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ACC.03: Guidelines for Air In-leakage in Air-Cooled Condensers

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Guidelines for Air In-leakage in Air-Cooled Condensers

Introduction

Steam condensing in thermal power generation creates a vacuum that is important for process efficiency. Air-cooled condensers (ACCs) are subject to inefficiency based on the use of ambient air as the primary agent of cooling rather than water, which is typically cooler than ambient air and therefore produces a better vacuum due to a faster rate of steam condensation. This vacuum is critical to efficient thermal power generation, with a high (stronger) vacuum resulting in a more efficient steam cycle, and therefore a lower rate of fuel consumption. Furthermore, if the vacuum is poor, a reduction in the production of steam may be necessary to protect the steam turbine; consequently, power generation is also reduced. It is routine for thermal power generating plants with ACCs to be required to reduce power output from the steam turbine by 10 to 20% or more during periods of high ambient temperatures (Figure 1).

The vacuum in power plant condensers results in air ingress at any point where the integrity of isolation is compromised. When air enters the vacuum environment of an ACC, routinely installed equipment normally removes the air and no effect on system performance occurs. However, if the rate of air ingress exceeds its rate of removal, air can accumulate in steamside locations and obstruct heat transfer by preventing steam from contacting the surfaces of heat exchange tubing. This effectively reduces the heat exchange surface area and therefore the cooling capacity of the ACC and results in deterioration of the system vacuum. Therefore, it is necessary to monitor the rate of air in-leakage (AIL) and to periodically identify and correct locations of air ingress.

In addition to affecting the vacuum and performance of the plant, oxygen and carbon dioxide present in air can dissolve in condensate and influence steam cycle corrosion and chemistry measurements.[1,2]

Note: The information contained in this Guideline is believed to be accurate based on available knowledge. It is the responsibility of any user of this Guideline to confirm the accuracy of information herein and to apply the information appropriately to any specific situation. This Guideline is focused on AIL for ACCs; an international guidance document on AIL that includes non-ACC systems is openly available from IAPWS (www.IAPWS.org).[1]

Effects of Air In-leakage

A routine quantity of air drawn into the vacuum of power plant steam condensers is unavoidable due to many points of potential ingress, some of which have sealing mechanisms that physically deteriorate over time. In an ACC this problem is compounded by the large structure with many more points of potential ingress than are present in water-cooled condensers (WCCs). ACCs are designed with primary tube bundles where most of the steam condensing takes place with downward flow of condensate and non-condensable gases, and secondary tube bundles (dephlegmators) that provide a subsequent upward flow of non-condensable gases (primarily nitrogen and oxygen) that are isolated and removed from condensing steam (Figure 2).[3] These gases are exhausted to air by apparatus similar to that found in WCCs - steam jet air ejectors (SJAE) or vacuum pumps. This dephlegmator / air removal system functions routinely during ACC operation and prevents non-condensable gas concentrations from increasing to problem levels when air ingress is adequately controlled.

For situations where increased air removal is needed, ACCs typically have a steam-driven pump known commonly as a ‘hogger’ that can remove non-condensable gases at a much greater rate than the routine air exhaustion pumps and may in some situations compensate directly for a deficient vacuum. The hogger may be used during startups to clear air out of the ACC rapidly and can also be employed for maintaining condenser vacuum when AIL is greater than the dephlegmator / air removal system can handle. However, the hogger requires a significant amount of steam to function and can be very loud; it is not generally a good routine solution for managing excessive AIL.

If excessive AIL exists and is not addressed, non-condensable gases may accumulate within the steam distribution ducts and condensing bundles, resulting in areas where steam is prevented from contacting heat transfer surfaces. This loss of cooling capacity results in a poor vacuum coincident with degraded plant performance, with heat transfer efficiency reduced by as much as 20% [1]. Under severe conditions the plant may trip offline if the vacuum is inadequate to allow turbine operation.

