SKF 4163 : Safety in Process Plant Design

Industrial Hygiene

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Industrial Hygiene

Science and art devoted to the anticipation, recognition, evaluation, and control of those environmental factors or stresses arising in or from the workplace which may cause sickness, impaired health and well being, or significant discomfort among workers or among citizens of the community

Industrial Hygiene

- Industrial hygiene involves,

  - Identification (recognition),
  - evaluation and
  - control

  of occupational conditions that cause sickness and injury.

- Toxic chemicals can be safely used if principles of industrial hygiene are appropriately applied.

Industrial Hygienists

- Industrial hygienists are scientists and engineers committed to protecting the health and safety of people in the workplace and the community.

- Check with NIOSH and DOSH for certification for professional industrial hygienists.

  Assessor, IAQ Assessor

  Hygiene technician I (chemical monitoring),

  Hygiene technician II (engineering control).

- Industrial hygienists responsible for
  - selecting and using instrumentation to monitor workplace during the identification and control phases of industrial hygiene projects.
  - Recommend relevant control techniques
  - Maintain control measure (e.g. ECE in OSHA 1994 (Malaysia) is maintained by hygiene technician)

- Successful implementation of any safety and loss prevention program in a chemical process complex requires concerted efforts among

  - Management (Plant manager)
  - Industrial hygienists,
  - Process engineers (Shift Engineer),
  - Operators,
  - Panelman
  - Security personnel
  - Laboratory personnel etc.

EXAMPLES OF Industrial hygiene activity

- Monitoring toxic airborne concentration
- Reducing toxic airborne by using ventilation (an example of ECE)
- Selecting PPE (e.g. suitable respirator) to prevent worker exposure
- Developing procedure for handling hazardous material
- Monitoring and reducing noise, heat, radiation.
- Any other activity to ensure workers are not expose to harmful levels

Three phases of industrial hygiene

1. Identification:
   – Determination of the presence or possibility of workplace exposures.

2. Evaluation:
   – Determination the magnitude of the exposure.

3. Control:
   – Application of appropriate technology to reduce/control workplace exposures to acceptable levels

Phase 1: Identification

Determination of the presence or possibility of workplace exposures.

- There are numerous potential hazardous conditions due to use of toxic/flammable chemicals.
- All these need to be identified and controlled.
- The success depends on discipline, skill, knowledge, concern and attention to details.

Identification Process

- Through study of the process, operation conditions and operating procedures
- List the potential hazards (e.g. vapor, dust, temperature);
  - including entry modes and
  - potential damage to organs
- List the required physical and chemical data for hazardous chemicals
- Might also involve risk assessment (i.e. study on potential for hazards to result in an accident and its consequences)

IDENTIFICATION: MSDS

- MSDS is one of the most important references for physical and chemical properties of hazardous chemical.
- Available from manufacturer or supplier of the chemicals, library, internet etc.
- Industrial hygienist should be able to interpret the information,
  - to determine the hazard associated with the chemicals
  - to develop proper control and handling

Phase 2: EVALUATION

Determination the magnitude of the exposure to toxicants and other physical hazards (e.g. dust);

- Sampling for exposure data to determine workers exposure conditions
- Placement of monitoring equipment (concentration may vary depends on locations)
- Interpretation of data
- Compare with acceptable OSH standards (TLV, PEL, IDLH)
- Also study the effectiveness of existing control measures

Level of exposure

- Sudden exposure to high concentration (e.g. due to large leak)
  - Immediate acute effect:
    Unconsciousness, burning eyes, fits of coughing

- Repeated exposure to low concentration (unseen small leak)
  - Chronic effects (long-term permanent or serious impairments effect)
  - Detection requires periodic sampling
  - If problem is evident, immediate implementation of controls (ECE)
  - Temporary solution such as PPE (e.g. respirator) could be used before permanent controls installed

Evaluating exposures to volatile toxicants by monitoring

- Worker exposures using online continuous monitoring of air concentrations (C) of toxicants.

