



Casting Emission Reduction Program

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**US Army Task N256  
No-Bake Urethane Aluminum  
Capability Study**

**Technikon # 1256-2311 CQ**

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# Capability Study to Determine the Requirements Of Aluminum No-Bake Mold Systems for Emission Testing

CERP Test CQ  
WBS 2.3.1.1

29 March 2001


**Pre-Production Capability Study, Test Series CQ – Results**

WBS 2.3.1.1

Reviewed and Approved by:  Date: 29 March 2001

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Measurement Technologies

Reviewed and Approved by:  Date: 29 March 2001

George Crandell

Operations

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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## INTRODUCTION

The Casting Emission Reduction Program (CERP) conducted a Capability Study at its Pre-Production foundry involving Aluminum and Glycol Epoxy No-Bake molds. “No-Bakes” represent a class of materials and manufacturing methods that were previously untested at CERP. No-Bake is a molding process that can be used for aluminum and gray iron casting. This Study uses strictly aluminum casting. To avoid redundancy, the Glycol Epoxy No-Bake molds will be referred to as “No-Bake” throughout this Report. The purpose of the capability study was to determine the manufacturing requirements and the range of process and air emission measurement variation involved with No-Bake molds in aluminum.

The conclusions formed from the CQ Test Series were used as the basis for the test study to examine Aluminum No-Bake Baseline Emissions (published under a separate cover). As a result of the test, the methods and criteria essential for all aluminum No-Bake baseline testing have been developed.

The Appendix to this report contains the detailed process and operational information that supports the text of this report. It is not included in this document but can be obtained electronically or in hard copy by contacting the Technikon offices at (916) 929-8001 or by logging on to <http://www.technikonllc.com> and requesting an electronic version.

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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## Test Series Summary

The objective of this test series was to identify the sampling flow rates that would provide sufficient sample for the determination of each target compound on its specific sampling media. Samples were collected at several sampling flow rates for each chemical family during the 75-minute test. The samples were analyzed for selected target compounds.

The following flow rates were determined to be appropriate for the Aluminum No-Bake baseline testing.

M-18 (by Gas Chromatograph/Flame Ionization Detector (GC/FID): 200 ml/min  
M-18 (by Gas Chromatograph/Mass Spectrometer (GC/MS): 25 - 40ml/min  
NIOSH 1500: 1,000 ml/min  
NIOSH 2002: 1,000 ml/min  
TO-11: 1,000 ml/min

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.

## Experimental Procedure

In the Pre-production foundry, castings are produced individually. Molds are constructed manually and brought into a hooded enclosure containing a shaker table, where the castings are poured. A heated sample probe is set into the exhaust stack of the hood to enable collection of total emissions from the pouring, cooling, and shakeout phases of the casting process.

A 13-channel sample train was used to collect stack samples. A sorbent tube was placed in each channel, with a critical orifice in line with the tube to control the sampling flow rate, and thereby, the volume of stack gas to be sampled. For each analytical method, a high and low volume sample was collected over the course of the 75-minute sample collection period.

Hazardous air pollutant (HAP) and Volatile Organic Compound (VOC) emissions were collected on sorbent tubes to determine optimal tube loading for the Aluminum No-bake baseline. The molds were poured with aluminum, and were the standard 4-on American Foundry Society (AFS) variable-tooth gear made from Okie 90 sand, bonded with a three part No-bake resin at 1.10% resin in the ratio of 55% Delta-HA Techniset® 20-260.2 resin, 45% Delta-HA Techniset® 23-227 co-reactant, and 5% Delta-HA Techniset® part III activator.

Stack gas samples were collected on sorbent tubes from the fourth test pour only, out of a total of nine pours in test series CQ. Samples were collected at high and low tube loadings for Method M-18, to determine the loading that provided the lowest detection limits for each analytical method, while maintaining the integrity of the analytical data. Results are discussed in the conclusions section of this report for each analytical method.

Sorbent tube samples were submitted to Clayton Group Services Laboratory for analysis. Analytical results were examined for evidence of sample overload, characterized by breakthrough, analyte results that grossly exceeded the calibrated range of the method, poor chromatographic performance, or other factors having a detrimental effect on the data.

## Results

Raw data for this test series for all detected HAP and VOC compounds may be found in appendices that are being maintained in the Technikon offices. Results will be discussed for each analytical method separately.

### METHOD M-18 (GC/FID)

**A flow rate of 200ml/min will be utilized for further testing based on the lower detection limits that can be achieved with little or no detrimental effect on data quality.**

Samples for this method were collected on Carbopak thermal desorption tubes. Initial total hydrocarbon (THC) results suggested reduced emissions from the aluminum No-Bake system when compared to iron, so samples were collected at an increased flow rate to preserve detection limits for the method. A flow rate of 200 ml/min was selected for the aluminum system, and additional samples were collected at the nominal iron flow rate of 25 ml/min as well. Over the course of the 75 minute sample collection period, these flow rates translated to sample volumes of 15,000 and 1,900 ml respectively, on the Carbopak tubes.

