KLM Technology Group
P. O. Box 281
Bandar Johor Bahru,
80000 Johor Bahru,
Johor, West Malaysia

Kolmetz Handbook of Process Equipment Design

PROCESS PLANT FACILITY SITING

ENGINEERING DESIGN GUIDELINES

Co Author

Rev 01 Apriliana Dwijayanti

Editor / Author

Karl Kolmetz

Table of Contents

LIST OF FIGURE

LIST OF TABLE

INTRODUCTION

Scope

Appropriate siting and layout establishes a foundation for a safe and secure site. A site that is well laid out will have a lower risk level than a poorly laid out site. The potential for toxic impacts, fire escalation, and explosion damage will be lower. The risk to personnel and the surrounding community will be reduced. Additionally, maintenance will be easier and safer to perform.

Building a new site or adding equipment to an existing one is often an exciting, but daunting, proposition. If it is done well, capital is well invested, goals are met, and the future looks promising. If it is done poorly, money may be wasted, goals unachieved, and the future could be unwittingly compromised.

In designing and building a project, the difference between these two outcomes is greatly influenced by consideration of siting, layout, and other inherently safer design concepts early in the project evolution. If these fundamental issues are addressed too late, costly changes may be required, opportunities for cost-effective protection may be unrecognized, and the new site could actually increase company liability.

General Design Consideration

"Siting" means conducting a review of the location of equipment and piping with regard to:

1) possible impact on human or environmental receptors, or
2) where other plant operations could have impact on the phosgene equipment.

In case one, for example, design layout might consider such items as predominant wind direction and populated areas down wind. In case two, the considerations might include items such as any flammable or potential explosive processes, which - if an event occurred - could have impact on the phosgene equipment

The facility siting study must expand its scope to include evaluation beyond a consequence-only approach. This could include some of the following options:

- Implementation of mitigation measures
- Qualitative risk evaluation
- Event probability assessment
- Fire evacuation, escalation, or dosage analysis
- Pressure-impulse (P-I) curves, structural analysis
- Infiltration analysis

If the above options are not sufficient to qualitatively demonstrate an acceptably low level of risk at a facility, there are several quantitative risk-based methodologies that could be considered:

- Overpressure exceedance
- Probability of building damage
- Full quantitative risk analysis (QRA)
- F-N for occupants

The challenge in facility siting is applying detailed or risk-based analyses in a manner such that building occupant protection is handled consistently for all hazards and for different facilities.

Traditional facility siting studies have for years focused on the overpressure (or blast wave) hazard associated with vapor cloud explosions. Analyses often took the form of overpressure prediction at occupied buildings, with little detailed analysis of other hazards. Fire radiation was sometimes addressed with spacing tables or simple rules. In recent years, more attention has been given to other hazards which may be capable of affecting occupants of buildings.

Clearly, most facility will provide occupant protection in the event of an external flash fire, but the evaluation of flammable gas infiltration has not been extensively applied. Likewise, where toxic gases are present at the facility, dispersion analyses may have evaluated outdoor toxic gas levels, but the additional check for infiltration was often ignored. In addition, most facility do provide shielding against thermal radiation, but an analysis of occupant vulnerability and the potential for escape may have not been performed.

In the comprehensive facility siting study, the list of specific hazards is defined as:

1. Exposure to a blast wave following an explosion which may affect facility occupants
2. Exposure to fire radiation (jet fires, pool fires, and fireballs) which may be capable of igniting the facility or its contents, therefore threatening the occupants
3. Exposure to flammable gas infiltration into the facility, with subsequent build-up to a flammable concentration and ignition, causing occupant impact
4. Exposure to toxic gas infiltration into the facility, with subsequent build-up to a harmful concentration, causing occupant impact

Evaluation of facility acceptability is to be made based on occupant vulnerability, which can be related to facility exposure and/or facility damage.

As a facility siting study progresses, certain facility may be found to be vulnerable to one or more hazard impacts. If a facility siting study reaches this state, there are several options within the comprehensive approach.