- The measured time–weighted average (TWA) concentration is,

$$TWA = \frac{1}{8}\int_0^{t_w} C(t)\,dt$$

- *C(t)* is concentration in *ppm* or *mg/m*^{3} *of chemical in air*
- t_w is the worker shift time in *hours*
- The division by 8 indicates the computation is normalized to 8 hours

- Note: This is not *TLV_TWA*
  TLV_TWA is tabulated in regulation such as in USECHH

- So if workers are exposed to *TLV-TWA* level for 12 continuous hours, the *TWA* > *TLV_TWA*

$$TWA = \frac{1}{8}\int_0^{12} C(t)\,dt$$
$$= \frac{1}{8}C(t)\Delta t$$
$$= \frac{1}{8}(TLV\_TWA)(12-0)$$
$$= 1.5(TLV\_TWA)$$

- This means the workers are overexposed.

- So if workers are exposed to 1.2(*TLV-TWA)* level for only 6 continuous hours per day, the *TWA* > *TLV_TWA*

$$
\begin{aligned}
TWA &= \frac{1}{8}\int_0^6 C(t)\,dt \\
&= \frac{1}{8}C(t)\Delta t \\
&= \frac{1}{8}1.2(TLV\_TWA)(6-0) \\
&= 0.9(TLV\_TWA)
\end{aligned}
$$

- This means the workers are not overexposed as far as TLV_TWA is concerned.

- For a worker who works at various locations in the plant, his/her exposure is measured using intermittent samples at fixed points,

$$TWA = \frac{\int_0^{T_1} C_1(t)dt + \int_0^{T_2} C_2(t)dt + ... + \int_0^{T_n} C_n(t)dt}{8}$$

- T_i is period of time at each location

- If C_i is constant.

$$TWA = \frac{C_1T_1 + C_2T_2 + ... + C_nT_n}{8}$$

- For exposure to mixture of toxicants and assuming the effects are additive, the *TWA* for mixture is,

$$TWA_{mix} = \Sigma TWA_i$$

- The *TLV_TWA* for mixture is calculated as,

$$(TLV\_TWA)_{mix} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} \frac{C_i}{(TLV\_TWA)_i}}$$

If $TWA_{mix} > (TLV\_TWA)_{mix}$, the workers are overexposed!

Evaluating exposures to volatile toxicants by monitoring

Alternatively, calculate

$$\sum_{i=1}^{n} \frac{C_i}{(TLV\_TWA)_i} = ?$$

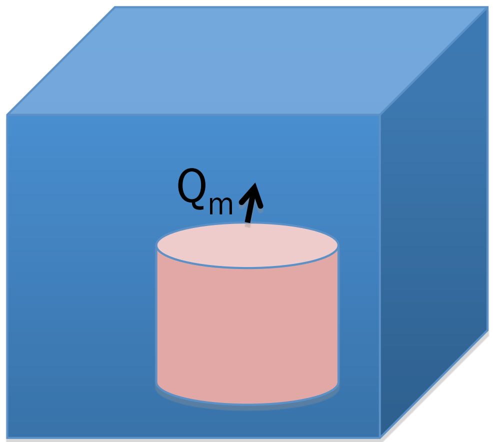
- If the value is >1, overexposed!

Estimating worker exposure to toxic vapor

Estimation of Vaporization (or Evaporation) Rate of a Liquid:

- Liquid with high vapor pressure (P^{sat}) evaporate faster (i.e. it has low boiling point or very volatile)
- Here vaporization or evaporation refers to disappearance of liquid to vapor (and no boiling involve)
- Evaporation rate, Q_m (*mass/time*) is a function of vapor pressure
- For vaporization into stagnant air,

$$Q_m \propto \left(P^{sat} - p\right)$$



- p is partial pressure in the bulk stagnant air.

