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	Page 14	Estimation of AIT for a multi-component mixture
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SCOPE

This section covers the requirements, which must be incorporated into plant designs to insure that the risks of fire, explosion and other accidents are minimized.

REFERENCES

DESIGN PRACTICES (BESIDES OTHER SECTIONS OF SECTION XV)

Section II	Design Temperature, Design Pressure and Flange Rating
Section V	Drums
Section VIII	Fired Heaters
Section X	Pumps
Section XI	Compressors
Section XIV	Fluid Flow

ENVIRONMENTAL DESIGN PRACTICES

Section XVIII-A2	Control of Hydrocarbons, VOC and Air Toxic Emissions
Section XVIII-B2	Emission/Equipment/Exposure Review (EEER)

OFFSITE DESIGN PRACTICES

Section XXII	Storage Facilities

GLOBAL PRACTICES

The Global Practices listed below are referred to in this section. However, in view of the broad scope of this section, reference to other Global Practices may be necessary for particular safety design problems.

GP 03-02-01,	Sewer Systems
GP 03-02-02,	Foam Systems for Storage Tanks
GP 03-03-02,	Suction and Discharge Piping for Centrifugal Pumps
GP 03-03-03,	Flushing and Drain Piping for Centrifugal and Rotary Gas Compressors
GP 03-03-05,	Suction, Discharge and Interstage Piping for Reciprocating Compressors
GP 03-03-06,	Closed Cooling Water Systems for Internal Combustion Engines and Reciprocating Compressors
GP 03-03-07,	Inlet and Exhaust Piping for Steam Turbines
GP 03-03-08,	Washing Systems for Steam Turbines
GP 03-03-10,	Strainers for Mechanical Equipment
GP 03-03-12,	Oil Mist Lubrication Systems
GP 03-04-01,	Piping for Fired Equipment
GP 03-05-01,	Fill and Discharge Lines, and Auxiliary Piping for Storage Tanks and Vessels
GP 03-06-03,	Utility Connections to Piping and Equipment
GP 03-09-01,	Winterizing and Protection Against Ambient Temperatures
GP 03-12-01,	Valve Selection
GP 04-02-01,	Auxiliary Structures for Operation and Maintenance
GP 04-03-01,	Plant Buildings for Operation and Storage
GP 04-03-02,	Blast Resistant Buildings
GP 04-06-02,	Supporting Structures and Foundations for Heavy Machinery
GP 07-01-01,	Fired Heaters
GP 07-02-01,	Industrial Boilers
GP 09-01-01,	Spacing and Dikes for Storage Vessels and Tanks
GP 09-04-01,	Atmospheric Storage Tanks
GP 09-07-01,	Accessories for Atmospheric Storage Tanks

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GP 09-07-03, Vents for Fixed Roof Atmospheric Storage Tanks
GP 10-01-01, Centrifugal Pumps
GP 10-02-01, Positive Displacement Pumps - Reciprocating
GP 10-03-01, Special Purpose Centrifugal Compressors
GP 10-03-02, Packaged, Integrally Geared Centrifugal Air Compressors
GP 10-03-03, Rotary Screw Compressors
GP 10-04-01, Reciprocating Process Compressors
GP 10-07-01, General Purpose Steam Turbines
GP 10-07-02, Special Purpose Steam Turbines
GP 10-08-01, Combustion Gas Turbines
GP 10-09-01, Mechanical Agitators
GP 10-10-01, Special Purpose Gear Units
GP 10-11-01, Sizing of Drivers and Transmissions for Compressors, Fans and Pumps
GP 10-12-01, Vibration, Axial Position and Bearing-Temperature Monitoring Systems for Compressors and Drivers
GP 10-13-01, Special Purpose Centrifugal Fans
GP 14-01-01, External Insulation
GP 14-03-01, Fireproofing
GP 15-01-01, Instrumentation for Fired Heaters
GP 15-07-01, Electric Power Branch Circuit Design for Instrumentation
GP 15-08-01, Process Stream Analyzers
GP 15-10-01, Instrument Transmission Systems
GP 16-01-01, Area Classification and Related Electrical Design for Flammable Liquids, Gases, or Vapors
GP 16-01-02, Area Classification and Related Electrical Design for Combustible Dust
GP 16-03-01, Wiring Methods and Material Selection
GP 16-04-01, Grounding and Overvoltage Protection
GP 16-06-01, Substation Layout
GP 17-04-01, Safety Shields for Piping and Equipment
GP 18-04-01, Postweld Heat Treatment of Equipment Handling Alkaline Solutions
GP 18-10-01, Additional Requirements for Materials
GP 19-05-01, Cathodic Protection

