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VAPOR EMISSION CONTROLS

1. GENERAL

There are increasing concerns about the environmental and health effects of emissions of volatile organic compounds (VOCs). The principal man-made sources of VOCs in the developed countries are solvents and gasolines. The distribution and storage of gasoline contributes to these emissions.

Legislation limiting VOC emissions from the storage and distribution of gasoline has been implemented in a number of industrialized countries around the world, including the USA, Japan, Australia and the countries of the European Union.

The reduction of emissions during the storage, loading and off-loading of gasoline is known as “Stage 1” vapor control. Stage 1 is subdivided into:

Stage 1a: The control of emissions during the storage and loading of gasoline at loading terminals.

Stage 1b: The control of emissions during off-loading at service stations.

The control of emissions generated during automobile refueling can be undertaken either by using a system on-board the automobile (e.g. carbon canister) or by modifying the gasoline dispenser and feeding the vapors back to the service station storage tank. The latter is known as “Stage 2” vapor control.

Both Stages 1 and 2 comprise “closed” systems. Uncontrolled emissions occur when any of the “open” tanks in the distribution and marketing chain are filled, e.g. the compartment of a road tanker, a rail tank car, the hold of a marine vessel, the underground tank at a service station, or the fuel tank on an automobile.

In a closed system, vapors are prevented from being emitted to the atmosphere by being captured and collected either for recovery in a vapor recovery unit (VRU) or for destruction by incineration.

2. EMISSION STANDARDS

At loading terminals in the USA, the Environmental Protection Agency (EPA) stipulates a maximum level of VOC emissions of 35 mg/l of gasoline loaded. This equates to a maximum outlet concentration in the VRU effluent vent gas of around 50 g/m^3.

The German "Technical Instructions on Air Quality Control" (TA Luft) prescribe maximum emission levels for three categories of VOCs. Most gasoline vapor constituents belong to category III, which means that the total emission of hydrocarbons, excluding methane, should not exceed an amount of 150 mg/m^3 of vent gas. This limit applies if the total emission exceed the 3-kg/h threshold. Benzene belongs to category I, with a prescribed limit of 5 mg/m^3 above a mass flow of 25 g/h. The TA Luft standard is much more stringent than the EPA standard and requires a VRU efficiency of around 99.99%.

The European Commission has issued a directive on the control of VOC emissions, which covers the receipt, storage and delivery of gasoline. The limit for VOC emission is 35 g/m^3 in the VRU effluent. The requirements of this directive can be met with a single-stage VRU operating at a recovery efficiency of 98%.

3. APPLICATION OF VAPOR EMISSION CONTROLS

3.1 Reduction of vapor generation

Considerable reduction in vapor emissions can be achieved not only by installing a vapor collection system but also by avoiding free fall and splashing of volatile products in top and bottom filling operations. Loading facilities should therefore be designed as follows:

1. Top loading

   The loading arms should be sufficiently long to reach the end compartments of a vehicle tank so that the down pipe can be inserted vertically to the bottom of the compartment.

2. Bottom loading

   Deflectors should be fitted in the vehicle tank at the point of entry of the product into the compartment in order to prevent “jetting”.

3. Loading rates

   It is normal practice to begin and end a loading operation with a filling rate substantially lower than the normal high flow rate of the loading system. The lower start loading rate will assure that the loading arm or deflector will be submerged before the high flow rate will be reached.

4. VAPOR COLLECTION SYSTEM

A vapor collection system routes the vapors from the emission sources (e.g. road tanker, rail tanker car, marine vessel or storage tank) to the vapor recovery unit or incinerator or to a safe location for venting to atmosphere (assuming no local regulation for VOC emissions). The following types of systems are available:

4.1 Direct system

In this system, the vapors collected during vehicle loading are passed directly to the vapor recovery unit or incinerator. The vapor recovery unit can be activated by a signal that loading is about to commence, from either the product pump or loading arm.

