

# ENVIRONMENTAL ENGINEERING WORLD

**NO LEAKS  
NO SPILLS**

**KEEP TANK CONTENTS  
WHERE  
THEY BELONG**

(p. 8)



**Annual  
Editorial  
Index**

**Calculate the ground-level  
concentrations of stack emissions**

**Stalking an elusive pollutant:  
Here's help for mercury-laden sites**

**Soil washing leaches lead from soil**

**CAD and GIS: Powerful tools for facility  
management and site remediation**

**A hermetically sealed pump outperforms  
mag-drive and canned-motor options**

**A salute to those who excelled in  
EPA's voluntary 33/50 program**

**Vatavuk Air Pollution Control Indexes  
(VAPCCI)**

# SIX REASONS FOR USING ACOUSTIC EMISSION TESTING ON FRP VESSELS

Lester Robinson, P.E., Non-Destructive Evaluation International

**W**hen it comes to fiberglass reinforced plastic (FRP) tank or pipe inspection, even a trained eye has a few blind spots. While dye penetrant, a barcol hardness tester and a flashlight will usually enable an experienced visual inspector to locate large surface defects in process vessels, small or subsurface defects – potentially just as dangerous, and perhaps even more so – very often go unnoticed.

And the decision as to whether any defect requires attention is a judgment call that can vary significantly from inspector to inspector. Add to this the need for emptying the vessel first in order to let the inspector in, and it becomes clear why supplemental methods of inspection are gaining popularity.

One of the most effective of these is acoustic emission (AE) testing. In a single test, AE determines the severity and approximate locations of all of a vessel's growing defects, i.e., those likely to cause problems down the road.

Despite its name, AE has nothing to do with sound. Instead, the test finds defects by monitoring elastic strain waves induced in the vessel by placing it under load (box, pp. 10–11). Applicable to nearly any FRP (as well as non-FRP) structure, the test can often be performed on vessels that are partially full. The technique is ideal not only for aging tanks and piping, but also for verifying the integrity of repairs, and for checking on new vessels, to make sure they haven't been damaged during shipping.

In all, there are six reasons to consider the use of AE testing:

**1. The whole vessel is tested at once.** Unlike visual inspection and other "spot check" methods, such as ultrasonic testing, AE detects all of a vessel's defects at once – whether they are on the inner or

**A single test detects all of a vessel's growing defects – and reveals their severities**

outer surface, inside the shell itself, or hidden in nozzle or entryway welds, baffle attachments or seam joints. The benefits of this are clear: As a holistic test, AE eliminates the level of thoroughness and attention of the inspector as a variable in the accuracy of the results.

**2. Only 'malignant' defects are found.** Visual inspection and ultrasonic testing lack the ability to "see" a defect's activity at the microscopic level. As a result, plants that rely on these methods alone – and use them sporadically – often waste time and money fixing defects that look bad, but which pose no threat to vessel integrity.

AE, on the other hand, detects only those defects that are changing – i.e., growing. And, not only can a defect's activity be monitored, its rate of change in activity can be tracked. As a result, the implications of a defect can be determined and predicted long before reaching a threshold of concern.

In an AE test, unchanging (structurally stable) defects, on the other hand, remain "silent." In this way, AE testing improves the efficiency and costs of an only-when-necessary maintenance program, by preventing labor and time from being wasted on fixing defects that are only cosmetically significant.

**3. Only one test is necessary.** To filter out benign defects, visual and ultrasonic inspectors typically repeat the inspection later, and compare the two results. Unfortunately, this means waiting long enough

for any change in active defects to be noticeable – generally 6-12 months. Depending on operating conditions and the severity of the defect, such a long wait could be very risky. However, AE eliminates this risk, as it detects both the defects and their activity-growth levels in a single test.

**4. The results are quantitative – not subjective.** Visual inspectors have no gage but their own experience by which to rank the severity of a defect – and "20 years' experience" could mean 20 years of doing it wrong. By contrast, AE inspection provides an objective, numerical result: the rate of change of each defect. This lets the inspector deduce how soon the defect will require attention, allowing the plant to schedule downtime and allocate repair personnel and resources accordingly.