OTHER COMPANY REFERENCES

Refinery Construction Materials Manual, ER&E Manual No. EETD 028, December 1, 1996.
Chemical Construction Materials Manual, ER&E Manual No. CED 009, July 1, 1997.
The Metal Carbonyls, Report No. MDR-14-70.
BELA-5 Acetylene Safety Problems, EE Letter No. 50633, January 26, 1971.
G/L for the Evaluation of Dead-Legs in Refinery Piping Systems, Report No. EE.37E.80.
Guidelines for Prevention of Electrostatic Ignitions, Report No. EE.3M.96.
Design and Operating Guidelines for Filling Small Plastic Drums with Flammable Liquids, Report No. EE.70E.83.
Guidelines for Protecting Atmospheric Storage Tanks from Rundown Heat Exchanger Tube Failure, Report No. EE.84E.83.
Safe Storage and Handling of Asphalts, Report No. EE.85E.83.
Electrostatic Precautions with Metal Filters, Report No. EE.86E.83.
Safety and Fire Protection - Newsletter 84-3, Frangible Roofs - Are They Needed?, Report No. EE.36E.84.

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Fire Safety of Plate Heat Exchangers, Report No. EE.47E.87.

Safe Asphalt Operations Study, Letter No. 91 ECS3 016.

Preventing Fires and Explosions Caused by Pyrophoric Materials, Report No. EE.84E.92.

Pump Sealing Technology Manual, ER&E Manual No. TMEE.23.

Safety Technology Manual, ER&E Manual No. TMEE 073.

OTHER LITERATURE

API RP 500, *Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class 1, Division 1 and Division 2*

API 610, *Centrifugal Pumps for Petroleum, Heavy Duty Chemical and Gas Industry Services*

API 611, *General Purpose Steam Turbines for Refinery Service*

API 612, *Special Purpose Steam Turbines for Petroleum, Chemical and Gas Industry Services*

API 613, *Special Purpose Gear Units for Petroleum, Chemical and Gas Industry Services*

API 616, *Gas Turbines for General Refinery Services*

API 617, *Centrifugal Compressors for Petroleum, Chemical and Gas Industry Services*

API 618, *Reciprocating Compressors for Petroleum, Chemical and Gas Industry Services*

API 650, *Welded Steel Tanks for Oil Storage*

API 2000, *Venting Atmospheric and Low Pressure Storage Tanks*

API 2003, *Protection Against Ignition Arising out of Static, Lightning, and Stray Currents*

API 2216, *Ignition Risk of Hydrocarbon Vapors by Hot Surfaces on the Open Air*

Bulletin 627, *Flammability Characteristics of Combustible Gases and Vapors*, U.S. Bureau of Mines

Safety Health and Welfare Booklet No. 34, *Guide to the Use of Flame Arresters and Explosion Reliefs*, Ministry of Labour (U.K.)

Factory Mutual Engineering Corp., *Handbook of Industrial Loss Prevention*, 1967

NFPA 30, *Flammable and Combustible Liquids Code*

NFPA 68, *Explosion Venting Guide*

NFPA 70, *National Electrical Code*

NFPA 325, *Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids*

NFPA 496, *Purged Enclosures for Electrical Equipment in Hazardous Locations*, National Fire Protection Association

NFPA 497, *Classification of Flammable Liquids, Gases or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*

NFPA 499, *Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*

NFPA 505, *Powered Industrial Trucks Including Type Designations, Areas of Use, Maintenance, and Operation*

National Materials Advisory Board, NMAB 353-5, *Classification of Gases, Liquids, and Volatile Solids Relative to Explosion-Proof Electrical Equipment*

GENERAL

The basic principles underlying the incorporation of safety into plant designs are described in Section XV-A. The first of these, the recognition and elimination of hazards, includes the consideration of fire, explosion and other accident potentials. To minimize the risks of fire, explosion and other accidents, the general design approach consists of the following:

- Preventing uncontrolled releases of flammable or toxic materials, such as those, which may result from equipment failure, improper materials or incorrect procedures.
- Minimizing the number of ignition sources.
- Preventing the formation of hydrocarbon/air mixtures in the flammable range within process equipment.
- Insuring that the plant is safe and operable for personnel.
- Preventing runaway exothermic reactions.

These five general areas of design are described in detail in this section. The design of protective features to prevent equipment failure from overstressing as a result of instrumentation malfunctions, utility failure, maloperations, etc. is covered in Section XV-C.

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INHERENT SAFETY IN DESIGN

The risk associated with flammable and toxic materials is a combination of the probability and the consequences of their release. To reduce risk, a design must reduce the probability or the consequence of a release, or both. Risk is reduced by inherent and extrinsic safety features. (Inherent is used instead of intrinsic to avoid confusion with the “intrinsically safe" electrical classification.)

