Enabling the decarbonisation of Australia's energy networks

RP3.2-13: Ammonia pipelines – review of dispersion characteristics and threat mitigation

Overview & background

In the Australian context, ammonia produced from renewable hydrogen may emerge as an energy carrier and an export product, possibly requiring cross-county ammonia pipelines, which to date do not exist in Australia. One of the main concerns of ammonia pipelines is the potential safety hazard due to loss of containment. Anhydrous ammonia leaks rarely ignite, but toxicity is greater than other energy products transported by pipeline, and impacts on aquatic life can be significant if a leak enters waterways. This project reviews the current knowledge of ammonia toxicity in the context of transmission pipelines, accompanied by preliminary modelling of dispersion behaviour and consequences of ammonia releases.

Ammonia toxicity thresholds

The USA EPA has suggested Acute Exposure Guideline Levels (AEGLs) for periods from 10 minutes to 8 hours, categorised as:

- AEGL1 = no long-term effects
- AEGL2 = long term health effects
- AEGL3 = life threatening effects or death.

For 10 to 30 minutes exposure, AEGL1 for ammonia is 30 ppm, AEGL2 is 220 ppm and AEGL3 is 2700 ppm. As exposure times increase, the concentrations decrease. These various categorisations underline the importance of minimising the exposure to ammonia. Ammonia is readily detectable at levels well below 20 ppm, so no odorant is required.

Review of ammonia incidents and dispersion behaviour

The literature review details information on existing pipelines throughout the world, and ammonia accidental releases. Various experimental releases have been conducted with measurements of ammonia concentrations as a function of location and time. The results show that since anhydrous ammonia is stored as a liquid, it boils and self-cools as it is released, and cools the air it mixes with, producing a two-phase cloud that is normally denser than air and so hugs the ground and can flow to low lying regions. The implications for pipeline routing are clear.

Ammonia accidents have mainly occurred from refrigeration or process plants or when transferring tanker storages in the agricultural sector. In the USA 91 ammonia accidents have been reported which resulted in injury or death since 2002. In Europe there have been 85 major incidents involving ammonia since 1985. Environmental impacts were rare in both cases, but there is a high fatality rate of approximately 16% in US accidents and almost 50% in the European accidents, which may reflect a difference in reporting threshold. These consequences illustrate the need for a detailed risk / consequence assessment (quantitative risk assessment – QRA) for any cross-country ammonia pipeline, from which the required design and controls can be specified, such as material thickness, welding procedures and tests, leak detection, shutdown options and location relative to population centres and taking topography into account.

Review of Australian and international standards and codes

AS/NZS 2022:2003 is the current standard for anhydrous ammonia storage and handling but does not apply to large-scale ammonia pipeline transportation. Ammonia is not specifically covered under the AS2885 standard series for high pressure pipeline systems, however as per AS 2885.0, transportation of other non-hydrocarbon fluids is not precluded, but requires special consideration for the differences introduced by the fluid. It is possible that the series will be updated to include ammonia as a specifically listed substance with design, construction and operating requirements.

AS/NZS 2885.6, Part 6: Pipeline Safety Management defines the safety management process for a pipeline system and will generally apply to a new ammonia pipeline. However, modifications will be required to address failure outcomes associated with releases that are different to the fluids already covered and consider the different dispersion and human and aquatic toxicity of ammonia. The definition of the 'measurement' length and associated assessment will need to be adapted to cover the safety limits associated with ammonia toxicity as was discussed in AS/NZS 2885.1 Appendix T for CO_2 concentration (in that case as an asphyxiant). As for CO_2, local topography may need assessment to determine the potential for a release to travel to sensitive locations and influence both the route selection and controls required to mitigate, including automated isolation valves. Failure modes specific to ammonia, such as internal SCC in carbon steels, should also be addressed by the Safety Management process, noting that controls to prevent this are generally well known in the ammonia sector.

International codes for ammonia pipelines include the USA standard ASME B31.04 which covers the design and operation and maintenance of liquid pipeline systems, mainly focused on liquid hydrocarbons, but includes anhydrous ammonia within the scope. The US Code of Federal Regulations, CFR 2011 Part 195: transportation of liquids by pipeline, has more details on construction, operation, safety, corrosion control and maintenance, and has no significant differences for anhydrous ammonia from the other liquids covered by the code. It notes that ammonia is one of the liquids that is highly volatile and has a high safety risk factor. A European guideline has been produced by the fertiliser industry and includes additional useful information.

Consequence modelling: GPA Engineering Report

The literature review was complemented by a separate report by GPA Engineering (230675-CALC-001-r0 - Ammonia Pipelines Consequence Modelling), based on consequence modelling of ammonia releases, using the DNV Phast™ v9.0 software. Several scenarios were modelled based on discussion with the advisory team, including full bore ruptures and small leaks for a range of pipeline diameters. The modelling results demonstrate that the toxic dispersion extent of ammonia at harmful concentrations can greatly exceed the extent of flammable vapor dispersion and thermal radiation consequences from hydrocarbon pipelines.

For typical transmission pipeline diameters, reducing the pipeline diameter has an appreciable effect on reducing toxic dispersion extent, although the extent remains considerable. Conversely, decreasing the isolatable segment length does not appreciably reduce the extent of toxic dispersion. As a result, reducing pipeline isolatable section length (e.g. from several tens of kilometres to a few kilometres) may not be the most effective approach for reducing consequence footprint from the source of release.

This report also outlined potential future work in this area, such as performing a QRA and/or advanced modelling techniques (e.g. CFD) to incorporate terrain features and specific considerations for buried pipelines.

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