Process Safety Engineering:

Industrial Hygiene

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Industrial Hygiene: Definition

- **Industrial hygiene** is a science devoted to the identification, evaluation, and control of occupational conditions that cause sickness and injury

- **Industrial hygiene** is concerned with predicting, recognizing, assessing, controlling, and preventing workplace environmental stressors that can cause sickness or serious discomfort to workers.

  - An environmental stressor is any factor that can cause enough discomfort to result in lost time or illness.

    - *Gases, fumes, vapors, dusts, mists, noise, and radiation.*

Industrial Hygiene Phases

1. **Identification:** determination of the presence or possibility of workplace exposures.

2. **Evaluation:** determination of the magnitude of the exposure.

3. **Control:** application of appropriate technology to reduce workplace exposures to acceptable levels.

What Is an Industrial Hygienist?

- A person who by study, training, and experience can:

  - ✓ Anticipate
  - ✓ Recognize
  - ✓ Evaluate
  - ✓ Control

ANTICIPATION	Expectation of hazard existence
IDENTIFICATION	Presence of workplace exposure
EVALUATION	Magnitude of exposure
CONTROL	Reduction to acceptable levels

workplace environmental hazards

- **Anticipation/recognition** of potential or actual hazards through knowledge of:

  - Materials
  - Operations
  - Processes
  - Conditions

- **Evaluation** of environmental factors through:

  - Measurement of exposure intensity
  - Determination of exposure frequency, and duration
  - Comparison with regulatory, professional, and internal standards
  - Judgment: weigh all factors

- ✓ **Control** by employing of methods to eliminate or reduce exposure resulting in elimination or reduction of the occurrence of occupational disease through:
  - ➢ Engineering (including process) interventions
  - ➢ Administrative/programmatic measures
  - ➢ Personal protective equipment

OSHA: Process Safety Management

- **Process safety management (PSM)** was developed after the Bhopal accident (1985), to prevent similar accidents.

- Activities undertaken in Emergency management:

  - Before the emergency situation → **PSM**
  - During the emergency situation → **PSM**
  - Immediately After the emergency situation → **PSM**

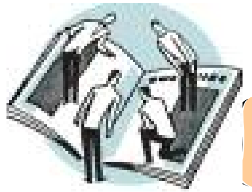
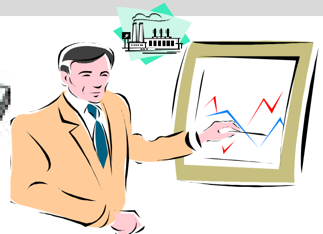
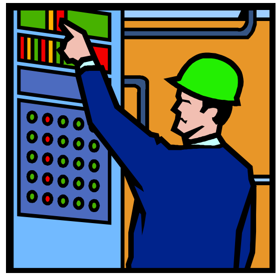
- Emergency management is a part of PSM (in chemical-related industries)

Purpose Of PSM

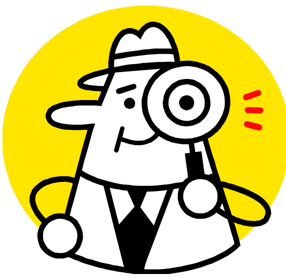
- **Proactive** and **systematic** Preventing or minimizing the consequences of catastrophic release of toxic, flammable, reactive or explosive chemicals

The PSM standard major sections

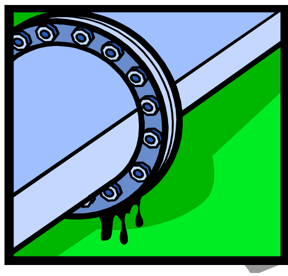
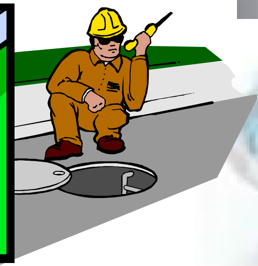


- Process safety Information (PSI)
- Employee participation
- Process Hazard Analysis (PHA)
- Operating procedure
- Training
- contractors safety
- Pre-Start-up Safety Review (PSSR)
- Mechanical Integrity
- Nonroutine work authorization (Hot Work Permits)
- Management of Change
- Emergency Planning and Response
- Incident Investigation
- Audit of PSM
- Trade secrets






EPA: Risk Management Plan (RMP)

- The RMP regulation is aimed at decreasing the number and magnitude of accidental releases of toxic and flammable substances.

