EMISSION CHARACTERISTICS OF THE EVAPORATIVE PATTERN CASTING PROCESS

Michael G. Gressel[1]
Dennis M. O'Brien[1]
Richard D. Tenaglia[2]

January 20, 1987

[1]NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
Division of Physical Sciences and Engineering
Engineering Control Technology Branch
4676 Columbia Parkway
Cincinnati, Ohio 45226

[2]BATTELLE COLUMBUS DIVISION
Melting and Casting Technology
Process Metallurgy Section
505 King Avenue
Columbus, Ohio 43201

ECTB Report No.
161-04

ABSTRACT

In the evaporative pattern casting 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 vaporize. Emissions from the flask were determined for production of both aluminum and gray iron water pump castings using conventional green sand technology and the evaporative pattern casting process (EPC). Testing was performed using an enclosing hood with a sampling stack. Sampling was conducted during pouring, cooling and casting removal. Using gas chromatographic/mass spectrometric (GC/MS) techniques and real-time instrumentation, the study attempted to identify the contaminants produced, to quantify the major contaminants, and to determine the temporal nature of these emissions. Direct reading instruments for aerosols, carbon monoxide, and hydrocarbons were connected to a sampling manifold. The instrument outputs were connected to a personal computer. Integrated sampling was performed via charcoal tubes, glass fiber filters, porous polymer tubes, and polytetrafluoroethylene filters. 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. During cooling and casting removal, relative carbon soot and hydrocarbon levels were variable. Carbon monoxide concentrations were extremely high during pouring and casting removal of the iron castings made with green sand; concentrations with EPC were an order of magnitude lower. Carbon monoxide

levels were not significant during production of aluminum castings with either process. 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.

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. The process is claimed to be a lower cost method of producing complex shaped castings from a variety of base metals. Since the reported cost savings range from 10 to 20 percent, this process could become a substantial part of the foundry industry in the future.[1]

The EPC process offers promise of improved working conditions due to inherent process advantages. Environmental advantages compared to conventional bonded-sand processes cited[2] for this process include:

- Casting cleaning is minimized since there are no parting lines or core fins.
- No binders or other additives are required for the sand (which is reusable). Because no cores are used, no core binders are present.
- Shakeout is simplified by the use of free-flowing sand; noisy shakeout machines can be eliminated.

Since dry sand is used, the silica hazard during sand handling may be higher. This may be offset by improved casting surfaces which require less chipping and grinding and which contain less burned-on silica, both of which result in lower exposures.

This study characterized the emissions generated during the pouring, cooling, and shakeout of castings made with the EPC process. Kobzar and Ivanyuk[3] 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 the major decomposition products were, in order of decreasing concentration, carbon dioxide, benzene, styrene, carbon, methane, and carbon monoxide. At ferrous melting temperatures the major decomposition products were, in order of decreasing concentration, carbon, methane, acetylene, carbon monoxide, and hydrogen. Decomposition products in an actual casting operation may be different from those reported, due to limited oxygen availability, higher rates of decomposition of the polystyrene pattern, and quenching effects in a sand mold.

Using gas chromatographic/mass spectrometric (GC/MS) techniques and real-time instrumentation, the study attempted to identify the contaminants produced, to quantify the major contaminants, and to determine the temporal nature of these emissions. Since the polystyrene decomposition products filter through and condense on the sand (which is reused), recycled sand for use in this study was obtained from the production lines of foundries currently using this process. 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 conventional green sand technology, and emissions from these molds were determined as a basis for comparison.

Experimental procedures

A sampling hood similar to one used by Toeniskoetter and Schafer[4] was constructed to contain the process emissions and deliver them to a convenient sampling point. The hood utilized in this study is shown in Figure 1. A schematic representation is presented in Figure 2. 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 observation and videotaping of the pour operation and cooling of the molds. The exhaust takeoff was connected to a 74 cm (30 in) length of 7.6 cm (3.0 in) diameter pipe, which terminated in a filter holder and blower assembly. A pre-weighed 20 cm x 25 cm (8 in x 10 in) glass fiber filter was placed in the filter holder. A blower connected to the filter holder was set at a volumetric flowrate of 190 l/min (40 ft^3/min), which corresponds to a duct velocity of 3.4 m/s (660 ft/min). The Reynolds number (N_{Re}) for this flow is approximately 20,000, which indicates that the flow is turbulent. This ensured good mixing of the contaminants and a relatively flat velocity profile.

Sampling--

Two aerosol sampling ports and two gas sampling ports were located along the length of the pipe. Total volume was measured by monitoring the pressure differential across an orifice plate; constant flow volume was maintained by manual adjustment of a variable transformer attached to the blower motor. The aerosol sampling nozzles were sized at 0.325 cm (.128 in) diameter (internal) to provide isokinetic sampling conditions at a volumetric sampling rate of 1.7 lpm.

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); the second for 30 minutes (the duration of the entire casting operation - pouring, cooling, 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 um 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, listed in Table 1, as outlined in NIOSH method No. 5515[5]. 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 x 25 cm glass fiber filter. This filter was then extracted with benzene for quantification of specific polynuclear aromatic hydrocarbons.

Direct-reading instrumentation--

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. The data acquisition system consisted of an AI13® analog-to-digital convertor (Interactive Structures Inc., Bala Cynwyd, PA) coupled to an Apple IIplus® 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 (e.g., light off) with any emission peaks.

Casting parameters--

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: horizontal for green sand, vertical for EPC. Casting weight and gating designs were the same for both EPC and green sand castings. 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. The 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. Identical pouring temperatures were used for the EPC and green sand processes (760 C for aluminum, 1425 C for iron). No vacuum assist was applied to the EPC mold box during the pour. The same cooling/test times were used for both processes. Complete casting parameters are listed in Table 2.

Procedures--

The hood was placed over the flask prior to pouring and was allowed to rest on the floor. The direct reading instruments were started and allowed to stabilize for 30 minutes prior to pouring. The high-volume blower, portable pumps, and the data acquisition system were switched "on" approximately one minute before the pour. The molten metal was poured through the pouring tube at the side of the hood into the ceramic pouring cup and into the mold. After pouring the casting was allowed to cool for approximately 20 minutes. One charcoal tube was removed from the sampling manifold at this time and its pump switched "off". The sampling hood was lifted above the flask by crane (with all other pumps and instruments still running) and the casting pulled from the flask or dumped on the floor. The hood was then lowered back over the exposed casting/flask as quickly as possible and sampling continued for an additional ten minutes. 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. The background levels were subtracted from the process emission where background contaminants were present.

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 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 ug/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 x 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 ug/sample, which corresponds to minimally detectable emission rates ranging from approximately 160 to 640 ug/kg aluminum and 60 to 240 ug/kg iron. The limits of detection of the

17 PNAs, as determined from the glass fiber filters, varied from 10 to 50 ug/sample, which corresponds to minimally detectable emission rates ranging from approximately 5 to 23 ug/kg aluminum and 2 to 9 ug/kg iron.

The extract obtained from the 37 mm diameter PTFE filter was filtered through a 0.45 um 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/sample, which corresponds to a minimally detectable emission rate of approximately 16 mg/kg aluminum and 6 mg/kg iron.

Results - Real-time data

The computer aided data acquisition system allowed the recording of over 45000 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 3 for aluminum and Figure 4 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 percent 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. The highest carbon monoxide emission for both metals with the EPC process occurred during pouring.

Aerosol mass--

The raw real-time data from the RAM was integrated and compared to the gravimetrically determined aerosol mass to obtain a calibration factor. The corrected aerosol mass concentration is presented in Figure 5 for aluminum and Figure 6 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 is 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—

Real-time analysis of the relative hydrocarbon concentration is presented in Figure 7 for aluminum and Figure 8 for gray iron. Data is 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.

Results - Integrated Sampling

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 (mg) by the weight of the casting (kg). Confidence limits (95 percent) for these figures were calculated using the Students-t statistic.

Simple organics (benzene, toluene, ethyl benzene, styrene)--

Emission data for benzene, toluene, ethyl benzene, are presented in Figure 9. Figure 9a presents the data for pouring and cooling; Figure 9b presents the data for pouring, cooling, and shakeout. The data for shakeout (Figure 9c) was obtained by difference. During pouring and cooling of aluminum castings in EPC, styrene, the only contaminant detected, had an emissions rate of 20 ±19 mg/kg. During shakeout of the aluminum castings in EPC, toluene emissions were 8.1 ±7.5 mg/kg while styrene emissions were 43 ±14 mg/kg. 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 emissions were 32 ±0.4 mg/kg and 5.7 ±0.5 mg/kg respectively; for EPC during the same period, benzene, toluene, and styrene emissions were 80 ±20 mg/kg, 2.6 ±4.1 mg/kg, and 6.8 ±6.4 mg/kg respectively. During shakeout of the green sand (iron) castings, benzene emissions were 7.8 ±2.9 mg/kg, while toluene emissions were 3.7 ±0.7 mg/kg. Emissions from the EPC (iron) castings during shakeout were 78 ±66 mg/kg, 25 ±20 mg/kg, 9.4 ±8.9mg/kg, and 198 ±131 mg/kg for benzene, toluene, ethyl benzene, and styrene respectively. 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.

Aerosol mass--

Emission data for aerosol mass are presented in Figure 10 for pouring, cooling, and shakeout for both metals cast and both molding methods. 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. These results do not differentiate between aerosol generated in EPC flasks at the pouring cup and aerosols generated through the mold top surface.

Benzene soluble aerosol mass--

The benzene soluble fraction of the aerosol mass has been used as an index of exposure to the volatile materials in coal tar pitch[6]. Emission data for the benzene soluble fraction of the aerosol mass are presented in Figure 11 for pouring, cooling, and shakeout for both metals cast and both molding methods. 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.

Polynuclear aromatic hydrocarbons—

Emissions data for polynuclear aromatic hydrocarbons are presented in graphical format in Figures 12 - 14 and in tabular format in Tables 3 and 4. 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 non-volatile PNAs were identified on the glass fiber filter only. Lower molecular weight species (Figure 12) were found in the air samples (XAD-2 resin tubes) from both metals using both molding systems. Higher molecular weight species (Figures 13 and 14) 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 either process, but rather to serve as a screening test that will provide information for the foundry industry, to aid in process development and to 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 a 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 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 (kg/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.

Under the conditions tested in this comparison 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 polynuclear aromatic hydrocarbons (PNAs) showed the presence of more species at generally higher concentrations with the EPC molds than with the green sand molds.

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[7]. 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.

Previous to this investigation, the most complete information available on decomposition products of polystyrene foams was a laboratory furnace study by Kobzar and Ivanyuk[3]. It should be noted that the heating rates and furnace atmosphere were considerably different from those likely to occur under actual casting conditions and that these differences can affect significantly the quantities and species of decomposition products. The results of their laboratory study are contrasted to NIOSH/Battelle results in Table 5. Much less of the measured contaminants were produced in the actual casting of aluminum. This difference can be attributed to either much greater production of the lighter hydrocarbons, or, more probably, condensation of the contaminant materials in the sand near the surface of the casting due to the lower casting temperature of the aluminum (760 C) versus gray iron (1425 C). The measured contaminants produced in the actual casting of gray iron were more comparable. Benzene, toluene, and ethyl benzene were produced in slightly greater amounts than indicated in the laboratory experiment; styrene was produced in much greater quantities than predicted by the laboratory simulation. Carbon monoxide emissions were similar. The aerosol (carbon soot) produced in the actual casting process was only about ten percent that of the laboratory simulation, further suggesting that condensation in the sand or at the casting surface is taking place.

Concurrent to the NIOSH/Battelle study, Lost Foam Technologies[8] (LFT) has conducted a pilot scale study of organic emissions during the shakeout of both aluminum and gray iron castings. Emission of the organics benzene, toluene, ethyl benzene, and styrene from both studies are compared in Table 6. Measurements made by NIOSH/Battelle during the shakeout of aluminum castings were similar; during the shakeout of the iron castings, the results were several orders of magnitude greater than the LFT study. The reasons for the discrepancy in results for iron castings are not apparent.

In order to place the results of this study in perspective, the results of this study were compared to those obtained by Kaiser-Farrell, et al[9]. They evaluated the mutagenicity of emissions from eight binder systems used in steel foundries; samples were collected using an apparatus similar to that used in this study, but a larger, steel casting was produced. Aerosol mass and soluble mass of the gray iron in EPC and green sand systems are compared to the values calculated from their data in Table 7. Although the metals used were different, the pouring temperatures were similar. The values for soluble mass reported by Kaiser-Farrell were methanol soluble mass rather than benzene soluble mass. The comparison of the green sand emission from this study with the green sand/reclaimed sand values of Kaiser-Farrell showed that both the total aerosol mass and the soluble mass were similar on a "per mass of metal" basis. When compared to the other binder systems evaluated in their study, EPC emissions fall squarely in the middle for both total and soluble aerosol mass.

