Part V
Occupational Health and Environmental Engineering

Handbook of Loss Prevention Engineering, First Edition. Edited by J. M. Haight.

31
Control of Chemical Hazards

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31.1
Introduction

During the design and construction of chemical processes, engineers can encounter various needs that the client wants to have met. This can pose a challenge for the engineer. In order to design a safe, useful, and practical process, there are several points which must be considered as there may be regulations controlling how certain materials are used based upon the hazards they may present to people and the environment. This chapter discusses some considerations relating to chemical hazards and then examines some possible methods of abating or controlling those hazards and assuring the safety of people, property, and the environment.

31.2
Considerations

Engineers are frequently enlisted to design processes for businesses that utilize chemicals either entirely or as a part of the intended process. The Occupational Safety and Health (OSH) Act contains permissible exposure limits (PELs) (OSHA, 2010), the American Conference of Governmental Industrial Hygienists (ACGIH) has determined threshold limit values (TLVs) (ACGIH, 2011a), and the National Institute for Occupational Safety and Health (NIOSH) has developed recommended exposure limits (RELs) (NIOSH, 2003) for personnel who work with chemicals, and these need to be considered by the engineer as design progresses. A slight flaw in the design could result in the exposure of personnel to chemical vapors, gases, fluids, and/or solids, thus creating a risk to the exposed individual. Effects of chemical exposure can range from mild irritation to death, so the considerations below must be carefully attended to so that adverse effects can be prevented.

It is important to remember that the PELs set forth in Occupational Safety and Health Administration (OSHA) Regulations are enforceable by law and that ACGIH and NIOSH levels are not. However, for some safety professionals the ACGIH and NIOSH levels are considered more current and a best practice to

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follow as they are updated regularly and are therefore more current than PELs. It is also important to remember that not all chemicals will appear in each of these documents, nor has every known chemical been evaluated. The process described below is one used by the author and may be helpful to the design engineer.

31.2.1
What Is the Process Being Developed?

The first item to consider is, exactly what is the process to be developed or revised? Will the process be a refining operation, fuel delivery system, or simply a laboratory process used to evaluate other materials? Knowing this information sets the engineer on the right path towards the development of a safe, practical, and useful process.

Some processes will require large containment tanks and some will require the smallest of reagent bottles. Each of these will pose varying hazards to users. For example, will the chemical in a bottle be enough to burn the skin of an individual if the bottle should break? If it will, this may be an appropriate place to automate the process and avoid any human injury, or institute other controls, or, if the risk probability for personal injury is low, then personal protective equipment (PPE) may be a sufficient answer. Possible controls are discussed in Section 31.3.

31.2.2
What Chemical(s) Will Be Used?

The next step in the design should be to break the process down into separate topics. The first important topic to consider, in the opinion of the author, is, what chemical(s) will be used, and what hazard(s) does each present, in the process being designed?

There are many chemicals that can be involved when designing a chemical process and not all hazards about them are known. Known hazards for these chemicals are generally broken down into four categories for hazard rating labels as determined by the National Fire Protection Association (NFPA) and the Hazardous Materials Identification System (HMIS) (examples of these labels can be found in Figures 31.1 and 31.2). These categories are:

1) **Health**–These effects can range from minor irritation of the skin or respiratory tracts to fatality. Knowing the level of health risk is of primary importance in protection of workers. (Adapted from NFPA 704, Section 5, Table 5.2.)
2) **Flammability**–This is a measure of how readily the chemical will ignite and burn. This is a primary consideration for protection of people and property. (Adapted from NFPA 704, Section 6, Table 6.2.)
3) **Reactivity**–This will tell you how stable a chemical is on its own and in the presence of, or in combination with, other chemicals. For example, if aluminum is used in conjunction with non-stainless steel, a galvanic reaction will occur, causing breakdown of the metals. (Adapted from NFPA 704, Section 7, Table 7.2.)

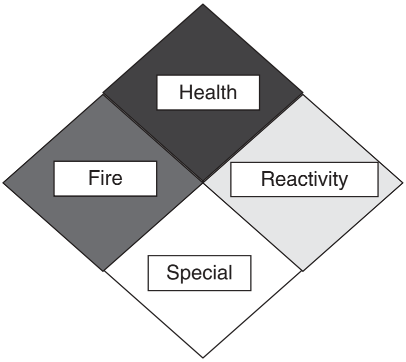


Figure 31.1 NFPA diamond. (Adapted from NFPA 704 Section 9. (NFPA 2007d))

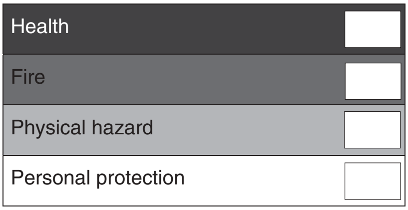


Figure 31.2 HMIS label. (Adapted from National Paint and Coatings Association (NPCA). (ACA, 2011))

4) **Special**–Finally, there are certain characteristics listed under Special Hazards. These include pyrophoric (will react with air) and water-reactive (will react with water) chemicals and also symbols that indicate caustic to skin. (Adapted from NFPA 704, Section 8.)

Hazard severity under Health, Flammability, and Reactivity is indicated by the use of numbers 1–4, 4 being highly hazardous and 1 being minimally hazardous. The Special category is filled in with various symbols indicating whether the chemical is corrosive, water-reactive, flammable, or oxidizing (adapted from NFPA 704, Section 8).

At this stage, make a list or a spreadsheet that shows every chemical involved in the process being developed, the hazards presented by each chemical, and the severity of each hazard. A spreadsheet is, in the author's opinion, the simplest and most effective means to lay out this information. A sample spreadsheet developed by the author for laying out chemical hazard information can be found in Table 31.1. Once this information has been gathered, it will guide design choices. Maybe a closed system will be best and safest, or maybe the chemicals have very minor hazards and an open system will be more efficient and just as safe. Knowing the information just gathered will enable the design engineer to find a way, during the design process, to address each of the hazards presented, making the process safe for people and the environment. Having this accomplished while design is

Table 31.1 Chemical analysis spreadsheet.

