Designing for Safety in Ammonia Plants

Safety is Everybody's Responsibility

Part 1of 2

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Around 40 Hospitalised as Ammonia Gas Leaks in Taloja

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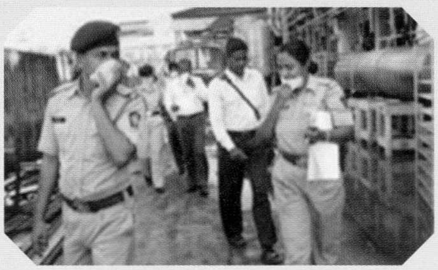
By Kunal Chonkar & Tariq Khan

Around 40 people were hospitalised after they were found suffering from the ill-effects of breathing ammonia in Navi Mumbai on Tuesday morning. Twenty eight patients were admitted to MGM Hospital in Kamothe, five to Satyam Hospital in Kalamboli and another six to Central Hospital in Taloja. All the patients are stable and undergoing further treatment.

According to fire brigade officials, the gas leaked from a cylinder tanker of a cold storage unit of a local company and poisoned locals in Taloja. "The leakage was suspected to be caused from a tanker in the R. Naik Company that is a cold storage house for fresh and dry sea foods. The leak came to be known after workers inside the company started complaining of burning sensation of eyes and irritation in throat," informed A. Shinde, Deputy Commissioner of Police, Navi Mumbai.

"Preliminary reports have been initiated and the fire brigade along with chemical experts, who were roped in early morning, were still examining the site to conclude reports. If a case of negligence is detected, we will file a complaint and move on with the legal proceedings against the owner of the plant for endangering lives and violating industrial norms," asserted Shinde.

"The entire plant area and the nearby premises have been evacuated by the rescue crew while analysts are still investigating and sanitising the premises," added Shinde.



"At around 8:30 am, we got a call from a local, Nitesh Sheikh, who informed us about the gas leak. We quickly rushed to the spot with a team that was lead by R.B. Patil and Kiran Hatyal and secured the area," informed Rajesh Gharat, sub-officer, fire brigade.

The situation had grown out of control while the team arrived as locals, who had come out protesting, started pelting stones on the company and even broke windshields of fire engine and police vehicles.

According to Dr. Mandar Phatak, KEM, "Ammonia is a corrosive chemical. The severity of health effects on any subject exposed to ammonia depends on the route of exposure as well as the dose and the duration of exposure.

"Exposure to high concentrations of ammonia in air causes immediate burning of the eyes, nose, throat and respiratory tract and can result in permanent blindness, lung damage or death. Inhalation of lower concentrations can cause coughing, nose and throat irritation," added Phatak

Ammonia refrigeration installations require precautions to be taken at every stage to ensure safety. Many users, after an accident is reported at some other place in an ammonia installation, approach consultants/ designers and request that their plants be made safe. Safety is not some accessory that can be added later on, once the plant starts operation. Safety is everybody's responsibility from inception to designing/commissioning and operation of the plant.

In the month of November 2010 there was a massive leak of ammonia from a refrigeration plant in a thickly populated area. The news paper article is reproduced here and speaks for itself.

After reading about this incident, many prospective customers who were about to order equip-

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ment for their ammonia-based refrigeration plants indicated that they intend to shift their planned facility to other refrigerants and would not like to use ammonia.

If however one goes into the cause of such accidents, generally they can be attributed to one of the following deficiencies:

- Owner with meager awareness about the specifications and needs, goes to a contractor to design and build at minimum cost.
- A definite lack of competency exists with the contractor in areas of design, installation and commissioning practices.
- Unqualified personnel involved in erection/operation of plant.
- Owner unprepared to handle an incident involving the release of ammonia.
- Owner avoided taking action to correct problems or unusual conditions brought to their notice.
- Owner making changes or alterations to equipment or systems without competent consultation and uses personnel not qualified to do work.
- Operators do not maintain log books and avoid routine inspection of equipment and system components.

Why Use Ammonia?

Why then do designers/customers continue to use ammonia refrigerant in spite of its drawbacks such as toxicity and flammability? The reasons being, it has the highest efficiency compared to any other presently available refrigerant, it has zero ODP/GWP, it is a refrigerant that occurs naturally on earth just like water, it is not a man-made chemical and consists of natural elements such as Nitrogen and Hydrogen. Ammonia refrigerant is also available at a low cost all over the country.

