Troubleshooting Wastewater Treatment Plants

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Use statistical analysis to find a cure for a "sick" wastewater treatment plant.

Wastewater treatment plants (Figure 1) can function improperly for a variety of reasons: Plants sometimes receive materials they are not designed to handle; and some facilities are poorly specified, designed, constructed, operated, and/or maintained. If your plant is "almost working" or "often working," then your plant is not working, and much effort may be necessary to move from "almost" or "often" to "actually."

I have found that operators of poorly functioning plants are pressured to accept any effluent sent to them to maintain the capacity of the primary production process. As manufacturing facilities increase production volumes and product diversity, plant owners often fail to upgrade the effluent treatment plant to handle the changes. Even at plants that have not increased production, wastewater treatment plants are often required to handle troublesome liquids that they were not designed to process. Owners prioritize getting the main process back online as quickly as possible, rather than accepting the delay and expense of proper disposal.

I have seen the entire contents of hypochlorite scrubbers at a coking works dumped directly into a biological effluent treatment plant by night shift crews, which killed all of the biological life. I also know of a facility that dumped tons of out-of-spec concentrated detergent directly into the drains of the oil-water separators, totally and irreversibly destroying the effectiveness of downstream granular activated-carbon filters. Both of these examples cost tens of thousands of dollars and took several weeks to fix, only to save operations a few minutes and a few hundred dollars.

Sick process syndrome

Throughout my career conducting several hundred waste minimization analyses at manufacturing facilities, I saw many processes that, at best, could be described as "barely in control." I dubbed these sick processes, and they can be recognized by the following characteristics:

- high and variable rates of process failure
- staff constantly searching for technical fixes
- control taken away from operators
- many theories about the cause of the problem
- denial of problems
- a history of failed attempts to improve control
- staff considering the process an art more than a science.

The way to cure the sick process is to get past denial and folk wisdom, and instead use statistical analysis to accurately characterize the problem and verify that the attempted cure worked.

Data analysis

When you begin a statistical analysis of a wastewater treatment plant, typically very little concrete information is available. In some cases, though, there is so much data that personnel feel paralyzed by the information overload.

Too little data. It is preferable to start with at least 20 analysis results of various quality parameters. However, usually fewer than ten are available and plants are reluctant to pay for additional testing.

A standard set of analyses of incoming and outgoing effluent includes chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), ammonium (NH_4), pH, and temperature, as well as data on flowrates. If these data are not available, or if very little data is available, use a site test kit (Figure 2) to obtain a quick snapshot estimate of BOD, TSS, pH, and temperature.

First, perform some basic statistical analyses of the available data, including minimum, maximum, and, when appropriate, the average and the upper and lower limits of the 95% confidence interval. It is ideal to have enough data to do this for TSS; BOD; pH; coliforms; NH_4; chlorine; fats, oils, and grease (FOG); heavy metals; detergents; and temperature.

If you are able to obtain only a small number of analyses, you will typically have a wide range of values; if you do not, be suspicious. Results (or the lack of) may also reveal that analyses that should have been conducted were not, that instruments have not been read, or that readings have not been recorded. Missing data may be shown as a blank, a (misleading) zero, or a suspiciously frequent number. Suspicious data could indicate a lab analysis error, an instrumentation fault, or a limit of detection of an instrument or test. Try to determine the source of any missing or faulty data.

It is also important to check correlation coefficients between parameters that may be related, such as FOG and TSS, as well as pollutants that partition into oil, solids, or both (*e.g.,* polychlorinated biphenyls [PCBs]). Calculate the standard error by taking the inverse of the square root of the sample size and compare that to the correlation coefficient. You will usually find a possible correlation (test statistic:standard error = 2), rather than a probable correlation (test statistic:standard error = 3). In scientific research, these rough results would be of little use, but hints and weakly negative evidence can be useful for troubleshooting.

Too much data. In some cases, you may encounter an abundance of data (tens of thousands of data points) that have not been subjected to any simplifying analysis. Many plants restrict data analysis to simply plotting a parameter vs. time. This approach has little practical use. Instead, large data sets need to be summarized with appropriate statistics to enable you to draw conclusions with any certainty.

