Casting Emission Reduction Program

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FY 2003 Tasks

The Effect of Mold Surface Air Velocity On No-Bake PCS Emissions

Technikon # 1410-151 FM

10 December 2003

(This document revised for public distribution)

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The Effect of Mold Surface Air Velocity On No-Bake PCS Emissions

Technikon Test # 1410-151 FM

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

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President:	*// Original Signed //* William Walden	Date

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

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Executive Summary

The objective of this test was to determine the impact of varying the velocity of air across the mold surface on the emissions from pouring, cooling, and shakeout of No-Bake molds poured with iron. The molds were prepared from a standard phenolic urethane No-Bake system. Three average surface velocities were evaluated each in triplicate. Air velocities were documented at points approximately 0.5 inches from the vertical mold surface on each mold side. The test protocol was designed to evaluate the hypothesis that higher air velocities at the mold surface would result in higher VOC emissions.

The testing was conducted at the Technikon Research Foundry, which is a simple, general purpose manual foundry that was adapted and instrumented to allow the collection of detailed organic emission measurements, using methods based on US EPA air testing protocols. For this test series, the only source of organic matter present in the molds was the binder used to make the mold.

Measurements were performed on discrete mold packages under tightly controlled conditions not practical in a commercial foundry. The testing involved continuous monitoring of the stack exhaust during each test run that included the mold pouring, cooling, and shakeout periods. The process parameters measured included: the weight of the sand used in the mold, the weight of the binders used to make the mold, the temperature of the metal poured, the weight of the casting, and the % Loss on Ignition (LOI) for the sand binder.

US EPA Method 25A, Total Gaseous Organic Concentration (TGOC), was used to measure the air borne emissions in all segments of the test and the results are reported in both pounds of emissions per ton of metal and pounds of emissions per pound of binder.

The results of the testing are shown in the following table, reported as lbs/tn of metal and lbs/lb of binder. The data show that the emissions do not increase with increased air velocity. The data actually suggest that the VOC emissions may decrease with increased surface air velocity. The approved test protocol that specified three (3) molds at each velocity point did not provide enough data to determine statistically whether the variation in emissions was due to the variation in surface air velocity or due to the inherent sampling and analysis uncertainty.

Analytes	51 ft/min Average Velocity	78 ft/min Average Velocity	128 ft/min Average Velocity
TGOC as Propane (Lb/Tn Metal)	9.492	8.836	7.454
TGOC as Propane (Lb/Lb Binder)	0.1585	0.1421	0.1253

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1.0 Introduction

1.1 Background

Technikon LLC is a privately held contract research organization located in McClellan, California, a suburb of Sacramento. Technikon offers emissions research services to industrial and government clients specializing in the metal casting and mobile emissions areas. Technikon operates the Casting Emission Reduction Program (CERP). CERP is a Cooperative initiative between the Department of Defense (US Army) and the United States Council for Automotive Research (USCAR). The parties to the CERP Cooperative Research and Development Agreement (CRADA) include The Environmental Research Consortium (ERC), a Michigan partnership of DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation; the U.S. Army Tank-automotive and Armaments Command, Armament Research, Development, and Engineering Center (TACOM-ARDEC), a laboratory of the United States Army; the American Foundry Society (AFS); and the Casting Industry Suppliers Association (CISA). Other technical partners directly supporting the project include: The US Environmental Protection Agency (US EPA); The California Air Resources Board (CARB) and individual foundries and industry suppliers.

CERP's purpose is to evaluate alternative casting materials and processes that are designed to reduce air emissions and/or produce more efficient casting processes

1.2 CERP Objectives

The primary objective of CERP is to evaluate the impact of new materials, equipment, and processes on airborne emissions from the production of metal castings. To accomplish this objective, the Technikon facility has been created to evaluate alternate materials and production processes designed to achieve significant airborne emission reductions, especially for organic Hazardous Air Pollutants (HAPs). HAP emissions reduction from the alternative materials, equipment and production processes is expressed as a comparison to similar emissions from a baseline or reference test. 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 specifically designed to facilitate the collection and evaluation of airborne emissions, and associated process data. Candidate materials and/or processes are screened for emission reductions in the Pre-production Foundry and then further evaluated in the Production Foundry. The data collected during the various testing projects are evaluated to determine the impact of the alternate materials and/or processes on airborne emissions as well as on the quality and economics of casting and core manufacture. These alternate materials, equipment, and processes may need to be further adapted and defined so that they will integrate into current commercial green sand casting facilities smoothly and with minimal capital expenditure.

Pre-production testing is conducted in order to evaluate the impact on air emissions from a proposed alternative material, equipment or process. The Pre-Production Foundry is a simple, general-purpose mechanized foundry, which was adapted and instrumented to allow the collection of detailed emission measurements, using methods based on USEPA air testing protocols. Measurements are taken during pouring, casting cooling, and shakeout processes performed on discrete mold and/or core packages under tightly controlled conditions not feasible in a commercial foundry.

Alternative materials, equipment and processes that, during their testing in the Pre-Production Foundry, demonstrate significant air emission reduction potential and preserve casting quality parameters are further evaluated in the Production Foundry. The Production Foundry's design as a basic green sand foundry was deliberately chosen so that whatever is tested in this facility could be easily converted for use in existing mechanized commercial foundries. The Production Foundry emulates an automotive foundry in the type and size of equipment, materials, and processes used. A single cavity automotive I-4 engine block mold is used to further evaluate materials, equipment, and processes in a continuous real-world production-like environment. The Production Foundry provides simultaneous, detailed, individual emission measurements, according to methods based on US EPA air testing protocols, of the melting, pouring, sand preparation, mold making, and core making processes. The Production Foundry is instrumented so that process data on all activities of the metal casting process can be simultaneously and continuously collected in order to complete an economic impact evaluation of the prospective emission reducing strategy. Castings are randomly selected to evaluate the impact of the alternate material, equipment, or process on the quality of the casting.

Test results for a particular process or product may not be the same from both foundries due to differences in the testing process. The Pre-production Foundry is designed to screen new products, processes, or equipment, whereas the Production Foundry is designed to test the effect of the product, process, or equipment in a continuous production-like environment.

The results of the testing conducted at both the Production and Pre-production Foundries are not suitable for use as general emission factors. The specific materials used (gray iron from an electric melt furnace, greensand with seacoal, and a cold box core with a relatively old resin binding system); the specific castings produced; the specific production processes employed (a stationary hand-poured mold in the Pre-production Foundry and an impact mold line in the Production Foundry); and the specific testing conditions (relatively low stack velocity, long sampling times, high capture rates, and combined emissions from pouring, cooling and shakeout processes at the Production Foundry) produce emission results unique to the materials, castings, casting processes and measurement conditions used. The data produced are intended to demonstrate the relative emission reductions from the use of alternative materials, equipment and processes, and not the absolute emission levels that would be experienced in commercial foundries. A number of process parameters such as casting surface area, sand to metal ratios, pouring temperatures, stack flow rates, LOI levels, seacoal and resin contents, and the type of foundry (Cope & Drag versus Disa for example) can have a significant impact on actual emission levels.

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/Carver to produce dogbone tensile test specimens.