It is common for ACC plants with significant AIL to achieve adequate condenser vacuum during cooler ambient weather periods, but for vacuum to be inadequate when ambient temperature is high. With this in view, AIL in should be evaluated and corrected during cooler seasons so it is not present moving into hot weather periods.

Additionally, concentrations of oxygen in the steam cycle may be elevated and promote carbon steel corrosion; carbon dioxide may also increase resulting in elevated CACE (conductivity after cation exchange, also commonly called ‘cation conductivity’ or ‘acid conductivity’), which introduces challenges in monitoring water purity. Condensate polishers, if present, may experience rapid exhaustion of anion resin due to carbon dioxide.[2,4]

Recognizing the Presence of Air In-leakage

Minor quantities of AIL routinely are always present in power plant condensers, but because in-leakage can cause significant system challenges when excessive, it is important to regularly identify and measure AIL. Evidence of increased AIL may be an important signal that an effort to locate the source(s) of in-leakage is needed.

Common indications of increasing AIL include the following: [2,3,5]

- deteriorating condenser vacuum under conditions that are otherwise constant
- increased air removal flow rate
- increased oxygen and/or carbon dioxide dissolved in condensate
- results of a vacuum decay test more rapid than prior testing
- non-uniformity of heat exchanger tube temperatures
- rapid exhaustion of anion resin in condensate polisher due to carbonate

Leak Detection

Approaches to identify the specific locations of AIL are very similar for both WCCs and ACCs.[1] One major difference is the need to detect leaks at difficult-to-access locations with ACCs, which sometimes is more feasible with the use of remote-measurement techniques. A second difference is that ACC plants tend to have overall higher baseline AIL because of many more locations for potential small leaks than in WCC plants. These small leaks may be difficult to impossible to locate in either condenser, but cumulatively there are likely to be more in an ACC plant, and therefore more overall AIL.

One of the issues facing operators of ACC plants is the decision of whether to perform leak detection in-house or through a contractor. A contractor may be preferred in cases where a company has only one or two plants, since purchasing equipment, training for its use, and developing expertise may not be cost-effective or feasible. In addition, contractors can be more efficient, thorough, and effective at locating leaks, given their experience with the equipment and process. The upfront cost could be greater over the life of the plant if the work is contracted out, but the results can be much more valuable. It is not uncommon for plants that do the work in-house to bring in a contractor if in-house efforts to locate leaks prove unsuccessful. On the other hand, there may be some advantages to performing the work in-house, or at least having the capability, when a company has several plants, especially considering that the same equipment can be used for both ACCs and WCCs. If the testing is performed from a central support group and/or with specific personnel assigned to do the testing, expertise will develop over time. Immediately available in-house equipment can allow suspected leak areas to be checked out quickly and on a limited basis. With the challenges of leak testing on ACCs, it may be advisable to hire contractors for initial ACC leak testing and observe their protocols and processes to evaluate whether in-house testing is a direction to consider.

Regardless of the personnel performing the test, an initial review of more likely leak locations can potentially save a significant amount of resources. Excessive AIL can potentially be resolved quickly if there are suspected areas that can be tested first, such as previous leak locations or other indication of a likely leak area. If this suspicion is confirmed, the leak is repaired quickly, and AIL drops to an acceptable level, there may be no need to proceed with further testing. For example: when steam turbine rupture disks fail, there is typically a significant, rapid incremental increase in AIL. Therefore, it would be prudent to check the rupture disks first if this pattern is present.

On the most basic level, any technique that can detect air flow or air being drawn into the condenser vacuum can be labeled a 'leak detection method.' Some such methods include the following:[1]

- physical touch, e.g. sensing flowing air or suction on a pipe with poor valve seal
- application of foam (e.g. shaving cream) to a suspected leak area
- holding a candle near a suspected leak and observing flame movement
- applying smoke to a suspected leak area and observing movement to the leak

In most cases these rudimentary approaches are not applicable to ACCs, except perhaps where a very limited number of specific locations are to be checked.

