Pharmaceutical unit operations

Weighing and dispensing

Weighing and dispensing of solids and liquids is a very common activity throughout the pharmaceutical industry. Usually workers dispense materials by hand-scooping solids and pouring or pumping liquids. Weighing and dispensing are often performed in a warehouse during bulk chemical production or in a pharmacy during pharmaceutical dosage-form manufacturing. Due to the likelihood of spills, leaks and fugitive emissions during weighing and dispensing, proper workplace control measures are necessary to protect workers. Weighing and dispensing should be performed in a partitioned workplace area with good dilution ventilation. The work surfaces in areas where materials are weighed and dispensed should be smooth and sealed, permitting their proper cleaning. LEV with backdraft or sidedraft hoods prevents the release of air contaminants when weighing and dispensing dusty solids or volatile liquids. Weighing and dispensing highly toxic materials may require additional control measures such as laminar ventilation hoods or isolation devices (e.g., glove boxes or glove bags).

Charging and discharging solids and liquids

Solids and liquids are frequently charged and discharged from containers and process equipment in pharmaceutical manufacturing operations. Charging and discharging of materials are often performed manually by workers; however, other methods are employed (e.g., gravity, mechanical or pneumatic transfer systems). Contained process equipment, transfer systems and engineering controls prevent worker exposures during charging and discharging of highly hazardous materials. Gravity charging from enclosed containers and vacuum, pressure and pumping systems eliminate fugitive emissions during charging and discharging operations. LEV with flanged inlets captures fugitive dusts and vapours which are released at open transfer points.

Liquid separations

Liquids are separated based upon their physical properties (e.g., density, solubility and miscibility). Liquid separations are commonly performed during bulk chemical production and pharmaceutical manufacturing operations. Hazardous liquids should be transferred, processed and separated in closed vessels and piping systems to reduce worker exposures to liquid spills and airborne

vapours. Eyewashes and safety showers should be located near operations where hazardous liquids are transferred, processed or separated. Spill control measures and fire and explosion prevention and protection are needed when using flammable liquids.

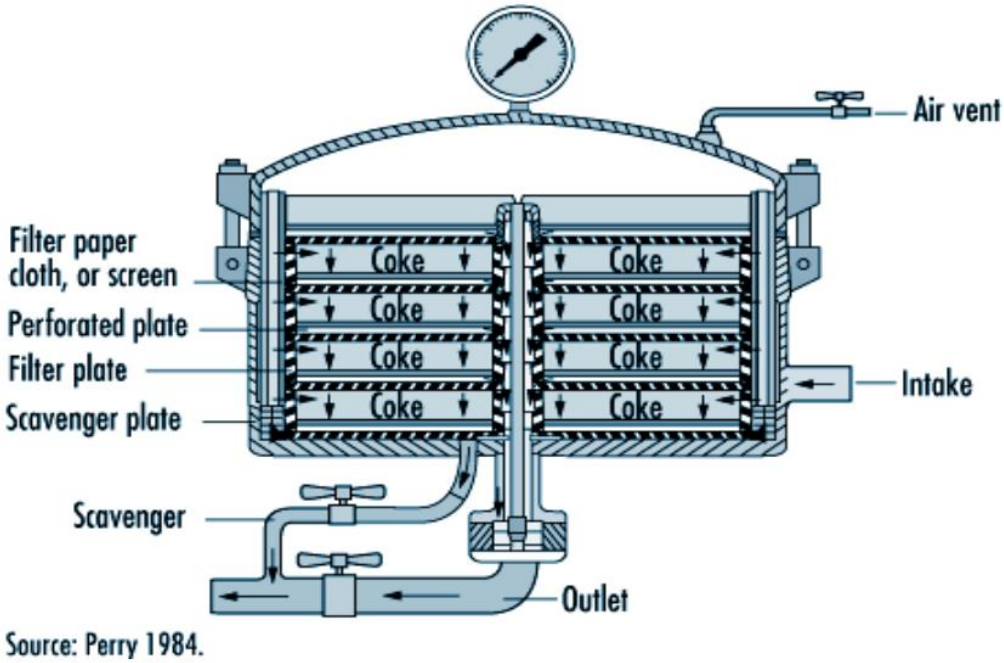
Transferring liquids

Liquids are often transferred between storage vessels, containers and process equipment during pharmaceutical manufacturing operations. Ideally, facility and manufacturing processes are designed to minimize the need for transferring hazardous materials, thereby decreasing the chance of spills and worker exposures. Liquids may be transferred between process vessels and equipment through manifold stations, areas where many pipe flanges are located close together. This allows temporary connections to be made between piping systems. Spills, leaks and vapour emissions may occur at manifold stations; therefore proper gaskets and tight seals on hoses and pipes are needed to prevent environmental pollution and workplace releases. Drainage systems with sealed tanks or sumps capture spilled liquids so they can be reclaimed and recovered. Sealed vessels and containers and piping systems are highly desirable when transferring large volumes of liquids. Special precautions should be taken when using inert gases to pressurize transfer lines or process equipment, since this may increase the release of volatile organic compounds (VOCs) and hazardous air pollutants. Recirculation or condensation of exhaust gases and vapours reduces air pollution.