With bottom loading of road tankers the vapors from all compartments are collected, including those from non-gasoline loading (e.g. automotive gasoil). These additional vapors, plus the vapors generated during the loading itself (e.g. by evaporation of the product), are taken into account when sizing the vapor collection and vapor recovery unit or incinerator.

4.2 Direct system with vapor holding tank

To even out fluctuations in the vapor flow a variable volume vapor holder can be installed in the vapor line to the vapor recovery unit or incinerator. The vapor holder is sized to contain the vapor produced in excess of the vapor recovery unit’s or incinerator’s capacity.

The advantages of a vapor holding tank are:

- Lower peak capacity of VRU;
- Lower energy use due to smaller VRU running at optimum working point;
- Higher reliability as vapor holding tank can buffer vapors during short shutdowns/ maintenance of VRU

The vapor holding tank is protected against over and under pressure.

4.3 Vapor balancing system

In this system the vapors displaced during loading are routed back to the ullage of the tank from which product is being pumped. The vapors are fed to the vapor recovery unit or incinerator when the tank is being filled. A vapor holder may be included in the system. To prevent product contamination due to vapor condensation only gasoline storage tanks should be connected into the balancing system.

4.4 Design of vapor collection systems

Vapor collection systems are generally designed and sized according to the IP "Guidelines for the Design and Operation of Gasoline Vapor Emission Controls". The vapor collection system shall be adequate to cater for the peak-loading rate anticipated at the loading gantry, including displacement from gasoil compartments on mixed loads in multi-product gantries. In direct systems the vapor generation in product tanks due to ambient temperature changes and solar radiation should be considered.

Consideration should be given to:

- Collection, detection and draining of any product carried over into the connection line during an overfill or any condensate formed in the vapour line;
- Prevention of vapor leakage from the connection when it is not in use due to pressure in the vapour collection system.

5. VAPOR RECOVERY UNITS

5.1 Types of vapor recovery units

Vapor recovery units are devices, which separate hydrocarbons from air and convert them back into liquid. The main types of vapor recovery units on the market are:

5.1.1 Carbon adsorption

The incoming vapor stream is passed through a bed of granular carbon. The hydrocarbons in the stream are adsorbed onto the surface of the carbon. Pulling a vacuum with a liquid ring pump and flushing it with air in the reverse direction regenerate the carbon bed. The hydrocarbons liberated during the regeneration are recovered by passing them counter current to a gasoline stream from storage in a reabsorber column or are condensed by refrigeration.

This technology has been used extensively in the USA and Europe. The technology has matured and the initial overheating and carbon filter problems have been overcome. However, the processing of solvent, additive or chemical vapors can still result in overheating. This is the only well-proven recovery technology for obtaining very low outlet concentrations with a single stage unit.

5.1.2 Lean oil absorption

The incoming vapors are absorbed into a liquid of low vapor pressure, e.g. chilled kerosene. The mixture is distilled and separated into concentrated gasoline vapors and the absorbing medium. The absorbing medium is chilled and recycled to a buffer capacity. The gasoline vapors are recovered by passing them counter current to a gasoline stream in a reabsorber column. To prevent icing an anti-icing additive, e.g., methanol has to be injected. This additive will end up in the wastewater, which can pose environmental problems.

This technology has been used extensively in Europe. This technology has a high peak-handling capacity, as the absorbing medium can be stored. It could be considered for recovery of chemical vapors and crude vapors.

5.1.3 Refrigeration/Condensation

The incoming vapors are condensed at very low temperature (around -90 °C) using a cold heat exchange medium. This medium can use refrigeration processes or a liquefied gas such as nitrogen. The condensed product can be pumped straight to storage and the amount of recovered product can thus be measured very easily. The system has to be defrosted on a regular basis.

The energy efficiency of this process is low due to the very low temperatures needed. The system based on liquid nitrogen is very simple to operate and could be suitable for small loading terminals (annual throughput less than 50 000 m^3).

