



Casting Emission Reduction Program

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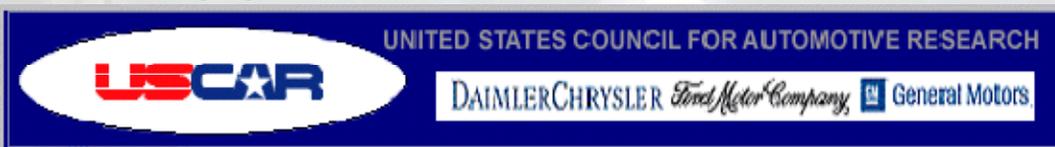
CERP Organic HAP Emission Measurements for Iron Foundries and Their Use in Development of an AFS HAP Guidance Document

(First Publication – AFS Paper 06-031)

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**CERP Organic HAP Emission Measurements
for Iron Foundries and Their Use in
Development of an AFS HAP Guidance
Document
(First Publication – AFS Paper 06-031)**

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Executive Summary

Since the 1990 promulgation of Title III (Hazardous Air Pollutants or HAPs) of the Clean Air Act Amendments, many industry and regulatory initiatives have focused on identifying and quantifying ferrous foundry hazardous air pollutants. The applicability of these regulations to individual facilities is determined by the facilities HAP emission level. This paper summarizes the efforts of the American Foundry Society (AFS), research institutions, and individual foundries to identify and quantify HAP emissions from iron foundry sources. The objective was to supply the industry and regulators with HAP emission guidance documents that can be utilized in determining a facilities HAP emission inventory profile.

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1.0 INTRODUCTION AND BACKGROUND

Regulatory drivers in the form of the National Emission Standards for Hazardous Air Pollutants (NESHAPs) required under Title III of the 1990 Clean Air Act Amendments and state specific air toxic regulations, promulgated by many states, have resulted in a need to quantify HAP emissions. These new and existing regulations will affect foundries in many ways. The NESHAP regulations, also known as the Maximum Achievable Control Technology (MACT) rules, require certain existing foundry operations to meet the HAP emission limits based on the average of the top 12% of sources in the industry. This is based on both work practices and installed air pollution control equipment as appropriate. The MACT emission limits can be achieved through the use of work practices and technology-based limits, which will require certain control equipment or process changes. MACT requirements will apply to Major Sources of HAPs, which are those facilities emitting 10 tons per year of an individual HAP, or 25 tons per year of all HAPs. This determination is made on a case-by-case basis by individual foundries, and is based on Potential to Emit (PTE). PTE is calculated using maximum permitted emission rates, taking into consideration federally enforceable permit limitations and facility operational constraints. Absent from any federally enforceable permit restrictions, a facility must determine its PTE based on maximum capacity for 8,760 hours per year.

The future Residual Risk regulations under Title III will require evaluation of the risk remaining after implementing MACT level controls usually at least eight (8) years after the effective date of the MACT. Additionally, Area Source regulations have listed the metalcasting industry, that is, those facilities with less than 10 tons per year of an individual HAP, or 25 tons per year of all HAPs as their total HAP emission inventory as area sources of HAPs that will also need to be regulated.

The applicability of these regulations to an individual foundry will be determined by the foundry's PTE HAPs. Therefore, having accurate emission rates to perform the PTE analysis is critical in determining the impact of the MACT regulation on an individual foundry.

This paper provides an overview of the different iron foundry HAP emission factors available to the metalcasting industry and discusses the variability of HAP emissions with respect to process parameters. This paper also documents the research sources used to develop the AFS HAP

emission factor article publications of 2001 and 2005. Many of the emission factors and variability studies provided in this paper were developed by the Casting Emission Reduction Program (CERP). This program has been in existence since 1994, and is funded by the Department of Defense. The CERP program's Steering Committee consists of the AFS, the Casting Industry Supplier Association (CISA), USCAR, and the Department of Defense. CERP meeting participants have included universities, foundries, suppliers, the United States Environmental Protection Agency (EPA), and the California Air Resources Board (CARB).

The original AFS HAP emission factor table, shown on Table 2 at the end of this paper, contains recommended HAP emission rates for typical foundry processes, and was based on early worst-case emission estimates. The emission table and accompanying instructions were made available in 2001 to foundries and EPA as a screening tool to be utilized by foundries in determining their HAP emissions. A conservative approach to performing a screening analysis was recommended, and the emission factors stated in the table consisted of both organic and inorganic HAPs for the listed process areas. The data sources used for these recommended emission factors included the EPA MACT long form survey database, CISA, and many research tests performed at CERP for pouring, cooling, and shakeout emissions (PCS). The table was approved and published by the AFS 10-E Air Quality Committee.

The screening analysis provided by AFS was appropriate as an initial approach at determining MACT applicability. However, a more accurate method was needed to better quantify HAP emissions for a wider range of processes. Since the major sources of HAP emissions from foundries are organic emissions from PCS, the new emission table focuses primarily on PCS organic HAP emissions. Input from foundry associations, suppliers, and individual foundries guided CERP testing to provide the more process specific testing needed to develop a better guidance document. Table 3 represents the new AFS HAP emission factors incorporating newer emission data for a variety foundry processes and binder systems. This guidance was approved by the AFS 10-E Air Quality Committee in September 2005, and is available on the AFS Web Site, www.afsinc.org, as Organic Hazardous Air Pollutant Air Emission Factors for Iron Foundries. The research data provided in the following discussions are the basis for 2005 AFS emission factors publication. These discussions include specific process emissions, process variability, and the testing results of new products not yet widely used by production foundries. The research reports providing the bases for this document are available at www.cerp-us.org.

2.0 DISCUSSION

2.1. METHODS OF ESTIMATING HAP EMISSION RATES

Foundries currently utilize several different methods to estimate their HAP emission rates including the following:

- Process Emission Factors
 - From Stack Testing
 - From Research Initiatives
- Mass Balances
- Engineering Estimates

It is imperative that HAP emission estimates be accurate and somewhat conservative. If they are too high, then capital spending and operating costs will be increased unnecessarily. If they are low, then at some future date, stack testing could show non-compliance, resulting in penalties, as well as, increased capital and operating costs.

Mass Balance and Engineering Estimates are the last resort, when all other methods fail to provide representative emission estimates. The problem with these approaches is pouring, cooling and shakeout air emissions are the result of thermal decomposition, and that is not completely related to binder or molding sand systems used in the process.

The most commonly utilized method of estimating emissions is using Established Emission Factors (EEF). Emission Factors, as discussed in this paper, refer to emission rates established by actual stack tests done at CERP. When estimating emissions using emission factors, it is important to insure that the production processes match the operation in question. The most accurate estimates will typically come from testing the facility or process in question. This is not always possible due to the relatively high cost of HAP testing or the facility in question may not yet exist.

Traditional sources of foundry HAP emission factors are the following:

- Foundry Specific Testing
 - Site Specific
 - Similar Sources
- EPA Testing (Performed in conjunction with Iron Foundry MACT rule development)
- NCMS/UAB Database

- Wisconsin Cast Metals Association (WCMA) Study
- Ohio Cast Metals Association (OCMA) Study
- Form R Manual Reporting of Binder Chemicals Used in Foundries, AFS/CISA
- EPA Long Form Survey Results (ICR) and Summaries
- AP-42, FIRE and Other EPA References
- AFS Modern Casting Article Calculating Emission Factors for Pouring, Cooling and Shakeout / October 1994 by Gary Mosher)

These data sources must be scrutinized closely due to the poor quality of some stack testing protocols and the frequent lack of process information. Much of the data available lacks sufficient detail to adequately describe the processes being tested or the process rates. In some instances the entire process was not tested yielding low emission rates. Other causes of error are the problems associated with determining capture efficiencies. Typically, many processes have very high capture efficiencies whereas others are quite low. Since emission rates estimated for the purpose of determining regulatory applicability or emission inventories are typically based on total emissions (including fugitive emissions), the level of capture on which the emission factor is based becomes important. The sources of HAP emission factors listed above may provide information in the area of inorganic HAP emissions, but very little accurate organic HAP emission data.

