CHEMICAL ENGINEERING TRANSACTIONS
VOL. 31, 2013
Guest Editors: Eddy De Rademaeker, Bruno Fabiano, Simberto Senni Buratti

ISBN 978-88-95608-22-8; **ISSN** 1974-9791

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at: www.aidic.it/cet

DOI: 10.3303/CET1331094

Comparison of the Operating Life of Tank Containers, Tank Vehicles and Rail Tank Cars for the Carriage of Dangerous Goods in Practice, Analysis of Causes of Damage

Margit Weltschev*, Stephanie Schwarzer, Frank Otremba

Federal Institute for Materials Research and Testing (BAM), Division 3.2, D-12200 Berlin, Unter den Eichen 87
Margit.Weltschev@BAM.de

More than 400 Mt of dangerous materials are transported in Germany every year, of which 150 Mt are by road. Tank containers, tank vehicles and rail tank cars are used for the carriage of dangerous goods in large quantities. Data on the operating life of tanks are only available, in practice, to a minor degree. They are only partly published, mainly after accidents.

The BAM-List - Requirements for Tanks for the Carriage of Dangerous Goods, which has compatibility evaluations of metallic and polymeric materials, has been the basis for substance-related prototype approvals for tank containers and portable tanks designed for the carriage of dangerous goods by the BAM since publication of the first edition in 1989. These data are also used for the approval of rail tank cars and road tank cars and are used as a source of knowledge not only in Germany but also worldwide. Tank leakages caused by tanks or rail tank cars being made of tank and sealing materials which are not resistant to the fill goods are avoided by using the material resistance data of the BAM.

Corrosion damage is among the main causes of damage. Uniform and non-uniform area corrosion without mechanical stress in aqueous substances is one of the most frequent types of corrosion during the transport of chemicals in tanks. Much damage by pitting corrosion occurs during the transport of substances containing chlorides or substances which separate chloride ions in the presence of moisture.

Operational stresses are caused by the effects of both the road and the dangerous goods being transported. Mechanical damage often results from long-term overstressing and occurs after longer operating times.

Operational failures cause damage which may appear during the service of tank containers, road tank cars or rail tank cars. The damage results from the inattention of employees when opening and closing the valves. Traffic accidents also cause damage to tanks and frames.

Many cases of damage are due to weld area cracks resulting from four basic errors in construction, material, manufacturing and operation. Manufacturing errors can be undetected and the starting point of cracks which only grow under service conditions.

Manufacturing errors result from variations in measurement and design, fittings, state of surface (hardness, abrasiveness) and mechanical surface damage (scratches, cracks). Incorrectly welded joints and errors during mechanical deformation are typical mistakes when installing the component parts. Variations in the wall thickness or combinations of different materials lead to manufacturing errors too.

A lot of tanks are not used for the transport of dangerous goods before the end of their service life as they do not fulfil the revised technical safety requirements in the Dangerous Goods Regulations.

Predictions in the BAM-List based on literature data and corrosion test results are reflected in the service (operating) life. Rail tank cars made of carbon steel, for example, which are mainly used for the transport of petroleum products, can achieve a service life of 40 – 50 y.

Rail tank cars produced of austenitic CrNi- or CrNiMo-steel can reach an operating life of at least 30 y, whereby the corrosiveness of the transport substances plays an important role.

Please cite this article as: Weltschev M., Schwarzer S. and Otremba F., 2013, Comparison of the operating life of tank containers, tank vehicles and rail tank cars for the carriage of dangerous goods in practice, analysis of causes of damage, Chemical Engineering Transactions, 31, 559-564 DOI: 10.3303/CET1331094