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 the variability of emissions from the No-Bake mold making, pouring, and cooling processes. Section 2 of this report includes a summary of the methodologies used for data collection and analysis, emission calculations, QA/QC procedures, and data management and reduction methods. Section 3 of this report contains the summarized test results and Section 4 contains a discussion of the results. Detailed emissions and process data are included in the Appendices.

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

1.4 Specific Test Plans and Objectives

This report contains the results of testing performed to assess the emissions impact of varying the exhaust velocity. A summary of the test plan for the individual test series is shown in Table 1-1.

Table 1-1 Test Plan Summary

	Test Plan
Type of Process Tested	Impact of Air Velocity Across the Mold Surface on No-Bake Air Emissions
Test Plan Number	1410 151 FM
Binder System	HA Int’l 20-665/23-635/17-727
Metal Poured	Iron
Casting Type	4-on Gear
Number of Molds Poured	9
Test Dates	9/17/03 > 9/24/03
Emissions Measured	TGOC as Propane
Process Parameters Measured	Total Casting, Mold, and Binder Weights; Metallurgical data, % LOI; Stack Temperature, Moisture Content, Sand Temperature, Pressure, Air Velocity Around Mold, and Volumetric Flow Rate

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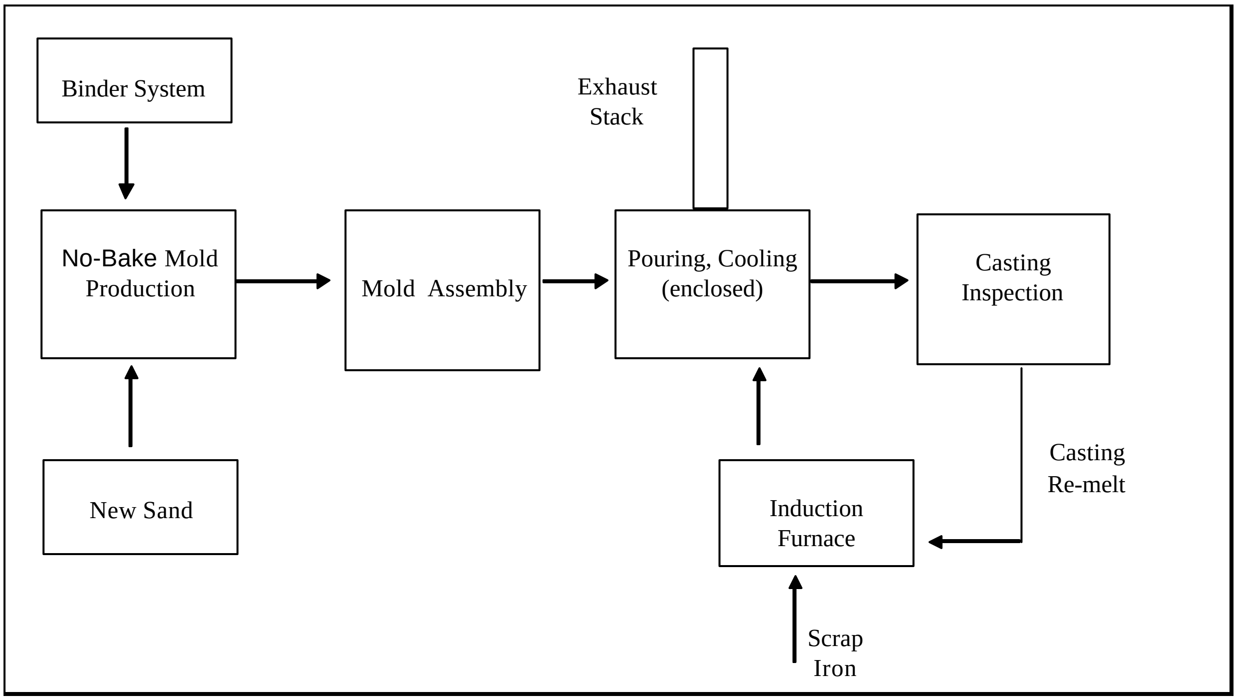
2.0 Test Methodology

2.1 Description of Process and Testing Equipment

Figure 2-1 Pre-Production Foundry No-Bake Process Flowchart



2.2 Description of Testing Program

The process parameters not being evaluated were maintained within prescribed ranges in order to ensure the reproducibility of the tests. Emissions were measured according to US EPA Method 25A, Total Gaseous Organic Concentration, calibrated with propane.

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

1. **Mold Preparation:** The No-Bake mold sand was prepared in a Kloster paddled turbine sand mixer to a calibrated standard composition using Lakesand preheated to 85 to 95 ^{o}F. The sand was placed in 24 x 25 x 5 flasks and vibrated from the time the flasks were half full until 5 seconds after they were full. Sand and binder calibration and mold weight was recorded on the Process Data Summary Sheet.

2. **Metal Preparation:** Iron was melted in a 1000 lb. Ajax induction furnace. The amount of metal was determined from the poured weight of the casting and the number of molds to be poured. The weight of metal poured into each mold was recorded on the Process Data Summary Sheet.

3. **Individual Sampling Events:** The mold packages were placed in an enclosed test stand. The molten metal was poured through an opening in the top of the enclosure. Continuous air sampling was conducted during the seventy-five minute pouring, cooling, and shakeout process at the three stack velocities, and triplicate runs were performed for each flow rate. The weights of the molds were recorded on the Process Data Summary Sheet. In addition, the metal pour temperature and % LOI were recorded on the Process Data Summary Sheet.

4-on Gear Pattern Castings

The insulated emission hood was supplied with air heated to 85 to 90°F and exhausted through a 6-inch diameter heated duct attached to the top of the hood. Emission samples were drawn from a sampling port located to ensure conformance with US EPA Method 1. The tip of the sample probe was located in the centroid of the stack. The emissions were monitored using the California Analytical Total Hydrocarbon Analyzer that provides a continuous measurement of emissions over the entire test period.

Total Enclosure Test Stand

4. **Test Plan Review and Approval:** The proposed test plan was reviewed by the Technikon staff and the CERP Emissions and Test Design Committees, and approved. Table 2-1 lists

the process parameters that were monitored during each test. The analytical equipment and methods used are also listed.

Table 2-1 Process Parameters Measured

Parameter	Analytical Equipment and Methods
Mold Weight	Westweigh PP2847 Platform Scale (Gravimetric)
Casting Weight	OHAUS MP-2 Platform Scale (Gravimetric)
LOI% at mold	Denver analytic (AFS procedure 5100-00-S)
Pouring Temperature	Electro-Nite DT 260 (T/C immersion pyrometer)
Carbon/Silicon	Electro-Nite DataCast 2000 (Thermal Arrest)
Alloy Weights	Mettler PJ8000 (Gravimetric)
No-Bake Binder Weight	Mettler PJ8000 (Gravimetric)

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

Table 2-2 Sampling and Analytical Methods

Measurement Parameter	Test Method
Port Location	EPA Method 1
Number of Traverse Points	EPA Method 1
Gas Velocity and Temperature	EPA Method 2
Gas Density and Molecular Weight	EPA Method 3a
Gas Moisture	EPA Method 4, gravimetric
TGOC as Propane	EPA Method 25A

6. **Data Reduction, Tabulation and Preliminary Report Preparation:** The analytical results of the emissions tests and average stack flow rate provided the mass emissions for Total Gaseous Organic Concentration as propane emitted during each test run. The mass of emissions is calculated as propane and then divided by both the casting weight and the weight of the binder to provide emissions data in both pounds per ton of metal and pounds per pound of binder. The specific calculation formulas are included in the Technikon Testing, Quality

Control and Quality Assurance, and Data Validation Procedures Manual. The results of each of the runs and the corresponding process data are included in Section 3 of this report.

