MAKING SURE PRODUCTION EQUIPMENT LAYOUT AND SPACING ARE CORRECT

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ABSTRACT

Determining the optimal equipment layout for an oil and gas facility must consider hazards resulting from a fire, explosion or toxic gas releases. Over the years, many incidents have occurred where workers were injured or equipment was damaged by explosions, fire or toxic gas releases when equipment or occupied structures were not located properly. This paper presents "state of the art" techniques to allow facility designers to optimally locate equipment to reduce the risk of injury and equipment damage.

This paper reviews current industry "best practices" and also presents examples for the proper layout and spacing of equipment at oil and gas facilities. The techniques presented in the paper enable the facilities designer or Engineer to quickly gather the information needed for the analysis, evaluate credible scenarios and then make the necessary judgments to properly locate equipment. The result of using the information presented in this paper is that equipment and occupied structures are properly located and spaced to reduce operational and safety risk.

INTRODUCTION

Investigations of incidents at oil and gas facilities clearly show that fires and explosions can result in significant property damage. Additionally, many well streams contain hydrogen sulfide gas (H2S) which is extremely toxic to human life. Proper layout of oil and gas processing equipment with adequate spacing between equipment items can greatly reduce losses and even save human lives. Facilities can be designed to include passive or inherently-safe safeguards though proper layout and spacing.

Keep in mind that layout pertains to the relative position of equipment and spacing relates to the minimum distances between equipment.

The analysis of determining the proper layout of facilities involves many variables that the facility designer or Engineer must evaluate. These variables include the properties of the hydrocarbons that are being processed, toxic components (i.e. hydrogen sulfide), operating parameters, loss of containment scenarios, ignition scenarios, prevailing winds, safety systems and operating and maintenance practices. Each of these different variables can have a significant impact on where equipment and/or building should be located within a facility. The person designing the facility must consider these variables for impacts caused by fire, blast or toxic gas dispersion on human health, the environment and equipment located at the site.

HAZARDS RELATED TO FACILITY LAYOUT AND SPACING

The hazards that must be considered when laying out equipment at a facility and determining the spacing between such equipment include:

- Explosions and Blast Loads
  - Blast load is defined by the API (American Petroleum Institute, 2009) as being, "The load applied to a structure or object from a blast wave…" A hydrocarbon blast or explosion may generate a blast wave of many pounds per square inch (psi) that can damage tanks, pressure vessels, buildings and all types of equipment. There are many documented cases of storage tanks that explode due to explosive mixtures present in the tanks. However, significant open air blast events at oil and gas

production facilities are extremely rare because of the hydrocarbons being processed and the open or non-congested layout of equipment. Fixed (American Petroleum Institute, 2009) and portable buildings (American Petroleum Institute, 2007) are of the most concern when examining explosions at mid-stream facilities.

- *Design Considerations:* The design of facilities should include measures to prevent mixtures of hydrocarbons and air creating an explosive mixture; and to eliminate an ignition source. Typically, tanks are maintained with a positive pressure and all fired equipment is equipped with flame arrestors. Electrical equipment should be classified per API RP 500, "Recommended Practice of Location for Electrical Installations at Petroleum Facilities Classified as Class 1, Division 1 and Division 2" (American Petroleum Institute, 2012) to minimize ignition hazards. Equipment needs to be spaced properly so that ignition sources are located far enough away from possible explosive mixtures.

- Fires and Thermal Exposure
  - Thermal exposure occurs when a person or object is subject to radiant heat caused by a fire, flame or inherently high temperature processes. The most common concerns at an oil and gas production facility would be the amount of heat a person is exposed to if the flare were to be overloaded or from a process fire.
  - *Design Considerations:* Flares should be designed tall enough to make sure that the thermal flux during full operation does not exceed the amount needed to cause burns. Non-combustible berms should be built around storage tank, heater- treaters, glycol reboilers and other equipment where a liquid hydrocarbon accumulation could lead to a fire. Berms are the primary means to contain and reduce the impact of pool fires once they occur.

