# <u>Zero Ammonia Emissions Project</u>

***for***

**Petrochemical Industries Company (PIC) Urea Plant**
**Shuaiba, Kuwait**

## ***"NH3-CO2-H2O Mixture Flaring to Reduce Emissions"***

***by***

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## GENERAL:

Petrochemical Industries Company (PIC), Kuwait is currently operating two Ammonia Plants and three Urea Plants for the manufacture of liquid ammonia and Urea granules. The total capacities of the respective Ammonia plants and Urea Plants are 1880 MTPD and 3150 MTPD. Ammonia Plants are based on M/s Haldor Topsoe technology and Urea Plants are based on Stamicarbon Stripping technology. The first Ammonia/Urea plants were commissioned in the year 1966. Over the years, PIC have installed additional ammonia and urea plants. In the year 1970, two ammonia and two Urea plants were added. With the installation of another ammonia plant in the year 1984, the production capacity of PIC's Ammonia and Urea complex became the biggest in the Middle East.

PIC has always been very proactive in working with the community to meet or exceed all environmental requirements. The goal of the facility is to always be ahead of any mandatory requirements.

Traditionally, the disposal of ammonia containing process gases from emergency relief systems (safety valves or rupture discs) in Urea plants has been done by discharging directly to atmosphere. This was the accepted practice for this type of facility, and continues to be the accepted practice at many locations around the world. Although direct discharge to atmosphere can be done in a safe way, it causes considerable pollution to the direct plant environment and surrounding areas. PIC as a socially responsible corporate citizen decided to eliminate ammonia pollution both inside and outside the PIC complex from such a discharge by implementing the “Zero Ammonia Emission Project”. To accomplish this task involved a major commitment on the part of PIC, in both man-hours and funding. This task involved many aspects, including:

1. Design and implementation of a major collection system for the ammonia sources in the facility.
2. Review and analysis of the relief devices and sources in the facility to determine the impact of their relieving into a collection system in lieu of discharge to atmosphere.
3. Analysis of the possible relief scenarios to determine sizing of the relief system.

4. Analysis of the collection network for both hydraulic and mechanical considerations.
5. Determination of the appropriate technology for disposal or destruction of the captured ammonia vapors.

After thoroughly analyzing the pros and cons of various available alternatives for the disposal of $NH_3$-$CO_2$ mixtures, flaring was selected as the appropriate technology. The purpose of this paper is to review the history of ammonia and low btu gas flaring and the effectiveness of the same for the flare project design adopted for the PIC project.

## HISTORY:

Flares have been used for the disposal of ammonia vapors since the early 1970's. Many of the ammonia storage tanks that were installed in the 70's, and 80's were equipped with small flares that were designed to combust the vapors that were generated due to breathing and loading of these large storage tanks. The flares were generally small, 2 inch to 4 inch in size, and the design flow rate was also very small.

During this time, there was little definitive information about the efficiency or effectiveness of using flares for the destruction of ammonia vapors. Available testing information generally indicated that 100% pure ammonia vapors could not be burned in a flare system. Engineering design guideline documents and books on the handling of ammonia vapors for refrigeration processes almost universally agreed that flaring of 100% ammonia vapors was not possible, as ignition of the ammonia could not be maintained unless it was premixed with air.

Flare vendors typically approached the flaring of low btu gases, including ammonia, as follows:

1. Design the flare tip barrel diameter and exit area for the available pressure drop and resultant vapor velocity at the tip.
2. Include in the design some type of gas assist injection ring at the flare tip exit point to create a fire the ammonia vapors can pass through.

This was the basic design concept for flaring of low btu and ammonia vapors for most flare vendors until the early 1980's. This is still the concept that is used by some flare vendors today. For destruction of ammonia vapors, this concept has been fully proven to be not effective. The injection of assist gas at the flare tip outlet has been shown to actually reduce the destruction efficiency of the ammonia vapors.

During the mid 1980's there were multiple tests conducted in the USA by the EPA authorities on the destruction of low heating value gases in flares. These tests were performed on a large variety of gases, using CO2 and Nitrogen as the inerts. The basic conclusion was gases with lower heating values of 200 btu/scf or higher could be combusted to high efficiency in an open flame flare system.

## AMMONIA TESTING:

The first definitive testing of the combustion of ammonia vapors in a flare tip was performed in the early 1980's. The testing was performed for a major chemical company located near Houston, Texas, USA. The chemical company was expanding their facility, and needed to modify their permit for flaring to increase the total allowable emissions.

