Leak Testing Steam Turbine Condensers

Application Note

Introduction

Power generation turbines, regardless of the type of fuel used, are driven by steam generated in a boiler. The boiler heats water and converts it to steam, spinning the turbine and in turn, driving the generator that produces electrical power. After exiting the turbine, the steam is routed through a condenser, cooling the steam back to water, which is then returned to the boiler to start the cycle again.

The efficiency of this process is dictated by the pressure gradient across the turbine and condensing system. Leaks in the system degrade the pressure differential and can easily result in power loss in excess of one megawatt per turbine.

However finding leaks in power plant circuits presents a challenging set of problems. Agilent Technologies, Vacuum Products Division, (formerly Varian Vacuum Technologies) has developed a leak test solution specifically designed for the demanding conditions found in power generation condensers.

Steam Turbine Operation

The high pressure region of a turbine is working at pressures as high as 165 bar, while the low pressure region operates at a pressure of 0.03 to 0.07 bar. Turbine back pressure is a key parameter in steam to power efficiency. The typical design back pressure for a system is around 0.08 bar. If this vacuum level deteriorates, due to air in-leakage, leaky valves, or cooling tower problems, the efficiency of the entire system can decline rapidly.

If even small amounts of non-condensable gas (air) are allowed to accumulate, they will inhibit heat transfer in the condenser and adversely affect performance. Large amounts can virtually block the condensation process, which of course will cause a substantial rise in back pressure. To prevent excessive accumulation, most power plants use steam jet air ejectors and/or liquid ring vacuum pumps to remove the non-condensable gases. When these methods cannot keep pace with the rate of air in-leakage then the leaks must be found and repaired.

The most widely accepted method to identify air in-leakage is the use of helium as a tracer gas and a mass spectrometer to detect helium. Various other methods have been used with limited success including ultrasonic leak detectors. However, the latter do not work effectively in a noisy plant environment and have limited sensitivity.

Condenser Leak Testing Using Helium

A helium leak detector is comprised of a high vacuum pump and backing pump, which provides the correct vacuum conditions for a small mass spectrometer.
In a mass spectrometer, gasses are ionized and accelerated through a magnetic field which isolates gas molecules by mass. This separation allows extremely small concentrations of helium to be detected, thus making it ideal for condenser leak testing. Helium is sprayed around the vacuum portions of the condenser (Figure 1), while a mass spectrometer detects low concentrations of the gas at the outlet of the extractor or at other sites within the vacuum region of the condenser.

