Casting Emission Reduction Program

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Baseline Test: Steel Greensand Formulation Pouring, Cooling, Shakeout

Technikon #1410-125 FS

May 2004
(revised for public Distribution)

United States Environmental Protection Agency

CISA

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Baseline Test: Steel Greensand Formulation Pouring, Cooling, Shakeout

1410-125 FS

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

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The data contained in this report were developed to provide a relative emissions baseline profile for future product or process evaluation. You may not obtain the same results in your facility. Data was not collected to assess cost or producibility.

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Executive Summary

This report contains the results of emission testing to evaluate the pouring, cooling, and shakeout emissions from Test FS, a sodium silicate core in a typical steel greensand formulation (without seacoal). Test FS will be used as a baseline against which other steel greensand products and processes are to be compared. Test FS was designed to be a steel greensand baseline to demonstrate the effect of the high pouring temperature of the metal on the overall emissions. Due to unforeseen metal handling complications, the metal composition was amended to more easily accommodate pouring at such high temperatures. The results in this document are only from the validated test runs. All testing was conducted by Technikon, LLC in its Pre-Production foundry. The emissions results are reported in pounds of analyte per ton of metal poured.

The testing performed involved the collection of continuous air samples over a seventy-five minute period, including the mold pouring, cooling, shakeout, and post shakeout periods. Process and stack parameters were measured and include: the weights of the casting and mold; Loss on Ignition (LOI) values for the mold prior to the test; metallurgical data; and stack temperature, pressure, volumetric flow rate, and moisture content. The process parameters were maintained within prescribed ranges in order to ensure the reproducibility of the tests runs. Samples were collected and analyzed for sixty-six target compounds using procedures based on US EPA Method 18. Continuous monitoring of the Total Gaseous Organic Concentration (TGOC) of the emissions was conducted according to US EPA Method 25A.

The mass emission rate of each parameter or target compound was calculated using the Method 25A data or the laboratory analytical results, the measured source data and the weight of each casting. Results for structural isomers have been grouped and reported as a single entity. For example, ortho-, meta-, and para-xylene are the three structural isomers of dimethyl benzene. The individual isomer results are available in Appendix B of this report. Other "emissions indicators," in addition to the TGOC as Propane, were also calculated. The HC as Hexane results represent the sum of all organic compounds detected and expressed as Hexane. All of the following sums are sub-groups of this measure. The "Sum of VOCs" is based on the sum of the individual target VOCs measured and includes the selected HAPs and selected Polycyclic Organic Material (POMs) listed in the Clean Air Act Amendments of 1990. The "Sum of HAPs" is the sum of the individual target HAPs measured and includes the selected POMs. Finally, the "Sum of POMs" is the sum of all of the polycyclic organic material measured.

Results for the emission indicators are shown in the following table reported in lbs/tn of metal.

Test Plan FS Emissions Indicators

Analytes	TGOC as Propane	HC as Hexane	Sum of VOCs	Sum of HAPs	Sum of POMs
Test FS (Lb/Tn Metal)	0.4251	0.0449	0.0839	0.0751	0.0086

Results of this test represent a new steel greensand baseline that is different from previous CERP greensand baseline. The major differences are:

- ~ A new pattern was used with four inorganic core cavities versus the previous 8-on pattern.
- ~ The sand included cereal and dextrin in lieu of seacoal.
- ~ The pour temperature mean was 2925^{o}F versus 2630^{o}F for iron.
- ~ For ease of handling cast iron was substituted for steel to aid pouring and reduce mold metal reactivity.

The metal carbon content did not appear to enhance the emission output.

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

1.0 Introduction

1.1 Background

Technikon LLC is a privately held contract research organization located in McClellan, California, a suburb of Sacramento. Technikon offers emissions research services to industrial and government clients specializing in the metal casting and mobile emissions areas. Technikon operates the Casting Emission Reduction Program (CERP). CERP is a cooperative initiative between the Department of Defense (US Army) and the United States Council for Automotive Research (USCAR). Its purpose is to evaluate alternative casting materials and processes that are designed to reduce air emissions and/or produce more efficient casting processes. Other technical partners directly supporting the project include: the American Foundry Society (AFS); the Casting Industry Suppliers Association (CISA); the US Environmental Protection Agency (US EPA); and the California Air Resources Board (CARB).

1.2 Technikon Objectives

The primary objective of Technikon is to evaluate materials, equipment, and processes used in the production of metal castings. Technikon's facility was designed to evaluate alternate materials and production processes designed to achieve significant air emission reductions, especially for the 1990 Clean Air Act Amendment. The facility has two principal testing arenas: a Pre-Production Foundry designed to measure airborne emissions from individually poured molds, and a Production Foundry designed to measure air emissions in a continuous full scale production process. Each of these testing arenas has been specially designed to facilitate the collection and evaluation of airborne emissions and associated process data.

The Production Foundry provides simultaneous detailed individual emission measurements using methods based on US EPA protocols for the melting, pouring, sand preparation, mold making, and core making processes.

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

1.3 Report Organization

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

The raw data for this test series are included in a data binder that is maintained at the Technikon facility.

1.4 Specific Test Plan and Objectives

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

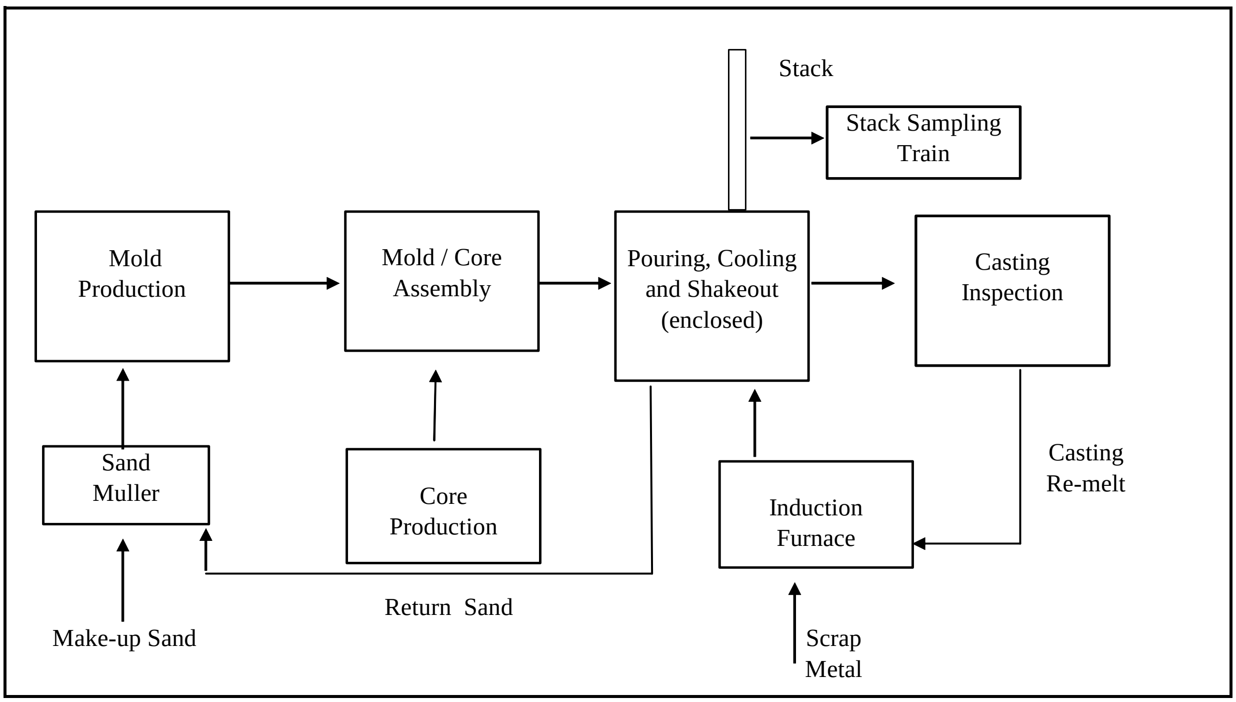
	Test Plan
Type of Process tested	Sodium Silicate Core, Steel Greensand without Seacoal, Iron PCS Baseline
Test Plan Number	1410 125 FS
Greensand System	Wedron 530 sand, Western and Southern Bentonite, Cereal, and Dextrin
Metal Poured	Semi Steel, White Iron, and Gray Cast Iron
Casting Type	4-on Step Core
Core	Sodium Silicate
Number of molds poured	4 Conditioning + 9 Sampling
Test Dates	2/18/04 > 3/11/04
Emissions Measured	TGOC as Propane, HC as Hexane, 66 Organic HAPs and VOCs
Process Parameters Measured	Total Casting, Mold, Binder Weights; Metallurgical data, % LOI; Stack Temperature, Moisture Content, Sand Temperature, Pressure, and Volumetric Flow Rate

2.0 Test Methodology

2.1 Description of Process and Testing Equipment

Figure 2-1 is a diagram of the Pre-Production Foundry process equipment.

Figure 2-1 Pre-Production Foundry Layout Diagram



2.2 Description of Testing Program

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

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

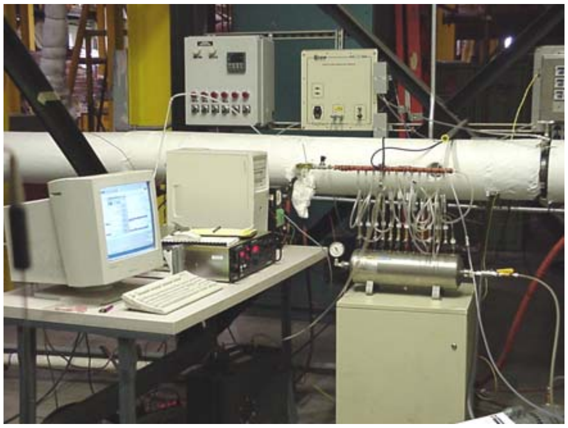
2. **Mold, Core and Metal Preparation:** The molds and cores were prepared to a standard steel sand composition by the Technikon production team. The cores prepared were hand rammed sodium silicate. Relevant process data was collected and recorded. Iron was melted in a 1000 lb. Ajax induction furnace. The amount of metal melted was determined from the poured weight of the casting and the number of molds to be poured. The metal composition varied from steel, to semi steel, to white iron to gray iron as prescribed by a metal composition worksheet. The weight of metal poured into each mold was recorded on the process data summary sheet.