- Although the RMP is similar to the PSM regulation in many respects, the RMP is designed to protect off-site people and the environment, whereas PSM is designed to protect on-site people.

> **The RMP has the following elements:**
>
> - ✓ hazard assessment,
> - ✓ prevention program,
> - ✓ emergency response program,
> - ✓ documentation that is maintained on the site and submitted to authorities. This information is also shared with the local community.

Industrial Hygiene: Identification

- In order to safely handle many hazardous chemicals on a daily basis within chemical plants, **all potential hazards must be identified and controlled.**

- **The identification step requires a thorough study of** the chemical process, operating conditions, and operating procedures.

- The sources of information include: process design descriptions, operating instructions, safety reviews, equipment vendor descriptions, information from chemical suppliers, and information from operating personnel.

- The quality of this identification step is often a function of the number of resources used and the quality of the questions asked.

Potential hazards

- CHEMICAL PROCESS
- OPERATING CONDITIONS
- OPERATING PROCEDURES

←

- Process design
- Operating instructions
- Safety reviews
- Equipment description
- Chemical properties MSDS's

Potential hazards	
Liquids	Noise
Vapors	Radiation
Dusts	Temperature
Fumes	Mechanical
Entry mode of toxicants	
Inhalation	Ingestion
Body absorption (skin or eyes)	Injection
Potential damage	
Lungs	Skin
Ears	Eyes
Nervous system	Liver
Kidneys	Reproductive organs
Circulatory system	Other organs

[1] Olishifski, *Fundamentals of Industrial Hygiene*, pp. 24–26.

Data Useful for Health identification
Threshold limit values (TLVs)
Odor threshold for vapors
Physical state
Vapor pressure of liquids
Sensitivity of chemical to temperature or impact
Rates and heats of reaction
Hazardous by-products
Reactivity with other chemicals
Explosive concentrations of chemicals, dusts, and vapors
Noise levels of equipment
Types and degree of radiation

RISK ASSESSMENT: potential for hazard to result in an accident

Industrial Hygiene: Evaluation

- The evaluation phase determines the extent and degree of employee exposure to toxicants and physical hazards in the workplace environment.
- The various types of existing control measures and their effectiveness are also studied in the evaluation phase.
- Sudden exposures to high concentrations: ready access to a clean environment is important.
- Chronic effects arise from repeated exposures to low concentrations: preventing and controlling through continuous or frequent and periodic sampling and analysis.
- After the exposure data are obtained, it is necessary to compare actual exposure levels to acceptable occupational health standards to identify the potential hazards requiring better or more control measures.

Evaluating Exposures to Volatile Toxicants by Monitoring

- Continuously monitoring the air concentrations of toxicants on-line in a work environment (the monitoring depends on equipm availability)

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

where,

- $C(t)$ is the concentration (in ppm or mg/m^3) of the chemical in the air and
- t, is the worker shift time in hours.

- **For one chemical**, if we assume that the concentration C_i is fixed (or averaged) over the period of time T_i , the TWA concentration is computed by

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

- The combined exposures from multiple toxicants with different TLV-TWAs is determined from the equation:

$$\sum_{i=1}^{n} \frac{C_i}{(\text{TLV-TWA})_i},$$

where

n is the total number of toxicants,
C_i is the concentration of chemical i with respect to the other toxicants, and
$(\text{TLV-TWA})_i$ is the TLV-TWA for chemical species i.