In addition, a series of regular AE data over time shows plant managers the pattern of vessel defects and repairs – information that could improve the accuracy of quarterly and yearly projections for maintenance outlays.

**5. The tank may not have to be emptied.** Other incidental costs of visual inspection stem not only from the need to empty the vessel, but also from properly disposing of the product inside. AE testing often avoids both of these costs. Though the product level or pressure is generally lowered prior to AE inspection to "relax" the tank, production does not have to be interrupted. In addition, procedures for confined-space entry and waste or hazardous-waste disposal are necessary only if AE reveals a growing defect on the inside\*.

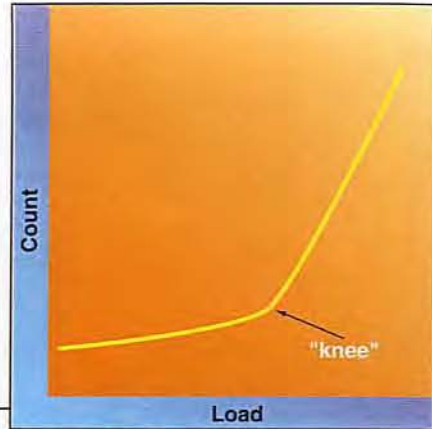
\* In all fairness, a company beginning to implement a preventive-maintenance program that incorporates AE technology may have as high as a 50% follow-up rate requiring confined-space entry at the front end. This is usually because there had been no previous inspection program, or the previous inspection program did not provide a thorough-enough assessment of the condition of the tank or vessel. Nevertheless, the promise of reduced need for confined-space entry is not usually realized until after the first round of inspections.



**FIGURE 1** (above). AE testing doesn't require much set-up beyond attaching piezoelectric sensors to the shell of the tank



**FIGURE 2** (right). The instrumentation in the foreground records stresses induced by flaws in the vessel



**FIGURE 3** (above). The "knee" in the curve of acoustic emissions received ("hits") versus load indicates where failures begin to occur

than alternative methods can, remember the following:

1. Perhaps most importantly, the AE test cannot ascertain the structural significance of an active defect. That is, one is just as likely to get the same signal intensity from a crack in the shell as from a delamination in a baffle weld. Although both have the same intensity, and are significant structurally, the near-term implications of each are dramatically different.

Therefore, follow-up inspection, using visual observation and dye penetrant, for example, is very important if a defect is to be fully evaluated. The company that performs the AE test should also have the capability of performing the internal visual inspection. This implies that the inspection firm should have inspectors familiar with FRP and FRP structures.

2. AE cannot determine how large a defect is. A delamination 1/4 in. in dia. can produce the same acoustic-emission activity as a delamination 2 in. in dia. What the AE test can tell is how active a defect is. At what rate it is releasing energy. This rate is proportional to how rapidly the defect is growing.

3. Even using a triangulation method, AE cannot pinpoint to the exact centimeter where a defect is located on an FRP tank. This has much to do with the anisotropic nature of FRP: Wave travel through composites is complex because of the number of interfacial boundaries between the matrix and the fibers. This results in numerous mode and wave-speed conversions in the signals being sensed. Thus, as with ultrasonic measurements in FRP, the wave speed variability limits the practical usefulness of location algorithms. Further, a vessel or tank full of product

**6. The standards say so.** AE testing of process vessels is recommended by several industrial standards, including ASTM E1067-85, ASME Section V Article 11, ASME Section X, and CARP—the Committee on Acoustic Emission from Reinforced Plastics [1-5]. While these standards carry no legal weight themselves, their support can be helpful to plants hoping to comply with the Chemical Process Safety Standard or the "Good Engineering Practice" requirement of OSHA [6]. The latter even mentions ASTM and ASME specifically—suggesting that the "blessing" of either organization may make it much easier to demonstrate compliance.

### Some cautions are in order

As with most techniques, AE testing has gone through some ups and downs since its emergence from the laboratory in the mid 1970s. When the technology was first introduced to industry, manufactur-

ers and potential users of AE testing equipment had visions of it being able to identify specific failure mechanisms in the field, provide accurate locations of defects on the structure under test, and make determinations as to when a defect would finally result in structural failure.

