The author has been an expert legal witness for more than 10 years for over 120 cases and wrote his first report about a biogas plant accident more than 15 years ago. In this personal account, we learn about an investigation into an accident at a biogas plant

First-person sleuthing, gas holder roof rupture

The situation was a standard one; an insurance company sent a short message saying that there was an accident on a biogas plant. A broken gas holder roof, "Please visit the site and write a report."

My reaction

So many accidents are because of the gas holder roof. Standard report. No big deal.

Visit, initial site assessment

The site visit is one of the most important parts of the accident investigation and was certainly an eye-opener that day.

It was not just another day at the office; neither the digester tank nor the gas holder roof were in any way standard. So exotic was this digester tank design, that I'd never come across it before – at least not while in the line of duty. Nothing about this day was business as usual and this was to be a different case to any I had encountered before.

The digester tank consisted of two concrete rings and the space between the two rings was divided into several chambers with the gas holder roof covering the entire tank diameter, Figures 1 and 3. It is not the subject of this very report to discuss different digester tank designs. However, it shows that field work for an expert witness means being confronted with a variety of different problems requiring different technical solutions. In the centre of the tank was a column that was the basis for the gas holder structure, Figure 5. While the digester tank was uncovered and open, you could see the centre column had been placed next to the tank, Figure 6. The biogas plant had been in operation for 3.5 years.

Figure 1: showing the space between the two rings

Figure 2: the outer wall

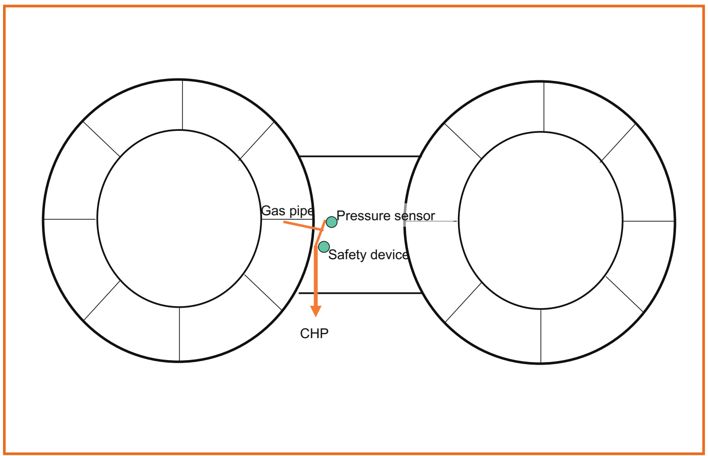

Figure 3: showing the digester-tank chambers from the top down

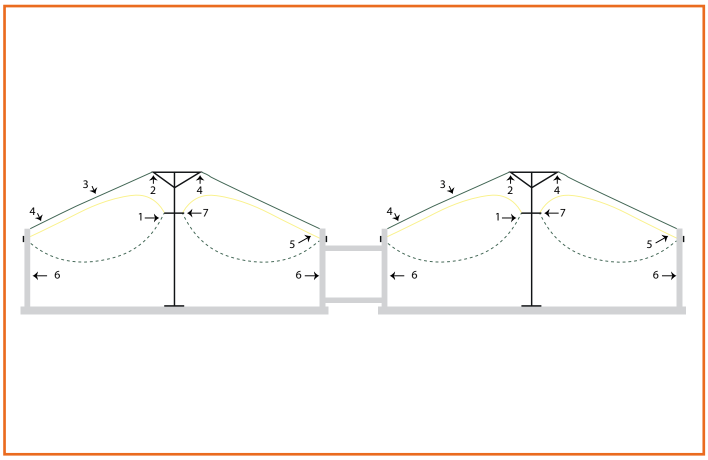

Figure 5: showing a side-on view of the identical tanks

Questions coming up

What was the reason for the rupture? Why did it happen to one of two digester tanks that are supposed to be operating identically?

Different details

The inner digester tank had no mechanical mixing. Unlike 98% of all digester tanks, the biogas itself was doing the mixing; the gas was being introduced into the bottom of the tank and bubbling up through the substrate. The chambers were used as hydrolyses or storage tanks. Maximum operational pressure of the biogas inside the gas holder was 3.5 mbar. There was an overpressure valve that was adjusted to exactly this value – in order to protect the gas holder membrane, Figures 3 and 4. A pressure sensor right in front of this safety device was used for continuously measuring the pressure inside the gas holder, Figures 3 and 4. The gas holder on its own was a kind of double-membrane gas holder. The weather membrane (outside) was spanned over the centre column and fixed at the outside top of the digester tank. The inner membrane – responsible for the gas holding – was fixed in a ring that was located about two thirds, up from the bottom of the centre column, Figures 5 and 6.