If the sum in the above Equation exceeds 1, then the workers are overexposed

The mixture TLV-TWA can be computed from

$$(\text{TLV-TWA})_{\text{mix}} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} \frac{C_i}{(\text{TLV-TWA})_i}}.$$

If the sum of the concentrations of the toxicants in the mixture exceeds this amount,

$$(\text{TLV-TWA})_{\text{mix}} < \sum_{i=1}^{n} C_i$$

then the workers are overexposed.

Example

Air contains 5 ppm of diethylamine (TLV-TWA of 10 ppm), 20 ppm of cyclohexanol (TLV-TWA of 50 ppm), and 10 ppm of propylene oxide (TLV-TWA of 20 ppm). What is the mixture TLV-TWA and has this level been exceeded?

Solution

From Equation 3-4,

$$(\text{TLV-TWA})_{\text{mix}} = \frac{5 + 20 + 10}{\dfrac{5}{10} + \dfrac{20}{50} + \dfrac{10}{20}}$$

$$= 25 \text{ ppm}.$$

The total mixture concentration is 5 + 20 + 10 = 35 ppm. The workers are overexposed under these circumstances.

An alternative approach is to use Equation 3-3:

$$\sum_{i=1}^{3} \frac{C_i}{(\text{TLV-TWA})_i} = \frac{5}{10} + \frac{20}{50} + \frac{10}{20} = 1.40.$$

Because this quantity is greater than 1, the TLV-TWA has been exceeded.

Evaluation of Worker Exposures to Dusts

Dust evaluation calculations are performed in a manner identical to that used for volatile vapors. Instead of using ppm as a concentration unit, **mg/m³** or **mppcf** (millions of particles per cubic foot) is more convenient.

$$(\text{TLV-TWA})_{\text{mix}} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} \frac{C_i}{(\text{TLV-TWA})_i}}.$$

Example 3-5

Determine the TLV for a uniform mixture of dusts containing the following particles:

Type of dust	Concentration (wt.%)	TLV (mppcf)
Nonasbestiform talc	70	20
Quartz	30	2.7

Solution

From Equation 3-4:

$$\text{TLV of mixture} = \frac{1}{\dfrac{C_1}{\text{TLV}_1} + \dfrac{C_2}{\text{TLV}_2}}$$

$$= \frac{1}{\dfrac{0.70}{20} + \dfrac{0.30}{2.7}}$$

$$= 6.8 \text{ mppcf.}$$

Special control measures will be required when the actual particle count (of the size range specified in the standards or by an industrial hygienist) exceeds 6.8 mppcf.

Evaluating Worker Exposures to Noise

Noise evaluation calculations are performed identically to calculations for vapors, except that dBA is used instead of ppm and hours of exposure is used instead of concentration

$$\sum_{i=1}^{n} \frac{C_i}{(\text{TLV-TWA})_i},$$

$$(\text{TLV-TWA})_{\text{mix}} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} \frac{C_i}{(\text{TLV-TWA})_i}}.$$

Table 3-8 Permissible Noise Exposures[1]

Sound level (dBA)	Maximum exposure (hr)
90	8
92	6
95	4
97	3
100	2
102	1.5
105	1
110	0.5
115	0.25

[1]B. A. Plog, ed., *Fundamentals of Industrial Hygiene*, 3d ed. (Chicago: National Safety Council, 1988), p. 176.