3.0 SOURCES OF HAP EMISSIONS IN FOUNDRIES

The sources of HAP emissions in a ferrous metalcasting facility include both foundry processes, as well as, other non-foundry processes utilized within the same facility or location. For the purpose of this paper, the non-foundry sources present, such as machining, parts cleaning, or painting, will not be discussed although the HAP emissions from these sources may be required for inclusion when determining MACT applicability.

The major iron foundry processes and operations that emit HAPs are shown in Figure 1.

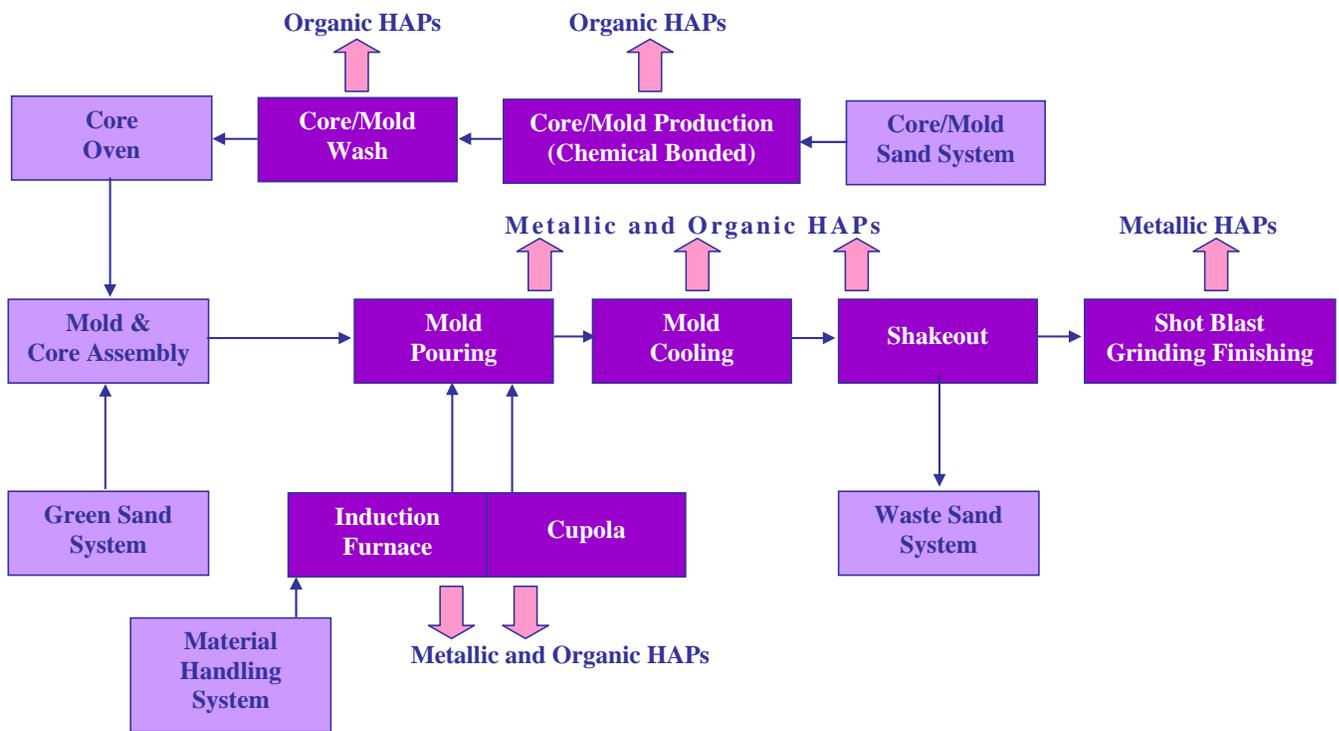


Figure 1 Source of Ferrous Foundry HAP Emissions

As shown above, there are many potential sources of HAPs in a foundry and the relative importance of each greatly depending on the specific processes and materials used. Core and molding sand release agents and pattern sprays can range from contributing significantly to HAP emissions to containing no measurable HAPs. Most of these materials can be quickly evaluated for their HAP emission potential by reviewing their Material Safety Data Sheets (MSDS), and more detailed information obtained from material suppliers.

4.0 TYPES OF HAP EMISSIONS

4.1. Inorganic HAP Emissions

Metallic (inorganic) HAPs are emitted from foundry processes, particularly the melting and casting cleaning processes. The metallic HAPs are primarily manganese with lower levels of lead and other metallic HAPs. Stack testing performed by the United States Environmental Protection Agency (EPA) and included with the Long Form Survey Analysis, as well as, data from the CERP Mexico Study yielded these results. Bag house catch data submitted to EPA and included in the Long Form Analysis also confirms this for PCS, as well as, shot blast cleaning and casting grinding. Manganese, identified as the major metallic HAP, is not a contaminant, but is utilized as an alloy necessary in the production of gray and ductile iron castings. The lower levels of lead are not intentionally added to charge materials, but are contaminants in recycled scrap ferrous materials. Levels of lead emissions have decreased in the past twenty years as lead has been eliminated or reduced in vehicles and appliances recycled by foundries as their primary feedstock in melting processes.

At normal stack temperature, metallic HAPs are part of the particulate matter emitted by some foundry processes. Methods utilized to control particulate matter will also control metallic HAPs as was demonstrated by EPA stack tests included in the Long Form Survey Analysis. Metallic HAPs are frequently stated as a percentage of the particulate matter (PM) emissions for the purposes of calculating metallic HAP emissions. Bag house catch analysis is sometimes utilized instead of stack testing to determine the appropriate HAP factor to apply to process PM emissions. PM emissions are, therefore, frequently considered a surrogate for metallic HAPs. This paper does not cover information on metallic HAPs but, as indicated, they are fairly insignificant and testing data are relatively easy to find.

4.2. Organic HAP Emissions

Organic HAPs, from Figure 1, comprise 96% of the total HAPs in the example of the "typical foundry. The organic HAPs in the core/mold make operations are emitted from different binder systems during mixing, core making, and storage. Some of the catalysts utilized in the production of phenolic urethane cores such, as triethylamine (TEA), are also HAPs. The tables listed in the Form "R" Manual - Reporting of Chemicals Used in Foundries, published by AFS & CISA, give estimates of the HAP emissions based on HAP components in the binder systems and estimates on the amounts reacted, released, or which remain in the cores. Other core related HAP emissions

could also be the use of release agents utilized to maintain core equipment. Pattern sprays or releases utilized in the molding processes can also be sources of HAP emissions. Material Safety Data Sheets (MSDS) can also be utilized to determine the HAP content of these materials, but with certain caution as the ingredients are not always accurate. Facilities that use high methanol binder systems, methanol based coatings, or have uncontrolled TEA emissions, will be the exceptions to these rules.

