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Processing Emissions and Occupational Health in the Ferrous Foundry Industry

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A summary of the available information about ferrous foundry effluent produced during melting, pouring and casting shakeout is presented. Some decomposition products of four types of organic foundry mold resins have been identified using gas chromatographic and infrared methods. The survey may provide some insight into the types of materials that should be considered when making an industrial hygiene survey of foundry operations.

Introduction

THE OCCUPATIONAL SAFETY AND HEALTH ACT of 1970 requires that employers provide a place of employment free of recognized hazards to health and safety. The standards for compliance are not completely established, but it is clear that some control will be required over many agents often found in the foundry environment including heat, dust, fume, gases, noise, and vibration.

Relatively little is known about the effects of many types of foundry effluents on humans. Practically any material can be dangerous to health in excessive amounts. The difficulty lies in defining the concentrations of materials that can be safely tolerated. It seems evident that some compromise will be reached between the ideal of providing a job environment totally free of recognized hazards to health and the goal of providing jobs and manufactured products that will maintain our standard of living.

This survey summarizes the currently available information about ferrous foundry effluent during melting, pouring, and casting shakeout and the potential effect of different types of effluent on the health of foundry workers. The survey may provide some insight into the types of materials that should be considered when making an industrial hygiene survey of foundry operations.

Ferrous Casting Production

The foundry industry is one of the largest and most basic industries in the United States. According to the 1970 Census, the industry ranks as the sixth largest in terms of value added during manufacturing. Foundry castings are used in transportation, construction, home appliances, farm equipment, textile manufacturing, paper manufacturing, water and gas transmission, and a host of other applications. The industry produced some 15,000,000 tons of gray and ductile iron and 1,800,000 tons of steel in 1970.[1] Production is expected to be about 15 to 20% higher in 1974.

In general, cast iron is melted in cupolas or electric furnaces, and steel in electric furnaces and open hearths. Most ferrous castings are produced in green sand molds using silica as the molding aggregate. The term "green sand" implies that the bonding agent in the sand is some form of clay, usually western or southern bentonite, that has been

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plasticized with 3 to 5% water.

In most cases green sand will contain organic additives such as dextrine, oat hulls, wood flour, pitch, or pulverized coal.[2] These agents are present in amounts of up to about 6% of the weight of the sand. As the molding sand mixture is heated by the metal, the organic materials are decomposed and a variety of lighter-weight chemical compounds are formed, which may be driven into the foundry atmosphere as particulate and gas. Heavy organic fractions are often driven from the vicinity of the casting and condensed in cooler portions of the molds. As the entire mold heats up, even the heavy fractions may be driven into the foundry atmosphere.

During the shakeout operation, combustion or partial combustion of readily oxidizable materials may occur. The shaking action also causes air entrainment of silica, clay, organic fines, and any other dust present.

Abrasive cleaning and grinding can also produce considerable amounts of dust and metal fines. The fines are removed from the workplace by exhaust ventilation and discharged into a dust collector.

The sand is reconditioned for use after the casting is removed from the mold. This operation consists in adding a small amount of new sand to replace that lost during the cycle and making appropriate additions of wood flour, bentonite, coal dust, etc., to replace that burned out or dissipated when the castings were poured and shaken out. After thorough mulling, the sand is ready for reuse.

Melting Furnace Emissions

Cupola Iron Melting

Most of the cast iron produced in the United States is melted in cupolas. When charged with the correct proportions of pig iron, scrap, coke, flux, and combustion air, combustion of the coke melts the charge. Considerable quantities of both gaseous and particulate effluent are produced, and the amount is seldom constant except for short periods of time. The effluent rate varies with blast rate, coke consumption, physical properties of coke, type and cleanliness of metal scrap in the charge, coke-to-iron ratio, bed height, burden height, and air preheat temperature. The effluent rate also changes at intervals when the furnace is being charged with iron, steel scrap, coke, and flux.[3,4]

The gaseous emissions from cupolas consist essentially of carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen, and oxygen. Of these, sulfur dioxide and carbon monoxide are probably the most objectionable. Concentrations of sulfur dioxide over a range of 25 to 250 parts per million by volume have been observed.[3] Carbon monoxide concentrations of 5 to 20% are relatively common in the stack gases. Sometimes the carbon monoxide is burned to CO_2 in an afterburner, but if it is not burned, it can present a health hazard and a possible explosion hazard in pollution control equipment. Carbon monoxide monitors are desirable to help protect charging crane operators and men on the charging floor from asphyxiation.

