Torsten Fischer of Krieg + Fischer Ingenieure discusses an accident investigation involving a destroyed gas holder roof on top of a digestate storage tank at a biogas plant in Germany

First-person sleuthing – destroyed gas holder roof

Torsten Fischer, founder and managing director at Krieg + Fischer Ingenieure, has been an expert legal witness for more than 10 years, covering 120 cases, and wrote his first report about a biogas plant accident more than 15 years ago. In this personal account, Torsten discusses an investigation into an accident at a biogas plant, exclusively for *Bioenergy Insight*.

Setting

The biogas plant with agricultural input substrates was built in 2008, including a digester tank, a secondary digester tank, a storage tank for digestate, and a CHP with 500 kWe. The storage tank was originally covered with a single membrane gas holder roof. Back in 2012, this was damaged and substituted by a high-quality double membrane gas holder roof, which was in operation for four years. In 2016, the whole gas holder roof came down, the centre column crooked, and the mixers blocked as seen in Figure 1.

My reaction

Massive damages; I had no idea how this could have happened.

Visit and initial site assessment

Retrospect 2012: the switch from the single membrane to the high-quality double membrane gas holder roof required a centre column.

Retrospect 2012-2016: according to the statements of the operator, the new gas holder roof never worked properly. As soon as the operator took biogas for the CHP out of the gas holder roof from the digestate tank, the CHP stopped working. This was due to low methane concentrations. Conclusion from the operator: there must be cracks in the inner membrane. According to the statements of the operator, the new roof never worked properly.

Figure 1: Looking into the digestate storage tank. The gas holder roof membranes already removed. Belts, net, crooked centre column. Background right hand side: secondary digester tank with double membrane gas holder roof

Figure 2: Fully visible centre column, crooked, with massively deformed stainless steel construction on top. Tank still filled with about 1 m of digestate. Net and some belts lying in the digestate

Initial thoughts

It is no surprise that the change from a single membrane gas holder roof to a double membrane gas holder roof on a digestate storage tank with a diameter of 34 metres (m) caused difficulties. As the storage tank here is the largest tank in diameter and significantly bigger than the digester and the secondary digester tanks, the whole biogas pressure situation is defined by the pressure underneath the new gas holder roof on top of the storage tank.

As a result, in every such case, the new pressure balance needs to be found and it is part of the process to have test-runs and to adjust all the pressure and the biogas flows to the gas engine anew. This was not done in 2012. The situation was not satisfactory and in 2013 and again in March 2016, the supplier showed up again to resolve the issues.

During spring and summer 2016, the operator tested the submerged mixers – there are three of them in the storage tank. It was interesting to learn how this was done. As there was no possibility to start/stop the mixers on site, each mixer was first moved into the highest position and was visually inspected. Then, the worker went to the central process control system and turned on the mixer. Walking back to the mixer site, investigating the situation with the mixer being above the substrate and in operation, returning to the process control room and turning off the mixer took a few minutes each time.

In mid-August 2016, accidentally, the flexible pipe that delivered air from the air support in between the two membranes of the gas holder roof on top of the digestate storage tank slipped out of place. As a result, the outer membrane laid down onto the inner membrane. In this situation, it could be observed by the operator that the centre column was no longer standing upright and was significantly reduced in height. After repairing the air support connection, it was no longer possible to inflate the outer membrane. We received an order to investigate the case.

On site, the situation was a mess. With the two membranes already being removed, the situation that we found showed the centre column with its unique design was crooked (see Figure 2); dozens of belts from the roof's under-structure were either cracked or hanging loose or lying in the digestate (see Figure 3); the net from the roof's under-structure was torn, partly hanging at the tank wall and partly hanging loose, (see Figures 1-3).

Our job was to determine: what was the reason for the breakdown and what was the result? Could it be that the centre column was the starting point and it broke and tore the roof's under-construction down, which cracked the belts? Or was it the opposite and the roof for whatever reason came down and broke the centre column?

Accident Investigation

Rain and storm winds were excluded almost immediately.

The correct approach of the supplier back in 2012 would have been to communicate with the operator to find out the basis for forces and moments during assembly and operation. From an operating point of view, the hazard assessment defines the operation modes and its risks: gas pressure, safety valves, and flow-rates, for example. In real life, none of this happened. The operator, as well as the supplier, ignored every kind of safety aspects.