Use appropriate statistics

Even the most experienced engineer can misapply statistics. You cannot, for example, produce a valid average of integers by summing them and dividing by the count of numbers. For instance, the average number of children per household in the U.K. was at one point 2.4. However, children only come in integer quantities, and 40% of a child is no child at all.

Most of us are familiar with parametric statistics, which

▲ **Figure 1.** Wastewater treatment is typically not given the same priority and attention as the primary process plant. Neglected plants may suffer from numerous issues.

▲ **Figure 2.** A typical portable site analysis kit such as this one contains acidifying sewage effluent (SE) tablets, permanganate value tablets, universal pH tablets, sample containers, plastic test tubes, a turbidity tube, a test-tube brush, and a thermometer.

can only be applied if data points are continuous, independent, and distributed in accordance with a mathematical model, typically the normal distribution. Parametric statistics produce more certain results than nonparametric statistics, which involve fewer assumptions. However, if the assumptions are not true, then they will provide a misleadingly certain answer.

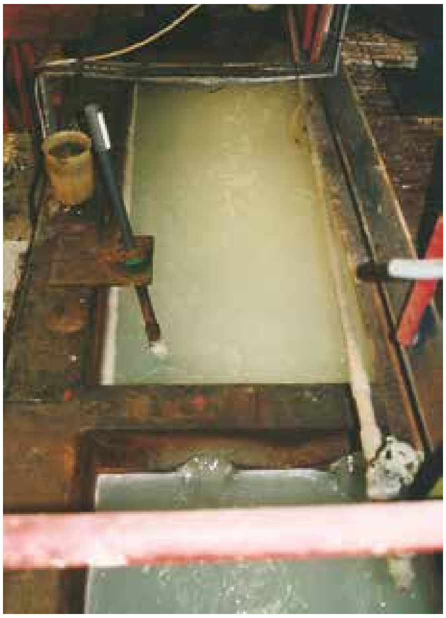
It is possible to apply nonparametric statistics to ranked lists of data. For example, structural equipment failures across sites can be ranked by degree of failure. The ranking can be compared to time since installation, water aggressiveness, pH, or hardness to determine if there is a correlation and to what degree.

Site visits

It is critical to visit the site you are troubleshooting, because some things cannot be determined remotely and should be personally and directly verified. Once on-site, ask to see the operating and maintenance (OM) manual and interview as many operators, managers, and technical support staff involved in the process as possible.

Interviewing operators. Interview operators individually and informally whenever possible. Use open-ended questions to encourage them to talk freely about day-to-day operations, incidents, accidents, and emergencies. Exercise discretion when reporting your findings to management so as to not impugn any one individual.

The operating and maintenance manual. Plants may not be being operated in accordance with the designers' intentions if, for example, no one knows where to find the OM manual, it is found dusty and neglected, or it has been hand-amended.



▲ **Figure 3.** Large pH dosing tanks may be the source of inefficient pH control.

Maintenance logs. Although OM manuals are frequently neglected (or even lost), all but the very worst sites have a maintenance log. It is typically kept in a logbook, and most commonly, kept by hand using forms in a loose-leaf binder. If you find the handwriting is illegible, ask for a transcript.

Once deciphered, these logs are often very informative. They provide a candid account of operator activities, which can be compared to the activities listed in the OM manual.

Operator training. If the OM manual cannot be located, find out how many of the operating and management team were trained in plant operation by the company that constructed the plant. Also find out how many of them worked alongside the commissioning crew. During commissioning, operators may learn tricks or shortcuts suitable for commissioning that are inappropriate for everyday operation, or they gain access codes for instrumentation, programmable logic controllers (PLCs), etc., that they should not have. Tricks, shortcuts, and unauthorized access have caused several fatal accidents in process plants. In effluent treatment plants, such interventions may be at the root of mysterious problems.

Overcoming folk wisdom

During interviews, staff may express their opinions about the source of operational problems and other issues and may provide only the data that support their own theory. Ask detailed questions to overcome biased explanations of signs and symptoms so that you can make your own judgment.

