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Emissions from the Evaporative Casting Process

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This study characterized the emissions generated during the pouring, cooling, and shakeout of castings made with the evaporative pattern casting (EPC) process. In addition, emissions from molds produced using conventional green sand technology were determined as a basis for comparison. Tests were performed under pilot-scale foundry conditions for production of both aluminum and gray iron water pump castings using an enclosing hood with a sampling stack. Sampling was conducted during pouring, cooling, and casting removal. Gas chromatographic/mass spectrometric (GC/MS) techniques and real-time instrumentation were used to identify the contaminants produced, to quantify the major contaminants, and to determine the temporal nature of these emissions. Major gaseous contaminants were identified as styrene, benzene, toluene, and ethyl benzene. Analysis of the real-time data indicated that the EPC molds produced more carbon soot and hydrocarbons during pouring than the green sand for both iron and aluminum castings. Screening analyses for 17 polynuclear aromatic hydrocarbons showed the presence of more species at generally higher concentrations with the EPC molds than with the green sand. Heavy soot generation (and the associated release of polynuclear aromatic hydrocarbons) during pouring and benzene release (gray iron only) during pouring and shakeout were identified as the principle hazards associated with the EPC process under the conditions tested. Consequently, considerable care should be taken in production operations to safeguard the metal pourers. **Gressel, M.G.; O'Brien, D.M.; Tenaglia, R.D.: Emissions from the Evaporative Casting Process. App. Ind. Hyg. 3:11–17; 1988.**

Introduction

In the evaporative pattern casting (EPC) process (also known as the lost foam process), a low density polystyrene foam facsimile of the part to be cast is formed, coated with a refractory wash, then packed in a flask with dry, unbonded sand. Molten metal introduced into the flask onto the foam causes the polystyrene to evaporate. Since the process is claimed to be a lower cost method of producing complex shaped castings from a variety of base metals, EPC could become a substantial part of the foundry industry in the future.[1]

Because of the potential growth of the EPC process, data on the emission characteristics of this process was essential. Kobzar and Ivanyuk[2] reported on the decomposition of foundry-grade polystyrene foams in a laboratory furnace at temperatures from 100° to 1500°C in 100° increments. At aluminum melting temperatures (700°–800°C), the major decomposition products were, in order of decreasing concentration, carbon dioxide, benzene, styrene, carbon, methane, and carbon monoxide. At ferrous melting temperatures (1400°–1500°C), the major decomposition products were carbon, methane, acetylene, carbon monoxide, and hydrogen. Decomposition products in an actual casting operation may be different due to limited oxygen availability, higher rates of decomposition of the polystyrene pattern, and quenching effects in a sand mold. Because of the lack of environmental data generated in actual foundry operations, a study of the emission characteristics under pilot-scale foundry conditions was begun.

This study had three objectives: to identify the contaminants produced, to quantify the major contaminants, and to determine the temporal nature of the emissions. As a basis for comparison, emissions from castings produced using conventional green sand technology were also measured. Since the mold decomposition products filter through and condense on the sand (which is reused), recycled sand was obtained from foundries currently using these processes. Emissions were determined for production of both aluminum and gray iron castings using an Eaton® water pump housing as the test casting. Identical castings were produced using the EPC and conventional green sand processes.

Experimental Procedures

A sampling hood similar to one used by Toeniskoetter and Schafer[3] was constructed to contain the process emissions and deliver them to a convenient sampling point. A schematic representation of the hood utilized in this study is shown in Figure 1. It consists of a stainless steel box, measuring 86 cm (34 in.) on a side, open on the bottom, with an exhaust takeoff located at the top. Metal was poured into the mold through a mullite tube extending into the hood. Two quartz windows were provided to permit obser-

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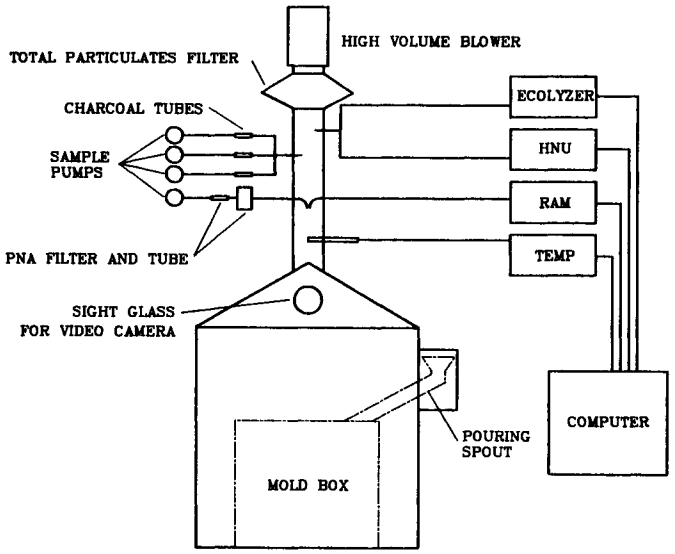

