranking.

Three benchmark visual casting quality rankings consisting of the best, the median, and the worst casting were assigned to three of the castings from the baseline Test HRb. The "best" designation means that the internal surface of a casting is the best appearing of the lot of 8, and was given an in-series rank of 1. The "median" designation, given an in-series rank of 4 means that three castings are better in appearance and four are worse. The "worst" designation is assigned to that casting which is of the poorest quality, and is assigned an in-series rank of 8.

The castings from the printed molds all looked very good. The roughness of each casting was similar; most castings still had small lines that are indicative of the printing process. The castings had practically no burn-in and some veining.

Table 3-4 Rank Order of Casting Appearance

Rank Order	Emissions Mold #	Rank Description
Rank1	HRb002	Best
Rank2	HRb006	
Rank3	HRb001	
Rank4	HRb004	Median
Rank5	HRb008	
Rank6	HRb003	
Rank7	HRb005	
Rank8	HRb007	Worst

Appearance=Overall Best Casting to Overall Worst Casting

The four appendices in this report contain detailed information regarding testing, sampling, data collection and results for each sampling event. Appendix A contains test plans, instructions, and the sampling plans. Appendix B contains detailed emissions data and average results for all targeted analytes. Target analyte practical quantitation limits expressed in both lb/lb binder and lb/ton metal are also shown in Appendix B. Appendix C contains detailed process data and the pictorial casting record. Appendix D contains continuous monitor charts. The charts are presented to show TGOC, carbon monoxide, carbon dioxide, methane, and oxides of nitrogen time-dependent emissions profiles for each individual emissions test pour. These charts have not been background corrected. Appendix E contains acronyms and abbreviations.

APPENDIX A TEST AND SAMPLE PLANS AND PROCESS INSTRUCTIONS

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Technikon Test Plan

Fill-in and check all that apply

♦ CONTRACT NUMBER: 1412 TASK NUMBER 124 DOUBLE ALPHA HR-b

♦ SITE:	☒ On Site at Research Foundry ☐ Off Site at _____
♦ DATE RANGE:	From Jun. 1, 07 to Jul. 30, 07
♦ TEST OBJECTIVE:	☒ Emissions Testing ☐ Mechanical Properties ☐ Casting Quality ☐ Comparison to _____ ☐ Other _____
♦ PROCESSES:	☒ Pouring ☒ Cooling ☒ Shakeout ☐ Mixing ☐ Making ☐ Storage ☐ Other _____
♦ TEST TYPE:	☒ Baseline ☐ Product ☐ Other _____
♦ METAL:	☒ Iron ☐ Aluminum ☐ Steel ☐ Other _____ Alloy _____ Pour Temp: 2630±10°F
♦ RUNS:	Number for Conditioning _____ Duration _____ minutes Number for Testing Samples 9 Duration 75 minutes
♦ PROPERTIES TO BE TESTED:	☐ Mold Strength ☐ Moisture Content ☒ 1800 °F LOI% ☐ _____ °F Volatiles ☐ Release Agent ☐ Binder ☐ Clay ☐ Sand ☐ Activator Other _____
♦ RESULTS TO BE ANALYZED AND REPORTED:	☒ Emissions: ☒ HAPs ☒ POMs ☒ Criteria Pollutants ☒ Greenhouse Gases ☐ Other _____ ☐ Casting Quality: ☐ Coated Cores ☐ One Cavity ☐ All Cavities ☐ Other _____ ☐ Mechanical Properties: ☐ Tensile Strength ☐ Weight Change ☐ Flowability ☐ Compressibility ☐ Other _____
♦ BRIEF OVERVIEW:	*This part of the test will measure emissions from the pouring cooling and shakeout of 9 printed 4-on gear molds.*
♦ ADDITIONAL COMMENTS:	*The molds will be wrapped in plastic after being mated out of the print box. Mold storage time wil be greater than 24 hours because the box will take at least 40 hours to print. Molds will likely be older than 1 week.*

Technikon Test Plan

page 2 of 3

Fill-in and check all that apply

♦ CONTRACT NUMBER: 1412 TASK NUMBER 124 DOUBLE ALPHA HR-b

	Cores	Molds	Other
♦ PATTERN:	☐ Step ☐ Other _____ Number _____ Number Cavities _____ Storage Temp: _____°F Storage Age: _____ Dimensions: ☐ Standard (24x24x10/10) ☐ Other _____	☐ Step ☐ Star ☒ Irregular Gear ☐ Other _____ Number 8 Number Cavities 4 Storage Temp: 60-90°F Storage Age: >40 hours Dimensions: ☐ Standard (24x24x10/10) ☒ Other 25.25x23.5x5/5.5	☐ Dogbone ☐ Shakeout ☐ Flowability ☐ Other _____ Number _____ Number Cavities _____ Storage Temp: _____°F Storage Age: _____ Dimensions: ☐ Standard (24x24x10/10) ☐ Other _____
♦ BINDER :	☐ Cold box ☐ Warm box ☐ Hot box ☐ No-bake ☐ Shell ☐ Oil ☐ Other _____ Concentration _____ (BOS) Ratio ($\frac{P1}{P2}$) _____ Product Name(s) _____	☐ Cold box ☐ Warm box ☐ Hot box ☐ No-bake ☐ Shell ☐ Oil ☒ Other Printed Concentration 1.5% (BOS) Ratio ($\frac{P1}{P2}$) _____ Product Name(s) Prometal RCT Binder FB-001 EU	☐ Cold box ☐ Warm box ☐ Hot box ☐ No-bake ☐ Shell ☐ Oil ☐ Other _____ Concentration _____ (BOS) Ratio ($\frac{P1}{P2}$) _____ Product Name(s) _____
♦ CHEMISTRY:	☐ Phenolic Urethane ☐ Furfural ☐ Low Emission (inc. Sodium Silicate) ☐ Epoxy-Acrylic ☐ Alkaline Phenolic Ester ☐ Other _____	☐ Phenolic Urethane ☒ Furfural ☐ Low Emission (inc. Sodium Silicate) ☐ Epoxy-Acrylic ☐ Alkaline Phenolic Ester ☐ Other _____	☐ Phenolic Urethane ☐ Furfural ☐ Low Emission (inc. Sodium Silicate) ☐ Epoxy-Acrylic ☐ Alkaline Phenolic Ester ☐ Other _____
♦ CATALYST:	☐ CO_2 Cured ☐ SO_2 Cured ☐ Acid Cured ☐ TEA Cured ☐ Hot Air Cured ☐ Methyl Formate Cured Concentration _____ BOS Concentration_____ BOR ☐ Other _____	☐ CO_2 Cured ☐ SO_2 Cured ☒ Acid Cured ☐ TEA Cured ☐ Hot Air Cured ☐ Methyl Formate Cured Concentration 0.32% BOS Concentration_____ BOR ☒ Other Prometal RCT Activator FC001-EU (sulfonic acid)	☐ CO_2 Cured ☐ SO_2 Cured ☐ Acid Cured ☐ TEA Cured ☐ Hot Air Cured ☐ Methyl Formate Cured Concentration _____ BOS Concentration_____ BOR ☐ Other _____

Technikon Test Plan

page 3 of 3

Fill-in and check all that apply

♦ CONTRACT NUMBER: 1412 TASK NUMBER 124 DOUBLE ALPHA HR-b

	Cores	Molds	Other
♦ SAND:	☐ Greensand ☐ No-Bake ☐ Other _____ Additives _____ to yield ______ %LOI Product Name(s) _____	☐ Greensand ☒ No-Bake ☐ Other _____ Additives _____ to yield ______ %LOI Product Name(s) Prometal FS001-EU (silica sand)	☐ Greensand ☐ No-Bake ☐ Other _____ Additives _____ to yield ______ %LOI Product Name(s) _____
♦ RELEASE AGENT:	Concentration _____ Application Method _____ Product Name(s) _____	Concentration _____ Application Method _____ Product Name(s) _____	Concentration _____ Application Method _____ Product Name(s) _____
♦ COATING:	☐ None ☐ All Runs ☐ Conditioning Runs Only ☐ Test Runs Only ☐ Baumé _____ ☐ Other _____ Application Method _____ Drying Method _____ Product Name(s) _____	☒ None ☐ All Runs ☐ Conditioning Runs Only ☐ Test Runs Only ☐ Baumé _____ ☐ Other _____ Application Method _____ Drying Method _____ Product Name(s) _____	

This test plan routed to or reviewed by:

- Senior Process Engineer
- Technical Director/Foundry Manager
- Director of Measurement Technologies
- Vice President of Operations
- Applicable Steering Committee Members

