Casting Emission Reduction Program

Prepared by:

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US Army Contract DAAE30-02-C-1095
FY 2002 Tasks

No-Bake Pouring and Cooling

Vendor Product
HA International
TECHNISET® 7211/7706/17-727

Test #1409-116-FE

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This document has been revised for public distribution.

EPA United States Environmental Protection Agency

CISA

AFS AMERICAN FOUNDRY SOCIETY, INC.

USCAR UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

DAIMLERCHRYSLER Ford Motor Company General Motors

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VOC Emissions
From No-Bake Pouring and Cooling

1409-116 FE

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

Research Chemist:	*// Original Signed //* Carmen Hornsby	Date
Process Engineering Manager:	*// Original Signed //* Steven Knight	Date
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VP Operations:	*// Original Signed //* George Crandell	Date
President:	*// Original Signed //* William Walden	Date

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

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Executive Summary

This report contains the results of emission testing of a No-Bake Phenolic Urethane binder mold system poured with aluminum. The process studied involved pouring followed by either a 30-minute or a 240-minute extended cooling period.. All testing was conducted in the Technikon Pre-Production foundry.

The specific objective of the test was to measure selected Hazardous Air Pollutants (HAPs) and Volatile Organic Compounds (VOCs) emissions from pouring and cooling without shakeout, for No-Bake molds prepared with a phenolic urethane binder.

Process and stack parameters were measured and include: the weights of the casting, no-bake mold package, binder; 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 and the stack flow rate were maintained within prescribed ranges in order to ensure the reproducibility of the tests. Three (3) molds were poured for the 30-minute pour and cool segment and three (3) molds were poured for the pouring and 240-minute extended cooling segment. Samples were collected and analyzed using procedures based on US EPA Method 18. Continuous monitoring of the Total Gaseous Organic Concentration (TGOC) was conducted according to US EPA Method 25A. The table below summarizes the results for each of the test segments in lbs/tn of metal and lbs/lb of binder.

Summary Table for Lbs/Lb of Binder

Analytes	TGOC as Propane	HC as Hexane	Sum of VOCs	Sum of HAPs	Sum of POMs
30-Minute Cool (W/O Shakeout)	0.0102	0.0061	0.0015	0.0015	0.0011
4-Hour Cool (W/O Shakeout)	0.1523	0.0919	0.0174	0.0174	0.0125

Summary Table for Lbs/Tn of Metal

Analytes	TGOC as Propane	HC as Hexane	Sum of VOCs	Sum of HAPs	Sum of POMs
30-Minute Cool (W/O Shakeout)	1.987	1.157	0.2745	0.2745	0.2003
4-Hour Cool (W/O Shakeout)	27.96	18.21	3.448	3.448	2.481

It must be noted that the reference and product testing performed is not suitable for use as emission factors or for purposes other than evaluating the relative emission reductions associated with

the use of alternative materials, equipment, or processes. The emissions measurements are unique to the specific castings produced, materials used, and testing methodology associated with these tests, and should not be used as the basis for estimating emissions from actual commercial foundry applications.

1.0 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. The core making area of the Production foundry contains three core blowers, a Georg Fischer for the preparation of automotive block cores, a Redford that is used for the production of step cores, and a second smaller Redford to produce dogbone tensile test specimens.

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 relative emission reductions 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 should not be used as the basis for estimating emissions from actual commercial foundry applications.

1.3 Report Organization

This report has been designed to document the methodology and results of a specific test plan that was used to evaluate VOC emissions from the No-Bake mold making process. Section 2 of this report includes a summary of the methodologies used for data collection and analysis, emis-

sion 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 Appendix B 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 data Binderbinder" that is maintained at the Technikon facility.

1.4 Specific Test Plan and Objectives

This report contains the results of testing performed to provide data on selected VOC emissions from a No-Bake mold making system. Table 1-1 provides a summary of the test plan for Test FE. The details of the approved test plan are included in Appendix A.

Table 1-1 Test Plan Summary

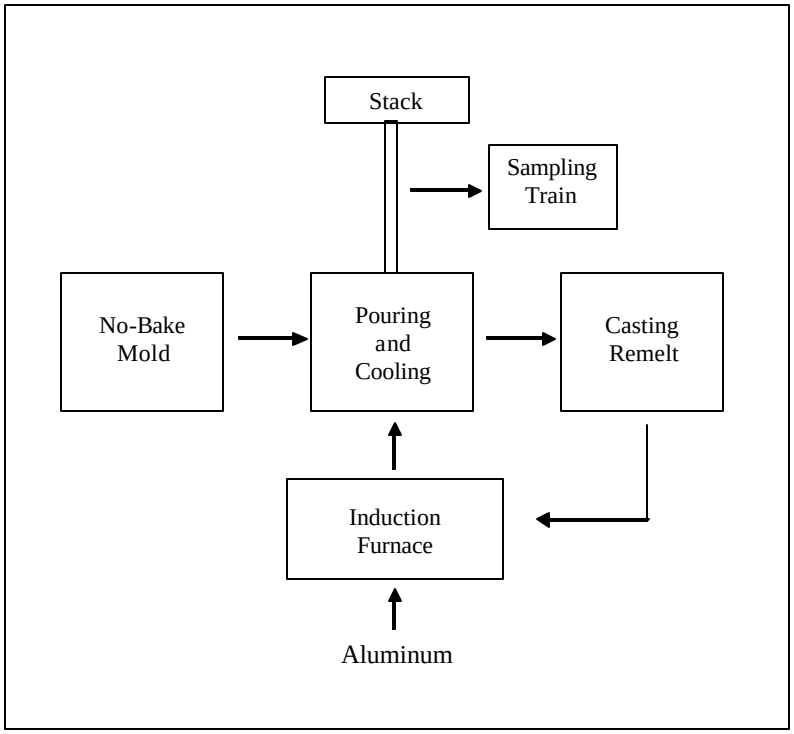
	Test FE
Type of Process Tested	No Bake Emissions Study
Test Plan Number	1409-116
Binder System	Phenolic Urethane No-Bake HA-International TECHNISET ® 7211/7706/17-727
Number of Tests	3 each of Pour and Cool for 30 minutes and 240 minutes
Test Dates	4/15/03 > 5/26/03
Emissions Measured	TGOC as Propane, HC as Hexane, Phenol, Naphthalene, 1 & 2-Methylnaphthalene, Formaldehyde
Process Parameters Measured	Total Casting and Mold Weights; Metallurgical Data, % LOI; Process Air Temperature, Moisture Content, Pressure, and Volumetric Flow Rate
Source Parameters Measured	Exhaust Duct 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 no-bake mold making process and testing equipment.

Figure 2-1 Mold Making and Testing Process

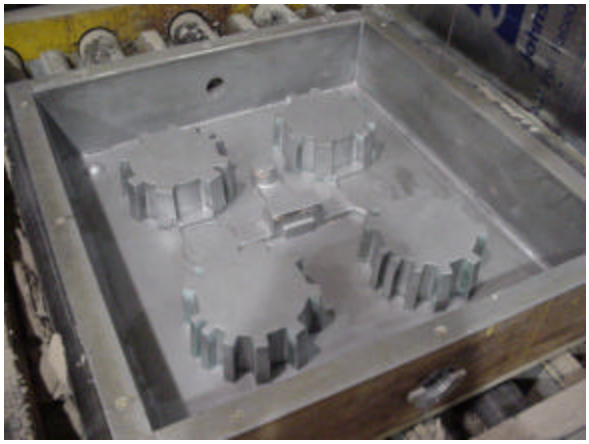


2.2 Description of Testing Program

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

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

2. **Sand Preparation:** Sands were mixed with quantities of designated binders in a Kloster paddle mixer. The sand was preheated or cooled as required to a standard temperature range.