- A more generalized expression for vaporization rate

$$Q_m = \frac{MKA(P^{sat} - p)}{R_g T_L}$$

- *M* is molecular weight
- *K* is mass transfer coefficient (*length/time*) for an area A.
- *A* is surface area of liquid and R_g is gas constant
- T_L is absolute temperature of liquid

- Where $p = y_i P$

- In most cases, mole fraction (y_i) of volatile (toxic) substance is small,

  so $p << P^{sat}$

$$Q_m = \frac{MKAP^{sat}}{R_g T_L}$$

Eqn 3-12

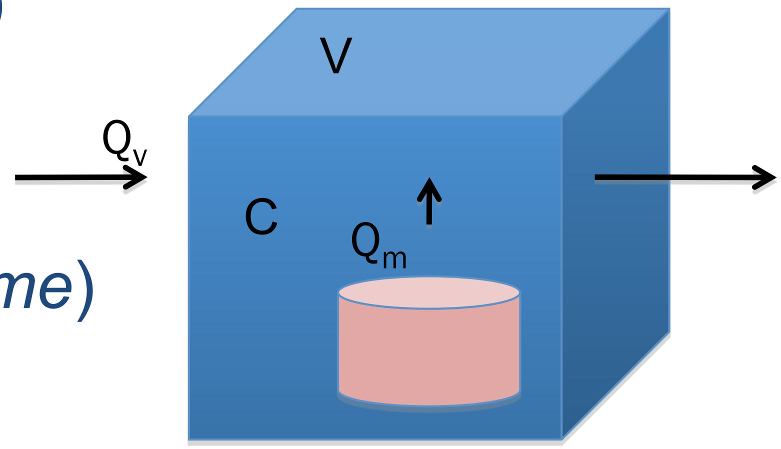
- Mass transfer coefficient can be estimated as follow with K_o and M_o are for reference species (if water is the ref species, K_o=0.83 *cm/s*)

$$K = K_o \left(\frac{M_o}{M} \right)^{0.3333}$$

Estimation of toxic vapor concentration (C) in an enclosure:

- Here we look at vapor concentration in enclosed spaces above area of spills or open container.

- C is average concentration (*mass/vol*)

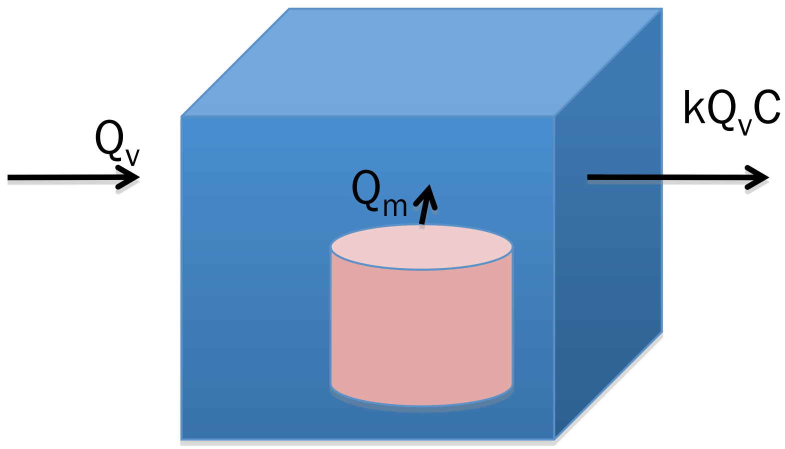


- Q_v ventilation rate of fresh air (*vol/time*)
- Q_m evaporation rate of liquid (hazardous chem) (*mass/time*)
- V volume of enclosure

- Mass balance volatile species (i.e. hazardous chemical):
- Accumulation = In–Out + ~~Generation~~ - ~~Consumption~~

$$\frac{d(VC)}{dt} = Q_m - kQ_v C = 0 \text{ (at steady state)}$$

$$C = \frac{Q_m}{kQ_v} \qquad \text{Eq. 3.7}$$



- k is non-ideal mixing factor , where k=1 for perfect mixing
- Typical k = 0.1 to 0.5
- Note: incoming fresh air (Q_v) has no volatile species.