- Flammable Gas Concentration
  - Flammable gas concentrations can exist at the discharge of relief valves, vents, blowdowns, thief hatches, sumps, pits, well cellars, containment areas and at other locations at the facility where hydrocarbons might accumulate. All gas discharge points should be designed so that the release point is not near an ignition source.
  - *Design Considerations:* Vents and PSV tail pipes should be designed to release hydrocarbon gases to a safe location (American Petroleum Institute, 2008). Release points should also be designed so that, in the case when vented gas is ignited, workers are not harmed by the flame or fire. Vent valves and other venting control devices need to be strategically placed so that they can be safely operated in the event of a fire.

- Toxic Concentration
  - Hydrogen sulfide (H2S) gas is the most common toxic substance found at oil and gas processing facilities. Exposure to even small concentrations (1000 ppm) of H2S can lead to instant death.
  - *Design Considerations*: The exposure radius for each possible release point at a facility needs to be determined to assess the hazard and to determine if equipment can be laid out to minimize exposure hazards. Common release points (i.e. tank thief hatches, vents, PSV discharges etc.) need to be evaluated when designing a facility. Release points should be downwind, relative to prevailing winds, of areas where workers are likely to be. For example, produced water loading areas should be upwind of produced water and oil storage tanks. Windsocks should be visible from any vantage point and should be lighted if the facility is manned at night. The Texas Railroad Commission document, "Statewide Rule 36 – Hydrogen Sulfide Safety" (Texas Railroad Commission, 2012) is an excellent resource for helping to determine the radius of exposure for various gas releases and concentrations of H2S.

Table 1 contains a listing of common hazards associated with lease production equipment.

LAYOUT

Two resources for information regarding proper facility layout are: 1) "Facilities Siting and Layout" (Center for Chemical Process Safety of the AICHE, 2003), and 2) the GAP Guideline "Oil and Chemical Plant Layout and Spacing" (Global Asset Protection, 2007). Each of these resources provides good information on how facilities should be laid out to minimize hazards. However, as stated above, each of these provides guidance, but are not specific to the upstream oil and gas industry.

Facility designers and Engineers should *not* rely on API RP 500, "Recommended Practice of Location for Electrical Installations at Petroleum Facilities Classified as Class 1, Division 1 and Division 2" (American Petroleum Institute, 2012) for placement of non-electrical equipment. Facilities have been constructed where flares, heater treaters and other high risk equipment items were placed and spaced based on just being outside of a Class 1, Division 1 or 2 areas. The hazards and risks associated with electrical and non-electrical equipment are very different. Use of API RP 500 for the layout and spacing of non-electrical equipment can lead to catastrophic fires and explosions resulting in harm to human life and the environment.

Guidelines for the Layout of Oil and Gas Lease Equipment

Equipment should be arranged to reduce the effects of both uncontrollable and controllable factors that can lead to safety related incidents. *Uncontrollable factors* include the slope of the pad (generally level), temperature and wind direction. *Controllable factors* include process design, process safety design, control philosophy, ignition sources, hydrocarbon release points, use of secondary containment, fire protection measures, and drainage around equipment.

Facility layout of oil and gas equipment is often governed by the shape of the pad available, size of the pad, location of the entrance road and the features on the adjoining property. Many facility layouts do not appear to take into account prevailing winds or the actual hazards at the site. Generally, ignition sources should be located upwind of potential gas discharges. Additionally, changes in regulations, such as the recent requirement to process tank vapors, necessitates the need to add additional, often hazardous equipment, to a site where such equipment was not contemplated.

Below are considerations when siting each major piece of equipment:

Wellheads: Wellheads are usually placed in the center of a drilling pad. This makes it necessary to place production equipment mostly on the perimeter of the well site to accommodate minimum spacing distances. However, operators may desire to work with the well designers to find an optimum location for the well on the pad. Being able to locate the well at alternative locations on a well pad provides greater flexibility when laying out surface production equipment.

