Proper Maintenance Practices Involving Condenser Cleaning and In-leakage Inspection

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Abstract

The proper performance of the condenser is critical to minimizing the operating costs of a turbogenerator unit, in terms of both heat rate and generation capacity. After reviewing the major causes for deteriorating condenser performance, a distinction is drawn between those causes that are cyclical or predictable and those that occur at random time intervals. In the first category, the fouling of condenser tubes and/or tubesheet can be corrected by cleaning, the intervals between which can be optimized. A number of cleaning techniques are reviewed. The second category is concerned with water or air in-leakage, the return of the condenser to normal operation depending on how quickly the source of the leak can be located and then corrected. Tracer gas techniques for leak detection have become the preferred method.

1.0 CONDENSER ECONOMICS

1.1 Performance of a clean condenser

Condenser design specifications define a maximum effective rate of removal of the latent heat in the exhaust vapor entering the condenser, as well as its transfer into the circulating water, given the condenser backpressure, cooling water flow rate and inlet temperature. Variations in the latter two parameters will change the backpressure and also affect the heat rate for a given load. In order to minimize condensate subcooling, caused by variations in inlet water temperature, some control over backpressure (and heat rate) may be achieved by varying the cooling water flow rate: but the reduced tube velocities can cause silt to become deposited on the tube surfaces and, thus, negatively affect heat rate. To avoid this, it may be possible to allow some of the circulating water returned from the condenser to bypass the cooling towers, so adjusting the inlet temperature to maintain the back pressure, but without reducing the total water flow rate or tube water velocity. These are the natural responses between these variables for a *clean* condenser.

Unfortunately, condensers seldom operate under clean conditions for very long periods of time and the ills to which they are prone during normal service fall into four major categories:

- Fouling of the tube surfaces
- Tube or Tubesheet Fouling due to shell fish or debris
- Circulating water in-leakage
- Excess ambient air in-leakage

The first two categories are related to fouling and tend to be cyclical in nature. They may, therefore, be regarded as *predictable*, although the actual fouling impact will vary from plant to plant, and even between units in the same plant. The second two categories, concerning water or air in-leakage, tend to be *random* in their occurrence. Either kind of leak is almost certain to develop at some point in the future and a correction strategy can be prepared: when it will occur can only be anticipated, not predicted.

1.2 Predictable maintenance problems

1.2.1 *Fouling of the tube surfaces*.

Almost every condenser experiences some kind of tube or tubesheet fouling, Most condenser circulating water sources contain dissolved solids that can precipitate and become deposited on the inner surfaces of the tubes, so adversely affecting the unit heat rate and/or limiting generation capacity. These deposits can also contribute to various types of corrosion and, if not removed periodically, the corrosion may eventually penetrate the tube wall, allowing circulating water to leak into and contaminate the condensate.

Fouling can affect not only unit heat rate but also the ability of the turbine to generate its design load capacity. In fossil-fired plants, an increase in heat rate is reflected in higher fuel costs for a given load and increases of 2% are not uncommon. In both fossil and nuclear plants, if the fouling becomes severe, it will cause the backpressure to rise to its upper limit, forcing a reduction in generated power. There are reports of up to 20 Mw having been recovered by the removal of severe accumulations of deposits.

Rabas et al(1) included a variety of fouling models (i.e. plots of fouling resistance vs. time) that were very site-dependent and cyclical in nature, sometimes affected also by the season of the year. Techniques based on ASME single-tube heat transfer calculations(2) can be used to estimate fouling resistance, although Putman and Karg(3) noted how account must be taken of the observed variation in the design cleanliness factor with respect to load. Having established the fouling model, and the mean monthly load and cooling water inlet temperature for a twelve-month period, Putman(4) described how this historical data could be integrated to create an optimum tube cleaning-frequency strategy. The strategy is suitable for both linear and non-linear fouling models and identifies those months in a twelve-month period during which the condenser should be cleaned, if the total cost of losses over the period due to fouling plus cleaning is to be minimized.