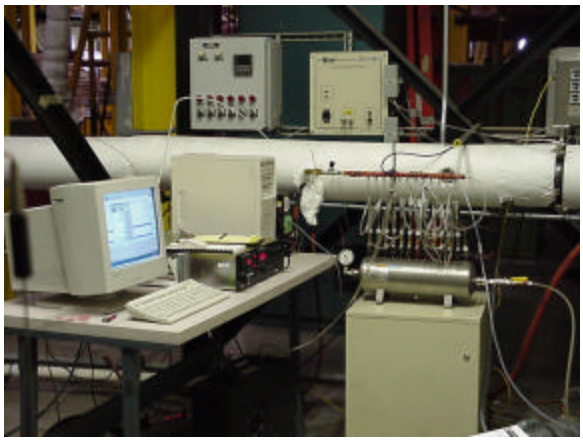


No Bake Irregular Gear Pattern

3. **Mold Preparation:** Mixed sand was dispensed into a No-Bake 4-on variable tooth gear mold patterns. Once the patterns were about one-half full, the vibration table was started to compact the mixed sand the vibration continued for an additional five (5) seconds after the flask was full.

Sampling Mold in Test Stand

4. **Individual Sampling Events:** Replicate tests were performed on the mold packages. The mold packages were each placed into an enclosed test stand heated to approximately 85°F. Aluminum was poured through an air screen opening in the top of the enclosure. Air samples were collected during the entire pouring and cooling periods of Test FE.



Method 25A (TGOC) and
Method 18 Sampling Train

5. Where new core materials are being evaluated, initial core emissions baseline data are gathered by placing five step-block cores under an**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
Binder Weight (mixing)	Mettler PJ8000 Digital Scale (Gravimetric)
Sand Weight (mixing)	OHAUS 110# digital platform scale
Sand Temperature (mixing)	Stem type dial thermometer
Cycle Time	Digital elapsed time clocks
Enclosure Air Temperature	Thermocouple
Mold and Casting Weight	Cardinal 748 Digital Platform Scale

5.6. Air Emissions Analysis: The specific sampling and analytical methods used in the No-Bake pour and cool 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, if any, 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
HC as Hexane, Naphthalene, Phenol, Formaldehyde, 1 and 2-Methylnaphthalene	EPA Method 18 (TO-11, NIOSH 1500, NIOSH 2002)
TGOC (THC) as Propane	EPA Method 25A

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

7. Data Reduction, Tabulation and Preliminary Report Preparation: The analytical results of the emissions tests provide the mass of each analyte in the sample. For all test segments, the total mass of the analyte emitted is calculated by multiplying the mass of analyte in the sample times the ratio of the sample volume to the total stack gas volume during the test. The total stack gas volume is calculated from the measured stack gas average velocity and duct diameter. The total mass of analyte is then divided by the weight of the binder and/or the total weight of the casting used to provide emissions data in pounds of analyte per pound of binder and pounds of analyte per ton of metal.

8. Report Preparation and Review: The Preliminary Draft Report is reviewed by the Manager, Process Engineering, and the 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. Comments are incorporated into a 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 Standard Operating Procedures and. 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 measured emission results for Test FE in lbspounds per ton of metal used are presented in Table 3-1.

The Average measured emission results for Test FE in pounds per pound of binder are presented in Table 3.2

Table 3-3 contains average test process and source data.

Appendix B contains the detailed emissions results and Appendix C the detailed process and source data.

Figures 3-1 to 3-4 represent the results from Tables 3-1 and 3-2 in graphical form.

Method 25A charts are shown in Appendix D of this document.

Table 3-1 Average Emission Results for Test FE – Lb/Tn Metal

Analytes	30- Minute Cool	4-Hour Cool
TGOC as Propane	1.987	27.96
HC as Hexane	1.157	18.21
Sum of VOCs	0.2745	3.448
Sum of HAPs	0.2745	3.448
Sum of POMs	0.2003	2.481
Individual HAPs and VOCs		
2-Methylnaphthalene	0.0860	1.016
Phenol	0.0713	0.9601
Naphthalene	0.0706	0.9100
1-Methylnaphthalene	0.0437	0.5552
Formaldehyde	0.0029	0.0068
Other Analytes		
Carbon Dioxide	19.01	0.8625
Methane	0.0334	0.2751
Carbon Monoxide	ND	131.2

ND: Non Detect

Background Methane and Carbon Dioxide were found at 0.0362 and 18.77 Lb/Tn Metal respectively

Table 3-2 Average Emission Results for Test FE – Lb/Lb Binder

Analytes	30- Minute Cool	4-Hour Cool
TGOC as Propane	0.0102	0.1523
HC as Hexane	0.0061	0.0919
Sum of VOCs	0.0015	0.0174
Sum of HAPs	0.0015	0.0174
Sum of POMs	0.0011	0.0125
Individual HAPs and VOCs		
2-Methylnaphthalene	0.0005	0.0051
Phenol	0.0004	0.0048
Naphthalene	0.0004	0.0046
1-Methylnaphthalene	0.0002	0.0028
Formaldehyde	<0.0001	<0.0001
Other Analytes		
Carbon Dioxide	0.1000	0.6639
Methane	0.0002	0.0043
Carbon Monoxide	ND	0.0026

ND: Non Detect

Background Methane and Carbon Dioxide were found at 0.0002 and 0.0987 Lb/Lb Binder respectively

Table 3-3 Average Process and Source Data for Test FE

No-bake Mold Mix/Make/Cure	Average
Emission Test NO.	**FE001-7**
Sand dispensing rate, Lbs/15 sec	30
Binder Part1 + Part3 Dispensing Rate, gms/15 sec	101.3
Binder Part 2 Dispensing Rate, gms/15 sec	75.6
Calculated Standard % Binder	1.28
Calculated % Binder (BOS)	1.30
Calculated Mold weight, Lbs. (Note 4)	332.4
Calculated Total Binder Weight, Lbs.	4.26
1800 F LOI, % (Note 1)	1.09
Ambient Temperature, Deg F	67
Sand Temperature, Deg F	78
Dogbone Core 2 Hr. Tensile Strength	95
No-Bake Mold Pour and Cool	**Average**
Emission Test NO.	**FE001-7**
Pour Temperature, Deg F	1412
Pour Time, sec.	28
Splash Metal Weight, Lbs	3.1
Cast Weight (all metal inside mold), Lbs	43.9
Total Metal Weight, Lbs.	47.0
Sand Temperature at Pour, Deg F	65
Process Air Temperature in Hood, Deg F (Note 2)	87
Mold Age When Poured, Hrs.	19
Test Length, Hrs	1 or 4