Wellheads should be located at least 80' away from equipment in the event that a workover rig mast fails or tubing falls from the derrick. Care must also be taken to make sure that the flare will not impact workers who may be up on the derrick of a drilling or workover rig. The placement of a wellhead must also take into consideration the location of any overhead electrical lines as well maintenance often includes the use of derricks, cranes and other specialized well workover equipment that can extend high above the wellhead.

Flares: Flares should be installed upwind of most process equipment. The reason for this is: vapors from upstream equipment, would ignite if they came in contact with the flame. Calculations should be made to make sure that the flame will not extend over or impact other pieces of equipment. Figure 1 is a graph using a method from API 521 "Guide for Pressure-Relieving and Depressuring Systems" (American Petroleum Institute, 2008) showing that the flame length for various quantities of gas burned. A flare burning 2000 MCFD will have a vertical flame length of approximately 38'. A 20 mph wind will cause the flame to have a horizontal reach of approximately 35'. This illustrates that a flare located at a reasonable distance upwind of other process equipment would not ignite hydrocarbon vapors or gasses being released from such equipment.

Spacing tables generally have the greatest distance between flare and all other pieces of equipment. The GAP guidelines (Global Asset Protection, 2007) state a distance of 300-400 feet while the British Columbia Oil and Gas Commission (BC Oil and Gas Commission, 2014) gives a figure of 164'.

Dispersion modeling should be conducted if toxic H2S streams are sent to a flare and for radius of lower explosive limit (LEL) in the event that the flare's flame is extinguished. The flare should be designed so that the ground level concentration of H2S is below acceptable values in the event that the flame on the flare is extinguished. Likewise, the LEL concentration should be checked to make sure there is enough natural dispersion of hydrocarbon vapors to prevent ignition if the flare's flame is extinguished.

Long distances between a flare (or vapor combustors) and a tank or group of tanks can result in extremely large diameter lines being installed between tanks and vapor flares/ combustors. Tanks generally operate with only a few ounces of pressure available to push the gases to the flare. Operators have the option to conduct a quantitative or a qualitative risk analysis to reduce the distances listed in the spacing tables.

Inlet Headers/ Pig Receivers: Inlet headers and pig receivers should be located to prevent any leaking hydrocarbons from being ignited by fired process equipment. Pig receivers should be orientated facing away from processing equipment and downwind whenever possible. This would reduce the potential of produced fluids being sprayed onto processing equipment which could result in a fire.

Unfired Pressure Vessels: Unfired pressure vessels (i.e. separators, heat exchangers etc.) can be located close to other non-fired equipment (i.e. tanks, headers etc.). Care should be taken to make sure that the relief valve discharge cannot be ignited by another piece of process equipment.

Fired Process Equipment GPU/ Heater Treaters/ Line Heaters: Fired pieces of process equipment (i.e. GPUs, heater treaters, line heaters etc.) should be located upwind or cross wind from atmospheric storage tanks. Much like flares, these devices have a continual source of ignition. Additionally, the fire tube can degenerate over time resulting in large leaks of hydrocarbons or other flammable fluids to the ground. A flame arrestor should be used to mitigate the possibility of igniting hydrocarbon releases from other pieces of equipment. Berms should be built around fired process vessels to contain any flammable liquids on the ground around the equipment in an effort to control the extent of a fire.

Oil and Water Storage Tanks: Storage tanks should be located downwind or cross wind from other processing equipment items. Tanks run the risk of containing an explosive mixture if a gas blanket or backpressure system is not used. Also, berms should be constructed around the tanks as a fire mitigation measure to keep any burning liquid hydrocarbons from spreading to other portions of the facility (American Petroleum Institute, 2008).

Vapor Recovery Units: Vapor recovery units need to be placed in close proximity to the oil and water storage tanks, but outside of the tank berm area. Hazards from VRUs include seal failure resulting in hydrocarbon gas leaks and possible ignition. Berms around VRUs are a good idea to help contain a fire if one should occur.

