

THE ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

Emission reduction from oil storage tanks and loading operations

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ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

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1. Introduction

1.1 Scope

The prevention and control of volatile organic compound (VOC) emissions from storage tanks containing oil or chemical feedstocks or products is of primary importance, not only for economic reasons (loss of product) but increasingly to minimize the impact on the environment. National and local authorities are becoming progressively more environmentally conscious, and various countries have introduced, or are introducing, statutory regulations aimed at minimising the risk of such emissions.

The EEMUA Storage Tanks Technical Committee decided that there was a lack of guidance in this area and has therefore developed this Publication to meet that need. In the first sections, this Guide addresses the main theory on how emissions can be minimised by focusing on the source of emissions. The theory is valid for most stored products including oil and chemical feedstocks. However, this Publication deals mainly with the storage of hydrocarbons and the consequent emission controls for such storage tanks.

'Stench', not originating from VOCs but from sulphur components, is not within the scope of this Publication.

EEMUA 213 therefore guides tank owners and operators, manufacturers, designers and specifiers to the most suitable tank type for particular feedstocks based on the true vapour pressure (TVP) of products. It provides background theories on possible solutions to prevent or reduce emissions from tanks and during loading operations. It also gives guidelines on the treatment of the escaping vapours when the achieved level of emissions does not match the intended level or statutory requirements. It describes:

- Each vapour treatment system currently available.
- The system configuration and where possible includes a sketch of the apparatus.
- The technical aspects of the system.
- Some requirement for utility connections and capacities.
- Possible achievements with respect to reduction of dangerous gases.
- The limitations of each system.

1.1.1 Note on Terminology

The term stored 'product' is used in the text. Stored **product** refers to whatever oil or chemical is stored in the tank, including feedstocks.

1.2 How to Use this Publication

The best solution to prevent and limit emissions to atmosphere of VOCs and vapour from stored products in tanks is to select the best type of tank for a particular product. The key parameters for such a selection process are the flashpoint and the TVP of a product. Chapter 2 describes how the use and interpretation of these parameters can be the basis for the selection of a suitable storage tank for hydrocarbon products. The sources of emissions from available storage tank types are also described in this Chapter.

Chapter 3 deals with emission reduction at the source of the emission. It covers methods and techniques that limit the evaporation of the stored product. Design features of storage tank components, product parameters, storage and operational conditions are described that influence the build-up of vapours and the subsequent emissions of these vapours to atmosphere. Amongst the described topics are:

- Design of tanks:
 - Type of internal/external floating roof.
 - Seams in roof panels (welded, bolted, laminated, etc.).
 - Number and features of penetrations in floating roof.
 - Type of rim seal (vapour mounted, liquid mounted, mechanical shoe seal).
 - Type of fixed roof (aluminium dome, steel roof).
 - Colour of shell, roof etc.
 - Connecting tank to vapour balancing system.
- Physical product parameters:
 - True vapour pressure.
- Storage conditions:
 - Storage temperature.
 - Wind factor.
- Tank operations:
 - Landings of floating roofs.
 - Velocity of product movements.
 - Mixing operations.

Where these measures are considered insufficient, Chapter 4 addresses the reasons that can be used to justify additional mitigating measures to reduce emissions including:

- Health reasons: toxicity of certain products to people and environment.
- Deterioration of ambient air quality through formation of smog and ozone from the photochemical reaction of VOCs with oxides and nitrogen (NO_x).
- Ozone depletion.
- Greenhouse effects.
- Odour problems.
- Legislation.
- Fire and explosion hazard following ignition.
- Economical reason due to vaporizing/loss of the stored or transferred product.

Also described in Chapter 4 (and shown in Figure 1) are various currently available systems for dealing with emissions (each with their own main characteristics based on the required flow of VOCs that need to be treated and their inlet concentrations) and available vapour destruction systems.

