

HANDBOOK OF OCCUPATIONAL SAFETY AND HEALTH

THIRD EDITION

EDITED BY

S. Z. MANSDORF

WILEY

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S. Z. Mansdorf

Consultant, Boca Raton, Florida

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FOREWORD

It has been almost two decades since Louis J. DiBerardinis edited the second edition of the *Handbook of Occupational Safety and Health*. The intent of this third edition is to add to some of the existing well-written chapters from a number of pioneers in the safety and health field. For the existing chapters that have been reprinted, the format for those chapters was not changed, while the chapters that were revised do not follow the original outline style. The third edition also includes some current developments in our field such as management systems. Finally, the third edition has also been rearranged into topic sections to better categorize the flow of the chapters.

The quality of the work in the handbook is a reflection of the dedication of the authors in contributing to future generations of those practicing one of the most noble of professions protecting the health and safety of all of us.

Boca Raton, Florida

S. Z. MANSDORF

PART I

RECOGNITION AND CONTROL OF HAZARDS

RECOGNITION OF HEALTH HAZARDS IN THE WORKPLACE

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Adapted from “Potential exposures in the manufacturing industry – their recognition and control” by William A. Burgess, Chapter 18 in F. Clayton and D. Clayton (eds.), *Patty’s Industrial Hygiene and Toxicology*, 4e, Vol. IA. New York: Wiley, 1991, pp. 595–674.

1.1 INTRODUCTION

Although employment in the United States is shifting from manufacturing to the service sector, manufacturing continues to employ in excess of 20 million workers in workplaces that present both traditional and new occupational health hazards. To understand the nature of these hazards, the occupational health professional must understand not only the toxicology of industrial materials but also the manufacturing technology that defines how contaminants are released from the process, the physical form of the contaminants, and the route of exposure. Physical stresses including noise, vibration, heat, and ionizing and nonionizing radiation must also be evaluated. Twelve specific unit operations representing both large employment and potential health hazards to the worker have been chosen for discussion in this chapter; these unit operations occur in many different industrial settings. This chapter is based on the previous reviews of the subject (Burgess 1991, 1995) as well as original scientific literature. The purpose of this chapter is to help the reader recognize potential health hazards that may exist in specific operations and industries. Other chapters in this text cover the evaluation and control of the recognized hazards.

1.2 ABRASIVE BLASTING

Abrasive blasting is practiced in a number of occupational settings, including bridge and building construction, shipbuilding and repair, foundries, and metal finishing in a variety of industries. The process is used in heavy industry as an initial cleaning step to remove surface coatings and scale, rust, or fused sand in preparation for finishing operations. Abrasive blasting is used in intermediate finishing operations to remove flashing, tooling marks, or burrs from cast, welded, or machined fabrications and to provide a matte finish to enhance bonding of paint or other coatings.

Various abrasives are used in blast cleaning operations. The most commonly heavy-duty abrasives for metal surfaces are silica sand, metal shot and grit, coal and metallurgical slags, and synthetic abrasives such as aluminum oxide and silicon carbide. For light-duty cleaning of plastic and metal parts where erosion of the workpiece is of concern, a number of ground organic products based on corn, oat, and fruit pits are available as well as baking soda, glass beads, plastic chips, and solid carbon dioxide pellets.

Three major methods of blasting are used to deliver the abrasive to the workpiece. In pressure blasting, compressed air is used to either aspirate or pressurize and deliver the abrasive from a storage “pot” to a nozzle where it is directed to the workpiece at high velocity by the operator. This type of process may be used in either open-air blasting or in blasting enclosures. In hydroblasting, a high-pressure stream of water conveys the abrasive to the work surface; this process is used principally for outdoor work. Finally, in the centrifugal wheel system, a high-speed centrifugal impeller projects the abrasive at the workpiece; this method is used primarily in some types of blasting enclosures.

1.2.1 Application and Hazards

Blasting operations may be performed either in a variety of enclosures or in open-air operations such as bridge and ship construction. The types of enclosures used in industrial applications include blasting cabinets, automatic tumble or barrel and rotating table units where the operator controls the process from outside the operation, and exhausted rooms, where the operator is inside the enclosure. In most cases, these industrial units have integral local exhaust ventilation systems and dust collectors.

In open-air blasting in construction and shipyard applications, general area contamination occurs unless isolation of the work area can be achieved. As a result, the blasting crew, including the operator, “pot man,” and cleanup personnel as well as adjacent workers, may be exposed to high dust concentrations depending on the existing wind conditions.

The most obvious health hazard of abrasive blasting operations is airborne dust contamination. Dust exposures may include the abrasive in use, the base metal being blasted, and the surface coating or contamination being removed. In the United States, the widespread use of sand containing high concentrations of crystalline quartz is still a major hazard to workers. Though elevated rates of silicosis were identified in blasters by the US Public Health Service in the 1930s, a National Institute for Occupational Safety and Health (NIOSH) alert published as recently as 1992 identified 99 cases of silicosis in abrasive blasters with 14 deaths or severe impairment (NIOSH 1992). In the United Kingdom, the use of sand was prohibited for in-plant abrasive blasting in 1949; a ban on the use of sand for both inside and outside applications has been adopted by the European Community. The use of abrasives based on metallurgical slags warrants attention owing to the presence of heavy metal contamination.

In most cases, the base metal being blasted is iron or steel, and the resulting exposure to iron dust presents a limited hazard. If blasting is carried out on metal alloys containing such materials as nickel, manganese, lead, or chromium, the hazard should be evaluated by air sampling. The surface coating or contamination on the workpiece frequently presents a major inhalation hazard. In the foundry it may be fused silica sand; in ship repair, the surface coating may be a lead-based paint or an organic mercury biocide. Abrasives used to remove lead paint from a bridge structure may contain up to 1% lead by weight. Used abrasives will often need to be disposed of as hazardous waste depending upon the level of heavy metal contamination.

Physical hazards of abrasive blasting include noise exposure and safety hazards from high-velocity nozzle discharge. The release of air by a blasting nozzle generates a wideband noise that frequently exceeds 110 dBA. This noise is greatly attenuated in a properly designed blasting enclosure, but open-air blasting requires the implementation of a hearing conservation program and frequently the use of both ear plugs and muffs (NIOSH 1975b).

1.2.2 Control

The ventilation requirements for abrasive blasting enclosures have evolved over several decades, and effective design criteria are now available (American Conference of Governmental Industrial Hygienists [ACGIH] 1995; American National Standards Institute [ANSI] 1978). The minimum exhaust volumes, based on seals and curtains in good condition, include 20 air changes per minute for cabinets with a minimum of 500 fpm through all baffled inlets. Abrasive blasting rooms require 60–100 cfm ft⁻² of floor for downdraft exhaust. Dust control on abrasive blasting equipment depends to a large degree on the integrity of the enclosure. All units should be inspected periodically, including baffle plates at air inlets, gaskets around doors and windows, gloves and sleeves on cabinets, gaskets at hose inlets, and the major structural seams of the enclosure.

Operators directly exposed to the blasting operation, as in blasting room or open-air operations, must be provided with NIOSH-approved type C air-supplied abrasive blasting helmets. NIOSH has assigned a protection factor of 25 for type C hooded respirators operating in a continuous flow mode and 2000 operating in the positive-pressure mode. The latter respirator is recommended for open-air blasting with crystalline silica-containing sand (NIOSH 1992). The intake for the air compressor providing the respirable air supply should be located in an area free from air contamination, and the quality of the air delivered to the respirator must be checked periodically. The respirator must be used in the context of a full respirator program (see Chapter 16).

1.3 ACID AND ALKALI CLEANING OF METALS

After the removal of major soils and oils by degreasing, metal parts are often treated in acid and alkaline baths to condition the parts for electroplating or other finishes. The principal hazard in this series of operations is exposure to acid and alkaline mist released by heating, air agitation, gassing from electrolytic operation, or cross-contamination between tanks.

