IV. ENGINEERING CONTROLS

The foundry environment may be a potential source of numerous toxic air contaminants such as silica, CO, and thermal decomposition products; physical hazards such as noise, heat, and vibration; and safety hazards, including contact with molten metal. The short- and long-term health and safety effects of the potential hazards, in general, and illustrated how they may affect foundry workers are reviewed in Chapter III. In order to reduce worker exposure, foundry hazards must be adequately identified and evaluated, and engineering controls, administrative controls, work practices, and, when appropriate, personal protective clothing and equipment should be applied [7,59,182]. Ventilation, enclosures, barriers, and substitution of less toxic materials and hazardous processes can be utilized to help control safety and health hazards in different foundry operations [7].

To improve working conditions in foundries, proper consideration should be given to controlling dust and fumes, especially silica dust, by engineering methods. A plant that is well-designed from environmental and production standpoints will have a substantially reduced need for dust control. However, when a plant design is not adequate to eliminate the dust and fume hazards, retrofit control procedures must be introduced.

A. Preparation of Mold Materials

The preparation of mold materials involves recovering sand and other materials from the shakeout and adding new binder materials and sand for mold production. The addition and recovery of sand and binders are major contributors to the crystalline silica and other dust hazards in the foundry air [183]. In addition to crystalline silica, other hazards may result during mold material preparation. For example, hot green sand may produce steam when passing through the sand preparation system, or smoke may result from high sand temperatures and the presence of organic corebinding materials [15,184].

Data from NIOSH Health Hazard Evaluations (HHE's) confirm that crystalline silica is a health hazard in sand preparation areas of ferrous and nonferrous foundries [35,36,37,38]. In a 1974 NIOSH HHE of a semiautomated foundry, concentrations of respirable free crystalline silica dust in 14 of 17 personal samples taken exceeded the NIOSH recommended 10-hour TWA of 50 $\mu g/m^3$. The major sources of atmospheric contamination in the sand preparation area were leakage of dust from containing bins, inadequate containment of hot sand at shakeout operations, inadequate exhaust ventilation, and sand spillage at transfer points [36].

In a brass foundry surveyed by NIOSH in 1975 [37], potentially toxic respirable crystalline silica dust concentrations were found in all the sampled areas. Utility workers assigned to sand pile and sand spillage cleanup, in areas where ventilation was minimal, were exposed to silica concentrations of 0.07 to 1.05 mg/m^3 during a 6-7 hour sampling time. Improving control of conveyor and muller leakage and enclosing and mechanizing the transfer of materials from the conveyor pit would reduce the environmental crystalline silica concentrations [37].

In a steel foundry surveyed by NIOSH [35], the molding sand (72% crystalline silica) was prepared in a muller loaded by a mechanical bucket lift but filled manually. After mixing, the sand was delivered to each work location by wheelbarrow. Used sand was recycled by processing the shakeout wastes through a riddle, which removed slag and solid wastes, and then the reusable sand was shot 10-20 feet (3-6 meters) through the air into a storage bin. Personal respirable crystalline silica exposure concentrations for mullers and laborers during an 8-hour workshift in the sand preparation area ranged from 0.10 to 0.82 mg/m^3, exceeding the NIOSH recommended TWA of 50 μg/m^3 [35].

In sand reclamation systems, the sand is usually dry from the knockout or shakeout process to the point at which binders and other materials are added [185]. To eliminate dust in the green-sand systems, this dry part of the cycle must be controlled as much as possible.

The basic foundry principle, that the temperature of a foundry sand system varies with the sand-to-metal ratio of the molding operation, was applied in developing the Schumacher process [186]. At normal molding ratios of 3 to 7 sand: 1 metal, the sand forming the mold becomes hot when the molten metal is poured into the mold cavity; therefore, a higher sand-to-metal ratio will result in a cooler sand temperature resulting in less dust. Management generally prefers a low sand-to-metal ratio because it permits more castings per mold; but the hot dry sand produces more dust during shakeout and subsequent sand-handling operations than do the low sand-metal ratios.

The Schumacher system may solve the problems of hot sand and resultant high dust exposure while still allowing high metal loading without sacrificing a low sand ratio in the sand system [7,186]. Moist sand from the mixer is diverted into two streams: about one-fourth of the total amount is transported to molding operations and the remaining three-fourths bypasses the molding operation and rejoins the used molding sand at the casting shakeout. The mass of cool, moist sand that bypasses the molding and pouring operations cools the molding sand. Thus, a foundry can pour a high number of castings in each mold with little regard for the heat build-up in the low sand-to-metal ratio molds [186]. The mixture of used sand and cool-damp sand, which was added at the shakeout, quenches dust and heat. Foundry sand that contains more than about 2% moisture evenly distributed is unlikely to be a significant source of dust [187].

The usual sand cooling methods, such as spraying with water or forcing large amounts of air through the sand, create steam or dust clouds which must be controlled by collectors under many local air pollution codes. The Schumacher process can decrease the need for dust-collecting devices used in conventional systems [7,186]. Another approach to controlling silica dust is the use of chemically-bonded sands. This requires less sand (approximately 3,000 pounds vs. 7,000 pounds for 1,000 pounds of castings) thus reducing the potential for sand spillage and dust dispersal.

Returned sand contains an increased amount of silica "fines," which may become entrained in the air as hazardous crystalline silica dust if the work area is not adequately ventilated [187,188]. This increased dust is due to the presence of bonding and other conditioning materials, as well as to the drying and the mechanical and thermal breakdown of the sand. Although fines are necessary for adequate permeability in sand molds, most can be removed by dry or wet reclamation systems. Conveyors, elevators, bins, and transfer points should be enclosed and ventilated to control the air concentration of free silica fines in areas where the sand contains less than 2% of moisture by weight [7,184,188,189]. Conveyor enclosures will also reduce the potential for sand spillage.

The condensation of water and oil vapors in the ducts with entrapment of dust, which can plug the duct when water- and oil-sand mixes are used, can seriously compromise an otherwise adequate exhaust system. Frequent inspection and duct cleaning are required.

An important ventilation point is under the knockout or shakeout grid [184], where the sand usually falls into a hopper with a conveyor at its base. If the sand is hot and moist, steam may have to be controlled by covering and exhausting the conveyor for some distance from the knockout grid. If the sand is hot and dry, the conveyor may also have to be covered and exhausted for a sufficient distance to control heat and dust. If local exhaust ventilation is needed, it should be applied to the cover of the conveyor at suitable points from 25 to 30 feet (7.6 to 9.1 meters) apart [184]. Figures IV-3, IV-4, and IV-5 show examples of ventilation for controlling exposures along conveyors and transfer points.

Adequate belt conveyor designs can reduce sand spillage in mechanized foundries [187]. Conveyor belts should be designed for peak loading, estimated as double the maximum sand flow needed for molding, even if this is only needed for short periods. To reduce sand spillage, belts should be run at speeds <1.25 m/s to allow for satisfactory operation of ploughs and magnetic separators. Trough angle, another design consideration, was previously limited to 20 degrees. With new nylon belts that permit angles up to 45 degrees, the belt capacity should be half that of the equivalent width of a 20 degree troughed belt, or spillage will occur. Belt inclination also affects the amount of slipping and rollback that takes place. The maximum belt inclination should be 17 degrees for knockout sand carried by 20 degrees troughed belts and 18 degrees for prepared molding sand. Special belts with molded crossbars may be used at inclinations up to 50 degrees. When sand sticks to the belt, belt cleaners which are enclosed and exhaust-ventilated should be used, e.g., a static scraper or a rotary cleaner. In addition, the type of belt-fastening used affects sand leakage. Only a vulcanized joint is leak-proof; it should be used instead of mechanical belt fasteners [187].

With pneumatic conveying, as an alternative to an elaborate conveyor belt system, the sand is moved by differential air pressure through pipes, which provide complete enclosures for the material being conveyed. Apart from being almost dust-free, pneumatic conveying permits complex plant layouts and takes up little space. Some of the advantages of the pneumatic conveyor system are cleanliness and the flexibility it provides for plant layout. Disadvantages are power consumption, maintenance costs, and initial capital cost [187].

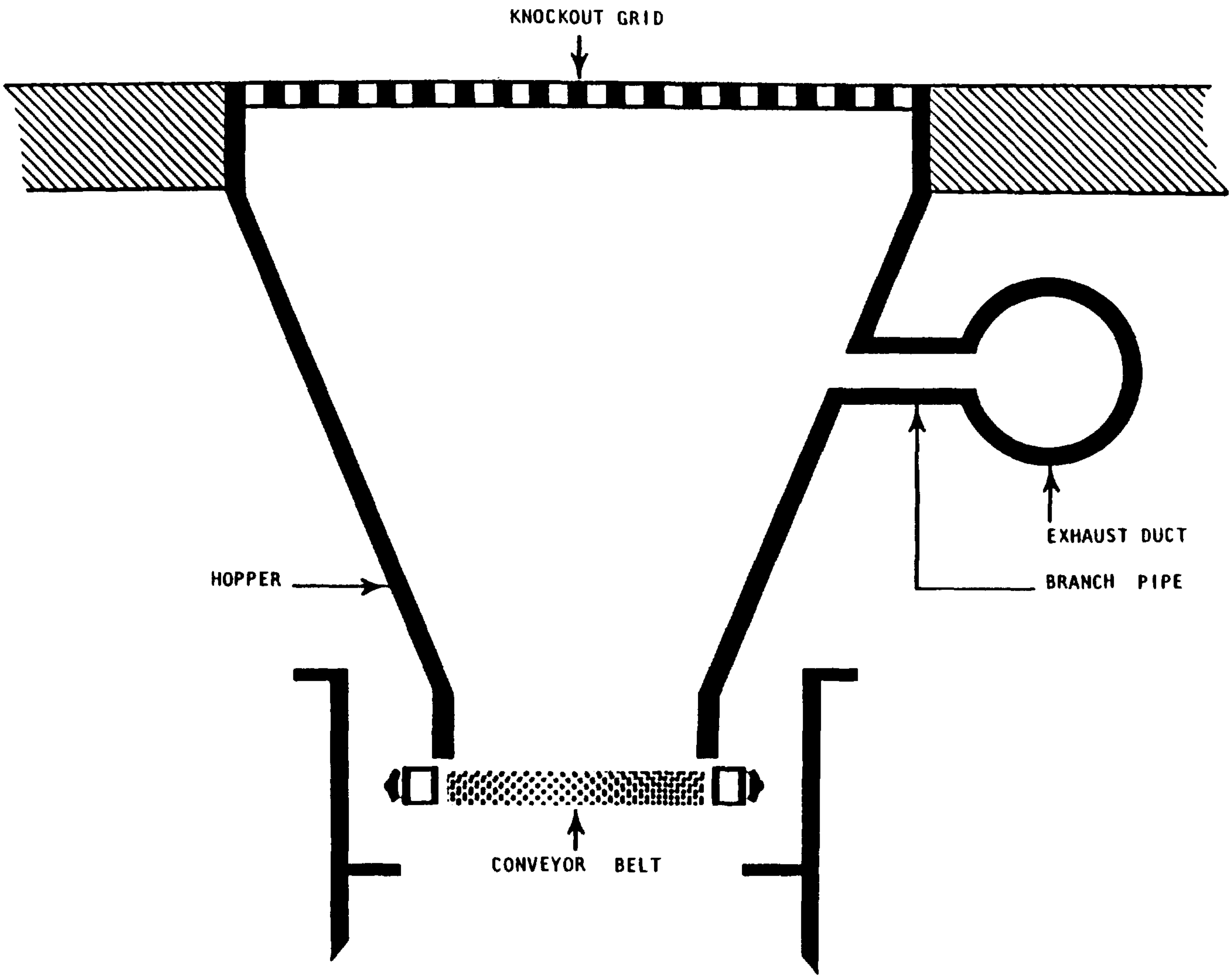


FIGURE IV-3. Local exhaust ventilation below knockout grid

Adapted from Health and Safety at Work Improving the Foundry Environment with the permission of the Controller of Her Britannic Majesty's Stationery Office.

