Rupture of a crude oil storage tank

25 October, 2005

Kallo – Belgium

Rupture
Flammable liquids farm
Storage tank
Crude oil
Corrosion
Periodic control
Thickness measurements

THE INSTALLATIONS IN QUESTION

The oil storage terminal contains 7 storage tanks in one large bund made with earth dikes. Between the tanks there are lower inner dikes.

- ✓ 4 crude oil storage tanks with a content of 40 000 m^3 each: D1, D2, D3 and D4;
- ✓ 2 storage tanks for the multifunctional storage of crude oil or rainwater contaminated with crude oil, slop oil, with a content of 24 000 m^3 each: D10 and D11;
- ✓ 1 small tank D26, with a content of 730 m^3 which is out of service.

The crude oil is delivered by pipeline from the port of Rotterdam and after some storage at the terminal at the left bank of the river Scheldt the feedstock is pumped by pipeline to a refinery, which is situated at the right bank of the river, where it is further processed.

The oil storage terminal was licensed by a decision of the Permanent Executive of the Province of East Flanders on February 7th, 1991 for a period expiring on February 6th, 2011.

The establishment falls within the scope of application of the Seveso II Directive because of the presence of more than 50.000 tonnes automotive petrol and other petroleum spirits. The license allows the company to store 208.000 m³ of crude oil. For that reason the terminal is an upper tier establishment.

On September 12th, 2005 a minor incident occurred at the storage tank D3. During this incident crude oil leaked from the bottom of the tank. In October 2005 the exact cause of this incident was not yet known, because the tank bottom was not yet fully cleaned to start the investigation of the incident. At the moment the major accident occurred with tank D2 cleaning operations for storage tank D3 had just started in order to inspect storage tank D3.

The storage terminal is permanently manned during daytime. In the evening and at night inspection rounds are performed by an external security company. The permanent supervision of the terminal (by means of cameras) and the filling and discharging operations of the storage tanks are completely managed from the control room at the refinery.

THE ACCIDENT, ITS BEHAVIOUR, EFFECTS AND CONSEQUENCES

The accident:

On October 25, 2005 around 18.15h a major leak at tank D2 was detected. The operators in the control room of the refinery were alerted by a low level alarm for tank D2. Storage tank D2 contained almost 37 000 m^3 crude oil before the release. The level history in the control system situated in the control room of the refinery indicates that after a short period of increasing leakage almost the full inventory of storage tank D2 was released within 15 minutes.

The accident has been considered a ‘major accident’ according to the criteria set in Annex VI of the Seveso II Directive.

The consequences:

Consequences for the installation

Because the content of the storage tank was released in such a short time, an enormous crude wave was created. This wave moved in the direction of the several meters high earth dike, which fortunately resisted against the power of the wave. The released crude oil filled the whole bund (40 000 m^2 large) with crude up to a height of 1 m.

After the release the storage tank was leaning forward and a part of the foundation of the storage tank had disappeared.

Consequences for the environment

- ✓ *Air pollution:* the enormous amount of crude oil that was captured in the bund caused strong odour pollution in the wide surroundings of the depot. Odour pollution was reported close to the border with the Netherlands due to the very strong wind in Northwest direction that evening. Although the company took several measures to fight the odour pollution (like covering the bund with sand and foam), odour complaints were reported during several days after the accident. Another series of odour complaints occurred two weeks after the accident at November 11th 2005, at the moment that the floating roof of the tank has landed by which means the function of the seal of the floating roof was lost.
- ✓ *Surface water pollution:* There was a very slight contamination of surface water in the surroundings. Due to the height of the dike only a small amount of crude oil (approximately 3 m^3) was ejected out of the bund. This caused a confined pollution of the polder ditch which is situated at the outside of the terminal.
- ✓ *Soil pollution:* the upper layer of the bund is a clay-layer. In the past a layer of sand of approximately 50 cm was placed above this clay-layer in the area of the bund where there are no tanks. Under this layer, about 1,2 m deep, there is a sand layer. Samples of the soil were taken to determine the soil pollution. These samples showed that the clay-layer stopped the pollution. The part above the clay-layer was polluted over the whole area of the bund, the depth of this pollution varied from 10 cm up to 1 m.

  Also on the other side of the road near the terminal samples of the soil were taken because of the presence of a nature area. Due to the accident some of the grass in this area was covered by a mist of crude oil. Analysis of these samples showed that no soil pollution occurred in this area.