Filtration

Solids and liquids are separated during filtration operations. Filters have different designs and features with varying containment and control of liquids and vapours. When open filters are used for hazardous materials, workers may be exposed to liquids, wet solids, vapours and aerosols during loading and unloading operations. Closed process equipment can be used to filter highly hazardous materials, reducing vapour emissions and preventing worker exposures (see figure:9). Filtration should be performed in areas with spill control and good dilution and LEV. Volatile solvent vapours can be exhausted through vents on sealed process equipment and controlled by air emissions devices (e.g., condensers, scrubbers and adsorbers).

Figure :9 A sparkler filter



Compounding

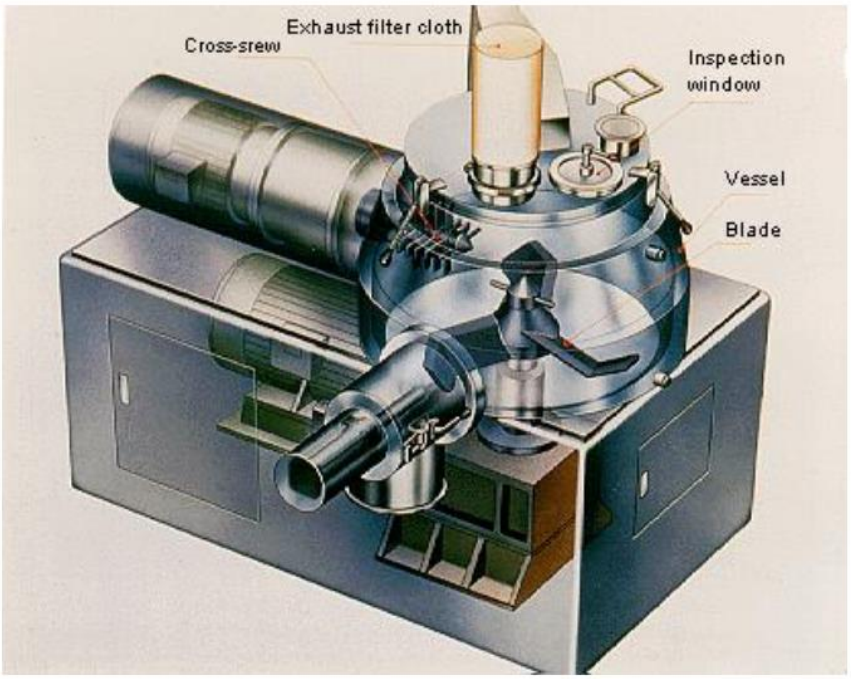
Solids and liquids are mixed in compounding operations to produce solutions, suspensions, syrups, ointments and pastes. Contained process equipment and transfer systems are recommended when compounding highly hazardous materials (Kroschwitz 1992; Perry 1984). Buffering agents, detergents and germicides that are neutralizing, cleaning and biocidal agents may be hazardous to workers. Eyewashes and safety showers reduce injuries, if workers accidentally contact corrosive or irritating substances. Due to the wet surfaces in compounding areas, workers need to be protected from electrical hazards of equipment and utilities. Thermal hazards are posed by steam and hot water during compounding and cleaning activities. Worker injuries from burns and falls are prevented by installing insulation on hot surfaces and maintaining dry non-slip floors.

Granulation

Dry and wet solids are granulated to change their physical properties. Granulators have different designs and features with varying containment and control of mechanical hazards and airborne dusts and vapours (Perry 1984; Swarbick and Boylan 1996). Enclosed granulators can be vented to air-control devices, reducing emissions of solvent vapours or dusts to the workplace and

atmosphere (see figure :10). Material-handling concerns arise when loading and unloading granulators. Mechanical equipment (e.g., elevated platforms, lift tables and pallet jacks) assists workers to perform heavy manual tasks. Eyewashes and safety showers are needed, if workers accidentally contact solvents or irritating dusts.