Conclusions and Recommendations

This study has identified heavy soot generation during pouring and benzene release (cast 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 less toxic than benzene and therefore represents a 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 Soviet literature 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 analyses 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.

Development of new resin systems based on non-aromatic hydrocarbons should be encouraged. This study is expected to spur the on-going development of non-polystyrene resin systems for use in this process, to minimize the release of benzene, styrene, and the formation of PNAs. An evaluation of these new resins, similar to that performed here, should be made.

Acknowledgements

Funds for the foundry phase of this study were provided by the nine sponsoring companies participating in the Battelle multi-client study of the evaporative pattern casting process. Partial funding for the joint study was provided by the Environmental Protection Agency under Interagency Agreement No. DW

75931706-01-0. GC/MS analyses were capably performed by Ardith Grote of NIOSH. PNA determinations were made by Kenneth Spaulding of UBTL, Inc.

References

1. P. G. Kohler, "Evaporative Pattern Process: A New Dimension for the Foundry," Modern Casting vol 71, p 36-7. (1981)

2. E. J. Sikora, "Evaporative Casting Using Expandable Polystyrene Patterns and Unbonded-Sand Casting Techniques", AFS Transactions, vol-86, p 65-68 (1978).

3. A. I. Kobzar, and E. G. Ivanyuk, "Thermal Degradation Products of Foundry Foamed Polystyrene", Liteinoe Proizvodstvo, vol 7, p 31-32 (1975).

4. R. H. Toeniskoetter, and R. J. Schafer, "Industrial Hygiene Aspects of the Use of Sand Binders and Additives", Presented at the BCIRA International Conference "The Working Environment in Iron Foundries" University of Warwick, England (March 22-24, 1977).

5. National Institute for Occupational Safety and Health, "NIOSH manual of analytical methods", 3rd ed. National Institute for Occupational Safety and Health, DHHS (NIOSH) publication no. 84-100, Cincinnati, Ohio (1984)

6. American Conference of Governmental Industrial Hygienists, "Documentation of the threshold limit values", 4th ed. ACGIH, Cincinnati, Ohio (1980).

7. W. G. Palmer, and W. D. Scott, "Lung Cancer in Ferrous Foundry Workers: a Review", Am. Ind. Hyg. Assoc. J., vol 42, p 329-340 (1981).

8. R. Rooker, Personal Communication - Lost Foam Technologies, (1986).

9. C. Kaiser-Farrell, C. Sheldrake, D. R. McCalla, E. S. Gibson, A. A. Kerr, and J. N. Lockington, "The Mutagenicity of Emissions from Eight Binder Systems Used in Steel Foundries", Am. Ind. Hyg. Assoc. J., vol 47, p 578-586 (1986)

Table 1. Polynuclear aromatic hydrocarbons

Code	Compound	Limits of Detection (ug/sample) XAD-2 resin tube	PTFE filter	Glass fiber filter
a	Naphthalene	2	2	20
b	Acenaphthylene	0.5	1	20
c	Acenaphthene	0.6	1	20
d	Fluorene	0.7	1	20
e	Phenanthrene	0.5	1	20
f	Anthracene	0.5	1	20
g	Fluoranthene	0.5	1	10
h	Pyrene	0.5	1	10
i	Benz(a)anthracene	0.5	1	30
j	Chrysene	0.5	1	20
k	Benzo(b)fluoranthene	0.5	1	20
l	Benzo(k)fluoranthene	0.5	1	20
m	Benzo(e)pyrene	0.5	1	20
n	Benzo(a)pyrene	0.5	1	50
o	Indeno(1,2,3-cd)pyrene	1	1	40
p	Dibenz(a,h)anthracene	1	1	40
q	Benzo(ghi)perylene	1	1	40

Table 2. Casting Parameters

Parameter		EPC	Green Sand
Casting weight (kg)	Aluminum	2.2	2.2
	Iron	5.9	5.9
Flask size (L x W x H, cm)		41 x 20 x 41	41 x 31 x 25
volume (liters)		3.4	3.3
Top surface area (cm^2)		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

Table 3. Polynuclear Aromatic Hydrocarbon Emissions During Pouring, Cooling, and Shakeout of Aluminum Castings.

Compound	Limit of Detection (ug/kg)	EPC (ug/kg)	Green Sand (ug/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 of the samples; however, mean value below limit of detection.

Table 4. Polynuclear Aromatic Hydrocarbon Emissions During Pouring, Cooling, and Shakeout of Iron Castings.

Compound	Limit of Detection (ug/kg)	EPC (ug/kg)	Green Sand (ug/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 of the samples; however, mean value below limit of detection.

Table 5. Measured and Predicted Thermal Degradation Products

Substance	Aluminum		Iron	
	Predicted[a] (mg)	Measured (mg)	Predicted[a] (mg)	Measured (mg)
H_2	285	na	1710	na
C	1140	115	5700	166
CO	1425	110	2375	1695
CH_4	1615	na	2850	na
CO_2	3325	na	760	na
C_2H_2	380	na	1900	na
C_2H_4	1045	na	665	na
C_2H_6	570	na	285	na
C_3H_6	570	na	19	na
C_5H_{12}	85	na	-	na
C_6H_6 (benzene)	2660	23*	570	997
C_7H_8 (toluene)	1520	23*	85	174
C_8H_8 (styrene)	3800	70	285	1221
C_8H_{10} (ethyl benzene)	190	23*	10	62

[a] based on laboratory simulation data of Kobzar and Ivanyuk(3)
na - not analyzed
*limit of detection

Table 6. Comparison to Lost Foam Technologies Data[8]

Substance	Aluminum		Iron	
	NIOSH (mg/gm foam)	LFT (mg/gm foam)	NIOSH (mg/gm foam)	LFT (mg/gm foam)
Benzene	0.9*	0.02	24	0.06*
Toluene	0.9	0.21	7.5	0.03
Ethyl benzene	0.9*	0.11	2.8	0.01*
Styrene	5.0	12.5	59	0.01
Pentane	na	0.004	na	0.02*

na - not analyzed
*limit of detection

Table 7. Comparison of EPC aerosol emissions with the emissions from other binder systems. (NIOSH - gray iron; Kaiser-Farrell[9] - steel)

Casting System	Aerosol Mass (mg/kg metal)	Soluble Mass* (mg/kg metal)
NIOSH		
EPC	19.4	4.76
Green Sand	8.55	3.02
Kaiser-Farrell		
Green Sand (new)	9.07	4.05
Green Sand (reclaimed)	9.53	5.40
Green Sand (reclaimed w/ hot topping compound)	28.8	18.6
Shell Core	179	144
Oil/Clay/Cereal	82.8	74.7
Sodium Silicate	13.5	10.3
Furan	6.98	2.19
Kold Set	16.7	15.8

* All values are methanol soluble mass except for NIOSH values which are benzene soluble mass.

FIGURE CAPTIONS

Figure 1. Experimental arrangement.

Figure 2. Schematic drawing of experimental arrangement.

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

Figure 4. Average carbon monoxide concentration during the production of gray iron castings using EPC and green sand molds during pouring and cooling, and shakeout.

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

Figure 6. Average aerosol mass concentration during the production of gray iron castings using EPC and green sand molds during pouring and cooling, and shakeout.

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

Figure 8. Average relative hydrocarbon concentration during the production of gray iron castings using EPC and green sand molds during pouring and cooling, and shakeout.

Figure 9. Average organic emissions in mg/kg metal for the production of aluminum and gray iron castings using EPC and green sand molds during a) pouring and cooling; b) shakeout; and, c) pouring, cooling, and shakeout.

Figure 10. Average aerosol mass emissions in mg/kg metal for the production of aluminum and gray iron castings using EPC and green sand molds during pouring, cooling, and shakeout.

Figure 11. Average benzene soluble aerosol mass emissions in mg/kg metal for the production of aluminum and gray iron castings using EPC and green sand molds during pouring, cooling, and shakeout.

Figure 12. Average polynuclear aromatic hydrocarbon emissions as collected by XAD-2 resin tubes and PTFE filters, in ug/kg metal for the production of aluminum and gray iron castings using EPC and green sand molds during pouring, cooling, and shakeout: (Limits of detection in ug/sample are indicated in parentheses)
a) naphthalene (2), b) acenaphthylene, (0.5), c) acenaphthene (0.6), d) fluorene (0.7) e) phenanthrene (0.5), f) anthracene (0.5).

Figure 13. Polynuclear aromatic hydrocarbon emissions as collected by a glass fiber filter, in ug/kg metal for the production of aluminum and gray iron castings using EPC and green sand molds during pouring, cooling, and shakeout: (Limits of detection in ug/sample are indicated in parentheses) g) fluoranthene (10), h) pyrene (10), i) benz(a)anthracene (30), j) chrysene (20), k) benzo(b)fluoranthene (20), l) benzo(k)fluoranthene) (20).

Figure 14. Polynuclear aromatic hydrocarbon emissions as collected by a glass fiber filter, in ug/kg metal for the production of aluminum and gray iron castings using EPC and green sand molds during pouring, cooling, and shakeout: (Limits of detection in ug/sample are indicated in parentheses) m) benzo(e)pyrene (20), n) benzo(a)pyrene) (50), o) indeno(1,2,3-cd)pyrene) (40), p) dibenz(a,h)anthracene) (40), q) benzo(ghi)perylene) (40).

Table 1. Polynuclear aromatic hydrocarbons

Table 2. Casting Parameters

Table 3. Polynuclear Aromatic Hydrocarbon Emissions During Pouring, Cooling, and Shakeout of Aluminum Castings.

Table 4. Polynuclear Aromatic Hydrocarbon Emissions During Pouring, Cooling, and Shakeout of Iron Castings.

Table 5. Measured and Predicted Thermal Degradation Products

Table 6. Comparison to Lost Foam Technologies Data[8]

Table 7. Comparison of EPC aerosol emissions with the emissions from other binder systems. (NIOSH - gray iron; Kaiser-Farrell[9] - steel)