More sophisticated and reliable methods of leak identification include the following:

Tracer gas

A gas that is not normally present at significant levels in air and can be detected reliably. Normally helium (He) is used but occasionally sulfur hexafluoride (SF_6) is preferred. The tracer gas is applied to a specific location or general area. If there is a leak, some of the gas will be drawn into the leak by the condenser vacuum and can be detected in the air removal system exhaust stream.

The primary technique used for AIL detection is the use of helium as a tracer gas due to its reliability, sensitivity, relatively low cost, and environmental acceptability - helium is chemically inert and is naturally present at low concentrations in air. SF_6 is much more sensitive than helium, and while this sensitivity can be helpful with locating very small leaks, it also results in extended waiting periods for the sprayed gas to dissipate when used indoors. In addition, SF_6 is considered a "greenhouse gas," and its use therefore undesirable; it also is much more expensive than helium. While there may be situations where SF_6 has a technical advantage over helium, it is generally not the best choice for tracer gas testing for AIL except for unusual circumstances. The very small leaks that can be identified with SF_6 are often not significant.

Helium leak detection typically requires two persons in remote communication, one at the detector and the other spraying helium. It is also possible for a single person to perform helium leak detection, with the detector transmitting signals to a hand-held device. However, signal transmission may be limited for single-person leak testing on an ACC, as there will be a considerable distance between detection at the air removal exhaust and many locations where helium is applied.

Helium is sprayed perhaps over an area that includes several potential leak locations, and after a pre-determined time interval (commonly 15 to 45 seconds), results from the detector are reported. By repeating this process, helium is eventually applied to all external condenser surfaces and piping under vacuum. When a positive response from the detector is reported, helium spray is repeated at more specific locations until the point of in-leakage is identified. This location is then labeled for repair including an estimate of the size of the leak (e.g. large, medium, small, trace) and the area photographed and tagged for location documentation.

IR camera

Real-time images that show approximate temperatures based on infrared emission can be observed and saved for documentation. Standard temperatures will closely match those of internal steam; where a leak is present, the air drawn in will cause a local temperature reduction (Figure 3).

An infrared (IR) camera gives temperature-based readouts, typically converted to color differentiation over ranges that can be pre-set and adjusted. Potential leak areas are viewed with the camera and images taken when a likely leak is identified by the presence of locally cooler spots. The IR camera is also useful for identifying banks of ACC finned tubes that are abnormally cool, as this is an indication of air binding resulting from AIL. Leak testing by IR may be followed up by helium testing if a specific leak location is not clearly evident.

Acoustic detection

Leaks into a condenser vacuum are typically associated with a high-pitched sound that may be measurable with a sensitive acoustic receiver and earphones that help limit background noise. The acoustic system can isolate and enhance the volume at a leak; a receiver is directed towards the sound formed by air ingress at a leak point and focused until a relatively specific leak area is confirmed by maximum volume. Acoustic systems may include imaging capability that helps pinpoint the location of the leak (Figure 4). As with IR testing, it may be necessary to follow-up acoustic evaluation with tracer gas testing to confirm the precise leak location.

Other considerations

Leak locations may be observed with light penetrating the upper steam distribution duct during an internal inspection, or by an increase in online conductivity measurements when water from finned tube cleaning operations is drawn into a leak (excepting if demineralized water is used for the cleaning).

The ACC should never be ‘flooded’ with condensate as is sometimes done with WCCs, as it is not designed to handle the water weight in steam ducts.

Application of Air In-leakage to Air-Cooled Condensers

The significance of AIL into the vacuum of WCCs has been recognized and managed for decades and is covered in the IAPWS AIL guidance document.[1] In many respects the same issues and management approaches apply to ACCs; for example, AIL around steam turbines is common to both, and must be isolated from the condenser to provide a full indication of AIL in either the WCC or ACC. However, there are significant differences that are involved with ACCs, many of which present challenges in leak detection. These challenges include the following:

Size / volume

Steam transport ducts and condensing heat transfer tubing in ACCs are far larger and contain much greater volume than those in WCCs. This implies increased need for initial clearance of air during unit startups, and additional locations where air accumulation and blanketing of heat transfer surfaces may occur.