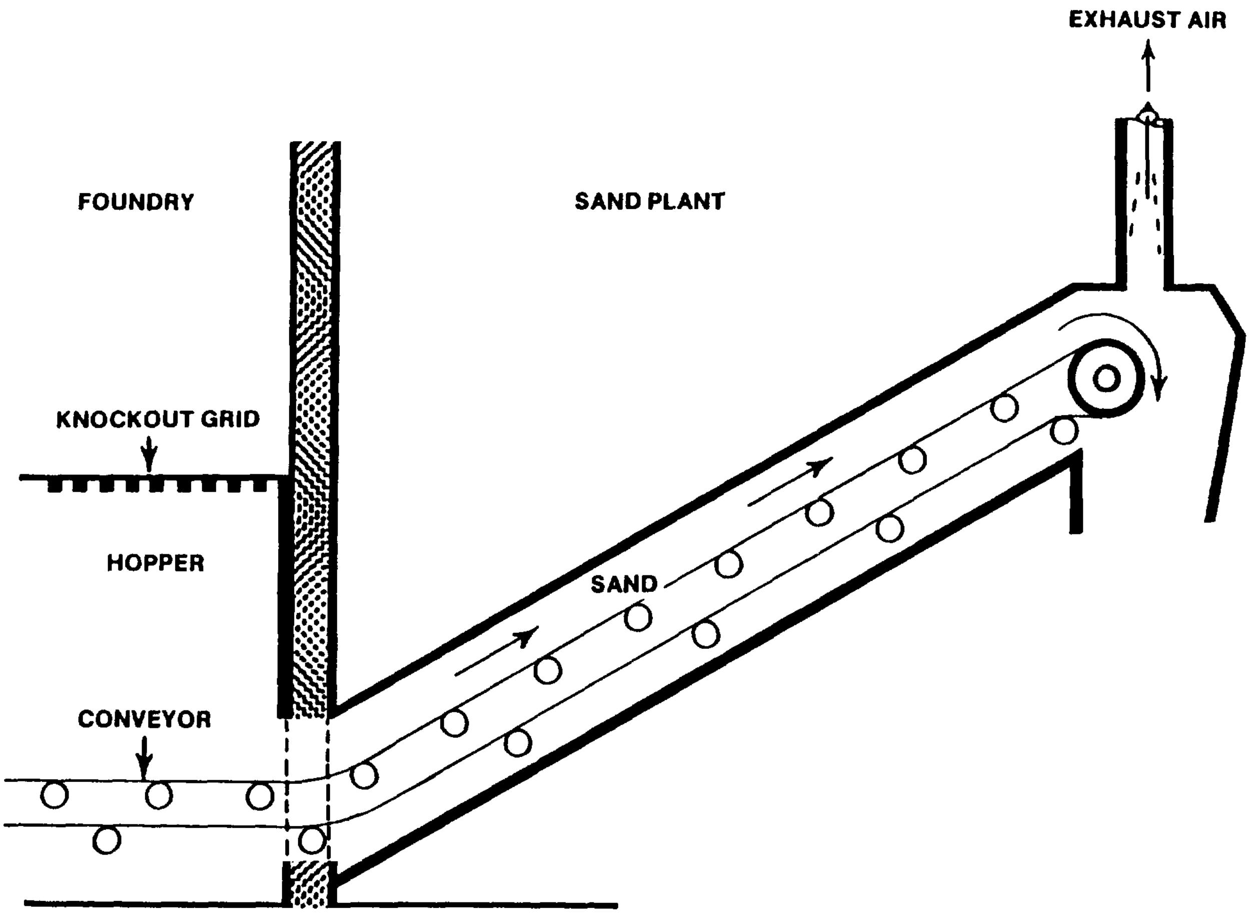


FIGURE IV-4. Local exhaust ventilation on conveyor

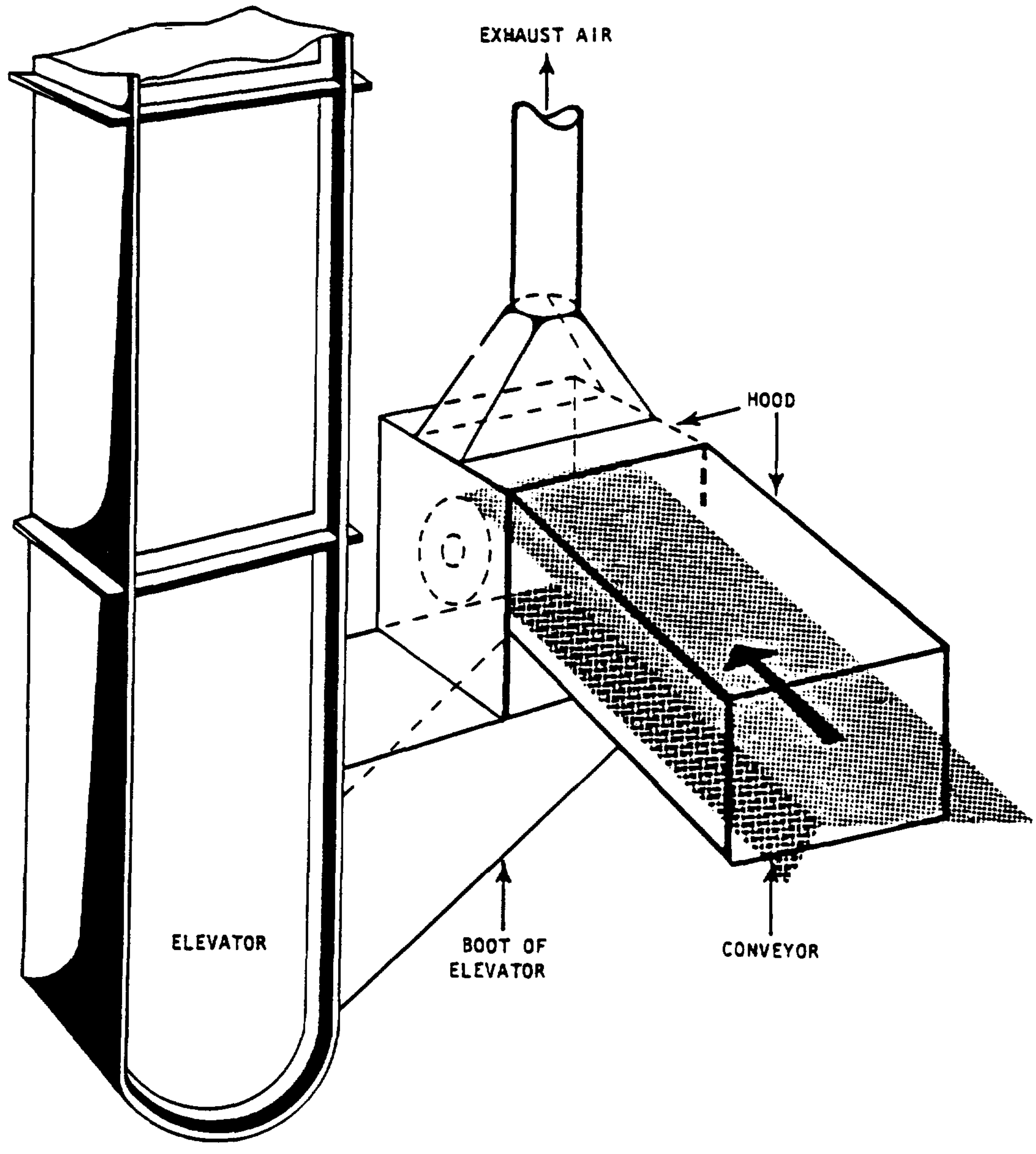


FIGURE IV-5. Hood over transfer point

Returned and new sand are conditioned by screening, cooling, blending, and adding bonding ingredients and moisture. Local exhaust ventilation is usually necessary at all screens, transfer points, bins, sand mullers and conditioning machinery because of the dusty conditions created during sand handling [184,188,190]. In ventilating vibrating flat deck screens and rotary screens, exhaust air velocities entering the duct connection must be as low as possible to minimize the loss of usable sand fines (Figure IV-6). At the same time, air velocity in the duct must be high enough to prevent the coarse fraction of dust from settling out in order to minimize plugging [188]. Recommendations for controlling dust from mixer and mulling operations are shown in Figures IV-7 and IV-8.

Where sand and other mold materials are handled, local exhaust ventilation should be applied. However, applying local exhaust ventilation is difficult in certain manual operations, e.g., shoveling and sweeping operations [191]. In some cases, moisture can be added to satisfactorily reduce the dust hazard, but the added moisture may increase the level of heat stress by increasing the humidity. Because local exhaust ventilation cannot always be applied in sufficient amounts in pits below conveyor lines, workers who clean these areas may have to wear respirators [192]. Handling bagged additions of clay and coke can be a dusty and dirty operation, and local exhaust ventilation should be provided [184].

Dust, vapors, and gases may be produced in and around mullers and other sand-handling equipment during the preparation of materials for molding [76]. In foundries that use shell molding, the dust concentrations, particle size, and crystalline silica content of the airborne dust can create the same risks to workers as those present in conventional foundry operations. In addition, combustible concentrations of resin may be present at sand-conditioning areas in which the dry blending method is used, producing a dust explosion hazard. Solvents such as methyl and ethyl alcohol, which are used to dissolve the resins sufficiently to produce a suitable uniform particle coating, can produce vapor concentrations that approach the lower explosive limit (LEL). To decrease potential exposure to crystalline silica and solvents, local ventilation should be used at the mixer, with increased exhaust volumes for solvent vapor control [76]. When resins and sand are mixed in the foundry, control should be provided by exhausting sufficient air through the system to ensure the maintenance of explosive vapor concentrations at or below 25% of the LEL for the vapor [188,193]. Local exhaust ventilation may also be necessary at the opening of chutes through which the resin is added and the mixture discharged [184]. Because of ventilation requirements and sand availability, more foundries are converting to precoated sand for shell and no-bake operations [175].

B. Molding Operations

The molding process involves several distinct operations, including blowing old sand off the pattern, discharging a measured amount of tempered sand into the flask, jolting or vibrating the flask to settle and pack the sand, and squeezing the pattern into the sand [3,5]. Each of these operations, although performed by a variety of methods, may produce high levels of noise [7,115,194] and dust [7,38,57,115,195].

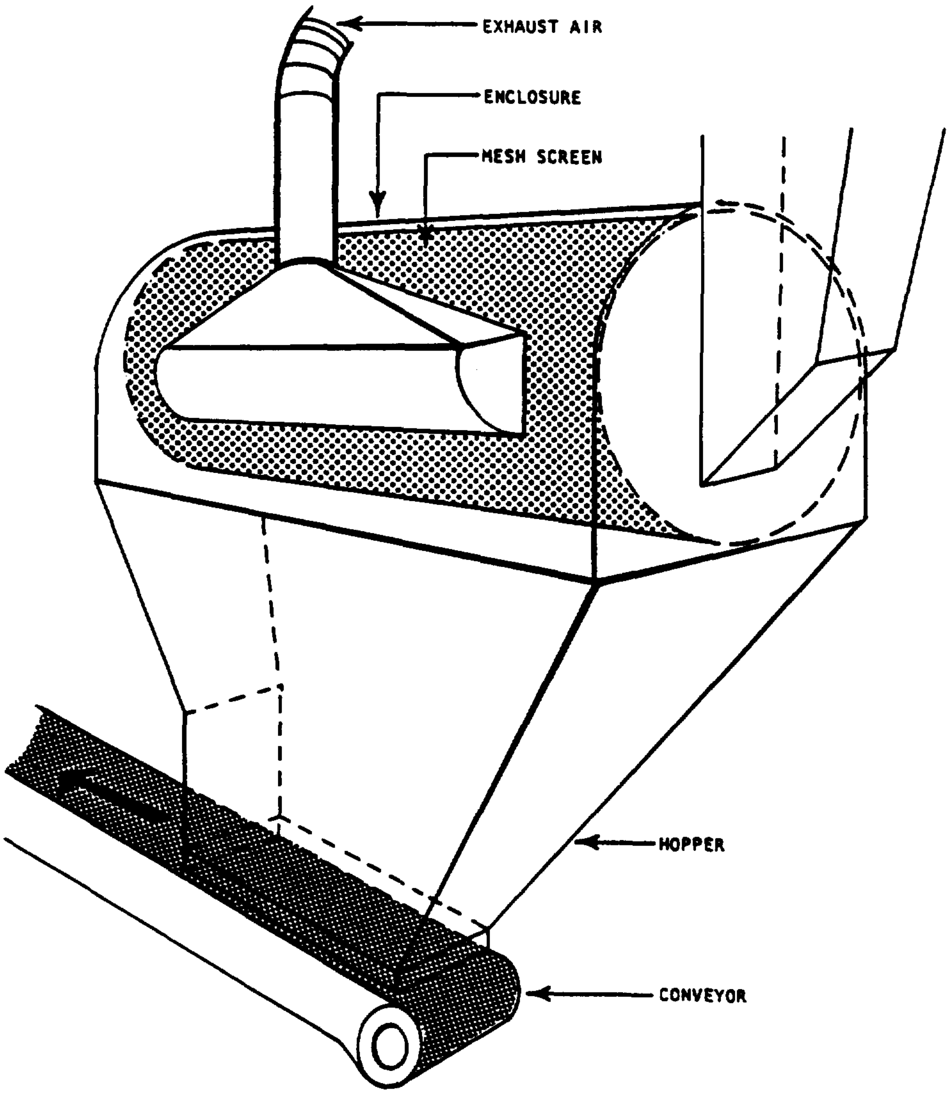
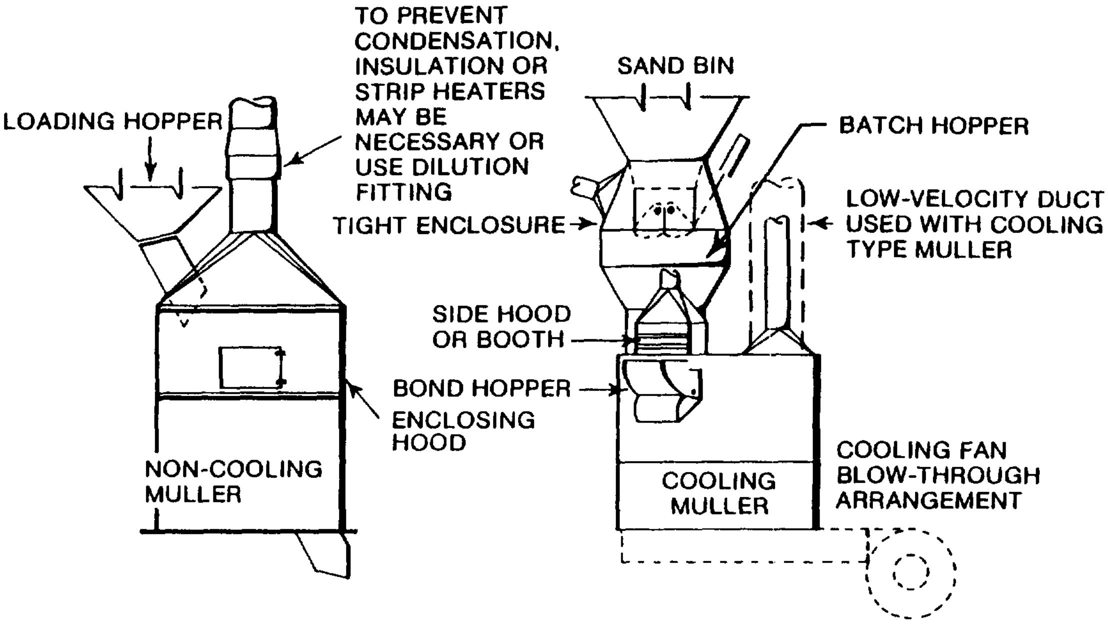


FIGURE IV-6. Local exhaust ventilation at a rotary screen



MIN. EXHAUST VOLUME FOR NON-COOLING MULLERS	
MIX. DIAMETER (FEET)	MIN. EXHAUST (CFM)
4	750
6	900
7	1050
8	1200
10	1575

- Q = 150 CFM/SQ FT THROUGH ALL OPENINGS, BUT NOT LESS THAN THE TABLE VALUES FOR NON-COOLING MULLERS
- DUCT VELOCITY FOR NON-COOLING MULLER = 3500 FPM MINIMUM
- DUCT VELOCITY FOR COOLING MULLER = 4500 FPM MINIMUM
- ENTRY LOSS FOR TAPERED HOOD = ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP
- ENTRY LOSS FOR SLOTTED SIDE DRAFT HOOD = 1.78 SLOT VP PLUS ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP
- ENTRY LOSS FOR ROUND DUCT WITH FLANGE = 0.49 DUCT VP

FIGURE IV-7. Mixer and muller ventilation

Adapted from reference [190]