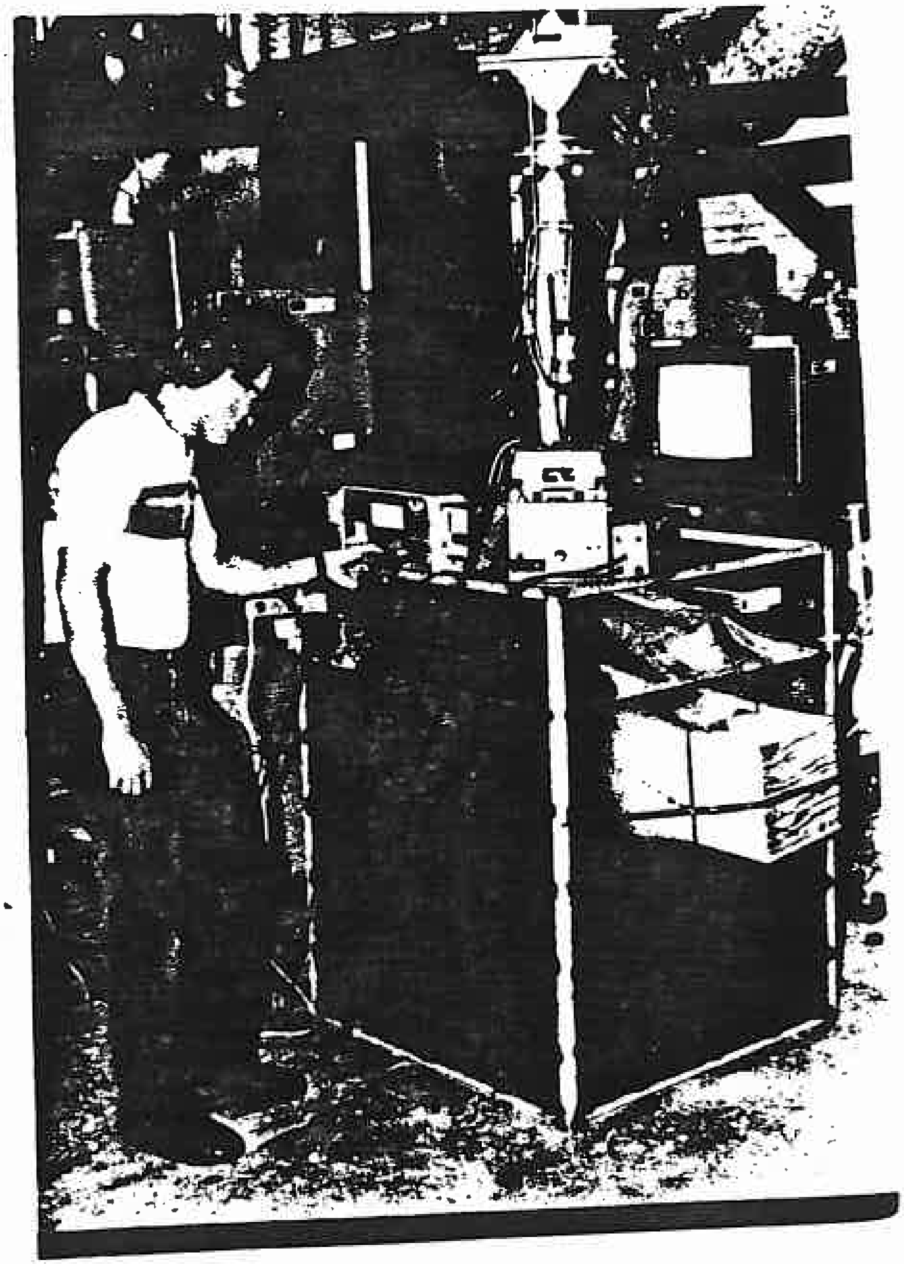


Figure 1

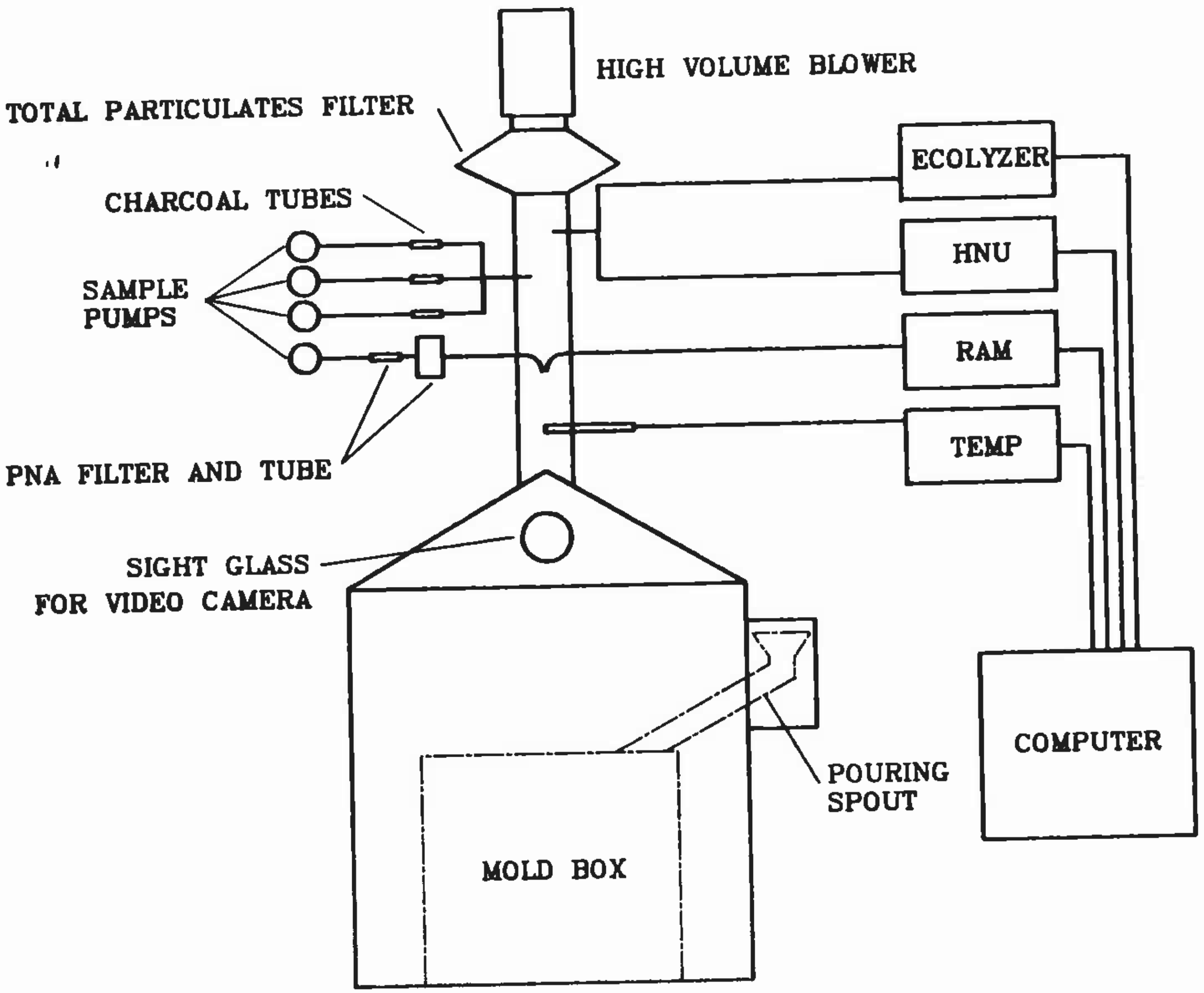
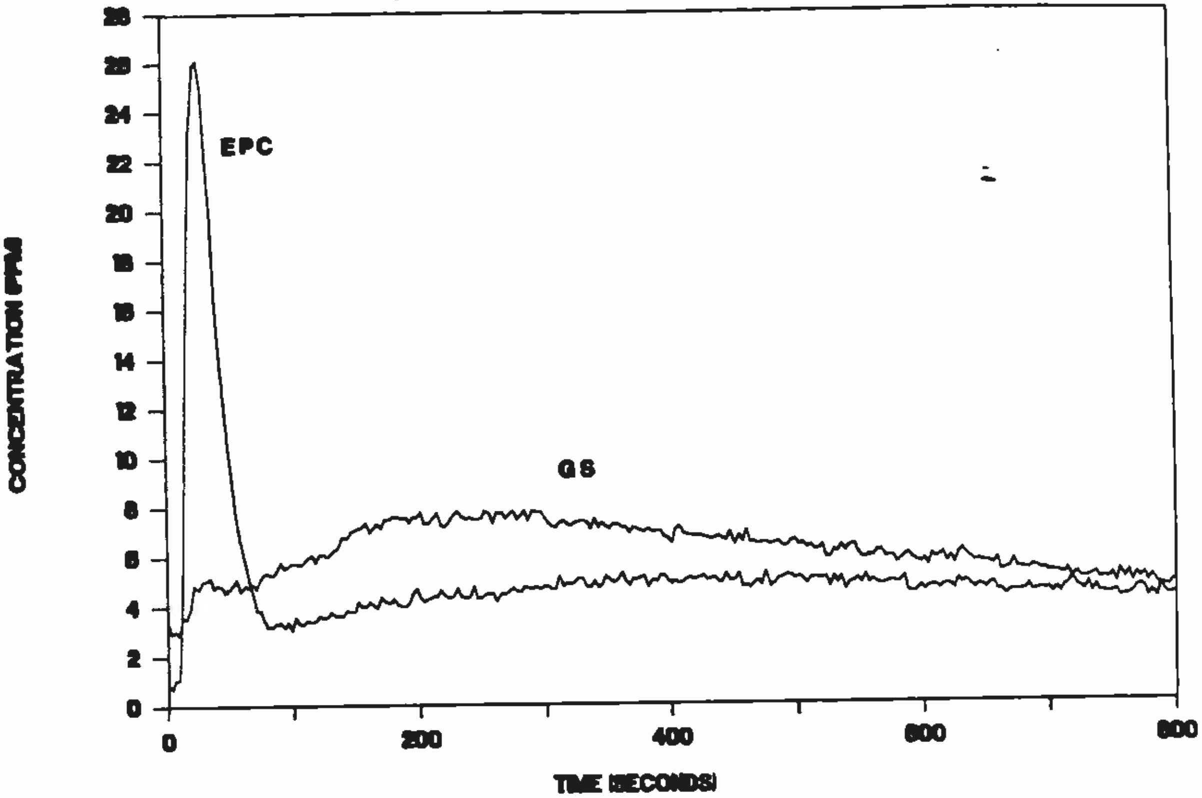

HIGH VOLUME BLOWER
TOTAL PARTICULATES FILTER
CHARCOAL TUBES
SAMPLE PUMPS
PNA FILTER AND TUBE
SIGHT GLASS FOR VIDEO CAMERA
ECOLYZER
HNU
RAM
TEMP
COMPUTER
POURING SPOUT
MOLD BOX