Connections

There are many more welds, flanges, expansion joints, etc. in ACCs than in WCCs. A large ACC may have more than 30,000 tube-to-tubesheet welds, as well as large flanges, expansion joints and butterfly valves in steam transport and upper ducts. These connections may be initially vacuum-tight but are subject to weakening and loss of integrity over time with corrosion and thermal expansion/contraction.

Heat transfer tube steam entry

Flow-accelerated corrosion (FAC) at the point where steam enters finned heat transfer tubing has been routinely identified in operating ACCs.[6] These locations are commonly referred to as “tube entries” (Figure 5). Because the tubing is thin-walled to enhance heat transfer, the risk of through-wall corrosion is possible, whereas most other carbon steel structures in ACCs as well as WCCs being relatively thick and unlikely to experience significant thinning.

Number of potential leak locations

It follows from the size of ACCs and the number of components and connections that there are many more potential leak locations in an ACC than in a WCC.

Access for testing

Finned tubing on A-frames is typically greater than 10 meters (~30 feet) in length, making access to the upper end difficult (Figure 6).[5,7] Steam distribution headers with flanges and expansion joints are commonly impossible to access without manlifts or extensive scaffolding (Figure 7). Access challenges cause difficulty in the delivery of tracer gas to leak locations, although these challenges may be met with remote detection approaches such as acoustic systems or IR cameras (Figures 3,4).

Outdoor environment

Tracer gas testing can be very challenging in a scenario where light breezes may limit the delivery of the gas to leak locations.[7] This is one reason that more remote testing methods such as infrared and acoustic cameras are potentially more feasible.

ACC fans and air movement

Generally, the ACC must be operating to generate the vacuum that allows identification of leak locations. While fans may be turned off in the immediate region being tested, airflow from other operating fans will be present. This contributes to rapid dispersion of tracer gas and increases the difficulty of its application.

Leak repairs

The same access issues that make testing and inspection difficult also cause repairs to be challenging. Repairs may take longer due to access issues, and therefore could be delayed, potentially until coordination with a future unit shutdown. This will delay confirmation of AIL test results and resolution of the problem.

Common Locations of Air In-leakage in Air-Cooled Condensers

The low-pressure (LP) steam turbine is common to both conventional coal- or gas-fired power plants as well as combined cycle plants, and to both WCCs and ACCs. LP steam turbines are under vacuum and need to be tested for AIL. Common locations for leaks at the LP turbine include shaft seals and rupture disks, but all surfaces including bolts, welds and piping should be leak-tested. Many steam turbines are located inside a plant facility, but for those not housed in a building, air currents may be a troublesome issue with tracer gas testing.

Areas within the ACC envelope that should always be tested, if accessible, include the following:[3,5]

Welds

A weld between two pieces of metal is typically designed to be a permanent, strong connection. If a welding process is designed and performed properly, this should be the case. However, a variety of circumstances can cause certain types of welds to be susceptible to cracking and corrosion, resulting in a risk of AIL; this is more of a concern with field welds, where fit-up and other processes are not as precise. In ACCs, there are many thousands of welds, including the following locations:

- both ends of each finned tube to a tubesheet; these are typically precision-welded in a shop, so can be more reliable than field welds but are a potential leak location due to the large number of these welds in an ACC (Figure 8)
- sections of steam transport ducts, including those with large diameters, are welded together; there may also be supports, piping, metal ladders and other structures welded to the wall of the duct that could result in local duct wall cracking (Figure 9)
- condensate collection headers, particularly if they may have been subjected to freezing while containing condensate (Figure 10).

There is not a strong pattern of particular weld types or locations in an ACC being more likely to leak than others. The common denominator that results in failures associated with welds appears to be poor quality workmanship or a failure of processes, including inadequate inspections. Testing welds for AIL should be a routine process.