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 emissions data are included in the "Technikon Testing, Quality Control and Quality Assurance, and Data Validation Procedures Manual" In order to ensure the timely review of critical quality control parameters, the following procedures are followed:

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

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

3.0 Test Results

Table 3-1 shows the TGOC as propane measured from the seventy-five minute pouring, cooling, and shakeout cycles at three mold surface velocities. The results are expressed as TGOC concentration, total weighted TGOC emitted and pounds per ton of metal as well as pounds per pound of binder.

The stack volumetric flow rate is also shown in standard cubic feet per minute (scfm).

Detailed emission results are shown in Appendix B.

Table 3-2 includes the averages of the key process parameters. Detailed process data are presented in Appendix C.

Figure 3-1 shows the variation in TGOC emissions as propane with mold surface velocity from Table 3-1 in graphical form expressed in pounds of emissions per ton of metal.

Figure 3-2 shows the variation in TGOC emissions as propane with mold surface velocity from Table 3-1 expressed in pounds of emissions per pound of binder.

Figure 3-3 shows the average air velocities measured at four points around the mold. The figure's legend shows the respective stack volumetric flow rates associated with each surface velocity.

Figure 3-4 shows the average TGOC as Propane concentration in relation to the average air velocities around the molds.

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

Table 3-1 Test FM Average Emissions Data

Parameters	51 ft/min (200 scfm)	78 ft/min (700 scfm)	128 ft/min (1300 scfm)
TGOC as Propane (ppm)	332.1	103.0	53.50
TGOC as Propane (Lb Emission)	0.5616	0.5223	0.4433
TGOC as Propane (Lb/Tn Metal)	9.492	8.836	7.454
TGOC as Propane Lb/Lb Binder	0.1585	0.1421	0.1253
Average Air Velocity Around Mold (fpm)	51	78	128