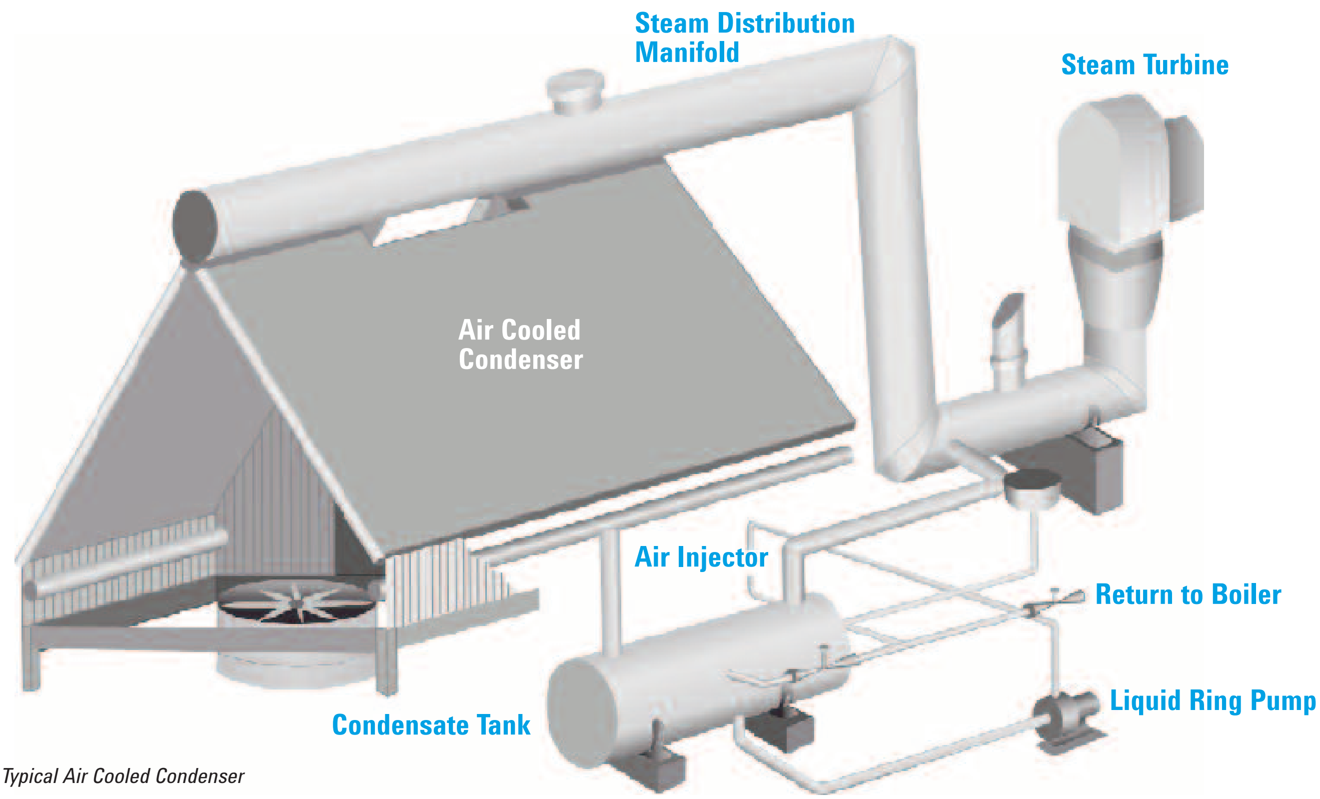

Figure 1: Typical Air Cooled Condenser

In general, helium tracer gas testing works very well because leaks can be sealed as soon as identified, and subsequent testing can be performed immediately to confirm that the leaks are sealed. The use of helium is advantageous as the gas is non-toxic, non-flammable non-reactive with other chemicals and very quickly diffuses though small leaks. The helium method allows a maintenance engineer the flexibility to perform leak tests while the plant is operating, without the need to isolate the section under test.

Difficulties in Condenser Leak Testing

While from a detection standpoint finding the leak is very easy, the potential to damage the mass spectrometer is great. This is due to the environmental conditions inside the condenser. The gas being sampled is very hot, is almost entirely water vapor, and can be corrosive. Any of these conditions can potentially damage the leak detector, yet the gas must be sampled in order to find the leak.

The helium leak detector normally operates at vacuum levels lower than the condenser, so a special test probe (commonly called a sniffer probe) is used that permits detection at atmospheric level, which could be at the exhaust of the pumping system used to create the vacuum conditions in the condenser. However, use of a conventional sniffer probe would be a serious problem, since water vapor in the exhaust would be pumped directly into the leak detector resulting in breakdown of the pump lubricating oil and other damage to the unit. The sniffer probe performance would be quickly degraded by water vapor condensing and blocking the orifice and probe line.

If a water/steam ejector pump is used for the condenser evacuation, connection to a conventional sniffer probe is not possible. In this case, an auxiliary vacuum pump is commonly used just before the ejector pump with the sniffer probe inserted into the exhaust of this auxiliary pump. This arrangement has the same shortcomings because the sample is still mostly water vapor. However, the steam can be conditioned with the use of a desiccant cartridge or a cold trap, thereby condensing water vapor that would otherwise enter the auxiliary pump and the leak detector. This solution adds significant cost and complexity to the leak test process.