1. Introduction

The national and international transport of dangerous goods has a key function in the work-sharing economy. Multifarious results in the global manufacturing chains depend on the cost-effectiveness, reliability and safety of transport. More than 400 Mt of dangerous materials are transported every year, of which 150 Mt are by road. Therefore, guaranteeing safety is of high relevance.
The United Nations (UN) publishes every two years regulations for the transport of dangerous goods by all transport modes according to the state of art. These model regulations are extended for international transport by rules which are specified for carriers and are legally binding worldwide. The Regulations for land, railway and inland waterway traffic have to conform to the specific local conditions in the different regions in the world. Therefore the UN guidelines have to be applied accordingly for all transport modes.
The safety requirements for tanks mostly depend on the danger of the transported substance. A partial or complete release of the transported substance has to be prevented for tanks filled with a substance which has a high hazard potential, such as substances containing dioxin. In the regulations criteria are defined for construction, quality control and approved loading of these tanks. A framework enclosing the tank completely, the exclusive use of stainless steel as tank material with a minimum wall thickness and a solid insulation at least 50 mm thick serve to protect the environment and humans against the release of dangerous substances.
Transport tanks for dangerous goods have a service life of years, sometimes even of decades, and they are exposed to operational demands which may change with time.
Data on the cause of damage such as corrosion damage or mechanical damage and the operating life of tanks are only available, in practice, to a minor degree. They are only partly published, mainly after accidents with high amounts of dangerous goods lost by leakage of the tanks.

2. Corrosion

Operational stresses are caused by the effects both of the road and the dangerous goods being transported. Construction regulations for tanks according to the ADR/RID require that tanks resist static and dynamic stresses under normal transport conditions and fulfill the minimum requirements of the material parameters.
The BAM-List - Requirements for Tanks for the Carriage of Dangerous Goods, which has compatibility evaluations of metallic and polymeric materials, has been the basis for substance-related prototype approvals for tank containers and portable tanks designed for the carriage of dangerous goods by the BAM since publication of the first edition in 1989. These data are also used for the approval of rail tank cars and road tank cars and are as a source of knowledge not only used in Germany but also worldwide. Tank leakages caused by tanks or rail tank cars being made of tank and sealing materials which are not resistant to the fill goods are avoided by using the material resistance data and information service of the BAM.
Corrosion damage is among the main causes of damage. Such damage to tanks always occurs if dangerous goods are transported with corrosive ingredients which are not known, such as chlorides.

2.1 Surface corrosion

Uniform and non-uniform surface corrosion in aqueous substances is the type of corrosion which most frequently appears during the transport of chemicals in tanks. Heterogeneous surface conditions and inhomogeneous surface coverage of the material with corrosion products during corrosion are the cause of a trough-shaped progress (Kaesche, 1990). Uniform surface corrosion especially occurs by an attack of strong acids if there are no insoluble corrosion products precipitating on the surface. This type of corrosion is controllable in the majority of cases because it is monitored by non-destructive test methods and by increasing the wall thickness. Unalloyed and low alloyed steels are predominantly subject to surface corrosion in aqueous substances, because they are liable to active corrosion in contrast to the passivating stainless steels (Figure 1).

Figure 1: Corrosion in the bottom area of a railway tank car made of unalloyed steel after transport of hydrocarbon products

2.2 Pitting corrosion

Much damage by pitting corrosion occurs during the transport of substances containing chlorides or substances which separate chloride ions in the presence of moisture. Moisture in the substance itself, water in the tank before filling or wetness penetrating into the tank interior during transport are some of the reasons for corrosion (Figure 2).

An effective, operational measure to prevent pitting corrosion is flushing the tanks with an inert gas such as nitrogen before filling. Covering the fill goods with nitrogen during transport prohibits the ingress of moisture during transport. Pitting and trough-shaped corrosion lead to wall thinning of the tanks due to residual moisture in the tanks after emptying, especially after transport of products containing chloride. Covering the fill goods with nitrogen when filling and emptying the tanks with nitrogen is highly recommended to prevent corrosion damage. Pitting corrosion damage often occurs during transport of chlorous products in tank containers by sea from Asia to Europe because the containers are not checked.

Much damage in the form of pitting corrosion under the thermal insulation of tanks was observed in the past. The insulation material contained chlorides which initiated pitting corrosion together with condensation water.