1.3.1 Acid Pickling and Bright Dip

Pickling or descaling is a technique used to remove oxide scales formed from heat treatment, welding, and hot forming operations prior to surface finishing. On low- and high-carbon steels, the scale is iron oxide, whereas on stainless steels it is composed of oxides of iron, chromium, nickel, and other alloying metals (Spring 1974). The term *pickling* is derived from the early practice of cleaning metal parts by dipping them in vinegar.

Scale and rust are commonly removed from low and medium alloy steels using a nonelectrolytic immersion bath of 5–15% sulfuric acid at a temperature of 60–82 °C (140–180 °F) or a 10–25% hydrochloric acid bath at room temperature. Nitric acid is frequently used in pickling stainless steel, often in conjunction with hydrofluoric, sulfuric, and hydrochloric acids. The most common stainless steel descaling process uses nitric acid in the concentration range of 5–25% in conjunction with hydrochloric acid at 0.5–3%. For light scale removal, the concentrations are 12–15% of nitric acid and 1% of hydrofluoric acid by volume at a bath temperature of 120–140 °F; for heavy oxides, the concentration of hydrofluoric is increased to 2–3%. Pickling operations on nonferrous metals such as aluminum, magnesium, zinc, and lead each have specific recommended acid concentrations.

Acid bright dips are usually mixtures of nitric and sulfuric acids employed to provide a mirrorlike surface on cadmium, magnesium, copper, copper alloys, silver, and, in some cases, stainless steel.

The air contaminants released from pickling and bright dips include not only the mists of the acids used in the process but also nitrogen oxides, if nitric acid is employed, and hydrogen chloride gas from processes using hydrochloric acid. Extensive information is available on the effects of exposure to inorganic acids. Accidental contact with the skin and eyes produces burns, ulcers, and necrosis. For most acids, the acute effects of contact exposure are rapid and detected immediately by the affected individual. However, hydrogen fluoride penetrates the skin, and the onset of symptoms may be delayed for hours, permitting deep tissue burns and severe pain. Airborne acid mists produce upper and lower respiratory irritation. Chronic exposure to nitrogen oxides can produce pulmonary edema. One series of epidemiological studies found excess laryngeal cancer in steel workers who conducted pickling operations using sulfuric and other acids (International Agency for Research on Cancer [IARC] 1992).

An extensive listing of bath components and potential air contaminants for all common pickling and bright dip baths is provided in ACGIH Ventilation Manual (ACGIH 1995). The extent of exposure will depend on bath temperature, surface area of work, current density (if bath is electrolytic), and whether the bath contains inhibitors that produce a foam blanket on the bath or that lower the surface tension of the bath and therefore reduce misting. It is a general rule that local exhaust ventilation is required for pickling and acid dip tanks operating at elevated temperature and for electrolytic processes. Extensive guidelines for local exhaust ventilation of acid dip tanks have been developed (ACGIH 1995; ANSI 1977; Burgess et al. 1989).

Minimum safe practices for pickling and bright dip operators have been proposed by Spring (1974): (i) Hands and faces should be washed before eating, smoking, or leaving plant. Eating and smoking should not be permitted at the work location. (ii) Only authorized employees should be permitted to make additions of chemicals to baths. (iii) Face shields, chemical handlers' goggles, rubber gloves, rubber aprons, and rubber platers' boots should be worn when adding chemicals to baths and when cleaning or repairing tanks. (iv) Chemicals contacting the body should be washed off immediately, and medical assistance obtained. (v) Supervisor should be notified of any change in procedures or unusual occurrences. Because the symptoms of hydrofluoric acid exposure can be delayed and the consequences so severe, any suspected exposure should be reported to a responsible medical authority immediately.

1.3.2 Alkaline Treatment

1.3.2.1 Alkaline Immersion Cleaning Acid and alkaline cleaning techniques are complementary in terms of the cleaning tasks that can be accomplished. Alkaline soak, spray, and electrolytic cleaning systems are superior to acid cleaning for removal of oil, gases, buffing compounds, certain soils, and paint. A range of alkaline cleansers including sodium hydroxide, potassium hydroxide, sodium carbonate, sodium meta- or orthosilicate, trisodium phosphate, borax, and tetrasodium pyrophosphate are used for both soak and electrolytic alkaline cleaning solutions.

The composition of the alkaline bath may be complex, with a number of additives to handle specific tasks (Spring 1974). In nonelectrolytic cleaning of rust from steels, the bath may contain 50–80% caustic soda in addition to chelating

and sequestering agents. The parts are immersed for 10–15 minutes and rinsed with a spray. The usual temperature range for these baths is 160–210°F, and alkaline mist and steam are potential air contaminants. Guidelines for local exhaust ventilation of these baths have been provided (ACGIH 1995).

Electrolytic alkaline cleaning is an aggressive cleaning method. The bath is an electrolytic cell powered by direct current with the workpiece, conventionally the cathode, and an inert electrode as the anode. The water dissociates; oxygen is released at the anode, and hydrogen at the cathode. The hydrogen gas generated at the workpiece causes agitation of the surface soils with excellent soil removal. The gases released at the electrodes by the dissociation of water may result in the release of caustic mist and steam at the surface of the bath.

Surfactants and additives that provide a foam blanket are important to the proper operation of the bath. Ideally, the foam blanket should be 5–8 cm thick to trap the released gas bubbles and therefore minimize misting (NIOSH 1985b). If the foam blanket is too thin, the gas may escape, causing a significant alkaline mist to become airborne; if too thick, the blanket may trap hydrogen and oxygen with resulting minor explosions ignited by sparking electrodes.

1.3.2.2 Salt Baths A bath of molten caustic at 370–540° (700–1000°F) can be used for initial cleaning and descaling of cast iron, copper, aluminum, and nickel with subsequent quenching and acid pickling. The advantages claimed for this type of cleaning are that precleaning is not required and the process provides a good bond surface for a subsequent finish.

Molten sodium hydroxide is used at 430–540°C (800–1000°F) for general-purpose descaling and removal of sand on castings. A reducing process utilizes sodium hydride in the bath at 370°C (700°F) to reduce oxides to their metallic state. The bath utilizes fused liquid anhydrous sodium hydroxide with up to 2% sodium hydride, which is generated in accessory equipment by reacting metallic sodium with hydrogen. All molten baths require subsequent quenching, pickling, and rinsing. The quenching operation dislodges the scale through steam generation and thermal shock.

These baths require well-defined operating procedures owing to the hazard from molten caustic as well as safety hazards from the reaction of metallic sodium with hydrogen. Local exhaust ventilation is necessary, and the tank must be equipped with a complete enclosure to protect the operator from violent splashing as the part is immersed in the bath. Quenching tanks and pickling tanks must also be provided with local exhaust ventilation. Ventilation standards have been proposed for these operations (ACGIH 1995; ANSI 1977).

1.4 DEGREASING

For many decades the principal application of degreasing technology has been in the metalworking industry for the removal of machining oils, grease, drawing oils, chips, and other soils from metal parts. The technology has expanded greatly prompted by advances in both degreasing equipment and solvents. At this time it is probably the most common industrial process extending across all industries, including jewelry, electronics, special optics, electrical, machining, instrumentation, and even rubber and plastic goods. The significant occupational health problems associated with cold and vapor-phase degreasing processes are described below.

1.4.1 Cold Degreasing

The term *cold degreasing* identifies the use of a solvent at room temperature in which parts are dipped, sprayed, brushed, wiped, or agitated for removal of oil and grease. It is the simplest of all degreasing processes, requiring only a simple container with the solvent of choice. It is widely used in small production shops, maintenance and repair shops, and automotive garages. The solvents used have traditionally included low-volatility, high-flash petroleum distillates such as mineral spirits and Stoddard solvent to solvents of high volatility including aromatic hydrocarbons, chlorinated hydrocarbons, and ketones. The choice of degreasing agent has changed significantly since the 1987 Montreal Protocol. The ozone depletion potential (ODP) of a given degreaser has become an important variable in choice.