Finally in Chapter 5, evaluation tables are included that give guidance to the effective selection of suitable emission control measures, all based on the described systems as highlighted throughout this Publication. The following evaluation tables are provided:

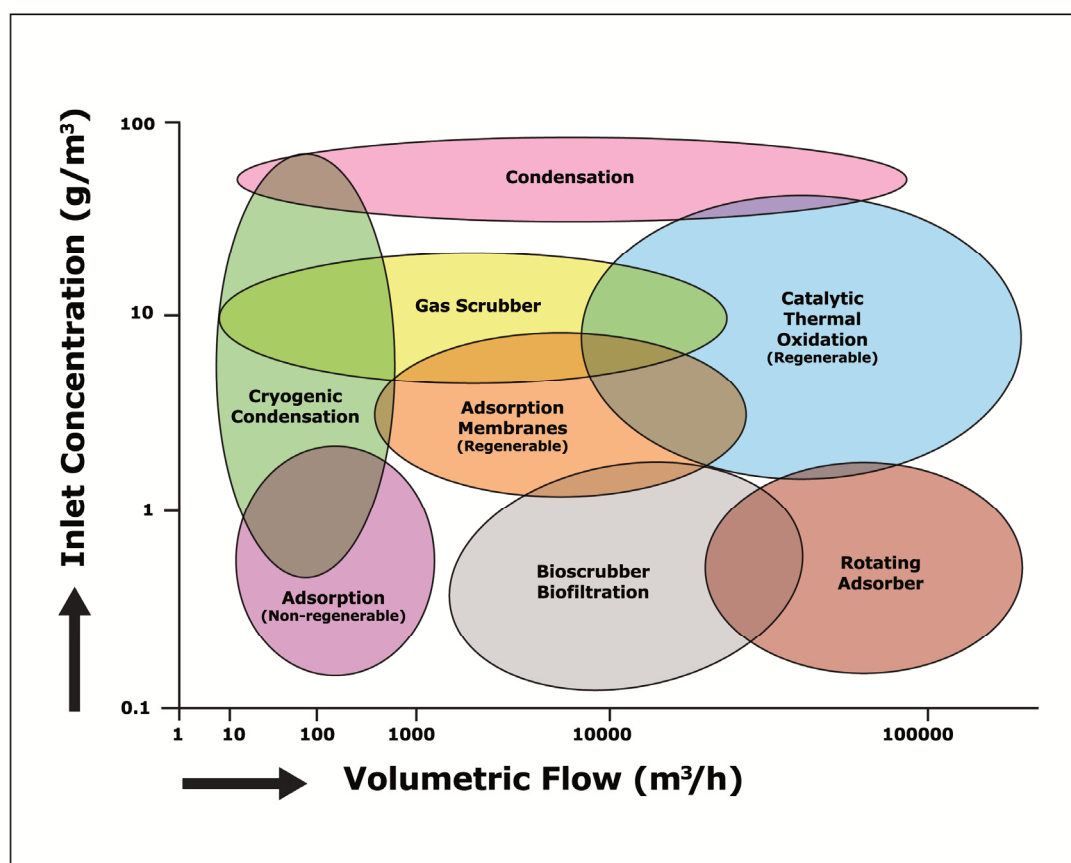


Figure 1 Applicable different techniques for treatment or removal of VOCs

Source: BREF Refineries (EU-IPPC Bureau, Sevilla)

- Table 4 Emission reduction measures applicable to fixed roof tanks.
- Table 5 Emission reduction measures applicable to floating roof tanks.
- Table 6 Emission reduction measures for loading facilities.

In Appendix A, a method for measuring the efficiencies of various emission prevention systems is described. It can be used as a tool to establish a datum for comparison of the available techniques and allows a sound evaluation of the various emission prevention and control systems. In order to distinguish the emissions prevention efficiency between different types of Internal Floating Covers (IFC) an evaluation questionnaire is given in Appendix B. Similarly, an evaluation questionnaire on various rim seal systems on floating roofs and IFC's is included in Appendix C.

A list of Standards and other publications referred to in the text is given in the References.

2. Guidelines for Selection of Types of Conventional Storage Tanks

2.1 Introduction

For over a hundred years, industry has used the Class⁽¹⁾ of the product when selecting a suitable tank type for a particular product. The product Class is dependent on, amongst other parameters, the flash point of the product, see Table 1 below. This Class categorisation is based on fire prevention/detection, safety distances and spill capacities of tank pits.