Figure 1 shows a picture of the situation in the bund the morning after the major accident happened.

- ✓ *Groundwater pollution:* analysis of the groundwater showed that there was no groundwater pollution due to the accident. First some increased concentrations of benzene were measured near tank D2, but after the removal of the polluted soil the situation was normalised.

Consequences for the people : There were no injuries caused by this accident.

European scale of industrial accidents:

By applying the rating rules of the 18 parameters of the scale made official in February 1994 by the Committee of Competent Authorities of the Member States which oversees the application of the 'SEVESO' directive, the accident can be characterized by the following 4 indexes, based on the information available.

The parameters which compose these indexes and the corresponding rating method are indicated in the appendix hereto and are available at the following address: http://www.aria.ecologie.gouv.fr.

The level of the dangerous substances index is 4 because approximately 30.000 tons of crude were released (parameter Q1).

The level of the human and social index is 0 because there were no injuries.

For the environmental consequences the index is 3 because the surface area of soil requiring cleaning is 4 ha (parameter Env 13) .

The index for the economic consequences is 5 due to the high cleaning costs (€ 18).

ORIGIN, CAUSES AND CIRCUMSTANCES OF THE ACCIDENT

History and construction information of the storage tank D2:

The storage tank was an atmospheric storage tank with an external floating roof and with a cone-up bottom. The storage tank had a diameter of 54,5 m and a height of 17 m. Because of the cone-up bottom the present water in the crude oil flowed towards the shell of the storage tank, where one water sump system was installed. The storage tank also contained two mixers, to put a part of the sludge back into suspension.

The foundation of storage tank D2 consisted of a crushed rock annular ring. The rocks had a diameter between 50 mm and 150 mm. The crushed rock annular ring had a height of approximately 120 cm of which a part was below the ground level. The crushed rock ring had a width of approximately 340 cm at the bottom and 100 cm at the top. The shell was situated in the middle of the width of the crushed rock ring. The inner part of the annular ring was filled with compacted sand. Above this sand there was a layer of 5 cm consisting of oiled sand, to avoid external bottom corrosion. Figure 2 provides a schematic view of the foundation of storage tank D2.

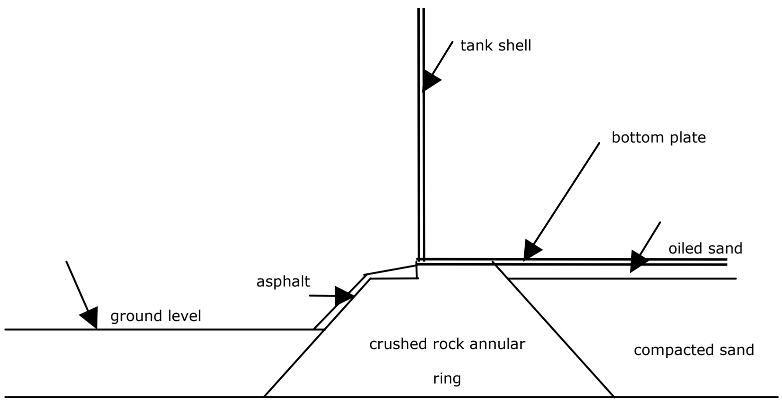

Figure 2: Schematic view of the tank foundation

The annular plates, these are the bottom plates on which the shell of the storage tank is welded, have a design thickness of 12,7 mm. The other bottom plates are designed with a thickness of 6,35 mm.

The underground of the storage terminal existed of a soft clay layer with a thickness of 1 m with a sand layer of 3 m underneath.

The storage tank was built in 1971 according to specific construction standards code API 650. At that moment the storage terminal belonged to another owner. In 1990 the storage terminal was sold to the refinery. At that time all the storage tanks were fully inspected and repaired if necessary. Storage tank D2 was fully inspected in 1990 and was put into service in 1991.

Since 1994 each 3 years external inspections were performed on storage tank D2. The reports of these inspections showed almost no remarks. A full inspection of storage tank D2 was scheduled for 2006, after the full inspection of D1 had been finished. Each three years foundation settlement measurements were performed on the storage tanks. The latest measurements were performed in 2004 and showed no abnormal results.