Skin contact with cold degreasing materials should be avoided by work practices and the use of protective clothing. Glasses and a face shield should be used to protect the eyes and face from accidental splashing during dipping and spraying. Solvent tanks should be provided with a cover, and, if volatile solvents are used, the dip tank and drain station should be provided with ventilation control.

Spraying with high-flash petroleum distillates such as Stoddard solvent, mineral spirits, or kerosene is a widely used method of cleaning oils and grease from metals. This operation should be provided with suitable local exhaust ventilation (ACGIH 1995). The hood may be a conventional spray booth type and may be fitted with a fire door and automatic extinguishers. The fire hazard in spraying a high-flash petroleum solvent is comparable with spraying many lacquers and paints.

1.4.2 Vapor Degreasing

A vapor degreaser is a tank containing a quantity of solvent heated to its boiling point. The solvent vapor rises and fills the tank to an elevation determined by the location of a condenser. The vapor condenses and returns to the liquid sump. The tank has a freeboard that extends above the condenser to minimize air currents inside the tank (Figure 1.1). As the parts are lowered into the hot vapor, the vapor condenses on the cold part and dissolves the surface oils and greases. This oily condensate drops back into the liquid solvent at the base of the tank. The solvent is continuously evaporated to form the vapor blanket. Because the oils are not vaporized, they remain to form a sludge in the bottom of the tank. The scrubbing action of the condensing vapor continues until the temperature of the part reaches the temperature of the vapor, whereupon condensation stops, the part appears dry, and it is removed from the degreaser. The time required to reach this point depends on the particular solvent, the temperature of the vapor, the weight of the part, and its specific heat. The vapor-phase degreaser does an excellent job of drying parts after aqueous cleaning and prior to plating; it is frequently used for this purpose in the jewelry industry.

1.4.2.1 Types of Vapor-Phase Degreasers and Solvents The simplest form of vapor-phase degreaser, shown in Figure 1.1, utilizes only the vapor for cleaning. The straight vapor-cycle degreaser is not effective on small, light work because the part reaches the temperature of the vapor before the condensing action has cleaned the part. Also, the straight vapor cycle does not remove insoluble surface soils. For such applications, the vapor-spray-cycle degreaser is frequently used. The part to be cleaned is first placed in the vapor zone as in the straight vapor-cycle degreaser. A portion of the vapor is condensed by a cooling coil and fills a liquid solvent reservoir. This warm liquid solvent is pumped to a spray lance, which can be used to direct the solvent on the part, washing off surface oils and cooling the part, thereby permitting final cleaning by vapor condensation (Figure 1.2).

A third degreaser design has two compartments, one with warm liquid solvent and a second compartment with a vapor zone. The work sequence is vapor, liquid, and vapor. This degreaser is used for heavily soiled parts with involved geometry or to clean a basket of small parts that nest together. Finally, a three-compartment degreaser has vapor, boiling and warm liquid compartments with a vapor, boiling liquid, warm liquid, and vapor work sequence. Other specialty degreasers encountered in industry include enclosed conveyORIZED units for continuous production cleaning.

Ultrasonic cleaning modules installed in vapor degreasers have found broad application for critical cleaning jobs. In an ultrasonic degreaser, a transducer operating in the range of 20–40kHz is mounted at the base of a liquid immersion solvent tank. The transducer alternately compresses and expands the solvent forming small bubbles that cavitate or collapse at the surface of the workpiece. The cavitation phenomenon disrupts the adhering soils and cleans the part. Ultrasonic degreasers use chlorinated solvents at 32–49°C (90–120°F) and aqueous solutions at 43–71°C (110–160°F). These degreasers commonly employ refrigerated or water-chilled coils for control of solvent vapors; the manufacturers claim that local exhaust ventilation is not needed in this configuration.

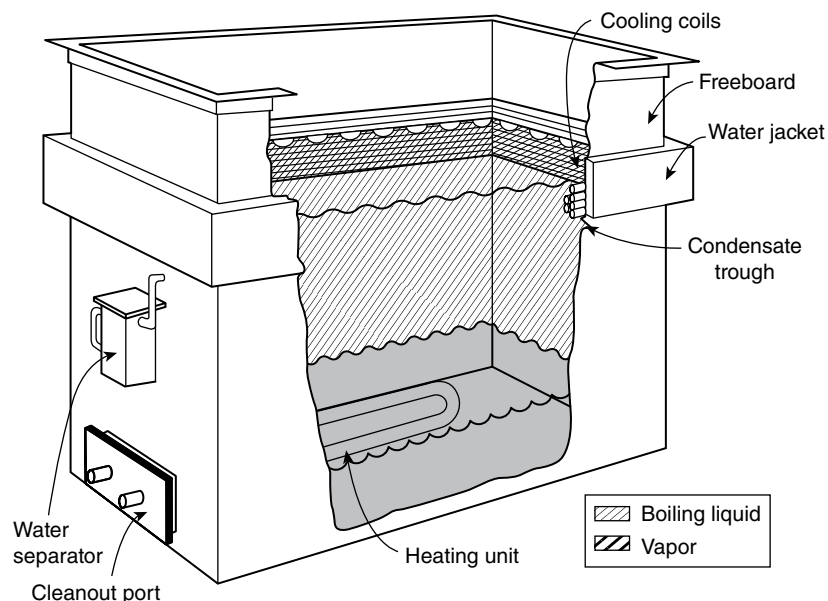


Figure 1.1 Major components of a vapor-phase degreaser.

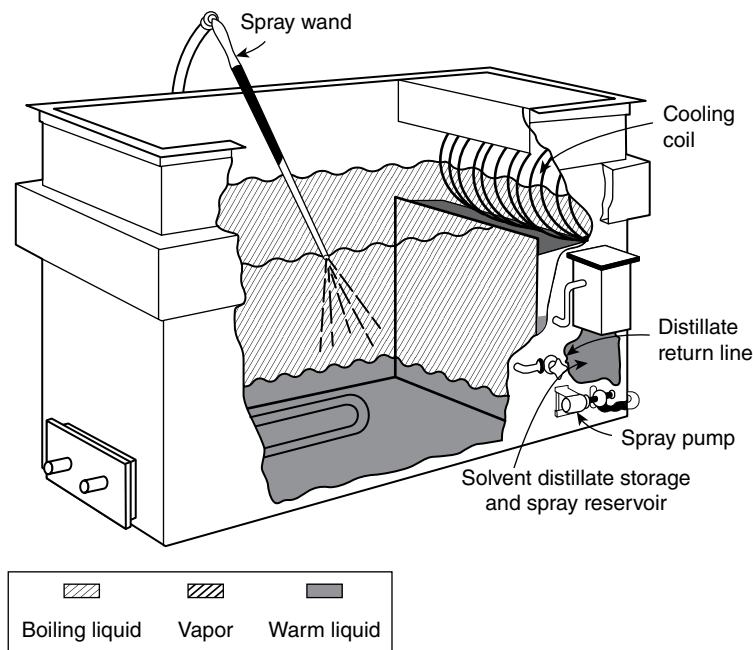


Figure 1.2 A vapor-phase degreaser with a spray wand.

The solvents commonly used with vapor-phase degreasers have traditionally included trichloroethylene, perchloroethylene, 1,1,1-trichloroethane, methylene chloride, and a series of Freon® solvents (Table 1.1) (Dow Chemical Co. 1978; DuPont 1987). The degreaser must be designed for and used with a specific solvent. Most chlorinated degreasing solvents sold under trade names contain a stabilizer present in a concentration of less than 5%. The purpose of the stabilizer is to neutralize any free acid that might result from oxidation of the degreasing liquid in the presence of air, hydrolysis in the presence of water, or pyrolysis under the influence of high temperatures. The stabilizer is not a critical issue in establishing health risk to the worker owing to its low concentration; the solvent itself is usually the predictor of risk.