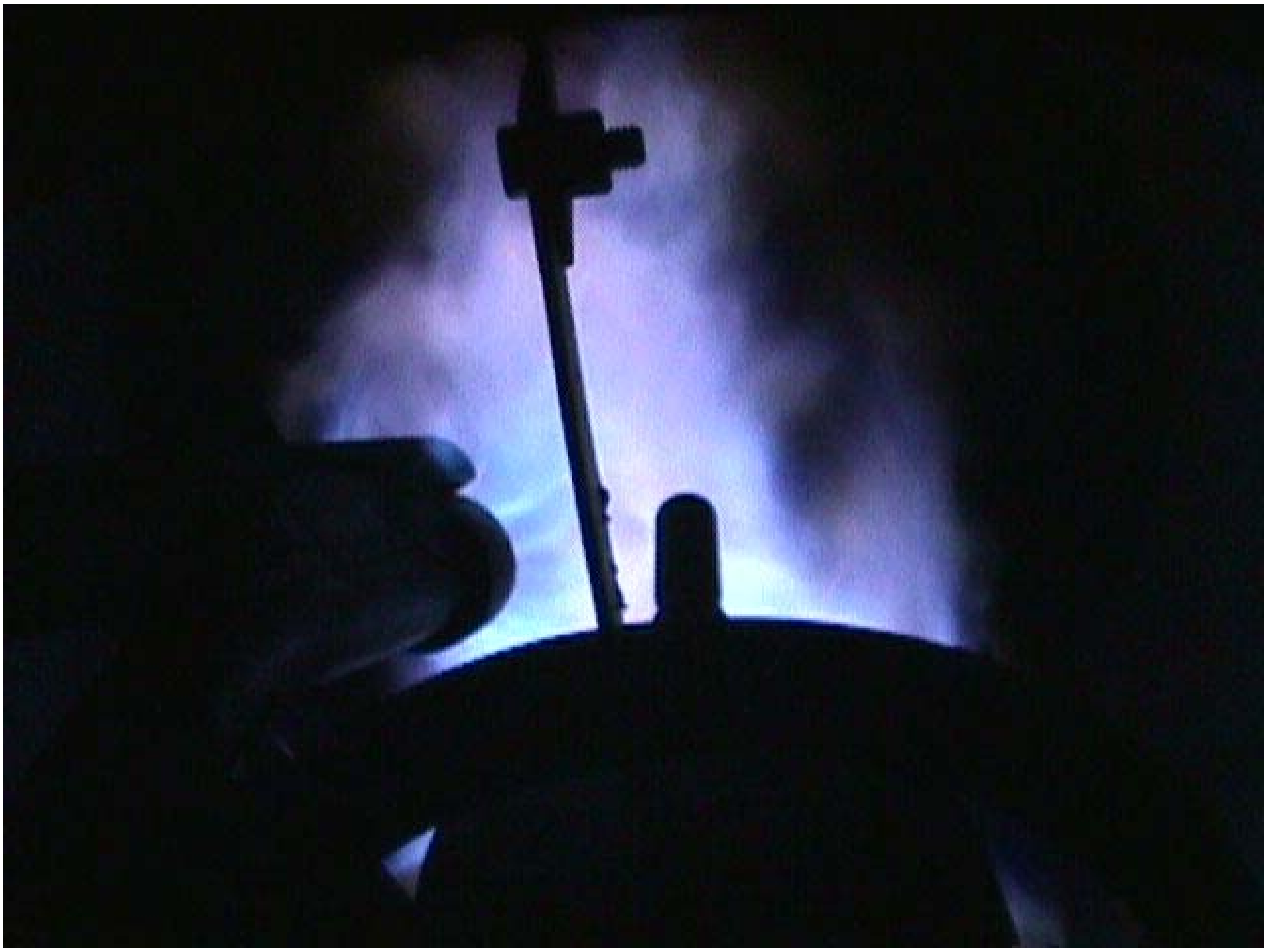
The local environmental authorities would not allow the facility to increase ammonia emissions from the flare. Therefore, to expand the capacity of the facility, the company had to either install incineration equipment for the vented ammonia vapors, or prove the destruction efficiency of ammonia in the flare was actually higher than as shown in the current permit.

The flare system that was installed at the facility was a standard unit with a gas assist ring to create turbulence and to create a combustion zone at the flare tip exit point. The chemical company contracted to determine the effectiveness of this flare tip arrangement versus other possible options.

Testing was performed on 100% ammonia gases. The flow rate of the gas was varied to evaluate the influence of exit velocity at the flare tip discharge point on the combustion efficiency. The testing specifics are as follows:

- Testing was performed on a nominal 12 inch diameter utility type flare tip with a full flame retention ring. The following were options that were fitted to the tip as part of the evaluations.
    - Extended large diameter windshield assembly that enclosed the discharge of the flare tip and the pilots.
    - Gas injection assist ring at the flare tip exit point to produce turbulence and increased air inspiration into the combustion zone.
    - Multiple pilots (three maximum) were available to determine the impact of ignition flames on the combustion process.

The testing included analysis of the performance of the flare tip assembly using various flows of ammonia, using from 1 to 3 pilots, using a gas injection ring, using the extended windshield, and using combinations of the above. The amount of ammonia present in the plume from the flare was determined using a heated probe that sampled in a position relative to the measured temperature (to ensure the probe was located in the hottest portion of the plume). See typical ammonia test flame color in the photo below.



The conclusions from the testing were as follows:

- Ammonia will burn to technically complete combustion (99% or higher) if the exit velocity at the flare tip discharge point is kept very low. The acceptable velocity is a function of the nominal flare tip diameter. See attached graph for guideline exit velocities.
- Higher flare gas exit velocities result in the inspiration of too much ambient air into the combustion zone, which dilutes the ammonia / air mixture to

below the combustible limit. Ammonia has a lower explosive / combustible limit that is 16% in air. This is in comparison to most hydrocarbons that have LEL values that are from 1 to 3%. This means the ammonia and air mixture can easily be diluted to a point where the ammonia will not burn.

