Casting Emission Reduction Program

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No-bake Variables - Aluminum Study

Test #1409-151-EZ

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United States Environmental Protection Agency

CISA

AMERICAN FOUNDRY SOCIETY, INC.

UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

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No-bake Variables - Aluminum Study

1409-151 EZ

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

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The data contained in this report were developed to assess the relative emissions profile as the process parameters were varied using the equipment installed at Technikon. 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 testing was to determine the relationships of emissions from pouring and cooling of aluminum into No-Bake Molds to the manufacturing process parameters using a CERP standard phenolic urethane (PU) binder system.

The Pouring was conducted within an enclosure meeting the criteria for a temporary total enclosure (TTE) as specified in US EPA Method 204. All sampling locations were consistent with US EPA Method 1. US EPA Method 25A, Total Gaseous Organic Concentration (TGOC), was used to measure emissions in all segments of the test.

Process variables (casting surface area, cast weight, aluminum pouring temperature, & binder content) were evaluated regarding their influence on the air borne emissions during pouring and cooling for a total of 60 minutes. These variables were chosen because they were found to be the emission drivers during the pouring, cooling, and shakeout variability studies previously done by Technikon on Greensand and no-bake molds poured with iron.

The major emissions from the PU binders were caused by the evaporation, combustion, and recombination of the solvents and resins within the binder.

Surface area variation (317 to 2198 square inches) was achieved by using finned plate, flat plate and spherical patterns having the required surface area but which poured to a nearly constant weight. The cast weight variation (16 to 42 pounds) was achieved with flat plate patterns of different thickness whose surface areas were nearly the same. The pour temperature variation (1400 to 1800^{o}F) and the binder composition variation (0.8 to 1.3%) were achieved with only the finned plate pattern and changes in metal temperature and binder content.

All four of the chosen process variables demonstrated increases in emissions with increases in the parameter.

The total TGOC emissions as Propane by all methods ranged from 0.02 to 0.05 pounds from a 950 pound mold. The table below delineates the aluminum regression equations by process parameter and the relative impact on the emissions over the test range.

Process Event	No-bake P,C,S Regression Equations Lbs	Correlation Coefficient R^2	Relative Emission Change over the Parameter Range
Cast Surface Area, sq. in	Y = 0.00001 X + 0.0142	0.89	3.6
Cast weight, Lbs	Y = 0.0002 X +0.0207	0.48	1.0
Pour Temperature, F	Y = 0.00003 X + 0.0009	0.65	2.7
Binder Content, %	Y = 0.0243 X + 0.0052	0.53	2.4

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.

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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). 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 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 manual 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 <u>discrete</u> 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 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. Detailed data is included in Appendix B of this report. Section 3 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 Plans and Objectives

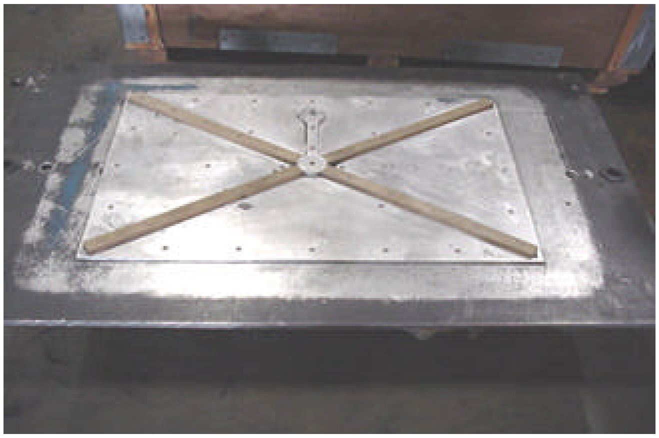
This report contains the results of testing performed to assess the emissions impact of several casting and process variables. Various test patterns were used to prepare the molds, based on the specific test objectives. The patterns included flat plates, a sphere, and a finned plate. Table 1-1 provides the specific geometry for each of the test patterns. Figure 1-1 includes pictures of the test patterns used. The use of the various patterns allowed for evaluations of the impact of variable cast weight and surface area. A summary of the test plan for the individual test series is shown in Table 1-2.

Table 1-1 Mold Pattern Characteristics

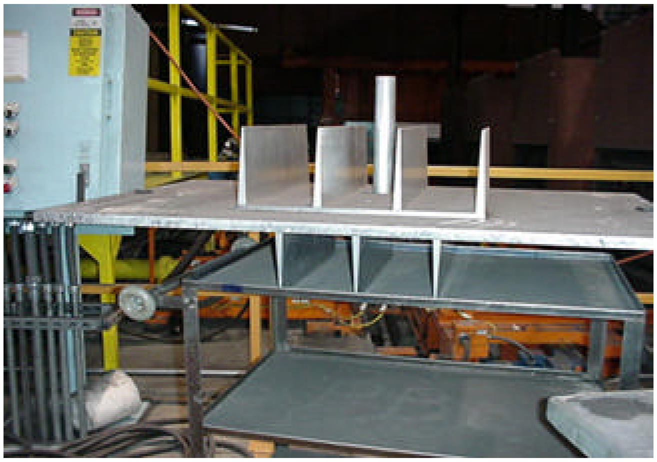
Pattern	Shape	Dimensions (inches)	Pattern Surface Area (in^2)	Poured Surface Area (in^2)	V/SA Ratio[a] (in.)	Design Cast Weight, lbs.
P1	Plate	18 x 28 x ¼	1031	1164	0.131	17
P3	Plate	18 x 28 x ¾	1077	1210	0.363	38
FP3	Finned Plate	18 x 17.5 x 0.8 plate plus 7 – 6 x 18 x 3/8 fins	2121	2198	0.198	40
SP3	Sphere	9 $^{3}/_{16}$ Diameter	265	317	1.360	40