The emphasis on using non-ozone-depleting chemicals in degreasing operations has greatly influenced the choice of degreasers. The use of 1,1,1-trichloroethane and many of the Freons® has diminished, while trichloroethylene is being used more frequently. The flammability and toxicity of the new generation of materials requires careful review before use. New materials, such as *D*-limonene, have been found to have their own set of issues including dermatitis and low odor thresholds. Semiaqueous processes using terpenes, dibasic esters, *n*-methyl pyrrolidone, and other materials have been used in conjunction with surfactants to provide effective systems. In many cases, nonchemical cleaning substitutes have been chosen, such as bead blasting with plastic pellets or frozen carbon dioxide pellets.

The loss of degreaser solvent to the workplace obviously depends on a number of operating conditions, including the type and properties of contaminants removed, cleaning cycle, volume of material processed, design of parts being cleaned, and, most importantly, work practices. The effort to dry parts quickly with an air hose, for example, will lead to higher exposures. Maintenance and cleaning of degreasers can yield high acute exposures and may require the use of respiratory protection.

1.4.2.2 Control The vapor level in the degreaser is controlled by a nest of water-fed condensing coils located on the inside perimeter of the tank (Figure 1.1). In addition, a water jacket positioned on the outside of the tank keeps the freeboard cool. The vertical distance between the lowest point at which vapors can escape from the degreaser machine and the highest normal vapor level is called the *freeboard*. The freeboard should be at least 15 in. and not less than one-half to three-fifths the width of the machine. The effluent water from the coils and water jacket should be regulated to 32–49°C (90–120°F); a temperature indicator or control is desirable.

Properly designed vapor degreasers have a thermostat located a few inches above the normal vapor level to shut off the source of heat if the vapor rises above the condensing surface. A thermostat is also immersed in the boiling liquid; if overheating occurs, the heat source is turned off.

There is a difference of opinion on the need for local exhaust ventilation on vapor-phase degreasers. Authorities frequently cite the room volume as a guide in determining if ventilation is needed: local exhaust ventilation is needed if there is less than 200 ft³ in the room for each square foot of solvent surface or if the room is smaller than 25 000 ft³. In fact, ventilation control requirements depend on the degreaser design, location, maintenance, and operating practices. Local exhaust increases solvent loss, and the installation may require solvent recovery before discharging to outdoors.

TABLE 1.1 Properties of Vapor Degreasing Solvents

	Trichloroethylene	Perchloroethylene	Methylene chloride	Trichlorotrifluoroethane ^a	Methyl chloroform (1,1,1-trichloroethane)
Boiling point	87	121	40	48	74
°C	188	250	104	118	165
°F					
Flammability		Nonflammable under vapor degreasing conditions			
Latent heat of vaporization (b.p.) Btulb ⁻¹	103	90	142	63	105
Specific gravity					
Vapor (air = 1.00)	4.53	5.72	2.93	6.75	4.60
Liquid (water = 1.00)	1.464	1.623	1.326	1.514	1.327

^a Binary azeotropes are also available with ethyl alcohol, isopropyl alcohol, acetone, and methylene chloride.

To ensure effective use of local exhaust, the units should be installed away from drafts from open windows, spray booths, space heaters, supply air grilles, and fans. Equally important are the parts loading and unloading station. When baskets of small parts are degreased, it is not possible to eliminate drag out completely, and the unloading station usually requires local exhaust.

Later in this chapter under the discussion of welding, reference is made to the decomposition of chlorinated solvent under thermal and UV stress with the formation of chlorine, hydrogen chloride, and phosgene. Because degreasers using such solvents are frequently located near welding operations, this problem warrants attention. In a laboratory study of the decomposition potential of methyl chloride, methylene chloride, carbon tetrachloride, ethylene dichloride, 1,1,1-trichloroethane, *o*-dichlorobenzene, trichloroethylene, and perchloroethylene, only the latter two solvents decomposed in the welding environment to form dangerous levels of phosgene, chlorine, and hydrogen chloride (Dow Chemical Co. 1977). All chlorinated materials thermally degrade if introduced to direct-fired combustion units commonly used in industry. If a highly corroded heater is noted in the degreaser area, it may indicate that toxic and corrosive air contaminants are being generated.

Installation instructions and operating precautions for the use of conventional vapor-phase degreasers have been proposed by various authorities (American Society for Testing and Materials 1989). The following minimum instructions should be observed at all installations:

1. If the unit is equipped with a water condenser, the water should be turned on before the solvent is heated.
2. Water temperature should be maintained between 27 and 43°C (81 and 110°F).
3. Work should not be placed in and removed from the vapor faster than 11 fpm (0.055 m s⁻¹). If a hoist is not available, a support should be positioned to hold the work in the vapor. This minimizes the time the operator must spend in the high exposure zone.
4. The part must be kept in the vapor until it reaches vapor temperature and is visually dry.
5. Parts should be loaded to minimize pullout. For example, cup-shaped parts should be inverted.
6. Overloading should be avoided because it will cause displacement of vapor into the workroom.
7. The work should be sprayed with the lance below the vapor level.
8. Proper heat input must be available to ensure vapor level recovery when large loads are placed in the degreaser.
9. A thermostat should be installed in the boiling solvent to prevent overheating of the solvent.
10. A thermostat vapor level control must be installed above the vapor level inside the degreaser and set for the particular solvent in use.
11. The degreaser tank should be covered when not in use.
12. Hot solvent should not be removed from the degreaser for other degreasing applications, nor should garments be cleaned in the degreaser.
13. An emergency eyewash station would be located near the degreaser for prompt irrigation of the eye in case of an accidental splash.

To ensure efficient and safe operation, vapor-phase degreasers should be cleaned when the contamination level reaches 25%. The solvent should be distilled off until the heating surface or element is 1½ in. below the solvent level

or until the solvent vapors fail to rise to the collecting trough. After cooling, the oil and solvent should be drained off and the sludge removed. It is important that the solvent be cooled prior to draining. In addition to placing the operators at risk, removing hot solvent causes serious air contamination and frequently requires the evacuation of plant personnel from the building. A fire hazard may exist during the cleaning of machines heated by gas or electricity because the flash point of the residual oil may be reached and because trichloroethylene itself is flammable at elevated temperatures. After sludge and solvent removal, the degreaser must be mechanically ventilated before any maintenance work is undertaken. A person should not be permitted to enter a degreaser or place his or her head in one until all controls for entry into a confined space have been put in place. Anyone entering a degreaser should wear a respirator suitable for conditions immediately hazardous to life, as well as a lifeline held by an attendant. Anesthetic concentrations of vapor may be encountered, and oxygen concentrations may be insufficient. Such an atmosphere may cause unconsciousness with little or no warning. Deaths occur each year because of failure to observe these precautions.

The substitution of one degreaser solvent for another as a control technique must be done with caution. Such a decision should not be based solely on the relative exposure standards but must consider the type of toxic effect, the photochemical properties, the physical properties of the solvents including vapor pressure, and other parameters describing occupational and environmental risk.

1.5 ELECTROPLATING

Metal, plastic, and rubber parts are plated to prevent rusting and corrosion, for appearance, to reduce electrical contact resistance, to provide electrical insulation as a base for soldering operations, and to improve wearability. The common plating metals include cadmium, chromium, copper, gold, nickel, silver, and zinc. Prior to electroplating, the parts must be cleaned, and the surfaces treated as described in Sections 1.2 and 1.3.

There are approximately 160,000 electroplating workers in the United States; independent job shops average 10 workers, and the captive electroplating shops have twice that number. A number of epidemiologic studies have identified a series of health effects in electroplaters ranging from dermatitis to elevated mortality for a series of cancers.

1.5.1 Electroplating Techniques

The basic electroplating system is shown in Figure 1.3. The plating tank contains an electrolyte consisting of a metal salt of the metal to be applied dissolved in water. Two electrodes powered by a low-voltage DC power supply are immersed in the electrolyte. The cathode is the workpiece to be plated, and the anode is either an inert electrode or, most frequently, a slab or a basket of spheres of the metal to be deposited. When power is applied, the metal ions deposit out of the bath on the cathode or workpiece. Water is dissociated, releasing hydrogen at the cathode and oxygen at the anode. The anode may be designed to replenish the metallic ion concentration in the bath. Current density expressed in amperes per unit area of workpiece surface varies depending on the operation. In addition to the dissolved salt containing the metallic ion, the plating bath may contain additives to adjust the electrical conductivity of the bath, define the type of plating deposit, and buffer the pH of the bath.