- Ammonia needs to have a good source of ignition. This is typically provided by a very reliable pilot flame, and also a sufficient number of pilots around the perimeter of the flare tip. During the testing, if the ignition source was removed, the ammonia would not sustain a stable flame.
- A windshield is very useful in limiting the amount or air inspirited into the ammonia flare gas stream to facilitate ignition of the gases in an area that is protected from cross winds.
- Burning of the ammonia vapor eliminates any ammonia smell. This process will also produce NOX. Any mole of ammonia will produce one mole of NOX. The temperature of combustion in an ammonia flame is actually much lower than in a hydrocarbon flame. The NOX produced will typically be colorless, NO and NO2.

From this testing, it was concluded that ammonia can be burned in a flare system with very high efficiency, if the flare system is designed correctly.

Please note there has been other testing in the industry that has shown different results. Testing that was performed for the US EPA by EER in approximately 1986 in their flare screening facility showed that ammonia could not be ignited and would not burn. However, that test was performed on a 1/16 inch diameter orifice with the ammonia exiting the orifice at a high velocity and with no continuous pilot for ignition. Therefore, this test was not a viable reflection of the performance of an actual flare tip assembly.

Testing of other mixtures of low heating value gases has confirmed a lower limit of approximately 200 btu/scf for the efficient combustion of gas mixtures. The ammonia can be mixed with inerts down to a minimum heating value of approximately 200 btu/scf. If the lower heating value is not maintained at this minimum level, assist gas must be injected / added to the flare header to ensure the lower heating value is maintained at 200 btu/scf or higher. The assist gas should be controlled to ensure this minimum lower heating value. The gas can be controlled using a ratio controller as a function of the flare gas flow rate.

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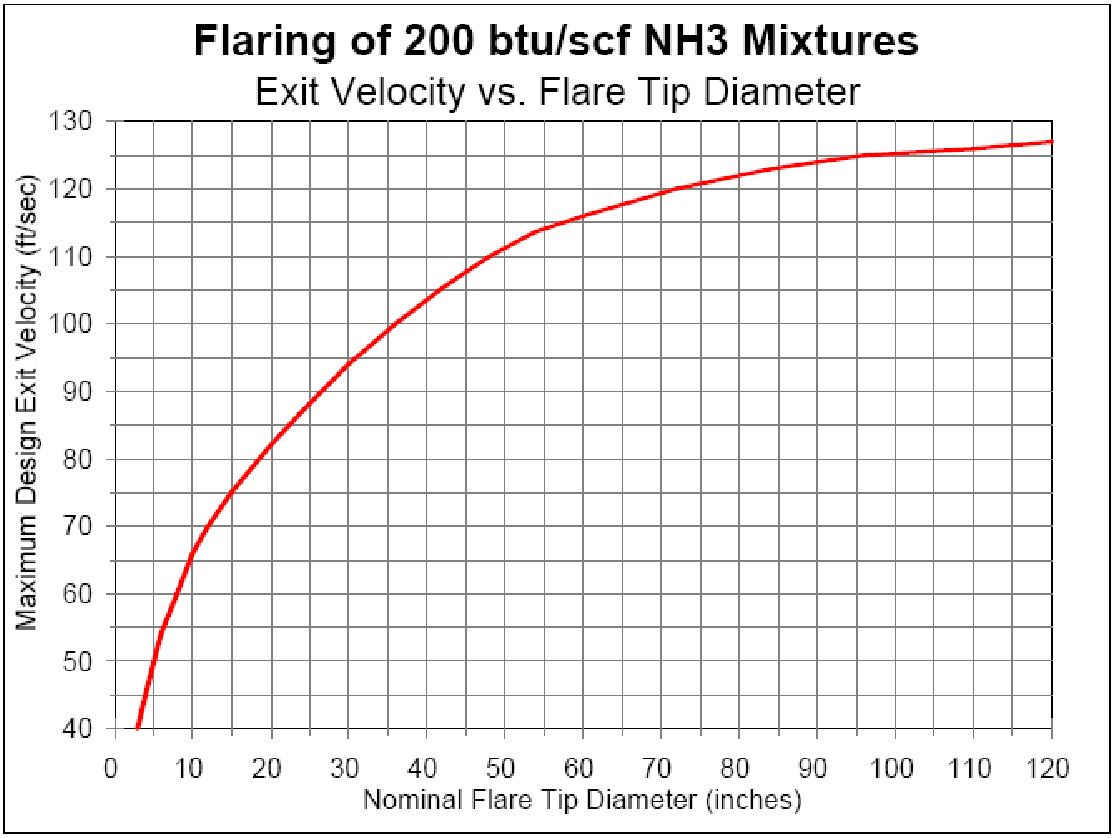


Basis is 98% or Better Ammonia Destruction Efficiency

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ASSIST GAS INJECTION SYSATEM FOR MAIN FLARE TIP

Pressure indicators, temperature indicators and ammonia analysers are installed in the flare gas header of Main tip to sense the opening of any PSV's into the flare header. When any one of the above process sensors is activated, Assist Gas will be automatically injected into the flare gas header at an appropriate location to ensure thorough mixing of NH3-CO2-H2O gas mixture being relieved and assist gas for complete destruction of ammonia.