FIGURE 1. Schematic drawing of experimental arrangement.

vation and videotaping of the pour operation and cooling of the molds. The exhaust takeoff was connected to a pipe which terminated in a filter holder and blower assembly. The blower was set at a volumetric flowrate of 190 lpm (40 ft³/min), corresponding to a duct velocity of 3.4 m/s (660 ft/min), resulting in turbulent flow. This ensured good mixing of the contaminants and a relatively flat velocity profile.

Two isokinetic aerosol sampling ports and two gas sampling ports were located along the length of the pipe. Samples for qualitative analysis were collected on two-part 100/50 mg charcoal tubes at a flow rate of 0.1 lpm for approximately 30 minutes (total sample volume of 3 liters). A battery powered pump with a constant flow controller served as the air mover. Quantification of specific contaminants was determined by the collection of aerosols on filters and of gaseous samples on charcoal and porous polymer tubes. Samples for organic vapors were collected on two-part 100/50 mg charcoal tubes at a flow rate of 0.05 lpm. Two charcoal tube samples were collected: one for 20 minutes (for the duration of the pouring and cooling operation) and the second for 30 minutes (the duration of the entire casting operation—pouring, collecting, and shakeout). The contribution of the shakeout operation to the organic emissions was determined by the difference between these two samples. Aerosol and gaseous polynuclear aromatic hydrocarbon (PNA) samples were collected on 2 μm pore size, 37-mm-diameter polytetrafluoroethylene (PTFE) filters connected in series with 100/50 mg XAD-2 resin sorbent tubes, at a flow rate of 1.7 lpm for approximately 30 minutes (total sample volume 50 liters). These samples were analyzed for 17 specific PNAs as outlined in NIOSH Method No. 5515.[4] The benzene soluble fraction of the aerosol was determined by analysis of the PTFE filter. Total particle emissions were determined by gravimetric analysis of the 20 cm × 25 cm glass fiber filter. This filter was then extracted with benzene for quantification of specific polynuclear aromatic hydrocarbons.

Temporal analysis of particle generation was evaluated by means of a GCA real-time aerosol monitor (RAM) (GCA Inc., Bedford, MA) connected to one of the isokinetic sampling ports. Output of this instrument was fed to a data collection system, consisting of an AI13® analog-to-digital convertor (Interactive Structures, Inc., Bala Cynwyd, PA) coupled to an Apple II plus® computer (Apple Computer Inc., Cupertino, CA). The GCA aerosol monitor was calibrated for total particle mass *in situ* using the gravimetric data from the glass fiber filter, uncorrected for background particle levels. Temporal variation of the gaseous contaminants was determined using an HNu® photoionization detector (HNu Systems Inc., Newton, MA) with a 10.2 ev lamp, calibrated for hexane, and an Ecolyzer® carbon monoxide monitor (Energetics Science Inc., Elmsford, NY). Both instruments were connected to the data acquisition system described above. The data acquisition system recorded sample time and voltage outputs of the three instruments at 3-second intervals. Two video cameras recorded the activity within the hood. Each camera was equipped with an on-screen clock which was synchronized with that of the data acquisition system. This permitted associating casting events with any emission peaks.

Casting Parameters

Casting parameters are listed in Table I. Emissions were determined for production of both aluminum and gray iron castings. An Eaton water pump housing was selected as the test casting. The casting orientation in the flask was selected as typical of the process: vertical for EPC, horizontal for green sand. Production sand systems were used, with the sand/metal ratio and mold surface areas as similar as possible. The aluminum green sand system contained silica sand, clay cereal, and core returns. The iron green sand system contained silica sand, seacoal, Western bentonite, and core returns. Both the aluminum and iron green sand castings were cored using a phenolic urethane binder (Pep Set 1600/2600® used at a 1.5% binder level and a 50/50 Part I/Part II ratio). Refractory coatings typical of gray iron and aluminum practice were used on the EPC patterns. No mold coatings were used with the green sand systems. Mold clamps were used with the green sand molds to prevent run-out during pouring. The same cooling/test times were used for both green sand and EPC processes. Four flasks were poured for each combination of metal type and molding method. Three runs were repeated with no casting to determine background contaminant levels.