The presence of rusted locations on external surfaces that are otherwise uncorroded may be evidence of condensate leaking through a penetration of the vacuum barrier (Figure 11).

Valves

Butterfly valves for riser isolation can leak around packing, especially after repeated use over an extended time frame, if not properly maintained (Figure 12).

Expansion joints

Thermal expansion stresses are relieved by the selective positioning of expansion joints, including the bellow-type joints typically present in riser ducts (Figures 13, 14). However, repeated flexing of the thin-walled material can result in fatigue cracking and failure. Turbine-to-ductwork expansion joints also deteriorate and leak over time, similarly to those in WCCs.

Bolts

Wherever bolts are maintaining a seal that protects a vacuum, including flanges and manways, there is a potential for loose bolts or loosening from corrosion that could allow AIL (Figure 15). The presence of vibration or thermal stresses could accelerate this process. Over-torquing bolts or flanges can result in failure / leaks as well.

Corrosion

Where wall thickness is small, primarily in the finned heat transfer tubing, through-wall corrosion can occur. In practice corrosion at the point of steam entry into the tubes has been commonly observed, although through-wall corrosion has not been frequently identified (Figure 16). Corrosion on finned tubing also can occur from the exterior when a combination of poor water quality for tube cleaning and debris accumulation allows wet material to remain on tube surfaces for an extended period (Figure 17). In humid areas, water may condense from air and remain on the upper regions of dephlegmator tubes, which are cool due to the air removal process (Figure 18). This issue is also exacerbated by debris accumulation in the area. Access to the upper end of tube-to-tubesheet connections may be challenging but the area is important to evaluate.

ACC rupture disks

The rupture disks on ACCs are typically a different design from those on steam turbines, but they may fail to seal tightly due to the presence of debris or from mechanical failure (Figure 19).

Piping under insulation

If insulation is not sealed adequately from atmospheric moisture, water can accumulate and corrode carbon steel piping over an extended period (Figure 20).

Previous leak repairs

If leak repairs have been done previously, it is always good to re-check to confirm that the repair is still functioning properly. Any repair should have been checked after completion to confirm whether it resolved the leak.

Prioritization of Air In-leakage Repairs

AIL repairs are not necessarily prioritized by a plan or formula as there are many factors to consider including the effect of the leak on plant performance and the immediate urgency for power generation. The largest leaks that are identified are highest priority Any simple repairs that can be performed with the unit online, such as tightening bolts or closing a valve, should be done as soon as convenient. More complex repairs such as replacing an expansion joint, sealing tube leaks, or repairing LP turbine seals may require considerable expense including taking the unit offline. In some cases, it may be possible to apply a sealant as a temporary repair, such as with cracks or small leaks in finned tubing. For LP turbine seals, increasing the water pressure on seals may reduce AIL until more in-depth work can be done.

Air In-leakage Program

Effective management of AIL requires an organized program, at least on a basic level.[1] For companies that have both WCCs and ACCs, both types should be included in the program. Overall program responsibility is probably best given to corporate personnel and can be assigned to management, but a relatively experienced corporate individual who understands plant performance engineering should be expected to manage program implementation. This should include the following actions:

- Identify a lead on-site individual for each power plant.
- Assist the plant lead in setting up the program at each plant, including routine monitoring / reporting on AIL status.
- Work with the plant lead to manage inspections, including timing and arranging for leak testing.
- Review leak testing results and identifying actions to take; managing completion of actions (including repairs).
- Report outcomes of AIL situations, testing and resolutions to corporate management.