[a] Volume to Surface Area Ratio of the casting pattern

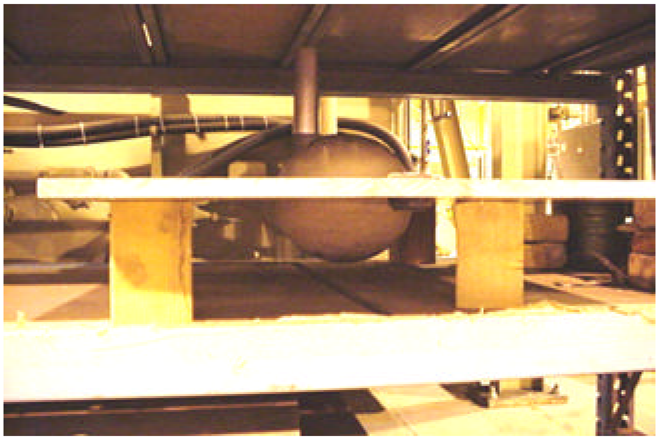
Figure 1-1 Test Patterns



Flat Plate



Finned Plate



Sphere

Table 1-2 Test Plan Summary

Parameter Varied	"Cast Weight"	Cast Surface Area	Binder Content	Pour Temperature
Casting Type	Plates	Sphere, Plate, and Finned Plate	Finned Plate	Finned Plate
Patterns Used	P1, P3	SP3, P3, & FP3	FP3	FP3
Metal Cast	Aluminum	Aluminum	Aluminum	Aluminum
Total Test Time(s), min.	60	60	60	60
Number of molds poured	6	6 (9*)	6 (9*)	3 (6*)
Mold Type	HA International 20-665/23-635/17-727 No-Bake			
Emissions Measured	Total Gaseous Organic Concentration (TGOC)			
Process Parameters Measured	Total Casting Weight, Surface Area, Sand Weight, Binder Weight, Pour Temperature, Poured Metal Weight, % LOI, Metal Chemistry			

(*) Molds are shared in common for the evaluation of a given parameter leading to the number of molds in parentheses being used to generate regression curves.

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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

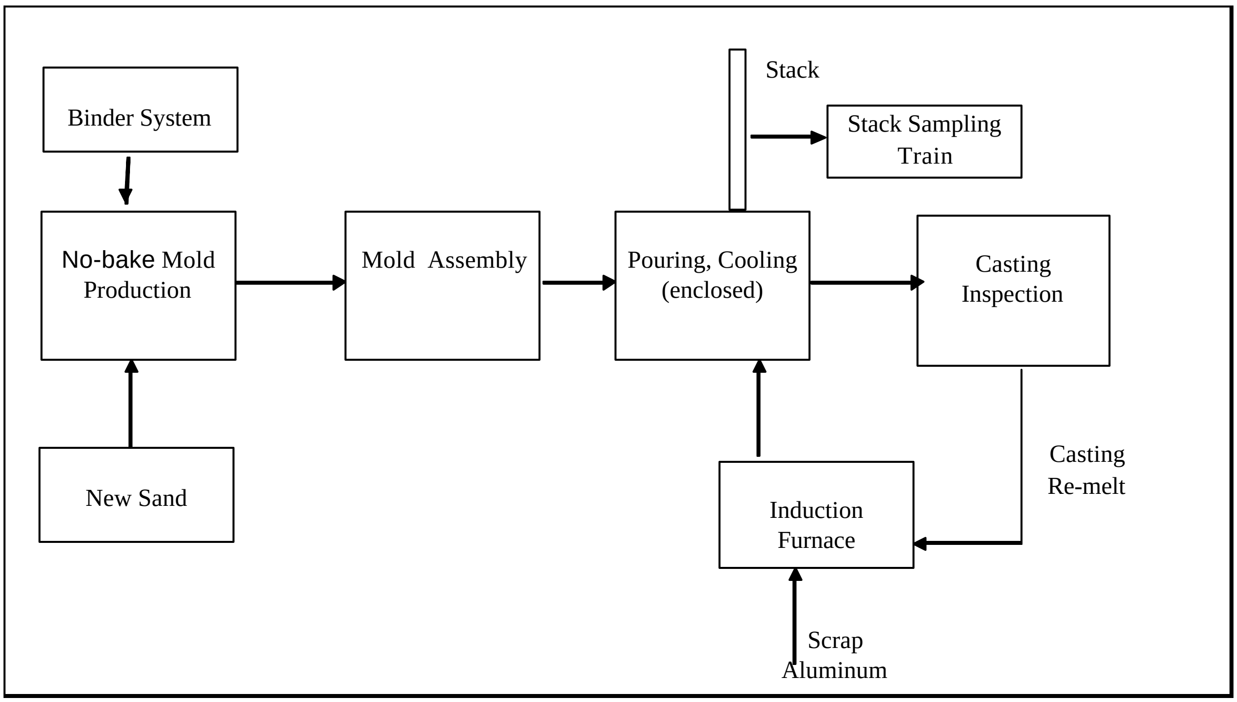


Figure 2-2a Picture of the No-Bake Mixing and Compaction Table Equipment

Figure 2-2b Picture of the Pouring Enclosure Used During the Pouring Process in the Pre-Production Foundry