3. **Individual Sampling Events:** Replicate sampling tests were performed on nine (9) mold packages. The mold packages were placed into an enclosed test stand heated to approximately 85°F. Iron was poured through an opening in the top of the emission enclosure, after which the opening was closed.

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

Step Cores in Mold

Total Enclosure Test Stand



Method 25A (TGOC) and Method 18 Sampling Train

4. **Process Parameter Measurements:** Table 2-1 lists the process parameters that are monitored during each test. The analytical equipment and methods used are also listed.

Table 2-1 Process Parameters Measured

Parameter	Analytical Equipment and Methods
Mold Weight	Cardinal 748E platform scale (Gravimetric)
Casting Weight	Cardinal 748E platform scale (Gravimetric)
Muller water weight	Ohaus MP2 Scale (Gravimetric)
Binder Weight	Mettler SB12001 Digital Scale (Gravimetric)
Volatiles	Mettler PB302 Scale (AFS Procedure 2213-00-S)
LOI, % at Mold and Shakeout	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
Mold Compactability	Dietert 319A Sand Squeezer (AFS Procedure 2221-00-S)
Carbon/Silicon	Electro-Nite DataCast 2000 (thermal arrest)

5. **Air Emissions Analysis:** The specific sampling and analytical methods used in the Pre-Production Foundry tests are based on the US EPA reference methods shown in Table 2-2. The details of the specific testing procedures and their variance from the reference methods are included in the Technikon Standard Operating Procedures.

Table 2-2 Sampling and Analytical Methods

Measurement Parameter	Test Method
Port Location	EPA Method 1
Number of Traverse Points	EPA Method 1
Gas Velocity and Temperature	EPA Method 2
Gas Density and Molecular Weight	EPA Method 3a
Gas Moisture	EPA Method 4, gravimetric
HAPs Concentration	EPA Method 18, TO11, NIOSH 1500,
VOCs Concentration	EPA Method 18, 25A, TO11, NIOSH 1500,

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

6. **Data Reduction, Tabulation and Preliminary Report Preparation:** The analytical results of the emissions tests provide the mass of each analyte in the sample. The total mass of the analyte emitted is calculated by multiplying the mass of analyte in the sample times the ratio of total stack gas volume to sample volume. The total stack gas volume is calculated from the measured stack gas velocity and duct diameter, and corrected to dry standard conditions us-

ing 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 to provide emissions data in pounds of analyte per ton of metal.

The results of each of the sampling events are included in the appendices of this report. The emissions results are also averaged and are shown in Table 3-1.

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

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

Detailed QA/QC and data validation procedures for the process parameters, stack measurements, and laboratory analytical procedures are included in the Technikon Emissions Testing and Analytical Testing Standard Operating Procedures. In order to ensure the timely review of critical quality control parameters, the following procedures are followed:

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

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

3.0 Test Results

The average emission results in pounds per ton of metal are presented in Table 3-1. The table includes the individual target compounds that comprise at least 95% of the total VOCs measured, along with the corresponding Sum of VOCs, Sum of HAPs, and Sum of POMs. The table also includes the TGOC as propane, HC as hexane, carbon monoxide, and carbon dioxide.

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

Appendix B contains the detailed emissions data including the results for all analytes measured. Table 3-2 includes the averages of the key process parameters. Detailed process data are presented in Appendix C.

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

Table 3-1 Summary of Test Plan FS Average Results – Lb/Tn Metal

Analytes	Test FS (Lb/Tn Metal)	STDEV
TGOC as Propane	0.4251	0.0392
HC as Hexane	0.0449	0.0049
Sum of VOCs	0.0839	0.0107
Sum of HAPs	0.0751	0.0088
Sum of POMs	0.0086	0.0019
Individual Organic HAPs		
Benzene	0.0189	0.0029
Acetaldehyde	0.0161	0.0013
Toluene	0.0102	0.0012
o,m,p-Xylene	0.0063	0.0008
Phenol	0.0041	0.0008
Formaldehyde	0.0030	0.0011
Hexane	0.0027	0.0003
Naphthalene	0.0024	0.0006
2-Butanone*	0.0021	0.0003
Methylnaphthalenes	0.0021	0.0006
o,m,p-Cresol	0.0020	0.0006
Styrene	0.0018	0.0003
Propionaldehyde*	0.0017	0.0002
Ethylbenzene	0.0011	0.0002
Other VOCs		
Trimethylbenzenes	0.0025	0.0002
Benzaldehyde	0.0011	0.0001
Indene	0.0011	0.0002
Crotonaldehyde	0.0011	0.0001
Butyraldehyde/Methacrolein	0.0011	0.0001
Other Analytes		
Carbon Dioxide	16.36	1.276
Carbon Monoxide	ND	NA

Individual results constitute >95% of mass of all detected VOCs.

All "Other Analytes" are not included in the Sum of VOCs or HAPs.

***Results reported as a minimum due to apparent breakthrough.**

Table 3-2 Summary of Test Plan FS Average Process Parameters

	Test FS
Test Dates	2/18-3/11/04
Cast Weight (all metal inside mold), Lbs. Note 1	120.93
Pouring Time, sec.	21
Pouring Temp ,°F	2926
Pour Hood Process Air Temp at Start of Pour, °F	87
Mixer mannually weighed batch weight, Lbs	50.00
Manually weighed sodium silicate binder weight, Lbs	2.00
Core binder calculated weight, %BOS	4.00
Core binder calculated weight, %	3.85
Total uncoated core weight in mold, Lbs.	28.63
Total binder weight in mold, Lbs.	1.10
Muller Batch Weight, Lbs.	900
GS Mold Sand Weight, Lbs.	609
Western Bentonite, Lbs	2.15
Southern Bentonite, Lbs.	0.90
Dextrin weight, Lbs.	0.20
Cereal weight, Lbs.	0.25
Mold compactability, %	47
Mold Temperature, °F	76
Average Green Compression , psi	23.90
GS Compactability, %	26
GS Moisture Content, %	1.79
GS MB Clay Content, %	9.37
MB Clay reagent, ml	36
1800°F LOI - Mold Sand, %	1.30
900°F Volatiles , %	0.78