If ammonia leaks from an installation, it's pungent smell is easily detected if the concentration is more than 5 PPM and the operator must take action to detect and rectify such leaks. Continuous inhalation of ammonia in concentration of 25 PPM does not cause harmful effects. Even 100 PPM for a short duration does not have dangerous effects. Only above 400 PPM it causes irritation in eyes, nose and respiratory organs. Flammability limits are above 15% concentration and ammonia does not ignite below 651°C

Ammonia is the refrigerant which has therefore survived for centuries and continues to play a dominant role in cold storage installations, ice plants, industrial process plants, meat and fish freezing and ice cream making plants and numerous other applications. Many developed countries use ammonia, even for air conditioning installations like Heathrow Airport London, Oslo Airport and for many offices, telephone exchanges and supermarkets by indirect cooling, using chilled water/brine circulation in utility area. Use of ammonia is therefore increasing all over the world.

As against this the currently available HFC refrigerants are less efficient than ammonia, have high global warming impact, high cost and are man-made chemicals, highly hygroscopic, and are very expensive. They also require synthetic oil for lubrication, which is expensive and causes problems of oil return in most of the installations that are not properly designed. The only major advantage is they are not harmful to humans when persons come in contact in case of leaks. HFC/HCFC refrigerants are therefore preferred where the refrigerant-containing-components are exposed to human occupancy.

It is also worthwhile to mention here that plants using refrigerants like HCHC/HFC have far more refrigerant leakage occurrences than ammonia plants but these never get recorded in news papers and other users do not become the aware, since only loss to the customer is loss of cooling effect due to leakage of expensive refrigerant from the system. The leakage never gets noticed till the plant fails to maintain desired temperatures. This is due to the fact that HCFC/HFC refrigerants are odourless, and hence when the leak develops it goes unnoticed for considerable time before one notices the deficiency in cooling performance.

So, if we design ammonia plants and take adequate care to ensure that plants are leak proof, then we can get all the benefits of ammonia refrigerant.

Certification to Handle Refrigeration Plants

In many countries, unless refrigeration plant designers/contractors and maintenance staff have special training and certification they are not allowed to handle ammonia refrigeration systems, which unfortunately is not the case in India. In our country every erection engineer, whether qualified or not, considers himself a consultant/designer/fabricator and lack of proper knowledge therefore leads to such unfortunate accidents.

Many customers also depend entirely on their operators/consultants blindly, and in order to reduce capital investment costs unknowingly allow them to design and install plants which are not engineered to the required standards.

Reliable system installations do not happen by accident. They require careful consideration at each and every stage.

Let us start from the basic planning/designing stage and what the owner/designer's role is in this process.

Selection of Site for Machine Room

- The site should be chosen so that it prevents any possibility of an ammonia spill reaching surface water such as creeks, streams. rivers, lakes or ponds.
- Machinery rooms should be located preferably away from major traffic thoroughfares as well as nearby neighbors and prevailing wind directions
- Preferred locations for machine rooms (IIAR Bulletin 112) are:
  - Ground level- (never have the plant room in a basement or building floors above ground level)
  - Separate building or sharing with other utility systems
  - Part of the main building with three exposed walls and exposed roof

– If possible remote from heavily occupied areas.

- Factory inspector's approval/construction permits to meet local standards, electrical authority's approval, and labor department's approval for contract labor must be obtained and environmental concerns must be addressed before proceeding with the project. This will help in avoiding inconveniences, delays and costs.

Refrigeration System Designer's Role

References to standards to be followed are given wherever required. The points that need specific attention are indicated from these standards. All the requirements of standards are not indicated for obvious reasons, that this article does not intend to reproduce the entire standards which are voluminous in size. The designer must however go through the entire standard carefully to meet each and every requirement before undertaking the assignment.

Selection of Major Equipment

Given below some of the aspects normally overlooked in designing ammonia plants:

Compressors

A refrigeration compressor is the heart of the system and the only moving component. Hence malfunctioning anywhere else due to design/operation/installation deficiencies leads to compressor malfunction and breakdown. Currently, all ammonia installations use open drive arrangement with separate electric motors hence the possibility of ammonia/oil leaking through a shaft seal also exists.