As with all effective corporate programs, support for the AIL program must be provided at upper management levels (e.g. Vice-President of Generation).[4]

Guidance for specific personnel involvement in the AIL program is provided from Reference [1], as follows:

> *The following provides an outline of the membership and responsibilities of the Air In-leakage Program Team:*
>
> *• Unit Operators. Checking at least every shift on the instruments provided for their unit: vacuum, air extraction, etc. Informing Team if there is a problem and asking chemists to confirm oxygen levels at CPD. Many plants monitor vacuum continuously and have limits and an alarm.*
>
> *• Plant Chemists or personnel responsible for plant chemistry. Monitoring dissolved oxygen at the CPD on a daily basis, which should be < 10 ppb (μg/kg)*

even for units on OT. Observing closely the values for CACE. Informing Team if oxygen and/or CACE is elevated/out-of-specification. This may correspond with the operators' monitoring, but there is not always a one-to-one agreement.

• Performance Group / Plant Engineer. Identify if performance has been degraded.

• Maintenance and/or Inspection Group. Using appropriate tools to identify location of AIL. This may require an outside testing organization, but many plants now have the equipment to conduct these inspections in house.

• Maintenance Group. Repair leakage as soon as possible.

Conclusions

AIL is an issue that can degrade power plant performance and contribute to forced outages and steam cycle corrosion. Leak detection for ACCs is challenging and it is important to recognize and suitably address those challenges to resolve AIL problems. A well-organized program will help ensure that AIL situations are recognized and resolved in a timely manner.

Note: Presentations discussing this and other issues involved with air-cooled condensers can be viewed on the website of the Air Cooled Condenser Users Group at http://acc-usersgroup.org/.

References

[1] International Association for the Properties of Water and Steam, IAPWS TGD9-18, T*echnical Guidance Document: Air In-leakage in Steam–Water Cycles*

[2] Condenser In-Leakage Guideline, EPRI TR-112819, January 2000: https://www.epri.com/research/products/TR-112819

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[4] Air In-Leakage and Intrusion Prevention Guidelines, EPRI 1014125, March 2008: https://www.epri.com/research/products/000000000001014125

[5] Leavitt, Andrew: "The Practical Application of Tracer Gas Leak Detection for Air Cooled Condensers." Air-Cooled Condenser Users Group presentation: Colorado Springs, CO, 2018.

[6] ACC.01: Guidelines for Internal Inspection of Air-Cooled Condensers: https://acc-usersgroup.org/wp-content/uploads/2011/02/ACC-inspection-guidelines-05.12.2015-Initial-Version.pdf, 2015.

[7] Howell, Andrew: "Air In-leakage with ACCs." Air-Cooled Condenser Users Group presentation: Colorado Springs, CO, 2018.