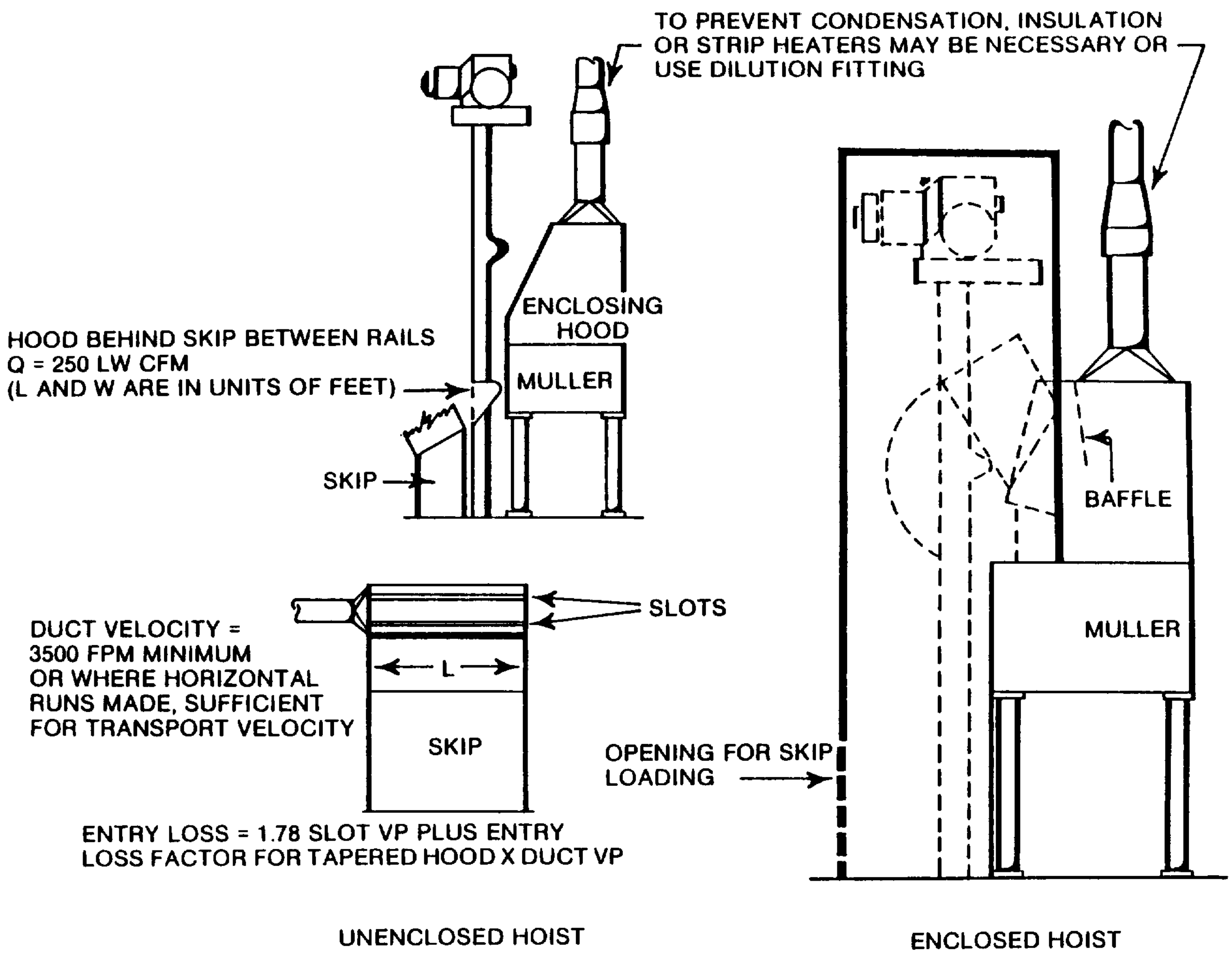


FIGURE IV-8. Skip hoist ventilation for mixers and mullers

Adapted from reference [190]

In the past, the primary source of silica exposure of molders was from the use of silica parting powders [115,195,196]. Renes et al. [115], in 1948-49, performed time-motion studies of machine molding operators in ferrous foundries and found that more than an hour of the molders' time over a 9-hour workshift was spent applying parting compounds to molds and patterns. The average dust exposure during that time was 2.5 million particles per cubic foot (mppcf), contributing 70% of the molders' total exposure. Because of the health hazards of silica dust exposure and with the development of liquid parting fluids and suitable replacements such as calcium carbonate, calcium phosphate, and talc [197], parting powders containing more than 5% crystalline silica should be avoided in foundry molding operations [196]. The use of silica flour as a parting agent is prohibited in the United Kingdom [184,185,198].

Although mold material is generally moist, levels of respirable silica have been shown to exceed the NIOSH REL's [35,38,199]. In a 1977 ferrous foundry survey [38], crystalline silica environmental concentrations over an 8-hour workshift for workers at pin-lift, squeezer, and roll-over molding operations ranged from 0.05 to 0.97 mg/m^3; 12 of the 13 personal samples exceeded the NIOSH REL of 50 μg/m^3 (0.05 mg/m^3).

In 1976, a comprehensive survey was conducted in Finland [195] determining crystalline silica exposure among molders using mold process equipment similar to that of U.S. foundries. Dust and silica measurements were taken during various foundry operations for an entire shift on at least two different days in 51 iron, 9 steel, and 8 nonferrous foundries; a total of 4,316 foundrymen were employed. Samples were taken on at least two different days for an entire shift during various operations in each foundry. About half of the samples were collected in the workers' breathing zones. The sample collection and analysis methods used were similar to NIOSH methods used in the United States. Mean respirable silica (<5 micron particle size) concentrations for molding operations were 0.31 mg/m^3 in iron foundries, 0.27 mg/m^3 in steel foundries, and 0.22 mg/m^3 in nonferrous foundries.

The crystalline silica content and total dust levels at the various foundry operations were influenced by the size and mechanization of the foundry facilities [57]. For molding operations, total environmental dust levels decreased slightly, from 10 to 7 mg/m^3, as the size of the foundries increased. This was attributed to the increased mechanization of molding operations in larger foundries.

To reduce the exposure of molders to crystalline silica and other dust hazards, sand moisture content must be retained, sand binders or sand substitutes can be used, or adequate ventilation and spill protection must be provided. High levels of dust may be generated from dry sand during flask filling when sand is discharged from a hopper immediately overhead and in front of the operator and falls freely past the worker's breathing zone, and when sand builds up due to spillage around mold machines and during portable vibration and agitation in manual core and mold ramming [7,115]. Silica sands can be kept moist by proper cooling and rewetting before and during mulling and by restricted storage time of prepared sand [7]. Pits under mold machines should be provided to catch spills, and sand should be removed before it is allowed to dry [7]. This can be achieved by having a conveyor system beneath the pits to remove sand from the area and return it to the muller.

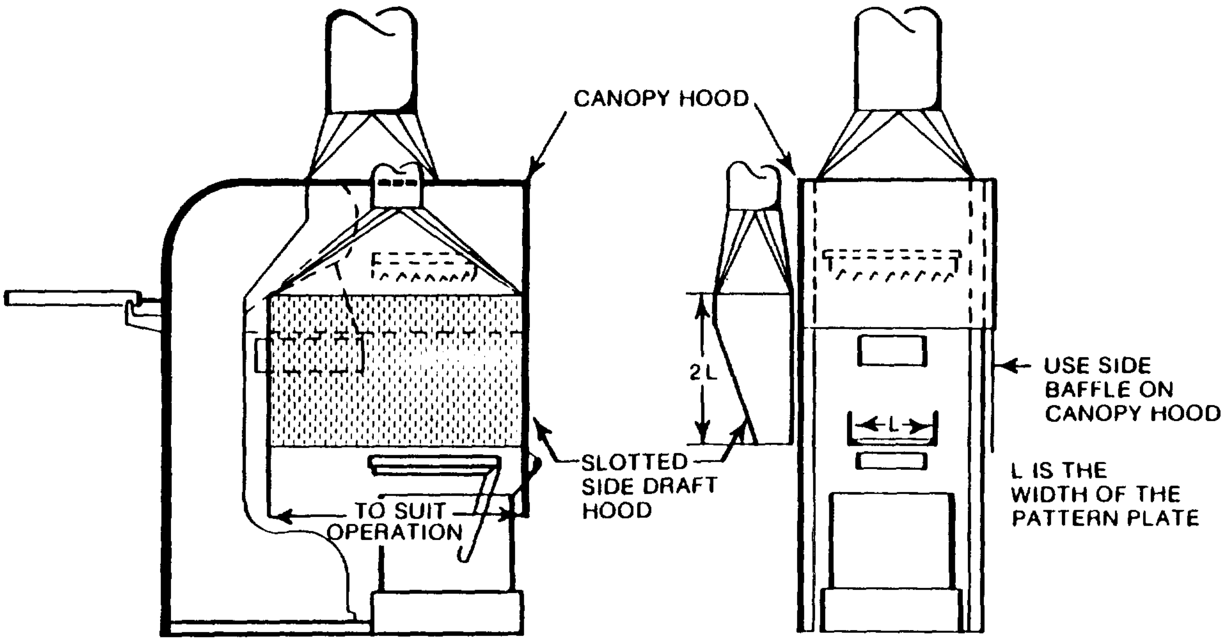
Dust exposure near sand slingers is usually excessive because of the high velocity release of finely divided dry sand particles near the slinger head [7]. Enclosing the slinger operation or isolating the slinger operator in a remote control station are effective ways to reduce the dust contamination of the breathing-zone air of the operator. Exhaust ventilation in the spill pit below the slinger will cause a low-velocity downdraft around the flask which, although insufficient to capture the dust at its source, will cause a constant turnover of air around the flask and help reduce dust in the area. Such ventilation is important not only to the slinger operator but also to other line workers who are close to the slinger.

Substitution of non-silica (e.g. olivine) molding aggregate can substantially reduce the airborne crystalline silica concentration. Field tests have been conducted to compare the air quality in a foundry before and after changing the molding material from silica-based sand to olivine. Processes involving no-bake molding and coremaking continues to use the standard silica-based sand. The data indicates a decline in the average crystalline silica content after the changeover by a factor of 2 to 5 (from 12.7 to 2.6% by weight in the shakeout area, and 8.2 to 4.9% on the main floor). More significantly, the deviation of the values from the mean was reduced, as was the range [17].

In a 5-year study of the use of olivine in nonferrous foundries, it was found that the pattern of contamination of the olivine sand by clays and silica cores was such that a constant concentration of silica sand dust in the system was reached in about a year after the olivine mold sand was first installed in the sand system [18]. The airborne crystalline silica concentrations also increased during this period, following the same pattern. However, the level of airborne dust and crystalline silica in the foundries using olivine was lower than that in other foundries; the percent by weight of crystalline silica was 80% less than in foundries using silica sand.

At present, there does not appear to be a practical method for separating the silica core material from the olivine mold sand during recycling. If the olivine is not recycled, it becomes too expensive for routine use. The substitution of non-silica materials for silica cores is becoming more widespread and would appear to be a good method for reducing worker exposures to crystalline silica. However, more research is needed to determine the toxicity of silica sand substitutes and the cost of the changeover.

Shell molding machines pose special exposure problems because dust, heat, vapors, and gases are released, especially following removal of the mold from the molding machine [76,188]. Figure IV-9 illustrates a recommended method for ventilation control of shell molding equipment (also see reference [76]).



FOR SLOTTED SIDE DRAFT HOOD:
Q = 75 (10 x^2 + HOOD AREA) CFM
ENTRY LOSS = 1.78 SLOT VP PLUS ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

FOR CANOPY UNITS:
Q = 250 CFM/SQ FT OF THE FACE OF THE CANOPY FOR SINGLE UNITS
= 150 CFM/SQ FT OF THE FACE OF THE CANOPY FOR DOUBLE UNITS
ENTRY LOSS = ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

FIGURE IV-9. Shell coremolding equipment

Adapted from reference [190]

The noise created by molding machinery is complex due to the wide variety of noise sources within the area. Excessive noise is caused by the action of the machines, such as when jolt molding machines produce noise from the rapid impact of the jolt piston against the table, as well as by ancillary processes, such as compressed air blowoff to clean the pattern for the next molding run [194].

In a NIOSH control technology study [7], the complexity of the noise problem was described and some control solutions recommended for large iron and steel foundries. The molding area in the foundry studied was composed of 18 jolt-squeeze machines located in a line. The overall noise level generated during the molding operation ranged from 75 to 125 dBA (the OSHA PEL is 90 dBA for an 8-hour TWA). The major noise sources were the jolt and squeeze operations, pattern vibrators, the air nozzle during cleaning, air circulation fans, and the vibration of the hopper during flask filling.

Various types of elastomer pads were used to try and reduce the high jolting impact noise. Initially, the pads reduced peak noise, but they wore out very quickly. In addition, mold quality suffered because the jolting force was reduced by the cushioning action of the elastomer pads. To reduce the noise from squeeze operations, the molding machines were retrofitted with a quiet, rapper-type mechanism used to compress the pattern into the molding sand; it performed well and substantially quieted this part of the operation.

Piston-type vibrators were found to generate the greatest force to compact the mold and the loudest noises. Turbine and rotary vibrators generated much less noise yet produced sufficient force to separate the sand from the pattern or shake it loose from the hopper. In addition, lining the sand hoppers with a plastic material allowed the sand to flow more freely, requiring less vibration.

A nozzle with a flow-through design decreased noise from the air nozzle used to blow excess sand off the flasks and patterns. This substitution resulted in a 10-dBA decrease in the overall sound levels. Installation of exhaust mufflers on the high pressure discharge air of the molding machines decreased the noise levels.

With these equipment changes, the ambient noise level in the area emanating from the shakeouts and other processes was greater than the level generated by the molding machine. The noise generated by a single molding machine with exhaust mufflers was about 85 dBA for an 8-hour TWA. Before the noise reduction, the operator was exposed to a noise level of 85 to 106 dBA. The overall reduction was about 8 dBA over an 8-hour period [7].

C. Coremaking Operations

Coremaking operations, depending on the type of coremaking system, can be a source of heat, dust, noise, and chemical emissions [7]. In sand-casting foundries, coremaking processes may expose workers to high levels of crystalline silica dust, sometimes exceeding the 10-hour TWA, NIOSH REL of 50 $\mu g/m^3$ (based on a 40-hour workweek) [38]. Respirable crystalline silica concentrations in 6-hour dust samples taken at two types of coremaking processes in a ferrous foundry (a no-bake core and a shell core operation) ranged from 0.12 to 0.33 mg/m^3 in the no-bake core and from <0.04 to 0.06 mg/m^3 in the shell core operation. All of the crystalline silica concentrations at the no-bake operation exceeded 0.05 mg/m^3, as did one of two samples collected at the shell core operation. The crystalline silica concentrations at the no-bake core process were attributed to its location immediately adjacent to sand molding and metal pouring stations; the shell core process was located in a separate room, removed from dust generated by processes such as sand molding and metal casting [38].

Silica in coremaking operations can be controlled by maintaining optimal sand moisture content [7], by providing adequate ventilation [7,190], and/or by using non-silica sands [200]. Figure IV-10 gives recommended ventilation controls for small rollover-type coremaking machines in areas where air contaminant concentrations exceed recommended exposure limits. Using non-silica aggregates for aggregate sand reduces adhering sand defects, thereby reducing silica exposures in the cleaning room and the coreroom [200].