There are five inherent safety principles, which can reduce the risk associated with hazardous material:

1. **Substitute a less hazardous material for a more hazardous one, where feasible.** The substitution can involve process raw materials or utility materials. Process raw materials usually have to be considered early in the development stage, but utility materials may be substituted even in the later design stages. For instance, in selecting water treatment chemicals, chlorine can be replaced by sodium hypochlorite.
2. **Reduce the inventory in storage and process vessels to a practical minimum.** Inventory can be reduced in the obvious way by reducing hold up or surge capacity. Less obvious ways include increasing the reaction rate, possibly through better mixing or increasing yield to reduce recycle rate, both reduce reactor volume.
3. **Reduce the severity (attenuation) of the conditions under which hazardous material is used.** For exothermic or decomposition reactions, heat input might be limited by selection of an appropriate temperature heating medium. The reactant might also be diluted to reduce the size of the exotherm. Several guidelines are given in this section on how to avoid the generation of static electricity, which is another form of attenuation.
4. **Simplify the process to reduce the potential for operating error.** When flexibility is desired, it should be weighed against the increased complexity, which it creates, and the increase in the associated risk of operating error.
5. **Avoid or mitigate potential operating errors or equipment failures through fault tolerant design.** For example, incompatible connectors are used on plant air and nitrogen utility stations to avoid cross connection, and appropriate spacing between process units will mitigate the impact of a problem from one unit on another.

Extrinsic safety features are devices, which are added on to the process. Extrinsic devices are used to reduce the probability of a loss of containment, such as alarms, cutouts, and deluge systems. They also mitigate the consequences of a release, such as emergency isolation valves; water curtains to disperse vapor clouds and firewater systems.

Inherently safe features may be considered to be passive and built in while extrinsic features are devices, which are active and added on. Extrinsic devices must be maintained and tested to be reliable, while designed in inherent safety remains reliable with no continuing maintenance or cost.

Properly applied, inherent safety can result in a reduction in cost. Vessels get smaller or are eliminated, operating conditions change, and less add-on safety equipment may be required. To get the maximum benefit, inherent safety features should be incorporated as early as possible in the design. However, even after inherent safety principles are applied, extrinsic safety devices will still be required to further reduce the risk of a loss of containment.

Example Problem - Inherent Safety

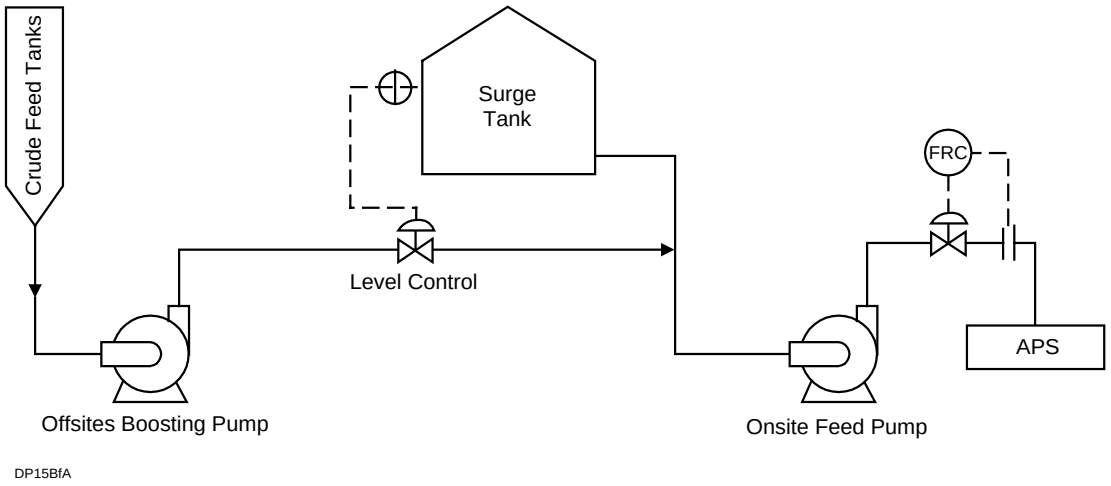
An Exxon refinery pumped crude oil from offsite tankage to an atmospheric pipestill. Because of concerns over the reliability of the offsite pumps, an onsite feed surge tank was included in the design. The surge tank was normally full and provided 20 minutes of holdup to allow offsite pumps to be restarted without affecting the pipestill operation. The tank had a single level controller, which alarmed at high and low levels. The tank was also surrounded by a dike, which held the full volume of the tank.

An overfill of this crude oil surge tank, due to level indication failure, ultimately resulted in a fire.