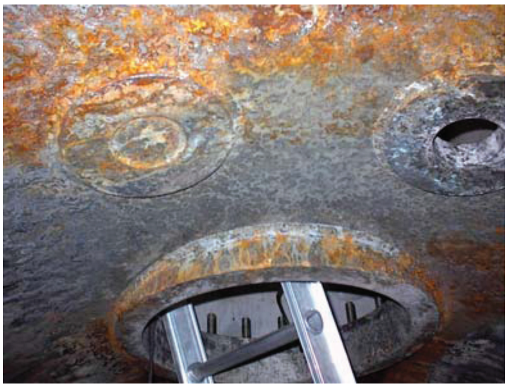

Figure 2: Corrosion in a tank container made of austenitic CrNiMo-steel (1.4571) after transport of sulphur dichloride

One possibility to solve this problem is coating or lining the tanks by a polymeric material. An alternative is the application of high-alloyed steels and nickel alloys for transport of such corrosive substances. Based on the standard steels higher alloying contributions of chromium, molybdenum and nickel, in part of nitrogen, copper and manganese improve the corrosion resistance in strong acids and chloride containing solutions. Weltschev et al. (2005, 2009) have reported that Alloy 31 (X1NiCrMoCu32-28-7, 1.4562) is a good alternative to coated or lined tanks for transport of corrosive chemicals and waste due to its good resistance against pitting and crevice corrosion and a cost ratio of 4.5 : 1 to AISI 316L (X2CrNiMo17-12-2, 1.4404). Due to the higher strength of the material the tank wall thicknesses can be reduced considering the requirements of the international regulations for transport of dangerous goods. This allows a reduction of the tank weight. This material is commonly used in flue gas purification where highly concentrated hot salt solutions appear. Due to its high corrosion resistance this "super austenite" is applied in many corrosive areas, where formerly much more expensive materials were used.

2.3 Stress corrosion cracking

Stress corrosion cracking can be avoided by choosing a material which is resistant to stress corrosion cracking initiated by the transported substance. Impurities in the substances which cause stress cracking should be avoided too. Reliable loss prevention by limiting mechanical stress is rarely achieved because the tensile stress initiating the crack is often lower than the tensile yield point and is present in the form of internal stress in the construction component. Stress relief annealing of welded components is regarded as a preventative measure. Damage by stress corrosion cracking can be assessed as low compared with the damage by surface and pitting corrosion during the transport of dangerous goods due to these preventative measures.

2.4 Intergranular corrosion

An example of selective corrosion is intergranular corrosion (intergranular attack). Eluviations of alloying elements which are important for the corrosion resistance due to precipitation with high contents of these elements on the grain boundaries, can lead to intergranular susceptibility. Such a process occurs during heat treatment or heat impact when welding alloys which are susceptible to precipitation due to oversaturation with critical elements. Wendler-Kalsch (1998) has reported that the loss of chromium by chromium carbide precipitation is a typical example of damage in stainless steels. Susceptibility to intergranular corrosion does not apply to unalloyed and low-alloyed steels in practice, and therefore also not to the transport of dangerous goods.

Austenitic CrNi-steels which are often used for tank construction are damaged by intergranular corrosion through the loss of chromium. The critical temperature range for the precipitation of chromium carbide on the grain boundaries is between 350 °C and 800 °C for austenitic CrNi-steels. This critical temperature range is best reached during welding. Therefore, damage by intergranular corrosion mainly occurs in the heat-affected zone of austenitic steels.

3. Crack of welding seams

Much loss is due to cracks in the welding area. The microstructure and, thereby, material properties may change as the material is subject to thermal and mechanical influences in the welding area. Disadvantageous material and stress conditions in the welded metal and, especially, in the heat affected zone may occur if construction, material and welding parameters are not coordinated.

Many cases of damage due to welding area cracks result from: four basic errors in construction, material, manufacturing and operation. Manufacturing errors can be undetected and the starting point of cracks which only grow under service conditions.

A first check of tanks for the transport of dangerous goods before the initial start-up is required to prevent damage of welded seams. This check requires a welding certificate and a welding procedure test according to the technical guideline.