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 1											
THC, CO, CO2, NOx and CH4	HR201	X									TOTAL
TO-17 MS	HR20101		1						100	1	Carbopak charcoal
TO-17 MS	HR20102				1				0		Carbopak charcoal
	Excess								100	2	BLOCKED
	Excess								100	3	BLOCKED
Acetophenone	HR20103		1						200	4	15/30 Tenax (SKC 226-35-03)
Acetophenone	HR20104				1				0		15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20105		1						1000	5	Soda Lime (SKC 226-28)
NIOSH 6010	HR20106				1				0		Soda Lime (SKC 226-28)
TO-11	HR20107		1						1000	6	DNPH Silica Gel (SKC 226-119)
TO-11	HR20108				1				0		DNPH Silica Gel (SKC 226-119)
TO-11	HR20109			1					1000	7	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20110		1						1000	8	Acid Silica Gel (SKC 226-10-06)
NIOSH S347	HR20111				1				0		Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20112		1						1000	9	100/50 mg Carbon Bead (SKC 226-80)
OSHA-ID200	HR20113				1				0		100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20114		1						1000	10	XAD-2 (SKC 226-117)
NIOSH 2529	HR20115				1				0		XAD-2 (SKC 226-117)
NIOSH 2002	HR00116		1						1500	11	150/75 mg Silica Gel (SKC 226-10)
NIOSH 2002	HR20117				1						150/75 mg Silica Gel (SKC 226-10)
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 2											
THC, CO, CO2, NOx and CH4	HR202	X									TOTAL
TO-17 MS	HR20201		1						100	1	Carbopak charcoal
TO-17 MS	HR20202			1					100	2	Carbopak charcoal
	Excess								100	3	BLOCKED
Acetophenone	HR20203		1						200	4	15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20204		1						1000	5	Soda Lime (SKC 226-28)
NIOSH 6010	HR20205			1					1000	6	Soda Lime (SKC 226-28)
TO-11	HR20206		1						1000	7	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20207		1						1000	8	Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20208		1						1000	9	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20209		1						1000	10	XAD-2 (SKC 226-117)
NIOSH 2002	HR20210		1						1500	11	150/75 mg Silica Gel (SKC 226-10)
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 3											
THC, CO, CO2, NOx and CH4	HR003	X									TOTAL
TO-17 MS	HR20301		1						100	1	Carbopak charcoal
TO-17 MS	HR20302					1			100	1	Carbopak charcoal
TO-17	HR20303		1						100	2	Carbopak charcoal
TO-17	HR20304			1					100	3	Carbopak charcoal
Acetophenone	HR20305		1						200	4	15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20306		1						1000	5	Soda Lime (SKC 226-28)
TO-11	HR20307		1						1000	6	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20308		1						1000	7	Acid Silica Gel (SKC 226-10-06)
NIOSH S347	HR20309			1					1000	8	Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20310		1						1000	9	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20311		1						1000	10	XAD-2 (SKC 226-117)
NIOSH 2002	HR20312		1						1500	11	150/75 mg Silica Gel (SKC 226-10)
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 4											
THC, CO, CO2, NOx and CH4	HR204	X									TOTAL
TO-17 MS	HR20401		1						100	1	Carbopak charcoal
	Excess								100	2	BLOCKED
Acetophenone	HR20402		1						200	3	15/30 Tenax (SKC 226-35-03)
Acetophenone	HR20403			1					200	4	15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20404		1						1000	5	Soda Lime (SKC 226-28)
TO-11	HR20405		1						1000	6	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20406		1						1000	7	Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20407		1						1000	8	100/50 mg Carbon Bead (SKC 226-80)
OSHA-ID200	HR20408			1					1000	9	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20409		1						1000	10	XAD-2 (SKC 226-117)
NIOSH 2002	HR20410		1						1500	11	150/75 mg Silica Gel (SKC 226-10)
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 5											
THC, CO, CO2, NOx and CH4	HR205	X									TOTAL
TO-17 MS	HR20501		1						100	1	Carbopak charcoal
	Excess								100	2	BLOCKED
	Excess								200	3	BLOCKED
Acetophenone	HR20502		1						200	4	15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20503		1						1000	5	Soda Lime (SKC 226-28)
TO-11	HR20504		1						1000	6	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20505		1						1000	7	Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20506		1						1000	8	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20507		1						1000	9	XAD-2 (SKC 226-117)
NIOSH 2529	HR20508			1					1000	10	XAD-2 (SKC 226-117)
NIOSH 2002	HR20509		1						1500	11	150/75 mg Silica Gel (SKC 226-10)
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 6											
THC, CO, CO2, NOx and CH4	HR206	X									TOTAL
TO-17 MS	HR20601		1						100	1	Carbopak charcoal
	Excess								100	2	BLOCKED
	Excess								200	3	BLOCKED
Acetophenone	HR20602		1						200	4	15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20603		1						1000	5	Soda Lime (SKC 226-28)
TO-11	HR20604		1						1000	6	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20605		1						1000	7	Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20606		1						1000	8	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20607		1						1000	9	XAD-2 (SKC 226-117)
NIOSH 2002	HR20608		1						1500	10	150/75 mg Silica Gel (SKC 226-10)
NIOSH 2002	HR20609			1					1500	11	150/75 mg Silica Gel (SKC 226-10)
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 7											
THC, CO, CO2, NOx and CH4	HR207	X									TOTAL
TO-17 MS	HR20701		1						100	1	Carbopak charcoal
	Excess								100	2	BLOCKED
	Excess								200	3	BLOCKED
Acetophenone	HR20702		1						200	4	15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20703		1						1000	5	Soda Lime (SKC 226-28)
TO-11	HR20704		1						1000	6	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20705		1						1000	7	Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20706		1						1000	8	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20707		1						1000	9	XAD-2 (SKC 226-117)
NIOSH 2002	HR20708		1						1500	10	150/75 mg Silica Gel (SKC 226-10)
	Excess								1500	11	BLOCKED
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 8											
THC, CO, CO2, NOx and CH4	HR208	X									TOTAL
TO-17 MS	HR20801		1						100	1	Carbopak charcoal
	Excess								100	2	BLOCKED
	Excess								200	3	BLOCKED
Acetophenone	HR20802		1						200	4	15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20803		1						1000	5	Soda Lime (SKC 226-28)
TO-11	HR20804		1						1000	6	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20805		1						1000	7	Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20806		1						1000	8	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20807		1						1000	9	XAD-2 (SKC 226-117)
NIOSH 2002	HR20808		1						1500	10	150/75 mg Silica Gel (SKC 226-10)
	Excess								1500	11	BLOCKED
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION HR(b) - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 9											
THC, CO, CO2, NOx and CH4	HR209	X									TOTAL
TO-17 MS	HR20901		1						100	1	Carbopak charcoal
	Excess								100	2	BLOCKED
	Excess								200	3	BLOCKED
Acetophenone	HR20902		1						200	4	15/30 Tenax (SKC 226-35-03)
NIOSH 6010	HR20903		1						1000	5	Soda Lime (SKC 226-28)
TO-11	HR20904		1						1000	6	DNPH Silica Gel (SKC 226-119)
NIOSH S347	HR20905		1						1000	7	Acid Silica Gel (SKC 226-10-06)
OSHA-ID200	HR20906		1						1000	8	100/50 mg Carbon Bead (SKC 226-80)
NIOSH 2529	HR20907		1						1000	9	XAD-2 (SKC 226-117)
NIOSH 2002	HR20908		1						1500	10	150/75 mg Silica Gel (SKC 226-10)
	Excess								1500	11	BLOCKED
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

Series – 1412-124 HR-b

Mold Emission, PCS of Digitally Printed Mold Emissions Test
Process Instructions

A. The Experiment:

a. Measure total selected emissions from pouring, cooling, and shakeout of ProMetal S15 4-on irregular gear molds.

B. Materials:

1. Prometal FS001 Sand
2. Prometal RCT Binder FB001-EU
3. Prometal RCT Activator FC001-EU

C. Machine setup.

1. The ProMetal S15 machine is to be operated by trained personnel only.

D. Mold making:

1. Load the ProMetal S15 machine with the correct print box layout file.
2. Fill the ProMetal S15 machine binder, activator, cleaner and sand bins for printing.
3. In synchronization with the emissions team start the printer.
4. Allow the ProMetal S15 machine to run continuously during the entire emissions sampling event.
5. Refill the ProMetal S15 machine binder, activator, cleaner and sand bins during the run so to not run out during the printing time.
6. After the print job has finished allow the machine to sit, undisturbed, for 1 hour of emissions sampling.
7. When the molds have cured, remove the print box from the ProMetal S15 machine.
8. Clean, mate, and wrap the molds for pouring, cooling and, shakeout tests. Record mold weight.

E. Emission hood pouring ,cooling, shakeout:

1. Loading.
   - **a.** Hoist the mold onto the shakeout deck fixture within the emission hood with the pouring cup side toward the furnace.
   - **b.** Place the weights on top of the mold.
   - **c.** Install ½ re-rod hanger in each riser vent and hang over shakeout supports.

d. Close and seal the emission hood and lock the ducts together.
e. Attach the heated ambient air duct to plenum
f. Wait to pour until the process air thermocouple is in the range 85-90 ^{o}F.
g. Record the ambient & process ambient air temperature.

2. Shakeout.
a. After 45 minutes of cooling time has elapsed turn on the shakeout unit and **run for a full 15 minutes** as prescribed in the emission test plan.
b. Turn off the shakeout. The emission sampling will continue for an additional 15 minutes or a total of 75 minutes
c. Wait for the emission team to signal that they are finished sampling.
d. Open the hood, remove the castings
e. Clean core sand out of the waste sand box, off the shakeout, and the floor.
f. **Immediately load the next prepared mold** and close the hood.
g. Weigh and record cast metal weight adjusted for the re-rod hanger weight.

3. Melting:

a. Initial charge:
1) Charge the furnace according to the **Generic Start Up Charge for Pre-production** heat recipe bearing effectivity date 6 Apr 2004.
2) Place part of the steel scrap on the bottom, followed by carbon alloys, and the balance of the steel.
3) Place a pig on top.
4) Bring the furnace contents to the point of beginning to melt over a period of 1 hour at reduced power.
5) Add the balance of the metallics under full power until all is melted and the temperature has reached 2600 to 2700 °F.
6) Slag the furnace and add the balance of the alloys.
7) 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^{o}F.
8) Hold the furnace at 2500-2550^{o}F until near ready to tap.
9) When ready to tap raise the temperature to 2700^{o}F and slag the furnace.
10) Record all metallic and alloy additions to the furnace & tap temperature. Record all furnace activities with an associated time. Record Data Cast TPL, TPS, CE, C, & Si.

b. Back charging.
1) If additional iron is desired back charge according to the **Generic Pre-production Last Melt** heat recipe bearing effectivity date 18 Mar 1999.
2) Charge a few pieces of steel first to make a splash barrier, followed by the carbon

alloys.

3) Follow the above steps beginning with 3.a.6

c. Emptying the furnace.

1) Pig the extra metal after pouring the last test mold.

d. Pouring:

1) Preheat the ladle.
2) Tap 400 pounds more or less of 2700°F metal into the cold ladle.
3) Casually pour the metal back to the furnace.
4) Cover the ladle.
5) Reheat the metal to 2780 +/- 20 °F.
6) Tap 450 pounds more or less of iron into the ladle while pouring inoculating alloys onto the metal stream near its base.
7) Cover the ladle to conserve heat.
8) Move the ladle to the pour position, open the emission hood pour door and wait until the metal temperature reaches 2630 +/- 10 °F.
9) Commence pouring keeping the sprue full.
10) Upon completion close the hood door, return the extra metal to the furnace, and cover the ladle.
11) Record Pouring temperature and pour duration.

F. Casting cleaning

1. Spin blast set up.
2. Load the spin blast shot storage bin with 460 steel shot.
3. Turn on the spin blast bag house.
4. Turn on the spin blast machine.
5. Increase the magnetic feeder so that the motor amperage just turns to 12 amps from 11 amps.
6. Record the shot flow and the motor amperage for each wheel

a. Cleaning castings.
b. Place the four (4) castings from a single mold on one (1) casting basket.
c. Process each rotating basket for eight (8) minutes.
d. Remove and remark casting ID on each casting.

G. Casting Ranking

1. Rank order evaluation.
2. The supervisor shall select a group of four or five persons to make a collective subjective judgment of the casting's relative surface appearance.
3. Review the general appearance of the castings and select specific casting features to compare. Generally for the gear mold the material related casting features should be metal penetration, veining, expansion defects and texture (tactile feel). Defects

arising from loose sand, slag, broken molds, double striking, and shrinkage should be disregarded.

4. For each cavity casting:
  - **a.** Place each casting initially in sequential mold number order.
  - **b.** Beginning with casting from cavity 3 mold HR001 compare it to castings from cavity 3 mold HR002.
  - **c.** Place the better appearing casting in the first position and the lesser appearing casting in the second position.
  - **d.** Repeat this procedure with cavity 3 mold HR001 to its nearest neighbors until all castings closer to the beginning of the line are better appearing than cavity 3 mold HR001 and the next casting farther down the line is inferior.
  - **e.** Repeat this comparison to next neighbors for each cavity 1 casting number from molds HR001-HR009.
  - **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 evaluators concur with the ranking order.