The largest overall areas of organic and total HAPs are those released during the pouring, cooling, and shakeout of either greensand or no bake molds. When iron is poured into organic molds at temperatures of typically 2600 to 2700°F, many different types of organic species and criteria pollutants are emitted. The extreme temperature variations along with a lack of sufficient oxygen to complete the chemical degradation reactions produce wide variations of organic emissions. Green sand molds contain carbonaceous additives such as seacoal or gilsonite along with cores made from many different types of binder systems. The carbonaceous additives in greensand molds are necessary for the production of quality castings. No-bake® molds typically utilize binder systems similar to core binders.

Cores are utilized with different molding processes to form the internal passages in castings produced and need to be much stronger than greensand to produce acceptable castings. The typical core binders utilized by the industry contain organic constituents that produce HAP emissions when iron is poured into the mold.

The organic binders and additives utilized in both molds and cores are the major sources of HAP emissions in most foundry operations. The different binders and mold additives utilized frequently have properties or characteristics tailored to different molding process or casting quality requirements. Permanent molds utilized in such operations as centrifugal molding for cylinder liner or pipe foundries have very few organic sources, and therefore, extremely low organic emissions.

Each different organic HAP source, binder type, or carbonaceous additive has some degree of variability associated with its use. This variability may be from the technology, proprietary formulation, or from the binder levels required by different types of applications.

Baseline and variability studies performed by CERP yield a good understanding of the emission sources and to some extent the variability of emissions.

4.3. Organic HAP Variability- General

This emission profile indicates that the entire pouring, cooling and shakeout areas must be tested to determine an appropriate emission factor for the process. It was also determined, through analyzing other foundry emission data that the actual profile changes depend on the type of molding equipment being utilized. This profile was for a horizontally parted mold that is poured, cooled, and shaken out in the same location. Mold movement, or shifting, as takes place in vertically parted molding equipment, may release organics at different times prior to shakeout. The data presented from CERP testing are typical of the majority of greensand and No-Bake® molding processes. Figure 2 reflects the real time emissions from the pouring, cooling and shakeout process of a single greensand mold at the CERP test hood over a period of 75 minutes. Similar data on CERP s continuous Impact Molding Line (at 50 molds per hour) followed the same pattern.

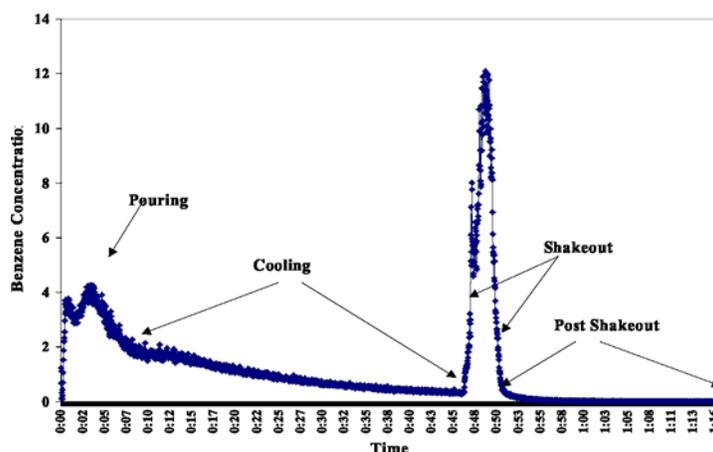


Figure 2 CERP Benzene Emission Profile (Cored Greensand Mold)

4.4. Organic HAP Variability- Greensand Variability Study

The purpose of this emission discussion is to explain some of the variability seen in stack test results that could not be explained by inappropriate stack testing protocols. CERP committees designed a variability test to determine the process variables affecting greensand emissions. The testing was performed primarily on no-cored greensand castings as a first step in describing how different greensand properties and casting configurations affect emissions of HAPs. This variability test report is available as a research report (0001-037 CJ “Greensand Process Variable Evaluation”) on the CERP Web Site (www.cerp-us.org), and was presented as a research paper at the 2002 Casting Congress.

The process variables tested were as follows:

- Cast Weight,
- Sand to Metal Ratio
- Cast Surface Area
- Pour Temperature
- Sand Moisture Content
- Sand Organic Content (% LOI)
- Clay Content
- Time to Shakeout

Since the testing was performed primarily on greensand molds with seacoal as the carbonaceous additive, the emissions were analyzed primarily for benzene. Benzene is the major HAP in greensand emissions, and has been shown as an appropriate organic HAP surrogate where the only emissions are from greensand combustibles. The variables that proved to affect greensand emissions were the following:

- Sand Organic Content (% LOI)
- Cast Weight
- Cast Surface Area
- Time to Shakeout

The following figures 3 thru 6 represent the results of the process variable study:

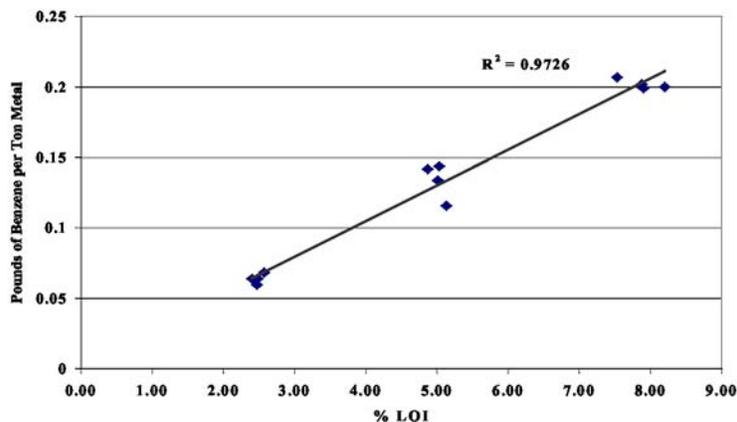


Figure 3 CERP Variability Study, Variable Combustible Level (Seacoal)

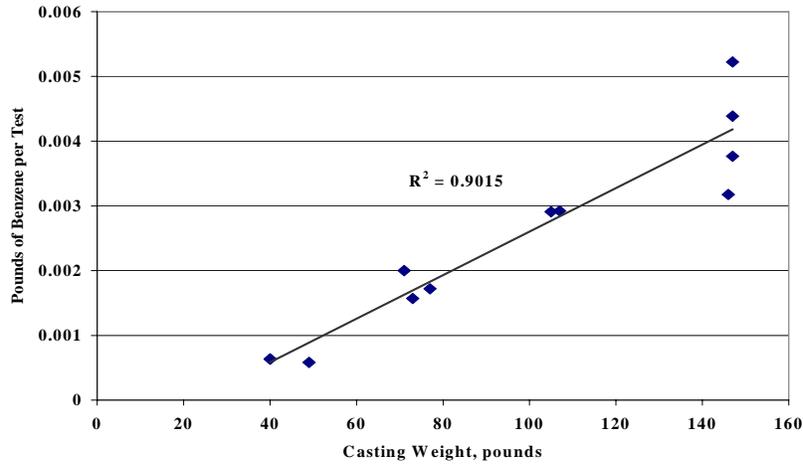


Figure 4 CERP Variability Study, Cubes with Constant Surface Area to Volume Ratio