In some cases, a permeable membrane has been used in the tube connecting the leak detector to the condenser piping. While this can keep water vapor out of the leak detector, it also severely limits the leak test sensitivity and makes the leak test process questionable. This is because the vacuum pressure in the condenser piping, at 0.08 bar, is sufficiently high to insure laminar viscous flow conditions. This means even though there is slight vacuum, there is also a very high density of gas molecules in the pipe and the mean free path for helium is only about 2 millimeters (0.08 inches). Any given helium molecule can only move laterally 2 mm before it collides with other gas molecules. Helium flowing within the gas stream in the pipe being tested is therefore swept along in the flow and cannot migrate laterally to an outlet in the side of the pipe where the leak detector is connected.

In simple terms, even though a leak is present, and even with helium flowing down the pipe, the helium frequently will not reach the test connection, and the leak detector will not recognize the leak. This condition is portrayed in the series of graphics in Figure 2, next page. These pictures will show: A The behavior of the flow through a pipe, B The concentration of helium within the flow, C Sampling with a membrane mounted on the side wall of the pipe, and D Using an insertable membrane probe to sample in the center of the pipe.

Another aspect to consider is the logistics of leak testing in a large, multi-story power plant where the leaks are usually a long distance from the mass spectrometer. Since most helium leak detectors are not equipped with remote readout and control capability, leak detection is typically a 2- or 3-person operation where contact between one operator spraying helium and another observing the leak detector display is conducted literally by shouting or by two-way radio.

