Casting Emission Reduction Program

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Process Improvement: The Effect of Volumetric Flow Rates on Shell Mold Pouring, Cooling, & Shakeout Emissions

Technikon #1411-614 GP

August 2005
(Revised for public distribution.)

United States Environmental Protection Agency

UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

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Process Improvement:
The Effect of Volumetric Flow Rates on Shell Mold Pouring, Cooling, & Shakeout Emissions

Technikon #1411-614 GP

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

Process Engineering Manager	*// Original Signed //* Steven M. Knight	______________ Date
V.P. Operations	*// Original Signed //* George R. Crandell	______________ Date

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

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Executive Summary

Previous Casting Emission Reduction Program (CERP) investigations have established that the rate of hydrocarbon emission generation is driven by the temperature, of the organic materials in the mold and the geometry of the mold cavity. That temperature is driven by heat content of the metal poured into the mold cavity and heat transfer characteristics of the mold material.

In this test, emissions of TGOC, CO, CO_2, and NO_x were monitored, from shell molds, poured with iron with varied volumetric flow rates (312, 728, and 1033 scfm) that were measured in the exhaust duct downstream of the test enclosure. Data from an earlier test (1411-115 GN) that used the same molds with an average volumetric flow rate of 310 SCFM was incorporated into the test results for the report. Additionally, photographs were taken to document the character and duration of the flames at varying volumetric flow rates.

The shell molds had significantly less organic content than seen in typical greensand and No-Bake® sands that are Technikon baselines. Measurable hydrocarbon emissions were complete in 25-50 % of the time period used for this test. This was evidenced by no measurable output signal from the TGOC analyzer at shakeout, even though the CO, CO_2, and NO_x analyzers indicated this event.

Table 1 shows the different characteristics of the burning portion of the test that lead to different measurable organic content as a function of volumetric flow rates. The time to cessation of flame and CO_2 generation, as well as overall emission time, reduced as volumetric flow rate increased.

Table 1 Analysis of Total Organic Gasses Emitted

Volumetric Flow Rate (scfm)	Time to End of Visible Burning- CO_2 Production (seconds)	Average Time to 90% of Mass Emitted (seconds)	Total Test Time	Average Lbs /Ton TGOC	Average Lbs/Ton CO	Average Lbs/Ton CO_2
312	1100	1900	4500	1.475	12.07	70.43
728	780	1470	4500	2.782	14.62	66.79
1033	570	1160	4500	3.091	13.00	44.85

This data indicate that for this shell mold:

> The combustion conditions are materially influenced by the air velocity moving past the mold. Velocity affects the intensity of the resulting flaming and heat generation. It also affects the duration of the visible flames. The flames are extinguished earlier for the higher volumetric flow. The resulting thermal profiles that exist in the vicinity of the mold have an impact on the breakdown of the organic components of the mold material. This potentially could affect the distributions of the resultant species that are generated during the thermal decomposition and transformation of binder material. NO_x and CO_2 generation are also influenced by the intensity and duration of the flame.

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 Research, Development, and Engineering Command (RDECOM-ARDEC), a laboratory of the United States Army; the American Foundry Society (AFS); and the Casting Industry Suppliers Association (CISA). The US Environmental Protection Agency (US EPA) and the California Air Resources Board (CARB) also have been participants in the CERP program and rely on CERP published reports for regulatory compliance data. All published reports are available on the CERP web site at www.cerp-us.org.

1.2. 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. The facility's principal testing arena is designed to measure airborne emissions from individually poured molds. This testing arena has been specially designed to facilitate the repeatable collection and evaluation of airborne emissions and associated process data.

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 impact of emission collection air velocity on measurable emissions from a shell mold. 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

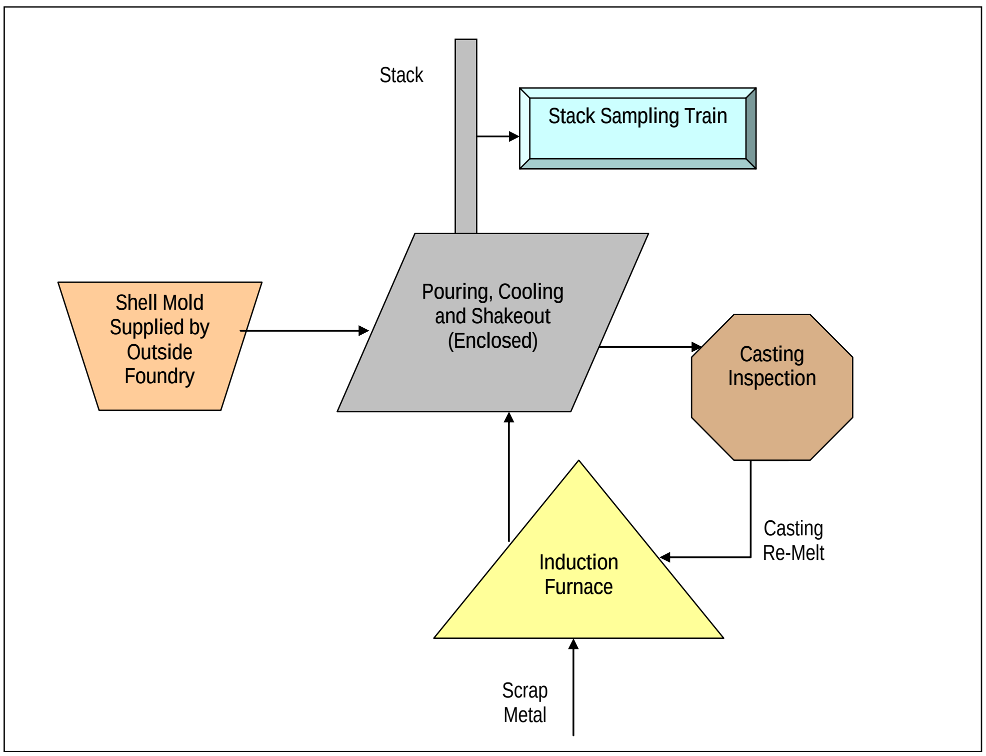
	Baseline Test Plan GP
Type of Process tested	Shell mold, Iron, PCS
Test Plan Number	1411 614 GP
Metal Poured	Iron
Casting Type	6-on Shell mold
Mold	HA Super F2 E/J19P12689W pre-coated shell Sand
Core Coating	None
Number of Molds Poured	7 Sampling
Test Dates	4/5/05 > 4/7/05
Emissions Measured	TGOC as Propane, CO,CO_2,NOx
Process Parameters Measured	Total Casting, Mold Weights; Metallurgical data, % LOI; Stack Temperature, Moisture Content, Air Volumetric Flow Rate Temperature, and Pressure

2.0 TEST METHODOLOGY

2.1. Description of Process and Testing Equipment

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

Figure 2-1 Foundry Layout Diagram



2.2. Description of Testing Program

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

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

2. **<u>Mold, Core and Metal Preparation:</u>** The shell molds were prepared by an outside foundry to a standard composition. Each mold was placed on a bed of new silica sand in a tray for pouring. Relevant process data were 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 was Class-30 Gray Iron as prescribed by a metal composition worksheet. The weight of metal poured into each mold was recorded on the process data summary sheet.

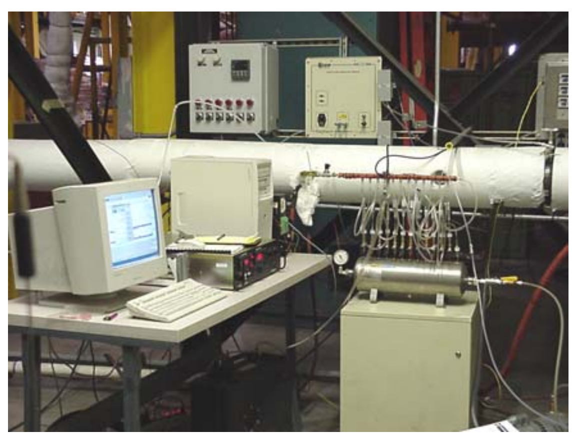
3. **<u>Individual Sampling Events:</u>** Replicate tests were performed on seven (7) mold packages. Each replication differed only in the flow rate of the emission capture air, nominally 300, 700, or 1000 scfm. The mold packages were placed into an enclosed test stand heated to approximately 85°F. Iron was poured through an opening in the top of the emission enclosure, after which the opening was closed.

   Emissions were monitored during the 60 minute pouring and cooling process, during the five minute shakeout of the mold, and for an additional ten minute period following shakeout. The total sampling time was seventy-five minutes.

Figure 2-2 6-on Shell Mold in Emission Hood

Figure 2-3 Total Enclosure Test Stand

Figure 2-4 Method 25A (TGOC) and Method 18 Sampling Train



4. **<u>Process Parameter Measurements:</u>** 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
Shell Mold Weight	Ohaus MP2 Scale
Casting weight	Ohaus MP2 Scale
LOI, % Shell Mold before pour	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
Carbon/Silicon	Electro-Nite DataCast 2000 (thermal arrest)

5. **<u>Air Emissions Analysis:</u>** 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 <u>Technikon Standard Operating Procedures.</u>

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	EPA Method 25A
CO	EPA Method 10
CO2	EPA Method 3A
NOx	EPA Method 7E

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

6. **<u>Data Reduction, Tabulation and Preliminary Report Preparation</u>:** The monitoring results of the emissions tests provide the concentration of each analyte in the exhaust. The total mass of an analyte emitted is calculated by converting the concentration to mass per unit volume and 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 using the measured stack pressures, temperatures, gas molecular weight and moisture content. The total mass of analyte is then divided by the weight of the binder or casting poured to provide emissions data in both pounds of analyte per pound of binder and 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 Tables 3-1 and 3-3.