On the activation of the above defined interlock, approximately 3000 Kg/hr of assist gas will be instantaneously injected into flare gas header. The maximum quantity of 3000 Kg/hr of assist gas was required for one of the PSV discharge cases whose calorfic value is lower than the threshold value of 200 btu/scf. To facilitate instantaneous injection of assist gas into Flare header on PSV blow-off, quick opening valves are installed in the assist gas line. In addition, a HCV is also provided in the line to remotely regulate the assist gas flow by the operator monitoring the color of the flame at main tip with the help of the camera provided for this purpose. Assist gas will be completely isolated once the operating staffs confirm that there is no more ammonia flow into the flare gas header.

In order to avoid inadvertent closure of HCV by operating staff when quick shutoff valves are closed, an additional interlock has been put in place. This interlock will ensure that HCV remains fully open when quick shutoff valves remain closed during normal operation by inhibiting the operation of HCV by operating staff.

## FLARING EQUIPMENT FOR PIC:

For the PIC application in Kuwait, there are two (2) separate plants, Urea Plant A and Plant B. Taking into consideration the locations of Urea Plants A & B and pressure drop constraints, it was decided that each plant would have dedicated flaring systems. Further, in each plant, there are three (3) collection systems for the ammonia vapors: NH3-CO2 mixtures from PSVs, pure ammonia vapors from PSVs, and NH3-CO2-H2) mixtures from the Atmospheric Drain tank. Each flare system (Plant A and Plant B) consists of three Flare Tips, one tip dedicated for each collection system.

- Main flare tip for NH3-CO2-H2) mixture from PSV Vent Header
- Utility Flare Tip 1 for 100% ammonia from PSVs
- Utility Flare Tip 2 for NH3-CO2-H2O mixtures from the Atmospheric Drain Tank Vent

It was a major challenge for PIC to identify an suitable location for the new Flare System in the existing Urea Plants, as there is not an obvious location with enough space either within the plant or in the adjoining areas. After analyzing the merits and demerits of the limited alternatives that were available, PIC made the decision to mount the flare systems on the top of the existing prilling towers that are located in Urea Plant A and Urea Plant B. Prilling towers were used in the process in the past to produce prills (pellets). The prilling towers are large diameter, concrete structures and are approximately 45-60 meters overall height above grade. The structures are approximately 16-21 meters in diameter, and have a flat concrete top. An engineering study was performed and it was determined the prilling towers had sufficient strength to support flare stacks. By placing the flare stacks on the top of the prilling towers, any and all possible problems due to radiative heat from the flare flames to personnel at grade was eliminated and in addition the need for an elaborate structure to install a tall self supporting structure in a grass root location was avoided.

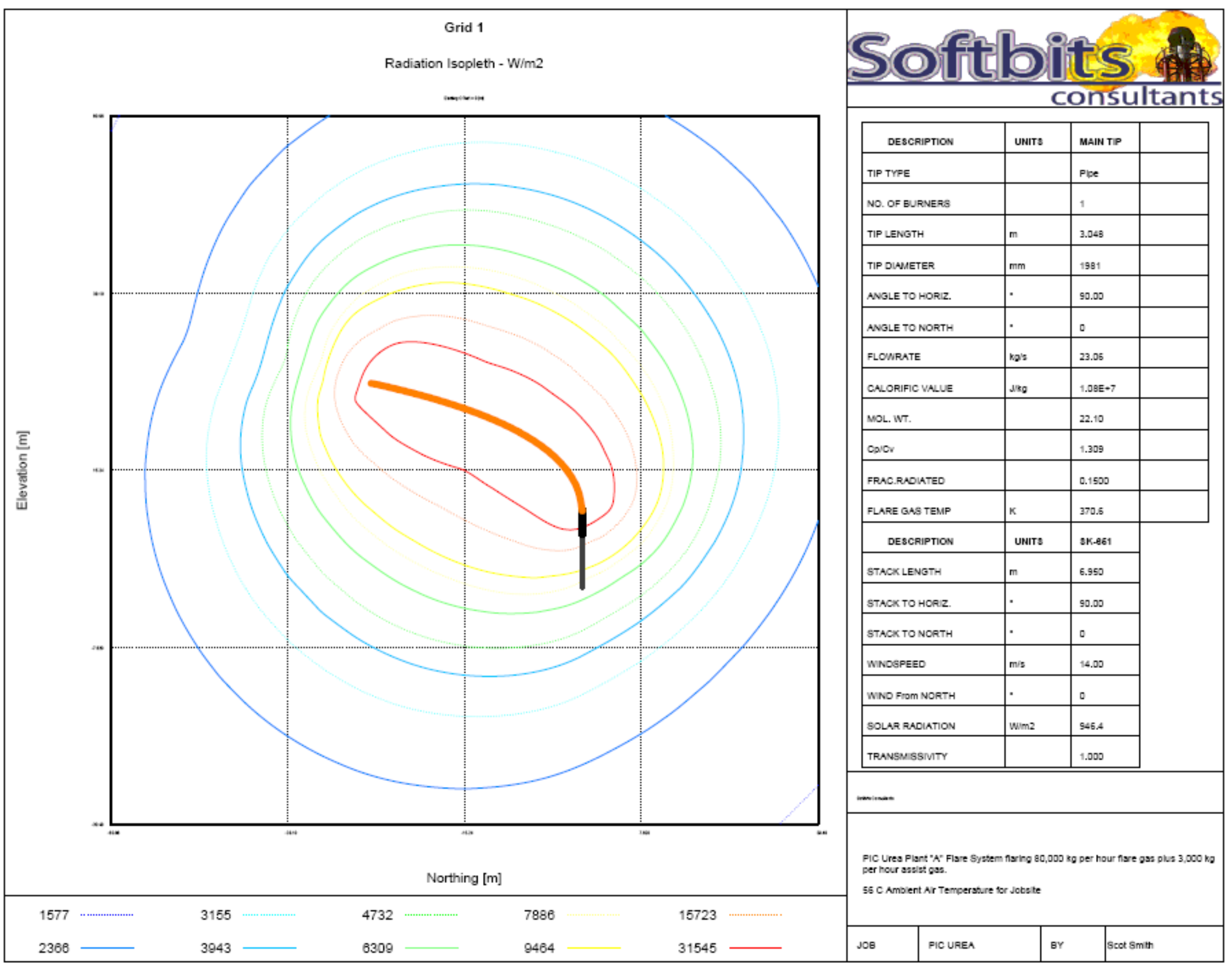
As the prilling towers are quite old, and were originally not designed to have this additional weight and wind load from flare stacks, the possible height of the flare stacks on top of the towers was limited. Based on the load stability calculations for the existing Prilling Towers inclusive of the new flare stacks, the heights of the new flare stacks were limited to 10 meters for Urea Plant A and 15 meters for Urea Plant B. At the top of the prilling tower in Urea Plant B, other process equipment, instrumentation, and electrical equipment are installed, and hence frequent plant personnel movement will be present. As the flare stack heights on the top of the prilling towers are limited due to structural constraints, the radiation levels at the top of the Prilling towers can be quite high. In addition, depending on the duration of the relief event, the associated temperatures can also be quite high.