Figure 2

Figure 3

ALUMINUM EPC VS. GREEN SAND

CO READINGS DURING POURING AND COOLING



ALUMINUM EPC VS. GREEN SAND

CO READINGS DURING SHAKEOUT

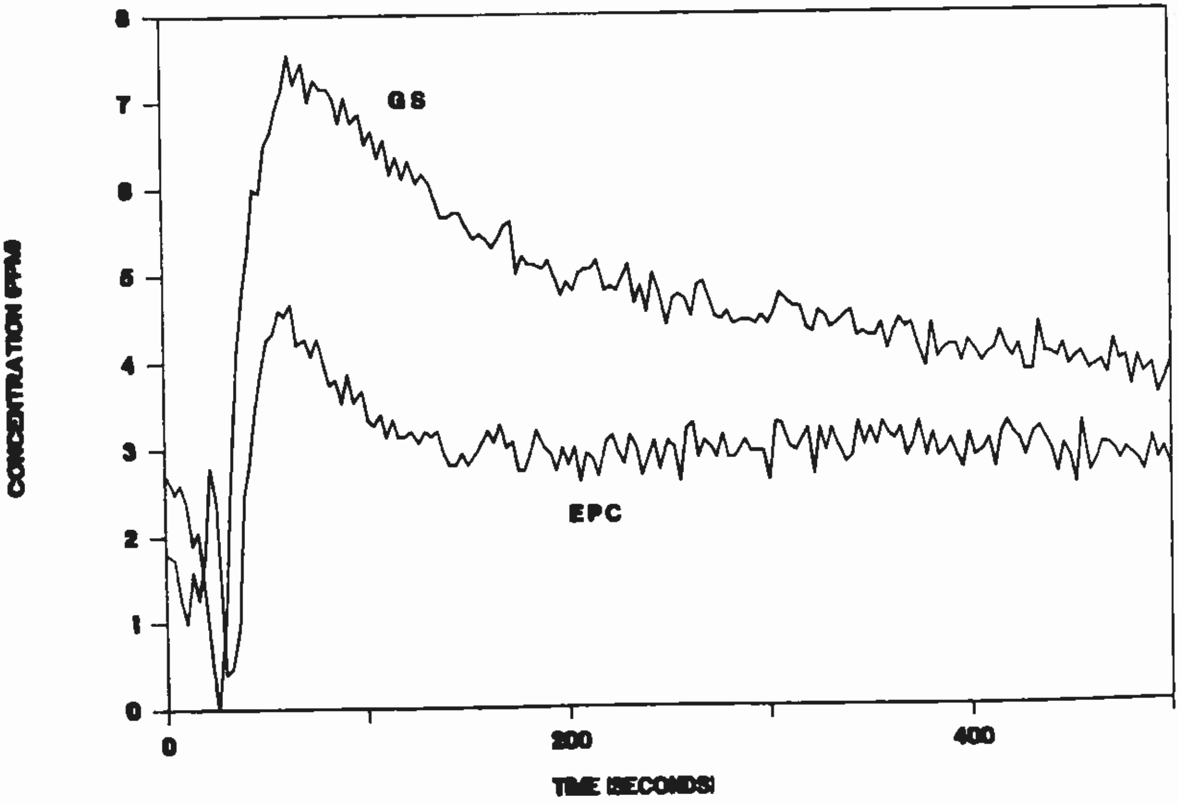
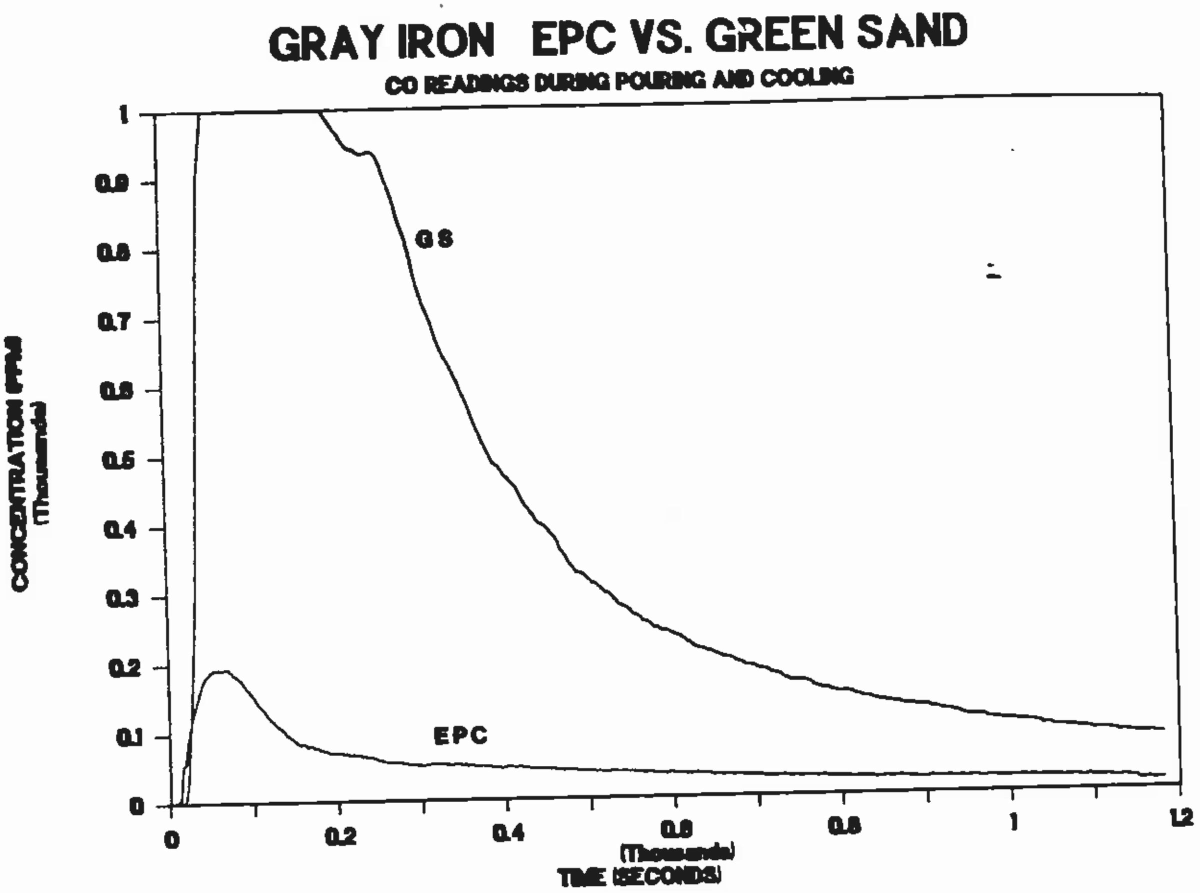
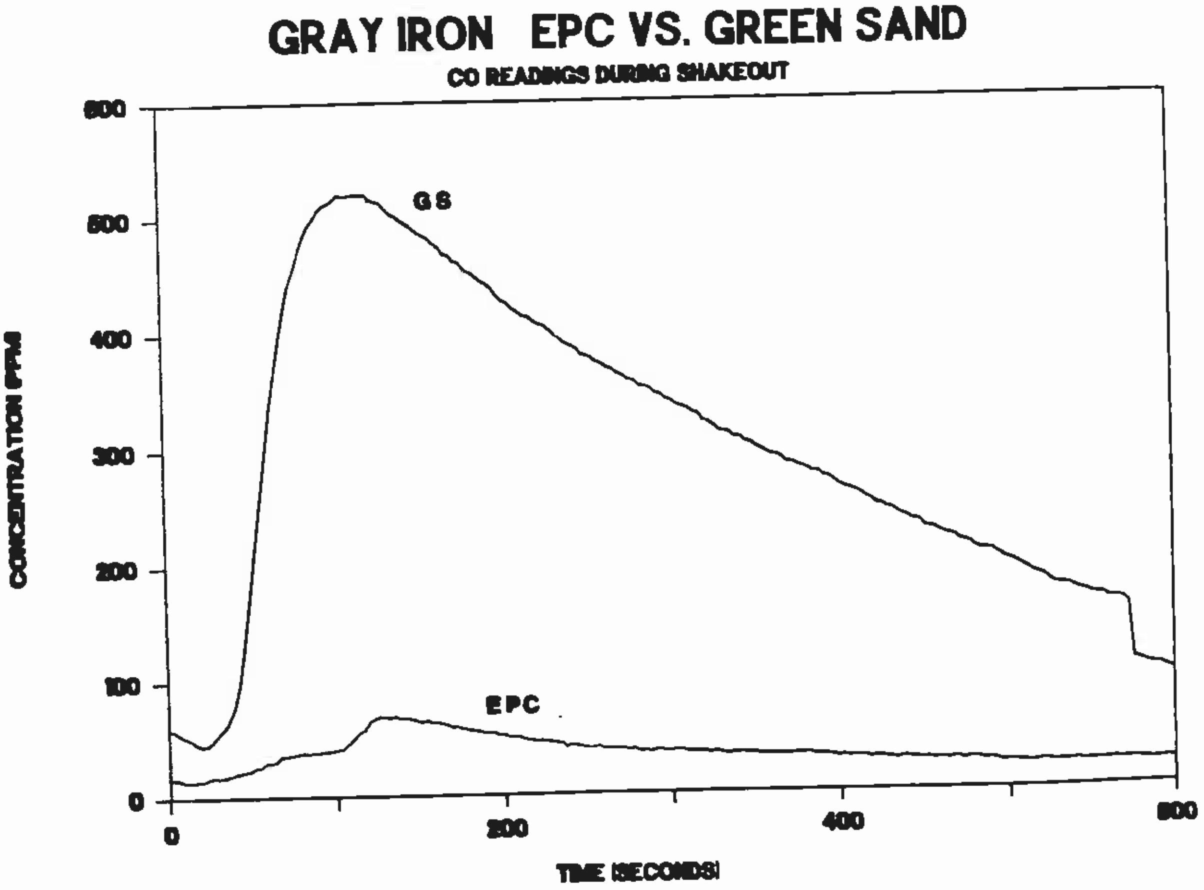