Analysis

Charcoal tubes submitted for GC/MS analysis were desorbed with 1 ml of carbon disulfide and screened by gas chromatography (FID) using a 30-meter fused silica capillary column (splitless mode). Samples were grouped into four classes based on the different metals and molding methods. Since the chromatograms

TABLE I. Casting Parameters

Parameter		EPC	Green Sand
Casting orientation		Vertical	Horizontal
Pouring temperature	Aluminum	760°C	760°C
	Iron	1425°C	1425°C
Casting weight (kg)	Aluminum	2.2	2.2
	Iron	5.9	5.9
Flask size (L × W × H, cm)		41 × 20 × 41	41 × 31 × 25
volume (liters)		3.4	3.3
Top surface area (cm²)		839	1283
Sand weight (kg)		51.7	49.4
Sand metal ratio	Aluminum	23.3/1	22.3/1
	Iron	8.73/1	8.35/1
Core weight (kg)		NA	0.54
Casting/core ratio	Aluminum	NA	4.1/1
	Iron	NA	11/1
Mold/core ratio		NA	92/1
Foam weight (g)	Aluminum	19.0	NA
	Iron	19.0	NA
Adhesive weight (g)	Aluminum	4.6	NA
	Iron	5.1	NA

from each grouping were similar to each other, representative samples from each group were further analyzed by GC/MS. Both the aluminum and the gray iron groups of samples from the EPC molds contained the same compounds, though the aluminum group was at a much lower concentration.

Based on the GC/MS results, the remaining sample tubes were then quantified. Samples for quantitation were desorbed with 1 ml methylene chloride and analyzed using the same column described above. Samples were desorbed with methylene chloride instead of carbon disulfide because benzene was suspected to be present. Carbon disulfide contains benzene as an impurity, and it would have interfered with quantitation at the low levels expected. Methylene chloride was chosen because it contained no contaminants in that region. Desorption efficiencies with methylene chloride were determined for all analytes quantitated by using spiked samples.

Charcoal tube extract samples from both green sand groups were concentrated prior to analysis since most components were present at very low concentrations. Compounds found on these sample tubes were mainly toluene and several higher molecular weight aromatics. Samples from the EPC/iron group were found to contain benzene, toluene, styrene, and ethyl benzene.

All samples were quantitated for benzene, styrene, toluene, and ethyl benzene. Analyses were corrected for desorption efficiency where necessary. Since the desorption efficiency for styrene was low, reported results may be somewhat low. The limit of detection for all the analytes was 1 μg/sample, which corresponds to a minimally detectable emission rate of approximately 11 mg/kg aluminum and 4 mg/kg iron.

Sorbent tubes and filters were screened for the presence of 17 polynuclear aromatic hydrocarbons by gas chromatography using NIOSH Method 5515. Sorbent tubes and 37-mm-diameter PTFE filters were desorbed in 5 ml of benzene with sonication for 20 minutes. Large (20 cm × 25 cm) glass fiber filters were desorbed in 100 ml benzene with sonication for 20 minutes. Standards were prepared by spiking aliquots of a stock solution containing the PNAs into 5 ml of benzene. Analytes were identified by comparing the retention times in the sample chromatograms to those in the standards. The limits of detection of the 17 PNAs, as determined from the sorbent tubes and PTFE filters, varied from 0.5 to 2 μg per sample, which corresponds to minimally detectable emission rates ranging from approximately 160 to 640 μg/kg aluminum and 60 to 240 μg/kg iron. The limits of detection of the 17 PNAs, as determined from the glass fiber filters, varied from 10 to 50 μg per sample, which corresponds to minimally detectable emission rates ranging from approximately 5 to 23 μg/kg aluminum and 2 to 9 μg/kg iron.

The extract obtained from the 37 mm diameter PTFE filter was filtered through a 0.45 μm pore size nylon filter. One milliliter of each sample was transferred into a tared PTFE cup and evaporated to dryness in a vacuum oven at 40°C. The PTFE cups were again weighed and the difference recorded, the weight gain of the cup being one fifth the total benzene solubles per sample. The limit of detection for benzene soluble particulate matter was 0.05 mg per sample, which corresponds to a minimally detectable emission rate of approximately 16 mg/kg aluminum and 6 mg/kg iron.

Results

The data generated for each of the four castings was averaged for each metal/process combination. These averaged results are segregated into the individual contaminant class for each metal type. In order to generalize the data, the results were normalized by dividing the total emission by the weight of the casting. Confidence limits (95%) for these figures were calculated using the Students-t statistic. The computer-aided data acquisition system allowed the recording of over 45,000 data points generated by the real-time instruments. The data generated for each of the four castings was averaged to form a composite picture of each metal/process combination. These composite results are segregated into the pouring and cooling phase and into the shakeout phase for each metal type by individual contaminants.