However, with nuclear plants, there is less flexibility and it is considered good practice to clean at every refueling outage. Even where a nuclear unit is equipped with an on-line cleaning system, an annual or biannual off-line mechanical cleaning assures that condenser effectiveness will be maintained, reduces the risk of pitting from the stagnant water in those tubes which may become blocked by stuck sponge balls, and ensures that *every* tube is cleared and cleaned at least once or twice a year.

1.2.2 *Tube or tubesheet fouling due to shell fish or debris.*

When this occurs, the circulating water flow becomes restricted and the thermal conductivity of the tube side water film is reduced, again affecting heat rate and/or generation capacity. Putman and Hornick(5) found that a useful estimate of the circulating water flow rate could be obtained by interpreting condenser operating data in terms of turbine heat balance and low pressure expansion line relationships. Their reference plant was located on the Gulf of Mexico, where shellfish attached themselves to both tubes and tubesheet, causing condenser performance to decrease fairly rapidly. ASME type single-tube heat transfer calculations were again used to estimate fouling resistance, based on the observed variation in water flow rate. Plots showed a close and cyclical (saw-toothed) relationship between flow rate, fouling resistance and backpressure, a study of which allowed intervals between tubesheet cleanings to be extended, rather than conducted at fixed intervals.

Of course, while the progress of tubesheet fouling is generally predictable, an exception would occur should a school of small fish pass through the screens and enter the waterbox.

1.3 Random maintenance problems

1.3.1 *Circulating water in-leakage*.

Circulating water in-leakage can result from penetrations through the tube walls, from joints between tubes and tubesheet that have developed leaks, or from other penetrations between the water box and condenser shell that have lost their integrity. The contaminants in the circulating water change condensate chemistry and/or pH, tending to increase boiler or steam generator corrosion; or result in an increased consumption of water treatment chemicals in the attempt to compensate for the change in water chemistry. Poor water chemistry can also cause stress corrosion cracking of steam turbine components.

Even a small circulating water in-leakage into the condensate can be damaging to the unit as a whole and is often the cause of an unscheduled outage. The length of that outage will depend on the means adopted to locate the source of the leak *quickly*, the on-line and off-line use of tracer gases (helium or SF_6) being the preferred method.

The EPRI Condenser In-Leakage Guideline(6) explores these problems in detail and shows how the use of the tracer gases referred to above can be used to rapidly locate the source of either water or air in-leakage, allowing the problem to be corrected quickly.

1.3.2 *Excess ambient air in-leakage.*

The design of condensers routinely allows for a normally acceptable level of air in-leakage, often considered to be 1 scfm (2.13 kg/h) per 100 MW, although a new ASME Standard(7) shows the limit to vary with the number of condenser compartments and exhaust flow rate. The sources of such leaks can be labyrinth glands on steam turbine shafts, as well as packings and seals that are less than leak-tight. As with fouling, air in-leakage rates above the acceptable values can detrimentally affect heat rate as well as limit generation capacity. Excessive air in-leakage also affects the concentration of dissolved oxygen in the hotwell, which can cause corrosion damage to other parts of the unit. Of course, high dissolved oxygen levels can also be caused by a change in the performance of the air removal equipment and this should be checked before undertaking the search for leaks. In many cases, the increased reliance on deaeration taking place within the condenser makes minimizing air in-leakage even more important.

2. CONDENSER TUBE CLEANING METHODS

Regardless of the tube material, the most effective way to ensure that tubes achieve their full life expectancy is to keep them clean. Each time the tube deposits, sedimentation, biofouling and obstructions are removed, the tube surfaces are returned almost to bare metal, providing the tube itself with a new life cycle, the protective oxide coatings quickly rebuilding themselves to re-passivate the cleaned tube.

The majority of cleaning procedures are performed *off-line*, the most frequently chosen and fastest method being mechanical cleaning.