Analytical results for the 200-ml/min sample showed that only a single analyte on one of the thermal tubes exceeded the upper limit of calibration for the method, 10,000 nanograms (ng). This analyte, 2,3-Dimethylphenol, was found at 14,000 ng in one of the 200 ml/min samples, but not in the duplicate taken at this flow rate. Although inaccuracies may be introduced into the analytical results for this compound during further testing, this compound is not a HAP, so the effect of exceeding the calibrated range should be minimal to the overall data quality.

### METHOD M-18 (GC/MS)

**The recommendation for this analysis is to use a flow rate of 25 ml/min, or, if possible, an intermediate flow rate of 40 ml/min.**

Although samples for this method were not collected during this test series, correct flow rates for the method can be inferred due to the fact that samples are collected on the same media as the M-18 samples analyzed by GC/FID. The most important difference between the two methods is

that the M-18 (GC/MS) method has a calibrated maximum of 2,000 ng, whereas the maximum for the M-18 (GC/FID) method is five times higher, at 10,000 ng. For this reason, collection of samples at the higher flow rate of 200 ml/min would not provide acceptable results.

## **HYDROCARBON AS HEXANE**

**A flow rate of 1,000 ml/min, the only flow rate examined for this analysis, will be used for No-Bake Aluminum testing.**

Samples for this method are collected on activated charcoal sorbent tubes containing a front and back section. Therefore, it is not necessary to collect separate breakthrough samples, since the back section of the tube is analyzed separately and provides breakthrough information. In this case, breakthrough is defined as a result for any analyte detected in the back section that exceeds 10% of the total amount detected in the sum of the front and back sections.

Samples were collected at a single flow rate of 1,000 ml/min for this analysis, corresponding to a sample volume of 75,000 ml. The initial flow rate was selected based on preliminary THC results. Method results showed HC as Hexane detected at 920 micrograms (ug), well below the maximum calibrated range for the method. The largest amount of any single analyte detected was benzene, at an average of 36 ug. At these loadings, the adsorption capacity of the charcoal tube is also not a factor, and no breakthrough was observed from the back half of the tube.

## **NIOSH 2002**

**A flow rate of 1,000 ml/min, the only flow rate examined for this analysis, will be used for No-Bake Aluminum testing.**

Samples for this method are collected on silica gel sorbent tubes. These tubes also contain a front and back section, which are analyzed separately, so that sample breakthrough may be evaluated without need of a separate breakthrough tube.

Samples were also collected at a single flow rate of 1,000 ml/min for this analysis, corresponding to a sample volume of 75,000 ml. The initial flow rate was selected based on preliminary THC results. Method results showed Dimethylaniline detected at 100 ug, well below the maximum calibrated range for the method. Aniline was also detected at 34 ug, and phenol at 14 ug. At these loadings, the adsorption capacity of the silica gel tube is not a factor, and no breakthrough was observed from the back half of the tube.

## **METHOD TO-11**

**A flow rate of 1,000 ml/min, the only flow rate examined for this analysis, will be used for the testing.**

Samples for this method are collected on Waters Sep-Pak Cartridges. Analytes are derivatized with a reagent contained in the cartridge, during extraction. Due to the fact that these samples

are extracted, and can therefore be diluted for re-analysis if the upper limit of calibration for the method is exceeded, considerably more flexibility in selecting a sample flow rate is available.

Samples were also collected at a single flow rate of 1,000 ml/min for this analysis, corresponding to a sample volume of 75,000 ml. The initial flow rate was selected based on preliminary THC results. Method results showed Propionaldehyde detected at 46 ug, well below the maximum calibrated range for the method. Acetaldehyde was also detected at 39 ug, and additional minor constituents were also detected from 20 ug down to less than 1 ug. Although a breakthrough sample was not analyzed, at these loadings, the adsorption capacity of the Sep-Pak cartridge is also not a factor.

### **Test Series Conclusions**

The objective of this test series was accomplished by identifying the sampling flow rates that provide sufficient sample for the determination of each target compound on its specific sampling media. Flow rates have been assigned for the upcoming Aluminum No-Bake baseline testing, based on discussion of results given in the previous section of this report.

The flow rates assigned here are the best possible estimates that can be arrived at through a single sampling event.

## Study Results Summary

This report contains the results of the study that determined the process requirements necessary to manufacture no-bake molds for emission testing from the hybrid chemical family Glycol Epoxy Urethane intended for use with Aluminum.

## Background

The research conducted at CERP has measured the emissions from several other core and greensand mold materials. Emission testing of foundry sand molds bound with a family of chemical binders known as “No-Bakes” is a logical extension of the current and historical research activities conducted at CERP. The equipment available for this type of research includes two emission testing foundries, one for discreet single mold detailed material testing, and one for dynamic material testing under production conditions.

No-Bakes represent a family of core/mold manufacturing materials in general use in the foundry industry. Historically, cores were manufactured from animal protein and oxidizable vegetable oils requiring drying or baking. While still in use, these materials tend to be inconsistent and are either slow or energy and labor intensive. By contrast, No-Bakes lend themselves to mechanization and cure without baking by delayed chemical interaction of their components. Use of this class of material requires definition of a “*strip time*”. This is when the material strength has sufficiently developed to permit removal of the core/mold from the core box. Additionally, it is important to not exceed the “*bench life*” when placing the material in the corebox. If exceeded, the chemical curing will have processed to such an extent that the coated sand grains will not bind together to form the desired shape.