Carbon Monoxide

Real-time analyses of carbon monoxide emissions are presented in Figure 2 for aluminum and Figure 3 for gray iron. Carbon monoxide concentrations were extremely high during pouring, cooling, and shakeout of the iron castings made with green sand; concentrations exceeded the maximum 500 ppm indicated on the Ecolyzer's meter. However, the analog voltage output continued to increase to a level in excess of 1000 ppm. The error in the 500 to 1000 ppm range may have been substantially higher than that for the 0 to 500 ppm range since the instrument was calibrated for the lower range. Integration of the real-time data yielded a total carbon monoxide emission of 50 ± 22 mg/kg metal (95% confidence limits) and 58 ± 24 mg/kg for EPC and green sand molds, respectively, during the production of aluminum castings. Total carbon monoxide emission amounted to 301 ± 17 mg/kg metal and 2430 ± 80 mg/kg for EPC and green sand molds, respectively, during the production of iron castings.

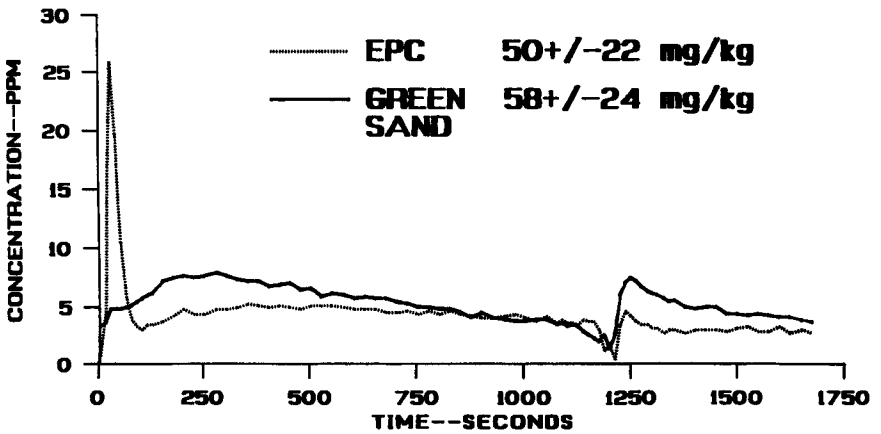

FIGURE 2. Average carbon monoxide concentration during the production of aluminum castings using EPC and green sand molds during pouring and cooling, and shakeout.

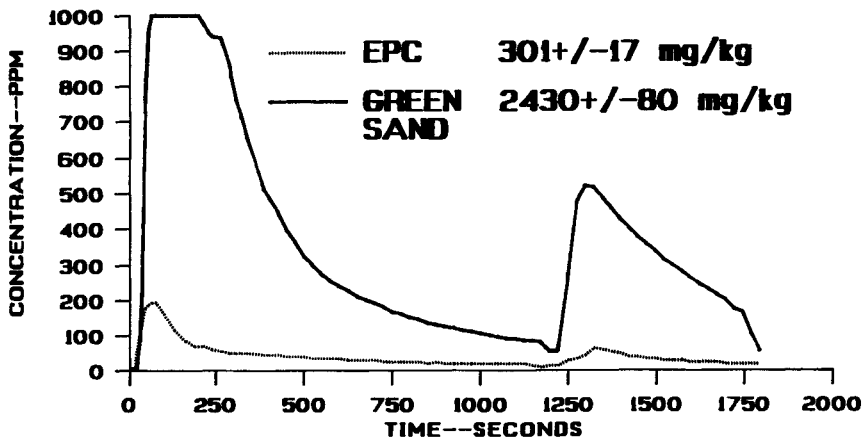

FIGURE 3. Average carbon monoxide concentration during the production of gray iron castings using EPC and green sand molds during pouring and cooling, and shakeout.