Figure :10 A high steam granulator

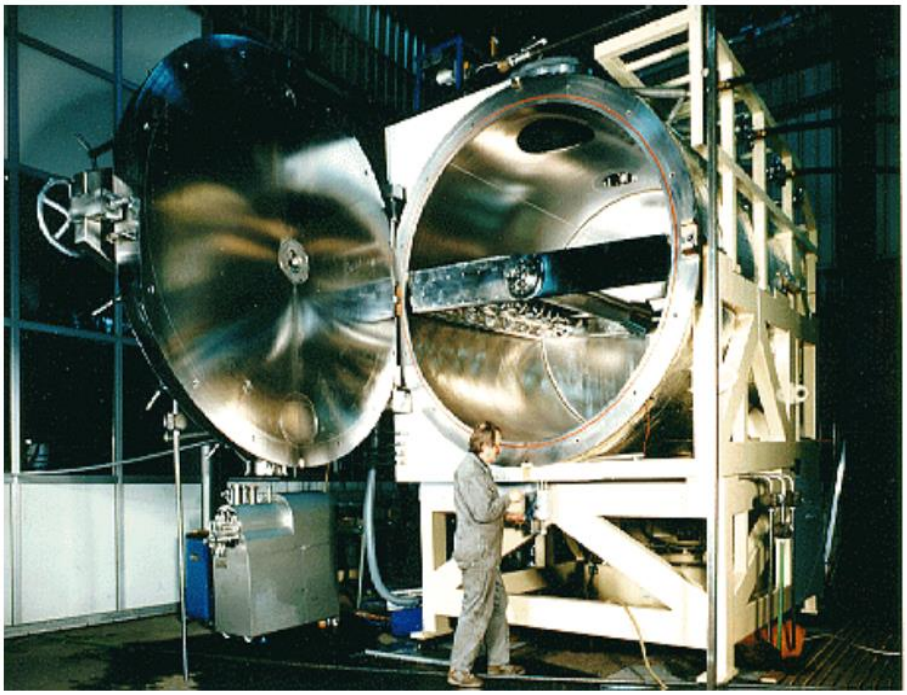


Drying

Water- or solvent-wet solids are dried during many pharmaceutical manufacturing operations. Dryers have different designs and features with varying containment and control of vapours and dusts (see figure :11). Flammable solvent vapours and explosive airborne dusts may create flammable or explosive atmosphere; explosion relief venting is particularly important on contained dryers. Dilution and LEV reduces the risk of fire or explosion, in addition to controlling worker exposures to solvent vapours when handling wet cakes, or to airborne dusts when unloading dried products. Heavy material handling may be involved when loading or unloading dryer trays, bins or containers (see figure :12).

Mechanical equipment (e.g., drum jacks, lifts and work platforms) assists these manual tasks. Eyewashes and safety showers should be located nearby, in case workers accidentally contact solvents and dusts.

Figure :11 A rotary vacuum dryer



Glatt Air Techniques, Inc.

Figure :12 A vacuum shelf dryer

Source: EPA 1993

Milling

Dry solids are milled to change their particle characteristics and produce free-flowing powders. Mills have different designs and features with varying containment and control of mechanical hazards and airborne dusts. Prior to milling materials, their physical properties and hazards should be reviewed or tested. Explosion prevention and protection measures involve installing dust-tight electrical equipment and utilities, grounding and bonding equipment and accessories to eliminate electrostatic sparking, installing safety relief valves on enclosed mills, and constructing blast relief panels in walls. These measures may be necessary due to the explosivity of some drug substances and excipients, high dust levels and energies associated with milling operations.

Blending

Dry solids are blended to produce homogeneous mixtures. Blenders have different designs and features with varying containment and control of mechanical hazards and airborne dusts. Worker exposures to drug substances, excipients and blends may occur when loading and unloading blending equipment. LEV with flanged inlets reduces fugitive dust emissions during blending. Heavy material handling may be required when charging and discharging solids from blenders. Mechanical equipment (e.g., work platforms, hoists and drum and pallet jacks) reduces the physical demands of heavy material handling.

Compression

Dry solids are compressed or slugged to compact them, changing their particle properties. Compression equipment has different designs and features with varying containment and control of mechanical hazards and airborne dusts. Compression equipment may pose serious mechanical hazards if inadequately guarded. High noise levels may also be produced by compression and slugging operations. Enclosing impact sources, isolating vibrating equipment, rotating workers and using hearing-protective devices (e.g., ear muffs and plugs) reduce the impact of noise exposures.

Solid dosage-form manufacturing

Tablets and capsules are the most common oral dosage forms. Compressed or moulded tablets contain mixtures of drug substances and excipients. These tablets may be uncoated or coated with solvent mixtures or aqueous solutions. Capsules are soft or hard gelatin shells. Tablet presses (see figure :13), tablet-coating equipment and capsule-filling machines have different designs and features with varying containment and control of mechanical hazards and airborne dusts (Cole 1990). Workers may be exposed to solvent vapours when spray-coating tablets. Modern tablet-coating equipment is highly contained; however, LEV can be installed in older open coating pans to control

fugitive solvent vapours. Tablet-coating equipment can be vented to air emission devices to control VOCs from the process (see figure :14). Whenever possible, recovered solvents should be reused by the process or aqueous mixtures substituted for solvent mixtures for tablet coating. Modern tablet presses and capsule-filling machines are enclosed by interlocked panels, reducing the hazards of fast-moving parts, high noise levels and dust emissions during their operation. Hearing-protective devices can reduce worker noise exposures during tablet and capsule operations.