Inorganic particulate material emitted from the cupola stack consists primarily of the oxides of silicon, iron, calcium, aluminum, magnesium, zinc, and manganese. The amount evolved may range from 10 to 45 pounds per ton of iron melted. The particle size distribution ranges between wide limits, depending on melt rate, coke usage, scrap formulation, and furnace operating variables. Under some conditions, over 50% of the dust may be less than 1 micron in diameter, and in other cases less than 5% by weight of the total particulate may be under 2 microns in diameter.[4]

Materials such as rubber, oil, and grease may produce considerable amounts of organic particulate when charged into the cupola. These materials can be partially burned, evaporated, or pyrolyzed in the up-per portion of the stack and driven from the furnace along with the inorganic particulate.

Destructive distillation of organic materials may produce a complex mixture of new materials, including polyaromatic hydrocarbons such as anthracenes and benzo(*a*)pyrene, which can have carcinogenic action on exposed body tissue. Benzo(*a*)pyrene has been found in dust samples taken around iron works in concentrations of 0.1 to 13 μg/gm of dust.[5] Cupola particulate effluent may be controlled with an efficient dust control system, but consideration must also be given to employees on the charging floor or crane who are exposed to both gaseous and particulate effluent.

Electric Arc Steel Melting Emissions

Electric arc furnaces employed for melting and refining iron and steel are cylindrical, refractory-lined structures. The furnaces range in size from a diameter of about 7 feet, with a hot metal capacity of about 4 tons, to a diameter of 24.5 feet, with a metal capacity of 200 tons. Because of the flexibility of operation, the electric arc furnace is used to produce steel with a wide range of composition.

Very little air is admitted to the electric arc furnace during the meltdown period, and during this time the furnace operates with an atmosphere containing a small amount of carbon dioxide and hydrogen, but predominately carbon monoxide.[6] The emissions from the electric arc furnace during this meltdown period are composed primarily of iron oxide, zinc oxide, and volatile matter from the charged scrap, such as oil, grease, and their decomposition products.

After meltdown of the complete charge, oxygen is lanced into the furnace. The oxygen combines with carbon, silicon, and manganese in the melt to produce a furnace atmosphere containing primarily carbon monoxide, with some free oxygen, carbon dioxide, and hydrogen. Tests have indicated that the atmosphere in the furnace during lancing contains in excess of 80% carbon monoxide.[7]

The flue gases contain large carbon monoxide concentrations, and, because they constitute potential health and explosion hazards, they must be burned or significantly diluted with air. Monitors should be used around arc furnaces to warn of excessive carbon monoxide concentrations.

The flue gas volume from electric furnaces ranges from a minimum of twelve to as much as about two hundred times the volume of oxygen lanced into the furnace. The actual volume depends on the method used to collect and cool the waste gases. When exhaust ventilation is applied directly to the furnace shell, gas volumes range from twelve to fifteen times the volume of oxygen lanced.[8] In operations where a shop roof hood is used to collect fumes, it may be necessary to collect as much as two hundred times the volume of oxygen lanced into the furnace in order to control the effluent concentration in the plant. Because of the wide variety of methods used in collecting fume, the dust load and gas composition vary greatly from plant to plant.

The average quantity of dust and fume evolved is probably about 10 pounds per ton of steel, or about 0.5% of the metal charged into the furnace. The range is from 4.5 to 29.4 pounds of particulate per ton of steel melted. However, emissions as high as 37.8 pounds per ton have been reported,[9] and occasionally, with highly oxidized scrap materials, emissions as high as 75 pounds per ton have been reported.[6]

The wide variations in total fume emissions per ton of metal melted are attributable to several factors, including the size of the furnace and the melt practice employed, formulation of the charge, cleanliness of the scrap, melt refining procedure, and pouring temperature. The most important variables affecting effluent are probably quality and cleanliness of scrap and the metal-refining procedure.