1. Oven-Baked Cores

Oven-baked cores usually contain binding agents and other materials, e.g., oleoresinous binders (core oils), combinations of synthetic oils (fatty esters), petroleum polymers, and solvents or thinners, such as kerosene and mineral spirits [13,15,201]. During the baking of oil-bonded cores, smoke and fumes are produced from the thermal decomposition of the organic core materials and from the release of the solvents from the core [201,202].

To control the chemical emissions produced during oil-based, oven-baked coremaking, ventilation and good core-baking techniques are required [184,188]. Modern batch- and continuous-type core ovens are usually provided with internal ventilation to promote good air circulation and proper core drying [175,188]. However, if the ventilation is not adequate to capture the fumes released at the oven doors or other openings, small slot- or canopy-type hoods will be needed for effective fume control, even if the oven is in good condition and does not have serious leaks [188].

The sand used in oven-baked cores should be cool before mulling. Only the minimal necessary amounts of binder should be added to the formulation because excess oil for binding produces smoke, thermal decomposition products, and carbon monoxide gas when the cores are baked. In addition, oil-bonded cores should be properly baked because underbaked cores produce excess gas during casting [188,201].

2. Shell Coremaking

Shell cores are usually produced with phenol-formaldehyde resins, using hexamethylenetetramine as a catalyst. Phenol, hydrogen cyanide, carbon monoxide, formaldehyde, ammonia, and free silica are potential hazards in shell coremaking [13,22].

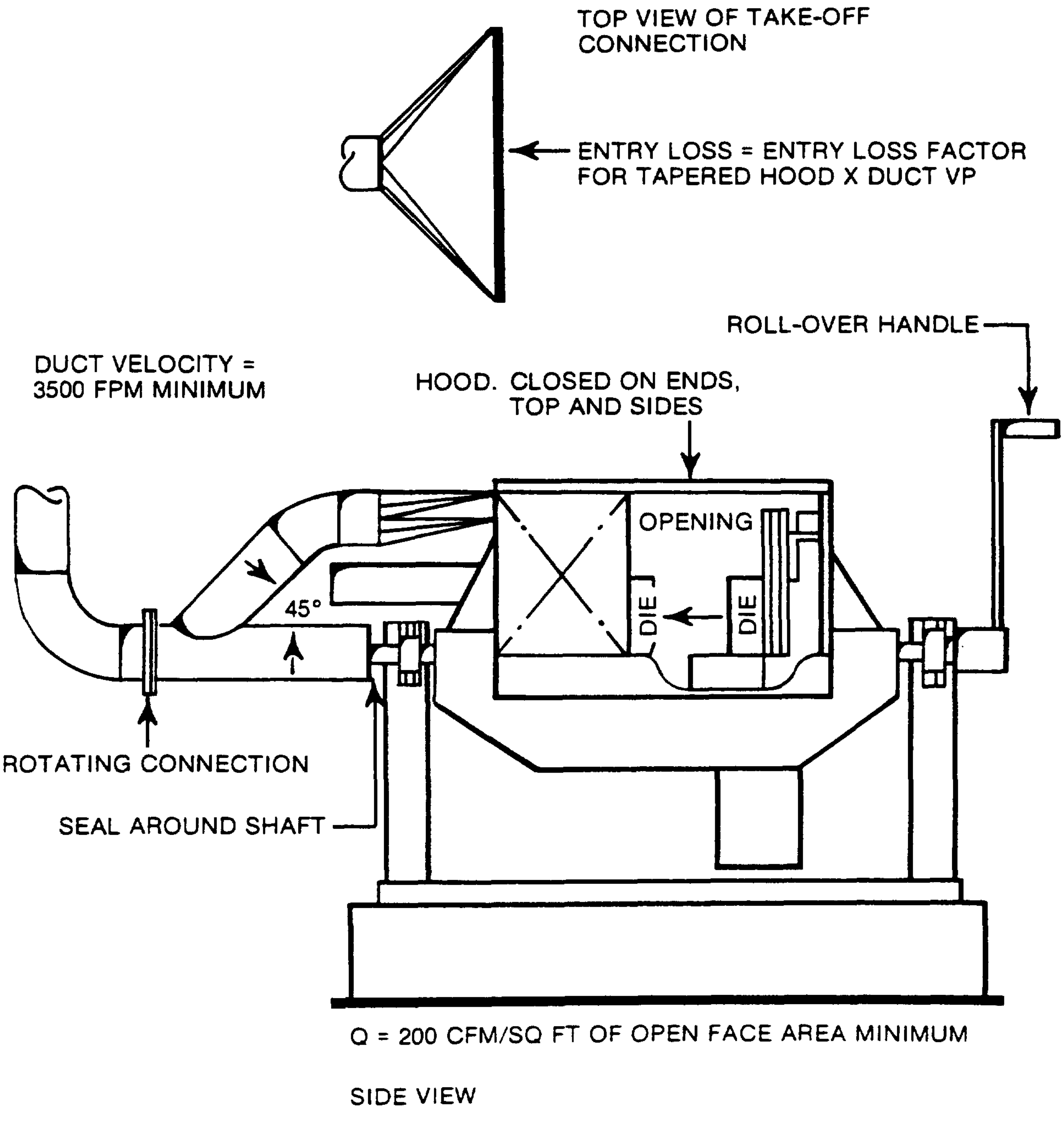


FIGURE IV-10. Small rollover-type coremaking machine

Adapted from reference [190]

The exposure of shell core machine operators to hazardous substances was recently investigated in a ferrous foundry [38]. The shell cores were prepared from a urea-phenol-formaldehyde sand mixture with hexamethylenetetramine as the catalyst. The core was produced by blowing the sand-binder mixture into a corebox preheated to 400-450°F (204-232°C), where it was held for approximately 30 seconds to allow the binder to cure, and then the finished core or core segment was removed from the corebox. To evaluate exposures of shell core machine operators to formaldehyde, fourteen 30-minute personal samples were collected during an 8-hour workshift. Airborne concentrations ranged from <0.02 to 18.3 ppm (<0.02 to 22.5 mg/m^3). Three of the samples showed concentrations of 4.4, 10.6, and 18.3 ppm (5.4, 13.0, 22.5 mg/m^3). The fluctuations of formaldehyde levels were mainly attributable to core types and sizes. During one 30-minute sampling period in which nine large cores (size unspecified) were formed along with some small cores, the formaldehyde concentration was 10.6 ppm (13.0 mg/m^3). Recommendations for controlling operator exposure included removing contaminants during core cooling by using a spray booth-type hood or by using a blowing/extraction ventilation system at transport points [38].

In the shell coremaking operations of three British foundries, high concentrations (not specified) of formaldehyde were found in areas where hollow cylindric cores were being produced in the absence of ventilation [203]. The cores were 2.6 X 0.5 feet and were closed at both ends. The hollow center of the mold contained phenol and ammonia vapor, as do other shell molds, but in this case the hot cores were removed from the machine and broken open across the middle, releasing hot vapor into the worker's face. This type of exposure can be prevented by allowing the sand to cool before breaking the core tree.

Control of exposures to phenol, ammonia, and formaldehyde in shell core production can be achieved by ventilation similar to that suggested for shell molding in Figure IV-9. A sidedraft hood can be used to remove smoke and vapors from the hot cores as they emerge from the equipment and are cooled [190].

3. Hot-Box Binders

Hot-box binders, resins that polymerize in the presence of acid salts or acid anhydrides and liberate heat to form a binder, are blends of three types of resins: furan, phenol-formaldehyde, or urea-formaldehyde resins [75,201]. Core blowing, core shooting, and curing and cooling hot-box cores may result in exposures to furfuryl alcohol, formaldehyde, and CO. Metal pouring may result in exposures to CO and hydrogen cyanide, depending on the formulation [7,201].

"High" concentrations of formaldehyde were measured in an English foundry that used hot-box binders [203] (specific concentrations were not given). In this foundry, the hot-box process was carried out on two multi-stage machines (a four-station and a six-station machine). Each mold was brought to a filling station, revolved around the back of the machine, and finally brought to the front of the machine for core removal. The curing time was 3-5 minutes at 200-250°C (392-482°F). At the six-station machine, an air velocity of 2.25 feet/sec into the exhaust hood was measured at the delivery point, from which the cores were then passed along a conveyor belt fitted with a canopy hood. After 5 minutes on the conveyor belt, the warm cores were taken out to remove minor blemishes by hand filing. There was no exhaust ventilation at this point, and insufficient time for core cooling was allowed before finishing the cores. The workers were exposed to 10 ppm (12 mg/m^3) of formaldehyde during this operation.

At the four-station machine, the air velocity into the hood at the delivery point was 1.1 feet/sec; no provision was made for removing fumes from the hot cores as they were placed on racks beside the machine to cool. The worker who removed and stacked the cores was exposed to up to 5 ppm (6 mg/m^3) of formaldehyde. It was concluded that control of emissions at the machines may not be sufficient because certain types of cores continue to generate formaldehyde as they are stacked and placed on conveyor systems or when blemishes are removed by hand. For this reason, exhaust ventilation is necessary during these operations [203].

Engineering controls for hot-box coremaking were described in the NIOSH foundry hazard technology study report of 1978 [7]. Cores were made in a room containing seven high-production horizontal-type hot-box core machines. Core constituents were of silica sand, red iron oxide, core oils, and catalysts containing urea and ammonia. The coremaking sequence consisted of core blowing and curing, core ejection and removal from the box, core finishing, core removal from the rack, inspection, and placement of cores on the storage rack. In addition to handling the cores, the operator cleared excess materials from the corebox with an air nozzle after the cores were removed.

However, the operator did not directly remove the core from the box. Rather, the core was ejected onto a lift-out rack, which indexed through four positions. After the corebox opened, the lift-out rack received the cured cores at the first position. It was then indexed to a second position where the cores were given a light finishing. The rack paused at the third position and, finally, the cores were indexed to a fourth position in front of the operator for unloading. The entire indexing cycle took about 1 minute.

Emissions were controlled by an overhead canopy hood above the core machines, operator station, and core storage racks and by an individual fresh air supply for each worker. The lowest edge of the canopy was 7.6 feet (2.3 meters) above floor level. An air exchange of 9,500 cubic feet per minute (ft^3/min) (4.5 m^3/s) provided an updraft velocity of 40 ft/min (0.2 m/s) into the hood. A flow-splitter baffle within the canopy proportioned the exhaust, drawing the greatest amount from the corebox that generated the most emissions. The baffle helped to control the fumes from entering the breathing zone (see Figure IV-11).

Most emissions occurred during and for a short period after the opening of the box after curing. Because of the 1-minute period between corebox ejection and removal of the cores by the operator (during which cooling

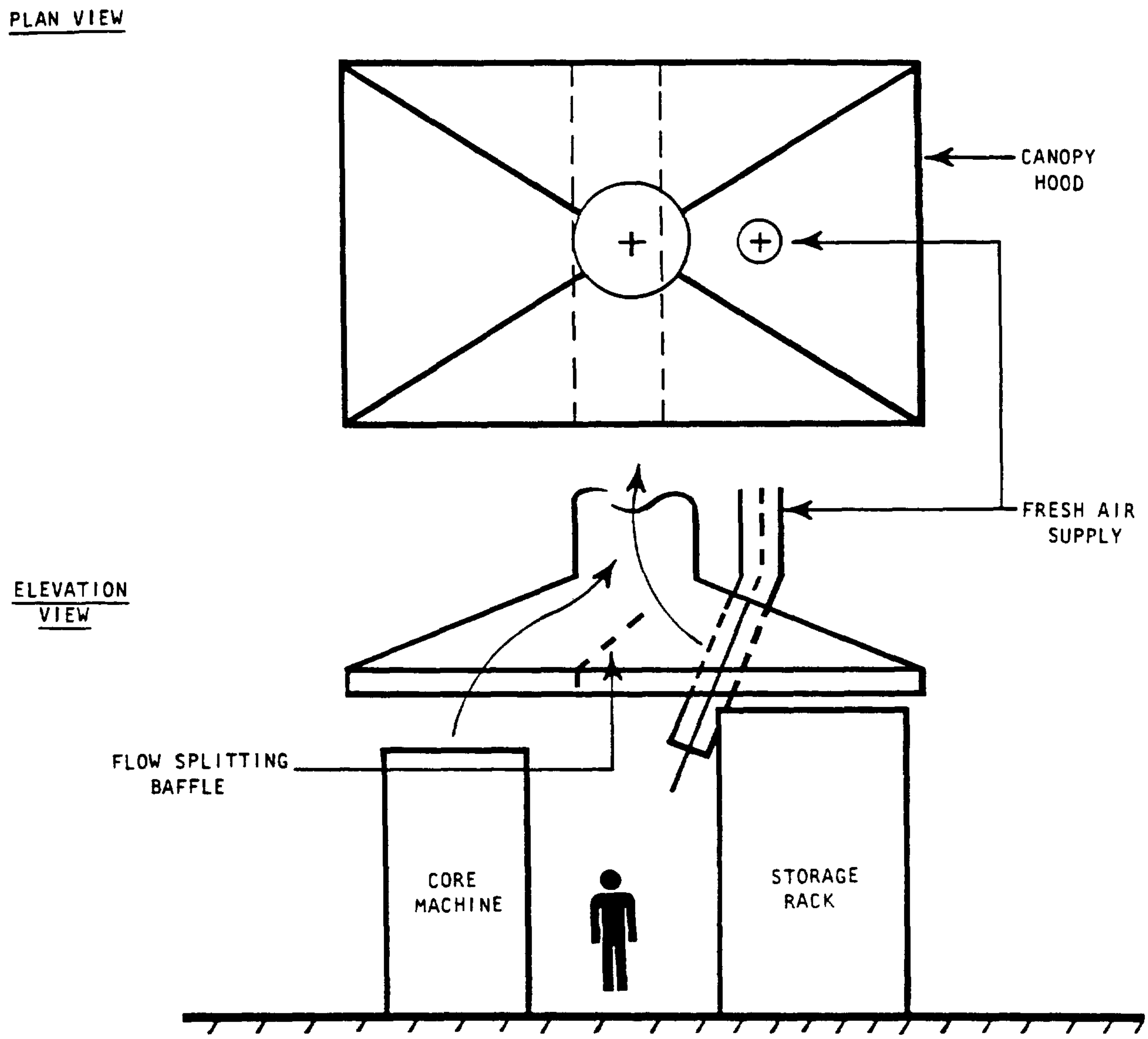


FIGURE IV-11. Canopy hood and fresh air supply for furan hot-box core machine

Adapted from reference [7]

and degassing of the cores took place), few air contaminants were emitted during handling. The engineering controls used, successfully held the airborne concentration of gases, vapors, and respirable crystalline silica well within the permissible exposure limits [7].