Radiation was analyzed using Zeeco proprietary software, and also using the industry available FlareSim software. Analysis was performed for several different flaring relief loads, several combination of flaring relief loads, and also for several wind speeds. For some flaring cases, the radiation levels at the base of the flare stacks on top of the prilling towers could be as high as 3,000 btu/hr-ft2. Note the recommended limits for radiation from flare systems for personnel access and for equipment are defined in the latest edition of the API RP-521 Recommended Practice "Guide for Pressure-Relieving and Depressuring Systems". The latest edition is Edition 5 from January of 2007. The recommended radiation levels for design and application of flare systems is as shown in the table below. Note the maximum allowable value for personnel actions lasting only a few seconds is 3,000 btu/hr-ft2. In reality, this predicted radiation level is extremely high, and therefore PIC determined to apply radiation shielding to all areas in the plant including the top of the prilling tower with radiation levels that could endanger personnel. In addition, additional protective measures are envisaged for the instrumentation and electrical items that could be impacted by the flare flame radiation levels or resultant temperatures.

**Table 9 — Recommended design thermal radiation for personnel**

| **Permissible design level** *K* kW/m² (Btu/h·ft²) | **Conditions** |
|---|---|
| 9,46 (3 000) | Maximum radiant heat intensity at any location where urgent emergency action by personnel is required. When personnel enter or work in an area with the potential for radiant heat intensity greater than 6,31 kW/m² (2 000 Btu/h·ft²), then radiation shielding and/or special protective apparel (e.g. a fire approach suit) should be considered.<br>**SAFETY PRECAUTION — It is important to recognize that personnel with appropriate clothing [a] cannot tolerate thermal radiation at 6,31 kW/m² (2 000 Btu/h·ft²) for more than a few seconds.** |
| 6,31 (2 000) | Maximum radiant heat intensity in areas where emergency actions lasting up to 30 s can be required by personnel without shielding but with appropriate clothing [a] |
| 4,73 (1 500) | Maximum radiant heat intensity in areas where emergency actions lasting 2 min to 3 min can be required by personnel without shielding but with appropriate clothing [a] |
| 1,58 (500) | Maximum radiant heat intensity at any location where personnel with appropriate clothing [a] can be continuously exposed |

[a] Appropriate clothing consists of hard hat, long-sleeved shirts with cuffs buttoned, work gloves, long-legged pants and work shoes. Appropriate clothing minimizes direct skin exposure to thermal radiation.