7. **<u>Report Preparation and Review</u>:** 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" publication. In order to ensure the timely review of critical quality control parameters, the following procedures are followed:

- Immediately following the individual sampling events performed for each test, specific process parameters are reviewed by the Manager - Process Engineering to ensure that the parameters are maintained within the prescribed control ranges. Where data are not within the prescribed ranges, the Manager - 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.

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3.0 TEST RESULTS

Table 3-1 lists the average real time concentrations for TGOC as Propane, CO, CO_2, and NOx vs. the volumetric flow rate in scfm for GP (1411-614) and GN (1411-115). These values are the numbers used to calculate the normalized quantities Lb/Ton metal and Lb/Lb binder.

Table 3-2 summarizes the process parameters for both tests GP & GN.

Table 3-3 is an analysis of TGOC as Propane, Carbon Monoxide, and Carbon Dioxide gasses for Test GP. Figure 3-1 through 3-3 contain information for Tests GP and GN. Figure 3-1 Charts TGOC as Propane, Carbon Monoxide, Carbon Dioxide concentration (ppm) vs. air flow rate (scfm). Figure 3-2 Charts TGOC as Propane, Carbon Monoxide, & Carbon Dioxide normalized as Lb/Ton of metal poured vs. air flow rate (scfm).

Figure 3-3 charts TGOC as Propane in ppm, Lb/Ton metal, & Lb/Lb binder for all volumetric flow rates to compare the influence of dilution to contributions from other phenomena like combustion and surface heating.

Figure 3-4 (Test GP) charts the full real time data set for TGOC as Propane in ppm vs. time for all runs at all volumetric flow rates.

Figure 3-5 (Test GP) shows a systemic reduction in time with air flow rate to the point when 90% of all the emissions had been emitted.

Figure 3-6 (Test GP) demonstrates the real time rise in the air temperature as it passes through the emission hood. The average 10 to 40^{o}F difference may shift combustion equilibrium for both the oxidation of the hydrocarbon to CO and CO to CO_2.

Figures 3-7, 3-8, & 3-9 were derived from the three 3-dimensional charts in Appendix B showing the real time relationship between the simultaneous concentrations of organics as TGOC as Propane, CO as an intermediate oxide and CO_2 as the end of the combustion chain. Figures 3-7, 3-8, and 3-9 are simplifications of those charts ignoring the end product CO_2 so that the timing of events and photographic evidence of the combustion can be more easily compared.

Measured process parameters indicated that all tests were run within acceptable established limits, and replicate tests were conducted following similar procedures.

Table 3-1 Summarize the Average Real Time TGOC as Propane, CO, CO_2, & NOx Emission Data for Tests GP & GN.

Table 3-1 Summary of Average Real Time Emissions over 4500 Seconds

Emissions Sample #	GN Average	GP001-3 Average	GP004-6 Average	GP007 Average
Test Dates	3/28-30/05	4/5/2005	4/6/2005	4/7/2005
Air flow, SCFM	310	734	1030	312
TGOC, ppm at Set Air Flow	12.66	9.82	7.64	12.31
TGOC, Lb/Lb. Binder	0.0237	0.0430	0.0463	0.0223
TGOC, Lb/Ton metal	1.5077	2.7818	3.0906	1.4752
CO, ppm at Set Air Flow	161.1550	81.0478	50.3821	158.2211
CO, Lb/Lb Binder	0.1925	0.2259	0.1946	0.1820
CO, Lb/Ton Metal	12.2216	14.6193	13.0028	12.0656
CO_2, ppm at Set Air Flow	586.5783	235.6410	110.4186	587.7334
CO_2, Lb/Lb Binder	1.1020	1.0321	0.6710	1.0625
CO_2, Lb/Ton Metal	69.9062	66.7884	44.8494	70.4302
NOx, ppm at Set Air Flow	2.2717	1.1999	0.6449	2.3970
NOx, Lb/Lb Binder	0.0029	0.0036	0.0027	0.0030
NOx, Lb/Ton Metal	0.1847	0.2316	0.1785	0.1958

Table 3-2 Summary of Process data for tests GP & GN

Greensand PCS Shells	Test GP	Test GP	Test GP	Test GN
Test Dates	4/5/2005	4/6/2005	4/7/2005	3/28-30/05
Sample #	GP001-3	GP004-6	GP007	GN001-6
Cast Weight (all metal inside mold), Lbs.	43.65	42.77	43.85	43.72
Pouring Time, sec.	19	18	18	18
Pouring Temp ,°F	2626	2630	2640	2632
Pour Hood Process Air Temp at Start of Pour, ºF	87	88	86	86
Total Shell mold Weight, Lbs.	31.13	31.53	32.05	30.57
Core Reported Binder Content, %BOS	4.75	4.75	4.75	4.75
Core Binder Calculated Resin Content , %	4.53	4.53	4.53	4.53
Total Binder Weight in Mold, Lbs.	1.41	1.43	1.45	1.39
Weight of mold remaining as core butts, Lbs	8.8	9.77	7.75	8.68
Shell mold LOI, %	5.12	5.05	5.10	5.12
Approximate Shell mold Age, days	18	19	20	11
Air Flow, SCFM	734	1030	312	310

Table 3-3 Test GP Total Organic Gasses Emitted in Lbs per Ton of Metal Poured TGOC as Propane and Combustion Byproducts CO and CO_2

Volumetric Flow Rate	Time to End of Visible Burning-CO_2 Production	Average Time to 90% of Mass Emitted, Seconds	Total Test Time	Average Lbs /Ton TGOC	Average Lbs/Ton CO	Average Lbs/Ton CO_2
312	1100	1900	4500	1.475	12.07	70.43
728	780	1470	4500	2.782	14.62	66.79
1033	570	1160	4500	3.091	13.00	44.85

Figure 3-1 Average Concentration of Real Time TGOC as Propane, CO, CO_2, & NOx Gasses vs. Capture Volumetric Flow Rate in Linear and Logarithmic Formats

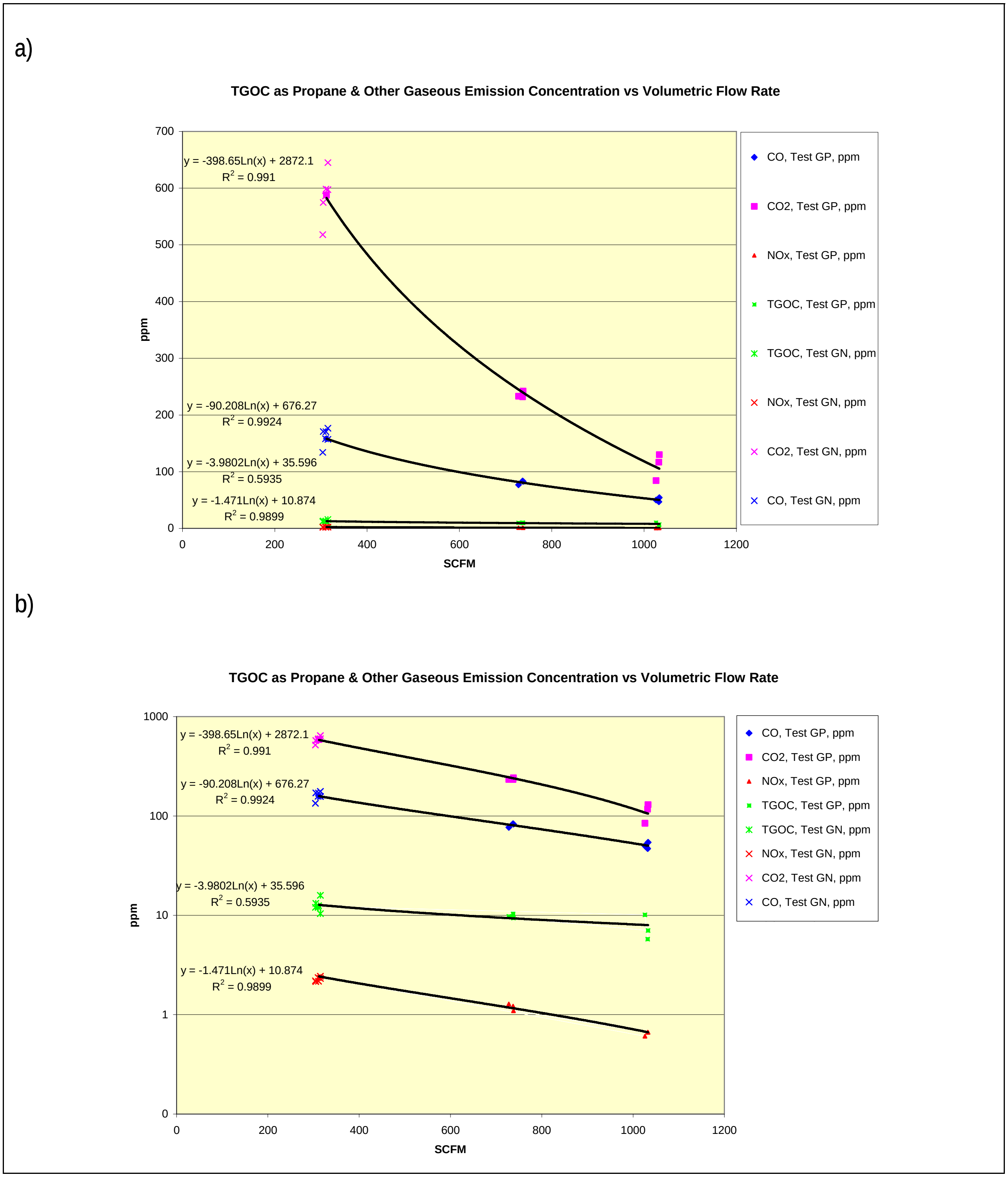
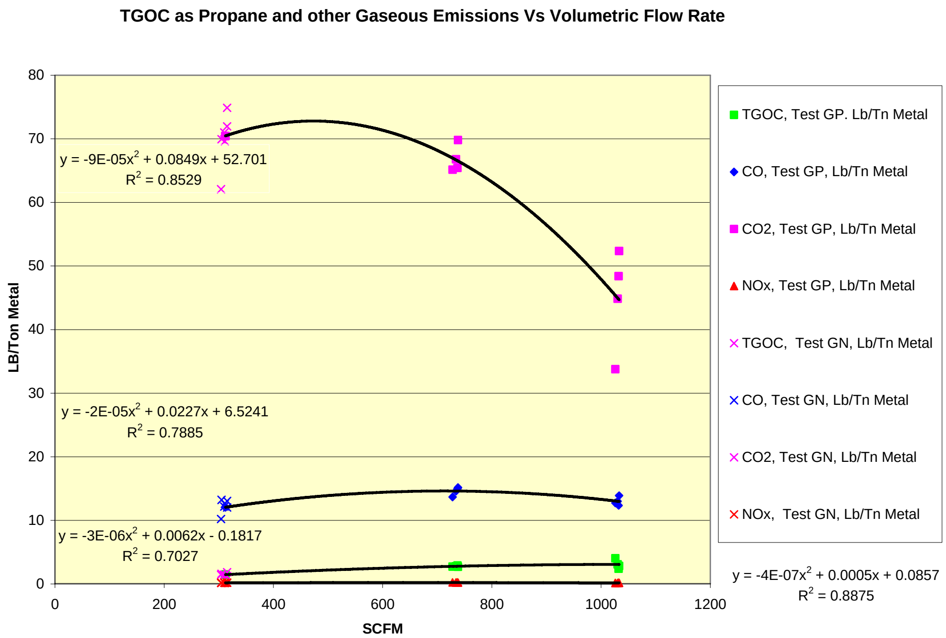