Chemical name	Common name	CAS No.	Exposure limit(s)	Hazard(s)	Severity
Anhydrous ammonia (NH_3)	Ammonia	7664-41-7	NIOSH = 25 ppm	Heath: eye/skin/respiratory; frostbite irritant; chest pain; pulmonary edema	3
			OSHA PEL = 50 ppm	Fire: flammable	1
			IDLH[a] = 300 ppm	Reactivity: incompatible with strong oxidizers, acids, halogens, salts of silver and zinc.	0
			TLV = 25 ppm	Special: corrosive	COR

[a] IDLH–Immediately Dangerous to Life or Health. Information gathered using NIOSH (2003) and ACGIH (2011a). ACGIH, (2011b)

in process will also result in lower costs for the entire project, as it will avoid refitting or re-engineering a finished process. For example, if a hazard is corrected during design, the effect on cost is minimal as the engineer is adding the control during the design and not having to re-engineer an existing process. However, if the hazard remains unidentified and uncorrected until the process is constructed, then redesign, demolition, and other costs will increase the overall cost of the project.

31.2.3
How Will Delivery of Chemicals Be Accomplished?

The next topic to tackle is consideration for how chemicals will be delivered to the facility and the process in which they are to be used. Delivery to a facility may be predetermined. The chemical manufacturer should know what type of vehicle is to be used and how to address chemical safety for transport. Also, most facilities have built-in loading docks that trucks will pull up to for delivery. This is where the loss prevention engineer or safety professional comes in.

How will the chemicals be transported from loading dock to storage and from storage to the process or equipment? Deliveries are normally brought between loading docks and storage areas via forklift or hand truck/dolly. This means manual handling and will require consideration of the identification and availability of PPE such as safety goggles, gloves, chemical-resistant footwear, and so on. This is a good topic to address with the company's Safety Specialist or Safety Engineer. If the chemicals in question require specific types of PPE, you need to identify that PPE early enough to assure its availability on-site, and conduct any required training in PPE use, prior to the first arrival of the chemicals to be used.

Transport of the chemicals to the process is a more complicated matter as it can be done in several ways, including:

1) manual handling
2) piping
3) vacuum tubes
4) conveyor belts

Each of these methods will require different controls. For example, while manual handling may only require the use of PPE, mechanical delivery may require splash shields, pinch point guards, emergency stop devices, and other types of guards. All of these need to be incorporated into the design of the process. If not included, the project may run the risk of exceeding budget allowances, due to re-engineering and retrofits. In addition, there may be incidents due to persons being struck against or caught by machinery. For example, OSHA reported the following incident in their Weekly Fatality/Catastrophe Report tabulated during the week ending 22 January 2010:

> Worker had entered a soil hopper system while the auger was rotating. Worker's clothes were caught in the rotating auger, pulling the worker's body into the auger. (OSHA, 2012b)

Had the designer of the hopper system anticipated that a worker might climb into the hopper for any reason, they may have been able to design a means to prevent this incident from occurring. The worker in this incident was killed as a result of being pulled into the auger. Re-engineering, retrofits, and incidents will result in monetary expenditures above and beyond that spent for the initial development. Preventing these expenditures and potential losses is why it is wise to have a loss prevention engineer or a safety professional involved, in any design, from beginning to end.

31.2.4
How and Where Will Process Chemicals Be Stored?

This is really a direct follow-on to the previous topic. Now that the chemicals have been delivered, where and how will they be stored? Designers need to consider that chemicals will need to be stored in varying quantities and forms prior to use, during use, and as waste products. Referring back to Figure 31.1, note that anhydrous ammonia (NH_3) is a flammable chemical and poses elevated health risks. So, what does this mean for storage? It means that this chemical must be kept contained, away from personnel and ignition sources, and possibly in an outdoor tank. Also note that the chemical is both reactive, although only slightly, and corrosive. This means that it requires storage separate from particular chemicals (oxidizers, acids, halogens, etc.) and in a location where it will not contact other materials. For example, an NH_3 Material Safety Data Sheet (MSDS) indicates that ammonia vapor in confined spaces might be a flammability hazard, especially

Figure 31.3 Justrite chemical storage cabinets (Western Safety Products, 2012).

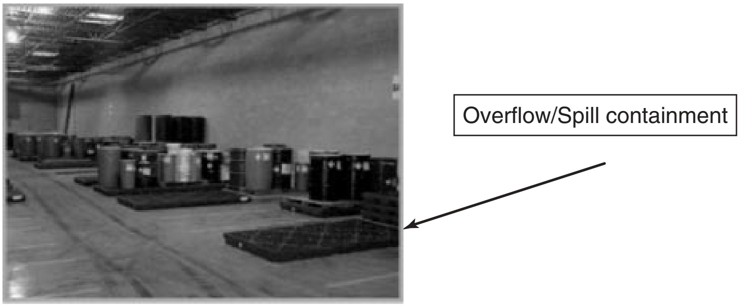


Figure 31.4 Picture of a hazardous waste storage area (Badger Disposal of WI, Inc., 2012).

if oils or other combustible materials are in the area (Tanner Industries, 2012). Therefore, to minimize the risk, storage and use of NH_3 should be away from oil and other combustible materials.

Storage can be complicated when different chemicals are used in the same facility. Some chemicals require special storage cabinets, others require fire-rated walls, and many, particularly when in waste form, require overflow/spill capture. Examples of storage options can be seen in Figures 31.3 and 31.4.

All of this must be carefully researched and the appropriate controls must be incorporated into the design.