The difference between a sign and a symptom is important. A sign can be observed directly, whereas a symptom is something operators or management feel might be happening. For example, a sign might be a high level of suspended solids in the effluent, while a symptom would be "we think the plant runs better when we use the magnetic water conditioner we bought." Rely more on signs and treat symptoms with caution.

Operator diagnoses and reports of symptoms have some evidenciary value. However, to find the underlying cause of the problem, start by assuming nothing. Others have typically already attempted fixes before you, and you do not want to be guided down the wrong path.

Use your senses

When walking around the site, do not simply look and listen to the plant and its operation — smell, too. Each scent tells its own story, usually of failures in biological treatment plant design and operation. A repulsive smell of fatty acids may indicate inefficient FOG handling and treatment. Sulfides and thiols smell of eggs, mercaptans of cabbage, amines of fish, and ammonia of urine.

The presence of sulfides, mercaptans, and/or thiols is associated with strong wastes held under anaerobic conditions and subsequently agitated, usually because of poor design. Amines form when proteins are partially broken down faster than a downstream process can accommodate them. Amines may also be present in some industrial wastewater and boilers. The smell of ammonia can come directly from a production process or it may indicate insufficient aeration in a biological stage. Insufficient aeration capacity for treating ammonia in sewage is a common mistake.

Classic mistakes

Look out for design elements that you know from experience are hard to control or actively create operational or maintenance problems. For example, large mixing tanks with hours of retention time are sometimes used to control pH in industrial effluent treatment plants (Figure 3). Although the pH may meet the overall plant specification, this approach often fails to provide sufficiently accurate control for other parts of the process. While the overall process may only require effluent with pH of 5–9, far tighter pH control (±0.1 pH value) may be crucial for downstream processes, such as flocculation, coagulation, precipitation, disinfection, and aerobic and anaerobic biological treatment.

Other common mistakes include using:

- poor layout
- flow- and load-balancing tanks
- high-shear centrifugal pumps on shear-sensitive materials, such as polymer flocs
- comminutors instead of screens to handle gross solids
- plastic piping on high-temperature effluent streams
- piping, fittings, equipment, or instrumentation incapable of handling entrained solids, gases, fats, oils, and greases present in effluent.

Be on the lookout for inelegant, expedient, and haphazard solutions to problems. Any fix that involves hitting a malfunctioning device, such as using a hammer to make solids flow more easily through a hopper, should be suspect.

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Verify the design

Request design data, drawings, and calculations, as well as plant specifications, to uncover the original intentions of the plant designers. Your best chance of finding these documents is within the OM manuals. Apply the same heuristic design methods used in early stages of plant design to estimate the capacity of each unit operation in the plant. This can reveal possible design bottlenecks and design errors. Design information can be difficult to obtain, but in the rare case it is available, compare it with current site operation.

Evaluate the change

Some plant owners are willing to pay for detailed investigations that can be used to produce statistically valid conclusions after an initial rough analysis reveals a potential problem.

You may only get a chance to characterize the waste treatment plant's function while testing to see if your proposed fix worked. Analyze enough samples before and after making a change to determine whether the change improved, worsened, or made no difference to the process. Use experimental design theory to find out how many samples are necessary to ensure statistical conclusions with a useful degree of certainty. (See the Jan. 2010 *CEP* article "Simplify Experimental Design," pp. 35–40, for more information on applying experimental design.)

Design the trial methodology by working backward from the requirements of the statistics used to analyze the results. Change only one variable at a time, and ensure you have enough of the correct types of samples to evaluate the change. Often the reason for multiple attempts to fix a problem is failure to carry out a rigorous trial before and after making changes.

Putting it all together

Once you have gathered all of the necessary information, start to generate some candidate theories regarding the source of plant operation disruptions. The problem may relate to design, construction, operation and maintenance, or a combination of factors. Delineate the problems you believe the plant has. Then devise ways to fix the issues, as well as ways to verify the fixes worked without generating new problems. CEP