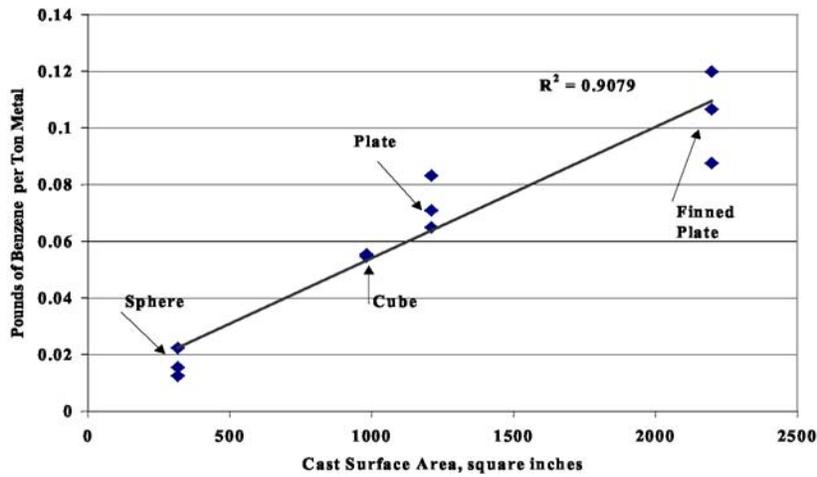


Figure 5 CERP Variability Study, Cubes, Spheres, Plates and Finned Plates with Constant Pour Weight

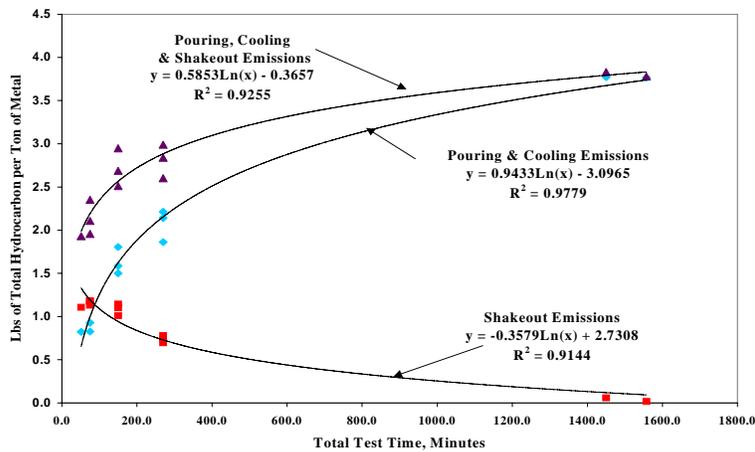


Figure 6 CERP Variability Study, Variable Shakeout Time, Cored Greensand Molds

This series of experiments is significant in that they describe the variables that foundries can control, and the variables \ that are the results of casting design issues. An engine block cannot be made to look like a bowling ball, and therefore will have different HAP emission levels per ton of iron poured.

These experiments were primarily designed to look at greensand emissions, and as such, only describe the emissions generated at the greensand/iron interface. Cored castings will have emissions resulting from both the greensand and core surfaces, and will be the addition of both emission sources. Foundries do, however, have some control over greensand carbonaceous additives and core binders, and they can work to reduce these emissions but must also at the same time manage the casting quality. The variability of the emissions from cores and No-Bake® molds show similar relationships. These reports and their data are also available on the CERP website.

4.5. Organic HAP Variability- Material Related Issues

In addition to the variables already described in this report, the materials supplied for specific applications also vary. Different suppliers of core and No-Bake® mold binders have proprietary formulations. Some are due to technological changes that take place with time and others due to customer's casting requirements. Different binder technologies and casting requirements also change the amounts of binders utilized for core/mold mixes. As with greensand carbonaceous additives, core materials are added in different amounts depending on the application and binder formulations. New binder technology may allow some applications with phenolic urethane cores to utilize core mixes containing 1.0% binder levels while other applications with older technology systems might require 1.75%.

Changes in carbonaceous additives utilized in greensand molds can also improve emissions from pouring, cooling, and shakeout areas. Many systems have been tested and utilized in many foundries to reduce emissions. Again, no formula fits all applications but depends largely on the quality and surface finish requirements of the castings being produced.

Many newer product formulations are now available to foundries that can have a significant effect on HAP emissions. Some of these replacement products do come with production trade offs and need to be evaluated prior to production at a foundry.

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5.0 HAP EMISSION TESTING RESULTS FOR IRON

The following tables reflect the accumulation of HAP Emission data for Iron divided into major categories. These categories represent families of products based on the process, and will allow a foundry to select a combination of factors to estimate HAP emissions. The data show that a foundry can select a greensand HAP number (Figures 7 or 8), add core emissions (Figure 9 or 10), and estimate the PCS emissions from a greensand molding line. The PCS tests performed on the combination of greensand molds with cores are also shown (Figure 11), and NoBake® PCS test results are reported on an additional table (Figure 12). PCS results are reported in lbs. of HAP emissions per ton of metal poured (Lbs/Ton). Core room emissions are reported in pounds per pound of binder (Figure 13).

Each Data Point on these charts is an average of 6 to 9 air emission tests, and is referred to by a unique test 2 digit alpha code. This Alpha code is the reference to the complete emission report available on the CERP website (www.cerpus.org).