Among other off-line methods is the use of very high-pressure water but, since the jet can only be moved along the tube slowly, the time taken to clean a condenser can become extended. Great care must be taken to avoid damaging any tubesheet or tube coatings which may be present; otherwise the successful removal of fouling deposits may become associated with new tube leaks or increased tube sheet corrosion, only observable after the unit has been brought back on-line.

Chemicals are also used for the off-line cleaning of condenser tubes. Several mildly acidic products are available and will remove more deposit than most other methods; but it is expensive, takes longer for the operation to be completed, and the subsequent disposal of the chemicals, an environmental hazard, creates its own set of problems. It has also been found quite frequently that some residual material still needs to be removed by mechanical cleaning methods.

Very few *on-line* methods are available to clean condenser tubes but the best known is the Taprogge system, which uses recirculated sponge rubber balls as the cleaning vehicle. These systems often operate for only a part of each day and, rather than maintaining absolutely clean tube surfaces, tend to merely limit the degree of tube fouling. Unfortunately, although the tubes may become cleaner if abrasive balls are used, tube wear can now become a problem.

Mussalli et al(8) showed some uncertainty concerning sponge ball distribution and therefore, how many of the tubes actually become cleaned on line. It is also not uncommon to find that numerous sponge balls have become stuck in condenser tubes and these appear among the material removed during mechanical cleaning operations. For these reasons, the tubes of condensers equipped with these on-line systems still have to be cleaned periodically off-line, especially if loss of generation capacity is of serious concern.

2.1 Mechanical cleaning of condenser tubes

Off-line mechanical cleaning is especially useful where fouling problems exist and are too severe to be handled by any of the other methods. Obviously, the tool selected has to be the most appropriate for removing a particular type of deposit. Moulded plastic cleaners (pigs) are quite popular for some light silt applications. Brushes can also be used to remove these soft deposits as well as some microbiological deposits. Brushes are also useful for cleaning tubes with enhanced surfaces (e.g. spirally indented or finned); or those tubes with thin wall metal inserts or epoxy type coatings.

With harder types of deposit, metal cleaners of various designs have been developed, often with a particular deposit in mind. Mechanical condenser tube cleaners were first introduced in 1923 and subsequent patents granted over the years to the both the Griffin brothers and to the Saxon family have improved on the original design. Figures 1.0(a) and 1.0(b) show some of the current versions of this cleaner, which consist of several U-shaped tempered steel strips arranged to form pairs of spring-loaded blades.

C3S (a) **C4S** (b) **Hex clnr.** (c) **Cal Buster** (d)

FIGURE 1

These strips are mounted on a spindle and placed at 90 degrees rotation to one another. Mounted at one end of the spindle is a serrated rubber or plastic disk that allows a jet of water to propel the cleaners through a tube with greater hydraulic efficiency. The water is directed to the tube being cleaned by a hand-held triggered device (also known as a gun), the water being delivered by a pump operating at only 300 psig (2.07 MPa). Since the pump is usually mounted on a wheeled base plate, the system can be conveniently moved from unit to unit within a plant or even moved to another plant.

A water pressure of 300 psig (2.07 MPa) is very effective for propelling the cleaning tools through the tubes, preventing their exit velocity from rising above a safe level. Some other cleaning systems use air or a mixture of air and water as the propelling fluid; but the expansion of the air as the cleaner exits the tube can convert the cleaner into a projectile and place the technicians at risk.

Another advantage of using water as the cleaner propellant is that the material removed can be collected in a plastic container for later drying, then weighing to establish the deposit density (g/m^2) and followed in many cases by X-ray fluorescent analysis of the deposit cake.

Most metal cleaners are designed to have a controlled spring-loaded cutting edge: but, if effective deposit removal is to be the result, the dimensions of the cutting surfaces have to be closely matched to the internal diameter of the tube being cleaned, not only to improve the peripheral surface contact but also to ensure that the appropriate spring tension will be applied as the cleaner is propelled through the tube. The effective life of cleaners designed in this way can be as high as 10 tube passes.