4. Cold-Box Binders

In 1967, a two-part polyurethane cold-box binder system was developed which uses a phenolic resin and a polyisocyanate [13]. In the presence of a gaseous catalyst, either dimethylethylamine (DMEA) or triethylamine (TEA), the phenolic resin and diphenylmethane diisocyanate (MDI) combine to form a strong binder. This process presents potential hazards not only as a result of the MDI solvent and resin materials but also the catalysts (DMEA or TEA). Area air samples taken in the coreroom of a ferrous foundry showed TEA concentrations of up to 32.4 ppm (134 mg/m^3), which exceeded the OSHA PEL of 25 ppm (100 mg/m^3) [154]. The catalyst's gaseous emissions from the process can be removed from the workroom atmosphere by a properly designed exhaust system which captures both the catalyst emitted from the freshly made cores and the gases under pressure leaking from poor seals in the corebox blowing system [7].

Air MDI, phenol, and TEA/DMEA concentrations were monitored in 25 to 28 iron and steel foundries where urethane binders were used in no-bake and cold-box core and mold-making processes. In none of the 90 samples collected at stations using phenolic urethane no-bake did the phenol concentration exceed the OSHA PEL of 5 ppm (19 mg/m^3); in a few cases when hot sand was used, the formaldehyde concentration did exceed 3 ppm. Of the 210 air samples collected for phenolic urethane at cold-box coremaking stations, only 25 exceeded the OSHA PEL of 25 ppm for TEA. The higher concentrations were usually associated with leaking fittings, use of excessive amine catalyst, or inadequate corebox seals and were readily corrected by improved engineering controls [204].

Examination of engineering controls for phenolic urethane cold-box core production were included in the NIOSH foundry technology studies [7]. In one operation studied, the core machine used was a vertical press-type consisting of a stationary sand hopper and attached matchplate and a vertical piston with a matchplate that opened and closed the corebox (see Figure IV-12). An automated core liftout rack moved the cores from the corebox to the worker position. The coremaking cycle consisted of automatically blowing, gassing, purging, core ejecting, retrieving, and storing the cores on racks. Core constituents consisted of lake sand and a two-part binder system of phenolic and isocyanate (MDI polymer) resins, with TEA gas used as the catalyst. The gases were controlled by using a negative pressure at the discharge side of the corebox. The exhaust gases were incinerated by an afterburner before being discharged into the atmosphere. A sidedraft hood was located at the corebox, and a canopy hood was over a setoff bench. By using a setoff bench, the core (or mold, in other cases) was removed from the corebox and immediately placed on the setoff bench for

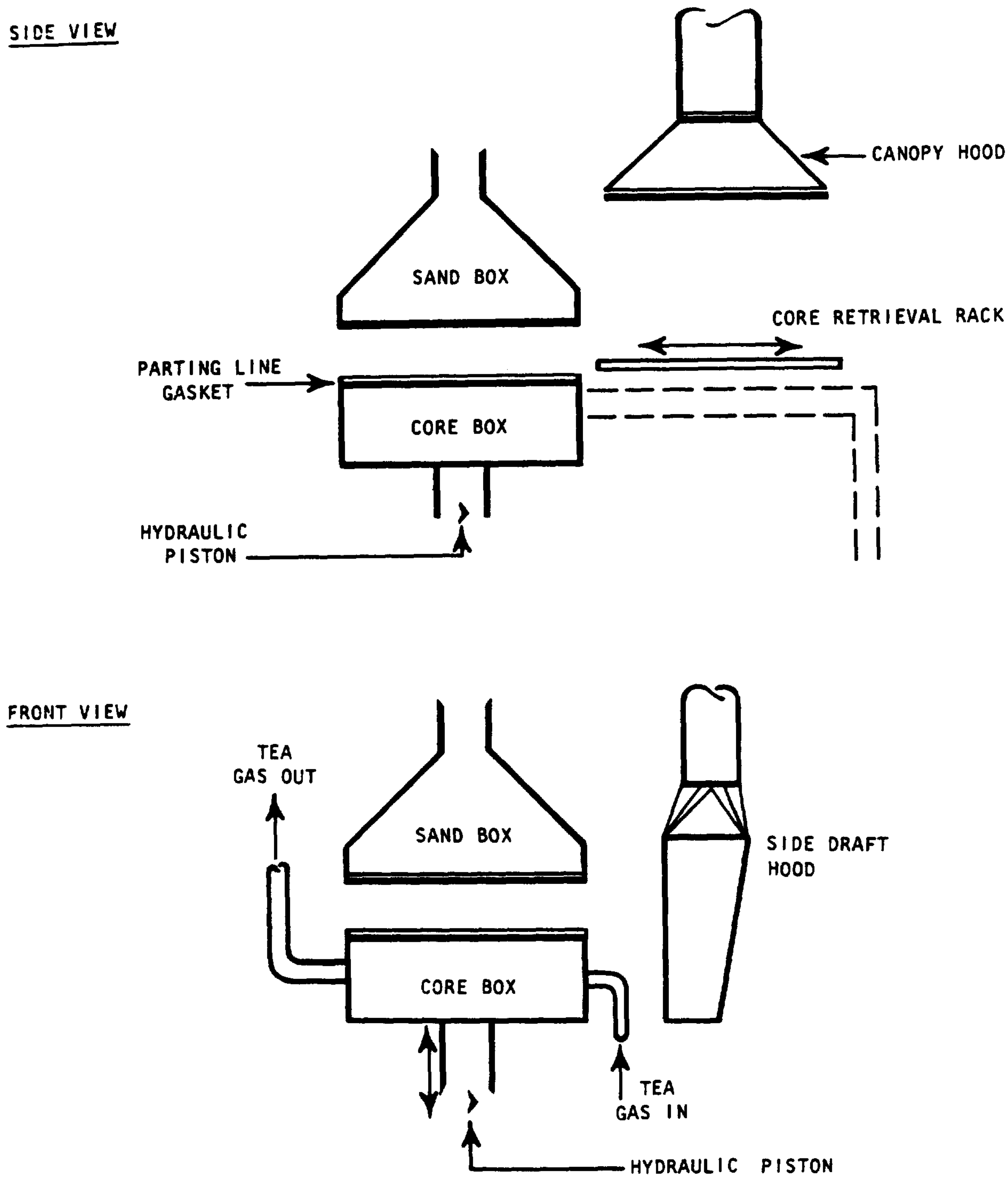


FIGURE IV-12. Cold-box coremaking exhaust

Adapted from reference [7]

1-2 minutes under a hood. The exposures of core machine operators to gases, vapors, and respirable silica were well below OSHA PEL's or NIOSH REL's [7].

In a second operation, exposures to TEA or DMEA in cold-box core production were evaluated. Emission sources in the coremaking area included gases leaking at corebox seals (parting line gaskets, blow seals, and stripper pin o-rings) and gases emitted from cores during handling and finishing. When seals were inadequate, dilution ventilation and exhaust of gases within the corebox were not effectively controlling TEA emissions; concentrations approached the OSHA 8-hour TWA PEL of 25 ppm (100 mg/m^3). Recommendations for reducing leaks included providing adequate vents in the pattern for TEA to be uniformly released [7].

5. No-Bake Binders

No-bake binders are a more recent development in the foundry industry and because of the reduced heat requirements have become increasingly attractive in the energy-shortage-conscious United States [13]. These binders are basically modifications of the processes previously described. Emissions generated from the binders in the no-bake process, as with other coremaking and molding processes, depend on the resin and catalyst composition, the sand quality, and the temperature [13,201]. No-bake cores successfully reduce the potential for heat stress in the coreroom.

In 1976, Virtamo and Tossavainen [205] surveyed 10 Finnish iron and steel foundry coremaking areas for gases formed from the furan no-bake system. The furan system was used at about 2% of the furan binder and 1% of phosphoric acid, based on the weight of sand. A total of 36 furfuryl alcohol and 43 formaldehyde personal samples were taken. Phenol concentrations were measured in one foundry (six samples) and phosphoric acid concentrations in two foundries (nine samples). The mean furfuryl alcohol concentration was 4.3 ppm (17 mg/m^3), with 22% of the measurements exceeding the Finnish furfuryl alcohol TLV of 5 ppm (20 mg/m^3). The highest furfuryl alcohol concentrations (10 to 40 ppm) occurred in areas where workers were filling and tucking large coreboxes. The mean formaldehyde concentration was 2.7 ppm (3.3 mg/m^3).

Workers who were filling large coreboxes were exposed to the highest formaldehyde concentrations (5-16 ppm or 6-20 mg/m^3). The highest phenol concentration measured was 0.35 ppm (9.3 mg/m^3), while the phosphoric acid concentrations were <0.1 mg/m^3 [205], both of which were well below the OSHA PEL's of 5 ppm (19 mg/m^3) and 1 mg/m^3, respectively [55]. Furfuryl alcohol was determined by the Pfalli method, formaldehyde by the Goldman and Yagoda method, phenol by the 4-amino-antipyrine method, and phosphoric acid by the molybdenic blue method [205].

Concentration of air contaminants was measured during a NIOSH HHE at a two-stage, furan no-bake core process in an iron foundry [206]. The first stage involved the construction of a large core and required 10-15 minutes; the second, the core cure stage, required 45 minutes. The substances used in the process included a mixture of furfuryl alcohol and paraformaldehyde, a phosphoric and sulfuric acid mixture, and sand. These substances were mechanically mixed and were poured into the mold, usually at room temperature; however, in cold weather simulation the sand was heated before mixing. Since the sand is not uniformly heated, some portion may become hot, and, when mixed with other substances, more vapors may be released.

Formaldehyde and furfuryl alcohol breathing-zone air samples were collected during normal conditions operating the day of sample collection and during simulated conditions that could occur on cold days. The furfuryl alcohol concentrations measured were 2.2 ppm during normal conditions the day of sampling and collected over a complete core production cycle (1-hour); 8.6 ppm under normal conditions and during the core preparation time only (15 min.); 10.8 ppm during the core preparation when the sand was heated to a warm condition (15 min.); and 15.8 ppm during the core preparation when the sand was hot (15 min.). The formaldehyde concentrations measured were 0.07 ppm during normal conditions over a complete core production cycle; 0.08 ppm during a complete cycle when the sand was warm and 0.33 ppm during the core preparation only when the sand was hot.

Charcoal tube air samples, using an MSA personal monitoring pump, were collected in an iron foundry where no-bake resin cores and molds were produced [207]. The materials used in the cores and molds were sand, a base resin (1.5% based on weight of the sand) containing furan resin, furfuryl alcohol, and some urea-formaldehyde resin, a catalyst (0.23%) containing toluene-sulfonic acid, isopropyl alcohol, and water. These ingredients were mixed in an automatic mixer and then poured into wooden molding forms. The 8-hour TWA-exposure concentrations of furfuryl alcohol were 6.25 ppm (25 mg/m^3) in the breathing zone of a coremaker and <6 ppm (<20 mg/m^3) in the breathing zones of an assistant coremaker and an apprentice. The highest value was 66 mg/m^3. None of the workers had any of the signs or symptoms considered to be attributable to furfuryl alcohol, i.e., ocular irritation, headache, nausea, or dizziness. It was concluded that furfuryl alcohol levels up to 66 mg/m^3 were not hazardous; this is consistent with the NIOSH REL level of 50 ppm (200 mg/m^3) of furfuryl alcohol as a 10-hour TWA (based on a 40-hour workweek) [86].

Recommended engineering controls for no-bake binders include (1) using binders free from or containing <0.5% free formaldehyde; (2) using new or reclaimed sand at 20-25°C (68-77°F) of such purity that it does not emit volatile material when treated with acid; (3) using catalysts that do not contain volatile solvents such as methanol; (4) using the lowest possible binder and catalyst content; and (5) placing functional exhaust ventilation fans along the mixer trough in a position so that the air can circulate away from the mixer trough and remove air contaminants from the work stations [208].

Although coremaking systems produce various types of air contaminants, ranging from silica dust to TEA gas, the free silica and chemical hazards resulting from coremaking operations can be effectively controlled by a combination of exhaust and supply air ventilation. Exhaust ventilation such as canopy hoods, sidedraft hoods, or specifically located flange exhaust duct openings should be used for controlling contaminants at coremaking machinery. Set-off booths or other similar controls for emissions releases while cores are cooling should also be used. Transferred fresh air directed at the operator can be effective in reducing negative plant pressures and worker exposures to emissions and in providing heat stress relief in coremaking operations that require heating [7].

6. Noise in Coremaking Operations

In addition to the hazards of dusts, fumes, gases, vapors, and heat present in coremaking, high noise levels create the potential for occupational hearing loss. In 1978, NIOSH [7] measured noise levels in a foundry coreroom, in which many styles and types of sand cores were made; this type of foundry was common at that time.

The most significant sources of noise in the core area were the fans, air nozzles, air exhaust from pneumatic equipment, pattern or mold vibration, gas jets, and noise from other shop operations. Efforts to reduce core area noise included the substitution of quieter equipment unless some other factor prevented their use, e.g., physical size. At stations where workers used air nozzles for pattern cleaning, several quiet air nozzles with sufficient force were tested, but only one model, which did not plug up with sand and dirt, performed the job both effectively and quietly.

Vibrators were used at most work stations to separate the sand core from the pattern. Piston-type vibrators were found to generate the loudest noises and often generated more force than was necessary. Turbine and rotary vibrators generated much less noise and generally had sufficient force to separate the sand from the pattern. Parting compounds, used to release the core from the pattern, reduced the overall noise levels in the area. Some type of pneumatic equipment was used on most of the machines. As a result, air exhausted at high pressure generated very loud noises, which contributed significantly to the overall noise exposure. Many types of commercially available exhaust mufflers performed adequately.

Noise exposure levels were measured for six different operators in the area who wore a noise dosimeter for 7-8 hours of a normal workshift. On the average, the noise levels in the coreroom were below the allowable OSHA PEL of 90 dBA as shown in Table IV-1, although some noise levels as high as 100 dBA were recorded. The results also suggest that binder substitution may be a method for reducing noise levels in the coreroom. Whenever noise levels in foundry corerooms exceed the NIOSH recommended 8-hour TWA of 85 dBA, engineering controls such as the substitution of less noisy equipment are recommended [7].