Compressors: Compressors may be both a hydrocarbon release point (i.e. packing failure, vent left open, etc.) and an ignition point (exhaust or ignition system). Compressors should be located upwind from most other processing equipment. Care should be taken to make sure that engine driven compressors do not ingest leaking hydrocarbon vapors which could over-speed the engine.

Glycol Dehydrators: These are fired vessels and should be sited much like GPUs and heater treaters. Take precautions to assure that flame arrestors are installed and that they are located far enough away from other equipment items as to not be a source of ignition. It is also a good idea to install a berm around the glycol re-boiler to contain any fire that might occur.

LACT Units: LACT Units may fail if the pump seal wears out. A faulty pump seal may leak liquid hydrocarbons on the ground. LACT units may be located near other non-fired process equipment, but should be contained in a berm to limit the extent of a fire.

Loading Areas: Loading areas should always be located upwind of the tanks. Being upwind allows personnel and the truck engines to not be subject to breathing in hydrocarbon vapors emanating from either the storage tanks or the truck itself. Many operators have opted to install dedicated truck loading vent lines to safely discharge truck vapors from a loading area.

SPACING

Spacing tables can be an effective means for determining proper equipment spacing for fire cases. Spacing tables were developed by Global Asset Protections Services (Global Asset Protection, 2007) and the Process Institute Practices (Process Industry Practices, 2007). Both of these spacing tables were developed for the general process industry. These recognized industry best practices, are not always applicable to upstream operations as they are more geared for the midstream and downstream types of facilities. They do not include all common oil field production equipment items such as wellheads, pits and thermal oxidizers. However, many pieces of equipment are included, and these references should be considered when spacing out equipment.

The British Columbia Oil and Gas Commission has developed a spacing table specifically for the oil and gas upstream industry. This has been offered to the industry in their publication titled, "Well Completion, Maintenance and Abandonment Guideline." (BC Oil and Gas Commission, 2014). Table 2 is the spacing table from the BC Oil and Gas Commission converted to commonly used English units:

Keep in mind that spacing tables give the minimum distances, and the user is directed to evaluate the possible blast loads or toxic effects. Assumptions made for the spacing tables may not be applicable to the specific facility being designed.

Alternate Spacing Methods

Often, it is not practical to locate or space equipment and structures in accordance with the spacing table approach. Common reasons for not using the tables may be that hydrogen sulfide is present, the pad size is limited, additional equipment must be installed, urbanization or other factors.

When the spacing table approach is not viable, then the next option is to conduct a consequence-based analysis. This generally involves the use of modeling software to determine the area of impact resulting from a fire, toxic gas release or an explosion. Equipment and structures can be spaced accordingly to the results from the model.

The next option, when the consequence based approach shows that there may still be some issues regarding fire, toxic releases or explosions, is to conduct a risk based study. The Risk-Based Approach involves conducting a quantitative analysis to determine risk based on the consequence and the frequency of the hazardous event. The likelihood (probability) of occurrence and the impact (severity) are used to determine if the risk of a particular scenario falls within the risk tolerance of the operator.

When locating buildings using API RP 752 (American Petroleum Institute, 2009), the spacing table approach is to only be used when determining the minimum distance from a fire to a building. Again, these tables are not appropriate for toxic or explosive events where the consequence is dependent on the release rate, length of release, wind direction, material released, and many other factors.

OTHER APPLICABLE RESOURCES AND REGULATORY REQUIREMENTS

The NFPA 30 "Flammable and Combustible Liquids Code" (NFPA, 2015) provides information concerning how close atmospheric storage tanks can be placed to property lines and the distance between tanks. In this Code, the NFPA states that tanks need to be at least one diameter from a property line and give a shell separation distance of 3'.

Similarly, OSHA requires (Occupational Safety and Health Administration, 2005) that shell to shell spacing of above ground storage tanks to be not less than 3'.

Several states have additional requirements. The list below is not intended to be a complete listing of all state and local requirements. Please check with your local authorities to determine if there are any regulations pertaining to the layout and spacing of equipment.