Figure 3-1 Test FM Average TGOC Emissions – Lb/Tn Metal

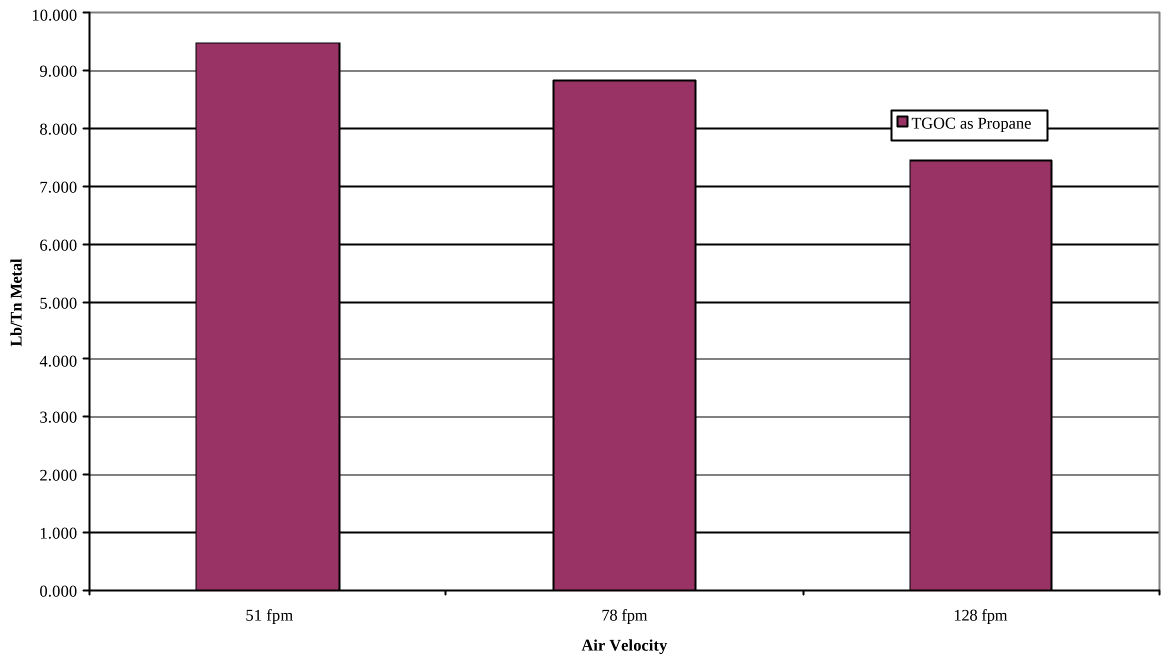


Figure 3-2 Test FM Average TGOC Emissions – Lb/Lb Binder

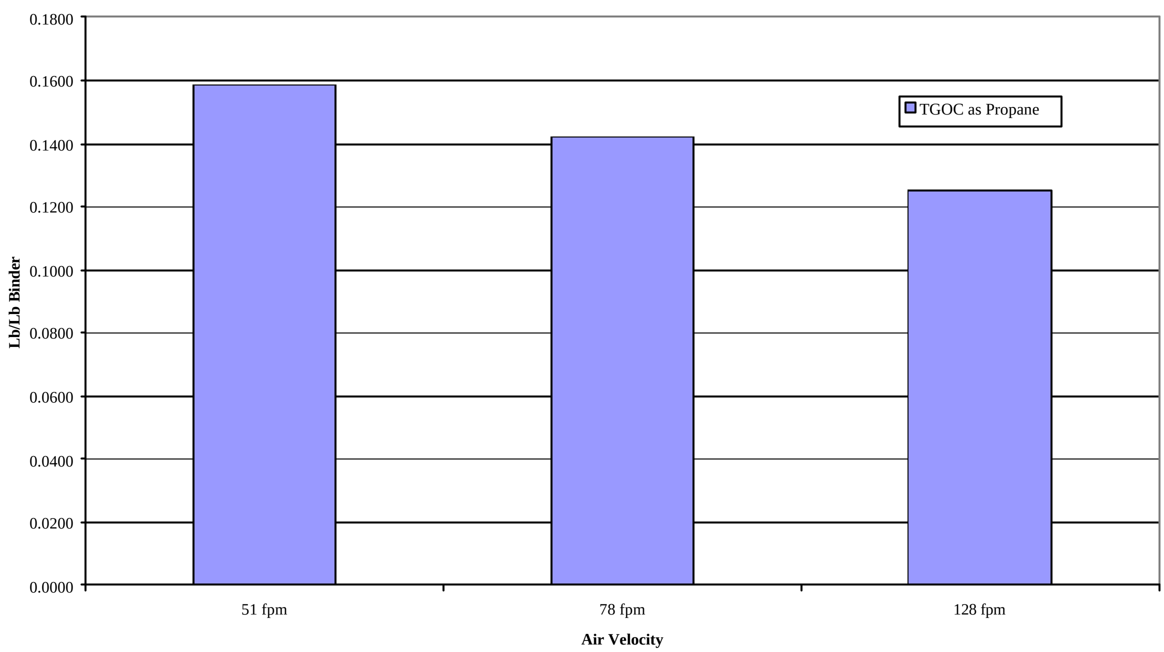


Figure 3-3 Test FM Average Air Velocities Around Molds

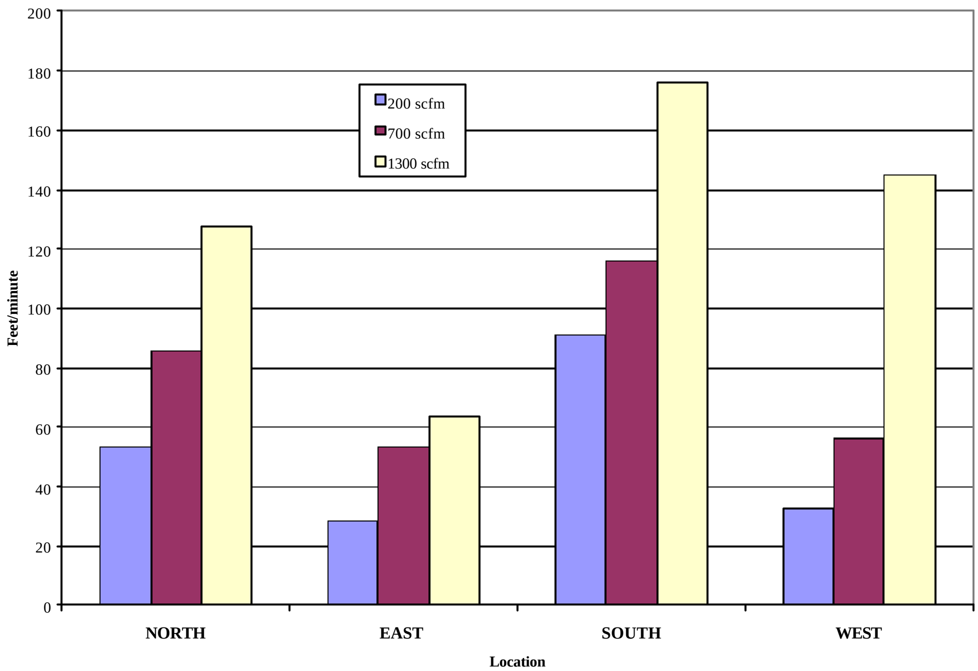


Figure 3-4 Test FM TGOC as Propane and Air Velocity

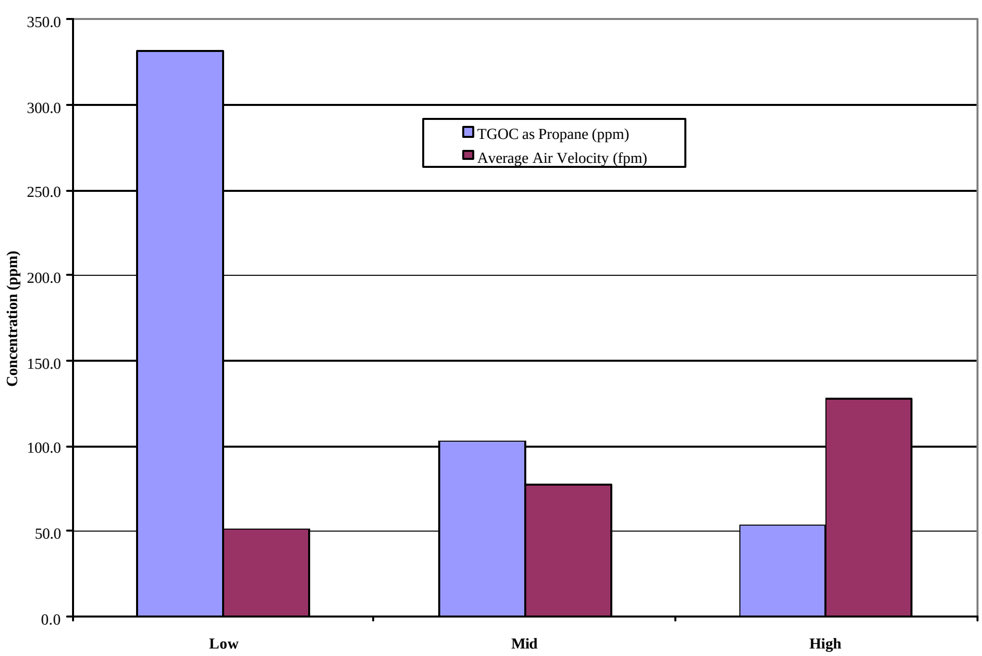


Table 3-2 Average Process Data Summary

No-Bake Mix/Make/Cure	
Test FM	**Average**
Sand Dispensing Rate, lbs/15 sec	**30**
Binder Part1 + Part3 Dispensing Rate, gms/15 sec	**85.8**
Binder Part 2 Dispensing Rate, gms/15 sec	**64.3**
Calculated Standard % Binder	**1.09**
Calculated % Binder (BOS)	**1.10**
Mold Weight, lbs	**328.9**
Calculated Total Binder Weight, lbs	**3.59**
1,800^{o}F LOI, %	**1.06**
Sand Temperature, deg F	**79**
Dogbone Core 2 hr. Tensile Strength, psi	**35**

No-Bake PCS	
Test FM	**Average**
Pouring Temp, deg F	**2,681**
Pouring Time, sec.	**35**
Cast Weight (all metal inside mold), Lbs.	**118.5**
Process Air Temperature in Hood, deg F	**88**
Ambient Temperature, deg F	**77**
Mold Age When Poured, hr	**23**
Test Length, hr	**1.25**

4.0 Discussion of Results

Testing was performed to determine the impact of varying the velocity of air moving across the surface of a No-Bake mold on the emissions from pouring, cooling, and shakeout. The molds were prepared from a standard phenolic urethane No-Bake system and three velocities were evaluated.

US EPA Method 25A, Total Gaseous Organic Concentration (TGOC), was used to measure the stack air emissions in all segments of the test and the results are reported in concentration of TGOC, pounds of emissions per ton of metal, and pounds of emissions per pound of binder. Air velocities were measured at four points around the vertical sides of the molds during testing using a Shortridge ADM 860D Fourier transformed electronically enhanced micro-manometer with an "air foil" attachment.

Three surface velocities were evaluated (approximately 51, 78, and 128 Ft/min). Visual observation of the flames during the pouring, cooling, and shakeout processes showed the following results:

Low Velocity

For the low velocity condition, flames that appeared were 'lazy' and continued to burn in this manner for times ranging from 20-38 minutes. The flame regions were not extensive, but rather contained to one area of the mold. Upon start of shakeout, the flames were larger than the 'lazy' flames during cooling but all were extinguished within 8 minutes after start of shakeout.

Mid Velocity

There was moderate flaming during one of the runs that lasted 11 minutes after pouring was completed. For the other two runs, there were no flames during cooling. Flames that appeared upon shakeout were large. They appeared to be "dancing" at the higher velocity associated with this test condition. The flames were extinguished within 5 minutes after start of shakeout.

