Air Cooled Condenser Users Group

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ACC.02: Guidelines for Finned Tube Cleaning in Air-Cooled Condensers

Original Issue: November 16, 2018
Revision due: November 16, 2021

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Guideline for Finned Tube Cleaning of Air-Cooled Condensers

Introduction

Steam condensing in air-cooled condensers (ACCs) takes place in specialized heat exchanger tubes designed for optimal heat transfer. Typically, the tubes are composed of carbon steel with exterior (air-side) aluminum coating/cladding, along with external aluminum fins to increase the air-side surface area for heat rejection. Some ACCs, mostly earlier designs, included carbon steel fins on carbon steel heat exchange tubes, with the entire exterior coated with zinc. ACC tubes are normally oval or rectangular in shape and approximately 0.059” (1.50 mm) wall thickness, with closely-spaced fins to facilitate maximum surface area exposure to cooling air flow (Figures 1-3). Air flow is provided by large fans typically positioned below the array of finned tubes, directing air upward in a so-called “forced draft” situation (Figures 4, 5), although an induced-draft design with fans above the array has been introduced that has some potential advantages. High-purity steam exhausted from the low-pressure steam turbine with a few percent moisture (condensed water) travels through large ducts at relatively high velocity, generally at 120 - 360 fps (35 - 110 mps). Steam velocity is dependent on the vacuum; upon reaching the condenser tubes, flow is redirected and drawn into the tubes with a 90^{o} turn. As the two-phase steam-water mixture moves down the 33 - 36 foot (10 - 11) meter tube length, the remaining steam is condensed to liquid water and releases the latent heat of vaporization.

Because air is a relatively inefficient medium of heat transfer, ACCs are large structures with considerable surface area; a moderately-sized power plant (~300 MW steam turbine) may have 20,000 finned condensing tubes. Efficiency optimization in design and operation are critical to viable plant performance.

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.

Operational Factors Limiting ACC Efficiency

Ambient temperature

Dry-bulb temperature is the primary variable that routinely affects ACC performance. Design is typically based on an Initial Temperature Difference (ITD, the difference between the temperature of the cooling airflow and that of the condensing steam) of 15 - 30 ^{o}C (27 - 54 ^{o}F). Steam inside the tubes can range from 100 – 170^{o} F (38 - 77 ^{O}C), and its conversion to liquid water and the associated reduction in volume creates a vacuum, commonly referred to as “backpressure”, that drives overall power plant efficiency. Backpressure in plant design for an ACC may be 3.0 - 3.5 inches of mercury (89 mm mercury or 12 kPa), which will be achievable at lower ambient temperatures (e.g. below 70 ^{o}F / 21 ^{o}C), but which degrades to higher pressure as ambient temperature increases.

As backpressure increases above the design point, more steam must be generated (and thus more fuel burned) to achieve the same megawatt output. At some higher level of backpressure, it becomes impossible to achieve design electricity generation. Backpressure can increase to the point that the steam turbine trips to prevent damage, resulting in complete loss of power generation. Hence, there exists an ambient temperature at which a power plant with an ACC cannot operate. Normally this possibility is minimized in the design phase, including plant siting decisions, although unexpected events (e.g. fans stalled by unmitigated gusts of wind or degraded heat exchanger performance due to excessive fouling) can result in inadequate cooling and unit trip due to high backpressure. This may occur in spite of operation within the design ambient temperature range.

Heat Exchange Tubing Structural / Operational Inefficiency Issues

While finned tube fouling is an inevitable source of performance deficiency, it should be considered as only one aspect of any program or effort to address performance limitations. For a cooling arrangement that invariably lacks efficiency under certain ambient conditions, any detail that improves heat transfer should be evaluated for cost-effective optimization. In addition to removing foulants from finned tubes (discussed in the subsequent sections of this document), other examples of these types of issues include bent aluminum fins (e.g. damaged by hail or other objects), pathways for air to bypass the cooling tubes (typically at tube-to-header regions and poor fit between pre-fabricated tube sections), and open doors in between fan bays, as well as the exterior doors at either end of the street (Figures 6 – 7). Fan pitch must be optimized if airflow is to be maximized, and increasing fan speed with new re-sized motors may result in cost-effective improvements. Airflow modifications such as windscreens, including automated movable screens, can be very beneficial as well, with maintaining windscreen cleanliness an important consideration. These and other similar sources of incremental loss of heat transfer efficiency can add up to a significant overall performance loss, with fuel and financial penalties incurred. Corrective actions are often possible, such as a “combing” tool that could restore a flow path through bent fins, and insertion of suitable material to block gaps between tubes or tube sections (Figure 8).