Figure :13 Tablet press with load hopper and spiral dust pickups for product recovery

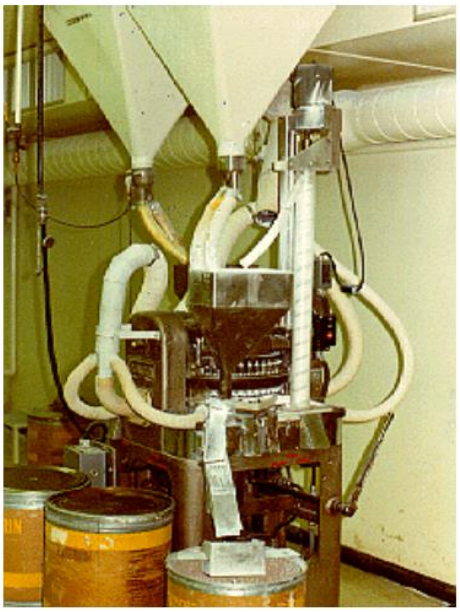
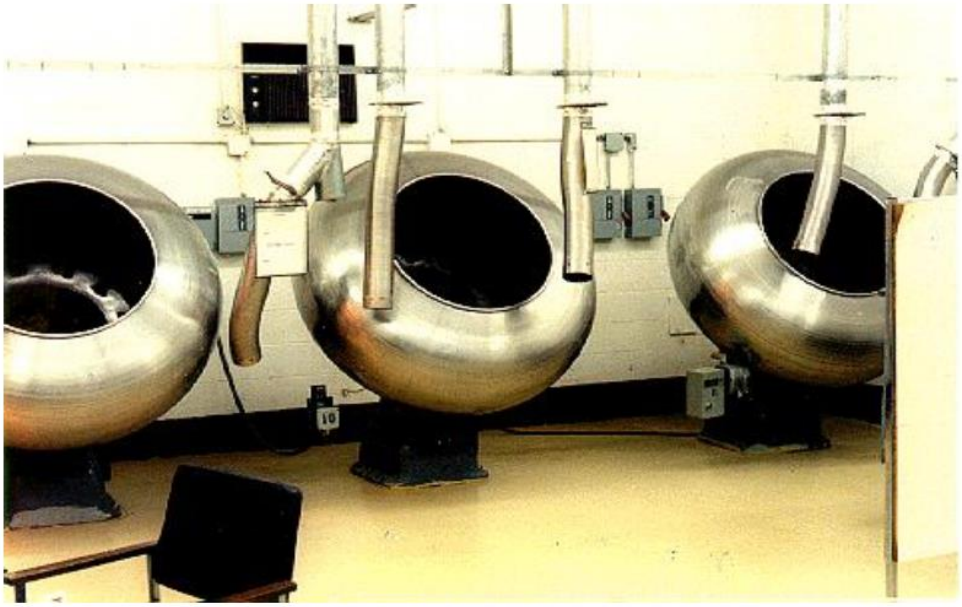


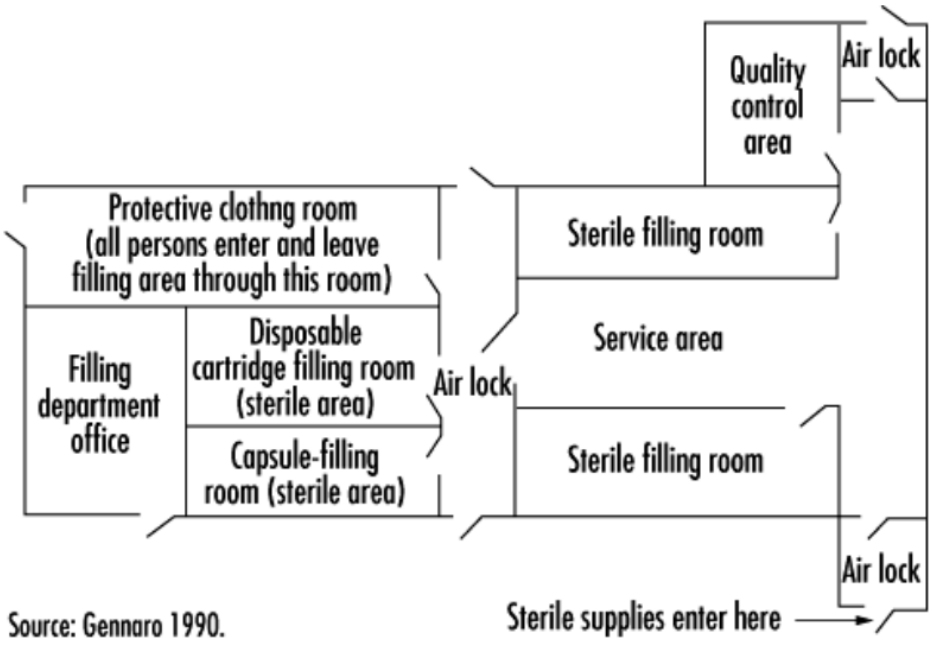
Figure :14 A tablet coating machine



Sterile manufacturing

Sterile products are manufactured in pharmaceutical manufacturing plants with modular design (see figure :15), clean workplace and equipment surfaces, and high efficiency particulate air (HEPA) filtered ventilation systems. The principles and practices of controlling contamination in sterile liquid manufacturing are similar to those in the microelectronics industry. Workers wear protective clothing to prevent them from contaminating products during sterile manufacturing operations. Sterile pharmaceutical technologies to control contamination involve freeze-drying products, using liquid germicides and sterilizing gases, installing laminar flow ventilation, isolating modules with differential air pressures and containing manufacturing and filling equipment.