Table 1: Class categorisation of products

Class 0	Products with a flashpoint < 0°C
Class 1	Products with a flashpoint between 0°C and 21°C
Class 2 (I)	Products with a flashpoint between 21°C and 55°C stored at a temperature above its flashpoint (these products are considered as Class 1 products)
Class 2 (II)	Products with a flashpoint between 21°C and 55°C stored at a temperature below its flashpoint
Class 3 (I)	Products with a flashpoint between 55°C and 100°C stored at a temperature above its flashpoint (these products are considered as Class 2 products)
Class 3 (II)	Products with a flashpoint between 55°C and 100°C stored at a temperature below its flashpoint
Class 4	Unclassified products and products with a flashpoint above 100°C

On the basis of this initial Class categorisation, choices can be made on which is the best type of tank for storing a specific product. It is appropriate to use floating roofs for Class 1 and Class 2 products.

The choice of a full-contact or a non-contact floating roof is also related to the applicable fire prevention scenario: rim seal fire scenario or full surface fire scenario. This is due to the presence of vapours underneath a non-contact floating roof.

A more suitable approach is to base the selection of the type of storage tank on the vapour pressure of the product at storage temperature, i.e. the true vapour pressure (TVP).

As shown in flow chart form in Figure 77, the decision process begins with the question of what type of product is to be stored and its physical properties especially, product volatility. Volatility is a function of the TVP of the liquid at storage temperature. All hydrocarbon products have the characteristic that the TVP rises with an increase in temperature. At the boiling point the TVP is equal to atmospheric pressure (approx. 14.7 psia).

The vapour pressure of a fluid is usually determined by using the Reid Method

which is a standard test⁽²⁾ whereby the vapour pressure is determined at 100°F (37.8°C). The vapour pressure determined according to this test is called the Reid vapour pressure (RVP). This is not the same as the TVP, which varies with temperature. However it is a convenient measure used in the decision process for selecting the most suitable type of storage for various products. The RVP of a product is a constant value whereas the TVP is a variable because it is a function of temperature. The nomograms in API 2518⁽³⁾ can be used to convert the RVP of a product to the TVP.

Although they are not dealt with further in this Publication, factors such as climatic conditions, air pollution, soil conditions and local regulations are all important factors and should also be taken into consideration when selecting the most suitable type(s) and size(s) of storage required. Establishing the most appropriate storage arrangement requires that the selection/decision process be based on a study of the prevailing circumstances and a thorough review/assessment of all factors involved.

Other than the more readily known properties of the products to be stored and the associated engineering issues the final selection will be influenced significantly by criteria established through a detailed review of local regulations, standards, codes, environmental requirements, cost considerations and space availability. The engineering designer should, in close cooperation with process engineering, evaluate all the appropriate factors in establishing the criteria for final selection and detailed design of the storage facility.

Within the petrochemical industry only three types of conventional storage tanks are being used:

- Fixed roof tanks (Section 2.1.1).
- External floating roof tanks (Section 2.1.2).
- Combi-tanks (Section 2.1.3).

2.1.1 Fixed Roof Tanks

The first tanks ever built for the petrochemical industry were fixed roof tanks. One of the oldest tanks, still in service, is one from the year 1900, Figure 22.



Figure 2 A tank constructed in 1900 and still in use (Asia)
Courtesy of Shell

More than 100 years later, this type of storage tank is still being designed and constructed - which is an indication of the fact that when operated within its design limits, this type of tank is reliable. However, one of the disadvantages of this type of tank is its major contribution to emissions of hydro-carbons to the atmosphere.

A vapour space exists above the liquid level of the stored product and during each filling cycle, vapours will be pushed out of the tank through vent openings. Also atmospheric temperature variations – e.g. the difference in temperature between day and night or warming up of the tank by solar radiation, for instance, after a rain shower - create an expansion of the vapours inside the tank, which cause vapours to be relieved from the tank, Figure 33.