Findings after the tank rupture:

The investigation of tank D2 showed that the bottom plates in a long, small circular band at approximately 1,5 m from the shell of the storage tank were extremely weakened due to internal corrosion. In this band the thickness of the bottom plates was nearly reduced to zero. This band had a length of approximately 35 m and a width of approximately 20 cm.

In this band the bottom of the tank formed a gutter. In this gutter uniform, internal corrosion was found and no pitting corrosion.

The bottom plates showed no external corrosion in the long, small band. The other bottom plates indicated no extreme corrosion.

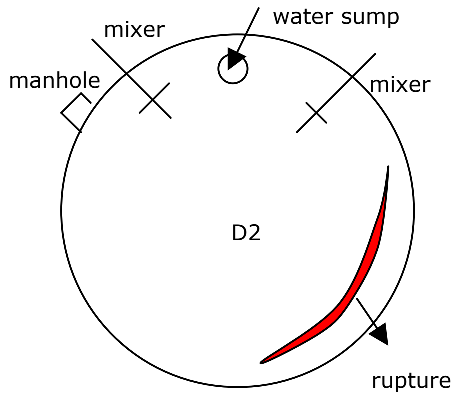

Figure 3: Schematic view of the bottom of storage tank

Primary causes:

During the exploitation of storage tank D2 a gutter was formed in the bottom of the tank. This gutter is situated at a distance of 1,5 m from the tank shell. Due to the formation of the gutter the present water could not longer flow to the drain water system to be removed. The accumulation of stagnant water in the gutter caused strong corrosion which strongly reduced the thickness of the bottom plates in that area.

The major release initially started with a small leak. Due to this small leak the compacted sand underneath the tank bottom was saturated with oil and a kind of quicksand of oil and sand is formed. This small leak has not been visually detected because the crushed rock annular ring had a lot of holes, which were initially filled with crude oil. In the second phase of the accident the resistance of the foundation under the tank was locally strongly reduced (due to the fluidisation of the sand bed) and due to the hydrostatic pressure of the crude oil on the tank bottom, the bottom has ruptured over the length of the gutter. The force of the discharged crude oil was that large that it destroyed a part of the tank foundation and swept away a part of the underground.

Underlying causes:

As mentioned before, a gutter was situated in the tank bottom at a distance of 1,5 m from the tank wall. This is just beyond the annular plates on which the tank shell is welded. The first normal bottom plates after the annular plates were cracked during the accident. The gutter has been formed due to settlements in the tank foundation, which at that place consists of compacted sand. The gutter has probably been formed during the first hydrostatic tests on the storage tank. The moment a storage tank is loaded for the first time, the compacted sand settles. In the neighbourhood of the crushed rock annular ring, which consists of coarse rocks, it is difficult to compact the sand bed in an appropriate manner during construction. At the moment the storage tank is loaded for the first time, the sand in that area will be more compacted, but because of the existing holes in de crushed rock annular ring a part of the sand will disappear in the holes between the coarse rocks. Due to these phenomena a gutter is formed in the bottom plates nearby the crushed rock annular ring. Calculations based on a finite element method showed that based on the information about the foundation of the tank in combination with the underground under the tank foundation and the size of the storage tank, the forming of the gutter could be predicted.

The gutter in the bottom plates has not been detected during the internal inspection of the storage tank in 1990-1991, probably because of the used inspection technique and the fact that inspections are performed when the storage tank is unloaded, in which case the elastic deformation can partially hide the gutter in de bottom plates. During the internal inspection in 1990-1991 all the bottom plates were visually inspected on pitting corrosion and ultrasonic thickness measurements of the bottom plates were performed at some places of the tank bottom. These thickness measurements were performed on all bottom plates situated on two perpendicular axes over the whole diameter of the tank (measurement in cross-bandage). The places in the bottom where pitting corrosion was detected have been repaired. The ultrasonic thickness measurements on the bottom plates gave good results for the thickness of the tank bottom.

In the gutter in the bottom of the tank, the present water could not longer flow towards the water sump. This situation of stagnant water in the gutter enabled very fast corrosion in the gutter with the rupture of the tank bottom as the major consequence.