Figure 3-2 Average Real Time Emissions of TGOC as Propane, CO, CO_2, & NOx Gasses Normalized to Lb./Ton of Metal Poured vs. Volumetric Flow Rate in Linear and Logarithmic Formats.

a)



b)

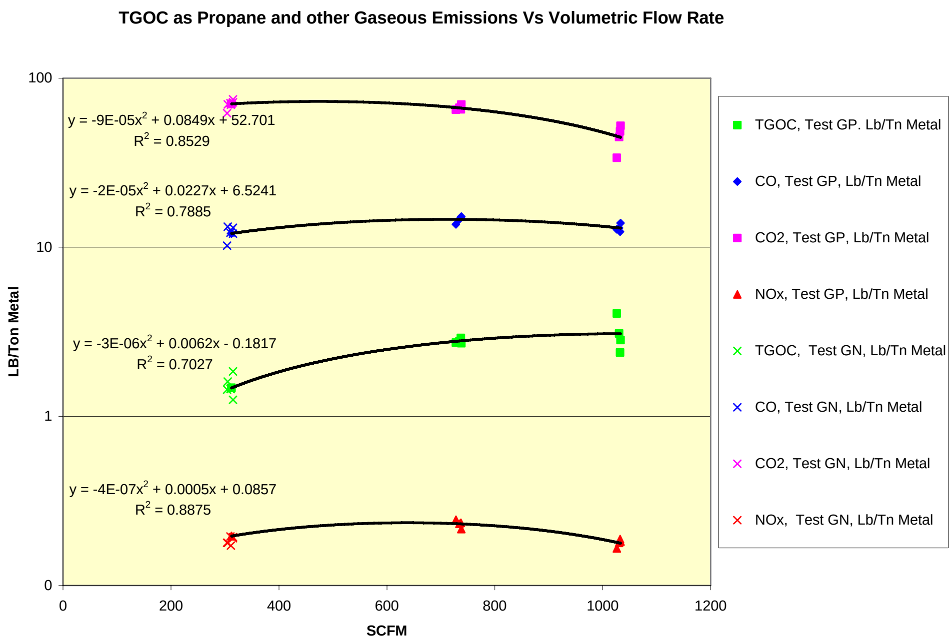


Figure 3-3 Average Real Time TGOC as Propane as ppm Normalized to Lb/Ton Metal and Lb/Lb binder vs. Volumetric Flow Rate in Linear and Logarithmic Formats

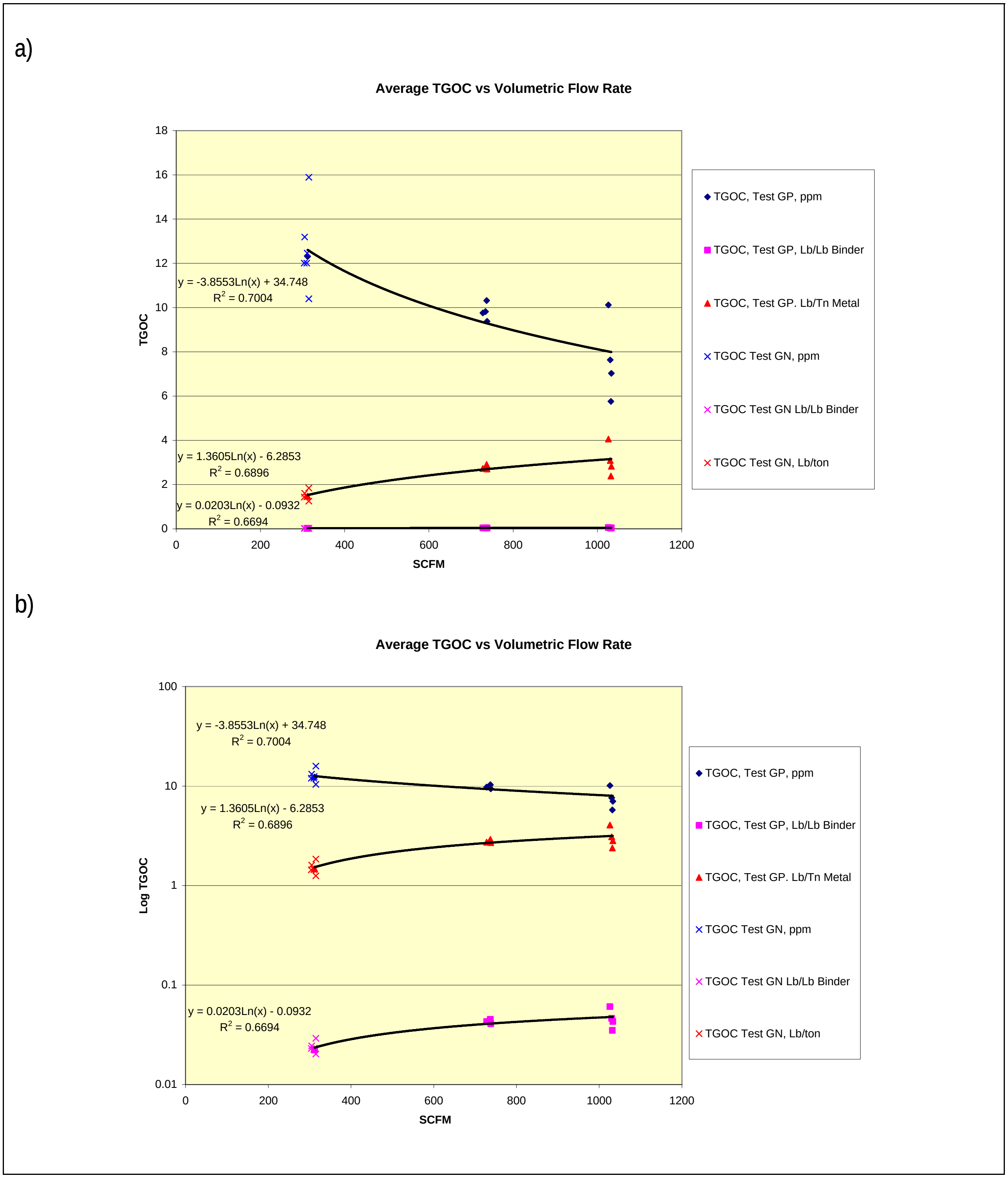


Figure 3-4 Real Time Concentration TGOC as Propane vs. Elapsed Time for 300, 700, & 1000 SCFM Volumetric Flow Rates.

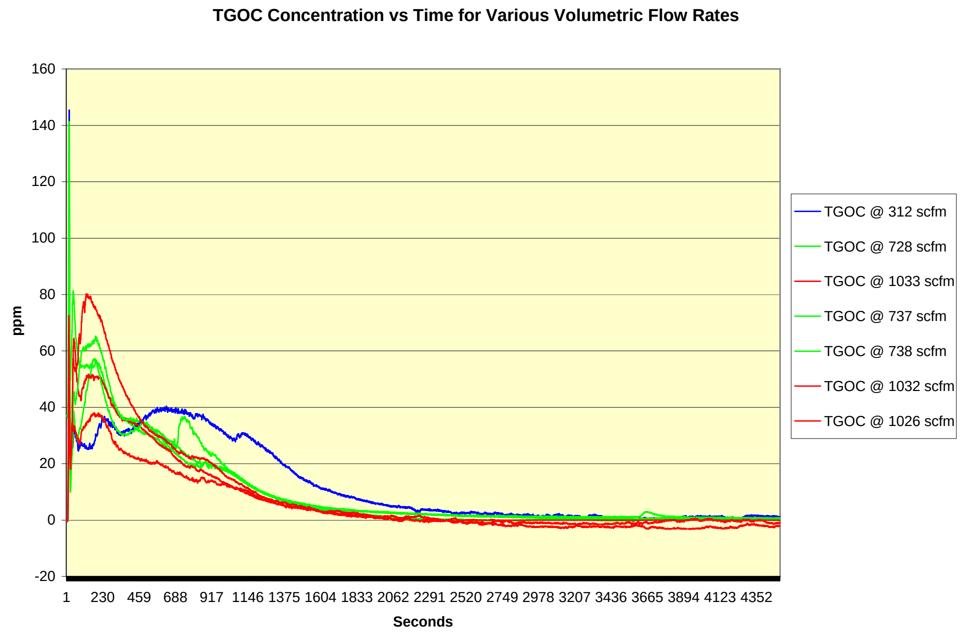


Figure 3-5 Elapsed Time to Emit 90% of Total Emitted TGOC as Propane vs. Volumetric Flow Rate.