Example 3-6

Determine whether the following noise level is permissible with no additional control features:

Noise level (dBA)	Duration (hr)	Maximum allowed (hr)
85	3.6	no limit
95	3.0	4
110	0.5	0.5

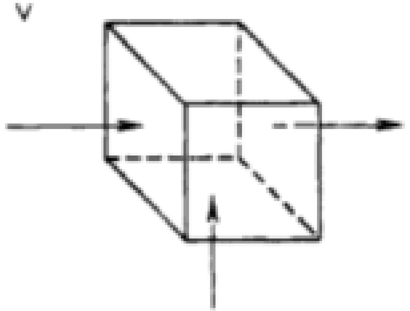
Solution

From Equation 3-3:

$$\sum_{i=1}^{3} \frac{C_i}{(\text{TLV-TWA})_i} = \frac{3.6}{\text{no limit}} + \frac{3}{4} + \frac{0.5}{0.5} = 1.75.$$

Because the sum exceeds 1.0, employees in this environment are immediately required to wear ear protection. On a longer-term basis, noise reduction control methods should be developed for the specific pieces of equipment with excessive noise levels.

Estimating Worker Exposures to Toxic Vapors



$$C_{ppm} = \frac{Q_m R_g T}{k Q_v P M} \times 10^6$$

C be the concentration of volatile vapor in the enclosure (mass/volume),
V be the volume of the enclosure (volume),
Q_v be the ventilation rate (volume/time),
k be the nonideal mixing factor (unitless), and
Q_m be the evolution rate of volatile material (mass/time).

R_g is the ideal gas constant,
T is the absolute ambient temperature,
P is the absolute pressure, and
M is the molecular weight of the volatile species.

- ✓ A steady-state condition is assumed
- ✓ The K varies from 0.1 to 0.5 for most practical situation. For perfect mixing k = 1.

Example 3-7

An open toluene container in an enclosure is weighed as a function of time, and it is determined that the average evaporation rate is 0.1 g/min. The ventilation rate is 100 ft^3/min. The temperature is 80°F and the pressure is 1 atm. Estimate the concentration of toluene vapor in the enclosure, and compare your answer to the TLV for toluene of 50 ppm.

Solution

Because the value of k is not known directly, it must be used as a parameter. From Equation 3-9

$$kC_{ppm} = \frac{Q_m R_g T}{Q_v P M} \times 10^6.$$

From the data provided

$$Q_m = 0.1 \text{ g/min} = 2.20 \times 10^{-4} \text{ lb}_m\text{/min},$$
$$R_g = 0.7302 \text{ ft}^3 \text{ atm/lb-mol °R},$$
$$T = 80°\text{F} = 540°\text{R},$$
$$Q_v = 100 \text{ ft}^3\text{/min},$$
$$M = 92 \text{ lb}_m\text{/lb-mol},$$
$$P = 1 \text{ atm}.$$

Substituting into the equation for kC_{ppm}:

$$kC_{ppm} = \frac{(2.20 \times 10^{-4} \text{ lb}_m\text{/min})(0.7302 \text{ ft}^3 \text{ atm/lb-mol°R})(540°\text{R})}{(100 \text{ ft}^3\text{/min})(1 \text{ atm})(92 \text{ lb}_m\text{/lb-mol})} \times 10^6$$
$$= 9.43 \text{ ppm}.$$

Because k varies from 0.1 to 0.5, the concentration is expected to vary from 18.9 ppm to 94.3 ppm. Actual vapor sampling is recommended to ensure that the TLV is not exceeded.

Estimating the Vaporization Rate of a Liquid

- The vaporization rate is proportional to the difference between the saturation vapor pressure and the partial pressure of the vapor in the stagnant air;

$$Q_m \alpha (P^{sat} - p),$$

Where,

P^{sat} is the saturation vapor pressure of the pure liquid at the temperature of the liquid
p is the partial pressure of the vapor in the bulk stagnant gas above the liquid.

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

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

When $P^{sat} >> p$

Q_m is the evaporation rate (mass/time),
M is the molecular weight of the volatile substance,
K is a mass transfer coefficient (length/time) for an area A,
R_g is the ideal gas constant, and
T_L is the absolute temperature of the liquid.