5. Record cavity 1 mold number by rank-order series.

6. Save the best, median, and worst castings of Cavity 3 for photographing and archiving.

Tom Fennell
Process Engineer

APPENDIX B DETAILED EMISSION RESULTS AND QUANTITATION LIMITS

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Detailed Emissions Data - Test HRb, lb/ton metal

TA	POM	HAP	Test Dates	6/28/2007	6/28/2007	6/28/2007	6/29/2007	6/29/2007	6/29/2007	7/2/2007	7/2/2007	Average –	Standard Deviation –
Emission Indicators													
			THC as Propane	2.26E+00	2.25E+00	2.20E+00	2.04E+00	2.12E+00	2.09E+00	2.08E+00	2.14E+00	2.15E+00	8.07E-02
			Non-Methane Hydrocarbons	1.66E+00	1.64E+00	1.62E+00	1.49E+00	1.57E+00	1.52E+00	1.52E+00	1.56E+00	1.57E+00	6.19E-02
			Sum of Target Analytes	2.10E-01	1.93E-01	2.38E-01	1.86E-01	1.77E-01	1.59E-01	2.06E-01	2.33E-01	2.28E-01	2.70E-02
			Sum of Target HAPs	1.98E-01	1.82E-01	2.26E-01	1.77E-01	1.68E-01	1.50E-01	1.96E-01	2.21E-01	2.18E-01	2.59E-02
			Sum of Target POMs	1.45E-03	6.74E-03	6.63E-03	6.40E-03	6.28E-03	1.41E-03	7.29E-03	7.82E-03	6.90E-03	2.56E-03
Selected Target HAPs and POMs													
TA		H	Phenol	I	6.65E-02	8.18E-02	6.43E-02	6.48E-02	I	7.29E-02	7.99E-02	7.17E-02	7.76E-03
TA		H	Benzene	1.37E-01	2.19E-02	3.52E-02	2.67E-02	1.82E-02	8.88E-02	2.26E-02	3.58E-02	4.83E-02	4.24E-02
TA		H	Toluene	I	2.88E-02	3.46E-02	2.42E-02	2.37E-02	I	2.92E-02	2.95E-02	2.83E-02	3.99E-03
TA		H	Cresol, mp-	1.64E-02	1.37E-02	1.83E-02	1.54E-02	1.48E-02	1.58E-02	1.58E-02	1.93E-02	1.62E-02	1.81E-03
TA		H	Acetaldehyde	1.37E-02	1.24E-02	1.35E-02	1.01E-02	1.08E-02	1.07E-02	1.11E-02	1.21E-02	1.18E-02	1.34E-03
TA		H	Formaldehyde	1.39E-02	1.08E-02	1.36E-02	1.02E-02	9.95E-03	8.70E-03	1.31E-02	1.11E-02	1.14E-02	1.90E-03
TA		H	Xylene, mp-	I	8.61E-03	8.73E-03	8.02E-03	8.23E-03	1.14E-02	9.91E-03	9.61E-03	9.22E-03	1.19E-03
TA		H	Cresol, o-	6.17E-03	5.67E-03	7.07E-03	5.60E-03	5.16E-03	5.92E-03	5.90E-03	7.38E-03	6.11E-03	7.53E-04
TA	P	H	Naphthalene	I	5.56E-03	5.51E-03	5.16E-03	5.10E-03	I	6.01E-03	6.20E-03	5.59E-03	4.45E-04
TA		H	Ethylbenzene	2.77E-03	1.82E-03	1.86E-03	1.71E-03	1.66E-03	2.01E-03	2.15E-03	2.24E-03	2.03E-03	3.62E-04
TA		H	Styrene	2.50E-03	1.92E-03	2.03E-03	1.54E-03	1.44E-03	1.71E-03	1.95E-03	2.27E-03	1.92E-03	3.58E-04
TA		H	Xylene, o-	2.08E-03	1.43E-03	1.44E-03	1.40E-03	1.44E-03	1.63E-03	1.73E-03	1.72E-03	1.61E-03	2.34E-04
TA		H	Biphenyl	1.18E-03	8.14E-04	8.06E-04	9.17E-04	8.95E-04	1.04E-03	9.46E-04	1.14E-03	9.66E-04	1.39E-04
TA	P	H	Methylnaphthalene, 2-	9.80E-04	8.07E-04	7.57E-04	8.51E-04	8.12E-04	9.78E-04	8.79E-04	1.09E-03	8.94E-04	1.12E-04
TA		H	Propionaldehyde (Propanal)	5.92E-04	5.67E-04	6.41E-04	4.18E-04	4.30E-04	4.43E-04	4.51E-04	5.24E-04	5.08E-04	8.47E-05
TA	P	H	Methylnaphthalene, 1-	4.68E-04	3.78E-04	3.64E-04	3.92E-04	3.67E-04	4.37E-04	4.00E-04	5.22E-04	4.16E-04	5.58E-05
TA		H	Acrolein	3.52E-04	4.58E-04	≤PQL	2.52E-04	2.59E-04	2.40E-04	3.37E-04	3.98E-04	3.12E-04	8.94E-05
TA		H	Hexane	≤PQL	≤PQL	≤PQL	≤PQL	3.10E-04	≤PQL	3.49E-04	3.42E-04	3.02E-04	2.86E-05
TA	P	H	Acenaphthalene	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	NA
TA	P	H	Anthracene	I	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,2-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,6-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,8-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 2,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 2,6-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 2,7-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Trimethylnaphthalene, 2,3,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA

≤PQL=less than or equal to the practica quanation limit
NA-Not Applicable
I=Invalidated
TA=Target Analytes
H=HAPs
P=POMs

Detailed Emissions Data - Test HRb, lb/ton metal

TA	POM	HAP										Average	Standard Deviation
			Test Dates	6/28/2007	6/28/2007	6/28/2007	6/29/2007	6/29/2007	6/29/2007	7/2/2007	7/2/2007	-	-
TA		H	Acetophenone	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA		H	Aniline	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA		H	Hydrogen Cyanide	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA		H	Isopropylbenzene	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
Additional Selected Target Analytes													
TA			Benzaldehyde	5.37E-03	5.02E-03	5.56E-03	3.90E-03	3.34E-03	4.05E-03	4.77E-03	5.20E-03	4.65E-03	7.96E-04
TA			2-Butanone (MEK)	2.58E-03	3.02E-03	2.84E-03	2.75E-03	2.80E-03	2.81E-03	2.58E-03	2.96E-03	2.79E-03	1.57E-04
TA			Indene	9.51E-04	9.14E-04	8.95E-04	7.14E-04	6.75E-04	7.14E-04	8.13E-04	1.12E-03	8.50E-04	1.51E-04
TA			o,m,p-Tolualdehyde	1.03E-03	8.95E-04	1.04E-03	6.16E-04	5.85E-04	6.48E-04	9.45E-04	8.98E-04	8.32E-04	1.87E-04
TA			Crotonaldehyde	6.95E-04	5.92E-04	8.88E-04	4.81E-04	4.79E-04	7.10E-04	5.32E-04	5.96E-04	6.22E-04	1.38E-04
TA			Trimethylbenzene, 1,2,4-	6.46E-04	5.27E-04	5.10E-04	5.55E-04	5.49E-04	6.98E-04	6.29E-04	6.59E-04	5.97E-04	6.97E-05
TA			Dimethylphenol, 2,4-	≤PQL	6.01E-04	7.18E-04	7.20E-04	6.70E-04	≤PQL	6.07E-04	7.43E-04	5.78E-04	1.89E-04
TA			Pentanal (Valeraldehyde)	4.54E-04	4.76E-04	5.60E-04	4.63E-04	4.55E-04	5.31E-04	5.96E-04	5.26E-04	5.08E-04	5.37E-05
TA			Ethyltoluene, 4-	4.91E-04	4.02E-04	3.95E-04	4.08E-04	4.17E-04	4.26E-04	4.73E-04	5.01E-04	4.39E-04	4.23E-05
TA			Ethyltoluene, 3-	4.88E-04	3.78E-04	3.67E-04	3.92E-04	3.91E-04	4.03E-04	4.41E-04	4.72E-04	4.17E-04	4.50E-05
TA			Butyraldehyde/Methacrolein	3.67E-04	3.52E-04	4.52E-04	≤PQL	≤PQL	3.53E-04	3.56E-04	3.32E-04	3.59E-04	4.03E-05
TA			Cyclohexane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Decane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Diethylbenzene, 1,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 2,6-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dodecane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Ethyltoluene, 2-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Heptane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Hexaldehyde	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Indan	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Nonane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Octane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Propylbenzene, n-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Tetradecane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	NA
TA			Trimethylbenzene, 1,2,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	≤PQL	≤PQL	NA
TA			Trimethylbenzene, 1,3,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	NA
TA			Undecane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			alpha-Methylstyrene	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Ammonia	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Butylbenzene, n-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Butylbenzene, sec-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA

≤PQL=less than or equal to the practica quanation limit
NA-Not Applicable
I=Invalidated
TA=Target Analytes
H=HAPs
P=POMs

Detailed Emissions Data - Test HRb, lb/ton metal

TA	POM	HAP										Average	Standard Deviation
			Test Dates	6/28/2007	6/28/2007	6/28/2007	6/29/2007	6/29/2007	6/29/2007	7/2/2007	7/2/2007	–	–
TA			Butylbenzene, tert-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Cymene, p-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Diethylbenzene, 1,2-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Diethylbenzene, 1,4-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Diisopropylbenzene, 1,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylaniline	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 2,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 2,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 3,4-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 3,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	NA
TA			Furfural	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Isobutylbenzene	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			o-Toluidine	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Tridecane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Trimethylphenol, 2,3,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Trimethylphenol, 2,4,6-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
Additional Analytes													
			Furan, 2-methyl-	I	2.95E-02	2.86E-02	2.64E-02	2.66E-02	4.89E-02	2.72E-02	I	3.12E-02	8.75E-03
			Acetic acid	3.78E-02	1.39E-02	2.55E-02	1.07E-02	3.24E-02	3.68E-02	2.28E-02	2.25E-02	2.53E-02	9.99E-03
			Phenol, 3-(1-methylethyl)-	1.36E-02	8.14E-03	9.28E-03	8.73E-03	8.62E-03	1.26E-02	8.24E-03	9.00E-03	9.77E-03	2.10E-03
			Furan, 2,5-dimethyl-	6.11E-03	3.57E-03	6.08E-03	6.10E-03	7.68E-03	8.77E-03	7.96E-03	8.16E-03	6.80E-03	1.68E-03
			Benzofuran	8.07E-03	3.97E-03	4.10E-03	3.52E-03	3.65E-03	5.76E-03	4.46E-03	4.81E-03	4.79E-03	1.51E-03
		H	Dibenzofuran	1.07E-03	6.40E-04	I	6.92E-04	6.75E-04	9.20E-04	I	7.77E-04	7.95E-04	1.66E-04
Selected Criteria Pollutants and Greenhouse Gases													
			Carbon Dioxide	1.84E+01	1.60E+01	1.96E+01	1.49E+01	1.27E+01	1.23E+01	1.81E+01	1.67E+01	1.61E+01	2.66E+00
			Carbon Monoxide	9.49E+00	9.68E+00	1.00E+01	8.79E+00	8.46E+00	8.35E+00	1.03E+01	9.51E+00	9.32E+00	7.12E-01
			Sulfur Dioxide	8.93E-01	8.21E-01	8.06E-01	8.06E-01	7.94E-01	7.48E-01	9.09E-01	7.99E-01	8.22E-01	5.32E-02
			Methane	5.93E-01	6.13E-01	5.84E-01	5.54E-01	5.50E-01	5.62E-01	5.60E-01	5.73E-01	5.73E-01	2.18E-02
			Nitrogen Oxides	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA

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H=HAPs
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Detailed Emissions Data - Test HRb, lb/lb binder