Figure 3-1 Test FE Average Emissions Results – 30-Minute Cool - Lb/Tn Metal

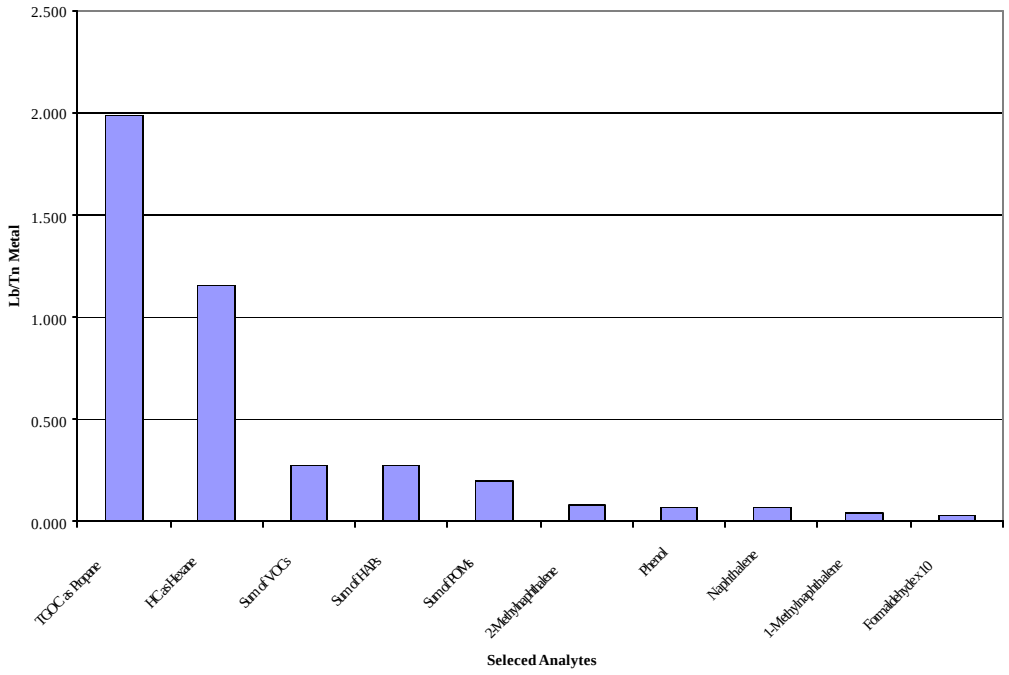


Figure 3-2 Test FE Average Emissions Results – 4-Hour Cool - Lb/Tn Metal

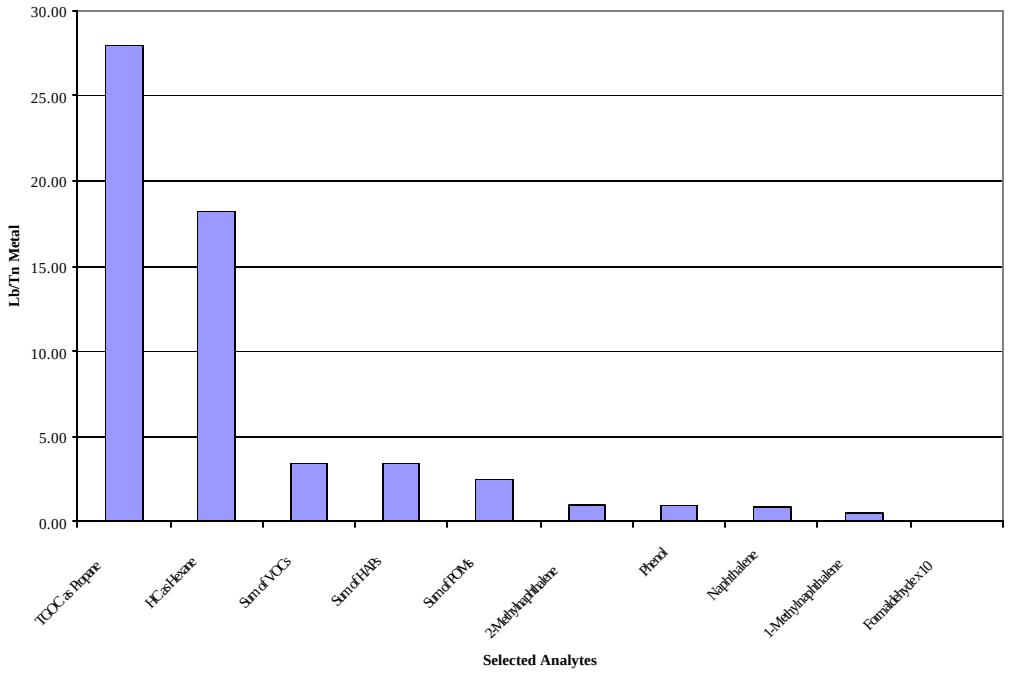


Figure 3-3 Test FE Average Emissions Results – 30 Minute Cool – Lbs/lb Binder

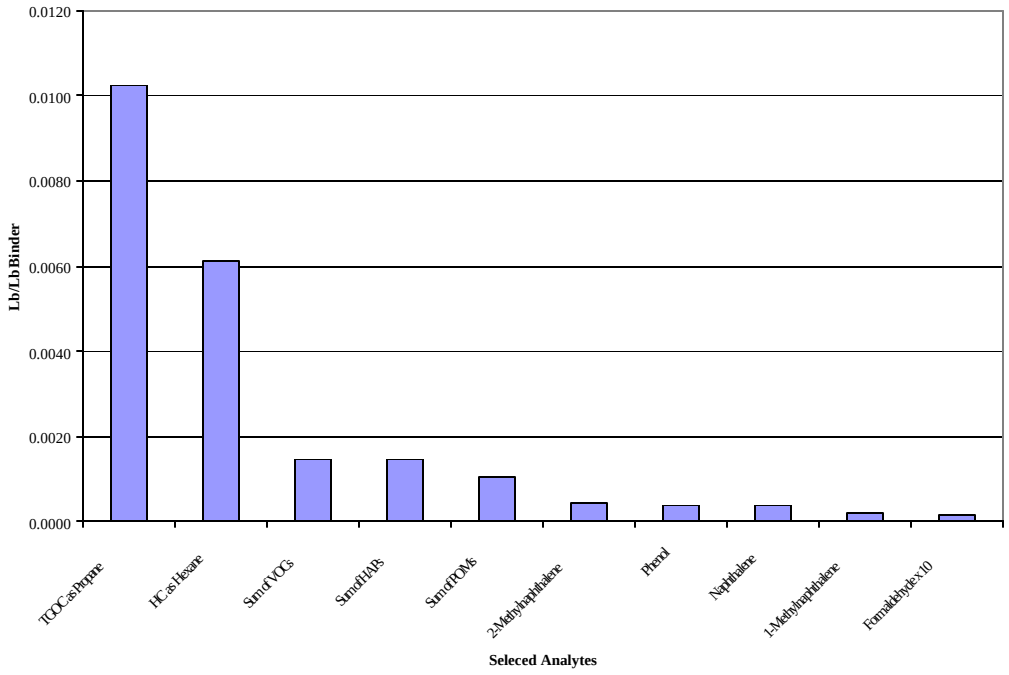
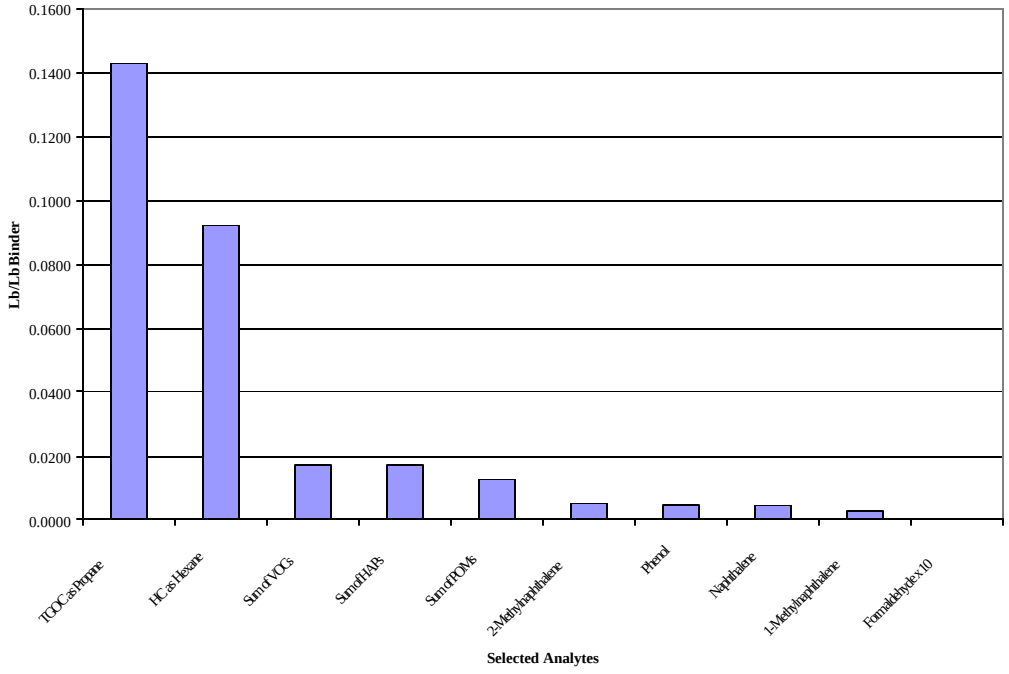


Figure 3-4 Test FE Average Emissions Results – 4-Hour Cool - Lbs/lb Binder



4.0 Discussion of Results

Volatile organic compound (VOC), hazardous air pollutant (HAP), and polycyclic organic material (POM) emissions were measured during No-Bake pouring and cooling activities associated with the use of phenolic urethane binder systems. A total of six pouring and cooling period sampling runs were performed for Test FE. Samples were collected over both thirty-minute and four-hour periods. The molds were not shaken out after sampling. The Method 25A charts are found in Appendix D of this report.