Figure 4


GRAY IRON EPC VS. GREEN SAND

CO READINGS DURING POURING AND COOLING

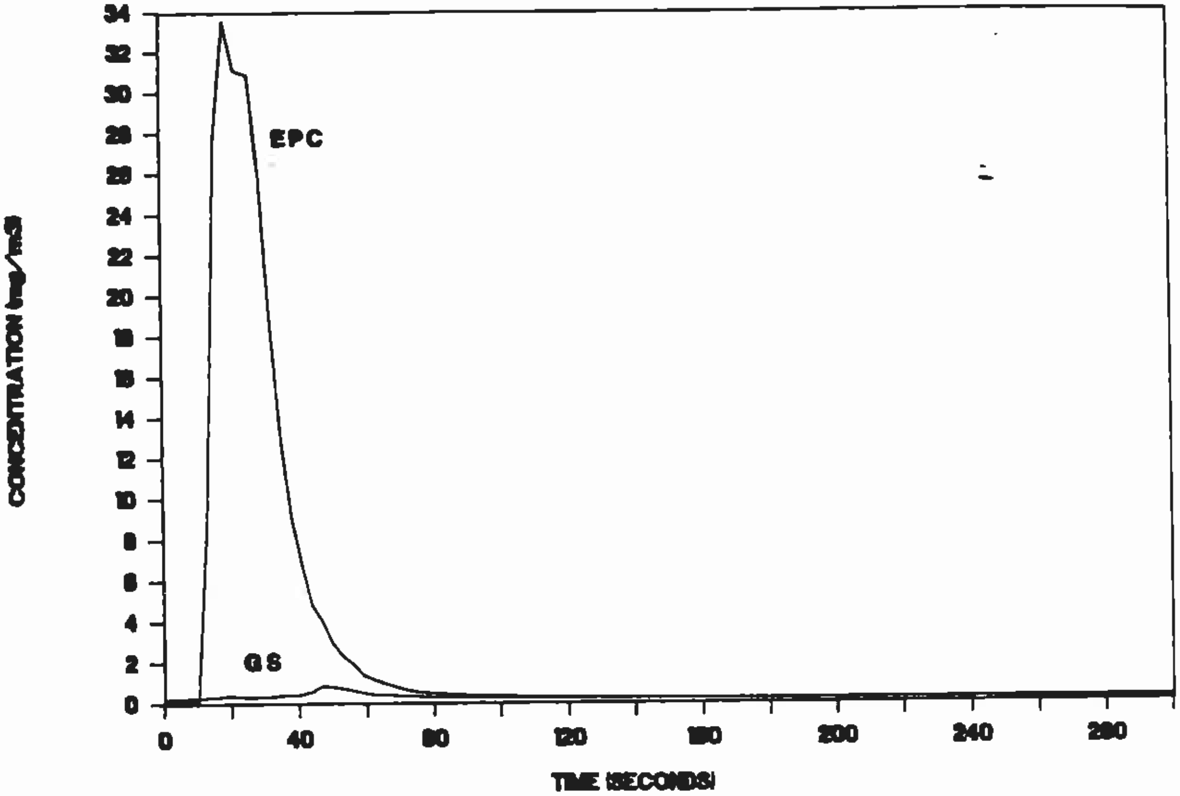

GRAY IRON EPC VS. GREEN SAND

CO READINGS DURING SHAKEOUT

Figure 5

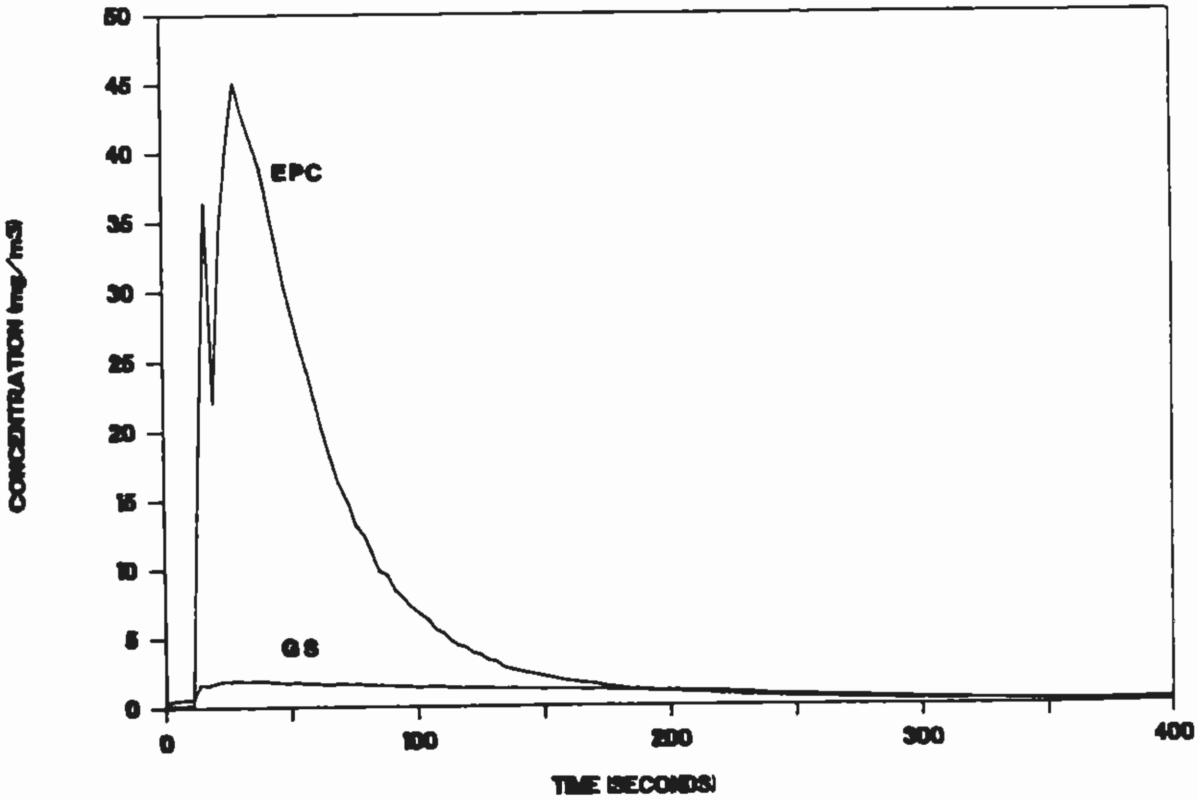
ALUMINUM EPC VS. GREEN SAND

RAM READINGS DURING POURING AND COOLING



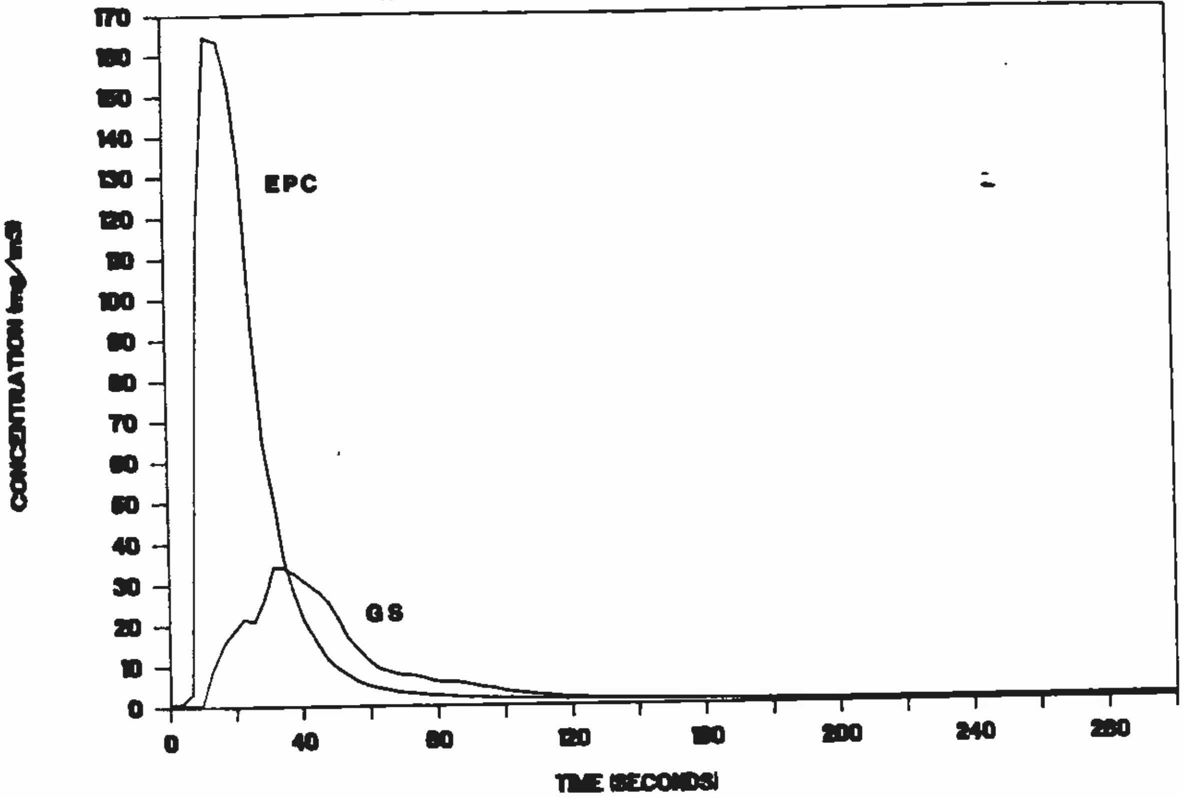
ALUMINUM EPC VS. GREEN SAND

RAM READINGS DURING SHAKEOUT



GRAY IRON EPC VS. GREEN SAND

RAM READINGS DURING POURING AND COOLING



GRAY IRON EPC VS. GREEN SAND

RAM READINGS DURING SHAKEOUT

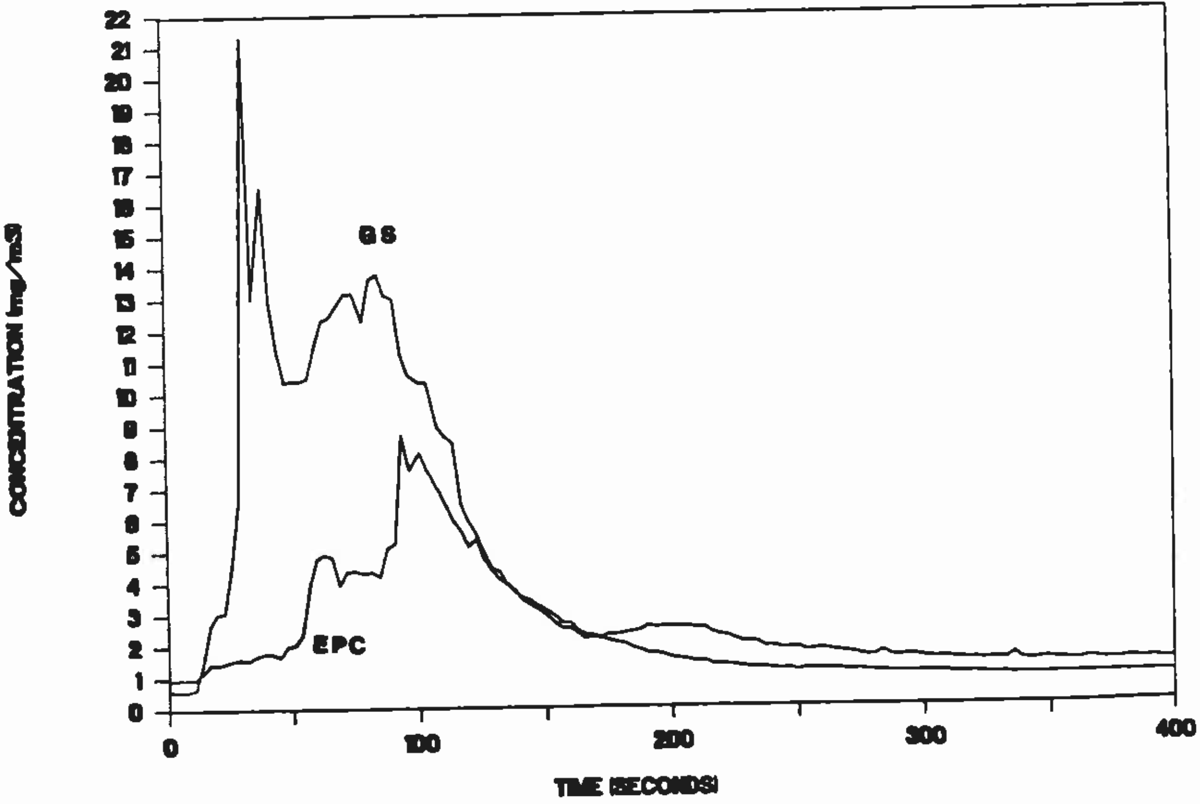
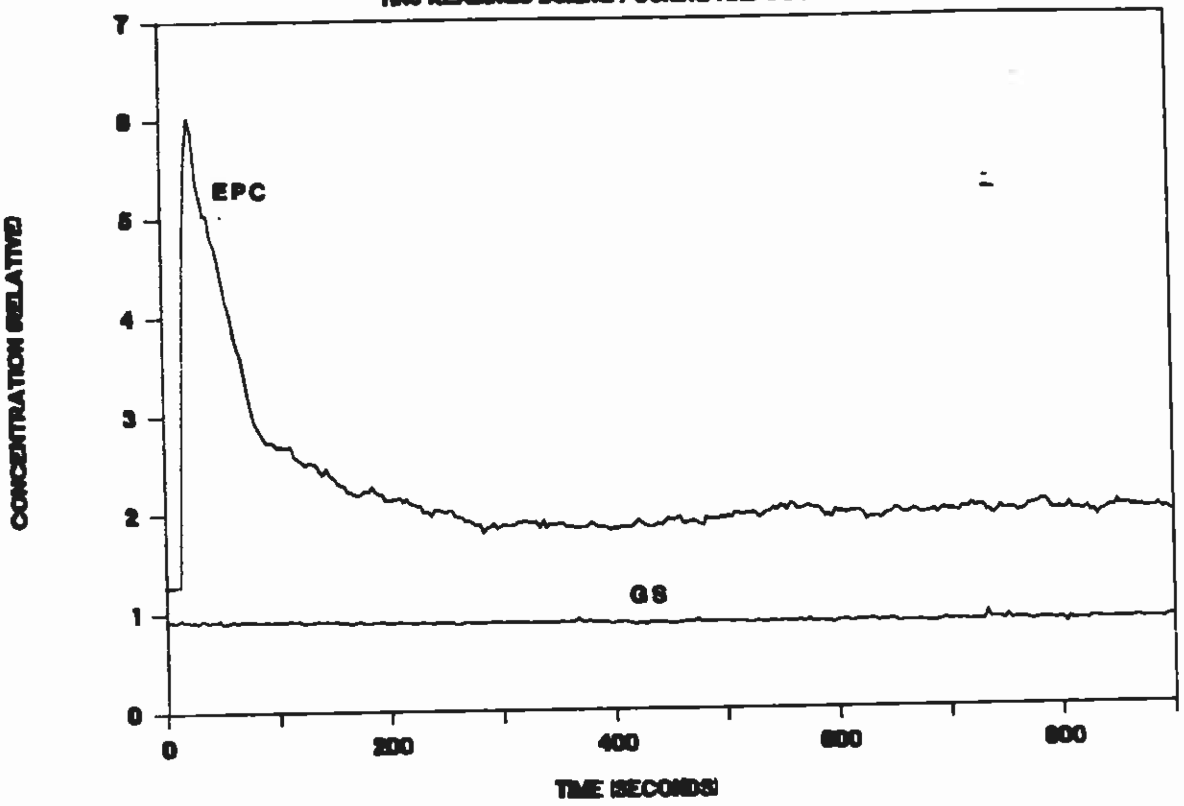
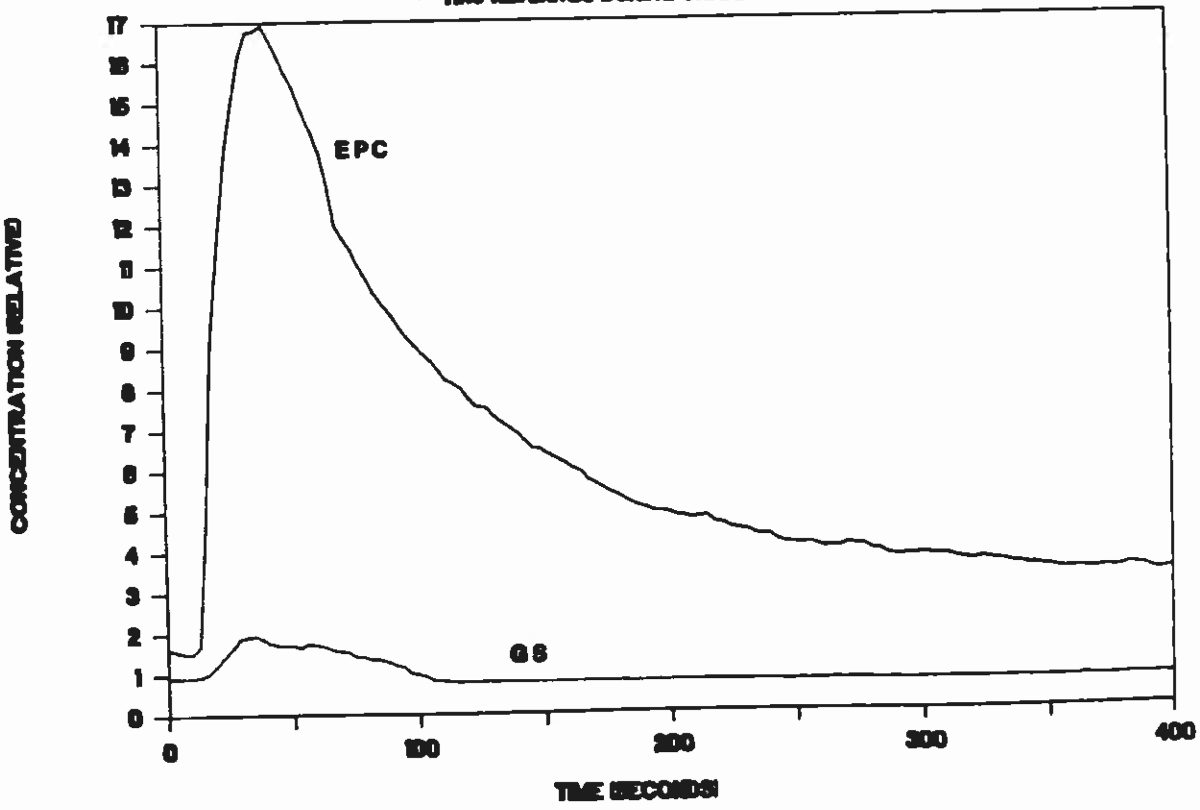