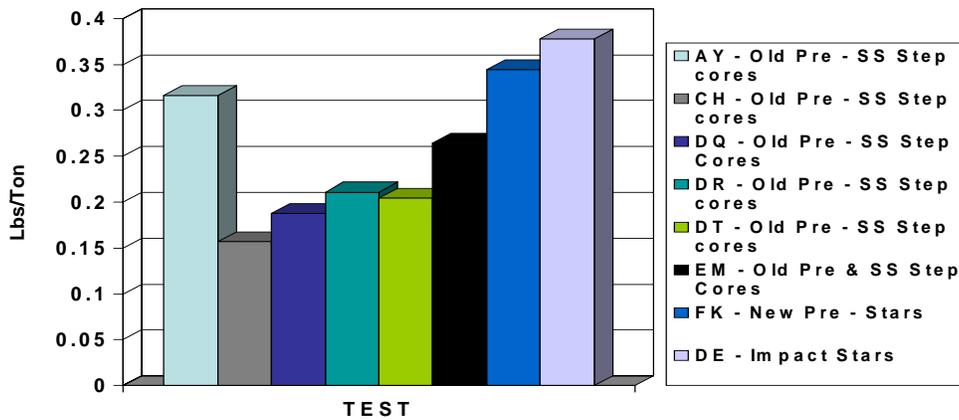


Figure 7 CERP PCS HAP for Greensand with Seacoal

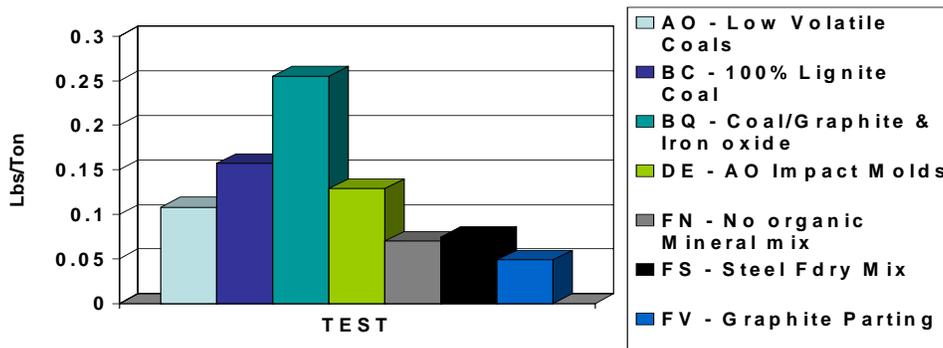


Figure 8 CERP PCS HAP Emissions from Seacoal Reduction or Replacement Products

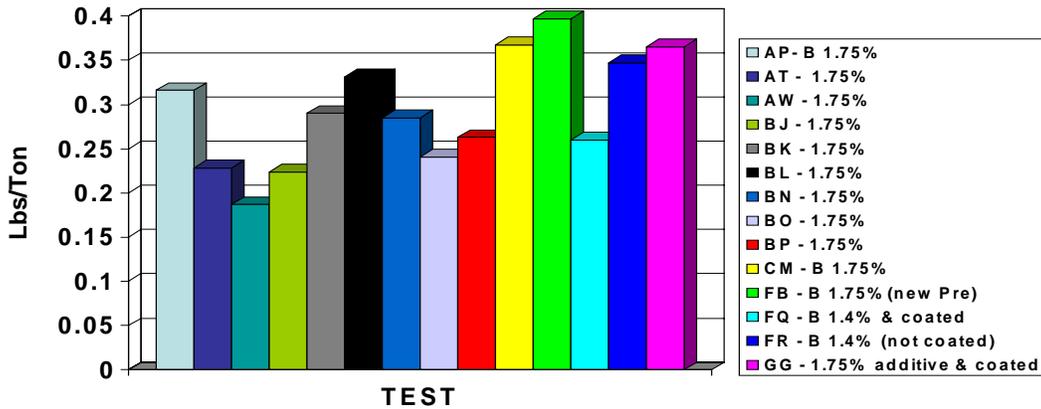


Figure 9 CERP PCS HAP Emissions for Molds Containing Phenolic Urethane Cores without Seacoal

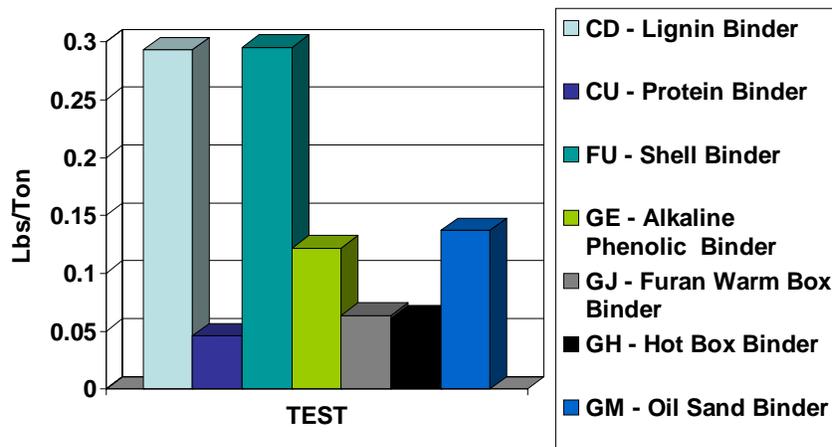


Figure 10 CERP PCS HAP Emissions for Molds Containing Misc. Cores Binders without Seacoal

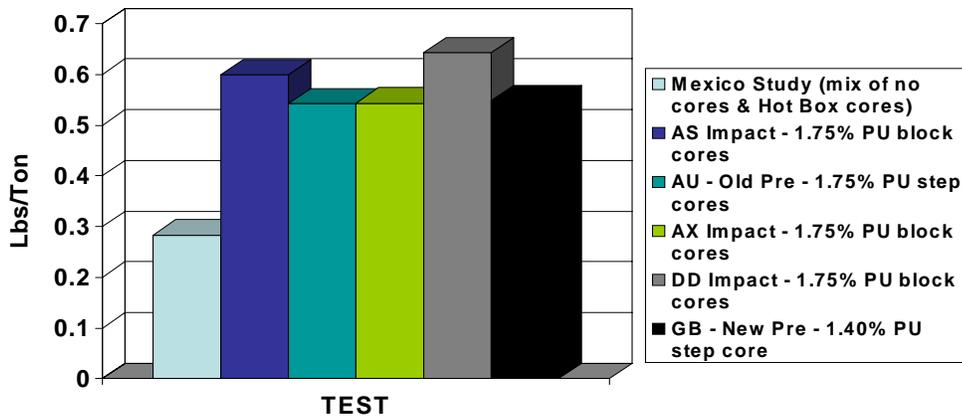


Figure 11 CERP PCS, HAP Emissions for Molds Containing Cores with Seacoal

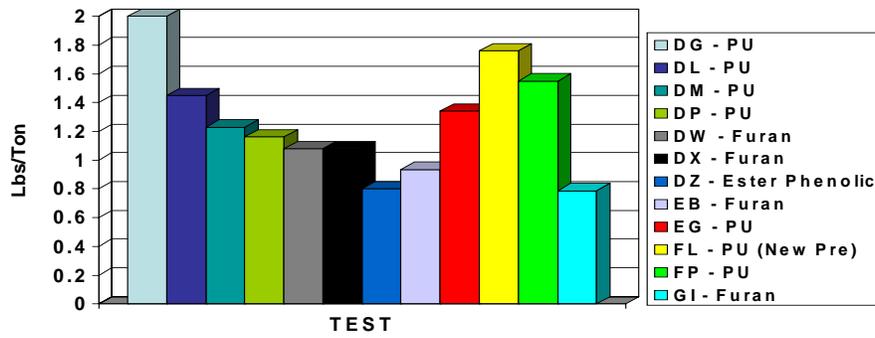


Figure 12 CERP PCS, HAP Emissions for No-Bake® Molds

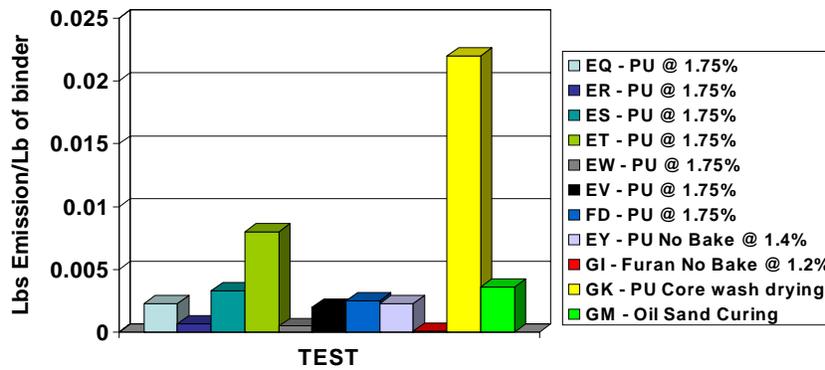


Figure 13 CERP HAP Core / Mold Emissions (Sand Mixing, Making and Storage)

Figure 14 presents data on Mold Release Agents that contribute to total HAP emissions, but are not normally separated from PCS emissions. Also included is data on Greensand Molding Sand System HAP emissions that would be characteristic of a large cope and drag molding line, and are emissions that may be in additive to PCS emissions.