1. Colorado
   a. § COCC 600Series Safety Regulations rule 604 Oil and Gas Facilities b. (5) – At the time of installation, fired vessels and heater treaters shall be a minimum of 200 feet from residences, building units, or well defined normally occupied outside areas.
   b. § COCC 600Series Safety Regulations rule 604 Oil and Gas Facilities a. Crude Oil and Condensate Tanks (2) – Tanks shall be located at least 2 diameters or 350 ft. whichever is smaller, from the boundary of the property on which it is built. Where the property line is a public way the tanks shall be 2/3 of the diameter from the nearest side of the public way easement.

2. North Dakota
   a. § NDCC 43-02-03-28. Safety Regulation – No well shall be drilled nor production or injection equipment installed less than 500ft. from an occupied dwelling unless agreed to in writing by the owner of the dwelling or authorized by order of the Commission.
   b. § NDCC 43-02-03-28. Safety Regulation No boiler, portable electric lighting generator, or treater shall be placed nearer than 150 ft. to any producing well or oil tank. Placement as close as 125 ft. may be allowed if flame arrestor is utilized on the equipment.

3. Wyoming
   a. § WY O&GC Section 4 Workmanlike Operations (a) (v) - On state and private surfaces, locate wellheads, pumping units, pits, production tanks and/or associated production equipment no less than 350 ft. from any residence, school, hospital, or other places as determined by the Supervisor. The Supervisor may impose greater distances for good cause and likewise, grant exception to the 350ft. rule.

EXAMPLE OF A PRODUCTION FACILITY SITE LAYOUT AND SPACING

For this example, it was assumed that an oil and gas treating facility was to be located on an existing well pad. The pad measures 350' by 250' and is located near Odessa, Texas. The operator desires to install an inlet header, separators, treaters, oil storage tanks, water storage tanks, a VRU, flare, LACT Unit, produced water loading area, a TEG dehydrator and compressors. The operator, not having their own internal spacing guidelines, asked that the BC Oil and Gas Commission Spacing Guidelines (BC Oil and Gas Commission, 2014) be used.

One of the first steps it to obtain wind data to determine the prevailing wind conditions. The Iowa State University produces "wind rose" diagrams which are extremely helpful when determining prevailing wind directions. A wind rose for the Odessa Texas airport was obtained from the Iowa State University system (Iowa State University of Science and Technology, 2015) and is shown as Figure 2.

Figure 2 shows the wind blowing predominantly from the SSE. The first step will then to place the flare in the SW corner of the property so that it will be upwind as much as possible and usually discharge over adjoining un-occupied acreage.

Next, the layout and spacing guidelines listed in this paper were used to determine the layout and spacing of key equipment items. Figure 3 shows the layout and spacing for this facility.

SUMMARY AND CONCLUSIONS

The proper layout and spacing of equipment can greatly increase the inherent design safety of an oil and gas facility. The risk of harm from fire, blast, heat and toxic exposure can be greatly reduced by laying out and spacing a facility in accordance with good industry practices. Layout of production equipment should be considered before the well is drilled so that the placement of wellhead allows for the safest and most cost effective layout and spacing of all equipment.

A great deal of information about the layout and spacing of facilities is available. However, much of this information was originally developed for the downstream and chemical industry and is not always applicable to upstream oil and gas operations. Many companies have developed their own internal spacing tables because there are no standard industry tables available for the upstream oil and gas industry. However, the guiding principles from the downstream industry can be used as the basis for forming spacing principles for the upstream oil and gas industry.

Often, it may not be possible to use facility spacing tables to site all equipment. The pad size may not accommodate the distances required, additional wells are added or changes are made to the pad. In these cases, it is possible to use alternative techniques such as a consequence based review, or a quantitative risk analysis to accurately model specific incidents leading to losses.

The layout guidelines presented in this paper and the spacing tables give the operator a great deal of leeway when laying out and spacing facilities. Care should be taken, as in any design to make sure that the final layout and spacing of equipment meets all safety and operational needs.