TA	POM	HAP										Average	Standard Deviation
			Test Dates	6/28/2007	6/28/2007	6/28/2007	6/29/2007	6/29/2007	6/29/2007	7/2/2007	7/2/2007	-	-
Emission Indicators													
			THC as Propane	3.13E-02	3.14E-02	3.03E-02	3.09E-02	3.11E-02	3.18E-02	3.09E-02	3.07E-02	3.11E-02	4.80E-04
			Non-Methane Hydrocarbons	2.31E-02	2.28E-02	2.22E-02	2.25E-02	2.30E-02	2.33E-02	2.26E-02	2.25E-02	2.28E-02	3.58E-04
			Sum of Target Analytes	2.94E-03	2.74E-03	3.33E-03	2.61E-03	2.48E-03	2.27E-03	2.88E-03	3.14E-03	3.18E-03	3.48E-04
			Sum of Target HAPs	2.76E-03	2.55E-03	3.13E-03	2.44E-03	2.33E-03	2.09E-03	2.70E-03	2.94E-03	3.00E-03	3.37E-04
			Sum of Target POMs	2.01E-05	9.44E-05	9.17E-05	8.81E-05	8.68E-05	1.97E-05	1.01E-04	1.04E-04	9.49E-05	3.49E-05
Selected Target HAPs and POMs													
TA		H	Phenol	I	9.30E-04	1.13E-03	8.84E-04	8.95E-04	I	1.01E-03	1.06E-03	9.85E-04	9.88E-05
TA		H	Benzene	1.90E-03	3.06E-04	4.87E-04	3.67E-04	2.52E-04	1.24E-03	3.12E-04	4.76E-04	6.68E-04	5.91E-04
TA		H	Toluene	I	4.02E-04	4.78E-04	3.33E-04	3.28E-04	I	4.03E-04	3.93E-04	3.89E-04	5.50E-05
TA		H	Cresol, mp-	2.28E-04	1.92E-04	2.53E-04	2.12E-04	2.04E-04	2.19E-04	2.18E-04	2.56E-04	2.23E-04	2.23E-05
TA		H	Acetaldehyde	1.90E-04	1.73E-04	1.87E-04	1.39E-04	1.49E-04	1.49E-04	1.53E-04	1.60E-04	1.62E-04	1.87E-05
TA		H	Formaldehyde	1.93E-04	1.51E-04	1.88E-04	1.40E-04	1.37E-04	1.21E-04	1.81E-04	1.48E-04	1.57E-04	2.64E-05
TA		H	Xylene, mp-	I	1.20E-04	1.21E-04	1.10E-04	1.14E-04	1.59E-04	1.37E-04	1.28E-04	1.27E-04	1.67E-05
TA		H	Cresol, o-	8.56E-05	7.93E-05	9.77E-05	7.71E-05	7.13E-05	8.25E-05	8.15E-05	9.81E-05	8.41E-05	9.49E-06
TA	P	H	Naphthalene	I	7.78E-05	7.62E-05	7.10E-05	7.05E-05	I	8.31E-05	8.25E-05	7.68E-05	5.43E-06
TA		H	Ethylbenzene	3.84E-05	2.54E-05	2.57E-05	2.35E-05	2.29E-05	2.80E-05	2.98E-05	2.98E-05	2.79E-05	4.96E-06
TA		H	Styrene	3.47E-05	2.69E-05	2.81E-05	2.12E-05	1.99E-05	2.39E-05	2.70E-05	3.03E-05	2.65E-05	4.83E-06
TA		H	Xylene, o-	2.89E-05	2.00E-05	1.98E-05	1.93E-05	1.99E-05	2.27E-05	2.38E-05	2.29E-05	2.22E-05	3.21E-06
TA		H	Biphenyl	1.63E-05	1.14E-05	1.11E-05	1.26E-05	1.24E-05	1.44E-05	1.31E-05	1.52E-05	1.33E-05	1.83E-06
TA	P	H	Methylnaphthalene, 2-	1.36E-05	1.13E-05	1.05E-05	1.17E-05	1.12E-05	1.36E-05	1.22E-05	1.45E-05	1.23E-05	1.42E-06
TA		H	Propionaldehyde (Propanal)	8.21E-06	7.94E-06	8.86E-06	5.75E-06	5.94E-06	6.17E-06	6.23E-06	6.97E-06	7.01E-06	1.18E-06
TA	P	H	Methylnaphthalene, 1-	6.49E-06	5.28E-06	5.03E-06	5.39E-06	5.07E-06	6.08E-06	5.53E-06	6.94E-06	5.73E-06	7.03E-07
TA		H	Acrolein	4.89E-06	6.41E-06	≤PQL	3.47E-06	3.57E-06	3.35E-06	4.66E-06	5.30E-06	4.31E-06	1.21E-06
TA		H	Hexane	≤PQL	≤PQL	≤PQL	≤PQL	4.28E-06	≤PQL	4.82E-06	4.55E-06	4.25E-06	2.88E-07
TA	P	H	Acenaphthalene	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	NA
TA	P	H	Anthracene	I	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,2-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 1,6-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA

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Detailed Emissions Data - Test HRb, lb/lb binder

TA	POM	HAP										Average	Standard Deviation
			Test Dates	6/28/2007	6/28/2007	6/28/2007	6/29/2007	6/29/2007	6/29/2007	7/2/2007	7/2/2007	-	-
TA	P	H	Dimethylnaphthalene, 1,8-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 2,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 2,6-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Dimethylnaphthalene, 2,7-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA	P	H	Trimethylnaphthalene, 2,3,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA		H	Acetophenone	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA		H	Aniline	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA		H	Hydrogen Cyanide	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA		H	Isopropylbenzene	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
Additional Selected Target Analytes													
TA			Benzaldehyde	7.45E-05	7.03E-05	7.68E-05	5.37E-05	4.61E-05	5.64E-05	6.60E-05	6.91E-05	6.41E-05	1.09E-05
TA			2-Butanone (MEK)	3.58E-05	4.23E-05	3.92E-05	3.79E-05	3.88E-05	3.91E-05	3.57E-05	3.94E-05	3.85E-05	2.11E-06
TA			Indene	1.32E-05	1.28E-05	1.24E-05	9.83E-06	9.33E-06	9.94E-06	1.12E-05	1.49E-05	1.17E-05	1.96E-06
TA			o,m,p-Tolualdehyde	1.43E-05	1.25E-05	1.44E-05	8.48E-06	8.08E-06	9.03E-06	1.31E-05	1.19E-05	1.15E-05	2.58E-06
TA			Crotonaldehyde	9.64E-06	8.29E-06	1.23E-05	6.61E-06	6.62E-06	9.89E-06	7.35E-06	7.92E-06	8.57E-06	1.94E-06
TA			Trimethylbenzene, 1,2,4-	8.96E-06	7.38E-06	7.05E-06	7.63E-06	7.58E-06	9.72E-06	8.69E-06	8.77E-06	8.22E-06	9.38E-07
TA			Dimethylphenol, 2,4-	≤PQL	8.41E-06	9.92E-06	9.90E-06	9.25E-06	≤PQL	8.38E-06	9.89E-06	7.99E-06	2.50E-06
TA			Pentanal (Valeraldehyde)	6.30E-06	6.66E-06	7.73E-06	6.36E-06	6.29E-06	7.41E-06	8.24E-06	6.99E-06	7.00E-06	7.34E-07
TA			Ethyltoluene, 4-	6.81E-06	5.63E-06	5.47E-06	5.61E-06	5.76E-06	5.94E-06	6.54E-06	6.66E-06	6.05E-06	5.35E-07
TA			Ethyltoluene, 3-	6.77E-06	5.29E-06	5.08E-06	5.39E-06	5.40E-06	5.61E-06	6.09E-06	6.28E-06	5.74E-06	5.83E-07
TA			Butyraldehyde/Methacrolein	5.09E-06	4.93E-06	6.24E-06	≤PQL	≤PQL	4.92E-06	4.92E-06	≤PQL	5.03E-06	5.06E-07
TA			Cyclohexane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Decane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Diethylbenzene, 1,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 2,6-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dodecane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Ethyltoluene, 2-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Heptane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Hexaldehyde	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Indan	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA

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Detailed Emissions Data - Test HRb, lb/lb binder

TA	POM	HAP	Test Dates	6/28/2007	6/28/2007	6/28/2007	6/29/2007	6/29/2007	6/29/2007	7/2/2007	7/2/2007	Average	Standard Deviation
												-	-
TA			Nonane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Octane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Propylbenzene, n-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Tetradecane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	NA
TA			Trimethylbenzene, 1,2,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	≤PQL	≤PQL	NA
TA			Trimethylbenzene, 1,3,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	NA
TA			Undecane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			alpha-Methylstyrene	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Ammonia	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Butylbenzene, n-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Butylbenzene, sec-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Butylbenzene, tert-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Cymene, p-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Diethylbenzene, 1,2-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Diethylbenzene, 1,4-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Diisopropylbenzene, 1,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylaniline	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 2,3-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 2,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 3,4-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Dimethylphenol, 3,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	I	≤PQL	NA
TA			Furfural	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Isobutylbenzene	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			o-Toluidine	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Tridecane	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Trimethylphenol, 2,3,5-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
TA			Trimethylphenol, 2,4,6-	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA
Additional Analytes													
			Furan, 2-methyl-	I	4.13E-04	3.95E-04	3.64E-04	3.68E-04	6.81E-04	3.76E-04	I	4.33E-04	1.23E-04
			Acetic acid	5.25E-04	1.94E-04	3.52E-04	1.47E-04	4.47E-04	5.13E-04	3.15E-04	3.00E-04	3.49E-04	1.39E-04

≤PQL=less than or equal to the practical quantitation limit
NA-Not Applicable
I=Invalidated
TA=Target Analytes
H=HAPs
P=POMs

Detailed Emissions Data - Test HRb, lb/lb binder

TA	POM	HAP										Average	Standard Deviation
			Test Dates	**6/28/2007**	**6/28/2007**	**6/28/2007**	**6/29/2007**	**6/29/2007**	**6/29/2007**	**7/2/2007**	**7/2/2007**	**-**	**-**
			Phenol, 3-(1-methylethyl)-	1.89E-04	1.14E-04	1.28E-04	1.20E-04	1.19E-04	1.75E-04	1.14E-04	1.20E-04	1.35E-04	2.97E-05
			Furan, 2,5-dimethyl-	8.48E-05	4.99E-05	8.40E-05	8.39E-05	1.06E-04	1.22E-04	1.10E-04	1.09E-04	9.37E-05	2.28E-05
			Benzofuran	1.12E-04	5.56E-05	5.67E-05	4.84E-05	5.04E-05	8.03E-05	6.17E-05	6.40E-05	6.61E-05	2.10E-05
			Dibenzofuran	1.48E-05	8.95E-06	I	9.52E-06	9.33E-06	1.28E-05	I	1.03E-05	1.10E-05	2.34E-06
Selected Criteria Pollutants and Greenhouse Gases													
			Carbon Dioxide	2.56E-01	2.23E-01	2.69E-01	2.26E-01	1.86E-01	1.88E-01	2.69E-01	2.40E-01	2.32E-01	3.29E-02
			Carbon Monoxide	1.32E-01	1.35E-01	1.38E-01	1.33E-01	1.24E-01	1.27E-01	1.52E-01	1.37E-01	1.35E-01	8.52E-03
			Sulfur Dioxide	1.24E-02	1.15E-02	1.11E-02	1.11E-02	1.10E-02	1.04E-02	1.26E-02	1.06E-02	1.13E-02	7.73E-04
			Methane	8.22E-03	8.56E-03	8.01E-03	8.37E-03	8.06E-03	8.57E-03	8.32E-03	8.24E-03	8.30E-03	2.05E-04
			Nitrogen Oxides	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	≤PQL	NA

≤PQL=less than or equal to the practical quantitation limit
NA-Not Applicable
I=Invalidated
TA=Target Analytes
H=HAPs
P=POMs