2.2 Description of Testing Program

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

Measurements were taken during pouring and casting cooling and were performed on discrete mold packages under tightly controlled conditions not practical in a commercial foundry. The testing involved continuous monitoring of the enclosed test stand exhaust during each test run that included the mold pouring and cooling periods. The process parameters measured included: the surface area of the casting, 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. Several of these process variables were controlled by the use of a variety of test patterns including flat plates, a sphere, and a finned plate.

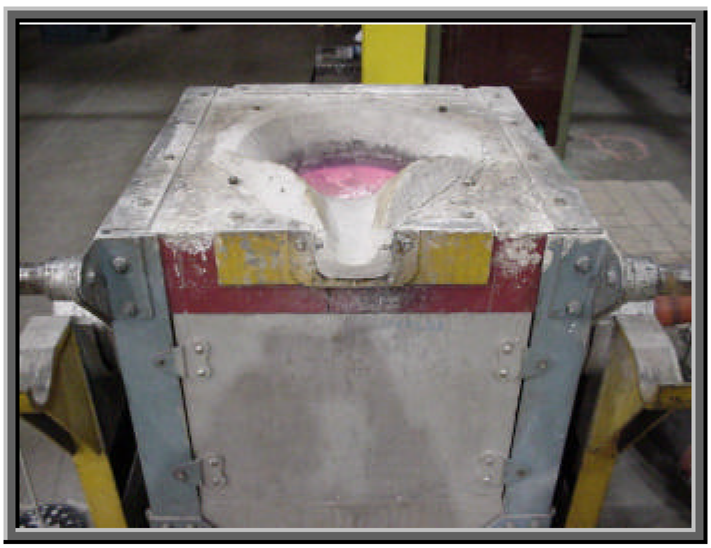
The process parameters not being evaluated were maintained within prescribed ranges in order to ensure the reproducibility of the tests. Emissions were measured according to US EPA Method 25A, Total Gaseous Organic Concentration, calibrated with propane.

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

1. **<u>Mold Preparation:</u>** 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 degrees Fahrenheit. The sand was placed in 24 x 36 x 11 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. **<u>Metal Preparation:</u>** A-356 aluminum was melted in a 200-pound 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 metal composition was assured using master alloys or re-melted metal there from. The weight of metal poured into each mold was recorded on the Process Data Summary Sheet.

Figure 2-2c Melting furnace



3. **<u>Individual Sampling Events:</u>** The 950 pound 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 sixty (60) minute pouring and cooling process. The weights of the molds were recorded for each mold on the Process Data Summary Sheet. In addition, the metal pour temperature & % LOI, was recorded on the Process Data Summary Sheet.

   The insulated emission hood was supplied with air heated to 85 to 90^{o}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.

Figure 2-2d Pouring Hood and Attached Sampling Stack

4. Test Plan Review and Approval

The proposed test plan was reviewed by the Technikon staff and the CERP Steering Committee, 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	Westweigh PP2847 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 USEPA 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	USEPA Method 1
Number of traverse points	USEPA Method 1
Gas velocity and temperature	USEPA Method 2
Gas moisture	US EPA Method 4 Gravimetric
Total Gaseous Organic Concentration	US 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 to provide emissions data in pounds. 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, the Technikon President, and the USCAR Representative. Comments are incorporated into a draft Final Report prior to final signature approval and distribution to USCAR.

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 Weight of TGOC (THC) emissions as propane recovered from 60 minute pouring and cooling cycle.

Figure3-1 shows the variation in TGOC emissions as propane derived from variation of the casting surface area in Lake sand phenolic urethane no-bake molds during 60 minutes of pouring and cooling .

Figure3-2 shows the variation in TGOC emissions as propane derived from variation of casting weight in Lake sand phenolic urethane no-bake molds during 60 minutes of pouring and cooling.

Figure3-3 shows the variation in TGOC emissions as propane derived from variation of pouring temperature in Lake sand phenolic urethane no-bake molds during 60 minutes of pouring and cooling

Figure3-4 shows the variation in TGOC emissions as propane derived from variation in binder content in Lake sand phenolic urethane no-bake molds during 60 minutes of pouring and cooling

Table 3-2 Emission regression equations for aluminum No-Bake molds and relative emission impact by process parameter.

Table 3-1 Weight of TGOC emissions as propane recovered from 60 minute pouring and cooling cycle.