Following the incident, an inherently safer operation was instituted by removing the surge tank from service. This reduced inventory rather than control it by adding on level alarms, foam systems, etc. The onsite feed pump was also eliminated by feeding directly from the offsite pumps. The operation of a second atmospheric pipestill with a feed surge tank was also changed to eliminate the tank and feed pump. The additional cost to provide good reliability from the offsite pumps was more than offset by the savings in reduced maintenance costs for the surge tanks and the feed pumps.

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PREVENTING UNCONTROLLED RELEASE OF FLAMMABLE MATERIALS

Containment is the key strategy for preventing fires, explosions, and toxic releases. Uncontrolled releases are likely to be the result of equipment failure or incorrect procedures. The following aspects of plant designs are particularly important in preventing such releases:

S

MATERIALS OF CONSTRUCTION

Appropriate materials of construction must be specified in plant designs, taking into consideration all anticipated service conditions, including variations in temperature and corrosive conditions that may occur during operation. Reference should be made to the Refinery Construction Materials Manual and the Chemical Construction Materials Manual for guidance. When materials of construction which are more than usually vulnerable to failure (e.g., low melting point alloys, Karbate, etc.) are used, the need for additional protection, such as emergency isolation valves or fireproofing should be considered. See Sections XV-F and H, respectively.

The selection of materials of construction for refrigerated or cryogenic processes, or where volatile materials may autorefrigerate, must be such as to avoid brittle fracture under all anticipated operating conditions. Abnormal situations such as emergency shutdowns, loss of heat exchange, depressuring, etc., must be analyzed to determine the most severe low-temperature conditions to which equipment can reasonably be expected to be exposed. Safety valve discharge headers, flare lines and vent stacks are especially vulnerable to low-temperature exposures during upset or emergency conditions, if liquid is released. Reference should be made to Section II for considerations, which must be included in the selection of design temperatures.

The Refinery Construction Materials Manual and the Chemical Construction Materials Manual provide the basis for materials selection. Impact requirements for materials are covered by **GP 18-10-01**.

Where ambient conditions may be below -20°F (-29°C), the design should recognize the potential for brittle fracture in carbon steel pipe during startup.

Monitoring and Control of Operating Conditions - In many processes, corrosion and other hazardous effects can be effectively limited by proper control of operating conditions. Instrumentation must be provided to monitor and control the appropriate equipment and process variables. Corrosion probes and analyzers (e.g., pH meters) are required in certain highly corrosive services, per the Refinery Construction Materials Manual.

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S SAFE MACHINERY INSTALLATIONS

Operating machinery is potentially hazardous, because of: (a) the kinetic energy which may be released in highly destructive form in the event of mechanical failure, and (b) the vulnerability of shaft seals to failures which may release large quantities of flammable fluids.

The protective features, which are provided in machinery designs, are summarized below. Further details of their design and application may be obtained from the following references:

- Section X, *Pumps*.
- Section XI, *Compressors*.
- **GP 10-01-01** to **GP 10-13-01** inclusive, covering Machinery.
- API Standards 610, 611, 612, 613, 616, 617, 618 and 619.

Driver Overspeed Protection

Protection against turbine overspeed which may result from control malfunctions, particularly when accompanied by sudden load reductions is required to prevent catastrophic destruction of the turbine. Section XI-M details the protection.

Remote Shutdown for Turbine Driven Pumps

Turbine driven pumps should be installed to allow for remote shutdown during a fire or emergency. Remote shutdown may be manual or automatic.

Protection Against Entry of Extraneous Liquids and Objects

1. Compressors must be provided with facilities to prevent the entry of entrained liquids. Knockout drums, alarms, continuous drains, heat traced suction lines, etc., are covered in the appropriate sections of the above references, and in Section V, **GP 03-03-03** and **GP 03-03-05**.
2. Onstream compressor flushing and steam turbine washing systems are designed to control the flow and atomization of liquid through the machine such that mechanical damage from liquid slugs cannot occur. Refer to **GP 03-03-03** and **GP 03-03-08**.
3. Gas-fired internal combustion engines and gas turbines must have means of removal of liquid condensate from the fuel gas stream. The facilities required are the same as those specified for fired heaters later in this section.
4. Temporary and permanent strainers are provided for the protection of pumps and compressors against entry of solid materials, in accordance with **GP 03-03-10**.

Reliable Lubrication Systems

1. A large proportion of machinery failures results from poor lubrication and bearing failure. The provision of reliable lubrication systems is therefore essential for safe operation. Provision of spare lube oil pumps, filters and coolers, monitoring instruments, alarms, cut-ins and trips, water separators, etc., are covered by the appropriate machinery GPs. Oil Mist Lubrication Systems are covered by **GP 03-03-12**.
2. Compressor shaft seal oil systems are specified in International Practices to meet similar requirements, since the oil has a lubricating as well as a sealing function.