Anodizing, a common surface treatment for decoration, corrosion resistance, and electrical insulation on such metals as magnesium, aluminum, and titanium, operates in a different fashion. The workpiece is the anode, and the cathode is a lead bar. The oxygen formed at the workpiece causes a controlled surface oxidation. The process is conducted in a sulfuric or chromic acid bath with high current density, and because its efficiency is quite low, the amount of misting is high.

In conventional plating operations, individual parts on a hanger or a rack of small parts are manually hung from the cathode bar. If many small pieces are to be plated, the parts may be placed in a perforated plastic barrel in electrical contact with the cathode bar, and the barrel is immersed in the bath. The parts are tumbled to achieve a uniform plating.

In a small job shop operation, the parts are transferred manually from tank to tank as dictated by the type of plating operation. The series of steps necessary in one plating operation (Figure 1.4) illustrates the complexity of the operation. After surface cleaning and preparation, the electroplate steps are completed with a water rinse tank, isolating each tank from contamination. In high production shops, an automatic transfer unit is programmed to cycle the parts from tank to tank, and the worker is required only to load and unload the racks or baskets. Automatic plating operations may permit exhaust hood enclosures on the tanks and therefore more effective control of air contaminants. Exposure is also limited because the worker is stationed at one loading position and is not directly exposed to air contaminants released at the tanks.

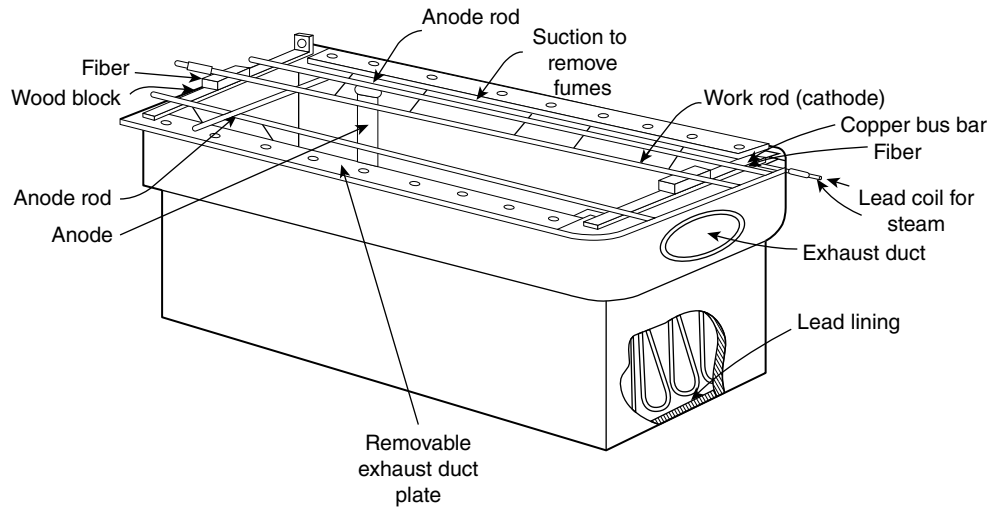


Figure 1.3 An electroplating tank.

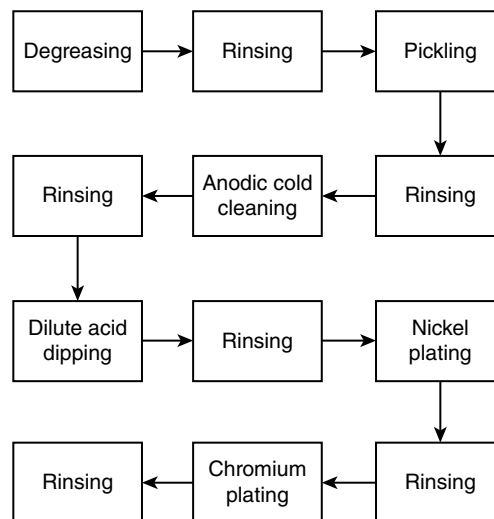


Figure 1.4 The steps involved in chromium plating of steel.

1.5.2 Air Contaminants

The principal source of air contamination in electroplating operations is the release of the bath electrolyte to the air by the gassing of the bath. As mentioned above, the bath operates as an electrolytic cell; so water is dissociated, and hydrogen is released at the cathode and oxygen at the anode. The gases released at the electrodes rise to the surface of the bath and burst, generating a respirable mist that becomes airborne. The mist generation rate depends on the bath efficiency. In copper plating, the efficiency of the plating bath is nearly 100%; that is, essentially all the energy goes into the plating operation and little into the electrolytic dissociation of water (Blair 1972). Nickel plating baths operate at 95% efficiency; so only 5% of the energy is directed to dissociation of water, and misting is minimal. However, chromium plating operations are quite inefficient, and up to 90% of the total energy may be devoted to dissociation of the bath with resulting severe gassing and resulting potential exposure of the operator to chromic acid mist. Although the contamination generation rate of the bath is governed principally by the efficiency of the bath, it also varies with the metallic ion concentration in the bath, the current density, the nature of the bath additives, and bath temperature. Air or mechanical agitation of the bath used to improve plating quality may also release the bath as droplets.

The health significance of the mist generated by electroplating processes depends, of course, on the contents of the bath. The electrolyte mist released from the bath is alkaline or acidic, depending on the specific electroplating process. A majority of the alkaline baths based on cyanide salt solutions are used for cadmium, copper, silver, brass, and bronze plating. Acidic solutions are used for chromium, copper, nickel, and tin. The exact composition of the baths can be obtained from an electroplater's handbook or, if proprietary, from the supplier. An inventory of the nature of the

chemicals in the common electroplating baths, the form in which they are released to the air, and the rate of gassing has evolved over the past several decades, drawing heavily on the experience of the state industrial hygiene programs in New York and Michigan (Burgess et al. 1989). These data are useful in defining the nature of the contaminant and the air sampling procedure necessary to define the worker exposure. As noted below, these data are also valuable in defining the ventilation requirements for various plating operations.

1.5.3 Control

Proprietary bath additives are available to reduce the surface tension of the electrolyte and therefore reduce misting. Another additive provides a thick foam that traps the mist released from the bath. This agent is best used for tanks that operate continuously. A layer of plastic chips, beads, or balls on the surface of the bath also traps the mist and permits it to drain back into the bath. Where possible, tanks should be provided with covers to reduce bath loss.

Although the use of the above mist suppressants is helpful, they will not alone control airborne contaminants from plating tanks at an acceptable level. Local exhaust ventilation in the form of lateral slot or upward plenum slotted hoods is the principal control measure.

The design approach described in the Industrial Ventilation Manual (ACGIH 1995) provides a firm basis for the control of electroplating air contaminants. This procedure permits one to determine a minimum capture velocity based on the hazard potential of the bath and the rate of contaminant generation. The exhaust volume is based on the capture velocity and the tank measurements and geometry. Owing to the severe corrosion of duct work, periodic checks of the exhaust systems in plating shops are necessary. Qualitative assessment of the ventilation is possible using smoke tubes or other tracers. In many cases, the use of partitions to minimize the disruptive effects of drafts may greatly improve the installed ventilation.

In addition to the proper design and installation of good local exhaust ventilation, one must provide adequate replacement air, backflow dampers on any combustion devices to prevent carbon monoxide contamination of the workplace, and suitable air cleaning.

Because a low-voltage DC power supply is used, an electrical hazard does not exist at the plating tanks. A fire and explosion risk may result from solvent degreasing and spray painting conducted in areas contiguous with the plating area. The major chemical safety hazards are due to handling concentrated acids and alkalis and the accidental mixing of acids with cyanides and sulfides during plating, bath preparation, and waste disposal with the formation of hydrogen cyanide and hydrogen sulfide.