External (air-side) tube fouling

Cooling fans moving high volumes of air through narrowly-spaced fins will inevitably result in the accumulation of airborne debris on the fan-side of the finned tube A-frame, with the closely-spaced fins acting somewhat as an air filter. Blockage in air passageways prevents optimal heat transfer, reducing steam condensing efficiency and degrading condenser vacuum. There is a wide variety of types of debris, which is location-specific. Typical blocking materials include those from animal sources (birds or bats, feathers, flying insects such as moths), vegetation (cottonwood seeds, leaves), and trash (plastic bags, paper) (Figures 9 - 10).

One particularly troublesome foulant is oil from fan gearboxes (Figure 11). Gearbox oil can leak and travel down fan blades, ultimately being discharged from the end of the blade and carried with airflow to the finned tubes. This oil is both heat-insulating and can serve as a ‘glue’ to which airborne sediment and other debris can adhere. As gearbox oil is very insoluble in water, its removal can be challenging. Appropriate gearbox monitoring and maintenance will reduce the extent of oil leakage and fouling.[1] It has also been recommended that the lower fan thrust bearing be lubricated with grease, which will keep gearbox oil from the bearing and help prevent its dispersion.

Debris / Foulant removal

Material trapped on the fan-side of finned tubes is normally removed with pressurized water, virtually always applied from the exterior (top-side), although it has been noted that debris accumulated on the fan-side at the top of the tubes may require special measures for removal if exterior spray does not adequately access this area.[2] Some less common variations to this approach include blowing with pressurized air or perhaps with readily removable solid materials such as sodium bicarbonate.

Water

Some degree of debris / foulant removal can be accomplished with a fire hose, or even by a heavy rain. However, effective removal normally requires the use of pressurized water and a well-designed, systematic cleaning system, which can provide reproducible, consistent cleaning action. Before applying water for finned tube cleaning, it is advisable to consult applicable site permits regarding the wastewater generated, including the use of any additives such as detergents or organic solvents.

In practice, pressurized water washing of finned tubes is usually done with a commercially-available semi-automatic system that moves multiple spray nozzles automatically in the vertical direction on a track that can be manually moved in the horizontal direction along a tube street (Figure 12). A cleaning system with full automation may be considered if temperatures on the ACC deck are too high for personnel safety, or if labor costs are high.

Exact nozzle position, pressure at the nozzle exit, rate of movement of the spray nozzles, volume of water used, and the number of passes on sections of tubing are critical to adequate cleaning, and these parameters must be selected based on both the specifications of ACC suppliers / consultants and a determination of effectiveness for debris / foulant removal. Suggested considerations for water-washing include the following:

- position nozzles about 8 inches (200 mm) from the fins
- use a supply water pump rated at approximately 22 kW of power, providing water exiting spray nozzles at about 600 - 1100 psi (4.1 – 7.6 MPa) for single-row heat exchange tubing, depending on the fin type and nozzle distance; higher pressures (to 1500 psi / 10.3 MPa) may be required to adequately clean multi-row designs
- variable-frequency drives allow adjustment of the flow rate and ensure soft-start of the motor
- total water volume to adequately flush off debris (40-50 gpm / 150-190 lpm) is critical, as well as setting the spray nozzles at the proper angle

- the pressure range selected should be adequate for thorough fin cleaning, but not so high that the aluminum or carbon steel fins will be damaged; the spray must also be fixed parallel to the fins, and in automated configuration, to ensure fins are not bent by water pressure
- it is better to use stainless steel than carbon steel piping for transporting the supply water, since corrosion products may detach and cause damage to fins; at a minimum, carbon steel transport piping should be flushed thoroughly before initiating high-pressure spray onto fins
- water quality is specified to avoid corrosion or scaling / deposition of mineral deposits on tube surfaces (Figures 13, 14); dissolved mineral content of potable quality or better is needed
- it may be advisable to install a strainer on the pump suction
- the cleaning pump may be equipped with a pressure switch to trip the pump in the event of loss of supply water
- depending on the nature of the foulant(s), it may be necessary to perform multiple passes to first loosen, then remove debris entrapped in the fins.

The fan in the cell being cleaned should be turned off to allow cleaning water containing fouling debris to drop to fan deck or ground level with gravity and avoid re-entrainment in the air flow (Figures 15, 16). Cleaning with the fan on may cause tubes to distort due to quenching and could also result in disbonding of external surface coatings. Some operators prefer to turn off all fans in the vicinity, to avoid debris being picked up with air flow and re-deposited in adjacent cells. Some of the removed material may end up on the fan deck, and other may be rinsed to the ground below the ACC. Material on the fan deck, as well as that rinsed to the ground, should be manually collected for disposal if possible, or else it may be swept up and foul tubes again after cell operation re-commences.