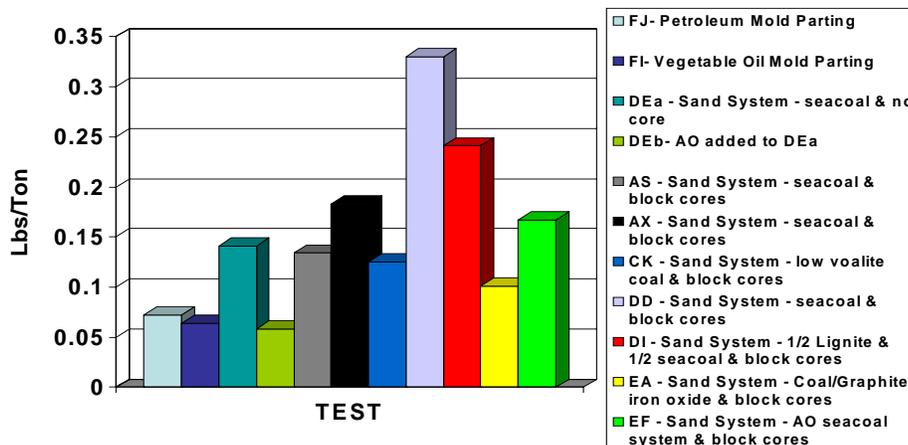


Figure 14 Other Greensand HAP Emissions Sources in Lbs. per Ton of Iron Poured

Emissions from greensand molds and phenolic urethane cores, as well as, the combination of greensand mold and phenolic urethane core were measured at CERP by running a series of three tests. Each test in the series consisted of 3 conditioning runs followed by 9 individual pours, and the result reported was the average of the 9 individual results. The molds utilized for this experiment had a 28% core loading. This means that the core weight was approximately 28% of the weight of the iron poured. The parts produced were AFS Step-Block Castings with cores (8-on) in a cope and drag, with a horizontally parted mold.

Figure 15 shows the emission profiles, as well as, the species characteristics for greensand and core baseline tests performed at CERP. The greensand baseline test utilized molding sand containing seacoal, clay, and water; however, the cores utilized for this test were made of an "inorganic" sodium silicate core binder. The core baseline test utilized phenolic urethane cores with no seacoal added to the molding sand. In this way, separate emissions profiles were developed for the greensand mold and for the polyurethane cores within the mold.

The individual HAP species shown in Figure 16 depicted only 75% to 80% of the total HAPs present. This profile clearly demonstrates the differences in the emission profiles of seacoal and phenolic urethane core binder systems. (FJ- Petroleum Mold Parting FI- Vegetable Oil Mold Parting)

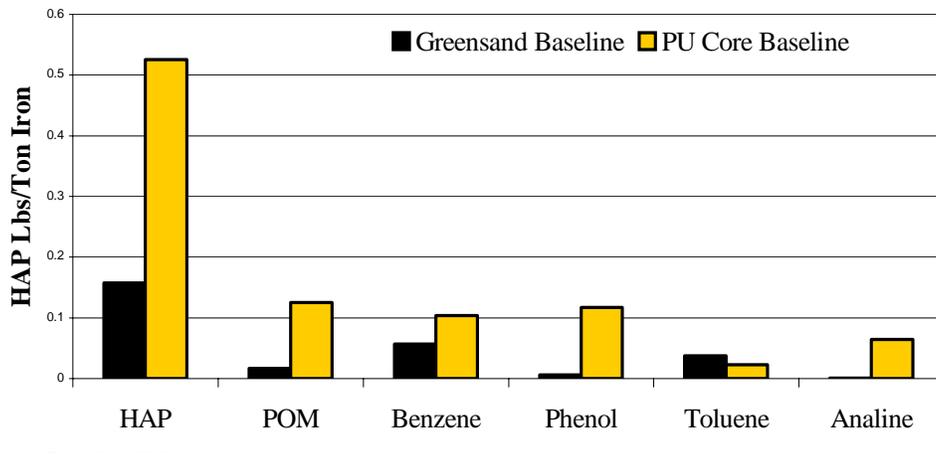


Figure 15 Baseline Emission Profile – PCS, Tests CY & CH, 2000

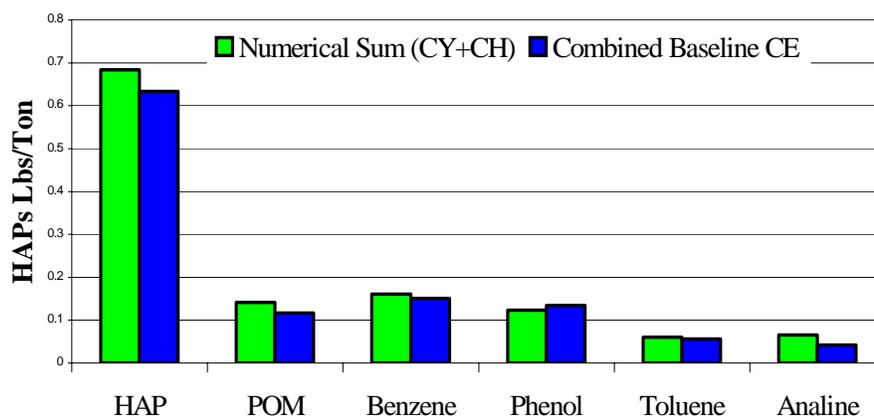


Figure 16 CERP Baseline Analyses – PCS, Tests CY, CH & CE, 2000

Figure 16, Test CE, clearly demonstrates the combined effect of emissions from a greensand mold with phenolic urethane cores. This test was run with normal greensand molds (i.e. containing seacoal) and phenolic urethane cores. The first bar for each parameter represents the mathematical sum of the greensand and core baseline tests shown in Figure 16. The second bar represents a combined baseline test (i.e. molds made with greensand containing seacoal and phenolic urethane cores). The differences between the two data sets in Figure 16 are well within the expected variability of the test protocols. This series of tests suggests that the emissions from organic cores can be mathematically added to those from the molding sand to yield the total emission profile of the combined package. This series of tests also shows the relative significance of the two emission sources under these specific test conditions. The total HAP emissions, as well as, individual species demonstrate the additive effect, suggesting that no interaction takes place within the mold between greensand mold emissions and core emissions.

The additive effect demonstrated in this test series can be assumed to apply to other binder systems. This relationship can be used to predict the emissions from different molding sand formulations and core binders. CERP testing of different greensand mold carbonaceous additives and different core binder systems can be added together, in any combination, to estimate the total emissions of the combined packages.

The relationships shown in the variability testing indicate that the organic levels of foundry processes affect the emission rate. The higher the organic level, the higher the emission rate. This

follows a direct relationship for greensand, and can be assumed for core binder levels. (The higher the binder level, the higher to potential organic PCS HAP emissions.)

These two relationships, combined, provide the tools necessary to allow foundries to estimate their organic PCS HAP emissions for many binder and sand formulations. Molding sand testing can be adjusted to account for varying seacoal content and core binder tests adjusted for binder levels lower or higher than those used during the their HAP emission testing.

6.0 CERP TESTING METHODS AND ACCURACY

The specific sampling and analytical methods used by CERP in the Research Foundry tests are based on the US EPA reference methods shown in Table 1. The details of the specific testing procedures and their variance from the reference methods are included in the Technikon Standard Operating Procedures.

Table 1 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
HAPs and POMs Concentration	EPA Method 18, TO11, NIOSH 1500, NIOSH 2002
VOCs Concentration	EPA Method 18, 25A, TO11, NIOSH 1500, NIOSH 2002, OSHA 72
Sulfur Dioxide*	OSHA ID200
Carbon Monoxide*	EPA Method 10
Carbon Dioxide	EPA Method 3A
Nitrogen Oxides*	EPA Method 7E

* Criteria Pollutants

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

The Pouring, Cooling and Shakeout (PCS) and core/mold making processes are all conducted within a hood-like chamber designed to meet the criteria for a temporary total enclosure (TTE) as specified in US EPA Method 204. Typically 6 to 9 individual runs are performed to obtain statistically accurate results, with three additional individual runs performed to heat up the system sands and proof the process.