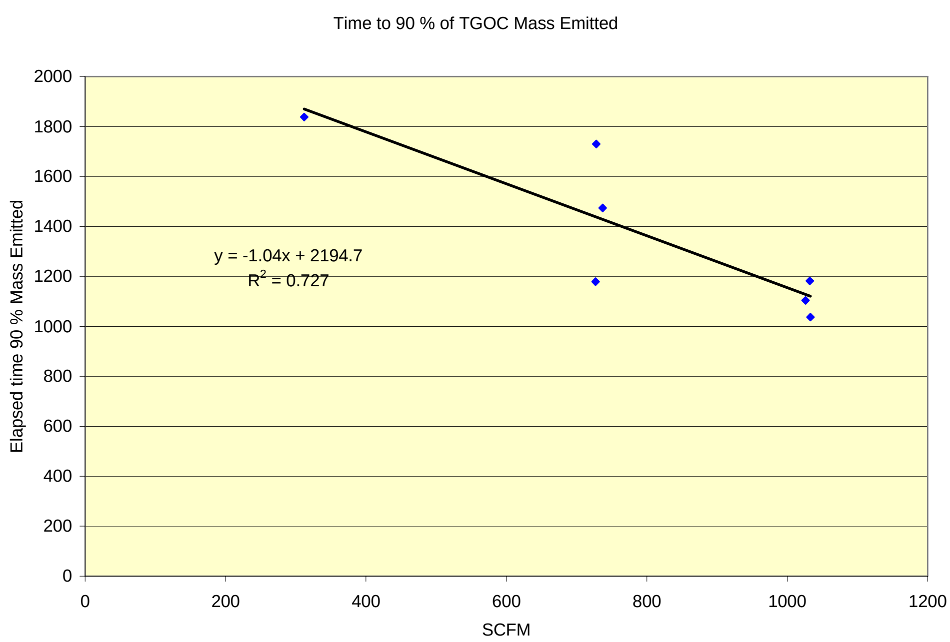


Figure 3-6 Emission Stack Temperature Rise, Stack Temperature- System Temperature vs. Time - For 312, 728, 1033 scfm Volumetric Flow Rates.

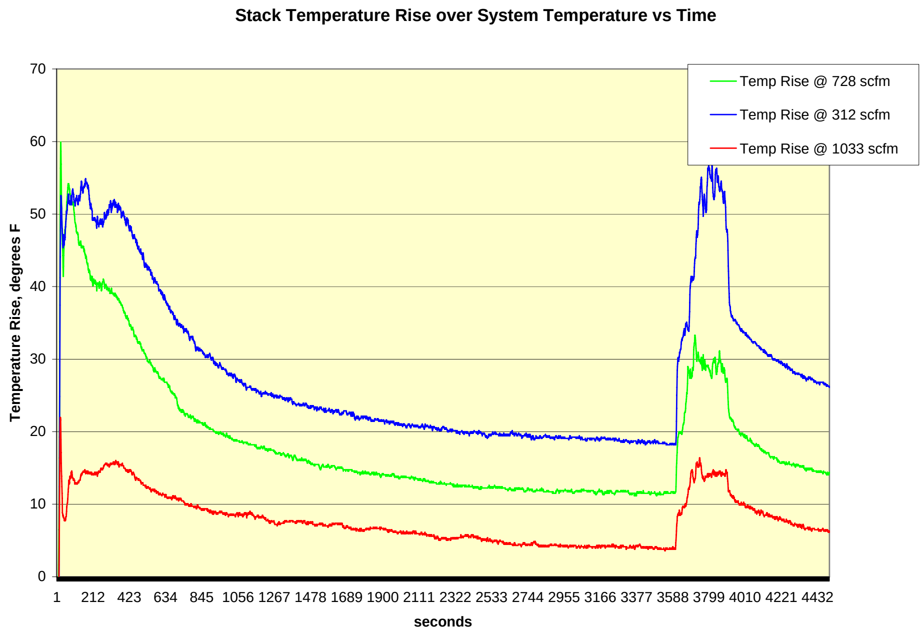


Figure 3-7 TGOC vs. CO at 312 scfm V9olumetric Flow Rate with Time and Flame Picture Event Markers.

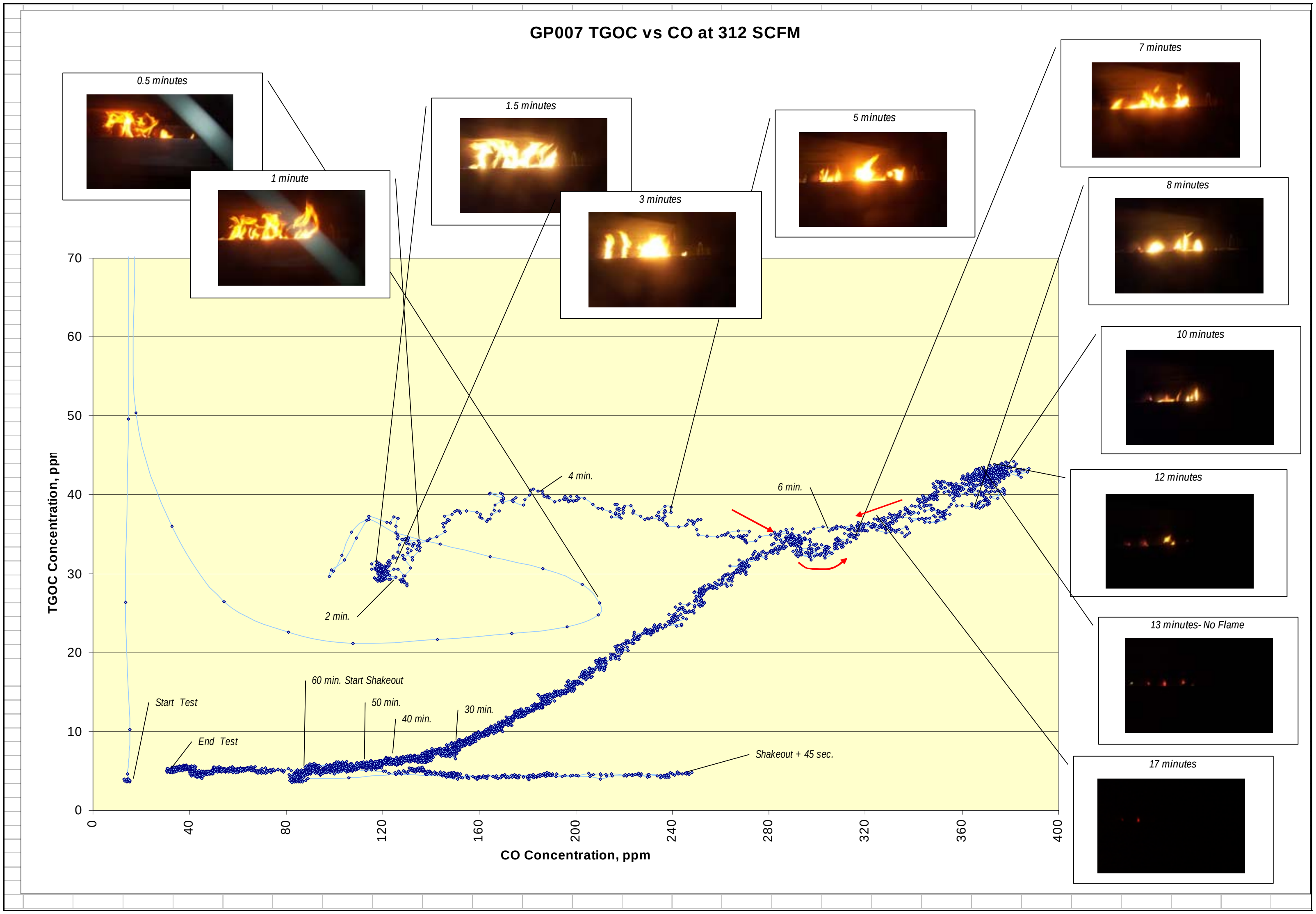


Figure 3-8 TGOC vs. CO at 728 scfm Volumetric Flow Rate with Time and Flame Picture Event Markers