After this incident the bottom plates of all other storage tanks in the terminal have been accurately inspected. All tanks showed the same gutter forming in the bottom plates at 1,5 m from the tank shells. For some storage tanks the length of the gutter was only a few meters long, while other storage tanks showed exactly the same phenomenon as the ruptured tank D2. The visibility of the gutter was different from tank to tank. Ultrasonic thickness measurements in the gutters indicated that locally the thickness of the bottom plates was reduced. In some storage tanks even small perforations in the bottom plates were found, while for storage tank D1 the thickness of the bottom plates in the gutter was never lower than 4 mm.

The inspections on the full tank bottoms of the other storage tanks had to be performed in a very accurate manner. Thickness measurements of the whole tank bottom of storage tank D1 by means of a so called “floor scan” initially did not detect that locally (in a gutter) the thickness of the bottom plates was more reduced. Only after a surveyor made a topographic map of the tank bottom, a small gutter was detected. Ultrasonic thickness measurements indicated that, as mentioned above, in this gutter the thickness of the bottom plates was reduced to 4 mm.

These inspections proved that the leak in the storage tank D3, which happened on the 12th September 2005, had the same causes as the rupture of storage tank D2. In contradiction to storage tank D2, the gutter in tank D3 was much shorter. After some time the leak has stopped, probably because sediment in the crude oil closed the perforated places in the bottom plates.

ACTIONS TAKEN

Emergency measures:

The fire brigade of the refinery, the fire brigades of the surrounding communities and civil protection started a massive intervention. Initially the intervention team started to cover the bund with fire fighting foam. Directly a large amount of fire fighting foam, 214 ton, was gathered from the refinery, other (petro)chemical companies, the fire brigade and civil protection to cover the very large bund area with foam. Due to the very strong wind that evening and the largeness of the bund they did not succeeded to cover the whole bund with foam. On the other hand the strong wind was in favour for not achieving an explosive atmosphere above the spill. The crude oil did not ignite. The release of the crude oil caused a lot of odour pollution in the wide surroundings. The rupture of the storage tank got al lot of attention from the national media.

After the major accident all the crude oil stored at the terminal was immediately pumped to the refinery and the contents of the bund was pumped to the storage tanks D10, D11 and D4 by using the existing drain water pump system. Immediately measures were taken to perform all cleaning activities in the storage terminal in a safe manner.

In the afternoon of October 27th, 2005 the major part of the bund was empty. On October 28th, 2005 activities were started to reduce the smell. The smell was effectively reduced by covering the entire bund with sand. Where possible the sand layer was placed by trucks and bulldozers. Between the tanks the sand layer was placed by blowing sand in these areas. This operation lasted for about two weeks.

The stability of all storage tanks was periodically measured. The stability of storage tank D2 on the place where the foundation was blown away, was achieved by hanging the storage tank on 4 large cranes (figure 4).

The intervention was only formally stopped on 18th of November 2005 when the storage terminal was completely free of product.

Figure 4: Major cranes stabilising tank D2

Corrective actions taken by the company:

After the major accident the company inspected all other storage tanks in the terminal. These inspections indicated that the gutter forming and the strong internal corrosion of the bottom plates in that gutter, which were the two main causes of the rupture of storage tank D2, were also found in the other storage tanks.

The storage tank D2 had been totally demolished.

The parts of the bottom plates of the other storage tanks of which the thickness and/or the deformation do not fulfil the prescriptions of the standards API 653 shall be repaired. The foundation of the other storage tanks was investigated to control if they still have enough stability (during the accident they were drawn in crude oil) to restart the exploitation of the storage tanks.

Before start-up all crude oil storage tanks shall be coated with a lining to stop the internal corrosion of the bottom plates.

The water at the bottom of the crude oil tanks is drained on a regular basis. After the accident the company decided to analyse the corrosive character of this drain water (by measuring the pH-value of it).

The company also decided to adjust the inspection program of all vertical storage tanks. Between two internal inspections acoustic emission measurements will be performed. Based on the results of these acoustic emission measurements, the next date for the internal inspection shall be adapted if necessary. During the internal inspection of the storage tanks the condition of the bottom of the tank is visually inspected. From the moment there is any doubt about the condition of the bottom plates, ultrasonic thickness measurements will no longer be performed in a cross banded pattern, but the whole bottom of the storage tank will be fully scanned. If a floor scan is performed, 5 additional ultrasonic thickness measurements will be carried out on each bottom plate.

In order to detect leaks in an early stage the company has decided to install a detection with alarm on abnormal level changes on crude oil tanks. Such systems were already available on product tanks in the refinery. Besides these measurements the company is still evaluating to install an on-line oil detection system under the storage tanks.