For both the thirty-minute and the four-hour cooling sampling periods, 2-methylnaphthalene was found to be approximately 30% of the total HAPs and VOCs. Phenol and naphthalene were found at approximately 26%, 1-methylnaphthalene at 16%, and formaldehyde at approximately 1%. See Appendix B for detailed results.

EPA Method 25A, TGOC (THC) 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 detection of relatively less volatile compounds and detects hydrocarbon compounds in the alkane range between C6 and C16, with results calibrated against a six-carbon alkane (hexane).

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APPENDIX A APPROVED TEST PLAN AND SAMPLE PLAN FOR TEST FE

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TECHNIKON TEST PLAN

> **CONTRACT NUMBER:** 1409 **TASK NUMBER:** 1.1.6 **Series:** FE

> **WORK ORDER NUMBER:** 1179

> **SAMPLE EVENTS:** 001 thru 006

> **SITE**: X **PRE-PRODUCTION** ___ **FOUNDRY**

> **TEST TYPE:** Product test Al No-bake pour & Cool

> **METAL TYPE:** A356 Aluminum

> **MOLD TYPE:** No bake 4-on gear sand mold made with HA International 7211 Resin, 7706 Co-reactant, and 17-727 Activator

> **NUMBER OF MOLDS**: 6

> **CORE TYPE**: None

> **TEST DATE:** **START**: 3 Apr 2003

FINISHED: 20 Apr 2003

TEST OBJECTIVES:

Measure selected HAP and VOC emissions using absorption tubes and TGOC using THC for pouring and cooling for four (4) contiguous hours.

VARIABLES:

The pattern will be the standard 4-on variable tooth gear mold. The no-bake mold binder will be 1.3% total binder (BOS) in 55/45 ratio of part I/part II and the activator is 10% of part 1. Molds shall be poured with A356 Aluminum at 1400 +/- 10^{o}F. The mold sand will be Amador 70 maintained at 80-85^{o}F during manufacture and pouring. The pouring hood shall be maintained at 85-90^{o}F.

BRIEF OVERVIEW:

No-bake molds are too strong to have a reproducible conventional shakeout process. No-bake molds test therefore will include only pouring and cooling. On this test 3 molds will be passed onto test FF after only 30 minutes of cooling. Three molds will be poured and cooled for 4 hours.

SPECIAL CONDITIONS:

All molds will set on a special frame in the hood to maintain height for ease of pouring.

Process Engineering Manager (Technikon)	**Date**
V.P. Measurement Technology (Technikon)	**Date**
V.P. Operations (Technikon)	**Date**
Test Design Committee Representative	**Date**
Emission Committee Representative	**Date**

Series FE

Alum No-bake Mold Pour & Cool WO 1179

A. Experiment: Alum No-bake mold emissions
   1. No-Bake sand mold:
      a) Amador 70 silica Sand
      b) HA International 7211 resin 7706 Co-reactant, & 17-727 activator.
   2. Metal: A356 aluminum.
   3. Three molds 30 minute cooling, 3 molds 4 hour cooling

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

B. Molds: Pouring basin made from Amador 70 sand and HA's No-bake binder.

C. Mold requirements:

   1. Make (6) molds, one each day, with the 4-on variable tooth gear pattern. Use 1.3% total binder. Pour three each with A356 aluminum at 1400+/-10^{o}F.

D. Phenolic urethane No-bake Mold Sand preparation:

   1. Each day 100^{o}F sand will be delivered from the Kloster sand heater/cooler.
   2. At the start of each day load the heated sand into the Kloster mixer sand storage hopper.
   3. The phenolic urethane no-bake sand shall be 1.3% total resin (BOS), Part I/Part II ratio 55/45, Part III at 10% of Part I except as noted other wise. The 10% Part III will be pre-mixed with the Part I.
   4. Calibrate the Kloster no-bake sand mixer to dispense 240 pounds/min more or less.
   5. Calibrate the resin pumps:
      a) Part I +Part III: Based on the actual measured sand dispensing rate calibrate the Part I + Part III resin to be 57.3% of 1.3% total binder.
      b) Part II: Based on the actual measured sand dispensing rate calibrate the Part II co-reactant to be 42.7% of 1.3% total binder.
      c) All calibrations to have a tolerance of +/- 1% of the calculated value.

   6. Run an 1800^{o}F core LOI on three (3) samples from each mold. Report the average value for each mold.

E. No-bake mold making:

   1. Inspect the mold boxes for cracks and other damage. Repair before use.

2. Prepare the mold flask and pattern with a light coating of Ashland Zipslip® IP 78. Allow to fully dry.
3. Install the 6 in sprue with the 11/16 collar as a choke.
4. Run a few pounds of waste sand then begin filling the box.
5. Manually spread the sand around the box as it is filling.
6. Start the table vibration when the flask is about 1/3 full.
7. Allow the vibrator to run an additional 10 seconds after the box is full.
8. Strike off the flask when it is full.
9. Make drag-molds first, allowing about 30 minutes to set, and then place them on a flat surface parting line up.
10. Remove the mold flask from the mold half by tapping lightly on the box with a rubber hammer and lifting the flask off the mold.
11. Make the cope molds, again allowing about 30 minutes to set. Un-box on a flat surface then immediately roll parting line down and close to the drag. Let harden overnight in the closed position.
12. Next morning separate, drill vents in riser tops, glue and re-close.
13. Secure the mold halves with two (2) steel straps, two (2) on either side of the pouring cup, with four (4) metal corner protectors each to hold the mold tightly closed.
14. Glue the pouring cup to the cope centered over the down sprue. Glue a second ½ pour cup on the top back half of the first to act as a splash guard
15. Transport the finished mold to heated core storage oven at 80-85°F to be used the next day.
16. Weigh and record the net weight of the closed mold.

F. Emission hood:

1. Loading.
   - **a)** Obtain a mold from the core storage oven.
   - **b)** Hoist the mold onto the shakeout deck with the pouring cup side toward the furnace using two nylon lifting slings.
   - **c)** Set the mold on the special no-bake stand. Load the special no-bake weight onto the mold.
   - **d)** Close, seal, and lock the emission hood.
   - **e)** Hoist the hood over the shakeout, first aligning the east side bottom with the two boots on the floor then letting the hood rock to the west to settle into the saddle on the exhaust pipe. The hood should set on four (4) ¼ inch thick plates to allow ambient air to enter the bottom of the hood.
   - **f)** Toggle clamp the flanges with the Teflon gasket in between.
   - **g)** Connect the heated air duct and adjust the heated air temperature so that the process temperature at mid height in the hood is 83-89°F.
   - **h)** Place the pouring plate on hood. The pouring plate may remain open so long as there is a negative draft into the pouring plate and also at the floor line.