Metal poured had carbon contents that ranged from 0.9-3.89%

Figure 3-1 Emission Indicators from Test Series FS – Lb/Tn Metal

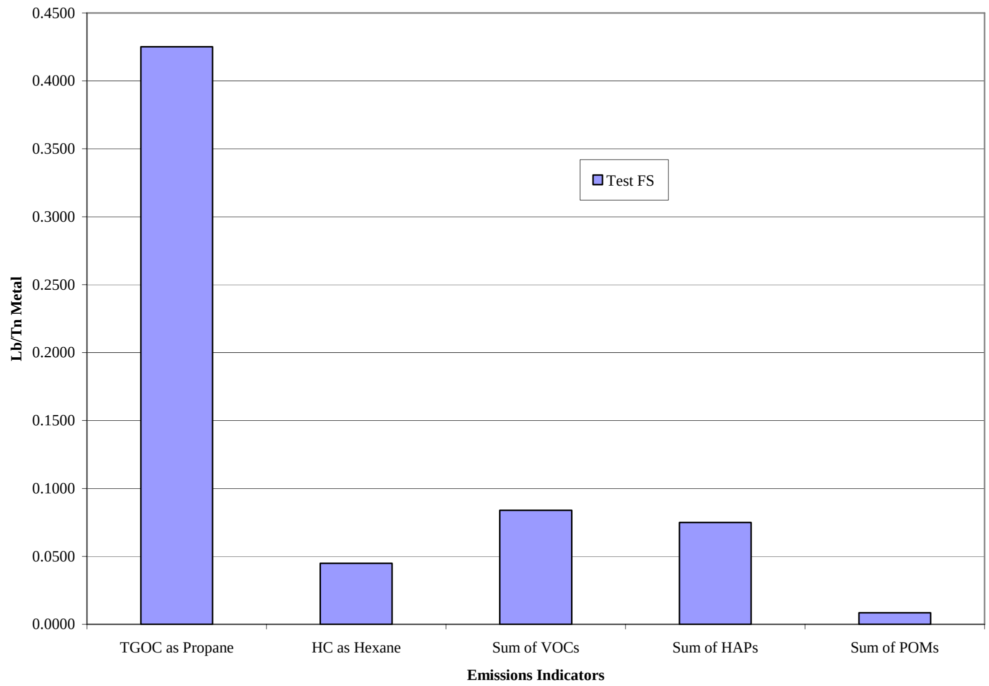


Figure 3-2 Selected HAP Emissions from Test Series FS – Lb/Tn Metal

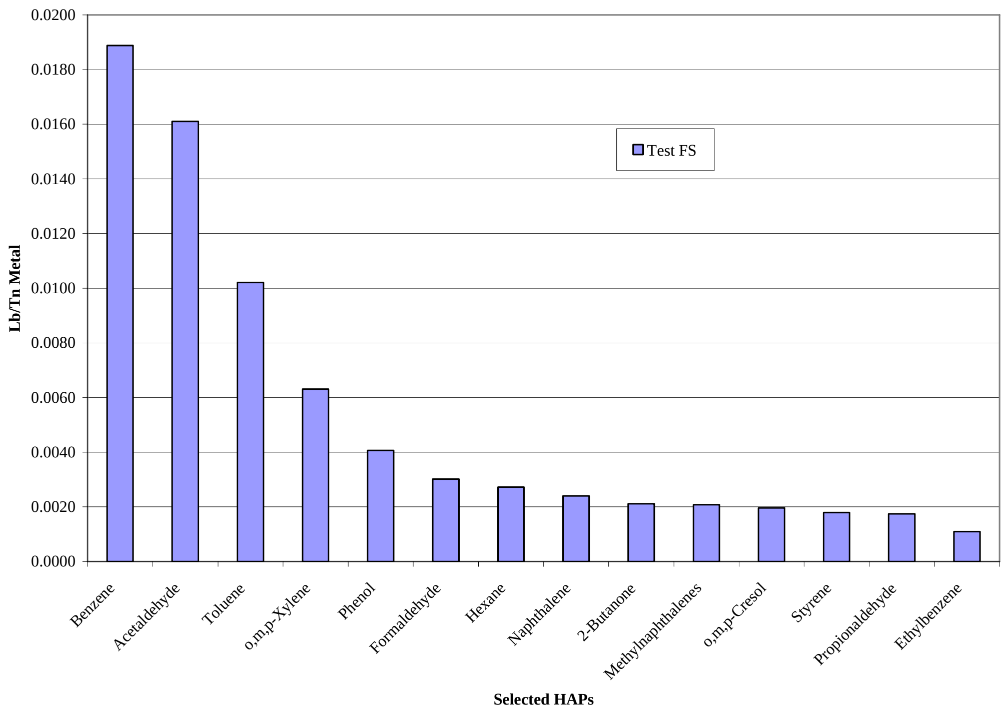
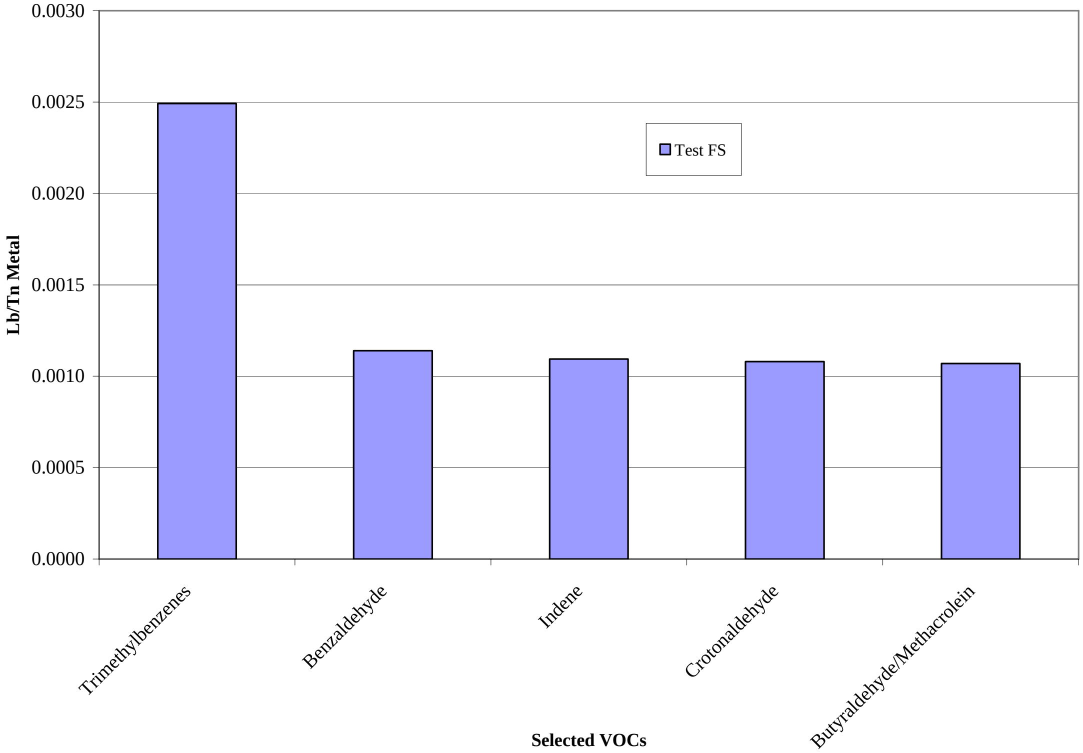


Figure 3-3 Selected VOC Emissions from Test Series FS – Lb/Tn Metal



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4.0 Discussion of Results

Test FS was designed to be a steel greensand baseline to demonstrate the effects of the high pouring temperature of the metal and the alternative source of organic material. The first two sample runs were short poured. Due to the higher pouring temperature and low carbon content of the steel, an unexpectedly high rate of fluid slag was generated and poured. This slag blocked the gating that was designed for cast iron. For this reason molds, FS001 and FS002 were disqualified. The carbon content was increased to the white iron and finally to the gray cast iron range where full molds were obtained. A conditioning run was done after the two misruns. The pour temperature was maintained at 2925^{o}F, typical of steel. The results in this document are only from the validated test runs. See the Detailed Process Data in Appendix C.

Nineteen of the measured compounds comprised greater than 95% of the mass of all VOCs detected by the Greensand Steel baseline test series. Benzene comprised approximately 24% of the total HAPs, acetaldehyde 21%, and toluene 14%. The remaining HAPs listed in the table individually contributed 1-8% each to the total HAPs. See Table 3-1.

Two methods were employed to measure undifferentiated hydrocarbon emissions, TGOC as propane, performed in accordance with EPA Method 25A, and HC as hexane. EPA Method 25A, TGOC (as propane), is weighted to the detection of more volatile hydrocarbon species, beginning at C1 (methane), with results calibrated against a three-carbon alkane (propane). HC as hexane is weighted to the detection of relatively less volatile compounds. This method detects hydrocarbon compounds in the alkane range between C6 and C16, with results calibrated against a six-carbon alkane (hexane). Certain analytes such as formaldehyde, phenol, and the cresols selected for analysis in test FS may not be represented in the HC as Hexane determination.

HC as hexane was found at lower amounts than the total Sum of VOCs. This observation is possibly due, in part, to the relatively high amount of aldehydes, cresols, and phenol detected that may not be represented in the HC as hexane as stated above.

2-Butanone, propionaldehyde, and acetone were all reported as minimums due to apparent breakthrough. Acetone is not included in the Sum of VOCs or HAPs. See Appendix B for the detailed results.

Carbon dioxide and methane were detected in the ambient sample for Test FS.

Target analyte reporting limits expressed in pounds per ton of metal are shown in Appendix B.

Observation of measured process parameters indicates that the tests were run within an acceptable range. The emission indicator results for run FS003 appear to be biased low. Detailed examination of the individual target analyte results showed random rather than systematic error; therefore, the results from this run were not invalidated.

Casting quality was not evaluated for this test series.

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APPENDIX A APPROVED TEST PLAN AND SAMPLE PLAN FOR TEST SERIES FS

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TECHNIKON TEST PLAN

> **CONTRACT NUMBER:** 1410 **TASK NUMBER:** 1.2.5 **Series:** FS

> **SITE:** Pre-production

> **TEST TYPE:** Baseline Test: Pouring, cooling, & shakeout of steel greensand with sodium silicate cores.

> **METAL TYPE:** ASTM A216 WCB steel

> **MOLD TYPE:** 4-on step-core with virgin steel greensand containing a nominal 7% western & southern bentonite, 0.8 % LOI, 0.2 % Dextrin, and 0.3 % cereal recycled after each pour.

> **NUMBER OF MOLDS:** Three engineering & conditioning runs + 9 sampling runs. Twelve (12) molds total.

> **CORE TYPE:** Step: sodium silicate

> **CORE COATING:** Cores shall be uncoated**.**

> **SAMPLE EVENTS:** 3 runs with TGOC only and 9 sample runs.

> **TEST DATE:** **START:** 13 Feb 2004

FINISHED: 12 Mar 2004

TEST OBJECTIVES:

Measure the airborne pouring, cooling, & shakeout emissions from a steel sand mold.

VARIABLES:

The pattern will be the 4-on step core. The mold will be made with Wedron 530 sand, western & southern bentonite to yield 7.0 +/- 0.3% MB Clay, 0.2 +/0.05% Dextrin as Stadex No.126 from A.E. Staley Co., 0.3 +/-0.05% cereal as Mogul from Con Agra Specialty Grain Products, no seacoal, 0.8% LOI and tempered to 2.6-3.4 % water, mechanically compacted. The molds will be maintained at 80-90 ^oF prior to pouring. The sand heap will be maintained at 900 pounds. Molds will be poured with steel at 2925 +/- 25^oF. Mold cooling will be 45 minutes followed by 15 minutes of shakeout, or until no more material remains to be shaken out, followed by 15 minutes additional sampling for a total of 75 minutes. Cores will be hand rammed with Wedron 530 sand and 4% (BOS) J.B. DeVennne CleanKast #1 sodium silicate binder, CO_2 activated. The cores will be maintained at 80-90^oF until placed in the mold. No emission sampling will be done during core manufacture.

BRIEF OVERVIEW:

This is the first test to be poured with steel. The mold will include materials specific to steel casting.

The greensand molds will be produced on the mechanically assisted Osborne 716 molding machines.

The emission results will be used to establish a steel baseline. In addition to a suite of selected emission analytes TGOC, CO & CO_2 content of the runs will be monitored using instruments specific to those gasses.

SPECIAL CONDITIONS:

The process will include rigorous maintenance of the size of sand heap and maintenance of the material and environmental testing temperatures to reduce seasonal and daily temperature dependent influence on the emissions. Initially for each subtest a 1300 pound greensand heap will be created from a single muller batch. Nine hundred (900) pounds will become the re-circulating heap. The balance will be used to makeup for attrition.