5.1.4 Membranes

Hydrocarbon-selective membranes are used to separate the incoming vapors from the air. Compressing the incoming vapors with a compressor and/or pulling a vacuum at the other side with a vacuum pump create the necessary pressure differential across the membranes. The concentrated gasoline vapors are recovered by passing them counter current to a gasoline stream from storage in a reabsorber column.

This technology has been extensively been used in Europe. As the process cannot cope with large variations in throughput, a vapor holder tank (gasometer) upstream of the VRU is normally needed. Special consideration shall be given to the safety aspects of having rotating equipment within the vapor collection system.

5.2 The choice of vapor recovery unit

The different types of units have different fields of application. The following considerations should be taken into account in the choice of a VRU:

1. Throughput profile (peak, 15 minutes, hourly, four hourly and daily capacity);
2. Required outlet concentration;
3. Type of vapors to be processed (only gasoline, or also diesel, solvent, chemicals, additive or MTBE vapours);
4. Energy, utility and other consumables (anti-icing additives, absorption liquid, carbon, glycol etc.) consumption;
5. Availability of utilities at the site (steam, electricity, cooling water, hot oil, sewage system, absorption liquid, instrument air, nitrogen etc.);
6. Simplicity of operation and maintenance;
7. Environmental aspects (waste water, spent active carbon, refrigeration medium);
8. Accuracy of recovered gasoline measurement (to allow the prepaid duty on the recovered gasoline to be reclaimed);
9. Experience of, and technical back-up (service organisation / spare parts) supplied by, the Manufacturer;
10. Safety.

The technology and market situation of vapor recovery units is rapidly evolving. Presently, carbon adsorption units are normally used in marketing installations, as they need only electricity as utility, are relatively easy to operate and maintain and have proven themselves in practice. For large capacity installations membrane units in combination with a vapor holder tank should be considered.

Liquid absorption units could be considered for high peak throughput units, which have to handle solvent, chemical or crude vapors at sites where the necessary utilities are available (typically refinery sites).

5.3 Design of VRUs

VRUs are generally designed and sized according to the IP “Guidelines for the Design and Operation of Gasoline Vapor Emission Controls”.

Most Manufacturers build their VRUs according to a standardized design. If a Manufacturer's design is proven in practice in similar situations, that design should be adopted (as far as possible) in order to prevent redesign resulting in excessive cost and the risk of improperly functioning units.

5.4 Incineration

An alternative to vapor recovery is incineration or flaring, which could be an alternative for difficult to handle products such as crude vapors or solvents. Installations are expensive because of the many safety precautions, and running costs are high since additional fuel is required for optimum combustion. Guidance for the selection and operation of incineration systems can be found in the IP “Guidelines for the Design and Operation of Gasoline Vapor Emission Controls”.

In several VRUs, incineration is used as a second stage. The outlet vapors of a conventional single stage VRU are fed to a gas or diesel engine and are burnt. Low outlet concentrations can be obtained if the exhaust is equipped with a catalytic converter. The energy produced can be used to generate electricity. This type of unit tends to be maintenance intensive.

6. FIRE AND EXPLOSION PROTECTION

Vapor collection systems connect different parts of the system. Often, vapors in the collection system are in, or pass through, the flammable range, for example during the start of loading or when a mixture of vapors of high flash (e.g. gasoil, kerosene) and low flash products (gasoline) are loaded through the system. If ignition occurs somewhere in the system, e.g. static electricity discharge during loading, fire in VRU, or lightning strike, the fire/explosion can spread through the system.

As the collection system consists of large bore pipe with lengths often of hundreds of meters and with obstructions such as valves and bends, the initial deflagration (a subsonic flame front) can rapidly develop into a detonation (a supersonic flame front). The consequences of a detonation, which can generate shock waves with pressures of over 50 times the initial pressure, are even much greater than the consequences of a deflagration, which generates pressures up to around 10 times the initial pressure.