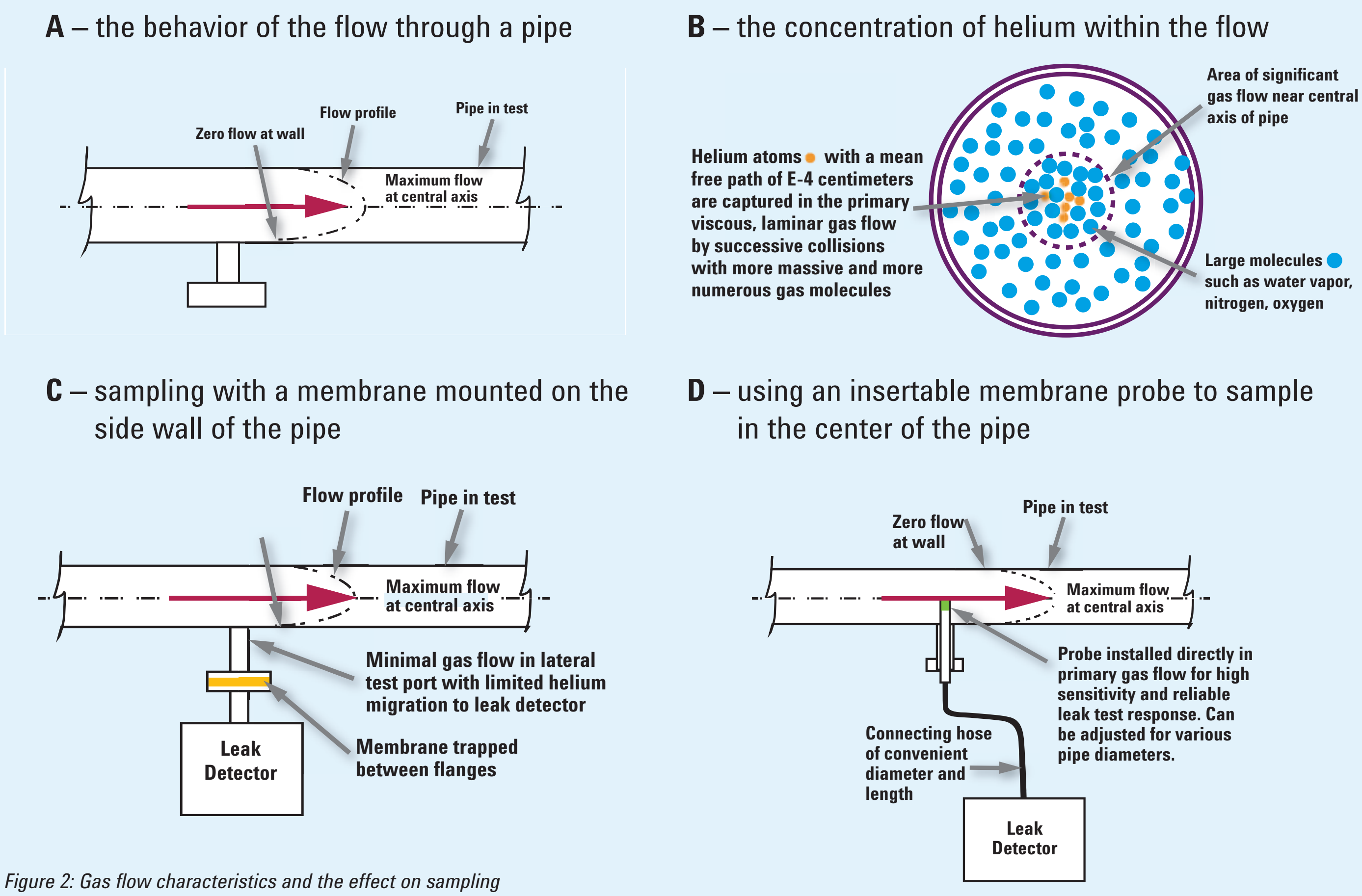

Figure 2: Gas flow characteristics and the effect on sampling

Summary

Successful leak testing of power plant systems requires overcoming three significant problems:

1. Heated water vapor in the piping to be tested
2. Detection of tracer gas helium in viscous laminar flow conditions
3. Communication with the leak detector over long distances within the power plant

The Agilent Solution

To address the challenges of leak testing in the harsh environments of the power generation industry, Agilent has developed a specialized sampling probe and leak detector configuration tailored to these requirements. The Agilent VS Harsh Environment (HE) Probe (Figure 3) is designed to withstand the wet environment and high temperatures inside condenser piping without dryers, chillers, a secondary vacuum pump, or throttling valves. The probe can be:

1. Positioned in the exhaust of a liquid ring pump on the condenser system,
2. Flange-mounted directly into the piping of the system under test (as shown to the right)

The probe is connected to the flange via an adjustable compression fitting so the probe tip can be positioned in the center of the pipe. This guarantees the probe tip is in the maximum helium flow for the best sensitivity.

Equipment damage or failure due to corrosion or water in the leak detector or roughing pump is eliminated. The Agilent HE Probe withstands water, amines (corrosive ammonia derivatives), and operates at temperatures up to 95°C (200°F). The probe connects directly to a VS leak detector with no additional water trapping or auxiliary pumping required.

The probe consists of a corrosion resistant 316L stainless steel tube with a composite permeable membrane at its tip. The membrane readily permeates helium tracer gas while protecting the leak detector from water vapor that would destroy the pumps, valves, and spectrometer.

Also, the Agilent VS Helium Leak Detector has an optional wireless remote control that permits an operator to work up to 100 meters from the leak detector. (Transmission distance may be affected by building walls and floors). The wireless remote gives a single operator the freedom to perform all leak test operations (Figure 4).