Series FS

PCS, Steel Greensand Formulation with Clay, Dextrin, & Cereal with Mechanized Molding

Process Instructions

A. Experiment:

1. Baseline test of sodium silicate cored steel greensand formulation. Measure emissions from steel greensand molds made with all virgin Wedron 530 sand, bonded with western bentonite to yield 3.6 +/- 0.3% MB Clay. The mold sand will also contain 0.2% dextrin and 0.3% cereal as corn flour. The molds shall be tempered with potable water to 2.6-3.4%, poured at constant weight, temperature, surface area, & shape factor. This test will recycle the same mold material, replacing burned materials after each casting cycle and compensating for core sand dilution.

B. Materials:

1. Mold sand: Virgin mix of Wedron 530 round grained sand, dextrin as Stadex # 126 from A.E. Staley Co., cereal as "Mogul" from Con Agra Specialty Grain products, and potable water per recipe.
2. Core: Step core as Wedron 530 sand and 4% (BOS) J.B. DeVennne CleanKast #1 sodium silicate binder, CO_2 gassed.
3. Metal: ASTM A216 CWB steel poured at 2925 +/- 25^{o}F.
4. Pattern Spray: Black Diamond hand wiped.

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

5. The following test shall be conducted:

   a. Sand batch: Single sand batch to be used for all FS molds.
   b. The recycled sand heap shall be maintained at 900+-10 pounds
   c. The first three (3) runs will be conditioning runs numbered FSCR1-3 and will be monitored by THC only.
   d. Emission sampling will begin on the 4th turn. Nine (9) satisfactory sampling runs numbered FS001-009 will be conducted monitored by both THC and sorption tubes. Should a run FS00X need to be repeated the run will be numbered FS00Xa, b, or c etc. The shop supervisor will monitor to assure the numbering consistency of the process data.

- **e.** The shop supervisor and the sampling team technician will coordinate the numbering between the two groups.
- **f.** FSCR1: Virgin mix as described above, un-vented mold.
- **g.** FSCR2, FSCR3, FS001-FS0XX: Re-cycled, re-mulled, reconstituted greensand**,** potable water, un-vented molds.

C. Sand preparation

1. Start up batch: make 1, FSCR1.

- **a.** Thoroughly clean the pre-production muller elevator and molding hoppers.
- **b.** Weigh and add 1225 +/-10 pounds of new Wedron 530 sand, per the recipe, to the running pre-production muller to make a 1300 batch.
- **c.** Add 5 pounds of potable water to the muller to suppress dust distributing it across the sand. Allow to mix for 1 minute.
- **d.** Add the clays and organics slowly to the muller to allow them to be distributed throughout the sand mass in proportion to the sand weight per the recipe for this test.
- **e.** Dry mull for about 3 minutes to allow distribution and some grinding of the clays to occur.
- **f.** Temper the sand-clay mixture slowly, with potable water, to allow for distribution.
- **g.** After about 2 gallons of water have been added allow 30 seconds of mixing then start taking compactability test samples.
- **h.** Based on each test add water incrementally to adjust the temper. Allow 1 minute of mixing. Retest. Repeat until the compactability is in the range 45-50%. (2.6-3.4% water)
- **i.** Discharge the sand into the mold station elevator.
- **j.** Grab sufficient sample from the mold hopper discharge to fill a quart zip-lock bag. Label bag with the test series and sequence number, date, and time of day and deliver it immediately to the sand lab for analysis
- **k.** Record the total sand mixed in the batch, the total of each type of clay and other material added to the batch, the amount of water added, the total mix time, the final compactability and sand temperature at charge and discharge.
- **l.** The sand will be immediately characterized for Methylene Blue Clay, Moisture content, Compactability, Green Compression strength, 1800^{o}F loss on ignition (LOI), and 900^{o}F volatiles. Each volatile and LOI test requires a separate 50 gram sample from the collected sand.
- **m.** Empty the extra greensand from the mold hopper into a clean empty dump hopper whose tare weight is known. Set this sand aside to be used to maintain the recycled batch at 900+/-10 pounds

2. Re-mulling: FSCR2

- **a.** Add to the sand recovered from poured mold **FSCR1** sufficient pre-blended sand so that the sand batch weight is 900 +/- 10 pounds. Record the sand weight.
- **b.** Return the sand to the muller and dry blend for about one minute.
- **c.** Add the clays and other materials, as directed by the process engineering staff, slowly to the muller to allow them to be distributed throughout the sand mass.

- **d.** Add 5 pounds of water to the muller to suppress dust distributing it across the sand. Allow to mix for 1 minute.
- **e.** Follow the above procedure beginning at B.1.f.

3. Re-mulling: FSCR3, FS001-FS0XX

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

D. Core making: Sodium silicate Core

1. Core sand mixing.

- **a.** Clean the core sand mixer.
- **b.** Add 50 pounds of Wedron 530 silica sand to the running mixer.
- **c.** Slowly pour 2.0 +/- .03 pounds of Sodium silicate resin into the sand. Distribute the resin as it is poured. Avoid pouring the resin on the plows or walls of the mixer or in one location or resin balling will occur preventing proper mixing.
- **d.** Mix for three minutes after the resin is all in.
- **e.** One batch will make about 6 cores.
- **f.** Once per hour catch a clean 50-100 gm sample of the raw sand for the sand lab to perform a core LOI test. Place the sample in a clean bag and label with date and time.

2. Making step cores.

- **a.** Place the core box on a flat surface large open side up.
- **b.** Place about 2 inches of sand in the bottom of the step section. Firmly tamp the sand into the 1inch diameter bottom using a ½ inch diameter rod.
- **c.** Place a few more inches of sand in the core box and compact it. Take care to avoid parting planes. Repeat until the box is full.
- **d.** Scrape off the excess. Remove the unused sand away from the gassing area.
- **e.** Place a gassing plate on the open end of the core box.
- **f.** Hold the plate down and gas the core for 20 seconds on each of the two gas holes with 20 psi CO_2 gas.
- **g.** Dry the cores for two hours at 250 ^{o}F and allow them to cool.
- **h.** Bag the cores in moisture proof bags for storage.
- **i.** Identify each bag by batch number.

- **j.** Record the date, batch number, the batch mix time, sand batch weight, resin weight, the gassing time, the gas pressure, individual dried core weight, good core count from each batch.
- **k.** The sand lab will determine the core LOI.

E. Molding: 4-on step core pattern.

1. Pattern preparation:

- **a.** Inspect and tighten all loose pattern and gating pieces.
- **b.** Repair any damaged pattern or gating parts.
- **c.** Affix DYMO tape mold identifier to each drag cavity.
- **d.** Hand wipe liquid parting on the pattern once each run.

2. Mount the drag 4-on step drag pattern into the north mold machine bolster and bolt it down tightly.
3. Mount the cope pattern with sprue on the south mold machine.
4. Use the overhead crane to place the pre-weighed drag/cope flask on the mold machine table, parting line surface down.
5. On the cope pattern hang a "double chicken foot gagger" from the flask bottom support bar and center between the gating and casting cavities.
6. Locate a 24 x 24 x4 inch deep wood upset on top of the flask.
7. Make the green sand mold on the Osborn Whisper Ram Jolt-Squeeze mold machine

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

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

- **a.** Open the air supply to the mold machine.

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

- **b.** On the operator's panel turn the POWER switch to ON.
- **c.** Turn the RAM-JOLT-SQUEEZE switch to ON.
- **d.** Turn the DRAW UP switch to AUTO
- **e.** Set the PRE-JOLT timer to 4-5 seconds.
- **f.** Set the squeeze timer to 8 seconds.
- **g.** Manually riddle a half to one inch or so of sand on the pattern using a ¼ inch mesh riddle. Source the sand from the overhead mold sand hopper by actuating the CHATTER GATE valve located under the operators panel. Hang a "double chicken foot gagger" on the flask bottom support.

- **h.** Fill the 24 x 24 x 10 inch flask and the upset with greensand from the overhead molding hopper.
- **i.** Manually level sand in the upset. By experience manually adjust the sand depth so that the resulting compacted mold is fractionally above the flask only height.

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

- **j.** Initiate the settling of the sand in the flask by pressing the PRE-JOLT push button. Allow this cycle to stop before proceeding.

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

- **k.** Using both hands initiate the automatic machine sequence by simultaneously pressing and releasing the green push buttons on either side of the operators panel. The machine will squeeze and jolt the sand in the flask and then move the squeeze head to the side.

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

- **l.** Remove the upset and set it aside.
- **m.** Screed the bottom of the mold flat if required.
- **n.** Press and release the LOWER DRAW/STOP push button to separate the flask and mold from the pattern.
- **o.** Use the overhead crane to lift the mold half and remove it from the machine.
- **p.** Finally, press and release the draw down pushbutton to cause the draw frame to return to the start position.

8. If the mold half is a drag, roll it parting line side up, set it on the floor, blow it out, and cover it to keep it clean.
9. Set the pre-weighed core in the drag mold half.
10. Set the gating filter in place.
11. Close the cope over the drag being careful not to crush anything.
12. Clamp the flask halves together.
13. Weigh and record the weight of the closed un-poured mold, the pre-weighed flask, and the sand weight by difference
14. Deliver the mold to the previously cleaned shakeout to be poured.
15. Cover the mold with the emission hood.

F. Shakeout.

1. After the cooling time prescribed in the test plan turn on the shakeout unit and run it until the greensand has passed into the hopper below. Turn off the shakeout.

2. When the emission sampling is competed remove the flask with casting, and recover the sand from the hopper and surrounding floor.

3. Weigh and record the metal poured and the total sand weight recovered and rejoined with the left over mold sand from the molding hopper.