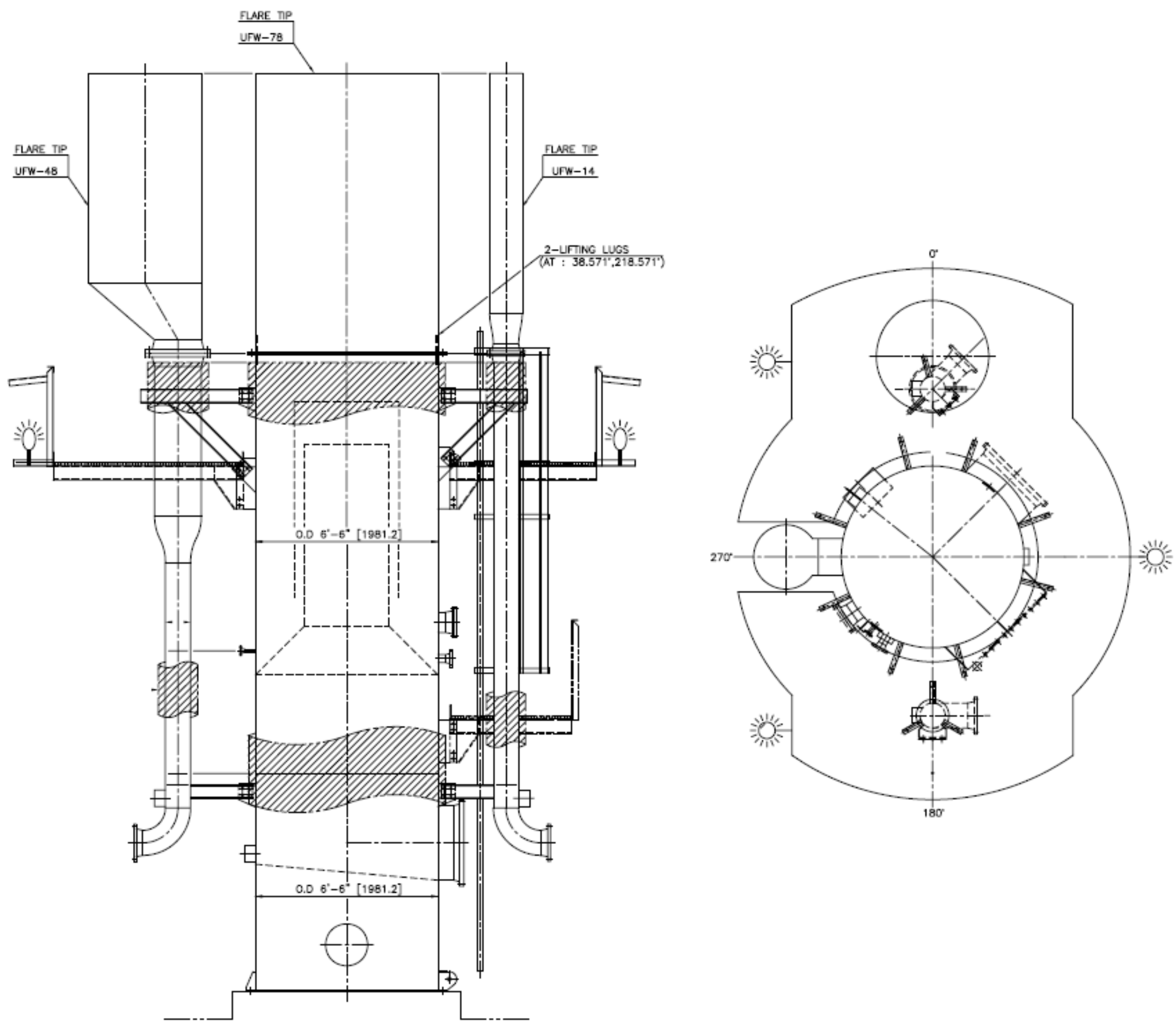


A typical radiation graph output from the FlareSim software for one of the ammonia flaring cases in a nominal 14 meter per second wind is shown above. Even though ammonia has a very low heating value, and a low emissive value, the radiation levels can be very high.

As noted before, the flare systems for each plant consist of three separate flare tips. The actual equipment that is being supplied for each plant consists of:

- Flare Tip Assemblies with Pilots and Windshields.
    - Nominal 78 inch diameter MAIN flare tip
    - Nominal 48 inch diameter UTILITY 1 flare tip
    - Nominal 14 inch diameter UTILITY 2 flare tip
- Flare support structure suitable for three (3) flare tips.
- Purge gas flow reduction seal devices.
    - Molecular type seal device for the MAIN flare tip
    - Velocity type seal devices for the UTILITY flare tips
- Utility piping and supports along the flare stack to flare stack base
- Retractable thermocouple assemblies from each pilot to the stack base
- Flare pilot ignition and status monitoring rack assembly located at grade at the base of the prilling tower. The FFG type pilot ignition system is designed to control all of the pilots on all flare tips.

The support structure was designed to support all three (3) flare tip assemblies. In addition, the site was reviewed and the wind rose information for each site was obtained to ensure the orientation of the flare tips provided the least amount of flame impingement from one flare tip to the adjacent flare tip. The three (3) flare tips are mounted on the stacks in a line, and that centerline is perpendicular to the predominant wind direction for the jobsite. See the picture below, both elevation view and top view, to understand the arrangement of the stack.




The flare stacks are equipped with ladders and platforms for access to the flare tips and pilots, aircraft warning lights and heat shields for same to warn aircraft in the area, and also with thermocouples that are retractable to the base of the stack for easy maintenance and replacement. The flare stacks including flare tips are identical in all respects except the height. As already noted, the height above the prilling tower is 10 meters for Urea Plant A and 15 meters for Urea Plant B.