- Implement mitigation measures,
- Further detailed analysis specific to the hazards of concern,
- Evaluate the hazards semi-quantitatively, or
- Use a quantitative risk-based approach to demonstrate facility acceptability.

Depending on the tools applied in the consequence analysis and the specific hazards of concern, there are multiple options available. The results of an initial consequence analysis can often be used to justify stopping the analysis, to demonstrate where further detailed analysis is needed, or to help identify effective mitigation measures.

Mitigation Measures

Potential mitigation measures include three major categories: active, passive, and procedural. Active measures are dependent on human, electrical, or mechanical activation; thus, their reliability cannot be guaranteed. Passive measures require no input (decisions or activation) and are inherent to the process, equipment, building, or layout. Procedural measures are written procedures performed by operators or another party that serve to mitigate a hazard.

Some examples of mitigation measures include: relocate personnel offices (passive), install gas detection and HVAC shutdown systems (active), or establishing escape and evacuation routes based on potential hazards (procedural).

Mitigation measures can change the analysis in one of two ways:

- Modification of the consequences to building occupants
- Modification of the probability of an undesired outcome(s)

Mitigation measures which change the consequence analysis can easily be quantified. However, modifications affecting probability can be difficult to properly quantify, so caution should be used when applying mitigation measures to modify event probabilities.

Mitigation measures can be reviewed and implemented at any time in the study, but implementation is more effective following a consequence analysis. This way a breakdown of the potential hazards can be utilized to determine the appropriate mitigation measures.

Explosion Impacts

If significant impacts to facility are found to result from explosion events, a detailed blast analysis can provide a better description of the potential impacts. Explosion (or blast wave) analysis involves three steps:

1. Blast impact calculation (overpressure, or overpressure and impulse)
2. Building damage level assessment (BDLA)
3. Occupant vulnerability assessment

Building occupant vulnerability is often tied directly to the BDLA, but is sometimes expressed by an independent function (e.g., occupant fatality as a function of the percent building damage). Care must be taken that BDLA categories match the actual building construction, or are selected conservatively (i.e., they tend to over-predict building damage and therefore occupant vulnerability).

A final concern for overpressure impacts on occupied buildings is windows. The inclusion of windows in buildings can introduce potentially lethal hazards that occur at lower overpressures (or lower P-I levels) than lethal hazards from building structural failures. Because of this, the placement, design, and construction of windows must be considered in addition to the structural impacts.

Radiation

Fire radiation hazards have the potential to ignite occupied facilitys. Facilitys may be screened for vulnerability based on a thermal radiation flux. If further analysis is required, a facility impact evaluation may be based on a transient exposure analysis, with consideration of the materials and type of construction for that facility. The total fire radiation exposure (or dose) is a function of the fire's intensity and the duration of exposure.

Evacuation from a building may also be considered. It is possible that a building can be ignited due to fire exposure and the occupants can still safely evacuate. An evacuation analysis should consider occupants' exposure as they evacuate, due to the fire event that is impacting the building, accounting for decision delay times, escape path and speed, and any potential shielding.

As with overpressure, windows must also be considered. Windows can allow thermal radiation into a building, potentially igniting flammable materials in less time than ignition of the building exterior.

Infiltration

All hazardous releases resulting in a hazardous gas exposure to a facility, whether it is toxic or flammable, should be included as infiltration hazards. Facility can be screened for gas infiltration by ensuring the impacts do not expose persons immediately outside the occupied building. A more detailed analysis may implement an infiltration model either at the start of the analysis or after the screening.

Infiltration models calculate the facility's exposure to an outside gas concentration that is necessary to create a hazardous environment inside the building. Infiltration is characterized by an infiltration rate (or air exchange rate), which is based on a building's construction type and condition. Special consideration should be taken when outside air intakes are present. When applying an infiltration model it is also important to consider the event duration and the vapor dispersion characteristics of multiple release hole sizes to capture the maximum impacts.