1. Before undertaking designing, discussions should be held with customers/consultants if the requirements specified are incorrect. The ammonia installations in our country use water cooled systems and in many instances the cooling water temperatures specified are very high like 35°C or more. It should be noted that wet bulb temperature anywhere in the country never exceeds 29°C and with proper design of cooling tower water, availability can be restricted to 32°C or lower, with resultant condensing temperature as 40°C max. Many times some consultants try to justify abnormally high water inlet and outlet temperatures, stating that it saves pumping power and cooling water line sizes. This is incorrect since the compressor consumes more power than any other accessory, and if operated at high discharge pressures and saving in power elsewhere cannot compensate for compressor power saving. They also overlook the fact that ammonia systems must operate at the lowest saturated condensing temperature to protect compressors from malfunction or breakdown or loss of lubricating properties, especially if one is using a reciprocating compressor.
2. The discharge temperature also should be limited to maximum 130°C to 140°C, to protect lubrication and oil properties, if one is using mineral oils normally recommended by compressor manufacturers.
3. If the temperature difference between saturated condensing temperature and saturated suction temperature exceeds 50K then the designer should go for multistages. Any ammonia plant working should therefore never be subjected to discharge pressures exceeding 14.8 kg/cm^{2}g or 210 psig corresponding to 40°C condensing temperatures.
4. The condensers, cooling towers and pump sets should be designed and selected accordingly. Any plant operating at higher than this pressure is a potential danger to equipment, consumes more power and possibility of ammonia leaks may increase.
5. The boundary limits for operating parameters as defined by the manufacturer should never be exceeded. Many engineers claim that although the reciprocating compressor manufacturer does not recommend use below 10°C with 40°C condensing temperature, they are using these single stage reciprocating compressors with minus 20°C evaporating temperatures. Using a compressor at these conditions does not mean that the compressor will immediately break, but the life will certainly get reduced, there will be frequent shut downs for repair, higher spare part consumption and efficiency will be very low.
6. Low temperature systems using two stage compressors need automatic capacity control systems with modulating inter-stage cooling arrangement. In most plants this is absent, leading to compressor operation not responding properly to load fluctuations and subsequent problems of compressor failures, especially the high stage cylinders. It is therefore recommended that in addition to proper automatic capacity control system a high temperature cut out should be provided in the discharge line so that when temperature exceeds the set limit, the compressor trips. The high stage cylinders can also get damaged due to overfeeding of liquid injection in the inter-stage, particularly at low load operation if modulating liquid feed control is not provided.

The other important components in the system besides compressor are condensers, receivers, and other pressure vessels.

Condenser/Receiver/Evaporator & other Pressure vessels

Heat exchangers like shell-and-tube condensers and evaporators need to be designed as per TEMA Standard and pressure vessels as per ASME sect. VIII div.1

The other standards to be used for designing are:

- IS 4503 Specifications for Shell-and-Tube Type Heat Exchangers
- IS 2825 –Code for Unfired Pressure Vessels
- ANSI-IIAR 2-Equipment Design & Installation of Closed Circuit Ammonia Mechanical Refrigeration Systems
- ANSI/IIAR 74-2 Equipment, Design, and Installation of Ammonia Mechanical Refrigeration Systems
- ANSI/UL 207

Some of the key important requirements are given below:

1. The condensers and high pressure side vessels should be designed for 300 psig pressure (21kg/cm^2) and the low side evaporators and vessels should be designed for 150 psig (10 kg/cm^2) pressures. Standard ANSI B9.1 has a rider that **"selection of higher design pressures may be required to satisfy actual Shipping, Operating and Standby conditions."** In India, many plants install liquid ammonia receivers outside the plant room, directly exposed to the Sun. In such instances due to solar radiation, the metal skin temperature may even reach 70°C with 40 to 45°C ambient temperatures and this should be considered while designing/locating the vessels. The vessels should never be exposed directly to Sun and should be kept in the shade all the time so that actual pressures do not exceed design pressures, leading to possibility of leaks and accidents.
2. Use of correct material is important. In many instances the tendency is to use used ship-break material which can lead to problems. Material obtained from dealer/stockist of manufacturers with mill certificate should be used. If cut plate is required, the mill stamp should be transferred so that traceability of the original material is available. The plates may require dye penetration/ultrasonic tests to detect internal cracks or laminations if any, before plates are rolled in shells.
3. The fabrication should be done using correct thickness calculations as per code. Corrosion allowance of at least 1.5 mm and mill allowance for rolled plates should be taken into account. The thickness calculation also depends upon whether radiography for weld joints is to be carried out.
4. The plates should be shot blasted to remove surface contaminants so that the internal parts of vessels coming in contact with ammonia remain clean.
5. Stress corrosion cracking results in tiny cracks if oxygen level in liquid ammonia exceeds few PPM and few thousand PPM in gaseous state and it can promote cracking. These cracks are very fine and not generally visible to the naked eye: they occur on the interior surface of vessels. These can be detected by ultrasonics or dye penetration techniques. IS 660 Code 6.1 para therefore calls for periodic hydraulic testing and examination under the Factory Act 1948 , which many times necessitates provision of two liquid storage receivers so that when one is under inspection, liquid ammonia can be shifted to the stand by receiver. It is therefore good practice to include automatic air purgers to get rid of non condensables periodically.
6. When the plant is not operating and if liquid ammonia is not pumped out from Low Pressure receiver then the standing pressures would be corresponding to surrounding plant room conditions and if the vessels are designed for 150 psig then the actual pressures would exceed this limit. It is therefore strongly recommended that Low pressure vessel should also be designed for 300 psig (20kg/cm^2) pressure. This has another advantage in that one need not pump out ammonia from LP receiver to high pressure receiver every time the plant is to be switched off and Low Pressure receiver would then act as ammonia storage vessel temporarily in case some maintenance is required to be carried out in other parts of the system.
7. The pressure testing of vessels can be hydraulic at 1.5 times the design pressure and/or pneumatic at 1.25 times the design pressure. If hydraulic testing is done the vessels should be thoroughly dried internally. In many instances it is observed that if water is not drained fully then, when plant is commissioned and ammonia comes in contact with water, rusting starts and continues for considerable duration and the strainers need frequent cleaning causing nuisance and delay in commissioning.
8. Proper care for transportation needs should be taken. Many times it happens that the nozzles get broken; the vessel drain pots get twisted/damaged while unloading, vessel lands on these protrusions. It becomes extremely difficult to repair such damages at site and even when done can be a potential area of leakages, ruptures as they become weak links.
9. As the code indicates, no welding should be carried out subsequently on the vessel once the pressure vessel is ready for shipment from factory. The vessels/heat exchangers should have the name plate welded indicating design/operating parameters and other details as per code requirements.