The type of scrap charged is important in determining the total emisisons from the furnace, since the inclusion of large quantities of low-boiling-point, nonferrous metallic impurities in the charge will inevitably lead to high concentrations of oxides of these metals in the effluent.[10] The cleanliness of the scrap is also significant because volatile impurities, including oil and grease, will be driven from the charge materials at relatively low temperatures during the early stages of meltdown, producing significant amounts of carbonaceous particulate matter.[11] Concentrations of benzo(*a*)pyrene as high as 286 μg/gm of suspended particulate have been measured around electric furnaces.[12]

The rate of metallic fume evolution increases after meltdown and reaches a peak during the boil and refining periods of the heat, particularly when an oxygen lance is employed.[13,14] The rate of fume evolution normally decreases after the slag is shaped up, because the slag blanket tends to entrap them.[11,15]

The composition of furnace effluent varies with the alloy as well as the furnace operating conditions. Table I presents some average chemical analyses of particulate emissions obtained from five alloy and stainless-steel heats produced in an arc furnace.[16] These data indicate that the metal fume is predominantly composed of the oxides of iron, calcium, magnesium, chromium, silicon, and the alkali elements. The range in composition of dust samples from an electric furnace shop is given in Table II and probably represents the maximum variations that might occur.[17]

TABLE I

Chemical Analysis of Fume Samples

(Filtered from five alloy and stainless heats during shell evacuation test by Firth Sterling, Inc.)

Analysis for:	Percent by Weight
Fe_2O_3	23.95
FeO	9.66
CaO	15.41
MgO	15.25
Soluble alkalis	11.25
Cr_2O_3	8.77
SiO_2	3.76
MnO	2.75
C	1.60
MoO_3	0.95
S	0.64
NiO	0.62
V_2O_5	0.51
Al_2O_3	0.47
Co_3O_4	0.08
TiO_2	0.05
N_2	0.014
P_2O_5	Trace
Moisture	0.90
Ignition loss (probably carbonates)	0.35

Some qualitative spectrochemical analyses and concentration estimates of minor constitutents in fumes from electric arc furnaces are given in Table III.[16] The oxides of zinc, manganese, and lead are the predominant minor constituents, with zinc probably coming from galvanized scrap, lead from terne sheet or free machining steels, and manganese from almost any type of scrap. Significantly higher zinc oxide contents of up to 37% have been reported.[9,11,18] The presence of such large amounts of zinc oxide is probably the result of a large amount of galvanized scrap being included in the charge. High zinc oxide concentrations could result in metal fume fever among workers. The heavy metals, including manganese, chromium, lead, and zinc, may present health hazards

TABLE II

Chemical Analysis Range of Electric Furnace Dust

Component	Range (%)
Fe_2O_3	19–44
FeO	4–10
Total Fe	16–36
SiO_2	2– 9
Al_2O_3	1–13
CaO	5–22
MgO	2–15
MnO	3–12
Cr_2O_3	0–12
CuO	<1
NiO	0– 3
PbO	0– 4
ZnO	0–44
Alkalis	1–11
P	<1
S	<1
C	2– 4

TABLE III
Qualitative Spectrochemical Analysis of Electric Furnace Fumes and
Concentration Estimates of Detected Constituents
(Based on three typical samples of fume
removed from hoppers of cloth filters)