31.2.5
Are There Any Compatibility Issues with the Chemicals To Be Used in the Process?

This topic relates directly to the topics above and below regarding chemical delivery and storage. In the topic above it was noted that anhydrous ammonia has certain issues with incompatibility as shown in Table 31.2.

This means that the design team must carefully consider and choose the appropriate materials in which and with which anhydrous ammonia (NH_3) will be used. For example, use of NH_3 with a chemical such as sulfuric acid may result in a reaction that will need to be contained within the process. It also means that delivery of NH_3 through pipes made of a galvanized metal may result in frequent repiping to replace corroded sections (Tanner Industries, 2012). Therefore, stainless steel or poly(vinyl chloride) (PVC) may be the best choice.

Another useful tool for conducting such analyses is the Reactivity/Compatibility Matrix. The National Oceanographic and Atmospheric Administration (NOAA) provides a worksheet for such analyses on their web site (NOAA, 2012) (Figure 31.5). This type of matrix is used to analyze the chemicals to be used in the process under design.

Creating a process and using chemicals require a great deal of research and thought on the part of the design team, as these last sections indicate. However, conducting this work during design will help to assure a good design and maintenance of funds at acceptable levels, and reduction of the risk of and/or potential for injury or death. If the design team can bring the design to fruition on time and within budget, and reduce the risk of and/or potential for injury or property damage (thus saving more money), they can build a strong reputation within the company.

31.2.6
What Are All the Ways in Which the Chemicals Will Be Used Within the Process?

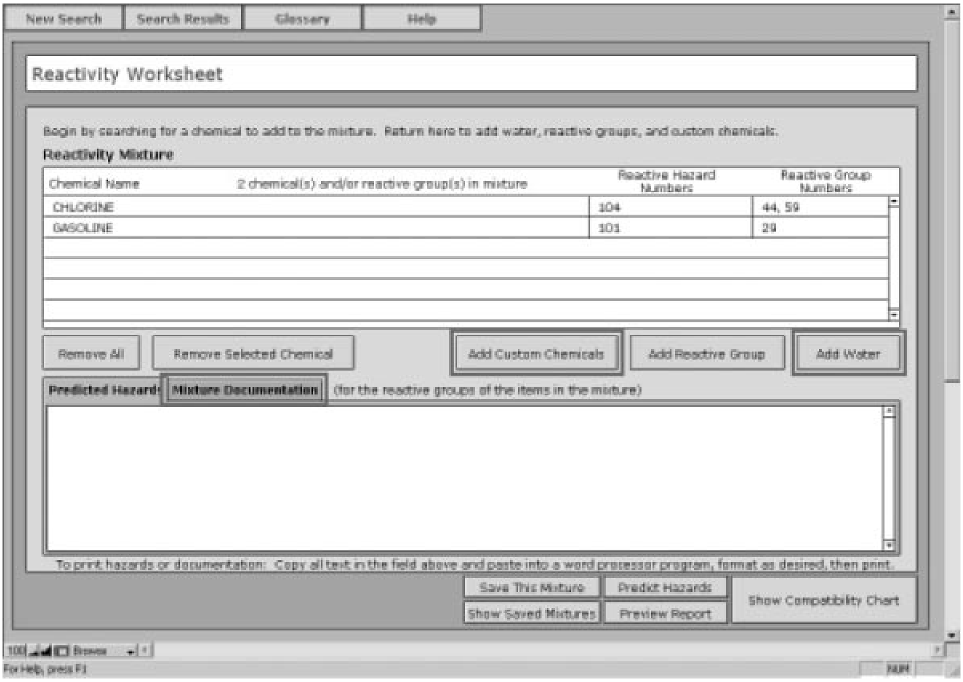
Following the above, chemicals can now be delivered to and stored at the facility. At this point, it will be advantageous to add a column to the spreadsheet. This new column will allow consideration for how each chemical will be used (Table 31.3, shaded).

For simplicity, assume that the process being designed uses only one chemical for a solitary purpose. The process will use NH_3 to create an oxygen-free atmosphere within an annealing furnace (Figure 31.6). Annealing is the process of heating metal to a desired temperature and color, and allowing it to cool slowly, thus

Table 31.2 Chemical analysis spreadsheet – cut away.

REACTIVITY: incompatible with strong oxidizers, acids, halogens, salts of silver and zinc. SPECIAL: corrosive

Information gathered using NIOSH (2003) and ACGIH (2011a).



Begin by searching for a chemical to add to the mixture. Return here to add water, reactive groups, and custom chemicals.

Reactivity Mixture

Chemical Name	2 chemical(s) and/or reactive group(s) in mixture	Reactive Hazard Numbers	Reactive Group Numbers
CHLORINE		104	44, 59
GASOLINE		101	29

(for the reactive groups of the items in the mixture)

To print hazards or documentation: Copy all text in the field above and paste into a word processor program, format as desired, then print.

Figure 31.5 Reactivity matrix (NOAA, 2012).

Table 31.3 Chemical analysis spreadsheet – new column added.

Chemical name	Common name	CAS No.	Exposure limit(s)	Hazard(s)	Severity	Use
Anhydrous ammonia (NH_3)	Ammonia	7664-41-7	NIOSH = 25 ppm	Health: eye/skin/respiratory; frostbite irritant; chest pain; pulmonary edema	3	Creation of oxygen-free furnace atmosphere
			OSHA PEL = 50 ppm	Fire: flammable	1	
			IDLH[a] = 300 ppm	Reactivity: incompatible with strong oxidizers, acids, halogens, salts of silver and zinc	0	
			TLV = 25 ppm	Special: corrosive	COR	

[a] IDLH–Immediately Dangerous to Life or Health.

Information gathered using NIOSH (2003) and ACGIH (2011a).

Figure 31.6 ICE wire line equipment fluid bed annealing furnace (Hot Frog, 2012).

