

## Thermoplastic cylindrical tanks

### 1. General

Tanks for storage of liquids are required in all areas of public life. Constructions made of thermoplastic plastics are playing a decisive role in this. Beginning with the traditional bucket, which have belonged to our lives since the earliest initiations of plastics technology, up to the 100 m<sup>3</sup> storage tank for chemicals and hazardous liquids – there is no way of avoiding constructions made of polyethylene and polypropylene today. Particularly if the cylinder is made of helical extruded pipes a multitude of possibilities for the design is provided. The wall-structure can be designed tailor-made to the load-characteristic. The wall thickness can be produced in every thickness as well as the sandwich-construction or profiled wall structure can be done. The worldwide success of thermoplastic tanks is also due to the perfect material properties regarding chemical resistance, durability, flexibility and mechanical strength. Furthermore the cost-effectiveness is a very important reason for using thermoplastic tanks.

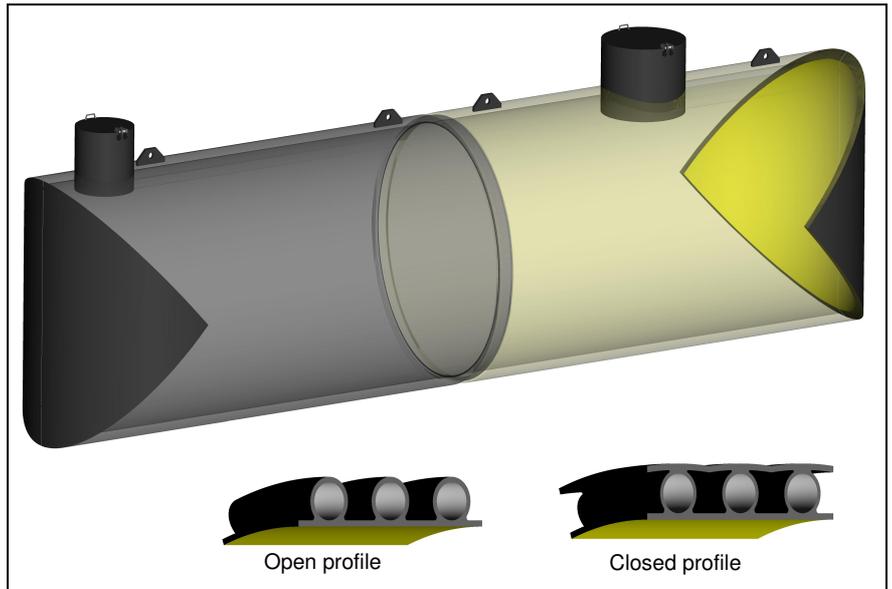
In the following report the main focus is on vertical tank installation, but some remarks and advice is also given for horizontal installations. Furthermore the most important influence factors for tank design are described and the main technical formulae are explained. The referring international standards are also mentioned.

### 2. Vertical- and horizontal tank installations

The majority of thermoplastic tanks are engineered for vertical installation, however horizontal tanks are also often used, especially for underground applications or in places with limitations for construction height.



Vertical storage tank, 68 m<sup>3</sup>,  
source: Benvitec, Belgium



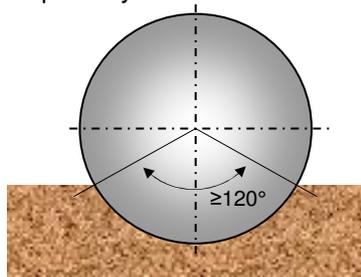
Design of horizontal tank  
with convex endcaps

For the horizontal tanks a wall structure with high moment of inertia is necessary to avoid buckling. A high moment of inertia is reached by using an open or closed profile instead of a solid wall, which is regularly used for vertical tanks.

For water application an open profile is mostly sufficient, but for industrial applications a closed profile is used very often, to provide beside the necessary stiffness with a double wall structure. Double wall structures have more or less double safety and are essential for integration of leakage-control-systems.