Element	Concentration Range (%)		
	Plant A	Plant B	Plant C
Iron	5 –50	Major constituent	Major constituent
Calcium	3 –30	0.05 – 0.05	0.05 – 0.50
Silicon	0.10 – 1.00	2.0 –20	2.0 –20
Zinc	0.01 – 0.10	0.30 – 3.0	0.05 – 0.50
Manganese	0.50 – 5	0.20 – 2.0	0.20 – 2.0
Magnesium	0.50 – 5	0.010 – 0.10	0.005 – 0.05
Sodium	0.50 – 5		0.010 – 0.10
Chromium	0.30 – 3.0	0.5 – 0.50	0.10 – 1.00
Nickel	0.05 – 0.50	0.02 – 0.20	0.05 – 0.50
Aluminum	0.05 – 0.50	0.20 – 2.0	0.05 – 0.50
Lead	0.05 – 0.50	0.20 – 2.0	0.01 – 0.10
Molybdenum	0.05 – 0.50	0.005 – 0.05	0.005 – 0.05
Copper	0.02 – 0.20	0.03 – 0.30	0.03 – 0.30
Tin	0.01 – 0.10	0.01 – 0.10	0.01 – 0.10
Titanium	0.0005– 0.005	0.01 – 0.10	0.01 – 0.10
Vanadium	0.005 – 0.05	0.001 – 0.01	0.01 – 0.10
Bismuth	0.005 – 0.05		
Strontium	0.005 – 0.05		
Cobalt	0.0005– 0.005	0.003 – 0.03	0.001 – 0.01
Silver	0.001 – 0.01	0.0005– 0.005	0.0005– 0.005
Cadmium	0.001 – 0.01	0.003 – 0.03	0.0005– 0.005
Potassium	0.30 – 3.0		

under certain operating conditions when recycling iron and steel scrap.

The composition of the fume changes during the different periods of melt production. The fume may contain 40 to 50% iron by weight during meltdown, particularly if thin sheet scrap is used as a charge material, and may maintain this value during the carbon boil.[15,19] The remainder of the particulate evolved after meltdown is composed of the oxides of calcium, silicon, phosphorus, manganese, and sulfur.[20] After the slag is shaped up on the metal bath, the iron oxide content may fall as low as 5%, with the calcium oxide content of the fume increasing to the 45 to 50% range.[19]

Fume from electric arc furnaces tends to be extremely fine, and data from several sources indicate that 90 to 95% of the fume is below 0.5 micron in size.[8,11]

Electric Furnace Iron Melting Emissions

Virtually nothing has been published in the United States on emissions from electric furnaces used to melt irons. Several problems are to be expected as the iron foundry industry shifts toward both induction and arc furnaces, particularly with regard to worker exposure to extremely small organic and inorganic materials. Zinc fume fever or similar metal fever reactions may be encountered. Exposure to lead and organic distillates and decomposition products from grease, etc., around electric furnaces and scrap preheaters is also likely to be higher than has previously been encountered when cupolas are used unless very efficient fume collection equipment[21-23] is installed and maintained. Data on such emissions are not yet available, however.

Molding, Pouring, and Shakeout Emissions

Most ferrous castings are produced in green sand molds. The molds consist primarily of silica with a clay binder, and various organic materials are needed to achieve special effects. When metal is poured into the mold, the sand adjacent to the mold cavity is heated very rapidly, resulting in fracture of silica sand grains and pyrolysis of organics. Some of the sand may be converted to a glass as a result of rapid cooling during shakeout or the presence of various impurities in the sand.

A portion of the fines and organic pyrolysis products will be driven into the foundry atmosphere during mold handling, shakeout, and subsequent transportation of the sand back to the muller. Some of the fines should be taken from the sand during reconstitution if there is a dust removal system on the muller. It is important that worker exposure to the fine crystalline quartz particles be minimized to reduce the chance of silicosis.

Organic green sand additives such as dextrine, oat hulls, wood flour, pulverized coal, pitch, fuel oil, and asphalt are commonly used to provide better dimensional stability, accommodation for sand expansion, hot strength, and improved casting surface finish. The additives are expected to evolve products of destructive distillation similar to those produced when coal, wood, or cellulose is thermally decomposed in a reducing environment. The amount of each specific compound produced during pyrolysis will depend on the composition of the organic material present, but the general classes of pyrolysis products are likely to be approximately the same irrespective of the specific organic additives.