TABLE IV-1. Coreroom noise levels

Process time**	ENL* (dBA)	Range (dBA)	Percentage of exposure					
			85-87	87-90	90-92	92-95	95-97	97-100
Core blower	88	87-100	0	13	61	20	4	2
Shell core No. 1	89	85- 92	69	30	1	-	-	-
Shell core No. 2	87	<85- 95	62	32	4	1	-	-
No-bake	82	<85- 97	5	2	1	1	0.5	-
Oil sand (bench)	86	<85-100	19	11	5	3	1	<0.5
Oil sand (bench)	83	<85-100	13	8	4	12	2	<0.5

*Effective Noise Level (ENL) = $90 + 16.61 \log \left(\frac{\%\ \text{count}}{100} \times \frac{\text{measure time}}{8\ \text{hr}}\right)$
**Based on 8 hours per day

Adapted from reference [7]

D. Melting

One of the major hazards common to foundry melting areas is molten metal splash which may account for approximately 25% of all occupational injuries occurring in melting and pouring areas [48,50]. To guard against such injuries, protective barriers should be placed wherever molten metal may splash on workers, and pits that allow for emergency molten metal spillage should be provided. Other hazards in melting areas are usually associated with the particular process equipment used. Hazards associated with metal melting varies with the type of melting equipment used and the composition of the melt.

1. Cupolas

Most of the cast iron produced in the United States is melted in cupolas [10,22,209]. Considerable quantities of both gaseous and particulate effluents are produced. The effluent production rate varies with blast rate, coke consumption, physical properties and composition of coke, type and cleanliness of metal scrap in the charge, coke-to-iron ratio, bed height, burden height, air heat temperature, and when the furnace is being charged with iron, steel, scrap, coke, and flux [210,211].

The gaseous emissions from cupolas consist mainly of CO_2, CO, SO_2, and nitrogen (N) [22]. Of these, SO_2 and CO are probably the most hazardous to foundry workers. Sulfur dioxide concentrations of 25-250 ppm (65-655 mg/m^3) by volume have been measured [211]. Carbon monoxide concentrations were monitored in the air at 52 iron, 5 steel, and 10 copper alloy foundries in Finland that used sand molding. About 1,000 area air samples were taken, and the same sampling sites and measurement times were used for each foundry. The workers' exposure was evaluated from 2-hour personal samples. The mean CO concentration in the breathing zone of casters was 85 ppm (98 mg/m^3), and 67% of breathing-zone samples of cupola tenders exceeded the Finnish and OSHA PEL of 50 ppm (55 mg/m^3), 8-hour TWA. The NIOSH recommended 8-hour TWA exposure concentration for CO is 35 ppm. Area CO concentrations around the cupola averaged 240 ppm (280 mg/m^3) and 110 ppm (127 mg/m^3) in the casting area [212].

Possible causes of cupola leaks and worker exposure to CO and other toxic gases are: (1) design restrictions in the stack above the charging door; (2) restrictions to gas flow caused by poor fitting of spark or dust arrestors or scrubbers; (3) stack location and failure to elevate the stack above adjacent structures (causing downdrafts); (4) the use of any charging device that momentarily restricts the gas flow from the stack; (5) leaks in the exhaust system on the pressure side of the fan; and, (6) insufficient ventilation of the gases coming from the cupola windbox when the blast air is turned off [184]. To provide adequate worker protection from CO, the cupola system must be designed to eliminate these problems. Uncontaminated makeup air should be provided, especially on the charging platform and in the area around the base of the cupola where CO concentrations of up to 0.1% have been measured. Sometimes CO is burned to CO_2 in an afterburner; if it is not burned, CO can present a potential health hazard to maintenance workers and a potential explosion hazard in pollution control equipment [23]. Carbon monoxide monitors are recommended to warn charging crane operators and workers on the charging floor of harmful levels of CO and thus protect against excessive CO exposure.

Carbon monoxide is also a hazard during cupola repair. Accidents can be prevented by proper confined-space entry and by providing CO monitoring alarms. Using sealed openings in the sides of the cupola stacks, adequate ventilation within the cupola, and a job crane and safety harness to ensure rapid removal of workers from the cupola in an emergency is recommended [213]. A special problem can develop during cupola repair when two cupolas are connected to a single common air pollution control system. Carbon monoxide can leak back from the used cupola into the unused one where repairs are in progress. A supplied-air respirator may be required in this situation.

Destructive distillation and volatilization of organic materials in the cupola may produce a complex mixture of potentially harmful materials [22]. An effective exhaust system for controlling cupola emissions requires two separate exhaust hoods, an exhaust from the top or near the top of the vertical combustion chamber, and a canopy over the tapping spout. Emissions from the top of the cupola are variable in temperature and amount of air contaminants; therefore, exhaust systems must be designed to provide sufficient indraft at the charge door to prevent escape of emissions under widely varying conditions [7].

The tapping spout, forehearth, and sometimes the charging door are other sources of in-plant atmospheric contamination from cupolas [183]. A canopy hood with side baffles and mechanical draft are recommended to control toxic metal fumes issuing from cupola spouts during tapping. Emissions occurring while workers tap the cupola are captured by a canopy hood if the exhaust flow is adequate. A minimum exhaust velocity of 150 ft/min (0.76 m/s) into all hood openings is recommended [190].

Safety hazards peculiar to cupolas include the possibility of falls from the charging deck into the cupolas and accidents in dropping the bottom. Accidents associated with dropping the cupola bottom can be avoided if: (1) bottom drops are performed with a long steel cable attached to a vehicle and all plant personnel are in a designated safe area; (2) the valve that controls the doordrop is relocated to a designated safe area where it can be manned at all times; and (3) audio and visual signaling; devices are installed around the cupola doordrop area to secure the area during drops [183,214].

During the cupola charging, the equipment used should be guarded to protect workers from accidents. When cupolas are mechanically charged, elevators, machine lift hoists, skip hoists, and cranes should be guarded to prevent material from dropping on workers in the area below. When cupolas are manually charged, a guardrail should be placed across the charging opening to prevent the operator from falling into the cupola [215].

2. Electric-Arc Furnaces

Direct-arc furnaces are used for melting steel and iron. The dense fumes, composed primarily of iron oxide, manganese oxide, and volatile matter from the charge scrap (such as oil, grease, and combustible products) that are emitted from the furnace during melting and tapping are best controlled by local exhaust [7].

Many existing arc furnaces employ overhead hoods with duct systems that are connected only during the melting cycle. Such systems require the use of roof ventilators above each furnace in conjunction with either distributed fresh air or enclosed and ventilated control rooms [7]. Some furnace hoods utilize mobile duct systems that provide exhaust during all furnace operations [24]. Interferences may occur, however, from the ladle hanger or overhead crane during the tapping process so that a sufficient amount of shrouding may not be available over the ladle to capture all the fumes carried in the thermal draft [24]. During charging and tapping, auxiliary canopy hoods may not completely capture emissions when high bridge cranes are used in the melting shops and if crossdrafts are present [7].

Fumes from electric-arc furnaces may also be controlled by using curtain walls. The curtain walls, however, limit the space from the roofline to the bottom chord of the roof trusses so that roof exhaust fans are needed to remove the contaminants from the confined space. This method is effective only in those cases where the contaminant has a tendency to rise quickly without spreading to any great extent, but it is not recommended if overhead crane cabs are on the same side of the bay as the furnace [7].

Electric-arc furnace noise can be reduced by an isolated control room. One such furnace operator's control room was located against one wall in one of the foundry's furnace buildings, about 10 feet (3 meters) from the furnace. All of the controls for the electric-arc furnace were located inside the room. Charging, adding alloying elements, and other operations were performed outside the room [7].

The noise attenuation of the control room and operator noise exposure were evaluated separately. Operator exposure was evaluated by comparing the noise exposure measured by a noise dosimeter worn by the operator with the noise exposure measured by a stationary monitor outside the control room. The attenuation of the room was evaluated by comparing the overall sound pressure level and the frequency spectra inside and outside the room. The data showed that the control room significantly reduced the noise exposure. Operator exposure inside the control room measured from 82-88 dBA and was therefore below the allowable OSHA PEL of 90 dBA for an 8-hour exposure. Outside the room, the noise level was above the OSHA PEL for 8 hours of exposure. The noise attenuation afforded by the control room was about 16 dBA. The baffling of the control room reduced the level of all frequencies above 20 Hz by 9-40 dB [7].

3. Electric Induction Furnaces

There are essentially three types of induction furnaces: the closed channel-type furnace, the open channel-type furnace, and the crucible or coreless induction-type furnace [216,217]. The major hazards that exist in foundries using induction furnaces are silica dust in charge bucket filling from scrap contaminated with silica; dust and gases during charge preheating; and metal fumes, dusts, and smoke in furnace operation [7]. Controls to prevent hazards include using clean and dry materials for melting, providing exhaust ventilation systems, and using shields or enclosing the melting operation [7]. The cleanliness and dryness of the scrap is necessary to keep the amount of dissolved gas in the metal low. Dry storage should be provided, or the charge should be preheated to 149°C (300°F) [216].

Emissions from an induction furnace can be successfully controlled by the use of a close-fitting exhausted furnace hood; if that is not feasible, general exhaust ventilation can be used. Close-fitting hoods are appropriate where the scrap contains lead, zinc, oil, and other contaminants and where the exhaust gases must be collected and cleaned before being discharged outdoors. General ventilation may be applied when: (1) the scrap is very clean and free from lead, zinc, and organic materials including oils; (2) the area above the furnaces is isolated by baffles and is exhaust ventilated; and (3) there are no disruptions to the thermal draft above the furnaces, such as crossdrafts through open doorways.

Close-fitting hoods are not necessarily effective in capturing all of the emissions throughout the entire furnace cycle, especially during furnace charging and tapping, and when they are used in conjunction with roof exhausters above the furnaces to provide general exhaust ventilation. Due to interferences from ladle hangers and crane cables, the portion of the hood that covers the pouring spout cannot be extended far enough to capture the fumes in the thermal draft from the hot ladle during furnace tapping. In addition, charge buckets used for furnace charging act as chimneys above the furnace, permitting fumes to escape the furnace hood. Fume exposure varies inversely with the boiling points of the metals present [7].

Defects of close-fitting induction furnace hoods are a common cause of fume emissions, especially during furnace tapping. To provide adequate breathing-zone protection during tapping, an overhead fan or mobile ladle hood may be required in addition to the furnace hood. Hoods that draw exhaust air into the furnace shell and across the hot metal require flow modulation during the melting cycle to prevent chilling of the furnace spout and the molten metal [7].

The making of solid aluminum castings in induction and other types of furnaces is complicated by the tendency of the metal to absorb hydrogen from the atmosphere and charge materials during melting and to form a tough oxide skin which is easily entrapped when the metal is poured. Fluxes and degassing agents can reduce melting fumes but have toxicity characteristics that must be considered. Fluxes should be dry because at high temperatures the presence of water in the flux increases the amount of fume produced. Fluxes are usually composed of chlorides or fluorides of the alkaline earth metals [218]. However, one type of flux contains, in addition to chlorides and fluorides, an oxidizing agent of either sodium sulfate or sodium nitrate. The temperature of the melt after mixing (approximately 1,000°C) may lead to the evolution of aluminum chloride fumes, together with some production of sulfur dioxide. Fluxes containing borofluoride and silicofluorides may form toxic gases, boron trifluoride and silicon tetrafluoride [184]. Because of inherent toxicity problems with metal fumes and fluxes, ventilation must be provided during these operations.

In addition to the fluxing procedure, it is customary to de-gas alloys by flushing the metal with a gas or by adding other materials that form a gas. The use of chlorine to de-gas light alloys is extremely effective, but because of its hazardous nature, caution must be exercised to safely introduce the gas into the melt. In addition, adequate ventilation must be available to dispose of the large volumes of hydrogen chloride produced [218]. Because of extreme toxicity of chlorine gas and its difficult handling techniques, tablets of chlorine-producing chemicals, usually hexachloroethane, should be used. Argon and nitrogen gas [184] are other degassing agents that can be substituted for chlorine. Nitrogen does not give rise to fumes but is less effective than chlorine [218].

E. Pouring Operations

After the metal is melted in the cupola or melting furnace, it is tapped or poured into a holding furnace or ladle. As the metal is discharged from the furnace, slagging (the removal of nonmetallic waste materials and metal oxides) is usually performed. Slagging operations are frequent sources of heat, hot metal splashes, metal fumes, dusts, and IR radiation. To control these hazards and the potential for burns, shields including radiant heat shields, exhaust hoods, and fresh air supply can be used [7]. Slag can be removed from a crane-transported ladle at a separate station where the workers are protected by a radiation shield with an opening large enough to allow the operation of a slag pole. Heat stress on the workers can be reduced by a fresh air stream directed to their backs, and metal fumes can be captured by a sidedraft exhaust (Figure IV-13).

Sometimes before the metal is poured, substances such as silicon, graphite, or magnesium are added to give the cast metal specific metallurgic characteristics [5]. The hazards present during the inoculation process are metallic dusts and fumes, IR radiation, and heat stress. During inoculation, proper shielding and local exhaust ventilation are required to protect the worker. In-mold inoculation is being developed as a control method for ductile iron-pouring emissions. In this process, magnesium or a rare earth added in the gating system increases inoculant recovery and produces no fumes [219].

Pouring operations include the transporting of molten metal from the melting or holding furnace by ladle monorails, crane and monorail cabs, and manual methods and the pouring of molten metal from a ladle into the prepared molds [5]. For small castings, hand ladles and crucibles are used. For larger castings and extensive pouring operations, larger ladles supported by a hoist during pouring and moved by monorail or on a wheeled carriage are used. Ladles with large holding capacities (up to 70 tons) can be transported by overhead cranes, and a geared mechanism tilts them for pouring.

A wide range of air contaminants are produced by thermal decomposition of mold and core materials during and after pouring. In simulated foundry pouring conditions, using green-sand molds, it was found that the CO concentration could serve as an indicator of the general emission levels over time. Peak emissions occurred shortly after mold pouring with the emission rate decreasing gradually until shakeout when it suddenly rose again to a new peak [220].

Airborne materials generated from 12 common molding systems which were simulated under laboratory conditions in every case were found to contain CO concentrations above the OSHA PEL [72]. Most of the other emissions measured were generally at levels considered nonhazardous to worker health. Exceptions to this were the SO_2 levels in the phenolic no-bake process and the ammonia levels which in certain hot-box molding and coremaking processes were generated in sufficient quantities to be considered hazardous to health during prolonged exposure. Based on these laboratory results, it was speculated that if the CO concentration was controlled to safe levels through ventilation, the concentration of most of the other chemical contaminants would also be reduced to below their respective TLV's. Whether this would also hold true for actual foundry conditions has not been proven.