Figure 6



ALUMINUM EPC VS. GREEN SAND

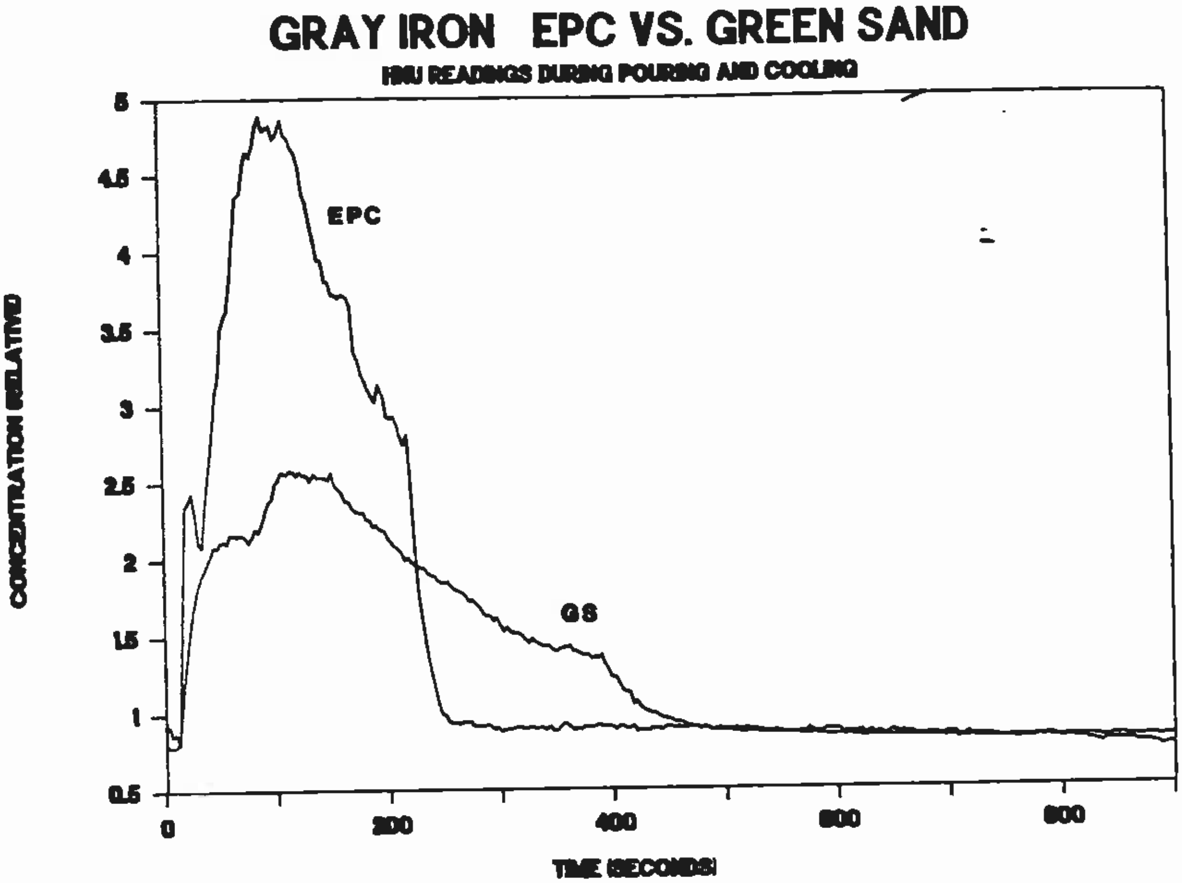
HNU READINGS DURING POURING AND COOLING



ALUMINUM EPC VS. GREEN SAND

HNU READINGS DURING SHAKEOUT

Figure 8


GRAY IRON EPC VS. GREEN SAND
HNU READINGS DURING POURING AND COOLING
CONCENTRATION (RELATIVE)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
EPC
GS
0
200
400
600
800
TIME (SECONDS)

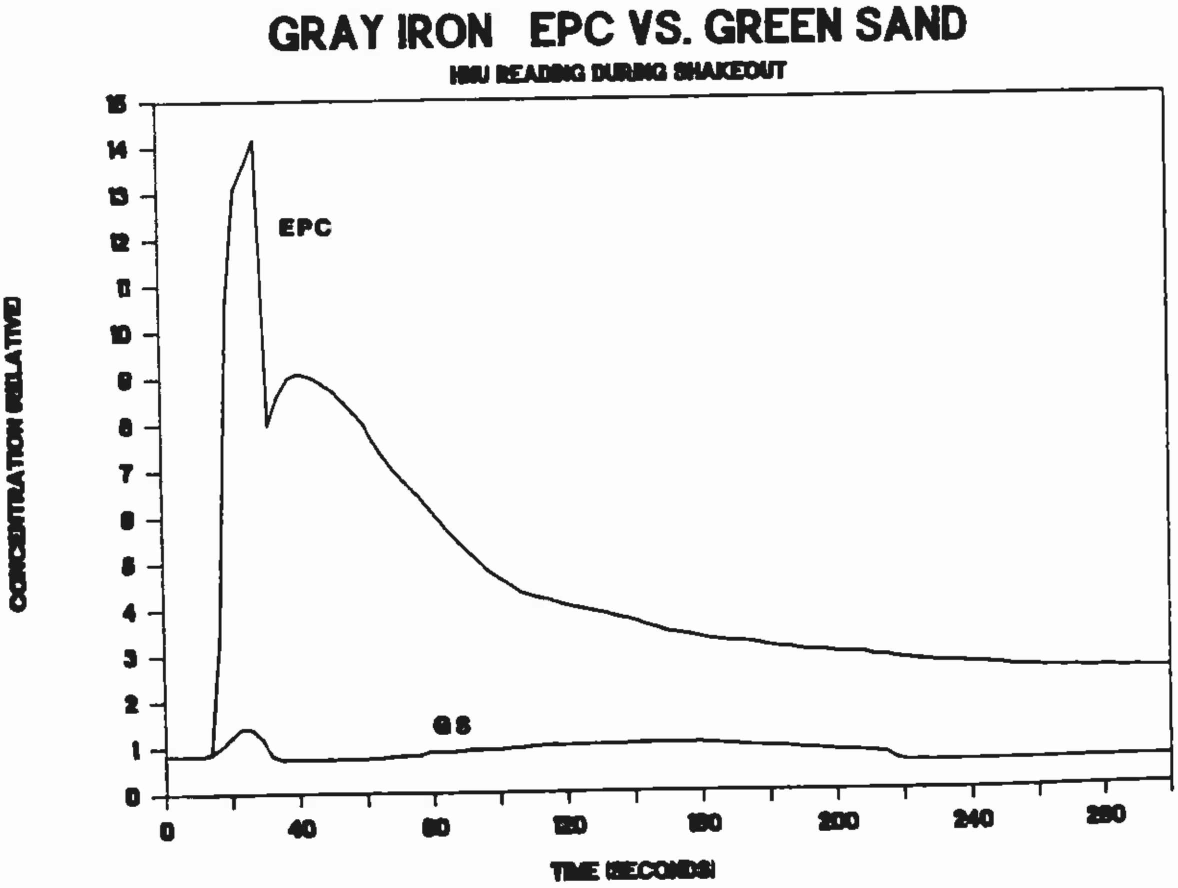

GRAY IRON EPC VS. GREEN SAND
HNU READING DURING SHAKEOUT
CONCENTRATION (RELATIVE)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
EPC
GS
0
40
80
120
160
200
240
280
TIME (SECONDS)