The company took several measures for cleaning and rehabilitation of the environment. As a result of the soil samples that were taken an area of about 4ha was excavated to a depth varying from 10 cm to 1m. This contaminated soil (including the sand that was used to cover the bund) was removed for further treatment. Several odour catchers were installed around the terminal to prevent possible odour pollution during the cleaning operations. The released crude oil, which was contaminated with 214 tonnes of foam, was recovered from the bund. The polder ditch at the outside of the terminal was cleaned. Several extra gauge wells were installed to establish possible groundwater pollution and to ensure further monitoring of the groundwater quality in the future.

LESSONS LEARNT

Detection of the problem:

Just as for each process equipment with risks for major accidents, the phenomena which can lead to a degradation of the containment, in this case the storage tank, should be identified and analysed.

This accident indicates the possible risks as a consequence of the presence of non mixable phases which can settle out. An investigation of the possible presence of such phases should form a part of the identification of possible corrosive phenomena. If necessary chemical analyses should be performed to determine the corrosive behaviour of these phases (chemical composition, pH,…).

This incident further shows that in the bottom of storage tanks gutters can be formed. In those gutters corrosive products can accumulate, what can result in local, uniform corrosion. In the case water and/or other corrosive products can induce corrosion of the tank bottom, it should be investigated if there is also a problem of gutter forming in the bottom.

Gutter forming in the bottom of storage tanks is induced by a combination of the size of the storage tank, the local compressibility of the foundation and a relative elastic underground. The gutters are not always visible by the eye. They can be mapped by performing a topographic investigation. The topographic maps are achieved by a surveyor who measures the bottom of the storage tank with a laser.

The local uniform corrosion which is a consequence of the gutter forming is not easily detected. The local reduction of the thickness of the bottom plate can be overlooked if ultrasonic thickness measurements are only performed on a cross banded pattern. If the risk of local corrosion due to gutter forming in the bottom exists, suitable techniques should be used to investigate the bottom plates. These techniques are described below.

Possible solutions:

If local, uniform corrosion induced by gutter forming is a problem, the company should take suitable measures to avoid a loss of containment as a consequence of the corrosion. In the next paragraph some different possible measures are listed according to the place they take in the prevention hierarchy. In function of the specific situation it can be necessary to take multiple measures, if necessary completed with additional measures which are not described here.

1. Avoiding or limiting the presence of corrosive products that can settle out.
2. Avoid that products settle out (mixing the different phases)

   Mixing of the products in the storage tank can avoid or limit that insoluble phases settle out. To achieve good results the effectiveness of the mixing is important.
3. Removing of settled out products

   It has to be assured by a procedure that settled out products are periodically removed. But note that the draining of settled out products does not guarantee that settlements are removed out of gutters in the bottom.
4. Avoiding the formation of gutters in the bottom

   Existing storage tanks can be lifted up and the foundation underneath can be restored. In this case it must be kept in mind that by performing a hydrostatic test it is possible that new settlements can take place. For existing tanks there is also the possibility to analyse the foundation and the underground under the storage tanks in order to gather enough information to perform calculations. These calculations can indicate if the risk of gutter forming exists or not. For new storage tanks a detailed calculations of the foundations can be performed during the design phase to reduce the risk of gutter formation.
5. Lining

   A lining is applied on the tank bottom and the first shell course. A lining which is well attached will largely reduce the corrosion velocity. A badly adjusted lining will still reduce the uniform corrosion but will promote pitting corrosion underneath the lining. A good attachment of a lining depends on a lot of parameters such as moisture, temperature, kind of lining, not stepping on a not fully hardened layer, … To achieve guarantee about the thickness of the lining and the attachment of the lining it is necessary to perform measurements on the thickness of the different layers, to perform a conductivity test and to perform a non porosity test. The code API 652 “Linings of aboveground petroleum storage tank bottoms” describes the advantages and disadvantages of different kind of linings.
6. Planning of internal inspections based on the corrosion velocity

   The intervals between internal inspections have to be defined based on the estimated corrosion velocity. This is a general principle that can be found in the API 653 standard “Tank Inspection, Repair, Alteration and Reconstruction”. Normally the corrosion velocity of the bottom plates is the most important one. In the case of major local corrosion, it will be this higher, local corrosion velocity which is determinative for the inspection interval.