4. Add the un-used pre-mixed sand to the recycled sand to return the sand heap to 900 +/- 10 pounds.

G. Melting:

1. Initial charge:

- **a.** Charge the furnace according to the heat recipe.
- **b.** Place part of the steel scrap on the bottom, followed by alloys, and the balance of the steel.
- **c.** Bring the furnace contents to the point of beginning to melt over a period of 1 hour at reduced power.
- **d.** Add the balance of the metallics under full power until all is melted and the temperature has reached 2700 to 2750^{o}F.
- **e.** Slag the furnace and add the balance of the alloys.
- **f.** Raise the temperature of the melt to 3000^{o}F and pour a spectrometer lug in the water chilled mold. Also pour a Data Cast lug to confirm the solidification temperature.
- **g.** Hold the furnace at 2775-2825^{o}F until near ready to tap.
- **h.** When ready to tap raise the temperature to 3000^{o}F and slag the furnace.
- **i.** Record all metallic and alloy additions to the furnace, tap temperature, and pour temperature. Record all furnace activities with an associated time.

2. Back charging.

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

3. Emptying the furnace.

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

H. Pouring:

1. Preheat the ladle.

- **a.** Tap 400 pounds more or less of 3000^{o}F metal into the cold ladle.
- **b.** Casually pour the metal back to the furnace.
- **c.** Cover the ladle.
- **d.** Reheat the metal to 3000-3025^{o}F.

- **e.** Tap 450 pounds of iron into the ladle.
- **f.** Cover the ladle to conserve heat.
- **g.** Move the ladle to the pour position, and wait until the metal temperature reaches 2925 +/- 10^{o}F.
- **h.** Commence pouring keeping the sprue full.
- **i.** Upon completion return the extra metal to the furnace, and cover the ladle.

I. Casting cleaning

1. Spin blast set up.

- **a.** Load the spin blast shot storage bin with 460 steel shot.
- **b.** Turn on the spin blast bag house.
- **c.** Turn on the spin blast machine.
- **d.** Increase the magnetic feeder so that the motor amperage just turns to 12 amps from 11 amps.
- **e.** Record the shot flow and the motor amperage for each wheel.

2. Cleaning castings.

- **a.** Sort the castings by the drag DYMO tape mold identifier cast impression.
- **b.** Place the (4) castings from a single mold on one (1) casting basket.
- **c.** Process each rotating basket for eight (8) minutes.
- **d.** Remove castings and remark casting ID on each casting. Refer to drag DYMO tape identifier.
- **e.** Weigh castings for each mold.
- **f.** Separate cope-marked cavity three (3) from each mold for Rank-order evaluation.

J. Rank order evaluation.

1. The supervisor shall select a group of five persons to make a collective subjective judgment of the casting relative surface appearance.
2. Review the general appearance of the castings and select specific casting features to compare.
3. For cavity 3 only:

- **a.** Place each casting initially in sequential mold number order.
- **b.** Beginning with casting from mold FS001, compare it to castings from mold FS002.
- **c.** Place the better appearing casting in the first position and the lesser appearing casting in the second position.
- **d.** Repeat this procedure with FS001 to its nearest neighbors until all castings closer to the beginning of the line are better appearing than FS001 and the next casting farther down the line is inferior.
- **e.** Repeat this comparison to next neighbors for each casting number.
- **f.** When all casting numbers have been compared go to the beginning of the line and begin again comparing each casting to its nearest neighbor. Move the castings so that

each casting is inferior to the next one closer to the beginning of the line and superior to the one next toward the tail of the line.

g. Repeat this comparison until all concur with the ranking order.

h. Record mold number by rank-order series for this cavity.

Steven Knight
Mgr. Process Engineering

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
2/16/2004											**FS CR-1**
FS CR-1											
THC		x									

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
2/17/2004											**FS CR-2**
FS CR-2											
THC		x									

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
2/17/2004											**FS CR-3**
FS CR-3											
THC		x									

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
2/18/2004											
RUN 1											
THC	FS001	X									TOTAL
M-18	FS00101		1						60	1	Carbopak charcoal
M-18	FS00102			1					60	2	Carbopak charcoal
M-18	FS00103				1				0		Carbopak charcoal
									60	3	Excess
Gas, CO, CO2	FS00104		1						60	4	Tedlar Bag
Gas, CO, CO2	FS00105				1				0		Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00106		1						1000	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	FS00107				1				0		100/50 mg Charcoal (SKC 226-01)
	Excess								1000	8	Excess
TO11	FS00108		1						1000	9	DNPH Silica Gel (SKC 226-119)
TO11	FS00109				1				0		DNPH Silica Gel (SKC 226-119)
	Excess								1000	10	Excess
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
2/18/2004											
RUN 2											
THC	FS002	X									TOTAL
M-18	FS00201		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
Gas, CO, CO2	FS00202		1						60	4	Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00203		1						1000	7	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	8	Excess
TO11	FS00204		1						1000	9	DNPH Silica Gel (SKC 226-119)
	Excess								1000	10	Excess
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
3/8/2004											**FS CR-4**
FS CR-4											
THC		X									

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
3/8/2004											
RUN 3											
THC	FS003	X									TOTAL
M-18	FS00301		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								30	3	Excess
Gas, CO, CO2	FS00302		1						60	4	Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00303		1						1000	7	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	8	Excess
TO11	FS00304		1						1000	9	DNPH Silica Gel (SKC 226-119)
	Excess								1000	10	Excess
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
3/9/2004											
RUN 4											
THC	FS004	X									TOTAL
M-18	FS00401		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
Gas, CO, CO2	FS00402		1						60	4	Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00403		1						1000	7	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	8	Excess
TO11	FS00404		1						1000	9	DNPH Silica Gel (SKC 226-119)
	Excess								1000	10	Excess
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
3/9/2004											
RUN 5											
THC	FS005	X									TOTAL
M-18	FS00501		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
Gas, CO, CO2	FS00502		1						60	4	Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00503		1						1000	7	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	8	Excess
TO11	FS00504		1						1000	9	DNPH Silica Gel (SKC 226-119)
	Excess								1000	10	Excess
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
3/10/2004											
RUN 6											
THC	FS006	X									TOTAL
M-18	FS00601		1						60	1	Carbopak charcoal
M-18 MS	FS00602		1						60	2	Carbopak charcoal
M-18 MS	FS00603			1					60	3	Carbopak charcoal
Gas, CO, CO2	FS00604		1						60	4	Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00605		1						1000	7	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	FS00606			1					1000	8	100/50 mg Charcoal (SKC 226-01)
TO11	FS00607		1						1000	9	DNPH Silica Gel (SKC 226-119)
TO11	FS00608			1					1000	10	DNPH Silica Gel (SKC 226-119)
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
3/10/2004											
RUN 7											
THC	FS007	X									TOTAL
M-18	FS00701		1						60	1	Carbopak charcoal
M-18	FS00702					1			60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
Gas, CO, CO2	FS00703		1						60	4	Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00704		1						1000	7	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	8	Excess
TO11	FS00705		1						1000	9	DNPH Silica Gel (SKC 226-119)
	Excess								1000	10	Excess
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
3/11/2004											
RUN 8											
THC	FS008	X									TOTAL
M-18	FS00801		1						60	1	Carbopak charcoal
M-18	FS00802			1					60	2	Carbopak charcoal
	Excess								60	3	Excess
Gas, CO, CO2	FS00803		1						60	4	Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00804		1						1000	7	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	8	Excess
TO11	FS00805		1						1000	9	DNPH Silica Gel (SKC 226-119)
	Excess								1000	10	Excess
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

PRE-PRODUCTION FS - SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
3/11/2004											
RUN 9											
THC	FS009	X									TOTAL
M-18	FS00901		1						60	1	Carbopak charcoal
	Excess								60	2	Excess
	Excess								60	3	Excess
Gas, CO, CO2	FS00902		1						60	4	Tedlar Bag
	Excess								500	5	Excess
	Excess								500	6	Excess
NIOSH 1500	FS00903		1						1000	7	100/50 mg Charcoal (SKC 226-01)
	Excess								1000	8	Excess
TO11	FS00904		1						1000	9	DNPH Silica Gel (SKC 226-119)
	Excess								1000	10	Excess
	Excess								1000	11	Excess
	Moisture		1						500	12	TOTAL
	Excess								5000	13	Excess

APPENDIX B TEST SERIES FS DETAILED EMISSION RESULTS

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Test Plan FS Individual Emission Test Results – Lb/Tn Metal