Adequate Mechanical Construction

1. Machinery design must be adequate for the anticipated most severe service conditions, i.e., corrosive or erosive properties of the fluid handled, particularly under turbulent or high velocity conditions, operating temperature, etc. Materials should comply with the Refinery Construction Materials Manual, impact requirements of **GP 18-10-01**, where applicable, and the relevant Machinery International Practices. Overpressure protection is covered in Section XV-C.
2. Centrifugal pump seal failures are a significant fire risk when handling light ends, pyrophoric fluids and fluids above their autoignition temperature. They are also a health risk when handling acutely toxic materials. The design of shaft sealing arrangements is critical in these services. Types of seals, selection criteria, flushing systems, seals for special services, etc., are covered by Section X-G, TMEE.23 - Pump Sealing Technology Manual, and **GP 10-01-01**. (Note that many pump fires are caused by bearing failure with a subsequent seal failure. Vibration monitoring, which can predict bearing failure, is also discussed in the references.)

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3. Sealless centrifugal pumps eliminate mechanical seals and sealing systems and reduce the potential for leaks and fires noted above. Sealless pumps rely on a thin, 0.04 - 0.08 in. (1 - 2 mm), metallic “can" to contain the pumped fluid. Although this “can" may still fail when the pump is operated abnormally, sealless pumps are able to incorporate containment secondary to the “can" at little additional cost. (Abnormal operation can include running dry, with a blocked discharge, or at conditions well away from the best efficiency point for extended periods.) When secondary containment is included in the sealless pump, and the pump is designed and installed correctly, the sealless pump is inherently safer than a pump with mechanical seals. Sealless pumps are less tolerant of running outside design conditions than sealed pumps and proper specification is particularly important. Consult with machinery engineering specialists when specifying sealless pumps to ensure that they are properly specified, including secondary containment.

   Note that environmental and health issues, in addition to fire, can drive the selection of sealless pumps. When seal leakage presents an environmental or toxicity problem, sealless pumps, as described above, have a significant advantage. See Section XVIII-A2 for further discussion.

Prevention of Machinery Imbalance, Vibration, and Resulting Failure

As far as practical, machinery designs include features which will minimize imbalance and vibration, and which will identify this condition at an early stage before it develops into a mechanical failure.

1. Machinery foundations are covered by **GP 04-06-02**.
2. Vibration monitors with alarm and shutdown functions are installed per **GP 10-12-01**.
3. Piping associated with machinery installations is covered by **GP 03-03-02** to **GP 03-03-10**, inclusive.
4. Prolonged surging of centrifugal compressors is likely to result in thrust bearing failure. As a minimum, appropriate recycle controls and low flow alarms should be incorporated. See Section XI-C.
5. Special mechanical seal features are available for centrifugal pumps to reduce the fire risk associated with seal failure. These are described in Section X-G.
6. If the pump can be “shut in" during normal operation (e.g., pumps supplying marine loading facilities), a high casing temperature shutdown device is required.

S MECHANICAL DESIGN OF PIPING SYSTEMS

Good design and construction of piping systems, in accordance with the Piping Global Practices, will eliminate many of the points of potential failure, which may cause fires and emergencies.

Pipe dead-legs in critical service, e.g., flammable or toxic fluids in combination with a corrosive material, should be eliminated or minimized. Dead-legs are piping sections, which normally contain a stagnant fluid. The stagnant zone may experience different conditions, e.g., temperatures, than the flowing fluid. Lower temperatures due to heat loss can cause condensation of corrosive vapors, or condensation and freezing of water. Higher temperatures, often caused by heat tracing, can increase corrosion rates. Where dead-legs are a required part of the process, e.g., bypass lines in critical service, the dead-leg should be inspected on a regular basis. See Report No. EE.37E.80, G*/L for the Evaluation of Dead-Legs in Refinery Piping Systems*.

Small bore piping, typically used for machinery and instrumentation connections should be strengthened to prevent mechanical or vibration damage per **GP 03-06-01**. Instruments themselves must be capable of withstanding the system design temperature and pressure, and be compatible with the system fluids.

S FIRED HEATER HAZARDS

Features, which minimize the possibilities of, fired heater tube failure and entry of fuel gas condensate into fired heaters, both of which are frequently the cause of fires, are required, as follows:

Minimizing Potential For Fired Heater Tube Failure

1. **Instrumentation for Flow Stoppage -** Provide all process heaters with a low flow fuel shutdown (i.e., low process flow actuating shutoff valves in all fuel streams to the fired heater, excluding pilot gas), also see **GP 15-01-01**.
2. **Reliable Fired Heater Feed Supply -** Provide the fired heater feed pump with a reliable spare. In most cases it is satisfactory to specify electric motor drives for a fired heater feed pump and its spare, supplied from the two sides of a secondary selective power distribution system. If a secondary selective system is not available, or if the source of power supply is unreliable, a steam turbine spare is normally provided. Automatic cut in of the spare pump is required only if special considerations apply, e.g., remote location or high coking rates.