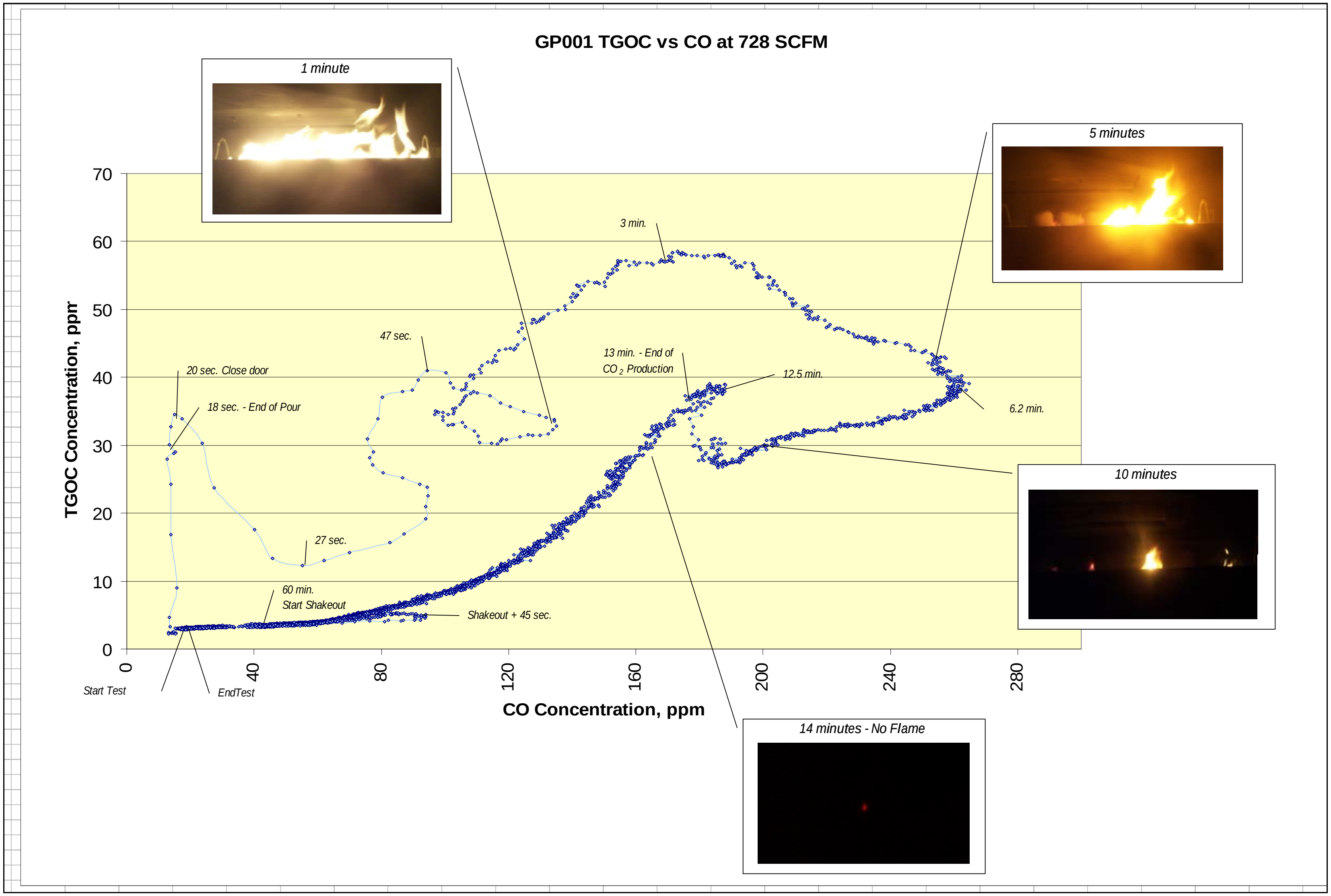
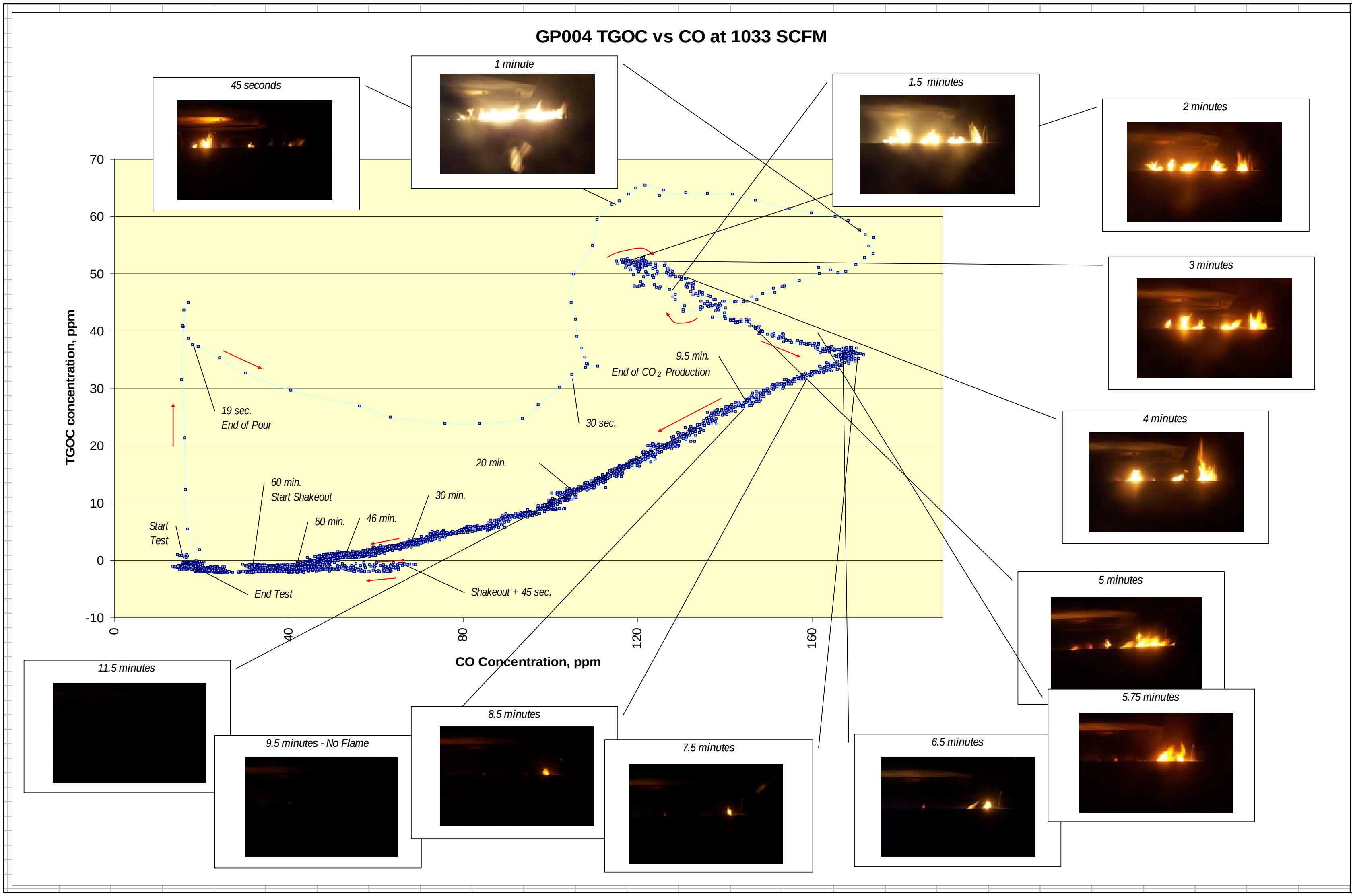


Figure 3-9 TGOC vs. CO at 1033 scfm Volumetric Flow Rate with Time and Flame Picture Event Markers



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4.0 DISCUSSION OF RESULTS

A previous CERP test, Test FM (1410-151) studied the emissions from a Furan No-bake® mold with varied volumetric flow rates and resultant mold surface velocity. At that time, capabilities at the Technikon Research Foundry existed only for measuring TGOC (as propane). None were available for measuring other species from the emissions stream (CO, CO_2 and NOx) that could provide a route to assess hydrocarbon breakdown and transformation to other hydrocarbons or to inorganic oxides. The result of the previous test was inconclusive about the effects of velocity around the surface of the mold on the net emissions from PCS operations at the Technikon Research Foundry.

This report deals with the impact of volumetric air flow rate on the measurable emissions as they escape the surface of a shell mold poured with molten iron. In this test shell molds were poured at the volumetric flow rates at 312, 728, and 1033 scfm. Data from an earlier test (1411-115 GN) that used the same molds with an average volumetric flow rate of 310 SCFM was incorporated in the test results. The flow rates were measured in the sample duct downstream of the pouring enclosure. No attempt was made to measure air velocities going past the mold surface.

In this test, shortly after a mold is poured with molten metal, flames of varying intensity are seen to burn for periods up to 15 minutes of the 75 minute test period. In general, the flames are small initially but grow rapidly in intensity and heat and gradually again subside until they eventually extinguish.

Simultaneous real time measurements were made of the principle combustion reactions in an attempt to understand how some of the emitted hydrocarbons were transformed into non-organic oxides such as CO & CO_2. It can be postulated that the first oxidation reaction is the formation of carbon monoxide from the emitted hydrocarbons. The second oxidation reaction oxidizes the CO generated to carbon dioxide. Both of these reactions are accompanied by the evolution of heat at the mold surface. These two reactions form an equilibrium that either generate heat or extract heat depending on which direction the reaction is driven.

Test GP was completed after test GN using the same shell molds at a volumetric air flow rate of 310 scfm. Data from both these tests were included in this report.

Figure 3-4 shows the full real time TGOC concentration data, as ppm, for all three air flow rates in test GP. Data show an apparent difference for the 312 scfm runs. The evolution of hydrocarbons appears to be complete after about 2100 seconds (35 minutes) of the 4500 second test (47%). Beyond 2100 seconds, the TGOC values for all stack flows look the same. If this test had been run on a full size mold typified by the greensand and No-Bake® molds used for Technikon baselines, the molds would have had significant emissions during the shakeout cycle at the end of the test period.

Figures 3-7, 3-8, and 3-9 present an opportunity to compare, at the three volumetric flow rates, the physical appearances and the principle gas emissions on a time line.