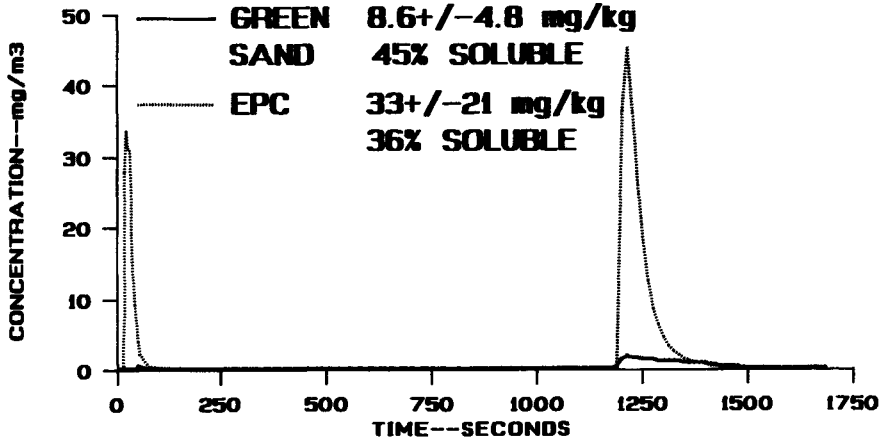

FIGURE 4. Average aerosol mass concentration during the production of aluminum castings using EPC and green sand molds during pouring and cooling, and shakeout.

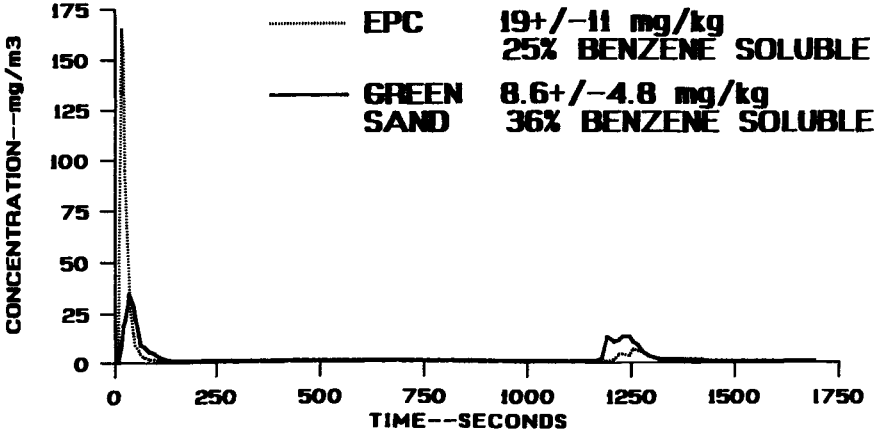

FIGURE 5. Average aerosol mass concentration during the production of gray iron castings using EPC and green sand molds during pouring and cooling, and shakeout.

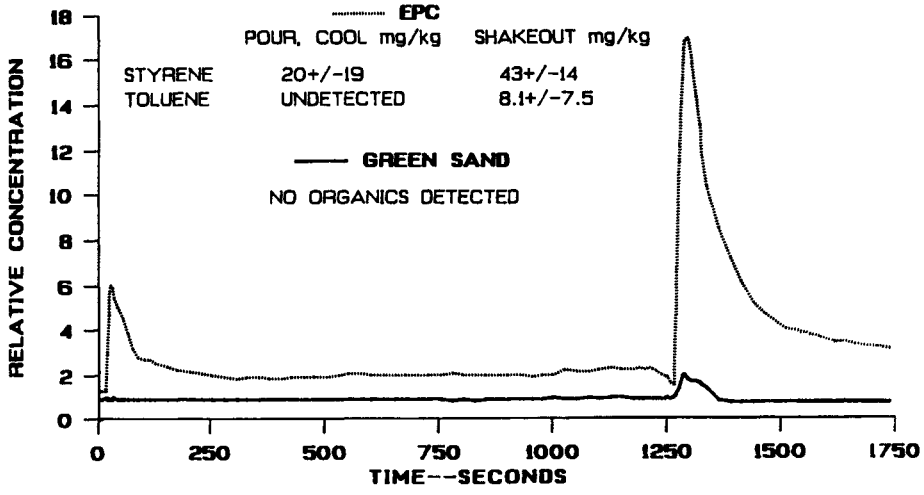

FIGURE 6. Average relative hydrocarbon concentration during the production of aluminum castings using EPC and green sand molds during pouring and cooling, and shakeout.