Figure :15 Diagram of a sterile liquid manufacturing facility



Source: Gennaro 1990.

Chemical hazards are posed by toxic germicides (e.g., formaldehyde and glutaraldehyde) and sterilizing gases (i.e., ethylene oxide). Whenever possible, less hazardous agents should be selected (e.g., alcohols, ammonium compounds). Sterilization of raw materials and equipment may be performed by high-pressure steam or toxic gases (i.e., diluted ethylene oxide gas mixtures) (Swarbick and Boylan 1996). Sterilization vessels can be located in separate areas with remote instrument and control systems, non-recirculated air and LEV to extract toxic gas emissions. Workers should be trained on standard operating instructions, safe work practices and appropriate emergency response. Gas sterilization chambers should be fully evacuated under vacuum and purged with air to minimize fugitive workplace emissions before sterilized goods are removed. Gas emissions from sterilization chambers can be vented to air control devices (e.g., carbon adsorption or catalytic converters) to

reduce atmospheric emissions. Occupational hygiene monitoring measures worker exposures to chemical germicides and sterilizing gases, helping to assess the adequacy of control measures. Safety hazards involve high-pressure steam and hot water, moving machine parts in washing, filling, capping and packaging equipment, high noise levels and repetitive manual tasks.

Cleaning and maintenance activities

Non-routine tasks may occur when cleaning, repairing and maintaining equipment, utilities and workplaces. Although unique hazards may arise during non-routine tasks, recurring health and safety concerns are encountered. Workplace and equipment surfaces may be contaminated by hazardous materials and drug substances, requiring them to be cleaned before unprotected workers conduct servicing or maintenance work. Cleaning is performed by washing or wiping liquids and sweeping or vacuuming dusts. Dry sweeping and blowing solids with compressed air are not recommended, since they create high worker exposures to airborne dusts. Wet mopping and vacuuming reduce worker exposures to dusts during cleaning activities. Vacuum cleaners with HEPA filters may be needed when cleaning hazardous substances and high-potency drugs. Explosion-proof equipment and conductive materials may be required in vacuum systems for explosive dusts. Eyewashes and safety showers and PPE reduce the effect of workers' accidental contact with corrosive and irritating detergents and cleaning liquids.

Hazardous mechanical, electrical, pneumatic or thermal energy may need to be released or controlled before equipment and utilities are serviced, repaired or maintained. Contract workers may perform special production or engineering tasks in pharmaceutical plants without adequate training on safety precautions. Careful supervision of contract workers is important, so they do not violate safety rules or perform work that creates a fire, explosion or other serious health and safety hazards. Special contractor safety programmes are required when working with highly hazardous materials (e.g., toxic, reactive, flammable or explosive) and processes (e.g., exothermic or high pressure) in bulk pharmaceutical and dosage-form manufacturing facilities.

Packaging

Pharmaceutical packaging operations are performed with a series of integrated machines and repetitive manual tasks (Gennaro 1990; Swarbick and Boylan 1996). Finished dosage-form products may be packaged in many different types of containers (e.g., plastic or glass bottles, foil blister packs, pouches or sachets, tubes and sterile vials). The mechanical equipment fills, caps, labels, cartons and packs the finished products in shipping containers. Worker proximity to packaging equipment necessitates barrier guarding on moving machine parts, accessible control switches and emergency

stop cables and employee training on machine hazards and safe work practices. Enclosure and isolation of equipment reduces sound and vibration levels in packaging areas. Use of hearing-protective devices (e.g., ear muffs and plugs) reduces worker exposures to noise. Good industrial design promotes the productivity, comfort and safety of employees, by addressing ergonomic hazards from poor body postures, material handling and highly repetitive tasks.

Laboratory operations

Laboratory operations in the pharmaceutical industry are diverse. They may pose biological, chemical and physical hazards, depending upon the specific agents, operations, equipment and work practices employed. Major distinctions exist between labs which conduct scientific research and product and process development and those which evaluate quality assurance and control activities (Swarbick and Boylan 1996). Lab workers may conduct scientific research to discover drug substances, develop manufacturing processes for bulk chemical and dosage-form products or analyze raw materials, intermediates and finished products. Lab activities should be evaluated individually, although good lab practices apply to many situations (National Research Council 1981). Clearly defined responsibilities, training and information, safe work practices and control measures and emergency response plans are important means for effectively managing environmental, health and safety hazards.