A general summary that could be derived from this test is provided below:

Combustion conditions are influenced by the velocity of air moving past the surface of a mold. This is due to the air velocity affecting the nature of the flame, duration of the flame, and time for extinction of the flame. The net effect of these is to create differences in thermal profiles across the surface of the mold and also its duration. The transformation/breakdown of the emitting material is different depending on the existing thermal environment. Consequently the nature of the hydrocarbon species emitted and the associated inorganic oxides released are different. It is evident from the results that the lowest air flow rate (312 SCFM) had the lowest TGOC emission rate, 1.48 lbs/Ton of Metal from test GP and 1.51 lbs/ton from test GN. The higher flow rates had emission rates at 2.78 (728 scfm) & 3.1 (1033 scfm) lbs/ton of metal.

APPENDIX A APPROVED TEST PLANS, INSTRUCTIONS, AND SAMPLE PLANS

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TECHNIKON TEST PLAN

- **CONTRACT NUMBER:** 1411 **TASK NUMBER** 6.1.4 **SERIES** GP
- **SITE:** Pre-production pour, cool & shakeout enclosure
- **TEST TYPE:** Improve CERP Process: Impact of emission capture velocity on shell mold pouring, cooling, shakeout emissions
- **METAL TYPE:** Clas-30 gray iron
- **MOLD TYPE:** 6-on shell mold; HA Super F2 E/J19P12689W coated shell sand
- **NUMBER OF MOLDS:** 12 Sampling
- **CORE TYPE:** none
- **CORE COATING:** none
- **SAMPLE EVENTS:** 12
- **TEST DATE(S):** **START:** 21 March 2005

  FINISH: 8 April 2005

TEST OBJECTIVES:

Measure TGOC emissions as a function of volumetric flowrate using THC for pouring, cooling, and shakeout for a total of 75 minutes. Measure the emissions for an Osco shell mold as tested in test GN

VARIABLES:

The principle variable will be air flow through the hood. The target air flow rate will be 300, 700, and 1300 SCFM. The mold shall be a 6-on shell mold provided by Osco Industries. The mold shall be made with 4.75% HA International Super F2 E/J19P122689W coated shell sand. Molds will be poured with iron at 2630 +/- 10^{o}F. Mold cooling will be 60 minutes followed by 5 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:

A previous test FM studied the TGOC emissions from a Furan No-bake® mold. In that test it was inconclusive as to whether there was or was not a velocity dependent emission rate, all else being the same. At that time we did not have the capability to measure all of the emission by-products of the casting process in simultaneous real time. We now have the capability to simultaneously measure hydrocarbons, CO, CO_2, & NOx in real time.

This chemical system does not have much if any evaporative component. That which is captured will be principally decomposition and combustion byproducts. The mold itself is very thin so diffusion will not play a large part in controlling emission rates. In this test temperature from the mold interior from the solidifying casting will be a strong driving force for emission.

SPECIAL CONDITIONS:

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

Series 1411-6.1.4 GP

PCS Shell Molds with HA International & OSCO Industries "Low Emission" Shell Sand Binders

Process Instructions

A. Experiment

1. Measure pouring, cooling, & shakeout emissions from shell sand molds made by OSCO Industries from new sand and HA International shell sand resin or from reclaimed OSCO shell sand and an OSCO Industries developed " low emission" shell sand resin Using various volumetric air flow rates.
2. Six (6) new HA molds will be tested at air capture flow rates of nominally 700 and 1300 SCFM. The new molds poured under test GN will be used to represent nominally 300 SCFM air capture rates. The total molds shell number twelve (12) total molds.

B. Materials

1. HA International supplied new material shell sand as a baseline mold.
2. Metal: Class-30 gray cast iron poured at 2630 +/- 10^{o}F.
3. Pattern: Six on housing. All molds made by OSCO Industries.

C. Briefing

1. The Process Engineer, Emissions Engineer, and the area Supervisor will brief the operating personnel on the requirements of the test at least one (1) day prior to the test.

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

D. Shell sand molds:

1. Shell molds will be manufactured for us by OSCO Industries, Jackson, Ohio.
2. Weigh and record the weight of all molds received.
3. Six (6) molds of the HA international resin sand most nearly alike in color and weight will be selected from the 15 molds supplied for the test.
4. The sand lab will sample from the corner of each of the 15 molds to be used. Those molds will be tested for LOI using the standard 1800^{o}F core LOI test method.

Caution: Do not breach the mold cavities when obtaining the lab samples.

E. Emission hood

1. Loading.
   a. Place a mold pouring tray containing 1-2 inches of clean dry Nevada 70 sand on the shakeout assembly within the emission hood.
   b. Place a shell mold with the pour basin near the pouring deck side onto the mold pouring tray within the emission hood.

Caution: Keep the parting line of the shell mold below the top of the pouring tray.

- **c.** Close, seal, and lock the emission hood
- **d.** Adjust the ambient air heater control so that the measured temperature of the blended air within the hood is 85-90^{o}F at the start of the test run.

2. Shakeout.
- **a.** After the 60 minute cooling time prescribed in the emission sample plan has elapsed turn on the shakeout unit and run for it the 5 minutes prescribed in the emission sample plan.
- **b.** Turn off the shakeout.
- **c.** Sample the emissions for 15 minutes after the start of shakeout, a total of 75 minutes.

3. When the emission sampling is completed remove the mold pouring pan, castings and sand.
- **a.** Weigh and record the metal poured and un-decomposed core butts.
- **b.** Clean any spilled sand from the hood, shakeout, and floor.

F. Melting:

1. Initial iron charge:
- **a.** Charge the furnace according to the heat recipe.
- **b.** Place part of the steel scrap on the bottom, followed by carbon alloys, and the balance of the steel.
- **c.** Place a pig on top 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^{o}F.
- **f.** Slag the furnace and add the balance of the alloys.
- **g.** Raise the temperature of the melt to 2700^{o}F and take a DataCast 2000 sample. The temperature of the primary liquidus (TPL) must be in the range of 2200-2350^{o}F.
- **h.** Hold the furnace at 2500-2550^{o}F until near ready to tap.
- **i.** When ready to tap raise the temperature to 2700^{o}F and slag the furnace.
- **j.** Record all metallic and alloy additions to the furnace, tap temperature, and pour temperature. Record all furnace activities with an associated time.

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

3. Emptying the furnace
- **a.** Pig the extra metal only after the last emission measurement is complete to avoid contaminating the air sample.

- **b.** Cover the empty furnace with ceramic blanket to cool.

G. Pouring

1. Preheat the ladle.

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

H. Pig molds

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

Steven M. Knight
Mgr. Process Engineering

PRE-PRODUCTION GP - SERIES SAMPLE PLAN											
Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
4/5/2005											**700 SCFM TEST**
RUN 1											
THC	GP001	X									TOTAL
CO, CO2, Nox	GP001	X									TOTAL

PRE-PRODUCTION GP - SERIES SAMPLE PLAN											
Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
4/5/2005											**700 SCFM TEST**
RUN 2											
THC	GP002	X									TOTAL
CO, CO2, Nox	GP002	X									TOTAL

PRE-PRODUCTION GP - SERIES SAMPLE PLAN											
Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
4/5/2005											**700 SCFM TEST**
RUN 3											
THC	GP003	X									TOTAL
CO, CO2, Nox	GP003	X									TOTAL

PRE-PRODUCTION GP - SERIES SAMPLE PLAN											
Method	Sample #	Data	Sample	Duplicate	Blank	Breakthrough	Spike	Spike Duplicate	Flow (ml/min)	Train Channel	Comments
4/6/2005											**1000 SCFM TEST**
RUN 4											
THC	GP004	X									TOTAL
CO, CO2, Nox	GP004	X									TOTAL

PRE-PRODUCTION GP - SERIES SAMPLE PLAN											
Method	**Sample #**	**Data**	**Sample**	**Duplicate**	**Blank**	**Breakthrough**	**Spike**	**Spike Duplicate**	**Flow (ml/min)**	**Train Channel**	**Comments**
4/6/2005											**1000 SCFM TEST**
RUN 5											
THC	GP005	X									TOTAL
CO, CO2, Nox	GP005	X									TOTAL

PRE-PRODUCTION GP - SERIES SAMPLE PLAN											
Method	**Sample #**	**Data**	**Sample**	**Duplicate**	**Blank**	**Breakthrough**	**Spike**	**Spike Duplicate**	**Flow (ml/min)**	**Train Channel**	**Comments**
4/6/2005											**1000 SCFM TEST**
RUN 6											
THC	GP006	X									TOTAL
CO, CO2, Nox	GP006	X									TOTAL

PRE-PRODUCTION GP - SERIES SAMPLE PLAN											
Method	**Sample #**	**Data**	**Sample**	**Duplicate**	**Blank**	**Breakthrough**	**Spike**	**Spike Duplicate**	**Flow (ml/min)**	**Train Channel**	**Comments**
4/7/2005											**300 SCFM TEST**
RUN 7											
THC	GP007	X									TOTAL
CO, CO2, Nox	GP007	X									TOTAL

PRE-PRODUCTION GP - SERIES SAMPLE PLAN											
Method	**Sample #**	**Data**	**Sample**	**Duplicate**	**Blank**	**Breakthrough**	**Spike**	**Spike Duplicate**	**Flow (ml/min)**	**Train Channel**	**Comments**
Test not run.											**500 SCFM TEST**
RUN 8											
THC	GP008	X									TOTAL
CO, CO2, Nox	GP008	X									TOTAL

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APPENDIX B DETAILED EMISSION RESULTS