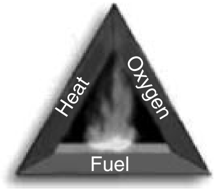


Figure 31.7 Fire triangle (OSHA, 2012).

softening the metal and making it easier to manipulate and shape into the needed form (Ryan, 2009). Removal of oxygen will prevent the oxidation of elements being annealed and insure product quality. What concerns does this raise for design?

The process will be using a flammable chemical, NH_3, that will mix with nitrogen (N_2) in the furnace to create the desired furnace atmosphere. Therefore, designers will need to assure that the fire triangle (Figure 31.7) cannot be completed so that the chemical does not ignite and start a sustained fire.

To be ignited, fires require fuel, oxygen, and an ignition source. The removal of oxygen here removes one of the three required elements needed to cause a fire. The design engineer must consider whether or not this is adequate control or if further methods should be employed to provide greater assurance of safety within this process. Perhaps removing a second element from the fire triangle to assure that the accidental infiltration of one of the two eliminated elements does not result in an unintended and/or catastrophic fire will be a good solution.

31.2.7
How Will Chemical Releases and Spills Be Controlled and Cleaned Up?

As mentioned in Section 31.2.4, waste products will be generated from the new process. Some of these will be the result of spills, leaks, and other releases. The design team must consider whether or not the company has an in-house spill response team that will include individuals who have been trained to respond to spills and understand the hazards of the chemical spilled, to both personnel and the environment. Whether or not they do will determine the necessary equipment that should be on hand to facilitate spill containment and clean-up. If there is not a team, does the process warrant the creation of such a team due to the type and/or quantity of chemicals used and stored? Spill teams are sometimes created by industrial entities to comply with safety and environmental regulations such as OSHA's Process Safety Management standard [29 CFR 1910.119(n)] or Hazardous Waste Operations and Emergency Response [29 CFR 1910.120 (p)(8) and (q)]. At other times, a facility will choose to use local emergency response personnel as a means of saving money and training time, if the emergency response station is close and personnel can respond within a desired time, indicated as being 3–4 min in industrial facilities and 15 min for office facilities (OSHA, 2012a). Generally, these teams and their creation are the responsibility of safety and environmental personnel, so the design engineer will only need to be informed of their existence to help in the design of a chemical process.

Recommendations will need to be made and cleanup/containment materials identified for purchase. A design engineer must consider carefully what is being brought into the process and how much there will be in-house on any given day. Spills and releases can result in expensive fines for a company, particularly if someone becomes ill or chemicals leach into ground water and sewers. The best course of action is to design protections against spills and releases and also to be prepared in the case that these protections fail. These protections may take the form of diked areas that will contain a spill or perhaps spill response equipment that is available commercially. If response equipment is used, the design engineer should also consider including space for equipment storage within the design of the process.

31.2.8
How Will Process Chemicals Be Disposed of?

With very few exceptions, processes and production generate waste products. The questions for the designer include:

1) What waste will be generated?
2) How much waste will be generated?
3) What if anything can be reused in the process or in another area of production?
4) What hazards are associated with this waste?
5) How will the waste be collected, stored, and removed?

Answers to these questions will be a guide in the development of appropriate controls and handling methods and equipment. The design team needs to include persons familiar with occupational safety and also with environmental protection as both OSHA and the US Environmental Protection Agency (EPA) have regulations governing the handling, storage, and disposal of waste.

31.2.9
OSHA Requirements

Now that the considerations that must be entertained when designing a process and using chemicals are to hand, there is some additional assistance that can be found in the OSHA Process Safety Management of Highly Hazardous Chemicals standard (29 CFR 1910.119). Section (e) of this standard outlines the Process Hazard Analysis. This section describes the methods that may be used to analyze hazards, what the analysis must address, how often such an analysis must be done, and other pertinent information. The following is quoted directly from the OSHA standard and gives an idea of what an analysis should look like (OSHA, (2011a)):

1) **1910.119(e)(2)**: The employer shall use one or more of the following methodologies that are appropriate to determine and evaluate the hazards of the process being analyzed.
   a. What-if.
   b. Checklist.
   c. What-if/Checklist.
   d. Hazard and Operability Study (HAZOP).
   e. Failure Mode and Effects Analysis (FMEA).
   f. Fault Tree Analysis.
   g. An appropriate equivalent methodology.
2) **1910.119(e)(3)**: The process hazard analysis shall address:
   a. The hazards of the process.
   b. The identification of any previous incident which had a likely potential for catastrophic consequences in the workplace.
   c. Engineering and administrative controls applicable to the hazards and their interrelationships such as appropriate application of detection methodologies to provide early warning of releases. (Acceptable detection methods might include process monitoring and control instrumentation with alarms, and detection hardware such as hydrocarbon sensors.)
   d. Consequences of failure of engineering and administrative controls.
   e. Facility siting.
   f. Human factors.
   g. A qualitative evaluation of a range of the possible safety and health effects of failure of controls on employees in the workplace.

An example of an excerpt from a What-if/Checklist adapted from an OSHA letter of interpretation dated 1 February 2005 (OSHA, 2005) is presented in Table 31.4.

In using this type of analysis, the design engineer enters all of the possible problems that could occur with the new process and determines what hazard each occurrence entails. Then the likelihood of occurrence and the possible consequences of occurrence are quantified based on Table 31.4. These quantifications are then compared on a risk matrix to identify the risk rating for each identified scenario. The risk rating tells the design engineer how serious a given error would

Table 31.4 Example of a What-if/Checklist.

What-if . . .	Consequences/ hazard	Safeguards	C[a]	L[b]	R[c]	Recommendations/ actions
Pipe delivering NH_3 into process ruptures	Asphyxiant	Interlocked fans that run when pipe breech occurs	4	2	B	Modify design to include safeguards
	Flammable	Deluge sprinkler system that engages upon breech	3	2	B	Provide regular emergency drills

[a] Consequence Class (C): 1 = no injury; 2 = single lost time injury/illness; 3 = multiple lost time injuries/illnesses; 4 = multiple lost time injuries with at least one fatality.
[b] Likelihood of Occurrence (L): 1 = unlikely; 2 = possible; 3 = probable; 4 = certain.
[c] Risk Matrix (R):

Consequence	4	C	B	A	A
	3	C	B	B	A
	2	D	C	B	B
	1	D	D	C	C
		1	2	3	4
Likelihood					

be and helps to identify the methods available to prevent such errors and therefore improve the safety of the process.