Qualitative Risk Assessment

If the consequence analysis shows that the occupants may be impacted and no feasible mitigation measures can be applied, then a qualitative risk-based argument regarding facility impacts can be considered. The selection of a maximum credible event (MCE) defines something that is considered more likely to occur than the worst-case events.

This is typically accomplished by defining a maximum release hole size to represent the MCE. Because smaller release hole sizes are generally more frequent than larger ones, the MCE magnitude is then expected to occur more frequently than worst-case scenarios. When a facility is outside the MCE vulnerability zone, an acceptable level of risk (semi-quantitatively) is often assumed. However, if the MCE hazards also impact a facility, there are further levels of probabilistic analysis that can be done.

Besides the hole size definition of an MCE, consider that the MCE impacts are often a function of:

- Release orientation (initially assumed horizontal, with the wind),
- Worst-case weather conditions, and
- Wind direction, where any direction is possible.

In some facility siting studies, the MCE impacts come from a small number of potential events. When this is the case, additional probabilistic evaluation can often show that the MCE with a horizontal orientation and worst-case weather conditions (including wind direction) represent only a small fraction of the range of potential outcomes. If so, this approach can be used to show that the risk to a facility is believed to be sufficiently low, such that its location is acceptable.

Facility Siting Study Methodology

The first step of any facility siting study serves to identify potential hazards and determine which facility, should be included in the analysis. This involves collection of information and a review of the process to determine the potential hazards that are inherent to the materials being handled.

Next, the consequence analysis serves to evaluate the potential consequences of the hazards identified in the screening analysis. The siting assessment can be stopped after the consequence analysis if it can be shown that adequate protection against either the worst-case or MCE scenarios is provided for facility occupants through facility spacing, facility construction, process controls, or other engineering methods (mitigation). A qualitative risk analysis combines consequence analysis and estimates of release frequencies to arrive at a qualitative measure of the risk posed to facility occupants.

An advanced step for a facility siting analysis involves the application of quantitative risk-based evaluations, which often take the form of a QRA, a much more rigorous process than the initial assessment or consequence analysis steps. Quantitative methods first generate hazard footprints for a full range of release sizes, locations, and weather conditions. Next, the frequency of occurrence of each hazard footprint is determined using equipment failure frequencies, conditional probabilities, and site-specific weather data.

All calculated hazard zones, with their respective probabilities and originating locations, are combined to produce measures of risk which demonstrate the frequency with which an event originating in the facility could adversely impact an occupied facility and its occupants. Selecting measures of risk is based on the type and nature of the hazards affecting the facility occupants, and is informed by the consequence analysis portion of the study.

The impact to facility occupants is determined by building damage levels or the selected hazard endpoints, which reflect the vulnerability of facility occupants due to vapor cloud explosions, fires, toxic vapor clouds, and/or flammable vapor clouds. If the level of risk to building occupants is found to be acceptable, the analysis is complete. If not, mitigation measures that reduce event consequences or probabilities (or both) are implemented. The risk-based analysis can then be repeated, with modifications of the event consequences and/or probabilities based on mitigation measures to determine the risk, ending when the risk is found to be below the selected criterion.