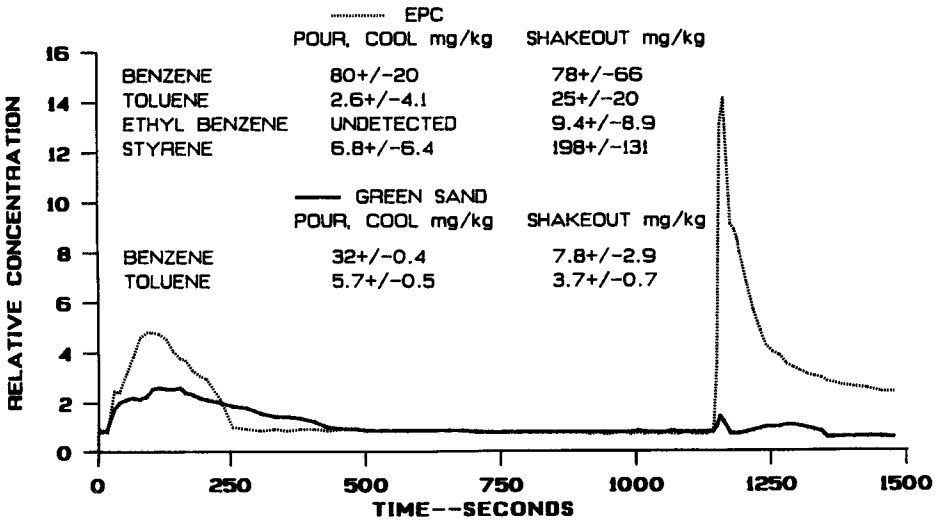

FIGURE 7. Average relative hydrocarbon concentration during the production of gray iron castings using EPC and green sand molds during pouring and cooling, and shakeout.

The highest carbon monoxide emission for both metals with the EPC process occurred during pouring.

Aerosol Mass

Aerosol mass emissions were 33 ± 21 mg/kg and 6.8 ± 3.6 mg/kg for aluminum castings made in EPC and green sand molds, respectively. Aerosol mass emissions were 19 ± 11 mg/kg and 8.6 ± 4.8 mg/kg for iron castings made in EPC and green sand molds, respectively. Aerosol mass emissions were significantly higher for both metals with the EPC molds than green sand. The benzene soluble fraction of the aerosol mass has been used as an index of exposure to the volatile materials in coal tar pitch.[5] For the aluminum castings, the benzene soluble fraction amounted to 36 and 45 percent of the total aerosol, respectively, for the EPC and green sand molds; for the iron castings, the benzene soluble fraction was 25 and 36 percent.

The raw real-time data from the RAM were integrated and compared to the gravimetrically determined aerosol mass to obtain a calibration factor. The corrected aerosol mass concentration is presented in Figure 4 for aluminum and Figure 5 for gray iron. These data indicate that the EPC molds produced more smoke during pouring than the green sand for both iron and aluminum castings. Much of this smoke was generated when molten metal first contacted polystyrene in the pouring cup. The volume of soot generated appeared to be affected by the amount of polystyrene in the pouring cup and by the pouring rate. During cooling, smoke levels were comparable for both processes. Smoke levels from the green sand castings during cooling were unexpectedly low both visually and by measurement. This result may be due in part to the absence of open risers and the use of the ceramic pouring cup. The cup eliminated mold/metal contact at the mold surface where normal contact could generate higher smoke levels. The EPC molds produced more smoke than the green sand during the shakeout of aluminum castings; for iron castings, the situation was reversed. The aerosol mass measured in this study does not reflect any dust produced in removing the sand from the casting. Castings produced by the EPC process were visibly cleaner and thus would probably require less aggressive shakeout. The core used in the aluminum/green sand casting showed little sign of any degradation; considerable effort was required to remove it from the casting. Production shakeout of this green sand casting could generate considerable dust.

Hydrocarbons

Results of the real-time analysis for hydrocarbons and the emission rates for the individual compounds are presented in Figure 6 for aluminum and Figure 7 for gray iron. Real-time data are presented in terms of relative concentration, since the sensitivity of the analyzer is a function of the specific compounds present. These data indicated that the EPC molds produced more hydrocarbons during pouring than the green sand, for both iron and aluminum castings. Again, it is likely that an initial burst of hydrocarbons occurs in EPC molds when molten metal first contacts the polystyrene in the pouring cup. During cooling, hydrocarbon levels were comparable. For iron castings, hydrocarbon concentrations were initially higher for EPC than for green sand, but decreased more rapidly to background levels. For aluminum castings, hydrocarbon concentration was somewhat higher for EPC than for green sand. During shakeout, peak hydrocarbon concentrations were about 15 times higher for EPC than green sand.

During pouring and cooling of aluminum castings in EPC, styrene was the only contaminant detected. During shakeout of the aluminum castings in EPC, both styrene and toluene were detected. No simple organics were detected from the aluminum castings in green sand. During pouring and cooling of the iron castings in green sand molds, benzene and toluene were found; for EPC during the same period, benzene, toluene and styrene were detected. During shakeout of the iron castings, benzene and toluene were detected from the green sand casting, while the EPC castings emitted benzene, toluene, ethyl benzene, and styrene during shakeout. For iron castings, benzene and styrene emissions were significantly higher for EPC than for green sand; toluene and ethyl benzene emissions were not significantly different from zero. No styrene was detected from the green sand castings.