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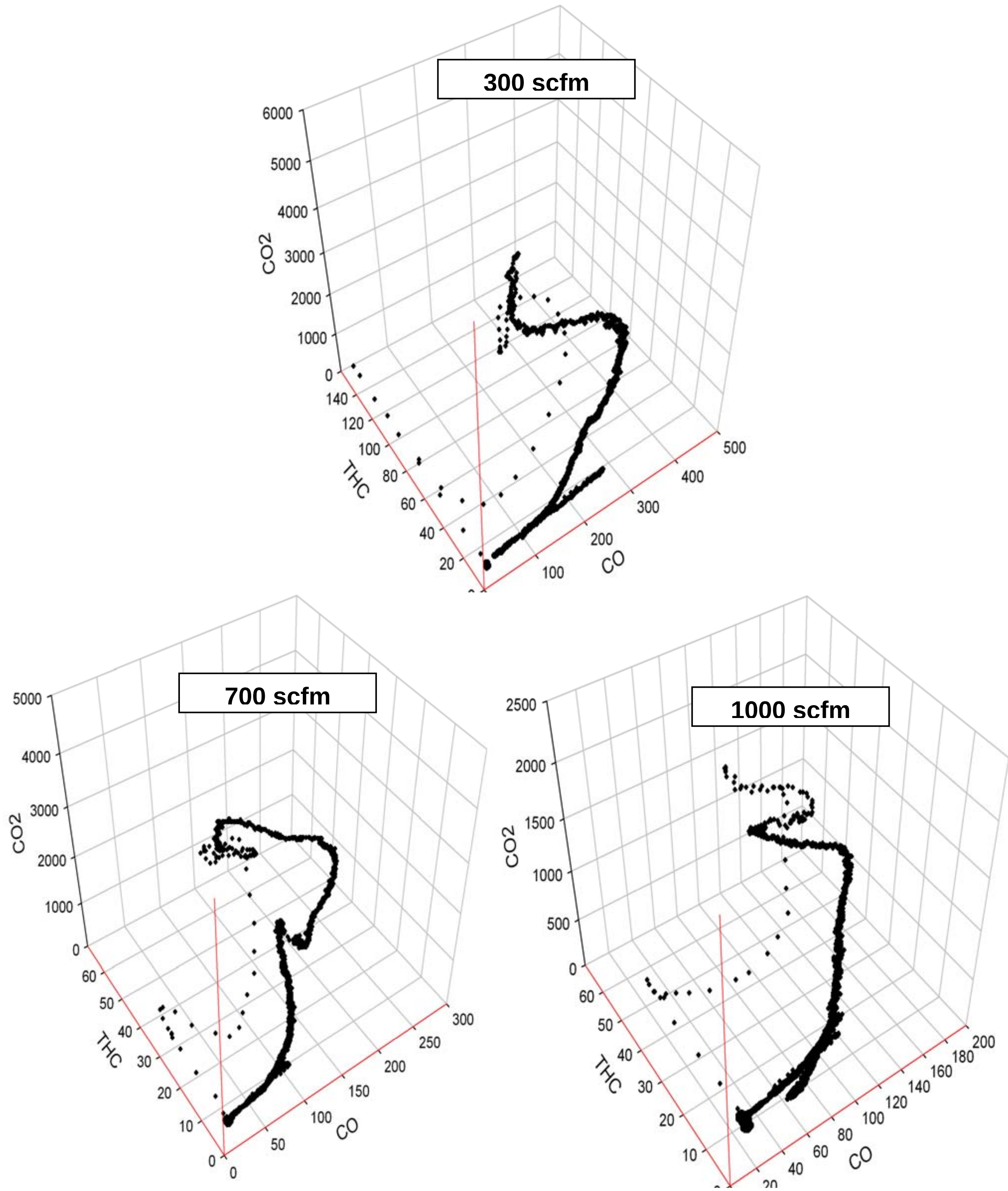
Shell Mold																	
Test Dates	03/28/05	03/28/05	03/29/05	03/29/05	03/29/05	03/30/05	Averages	4/5/05	4/5/05	4/5/05	Average	4/6/05	4/6/05	4/6/05	Average	4/7/05	Average
Emissions Sample #	GN001	GN002	GN003	GN004	GN005	GN006		GP001	GP002	GP003		GP004	GP005	GP006		GP007	
Production Sample #	GN001	GN002	GN003	GN004	GN005	GN006		GP001	GP002	GP003		GP004	GP005	GP006		GP007	
Air flow, SCFM	304	311	310	305	315	315	310	728	737	738	734	1033	1032	1026	1030	312	312
TGOC, ppm	12.01	12.46	12.01	13.19	15.89	10.40	12.66	9.76	10.32	9.38	9.82	7.03	5.76	10.12	7.637	12.31	12.31
TGOC, Lb/Lb. Binder	0.023	0.023	0.022	0.024	0.029	0.020	0.02	0.043	0.045	0.041	0.043	0.043	0.035	0.061	0.046	0.022	0.022
TGOC, Lb,Ton metal	1.439	1.450	1.454	1.605	1.845	1.253	1.51	2.729	2.911	2.705	2.782	2.828	2.387	4.057	3.091	1.475	1.475
CO, ppm	134	170.45	158.04	170.82	176.64	156.98	161.16	76.8	83.6	82.7	81.0	54.3	46.9	50.0	50.4	158.2	158.2
CO, Lb/Lb Binder	0.16	0.20	0.19	0.20	0.21	0.19	0.19	0.215	0.234	0.229	0.226	0.211	0.182	0.191	0.195	0.182	0.182
CO, Lb/Ton Metal	10.22	12.62	12.18	13.23	13.05	12.03	12.22	13.67	15.02	15.17	14.62	13.89	12.36	12.76	13.00	12.07	12.07
CO2, ppm	517.93	598.30	586.20	574.69	644.96	597.39	586.58	233.0	231.9	242.0	235.6	130.1	116.8	84.3	110.4	587.7	587.7
CO2, Lb/Lb Binder	0.99	1.11	1.10	1.06	1.18	1.17	1.10	1.024	1.019	1.053	1.032	0.796	0.711	0.506	0.671	1.063	1.063
CO2, Lb/Ton Metal	62.07	69.62	70.99	69.94	74.87	71.95	69.91	65.15	65.41	69.80	66.79	52.35	48.41	33.79	44.85	70.43	70.43
NOx, ppm	2.19	2.17	2.36	2.15	2.44	2.32	2.27	1.282	1.221	1.096	1.200	0.663	0.665	0.606	0.645	2.397	2.397
NOx, Lb/Lb Binder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0038	0.0037	0.0033	0.004	0.003	0.0028	0.0025	0.003	0.003	0.003
NOx, Lb/Ton Metal	0.18	0.17	0.19	0.18	0.19	0.19	0.18	0.2445	0.2348	0.2156	0.2316	0.1819	0.1879	0.1657	0.1785	0.1958	0.1958

The extensive real time data detail may be viewed at the Technikon Offices.

CO vs. THC vs. CO_2



APPENDIX C DETAILED PROCESS DATA

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Shell Mold																	
Test Dates	03/28/05	03/28/05	03/29/05	03/29/05	03/29/05	03/30/05	Averages	4/5/05	4/5/05	4/5/05	Average	4/6/05	4/6/05	4/6/05	Average	4/7/05	Average
Emissions Sample #	GN001	GN002	GN003	GN004	GN005	GN006		GP001	GP002	GP003		GP004	GP005	GP006		GP007	
Production Sample #	GN001	GN002	GN003	GN004	GN005	GN006		GP001	GP002	GP003		GP004	GP005	GP006		GP007	
Cast Weight (all metal inside mold), Lbs.	43.85	44	43.25	42.9	44.25	44.05	43.72	43.85	44.00	43.10	43.65	43.25	41.95	43.10	42.77	43.85	43.85
Pouring Time, sec.	21	17	22	17	17	16	18	18	17	21	19	19	18	18	18	18	18
Pouring Temp ,°F	2639	2630	2623	2624	2639	2637	2632	2621	2633	2625	2626	2632	2629	2629	2630	2640	2640
Pour Hood Process Air Temp at Start of Pour, ^{0}F	86	87	86	86	87	86	86	85.6	85.8	88.5	86.63	88	88	88	87.97	86	85.80
Total Shell mold Weight, Lbs.	30.25	30.35	30.85	31.05	30.95	29.95	30.57	30.75	31.15	31.50	31.13	31.35	31.50	31.75	31.53	32.05	32.05
Core Reported Binder Content, %BOS	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
Core Binder Calculated Resin Content , %	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53	4.53
Total Binder Weight in Mold, Lbs.	1.37	1.38	1.40	1.41	1.40	1.36	1.39	1.39	1.41	1.43	1.41	1.42	1.43	1.44	1.43	1.45	1.45
Weight of mold remaining as core butts, Lbs	7.45	9.7	10.1	8.1	8.3	8.6	8.7	9.30	8.50	8.45	8.75	9.20	9.45	10.65	9.77	7.75	7.75
Shell mold LOI, %	5.22	5.05	5.04	5.17	5.19	5.05	5.12	4.99	5.14	5.22	5.12	5.02	4.92	5.22	5.05	5.10	5.10
Approximate Shell mold Age, days	10	10	11	11	11	12	11	18	18	18	18	19	19	19	19	20	20

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APPENDIX D METHODS 3A, 7E, 10, 25A, & OTHER CHARTS