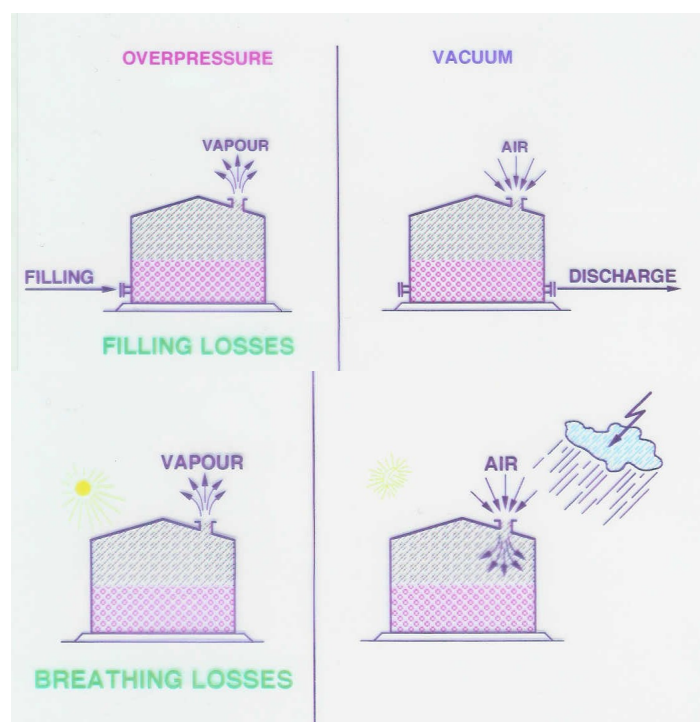


Figure 3 Vapour relief from a fixed roof tank

2.1.2 External Floating Roof Tanks

At the beginning of the twentieth century, a number of tank fires occurred. Flammable vapours escaping from roof vents would sometimes find sources of ignition. As these vents had large diameters, the resultant vapour velocities were low. The flames arising from the ignition of these vapours were then able to overcome the flow velocity present in the roof vent and enter the tank interior - causing secondary fires and explosions of the material inside.

The installation of pressure/vacuum relief devices introduces a build-up of positive pressure inside the tank before the vent opens. This increases the velocity of the vapours when they are eventually released from the vent, to speeds in excess of flame propagation. So if the vapours were now able to find a source of ignition, they would not be able to overcome the flow velocity in the roof vent and are thereby prevented from entering the tank interior. Prevailing emission levels are reduced by these pressure-vacuum devices, but only slightly.

This is limited to ambient losses, rather than throughput losses.

In 1923 the first test was performed with an open top tank, Figure 44 (a tank without a fixed roof) in which a floating roof was constructed.



Figure 4 Tests with an external floating roof in 1923 by CB&I (Houston)

In this tank the floating roof covered the whole liquid surface. At that time it was estimated this was realising a reduction of hydrocarbon emissions from approximately 3% of the total tank content/year for fixed roof tanks, to approximately 0.5% of the total tank content/year for tanks equipped with floating roofs.

The covering of the liquid surface was a major step in preventing emissions by reducing the evaporation process. This is enhanced by the weight of the floating roof as well as by the entrapment characteristics of vapours beneath the floating roof. However, evaporation of product may be initiated due to solar heat radiation. This is an intended scenario as these types of floating roof should be designed in such a way that the vapours will remain entrapped underneath the roofs without letting them escape to the atmosphere (see Figure 5).

Note: this scenario should be catered for in the structural design and stress analysis of the floating roofs.

This type of tank has a number of disadvantages such as increased maintenance costs associated with the rim seal placed between the floating roof and the tank's shell, and to the drain system that allows the accumulated rain water to be removed from the roof surface. Furthermore, since access to the floating roof is limited by safety measures, when a roof is in a low position during the unloading process, inspection of the roof plates, the bulk heads and the pontoons is seriously hampered.