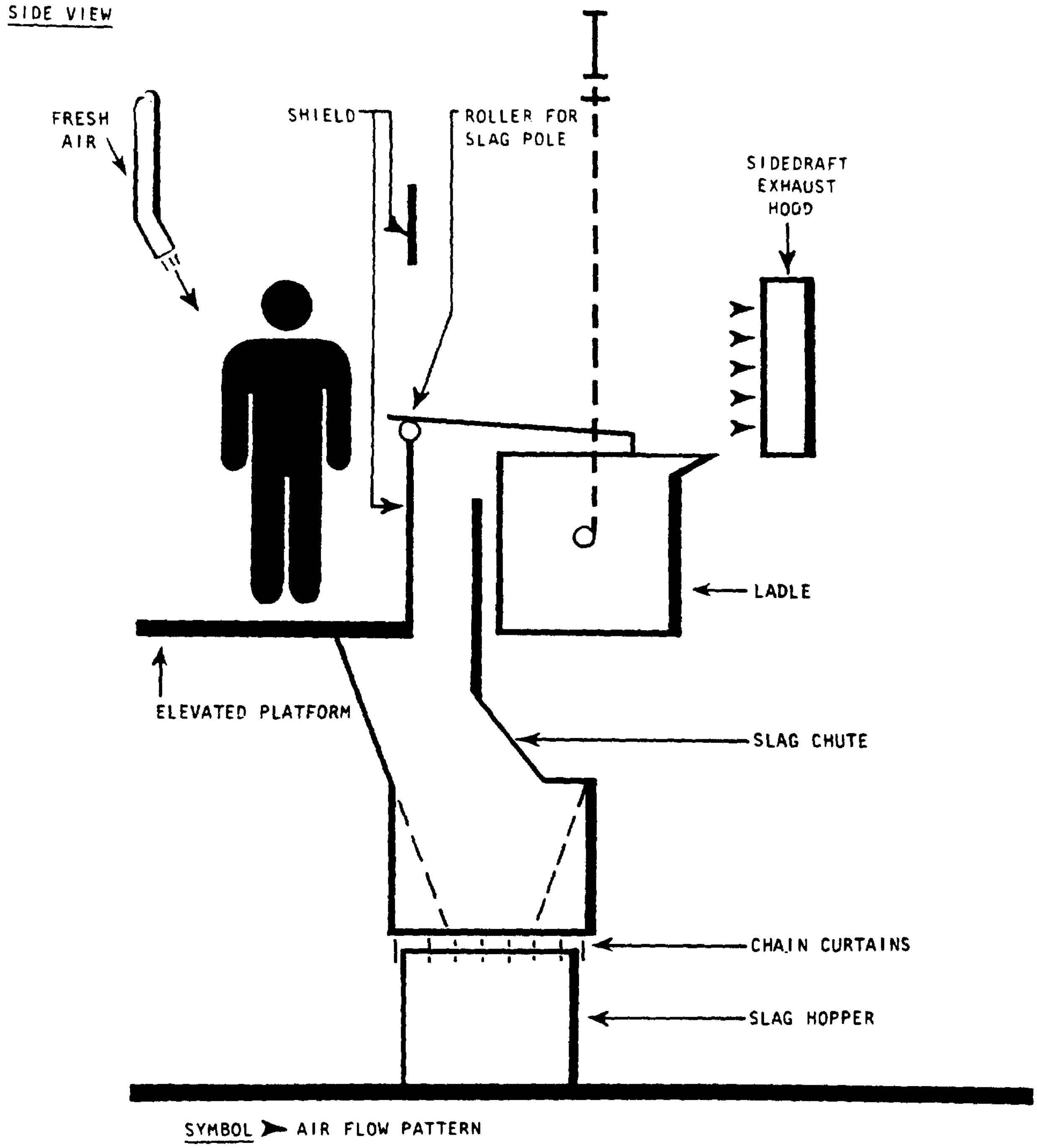


FIGURE IV-13. Slagging station

Adapted from reference [7]

Monitoring of the benzene-soluble fraction of total suspended particulates near pouring and furnace areas has shown measurable levels of benzo(a)pyrene, benzo(k)fluoranthene, benzo(a)anthracene, and pyrene and fluoranthene present near furnaces and pouring areas as well as in the cabs of cranes which frequently passed over the pouring areas [30]. These data (Table IV-2) suggest that when these potential carcinogens are present [175], engineering controls other than the general ventilation usually used for most pouring operations, especially in steel foundries, may be required.

Seacoal dust has long been used in foundries as an additive for mold sands to prevent "burn-on" on the casting surface, to aid in the separation of sand and casting at shakeout, to impart a good surface finish to the casting, and to reduce the incidence of expansion-type defects. However, the granular seacoal can contribute to the overall dirtiness in the foundry and introduce undesirable emissions including potential carcinogens into the foundry atmosphere during metal pouring. There are several coal dust substitute preparations based on, or containing, various combinations of synthetic polymers (polystyrene, polyethylene, and polypropylene), oils, asphalts (gilsonite and pitches), and bitumens which may be useful in reducing the carbonaceous dust in the sand preparation area and improve the overall cleanliness of the plant. However, the possibility that these

TABLE IV-2. PAH's near foundry pouring areas

	Unit	Furnace			Cranes		
		$\bar{X}$	Range	n	$\bar{X}$	Range	n
Total suspended particulates (TSP)	mg/m^3	3.75	1.80-5.78	10	1.76	0.58-3.04	25
Benzene-soluble fraction of TSP	mg/m^3	0.43	0.18-0.68	10	0.21	0.00-0.84	25
Benzo(a)pyrene	μg/m^3	0.139	0.107-0.172	2	0.085	0.024-0.149	7
Benzo(k) fluoranthene	μg/m^3	0.086	0.052-0.120	2	0.041	0.010-0.073	7
Benzo(a) anthracene	μg/m^3	0.049	0.031-0.067	2	0.038	0.008-0.065	7
Pyrene and fluoranthene	μg/m^3	0.053	0.040-0.066	2	0.052	0.034-0.117	7

$\bar{X}$ = mean
n = number of samples

Adapted from reference [30]

substitutes when heated may liberate potential carcinogens, even though they may be less carcinogenic than seacoal, has not been fully explored. Carbon monoxide production from molds after pouring under low temperature and nonreducing conditions may be reduced by 50% when coal dust substitutes are used [221].

Polystyrene has also been suggested as a coal replacement because of its effect on CO concentrations in the foundry. The average CO concentrations in the foundries studied which used coal dust were found to be about 350 ppm which was reduced to about 40 ppm after conversion to a polystyrene replacement. While these figures are averages and individual concentrations vary considerably depending on the foundry, they indicate that significant reductions in CO levels can be achieved by converting to polystyrene [222].

In addition to the hazard of various metal oxides, hydrocarbons, and destructive distillation emissions, the pouring operation is also one of the major sources of foundry heat. Although much of the heat in foundries is radiant heat from the hot molten metal and hot equipment, air temperature may also contribute significantly to the total heat stress on the foundry worker. Shielding or air-conditioned enclosures can significantly reduce radiant heat stress, especially during furnace tapping, pouring into ladles, transfer and pouring of molten metal and in holding furnaces.

The heat problem is usually severe during hot metal transfer using ladles manually pushed along a monorail, especially when one operator performs both the hot metal transfer and metal-pouring operations. Ladle covers and side baffles on ladle hangers, as well as fresh, cooled air distributed along metal transfer routes and protective clothing, can help to reduce the heat load. The supplied air should be used in combination with an exhaust system to remove contaminants from the pouring operation.

In mechanized casting lines in large iron casting foundries, a push-pull ventilation system is often used along the pouring line. Fresh air is blown towards the workers who are pouring metal into the molds and a large exhaust hood is on the other side of continuously moving mold lines. An effective pouring heat control, for a mechanized long pouring line producing ductile iron at the rate of 35 tons/hour, consisted of a supply-air rate provided behind the pourers of 52,000 ft^3/min (25 m^3/sec) and an exhaust rate on the opposite side of the flasks of 78,000 ft^3/min (37 m^3/sec). Air samples taken in worker breathing zones showed the concentrations of respirable crystalline silica, CO, organic vapors, and metal fumes to be below the OSHA PEL's [7].

General ventilation is often applied in open pouring floors [175]. As a dilution method, it is not effective at high emission rates during high production [7]. As new technology permits the foundry industry to increase production efficiency with increased mechanization, general ventilation will have a decreased application as a primary control for pouring and cooling processes. However, there will always be a need for general ventilation approaches where the lack of mechanization prevents the use of local exhaust systems, e.g., extra large casting operations and job shops pouring small runs in a variety of sizes and casting techniques. In general, only by controlling the emission at the source will ventilation be effective in preventing excessive worker exposures associated with pouring toxic metals that have low permissible exposure limits, e.g., lead, nickel, or copper. The need to control mold decomposition products at the source during cooling will depend on the organic materials present, as well as on variables such as pouring temperature, sand-to-metal ratio, cooling time, type and amount of binder, and production rate.

Another technique used to control mold emissions is to index the poured molds into a tunnel which is enclosed and exhausted. The operation can be performed from a control cubicle, thereby substantially reducing the potential for worker exposure to hazards [223].

F. Maintenance

One maintenance operation where workers may be exposed to high dust (including silica) and noise levels is the rebuilding of linings for the ladles used in handling the molten metal. During the curing of these linings, CO is produced from incomplete combustion caused by the premature cooling of the flames on the cool lining surfaces. To protect workers from exposure, an enclosure that has sliding doors to allow access for the placement and removal of the ladles can be used [7].

G. Knockout (Shakeout)

When the molten metal in a mold has solidified to a point where it will not distort when removed from the sand, the casting is removed from the flask in an operation called knockout or shakeout. Except for those molds produced without flasks or bottom boards, this procedure consists of opening the flask or mold frame and removing the casting. Usually the casting is then cleaned in the shakeout operation, which involves shaking off adhering sand and binder materials from the casting and sometimes breaking out the cores. The castings are then taken to the cleaning department and the flasks and sand are returned for recycling. These operations generally produce dust, and a green sand knockout gives off steam as well as dust. The shorter the interval between pouring and knockout, the larger the amount of steam but the smaller the quantity of dust liberated [188]. When the knockout process is performed at one location, local exhaust ventilation can be used to control the dust and steam [184].

The amount of dust and steam to be controlled will depend on several factors including the box size, the sand-to-metal ratio, the temperature of the sand, the casting size and configuration, etc. The types of exhaust ventilation that can be used to control the dust and steam are total enclosure, sidedraft, downdraft, and updraft. Care must be taken to prevent dust plugging when designing ventilation systems where steam and moist dust are involved. Recommended ventilation designs are presented in detail in Industrial Ventilation--A Manual of Recommended Practices [224], Recommended Industrial Ventilation Guidelines [190], and in Figures IV-14, IV-15, IV-16, IV-17.

Complete enclosure with ventilation is the best method of dealing with dust and fumes during shakeout, although access may become a significant problem. A complete enclosure has an opening on the inlet side for the entry of the molds and one on the discharge side for the removal of castings and boxes. The relatively small size of these openings allows the use of small volumes of air while still maintaining a high capture velocity at all openings.

If sidedraft ventilation is applied, a hood mounted above floor level and alongside the knockout grid should be used. The opening should be mounted above the top level of the moldbox and on the side of the knockout that is remote from the operator's working position. The hood should be placed along the long side of the knockout, and the top of the hood should extend over the knockout line as far as practicable. The use of shields increases the effective capture capacity of the ventilation system. Screens may also be needed to control erratic drafts if the knockout grid is subject to random air movement, which would reduce the ability of the duct to capture dust, gases, and fumes. This type of exhaust will control only fine airborne dust and not the dust that falls with the sand into the hopper below the knockout.

The shakeout can be a major source of noise in the foundry. To control worker exposure to noise, the shakeout where possible should be isolated from the other processes by a total enclosure. An enclosure constructed of standard 4-inch (10 cm) thick acoustic panels can significantly reduce the noise levels. The accumulation of dust within an acoustical panel can reduce its sound absorption capacity.

In one foundry without the enclosure, the noise level permitted an allowable exposure of about 3 hours per day. With the shakeout enclosure, the overall noise level was reduced by about 16 dBA. Noise levels at the operator position were 89 dBA with the enclosure and about 105 dBA without the enclosure. The enclosure reduced the noise level of all the frequencies above about 100 Hz by 8 to 25 dB [7].

H. Cutting and Cleaning

In iron and steel foundries, after the shakeout operation, the sprue or pouring hole is knocked off or cut off and the castings are sorted and cleaned. The main hazard in this process is respirable silica dust. Dust can be controlled by using a conveyor belt made of a metal mesh with a downdraft exhaust system [7]. Control of torch cutting and arc-air gouging operations is not within the scope of this document but is discussed in the NIOSH criteria document on welding, brazing, and thermal cutting [225] and in the NIOSH foundry technology study [7].

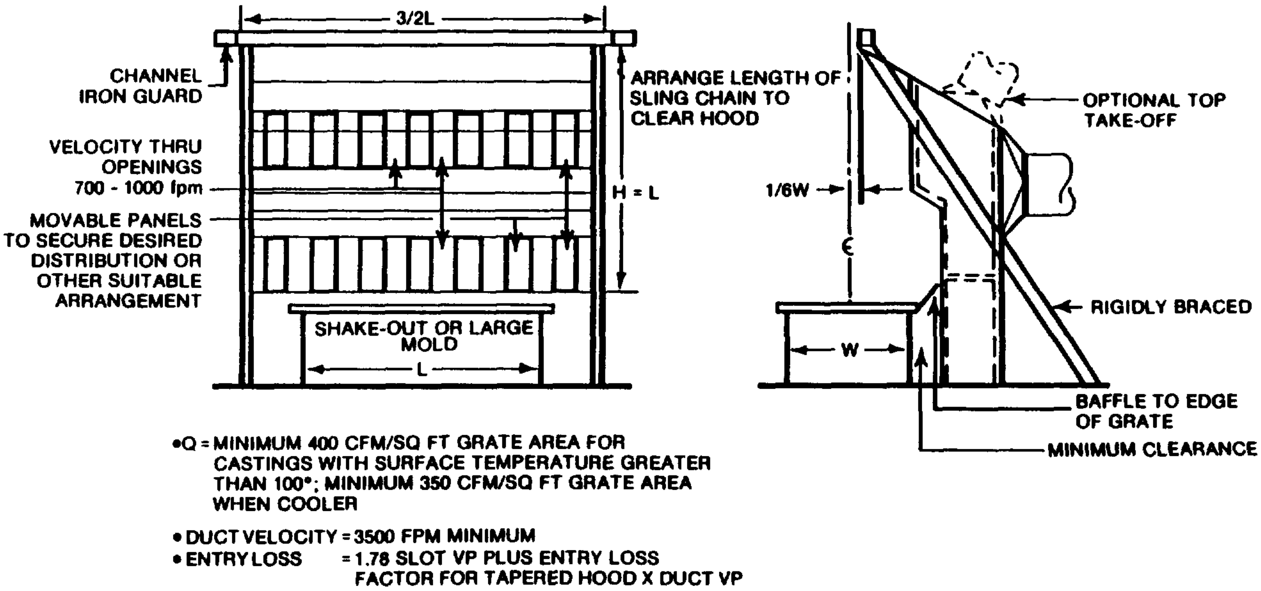
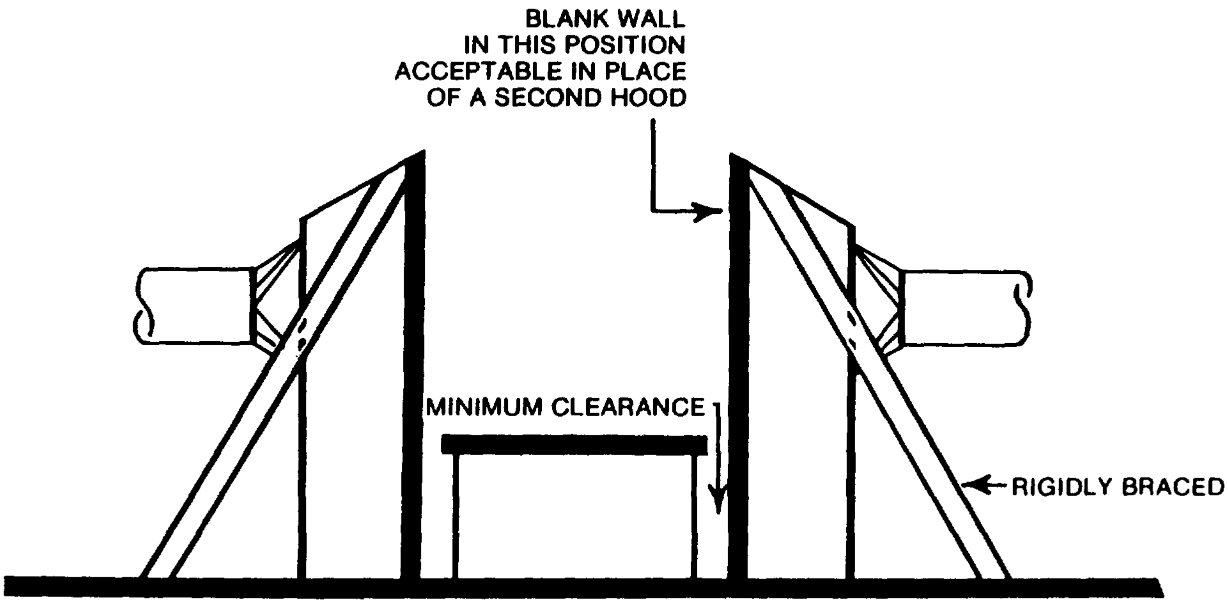