The educated use of protective equipment by electroplaters is extremely important in preventing contact with the various sensitizers and corrosive materials encountered in the plating shop. The minimum protective clothing should include rubber gloves, aprons, boots, and chemical handler's goggles. Aprons should come below the top of the boots. All personnel should have a change of clothing available at the workplace. If solutions are splashed on the work clothing, they should be removed, the skin should be washed, and the worker should change to clean garments. A shower and eyewash station serviced with tempered water should be available at the workplace. The wide range of chemicals presents a major dermatitis hazard to the plater, and skin contact must be avoided. Nickel is a skin sensitizer and may cause nickel itch, developing into a rash with skin ulcerations.

A summary of the health hazards encountered in electroplating shops and the available controls is presented in Table 1.2. More information on controls can be found in the references (American Electroplaters and Surface Finishers Society [AESF] 1989; NIOSH 1985a).

1.6 GRINDING, POLISHING, AND BUFFING

These operations are grouped together for discussion because they all involve controlled use of bonded abrasives for metal finishing operations; in many cases, the operations are conducted in the sequence noted. This discussion covers the nonprecision applications of these techniques.

1.6.1 Processes and Materials

Nondimensional application of grinding techniques includes cutoff operations in foundries, rough grinding of forgings and castings, and grinding out major surface imperfections in metal fabrications. Grinding is frequently done with wheels and disks of various geometries made up of selected abrasives in different bonding structural matrices. The common abrasives are aluminum oxide and silicon carbide; less common are diamond and cubic boron nitride. A variety of bonding materials are available to provide mechanical strength and yet release the spent abrasive granules to renew the cutting surface. Vitrified glass is the most common bonding agent. The grinding wheel is made by mixing

TABLE 1.2 Summary of Major Electroplating Health Hazards

Exposure	How contamination occurs
	<i>Inhalation</i>
Mist, gases, and vapors	
Hydrogen cyanide	Accidental mixing of cyanide solutions and acids
Chromic acid	Released as a mist during chrome plating and anodizing
Hydrogen sulfide	Accidental mixing of sulfide solutions and acids
Nitrogen oxides	Released from pickling baths containing nitric acid
Dust	Released during weighing and transferring of solid bath materials, including cyanides and cadmium salts
Fumes	Generated during on-site repair of lead-lined tanks using torch-burning techniques
	<i>Ingestion</i>
Workplace particles	Accidental ingestion during smoking and eating at workplace
	<i>Skin contact</i>
Cyanide compounds	Absorption through the skin
Solvents	Defatting by solvents
Irritants	Primary irritants contacting the skin
Contact allergens	Sensitization
	<i>Control technology</i>
Local exhaust ventilation	
Mist reduction	
Reduce surface tension	
Coat surface	
Tank covers	
Isolation of stored chemicals	

clay and feldspar with the abrasive, pressing it in shape, and firing it at high temperature to form a glass coating to bond for the abrasive grains. Resinoid wheel bonds, based on thermosetting resins such as phenol-formaldehyde, are used for diamond and boron nitride wheels and are reinforced with metal or fiber glass for heavy-duty applications including cutoff wheels. Other bonding agents are sodium silicate and rubber-based agents.

The abrasive industry utilizes a standard labeling nomenclature to identify the grinding wheel design (ANSI 1978) that includes the identification of the abrasive and bonding agent as well as grain size and structure and other useful information. Table 1.3 lists grinding wheel specification nomenclature.

Exact information on the generation rate of grinding wheel debris for various applications is not available. However, the wheel components normally make up a small fraction of the total airborne particles released during grinding; the bulk of airborne particles are released from the workpiece. After use, the grinding wheel may load or plug, and the wheel must be “dressed” with a diamond tool or “crushed dressed” with a steel roller. During this brief period, a significant amount of the wheel is removed, and a small quantity may become airborne.

Polishing techniques are used to remove workpiece surface imperfections such as tool marks. This technique may remove as much as 0.1 mm of stock from the workpiece. The abrasive, again usually aluminum oxide or silicon dioxide, is bonded to the surface of a belt, disk, or wheel structure in a closely governed geometry, and the workpiece is commonly applied to the moving abrasive carrier by hand.

The buffing process differs from grinding and polishing in that little metal is removed from the workpiece. The process merely provides a high luster surface by smearing any surface roughness with a lightweight abrasive. Red rouge (ferric oxide) and green rouge (chromium oxide) are used for soft metals and aluminum oxide is used for harder metals. The abrasive is blended in a grease or wax carrier that is packaged in a bar or tube form. The buffing wheel is made from cotton or wool disks sewn together to form a wheel or “buff.” The abrasive is applied to the perimeter of the wheel, and the workpiece is then pressed against the rotating wheel mounted on a buffing lathe.

1.6.2 Exposures and Control

The hazard potential from grinding, polishing, and buffing operations depends on the specific operation, the workpiece metal and its surface coating, and the type of abrasive system in use. A NIOSH-sponsored study of the ventilation requirements for grinding, polishing, and buffing operations showed that the major source of airborne particles in grinding and polishing is the workpiece, whereas the abrasive and the wheel textile material represent the principal sources of contamination in buffing (NIOSH 1975a).

TABLE 1.3 Grinding Wheel Specification Nomenclature

<i>Abrasives (first letter in specification)</i>	
A	Aluminum oxide
C	Silicon carbide
D or ND	Natural diamonds
SD	Synthetic diamonds
CB or CBN	Cubic boron nitride
<i>Bond (last letter in specification)</i>	
V	Vitrified
B	Resinoid
R	Rubber
S	Silicate

The health status of grinders, polishers, and buffers has not been extensively evaluated. One study did not find elevated cancer mortality in metal polishers (Blair 1980), while two other studies did (Jarvolm et al. 1982; Sparks and Wegman 1980). However, each of the polishing operations studied was unique; so it is difficult to generalize to the industry as a whole. A listing of the metal and alloys worked and information on the nature of the materials released from the abrasive system are needed in order to evaluate the exposure of a particular operator. In many cases, the exposure to total dust can be evaluated by means of personal air sampling with gravimetric analysis. If dusts of toxic metals are released, then specific analysis for these contaminants is necessary.

The need for local exhaust ventilation on grinding operations has been addressed by British authorities (United Kingdom Department of Employment 1974), who state that control is required if one is grinding toxic metals and alloys, ferrous and nonferrous castings produced by sand molding, and metal surfaces coated with toxic material.

The same guidelines can be applied to polishing operations. The ventilation requirements for buffing, however, are based on the large amount of debris released from the wheel, which may be a housekeeping problem and potential fire risk.

The conventional ventilation control techniques for fixed location grinding, polishing, and buffing are well described in the ACGIH (1995) and ANSI (1966) publications. It is more difficult to provide effective ventilation controls for portable grinders used on large castings and forgings. Flexible exterior hoods positioned by the worker may be effective. High-velocity, low-volume exhaust systems with the exhaust integral to the grinder also are suitable for some applications (Fletcher 1988). The performance of the conventional hoods on grinding, polishing, and buffing operations should be checked periodically.

The hazard from bursting wheels operated at high speed and the fire hazard from handling certain metals such as aluminum and magnesium are not covered here, but these problems affect the design of hoods and the design of wet dust collection systems.

The hazard from vibration from hand tools leading to VWF can result from portable grinders and also pedestal mounted wheels. A strategy for the protection of workers from VWF has been developed by NIOSH (1989a) and includes tool redesign, using protective equipment, and monitoring exposure and health.

1.7 HEAT TREATING

A range of heat treating methods for metal alloys is available to improve the strength, impact resistance, hardness, durability, and corrosion resistance of the workpiece (American Society for Metals 1982). In the most common procedures, metals are hardened by heating the workpiece to a high temperature with subsequent rapid cooling. Softening processes normally involve only heating or heating with low cooling.

1.7.1 Surface Hardening

Case hardening, the production of a hard surface or case to the workpiece, is normally accomplished by diffusing carbon or nitrogen into the metal surface to a given depth to achieve the hardening of the alloy. This process may be accomplished in air, in atmospheric furnaces, or in immersion baths by one of the following methods.