Figure 9a

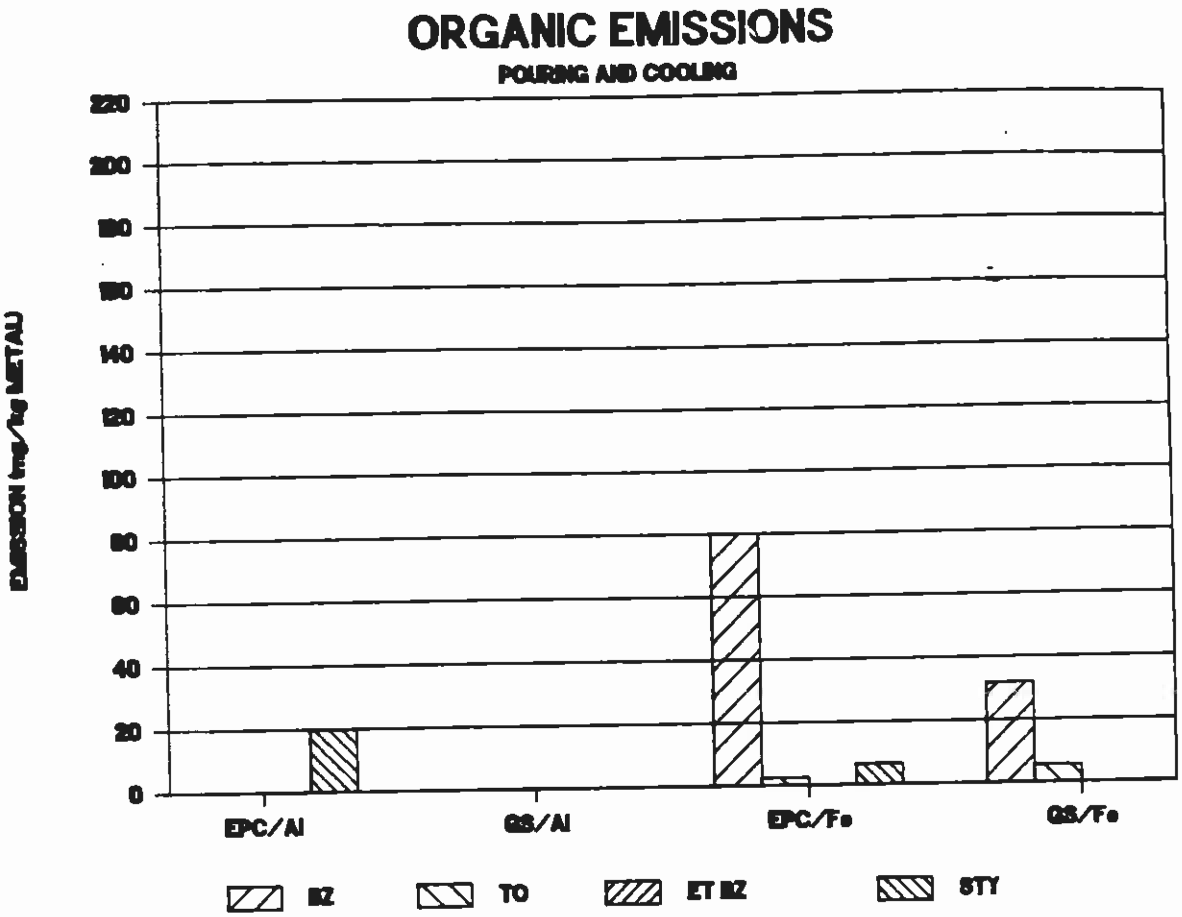


Figure 9b

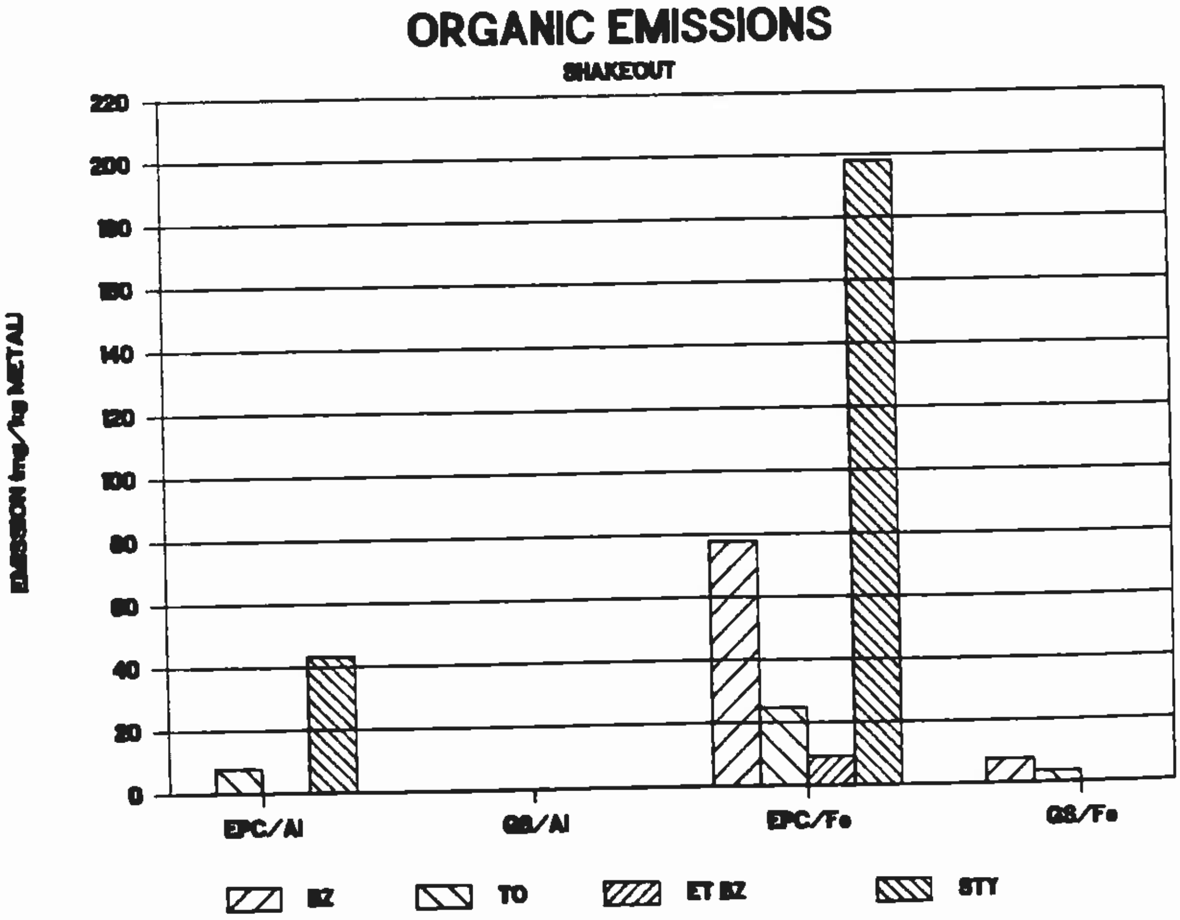


Figure 9c

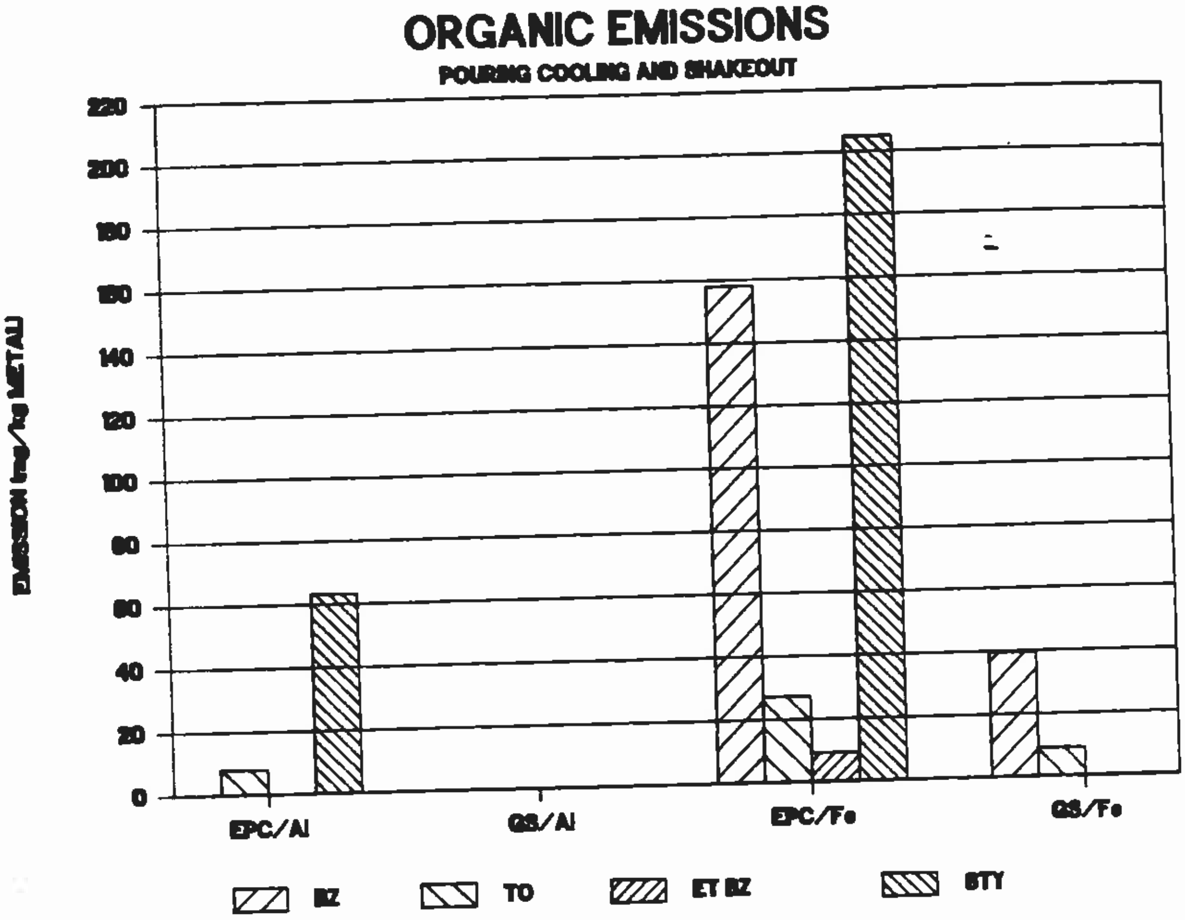

ORGANIC EMISSIONS
POURING COOLING AND SHAKEOUT
EMISSION (mg/kg METAL)
220
200
180
160
140
120
100
80
60
40
20
0
EPC/Al
GS/Al
EPC/Fe
GS/Fe
BZ
TO
ET BZ
STY

Figure 10

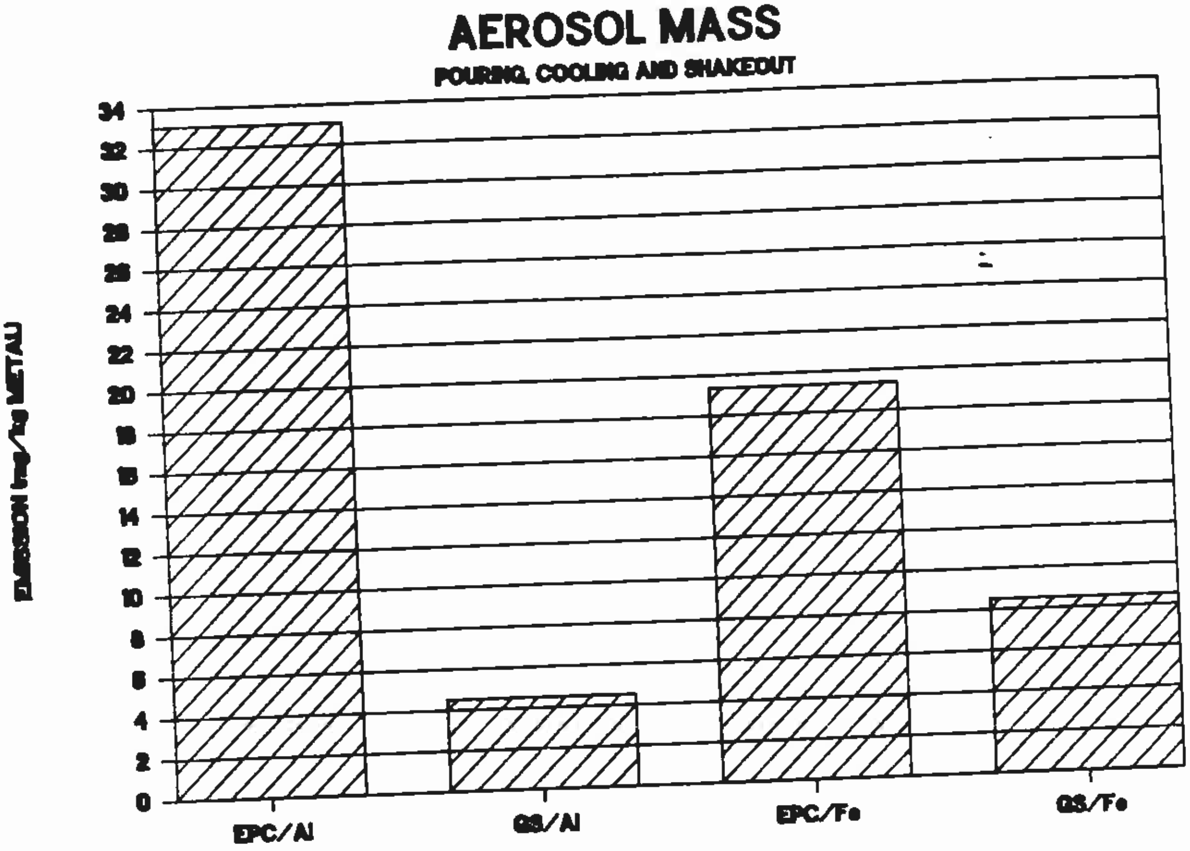
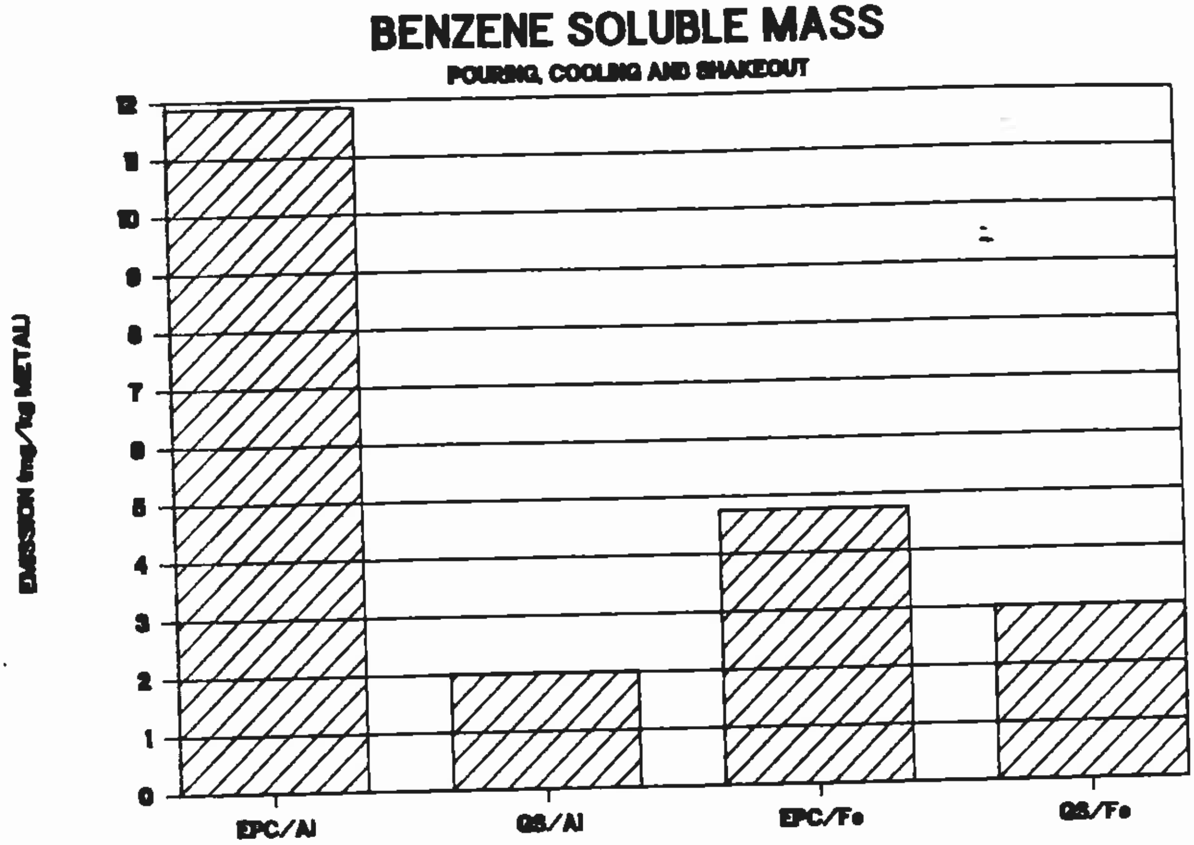

AEROSOL MASS
POURING, COOLING AND SHAKEOUT
EMISSION (mg/kg METAL)
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
EPC/Al
GS/Al
EPC/Fe
GS/Fe