- The vaporization rate of volatile from an open vessel or from a spill of liquid

- to estimate the concentration (in ppm) of a volatile in an enclosure resulting from evaporation of a liquid

$$C_{ppm} = \frac{KATP^{sat}}{kQ_v PT_L} \times 10^6.$$

- For most situations $T = T_L$

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

$$K = K_o\left(\frac{M_o}{M}\right)^{1/3}.$$

- Water is most frequently used as a reference substance; it has a mass transfer coefficient (K_0) of 0.83 cm/s.

Industrial Hygiene: Control

- This requires the application of appropriate technology for reducing workplace exposures.

- During the design process, the designer must pay particular attention to ensure that the newly designed control technique provides the desired control

- The two major control techniques are:
  - ✓ The Environmental controls and
  - ✓ Personal protection

- Respirators
- Ventilation

Type and explanation	Typical techniques
Enclosures	
Enclose room or equipment and place under negative pressure.	Enclose hazardous operations such as sample points. Seal rooms, sewers, ventilation, and the like. Use analyzers and instruments to observe inside equipment. Shield high-temperature surfaces. Pneumatically convey dusty material.
Local ventilation	
Contain and exhaust hazardous substances.	Use properly designed hoods. Use hoods for charging and discharging. Use ventilation at drumming station. Use local exhaust at sample points. Keep exhaust systems under negative pressure.
Dilution ventilation	
Design ventilation systems to control low-level toxics.	Design locker rooms with good ventilation and special areas or enclosures for contaminated clothing. Design ventilation to isolate operations from rooms and offices. Design filter press rooms with directional ventilation.
Wet methods	
Use wet methods to minimize contamination with dusts.	Clean vessels chemically vs. sandblasting. Use water sprays for cleaning. Clean areas frequently. Use water sprays to shield trenches or pump seals.
Good housekeeping	
Keep toxicants and dusts contained.	Use dikes around tanks and pumps. Provide water and steam connections for area washing. Provide lines for flushing and cleaning. Provide well-designed sewer system with emergency containment.
Personal protection	
As last line of defense.	Use safety glasses and face shields. Use aprons, arm shields, and space suits. Wear appropriate respirators; airline respirators are required when oxygen concentration is less than 19.5%.

Ventilation

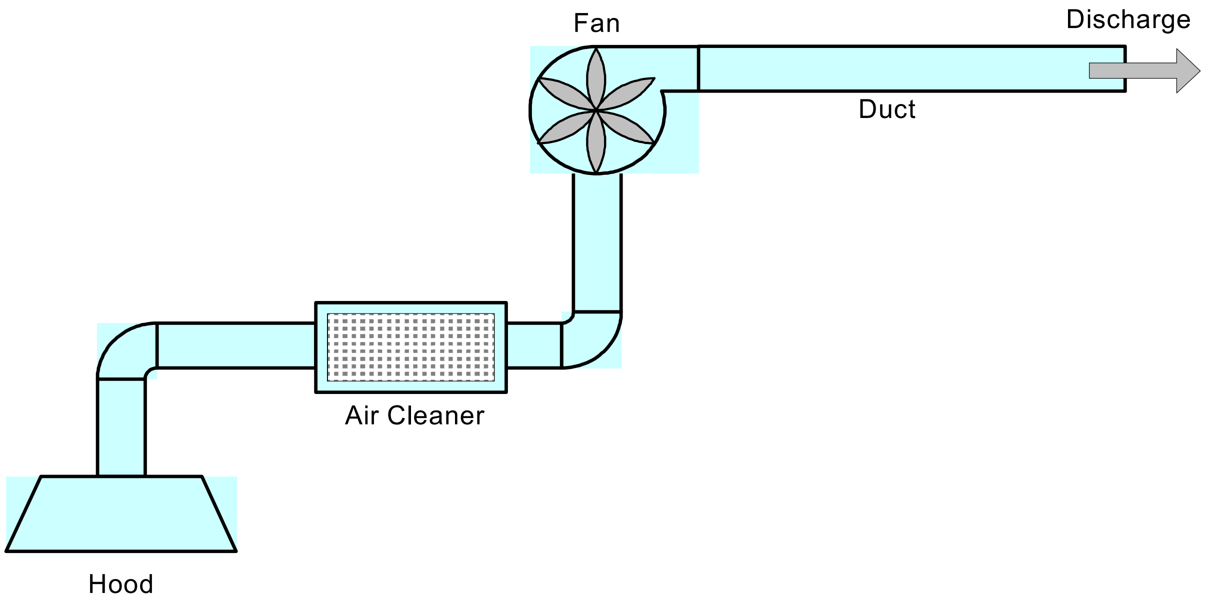
- Ventilation can quickly remove dangerous concentrations of flammable and toxic materials.
- Ventilation can be highly localized, reducing the quantity of air moved and the equipment size.
- Ventilation equipment is readily available and can be easily installed.
- Ventilation equipment can be added to an existing facility
- Ventilation is based on two principles: (1) dilute the contaminant below the target concentration, and (2) remove the contaminant before workers are exposed.