Pour Cool Parameter	Process Parameter Target Value	TGOC Emission Weight as propane, pounds
Casting Surface Area, Finned Plate	2198	0.0403
	2198	0.0341
	2198	0.0439
Casting Surface Area, Sphere	317	0.0178
	317	0.0187
	317	0.0324
Casting Weight, ¾ inch flat plate	1210	0.0306
	1210	0.0266
	1210	0.0252
Casting Weight, ¼ inch flat plate	1164	0.0218
	1164	0.0251
	1164	0.0235
Binder Content, %	1.16	0.0298
	1.16	0.0275
	1.14	0.0300
Aluminum pour temperature, F	1802	0.0496
	1818	0.0554
	1795	0.0458
Binder Content, %	0.79	0.0321
	0.79	0.0230
	0.79	0.0217

Figure 3-1 TGOC Emissions vs. Casting Surface Area

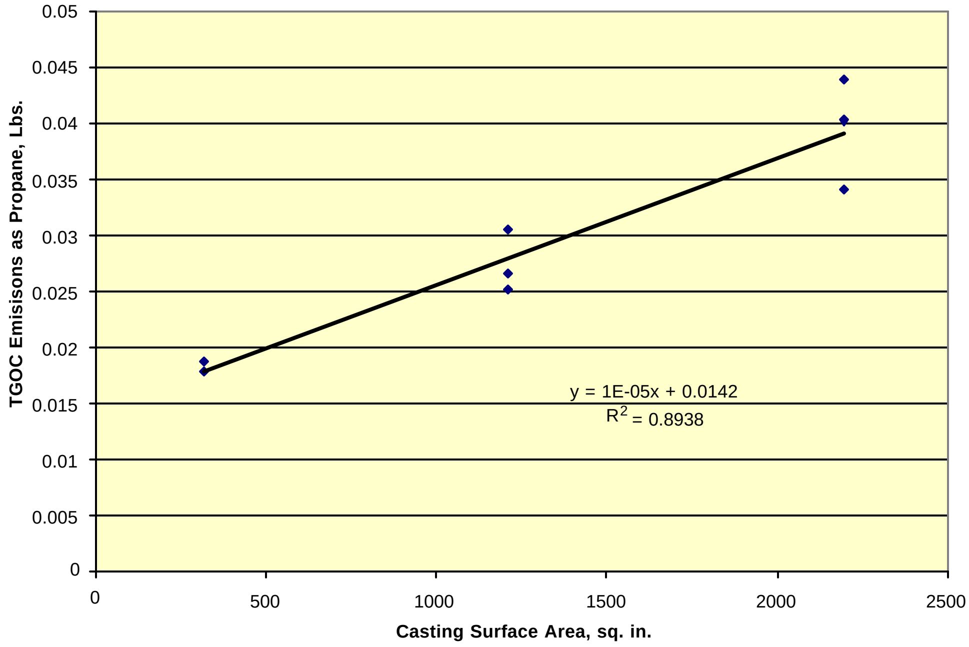


Figure 3-2 TGOC Emissions vs. Cast Weight

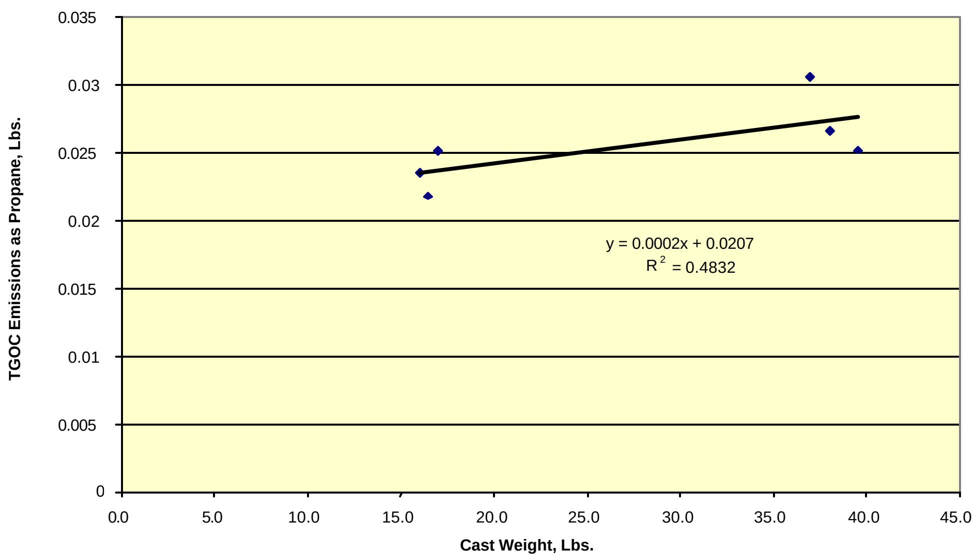


Figure 3-3 TGOC Emissions vs. Aluminum Pour Temperature

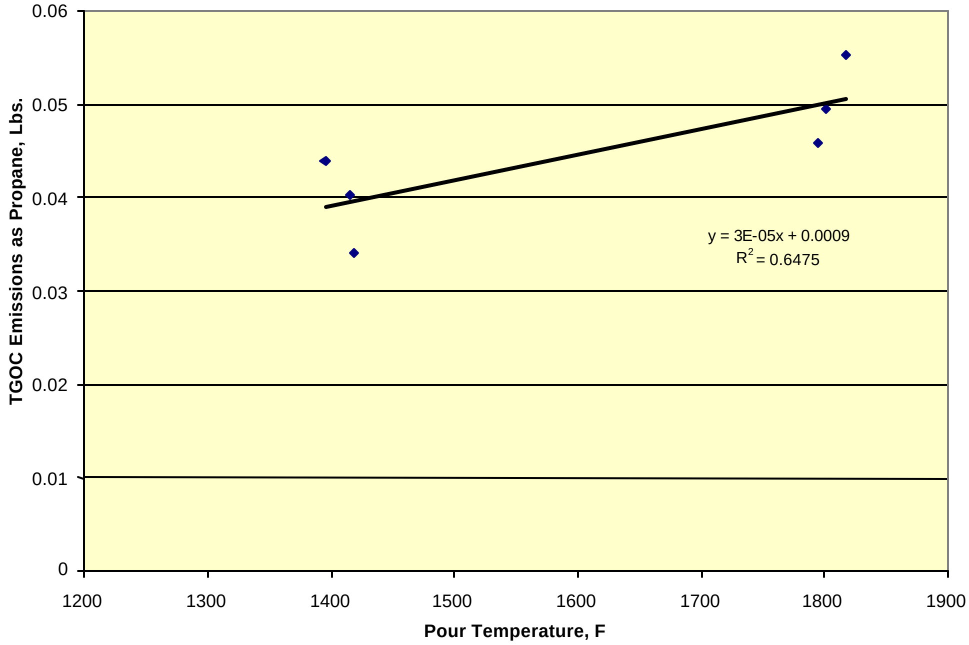


Figure 3-4 TGOC Emissions vs. No-Bake Binder Content