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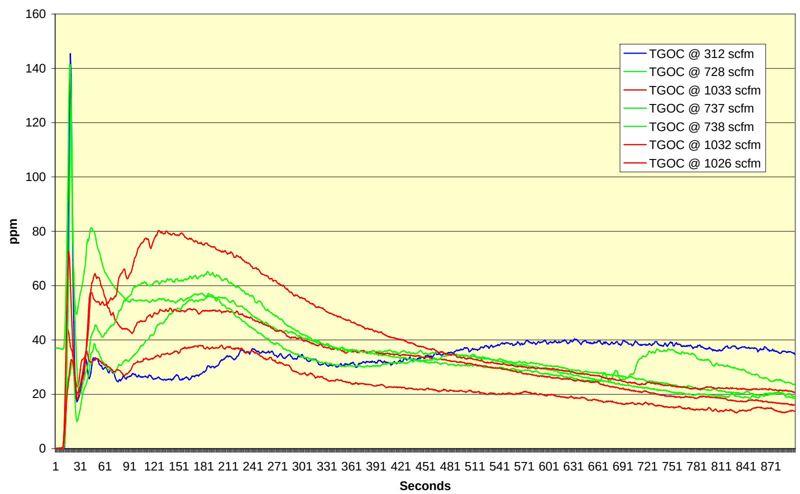
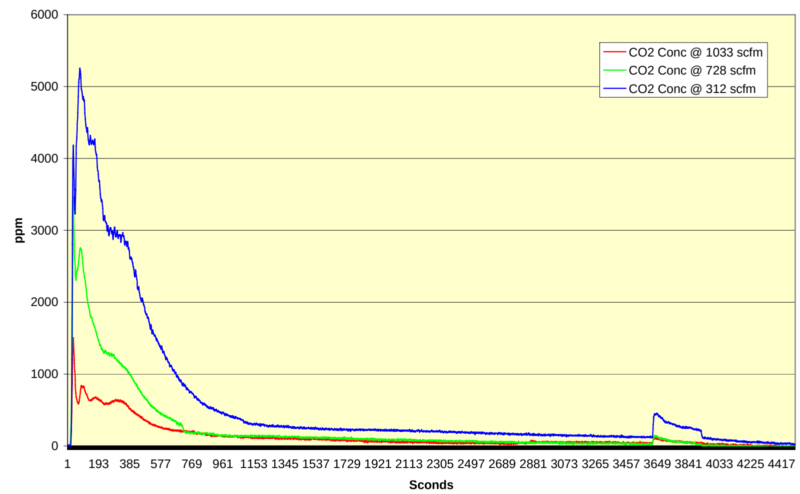
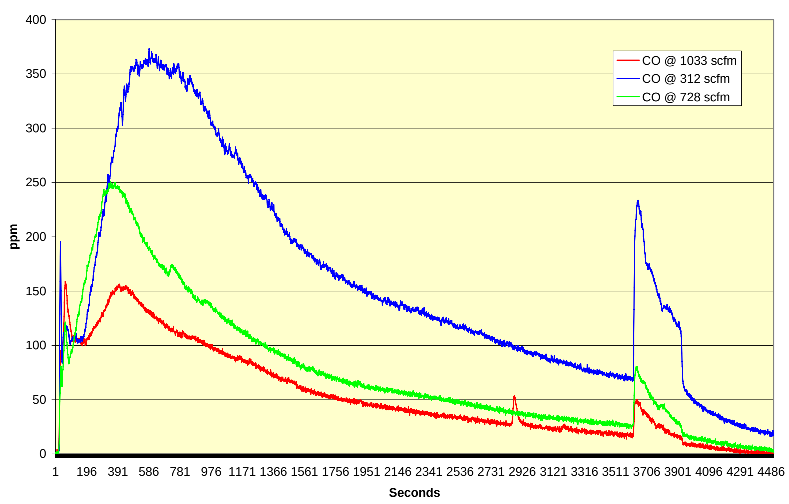
TGOC Concentration vs Time for Different Volumetric Flow Rates



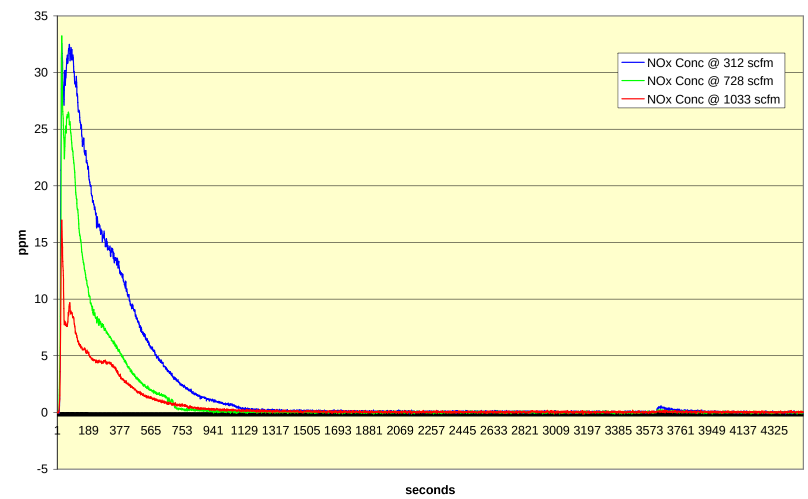
CO_2 Concentration vs Elapsed Time

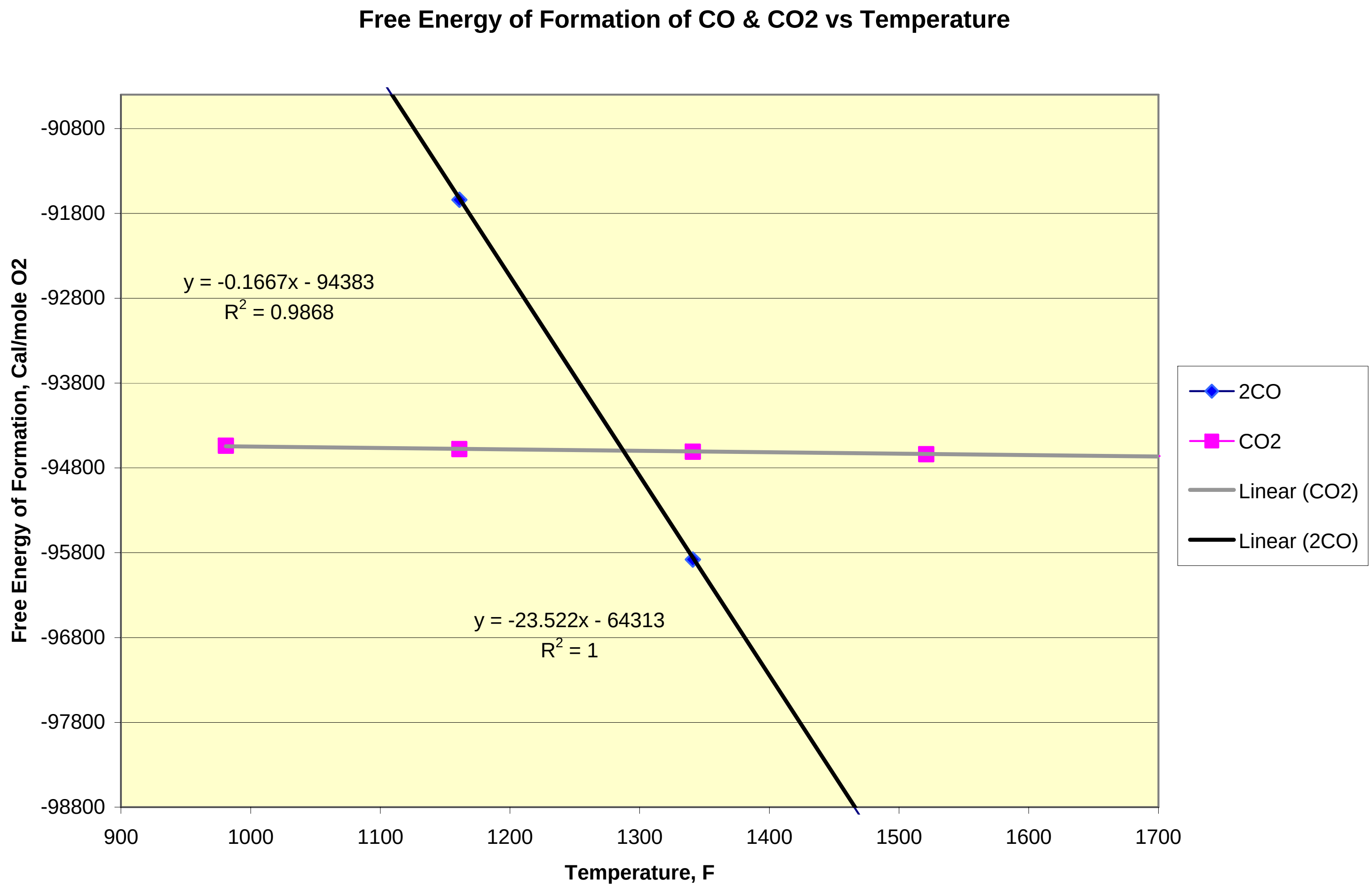


CO Concentration vs Time



NOx concentration vs Elapsed Time




Free Energy of Formation of CO & CO2 vs Temperature
Free Energy of Formation, Cal/mole O2
-90800
-91800
-92800
-93800
-94800
-95800
-96800
-97800
-98800
900
1000
1100
1200
1300
1400
1500
1600
1700
Temperature, F
y = -0.1667x - 94383
R2 = 0.9868
y = -23.522x - 64313
R2 = 1
2CO
CO2
Linear (CO2)
Linear (2CO)

APPENDIX E ACRONYMS & ABBREVIATIONS

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Glossary

BO	Based on ( ).
BOS	Based on Sand.
HAP	Hazardous Air Pollutant defined by the 1990 Clean Air Act Amendment
Free Energy of Formation	Thermodynamic quantity used to measure the probability that a chemical reaction will occur, specifically the compounds CO and CO_2, from their elements. The free energy of formation does not address the rate of progress.
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
scfm	Standard Cubic Feet Per Meter
PCS	Pouring, Cooling and Shakeout

Final page of report