Polynuclear Aromatic Hydrocarbons

Emissions data for PNAs are presented in Tables II and III. Because of the small sample size, the limits of detection were much higher for the XAD-2 resin tube and PTFE filter than for the larger glass fiber filter. Therefore, the nonvolatile PNAs were identified on the glass fiber filter only. Lower molecular weight species were found in the air samples (XAD-2 resin tubes) from both

TABLE II. Polynuclear Aromatic Hydrocarbon Emissions During Pouring, Cooling, and Shakeout of Aluminum Castings

Compound	Limit of Detection (μg/kg)	EPC (μg/kg)	Green Sand (μg/kg)
Naphthalene	640	ND	5700
Acenaphthylene	160	ND	ND
Acenaphthene	190	ND	ND
Fluorene	220	ND	230
Phenanthrene	160	ND	ND
Anthracene	160	240	160
Fluoranthene	5	15	ND
Pyrene	5	ND*	ND
Benz(a)anthracene	14	22	ND
Chrysene	9	9	ND
Benzo(b)fluoranthene	9	69	ND
Benzo(k)fluoranthene	9	21	ND
Benzo(e)pyrene	9	34	ND
Benzo(a)pyrene	23	61	ND
Indeno(1,2,3-cd)pyrene	18	ND*	ND
Dibenz(a,h)anthracene	18	ND	ND
Benzo(ghi)perylene	18	31	ND

ND: not detected in any of four samples
ND*: detected in one or more of the samples; however, mean value below limit of detection.

TABLE III. Polynuclear Aromatic Hydrocarbon Emissions During Pouring, Cooling, and Shakeout of Iron Castings

Compound	Limit of Detection (μg/kg)	EPC (μg/kg)	Green Sand (μg/kg)
Naphthalene	240	9800	2800
Acenaphthylene	60	350	80
Acenaphthene	70	230	ND
Fluorene	90	230	ND*
Phenanthrene	60	2000	ND
Anthracene	60	140	ND*
Fluoranthene	2	2	ND
Pyrene	2	ND*	ND
Benz(a)anthracene	5	7	ND
Chrysene	3	7	ND
Benzo(b)fluoranthene	3	28	ND
Benzo(k)fluoranthene	3	ND	ND
Benzo(e)pyrene	3	11	ND
Benzo(a)pyrene	9	11	ND
Indeno(1,2,3-cd)pyrene	7	9	ND
Dibenz(a,h)anthracene	7	ND	ND
Benzo(ghi)perylene	7	ND	ND

ND: not detected in any of four samples
ND*: detected in one or more of the samples; however, mean value below limit of detection.

metals using both molding systems. Higher molecular weight species were found only in air samples (glass fiber filters) from the EPC process.

Discussion

The purpose of this study was neither to condemn nor endorse the evaporative casting process, but rather to serve as a screening test that will provide information for the foundry industry, aid in process development, and safeguard the health of its workforce. Comparison of the data generated in this study to established safe levels for individual chemical species can only be considered on an individual foundry basis. The tests performed in this comparison study were not exhaustive and could not simulate all of the conditions likely to be encountered in production operations. Therefore, the results from this study should be applied with a degree of judgement. For example, actual shakeout may involve more aeration of the sand, raising emissions of organics that have condensed on the sand during pouring and cooling. Similarly, the metal cooling time used in this study may have differed from that used in a production facility, altering the amount of organic material condensed on the sand.

In order to convert the data of this study into estimates of total emissions for a given foundry, the production rate of the castings (mass/time) must be known. To determine potential workplace exposures, the degree of containment by the local exhaust systems (if any) must be estimated, and this corrected emission rate divided by the volumetric air flow rate in the area of concern. Actual emission rates may be different due to varying casting parameters such as casting size and shape.

Under the conditions tested in this study, EPC molds were found to produce more carbon soot and hydrocarbons during pouring than green sand molds, for both aluminum and iron castings. Hydrocarbon emissions from EPC molds were also greater than from green sand molds during cooling and shakeout. Smoke levels during cooling were similar from EPC and green sand molds. During shakeout a higher initial burst of smoke was observed with EPC aluminum castings than with their green sand counterparts, but within two minutes smoke levels were comparable. Conversely, smoke levels during shakeout of iron castings from green sand molds were initially greater than from EPC molds but fell to comparable levels within several minutes. Carbon monoxide levels were not significant from either EPC or green sand molds used to pour aluminum castings. Carbon monoxide levels from EPC molds for iron castings were an order of magnitude lower than for green sand molds.