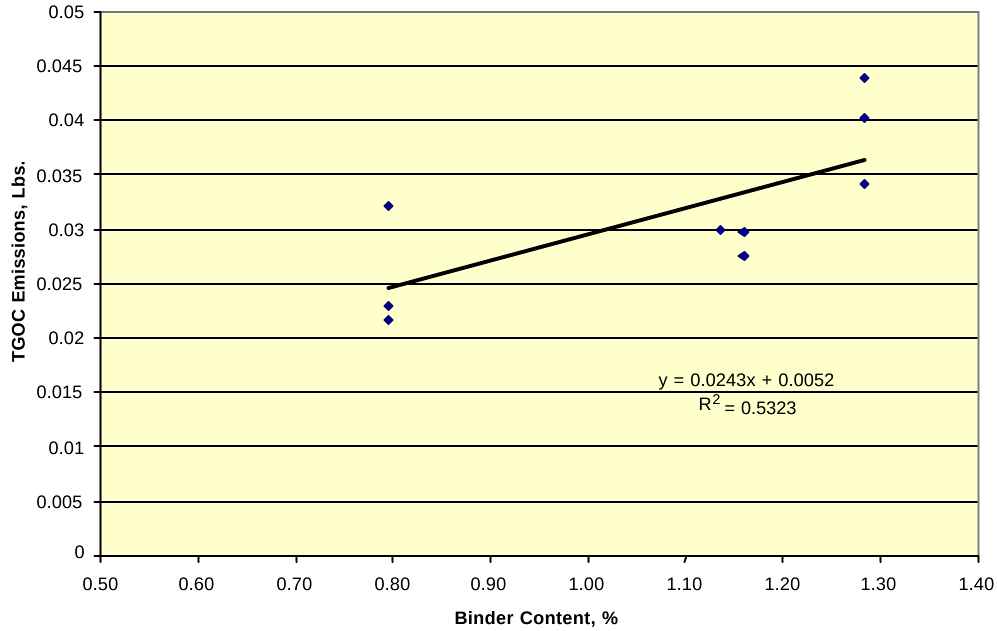


Table 3-2 Emission Regression Equations for Aluminum No-Bake Molds

Process Event	No-Bake P,C,S Regression Equations Lbs	Correlation Coefficient R2	Parameter Range		Calculated Emission Lbs.		Emission Range for Parameter Range Lbs.	Relative Emission Change over the Parameter Range
Cast Surface Area, sq. in	Y = 0.00001 X + 0.0142	0.89	417	2198	0.018	0.036	0.018	3.6
Cast weight, Lbs	Y = 0.0002 X +0.0207	0.48	15	40	0.024	0.029	0.005	1.0
Pour Temperature, F	Y = 0.00003 X + 0.0009	0.65	1400	1850	0.051	0.065	0.014	2.7
Binder Content, %	Y = 0.0243 X + 0.0052	0.53	0.8	1.3	0.025	0.037	0.012	2.4

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4.0 Discussion of Results

All of the pouring and cooling measurements were conducted within enclosures meeting the criteria for a temporary total enclosure according to US EPA Method 204. Results in this report are expressed in pounds.