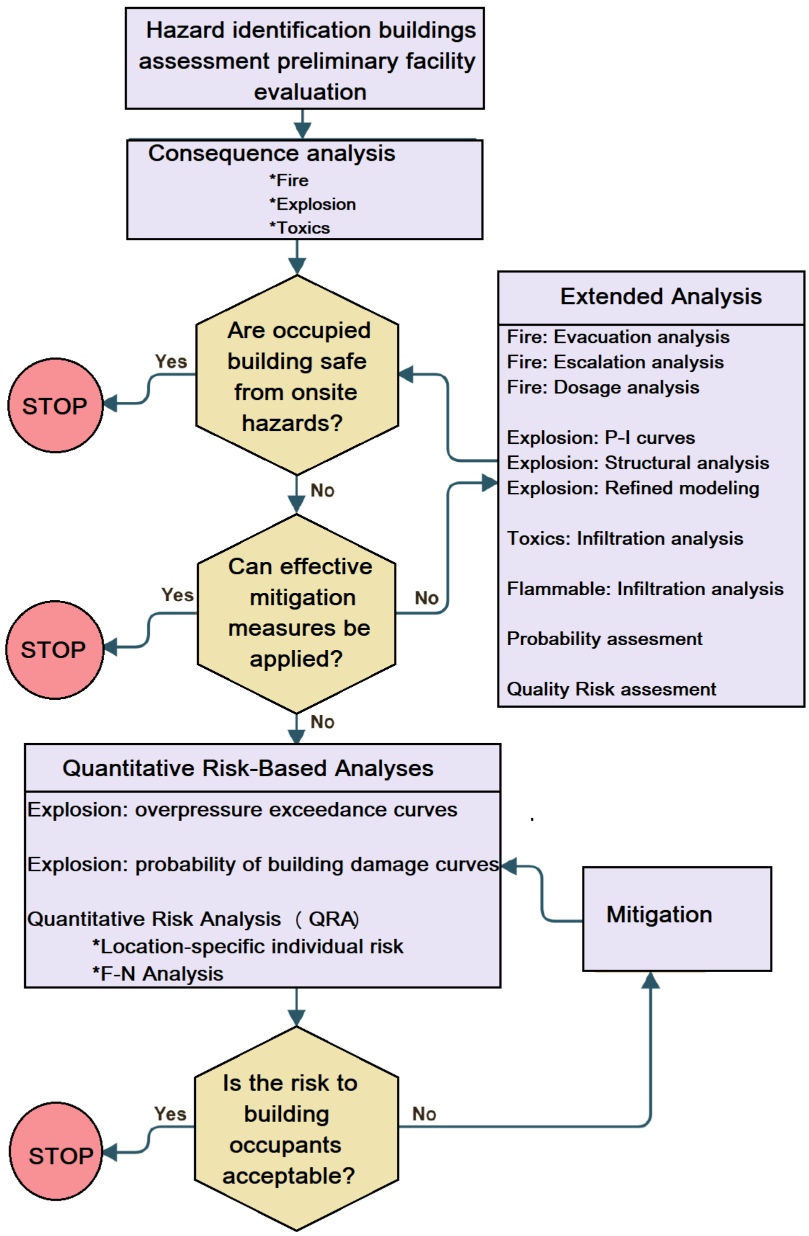

Figure 1. Summary of Building Siting Methodology

Good plant layout is as important as ever today. 79% of process plant accidents involved a design error, and the most common type of design error leading to accidents was poor layout.