Figures

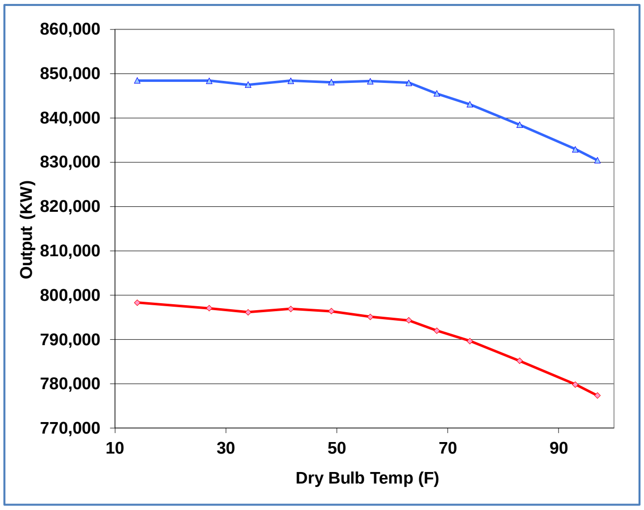

Figure 1: Ambient temperature vs. MW generation for a plant with ACC

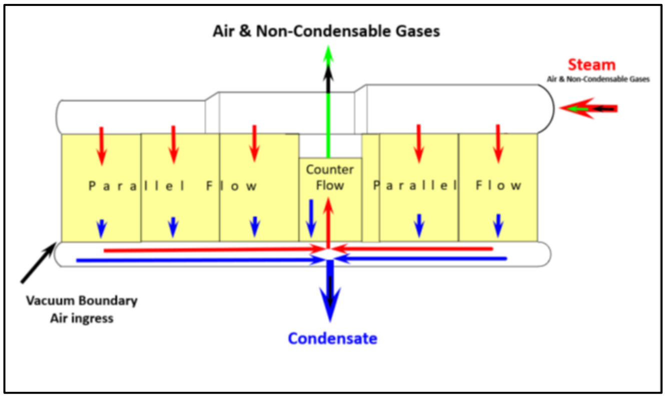

Figure 2: Primary/secondary sections in an ACC[3]

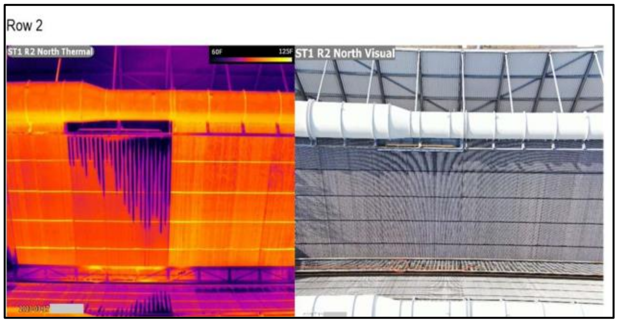

Figure 3: IR image on left; cooler air is present in ACC dephlegmator tubes

Figure 4: Acoustic detection of a leak in ACC tube

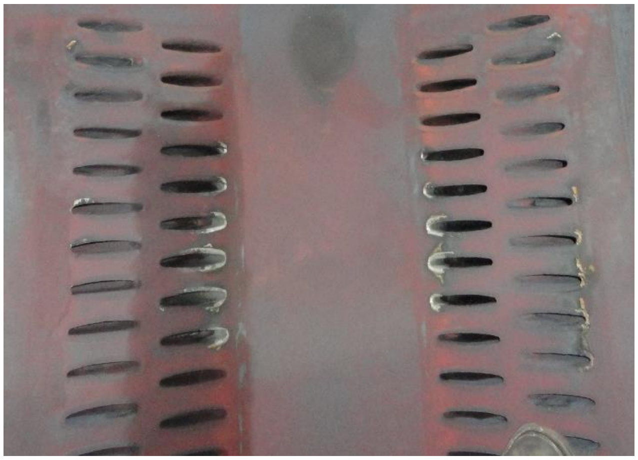

Figure 5: Finned tube entries; FAC is commonly present (bare metal areas)