Plant Room Design Requirements

Standards

- IS 660-Safety Code for Mechanical Refrigeration
- IS 3594 Code Practice for Fire Safety of Industrial Buildings: General Storage and Warehousing Including Cold Storages
- ANSI B9.1 –Safety Code for Mechanical Refrigeration
- IIAR 2 Section 13- Machinery room Design
- IIAR Bulletin 112 – Ammonia Machinery Room Design
- IIAR- Bulletin No. 111-Guidelines for Ammonia Machinery Room Ventilation
- NHB Standards for Cold Storages

Machinery Room Contents

Preferably, the ammonia refrigeration room should house only ammonia containing equipment and direct ancillary equipment such as water pumps. Boilers and other open flame producing equipment, including open flame space heaters must not be located in this machine room. Lubricants and other combustible materials shall not be stored in the machinery room. No electrical equipment shall be powered or controlled from the machinery room unless it is directly associated with the refrigeration system.

Machinery Room Layout

1. Sufficient space shall be provided to allow access to equipment for maintenance purposes. A minimum two exits must be provided from the machinery room. Exit doors shall swing outward, and shall not be locked when machinery room is occupied.
2. Means like over head crane or chain pulley block shall be provided for removal or replacement of any heavy motors or equipment.
3. Adequate space for tube cleaning of heat exchangers shall be provided.
4. Machinery room structural support systems should include provision for concentrated loading from piping, vessels and equipment.
5. Walls, floor and ceiling shall be air tight and not less than one hour fire resistant material for construction.
6. Floor should be designed to accommodate static and or vibrational/dynamic loads imposed by equipment. Foundations as per manufacturer's recommendations for reciprocating equipment are required.
7. All machinery piping, valves should be mounted in such a manner as to prevent vibrations being transmitted to the building structure.
8. Machinery floor should be slip-resistant and should be sloped to floor drains. Accumulation of water or running of waste water across the floor shall not be permitted.
9. Machinery or piping which may cause condensation or drips shall not be located over electrical equipment.
10. Elevated equipment and valves located more than seven feet above floor level should be provided with access platforms and or ladders designed as per code requirement.
11. There should be a clear head room of at least 2.2 m over passage ways
12. There shall be no portion or openings that permit passage of escaping refrigerant to other parts of the building. The points of passage of all piping and cable ducts through walls, ceilings and floor shall be tightly sealed.
13. Emergency remote control box to stop the action of refrigeration compressors shall be provided and located just outside the machinery room. This would also have provision to start exhaust ventilation fans.
14. For electrical wiring heavy duty galvanized conduit should be used in machinery room. The light fixtures should provide minimum 12 watt/sq.m at working height of 1 m above floor or platform. Condenser/receiver or other equipment located outside should be lighted to permit adequate night time inspection.
15. Access to machinery room shall be restricted to authorized personnel only. ❖