The analytical results of the emissions tests provide the mass of each analyte in the collected sample. The total mass of the analyte emitted is calculated by multiplying the mass of analyte in the collected sample times the ratio of total stack gas volume to sample volume. The total stack gas volume is calculated from the measured mean stack gas velocity and duct diameter, and then 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 used, the weight of the sand used, and/or the weight of the casting poured to provide

emissions data in pounds of analyte per pound of binder, pounds of analyte per ton of sand, and pounds of analyte per ton of metal.

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.

7.0 SUMMARY

Since 1990 numerous industry and government research initiatives have tried to quantify and understand HAP emissions from iron foundry processes. Most have focused on organic emissions from the pouring, cooling, and shakeout operations from greensand and No-Bake® molding processes. Quantifying these emissions has proven quite challenging due to differences in material specifications and performance, as well as, the lack of specific variability studies.

The Casting Emission Reduction Program (CERP) has created a consistent testing process for measurement and evaluation of HAP Emission from the majority of foundry processes. The quality of the emission and process data allow repeatable results that are very difficult and expensive to duplicate in field testing. Testing at CERP has been validated by emission tests from production foundries, and from the production foundry testing at CERP.

Much of the variability of organic HAP emissions can be explained by measurable process differences. The core binder type and mold greensand carbonaceous additives, or No-Bake binders, all affect emissions in a predictable manner. These relationships hold true provided the castings produced are not significantly different than those made in the emission tests.

The AFS recommended emission factors shown in Table 3, along with the instruction package, are based on the research and the testing described in this paper. Emissions from different core packages can be added to the molding sand emissions to arrive at total mold emissions estimate. The relative emissions of both the molding sand and the cores can be adjusted to compensate for differences in organic levels in the sand and cores.

This research can also be extended to include other casting processes. Permanent molds and centrifugal casting processes, where the steel molds have no organic binder component, would be expected to have no organic emissions whatsoever. If a core is used, the emissions would be relative only to the amount of cores, or core binder, used in the permanent mold or centrifugal casting processes.

Where foundry processes vary significantly from the processes depicted in Table 3, site specific testing or additional research testing will be required. Site specific testing will be a challenge considering the design and operation of most foundries' emission collection systems and their

inherent capture efficiencies. Process variables influencing emissions must be thoroughly understood and controlled while all emission points along the pouring, cooling and shakeout areas must be sampled under similar process conditions to determine the acceptable emission factor.

Research is continuing to improve the industries knowledge of organic HAP emissions. Some of the processes reviewed in this paper are not yet proven in actual foundry production conditions, however, lower emitting organic core/No-Bake® binders and greensand additives are continuing to be developed that provide an acceptable casting quality. These lower emitting products will be vital as a tool to allow foundries to continue reducing their HAP emissions while maintaining casting quality and controlling production costs, and reduce their regulatory air quality impacts.

Table 2 AFS Foundry Emission Factors for Preliminary Screening (2001)
 Total HAP Emission Factors* for Preliminary Screening Analysis – Iron Foundries
 Compiled by the AFS Air Quality Committee and MACT Task Force (Rev. 10/08/01)

Foundry Process	Pounds of Total HAPs per Ton of Metal Melted/Poured
Melting	
Electric Induction Furnace – Uncontrolled	0.040
Electric Induction Furnace – Baghouse	0.006
Cupola – Afterburner/Baghouse	0.044
Cupola – Baghouse	1.00
Cupola – Afterburner/Wet Scrubber	0.074
Cupola – Wet Scrubber	1.034
Electric Arc Furnace – Baghouse	0.0076
Electric Arc Furnace – Uncontrolled	0.363
Charging and Taping, Electric Arc Furnace – Controlled	0.0012
Charging and Tapping, Electric Arc Furnace – Uncontrolled	0.059

Melt Support Operations – Inoculation, Metal Treatment – Controlled or Uncontrolled

All Iron Except Ductile	0.0015
Ductile Iron	0.050

Pouring, Cooling, Shakeout – Controlled or Uncontrolled

Green Sand Molds – Lightly Cored or No Core	0.416
Green Sand Molds – Heavily Cored	0.983
Phenolic Urethane NoBake® Molds	1.5**
Furan NoBake® Molds	1.08
Centrifugal Casting	0.0005

Finishing Operations – Controlled or Uncontrolled

Grinding	0.0003
Shot Blasting	0.0007

Binder System/Process	Pounds of Total HAPs per Pound of Binder/Catalyst
Core/Mold Making – Chemical Binders	
Acrylic/Epoxy/SO ₂	0.00015
Furan hot box (Hot Box)	0.0015
Furan NoBake® - High Methanol Catalyst	0.056
Furan NoBake® - Low/No Methanol Catalyst	0.017
Furan/SO ₂	0.116
Furan warm box – High Methanol Catalyst	0.075
Furan warm box – Low/No Methanol Catalyst	0.0018
Phenolic baking	1.0005
Phenolic ester NoBake®	0.0001
Phenolic ester cold box	0.0001
Phenolic hot box	0.001
Phenolic NoBake® - High Methanol Catalyst	0.056
Phenolic NoBake® - Low/No Methanol Catalyst	0.017
Phenolic – Novolac flake (Shell)	Deminimus
Phenolic urethane NoBake®	0.0008
Phenolic urethane cold box – Part I + Part II***	0.0008
Phenolic urethane cold box – TEA Catalyst (with Acid Scrubber)	0.010
Phenolic urethane cold box – TEA Catalyst (without Acid Scrubber)	1.00
Urea formaldehyde	Deminimus

Miscellaneous Processes – Calculate Emissions Using Process-Specific Data

Lost Foam Casting (EPS)	Use process-specific data
Thermal Sand Reclamation	Use process-specific data
Casting Painting	Use process-specific data
Degreasing	Use process-specific data
Mold Sprays/Washes	Use process-specific data
Mold and/or Core Release	Use process-specific data
Core Washes/Drying	Use process-specific data
Shell Sand Coating	Use process-specific data
Pattern Repair and Cleaning	Use process-specific data

*Since foundry processes, operations and operating parameters vary significantly from foundry to foundry, the ballpark emission factors provided in this table may not be representative of your operations. They are intended to be used solely for the purpose of conducting a preliminary assessment of major/minor status and should not be relied upon for a final determination of MACT applicability. For a final determination of applicability, you will need to conduct a detailed assessment of HAP emissions from your facility using emission factors or test data that are more representative of your specific operations.

**The measured emission factors for PUNB pouring, cooling and shakeout vary between 1.0 and 2.0 pounds of HAPs per ton of metal poured. An average emission factor of 1.5 should be used for this analysis unless specific information for your operation is available.

***If a PUCB binder is used, in addition to calculating the HAP emission from Part 1 and Part 2 of the binder, calculate the annual TEA emissions (with or without acid scrubber as appropriate) using the emission factor given and the pounds of TEA catalyst used annually.

Table 3 AFS 2005 Emission Factor Table
AFS 10-E Database Subcommittee -- Foundry HAP Emissions
Iron Pouring, Cooling and Shakeout Organic Hazardous Air Pollutant Emissions

Table A. Greensand Casting Emissions (PCS) (lb/ton of metal)		
<i>Emission Factor Use</i>	<i>HAPs</i>	<i>CERP[*] Test Number, Publication/Revision Date and Process Description</i>
Average surface area greensand parts with seacoal as the only carbonaceous additive.	0.213	1256-1311DQ, 4/26/2001 - Greensand test using only seacoal at 5.0% LOI and sodium silicate (inorganic) step block cores.
Very high surface area greensand parts with seacoal as the only carbonaceous additive.	0.378	1256-1231DE, 7/30/2003 - CERP Production Foundry Test with seacoal at 5.0% LOI and star pattern. No cores.