However the profile is chosen, the required stiffness has to be guaranteed. For normal and not critical soil conditions – without groundwater and without traffic and other external loads – a stiffness class  $\geq$  SN2 kN/m<sup>2</sup> (ISO9969) is sufficient. In each case a structural static calculation has to be done to verify the static situation. If the tank is buried, the static design can be done according typical calculation-procedures – for example according the German ATV A127 or American AWWA M55.

For partially buried tanks it is recommended to consider a soil-support-angle bigger than 120°.



For vertical tanks a solid wall structure is the best choice to take the stress-load and provide sufficient stability for external loads, especially for axial induced loads. If the tank is additionally affected by underpressure, as it is typical for chemical apparatus (scrubber etc.), an additional profile on the top of the solid wall is make sense. The radial buckling resistance is improved significantly by using a profiled wall structure!

### 3. Influence factors for the tank design

The applied load on the tank constructions and influence factors can normally be derived from the operating conditions. Attention should be paid to the fact that the tank often is part of a complex construction, which means, it may need suitable additionally installed equipment. Tanks which are for example used in chemical engineering, in filling or decanting stations or as process containers, are often additionally equipped with stirring devices, pumps, metering or tempering devices. The resulting static and dynamic loads have to be considered along with these following general points:

#### 3.1 Hydrostatics and operating pressures

Hydrostatic conditions result from the kind of medium (density, viscosity) and the conditions of filling (filling cycle, filling level, duration of filling). The resulting operating pressures are decisive for the dimensioning of the cylinder wall, cylinder bottom and roof, as well as for additionally installed equipment. Additional pressures (negative or positive pressure) can be produced by the action of emptying and filling or by external influences like changing weather conditions or wind load.

#### 3.2 Chemical resistance

The medium which is filled in can influence the stability and strength durability of the chosen material of the tank. Although Polyethylene and Polypropylene generally have got a very good resistance to a multitude of acids and bases, there are limitations and boundaries of resistance. These boundaries can furthermore be changed by the influence of temperature and reaction time. In many cases the reduction ratio for the used medium is to be found in literature and standards, which make dimensioning easier.

Since thermoplastic materials have been used in the chemical industry (50's of last century), specialists have been collecting data about the excellent chemical resistance. Detailed evaluations of chemical resistance are mentioned also in technical rules e.g ISO/TR 10358 and DVS 2205-1

#### 3.3 Temperature

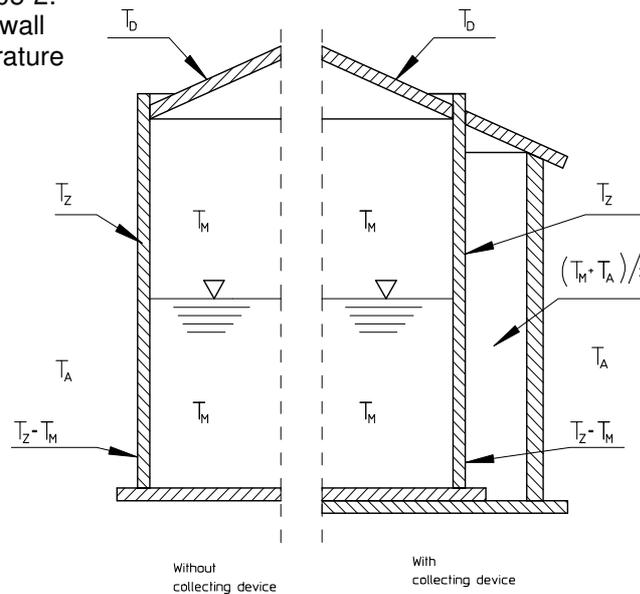
The behavior of Thermoplastics is depending on temperature, with increasing temperature the stability and stiffness change. This behavior has been adequately proven and follows principles, which allows an exact calculation. The required material data is provided by manufacturers of raw materials and are basics for the dimensioning of pressure pipe systems, sewers etc.