The health and safety hazards of flammable and toxic materials are reduced by minimizing their inventories in labs and storing them in separate cabinets. Lab assays and operations which may release air contaminants can be performed in ventilated exhaust fume hoods to protect workers. Biological safety hoods provide downward and inward laminar flow, preventing the release of micro-organisms (Gennaro 1990; Swarbick and Boylan 1996). Worker training and information describes the hazards of lab work, safe work practices and proper emergency response to fires and spills. Food and beverages should not be consumed in lab areas. Lab safety is enhanced by requiring supervisors to approve and manage highly hazardous operations. Good lab practices separate, treat and dispose of biological and chemical wastes. Physical hazards (e.g., radiation and electromagnetic energy sources) are often certified and operated, according to specific regulations.

General Health and Safety Hazards

Ergonomics and material handling

The materials shipped, stored, handled, processed and packaged in the pharmaceutical industry range from large quantities of raw materials to small packages containing pharmaceutical products. Raw materials for bulk chemical production are shipped in bulk containers (e.g., tank trucks, rail cars),

metal and fibre drums, reinforced paper and plastic bags. Pharmaceutical production uses smaller quantities of raw materials due to the reduced scale of the operations. Material-handling devices (e.g., fork-lift trucks, pallet lifts, vacuum hoists and drum jacks) assist material handling during warehousing and production operations. Heavy manual work may create ergonomic risks when moving materials and equipment if mechanical devices are not available. Good industrial engineering and facility management practices reduce injuries from material handling by improving the design and features of equipment and the workplace and decreasing the size and weight of containers (Cole 1990). Engineering control measures (e.g., ergonomic design of tools, materials and equipment) and administrative practices (e.g., rotating workers, providing worker training) reduce the risks of cumulative trauma injuries during highly repetitive production and packaging operations.

Machine guarding and control of hazardous energy

Unguarded moving machine parts in pharmaceutical manufacturing and packaging equipment create mechanical hazards. Exposed "crush and nip points" in open equipment may seriously injure workers. Mechanical hazards are exacerbated by the large numbers and different designs of equipment, crowded workplace conditions and frequent interactions between workers and equipment. Interlocked guards, control switches, emergency stop devices and operator training are important means of reducing mechanical hazards. Loose hair, long-sleeved clothing, jewellery or other objects may become trapped in equipment. Routine inspection and repair activities identify and control mechanical hazards during production and packaging operations. Hazardous electrical, pneumatic and thermal energy must be released or controlled before working on active equipment and utilities. Workers are protected from sources of hazardous energy by implementing lockout/tagout procedures.

Noise exposures

High sound levels may be generated by manufacturing equipment and utilities (e.g., compressed air, vacuum sources and ventilation systems). Due to the enclosed design of pharmaceutical workplace modules, workers are often located close to machines during manufacturing and packaging operations. Workers observe and interact with production and packaging equipment, thereby increasing their exposure to noise. Engineering methods reduce sound levels by modifying, enclosing and dampening noise sources. Employee rotation and use of hearing-protective devices (e.g., ear muffs and plugs) reduce workers' exposure to high noise levels. Comprehensive hearing conservation programmes identify noise sources, reduce workplace sound levels, and train workers on the hazards of noise exposure and proper use of hearing-protective devices. Noise monitoring and medical surveillance (i.e., audiometry) assess worker exposures to noise and their resulting loss of hearing. This helps to identify noise problems and evaluate the adequacy of corrective measures.

Solvent vapour and potent compound exposures

Special concerns may arise when workers are exposed to toxic solvent vapours and potent drugs as airborne dusts. Worker exposures to solvent vapours and potent compounds may occur during various manufacturing operations, which need to be identified, evaluated and controlled to ensure that workers are protected. Engineering controls are the preferred means of controlling these exposures, due to their inherent effectiveness and reliability (Cole 1990; Naumann et al. 1996). Enclosed process equipment and material handling systems prevent worker exposures, while LEV and PPE supplement these measures. Increased facility and process containment is needed for controlling highly toxic solvents (e.g., benzene, chlorinated hydrocarbons, ketones) and potent compounds. Positive-pressure respirators (e.g., powered-air purifying and supplied-air) and PPE are needed when highly toxic solvents and potent compounds are handled and processed. Special concerns are posed by operations where high levels of solvent vapours (e.g., compounding, granulating and tablet coating) and dusts (e.g., drying, milling and blending) are generated. Locker and shower rooms, decontamination practices and good sanitary practices (e.g., washing and showering) are necessary to prevent or minimize the effects of worker exposures inside and outside the workplace.

Process safety management

Process safety programmes are implemented in the pharmaceutical industry due to the complex chemistry, hazardous materials and operations in bulk chemical manufacturing (Crowl and Louvar 1990). Highly hazardous materials and processes may be employed in multi-step organic synthesis reactions to produce the desired drug substance. The thermodynamics and kinetics of these chemical reactions must be evaluated, since they may involve highly toxic and reactive materials, lachrymators and flammable or explosive compounds.