Figure 3: Agilent Harsh Environment Probe and VS Helium Leak Detector

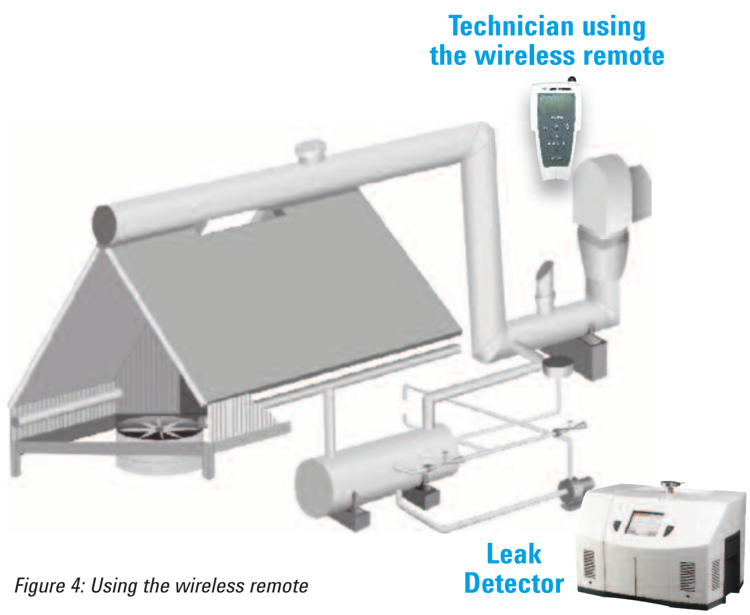

Figure 4: Using the wireless remote

Finally, it may be desirable to collect data from the test for analysis, recordkeeping and/or certification purposes. When helium is sprayed on a leak location at the condenser, it takes time for the helium to be detected and displayed by a leak detector. That time could be a few seconds to a few minutes depending on the helium concentration, the condenser and tube volume and the distance from the leak. The leak response of the VS leak detector can be viewed and recorded graphically using Agilent's "Leak Test Data Wizard" software. The PC-based program enables extensive VS control, display, and data acquisition capabilities.

Savings Analysis

It is well within reason to assume that leaks are causing an increase in condenser vacuum of 0.016 bar (0.5" HgA). If this is the case, here are the potential savings:

Each plant has different operating characteristics, but calculating the answer is simply a matter of gathering some data and multiplying*.

1. In your "Turbine Data File" there should be a graph or table that shows Turbine Efficiency Improvement as a function of turbine back pressure [condenser absolute pressure]. For this example the improvement is assumed to be 0.3%, from 0.08 bar to 0.07 bar (2.5" HgA to 2.0" HgA).
2. Determine the Turbine Heat Rate, which is the BTU input to the turbine required to produce a kilowatt of electricity. A typical value is about 8500BTU/kWh.
3. Determine the cost of fuel. A recent spot price for natural gas was $4.00 per million BTUs.

Use the following calculation: **[0.003] [8500 BTU/kWh] [$\$4.00/10^6$ BTU] = 1.02×10^{-4} $/kWh**

This appears to be insignificant until we factor in the amount of power produced over an entire year. If the plant is rated at 250 megawatts (250,000 kW) and it operates 8000 hours per year:

[1.02×10^{-4} $/kWh] [$2.5 \times 10^5$ kW] [8×10^3 hr/yr] = $204,000 per year

Detecting and stopping leaks with the VS Leak Detector and HE Probe delivers an outstanding return on your investment and potentially pays for itself on the first use. For more information contact Agilent Technologies Vacuum Products Division at 800.882.7426, or www.agilent.com/chem/leakdetection.

* *All of this depends on the conditions at your particular plant. Use the above formula to calculate your own potential savings. Calculation courtesy of Dekker Vacuum Technologies, Inc.*

HE Probe Specifications:

Criteria	Specification
Operating temperature range	+10° C (+50° F) to +95° C (+200° F)
Storage temperature range	–18° C (0° F) to +65° C (+150° F)
Operating vacuum pressure	Atmospheric pressure to low vacuum 1µ Hg, <1e-03 mbar/Torr, 1e-01 Pa
Maximum internal overpressure	1 Bar, (14.7 PSI), (105 Pa)
Probe length	450 mm (17.7") Hose High density polyethylene, 5 meters (16.4') long
Weight of probe assembly	0.5 kilogram (1 pound)
Hose fitting size	½" (12.7 mm) Swagelok™ compression or equivalent
Vacuum flanges	ISO KF25
Adaptor flange o-ring	Butyl rubber, Parker B2-016 or equivalent
Chemical resistance	Probe resists virtually all chemicals except complex halogenated compounds.