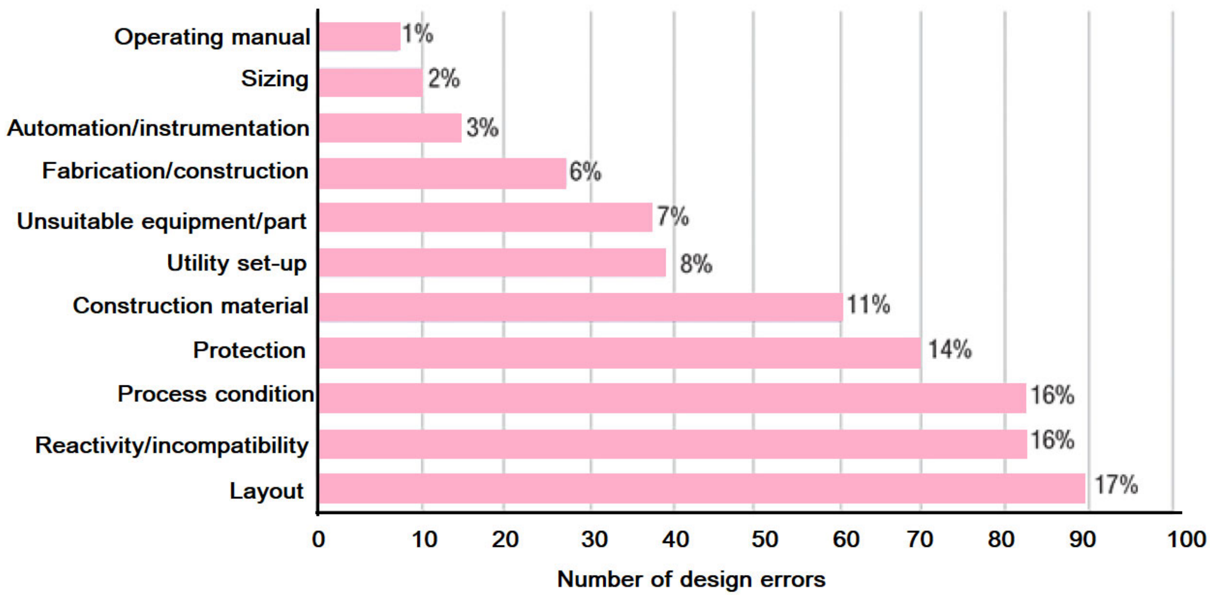

Figure 2. Design errors that occur most often in the CPI

Layout designers have to consider three separate things:

1. Site layout — How plots relate to each other within the overall site, and with other activities outside the site
2. Plot layout — The consideration of how process units relate to each other's disposition within a plot
3. Equipment layout — The consideration of the arrangement of process units and associated or attendant items around a process unit

DEFINITIONS

Autoignition temperature - The minimum temperature at which combustion can be initiated without an external ignition source.

Blast load - The load applied to a structure or object from a blast wave, which is described by the combination of overpressure and either impulse or duration.

Blast: A transient change in the gas density, pressure, and velocity of the air surrounding an explosion point.

Blast resistant buildings: Buildings that are structurally designed to withstand an explosion generated load (pressure and impulse) while sustaining a predetermined amount of damage.

Blast wave: The overpressure wave traveling outward from an explosion point

BLEVE: A Boiling Liquid Expanding Vapor Explosion is a blast resulting from the sudden release and nearly instantaneous vaporization of a liquid under greater-than-atmospheric pressure at a temperature above its atmospheric boiling point. The material may be flammable or nonflammable. A BLEVE is often accompanied by a fireball if the contained liquid is flammable and its release results from vessel failure.

Building - A rigid, enclosed structure.

facility siting evaluation - The procedures described in this document used to evaluate the hazards and establish the design criteria for new buildings and the suitability of existing buildings at their specific location.

Confinement - A physical surface that inhibits the expansion of a flame front of a burning vapor cloud in at least one direction. Examples include solid decks, walls, or enclosures.

Congestion - A collection of closely spaced objects in the path of the flame front that has the potential to increase flame speed to an extent that it can generate a damaging blast wave.

Consequence - The potential effects of an explosion, fire, or toxic material release. Consequence descriptions may be qualitative or quantitative. The direct, undesirable result of an accident sequence usually involving a fire, explosion, or release of toxic material. Consequence descriptions may be qualitative or quantitative estimates of the effects of an accident in terms of factors such as health impacts, economic loss, and environmental damage.

Consequence-based approach - The methodology used for facility siting evaluation that is based on consideration of the impact of explosion, fire, and toxic material release which does not consider the frequency of events

Combustible liquids: Any liquid that has a closed-cup flash point at or above 100ºF (37.8ºC), as determined by the test procedures defined in NFPA 30. Combustible liquids are classified as Class II or Class III as follows:

a. Class II Liquid. Any liquid that has a flash point at or above 100ºF (37.8ºC) and below 140ºF (60ºC).
b. Class IIIA. Any liquid that has a flash point at or above 140ºF (60ºC), but below 200ºF (93ºC).
c. Class IIIB. Any liquid that has a flash point at or above 200ºF (93ºC). (NFPA 30)

Combustion: exothermic chemical reaction with oxygen as a primary reagent.