- Convert C (mass/vol) to C_{ppm}

$$C_{ppm} = C \frac{R_g T}{PM} 10^6$$

$$= \frac{Q_m}{kQ_v} \frac{R_g T}{PM} 10^6$$

Note: T is the air temperature

$$C_{ppm} = \frac{Q_m}{kQ_v}\frac{R_g T}{PM}10^6$$

$$Q_m = \frac{MKAP^{sat}}{R_g T_L}$$

- After substitution of eqn 3.12, we have simple model for estimation of concentration (C_{ppm}) of a volatile in an enclosure resulting from evaporation of liquid,

$$C_{ppm} == \frac{MKAP^{sat}}{kQ_v R_g T_L}\frac{R_g T}{PM}10^6$$

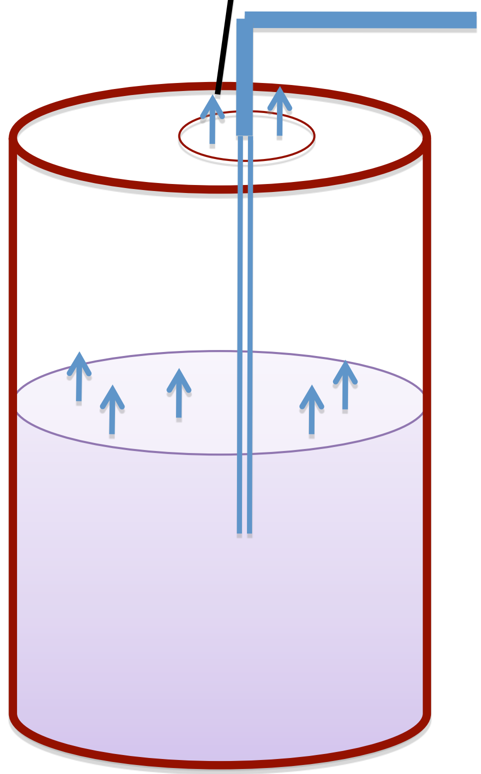
$$T \approx T_L$$

$$C_{ppm} == \frac{KAP^{sat}}{kQ_v P}10^6$$

Eq. 3.14

Estimating worker exposures to a vessel filling operation,

- Sources of volatile emission (out through filling hole)
  - Evaporation Q_{m1} (from eqn 3.12) and
  - Displacement of vapor by the entering liquid Q_{m2}



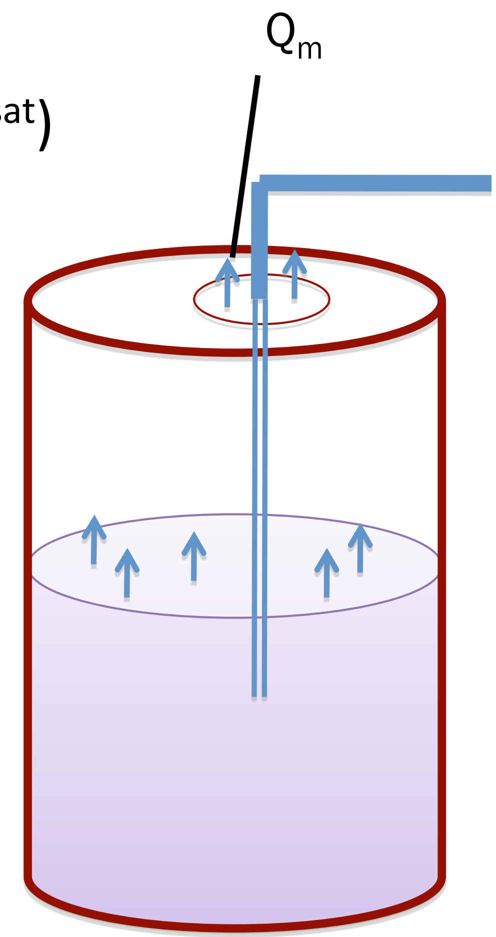
$$Q_m = Q_{m1} + Q_{m2} = \frac{MKAP^{sat}}{R_g T_L} + Q_{m2}$$

- If V_c vol container, r_f is filling rate (*time*$^{-1}$) and ρ_v is density of volatile vapor

$$Q_{m2} = r_f V_c \rho_v$$

- If the vapors are saturated with volatiles (vapor liquid equilibrium) i.e. at saturation ($P=P^{sat}$) From ideal gas law where V_v is vapor specific volume,

$$\rho_v = \frac{1}{V_v} = \frac{MP}{R_g T_L} = \frac{MP^{sat}}{R_g T_L} \qquad \text{Eq. 3.20}$$