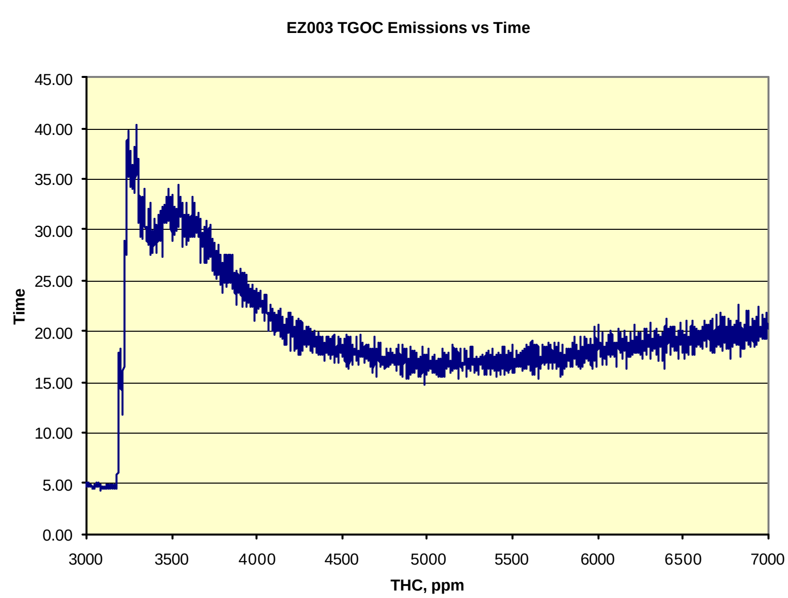
The TGOC as Propane represents the sum of all hydrocarbon compounds emitted from the source without regard to specie. The THC has a different response sensitivity to structurally different compounds with the same carbon content.

The stack air properties were measured and a ratio formed of mass flow rates of the THC sample and the stack. The TGOC concentration was converted to mass unit as propane and then multiplied by the ratio of stack volume to THC sample volume to arrive at the mass emitted expressed as Propane.

The emission mechanism is principally sand surface evaporation of binder solvents and combustion and recombination of both the resins and solvents driven by the thermal energy released from the metal. The metal mass and temperature reflects the quantity and quality of heat energy available to the mold binders. The casting surface area and the binder density (content) in the sand reflect the spatial opportunity for the metal's heat to come in contact with the organic binder components to generate emissions.

The relational results are consistent with previous studies done with iron in a different phenolic urethane No-Bake binder and iron done in green sand molds.

The following chart is typical of the TGOC measurements made of each pouring and cooling run.



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APPENDIX A APPROVED TEST PLAN FOR TEST EZ

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TECHNIKON TEST PLAN

>	**CONTRACT NUMBER:**	1409 **TASK NUMBER**: 1.5.1 **Test** EZ
>	**WORK ORDER NUMBER:**	1174
>	**SAMPLE EVENTS:**	001 thru 018
>	**SITE:**	__X__ **PRE-PRODUCTION**
>		_____ **FOUNDRY**
>	**TEST TYPE:**	Aluminum No bake Process Variability Study of Pouring and Cooling
>	**METAL TYPE:**	356 Aluminum
>	**MOLD TYPE:**	No bake sand mold made with HA International 7211 Resin, 7706 Co-reactant, and 17-727 Activator
>	**NUMBER OF MOLDS:**	18
>	**CORE TYPE:**	None
>	**TEST DATE:**	**START:** 28 Feb 2003
		FINISHED: 8 Apr 2003

TEST OBJECTIVES:

Define the process parameters that drive emissions from no-bake molds.

VARIABLES

All molds will be poured and cooled for 60 minutes with no shakeout. Emissions will be continuously monitored by the THC. The process variables will be cast weight, cast surface area, binder content and aluminum metal pour temperature The cast weight will be varied in the range of 15-40 pounds, the cast surface area will be varied in the range 317-2198 square inches, the binder content will be varied in the range of 0.8-1.3% (BOS), and temperature will be varied using only aluminum poured in the range 1400-1800^{o}F.

BRIEF OVERVIEW:

Technikon previously conducted process variable studies on coreless green sand molds that contained bituminous coal as the organic source and No-bake dry sand molds containing an organic binder. In the greensand test the process parameters, which are to be studied here, were established as the driving forces for emissions. The greensand also contained water that was observed to inhibit the temperature elevation of the materials with potential to emit. The first no-bake test, which contained no water, contained an organic binder intended for iron casting usage. In this No-bake study the organic binder, again containing no water, is intended for aluminum casting usage.

The green sand study also verified that emissions are continuous and accumulate with time until all materials cool below their characteristic threshold emission temperature. This feature is axiomatic and will not be repeated here.

SPECIAL CONDITIONS:

All molds will be 24 x 36 x 11/11 with a 4 inch pouring basin on top.

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 EZ

Alum No-bake Mold Process Variability Study

USARMY 1409-1.5.1, WO 1174

A. Experiment: Alum No-bake mold emissions vs. cast weight , surface area, binder content, and pour temperature, a total of 10 configurations repeated in triplicate.

1. No-Bake sand mold:

a. Amador 70 silica Sand
b. HA International 7211 resin 7706 Co-reactant, & 17-727 activator.

2. 2. Metal: A356 aluminum.

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. Emissions vs. cast surface area: Make three (3) molds each with pattern plate FP3 (finned plate, 2198 sq. in.), SP3 (sphere, 317 sq. in.). Total 6 new molds. Use 1.3% total binder. Pour with A-356 Aluminum at 1400^{o}F. Each mold has a cast weight of nominally 41 pounds in aluminum. The P3 (3/4 thick plate, 1210 sq. in.), mold poured in series 2 will complete this series of 9 molds.
2. Emissions vs. cast weight: Make three (3) molds each with the plate patterns P1 (1/4 inch thick, nominal 20 Lbs.), P3 (3/4 inch thick, nominally 41 Lbs.). Total 6 molds. Use 1.3 % total binder. Pour A-356 Aluminum at 1400^{o}F.
3. Emissions vs. Binder content: Make three (3) molds each with pattern FP3 (finned plate) with total binder contents of 0.8%. Total 3 new molds. Pour with A356 aluminum at 1400^{o}F. The FP3 molds poured at 1400oF and 1.3% binder from series 1 will complete this series of 6 molds.
4. Emissions vs. Temperature: Make (6) molds with the pattern FP3. Use 1.3% total binder. Pour three each with A356 aluminum at 1800^{o}F. The FP3 molds poured with aluminum at 1400^{o}F and 1.3% binder from series 1 will complete this series of 6 molds.