The cold hard reality, however, is that while it is easy to identify failure mechanisms in the laboratory, it is quite difficult to isolate them in the field. Defect-location algorithms have not lived up to their promise on structures made of homogenous materials, such as steel, much less composites that are discontinuous (anisotropic) in nature. Finally, while the "knee in the curve" concept (Figure 3) is applicable for determining the failure load of a composite coupon in the laboratory to within 10%, its practicality in the field for determining ultimate structural failure load or time is limited.

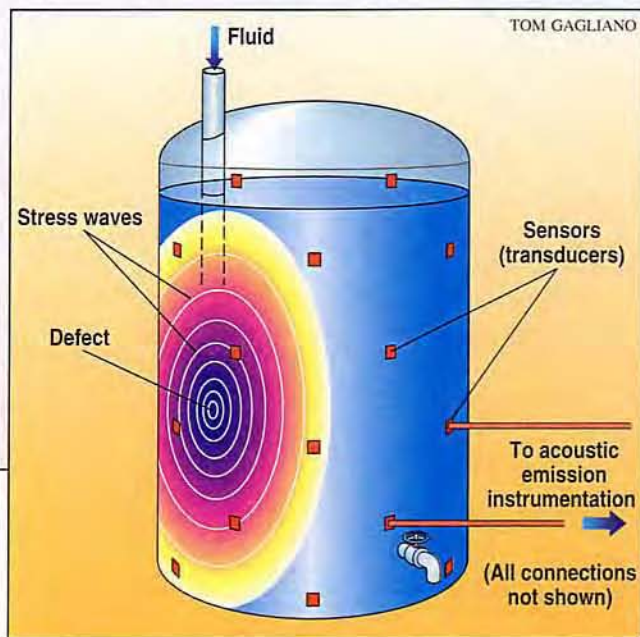
So, while AE testing provides more-thorough assessments of FRP equipment

## HOW ACOUSTIC EMISSION TESTING WORKS

The term "acoustic emission" is actually somewhat of a misnomer. Acoustic emission, as regards the testing, is not actually sound, but the transient elastic stress waves produced when a material, such as fiberglass, is placed under stress. In AE testing, this stress loading is done by filling the tank or vessel being tested with either process fluid or water. If a defect exists within the vessel structural material, it will generate stress waves that are detected by piezoelectric sensors mounted on the structure (Figure 4).

The sensors convert the mechanical stress wave into an electrical impulse that is then transmitted to instrumentation measuring the characteristics of the

**FIGURE 4.**  
Piezoelectric sensors detect stress waves induced by defects in the vessel



wave (Figure 5) including: amplitude, duration, counts (i.e., oscillations above a threshold amplitude – a "hit" – that strike a given sensor), signal strength, and rise time (the time it takes a "hit" to reach its maximum amplitude).

It was discovered early on that when a defect-free material is stressed a second time to a given load equal to the first loading, little significant acoustic emission will be produced. This is called the Kaiser Effect. If a material contains a defect, however, significant emissions will be produced during the second loading prior to reaching the magnitude of the first loading

The ratio of the onset of significant emission during the second loading divided by the magnitude of the first loading is called the Felicity

tends to support product-borne waves, which also contribute to wave-conversion problems.

(A workaround here is that the technique of zone location works well on FRP tanks and vessels. If a structure is covered with 24-36 sensors, the most active sensors indicate the areas of concern. In most cases, it is possible to narrow a defect location down to a 1- to 2-ft radius. If further resolution is desired, the sensors can be rearranged into a tighter configuration and the test rerun. This latter method has been found to work very well.)

4. In the field, exact defect-mechanism characterization is not practical. What may have been an 80-dB "hit" at the source (which could indicate a fiber break) may be a 60-dB hit at the sensor, due to attenuation.

The bottom line is that AE testing technology provides valuable information about the structural condition of a tank or vessel that was not available previously. While it is indispensable for customers wanting to establish a cost-effective maintenance program for FRP equipment, it is not an absolute cure-all.