- So,

$$Q_{m2} = r_f V_c \frac{MP^{sat}}{R_g T_L} = \frac{MP^{sat}}{R_g T_L} r_f V_c \qquad \text{Eq. 3.21}$$

  - Introduce Φ for 'unsaturated',

    Φ=1 for splash filling (saturated)

    Φ=0.5 for dip-leg filling

$$Q_{m2} = \frac{MP^{sat}}{R_g T_L} \phi r_f V_c \qquad \text{Eq. 3.22}$$

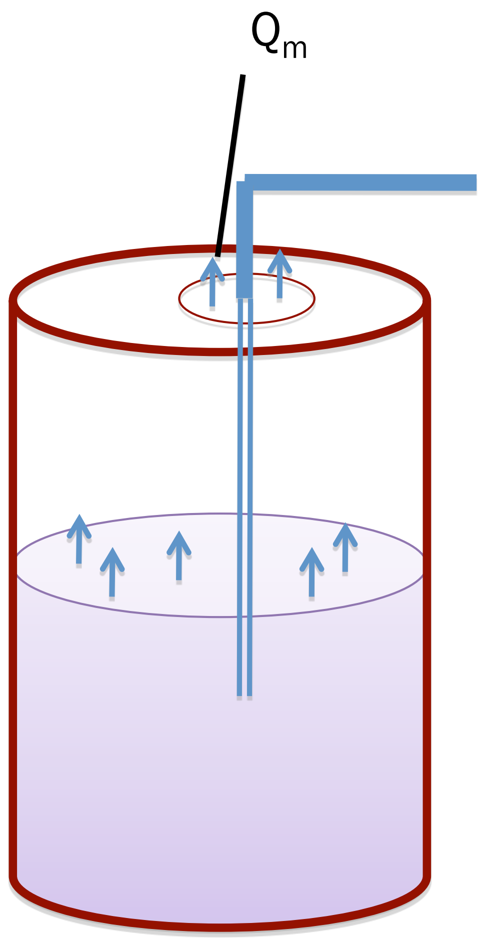
Substitute,

$$Q_m = Q_{m1} + Q_{m2} = \frac{MKAP^{sat}}{R_g T_L} + \frac{MP^{sat}}{R_g T_L}\phi r_f V_c$$