➢ The major disadvantage of ventilation is the operating cost.

- Ventilation systems are composed of fans and ducts.

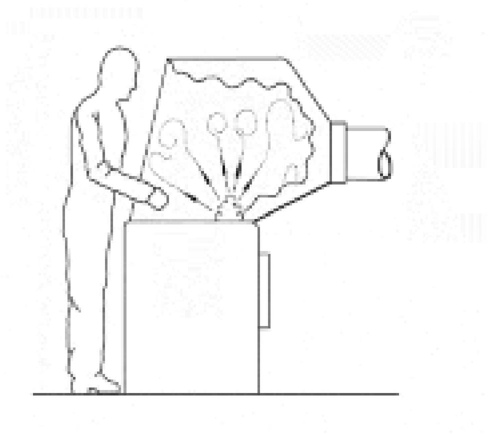
➢ The fans produce a small pressure drop (less than 0.1 psi) that moves the air.

➢ The best system is a negative pressure system, with the fans located at the exhaust end of the system, pulling air out.

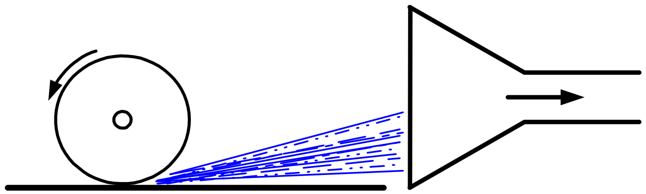


Local Ventilation

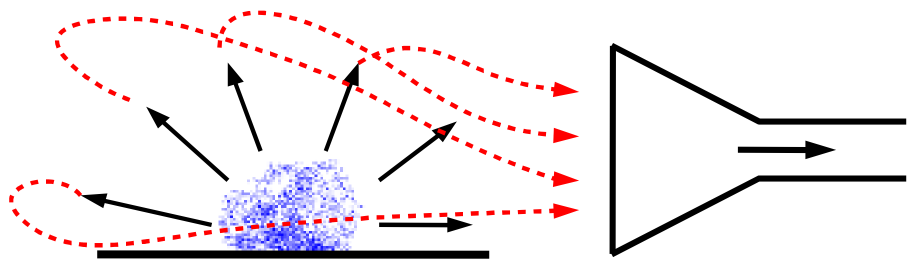
Enclosing (Contain and separate)



Receiving (Receive, contain & empty)



Capturing (Capture)