Practical Reporting Limits, Test HRb, lb/ton metal

Analyte	lb/tn	Analyte	lb/tn
2-Butanone (MEK)	1.97E-04	Ethyltoluene, 2-	2.83E-04
Acenaphthalene	2.83E-04	Ethyltoluene, 3-	2.83E-04
Acetaldehyde	1.97E-04	Ethyltoluene, 4-	2.83E-04
Acetophenone	1.12E-02	Formaldehyde	1.97E-04
Acrolein	1.97E-04	Furfural	4.68E-03
alpha-Methylstyrene	2.83E-04	Heptane	2.83E-04
Ammonia	1.10E-02	Hexaldehyde	1.97E-04
Aniline	1.52E-03	Hexane	2.83E-04
Anthracene	2.83E-04	Hydrogen Cyanide	7.67E-04
Benzaldehyde	1.97E-04	Indan	2.83E-04
Benzene	2.83E-04	Indene	2.83E-04
Biphenyl	2.83E-04	Isobutylbenzene	2.83E-04
Butylbenzene, n-	2.83E-04	Isopropylbenzene	2.83E-04
Butylbenzene, sec-	2.83E-04	Methylnaphthalene, 1-	2.83E-04
Butylbenzene, tert-	2.83E-04	Methylnaphthalene, 2-	2.83E-04
Butyraldehyde/Methacrolein	3.28E-04	Naphthalene	2.83E-04
Cresol, mp-	2.83E-04	Nonane	2.83E-04
Cresol, o-	2.83E-04	o,m,p-Tolualdehyde	5.25E-04
Crotonaldehyde	1.97E-04	Octane	2.83E-04
Cyclohexane	2.83E-04	Pentanal (Valeraldehyde)	1.97E-04
Cymene, p-	2.83E-04	Phenol	2.83E-04
Decane	2.83E-04	Propionaldehyde (Propanal)	1.97E-04
Diethylbenzene, 1,2-	2.83E-04	Propylbenzene, n-	2.83E-04
Diethylbenzene, 1,3-	2.83E-04	Styrene	2.83E-04
Diethylbenzene, 1,4-	2.83E-04	Tetradecane	2.83E-04
Diisopropylbenzene, 1,3-	2.83E-04	Toluene	2.83E-04
Dimethylaniline	2.66E-03	Tridecane	2.83E-04
Dimethylnaphthalene, 1,2-	2.83E-04	Trimethylbenzene, 1,2,3-	2.83E-04
Dimethylnaphthalene, 1,3-	2.83E-04	Trimethylbenzene, 1,2,4-	2.83E-04
Dimethylnaphthalene, 1,5-	2.83E-04	Trimethylbenzene, 1,3,5-	2.83E-04
Dimethylnaphthalene, 1,6-	2.83E-04	Trimethylnaphthalene, 2,3,5-	2.83E-04
Dimethylnaphthalene, 1,8-	2.83E-04	Trimethylphenol, 2,3,5-	2.83E-04
Dimethylnaphthalene, 2,3-	2.83E-04	Trimethylphenol, 2,4,6-	2.83E-04
Dimethylnaphthalene, 2,6-	2.83E-04	Undecane	2.83E-04
Dimethylnaphthalene, 2,7-	2.83E-04	Xylene, mp-	2.83E-04
Dimethylphenol, 2,3-	2.83E-04	Xylene, o-	2.83E-04
Dimethylphenol, 2,4-	2.83E-04	THC as Propane	7.97E-02
Dimethylphenol, 2,5-	2.83E-04	Carbon Monoxide	5.07E-02
Dimethylphenol, 2,6-	2.83E-04	Carbon Dioxide	7.97E-02
Dimethylphenol, 3,4-	2.83E-04	Nitrogen Oxides	5.43E-02
Dimethylphenol, 3,5-	2.83E-04	Methane	2.90E-02
Dodecane	2.83E-04	Sulfur Dioxide	2.38E-03
Ethylbenzene	2.83E-04		

Practical Reporting Limits, Test HRb, lb/lb binder

Analyte	lb/lb	Analyte	lb/lb
2-Butanone (MEK)	2.83E-06	Ethyltoluene, 2-	4.07E-06
Acenaphthalene	4.07E-06	Ethyltoluene, 3-	4.07E-06
Acetaldehyde	2.83E-06	Ethyltoluene, 4-	4.07E-06
Acetic acid	4.07E-06	Formaldehyde	2.83E-06
Acetone	2.83E-06	Furan, 2,5-dimethyl-	4.07E-06
Acetophenone	1.62E-04	Furan, 2-methyl-	4.07E-06
Acrolein	2.83E-06	Furfural	6.74E-05
alpha-Methylstyrene	4.07E-06	Heptane	4.07E-06
Ammonia	1.59E-04	Hexaldehyde	2.83E-06
Aniline	2.19E-05	Hexane	4.07E-06
Anthracene	4.07E-06	Hydrogen Cyanide	1.11E-05
Benzaldehyde	2.83E-06	Indan	4.07E-06
Benzene	4.07E-06	Indene	4.07E-06
Benzofuran	4.07E-06	Isobutylbenzene	4.07E-06
Biphenyl	4.07E-06	Isopropylbenzene	4.07E-06
Butylbenzene, n-	4.07E-06	Methylnaphthalene, 1-	4.07E-06
Butylbenzene, sec-	4.07E-06	Methylnaphthalene, 2-	4.07E-06
Butylbenzene, tert-	4.07E-06	Naphthalene	4.07E-06
Butyraldehyde/Methacrolein	4.72E-06	Nonane	4.07E-06
Cresol, mp-	4.07E-06	o,m,p-Tolualdehyde	7.56E-06
Cresol, o-	4.07E-06	Octane	4.07E-06
Crotonaldehyde	2.83E-06	o-Toluidine	2.19E-05
Cyclohexane	4.07E-06	Pentanal (Valeraldehyde)	2.83E-06
Cymene, p-	4.07E-06	Phenol	4.07E-06
Decane	4.07E-06	Phenol, 3-(1-methylethyl)-	4.07E-06
Dibenzofuran	4.07E-06	Propionaldehyde (Propanal)	2.83E-06
Diethylbenzene, 1,2-	4.07E-06	Propylbenzene, n-	4.07E-06
Diethylbenzene, 1,3-	4.07E-06	Styrene	4.07E-06
Diethylbenzene, 1,4-	4.07E-06	Tetradecane	4.07E-06
Diisopropylbenzene, 1,3-	4.07E-06	Toluene	4.07E-06
Dimethylaniline	3.83E-05	Tridecane	4.07E-06
Dimethylnaphthalene, 1,2-	4.07E-06	Trimethylbenzene, 1,2,3-	4.07E-06
Dimethylnaphthalene, 1,3-	4.07E-06	Trimethylbenzene, 1,2,4-	4.07E-06
Dimethylnaphthalene, 1,5-	4.07E-06	Trimethylbenzene, 1,3,5-	4.07E-06
Dimethylnaphthalene, 1,6-	4.07E-06	Trimethylnaphthalene, 2,3,5-	4.07E-06
Dimethylnaphthalene, 1,8-	4.07E-06	Trimethylphenol, 2,3,5-	4.07E-06
Dimethylnaphthalene, 2,3-	4.07E-06	Trimethylphenol, 2,4,6-	4.07E-06
Dimethylnaphthalene, 2,6-	4.07E-06	Undecane	4.07E-06
Dimethylnaphthalene, 2,7-	4.07E-06	Xylene, mp-	4.07E-06
Dimethylphenol, 2,3-	4.07E-06	Xylene, o-	4.07E-06
Dimethylphenol, 2,4-	4.07E-06	THC as Propane	1.15E-03
Dimethylphenol, 2,5-	4.07E-06	Carbon Monoxide	7.30E-04
Dimethylphenol, 2,6-	4.07E-06	Carbon Dioxide	1.15E-03
Dimethylphenol, 3,4-	4.07E-06	Nitrogen Oxides	7.82E-04
Dimethylphenol, 3,5-	4.07E-06	Methane	4.17E-04
Dodecane	4.07E-06	Sulfur Dioxide	3.43E-05
Ethylbenzene	4.07E-06		

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APPENDIX C DETAILED PROCESS DATA AND CASTING QUALITY PHOTOS

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Detailed Process Data - Test HRb

Test Dates	6/28/2007	6/28/2007	6/28/2007	6/29/2007	6/29/2007	6/29/2007	7/2/2007	7/2/2007	Averages
Emissions Sample #	HR201	HR202	HR203	HR204	HR205	HR206	HR207	HR208	
Production Sample #	HR001	HR002	HR003	HR004	HR005	HR006	HR007	HR008	
Cast weight, lbs.	121.00	122.00	120.50	120.00	120.50	121.50	120.50	116.00	120.25
Pouring time, sec.	23	41	30	27	30	32	24	34	30
Pouring temp ,°F	2631	2640	2633	2628	2627	2631	2633	2641	2633
Pour hood process air temp at start of pour, °F	90.0	88.5	86.5	89.4	85.3	87.3	87.4	88.9	87.9
Mold activator %, BOR	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Mold binder %, BOS (programmed)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Mold binder % , actual (programmed)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Mold weight, Lbs.	295.0	295.5	297.0	268.5	278.0	269.5	274.5	273.0	281.4
Binder weight in Mold, Lbs.	4.4	4.4	4.4	4.0	4.1	4.0	4.1	4.0	4.2
Mold 1800 LOI, %	1.8473	1.8363	1.9489	1.7268	1.8134	1.7804	1.7205	1.6161	1.7862
Mold age when poured, days	7.0	7.0	7.0	2.0	3.0	3.0	6.0	6.0	5.1
Mold temperature, °F	78.9	78.4	79.0	79.6	80.0	79.1	80.6	78.9	79.3

Detailed Digital Process Parameters - Test HRb

[Global]	
Manufacturer	PROMETAL_RCT
Model	S15
Name	S018
Job Start	5/21/2007 12:57
Job Completion	5/23/2007 0:15
Slices	1994
Height	558.3 mm
Last Entry	5/23/2007 0:15
[Build Time]	
Elapsed	1, 11:17:26
Remaining	0, 00:00:00
Estimated	5/23/2007 0:15
[Job Parameters]	
Print Resolution	x: 0.100 mm y: 0.127 mm z: 0.280 mm
Print Raster	x: 1 y: 1
Print Offset	x: -0.100 mm y: -0.150 mm
Print Speed	0.50 m/s
Recoater Speed	4200 RPM
Print Head Wave Form	12 ms 22 ms 22 ms
Initial Height Z	-0.160 mm
Start Layer	1
Stop Layer	1994
Activator Dosage	0.34%
Input File Path	H:\Build box for gear\
Input File	Build box for gear.r3d
[Material Usage]	
Activator Level before	38.47%
Activator left	37.00%
Binder Level before	20.41 L
Binder left	11.28 L
Cleaner Level before	19.92 L
Cleaner left	10.70 L
Build Dimensions	0.705 m^3
[Layer Time]	
Last	51.0 s
Average	63.0 s
Shortest	12.3 s
Longest	81.6 s
Total	1, 11:06:22
Quantity	1994
Amount	99.00%
[Recoating Time]	
Last	20.6 s
Average	18.2 s
Shortest	12.0 s
Longest	35.2 s
Total	0, 10:21:26
Quantity	1994
Amount	29.00%
[Printing Time]	
Last	30.2 s
Average	44.0 s
Shortest	0.0 s
Longest	51.0 s
Total	1, 00:40:40
Quantity	1994
Amount	69.00%