The temperature of the cylinder wall is influenced by the temperature of the medium on the one hand and by the ambient temperature on the other. Normally the average temperature is used for the dimensioning. This procedural method, in which the aspect of time also has to be taken into account, works best if there are only minor or medium differences in temperatures. A detailed observation of material property is useful if there are big differences in temperature.

The service life alternating temperatures and constant stress or also alternating stress can be determined according DVS 2205 part 1

Temperature design acc. DVS2205-2:

- $T_Z$ : temperature cylindric wall
- $T_A$ : environmental temperature
- $T_D$ : temperature roof
- $T_M$ : temperature liquid



### 3.4 Weathering

According to the installation site different climatic conditions can occur. If it is installed inside a building there has to be attention paid only to the ambient air temperature, other climatic conditions can normally be excluded or have just an extremely alleviated effect.

But outside buildings wind, sun, precipitation and ambient temperature have to be considered. The load by weather is naturally dependent on the season; furthermore different regions have to be considered differently. Regions are often divided into different areas of weather, for which the frequency and intensity of weather conditions have been empirically defined. A change of weather conditions caused by climate change should be noted if a long term dimensioning is carried out.

For outside installation mostly black Polyethylene tanks are used because of the excellent resistance against UV-radiation. The raw material already has stabilizers and ingredients (e.g. carbon) to provide the best protection against weathering. But if for thermal, chemical or mechanical reasons other thermoplastic materials are chosen, the weathering resistance has to be verified. For Polypropylene (grey) often a coating is used. If the tank is fabricated out of helical extruded pipes (Krah pipes), the production procedure provide a smart solution:

The wall structure is covered by a thin Polyethylene-layer, either by coextrusion or an additional layer.

### 3.5 Potential danger

Consideration of danger is the central point of all considerations concerning safety, especially if handling with chemicals or other hazardous substances. Here we differentiate between dangers for: persons, subjects and environment. Regulatory requirements differ a lot in the countries of the world, which has to be paid attention to when defining values and rules for safety. That is why there are no readable universal laws for safety.

Operating conditions are also very important because it is a difference if the load is static or varying a lot. Protections like overflow protection, devices for detecting leakages and alarms, as well as the possibility of remote supervision have to be clarified from case to case, but are in any case good instruments to reduce the potential danger. Normally a collecting device or collecting tank is prescribed for dangerous substances, which influences the static load of wind, precipitation and solar radiation in addition to security.

## 4. Dimensioning of tanks

Dimensioning of tanks takes place by using principles of strength of materials and plastics technology.

Thereby we can fall back on the experience of more than fifty years. For modern pipe material normally corresponding curves and tables are provided by the manufacturers when launching a product, from which you can read necessary figures for short- and long-term usage. In terms of static calculation and temporal scale, you often differentiate between applications. Calculation therefore normally is scheduled to run for 10 or 25 years, in individual cases for 50 years.

In order to be able to get the needed material characteristics for the respective time of calculation, you can, concerning to the consideration of load, fall back on hydrostatic strength diagram, which has been determined

exemplarily on an axial extruded pipe. The calculation of stability is carried out with material properties, which are based on the creep modulus, which can be extrapolated from measurement data form up to 10000h. Security of such extrapolations for pipe material made of polyethylene is given by continuing experience for many decades.

For raw materials with laboratory confirmed long-term-behaviour (hydrostatic strength curves acc. ISO 9080), a sufficient accuracy of extrapolation to 50 years from 2000 h data is approved. This means an extrapolation for 2.5 decades.

The first storage tanks made of polyethylene were produced in 1950s. Since this time computer programs for static calculation have gained credibility on the market, which can limit calculation costs. Standards and guidelines ensure the required standardization for this important market segment of the plastics industry. Calculation rules are also described in detail in standard EN 12573 or DVS 2205 part 2.

A simple wall dimensioning can often be estimated with sufficient accuracy by carrying out a calculation of stability to internal pressure on the one hand and to vacuum on the other.