   When the fired heater is fed from a tower or other process vessel, provide sufficient holdup time below the vessel low level alarm point to allow operating personnel time to prepare the fired heater for no feed - see Section XII-C.
3. Insuring Equalized Flow Distribution in Multipass Fired Heater

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a. For fired heaters in liquid or mixed-phase service, a means of controlling flow in the inlet to each pass should be provided in accordance with Section VIII-J.

b. For multipass, vertical tube fired heaters in vapor service, where the possibility of blockage exists from liquid slugs entering or being left in the coil (e.g., HYDROFINING, GOFINING, and HYDROCRACKING services), individual pass flow or temperature detection should be provided.

c. Provide process temperature measurement in accordance with Section VIII-B.

4. **Emergency Steam to Fired Heater Coils -** The use of steam injection into fired heater coils in the event of tube failure is generally not recommended and connections for this purpose are not normally provided. The main reasons for this are:

   a. In many services, the normal pressure in the fired heater feed line is greater than the steam header pressure.

   b. If steam injection is used in the case of tube rupture, it could displace additional oil into the firebox, causing an escalation of the existing fire or creating conditions for a firebox explosion.

   c. The steam may have a damaging effect on the process downstream of the fired heater, e.g., reactor catalyst or equipment that must be kept dry.

   d. If the steam lateral is not effectively drained, the sudden injection of emergency steam may introduce a slug of condensate into the heater coil, causing severe liquid hammer or pressure surge.

   However, steam connections may be installed for purging the firebox, snuffing header box fires, or for injection into the coils to reduce coke formation. The intended use of purging steam for the firebox is discussed later in this section under PREVENTION OF FIRES AND EXPLOSIONS IN FIRE HEATERS, BOILERS, AND GAS TURBINES. Purge steam is not recommended for smothering a “fire" which results from a tube failure in the firebox. If the steam pressurizes the firebox, unburned gas or liquid could exit and ignite outside the box. The use of “snuffing steam" to smother a fire in specific convection header boxes is described in **GP 03-04-01**.

5. **High Temperature Alarm -** All fired heaters should be provided with a high temperature alarm, independent of the temperature controller, in the coil outlet.

6. **Toe-Walls** - Spills resulting from tube failure should be contained as follows:

   a. The grade area below a fired heater should be concrete paved at least 10 ft (3 m) beyond the extremities of the heater and provided with a toe-wall at that point.

   b. Where two or more fired heaters are located adjacent to each other, dividing toe-walls should be provided.

   c. Catch basins should not be located directly below fired heaters. Catch basins necessary for draining fired heater areas should be located next to the toe-wall.

   d. Drains from other process equipment, which could contain hydrocarbons, should not be routed to the catch basins within fired heater areas.

Preventing Entry of Fuel Gas Condensate Into Fired Heaters

Fuel gas supply streams to any combustion device must pass through a knockout drum for removal of condensate, sized to handle a 50 ft (15 m) slug of liquid in the supply line from the fuel gas header. The drum must be fitted with a high level alarm and a 2 in. (50 mm) minimum size condensate dump line to a continuously available closed disposal system (safety valve header preferred). In all locations where ambient temperatures can fall below the dew point of the fuel gas (i.e., where condensation downstream of the knockout drum can occur), heat trace and insulate the gas header from the knockout drum to the burners and pipe the low point drains to the same condensate disposal system. Where fired heaters are widely spaced, such that tracing and insulation of the entire gas header is not practical, separate knockout drums should be provided. These requirements are detailed in Section V and in **GP 03-04-01**.

Process vessels discharging gas streams into fuel gas headers must be provided with a separate high level alarm independent from the normal process level controller alarms.

If the fuel is a low-pressure gas, fired directly from the same process unit (such as the gas from a pipestill distillate drum, fed directly to the burners), a fuel gas knockout drum is normally not provided. In such cases, the condensate is removed from the fuel gas manifold to an independent steam atomizing condensate burner located in the fired heater. This burner should be kept in continuous service while the heater is in operation. Since this arrangement cannot handle a large liquid spillover from the distillate drum, a high level-cut-out should be provided on the drum, to shut off the fuel gas line.

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S SAFE FAILURE MODE FOR INSTRUMENTS

Process instrumentation should be designed such that, upon loss of the control signal or the actuating medium, the final control element (usually a control valve) fails in the safest position. Depending on the specific application, this may require the control valve to fail open, fail closed or fail stationary in its last controlling position. For pneumatically operated valves that fail stationary, the direction (open or closed) in which the control valve should move as the air pressure in the actuator decays (due to leakage) should also be specified. The analysis must consider individual control loop failures as well as total loss of the actuating medium (instrument air, power, etc.).