[Cleaning Time]	
Last	12.2 s
Average	12.5 s
Shortest	10.1 s
Longest	26.4 s
Total	0, 01:38:56
Quantity	469
Amount	4.00%
[Hardware Dialog Time]	
Last	
Average	
Shortest	
Longest	
Total	
Quantity	
Amount	0.00%
[Idle Time]	
Last	
Average	
Shortest	
Longest	
Total	
Quantity	
Amount	0.00%
[Waiting for Cleaning Completion Time]	
Last	1.5 s
Average	3.3 s
Shortest	0.2 s
Longest	11.8 s
Total	0, 00:26:31
Quantity	469
Amount	1.00%
[Error Time]	
Last	0.0 s
Average	0.0 s
Shortest	0.0 s
Longest	
Total	0, 00:00:00
Quantity	1
Amount	0.00%
[Printhead Recovery Time]	
Last	
Average	
Shortest	
Longest	
Total	
Quantity	
Amount	

Mass properties of Mold Cope (Part Configuration - Default)

Output coordinate System: -- default --

Density = 1.414080 grams per cubic centimeter

Mass = 67826.355021 grams

Volume = 47964994.599640 cubic millimeters

Surface area = 1211738.613073 millimeters^2

Center of mass: (millimeters)
X = 311.126285
Y = 61.299676
Z = -330.653962

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)
Taken at the center of mass.
Ix = (-0.000001, 0.000040, 1.000000) Px = 2212567717.934013
Iy = (1.000000, 0.000000, 0.000001) Py = 2501637741.494572
Iz = (0.000000, 1.000000, -0.000040) Pz = 4533279975.100127

Moments of inertia: (grams * square millimeters)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 2501637741.494247 Lxy = -0.000000 Lxz = -307.619030
Lyx = -0.000000 Lyy = 4533279971.342672 Lyz = 93380.823222
Lzx = -307.619030 Lzy = 93380.823222 Lzz = 2212567721.691807

Moments of inertia: (grams * square millimeters)
Taken at the output coordinate system.
Ixx = 10172099423.281399 Ixy = 1293580215.411739 Ixz = -6977646010.592954
Iyx = 1293580215.411739 Iyy = 18514435613.342434 Iyz = -1374677714.712122
Izx = -6977646010.592954 Izy = -1374677714.712122 Izz = 9032997132.973963

Mass properties of Mold Drag (Part Configuration - Default)

Output coordinate System: -- default --

Density = 1.4140803 grams per cubic centimeter

Mass = 69329.8992473 grams

Volume = 49028261.0935812 cubic millimeters

Surface area = 1365119.8691779 millimeters^2

Center of mass: (millimeters)
X = 311.1517140
Y = 75.6612333
Z = -330.3862466

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)
Taken at the center of mass.
Ix = (0.0029442, 0.0003069, 0.9999956) Px = 2365867909.9977579
Iy = (0.9999957, -0.0000034, -0.0029442) Py = 2642707244.9926186
Iz = (0.0000025, 1.0000000, -0.0003069) Pz = 4791756988.1892109

Moments of inertia: (grams * square millimeters)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 2642704845.3246765 Lxy = -5201.5122192 Lxz = 815060.2515634
Lyx = -5201.5122192 Lyy = 4791756759.7094011 Lyz = 744467.9464428
Lzx = 815060.2515634 Lzy = 744467.9464428 Lzz = 2365870538.1455202

Moments of inertia: (grams * square millimeters)
Taken at the output coordinate system.
Ixx = 10607302469.9084030 Ixy = 1632167775.0493612 Ixz = -7126315701.5973091
Iyx = 1632167775.0493612 Iyy = 19071668075.3109890 Iyz = -1732324897.7181077
Izx = -7126315701.5973091 Izy = -1732324897.7181077 Izz = 9474959194.0583992

Casting Surface Quality Comparison Photos

Best
HRb002

Median
HRb004

Worst
HRb007

APPENDIX D CONTINUOUS EMISSION CHARTS

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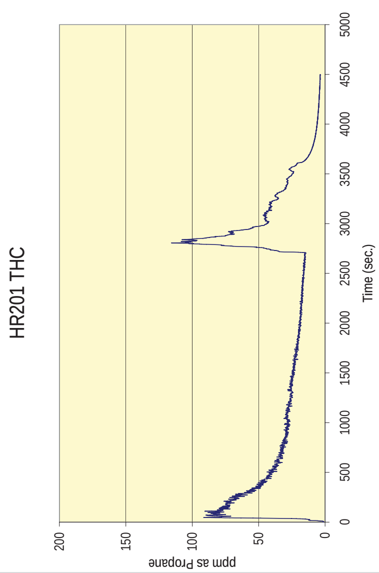
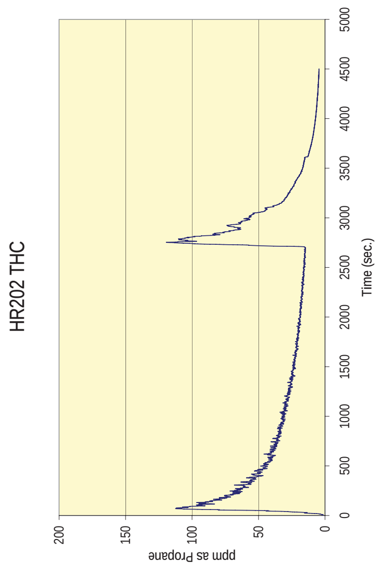
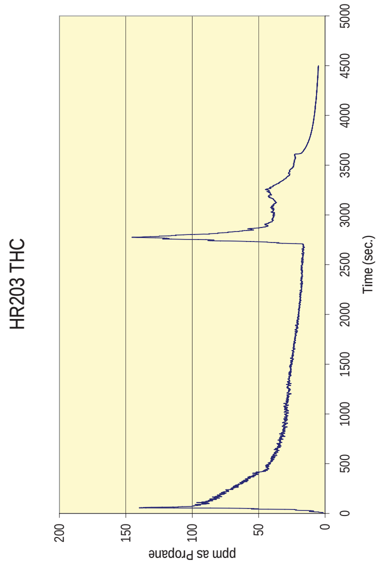
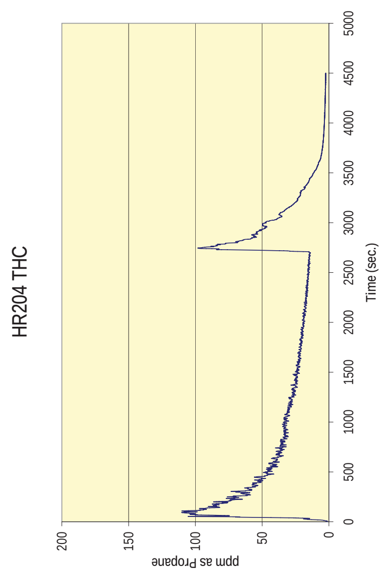
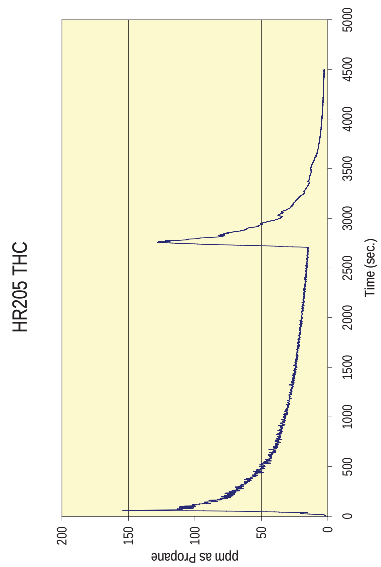
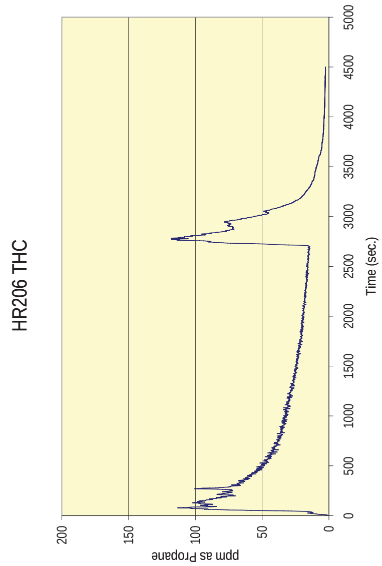

HR201 THC
ppm as Propane
Time (sec.)

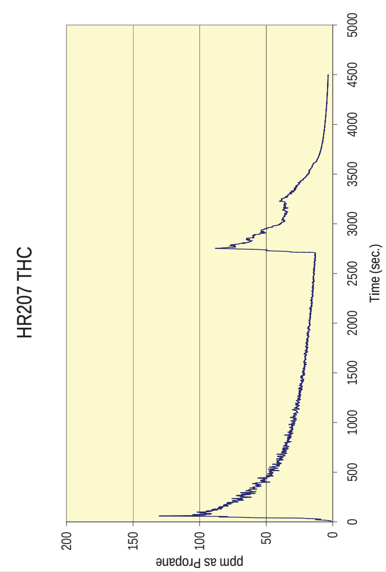

HR202 THC
ppm as Propane
Time (sec.)

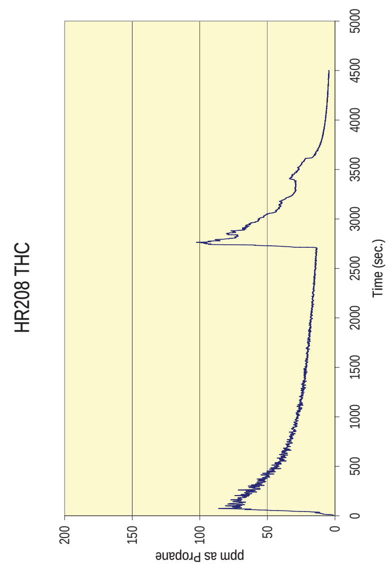

HR203 THC
ppm as Propane
Time (sec.)

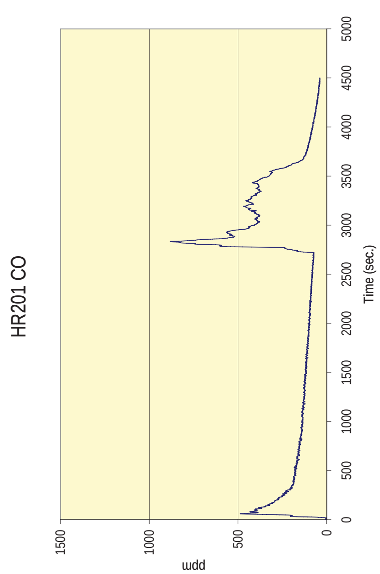

HR204 THC
ppm as Propane
Time (sec.)

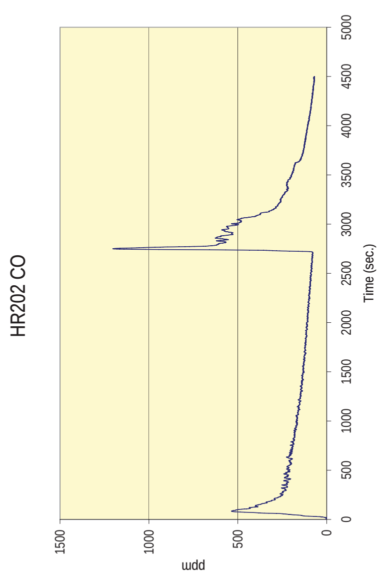

HR205 THC
ppm as Propane
Time (sec.)