Purge gas flow rate reduction devices are included in each of the flare tip assemblies. The MAIN flare tip has a diffusion or molecular type purge gas seal device. The UTILITY flare tips each have a velocity type purge gas seal device. These devices are applied as a function of the operation of the flare headers, the flare gas relief frequency, the required protection level for each flare, the amount of purge gas that is required for the nominated flare tip assembly, cost of purge gas, etc. Purge gas seal devices are described in detail in the latest edition of API RP-521 in section 4.4.3.4.2. The velocity seal devices are designed as an integral part of the individual flare tip assemblies. The diffusion seal device for the MAIN flare is designed as an integral part of the support flare stack structure. These will not be discussed in detail in this paper. The seal device types are depicted below:

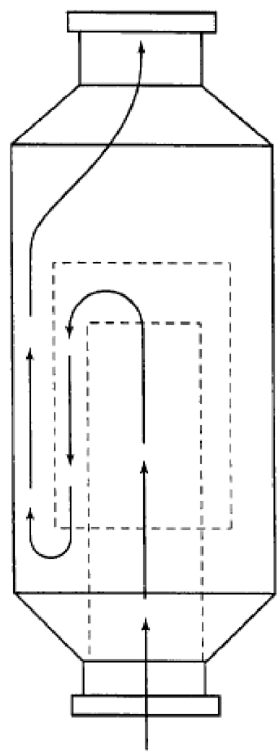


Figure 16—Purge Reduction Seal—Molecular Type

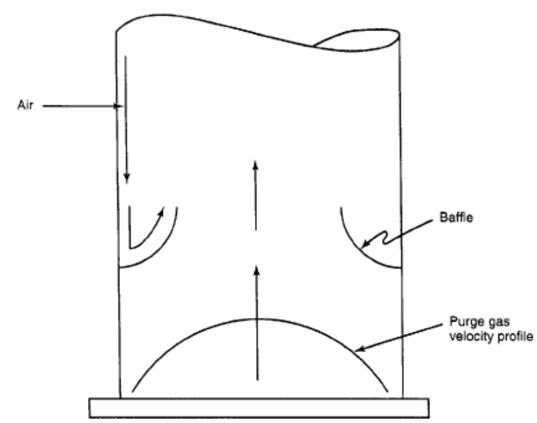
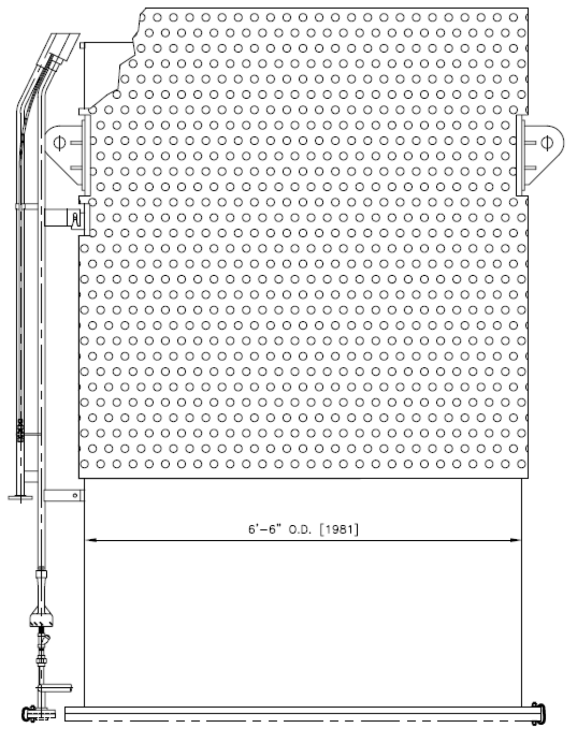
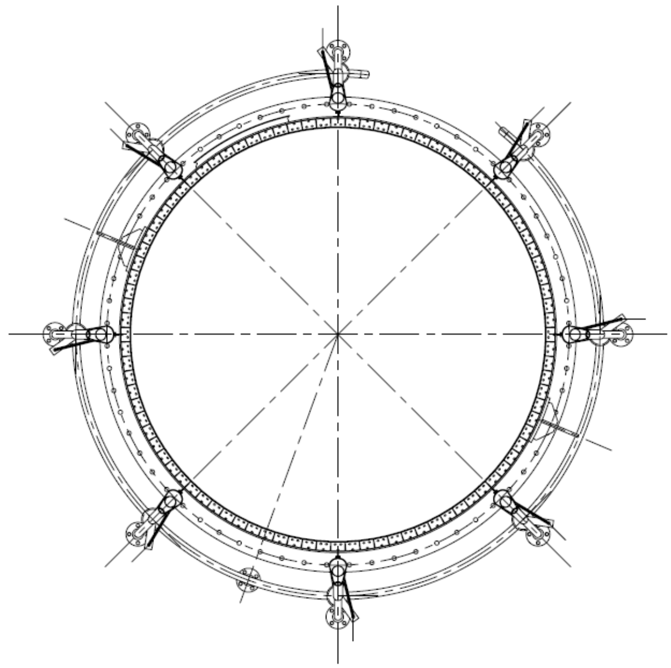



Figure 17—Purge Reduction Seal—Velocity or Venturi

The flare tip assemblies are designed with extended windshields, lifting lugs for handling, full flame retention ring for flame stability, and with multiple pilot assemblies for ignition. See the diagram below.