The primary region of interest as far as organic emissions is concerned are those from the portions of the mold heated from about 300° to 900°F. In this temperature range, organic materials form destructive distillation and rearrangement products, some of which have objectionable biological activity. If the external mold temperature is less than 300°F, the organics escaping from the mold are expected to have a relatively low molecular weight, and the biological activity will probably be greatly reduced compared to the heavy fractions. Temperatures above 900°F are expected to rupture the carbon–carbon bond system and produce low-molecular-weight materials such as carbon monoxide. Intermediate temperatures may result in the evolution of heavier organic material such as anthracene and benzo(*a*)pyrene, which have objectionable effects.

Destructive distillation also occurs when organic binders are used in molds and cores instead of clay binders with associated additives. The principal organic core binders in use in the United States are listed in Table IV. These are broadly categorized in the foundry industry with regard to the method of curing: by oven baking, by heating inside the core box, by gassing and by addition of a polymerization catalyst.

Oven-baked cores may employ one of about four types of binders. The oleoresinous binders are combinations of oils, petroleum polymers, and solvents or thinners such as kerosene and mineral spirits. These resins polymerize in the presence of oxygen to produce a high-molecular-weight material that functions as a sand binder. Some of these binders contain partially reacted synthetic resins, which require solvent evaporation and/or oxidation to become rigid.[24] As a class, the core oils are oleoresinous varnishes, and some 50 million pounds are consumed each year in the foundry industry. When metal is poured into a mold or core-bonded with these oils, they can be expected to decompose and evolve ammonia, carbon monoxide, aldehydes, various acidic compounds, carbon dioxide, various hydrocarbons, and water.[25]

Urea–formaldehyde resins represent a sec-

TABLE IV
Principal Organic Core Binders in Use in the United States

Binders	Approximate Annual Current Consumption (lb)	Organic
Oven bake	90×10^6	1. Oleoresinous 2. Urea–formaldehyde resins 3. Phenol–formaldehyde resins 4. Cereal binders
Heated core box		
Shell	85×10^6	1. Phenol–formaldehyde novolaks
Hot Box	45×10^6	1. Furan resins (UFFA) 2. Phenolic resins (UPF) 3. Phenol–modified resins
Gassed core	3×10^6	1. Cold box (isocyanate)
No-bake	20×10^6	1. Air set (oil–oxygen) 2. Furan no–bake 3. Oil no–bake 4. Urethane (phenolic–isocyanate)

ond type of baked core binder. They are usually blended with oleoresinous or phenol–formaldehyde resins to obtain the desired foundry characteristics of hot strength, collapsibility, and baking speed. When metal is poured onto cores bonded with a urea–formaldehyde resin, the polymer can be expected to decompose and produce water, ammonia, amines, carbon monoxide, and low-molecular-weight polyureas linked by methylene bridges.[26] Gases and vapors from urea–formaldehyde binders are notorious throughout the foundry industry for the obnoxious odor produced during pouring.

Phenol–formaldehyde resins are currently in use in the oven baking processes as well as in shell and hot-box processes. The baking time for the phenol–formaldehyde resins is approximately half that of core-oil binders, and they do not release the acrid, eye-burning fumes characteristic of most core oils.[25] Shell cores and molds are predominately made with phenol–formaldehyde resins. The cores and molds are produced by dumping or blowing a resin-coated sand onto a heated pattern, holding for a sufficient time to cure some of the binder, removing the excess sand, then stripping the cured shell from the pattern. A typical shell resin will be made by combining 100 parts of phenol, 72 parts of 37% formaldehyde, and 0.5% oxalic acid. This resin may be added to the sand as an alcohol or acetone solution, as a water solution, or in a flake or granular form. Hexamethylene–tetramine in amounts of 10 to 17% based on resin weight is used as a curing agent for two-step novolak phenol–formaldehyde resins, and a lubricant, usually calcium stearate in amounts of 4 to 6% of the resin weight, is often incorporated in the resin or added to the sand during the mixing process. Phenol, hydrogen cyanide, carbon monoxide, and ammonia are reported to be evolved from phenol–formaldehyde resins during the manufacture of molds and cores.[27]