Firstly must be calculated, with the traditional equation for inner pressure (acc. Barlow), the required cylinder wall. The inner pressure depends on filling height, density of the liquid and permitted load. This can be conducted in different heights of the cylinder to get a staged, and with it cost-efficient, wall structure.

The permitted stress is the result of typical creep rupture curves (hydrostatic strengths diagram) for the raw material, in consideration of the safety factor and the reduction coefficient for the specific ductility ( depending on the temperature), the joint factor (depending on the kind of welding) and the chemical loading by the liquid (tables of operating experience, inter alia DVS and DIBt, Germany). For the consideration of the bending moment you have to choose an additional factor, which takes into account the constraint of elongation of the cylinder in the area of joint between cylinder and bottom plate. The constraint of elongation respectively the stiffness depends by the thickness of the bottom plate. In practice this factor is between 1 (membrane bottom plate) and 1,82 (fixed bottom plate).

$$p = \rho \cdot g \cdot h_f$$

$$s_{zs} = C \cdot \frac{S \cdot p \cdot d_i}{2 \cdot \left( \frac{\sigma \cdot f_s}{A_1 \cdot A_2} \right) - p}$$

- p: hydrostatic pressure [N/mm<sup>2</sup>]
- g: acceleration of gravity [m/s<sup>2</sup>]
- ρ: density of the medium [kg/cm<sup>3</sup>]
- s<sub>zs</sub>: minimum wall thickness for the consideration of loads [mm]
- C: factor for bending moment [-]
- d<sub>i</sub>: inside diameter [mm]
- S: safety factor [-]
- σ: load from hydrostatic strength diagram for the present temperature [N/mm<sup>2</sup>]
- A<sub>1</sub>: reduction coefficient specific ductility [-]
- A<sub>2</sub>: reduction coefficient ambient medium [-]
- f<sub>s</sub>: long duration welding factor for homogenously manufactured helical extruded pipes = 1

specific ductility following DVS 2205 (dated 2010):

Material	Operating temperature			
	-10°C	20°C	40°C	60°C
Polyethylene	1,2	1	1	1
Polypropylene Homopolymer PP-H	1,8	1,3	1	1
Polypropylene Copolymer PP-R	1,5	1,1	1	1

Including the calculation of stability against vacuum, which can for example arise during emptying the tank or be caused by increasing wind suction, a good approach towards the statically required wall thicknesses can be reached. The minimum value for this vacuum, which could arise, has been set at 0,0003N/mm<sup>2</sup> by technical rule DVS 2205.

Equation for buckling of cylinders:

$$s_{zB} = 0,79 \cdot \left( S \cdot A_{2I} \cdot \frac{h_z \cdot \sum p_u}{E_K^{T^c} \cdot d_i} \right)^{0,4} \cdot d_i$$

s<sub>zB</sub>: minimum wall thickness for buckling load [mm]

S: safety factor [-]

A<sub>2I</sub>: reduction coefficient ambient medium for consideration of stability [-]

h<sub>z</sub>: high of cylinder [mm]

Σp<sub>u</sub>: total vacuum loads [N/mm<sup>2</sup>]

E<sub>K</sub>: creep modulus under consideration period and temperature [N/mm<sup>2</sup>]

d<sub>i</sub>: inside diameter [mm]

A concluding calculation can not be replaced by such a first consideration, as described before. However, it provides a good and quick indication to the required construction.