The choice of failure position for control valves frequently requires considerable engineering judgment since general rules may not be applicable to all situations. The main objectives are: 1) to bring the unit to a safe condition with minimal operator intervention, 2) to minimize upsets to other units, and 3) to facilitate the return to normal operation once the original problem is corrected. Meeting these objectives generally requires that control valves that bring energy or material into the unit fail closed, control valves that remove material from the unit fail closed and control valves that remove energy from the unit fail open.

Some examples of the application of these principles are listed below:

- Fired heater stack dampers, used to control draft, should fail to the open position.
- Tower reflux control valves should fail to the open position.
- Fired heater and boiler fuel control valves should fail to the closed position.
- Compressor anti-surge control valves should fail open or stationary drifting open.
- Fired heater feed control valves should fail open or stationary drifting open to minimize risk of tube rupture due to overheating. The use of fail stationary drifting open should be considered for fired heaters having few parallel passes (4 or less) and in which the individual pass flow controllers are reset by a total feed flow controller; under these conditions, failure of the flow control valve at the inlet of a single pass in the full open position could lead to starvation of the remaining passes, since their flow rates would be reduced by the action of the total feed flow controller.
- Unit feed and product control valves should fail to the closed position.

It is recognized that deviations from these practices are sometimes necessary. In such cases, the rationale for the deviation must be documented and formally accepted. Consultation with an EMRE Safety and Risk specialist is recommended.

S SAFE DISPOSAL OF EQUIPMENT DRAINAGE, CONTAMINATED EFFLUENTS AND VENTS

Safe means of disposal must be provided for the various drainage, effluent and vent streams, so that they do not constitute a safety, health or environmental risk. Disposal systems for drainage and contaminated aqueous effluents are detailed in Section XV-D. Vents through which flammable materials are released to the atmosphere must be safely located with respect to adjacent equipment and personnel working areas, including consideration of heat radiation in the event of ignition. See Sections XV-C and E.

S UNCONTROLLED RELEASES FROM ATMOSPHERIC TANKAGE

Dangerous releases of flammable materials from atmosphere tankage may occur as excessive vapor evolution from vents, or as a “boilover" or other form of spillage. For convenience, these hazards are covered together with the hazard of internal explosions in tankage later in this section.

S ON-STREAM BLINDING OF PROCESS EQUIPMENT

When a blind is installed on one side of an isolation valve, and where the other side of the valve is exposed to process conditions, valve leakage can result in pressurization of the space between the valve and the blind. Such leakage cannot be detected and can lead to a hazardous situation when the blind is removed. Any such blinding points that will be used for onstream isolation of equipment (e.g., heat exchangers) should be identified during design and should be provided with drains and vents required to ensure that the space in question can be safely depressured prior to removal of the blind.

S MINIMIZING SOURCES OF IGNITION

Typical sources of ignition which are commonly found in refinery or petrochemical plants are listed in the following paragraphs, together with design features which are used to minimize their potential for initiating fires or explosions.

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S FIRED HEATERS AND HOT EQUIPMENT

The risk of a vapor release being ignited by fired heaters or hot equipment can be minimized by good plant layout and spacing. These requirements are detailed in Section XV-G.

S AUTOIGNITION

The Auto-Ignition Temperature (AIT) is the lowest temperature required to cause self-sustaining combustion, without initiation by spark or flame. Auto-ignition temperatures of the majority of hydrocarbons fall in the range of 400 to 1000°F (200 to 500°C) (see Table 1). In certain phases of safety design, an arbitrary auto-ignition temperature of 600°F (315°C) is used (e.g., in layout, Section XV-G). This is judged to be a conservative estimate in the absence of experimental data. When experimental data are available, the actual value of the AIT or 600°F (315°C), whichever is lower, should be used as the governing criterion for equipment spacing and any other design features where AIT is a consideration.

Estimation of AIT for a Multi-component Mixture

Because of the characteristics of AIT with dependency on both thermal and chemical properties, there is no identified analytical method available to determine the "exact" AIT value for a multi-component mixture. An accurate AIT can be determined from experimental testing. However, testing has proven to be time consuming, and may not be necessary for the determination of an AIT as typically used in hydrocarbon processing.