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: all patterns.

1. A 24 by 36 x11 inch no-bake mold flask is to be used as a table for the pattern.
2. The patterns "plate" in configurations P1, P3, "finned plate" FP3, and "Sphere" SP3 are to be used.
3. Inspect the flask and patterns for cracks and other damage. Repair before use.
4. Prepare the mold flask and pattern with a light coating of Ashland Zipslip® IP 78. Allow to fully dry.
5. Place the pattern drag side up on a 24x36x14 drag green sand pre-production flask as a stand.
6. Place the mold flask on the pattern.

Warning: Do no lift the steel mold flask with the pattern, the wood mold flask, or sand mold attached as it is then significantly top heavy and can spontaneously invert potentially causing bodily injury or capital damage.

7. Place the assembly on the Kloster vibrating compaction table.
8. Run a few pounds of waste sand then begin filling the box.
9. Manually spread the sand around the box as it is filling.
10. Start the table vibration when the flask is about 1/3 full.
11. Allow the vibrator to run an additional 10 seconds after the box is full.
12. Strike off the flask when it is full.
13. Set the dry sand mold, still in the flask and still on the pattern, aside for15 minutes even if it is hard to the touch.

Warning: Do no lift the steel mold flask with the pattern, the wood mold flask, or sand mold attached as it is then significantly top heavy and can spontaneously invert potentially causing bodily injury or capital damage.

14. 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.
15. Set the mold flask aside as it will be used for other copes and drags.
16. Separate the dry sand mold from the pattern using the mold lift and roll over device.
17. Immediately rotate the drag, hot face up, and place it on a flat transport pallet. Place the drag on a fully supportive surface to avoid sagging. Use a pallet that will allow lifting straps to be inserted under the mold.
18. Turn the pattern over cope side up. Clean the pattern.
19. Place the mold flask on the pattern, the sprue on its alignment stud, and move the assembly onto the compaction table.
20. Follow steps D6-D16.
21. Immediately rotate the unboxed cope dry sand mold hot face up.
22. Transport the cope to the drag, re-invert it and set it on the drag. Leave for at least 2 hours to allow it to conform to the drag and become rigid.
23. Lift the entire mold and place a support plate, two steel straps, and two (2) corner angle irons on the support pallet. Set the mold down.
24. Lift the dry sand mold cope, rotate it, and set it down on its side.
25. Drill vent-holes as per template.
26. Plate pattern: Drill five (5) 1/2 inch holes into the "X" on the cope surface through to the cope top exterior surface.
27. Sphere pattern: Drill one (1) 1/2 inch hole high on the cope interior surface through to the top exterior surface. Do not get within 2 inches of the sprue. Finned plate: Drill two ½ -holes from the highest point on the ends each of three cope fins through to the top exterior surface. Blow sand out of the mold.
28. Blow loose sand out of both cope and drag halves.
29. Rotate the cope mold hot face down and move it directly over the drag.
30. Quickly apply a liberal 1/4-3/8 inch bead of sodium silicate/clay adhesive about 1/2 inch back from the cavity. Apply a second smaller bead to the outer edge. It is important to do this quickly so that the adhesive does not set before the mold is closed.
31. Quickly close cope onto drag. Visually check for alignment of the mold edges.
32. Wipe the glued parting line.
33. 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.
34. Glue the pouring cup to the cope centered over the down sprue. Glue a second 1/2 pour cup on the top back half of the first to act as a splash guard
35. Transport the finished mold to the heated core storage room to be used the next day.
36. Weigh and record the net weight of the closed mold.

F. Emission hood:

1. Loading.

a. Obtain an mold from the core storage room.
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 two (2) full-length steel angels to provide clearance for removing the straps and keep the molds from walking during shakeout.
- **d.** Clamp the mold to the shakeout with steel clamps, one (1) on each end.
- **e.** Close, seal, and lock the emission hood.
- **f.** 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) 1/4 inch thick plates to allow ambient air to enter the bottom of the hood.
- **g.** Toggle clamp the flanges with the Teflon gasket in between.
- **h.** 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.
- **i.** 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.