The strength of a core/mold depends on several factors such as temperature, resin content, ratio of resins or catalysts used to control the speed of the chemical reactions, and the mechanics of packing the coated sand together. To evaluate the sand and the resin coating systems, trial batches are made and tested using cured coated sand tensile test bars called “dogbones”. The dogbones are tested at various standard times after they are made. It is important to control the strength of the sand. Sand strength has a direct effect on the ability to handle the core/molds, and on the reliability of decomposition at the desired interval during shakeout. Controlling these factors assures a standard emission profile.

The Glycol Epoxy Urethane chemical system tested uses a two-part resin system consisting of a primary resin and a co-reactant activated by a liquid catalyst in a manner similar to the Phenolic Urethane (PU) resin system reported under CERP tests CW (2.3 GSA.1) & CP (2.3 GSA.2). The catalyst content is likewise similar to the phenolic urethane, typically 7 %. The reaction rates of all the core binder chemical resin systems are known to be temperature sensitive. To verify the performance of the catalyst a pre-test evaluation of the catalyst requirements was conducted. The targeted amount of 7 % catalyst, based on the resin content, was verified to perform well with sand maintained in the temperature range 70-80 °F.

It is intended for this resin system to be used with cast aluminum poured at 1250-1300 °F. One of the requirements of all core or mold binder systems is to breakdown after a designated period of time from the heat of the cooling casting to allow the sand to separate from the casting. Cast aluminum provides heat at a much lower temperature than cast iron (2600-2650 °F). Additionally, the core or mold used for casting aluminum must yield at a significantly lower strength or the aluminum casting could develop stress cracks. At the same time the physical handling strength requirements of the core for setting in a mold must be maintained.

### **Study Objective**

The objective of the CQ Test Series was to establish the limits of process variation associated with making and pouring aluminum in glycol epoxy urethane No-Bake molds.

### **Experimental Procedure**

Molds were made on CERP's No-Bake molding line and poured in the Pre-Production foundry. Listed below are the procedures developed from Test Series CW/CP that were used in the CQ Test Series. Refer to the Appendix for more comprehensive procedural information.

1. Measurement of the resin and sand delivery system flow rates of the Kloster core sand mixer. This was used to determine flow rates and their consistency over a range of resin pump speeds.
2. Comparison of five methods for manufacturing the dogbones. This was used to determine the optimum consistency and strength.
3. Determination of the capability of the dogbone strength measurement machine, the Dietert 405 Universal strength machine.
4. Evaluation of mixes of various ratios of resins and catalyst to select the optimum mixture.
5. Production of molds with various thicknesses poured with aluminum. The purpose of this was to determine the best combination of geometry and chemical content to get workable strip times, bench life, mechanical handling characteristics, and timely breakdown during shakeout.
6. Comparison to basic THC emission measurements to determine the emission gathering requirements used in the Aluminum Baseline Test Series.

### **Study Results**

A series of six molds were poured to determine the resin content, physical size and configuration, and hardware necessary to satisfy mechanical and emission test requirements to have a stable test cell. The final production methods and molding properties that will be used for emission testing are:

1. Cope height: 7 inches.
2. Drag height: 7 inches.
3. Resin content: 1.1 % based on sand for a phenolic urethane family binder system.
4. In-gates dimensions: 1.50 inches wide by 0.12 inches high so castings separate during shakeout and the cope mold can pass to the catch pan.
5. Vertical sprue: 3-inch diameter, round pouring cup to reduce splash.
6. Support frame height: Top of mold at 28 inches above where frame rests on the shakeout. This provides two-sided support to the mold.
7. Weighted frame setting: On the perimeter of the mold to minimize run outs.
8. Half-inch re-bar "J" hooks: Insert through 0.75-inch riser vents into the risers to hang castings separately from the sand during and after shakeout.
9. Pour time: 20-30 seconds.
10. Cooling time: 45 minutes.
11. Active shakeout time: 15 minutes.
12. Total emission-sampling time: 75 minutes.

## Study Results Conclusions

All of the conclusions for methods of manufacturing and testing developed under this test and test CW will be applied for aluminum testing.

**1. This Glycol Urethane system delivers physical properties that are 30% of the strength of the cores produced by the Phenolic Urethane system described in test series CW and CP.** In aggregate the conflicting requirements were met with a resin content of 1.1 % based on sand with a cope and drag height of 7 inches each. The sand was preheated as necessary to provide sand at the mixer in the range of 70-80 °F.

**2. The same tooling used to make Phenolic Urethane and Furan core/molds works well to make the Glycol Epoxy Urethane molds with the cope and drag halves each 7 inches high.** It was not be necessary to provide any special handling or supporting devices for the Glycol Epoxy Urethane molds to prevent distortion and subsequent metal leakage through the parting line joint.

**3. The Glycol Epoxy Urethane Resin system when configured as described above produced a stable mold qualified for emission testing.**