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Table 1 - Hazards Associated with Oil and Gas Facilities

Items	Ignition Source	Hydrocarbon Gas Vent Source	Hydrocarbon Liquid Leak Source	Excessive Heat Source	Toxic Vapor Source		
Inlet Header/ Pig Receivers	No	Receiver Door Open	Receiver Door open	No	Receiver Door open		
Separators	No	PSV Discharge	Drain to ground Open	No	PSV Discharge		
GPU/ Heater Treater	Fire Tube Failure	PSV Discharge	Drain to ground Open	Catching Fire	PSV Discharge		
Oil Storage Tanks	No	Thief Hatch Open	Leak or Drain Open	No	Thief Hatch Open		
Water Storage Tanks	No	Thief Hatch Open	No	No	Thief Hatch Open		
VRU	Mechanical Failure	PSV Discharge	Drain to ground Open	No	PSV Discharge		
IC Engine Driven Compressor	Exhaust manifold; Turbochargers	PSV Discharge; Blowdown	Lube oil on skid	No	PSV Discharge; Blowdown		
Glycol Dehy	Fire Tube Failure	Vent or PSV Open	Glycol in skid	Catching Fire	Vent or PSV Open		
LACT Unit	Yes	No	Drain left open	No	No		
Water Loading Area	From truck engine	Vapors from trucks	No	No	Vapors vented from truck		
Flare	Yes	If flame goes out	No	Open or exposed Flame	If flame goes out		

Table 2 - Equipment Spacing from the BC Oil & Gas Commission

	Wellhead	Flare or Incinerator	Boilers, Steam Generating Equipment, TEG*	Produced Water Tank	Other Sources of Ignitable Vapors	Separator	Flame Type Equipment	Produced Flammable Liquids Crude Oil & Condensate Tanks
Wellhead		164	82	NS	NS	NS	82*	164
Flare or Incinerator	164		NS	82	82	82	82	164
Boilers, Steam Generating Equipment, TEG*	82	NS		82	82	82	82	82
Produced Water Tank	NS	82	82		NS	NS	82*	NS
Other Sources of Ignitable Vapors	NS	82	82	NS		NS	82*	NS
Separator	NS	82	82	NS	NS		82*	NS**
Flame Type Equipment	82*	82	82	82*	82*	82*	T	82*
Produced Flammable Liquids Crude Oil & Condensate Tanks	164	164	82	NS	NS	NS**	82*	

All distances are in feet (ft.)

* 82' without flame arrestors, not specified with flame

** Separator cannot be in the same dike

T Treaters should be at least 16.5' (shell to shell) from other treaters

Note:

a) Boilers etc. Includes steam generating equipment, electrical generators and TEG units