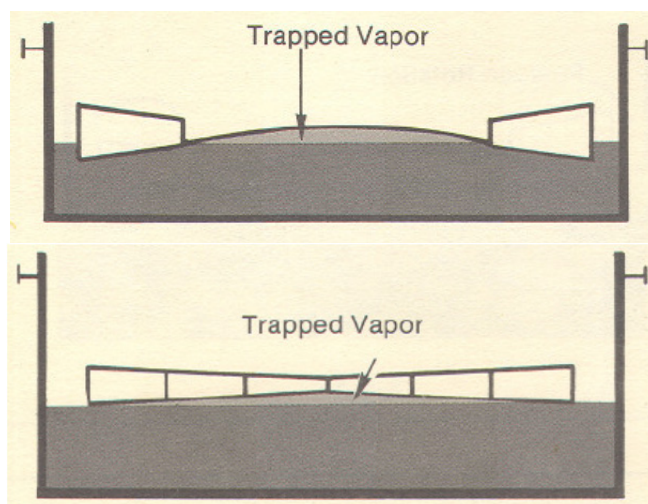


Figure 5 Schematic idea of prevention of emissions

2.1.3 Combined-tanks

Since 1980 a development was introduced that combined the advantages of both types of storage tank (fixed as well as floating roof tanks) by eliminating climate influence. The 'Combined-tank' was born. A 'Combined-tank' is a storage tank equipped with a fixed roof and an internal floating roof is placed on the liquid surface. The same description is valid for an external floating roof tank, where an aluminium dome is placed on the top of the tank covering the floating roof. Above the internal floating roof the vapour space is eliminated, allowing emissions levels to become much lower in comparison with both other types of storage tanks. Further advantages are:

- The wind induced movements of the floating roofs are eliminated which prevents emissions through initiated gaps between the tank shell and the rim seal (see Figure 66).

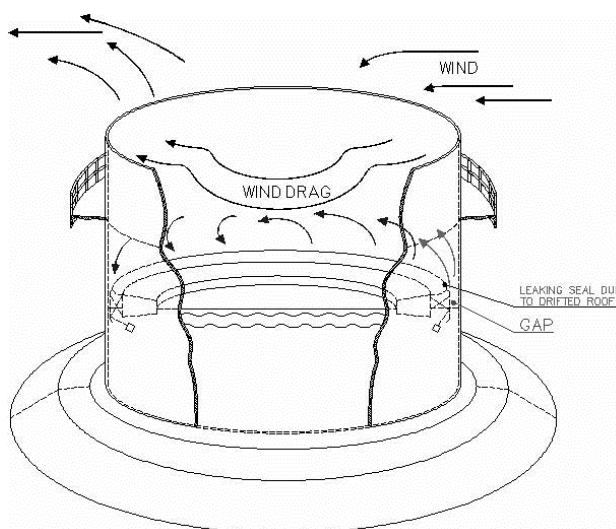


Figure 6 Schematic sketch showing wind drag and initiation of a rim seal gap in a non-covered floating roof tank

- The elimination of wind circulation in the tank (prevention of turbulence) reducing the diffusion process of hydrocarbon vapours.
- Rain water accumulation on the internal floating roof which in turn eliminates the need to install roof drain systems.
- Solar heat radiation is reflected by the aluminium dome surface, which caters for an average lower temperature within the tank of approximately 10-15°C.

Using materials other than carbon steel for internal floating roofs results in less degradation by corrosion and other chemical attacks due to the product characteristics. This impacts the inspection regime and minimises maintenance costs.

2.2 Tank Selection

Within the petrochemical industry it was common practice to use floating roof tanks for storing products having vapour pressures between 1.5 psia (103 mbara) and 11.1 psia (765 mbara). Products having lower vapour pressures than 1.5 psia (103 mbara) were stored in tanks with fixed roofs, whereas products having vapour pressures exceeding 11.1 psia (765 mbara) were stored in pressure vessels or spheres or in refrigerated or cryogenic storage tanks. However, in order to accommodate the storage of gasolines that are blended with ethanol the limit of 11.1 psia (765 mbara) for floating roofs was upgraded to 12.5 psia (862 mbara). That increase required the introduction of additional measures and risk control studies. For these high vapour pressures, specific design and operational changes to tank components are required.

Possible scenarios to mitigate risks of fires and to enhance safety of personnel are:

- The use of bronze wheels on the rolling ladder and bronze rollers along the guide pole.
- The installation of seals over openings on landing legs and over openings in the stilling wheels/guide poles.
- The installation of additional shunts on the rim seals.
- The decrease of rising and lowering speeds of the floating roofs in order to limit the building up of differential potentials.
- Limiting/denying access to the floating roofs since product gasses or dangerous vapour/air mixtures may develop above the floating roof when it's deeper than 1.3 m below the top curb angle of the tank shell.
- The installation of pressure/vacuum relief vents on the inner membrane in order to prevent the build-up of excessive gas pressures (see also Figure 77 showing the EEMUA advice for the selection of a suitable tank system, depending on the TVP of a product).