1.7.1.1 Carburizing In this process, the workpiece is heated in a gaseous or liquid environment containing high concentrations of a carbon-bearing material, that is, the source of the diffused carbon. In gas carburizing, the parts are heated

in a furnace containing hydrocarbon gases or carbon monoxide; in pack carburizing, the part is covered with carbonaceous material that burns to produce the carbon-bearing gas blanket. In liquid carburizing, the workpiece is immersed in a molten bath, that is, the source of carbon.

In gas carburizing, the furnace atmosphere is supplied by an atmosphere generator. In its simplest form, the generator burns a fuel such as natural gas under controlled conditions to produce the correct concentration of carbon monoxide, which is supplied to the furnace. Because carbon monoxide concentrations up to 40% may be used, small leaks may result in significant workroom exposure. To control emission from gas carburizing operations, the combustion processes should be closely controlled, furnaces maintained in tight condition, dilution ventilation installed to remove fugitive leaks, furnaces provided with flame curtains at doors to control escaping gases, and self-contained breathing apparatus available for escape and repair operations. In liquid carburizing, a molten bath of sodium cyanide and sodium carbonate provides a limited amount of nitrogen and the necessary carbon for surface hardening.

1.7.1.2 Cyaniding The conventional method of liquid carbonitriding is immersion in a cyanide bath with a subsequent quench. The part is commonly held in a sodium cyanide bath at temperatures above 870°C (1600°F) for 30–60 minutes. The air contaminant released from this process is sodium carbonate; cyanide compounds are not released, although there are no citations in the open literature demonstrating this. Local or dilution ventilation is frequently applied to this process. The handling of cyanide salts requires strict precautions including secure and dry storage, isolation from acids, and planned disposal of waste. Care must be taken in handling quench liquids because the cyanide salt residue on the part will in time contaminate the quench liquid.

1.7.1.3 Gas Nitriding Gas nitriding is a common means of achieving hardening by the diffusion of nitrogen into the metal. This process utilizes a furnace atmosphere of ammonia operating at 510–570°C (950–1050°F). The handling of ammonia in this operation is hazardous in terms of fire, explosion, and toxicity.

1.7.2 Annealing

Annealing is a general term used to describe many heating or cooling cycles that change the metallurgical properties of the workpiece. The process varies depending on the alloy and the use of the part, but in all cases it involves heating at a given temperature for a specific time and then cooling at a desired rate, frequently at slow rates. Different types of salt baths may be used, including a blend of potassium nitrate, sodium nitrate, and nitrite for low temperatures or a blend of sodium and potassium chloride and barium nitrite for high-temperature baths. Careful handling and storage procedures must be used for nitrate salts, because of their reactivity and explosivity.

1.7.3 Quenching

The quench baths may be water, oil, molten salt, liquid air, or brine. The potential problems range from a nuisance problem due to release of steam from a water bath to acrolein or other thermal degradation products from oil. Local exhaust ventilation may be necessary on oil quench tanks.

1.7.4 Hazard Potential

The principal problems in heat treating operations are due to the special furnace environments, especially carbon monoxide, and the special hazards from handling bath materials. Although the hazard potential is significant from these operations, few data are available.

The fire and safety hazards of these operations are considerable and have been extensively reviewed (National Fire Protection Association [NFPA] 1991). Salt bath temperature controls must be reliable, and the baths must be equipped with automatic shutdowns. Venting rods need to be inserted in baths before shutdown and reheating to release gases when the bath is again brought up to temperature. If this is not done and gas is occluded in the bath, explosions or blowouts may occur. Parts must be clean and dry before immersion in baths for residual grease, paint, and oil may cause explosions. Where sprinkler systems are used, canopies should be erected above all oil, salt, and metal baths to prevent water from cascading into them. Dilution ventilation for fugitive emissions as well as local exhaust ventilation for baths is often provided, but specific standards have not been developed.

The physical hazards for employees include heat stress from furnace processes and noise from mechanical equipment and combustion air. Personal protective equipment may include goggles, face shields, heavy gloves and gauntlets, reflective clothing, and protective screens. The Wolfson Heat Treatment Centre (WHTC 1981, 1983, 1984) reports provide detailed information on hazards and safe practices.

1.8 METAL MACHINING

The fabrication of metal parts is done with a variety of machine tools, the most common of which are the lathe, drill press, miller, shaper, planer, and surface grinder. The occupational health hazards from these operations are similar; so they are grouped together under conventional machining. Two rapidly expanding techniques, electrochemical and electrical discharge machining (EDM), are also discussed in this section.

1.8.1 Conventional Metal Machining

The major machining operations of turning, milling, and drilling utilize cutting tools that shear metal from the workpiece as either the workpiece or the tool rotates. A thin running coil is formed that normally breaks at the tool to form small chips. Extremes of temperature and pressure occur at the interface between the cutting tool and the work. To cool this point, provide an interface lubricant, and help flush away the chips, a coolant or cutting oil is directed on the cutting tool in a solid stream (flood) or a mist.

The airborne particles generated by these machining operations depend on the type of base metal and cutting tool, the dust-forming characteristics of the metal, the machining technique, and the coolant and the manner in which it is applied. Each of these concerns is addressed briefly in this section.

The type of metal being machined is of course of concern. The metals range from mild steel with no potential health hazard as a result of conventional machining to various high-temperature and stainless alloys incorporating known toxic metals including lead, chromium, nickel, and cobalt, which may present low airborne exposures to toxic metals depending on the machining technique. Finally, highly toxic metals, such as beryllium, do present significant exposures that require vigorous control in any machining operation. Under normal machining operations, excluding dimensional grinding, the airborne dust concentration from conventional metals and alloys is minimal.

A range of specialized alloys has been developed for use in the manufacture of cutting tools. These materials include (i) high-carbon steels with alloying elements of vanadium, chromium, and manganese; (ii) high-speed steels containing manganese and tungsten; (iii) special cobalt steels; (iv) cast alloys of tungsten, chromium, and cobalt; and (v) tungsten carbide. The loss of material from the cutting tool is insignificant during conventional machining, and therefore airborne dust concentrations from the tool do not represent a potential hazard. However, preparing the cutting tools may involve a significant exposure to toxic metal dusts during grinding and sharpening, and such operations should be provided with local exhaust ventilation.

Coolants and cutting fluids are designed to cool and lubricate the point of the cutting tool and flush away chips. These fluids are currently available in the form of (i) soluble (emulsified) cutting oils based on mineral oil emulsified in water with soaps or sulfonates; (ii) straight cutting oils based on a complex mixture of paraffinic, naphthenic, and aromatic mineral oils with the addition of fatty acids; (iii) synthetic oils of varying composition; and a mixture of (i) and (iii). A description of the composition of the three types of cutting fluids including special additives is shown in Table 1.4 (NIOSH 1978).

1.8.1.1 Health Effects Cutting fluids present two potential health problems: extensive skin contact with the cutting fluids and the inhalation of respirable oil mist. It has been estimated that over 400 000 cases of dermatitis occur in the United States each year from contact with coolants and cutting fluids. Soluble oils frequently cause eczematous dermatitis, whereas the straight oils (insoluble) cause folliculitis. One also notes occasional sensitization to coolants.

There continues to be a difference of opinion on the role of bacterial contamination of fluids in dermatitis; however, there is agreement that maintenance of coolants is of hygienic significance. A coolant sampling procedure is now available that permits evaluation of aerobic bacteria, yeasts, and fungi concentration in coolants using simple dip slides.