Process safety management involves conducting physical hazard testing of materials and reactions, performing hazard analysis studies to review the process chemistry and engineering practices, examining preventive maintenance and mechanical integrity of the process equipment and utilities, implementing worker training and developing operating instructions and emergency response procedures. Special engineering features for process safety include selecting proper pressure-rated vessels, installing isolation and suppression systems, and providing pressure relief venting with catch tanks. Process safety management practices are similar in the pharmaceutical and chemical industries when manufacturing bulk pharmaceuticals as speciality organic chemicals (Crowl and Louvar 1990; Kroschwitz 1992).

Environmental Issues

The different pharmaceutical manufacturing processes each have their own environmental issues, as discussed below.

Fermentation

Fermentation generates large volumes of solid waste which contains mycelia and spent filter cakes (EPA 1995; Theodore and McGuinn 1992). Filter cakes contain mycelia, filter media and small amounts of nutrients, intermediates and residual products. These solid wastes are typically non-hazardous, yet they may contain solvents and small amounts of residual chemicals depending upon the specific chemistry of the fermentation process. Environmental problems may develop if fermentation batches become infected with a viral phage which attacks the micro-organisms in the fermentation process. Although phage infections are rare, they create a significant environmental problem by generating large amounts of waste broth.

Spent fermentation broth contains sugars, starches, proteins, nitrogen, phosphates and other nutrients with high biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS) with pH values ranging from 4 to 8. Fermentation broths can be treated by microbiological wastewater systems, after the effluent is equalized to promote the stable operation of the treatment system. Steam and small amounts of industrial chemicals (e.g., phenols, detergents and disinfectants) maintain the sterility of the equipment and products during fermentation. Large volumes of moist air are exhausted from fermentors, containing carbon dioxide and odours which may be treated before they are emitted to the atmosphere.

Organic synthesis

Wastes from chemical synthesis are complex due to the variety of hazardous materials, reactions and unit operations (Kroschwitz 1992; Theodore and McGuinn 1992). Organic synthesis processes may generate acids, bases, aqueous or solvent liquors, cyanides and metal wastes in liquid or slurry form. Solid wastes may include filter cakes containing inorganic salts, organic by-products and metal complexes. Waste solvents in organic synthesis are usually recovered by distillation and extraction. This allows the solvents to be reused by other processes and reduces the volume of liquid hazardous wastes to be disposed of. Residues from distillation (still bottoms) need to be treated before they are disposed. Typical treatment systems include steam stripping to remove solvents, followed by microbiological treatment of other organic substances. Volatile organic and hazardous substance emissions during organic synthesis operations should be controlled by air pollution control devices (e.g., condensers, scrubbers, venturiimpingers).

Waste water from synthesis operations may contain aqueous liquors, wash water, discharges from pumps, scrubbers and cooling systems, and fugitive leaks and spills (EPA 1995). This waste water may contain many organic and inorganic substances with different chemical compositions, toxicities and biodegradabilities. Trace amounts of raw materials, solvents and by-products may be present in aqueous mother liquors from crystallizations and wash layers from extractions and equipment cleaning. These waste waters are high in BOD, COD and TSS, with varying acidity or alkalinity and pH values ranging from 1 to 11.

Biological and natural extraction

Spent raw materials and solvents, wash water and spills are the primary sources of solid and liquid wastes (Theodore and McGuinn 1992). Organic and inorganic chemicals may be present as residues in these waste streams. Usually, waste waters have low BOD, COD and TSS, with relatively neutral pH values ranging from 6 to 8.

Pharmaceutical manufacturing of dosage forms

Pharmaceutical manufacturing of dosage-form products generates solid and liquid wastes during cleaning and sterilization, and from leaks and spills and rejected products (Theodore and McGuinn 1992). Drying, milling and blending operations generate atmospheric and fugitive dust emissions. These emissions can be controlled and recycled to the manufacturing of dosage form products; however, quality control practices may prevent this if other residues are present. When solvents are used during wet granulation, compounding and tablet coating, VOCs and hazardous air pollutants may be released to the atmosphere or in the workplace as process or fugitive emissions. Waste waters may contain inorganic salts, sugars, syrups and traces of drug substances. These waste waters usually have low BOD, COD and TSS, with neutral pH values. Some antiparasitic or anti-infective drugs for humans and animals may be toxic to aquatic organisms, requiring special treatment of liquid wastes.

Environmental pollution prevention

Waste minimization and pollution prevention

Good engineering and administrative practices minimize the environmental impact of bulk chemical production and pharmaceutical manufacturing operations. Pollution prevention employs modifying processes and equipment, recycling and recovering materials and maintaining good housekeeping and operating practices (Theodore and McGuinn 1992). These activities enhance the management of environmental issues, as well as worker health and safety.

Process modifications

Processes may be modified to reformulate products by using materials that are less hazardous or persistent or changing manufacturing operations to reduce air emissions, liquid effluents and solid wastes. Reducing the amount and toxicity of wastes is wise, since it improves the efficiency of manufacturing processes and reduces the costs and impacts of waste disposal. Government drug approval regulations may limit the ability of pharmaceutical manufacturers to change hazardous materials, manufacturing processes, equipment and facilities (Spilker 1994). Drug manufacturers must anticipate the environmental, health and safety impacts of selecting hazardous materials and designing manufacturing process at an early stage. It becomes increasingly difficult to make changes during the later stages of drug development and regulatory approval, without considerable loss of time and expense.