HAPs	POMs	COMPOUND / SAMPLE NUMBER	FS003	FS004	FS005	FS006	FS007	FS008	FS009	Average	STDEV
		Test Dates	**3/8/04**	**3/9/04**	**3/9/04**	**3/10/04**	**3/10/04**	**3/11/04**	**3/11/04**		
		TGOC as Propane	3.42E-01	4.31E-01	4.49E-01	4.36E-01	4.64E-01	4.22E-01	4.32E-01	4.25E-01	3.92E-02
		HC as Hexane	3.68E-02	4.73E-02	4.32E-02	5.32E-02	4.57E-02	4.49E-02	4.33E-02	4.49E-02	4.94E-03
		Sum of VOCs	6.45E-02	8.13E-02	8.58E-02	9.85E-02	8.55E-02	7.98E-02	9.20E-02	8.39E-02	1.07E-02
		Sum of HAPs	5.97E-02	7.19E-02	7.67E-02	8.71E-02	7.69E-02	7.09E-02	8.24E-02	7.51E-02	8.84E-03
		Sum of POMs	3.30E-03	4.38E-03	4.12E-03	7.00E-03	4.84E-03	5.15E-03	5.70E-03	4.93E-03	1.19E-03
		Individual Organic HAPs									
x		**Benzene**	1.38E-02	1.68E-02	2.07E-02	2.04E-02	2.14E-02	1.78E-02	2.14E-02	1.89E-02	2.87E-03
x		**Acetaldehyde ***	1.48E-02	1.65E-02	1.59E-02	1.87E-02	1.50E-02	1.56E-02	1.61E-02	1.61E-02	1.30E-03
x		**Toluene**	7.83E-03	9.65E-03	1.12E-02	1.09E-02	1.10E-02	9.71E-03	1.12E-02	1.02E-02	1.24E-03
x		**m,p-Xylene**	3.17E-03	3.98E-03	4.50E-03	4.55E-03	4.55E-03	4.04E-03	4.84E-03	4.23E-03	5.56E-04
x		**Phenol**	2.86E-03	3.55E-03	3.92E-03	5.28E-03	4.21E-03	3.73E-03	4.87E-03	4.06E-03	8.19E-04
x		**Formaldehyde**	3.51E-03	4.24E-03	2.47E-03	4.54E-03	2.08E-03	2.02E-03	2.24E-03	3.02E-03	1.07E-03
x		**Hexane**	2.17E-03	2.80E-03	2.97E-03	3.02E-03	2.73E-03	2.42E-03	2.95E-03	2.72E-03	3.18E-04
x	z	**Naphthalene**	1.67E-03	2.22E-03	2.12E-03	3.38E-03	2.34E-03	2.23E-03	2.84E-03	2.40E-03	5.54E-04
x		**o-Xylene**	1.62E-03	2.02E-03	2.04E-03	2.33E-03	2.10E-03	1.91E-03	2.46E-03	2.07E-03	2.74E-04
x		**2-Butanone** [#]	1.71E-03	1.81E-03	2.21E-03	2.25E-03	2.24E-03	2.15E-03	2.45E-03	2.12E-03	2.64E-04
x		**Propionaldehyde** [#]	1.54E-03	1.86E-03	1.77E-03	2.09E-03	1.58E-03	1.68E-03	1.71E-03	1.75E-03	1.87E-04
x		**Styrene**	1.27E-03	1.70E-03	1.71E-03	2.08E-03	1.86E-03	1.69E-03	2.24E-03	1.79E-03	3.14E-04
x	z	**2-Methylnaphthalene**	8.59E-04	1.21E-03	1.08E-03	2.06E-03	1.39E-03	1.65E-03	1.50E-03	1.39E-03	3.96E-04
x		**o-Cresol**	7.18E-04	6.77E-04	1.21E-03	1.60E-03	1.25E-03	1.13E-03	1.63E-03	1.17E-03	3.78E-04
x		**Ethylbenzene**	7.08E-04	1.00E-03	1.08E-03	1.20E-03	1.22E-03	1.10E-03	1.37E-03	1.10E-03	2.09E-04
x		**m,p-Cresol**	5.07E-04	6.82E-04	8.13E-04	9.84E-04	7.82E-04	6.75E-04	1.04E-03	7.84E-04	1.86E-04
x	z	**1-Methylnaphthalene**	4.10E-04	5.64E-04	5.08E-04	1.01E-03	6.72E-04	8.31E-04	8.13E-04	6.86E-04	2.09E-04
x	z	**1,3-Dimethylnaphthalene**	3.69E-04	3.90E-04	4.14E-04	5.54E-04	4.40E-04	4.37E-04	5.38E-04	4.49E-04	7.11E-05
x		**Acrolein**	1.39E-04	1.76E-04	1.29E-04	2.30E-04	1.27E-04	1.28E-04	1.30E-04	1.51E-04	3.87E-05
x	z	**1,2-Dimethylnaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA
x	z	**1,5-Dimethylnaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA
x	z	**1,6-Dimethylnaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA
x	z	**1,8-Dimethylnaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA
x	z	**2,3,5-Trimethylnaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA

Test Plan FS Individual Emission Test Results – Lb/Tn Metal

HAPs	POMs	COMPOUND / SAMPLE NUMBER	FS003	FS004	FS005	FS006	FS007	FS008	FS009	Average	STDEV
		Test Dates	3/8/04	3/9/04	3/9/04	3/10/04	3/10/04	3/11/04	3/11/04		
x	z	**2,3-Dimethylnaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA
x	z	**2,6-Dimethylnaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA
x	z	**2,7-Dimethylnaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA
x	z	**Acenaphthalene**	ND	ND	ND	ND	ND	ND	ND	ND	NA
x		**Biphenyl**	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Other VOCs									
		1,2,4-Trimethylbenzene	I	1.74E-03	1.74E-03	2.11E-03	1.81E-03	1.96E-03	2.14E-03	1.92E-03	1.80E-04
		o,m,p-Tolualdehyde	7.29E-04	1.33E-03	7.41E-04	1.17E-03	5.16E-04	4.75E-04	5.03E-04	7.80E-04	3.40E-04
		Butyraldehyde/Methacrolein	9.42E-04	1.04E-03	1.06E-03	1.23E-03	9.53E-04	1.13E-03	1.14E-03	1.07E-03	1.05E-04
		Indene	8.19E-04	1.04E-03	1.01E-03	1.31E-03	1.07E-03	1.03E-03	1.39E-03	1.09E-03	1.92E-04
		Benzaldehyde	I	1.00E-03	1.17E-03	1.21E-03	1.10E-03	1.14E-03	1.22E-03	1.14E-03	7.93E-05
		Crotonaldehyde	1.14E-03	1.17E-03	1.17E-03	1.23E-03	9.46E-04	9.26E-04	9.73E-04	1.08E-03	1.27E-04
		Heptane	6.13E-04	7.44E-04	8.75E-04	8.76E-04	8.24E-04	7.58E-04	8.95E-04	7.98E-04	1.01E-04
		3-Ethyltoluene	3.90E-04	4.83E-04	5.64E-04	6.17E-04	5.72E-04	6.00E-04	5.65E-04	5.42E-04	7.91E-05
		1,2,3-Trimethylbenzene	I	6.36E-04	4.63E-04	6.99E-04	4.80E-04	5.90E-04	5.84E-04	5.75E-04	9.08E-05
		Hexaldehyde	2.01E-04	2.85E-04	2.67E-04	3.65E-04	2.87E-04	2.11E-04	2.83E-04	2.71E-04	5.49E-05
		Dodecane	ND	ND	ND	5.80E-04	ND	ND	ND	8.29E-05	2.19E-04
		1,3,5-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	NA
		1,3-Diethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	NA
		2,4-Dimethylphenol	ND	ND	ND	ND	ND	ND	ND	ND	NA
		2,6-Dimethylphenol	ND	ND	ND	ND	ND	ND	ND	ND	NA
		2-Ethyltoluene	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Cyclohexane	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Decane	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Indan	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Nonane	ND	ND	ND	ND	ND	ND	ND	ND	NA
		n-Propylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Octane	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Tetradecane	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Undecane	ND	ND	ND	ND	ND	ND	ND	ND	NA
		Pentanal	ND	ND	ND	ND	ND	ND	ND	ND	NA

Test Plan FS Individual Emission Test Results – Lb/Tn Metal

HAPs	POMs	COMPOUND / SAMPLE NUMBER	FS003	FS004	FS005	FS006	FS007	FS008	FS009	Average	STDEV
		Test Dates	**3/8/04**	**3/9/04**	**3/9/04**	**3/10/04**	**3/10/04**	**3/11/04**	**3/11/04**		
		Other Analytes									
		Acetone *	1.09E-02	1.09E-02	1.27E-02	1.27E-02	1.26E-02	1.26E-02	1.29E-02	1.22E-02	8.75E-04
		Carbon Dioxide	1.49E+01	1.65E+01	1.58E+01	1.59E+01	1.53E+01	1.78E+01	1.83E+01	1.64E+01	1.28E+00
		Carbon Monoxide	ND	ND	ND	ND	ND	ND	ND	ND	NA

 # Values reported as a minimum due to apparent breakthrough for samples FS004, FS006.

*** Values reported as a minimum due to apparent breakthrough for all samples.**

ND: Non Detect; NA: Not Applicable

All "Other Analytes" are not included in the Sum of VOC or HAPs

Test FS Quantitation Limits – Lb/Tn Metal

Analytes	Lb/Tn Metal
1,2,3-Trimethylbenzene	1.04E-04
1,2,4-Trimethylbenzene	1.04E-04
1,3,5-Trimethylbenzene	1.04E-04
1,3-Dimethylnaphthalene	1.04E-04
1-Methylnaphthalene	1.04E-04
2-Ethyltoluene	1.04E-04
2-Methylnaphthalene	1.04E-04
Benzene	1.04E-04
Ethylbenzene	1.04E-04
Hexane	1.04E-04
m,p-Xylene	1.04E-04
Naphthalene	1.04E-04
o-Xylene	1.04E-04
Styrene	1.04E-04
Toluene	1.04E-04
Undecane	1.04E-04
1,2-Dimethylnaphthalene	5.18E-04
1,3-Diethylbenzene	5.18E-04
1,5-Dimethylnaphthalene	5.18E-04
1,6-Dimethylnaphthalene	5.18E-04

Analytes	Lb/Tn Metal
1,8-Dimethylnaphthalene	5.18E-04
2,3,5-Trimethylnaphthalene	5.18E-04
2,3-Dimethylnaphthalene	5.18E-04
2,4-Dimethylphenol	5.18E-04
2,6-Dimethylnaphthalene	5.18E-04
2,6-Dimethylphenol	5.18E-04
2,7- Dimethylnaphthalene	5.18E-04
3-Ethyltoluene	5.18E-04
Acenaphthalene	5.18E-04
Biphenyl	5.18E-04
Cyclohexane	5.18E-04
Decane	5.18E-04
Dodecane	5.18E-04
Heptane	5.18E-04
Indan	5.18E-04
Indene	5.18E-04
m,p-Cresol	5.18E-04
Nonane	5.18E-04
o-Cresol	5.18E-04
Octane	5.18E-04