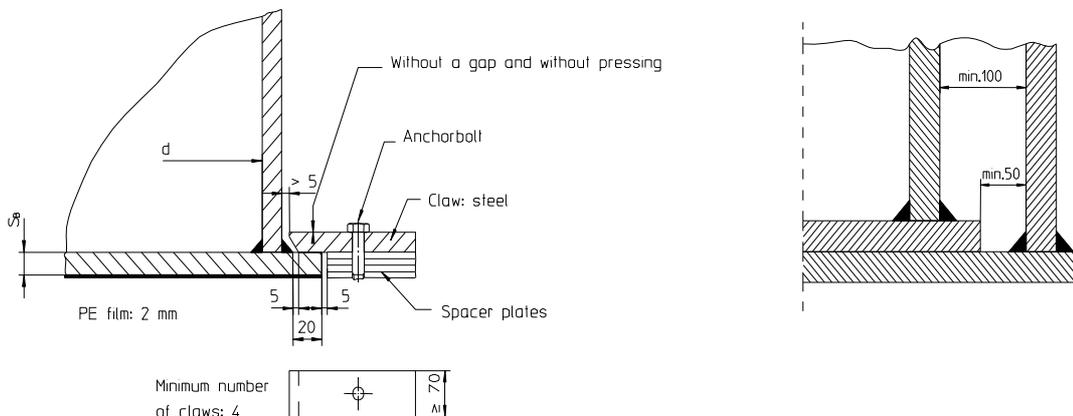
## 5. Design specifics

### 5.1 bottom and roof construction

The bottom construction for vertical tanks is carried out as flat, beveled or conical bottom. In most cases the simple flat bottom is sufficient. The cylinders are fixed onto the bottom plate with double fillet weld, with a ≥ 0,7 x s<sub>B</sub>. The bottom thickness s<sub>B</sub> should always be less than the thickness of the cylinder s<sub>z</sub>.

A rule of thumb for bottom plate dimensioning is s<sub>B</sub> = 0.8 x s<sub>z</sub>.

Beveled or conical bottom design is only considered for fluidic and procedural reasons. For example if 100% emptying is required for the process. The accessibility of the welding zone at beveled and conical bottoms is partly complicated and places special demands on the welder and welding apparatus.



Single tank with anchoring acc. DVS2205-2

tank in tank system acc. DVS2205-2

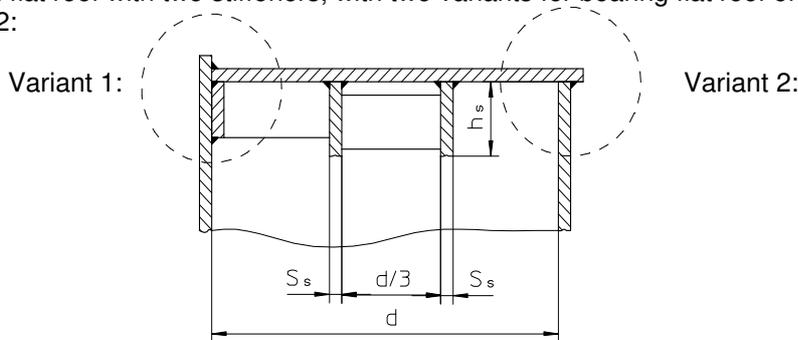
To give tanks the required stability, especially for use outdoors, the bottom plate often is anchored in the foundations. The anchors must be designed against the worst load case. This concerns primarily dimensioning against wind and the resulting bending moment but also increasing pressure fluctuations can affect the load conditions. If anchors are necessary, at least four fastening anchors are needed to ensure a

steady load bearing. The anchoring logically is to be carried out with help of separate fastening anchors so that the tank can move/slide sideward and relax. To ensure that the bottom plate of the tank can slide, an additional plastic plate with a thickness of app. 2 mm below the base is recommended. In this way no elongation under the influence of temperature or change of load can result in avoidable additional loads.

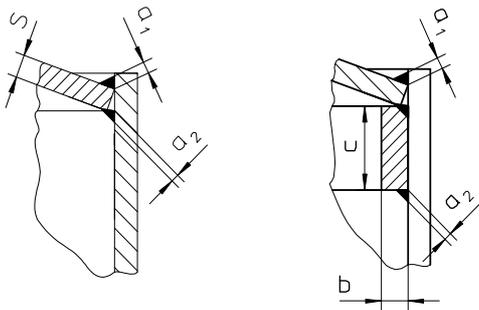
Instead of flat endcaps/bottoms especially for horizontal tanks it is recommended to use convex endcaps. The convex endcaps can be cut from same type of pipe that is used for the tank itself. In that way a self-stabilizing figure is achieved and additional support ribs can be avoided. This kind of convex endcaps are sometimes also used for roof construction. Important for an efficient manufacturing process is a proper cutting-device (Plaspittec), which guarantee the necessary accuracy of the cut. But more used for roof-construction is for inside installation the simple flat-roof, and for outside installation the conical roof-construction. Typical angle of the cone is 15°.