The Zeeco pilot assemblies are designed to remain ignited and burning in a wind speed up to and including 67 meters per second, or in a combination of a wind speed of 50 meters per second simultaneous with a rain storm that is producing rain at the rate of 100 millimeters per hour. The Zeeco pilot assemblies are designed and fabricated from stainless steel materials and castings that are very suitable for the anticipated temperature extremes likely from a large flare system. Each pilot is monitored by a type K thermocouple in a cast thermowell.

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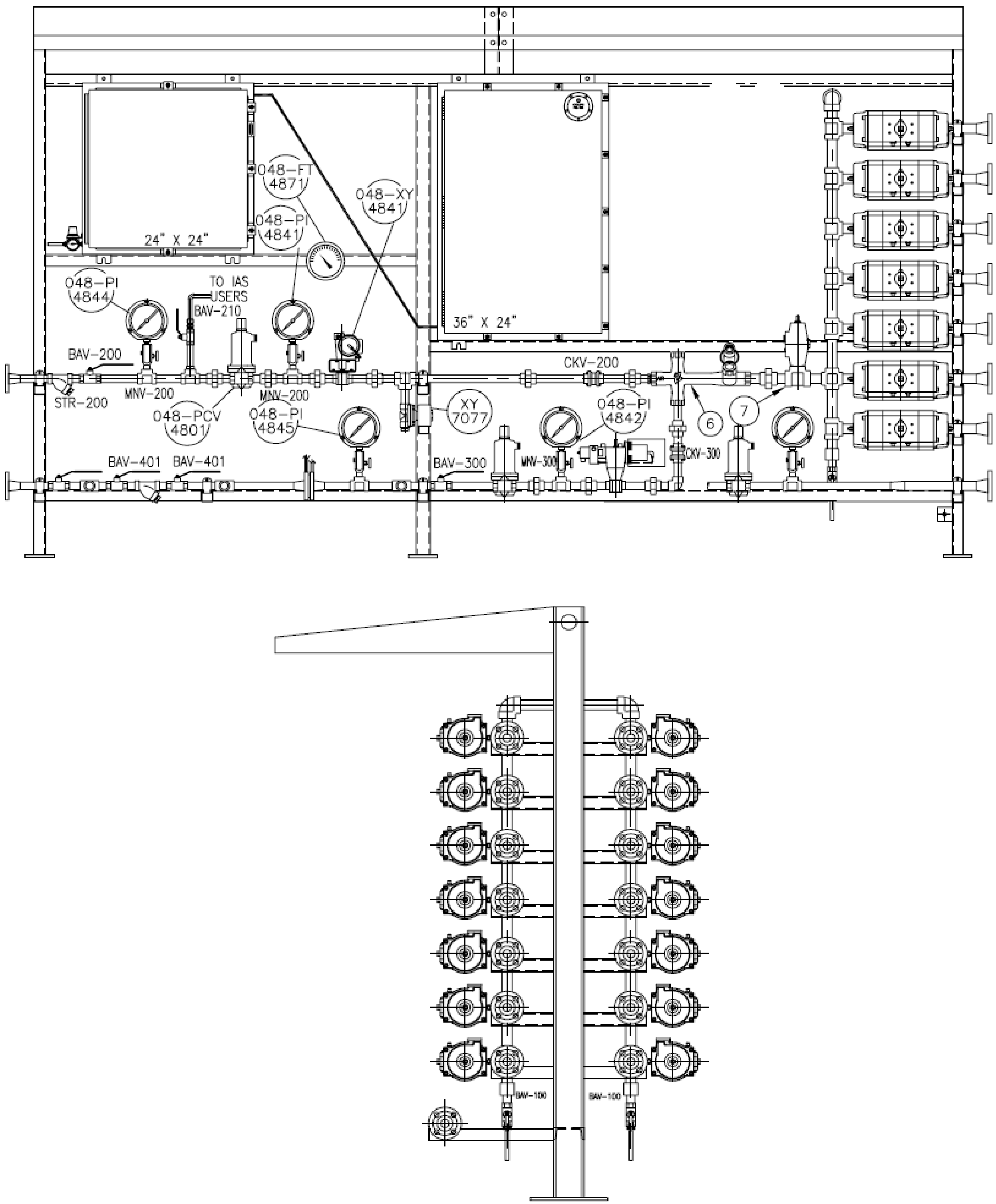
The pilots are ignited and monitored from a pilot ignition rack assembly that is located at grade at the base of the prilling tower. The ignition rack assembly provides for the manual ignition of the pilots, and also monitors the pilot status and will automatically relight any pilot that gives indication of not burning. The ignition rack assembly includes controls for regulating the pilot fuel gas pressure. The rack assembly also includes the controls for the aircraft warning lights that are mounted on the flare stacks. The rack assembly includes a sunshield for operator protection and to keep the direct sun off the control enclosures and control components. In the event all power is lost to the FFG rack assembly, there is also a piezoelectric spark device that can be used to create a spark and generate a flame front that would travel up to the pilots to provide ignition.




**<u>Zeeco Automatic / Manual FFG Pilot Ignition Rack Assembly</u>**