However, since such cleaners can behave as stiff springs, loading the cleaners into the tubes was sometimes rather tedious. To speed up this operation, while also providing the blades with more circumferential coverage of the tube surface, the cleaner shown in Figure 1.0(c) was developed. This design not only reduced the cleaning time for 1000 tubes but, due to the increased contact surface provided by the greater number of blades, it was found to be more efficient in removing tenacious deposits such as those consisting of various forms of manganese.

A later development involved a tool for removing hard calcite deposits, which were found to be difficult to remove even by acid cleaning. This is shown in Figure 1.0(d), and consists of a teflon body on which are mounted a number of rotary cutters, similar to those used for cutting glass. These are placed at different angles around the body, which is fitted with a plastic disk similar to those used to propel other cleaners through tubes. Used on condenser tubes that had accumulated a large quantity of very hard deposits, Stiesma et al(9) described how cleaners of this type removed 80 tons (72.48 tonnes) of calcite material from this condenser. It has now become a standard tool whenever hard and brittle deposits are encountered.

The experience gained from using these techniques has allowed the time to clean to be forecasted with confidence and cleaning to be performed to schedule. For instance, a normal crew can clean between 5,000 and 7,000 tubes during a 12-hour shift. Clearly, this number can rise with an increase in crew size, limited only by there being adequate space in the waterbox(es) for the crew to work effectively

The concern is occasionally expressed that mechanical cleaners can possibly cause damage to tube surfaces. With cleaners that have been properly designed and carefully manufactured, such damage is extremely rare. Indeed, Hovland et al(10) conducted controlled tests by passing such cleaners repeatedly through 30 feet long, 90-10 CuNi tubes. It was found that, after 100 passes of these cleaners, the wall thickness became reduced by only between 0.0005 and 0.0009 inches (12.5 and 22.86μ). If a 50% reduction in wall thickness is the critical parameter, extrapolating this series of tests would be equivalent to 2800 passes of a cleaner per tube, or 1000 years of condenser cleaning!

Clearly, all off-line cleaning methods sometimes need assistance where the deposits have been allowed to build up and even become hard. In such cases, it may still be necessary to acid clean, followed by cleaning with mechanical cleaners or high-pressure water to remove any remaining debris.

2.2 Developing an appropriate cleaning procedure

The selected cleaning procedure should remove the particular deposits that are present as completely as possible, while also causing the unit to be *out of service for the minimum amount of time*. Some other major considerations in the selection process are as follows:

2.2.1 *Removal of obstructions*

Many tube-cleaning methods are ineffective when there are obstructions within tubes, or various forms of macrofouling are present and, clearly, those cleaning methods should be avoided. Attention has already been drawn to the shell-fish, which constitute macrofouling, including Asiatic clams and zebra mussels. The selected tube cleaner must have the body and strength to remove such obstructions. The cleaning method must also be able to remove the byssal material that shell-fish use to attach themselves to the tube walls.

There are certain types of other debris which can become obstructions, among them being cooling tower fill, waste construction material, sponge rubber balls, rocks, sticks, twigs, seaweed and fresh water pollutants, any or all of which can become lodged in the tubes and have to be removed. Meanwhile, experience has shown that, if appropriate procedures are followed, properly designed cleaners should not become stuck inside tubes, unless the tube has been deformed.

2.2.2 *Removal of corrosion products*

With condensers equipped with copper alloy tubing, copper deposits grow continuously and the thick oxide coating or corrosion product can grow to the point where it will seriously impede heat transfer. Not only will the performance of the condenser be degraded but such deposits will also increase the potential for tube failure. When a thick outer layer of porous copper oxide is allowed to develop, it disrupts the protective inner cuprous oxide film, exposing the base metal to attack and causing under-deposit pitting to develop. Such destructive copper oxide accumulations together with any other deposits must be removed regularly.