### So what does this all cost?

The cost of an AE test is not inexpensive. (Actually, some numbers seen lately for other assessment techniques on FRP equipment have been significantly higher.) And, while the AE test method

can reduce the need for confined-space entry and waste and hazardous-waste disposal (thereby reducing production downtime), it should again be noted that on the first pass through the FRP equipment inventory, a follow-up rate as high as 50% could be required.

Further, for the customer accustomed to having an inspector come in during a shutdown and visually inspect six to eight tanks in 10-12 hours, there is going to be some adjustment necessary in scheduling. The AE test generally takes longer to perform than other types of tests, depending upon the rate at which the customer is able to fill the tank or vessel with water or product. In some cases, the customer is able to mesh the testing schedule with production so that the tank need not come off-line. This is not always the case, however.

Nevertheless, the infrequency with which AE testing needs to be performed on an FRP tank or vessel must be considered against the benefits derived. This must be calculated on an individual basis for each piece of equipment and each customer. Factors that should be considered include: equipment age, equipment construction, previous service, present service, previous inspections, previous

maintenance, applicable safety and environmental regulations, and the risks and costs that are associated with an unexpected release.

As discussed earlier, AE testing offers significant advantages over spot-check methods. While spot-checks and statistical techniques can be informative, the cost of a missed defect can far outweigh the cost of a maintenance program that includes AE testing.

### Two questions: Where? When?

Aside from testing in-process vessels and tanks, it is good practice to perform an AE test on a new tank or vessel, in order to identify, and isolate, any minor problems that may have occurred during production. FRP fabricators are generally conscientious, and rarely does one find a problem of significance. If a minor problem were detected, it would usually not impact the near-term service of the structure. Instead it may have an implication 5-7 years into the expected service life. Nonetheless, it is usually best to clear up those details early.

More importantly, AE testing can detect problems that may have occurred during vessel transport and installation. Whereas fabricators are usually very careful, some transportation companies and general contractors are not. And during installation, an improperly set tank can create stresses in the bottom

Ratio. This ratio is considered to be an indication of previously induced damage within a structure.

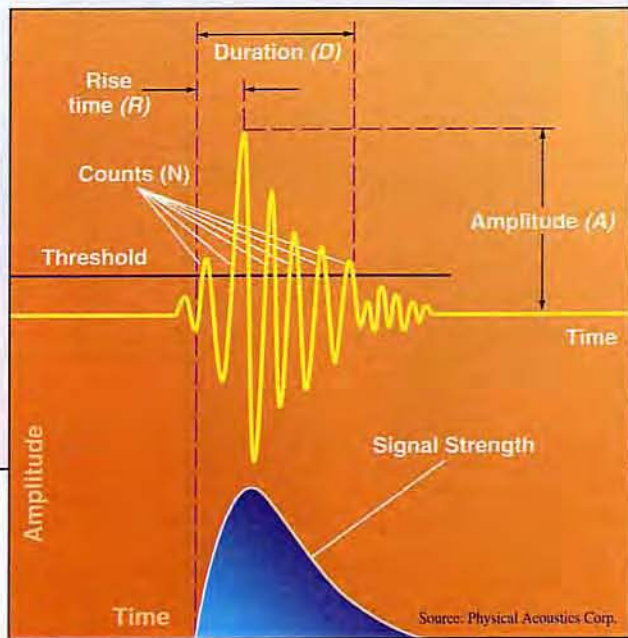
Other relationships that have found application include:

- Emissions during load hold – A measure of continuing damage
- Total count – A measure of the severity of previous damage
- High-amplitude hits – A measure of the number of high-energy microstructural failures, e.g., fiber breaks

These measures, and how to use them, were then incorporated into evaluation criteria, and formalized in a document of the Committee on Acoustic Emission from Reinforced Plastic (CARP) of the Soc. of the Plastics Industry (Washington, D.C.) [7].