4. Mechanical damage

Mechanical damage often results from long-term overstressing and occurs after longer operating times.

Tank vehicles often possess self-supporting tank semi-trailers. These must balance both the high stress from the fill goods (pressure, load and weight) and the stress from the vehicle handling of the driver. Moments of inertia as well as driving and load torques occur which, for instance, lead to cracks in tanks during longer service life.

5. Structural and dimensional mistakes

Structural and dimensional mistakes are systematic failures since they produce the same or similar failure modes for all the tanks in a series. Therefore, suitable material selection is a basic requirement for tank construction. Failures in the engineering design and dimensions lead to the wrong transmission of forces. Fracture or stress cracks in the frame construction are caused by this energy flow. Dimensionally joints are often too weak to withstand the real existing stress, so that they cannot bear the forces which results in shear, tension and bending. This does not apply to some joint connections if the liquids can drain off in the right way, moisture evaporates and angles can be cleaned. Manufacturing mistakes may result from mechanical surface damage (scratches and cracks) and deviations from mass, design, fittings and surface quality (hardness, surface finish). Typical errors when assembling the components are the wrong welded

joints and shape errors. Large deviations in the wall thickness or combination of different materials lead to manufacturing mistakes too.
Damage such as cracks in welded seams used to be observed in tank frame joints. These frame cracks no longer appear today due to isolation of the tanks and thermal bridges.
Opening the manhole cover on the top or relevant venting valves is important when emptying the tank by pressure or an ascending pipe that allow air to pour into the tank. Otherwise, low pressure may damage or even break the tank. Vacuum damage involves high repair costs (Figure 3). Vacuum valves are used to prevent vacuum damage in isolated cases, but appropriate handling during emptying is relied on in most cases due to the high valve price.

Figure 3: Tank deformed by vacuum damage

6. Estimation of service life

A lot of tanks are not used for the transport of dangerous goods before the end of their service life because they do not fulfil the revised technical safety requirements in the Dangerous Goods Regulations.
Predictions in the BAM-List based on literature data and corrosion test results are reflected in the service (operating) life.
Vacuum-operated waste tanks made of unalloyed steels are mainly used for the transport of waste mixtures. They have an average service of 15 y because they contain both sand and slurries, and the bottom of the tank shell erodes more due to the solid particles. Corrosive substances, such as chlorides and sulfates are part of the waste mixtures and reduce the service life of these tanks by corrosion.
Tanks made of unalloyed steels are mostly used for the transport of fuel oil and have an average service life of 10 – 15 y. The petroleum product itself does not corrode unalloyed steels, and corrosion damage is observed in the bottom area of the tanks where water accumulates.
Tank containers made of austenitic CrNi steels or CrNiMo steels (e.g. 1.4301, 1.4404 or 1.4571) have a service life of about 20 – 25 y with low product change. However, there are tanks which are only used for 8 – 10 y for dangerous goods transport because increased corrosion by corrosive impurities such as chlorides leads to a reduction in the wall thickness. These impurities are not listed in the safety data sheets and are not known to the transport companies. The containers are not always scrapped but can be used for the transport of non-dangerous goods because no minimum wall thickness is required for this purpose.
It is no problem if the tanks were filled with non-corrosive products, even in exchange traffic or one-way traffic, but the factor supervision played an important role if corrosive products were transported. Corrosion damage was observed if these products were transported by one-way traffic and the tanks were not under control. Corrosion damage was not found if the tanks were filled in exchange traffic and transported under the control of the transport company.
Experience has shown that tanks used for the transport of different waste disposal products disposal need repairs 9-12 y and have been damaged by corrosion.
Tanks made of aluminium and aluminium alloys (e.g. $AlMg_{4,5}Mn$), which are primarily used for the transport of mineral oil products, have a service life of 20 y. Pitting corrosion occurs due to the presence of moisture. The cracks detected, especially in the area of the baffle of the tank vehicles after 20 y, can be attributed to the age of the vehicles. The question cannot be answered if the cracks are formed due to torsion or other mechanical influences as no damage studies have been performed. Corrosion is not detected since refined petroleum products are not corrosive.