2.2.3 *Surface roughness*

Rough tube surfaces, as are created by the accumulation of fouling deposits, are associated with increased friction coefficients while the reduced cooling water flow rates allow deposits to accumulate faster. It has also been found that rough tube surfaces tend to pit more easily than smooth surfaces. Thus smooth tube surfaces, which result from cleaning, can improve condenser performance through:

- Improved heat transfer capacity and a lower water temperature rise across the condenser, reducng the heat lost to the environment
- Increase in both flow volume and water velocity, often resulting in reduced pumping power
- Increased time required between cleanings, by reducing rate of re-deposition of fouling material on the tube surfaces.
- Reduced pitting from turbulence and gas bubble implosion

3. IN-LEAKAGE DETECTION METHODS

The EPRI Condenser In-Leakage Guideline(6) discusses in great detail the sources of both water and air in-leakage and their consequences, together with methods for their location and correction. The techniques have evolved from earlier methods (e.g. use of foam and plastic wrap), to the current techniques that involve the use of tracer gases, principally helium and sulfur hexafluoride (SF_6), both of which are non-toxic. Most of the innovations were stimulated by the need to locate small circulating water in-leaks but, eventually, the same techniques became used for the location of air in-leaks as well.

3.1 Water in-leaks

The condenser is supposed to form a barrier between the cooling water - which flows between the waterboxes through the condenser tubes - and the shell side of the condenser, in which the exhaust vapor is collected as condensate. However, even small circulating water leaks will quickly find their way into the condensate, contaminating it with undesirable dissolved solids which tend to cause corrosion in the feedwater heaters, boilers or steam generators. On-line conductivity or salinity instruments are used to indicate the presence of a leak and steps should be taken to rectify the problem as soon as possible. Unfortunately, this usually means taking the unit out of service, the associated loss of revenue depending on the length of the outage. Thus the time taken to locate and correct the problem can be economically significant. This time can be reduced significantly if the waterbox associated with the leak can be identified while the unit is still on-line.

Among the leak detection methods commonly employed in the past were smoke generators, foam or plastic wrap applied to the tubesheet, ultrasonics, tube pressure testing and membrane type rubber stoppers. These earlier techniques also left some uncertainty as to whether the leak was confined to only one tube; so that adjacent tubes were often plugged as well (often unnecessarily) as a form of "insurance plugging". All these methods require that the shell side of the condenser be under vacuum, provided either by the air removal system or, if the waterbox is divided, by continuing to run the unit at low load, taking each waterbox out of service in turn and checking it for leaks.

The development of the helium tracer gas technique in 1978 not only reduced the time required to locate a leak; it also eliminated much of the former uncertainty whether the actual source of the leak had been found. However, the lowest detectible concentration of helium is one part per million above the background level, and helium was often unable to detect small water in-leaks. Thus a tracer gas with greater sensitivity was sought and, in 1982, a tracer gas leak detection technique using SF_6 was developed. It was found that SF_6 in concentrations as low as one part per 10 billion (0.1ppb) can be detected, so that small leaks could now be located and with confidence.