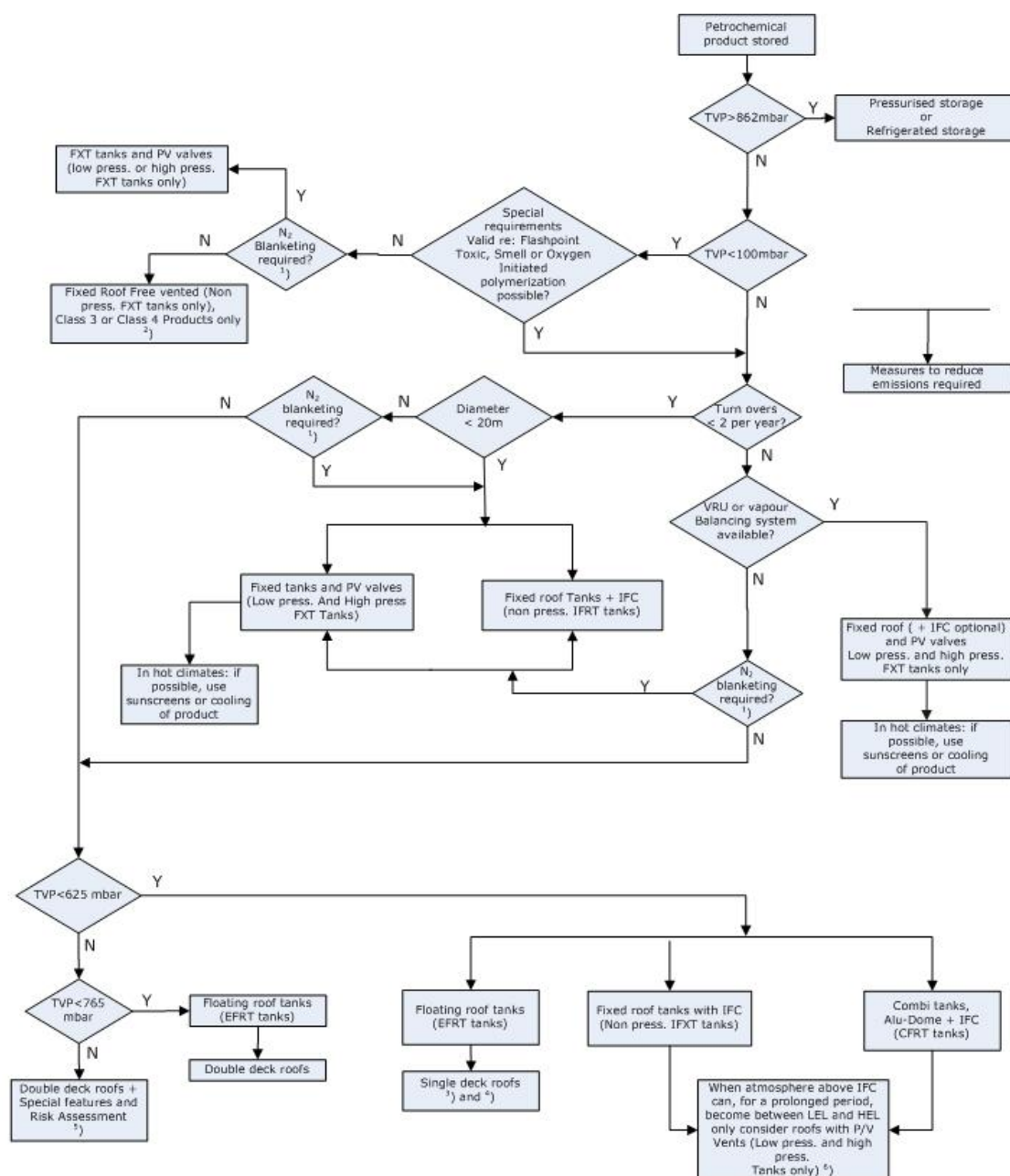


Figure 7 Selection of storage tank type based on emission best efficiency

3. Emission Reduction at the Source

3.1 Introduction

Only limited literature exists that deals with the determination of the loss of hydrocarbons through emission from storage tanks. The theory used worldwide was developed by the American Petroleum Institution (API) and has been published in their publication: Manual of Petroleum Measurement Standards, Chapter 19, Section 1 - Evaporative Loss from Fixed Roof Tanks⁽¹⁾. This Publication was previously issued under its own API-number, API 2518 Evaporative Loss from Fixed Roof Tanks⁽³⁾.