The application of the cutting fluid to hot, rotating parts releases an oil mist that causes the characteristic smell in the machine shop. The health effects from extended exposure to airborne mists of mineral oil and synthetic coolants are not clear. The association between mineral oil-based fluids and squamous cell carcinoma was observed in the United Kingdom in the 1800s. Unrefined or partially refined mineral oil has been classified as a carcinogen by IARC (1987); one suspected causative agent is the polycyclic aromatic hydrocarbons (PAHs) that are not removed by mild refining techniques. A study conducted in the automotive parts fabrication industry found a twofold increase of larynx cancer for straight oil exposure (Eisen et al. 1994). Other studies have found increased digestive tract and other malignancies (Decoufle 1978; Jarvolm et al. 1982; Vena et al. 1985). The exact agent(s) responsible for the increased cancer rates have not been determined. OSHA has recommended the use of severely refined mineral oils since the mid-1980s in order to minimize PAH exposure. Also the use of synthetic fluids containing both ethanolamines and nitrites has been eliminated. These mixtures have been shown to contain nitrosamines, known animal carcinogens.

TABLE 1.4 Composition of Cutting Fluids

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- I. Mineral oil
 - 1. Base 60–100%, paraffinic or naphthenic
 - 2. Polar additives
 - a. Animal and vegetable oils, fats, and waxes to wet and penetrate the chip/tool interface
 - b. Synthetic boundary lubricants: esters, fatty oils and acids, poly or complex alcohols
 - 3. Extreme pressure lubricants
 - a. Sulfur-free or combined as sulfurized mineral oil or sulfurized fat
 - b. Chlorine, as long-chain chlorinated wax or chlorinated ester
 - c. Combination: sulfo-chlorinated mineral oil or sulfo-chlorinated fatty oil
 - d. Phosphorus, as organic phosphate or metallic phosphate
 - 4. Germicides
 - II. Emulsified oil (soluble oil) – opaque, milky appearance
 - 1. Base: mineral oil, comprising 50–90% of the concentrate; in use the concentrate is diluted with water in ratios of 1:5 to 1:50
 - 2. Emulsifiers: petroleum sulfonates, amine soaps, rosin soaps, naphthenic acids
 - 3. Polar additives: sperm oil, lard oil, and esters
 - 4. Extreme pressure lubricants
 - 5. Corrosion inhibitors: polar organics, e.g. hydroxylamines
 - 6. Germicides
 - 7. Dyes
 - III. Synthetics (transparent)
 - 1. Base: water, comprising 50–80% of the concentrate; in use the concentrate is diluted with water in ratios of 1:10 to 1:200. True synthetics contain no oil. Semisynthetics are available that contain mineral oil present in amounts of 5–25% of the concentrate
 - 2. Corrosion inhibitors
 - a. Inorganics: borates, nitrites, nitrates, phosphates
 - b. Organics: amines, nitrites (amines and nitrites are typical and cheap)
 - 3. Surfactants
 - 4. Lubricants: esters
 - 5. Dyes
 - 6. Germicides
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Source: NIOSH 1978.

Bronchitis and asthma may also be associated with machining fluid exposure; cross-shift changes in pulmonary function were demonstrated by Kennedy et al. (1989).

1.8.1.2 Control An excellent pamphlet on lubricating and coolant oils prepared by Esso outlines procedures to minimize exposure to cutting fluids (Esso Petroleum Company 1979). Selected work practice recommendations are the following: (i) Avoid all unnecessary contact with mineral or synthetic oils. Minimize contact by using splash guards, protective gloves, protective aprons, etc. (ii) Encourage workers to wear clean work clothes, since oil-soaked clothing may hold the oil in contact with the skin longer than would otherwise occur. (iii) Remove oil from the skin as soon as possible if contact does occur; this means the installation of easily accessible wash basins and the provision of mild soap and clean towels in adequate supply. (iv) Do not allow solvents to be used for cleansing the skin. Use only warm water, mild soap, and a soft brush or in combination with a mild proprietary skin cleanser.

In many cases, the machining operations on such metals as magnesium and titanium may generate explosive concentrations of dust. Frequently, these operations must be segregated, and the operations must be conducted with suitable ventilation control and air cleaning. High-density layout of machine tools frequently results in workplace noise exposures above 85 dBA, the level that triggers the OSHA hearing conservation program.

Since the 1950s, exposures to machining fluid particulates in large production facilities has decreased due to the installation of enclosures, local exhaust ventilation, general air cleaning, and probably the increased use of soluble and synthetic fluids (Hallock et al. 1994). Today most high-volume machine tools are designed with complete enclosures and local exhaust ventilation. As of this writing, the PEL for mineral oil remains 5 mg m^{-3} total particulate, but OSHA has announced its plan to reexamine this value.

1.8.2 Electrochemical Machining

The electrochemical machining (ECM) process utilizes a DC electrolytic bath operating at low-voltage and high current density. The workpiece is the anode; and the cutting tool, or cathode, is machined to reflect the geometry of the hole to be cut in the workpiece. As electrolyte is pumped through the space between the tool and the workpiece, metal ions are removed from the workpiece and are swept away by the electrolyte. The tool is fed into the workpiece to complete the cut. The electrolyte varies with the operation; one manufacturer states that the electrolyte is 10% sulfuric acid.

Because the ECM method is fast, produces an excellent surface finish, does not produce burrs, and produces little tool wear, it is widely used for cutting irregular-shaped holes in hard, tough metals.

In the operation, the electrolyte is dissociated and hydrogen is released at the cathode. A dense mist or smoke is released from the electrolyte bath. Local exhaust ventilation must be provided to remove this mist and ensure hydrogen concentrations do not approach the lower flammability limit.

1.8.3 Electrical Discharge Machining

A spark-gap technique is the basis for the EDM procedure, which is a popular machining technique for large precise work such as die sinking or the drilling of small holes in complex parts. In one system, a graphite tool is machined to the precise size and shape of the hole to be cut. The workpiece (anode) and the tool (cathode) are immersed in a dielectric oil bath and powered by a low-voltage DC power supply. The voltage across the gap increases until breakdown occurs, and there is a spark discharge across the gap, which produces a high temperature at the discharge point. This spark erodes a small quantity of the metal from the workpiece. The cycle is repeated at a frequency of 200–500 Hz with rather slow, accurate cutting of the workpiece. In more advanced systems, the cutting element is a wire that is programmed to track the cutting profile. The wire systems can also be used to drill small holes.

The hazards from this process are minimal and are principally associated with the oil. In light cutting jobs, a petroleum distillate such as Stoddard solvent is commonly used, whereas in large work a mineral oil is the dielectric. When heavy oil mists are encountered, local exhaust ventilation is needed. The oil gradually becomes contaminated with small hollow spheres of metal eroded from the part. As in the case of conventional machining, these metals may dissolve in the oil and present a dermatitis problem. An ultrahigh-efficiency filter should be placed in the oil recirculating line to remove metal particles.

1.9 NONDESTRUCTIVE TESTING

With the increase in manufacturing technology in the last decade of the twentieth century, a need has developed for in-plant inspection techniques. The most common procedures now in use in the metalworking industries are discussed in this section.

1.9.1 Industrial Radiography

Radiography is used principally in industry for the examination of metal fabrications such as weldments, castings, and forgings in a variety of settings. Specially designed shielded cabinets may be located in manufacturing areas for in-process examination of parts. Large components may be transported to shielded rooms for examination. Radiography may be performed in open shop areas, on construction sites, on board ships, and along pipelines.

The process of radiography consists of exposing the object to be examined to X-rays or gamma rays from one side and measuring the amount of radiation that emerges from the opposite side. This measurement is usually made with film or a fluoroscopic screen to provide a visual, two-dimensional display of the radiation distribution and any subsurface porosities.

The principal potential hazard in industrial radiography is exposure to ionizing radiation. This section deals with the minimum safety precautions designed to minimize worker exposure to radiation (X-rays and gamma rays) sources.

1.9.1.1 X-Ray Sources X-rays used in industrial radiography are produced electrically and therefore fall into the category of “electronic product radiation.” For this reason the design and manufacture of industrial X-ray generators are regulated by the Food and Drug Administration, Center for Devices and Radiological Health. ANSI has developed a standard for the design and manufacture of these devices (ANSI 1976). These standards specify maximum allowable radiation intensities outside the useful beam. They require warning lights on both the control panel and the tube head to indicate when X-rays are being generated.