b) Other sources of ignitable vapors include compressors

c) Flame type equipment includes: treaters, reboilers, and line heaters

d) All electrical installations must conform to the Canadian Electrical Code

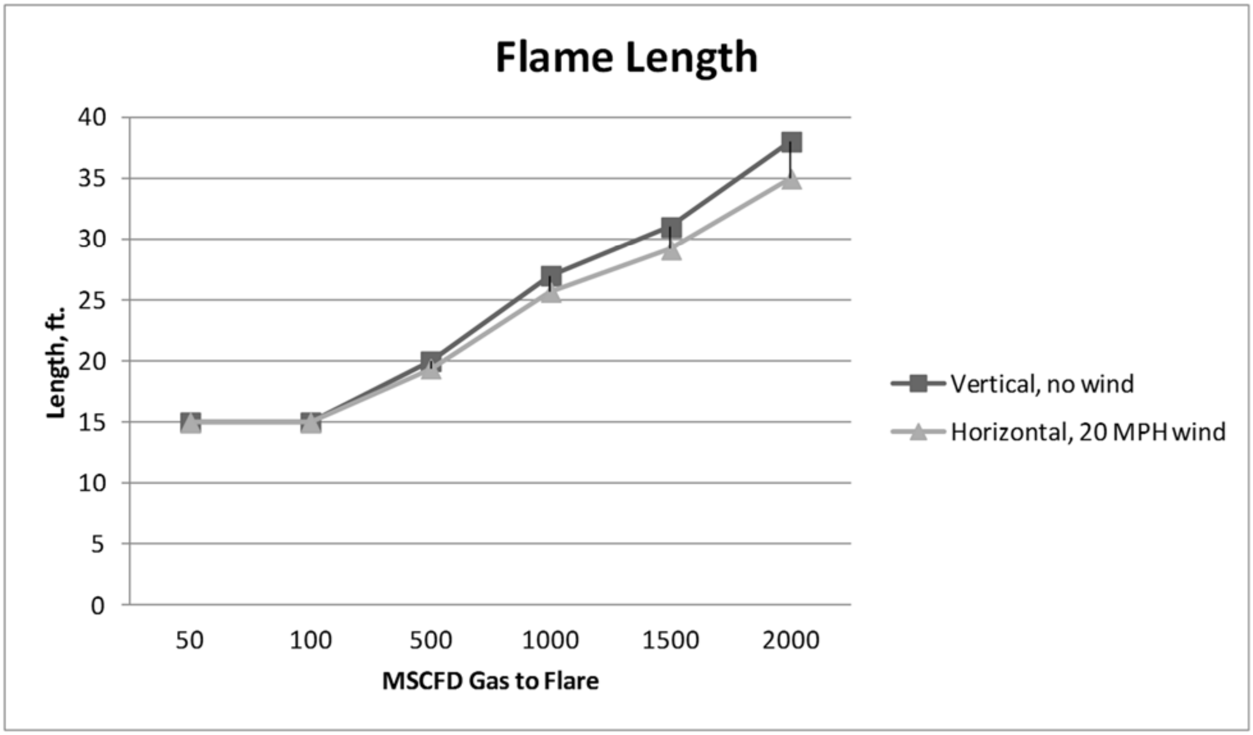