2. Shakeout.

   - **a)** No shake out shall be used as the mold is too strong to break up in reasonable time.

b) Wait for the emission team to signal that they are finished sampling.
c) Remove the pouring plate.
d) Disconnect the heated air duct.
e) Open the hood by lifting it and allowing it to tilt to the east. When clear of the exhaust duct lift up to clear everything inside and set the hood aside.
f) Remove the castings.
g) Clean sand off of and out from under the shakeout.
h) Weigh and record cast metal weight.
i) Record all observations including the pattern configuration, organic binder content, mold weight, and poured metal weight on the melt log.

3. Cooling

a) Allow to cool as prescribed in the sample plan.

G. Melting:

1. Initial charge:

a) Use the 75 KW Ajax induction furnace or the Thermtronics 600 # electric resistance furnace.
b) Charge the furnace with A-356/357 aluminum sows.
c) No other alloys need to be added for emission testing purposes.
d) Set the furnace temperature set point to 1200^{o}F.
e) When the metal is liquefied, about 1050^{o}F, add the balance of A-356/357 aluminum sows until all is melted and the temperature has reached 1250-1300^{o}F.
f) Slag the furnace and cover it.
g) Hold the furnace at 1250-1300^{o}F until near ready to tap.
h) When ready to tap adjust the temperature to 1500-1525^{o}F and slag the furnace.
i) Record all metallic additions to the furnace, tap temperature, and pour temperature. Record all furnace activities with the associated time.

2. Back charging.

a) Back charging may be necessary because of the pour weight of about 45 pounds. If additional aluminum is desired back charge with A-356/357 Aluminum sows or scrap aluminum of the same source.
b) Follow the above steps beginning with G.1.e

3. Emptying the furnace.

a) Pig the extra metal into steel sow molds away from the test hood.
b) You need not wait for emission testing to be concluded to pig the metal.

H. Pouring:

1. Preheat the ladle.

a) Tap 150 pounds more or less of 1510^{o}F +/- 10^{o}F metal into the cold ladle.
b) Cover the ladle to conserve heat.
c) Move the ladle to the pour position, open the emission hood pour door and wait until the metal temperature reaches 1410+/- 10^{o}F.
d) Commence pouring keeping the sprue full. Target pour time is 20-30 seconds.

Steven Knight
Mgr. Process Engineering

PRE-PRODUCTION FE SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 1											**30 min.**
5/6/2003											**Pour and Cooling**
THC	FE00101	X									TOTAL
Gas, CO, CO2	FE00102		1						60	1	Tedlar Bag
Gas, CO, CO2	FE00103				1				0		Tedlar Bag
Moisture	FE001		1						100	2	Moisture
TO-11	FE00104		1						400	3	DNPH SKC 226-119
TO-11	FE00105			1					400	4	DNPH SKC 226-119
TO-11	FE00106				1				0		DNPH SKC 226-119
NIOSH 1500	FE00107		1						1000	5	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	FE00108			1					1000	6	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	FE00109				1				0		100/50 mg Charcoal (SKC 226-01)
NIOSH 2002	FE00110		1						1000	7	150/75 mg Silica Gel (SKC 226-10)
NIOSH 2002	FE00111			1					1000	8	150/75 mg Silica Gel (SKC 226-10)
NIOSH 2002	FE00112				1				0		150/75 mg Silica Gel (SKC 226-10)
										9	
										10	
										11	
										12	
									7800	13	Excess

RUN 2											**30 min.**
5/7/2003											**Pour and Cooling**
THC	FE00201	X									TOTAL
Gas, CO, CO2	FE00202		1						60	1	Tedlar Bag
Moisture	FE002		1						100	2	Moisture
TO-11	FE00203		1						400	3	DNPH SKC 226-119
										4	
NIOSH 1500	FE00204		1						1000	5	100/50 mg Charcoal (SKC 226-01)
										6	
NIOSH 2002	FE00205		1						1000	7	150/75 mg Silica Gel (SKC 226-10)
										8	
										9	
										10	
										11	
										12	
									7800	13	Excess

PRE-PRODUCTION FE SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 3											**30 min.**
5/7/2003											**Pour and Cooling**
THC	FE00301	X									TOTAL
Gas, CO, CO2	FE00302		1						60	1	Tedlar Bag
Moisture	FE003		1						100	**2**	Moisture
TO-11	FE00303		1						400	3	DNPH SKC 226-119
										4	
NIOSH 1500	FE00304		1						1000	5	100/50 mg Charcoal (SKC 226-01)
										6	
NIOSH 2002	FE00305		1						1000	7	150/75 mg Silica Gel (SKC 226-10)
										8	
										9	
										10	
										11	
										12	
									7800	13	Excess

RUN 4											**4 Hour**
4/15/2003											**Pour and Cooling**
THC	FE00401	X									TOTAL
Gas, CO, CO2	FE00402		1						60	1	Tedlar Bag - Hour 1
Moisture	FE004		1						100	2	Moisture
TO-11	FE00403		1						400	3	DNPH SKC 226-119
TO-11	FE00404			1					400	4	DNPH SKC 226-119
NIOSH 1500	FE00405		1						1000	5	100/50 mg Charcoal (SKC 226-01)
NIOSH 1500	FE00406			1					1000	6	100/50 mg Charcoal (SKC 226-01)
NIOSH 2002	FE00407		1						1000	7	150/75 mg Silica Gel (SKC 226-10)
NIOSH 2002	FE00408			1					1000	8	150/75 mg Silica Gel (SKC 226-10)
										9	
										10	
										11	
										12	
									7800	13	Excess
Gas, CO, CO2	FE00409		1						60	1	Tedlar Bag - Hour 2
Gas, CO, CO2	FE00410		1						60	1	Tedlar Bag - Hour 3
Gas, CO, CO2	FE00411		1						60	1	Tedlar Bag - Hour 4

PRE-PRODUCTION FE SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 5											**4 Hour**
4/17/2003											**Pour and Cooling**
THC	FE00501	X									TOTAL
Gas, CO, CO2	FE00502		1						60	1	Tedlar Bag - Hour 1
Moisture	FE005		1						100	2	Moisture
TO-11	FE00503		1						400	3	DNPH SKC 226-119
										4	
NIOSH 1500	FE00504		1						1000	5	100/50 mg Charcoal (SKC 226-01)
										6	
NIOSH 2002	FE00505		1						1000	7	150/75 mg Silica Gel (SKC 226-10)
										8	
										9	
										10	
										11	
										12	
									7800	13	Excess
Gas, CO, CO2	FE00506		1						60	1	Tedlar Bag - Hour 2
Gas, CO, CO2	FE00507		1						60	1	Tedlar Bag - Hour 3
Gas, CO, CO2	FE00508		1						60	1	Tedlar Bag - Hour 4

RUN 6											**4 Hour**
4/16/2003											**Pour and Cooling**
THC	FE00601	X									TOTAL
Gas, CO, CO2	FE00602		1						60	1	Tedlar Bag - Hour 1
Moisture	FE006		1						100	2	Moisture
TO-11	FE00603		1						400	3	DNPH SKC 226-119
										4	
NIOSH 1500	FE00604		1						1000	5	100/50 mg Charcoal (SKC 226-01)
										6	
NIOSH 2002	FE00605		1						1000	7	150/75 mg Silica Gel (SKC 226-10)
										8	
										9	
										10	
										11	
										12	
									7800	13	Excess
Gas, CO, CO2	FE00606		1						60	1	Tedlar Bag - Hour 2
Gas, CO, CO2	FE00607		1						60	1	Tedlar Bag - Hour 3
Gas, CO, CO2	FE00608		1						60	1	Tedlar Bag - Hour 4