Additional information that may be useful to the designer can be found in the four appendices of the Process Safety Management of Highly Hazardous Chemicals standard, 1910.119 App. A–D (OSHA, 2011a). The appendices include a chemicals list, sample flow diagrams, compliance guidance, and a list of additional resources. It is strongly suggested that all engineers obtain and become familiar with the OSHA standards and pay close attention to this particular standard and the guidance it provides in conducting adequate chemical hazard analyses.

31.3
Control Methods

Now that research has been completed, it is time to put controls in place based upon the information gathered. There are many types, and different levels, of control.

The next section discusses the hierarchy of controls and some specific controls that may be of use in controlling chemical hazards. This hierarchy is laid out in the American National Standards Institute (ANSI) standard ANSI/AIHA/ASSE Z10-2005 and is represented by varying graphic diagrams from different sources.

31.3.1
Hierarchy of Controls

In controlling hazards, there is a preferred hierarchy to follow. This hierarchy provides for decreasing levels of control as deemed feasible for a specific task or operation. The hierarchy is shown in Table 31.5 (ANSI, 2011).

The idea behind this hierarchy is that the best, most effective, and most feasible means of protection is to be used for control of any hazard. The designer should always start at the top of the hierarchy and work down as controls are proven infeasible for some documentable reason.

Risk avoidance is what ANSI's Prevention Through Design standard (ANSI, 2011) is all about. Prevention Through Design is a process by which products, processes, facilities, and equipment are designed so as not to introduce safety hazards. Design engineers use this process when they consider the hazards that may be involved in a process under development, as discussed throughout this chapter. In process design, a design engineer incorporates risk avoidance when the process is designed to use a chemical with little risk to people, property, or the environment.

Elimination is the complete elimination of the hazard in question. For example, if a process involves a given hazard, such as a fall hazard due to personnel needing to climb to a height to reach valves, then the valves could be moved to the floor to eliminate the need to climb and therefore eliminate the hazard.

The next most effective means is substitution. In this control method, a lower hazard chemical or material is substituted for one that poses a higher hazard. For

Table 31.5 ANSI hierarchy of controls.

Most preferred	Risk avoidance: prevent entry of hazards into a workplace by selecting and incorporating appropriate technology and work methods criteria during the design process
↓	Eliminate: eliminate workplace and work methods risks that have been discovered
	Substitution: reduce risks by substituting less hazardous methods or materials
	Engineering controls: incorporate engineering controls/safety devices
	Warning: provide warning systems
	Administrative controls: apply administrative controls (organization of work, training, scheduling, supervision, etc.)
Least preferred	Personal protective equipment: provide personal protective equipment (PPE)

example, let us assume that the designer considered using gaseous hydrogen and nitrogen separately to create a furnace atmosphere, instead of breaking anhydrous ammonia down into its component parts hydrogen and nitrogen. Owing to the high flammability of hydrogen (which has a flammability rating of 4), storage would be riskier as hydrogen will quickly spark in an oxygen atmosphere and cause a facility fire. On the other hand, we can store anhydrous ammonia at a lower risk of fire as its flammability rating is 1, making its storage and use safer for creating a furnace atmosphere. Flammability ratings are determined, based upon their flashpoints, by the NFPA, and incorporated by reference in OSHA 29 CFR 1910.106 Flammable and Combustible Liquids (OSHA (2011d)). Both will displace oxygen and give a controlled furnace atmosphere; however, hydrogen will ignite at a much lower temperature than anhydrous ammonia, thereby increasing the hazard. Therefore, we substitute ammonia for hydrogen in our process.

Engineering controls are varied and are usually accomplished by developing a means of keeping the hazard and the operator, or materials, separate. For example, if a process is designed to be entirely contained within a closed system, then complete separation of people and chemicals can be maintained.

Continuing down the hierarchy, warning systems are next. This control involves placement of a system to detect hazards and warn personnel that the hazard is present. A simple example is warning lines used in the construction industry to prevent workers from falling from heights. This type of system is person dependent as it relies on the worker or a person assigned as a safety watch recognizing the warning line and acting in time to prevent a fall. A more complex system might be an automated alarm that is incorporated into the work area to detect a chemical leak. A sensor might be placed in the area to detect gaseous emissions and set to trigger an alarm when a given contamination level is reached. Warnings can range from signs posted in the work area to sophisticated monitoring devices, and can be effective at alerting personnel to problems; however, this is not ideal.

Another control feature is administrative controls. Simply implementing these controls amounts to written procedures for conducting a task or using some material. One such control could be the requirement for work to be done under an operating exhaust hood for volatile laboratory chemicals. Although the exhaust hood is an engineering control, in this situation it is combined with a written procedure which is an administrative control. The procedure would outline, step-by-step, how the work is to be completed down to the most detailed instruction. The downside to this control is that it allows for variation in work based upon personal preference or decision, thereby defeating the purpose of the procedure and increasing the hazard to personnel.

The final means of control, and the least effective, is PPE. PPE can only be used when none of the other controls can be feasibly accomplished or in combination with one or more of the other controls. PPE includes protective clothing, safety shoes, safety glasses, gloves, respirators, and the like. The problem that this control presents is that it is entirely reliant upon personal compliance with its use in order to provide any protection.