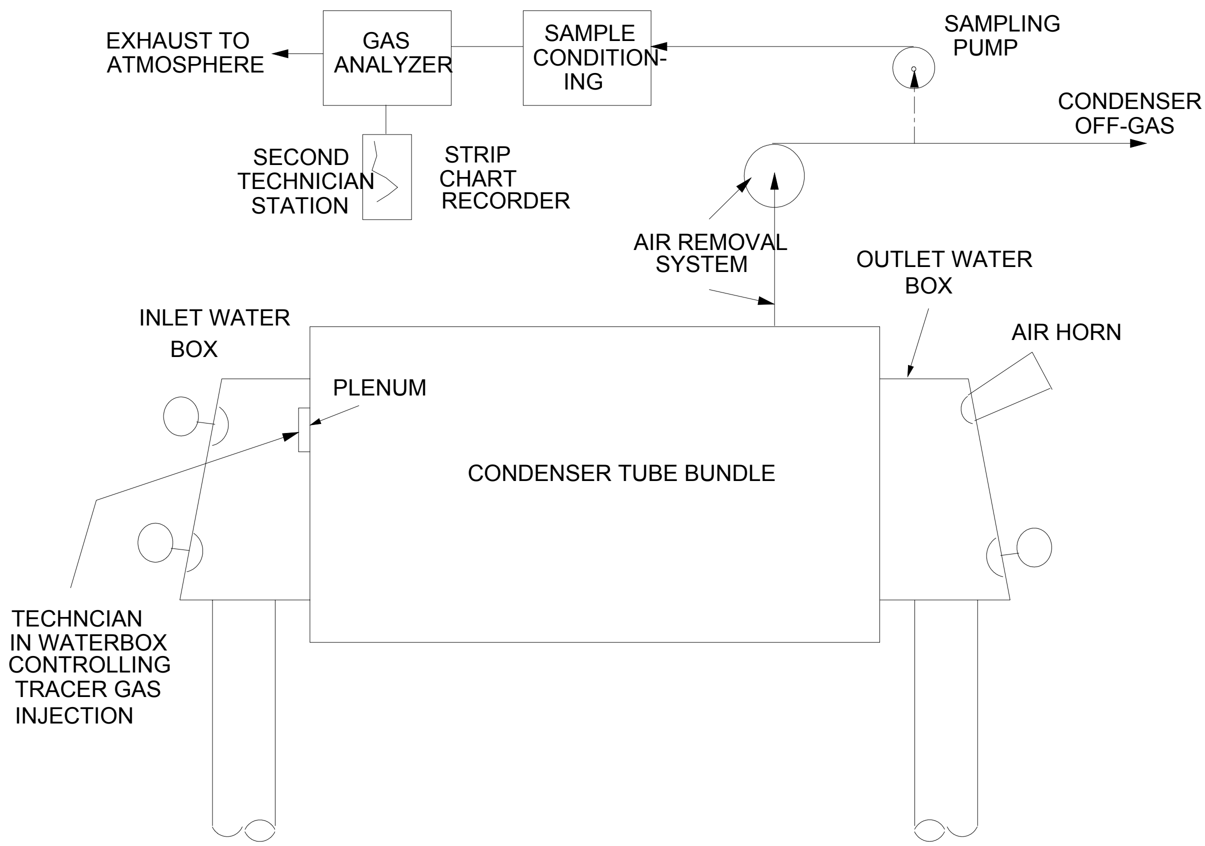

Figure 2 - General setup for tube water leak test

This method is illustrated in Figure 2, in which a tracer gas monitor is connected to the off-gas stream leaving the air removal system. A technician is stationed at the monitor to observe the shape of the trace on the strip chart recorder (See Figure 3.0), a typical response time being 30-45 seconds. Another technician is stationed in the waterbox and dispenses the tracer. The two technicians communicate through two-way sound-powered radios, chosen to avoid RF interference with other equipment.

Once the waterbox is open and the tubesheet exposed, a series of plenums is placed over a section of the tubesheet, each sized to cover an ever-smaller group of tubes. The technician in the waterbox injects the tracer gas into the plenum using a portable dispenser. The vacuum within the condenser allows the tracer gas to pass through any leaks that may be present and eventually appear in the off-gas stream leaving the air removal system. The technician watching the tracer gas detector monitor warns the other technician when the presence of the gas is observed. A smaller plenum is then used, and so on. By using this rigorous process of elimination, the problem tube can be rapidly identified.

As a guide to tracer gas selection, if the water in-leakage is less than 50 gallons per day (189.2 l/day), SF_6 is the preferred tracer gas; otherwise, either gas may be used. Similarly, if the unit is operating at more than 20% of full load, either gas may be used. If the leak is so bad that the unit cannot be brought on-line, then the use of helium would be the standard procedure.