Initial summary

It was unclear during the site visit as to why the accident happened at all. The ruptured inner membrane was obvious. But why did the overpressure valve not work? I disassembled the valve on site, in order to check the workings. But nothing came of it, the pressure sensor checked out fine. Nothing. And why was the roof on top of the neighbouring digester operating perfectly? With so little difference between the two, the reason for the accident was no clearer.

Investigation

Back in office the photos were checked again and

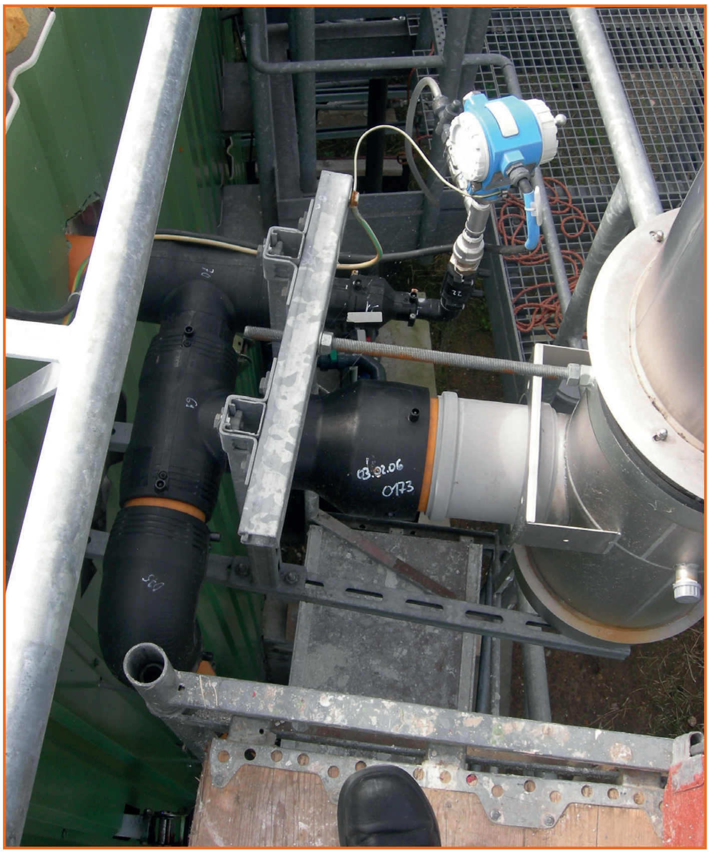

Figure 4: showing the overpressure valve

Figure 6: showing the centre column

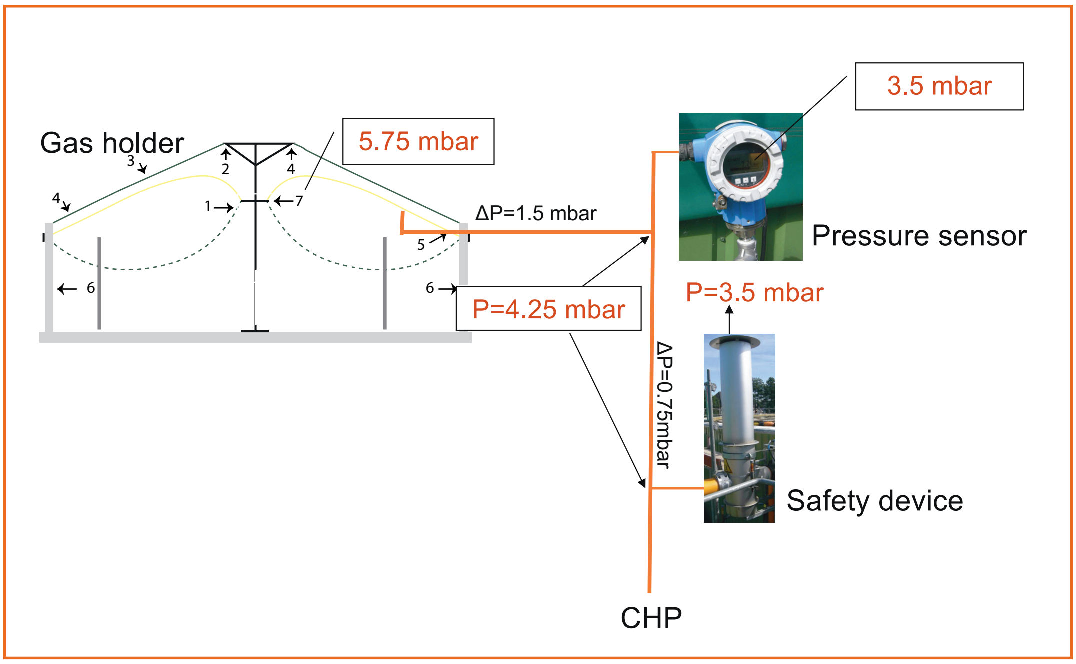

Figure 7: showing the pressure loss and resulting display

again. Slowly, the following was revealed. The gas exit pipe started in about the middle, between the two concrete tanks, Figure 2.

This pipe was covered with a kind of mask, preventing scum and solid particles form entering the gas pipe. These three pieces, pipe length, bow and mask, ended up with a pressure loss of about 1.5 mbar for the through-flowing biogas. Neither the pressure sensor, nor the overpressure valve, was mounted directly at the tank wall. Instead the pipe coming out of the tank was split at a T-piece, Figures 3 and 4. The left arm of the T ended at the pressure sensor and the right arm at the overpressure valve.

On the way to the overpressure valve there was another pressure loss of about 0.75 mbar, and the resulting display on the pressure sensor showed 3.5 mbar, but inside the digester tank it was actually 5.75 mbar (assuming no pressure loss, because of the very short distance, for the left arm of the T), Figure 7. In other words: at the moment the overpressure valve opens the real pressure inside the digester tank was 5.75 mbar. The question was: what pressure could the inner membrane stand?

Inner membrane

The data sheet for the inner membrane made no mention of the maximum pressure the membrane could withstand.

It turned out that the inner membrane fulfilled (at the time of construction) the standard requirements and safety regulations for biogas plants. Checking the documentation hadn't helped. However, my general experience was that the standard layout criteria for any such membrane was 5 mbar. This meant at that moment that – with the calculated maximum 5.75 mbar – we were in the area of the maximum stress that this membrane would be able to withstand/not withstand.

The final evidence came from checking the membrane fix point at the centre column, Figures 6 and 8. The original fixture involved drilling round holes into the membrane and these holes were widened, radially, and over time – an operating time of about 3.5 years – the holes grew too large.