Design engineers must carefully consider all available options in controlling chemical hazards and document why one or more of the control levels discussed above cannot be attained. They must also document which level can be attained and how it will be attained in order to provide the greatest control possible for the hazards introduced by the chemicals used in the process. Some specific controls, and how they may be effective, are defined below. It is up to the project design engineer to determine the usefulness of any of these controls during the design process.

31.3.2
Specific Controls

Some of the controls discussed below were introduced in Section 31.2. This section attempts to define these controls further and how they can be useful in the control of chemical hazards.

31.3.3
Ventilation and Hoods

Ventilation is a common means of controlling chemical concentrations in the ambient air. Ventilation can be handled in one of two ways, general dilution ventilation and local exhaust ventilation (LEV). Dilution ventilation is accomplished by controlling the exchange of air in and out of the building (Figure 31.8). Calculations are done to determine the precise flow needed thorough air intakes and outlets. Fresh air coming through intakes and chemical vapor concentrations being exhausted result in the maintenance of safe ambient air concentrations within the workplace.

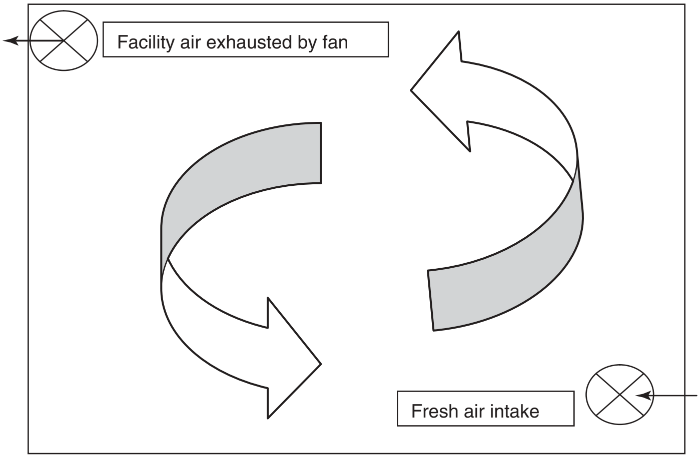


Figure 31.8 Diagram of dilution ventilation.

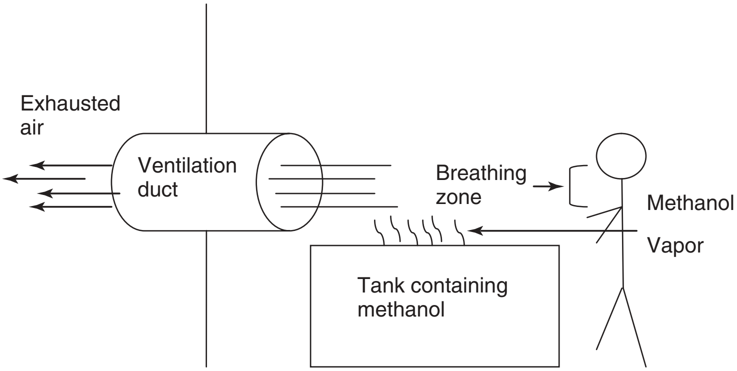


Figure 31.9 Diagram of local exhaust ventilation.

LEV is a means of attempting to capture the contaminant at its source; the basic premise is illustrated in Figure 31.9.

Laboratory hoods are a commonly recognizable means of LEV. The reader may recall from high school or college chemistry courses that certain chemicals are only handled under these hoods. The hood is activated and exhausts any vapors emitted by the chemical in order to maintain safe ambient air in a person's breathing zone.

Both types of ventilation result in the control of hazardous materials that could be inhaled by personnel. The type chosen will depend on the hazards of the chemical, the amount of the chemical being used, the chemical's evaporation rate, the size of the work environment, and other factors that help determine the most efficient and feasible means of controlling exposure to chemicals. For example, if a chemical is being used in a 100 ft^2 laboratory located within a 10 000 ft^2 facility, it probably makes sense to use LEV as the area to be controlled is small and LEV can be designed to maintain safe air concentrations within the laboratory. This is done by sizing fans to achieve the appropriate number of cubic feet per minute at which a given contaminant will be captured and exhausted.

31.3.4
Scrubbers

Along with ventilation, some operations also employ scrubbers. Scrubbers are placed within the ventilation stream and are used to remove hazardous particulates from the air stream. These are often used in stacks of facilities operating coal furnaces.

When coal is burned, it can produce sulfur dioxide. The smoke from burning coal is sent through a particulate filter in the stack where soot and ash are removed. It is then sent through a scrubber where a water spray produces a cloud of water droplets. This water is then mixed with crushed limestone that reacts with the sulfur and results in it being removed from the smoke exhaust (Brain, 2010). An example of a scrubber is shown in Figure 31.10.