More recently, the Dutch government funded a study known as the KWS 2000 project, which focused on emission control from storage tanks. TNO (Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek - Netherlands Organization for Applied Scientific Research) in close co-operation with companies from the petrochemical industry performed a study into the validity of the API measurement method and developed formulae and equations. It was concluded from the research⁽⁴⁾ that, based on the applied measuring method, the formulae and equations could lead to relatively sound assessments of emission levels even though they were only based on a limited number of measurements and on only one type of internal floating roof i.e. a non-contact floating roof with relatively small dimensions. The API-formulae do not differentiate between the efficiency on emission control of the various types of internal floating roof available on the market. The only differentiation that is used is whether roofs are seamless or not.

The KWS 2000 research study developed a standard measurement method and DOW Chemicals in Terneuzen *et al*, performed many measurements on tanks with different types of internal floating roofs and which were equipped with different types of rim seals. Based on these measurements a differentiation could be made between the two main types of internal floating roofs. TNO was able to verify, to assess the validity and to amend, the various API formulae and equations.

The TNO/DOW results were firstly published in the report produced by the Air Directorate of the Dutch Ministry of Housing, Physical Planning and Environment (VROM)⁽⁵⁾. In 2003 a new report was issued by VROM⁽⁶⁾ in which almost identical formulae and equations to those produced by TNO within the KWS 2000 project were used.

Within the frame work of BAT1 and the development of the BREF Reference Document on Emissions from Storage Tanks⁽⁷⁾, the study group TETSP (Technical European Tank Storage Platform)⁽⁸⁾ published results of VOC emission calculations using various techniques that contribute to emission control from storage tanks. Within this BREF only the results of the emission reduction calculations of internal floating roofs are published, which are calculated using the EPA Tanks 4.0 software which is fully based on the theory of the API.

¹ The European Integrated Pollution Prevention and Control (IPPC) Bureau was set up to organise an exchange of information between European Union Member States and industry on Best Available Techniques (BAT), associated monitoring and developments in them. The European IPPC Bureau produces reference documents on Best Available Techniques, called BREFs. BREFs are the main reference documents used by competent authorities in Member States when issuing operating permits for the installations that represent a significant pollution potential in Europe.

3.2 Emission Sources

Actual and calculated (theoretical) emission levels are depending on, amongst other characteristics, design of the storage tank, product physical parameters, storage conditions and tank operations.

Parameters that contribute to emissions of VOCs are:

- Design of tanks:
 - Type of internal/external floating roof.
 - Seams in roof panels (welded, bolted, laminated, etc.).
 - Number and features of penetrations in floating roof.
 - Type of rim seal (vapour mounted, liquid mounted, mechanical shoe seal).
 - Type of fixed roof (aluminium dome, steel roof).
 - Colour of shell, roof, etc.
 - Connecting tank to vapour balancing system.
- Physical product parameters:
 - True vapour pressure.
- Storage conditions:
 - Storage temperature.
 - Wind factor.
- Tank operations:
 - Landings of floating roofs.
 - Velocity of product movements.
 - Mixing operations.

3.2.1 Design of Tanks

3.2.1.1 Internal Floating Roof

Internal floating roofs can be constructed from different materials, such as, carbon steel, stainless steel, aluminium, and thermo-plastic. The majority of the roofs made from these materials are full contact floating roofs. Aluminium floating roofs can also be of the non-contact type as shown in Figure 88.

Although the initial API study⁽³⁾ did not show significant efficiency differences between the non-contact and full-contact internal floating roofs, the Dutch KWS 2000 studies came to a different conclusion.

The Dutch research was performed on tanks where degradation mechanisms were present. It resulted in, amongst other items, a graph that shows the differences in the efficiency on emission reduction between internal floating roofs of the 'non-contact' type and of the 'full-contact' type. This Graph is shown as Figure 99.

The measurements that resulted in this graph were performed as follows:

- The first measurement was done immediately after initial filling of the tank.
- The following measurements were performed after a number of hours in a stand-still situation.