HR206 THC
ppm as Propane
Time (sec.)


HR207 THC
ppm as Propane
Time (sec.)


HR208 THC
ppm as Propane
Time (sec.)


HR201 CO
ppm
Time (sec.)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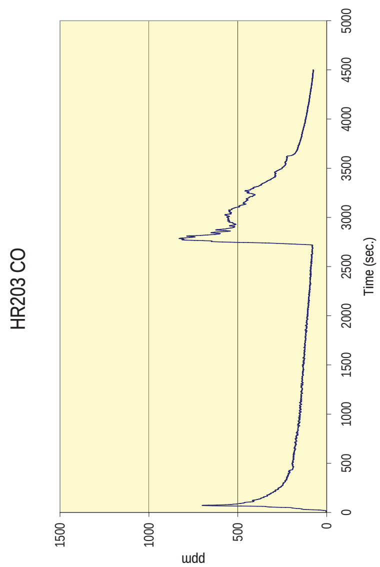
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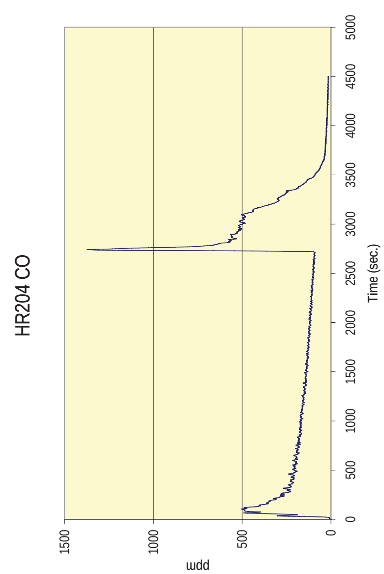
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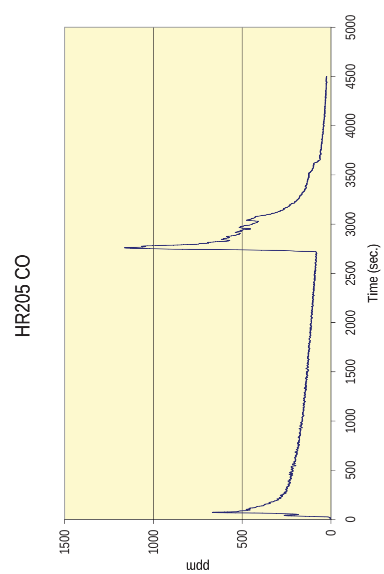
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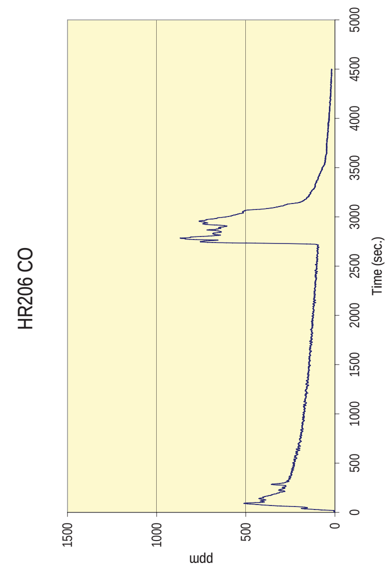
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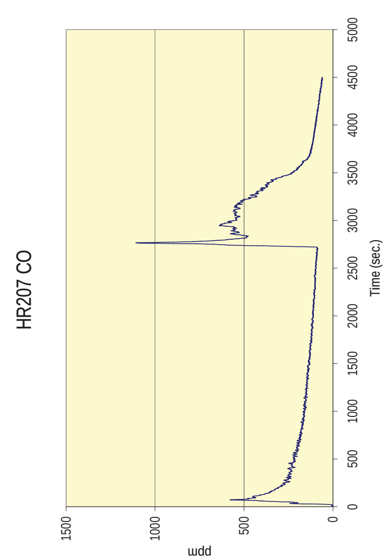
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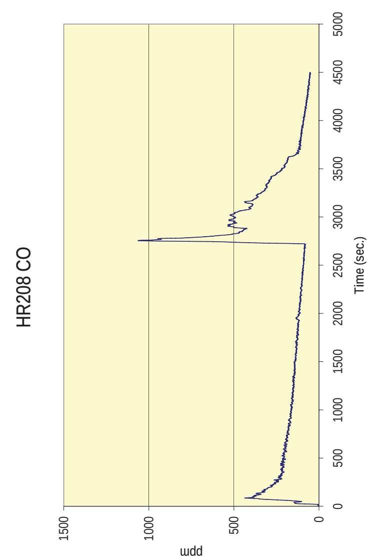
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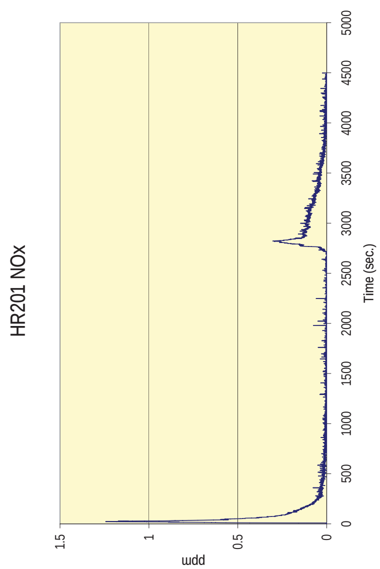
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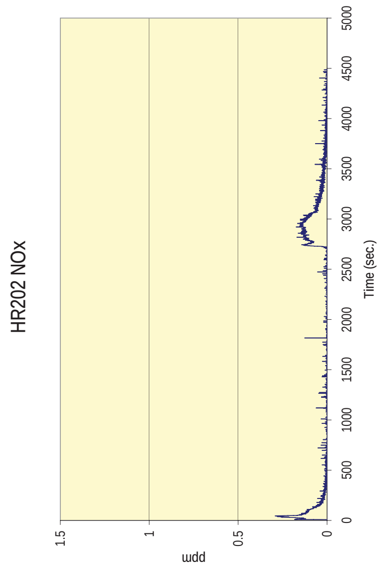
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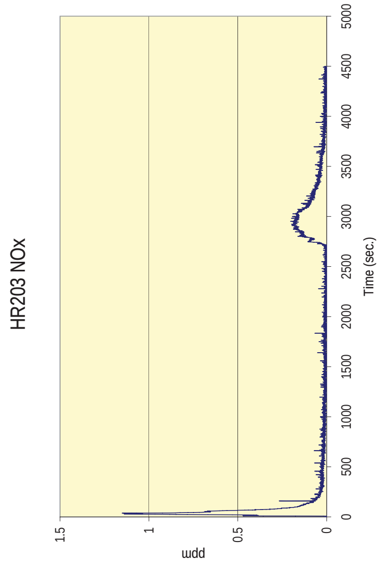
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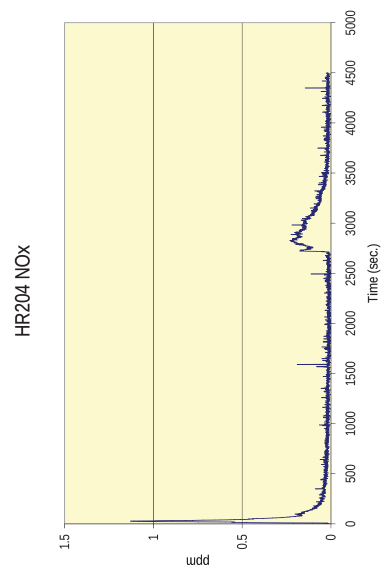
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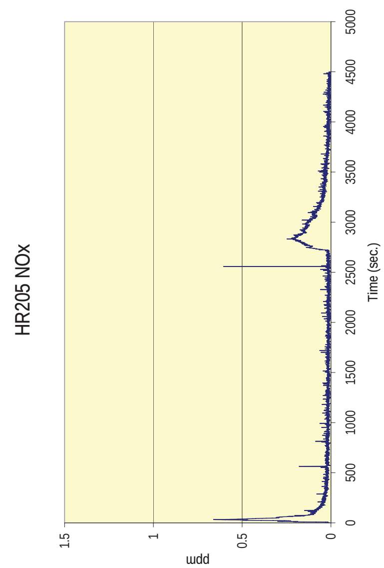
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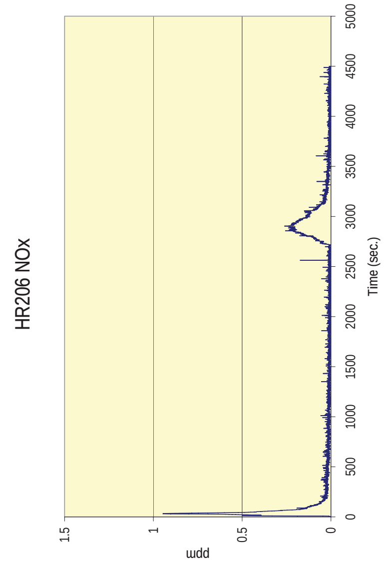
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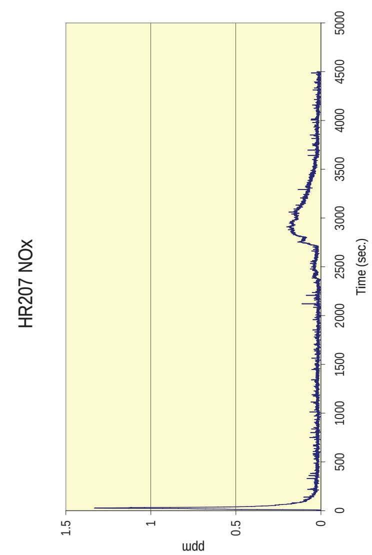
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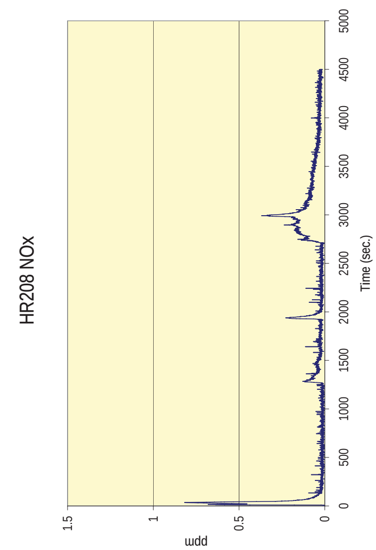
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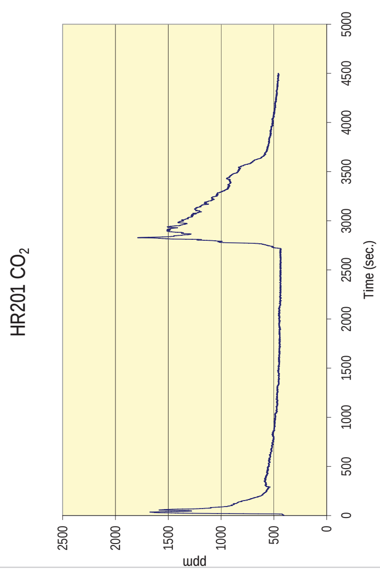
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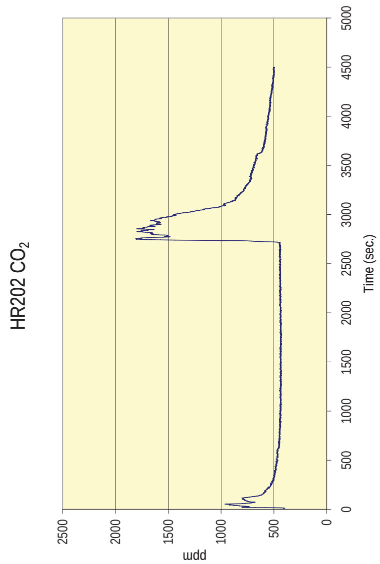
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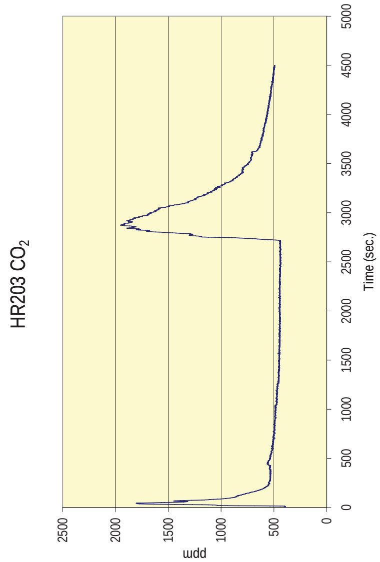
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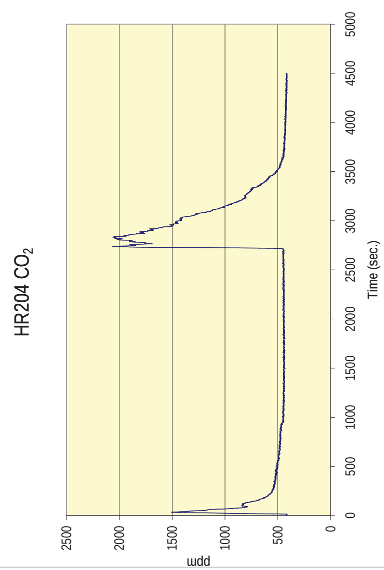
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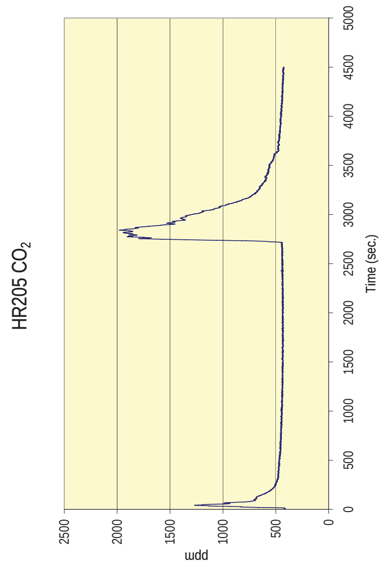
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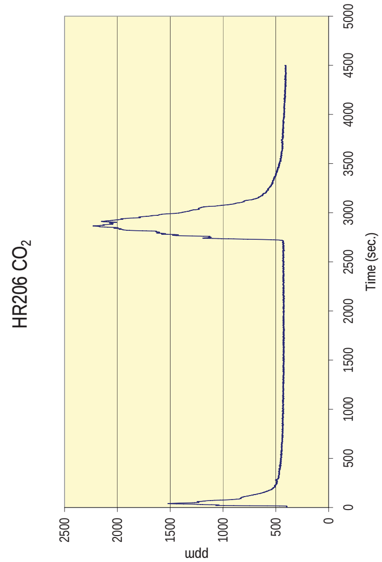
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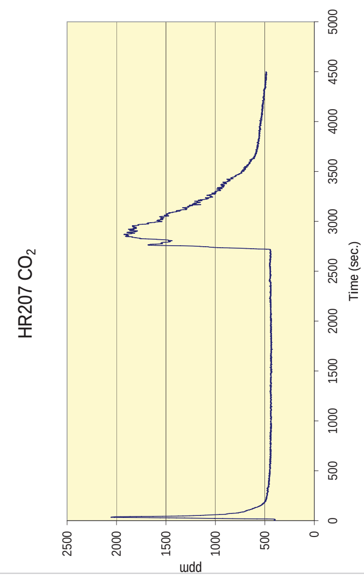
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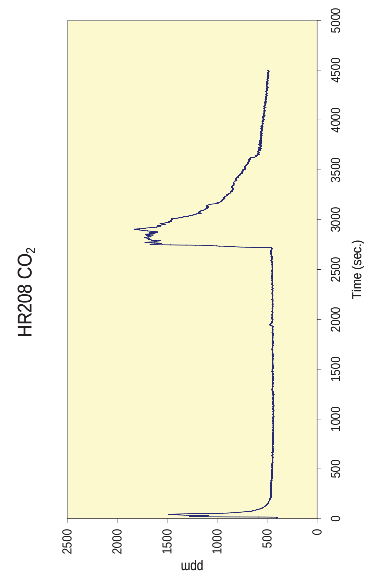
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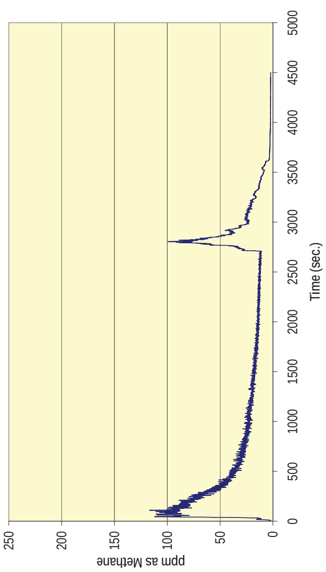