When molten metal is poured onto phenol–formaldehyde resin-bonded cores formed by cold-box, hot-box, or shell methods, the resin is expected to decompose to produce carbon monoxide, ammonia, cresols, toluene, benzene, aldehydes, benzoic acid, polyhydric phenols, carbon dioxide, water, and probably other chemicals. The relative quantities of these compounds is likely to depend on the conditions of decomposition—for example, heating rate, availability of oxygen and moisture, and the presence of catalytic agents.[28-31]

Hot-box binders are those resins that rapidly polymerize in the presence of acidic chemicals and heat to form a mold or core. The original hot-box resins were developed by modifying urea–formaldehyde resins with the addition of 20 to 45% of furfuryl alcohol. This type of hot-box resin is commonly referred to as a furan resin.[31,32] The furan resins were then modified with the addition of phenol to produce urea–phenol–formaldehyde hot-box resins, which are referred to as phenolic resins or UPF resins. The UPF resins have a pungent odor, and adequate ventilation at the core-making machines is required. More recently, urea-free phenol–formaldehyde–furfuryl alcohol binders have been developed. These have a much lower volatile content and odor compared with other hot-box resins as a consequence of eliminating urea from the formulation.[32,33]

Decomposition products of hot-box binders will vary depending on formulation, but in general they will be similar to those from the previously described urea–formaldehyde and phenol–formaldehyde resins. In addition to the foregoing products, amines and hydrogen cyanide will probably be included.

A two-part polyurethane cold-box binder system was developed about 1967 that required gassing rather than baking or heating to achieve a cure. Part I of the system is a phenolic resin, and part II is a polyisocyanate, both dissolved in solvents. In the presence of a catalyst, triethylamine (TEA) or dimethyl ethylamine (DMEA), the hydroxyl groups of the liquid phenolic resin combine with the isocyanate groups of the liquid polyisocyanate to form a solid urethane resin which serves as the sand binder.

Following introduction of the catalyst, air is used to sweep any remaining vapors through the core, after which the core is removed from the core box. The amine catalysts are volatile, flammable, organic liquids, and execessive vapors present safety hazards. The catalyst can be disposed of by combustion or chemical scrubbing before the core box is opened.[33,34] Decomposition of this type of binder under casting conditions probably produces carbon monoxide, hydrogen cyanide, methane, ammonia, phenol, and other compounds.

The so-called no-bake binders represent modifications of the oleoresinous, urea–formaldehyde, phenol–formaldehyde, and polyurethane binder systems previously described, in which various chemicals are incorporated to produce polymerization in an unheated core box. The products of binder decomposition will probably be much the same as those previously listed. Small amounts of chemical compounds from the activators and cross-linking agents will probably be present with the products of resin decomposition.

The concentrations of some gases produced during decomposition of four types of organic binders are presented in Tables V and VI (unpublished data, Southern Research Institute, Birmingham, Alabama). The products were determined by preparing a 2-inch-diameter core from each of four resins using commercially accepted amounts of binder. After resin curing, the core was placed inside a graphite mold having a vent pipe connected to it, such that the gases evolved could be collected in an evacuated plastic bag. Gray cast iron at about 2500°F was poured into the mold so as to produce a casting with about ½-inch-thick walls surrounding all but one side of the test core. Products of resin decomposition were vented from the uncovered side of the core through the exit pipe and collected in the evacuated bag. The gases collected were analyzed by gas chromatography and colorimetric tubes. The heavy hydrocarbon fractions that condensed in the sampling bag were dissolved in a solvent, and several fractional groups were identified by infrared spectroscopy. The identity, volume of gas collected, and approximate concentration of several gases in the gas mixture are presented in Table V for each of the four resins tested. The approximate weight of material in the con-

TABLE V
Products of Thermal Decomposition of Sand Binders

Product	Threshold Limit Value (ppm)[b]	Concentration in Effluent (ppm by volume)[a] Poly-urethane	Oil base	Urea–Formaldehyde	Phenolic
Carbon monoxide	50	40,000	40,000	40,000	40,000
Hydrogen cyanide	10	16	400	320	60
Methane	—	2,000	40,000	2,000	2,000
Ethylene	—	1,500	7,000	1,500	1,500
Acetylene	—	1,500	1,500	1,500	1,500
Carbon dioxide	5,000	7,000	11,000	7,000	1,000
Ammonia	25	>1,500	500	1,500	—
Aldehydes (as formaldehyde)	2	200	>400	400	>400
Phenol[c]	5	17.5 mg[d]	0.6 mg[d]	1.5 mg[d]	0.4 mg[d]