PRE-PRODUCTION FE SERIES SAMPLE PLAN

Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
RUN 7											**4 Hour**
4/29/2003											**Pour and Cooling**
THC	FE00701	X									TOTAL
Gas, CO, CO2	FE00702		1						60	1	Tedlar Bag - Hour 1
Moisture	FE007		1						100	2	Moisture
TO-11	FE00703		1						400	3	DNPH SKC 226-119
										4	
NIOSH 1500	FE00704		1						1000	5	100/50 mg Charcoal (SKC 226-01)
										6	
NIOSH 2002	FE00705		1						1000	7	150/75 mg Silica Gel (SKC 226-10)
										8	
										9	
										10	
										11	
										12	
									7800	13	Excess
Gas, CO, CO2	FE00706		1						60	1	Tedlar Bag - Hour 2
Gas, CO, CO2	FE00707		1						60	1	Tedlar Bag - Hour 3
Gas, CO, CO2	FE00708		1						60	1	Tedlar Bag - Hour 4

APPENDIX B DETAILED TEST DATA FOR TESTS FE

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Individual Results for Test FE– Lbs/Lb Binder

30-Minute Pour and Cool

HAPs	POMs	Compound/Sample Number	FE001	FE002	FE003	Average	STDEV
		Test Dates	**5/26/2003**	**5/7/2003**	**5/7/2003**		
		TGOC as Propane	1.05E-02	1.24E-02	7.81E-03	1.02E-02	2.31E-03
		HC as Hexane	5.50E-03	6.77E-03	I	6.13E-03	8.97E-04
		Sum of VOCs	1.30E-03	1.61E-03	I	1.46E-03	2.15E-04
		Sum of HAPs	1.30E-03	1.61E-03	I	1.46E-03	2.15E-04
		Sum of POMs	9.45E-04	1.18E-03	I	1.06E-03	1.65E-04
		Individual HAPs and VOCs					
x	x	**2-Methylnaphthalene**	4.04E-04	5.08E-04	I	4.56E-04	7.37E-05
x		**Phenol**	3.45E-04	4.11E-04	I	3.78E-04	4.63E-05
x	x	**Naphthalene**	3.36E-04	4.12E-04	I	3.74E-04	5.42E-05
x	x	**1-Methylnaphthalene**	2.05E-04	2.58E-04	I	2.32E-04	3.74E-05
x		**Formaldehyde**	1.33E-05	1.76E-05	I	1.55E-05	3.05E-06
		Other VOCs					
		Carbon Dioxide	1.01E-01	1.00E-01	9.87E-02	1.00E-01	1.08E-03
		Methane	1.43E-04	1.96E-04	1.89E-04	1.76E-04	2.85E-05
		Carbon Monoxide	ND	ND	ND	ND	NA
		Ethane	ND	ND	ND	ND	NA
		Propane	ND	ND	ND	ND	NA
		Isobutane	ND	ND	ND	ND	NA
		Butane	ND	ND	ND	ND	NA
		Neopentane	ND	ND	ND	ND	NA
		Isopentane	ND	ND	ND	ND	NA
		Pentane	ND	ND	ND	ND	NA

I: Data rejected based on data validation considerations.

ND: Non Detect; **NA:** Not Applicable

4-Hour Pour and Cool

HAPs	POMs	Compound/Sample Number	FE004	FE006	FE007	Average	STDEV
		Test Dates	**4/15/2003**	**4/17/2003**	**4/29/2003**		
		TGOC as Propane	1.35E-01	1.65E-01	1.57E-01	1.52E-01	1.55E-02
		HC as Hexane	8.98E-02	9.67E-02	8.93E-02	9.19E-02	4.14E-03
		Sum of VOCs	1.68E-02	1.89E-02	1.65E-02	1.74E-02	1.28E-03
		Sum of HAPs	1.68E-02	1.89E-02	1.65E-02	1.74E-02	1.28E-03
		Sum of POMs	1.21E-02	1.37E-02	1.18E-02	1.25E-02	9.90E-04
		Individual HAPs and VOCs					
x	x	**2-Methylnaphthalene**	4.95E-03	5.61E-03	4.83E-03	5.13E-03	4.19E-04
x		**Phenol**	4.72E-03	5.17E-03	4.65E-03	4.85E-03	2.83E-04
x	x	**Naphthalene**	4.45E-03	4.98E-03	4.35E-03	4.59E-03	3.37E-04
x	x	**1-Methylnaphthalene**	2.69E-03	3.07E-03	2.65E-03	2.80E-03	2.34E-04
x		**Formaldehyde**	2.92E-05	3.93E-05	3.37E-05	3.41E-05	5.06E-06
		Other VOCs					
		Carbon Dioxide	6.63E-01	5.59E-01	7.69E-01	6.64E-01	1.05E-01
		Carbon Monoxide	4.25E-03	7.65E-03	1.08E-03	4.33E-03	3.29E-03
		Methane	4.38E-03	1.71E-03	1.77E-03	2.62E-03	1.52E-03
		Ethane	ND	ND	ND	ND	NA
		Propane	ND	ND	ND	ND	NA
		Isobutane	ND	ND	ND	ND	NA
		Butane	ND	ND	ND	ND	NA
		Neopentane	ND	ND	ND	ND	NA
		Isopentane	ND	ND	ND	ND	NA
		Pentane	ND	ND	ND	ND	NA

ND: Non Detect; **NA:** Not Applicable

Individual Results for Test FE– Lb/Tn Metal

30-Minute Pour and Cool

HAPs	POMs	Compound/Sample Number	FE001	FE002	FE003	Average	STDEV
		Test Dates	**5/26/2003**	**5/7/2003**	**5/7/2003**		
		TGOC as Propane	1.85E+00	2.13E+00	I	1.99E+00	1.96E-01
		HC as Hexane	1.07E+00	1.25E+00	I	1.16E+00	1.30E-01
		Sum of VOCs	2.52E-01	2.97E-01	I	2.75E-01	3.13E-02
		Sum of HAPs	2.52E-01	2.97E-01	I	2.75E-01	3.13E-02
		Sum of POMs	1.83E-01	2.18E-01	I	2.00E-01	2.45E-02
		Individual HAPs and VOCs					
x	z	**2-Methylnaphthalene**	7.82E-02	9.38E-02	I	8.60E-02	1.10E-02
x		**Phenol**	6.68E-02	7.58E-02	I	7.13E-02	6.35E-03
x	z	**Naphthalene**	6.50E-02	7.61E-02	I	7.06E-02	7.85E-03
x	z	**1-Methylnaphthalene**	3.97E-02	4.76E-02	I	4.37E-02	5.60E-03
x		**Formaldehyde**	2.58E-03	3.25E-03	I	2.91E-03	4.78E-04
		Other Analytes					
		Carbon Dioxide	1.95E+01	1.85E+01	1.90E+01	1.90E+01	5.04E-01
		Methane	2.77E-02	3.61E-02	3.62E-02	3.34E-02	4.90E-03
		Carbon Monoxide	ND	ND	ND	ND	NA
		Ethane	ND	ND	ND	ND	NA
		Propane	ND	ND	ND	ND	NA
		Isobutane	ND	ND	ND	ND	NA
		Butane	ND	ND	ND	ND	NA
		Neopentane	ND	ND	ND	ND	NA
		Isopentane	ND	ND	ND	ND	NA
		Pentane	ND	ND	ND	ND	NA

I: Data rejected based on data validation considerations.
ND: Non Detect; **NA:** Not Applicable