An additional technique, Intensity Analysis, uses the measure of energy released from a growing defect or imperfection to determine "How bad is bad?" Intensity Analysis gives defects rankings of N, A, B, C and D, ranging from "N – Emission source is structurally insignificant" through "D – Major structural defect. Immediate shutdown and nondestructive examination." This method gives the inspector the ability to confirm defect indications and to weed out false positives.

The Intensity Analysis method will be incorporated into the next revision of the CARP document. Some companies, including NDEI, are already relying heavily on this technique. □



**FIGURE 5.** Analysis of the stress waves identifies the extent of structural damage

and sidewalls that can significantly shorten vessel life. AE testing can detect any damage just starting to occur, so that corrections can be made before the tank is commissioned and placed in full service.

It is imperative to note that some new tanks may produce more general overall AE activity than others. The customer must understand that this in no way implies that one tank is better than another, nor does it imply that one will last longer than another. This is an apparent misconception shared by some customers and fabricators alike. The AE test is to be used to isolate minor imperfections that may have occurred during production, transport and installation — not make categorical comparisons between vessels.

AE testing should also be considered for repaired equipment. There are ex-

treme variations in repair methods and repair quality. These can, and often do, include: types of resins used; how the resin is mixed; how much and what type of glass is used, and how many layers; how the glass is wet out; how the glass and resin are compacted, thereby affecting strength; surface preparations prior to applying the glass or resin, to eliminate chemical contamination; and in what manner the glass and resin are tapered to eliminate stresses in the final product.

Given this variability, it makes sense to use an inspection method that can verify the integrity of the repair. Further, the method should be capable of detecting:

bad bonding, delaminations, dry areas, rich areas, insufficient thickness, and insufficient taper. The AE test can do this.

By implementing an inspection program for repaired tanks and vessels that makes use of AE testing, the customer is providing engineering, maintenance, safety, and outside regulatory personnel with documentation and confirmation that deficiencies have been properly corrected and that the vessel may again be returned to service with confidence in its integrity.

AE testing technology is not a panacea nor is it a standalone inspection method. When coordinated, and used in conjunction, with other inspection methods, it can dramatically improve the quality and cost-effectiveness of maintenance and inspection programs on new, in-service and repaired FRP tanks and vessels. ■

*Edited by Philip M. Kohn*

## References

1. "Recommended Practice for Acoustic Emission Testing of Fiberglass Reinforced Plastic Resin (RP) Tanks/Vessels," The Composites Institute of the Soc. of the Plastics Industry, Inc., New York, N.Y., 1987.
2. "Acoustic Emission Examination of Fiber Reinforced Plastic Vessels," Section V, Article 11, Boiler and Pressure Vessel Code, American Soc. of Mechanical Engineers, New York, N.Y.
3. "Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels," E1067-85, American Soc. for Testing and Materials, Philadelphia, Pa.
4. "Standard Practice for Acoustic Emission Examination of Thermosetting Resin Pipe (RTRP),

E1118, American Soc. for Testing and Materials, Philadelphia, Pa.

5. "Recommended Practice No. SNT-TC-1A — Personnel Qualification and Certification in Nondestructive Testing," 1984 ed., American Soc. for Nondestructive Testing, Columbus, Ohio.
6. "29CFR 1910.119," Occupational Safety and Health Standards, July 1, 1992 edition.
7. Fowler, T., Blessing, J., and Strauser, F., "Intensity Analysis," Monsanto Co., St. Louis, Mo.
8. English, L., Listen and learn: AE testing of composites, *Materials Engineering*, May 1987.
9. Acoustic Emission Level II Course, Physical Acoustics Corp., Princeton, N.J.

## Author



**Lester Robinson** is president of Non-Destructive Evaluation International (P.O. Box 1537, Davidson, NC 28036; tel.: 800-892-4873; fax: 704-892-4473). He has 11 years experience in the application of AE testing to FRP structures. He graduated from North Carolina State University with a bachelor's degree in engineering, and is a registered professional engineer in that state. He holds an M.B.A. from the University of North Carolina (Charlotte). He has a wife, daughter and son, with another on the way. His interests include sailing, running and teaching fourth-grade Sunday school.