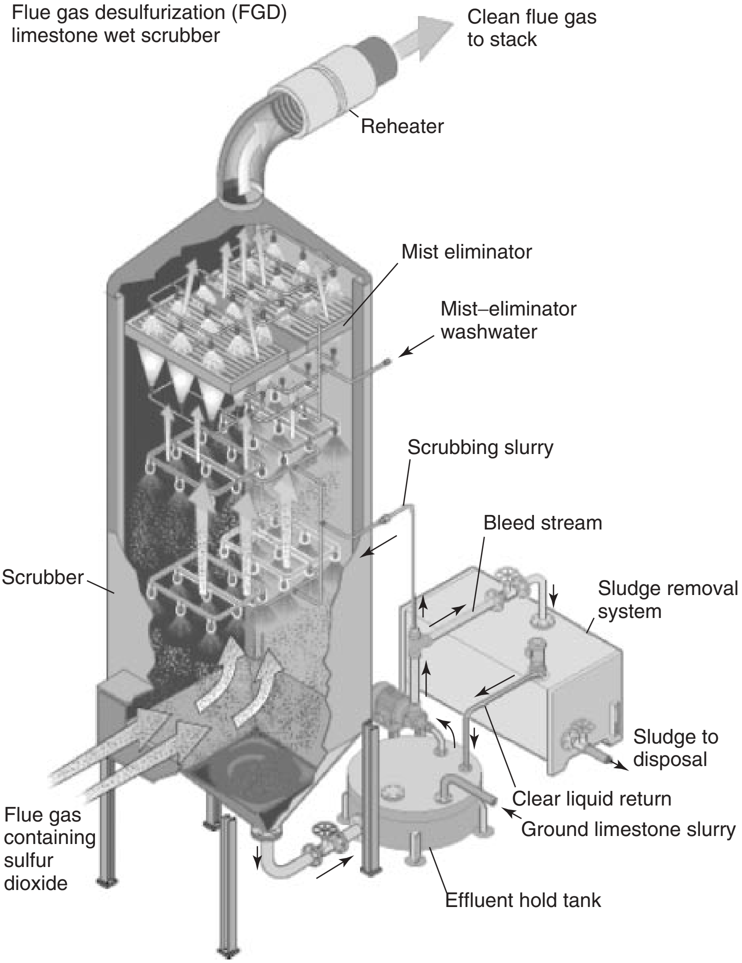


Figure 31.10 Wet scrubber diagram (Green Force Engineers Pvt. Ltd, 2012).

31.3.5
Closed Systems

A third option is use of a closed system (Figure 31.11 shows an example) for a new process. Closed systems provide several advantages, such as:

1) isolation of humans from the chemical
2) prevention of the insertion of contaminants
3) control of chemical contact with the surrounding environment.

In the example in Figure 31.11, the chemical is isolated to a tank and fed through piping to a dissociator, where it is broken down into hydrogen and nitrogen. The hydrogen and nitrogen are then pumped to the furnace to create an atmosphere

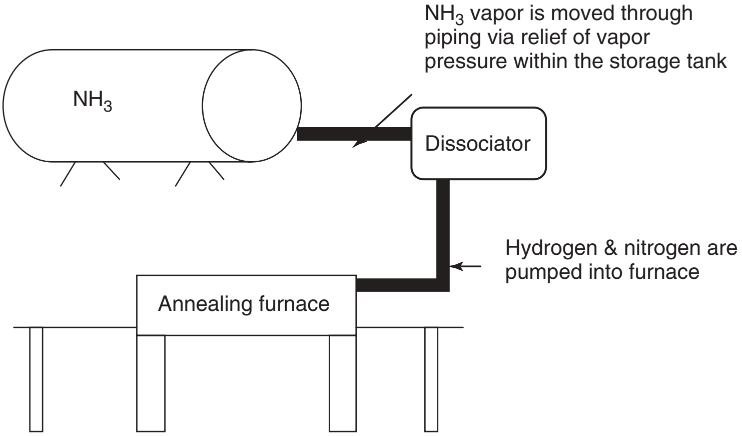


Figure 31.11 Closed system, NH_3 supplying atmosphere to an annealing furnace.

without oxygen. This prevents oxidation of product during the annealing process. No human interaction is required with the chemical during the operating process. This is an example of a simple closed system. Closed systems can be far more complicated depending upon the process and its function.

This type of system, however, will not alleviate all of the safety concerns. For instance, systems, being mechanical, require frequent maintenance and repair. These are jobs that must be accomplished by humans and that will result in the exposure of a worker to chemicals. Therefore, other considerations cannot be ignored, including:

1) readily isolatable energy sources to allow for lockout
2) proximity to safety showers and eyewash stations
3) emergency stop devices.

When feasible, closed systems can be an excellent means for controlling chemical hazards and exposure to them, and may be particularly advisable when using highly hazardous chemicals such as asphyxiants, pyrophorics, and water-reactive chemicals.

31.3.6
Automation

Another means of isolating people from chemicals is the process of automation. Automation can be useful in minimizing human contact with a given chemical. The fewer humans have to do with the process, the lower is the exposure risk. However, the same additional safety concerns must be considered here as with the closed system, since people will ultimately be responsible for system maintenance.

Always remember that with any system and any chemical, there is an ever-present possibility of failure and human error. Therefore, it is necessary always to include safety showers and eyewashes in the design to assure they are placed conveniently and close to where humans will be working with or near chemicals. This applies to all set-ups, whether open systems, closed systems, automated systems, or even storage areas.

31.3.7
Barriers, Dikes, and Other Separations

Separation of certain chemicals is required by OSHA. This applies to chemical storage areas, waste storage areas, and systems.

Separations prevent chemicals from mixing unintentionally after an accident or failure. For example, in a waste storage area (Figure 31.12), many drums of waste can be stored and each may contain a different material. Uncontrolled and unintentional mixing of chemicals, should a drum leak occur, could result in a catastrophic reaction leading to injury, property damage, and environmental impact. Therefore, the designer must consider what will be placed in a given area and fully research the associated reactivity hazards so as to assure the design of proper separations that will prevent reactions from occurring.

The layout in Figure 31.12 shows two types of hazardous waste, some acidic and some basic. In order to prevent a potential catastrophic combination, the wastes are collected in closed 55 gal drums and stored in diked areas that allow a region for drainage should any drum leak. The leaking chemicals are kept separate by a barrier wall, thus preventing the two types of chemicals from coming into contact with each other.