Table B. Core Emissions (PCS) (lb/ton of metal)		
<i>Emission Factor Use</i>	<i>HAPs</i>	<i>CERP Test Number, Publication/Revision Date and Process Description</i>
Old technology phenolic urethane cold box core emissions. This test is representative of an older binder system requiring high core binder levels.	0.397	FB, 7/1/2003 - Phenolic urethane step block core emission test at 1.75% binder level. CERP is finalizing this report.
Newer technology phenolic urethane cold box core emissions. This test is representative of a newer technology binder system capable of low binder levels.	0.368	1256-11 GSA.3 CM, 12/15/2000 - Phenolic urethane step block core emission test at 1.75% binder level. This binder system is capable of running at much lower than 1.75% binder levels.
Alkaline phenolic coated core emission factor.	0.122	1411-111 GE 8/1/2004 - Coated alkaline phenolic cores at 2% binder.
Phenolic Novolac (shell) core emissions.	0.295	1410-177 FU, 9/1/2004 - Uncoated cores at 3.0% resin level.
Furan hot box core emission factor.	0.061	1411-122 GH 10/1/2004 - Step block cores at 1.2% binder level.
Furan warm box core emission factor.	0.058	1411-123 GJ - Furan warm box step block cores.
Oil sand core emissions.	0.137	1411-124 GM - Oil sand step block cores.
Use for core emissions of a greensand mold with no core.	0.0000	Core emissions are not present in a mold with no core. Use zero.

Table C. Cored Greensand Molds (PCS) (lb/ton of metal)		
<i>Emission Factor Use</i>	<i>HAPs</i>	<i>CERP Test Number, Publication/Revision Date and Process Description</i>
Representative of very complicated castings with a high phenolic urethane core content using seacoal as the only greensand carbonaceous additive. This test is considered a very high emitting greensand cored mold package with an older phenolic urethane core binder at a high binder level.	0.643	1256-122DD, 4/10/2003 - A CERP production foundry test producing engine block castings. Greensand mix used seacoal as carbonaceous additive at a 5.0% LOI. Core package used an older technology phenolic urethane binder at 1.75% binder level.
Represents an average casting emissions with an older phenolic urethane core binder system at a very high binder levels and seacoal as the only carbonaceous additive.	0.5424	0001-003, 11/11/1999 - An emission test using seacoal as the only carbonaceous additive at 5.0% LOI and step block cores made with an older phenolic urethane binder system at 1.75% binder level.
Emission factor used by the USEPA in the MACT Background Document to represent the average greensand foundry HAP emissions. The emission factor is a composite of different systems but primarily heavily cored castings using furan hot box cores.	0.285	0001-002, 2/26/2003 - This CERP Mexico Study representing greensand molds with seacoal at 5.0% LOI and a combination of cores but primarily phenolic hot box. This study is quoted as the "general medium HAP emission estimate" in the MACT Background Document EPA-453/R-02-013.

Table D. No-Bake Mold Tests (PCS) (lb/ton of metal)		
<i>Emission Factor Use</i>	<i>HAPs</i>	<i>CERP Test Number, Publication/Revision Date and Process Description</i>
A high emitting phenolic urethane no-bake mold package with very high core tensile strengths.	2.00	1256-1211DG, 4/10/2003 - Irregular gear pattern in phenolic urethane no-bake molds at 1.10% binder level and high core tensile strengths.
An average emitting phenolic urethane no-bake mold package with average tensile strengths.	1.521	1410-113FP, 3/1/2004 - Irregular gear pattern in phenolic urethane no-bake molds at 1.10% binder level and medium core tensile strengths.
A low emitting phenolic urethane no-bake binder with low core tensile strengths.	1.16	1256-1112 DP, 12/1/2003 - Irregular gear pattern in phenolic urethane no-bake molds at 1.10% binder level and low core tensile strengths.
A average furan no-bake mold package.	1.08	1256-1115DX, 5/18/2001 - Irregular gear pattern in furan no-bake molds at 1.30% binder level with an irregular gear castings.
An ester cured phenolic no-bake mold package.	0.803	1256-1116DZ, 6/22/2001 - Irregular gear pattern in ester Cured Phenolic no-bake binder at 1.10% binder level.

Table E. Lost Foam Process (lb/ton of metal)		
<i>Emission Factor Use</i>	<i>HAPs</i>	<i>CERP Test Number, Publication/Revision Date and Process Description</i>
Lost foam casting process (LFC) or expendable pattern process (EPC).	1.02	EPA -453/R-02-013, 12/1/2002 - Emission factor referenced in EPA MACT background document. (Twarog, 1991m "Identification of Emissions and Solid Waste Generated from EPC Process." AFS, June 4, 1991)

Core/Mold Make Organic Hazardous Air Pollutant Emissions

Table F. Core/Mold Make, Mixing and Storage (lb/lb of resin)		
<i>Emission Factor Use</i>	<i>HAPs</i>	<i>CERP Test Number, Publication/Revision Date and Process Description</i>
Combined core mixing, core make, and storage emission factor for an older technology phenolic urethane core binder at a high binder level.	<0.0023	1409-123EQ, 12/9/2002 - Emissions from an older phenolic urethane core binder at 1.75% binder level. Test does not include TEA. Some analytes below quantitation level.
Combined core mixing, core make, and storage emission factor for a newer technology phenolic urethane core binder at two different binder levels.	0.0011 <0.0743	1409-111ER, 12/21/2002 - Emissions from a newer technology phenolic urethane core binder at 1.20% and 1.75% binder levels. Test does not include TEA. Some analytes below quantitation level.
Combined mold sand mixing, mold making, and storage emission factor for a new phenolic urethane no-bake mold package.	<0.0023	1409-124EY, 5/29/2003 - No-bake mold making emissions using a phenolic urethane binder at 1.30% binder level. Test does not include TEA. Some analytes below quantitation level.
Oil Sand core curing (baking)	0.0036	1411-124 GM, 10/28/2005 - Oil sand step block cores.

* CERP (Casting Emission Reduction Program, Technikon, LLC) Reports available at CERP-us.org.

APPENDIX A ACRONYMS AND ABBREVIATIONS

AFS	American Foundry Society
CARB	California Air Resources Board
CERP	Casting Emission Reduction Program
CISA	Casting Industry Suppliers Association
DOD	Department of Defense
EEF	Established Emission Factors
FIRE	Factor Information REtrieval
GS	Greensand
HAP	Hazardous Air Pollutants
ICR	Information Collection Request
Lb/Lb	Pounds per pound of binder used
Lb/Tn	Pounds per ton of metal poured
LOI	Loss on ignition
MACT	Maximum Achievable Control Technology
MMS	Mixing, Making, Storage
MSDA	Material Safety Data Sheets
NCMS/UAB	National Center of Manufacturing Science / University of Alabama at Birmingham
NESHAPs	National Emission Standards for Hazardous Air Pollutants
OCMA	Ohio Cast Metals Association
PCS	Pouring, Cooling, Shakeout
PM	Particulate Matter
PTE	Potential to Emit
PUCB	Phenolic Urethane Cold Box
PUNB	Phenolic Urethane No Bake
QA/QC	Quality Assurance/Quality Control
TEA	Triethylamine
TTE	Temporary Total Enclosure
US EPA	United States Environmental Protection Agency
USCAR	United States Council for Automotive Research
WCMA	Wisconsin Cast Metals Association

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