Major hydrocarbon contaminants from EPC/aluminum molds included styrene and toluene. The major contaminants from EPC/gray iron molds included styrene, benzene, toluene, and ethyl benzene. In general, these light organic species were present in higher concentrations during shakeout than during pouring and cooling of the molds. Screening analyses for 17 PNAs showed the presence of more species at generally higher concentrations with the EPC molds than with the green sand molds. The quantities found may be low due to evaporation of the sample from the media during the sampling period. These results are notable because benzene and polynuclear aromatic hydrocarbons have been scrutinized for their carcinogenicity. Polynuclear aromatic hydrocarbons have been identified in other studies in emissions from green sand molds.[6] The emission levels from green sand molds encountered in this study may be artificially low because of the use of a ceramic pouring cup and the absence of open risers with the test casting configuration.

When pouring EPC molds, an initial burning of polystyrene is usually observed when molten metal first contacts polystyrene in the pouring cup. This reaction typically lasts only a few seconds until a sufficient head is present to prevent polystyrene decomposition products from bubbling back up the downsprue. Although the duration is short, soot generation is high. Much of the aerosol (quite likely containing many of the PNAs) and a sizeable fraction of the simple organics are generated during this "pouring cup reaction." Consequently, considerable care should be taken in production operations to safeguard the metal pourers.

There are several techniques that can be used to minimize the EPC pouring cup reaction. The amount of polystyrene sprue protruding above the mold surface should be minimized. The

use of a hollow sprue can reduce the amount of material to be vaporized in the sprue and can decrease the time to establish the head necessary to suppress the pouring cup reaction. A high initial pouring rate is desirable to minimize burning, and the use of a large pouring cup may be helpful to accommodate the rapid pour rates. Some pouring cup designs move the initial point of contact between molten metal and polystyrene well below the mold surface, and this may further reduce the initial emission peak. A vacuum-assist applied to an EPC flask during pouring usually does not suppress the pouring cup reaction entirely but does decrease pouring times and provides a means for channelling gaseous emissions into an exhaust system for treatment. Further evaluations are needed to determine the effectiveness of each of these techniques.

Conclusions and Recommendations

This study has identified heavy soot generation during pouring and benzene release (gray iron only) during pouring and shakeout as potential hazards with the EPC process under the conditions tested. Soot generation represents the most severe hazard for both aluminum and iron castings because of the associated release of polynuclear aromatic hydrocarbons. The total mass of aerosol released is eight times greater with EPC than green sand for aluminum castings and twice as great for gray iron castings. Conventional control approaches for pouring operations (compensated air, side draft pouring hoods) may not be adequate to contain these increased emissions. Further work is needed to determine if the use of modified pour cup designs, hollow sprues, high pouring rates, and/or the use of a vacuum assist can suppress soot emissions from EPC molds.

Benzene is a significant hazard during both pouring and shakeout of iron castings made with the EPC process. Benzene levels during pouring were twice as great with EPC than with the green sand process. During shakeout, benzene levels were eight times as great. While styrene is the major organic contaminant produced in the pouring and shakeout of castings made with the EPC process, it is far less toxic than benzene and therefore represents a far less serious hazard.

Carbon monoxide has typically been used as an index of the hazard in mold pouring and cooling areas in gray iron foundries. Because of the relatively low levels (compared to green sand) of carbon monoxide produced relative to the other contaminants with EPC, carbon monoxide would *not* be a good indicator of safety in iron foundries using EPC.

Comparison of the data generated herein to that reported in the literature[2] suggests that the aerosol produced in the actual casting process condenses in the sand or at the casting surface. Careful analyses of production sands for PNAs and comparisons to similar analysis of green sands is advised. Because of the relative airborne levels (compared to green sand) of PNAs and benzene observed in this study, environmental measurements for these materials should be made in production foundries in both pouring and shakeout areas.

New EPC resin systems based on polymethyl methacrylate[7] or poly(akylene carbonates)[8] are currently being test marketed. These non-polystyrene resin systems may minimize the release of benzene, styrene, and the formation of PNAs. Characterization studies of the decomposition of these materials under foundry conditions is encouraged.

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Clarification

In connection with the article "Workplace assessment of exposure to 2-ethoxyethanol," which appeared in Appl. Ind. Hyg. 2:183 (1987), the authors wish to clarify that the work was accomplished in the course of a NIOSH investigation. Two of the authors, D. Clapp and C. Mosely, left NIOSH prior to publication. C. Mosely now is affiliated with the Agency for Toxic Substances and Disease Registry (ATSDR). D. Clapp (as indicated in the publication) is with the Center for Environmental Health (CEH), one of the Centers within the Centers for Disease Control. Both authors are located at 1600 Clifton Rd., Atlanta, GA 30333.