A stability check is to be carried out for the dead weight plus vacuum. Special attention has to be paid to arising operating- and ambient temperatures. An accessibility of thermoplastic roofs is usually not intended, according to the safety regulations, but is still guaranteed by grates on separate platforms or by suitable ladders. When used in connection with platforms and ladders you have to take the different elongation by temperature of steel and thermoplastics into account. In either case, suitable slide bearings in the construction are needed to avoid loads.

Section through flat roof with two stiffeners, with two variants for bearing flat roof on the cylinder acc. DVS2205-2:



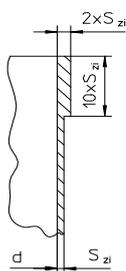
Conical roof - Different variants for bearing roof on cylinder acc. DVS2205-2:



## 5.2 Rim-Reinforcement

Tanks, which are open to the top, need to have a reinforced rim. The minimum wall thickness, which is the result of the hydrostatic design, does not lead to a sufficient stiffness, especially when talking about partial filling. There are several solutions to guarantee the needed stiffness. The most useful variation is to use the flexibility in manufacturing of helical extruded pipes and to thicken the wall thickness during production at the rim of the cylinder.

Rim-reinforcement acc. DVS2205-2:

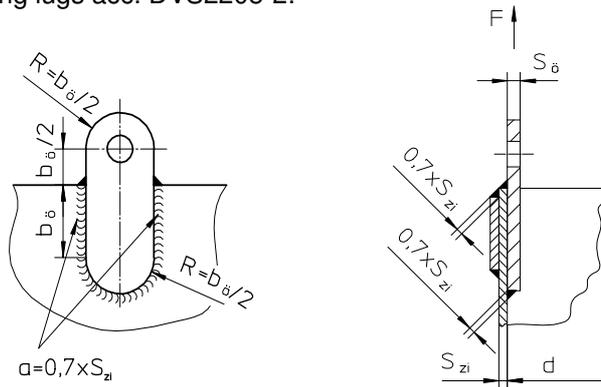


### 5.3 Lifting lugs

To make the lifting of a tank easier, two lifting lugs are welded on it. The dimensioning and the choice of the safety factor have to take account of possible dangers of floating loads. Account should be taken of the weight of the tank plus mounting parts. The required thickness of the lifting lug is situated within following limits:  $b_{\delta} > s_z$  and  $b_{\delta} < 3 \times s_z$

The use of traverses protect the rim of the tank against avoidable deformations and it guarantees a vertical lifting without additional loads. It is important to note that in setting up a tank, which was transported in a laying position, the lifting lug is temporary loaded by thrust, torsion and bending. Furthermore, the hole diameter has to be coordinated to the diameter of the shackle, to avoid inadmissible bearing stresses.

Design of lifting lugs acc. DVS2205-2:

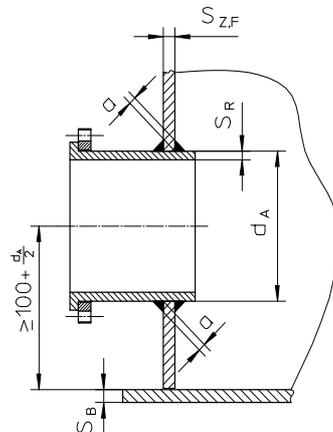


### 5.4 Nozzles

Number and suitable dimension of nozzles is important for the dimensioning of the wall thickness, because every cutout can present a weakening. The smaller the nozzle, the smaller the weakening.