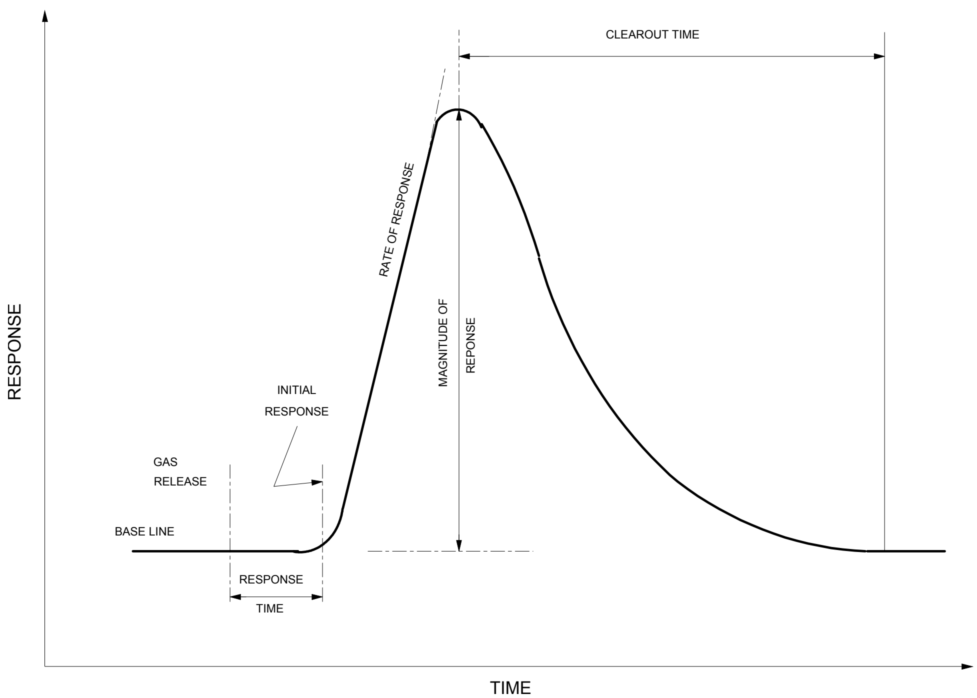

Figure 3 – Chart Recording of a typical leak response

Sulfur Hexafluoride can also be used *on-line* to identify the waterbox, even tube bundle, in which the leaking tube is located. The SF_6 is injected periodically into the circulating water before each waterbox while the unit is still on-line, and a permanently installed analyzer and monitor is used to identify the waterbox associated with the leak This reduces the time required to locate and repair the leaking tube, once the associated waterbox has been opened.

3.2 Air in-leakage

Condensers are designed to perform correctly with the unavoidable and low level of air in-leakage which is always present(7). However, greater air in-leakage than this low normal value will increase the concentration of non-condensibles in the shell side of the condenser and cause the thermal resistance to heat transfer to increase. An increase in backpressure and unit heat rate will result. The in-leakage may even rise to the point where the backpressure approaches its operating limit, forcing a reduction in load. Another effect of high air in-leakage is often an increase in the concentration of dissolved oxygen in the condensate, a concentration that will tend to increase with lower condensate temperatures. The consequences are increased corrosion of feedheaters, boilers and steam generators and/or an increase in the consumption of water treatment chemicals. All these consequences have a negative impact on unit profitability.

Using tracer gas techniques, the source of most air in-leaks can be located with the unit still on-line. Once again, a tracer gas monitor is installed in the off-gas line from the air removal system and the technician handling the tracer gas dispenser roams around the unit in a methodical manner until the technician at the monitor observes a response. The leak detection survey starts at the turbine deck level and proceeds from top to bottom of the unit, one deck at a time. Care must be taken when dispensing the tracer gas that only one potential source is sprayed at a time, otherwise the ability to associate a response with a particular source may become impaired.

Conclusion

The careful monitoring of condenser performance, the prompt detection of performance changes, the ability to identify and locate the source of the problem, and the provision of the appropriate techniques and means for correcting the problem, can minimize unit downtime and so make an important contribution to unit profitability.

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