$$Q_m = \frac{MP^{sat}}{R_g T_L}(KA + \phi r_f V_c)$$

$$Q_m = \frac{MP^{sat}}{R_g T_L}(\phi r_f V_c + KA)$$

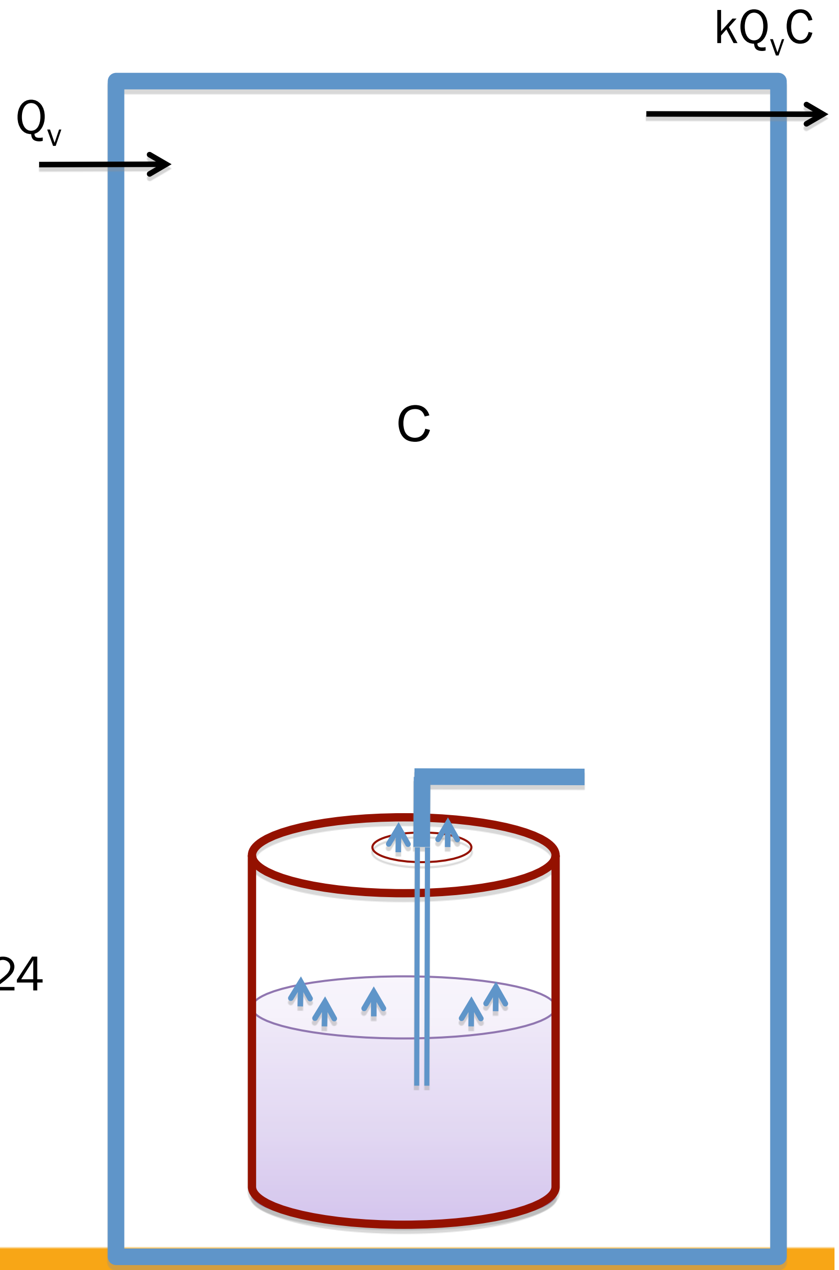
Eq. 3.23



- If the filling is within an enclosure, with T=T_L
  eq. 3.9 gives,

$$C_{ppm} = \frac{Q_m}{kQ_v}\frac{R_g T}{PM}10^6$$

$$= \frac{P^{sat}}{kQ_v P}(\phi r_f V_c + KA)10^6 \quad \text{Eq. 3.24}$$



PHASE 3: control

- Enclosure
  - Enclose room and equipment containing hazardous substance and place under negative pressure*, for example:
    - Enclose sampling area for hazardous chemical
    - Seal rooms
    - Seal sewer
    - Shield high temperature surfaces
    - Pneumatically convey dusty material
  - *negative pressure is to keep the hazardous substance from leaking out to the workplace environment.

- Ventilation
  - To control of atmospheric contaminant to healthful level (below TLV-TWA)
  - Also for prevention of fire & explosion
  - Also control of heat & humidity for comfort

- Ventilation System

  - Ventilation system contains fans and ducts (passageway, pipe)
  - The fan cause small pressure drop that moves the air
  - Best location for fan is at the exhaust end to create a negative pressure for pulling out the air (no contaminated air leaking back into the workplace)
  - Can quickly remove dangerous concentrations of flammable and toxic chemical
  - Readily available and easy to install and/or add to existing facility
  - Operating cost is due to the usage of large fans and also the need to heat or cool of fresh air (winter vs summer?)