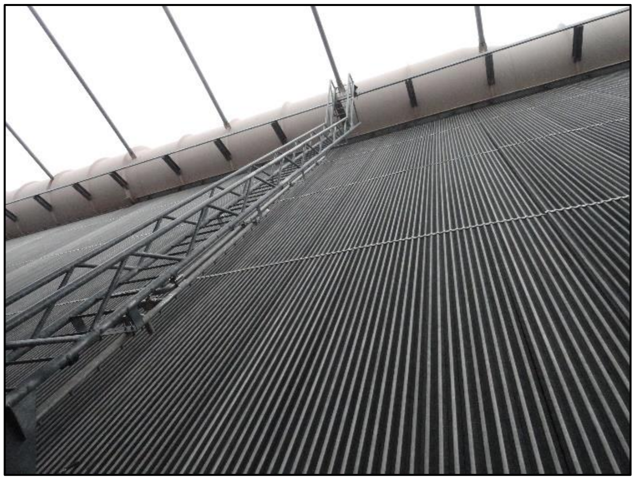

Figure 6: Access is challenging to the upper end of finned tubes

Figure 7: Access to exterior of risers for leak testing is challenging

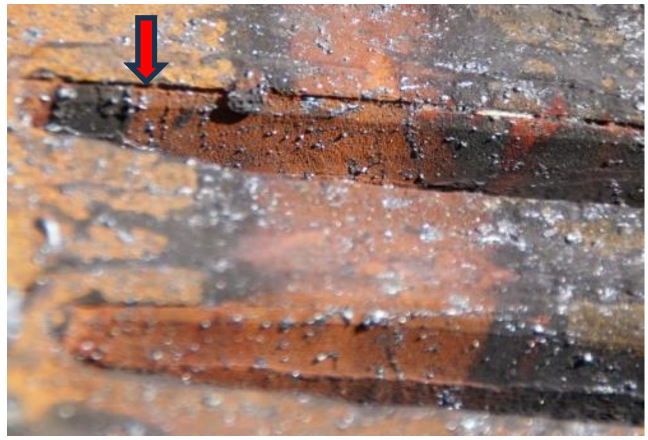

Figure 8: ACC tube-to-header weld crack

Figure 9: Crack in repair of ACC duct

Figure 10: Attachment weld to steam distribution duct

Figure 11: Local rust may indicate wall penetration.

Figure 12: Duct isolation valve

Figure 13: Flanges / expansion joints ACC risers

Figure 14: Leak at expansion bellows in riser duct

Figure 15: Manway entry cover, inadequate bolt torquing

Figure 16: Significant corrosion ('bare metal') at thin-walled finned tube entries

Figure 17: Through-wall exterior corrosion at lower tube due to cleaning water quality

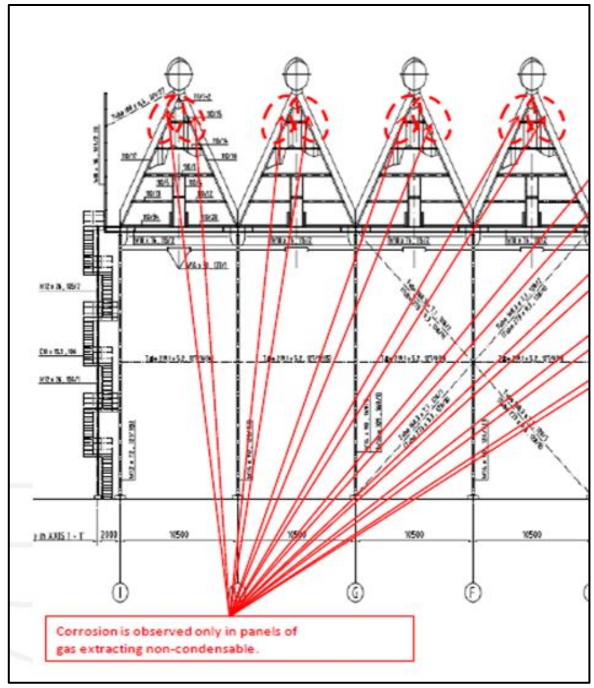

Figure 18: Through-wall corrosion due to external condensation onto cold air extraction region

Figure 19: ACC rupture disks

Figure 20: Leak resulting from corrosion under insulation

Definitions

A-frame: The A-shaped structure defined by a set of finned heat exchange tubes attached to an upper duct.

air-cooled condenser (ACC): A steam condensing device that employs air as the steam coolant.

air in-leakage (AIL): Air drawn into the vacuum caused by condensing steam, occurs when a point of air entry exists

backpressure: The vacuum created by condensing steam in a condenser.

condensate: Liquid water formed from condensed steam.

cation conductivity: The conductivity of a sample stream after cations in the sample are removed by ion exchange and replaced with hydrogen ion. Commonly also referred to as conductivity after cation exchange (CACE) and acid conductivity (AC).

dephlegmator: The section in an ACC that is designed to remove non-condensable gases from condensing steam, also known as ‘secondary section.’

finned tubing: Heat exchanger tubes for ACCs that have external fins to enhance cooling capacity.

primary tube bundles: the majority of the heat exchanger tubes in an ACC, where most steam condensation takes place.

secondary tube bundles: The section in an ACC that is designed to remove non-condensable gases from condensing steam; also known as the ‘dephlegmator.