Figure 3: Tank wall with belts still fixed at the wall. Most belts in this area cracked and hanging into the digestate. Left hand side: overpressure/vacuum valve with related outflow pipe (in orange) and mast for submerged mixer next to it

Result and reason

The key pieces of the puzzle were as follows:

1. Figure 3 shows the outflow pipe for the overpressure/vacuum device, with the lower part of the pipe entrance being well underneath the tank wall level. At least once in its lifetime the tank was overfilled and the pipe flooded. We could not verify that the functionality of the overpressure/vacuum valve was given afterwards.
2. There are 52 regular belts and 104 belt fixing points at the tank wall, equally distributed over the tank perimeter. Each one of these belts was fixed at one side of the tank wall, then passed via the centre column to the opposite site tank wall and fixed there.
3. On top of the centre column was mounted a 1.40 m high stainless steel construction, shaped like a mushroom. The 52 belts were led over the mushroom head but not tightly fixed, (see Figure 9).
4. While the centre column broke close to its foot and was bent to one side, the stainless steel construction was massively deformed and bent to the opposite site, (see Figure 1). Many belts were cut. One of the

Figure 4: Belts wound around submerged mixer. Top left hand side: belt package with cable tie. For more details details, see Figure 5

Figure 5: Belt package fixed with cable tie – located directly next to mixer mast. Belt fixed at wall. Snap hook for fixing net

Figure 6: Belt plate, half broken out of the tank wall

fixing plates of a belt was torn out of the tank wall. A significant number of such plates was deformed but still in place, (see Figure 6).

5. In all three submerged mixers we discovered belts wound up (see Figure 4).

We scrutinised the structural calculations. The concrete works on its own clearly followed the assumptions in the calculations. But something was different: in Figure 8, five belts can be seen fixed at the stainless steel construction, with the sixth being buried underneath the bent steel construction on the left hand side. What are these six belts? No such belts are included in the structural calculations, nor in any other documentation. Our best guess was that these six belts were used during assembly. After the centre column had been built, these six belt connections were the first ones assembled and they stabilised the whole construction during further assembly.

Such additional belts had been fixed fairly well and there was hardly any slack span. This may end up in extra horizontal forces that are effective into the stainless steel construction. Such forces are not included in the structural calculations and every kind of forces that are introduced by the regular 52 belts are also to be taken by the additional six belts. As these six belts are less than half as long as the regular belts, they can absorb lengthening to a significantly lesser extent.

The investigation finally led us to the submerged mixers. What if the belts being wound around the mixers were the starting point of all the construction's breakdown and the mixers in operation tore down the construction? Then again, how could it happen that any such belt could be 'caught' by the mixers?

We found another key detail: originally, the belts were too long for the diameter of the tank. Instead of cutting the excess length, during assembly, the workers rolled them up and fixed the rolls with cable ties, (see Figure 5). The overlength was about 3 m for each of the regular belts, and somewhat shorter for the six additional belts.

Cable ties are not supposed to be used in a biogas atmosphere or in such tanks, as they age and embrittle. As a result, after years, the cable ties break, the belt package unfolds, the belts hang around loose. Of course, it could also be that not all belts had been wound up properly, some may not have been wound up at all.

As a matter of fact, many cable ties broke as many belts hung around loosely, (see Figure 3). Due to the geometry in the tank, it must have been one of the additional six belts that was first caught by the mixer. The final result was that during the minute-long test of each of the mixers outside and above the substrate in the tank, back in spring and summer 2016, vibrations led to the failure of the cable ties and the loosening of the belt-ends. During the test-run, the mixer tore the fixing plate of the (first) additional belt out of the wall, rolled up the belt and tore the centre column towards the mixer. Next, the two additional belts opposite the mixer were torn apart. Slowly, the stainless steel structure with the mushroom head was deformed and began to bend down. Due to the (over-) stretching and relaxing of the belts and rasping over the concrete structure or scratching along sharp steel parts, the belts were – finally – cut. The ongoing stressing of the whole structure, regular belts and additional belts including plate connections at the tank wall, forces that take effect on the centre column, torn belts that fall down and are caught by the other mixers, and so on – led to the final picture of the accident.

The fine print

We could never identify perfectly how the breakdown process proceeded; however, once the mechanism was discovered, in principle, there was clear evidence that the mixers were the starting point and the loose ends of the belts and additional belts linked to the centre column.

Lessons learned

How could it happen that an experienced operator plus an experienced supplier ended up with such a mess? Bad craftsmanship came together with a poor documentation. Years of operating a non-operational gas holder roof combined with ignoring the most simple formal aspects (test-run, commissioning), came together here and resulted in high costs. ●

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

For more information:

This article was written by Torsten Fischer, founder and managing director at Krieg + Fischer Ingenieure. Visit: kriegfischer.de/en/biogas-plants/services/expert-opinions-and-studies. Fischer is happy to receive questions at fischer@kriegfischer.de

Figure 7: View on the top of the centre column. Massively deformed stainless steel construction. 'Mushroom' bent over to the left. Cracked belt visible on top left of the concrete head of the column

Figure 8: Fixing of the 'additional belts' that have been used for mounting the belt and membranes of the roof structure. Visible are five such belt connections to the stainless steel construction with the sixth one being buried underneath the bent steel structure

Figure 9: Mushroom head of the stainless steel structure. Bent over the centre column and deformed. On top of the steel structure are visible the sticks that have been used as guidance for the 52 belts laid over the mushroom head