- Type of Ventilation
  - 2 types of ventilation:

    -Local Ventilation and

    -Dilution Ventilation

Local exhaust ventilation

- Control at or near the place where the contaminant is created or released
- To contain contaminant in an enclosure and to remove through exhaust device (ducts and fans)
- Quickly remove dangerous concentrations of flammable and toxic materials.
- Reduce the quantity of air moved and equipment size
- Exhaust system should be under negative pressure

Example of local ventilation

- Enclosed laboratory hood (opening of window sash (sliding glass window) control the fresh air into the chamber)

  Advantages:

  - Completely eliminate exposure to workers
  - Minimal Air flow
  - Containment
  - Sliding door act as a shield to worker
  - Duct is either circular or rectangular
  - Air flow depends on sash height and fan speed.
  - Typical control velocity: 80-120 feet per minute

  Disadvantages:

  - Limited workspace, usually for small bench-scale operation

- Other examples of local ventilation are,
  - ventilation at drumming station for loading and unloading (e.g. using elephant trunk duct)
  - ventilation at source
  - ventilation at sampling point

- Dilution ventilation (General ventilation)
  - General ventilation design to control low-level toxics in an open area or room (also not for highly toxic chemical)
  - A room or an entire building is flushed by supplying and exhausting large volumes of air
  - The contaminant must not be highly toxic and evolve at uniform rate
  - Scrubbing systems not necessary to treat air prior exhaust to environment.

- Continue, Dilution ventilation (General ventilation)
  - Requires more air flow than local ventilation, so higher operating cost (especially if you need to heat up the air)
  - Workers are always exposed but the concentration is diluted by fresh air
  - Ventilation for locker rooms
  - Ventilation of enclosures for contaminated clothing
  - Design filter press rooms with directional ventilation
  - Design ventilation to isolate operations from rooms and offices

- Wet methods
  - To minimize dust contamination on the workplace environment, e.g.
    - Use chemical to clean vessel instead of sandblasting
    - Use water spray to shield trenches
    - Use water spray for cleaning dusty area

- Good housekeeping
  - To keep toxicants and dusts contained, e.g.
    - Area washing (Provide water and steam connections)
    - Provide lines for flushing and cleaning
    - Used dikes around tanks and pumps
    - Well design sewer systems with emergency containment

It is important that newly design control technique does not itself create another hazard

- Personal Protection Equipment
  - To prevent and reduce exposure by providing barrier between worker and workplace environment
  - As last line of defence (after implementation of other control techniques),

- Examples of Personal Protection Equipment (PPE)

  - Respirators
  - Use airline respirator for O_2 <19.5%
  - Chemical splash goggles (gas-tight)
  - PVC-coated gloves
  - Safety boot
  - PVC and nitrile knee boots
  - Vinyl aprons
  - Wrap-around face shield
  - Safety glasses
  - Hard hat
  - Ear plug, earmuffs
  - Aprons
  - Space suits

Respirators

- Only use,
  - On a temporary basis (until regular/permanent controls are implemented)
  - As emergency equipment (to ensure safety in the event of accident)
  - As last resort, in the event that environmental control techniques are unable to provide satisfactory protection
  - The usage, however, will compromise worker ability/mobility
  - The usage should follow standard requirement (fit testing, periodic inspection, specified use applications, training, record keeping,

Respirators USEFUL IN CHEMICAL INDUSTRY

- Mouth and nose dust mask,
  - O_2>19.5%, single use: PEL>0.05 mg/m3

- Mouth and nose (half face) with chemical cartridge,
  - O_2>19.5%, for concentration less than IDLH

  (IDLH is Immediately Dangerous to Life and Health)

- Full face mask with chemical canister,
  - O_2>19.5%, concentration<100PEL, for concentration less than IDLH

RESPIRATORS USEFUL IN CHEMICAL INDUSTRY

- Self-contained breathing apparatus (SCBA)
  - Use for toxic and noxious gases with concentrations below or above IDLH

Government regulations

- Laws and regulations are introduced to protect people and environment
- The safety laws and regulations in the textbook are in reference to USA
- There are interesting discussion of OSHA: Process Safety Management and EPA: Risk Management Plan in the textbook.
- Read and compare with what we have discussed on OSHA 1994 (+ regulations) and OSH-MS

Reference

- Crowl, Daniels A. and Louvar, Joseph F., Chemical Process Safety: Fundamentals with Applications, Prentice Hall, 1990, New Jersey, USA.
- Occupational Safety and Health Act (OSHA) and Regulations, MDC Publishers Sdn Bhd, Malaysia