Analytes	Lb/Tn Metal
Phenol	5.18E-04
Propylbenzene	5.18E-04
Tetradecane	5.18E-04
HC as Hexane	3.13E-03
2-Butanone (MEK)	9.27E-05
Acetaldehyde	9.27E-05
Acetone	9.27E-05
Acrolein	9.27E-05
Benzaldehyde	9.27E-05
Butyraldehyde	9.27E-05
Crotonaldehyde	9.27E-05
Formaldehyde	9.27E-05
Hexaldehyde	9.27E-05
Butyraldehyde/Methacrolein	1.54E-04
o,m,p-Tolualdehyde	2.47E-04
Pentanal (Valeraldehyde)	9.27E-05
Propionaldehyde (Propanal)	9.27E-05
Carbon Monoxide	2.46E-01
Carbon Dioxide	7.72E-01

APPENDIX C TEST SERIES FS DETAILED PROCESS DATA

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Test FS Detailed Process Data

Greensand PCS														
Test Dates	**2/16/2004**	**2/17/2004**	**2/17/2004**	**2/18/2004**	**2/18/2004**	**3/8/2004**	**3/8/2004**	**3/9/2004**	**3/9/2004**	**3/10/2004**	**3/10/2004**	**3/11/2004**	**3/11/2004**	**Averages of qualified molds**
Emissions Sample # (Note #	**FSCR001**	**FSCR002**	**FSCR003**	**FS001**	**FS002**	**FSCR004**	**FS003**	**FS004**	**FS005**	**FS006**	**FS007**	**FS008**	**FS009**	
Production Sample #	**FS001**	**FS002**	**FS003**	**FS004**	**FS005**	**FS006**	**FS007**	**FS008**	**FS009**	**FS010**	**FS011**	**FS012**	**FS013**	
Cast Weight (all metal inside	102.85	117.23	96.55	43.30	64.35	119.73	123.73	122.33	121.58	119.53	119.98	123.98	115.41	**120.93**
Pouring Time, sec.	17	17	22	23	17	25	20	21	26	23	19	17	22	**21**
Pouring Temp ,°F	2913	2938	2889	2938	2946	2916	2910	2902	2921	2936	2936	2948	2931	**2926**
Metal type	WCB Steel	WCB Steel	WCB Steel	Semi steel 0.9% C	Semi steel 0.9% C	White iron 2.4 % C	White iron 2.4 % C	White iron 2.4 % C	Gray CI 3.21%C	Gray CI 3.44 % C	Gray CI 3.89% C	Gray CI 3.25% C	Gray CI 3.27% C	
Pour Hood Process Air Temp at Start of Pour, °F	87	88	88	88	88	86	90	87	86	88	85	88	87	**87**
Mixer manually weighed batch weight, Lbs	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	**50.00**
Manually weighed sodium silicate binder weight, Lbs	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	**2.00**
Core binder mannually weighed weight, %BOS	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	**4.00**
Core binder manually weighed weight, %	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	**3.85**
Total uncoated core weight in mold, Lbs.	28.5	28.65	28.45	28.60	28.65	28.90	28.35	28.80	28.80	28.95	28.55	28.40	28.55	**28.63**
Total binder weight in mold, Lbs.	1.10	1.10	1.09	1.10	1.10	1.11	1.09	1.11	1.11	1.11	1.10	1.09	1.10	**1.10**
Muller GS Batch Weight, Lbs.	1210	900	900	900	900	900	900	900	900	900	900	900	900	**900**
GS Mold Sand Weight, Lbs.	601	591	609	615	599	603	599	599	615	603	610	615	619	**609**
Western Bentonite, Lbs	60	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	**2.15**
Southern Bentonite, Lbs.	40	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	**0.90**
Dextrin weight, Lbs.	3.85	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	**0.20**
Cereal weight, Lbs.	5.75	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	**0.25**
Mold compactability, %	55	56	42	42	44	50	45	51	48	42	48	45	50	**47**
Mold Temperature, °F	ND	67	73	65	71	68	77	72	80	73	80	73	78	**76**
Average Green Compression , psi	12.97	16.99	22.29	20.17	18.98	16.01	23.72	22.43	26.02	24.21	22.58	25.86	22.45	**23.90**
GS Compactability, %	48	49	24	29	29	40	23	27	24	26	25	27	30	**26**
GS Moisture Content, %	3.63	3.19	2.24	2.50	2.05	1.60	1.78	2.19	2.10	1.67	1.45	1.30	2.07	**1.79**
GS MB Clay Content, %	8.56	9.33	9.07	9.07	8.56	8.81	9.85	9.33	9.07	9.20	9.33	9.20	9.59	**9.37**
MB Clay reagent, ml	33.0	36.0	35.0	35.0	33.0	34.0	38.0	36.0	35.0	35.5	36.0	35.5	37.0	**36.1**
1800°F LOI - Mold Sand,	1.75	1.61	1.45	1.58	1.80	1.71	1.51	1.19	1.38	1.24	1.36	1.20	1.25	**1.30**
900°F Volatiles , %	1.14	0.96	0.83	0.85	1.16	1.08	0.74	0.84	0.96	0.74	0.77	0.57	0.83	**0.78**
				Note 1	Note # 2									

Note 1: Significant misrun. Each cavity only 1.5 inches tall. Disqualify

Note 2: Significant misrun and metal oxidized to a slag. Each cavity 1.5 inches of metal + 3 inches of oxidized metal. Disqualify

Note 3: Molds numbered FSCR001-003 & FSCR006 were conditioning runs.

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APPENDIX D METHOD 25A CHARTS

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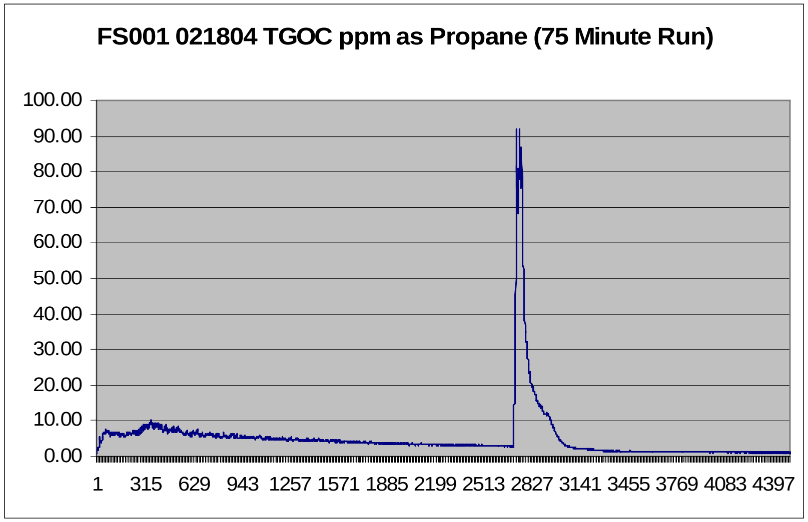
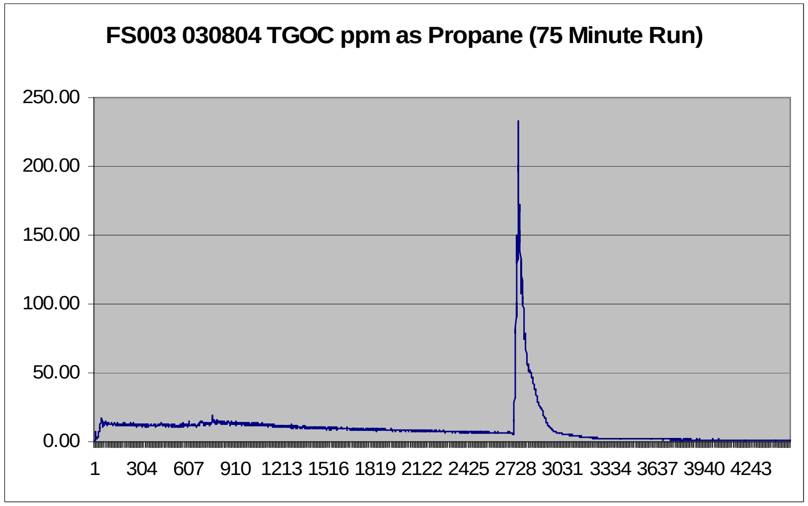
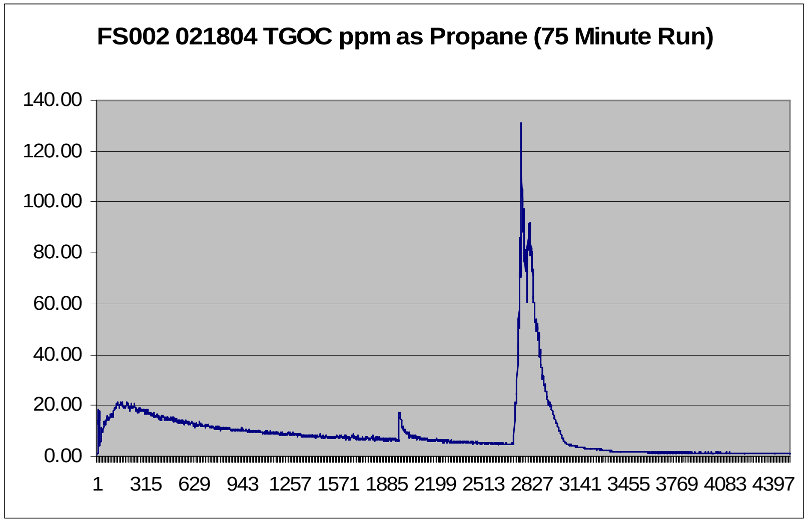
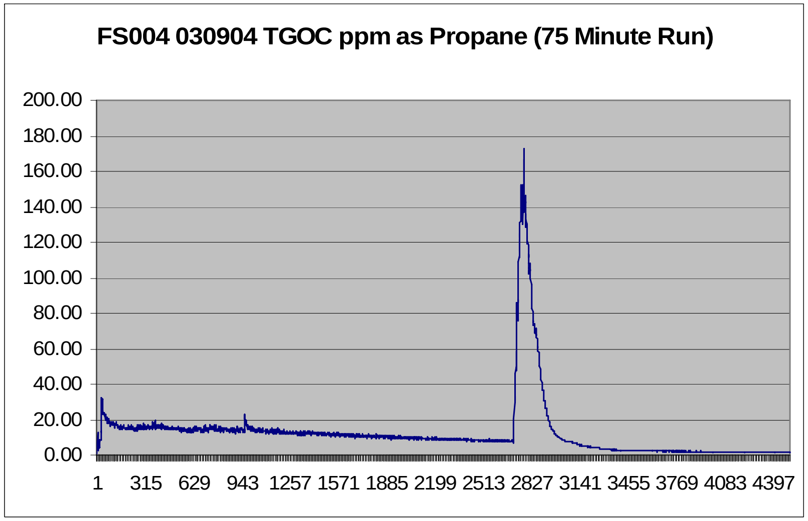
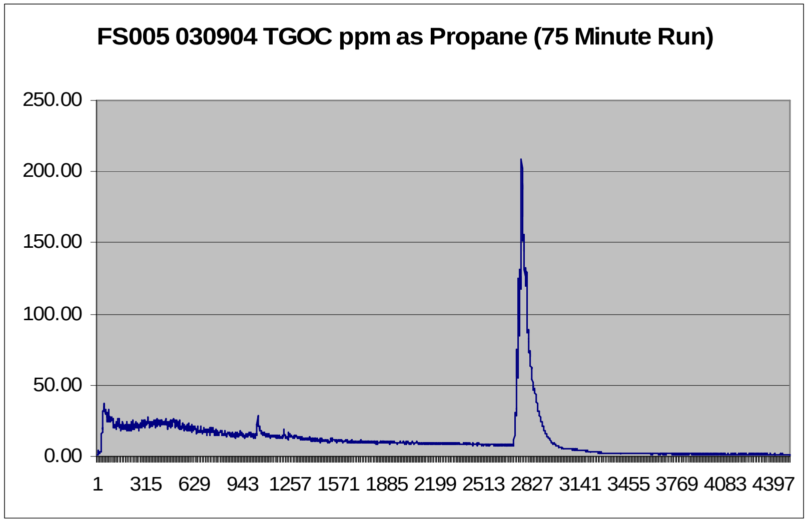
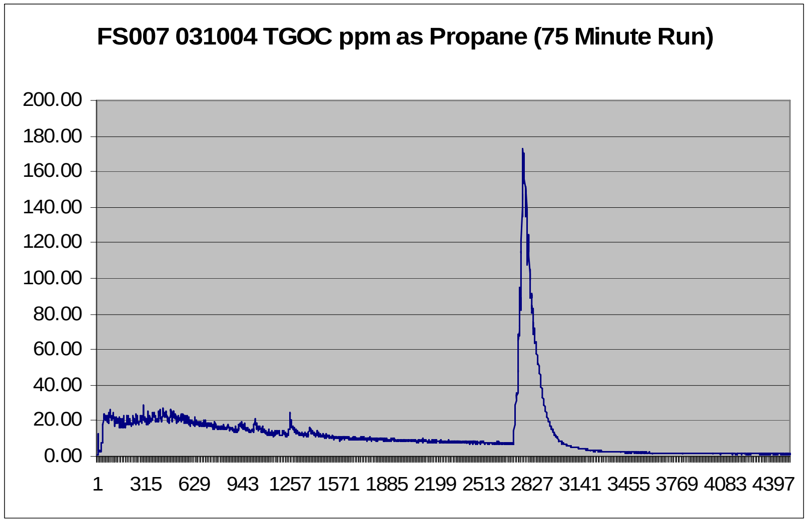