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°F.
- **e.** When the metal is liquefied, about 1050 oF, add the balance of A-356/357 aluminum sows until all is melted and the temperature has reached 1250-1300°F.
- **f.** Slag the furnace and cover it.
- **g.** Hold the furnace at 1250-1300°F until near ready to tap.
- **h.** When ready to tap adjust the temperature to 1500-1525°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 40 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

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APPENDIX B SUMMARY TABLE AND PROCESS DATA

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Mold Make date	Pour Date	Pour Day	Mold No.	Pattern ID	Metal	Calib Sand, Lbs/15 sec	Calib Resin + Activator, Gms/15sec	Coreactant, Gms/15sec	Binder, %	Binder weight, LBS	Mold LOI 1800 F	Test bar Ave. Tensile Strength, Psi	Mold sand weight, Lbs	Sand Temp when made, F	Ambient Temp when made, F	Pour temp, F	Casting weight, Lbs	Total Cast weight, Lbs	Cast surface area sq.in.	Extra metal, lbs	Pour time, sec
Area																					
26-Mar-03	27-Mar-03	Thursday	EZ001	FP3	Alum	30	99.5	77.6	1.28	12.09	ND	102	941.5	76	62	1416	35.5	42.0	2198	6.5	32
26-Mar-03	27-Mar-03	Thursday	EZ002	FP3	Alum	30	99.5	77.6	1.28	12.46	ND	99	970.0	65.0	64.0	1418	36.0	38.5	2198	2.5	29
27-Mar-03	28-Mar-03	Friday	EZ003	FP3	Alum	30	102.9	74.1	1.28	12.32	ND	146	959.5	NR	NR	1395	37.0	39.5	2198	2.5	57
27-Mar-03	28-Mar-03	Friday	EZ004	SP3	Alum	30	99.2	77.6	1.28	12.40	1.07	140	967.0	80.0	65.0	1406	36.5	36.5	317	0.0	19
31-Mar-03	01-Apr-03	Tuesday	EZ005	SP3	Alum	30	102.8	74.2	1.28	12.28	1.05	130	956.5	82.0	65.0	1424	36.5	36.5	317	0.0	20
31-Mar-03	01-Apr-03	Tuesday	EZ006	SP3	Alum	30	102.8	74.2	1.28	12.40	1.05	117	966.0	84.0	66.0	1393	41.0	41.0	317	0.0	30
Weight																					
01-Apr-03	02-Apr-03	Wednesday	EZ007	P3	Alum	30	102.7	74.3	1.28	12.25	1.07	119	954.5	83.5	64.5	1411	37.0	37.0	1210	0.0	18
01-Apr-03	02-Apr-03	Wednesday	EZ008	P3	Alum	30	102.7	74.3	1.28	12.27	1.06	120	955.5	84	64.5	1418	37.0	38.0	1210	1.0	19
01-Apr-03	02-Apr-03	Wednesday	EZ009	P3	Alum	30	102.7	74.3	1.28	12.34	1.05	131	961.0	84	65	1413	39.0	39.5	1210	0.5	20
02-Apr-03	03-Apr-03	Thursday	EZ010	P1	Alum	30	102.8	74.2	1.28	12.45	1.06	117	970.0	83.0	61.5	1411	16.0	16.5	1164	0.5	14
02-Apr-03	03-Apr-03	Thursday	EZ011	P1	Alum	30	102.8	74.2	1.28	12.45	1.13	140	970.0	83.5	62.0	1412	16.0	17.0	1164	1.0	16
02-Apr-03	03-Apr-03	Thursday	EZ012	P1	Alum	30	102.8	74.2	1.28	12.56	1.07	118	978.5	82.0	62.5	1401	15.5	16.0	1164	0.5	9
Binder																					
07-Apr-03	08-Apr-03	Tuesday	EZ013	FP3	Alum	30	91.5	68.2	1.16	10.97	0.97	72	945.5	81.5	61.0	1395	35.5	35.5	2198	0.0	30
07-Apr-03	08-Apr-03	Tuesday	EZ014	FP3	Alum	30	91.5	68.2	1.16	11.03	1.05	101	951.0	81.0	62.5	1409	36.0	36.0	2198	0.0	25
07-Apr-03	08-Apr-03	Tuesday	EZ015	FP3	Alum	30	89.8	66.7	1.14	10.81	1.11	131	951.0	81.0	63.0	1417	36.5	37.0	2198	0.5	29
Temp																					
08-Apr-03	4/9/2003	Wednesday	EZ016	FP3	Alum	30	101.6	75.4	1.28	12.01	1.08	143	935.5	84.5	64.5	1802	35.0	36.5	2198	1.5	27
08-Apr-03	4/9/2003	Wednesday	EZ017	FP3	Alum	30	101.6	75.4	1.28	12.03	1.28	123	937.5	84.0	66.0	1818	35.5	37.5	2198	2.0	27
08-Apr-03	4/9/2003	Wednesday	EZ018	FP3	Alum	30	101.6	75.4	1.28	12.22	1.03	129	952.0	80.0	67.5	1795	35.5	37.0	2198	1.5	26
Binder																					
14-Apr-03	4/15/2003	Tuesday	EZ019	FP3	Alum	30	62.5	46.5	0.79	7.61	0.66	63	958.0	79.0	67.0	1409	36.5	38.5	2198	2.0	28
15-Arp-03	4/16/2003	Wednesday	EZ020	FP3	Alum	30	62.5	46.5	0.79	7.61	0.69	52	958.5	81.5	69.0	1404	37.5	38.5	2198	1.0	27
16-Apr-03	4/17/2003	Thursday	EZ021	FP3	Alum	30	62.5	46.5	0.79	7.59	0.69	77	955.0	83.5	69.0	1411	36.0	37.0	2198	1.0	26

Note 1: EZ004 did not have heated air piped to pour hood **Note 2:** EZ005 mold poured about 45 seconds after last temperature taken

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APPENDIX C GLOSSARY

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Glossary

ACFM	Actual Cubic Feet Per Minute
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	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
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