High Velocity

No flames were observed immediately after pouring. Flames (rather large) appeared upon start of shakeout. The flames appeared to "dance" even more than those observed during the "Mid Velocity" runs. Most of the flames were extinguished within 4-5 minutes after start of shakeout.

A theory has been proposed that at low air velocities because the flames burn at a more uniform, steady rate, more organic material can be consumed/combusted into CO and CO_2 ultimately lowering the total VOC emissions. At higher velocities, the flames would be extinguished more rapidly potentially allowing for the release of more organic material due to less combustion. The TGOC as propane data from this test shows that emissions do not increase with increased velocities. The data suggests that the higher velocities may actually result in lower emissions. The approved test protocols that specified three (3) molds at each velocity point did not provide enough data to determine statistically whether the variation in emissions was due to the variation in surface air velocity or due to the inherent sampling and analysis uncertainty. Additional test runs three through six (3-6) would be needed to provide the data to determine if the apparent emission reduction is "real". No further testing is currently scheduled.

APPENDIX A APPROVED TEST PLAN FOR TEST FM

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TECHNIKON TEST PLAN

- > **CONTRACT NUMBER:** 1410 **TASK NUMBER:** 1.5.1 **Series:** FM
- > **SITE:** Pre-production No-bake molding and pour, cool, shakeout enclosure.
- > **TEST TYPE:** Modeling: Impact of emission capture velocity on no-bake pouring, cooling, shakeout.
- > **METAL TYPE:** Class 30 gray iron
- > **MOLD TYPE:** 4-on no-bake gear; HA 20-665, 23-635, 17-727
- > **NUMBER OF MOLDS:** 2 to 5 engineering + 9 Sampling
- > **CORE TYPE**: None
- > **SAMPLE RUNS**: 9
- > **TEST DATE:** **START**: 8 Sep 2003

  FINISHED: 15 Sep 2003

TEST OBJECTIVES:

To measure TGOC as a function of emission collection air velocity using THC for pouring, cooling, and shakeout for a total of 75 minutes. Measure the emissions for the standard iron phenolic urethane no-bake HA 23-665/23-635/17-727.

VARIABLES:

The principle variable will be air flow through the hood. Engineering trials will be conducted to determine the range of air flow that can be accommodated while maintaining the integrity of the sampling and stability of the physical process. The pattern shall be the 4-on gear. The mold shall be made with Wexford W450 sand. The no-bake mold binder will be 1.1% total binder (BOS) in 55/45 ratio of part I/part II and the activator is 10% of part 1. Molds will be poured with iron at 2630 +/- 10^{o}F. Mold cooling will be 45 minutes followed by 15 minutes of shakeout, or until no more material remains to be shaken out. The emission sampling shall be a total of 75 minutes.

BRIEF OVERVIEW:

Based on models for evaporation, increased air velocity over the wet surface enhances evaporation until the wet surface is depleted of available material to evaporate. From that point forward diffusion of vaporizable material from the interior of the resin coated body controls the emission rate. In this test however temperature from the mold interior from the solidifying casting will be a strong driving force for emissions complicating the simple evaporation model.

SPECIAL CONDITIONS:

The initial sand temperature into the hood shall be maintained at 80-90 ^{o}F. The initial process air temperature shall be 85-90 ^{o}F.

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 FM

Modeling Impact of Capture Air Velocity on Emissions from No-Bake Molds

Process Instructions

A. Experiment:

1. Measure emissions from an Iron No-Bake Phenolic Urethane binder using three (3) levels of capture air velocity

B. Materials:

1. No-bake molds:

   a. Wexford W450 Lakesand and
   b. % HA International Techniset® No-bake Phenolic-Urethane core resin composed of 20-665 (new 6066LV)part I resin, 23-635 (new 6435) part II co-reactant, & 17-727 part III activator. This binder is designed for iron applications.

2. Metal: Class-30 Gray cast iron.

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

C. Mold requirements

1. Make nine (9) Phenolic no-bake molds according standards determined in CW & CP capability studies.

D. Phenolic Urethane No-bake Core Sand preparation:

1. The phenolic urethane no-bake sand shall be 1.1% total resin (BOS), Part I/Part II ratio 55/45, Part III at 10% (diluted to 2-3%) of Part I.
2. Calibrate the Kloster no-bake sand mixer to dispense 240 pounds/min more or less.
3. Calibrate the resin pumps:

   a. Pre-mix Part I resin and Part III activator in a 10:1 (diluted to 40:1) weight ratio.
   b. Part I +Part III: Based on the actual measured sand dispensing rate calibrate the Part I + Part III resin to be 57.3% of 1.1% total binder.

c. Part II: Based on the actual measured sand dispensing rate calibrate the Part II co-reactant to be 42.7% of 1.1% total binder.

d. All calibrations to have a tolerance of +/- 1% of the calculated value.

4. Run an 1800°F core LOI on three (3) samples from each mold. Report the average value for each mold.

E. Dog bones:

1. Make 12 dog bones according to the protocol establish in capability study CW.
2. Place the core box on the vibrating compaction table.
3. Start the Kloster mixer and waste a few pounds of sand.
4. Flood the core box with sand then stop the mixer.
5. Strike off the core box to ½ inch deep
6. Turn on the vibrating compaction table for 15 seconds.
7. Screed off most of the excess sand.
8. Screed the core box a second time moving very slowly in a back and forth manner to remove **All** excess sand.

Note: It is important to neither gouge the sand nor leave excess sand in center neck portion of the dogbone or the test results will be affected

9. Set aside for about 6-7 minutes or until hard to the touch.
10. Carefully remove the cores from the core box by separating the corebox components.
11. Perform tensile tests on 12 bones at 2 hours after dogbone manufacture
12. Report the average and standard deviation for each set of twelve (12) for each mold.
13. Weigh each dogbone and record the weight to the nearest 0.1 grams using the PJ 4000 electronic scale at the time it is tensile tested.

Note: Maintain the correlation between the reported weight of a dogbone and its tensile strength and scratch hardness.

14. Run an 1800°F core LOI on three (3) of the tensile test dogbones. Report the average value for each mold.

F. No-bake mold making: 4 on gear core box.

1. Inspect the box for cracks and other damage. Repair before use.
2. Prepare the core box halves with a light coating of Ashland Zipslip® IP 78. Allow to fully dry.
3. Place the drag core box on the vibrating compaction table.
4. Begin filling the box.
5. Immediately start the table vibration.
6. Manually spread the sand around the box as it is filling.
7. Strike off the box until it is full.

8. Allow the vibrator to run an additional 10 seconds after the box is full.
9. Strike off the core box so that the core mold is 5-1/2 inches thick.
10. Set the core box aside for 5 to 6 minutes or until it is hard to the touch.
11. Invert the box and place on a transport pallet.
12. Remove the pivot-hole pins.
13. Remove the core mold half by tapping lightly on the box with a soft hammer.
14. Set the drag core box aside.
15. Place the cope core box on the vibrating compaction table.
16. Follow steps F3-F13 except that the cope mold is 5 inches thick.
17. Rotate the unboxed core to set it on edge.
18. Drill-vent holes as per template.
19. Immediately close cope onto drag. Visually check for closure.
20. Install two (2) steel straps, one on either side of the pouring cup, with 4 metal corner protectors each to hold the mold tightly closed.
21. Glue a pouring basin over the sprue hole with Foseco CoreFix 10 or equivalent no emission water base refractory adhesive
22. Weigh and record the weight of the closed mold.