FS001 021804 TGOC ppm as Propane (75 Minute Run)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397

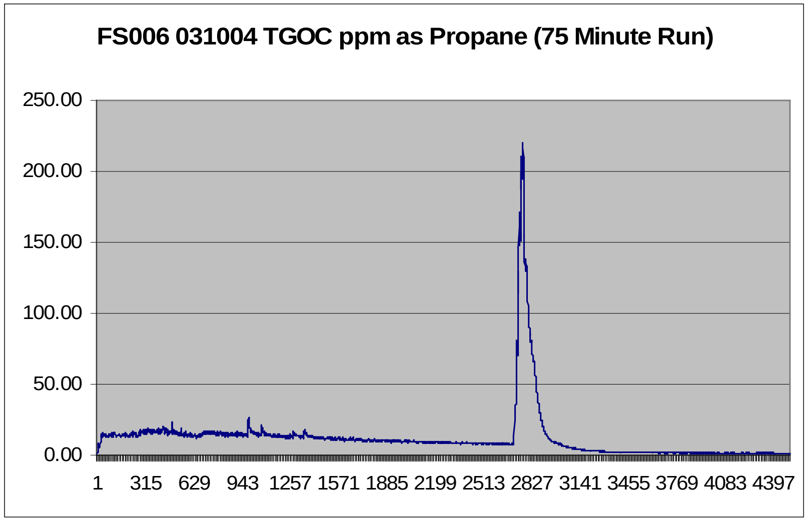

FS003 030804 TGOC ppm as Propane (75 Minute Run)
250.00
200.00
150.00
100.00
50.00
0.00
1 304 607 910 1213 1516 1819 2122 2425 2728 3031 3334 3637 3940 4243

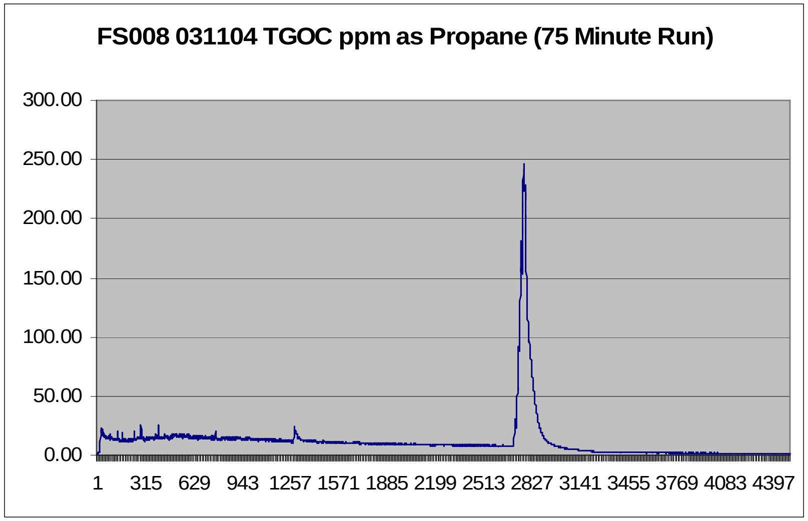

FS002 021804 TGOC ppm as Propane (75 Minute Run)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397

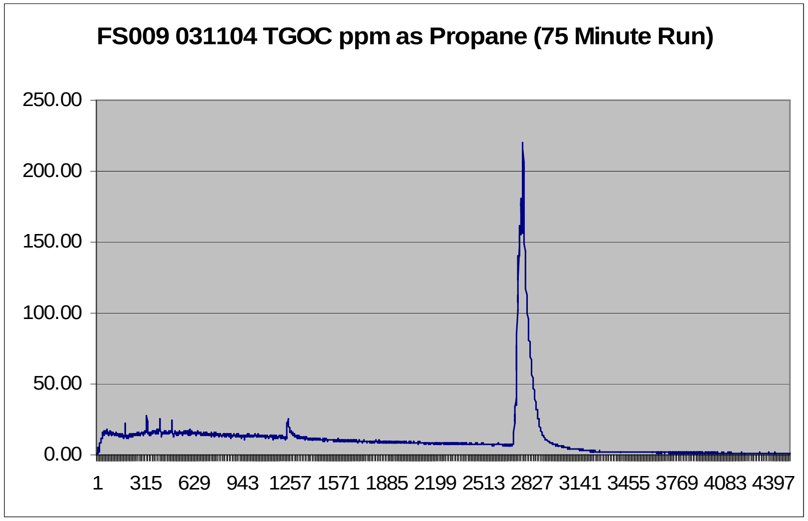

FS004 030904 TGOC ppm as Propane (75 Minute Run)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397


FS005 030904 TGOC ppm as Propane (75 Minute Run)
250.00
200.00
150.00
100.00
50.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397


FS007 031004 TGOC ppm as Propane (75 Minute Run)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397


FS006 031004 TGOC ppm as Propane (75 Minute Run)
250.00
200.00
150.00
100.00
50.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397


FS008 031104 TGOC ppm as Propane (75 Minute Run)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397


FS009 031104 TGOC ppm as Propane (75 Minute Run)
250.00
200.00
150.00
100.00
50.00
0.00
1
315
629
943
1257
1571
1885
2199
2513
2827
3141
3455
3769
4083
4397

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APPENDIX E GLOSSARY

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Glossary

BO	Based on ( ).
BOS	Based on Sand.
HAP	Hazardous Air Pollutant defined by the 1990 Clean Air Act Amendment
HC as Hexane	Calculated by the summation of all area between elution of Hexane through the elution of Hexadecane. The quantity of HC is performed against a five-point calibration curve of Hexane by dividing the total area count from C6 through C16 to the area of Hexane from the initial calibration curve.
I	Data rejected based on data validation considerations
NA	Not Applicable; Not Available
ND	Non-Detect
NT	Lab testing was not done
POM	Polycyclic Organic Matter (POM) including Naphthalene and other compounds that contain more than one benzene ring and have a boiling point greater than or equal to 100 degrees Celsius.
TGOC as Propane	Weighted to the detection of more volatile hydrocarbon species, beginning at C1 (methane), with results calibrated against a three-carbon alkane (propane).
VOC	Volatile Organic Compound