The service life of tanks made of aluminium and aluminium alloys depends on the requirements of the oil companies. The loads on these tanks are high.
The appropriate system and correct processing (structural design, surface treatment and application) are, in addition to the material selection, of great importance to long-term corrosion protection of the inside surface of the tank. This is reflected in the damage in practice. Tanks made of stainless steels with an inliner have the same service life as tanks with rubber coatings, but both have to be renewed after five or six y. A frequent cause of damage in tanks with rubber coatings is the slight overlapping of the welded seams, and rewelding is necessary. Tanks with a PFA (Perfluoro-alkoxyl copolymer) coating with very high resistance to chemicals can have a service life of 15 y.
Tanks with coatings are endangered during transport by sea because they are not supervised. Damage in the form of flaking off of the coatings may occur if the manhole cover is not carefully lowered back onto the tank. The transported substance may penetrate under the coating and peel it off over large areas if fine micro-cracks are included in the coating. The base material is damaged by corrosion.
The diversity of products transported in railway tank cars is much lower than those transported in tank containers and tank vehicles.
Rail tank cars made of carbon steel, for example, which are mainly used for the transport of petroleum products, can have a service life of 40 – 50 y according to the information from railway tank car leasing companies. These data have been confirmed by the Federal Railway Authority. Attention has to be paid to the connection of the tank and chassis frame during construction.
Rail tank cars produced of austenitic CrNi- or CrNiMo-steel can have an operating life of at least 30 y, whereby the corrosiveness of the transport substances plays an important role.
Products often transported are sodium hydroxide solution, sulphuric acid and mixed acids (Table 1).
These data apply to railway tank cars built up to 1990. Railway tank cars are optimised according to their weight and wall thickness by computerized simulation today.
All of the above data are based on information supplied by transport companies.

Table 1: Service life of railway tank cars

Transported substances	Service life of rail tank cars - mild steel- (y)	Service life rail tank cars -austenitic steels- (y)
mineral oil products	45	-
LPG	45 - 50	-
ammonia	40 - 45	-
non-corrosive chemicals	30 - 35	40
corrosive chemicals	25	30

References

Federal Institute for Materials Research and Testing (BAM), 2011, BAM-List: Requirements for Tanks for the Transport of Dangerous Goods, 11th edition, Berlin.

Intergovernal Organization for International Carriage by Rail, 2011, Regulations concerning the International Carriage of Dangerous Goods by Rail (RID), 15th revised edition.

Kaesche, H., 1990, Die Korrosion der Metalle, 3. Auflage, Springer-Verlag, Berlin, Heidelberg, New York.

United Nations, 2011, Recommendations on the Transport of Dangerous Goods: Model Regulations, 17th revised edition, New York, Geneva.

United Nations Economic Commission for Europe, 2013, ADR: European Agreement concerning the International Carriage of Dangerous goods by Road, 21th revised edition, New York, Geneva.

Weltschev, M.; Bäßler, R., Werner, H., Alves, H., Behrens, R., 2005, Use of Corrosion Resistant High-Alloyed Metallic Materials for Transport Tanks of Dangerous Goods and Water-Polluting Substances, EUROCORR 2005, Lisboa, Portugal.

Weltschev, M., Bäßler, R., Werner, H., Alves, H., Behrens, R., 2005, Use of Corrosion Resistant High-Alloyed Metallic Materials for Transport Tanks of Dangerous Goods, Stainless Steel World Conference, Maastricht, the Netherlands.

Weltschev, M., Bäßler, R., Langer, M., Alves, H., 2009, Suitability of Alloy 31 and 59 for Transport of Highly Corrosive Dangerous Goods, NACE International Conference, Corrosion 2009, Atlanta, USA.

Wendler, E. und H. Gräfen, 1998, Korrosionsschadenkunde, Springer-Verlag, Berlin, Heidelberg, New York.