4-Hour Pour and Cool

HAPs	POMs	Compound/Sample Number	FE004	FE006	FE007	Average	STDEV
		Test Dates	**4/15/2003**	**4/17/2003**	**4/29/2003**		
		TGOC as Propane	2.58E+01	3.01E+01	2.79E+01	2.80E+01	2.13E+00
		HC as Hexane	1.80E+01	1.93E+01	1.74E+01	1.82E+01	9.49E-01
		Sum of VOCs	3.37E+00	3.76E+00	3.22E+00	3.45E+00	2.78E-01
		Sum of HAPs	3.37E+00	3.76E+00	3.22E+00	3.45E+00	2.78E-01
		Sum of POMs	2.42E+00	2.72E+00	2.31E+00	2.48E+00	2.14E-01
		Individual HAPs and VOCs					
x	z	**2-Methylnaphthalene**	9.90E-01	1.12E+00	9.42E-01	1.02E+00	9.05E-02
x		**Phenol**	9.45E-01	1.03E+00	9.06E-01	9.60E-01	6.33E-02
x	z	**Naphthalene**	8.90E-01	9.91E-01	8.49E-01	9.10E-01	7.35E-02
x	z	**1-Methylnaphthalene**	5.38E-01	6.12E-01	5.16E-01	5.55E-01	5.02E-02
x		**Formaldehyde**	5.85E-03	7.83E-03	6.57E-03	6.75E-03	1.00E-03
		Other Analytes					
		Carbon Monoxide	8.48E-01	1.52E+00	2.16E-01	8.63E-01	6.54E-01
		Methane	2.60E-01	2.79E-01	2.86E-01	2.75E-01	1.33E-02
		Carbon Dioxide	1.32E+02	1.11E+02	1.50E+02	1.31E+02	1.97E+01
		Ethane	ND	ND	ND	ND	NA
		Propane	ND	ND	ND	ND	NA
		Isobutane	ND	ND	ND	ND	NA
		Butane	ND	ND	ND	ND	NA
		Neopentane	ND	ND	ND	ND	NA
		Isopentane	ND	ND	ND	ND	NA
		Pentane	ND	ND	ND	ND	NA

ND: Non Detect; **NA:** Not Applicable

Test FE Quantitation Limits

Analytes	Lb/Tn Metal	Lb/Lb Binder
HC as Hexane	1.03E-02	5.36E-05
1-Methylnaphthalene	1.03E-02	5.36E-05
2-Methylnaphthalene	1.03E-02	5.36E-05
Formaldehyde	7.06E-04	3.68E-06
Naphthalene	1.03E-02	5.36E-05
Phenol	5.13E-03	2.67E-05
Carbon Monoxide	7.67E-01	3.93E-03
Methane	4.38E-02	3.93E-04
Carbon Dioxide	1.20E+00	3.93E-03
Ethane	8.21E-01	3.93E-03
Propane	1.20E+00	3.93E-03
Isobutane	1.59E+00	3.93E-03
Butane	1.59E+00	3.93E-03
Neopentane	1.97E+00	3.93E-03
Isopentane	1.97E+00	3.93E-03
Pentane	1.97E+00	3.93E-03

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APPENDIX C DETAILED PROCESS AND SOURCE DATA FOR TEST FE

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Test FE Process and Source Data – Mix/Make/Cure & Storage

NO-bake Mold PCS Test

No-bake Mold Mix/Make/Cure	1	2	3	4	5	6	7	Average
Date	**5/5/2003**	**5/6/2003**	**5/6/2003**	**4/15/2003**	**4/16/2003**	**4/16/2003**	**4/29/2003**	
Emission test no.	**FE001**	**FE002**	**FE003**	**FE004**	**FE005**	**FE006**	**FE007**	
Sand dispensing rate, Lbs/15 sec	30	30	30	30	30	30	30	**30**
Binder Part1 + Part3 dispensing rate, gms/15 sec	101.5	101.2	101.2	101.4	101.2	101.2	101.1	**101.3**
Binder Part 2 dispensing rate, gms/15 sec	75.5	75.6	75.6	75.3	75.9	75.9	75.5	**75.6**
Calculated standard % binder	1.28	1.28	1.28	1.28	1.28	1.28	1.28	**1.28**
Calculated % Binder (BOS)	1.30	1.30	1.30	1.30	1.30	1.30	1.30	**1.30**
Calculated Mold weight, Lbs. Note 4	332.4	327.5	330.0	340.0	N/D	337.5	327.0	**332.4**
Calculated Total Binder weight, Lbs.	4.26	4.20	4.23	4.35	N/D	4.33	4.19	**4.26**
1800 F LOI, % (note 1)	1.14	1.07	1.09	1.00	1.13	1.01	1.18	**1.09**
Ambient temperature, Deg F	63	70	72	65	65	69	65	**67**
Sand temperature, Deg F	77	77	78	76	84	80	77	**78**
Dogbone Core 2 hr. tensile strength	114	56	87	127	48	105	128	**95**

NO-bake Mold Pour and Cool								Average
Date	**5/6/2003**	**5/6/2003**	**5/6/2003**	**4/15/2003**	**4/16/2003**	**4/16/2003**	**4/29/2003**	
Emission test no.	**FE001**	**FE002**	**FE003**	**FE004**	**FE005**	**FE006**	**FE007**	
Pour temperature, F	1406	1419	1403	1417	1404	1413	1419	**1412**
Pour Time, sec.	20	29	29	32	29	27	32	**28**
Splash Metal Weight, Lbs	4.5	3.5	0.5	2.0	N/D	4.0	4.0	**3.1**
Cast Weight (all metal inside mold), Lbs	44.0	45.5	44.0	43.5	N/D	43.5	43.0	**43.9**
Total metal weight, Lbs.	48.5	49.0	44.5	45.5	N/D	47.5	47.0	**47.0**
Sand Temperature at pour, F	N/D	N/D	N/D	N/D	N/D	N/D	65	**65**
Process air temperature in hood, F Note 2	87	88	88	88	85	89	86	**87**
Mold age when poured, hours	22	19	19	1	25	28	20	**19**
Test length, hrs	0.5	0.5	0.5	4.0	4.0	4.0	4.0	**NA**

Note 3

Note 1: 1800 F LOI is the net sample weight difference when combusted at 1800 F for 2 hours and includes decomposition of carbonates that originate in the source sand.

Note 2: Process air in the hood is ambient air infiltrated under the hood and controlled heated air from an oven blended at the base of the hood and measured at the level of the mold.

Note 3: FE005 invalidated by emission group

Note 4: FE001 Estimated weight as average of all others. Mold destroyed in engineering trial

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APPENDIX D METHOD 25A CHARTS