   The internal corrosion velocity can be determined by analysing the settled out products. Based on graphics which indicate the overall corrosion velocity of the construction material as a function of the corrosive character of these residues (e.g. pH-measurement), the corrosion velocity can be estimated. Based on the corrosion velocity it can be determined how long the storage tank can be safely used before a next internal inspection is necessary. Standards API 653 describes what minimum plate thicknesses have to be measured to use a storage tank safely. If it is expected that large differences can occur in the chemical composition and the properties of the residues, these analyses and the calculation of the inspection interval must be periodically repeated. The analysis of the bottom products can be used to trace other corrosion phenomena (e.g. bacteriological corrosion).
7. Adapted internal inspection techniques

   Internal inspections in which case ultrasonic thickness measurements are only performed in a cross banded pattern (just to achieve a general impression of the thickness of the bottom of the storage tank) are not sufficient to trace local, uniform corrosion.

   In order to achieve an entire image of all changes in the thickness of the bottom of a storage tank the bottom must be totally scanned. Floor scans are very useful to measure sudden volume changes in the floor (e.g. pitting corrosion). They can however also be used to trace gradual changes in the thickness of the bottom plates. To guarantee that a floor scan generates accurate information on the state of the entire bottom of the storage tank, certain conditions have to be satisfied.

   It must be checked if the presence of a lining has an influence on the results of the floor scan.

   Before the inspection it must be clearly discussed with the performers in which state the storage tank must be presented to achieve good measurements. In some cases the entire bottom of the storage tank must be sand blasted before measurements can be performed. In this case it is necessary to discuss the criteria for the sand blasting in advance. It is also favourable that the contractor who will perform the floor scan inspects the cleaning conditions of the bottom plates.

The signal that is generated by the floor scanning apparatus can suffer from drift. This phenomenon is not necessarily a problem if the floor scanning is used to detect pitting corrosion. The moment pitting corrosion is detected, the signal changes so much that even with some drift on the signal, the pitting corrosion is detected. The drift on the electric signal has however a much larger impact when floor scanning is used to detect gradual changes in the bottom floor. To solve this problem it is useful to perform a few ultrasonic thickness measurements on each bottom plate. The signal from the floor scanning apparatus can be gauged for each bottom plate in order to achieve accurate measurements on gradual changes in the bottom thickness.

8. Additional external inspection techniques

In addition to the above described internal inspections, intermediate external inspections can be performed in order to gather additional information on the corrosion status of the storage tanks. These inspection techniques, which can be applied when the storage tanks are in duty, are especially useful when there is large uncertainty on the corrosion phenomena and/or on the corrosion velocity.

A first technique uses acoustic emission measurements. Microphones are placed on the shell of the storage tank to receive sound waves coming out of the tank. Each sound wave is stored and the source of the noise is calculated by software. The sounds that can be associated with a general corrosion activity have a very high frequency. The data are processed in order to map the places where corrosion activity is found and to determine the density of the corrosion activity. The technique makes it also possible to determine different grades of corrosion activity, going from grade A (very small) to grade E (high corrosion activity). As a function of the established corrosion activity it can be decided to perform immediately an internal inspection on the storage tank (in case of grade E), to reschedule the next internal inspection to an earlier date or to repeat the acoustic emission measurements after a certain period.

The acoustic emission technique also allows to detect leaks. These leaks are detected at other frequencies than the frequencies at which the general corrosion activity is detected. This technique makes it possible to detect small perforations in the tank bottom.

Another technique to achieve an indication of certain corrosion phenomena is “long range ultrasonics”. This technique admits to achieve a qualitative image of the status of the annular bottom plates (not from the entire tank bottom) by using guided waves.

These external inspection techniques do not gather (quantitative) information about the corrosion velocity and can‘t be used to enlarge the inspection interval that is based on the corrosion velocity.

9. Applying leak detection techniques

Several techniques can be applied to detect a leak in the bottom of a storage tank while the storage tank is in duty.

A possible leak detection technique exists of cables placed in the underground at fixed distances. The conductivity of these cables changes if a product is detected in the underground.

Larger leaks can be detected by looking for abnormal deviations in the fluid level in the storage tank. If a continuous level measurement is installed on the storage tank, it is possible to install an extra alarm in the control program. The alarm is generated when the fluid level decreases when there are no pumping activities out of the storage tank.