It is very desirable to develop manufacturing processes with less hazardous solvents. Ethyl acetate, alcohols and acetone are preferable to highly toxic solvents such as benzene, chloroform and trichloroethylene. Whenever possible, some materials should be avoided due to their physical properties, ecotoxicity or persistence in the environment (e.g., heavy metals, methylene chloride) (Crowl and Louvar 1990). Substituting aqueous washes for solvents during filtrations in bulk chemical production reduces liquid wastes and vapour emissions. Also, substituting aqueous for solvent-based solutions during tablet coating reduces environmental, health and safety concerns. Pollution prevention is promoted by improving and automating process equipment, as well as performing routine calibration, servicing and preventive maintenance. Optimizing organic synthesis reactions increases product yields, often decreasing the generation of wastes. Incorrect or inefficient temperature, pressure and material control systems cause inefficient chemical reactions, creating additional gaseous, liquid and solid wastes.

The following are examples of process modifications in bulk pharmaceutical production (Theodore and McGuinn 1992):

· Minimize the quantities of hazardous materials used and select materials whose wastes can be controlled, recovered and recycled, whenever possible.

· Develop and install systems for recycling raw materials (e.g., solvents), intermediates, wastes and utility materials (e.g., cooling water, heat transfer liquids, lubricants, steam condensate).

· Examine reactants, solvents and catalysts to optimize the efficiency of chemical reactions.

· Modify the design and features of processing equipment to minimize pollution and wastes.

· Improve processes to maximize product yields and desired properties, eliminating additional processing (e.g., re-crystallization, drying and milling).

· Consider using multi-purpose equipment (e.g., reactors, filters and dryers) to reduce pollution and wastes during transfers, cleaning and additional process steps.

· Use appropriate instruments, automated control systems and computer programs to maximize the efficiency of processes and reduce pollution and wastes.

Resource recovery and recycling

Resource recovery uses waste products and reclaims materials during processing by separating waste impurities from desired materials. Solid wastes from fermentation (e.g., mycelia) may be added to animal feeds as a nutritional supplement or as soil conditioners and fertilizers. Inorganic salts may be recovered from chemical liquors produced during organic synthesis operations. Spent solvents are often recycled by separation and distillation. Air emission control devices (e.g., condensers, compression and refrigeration equipment) greatly reduce emissions of volatile organic compounds to the atmosphere (EPA 1993). These devices capture solvent vapours by condensation, enabling the reuse of solvents as raw materials or for cleaning vessels and equipment. Scrubbers neutralize or absorb acid, caustic and soluble gases and vapours, discharging their effluents to waste treatment systems.

Recycled solvents may be reused as media for performing reactions and extractions, and cleaning operations. Different types of solvents should not be mixed, since this reduces their ability to be recycled. Some solvents should be segregated during processing (e.g., chlorinated and non-chlorinated, aliphatic and aromatic, aqueous and flammable solvents). Dissolved and suspended solids are extracted or separated from the solvents, before the solvents are recovered. Laboratory analysis identifies the composition and properties of waste solvents and recycled raw materials. Many new waste prevention and control technologies are being developed for solid, liquid and gaseous wastes.

General housekeeping and operating practices

Written operating procedures, material-handling instructions and waste management practices reduce the generation and improve the treatment of wastes (Theodore and McGuinn 1992). Good operating and housekeeping practices identify specific responsibilities for generating, handling and treating wastes. Training and supervision of operating staff increases their ability to improve and maintain efficient manufacturing and waste management operations. Workers should be trained on the hazards of waste management practices and the proper means of responding to emergency spills, leaks and fugitive emissions. Worker training should address material handling, cleaning or neutralizing wastes and wearing respirators and PPE. Spill and leak detection devices prevent pollution by routinely monitoring production equipment and utilities, identifying and controlling fugitive emissions

and leaks. These activities may be successfully integrated with preventive maintenance practices to clean, calibrate, replace and repair equipment that creates pollution.

Written instructions describing normal operating procedures, as well as start-up, shut-down and emergency procedures, prevent pollution and reduce risks to worker health and safety. Careful management of material inventories decreases the excessive purchasing of raw materials and generation of wastes. Computer systems can assist the effective management of plant operations, maintenance practices and material inventories. Automatic weighing, monitoring and alarm systems can be installed to improve the management of materials and equipment (e.g., storage tanks, process equipment and waste treatment systems). Modern instrument and control systems often increase the productivity of operations, reducing pollution and health and safety hazards. Comprehensive pollution prevention programmes examine all wastes generated at a facility and examine the options for eliminating, reducing or treating them. Environmental audits examine the strengths and weaknesses of pollution prevention and waste management programmes, seeking to optimize their performance.