G. Emission hood:

1. Loading.

- **a.** Hoist the mold onto the shakeout deck fixture within the emission hood with the pouring cup side toward the furnace.
- **b.** Install a half inch re-rod casting hanger through the cope into each of the four riser cavities and suspend them over the horizontal mold retaining bars.
- **c.** Close, seal, and lock the emission hood
- **d.** Close the hood and lock ducts together
- **e.** Attach heated ambient air duct to plenum
- **f.** Wait to pour until the process air thermocouple is in the range 85-90^{o}F.
- **g.** Record the process ambient air temperature.

2. Shakeout.

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

H. Melting:

1. Initial charge:

- **a.** Charge the furnace according to the Generic Start-Up Charge for Pre-production heat recipe bearing effective date 18 March 1999.
- **b.** Place part of the steel scrap on the bottom, followed by carbon alloys, and the balance of the steel.
- **c.** Place a pig on top on top.
- **d.** Bring the furnace contents to the point of beginning to melt over a period of 1 hour at reduced power.
- **e.** Add the balance of the metallics under full power until all is melted and the temperature has reached 2600 to 2700°F.
- **f.** Slag the furnace and add the balance of the alloys.
- **g.** Raise the temperature of the melt to 2700°F and take a DataCast 2000 sample. The temperature of the primary liquidus (TPL) must be in the range of 2200-2350°F.
- **h.** Hold the furnace at 2500-2550°F until near ready to tap.
- **i.** When ready to tap raise the temperature to 2700°F and slag the furnace.
- **j.** Record all metallic and alloy additions to the furnace, tap temperature, and pour temperature. Record all furnace activities with an associated time.

2. Back charging.

- **a.** If additional iron is desired back charge according to the Generic Pre-production Last Melt heat recipe bearing effective date 18 March 1999.
- **b.** Charge a few pieces of steel first to make a splash barrier, followed by the carbon alloys.
- **c.** Follow the above steps beginning with H.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.

I. Pouring:

1. Preheat the ladle.

- **a.** Tap 400 pounds more or less of 2700°F metal into the cold ladle.
- **b.** Casually pour the metal back to the furnace.
- **c.** Cover the ladle.
- **d.** Reheat the metal to 2780 +/- 20°F.
- **e.** Tap 450 pounds more or less of iron into the ladle while pouring inoculating alloys onto the metal stream near its base.
- **f.** Cover the ladle to conserve heat.
- **g.** Move the ladle to the pour position, open the emission hood pour door and wait until the metal temperature reaches 2630 +/- 10°F.
- **h.** Commence pouring keeping the sprue full.

i. Upon completion close the hood door, return the extra metal to the furnace, and cover the ladle.

Steven Knight
Mgr. Process Engineering

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APPENDIX B DETAILED EMISSIONS DATA

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Analytes	FM001	FM002	FM003	FM004	FM005	FM006	FM007	FM008	FM009
	200 scfm			700 scfm			1300 scfm		
TGOC as Propane (ppm)	3.55E+02	3.22E+02	3.19E+02	1.03E+02	I	1.03E+02	5.33E+01	5.17E+01	5.55E+01
TGOC as Propane (Lb/Tn Metal)	1.04E+01	9.21E+00	8.88E+00	9.08E+00	I	8.59E+00	7.57E+00	7.17E+00	7.62E+00
TGOC as Propane (Lb/Lb Binder)	1.75E-01	1.52E-01	1.49E-01	1.47E-01	I	1.38E-01	1.24E-01	1.23E-01	1.28E-01

I: Data rejected based on data validation considerations.

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APPENDIX C DETAILED PROCESS DATA

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Test Series FM Detailed Process Data

No-Bake Mix/Make/Cure										
Test Dates	9/17/2003	9/17/2003	9/17/2003	9/23/2003	9/23/2003	9/23/2003	9/24/2003	9/24/2003	9/24/2003	Average
Emissions Sample # / Production Sample #	FM 001	FM 002	FM 003	FM 004a	FM 005a	FM 006	FM 007	FM 008	FM 009	
Sand Dispensing Rate, lbs/15 sec	30	30	30	30	30	30	30	30	30	**30**
Binder Part1 + Part3 Dispensing Rate, gms/15 sec	86.3	86.3	86.3	85.5	85.5	85.5	85.7	85.7	85.7	**85.8**
Binder Part 2 Dispensing Rate, gms/15 sec	64.4	64.4	64.4	64.3	64.3	64.3	64.3	64.3	64.3	**64.3**
Calculated Standard % Binder	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	**1.09**
Calculated % Binder (BOS)	1.11	1.11	1.11	1.10	1.10	1.10	1.10	1.10	1.10	**1.10**
Mold Weight, lbs	320.5	328.5	322.5	336.5	338.5	339.5	329.5	319.0	325.5	**328.9**
Calculated Total Binder Weight, lbs	3.51	3.59	3.53	3.66	3.68	3.69	3.59	3.47	3.55	**3.59**
1800F LOI, % (Note 1)	0.97	0.99	1.04	1.11	1.21	1.21	0.96	1.01	1.00	**1.06**
Sand Temperature, deg F	78	78	79	79	79	79	79	79	80	**79**
Dogbone Core 2 hr. Tensile Strength, psi: note 4	55	65	30	39	38	39	16	21	11	**35**

No-Bake PCS										
Test Dates	9/17/2003	9/17/2003	9/17/2003	9/23/2003	9/23/2003	9/23/2003	9/24/2003	9/24/2003	9/24/2003	Average
Emissions Sample # / Production Sample #	FM 001	FM 002	FM 003	FM 004a	FM 005a Note 5	FM 006 Note 3	FM 007	FM 008	FM 009	
Pouring Temp, deg F	2685	2677	2689	2689	2670	2677	2672	2689	2679	**2681**
Pouring Time, sec.	32	40	42	34	31	36	32	32	39	**35**
Cast Weight (all metal inside mold), Lbs.	117.90	118.40	118.75	118.20	101.15	118.25	118.00	119.65	119.20	**118.54**
Process Air Temperature in Hood, deg F (Note 2)	85	90	86	86	89	94	86	87	87	**88**
Ambient Temperature, deg F	68	71	77	79	83	87	75	77	81	**77**
Mold Age When Poured, hr	23	24	24	22	23	25	23	23	23	**23**
Test Length, hr	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	**1.25**

Note 1: 1800F LOI is the net sample weight difference when combusted at 1800F 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: Process air for FM006 exceeded specification of 90 oF even though no air was being heated in Baron oven.

Note 4: FM001-006 contained 10 % activator leading to short bench life. FM004a-006 contained 5% activator. FM007-009 contained 3% activator. Dogbone tensiles @ 2 hours reflected activator content.