To limit the consequences of an ignition the following techniques or a combination of them can be used:

6.1 Containment

The process is designed to contain the explosion event by ensuring that the entire process can withstand the maximum explosion/detonation pressure without rupture.

Road loading vehicles and storage tanks are generally not designed to withstand the forces of a deflagration. Normally it is not feasible to design the system to withstand the extreme forces of a detonation.

6.2 Explosion venting

This is a technique to relieve the explosion pressure and flame in a controlled manner to atmosphere by installing weak membranes in components or pipelines. The vents should be placed at intervals less than the predicted run-up distance to detonation and should be at least equal to the cross sectional area of the pipe. In normal operation the discharge of flame and pressure from the pipe can be considerable, therefore great care should be taken with the location of the vent and the direction in which the flame will be released. Explosion vents will reduce the effects of accumulated pressure within the pipe but are unlikely to prevent a flame from continuing past the vent.

6.3 Active explosion suppression or isolation

The flame is detected and suppressed by rapid injection of a chemical suppressant or is isolated by rapidly activating a valve. Due to their complicated design these techniques should not be employed.

6.4 Deflagration and detonation flame arresters

These are wound crimped steel ribbon devices installed in the pipe, quenching the flame by removing the heat as the gas passes through the numerous narrow channels.

There are two different types, deflagration and detonation flame arresters.

Deflagration flame arresters are not designed to withstand the forces of a detonation. Therefore, they should only be installed in positions where an initial deflagration cannot develop into a detonation before it reaches the flame arrester. The effects of obstructions in the pipe, such as bends and valves, should be taken into consideration as they can accelerate the flame front and considerably shorten the run-up length to a detonation. Deflagration flame arresters can be used for open vent stacks.

Detonation flame arresters are similar to deflagration flame arresters but they can also absorb and withstand the large forces of a shock wave. Therefore they are much heavier and more expensive. Care should be taken during installation as many detonation flame arresters are not bi-directional and can only protect against a shock wave coming from one direction.

In the design of the vapor collection system the often considerable pressure drop of flame arresters shall be taken into consideration and an extra allowance for fouling of the flame arresters shall be made.

Flame arresters are susceptible to fouling (by rust particles), freezing and corrosion, all of which will impair the functioning of the flame arrester. They are also prone to collecting condensate.

They should be installed so as to allow easy access for inspection and maintenance (often regular cleaning is necessary). Provisions for isolation should be considered.

Flame arresters shall have been demonstrated to work under actual conditions and shall have been tested to an appropriate standard, e.g. BS 7244 or US 33-CFR-154.

6.5 Risk assessment and cost effectiveness of protection

Detonation arresters do not reduce the frequency of explosion incidents but can mitigate the effects of knock-on effects (i.e. explosions and fires in other parts of the system). The cost-effectiveness of detonation arresters, in averting loss of life and loss of installations due to knock-on effects, may vary depending on the configuration and operation of the vapor collection network and on how the detonation arresters themselves are arranged.

Especially for large installations (more than 4 connected loading bays or more than 8 connected tanks) a Quantitative Risk Analysis study should be performed to determine the most cost effective arrangement of detonation arresters. Within such a study the following parameters should be considered:

1. Ignition probability of tank cars, VRU and product tanks;
2. Probability that the vapors within the vapor collection network are within the flammable range;
3. The number of loading bays and tanks (the larger the installation the greater the risk of an ignition and knock-on effects);
4. Cost of loss of installation (including loss of market business);
5. Probability of people being situated within areas which could be exposed to knock-on effects (e.g. road tanker drivers and operators close to tanks or the VRU);
6. Investment, maintenance and operating costs (pressure drop, blockage) of detonation arresters.

The installation of detonation arresters at the following positions is generally considered as cost effective:

1. On each product road/rail loading point;

2. On the VRU vapor header;
3. On vapor headers to groups of more than 4 tanks (in general a detonation arrester on every tank is not considered cost effective).

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