By following the standard calculation rules acc DVS 2205 for dimensioning, nozzles in the cylinder wall can be considered up to a diameter of 160 mm. Nevertheless it is also possible to integrate much bigger nozzles, but separate static proof is necessary. Especially the lower section near to the bottom should be avoided if possible, because of the stress and the disability of elongation. If using storage tanks, the nozzles should be integrated into the roof, which requires no special calculative proof. This applies in particular to manways and nozzles with large diameter. The weld has to be made with fillet welds on both sides, which requires a minimum distance to the basement or installed equipment.

Nozzle in the cylinder shell acc. DVS2205-2:



$$a > 0,7 \times S$$

$$d_A \leq 160 \text{ mm}$$

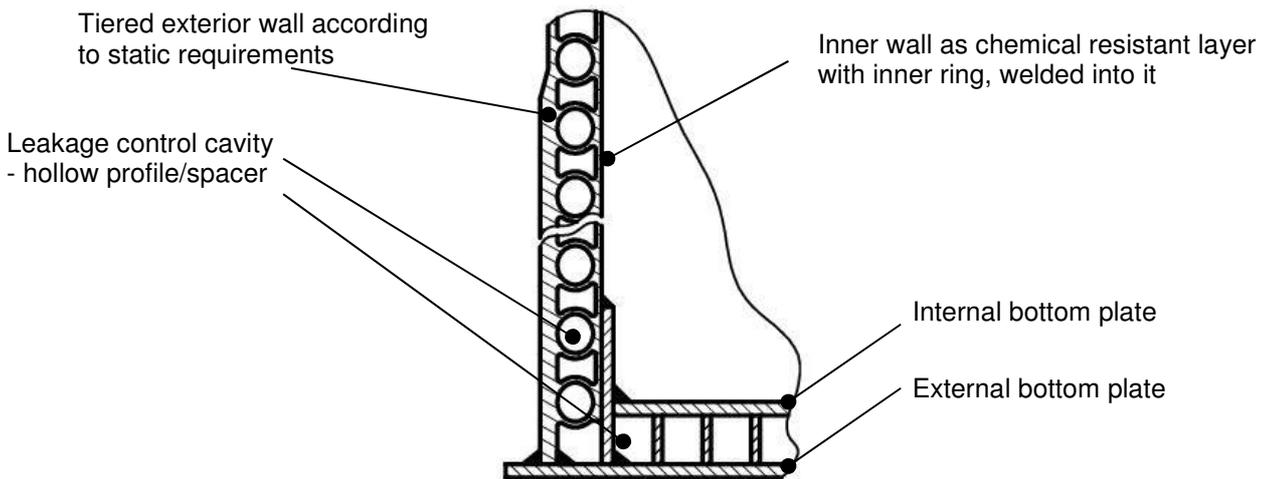
## 6. Double wall tanks for hazardous liquids

As mentioned in section 2 special arrangements needed for dangerous liquids where regulatory requirements differ by country. Widely similar is the requirement for a safety tank or a collection container, in which liquids can safely escape if there is a leakage. Tanks fabricated out of helical extruded pipes are available as a “tank in tank” solution also.

For this purpose a hollow profile is integrated in the cylinder wall, which separates the inner wall from the outer wall on the one hand, which gives them different functions and serve as a leakage warning cavity on the other. A leakage sensor can be arranged in a way that it gives alarm when there is only a minimal leakage, which ensures the best reaction time!

The inner wall performs a protective function and has to be statically designed in a way that it – supported by profile and outer wall – can cope with hydrostatic pressure under influence of chemical liquid. It also needs to have a suitable wall thickness to guarantee a proper welded joint to the double bottom.

The outer wall has to carry the total static load, which is transmitted from the inner wall over the profile outwards, which is why it is normally dimensioned in these premises. The outer wall normally is not exposed to long time affect by chemicals or hazardous liquids, which can be taken into account when calculating, which permits significant savings in the wall thickness. Moreover, the advantage is space-saving and is cheaper in manufacturing.



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