Torsten Fischer of Krieg + Fischer Ingenieure discusses an accident investigation involving a broken mixer in a digester tank at a biogas plant in Germany

First-person sleuthing, broken mixer in digester tank

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 situation was a standard one; an insurance company sent a short message saying that there was an accident at a biogas plant. A broken mixer in a digester tank: "Please visit the site and write a report about reason and height [value] of damage."

My reaction

A large digester tank. Standard report. No big deal.

Visit and initial site assessment

happened to be two site visits. The first one was for the inventory. Figures 1a and b show the situation when the mixer appeared during emptying of the digester tank. The second site visit was done when the broken mixer parts had already been removed from the tank, cleaned and placed nearby (Figure 2).

Figure 3 shows the general arrangements of tanks and mixers. There are two identical digester tanks with an additional secondary digester tank operated behind them. The input for the biogas plant is corn silage and sugar beets. In each digester tank there are four mixers: three submerged ones and a long-shaft, side-mounted mixer. The shaft of this side-mounted mixer was broken in digester tank 2. My first impression during the site visit was that the input substrate was fairly homogenous – which is good – as it has a tendency to rise to the top of the tank and sit as a floating layer. The only force that fights directly against this input substrate rising up is the vertical part of the force introduced by the side-mounted mixer. All other mixers only create a horizontal force direction with a lot of turbulence. This means that the side-mounted mixer will have to take a comparatively high load in order to keep all the substrate inside the digester tank down. The plant had been in operation for nearly five years when the accident happened.

Figure 1a

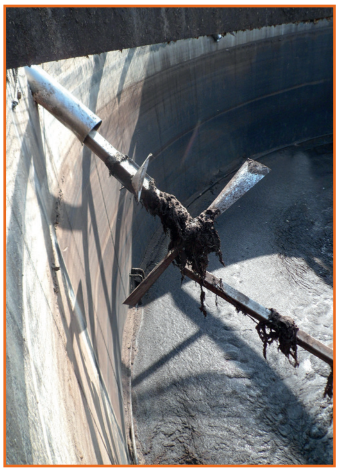

Figure 1b

Key questions

My role was to determine the following: What was the reason for the break? How expensive will the repair be? How much would it cost to interrupt operations?

Dealing with broken mixers always begs the question: Was the mixer operating using the substrate it was designed for? In this case, it emerged that there was no fixed input substrate as the basis for the mixer layout. Secondly, there was no commissioning or test run directly after the mixer assembly five years prior. This left me with virtually nothing that I could use as a basis. The failure to fix the input substrate was a massive engineering deficiency. Obviously, the engineering, procurement and construction (EPC) contractor did not appear concerned and used his standard mixer equipment, ignoring most major legal and technical aspects. The client, obviously, was not concerned whether any of the equipment was installed properly – there was no apparent supervision of the construction work. The biogas plant operator's documentation was a disaster. I did, however, discover that the total solids in the months before the accident were between 6.5% and 8.5% and, therefore, typical for an energy crop-based digestion.

Initial thoughts

When it comes to broken mixers, the key question is always: How quickly did the break develop? There are breaks forced by a unique

Figure 1a

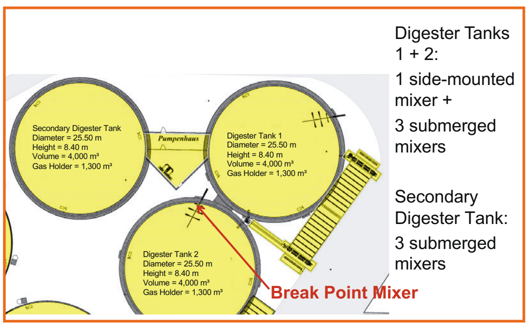

Figure 1b

Figure 4 - Photo 1

Figure 4 - Photo 2

situation in which the whole break happens from start to finish within fractions of a second. Then, there are breaks known as 'fatigue cracks' that are very common in steel structures, which start and proceed gradually, over days, weeks or even months until the final rupture. Those typical steel breaks are distinguished by 'crack growth lines'. So, what does the surface of this mixer's steel structure at the break look like?