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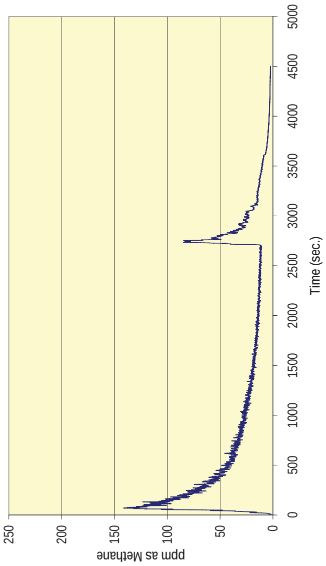

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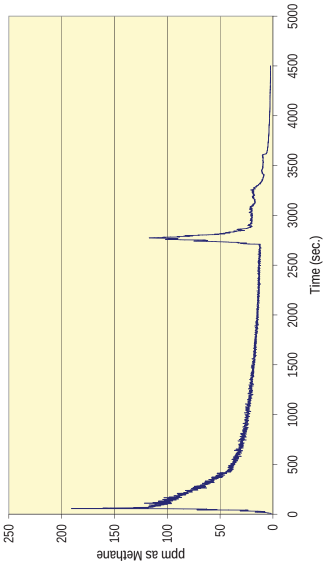

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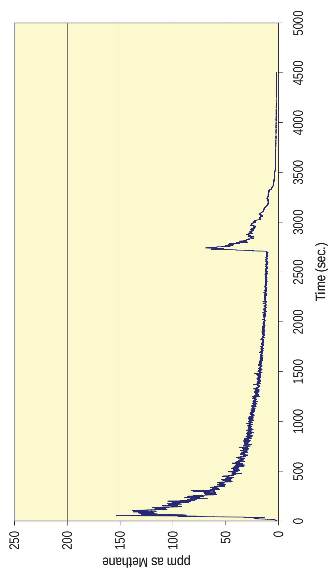

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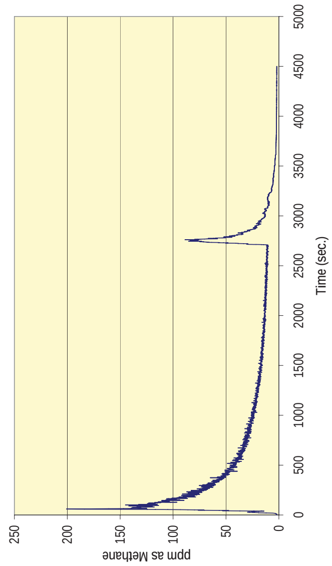

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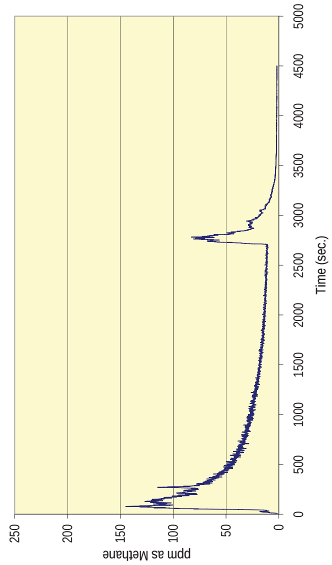

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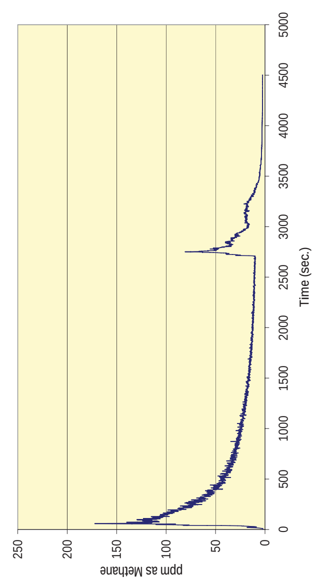

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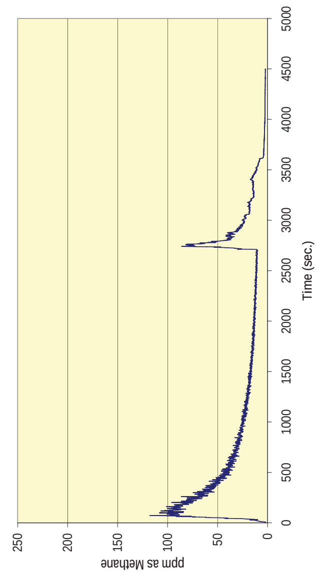

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APPENDIX E ACRONYMS AND ABBREVIATIONS

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ACRONYMS & ABBREVIATIONS

AFS	American Foundry Society
ARDEC	(US) Army Armament Research, Development and Engineering Center
BO	Based on ( ).
BOS	Based on Sand.
CAAA	Clean Air Act Amendments of 1990
CARB	California Air Resources Board
CERP	Casting Emission Reduction Program
CFR	Code of Federal Regulations
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/MS	Gas Chromotography/Mass Spectrometry
GS	Greensand
HAP	Hazardous Air Pollutant defined by the 1990 Clean Air Act Amendment
I	Invalidated Data
Lb/Lb	Pound per pound of binder used
Lb/Tn	Pound per ton of metal poured
LOI	Loss on ignition
NA	Not Applicable; Not Available
ND	Non-Detect; Not detected below the practical quantitation limit
NT	Not Tested - Lab testing was not done
PCS	Pouring, Cooling, Shakeout
POM	Polycyclic Organic Matter
PQL	Practical Quantitation Limit
QA/QC	Quality Assurance/Quality Control

SO_2	Sulfur Dioxide
TGOC	Total Gaseous Organic Concentration
TGOC as Propane	Quantity of undifferentiated hydrocarbons including methane determined by EPA Method 25A.
THC	Total Hydrocarbon Concentration
THC as Propane	Quantity of undifferentiated hydrocarbons including methane determined by EPA Method 25A.
US EPA	United States Environmental Protection Agency
USCAR	United States Council for Automotive Research
VOC	Volatile Organic Compound
WBS	Work Breakdown Structure