Note 5: FM005a invalidated due to runout, cast weight too low . Do not use

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APPENDIX D METHOD 25A CHARTS

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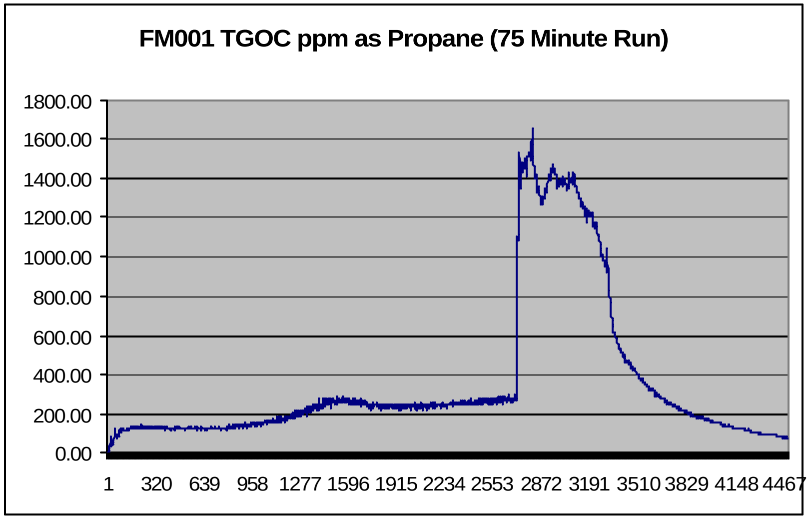
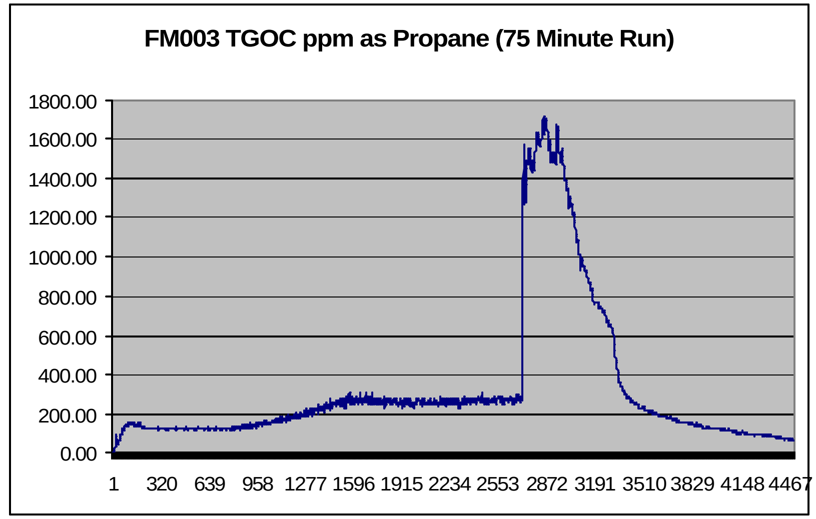
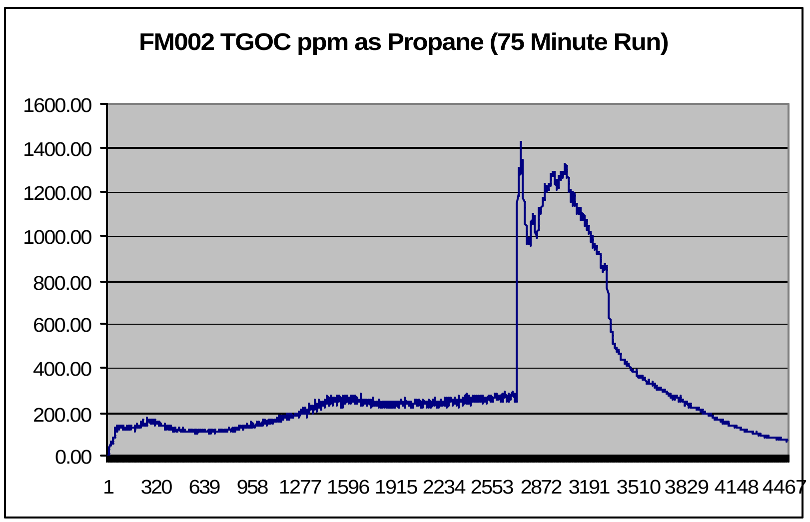
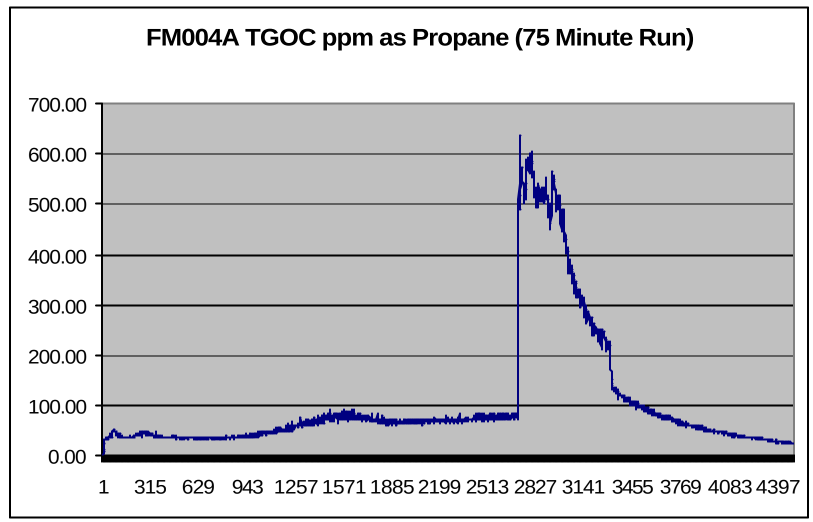
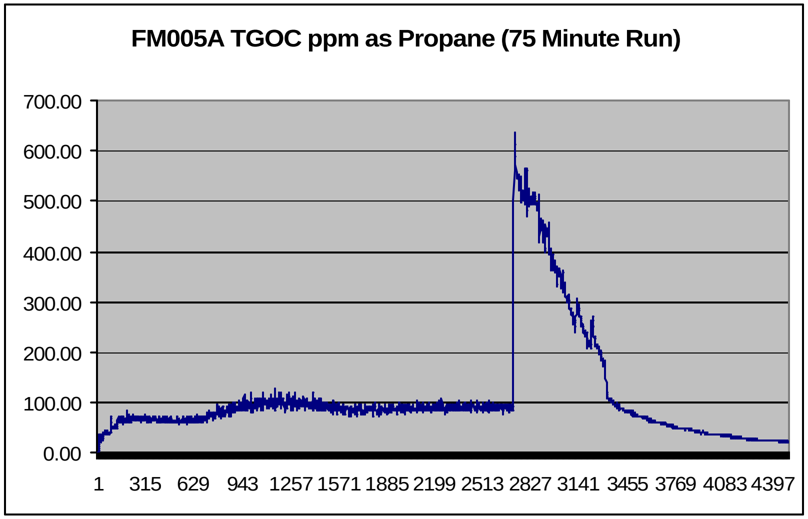

FM001 TGOC ppm as Propane (75 Minute Run)
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1 320 639 958 1277 1596 1915 2234 2553 2872 3191 3510 3829 4148 4467