Figure 1 - Flame Length for Flares – Calm and 20 mph wind

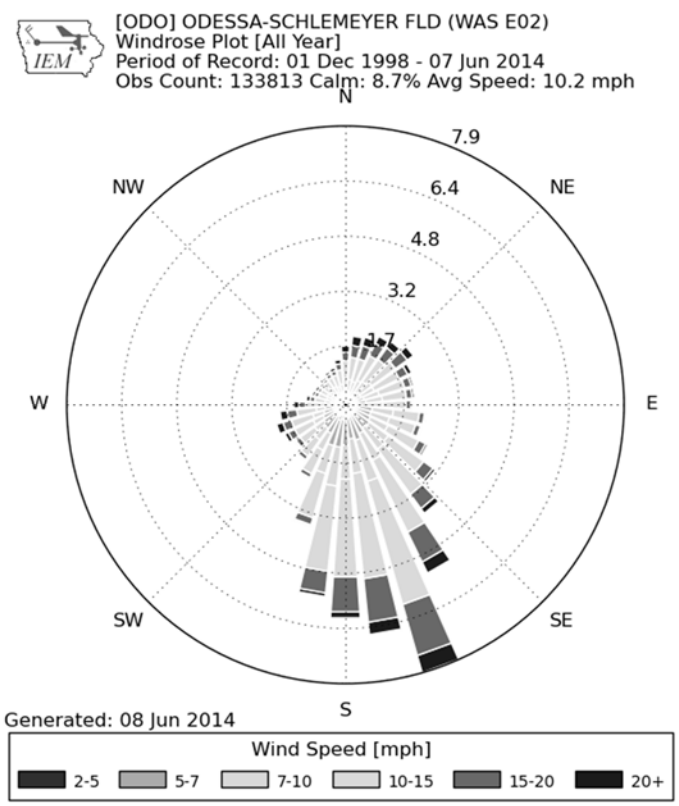

Figure 2: Wind Rose for Odessa, Texas

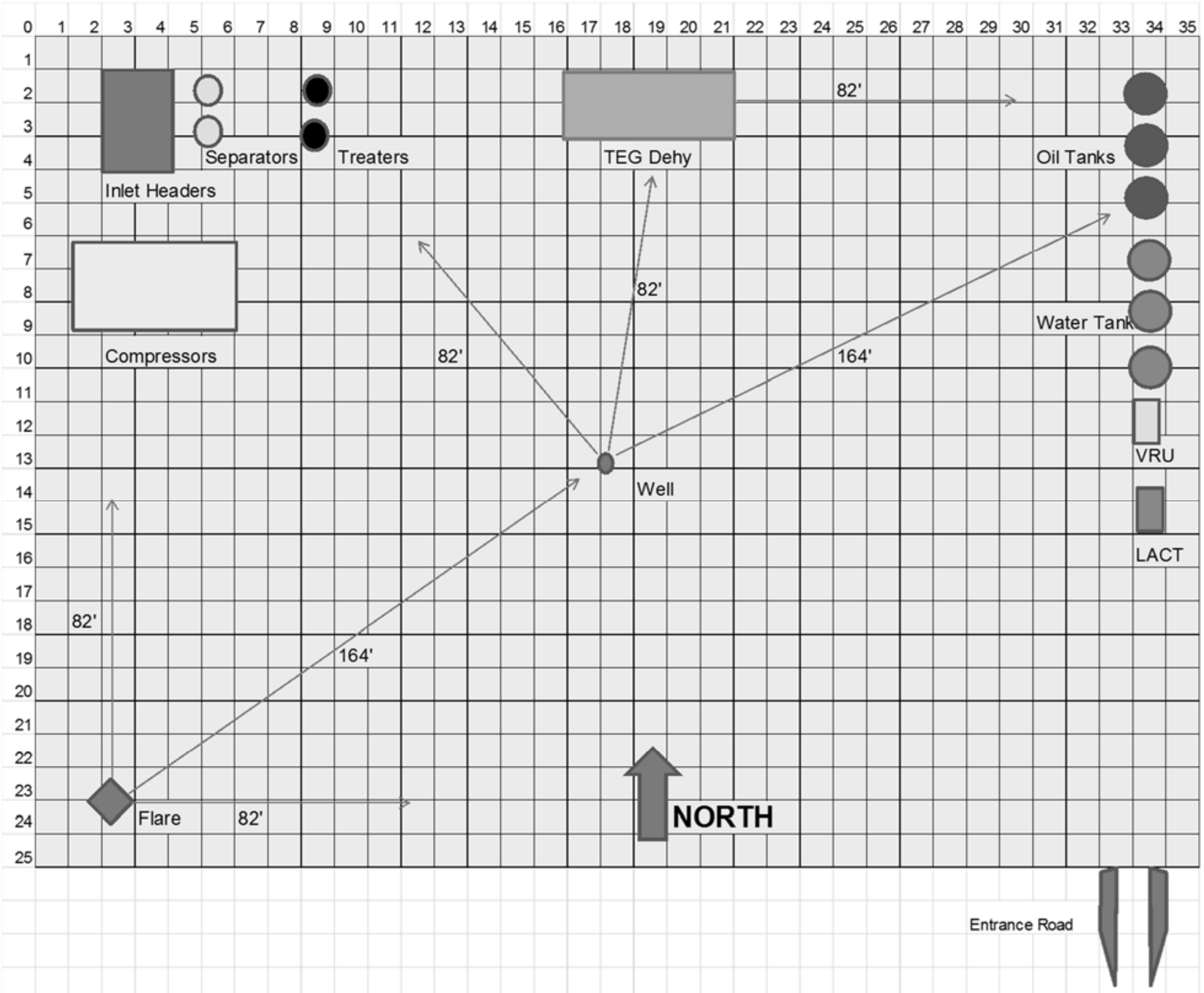

Figure 3 - Example Problem Oil and Gas Facility Layout