FIGURE IV-14. Sidedraft hood

Adapted from reference [190]



PROPORTIONS SAME AS SINGLE SIDE-DRAFT HOOD EXCEPT FOR OVERHANG.

Q = MINIMUM 400 CFM/SQ FT GRATE AREA FOR CASTINGS WITH SURFACE TEMPERATURE GREATER THAN 100°; MINIMUM 350 CFM/SQ FT GRATE AREA WHEN COOLER

DUCT VELOCITY = 3500 FPM MINIMUM

ENTRY LOSS = 1.78 SLOT VP PLUS ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

FIGURE IV-15. Double sidedraft hood

Adapted from reference [190]

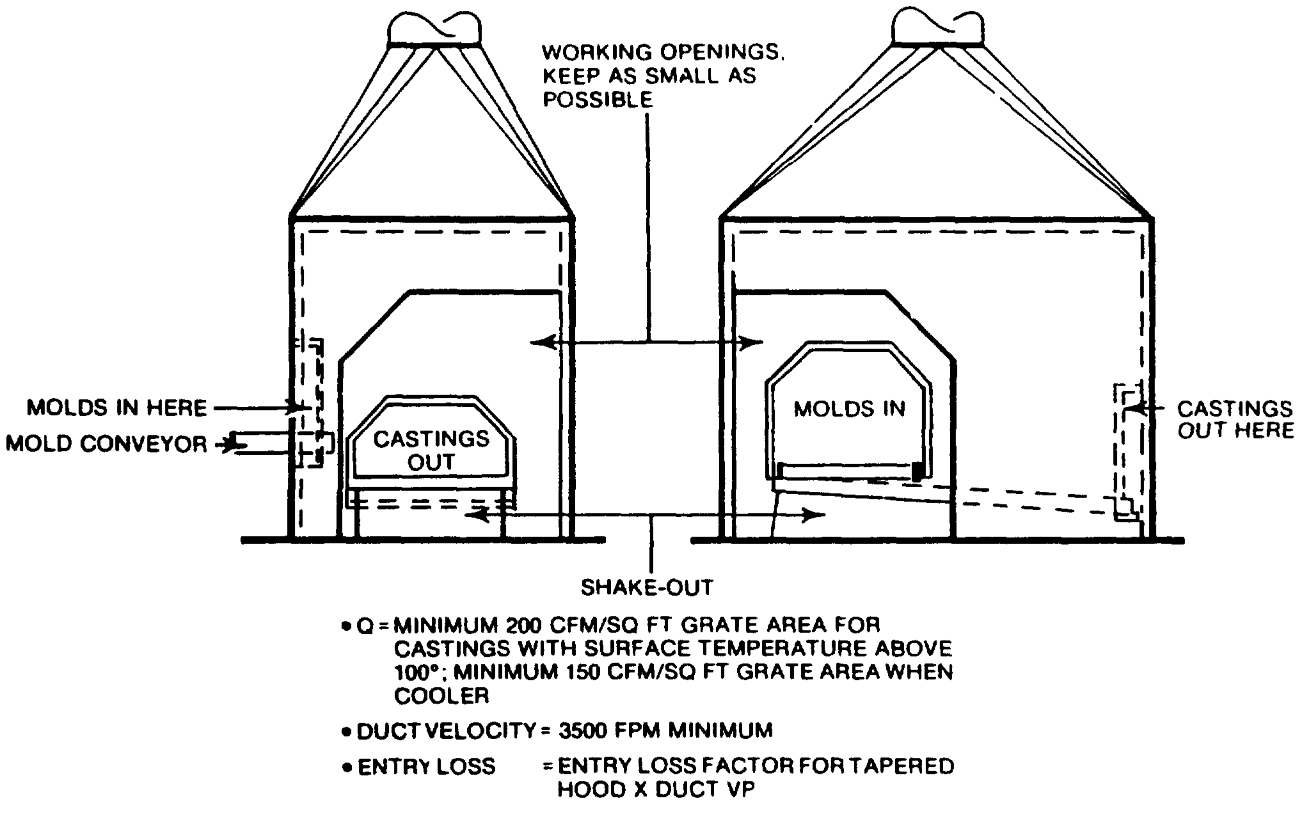


FIGURE IV-16. Enclosing hood

Adapted from reference [190]

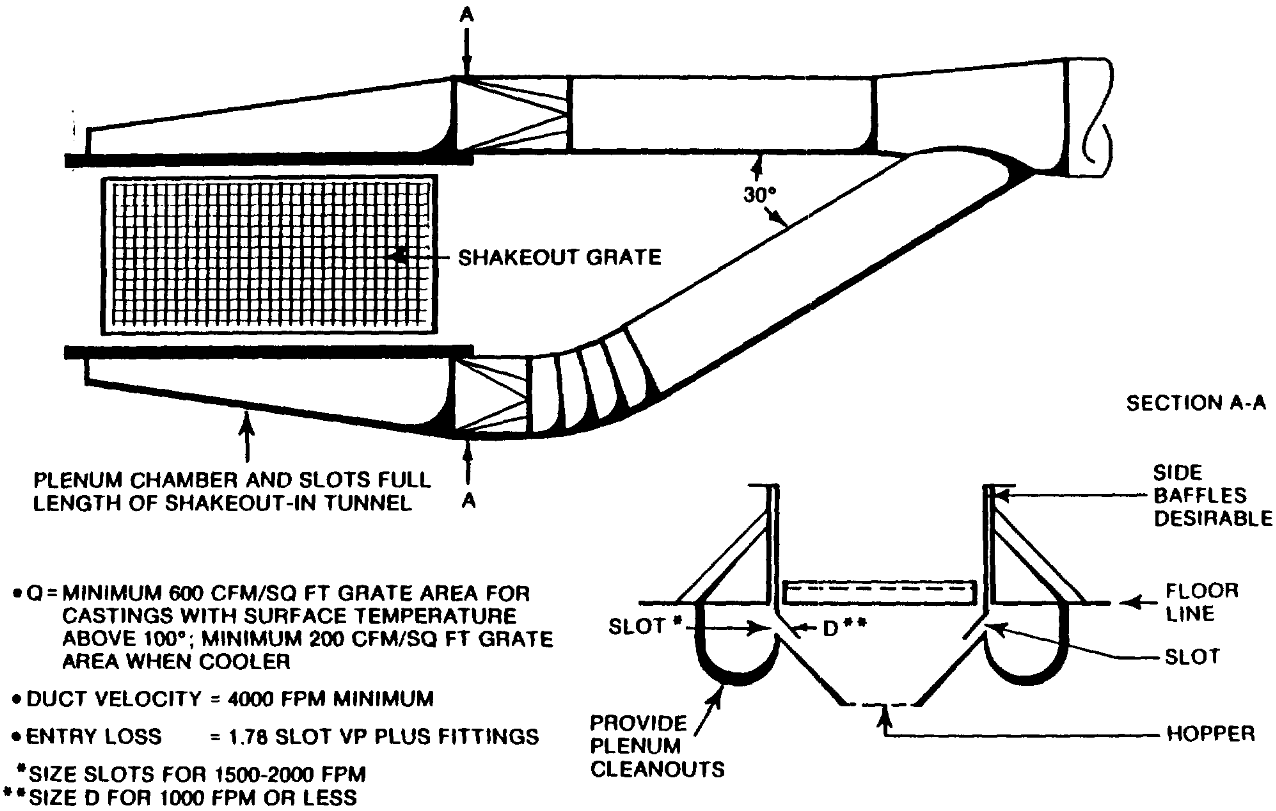


FIGURE IV-17. Downdraft hood

Adapted from reference [190]

Excess sand is removed from the castings by abrasive blasting operations and/or in tumbling mills. These operations produce high noise and dust levels. The engineering control of air contaminants in abrasive blasting booths is addressed in the NIOSH document, Abrasive Blasting Operations: Engineering Control and Work Practices Manual [226].

Tumbling mill noise has been measured in two different ferrous foundries [7]. In both cases, enclosures around the machines were used to protect workers from exposure to noise levels above 90 dBA. The tumbling mill operator was near the machines only during loading and unloading. Typically, the operator entered the enclosure, loaded one or both mills, started the cycle timer, and left the enclosure. After the cycle was completed or when convenient, the mill was unloaded and the cycle was repeated. The operator wore hearing protection while working in the enclosure. Tumbling mill noise exceeded the OSHA PEL's for an 8-hour exposure.

As a result of installing the engineering controls, noise levels in the casting, sorting, and inspection areas were reduced to below the OSHA PEL's. Without the enclosure, the allowable exposure time was estimated to be about 5 hours per day. The noise level inside the enclosure was about 105 dBA compared with 88 dBA outside. The enclosure reduced the noise level of all the frequencies above about 100 Hz by between 4 and 22 dBA.

Practical approaches to controlling dust in the cleaning operations after shakeout are to: (1) eliminate casting defects; (2) ensure that unnecessary cleaning operations are eliminated and essential ones are reduced to a minimum; (3) clean the castings as thoroughly as possible by abrasive blasting and tumbling operations before entering the cleaning room; and, (4) apply local exhaust ventilation to the cleaning operations [227]. Of the four considerations, the single most useful one to promote clean, healthy working conditions in cleaning rooms is to ensure that castings are cleaned as thoroughly as possible prior to entering the cleaning room.

Cleaning room workers are exposed to dust produced in the cleaning room itself, as well as to dust contamination from other foundry processes. Causes of increased background dust include (1) inadequate ventilation controls for chipping and grinding operations; (2) poorly maintained debris chutes from shot-sand separators on blast cabinets; (3) discharge of debris from sorting conveyors; (4) cleaning of castings with air nozzles; (5) operation of forklift trucks; (6) transfer of castings from hoppers into other hoppers or onto conveyors or benches; (7) use of hammers for gate, riser, and sprue removal from casting; (8) cleanout of swing grinder booths; (9) leaky seals on shot blast equipment; (10) sweeping with brooms; (11) throwing castings into sorting bins; and, (12) sand reclamation by clam bucket or crane. The accumulated airborne dust from all of these sources can result in high silica concentrations that may exceed the NIOSH REL and the OSHA PEL [7].

When elimination of dust production at the source is not possible, control of the dust by local exhaust ventilation is necessary. Methods for reducing the dust generated by hand-operated power-driven tools such as pneumatic chisels, portable grinders, and wire brushes include: (1) the castings may be cleaned on benches that are fitted with stationary sidedraft or downdraft local exhaust ventilation; (2) a mobile extraction hood may be used; (3) a low-volume, high-velocity ventilation system may be applied to the tool itself; and, (4) a retractable ventilation booth may be designed for castings too large for benches. Each method has advantages and disadvantages and one may be more suitable than the others in any given case. Local exhaust ventilation should always be used to control the dust produced by hand-fettling operations. Dust respirators and supplied-air hoods should be considered only when engineering controls are not practical [7,184].

Light castings can be dressed on benches fitted with exhaust air systems that can be applied to the bench itself. Although designs vary, the type of casting will probably determine the most suitable bench ventilation system layout. Portable hoods, although used in industry for many years, have the disadvantage that they must be placed close to the source of dust [184]. If the operator moves over a large area, constant hood adjustment is necessary. On the other hand, portable hoods can be used on work that is too large to dress on benches if the hood can be physically located near the grinding area. The low-volume, high-velocity system can effectively be applied to many dressing tools [184].

In a study of five foundries that used a combination of exhaust ventilation at the source of dust generation and a fresh air supply behind the worker for cleaning small to medium-sized castings, the breathing-zone concentrations of respirable silica were controlled below the allowable OSHA PEL's for a majority of workers. Limitations of the downdraft benches; portable hoods; high-velocity, low-volume ventilation on tools; and defects in applying the methods can result in incomplete dust control. Downdraft benches are ineffective in providing direct capture during processing of internal casting cavities and have limited capture efficiency during external finishing when the grinding swarf is directed away from the bench. The limitation of high-velocity, low-volume ventilation on tools is due to the interferences by some grinding hoods in certain operations; the lack of a practical hooding technique for chipping tools; the sensitivity of capture to tool position; the inconvenience of added air hoses for workers to handle; and clogging of high velocity, low volume inlet ports with dust [7]. When large castings (over 1,000 lbs.) are cleaned, local exhaust ventilation is not feasible or effective in most cases. In these instances, the use of air-supplied helmets or powered air-purifying respirators provides the most effective means of contamination control.