FM003 TGOC ppm as Propane (75 Minute Run)
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1 320 639 958 1277 1596 1915 2234 2553 2872 3191 3510 3829 4148 4467


FM002 TGOC ppm as Propane (75 Minute Run)
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1 320 639 958 1277 1596 1915 2234 2553 2872 3191 3510 3829 4148 4467


FM004A TGOC ppm as Propane (75 Minute Run)
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397


FM005A TGOC ppm as Propane (75 Minute Run)
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
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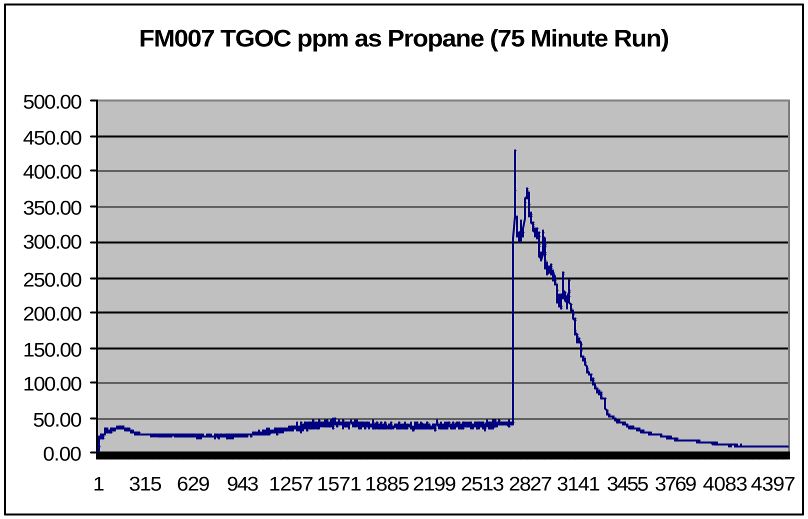
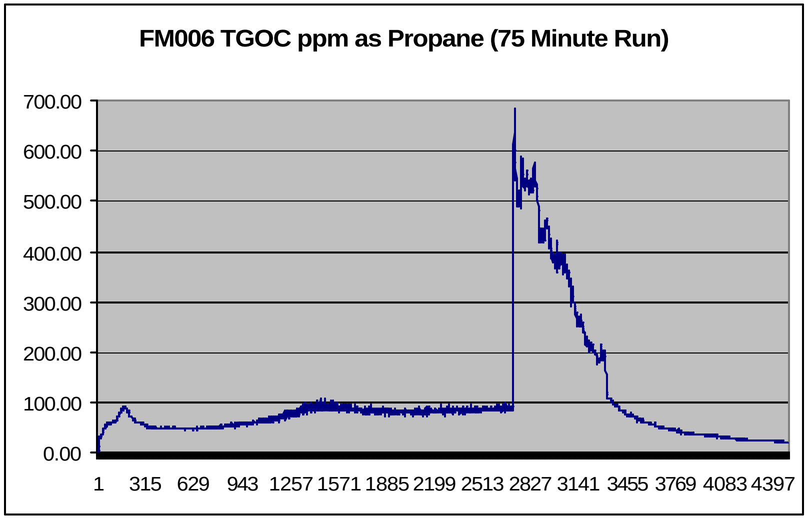

FM007 TGOC ppm as Propane (75 Minute Run)
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397


FM006 TGOC ppm as Propane (75 Minute Run)
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
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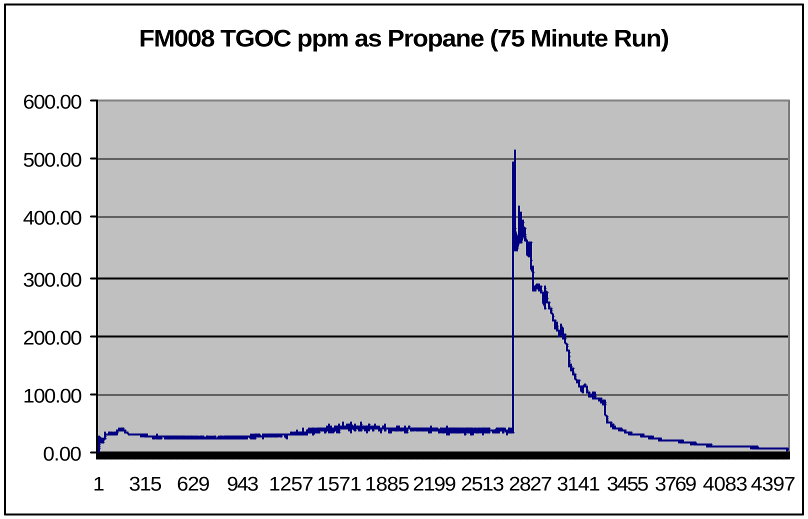
FM008 TGOC ppm as Propane (75 Minute Run)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
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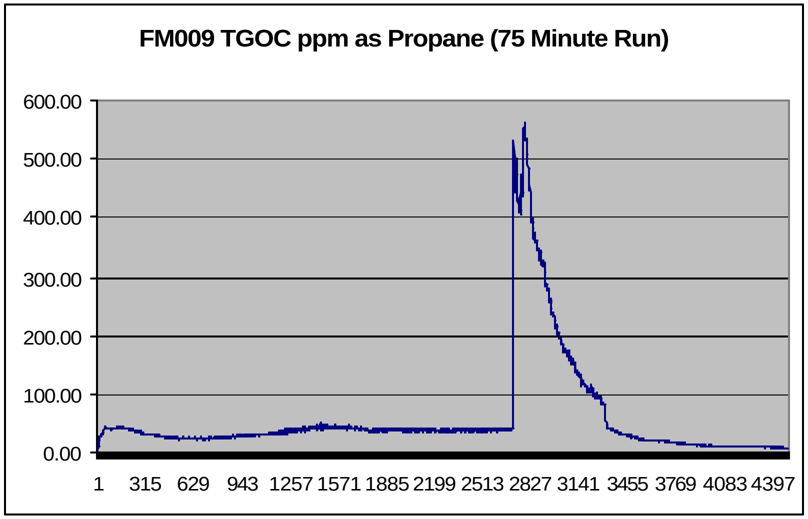
FM009 TGOC ppm as Propane (75 Minute Run)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1 315 629 943 1257 1571 1885 2199 2513 2827 3141 3455 3769 4083 4397

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APPENDIX E GLOSSARY

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Glossary

ACFM	Actual Cubic Feet Per Minute
BO	Based on ( ).
BOS	Based on Sand.
FPM	Feet Per Minute
HAP	Hazardous Air Pollutant defined by the 1990 Clean Air Act Amendment
HC as Hexane	Calculated by the summation of all area between elution of Hexane through the elution of Hexadecane. The 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	Invalid, Data rejected based on data validation considerations
NA	Not Applicable
ND	Non-Detect
NT	Not-Done, Lab testing was not done
POM	Polycyclic Organic Matter (POM) including Naphthalene and other compounds that contain more than one benzene ring and have a boiling point greater than or equal to 100 degrees Celsius.
PPMV	Parts Per Million by Volume
SCFM	Standard Cubic Feet per Minute
TGOC	Total Gaseous Organic Carbon
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