Conceptual design: The initial design of a project when basic parameters are known but design details have yet to be developed.

Consequence analysis: The analysis of the expected effects of incident outcome cases independent of frequency or probability

Essential personnel - Personnel with specific work activities that require them to be located in buildings in or near a process area for logistical and response purposes. The identification of essential personnel will vary with operation and work activities including normal operation, start-up, and planned shutdown. Examples of essential personnel include, but are not limited to, operators and maintenance personnel. Examples of persons who are not essential personnel include, but are not limited to, designers, timekeepers, clerical staff, administrative support, and procurement staff.

Emergency shutdown (ESD) system: The safety system which overrides the action of the basic control system when predetermined conditions are violated.

Explosion - A release of energy that causes a pressure discontinuity or blast wave.

Explosion Overpressure - Any pressure above atmospheric caused by a blast.

Facility - A portion of or complete plant, unit, site, complex or any combination thereof.

Fire - A combustion reaction accompanied by the evolution of heat, light, and flame.

Fire protection - Methods of providing for fire control or fire extinguishment

Flammable liquids - Any liquid that has a closed-cup flash point below 100ºF (37.8ºC), as determined by the test procedures described in NFPA 30 and a Reid vapor pressure not exceeding 40 psia (2068.6 mm Hg) at 100ºF (37.8ºC), as determined by ASTM D 323, Standard Method of Testfor Vapor Pressure of Petroleum Products (Reid Method). Flammable liquids are classified as Class I as follows:

a) Class IA liquids shall include those liquids that have flash points below 73ºF (22.8ºC) and boiling points below 100ºF (37.8ºC).
b) Class IB liquids shall include those liquids that have flash points below 73ºF (22.8ºC) and boiling points at or above 100ºF (37.8ºC).
c) Class IC liquids shall include those liquids that have flash points at or above 73ºF (22.8ºC), but below 100ºF (37.8ºC).

Flash fire - The combustion of a flammable gas or vapor and air mixture in which the flame propagates through that mixture in a manner such that negligible or no damaging overpressure is generated. (CCPS, 1994)

Flash point - The temperature at which the vapor-air mixture above a liquid is capable of sustaining combustion after ignition from an external energy source

Greenfield - Undeveloped property that is being considered as a site for construction.

Hazard

An inherent physical or chemical characteristic (e.g. flammability, toxicity, corrosivity, stored chemical energy, or mechanical energy) that has the potential for causing harm to people, property, or the environment.

Hazard evaluation - The analysis of hazardous situations associated with a process or activity, using techniques to identify weaknesses in design and operation.

Hazardous material - In a broad sense, any substance or mixture of substances having properties capable of producing adverse effects on people, property, or the environment. Such materials may be flammable, combustible, toxic, reactive, unstable or corrosive.

Hazardous waste - A solid waste, or combination of solid waste, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may (a) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

Incident - An unplanned event with the potential for undesirable consequences.

Inert - A chemical that does not react chemically with other substances.

Infrastructure - The basic facilities, services, and installations needed for the functioning of a site such as transportation and communications systems, water and power lines, and public institutions including emergency response organizations.

Inherently safer - A condition in which the hazards associated with the materials and operations used in the process have been reduced or eliminated, and this reduction or elimination is permanent and inseparable.

Jet fire - A fire type resulting from the discharge of liquid, vapor, or gas into free space from an orifice, the momentum of which induces the surrounding atmosphere to mix with the discharged material.

Layout The relative location of equipment or buildings within a given site.

LFG (Liquefied Flammable Gas): Any flammable gaseous material or mixture of materials that is in liquid form under pressure.