Figure 11


BENZENE SOLUBLE MASS

POURING, COOLING AND SHAKEOUT

POLYNUCLEAR AROMATIC HYDROCARBONS 1

POURING, COOLING AND SHAKEOUT

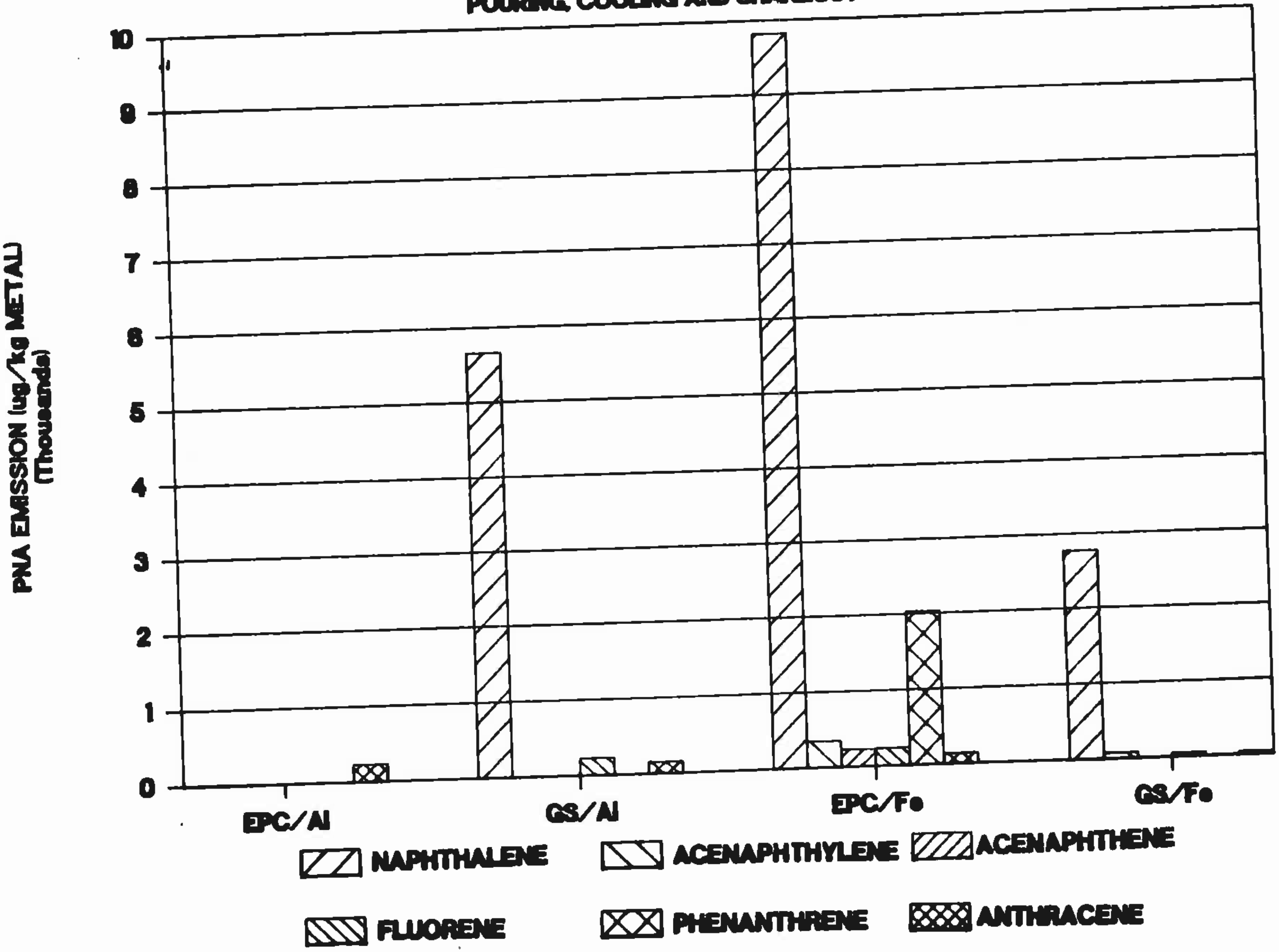


Figure 13

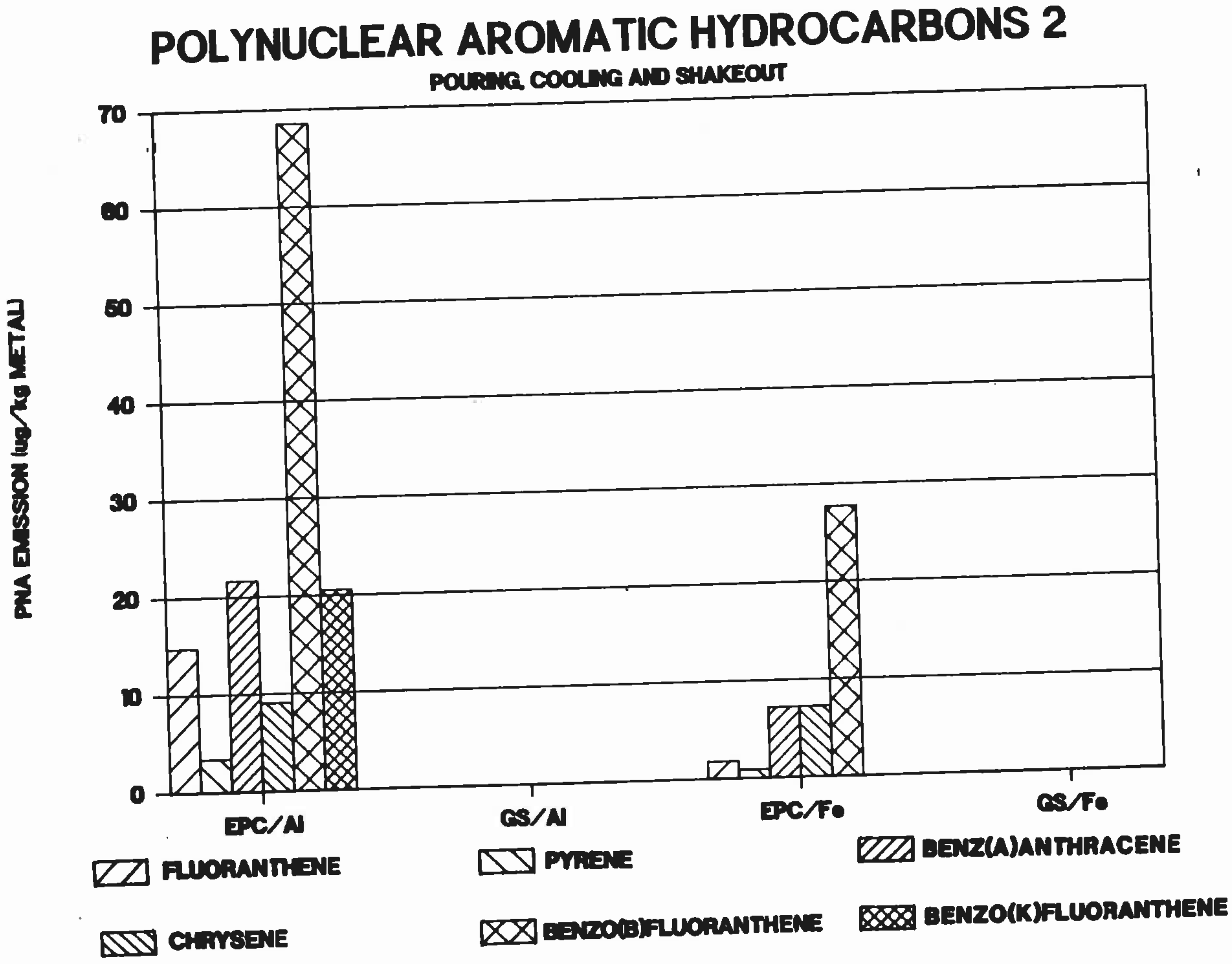
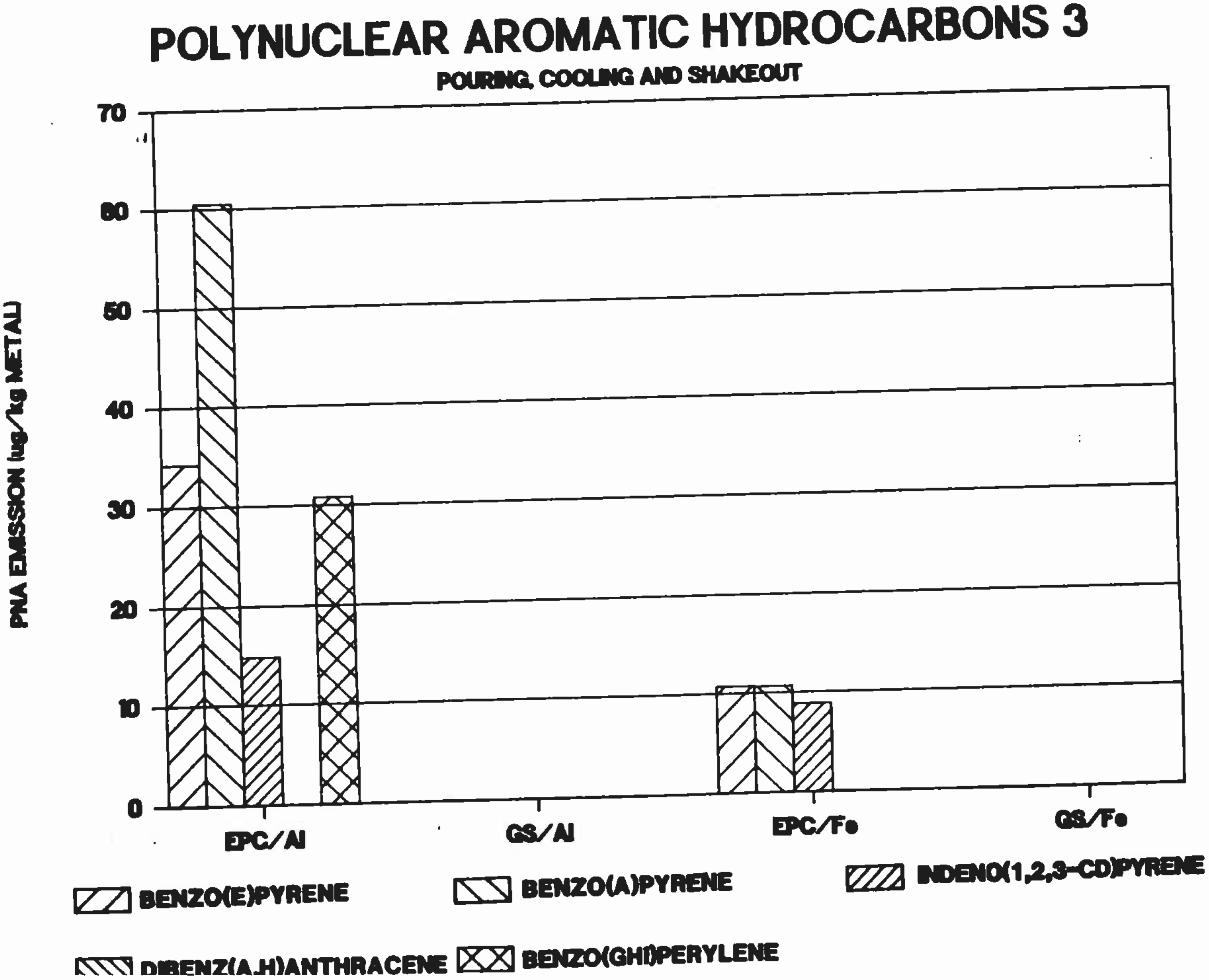

POLYNUCLEAR AROMATIC HYDROCARBONS 2
POURING, COOLING AND SHAKEOUT
PNA EMISSION (ug/kg METAL)
70
60
50
40
30
20
10
0
EPC/Al
GS/Al
EPC/Fe
GS/Fe
FLUORANTHENE
PYRENE
BENZ(A)ANTHRACENE
CHRYSENE
BENZO(B)FLUORANTHENE
BENZO(K)FLUORANTHENE

Figure 14


POLYNUCLEAR AROMATIC HYDROCARBONS 3
POURING, COOLING AND SHAKEOUT
PNA EMISSION (ug/kg METAL)
0
10
20
30
40
50
60
70
EPC/Al
GS/Al
EPC/Fe
GS/Fe
BENZO(E)PYRENE
BENZO(A)PYRENE
INDENO(1,2,3-CD)PYRENE
DIBENZ(A,H)ANTHRACENE
BENZO(GHI)PERYLENE