Investigation

The shaft on its own is a square-type tube with one welded seam. The shaft break was just below the second propeller roughly in the middle of the shaft. This is the place where there is the biggest bending moment, when you take the shaft as a beam placed on two supports (wall and bearing at tank bottom). The propellers induce a point load into the shaft at the very position they are mounted. The shaft is also loaded with a torsion moment. All three loads interact and must be added for the structural calculation of the shaft.

Figure 4 shows the break surface of the mixer shaft. In this case, the steel is a standard stainless steel SS304 (1.4301). Interestingly, there were hardly any 'proper' crack growth lines. The reason could be that the austenitic material on its own simply does not show the crack performance. Or, the reason for the crack is simply different. On site, it was decided to take the relevant mixer parts and send them to a lab for further investigation.

The lab investigation resulted in several surprises. Although a crack was visible in only one of the corners, in three of the four corners there used to be similar cracks. It was discovered that crack development happened from the inside to the outside of the corners of the pipe (Figure 5). The pipe was manufactured from a steel plate. The plate was bent and one of the corners was bent with almost no radius. The break happened to take place nearly vertical to the axis of the shaft. All three cracks ran along the direction of the axis of the shaft. The reason for the smooth break surface shows a low general force impact (low nominal strength).

Result and reason

Cracks in three corners of the shaft started at the inside and initially developed along the direction of the shaft. At the location of the biggest bending moment, where the force from a propeller had to be taken by the shaft, the crack also proceeded vertically until the shaft broke. The topography of the crack surface indicated fatigue corrosion. Therefore, obviously, we have an example of a fatigue crack, based on low fatigue strength for a poorly-mounted mixer.

What could be the reason for cracks starting from inside of a square pipe? The answer is that the main force that caused the cracks originated from a deformation process: the shaft profile was continuously widened and squeezed in a 24/7 operation. In other words, during the rotation, every corner of the shaft was repeatedly slightly opened and closed. This may happen if the shaft is either not absolutely straight from the beginning or was (strongly) bent during the year-long operation. Ultimately, it started with small cracks in the corners that grew over a long period.

Economic impact

The biogas plant was equipped with a biogas upgrading unit. Although this was not covered by guaranteed payments under the Renewable Energy Law, there have been contracts for the delivery of certain amounts of biomethane/compressed natural gas. While the cost for the mixer replacement turned out to be roughly €40,000, the resulting costs of pausing operations were five times higher. All costs were covered by the insurance. It took eight weeks between emptying the digester tank and returning to full power.

The fine print

No measurement of current consumption. It is not clear at what exact moment the mixer broke. Best practice for instrumentation standards would have included this. There was no intermediary control of the mixer at any stage – although it was required as a standard operator duty.

Lessons learned

There was no basis for the mixer design as there was no defined input substrate. The mixer composition in every digester tank was inadequate. The operator/financer/owner of the biogas plant intentionally ordered an EPC contractor to build his biogas plant. There did not appear to be any interest from the client to supervise the construction site. The EPC contractor did not test-run the mixers. The documentation was incomplete: there was no commissioning of the mixer from the mixer supplier. Although all the costs were covered by the insurance, it was clear that the reason for the problem stemmed from the beginning of the project.

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: www.kriegfischer.de.

Figure 5, MPA Bremen, Germany

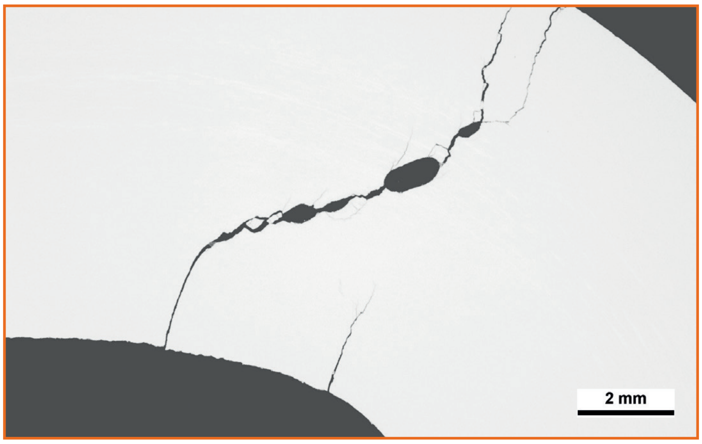

Figure 6, MPA Bremen, Germany