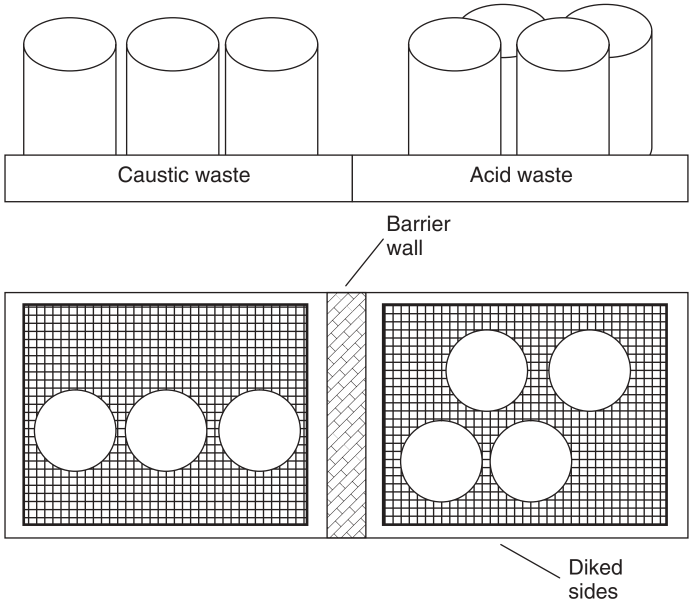


Figure 31.12 Waste collection site with separations.

Barrier walls are also used in the storage of compressed gas cylinders. Oxygen must be stored according to the following OSHA requirements (OSHA, 2011):

- **1910.104(b)(2)(i) "General."** Bulk oxygen storage systems shall be located above ground out of doors, or shall be installed in a building of non-combustible construction, adequately vented, and used for that purpose exclusively. The location selected shall be such that containers and associated equipment shall not be exposed by electric power lines, flammable or combustible liquid lines, or flammable gas lines.
- **1910.104(b)(2)(v) "Dikes."** Where it is necessary to locate a bulk oxygen system on ground lower than adjacent flammable or combustible liquid storage, suitable means shall be taken (such as by diking, diversion curbs, or grading) with respect to the adjacent flammable or combustible liquid storage to prevent accumulation of liquids under the bulk oxygen system.
- **1910.104(b)(3)(xviii) "Exceptions."** The distances in paragraphs (b)(3) (ii), (iii), (v) to (xi) inclusive, of this section do not apply where protective structures such as firewalls of adequate height to safeguard the oxygen storage systems are located between the bulk oxygen storage installation and the exposure. In such cases, the bulk oxygen storage installation may be a minimum distance of 1 ft from the firewall.

This standard further defines the distance required between oxygen cylinders and exposures such as flammable liquids, combustible structures, and ignition sources. Hence design considerations can become complex and it is in the engineer's best interests to be familiar with the design requirements outlined in OSHA standards.

31.3.8
Monitors and Monitoring Devices

Monitoring is generally the task of an industrial hygienist (IH) and it can be incorporated into processes with the help of an IH. Monitoring for chemical exposure by an IH requires conducting sampling for chemical concentrations in the work area through the use of various types of sampling pumps. However, monitoring can also include continuous air monitors such as the carbon monoxide monitors found in many homes.

The purpose of monitoring is to keep abreast of the concentrations in a work area, which allows actions to be taken when concentrations reach levels of concern, such as 10% of the lower explosive limit or personal exposure limits. These limits are levels that will be researched when preparing the design. Use of this type of control also requires the use of, or potential immediate access to, PPE and would therefore be a last-resort control. Monitoring should never be used as the sole or primary control for chemical hazards and/or chemical exposure, but is a suitable means to check how engineering controls are performing.

31.3.9
Other Controls

There are many other controls available to the engineer, including:

1) pressure relief devices for reactions
2) plant safety systems for catastrophic incidents (i.e., fire protection)
3) redundancy for equipment failure.

Pressure relief valves can be found on tanks, pipes, and other enclosed chemical containers. Their purpose is to relieve the build-up of pressure within the system and prevent a catastrophic failure such as a boiling liquid expanding vapor explosion (BLEVE). These are commonly used and should be familiar to the engineer. Figure 31.13 shows an example of such a valve (Sears, 2011).

Plant safety systems can include fire detection systems, fire suppression systems, security systems, and the like. These systems can be installed facility wide and can be customized for the hazard(s) present in a given area. For example, a sprinkler system would be inappropriate for an area where a water-reactive chemical is stored. However, oxygen displacement systems or chemical extinguishers (such as Halon or FM 200) may be perfect as they remove the hazard introduced if water is used. When using these types of suppression systems, it will be necessary to consider the time it will take for personnel to evacuate the area. Since such systems create an asphyxiating atmosphere, enough time must be allowed between alarm and activation to prevent loss of life. This is an important consideration in the design of such systems.

Finally, system redundancy can prevent or control chemical hazards by providing a back-up system to be automatically initiated in the case of a failure in the primary system. Nuclear power plants use this as a control in their safety systems. They prevent what is commonly known as meltdowns by providing several layers of redundancy to ensure continued operation in a safe mode. In this regard, 10 CFR Part 50 (NRC, 2011) partially reads as follows:

Figure 31.13 Pressure relief valve (Sears, 2011).

> *Criterion 44 – Cooling Water*. A system to transfer heat from structures, systems, and components important to safety, to an ultimate heat sink shall be provided. The system safety function shall be to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions.
>
> Suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

The controls discussed in this section are additional means that can be used in combination with other controls. These types of controls will add secondary and tertiary protections for employees, equipment, and the environment.

31.4
Conclusion

A fair amount of information to aid in process design and assurance of a safe process has been discussed. However, this is only a brief sample of what can be learned regarding each of the topics.

It is not only the job of the project design engineer to create a practical, effective, and efficient process, but also to create a process that will not cause harm to people, property, or the environment. In this case, it is advisable for project design engineers to familiarize themselves with safety standards and regulations. It is also strongly advised that project design engineers actively pursue prevention through design by involving safety and environmental professionals for the life of the project and beyond. The earlier in design these potential problems are identified, the easier it will be to correct them and the loss prevention engineer or safety professional will be able to aid in doing just that.

A project design engineer will not be expected to be an expert on safety and the regulations regarding safety, but will be expected to deliver a process that will not cause loss prevention-related concerns for the company. In designing processes, the design engineer must thoroughly and carefully research the components and function of the process. By doing this, the design engineer and the design team will build safe and effective processes for accomplishing any number of varied tasks.

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