Therefore, the following equation is often used to estimate the AIT for a multi-component mixture. Results are typically within 10% of the test results. Past comparisons have indicated that the equation results are normally conservative. That is, they normally predict a lower than testing results AIT.

$$AIT = \frac{1}{\frac{(\text{Mol. Frac.})_1}{(AIT)_1} + \frac{(\text{Mol. Frac.})_2}{(AIT)_2} + \frac{(\text{Mol. Frac.})_3}{(AIT)_3} + \bullet\bullet\bullet\bullet\bullet + \frac{(\text{Mol. Frac.})_N}{(AIT)_N}}$$

Where: AIT = Auto-ignition Temperature for a multi-component mixture

$(\text{Mol. Frac.})_{1...N}$ = Molar Fraction of Component 1 through N

$(AIT)_{1...N}$ = Auto-ignition temperature for component 1 through N

The following may be used for additional simplicity when using the above equation:

- Pure Components with less than 0.5 molar percent could be excluded from the above equation.
- For a mixture with a large number of components (e.g. using EDL, PROII), groups of pure components with similar AIT values, typically within 25 - 30 F (14 - 16 C), may be combined to simplify the calculation of AIT for the mixture. When this is done, use of the lower AIT is suggested to maintain conservative results.

Example: Calculate the AIT for the mixture of:

COMPONENTS	MOLE PERCENT	AIT (TABLE 1) °F	°C
Methane	60	999	537
Ethane	19	882	472
Propane	11	842	450
i-butane	5.1	860	460
n-butane	4.3	550	288
i-pentane	0.4	788	420
n-pentane	0.1	500	260
Hexane	0.1	437	225
	Total: 100		

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Customary Unit:

$$AIT = \frac{1}{\left(\frac{0.6}{999}\right)_{Methane} + \left(\frac{0.19}{882}\right)_{Ethane} + \left(\frac{0.161}{842}\right)_{Propane\ \&\ i\text{-}butane}} \approx 993\,^{\circ}F$$

Metric Unit:

$$AIT = \frac{1}{\left(\frac{0.6}{537}\right)_{Methane} + \left(\frac{0.19}{472}\right)_{Ethane} + \left(\frac{0.161}{450}\right)_{Propane\ \&\ i\text{-}Butane}} = 533\,^{\circ}C$$

Note: Components with less than 0.5 mole percent have been excluded from the calculation.

Propane and i-butane AITs are within 20 °F (9 °C) and are combined for simplification, using the lower AIT of the combined fractions.

S PYROPHORIC MATERIALS

Pyrophoric material (e.g., iron sulfide, acetylene polymers, spent Ni - catalyst) can rapidly oxidize in air. Oxidation can elevate the material temperature to its autoignition point or to the ignition temperature of any surrounding hydrocarbon deposits. Fires have occurred on-line in storage tanks and off-line in equipment prepared for, or undergoing maintenance.

Report EE.84E.92, *Preventing Fires and Explosions Caused by Pyrophoric Materials*, recommends:

1. Assume deposits in hydrocarbon systems are pyrophoric.
2. Continuously wet the material with water or maintain an inert atmosphere until work has been completed or the deposits are removed from the vessel.
3. Keep any material wet during transit to a safe disposal area.

These pyrophoric materials are process byproducts, which can be exposed to air during turnarounds or regenerations. Pyrophoric raw materials such as metal alkyls used in polymerization, which can be reactive with water, should be handled so that there is no exposure to oxygen.

S MAINTENANCE ACTIVITIES

The risk of ignition of flammable materials is always present during plant maintenance involving welding, burning, use of cranes, vehicles, etc., and other hot work. However, the risk can be reduced by providing adequate spacing between units that shut down for turnaround separately, per Section XV-G.

S VEHICLE TRAFFIC

The potential for ignition from vehicle traffic (including all mobile equipment drivers) from the vehicle electrical system, exhaust system, engine overspeed/valve bounce, can be minimized by traffic restrictions. Guidelines for the electrical classification of forklift trucks are given by **NFPA 505**, *Powered Industrial Trucks Including Type Designations, Areas of Use, and Maintenance and Operation*.

S DIESEL ENGINES

Diesel engines (stationary machinery drivers) can produce ignition mechanisms from the electrical system, exhaust system, engine overspeed/valve bounce. The risk of ignition can be minimized by complying with **NFPA 505** or local code requirements for diesel engines in classified areas (spark arrestors, flame traps, overspeed shutdown, explosion-proof electrical equipment, etc.).

S LIGHTNING

Lightning is a potential ignition source for flammable vapors, and appropriate design features should be provided as follows:

1. Lightning protection and equipment grounding per **GP 16-04-01**.
2. Installation of shunts for bonding between roof and shell of floating roof tanks having steel-shoe roof seals with the hanger mechanism in the vapor space below the seal (pantograph type). Refer to **GP 09-04-01**.
3. Provision of pressure-vacuum vents for cone roof tanks holding materials with flash points below 100°F (38°C). This type of vent functions as a flame arrester, preventing an internal explosion even though the vapor space is within the explosive

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