[a] All products except phenol were determined in the gas phase. The approximate volumes of the gas phases collected from each binder material were as follows: polyurethane, 200 ml; oil base, 300 ml; urea–formaldehyde, 1000 ml; phenolic, 200 ml.

[b] Threshold limit values (TLV) established by the American Conference of Governmental and Industrial Hygienists.

[c] Phenol was determined in the condensed liquid phase.

[d] The values given are the total weights of phenol found in the condensed liquid phase.

TABLE VI
Functional Groups Observed in Infrared Absorption Spectra of Condensed Liquid Phases[a]

Functional Group	Binder Material Poly-urethane	Oil base	Urea–Formaldehyde	Phenolic
Aliphatic CH	+	+	+	+
Aromatic CH	+	+		+
Ester C=O	+	+		+
COOH		+		+
Aldehyde C=O	+		+	
Amide	+		+	
Secondary amide				+
Acidic OH		+		
Phenyl	+	+		+
Substituted phenyl	+	+		+

[a] The total weights of the condensed liquid phases collected from each binder material were as follows: polyurethane, 120 mg; oil base, 500 mg; urea–formaldehyde, 200 mg; phenolic, 80 mg.

densed liquid phases and an indication of some of the functional groups found in each liquid are presented in Table VI. The presence of rather high concentrations of carbon monoxide, hydrogen cyanide, methane, ammonia, and phenols was observed in the effluent from all four types of binders tested. The actual concentrations of these constituents in a foundry atmosphere will no doubt depend on binder levels and foundry ventilation practices.

It is evident from Table V that mold pouring lines need to be ventilated if for no other reason than to control exposure of the workers to carbon monoxide. Small amounts of carbon monoxide below those that cause asphyxiation lead to loss of worker's perception. If sufficient ventilation air is brought in to dilute carbon monoxide to an acceptable range, the worker exposure to the organic materials should be adequately controlled.

It is anticipated that the odor-producing characteristics of some organic foundry materials will be of interest in the future. Odor-producing agents such as formaldehyde, amines, phenol, and ammonia may be evolved during preparation, curing, pouring, and shakeout of organically bonded sands. Some of these materials produce a noticeable odor at extremely small concentrations and pose a formidable control problem should this be required.

The Future

The function of the business enterprise system in the United States is to provide goods and services to people, business, and government that will give the consumer utility, satisfaction, and enjoyment. In producing these goods and services, it is becoming increasingly necessary to ensure that the health of individual employees not be impaired so they cannot enjoy the necessities and luxuries they expect as fruits of their labor. It is to be expected that increasing demands will be placed on employers to assure foundry employee health.

Many innovative materials and processes have been introduced into the industry in the past few years, and as early as 1964 Tubich began suggesting the need for studies to assess the potential liabilities.[31,35] The development of the shell molding process, sodium silicate binders, air-set resins, and chemically cured resins has dramatically improved foundry productivity, but the use of these chemicals also suggests the need for studies of the health effects of materials other than silica. There is no reason to suspect that the newer foundry materials will necessarily cause injury as long as reasonable concentrations are not exceeded. In fact, the use of alkyd urethane resin on silica sand has been found to inhibit the silicotic reaction in lung tissue.[36] This finding could result in significant reductions in the incidence of the disease. Similarly, other elements and compounds may be beneficial in certain concentration ranges.

Aluminum has been used for years in Europe and Canada to retard silicosis, and it is possible that the incorporation of some such material as sodium aluminate or a carbonaceous resin compound in molding sand could reduce the silicotic potential.

These approaches and others aimed at maintaining employee health and safety must be considered in the future to help ensure the healthfulness of each manufacturing operation and the health of each individual.

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