Maximum credible event (MCE) - A hypothetical explosion, fire, or toxic material release event that has the potential maximum consequence to the occupants of the building under consideration from among the major scenarios evaluated. The major scenarios are realistic and have a reasonable probability of occurrence considering the chemicals, inventories, equipment and piping design, operating conditions, fuel reactivity, process unit geometry, industry incident history, and other factors. Each building may have its own set of MCEs for potential explosion, fire, or toxic material release impacts.

Mitigation - An act that causes a consequence to be less hazardous

Mitigation factors - Systems or procedures, such as water sprays, foam systems, and sheltering and evacuation, which tend to reduce the magnitude of potential effects due to a release.

Occupant vulnerability - Proportion of building occupants that could potentially suffer a permanent disability or fatality if a potential event were to occur.

On-site personnel - Employees, contractors, visitors, service providers, and others present at the facility.

Off-site exposure - People, property, or the environment located outside of the site property line that may be impacted by an on-site incident

Pool fire - The combustion of material evaporating from a layer of liquid at the base of a fire

Process area - An area containing equipment (e.g. pipes, pumps, valves, vessels, reactors, and supporting structures) intended to process or store materials with the potential for explosion, fire, or toxic material release.

Quantitative risk assessment - The systematic development of numerical estimates of the expected frequency and consequence of potential accidents based on engineering evaluation and mathematical techniques. The numerical estimates can vary from simple values of probability/frequency of an event occurring based on relevant historical industry or other available data; to very detailed frequency modeling techniques.

Risk - A measure of potential injury, environmental damage, or economic loss in terms of both the incident likelihood and the severity of the loss or injury.

Risk-based approach - A quantitative risk assessment methodology used for facility siting evaluation that takes into consideration numerical values for both the consequences and frequencies of explosion, fire, or toxic material release.

Risk analysis - The development of a quantitative estimate of risk based on engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies.

Risk assessment - The process by which the results of a risk analysis are used to make decisions either through a relative ranking of risk reduction strategies or through comparison with risk targets. (

Spacing tables approach - The "spacing tables" approach uses established tables to determine minimum separation distances between equipment and buildings intended for occupancy. Industry groups, insurance associations, regulators, and owner/operator companies have developed experience-based spacing tables for minimum building spacing for fire.

Self-igniting - The ignition and sustained combustion of a substance without introduction of any ignition source besides thermal energy or heat of reaction resulting when combined with other substances in the surrounding environment. Self-igniting materials include materials above their autoignition temperature, chemicals that ignite due to heat of reaction with oxygen in air, and chemicals that are unstable and spontaneously combust when released.

Siting - The process of locating a complex, site, plant, or unit.

Toxic material - An airborne agent that could result in acute adverse human health effects.

Vapor cloud explosion (VCE) - The explosion resulting from the ignition of a cloud of flammable vapor, gas, or mist in which flame speeds accelerate to sufficiently high velocities to produce significant overpressure.

REFFERENCES

1. K Kolmetz et al, Kolmetz Handbook of Process Equipment Design, Process Plant Layout Selection and Sizing, Engineering Design Guidelines, 2020

2. K Kolmetz et al, Kolmetz Handbook of Process Equipment Design, Safety in Process Equipment Design, Engineering Design Guidelines, 2014

3. K Kolmetz et al, Kolmetz Handbook of Process Equipment Design, Process Safety Managment, Engineering Design Guidelines, 2015

4. K Kolmetz et al, Kolmetz Handbook of Process Equipment Design, Safery Risk Management and Loss Prevention, Engineering Design Guidelines, 2016

5. Jeffrey D. Marx and Benjamin R. Ishii. A Comprehensive Approach to API RP 752 and 753 Building Siting Studies. Mary Kay O'Connor Process Safety Center International Symposium. College Station, TX. 2015.

6. API 752. Management of Hazards Associated with Location of Process Plant Permanent Buildings. 2009

7. Guidelines For Facility Siting And Layout. Center for Chemical Process Safety of the American Institute of Chemical Engineers. 2003

8. Seán Moran, Process Plant Layout — Becoming A Lost Art? 2016