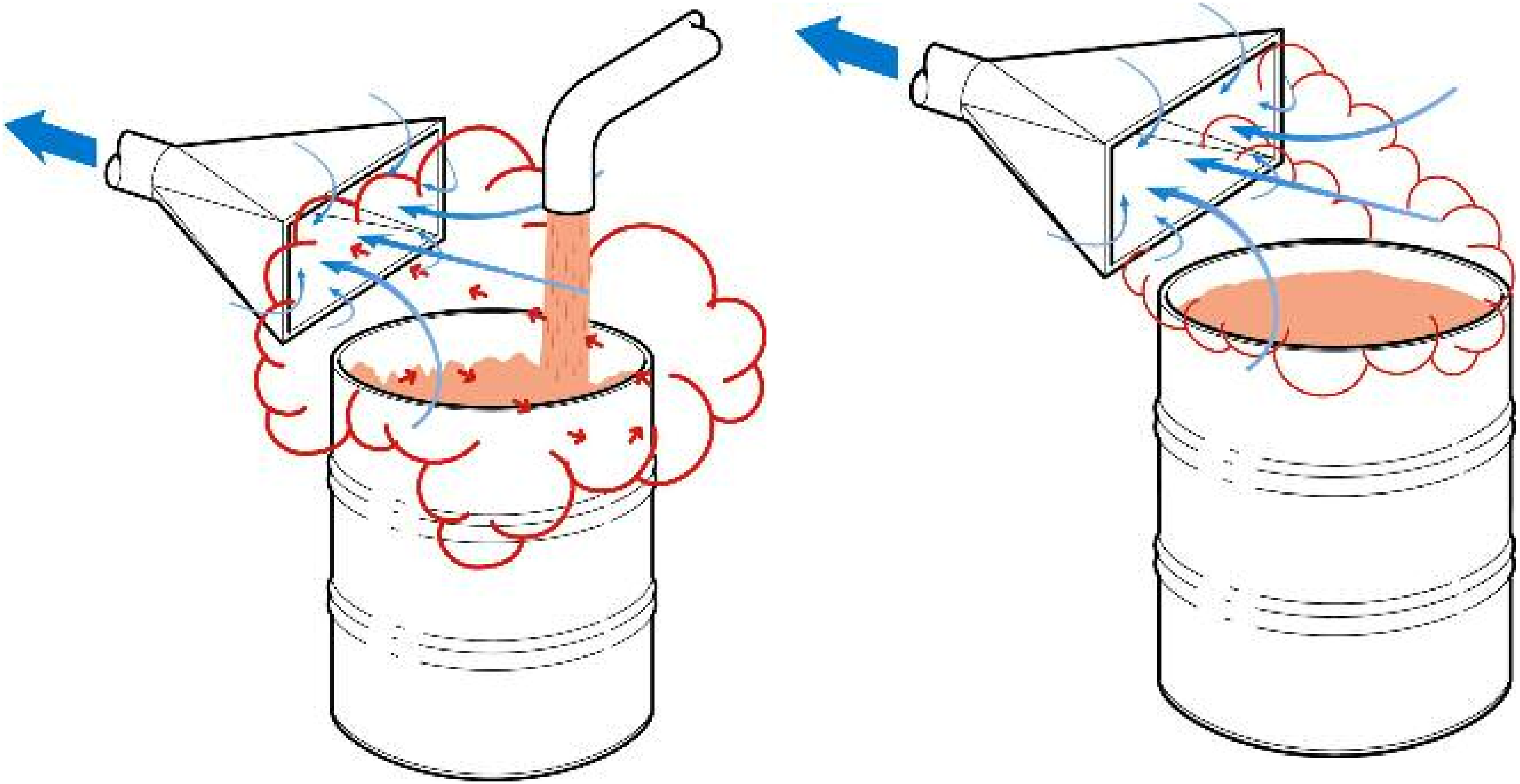


Source: HSE

Main reasons why systems fail to protect:

- Incorrect type of hood is chosen (and could never provide sufficient protection)
- The airborne contaminant isn't contained or captured.
- LEV hood design doesn't match the process and source(s)
- Insufficient airflow (various reasons).

Capturing Hoods



Air Cleaners - Filters

HW

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