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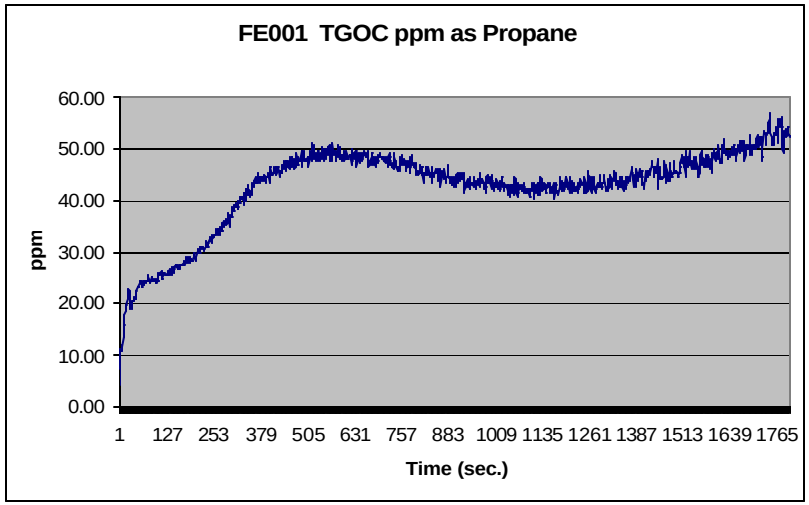
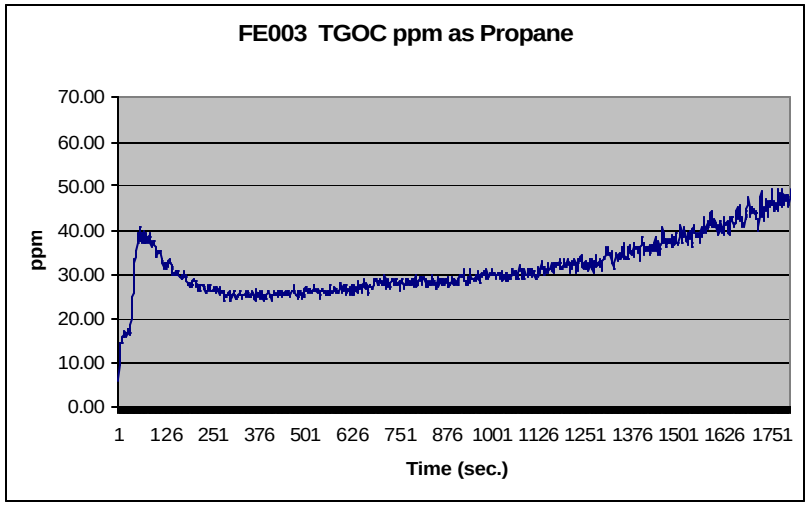
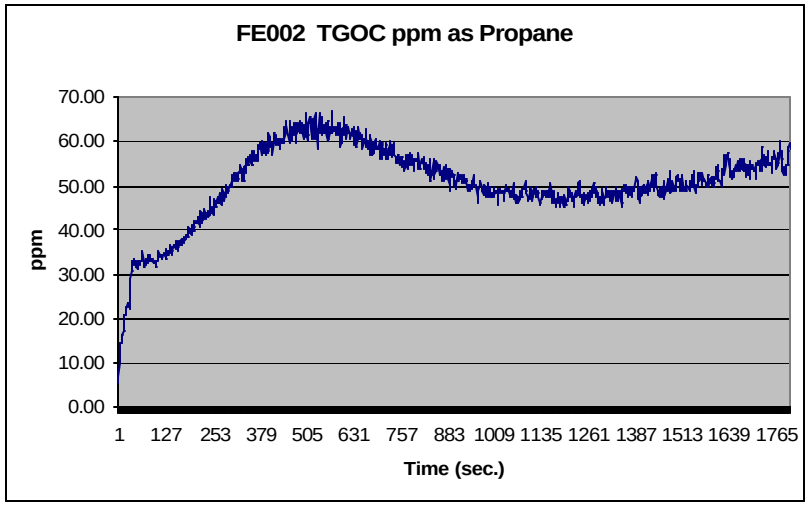
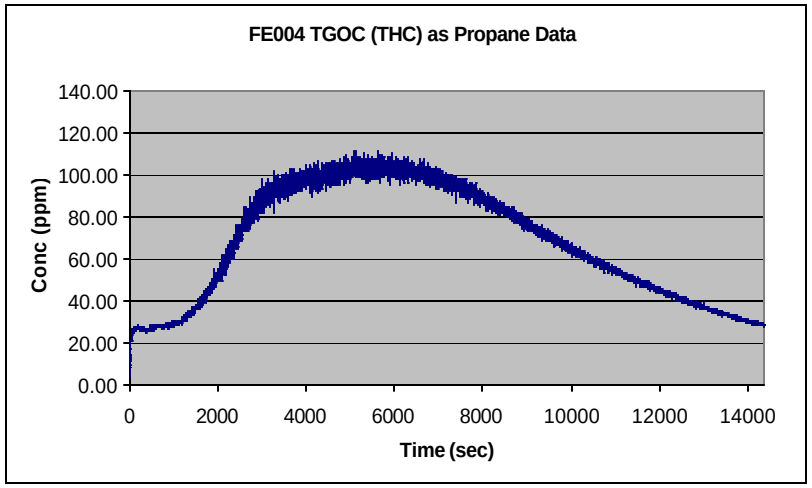
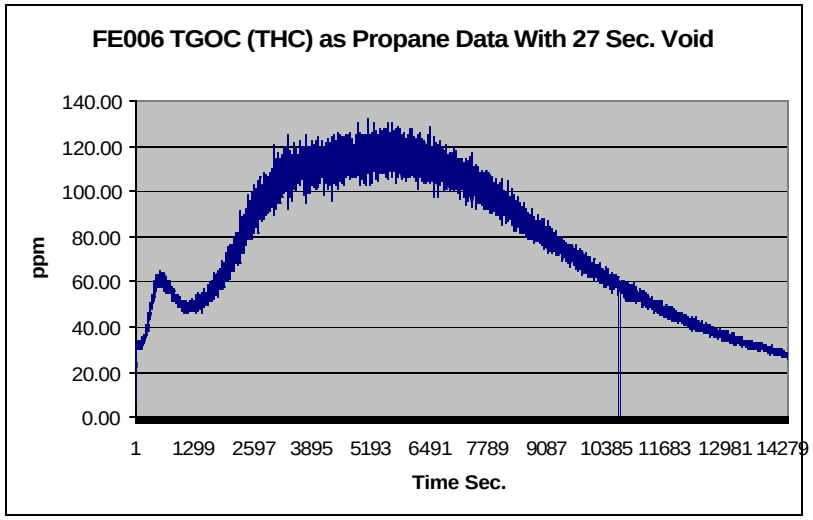
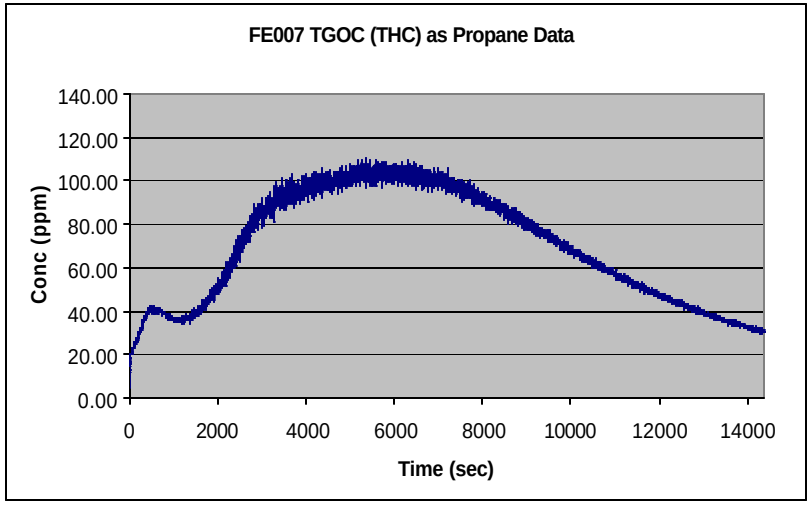

FE001 TGOC ppm as Propane
ppm
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1 127 253 379 505 631 757 883 1009 1135 1261 1387 1513 1639 1765
Time (sec.)


FE003 TGOC ppm as Propane
ppm
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1 126 251 376 501 626 751 876 1001 1126 1251 1376 1501 1626 1751
Time (sec.)


FE002 TGOC ppm as Propane
ppm
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1 127 253 379 505 631 757 883 1009 1135 1261 1387 1513 1639 1765
Time (sec.)


FE004 TGOC (THC) as Propane Data
Conc (ppm)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0 2000 4000 6000 8000 10000 12000 14000
Time (sec)


FE006 TGOC (THC) as Propane Data With 27 Sec. Void
ppm
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1
1299
2597
3895
5193
6491
7789
9087
10385
11683
12981
14279
Time Sec.


FE007 TGOC (THC) as Propane Data
Conc (ppm)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
2000
4000
6000
8000
10000
12000
14000
Time (sec)

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
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