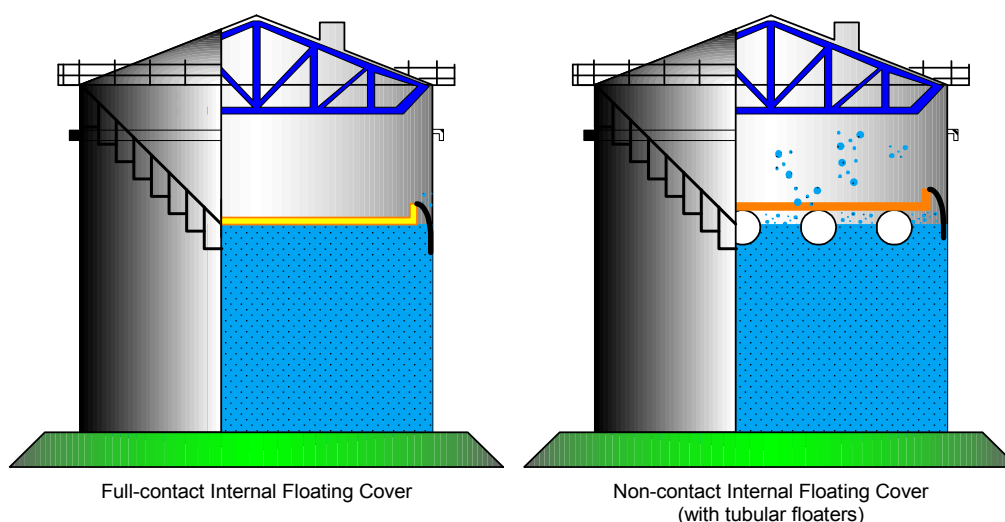
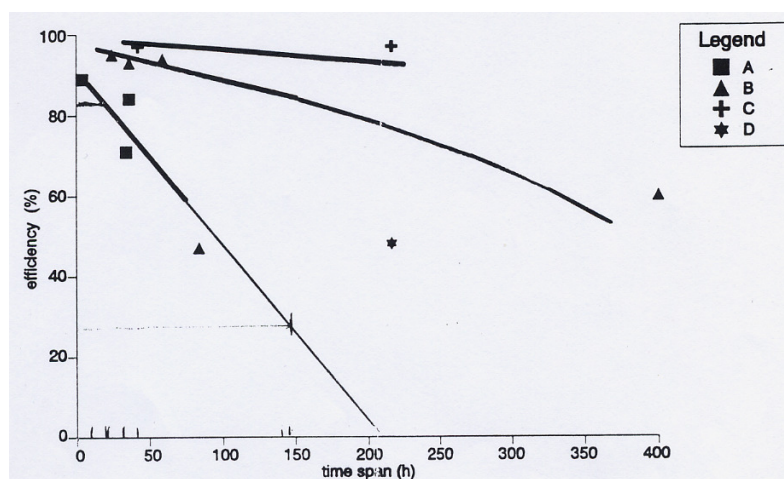


Figure 8 Different types of internal floating roof



Legend:

- A = 'Non-contact' internal floating roof, with seams, equipped with a vapour mounted seal.
- B = 'Full-contact' internal floating roof, with seams, equipped with a vapour mounted seal.
- C = 'Full-contact' internal floating roof, without seams, equipped with a mechanical shoe seal.
- D = 'Non-contact' internal floating roof, without seams, equipped with a mechanical shoe seal.

Figure 9 Efficiencies of different types of internal floating roofs, equipped with different types of rim seals

Initially, it seems that the differences in reduction efficiency between the two types of internal floating roofs are not that great but it appeared that the non-contact types were dramatically less efficient.

The ambiguity of the results of the non-contact roofs is most likely caused by deformations in the roofs and the loss of vapour tightness of the deteriorating seams between the panels. These roofs have a structural integrity that is less than those with welded or laminated seams.

The aforementioned VROM reports⁽⁵⁾⁽⁶⁾ appoint a factor to the number and type of seams in floating roofs. This factor, K_d , has a value of 0.34 in the API formulae (seams contribute only 34% to the leakage rates, dependent on the number of