Those long holes indicate too much stress having been loaded upon the inner membrane, call it a micro rupture; it's a sign that the membrane couldn't withstand the forces being applied.

Result and reason

While the operator intended the digester tank to run at a maximum 3.5 mbar, the real pressure in the tank was, very likely, anything up to 5.75 mbar.

It can be assumed that the inner membrane was designed for about 5 mbar maximum pressure. Over an operational period of 3.5 years, the inner membrane was stressed to its limits repeatedly. This could be shown 1., mechanically, with the long holes where the bolts hold the membrane at the centre column, Figure 8, and 2., by the values recorded in the process control system, ongoing stress gradually widened the holes.

It is interesting that none of the holes started the rupture, but instead the rupture started outside of the ring, at a distance of about 20 cm, Figure 9. This could be observed when the membrane was investigated in detail.

The rupture happened because the membrane was folded around the big hole for the centre column and, therefore, had twice its strength. The tension became too much close for the area where the overlapping ended. There, the crack started.

Economic impact

While the inner membrane needed to be replaced and a few changes were to be done to fix the overpressure valve directly at the digester tank wall, the main expense was due to the emptying of the digester tank and the loss of its gas production.

The fine print

It is a challenge to calculate pressure losses at such low pressures and with such low flow rates. Dust and debris inside the pipes can only be

Figure 8: showing the widened membrane holes

Figure 9: showing the holes causing the rupture

roughly accounted for in the calculations. The numbers shown in this report are to be understood as numbers for orientation only and not as 100% accurate.

Lessons learned

There is a reason why standard safety regulations require overpressure valves to be fixed directly at the tank surface. This way, pressure losses can be minimised. It is an absolute no-go to extend such biogas exit pipes into the digester tank without strict control of the pressure situation. Even the smallest pressure losses in line end up with – potentially – a risk for the plant operation. Operators need to understand their gas system.

And? Why was the gas holder roof on the second digester tank in operation? Just a matter of time: the second digester tank was built nearly one year after the first one. ●

For more information:
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Note: not all details have been presented in full and some elements have been simplified.