Gearbox oil may not be significantly removed by water washing, as it is not water-soluble. Sediment or other foulants embedded in gearbox oil deposition may also be difficult to dislodge with water-washing. Consequently, there has been interest in adding a solvent to the wash water to assist in gearbox oil removal. Detergent and organic solvents have been considered as additives, although their practical application and effectiveness has not yet been determined. One concern is that wash water containing additives, as well as potentially removed gearbox oil, will soak into the ground below the ACC and become an environmental issue. Constructing a concrete floor below the ACC, with sloping / channeling to collect wash water, has been considered as a means of addressing this concern, although noise level for the system would likely increase with a ground-level concrete base. Temporary use of tarps may also serve this purpose adequately.

It is common to site electronic controls at ground level beneath an ACC (Figure 17). While these are designed for protection from weather, deluge water such as may be encountered in finned tube washing poses a potential risk of an electrical short and damage to this equipment. In addition, it is important to protect the gearbox and motor from water exposure in a cell where cleaning is taking place by thoroughly protecting it with a waterproof barrier such as heavy plastic or by some similar means; this barrier must be tied down / attached firmly in place (Figure 18). In spite of these precautions, gearbox breathers should be checked after the cleaning to ensure that they have not become wet. The fan hoist and pendant must also be moved away from the cell being cleaned, or it may collect water and require replacement.

Personnel operating the pressurized water spray equipment must be given adequate safety equipment and training, including regarding precautions necessary to avoid slipping / falling on wet surfaces.

Air

Debris that is loosely adherent to finned tubing may be removed by simply turning off a fan cell. Besides certain materials that may drop off due to gravity, a reverse air flow will potentially exist due to air demand from adjacent fans, which may support removal of relatively loose material. Application of pressurized air would further support debris and foulant removal. Access to the entire length of finned tubes, however, is difficult. Since complete removal of foreign material by pressurized air is unlikely, this is not suitable as a routine method for finned tube cleaning.

Baking Soda

Baking soda (sodium bicarbonate) was reportedly used successfully as a non-toxic, somewhat abrasive material for successful removal of limestone scale that was difficult to remove by other means.[3]

Other Cleaning Approaches

Removal of debris / foulants by other means is under investigation, but no other approaches are known to be in field use at this time. Alternative options may hold promise, with the additional benefit that no liquid waste is generated; however, it may be necessary to address the issue of debris consolidation, since material normally carried to the ground by water-washing may be readily available for re-entrainment in air flow, and thus be returned to deposit on fins. Any such technology will also need to ensure that no damage is done to the fins.

Frequency of Finned Tube Cleaning

The need for debris / foulant removal should be evident by observing deterioration in condenser performance, if appropriate data is plotted over time. The following process is advised:[4]

1. Select data points under conditions of near full load, all fans in full operation, and low wind.
2. Plot turbine exhaust pressure vs. ambient temperature on the ACC performance curve supplied by the OEM.
3. Note whether data moves away from the curve over time:
    a. If data shift is relatively slow and gradual, the ACC is likely accumulating debris / foulants.

b. If data shift is sudden, it is likely that a new air leak into the vacuum has developed.
c. If data shifts erratically, wind influence on performance is indicated.

Regardless of how accurately condenser performance is measured, the performance loss is significant enough that the influence of debris on backpressure can typically be estimated. It is common for operators to report clear improvement in plant performance after a water wash cleaning is completed, so timely removal of airside debris / foulants is important. Finned tubes typically require cleaning about once per year, but specific site conditions may dictate more, or less, frequent cleaning; more than four cleanings annually would be unusual. In humid ambient conditions, condensation may routinely develop on cold regions of the exterior of dephlegmator panels; if debris removal is not frequent enough, this debris can retain moisture and promote corrosion. In particular, this may occur with multiple-row tube designs where material is more difficult to flush out; flushing water from the interior as well as the exterior may be beneficial. The presence of some fine material can be evident visually, particularly if sections of fins are completely blocked such that daylight through the fins is not visible (Figure 19). However, a thin surface layer of a foulant such as dust (fine particles of sediment) may readily allow visible light through fins; close examination may be required to identify the presence of a thin but insulating layer of such debris. Static pressure in the fan bay can be a good measure of the extent of fouling, provided a baseline pressure was measured when the fins were clean, for comparison. Cost-benefit evaluations should be undertaken to optimize cleaning frequency (e.g., Fouling Software or calculations developed for this purpose).[3]

Power stations may schedule tube cleaning prior to the season of hottest ambient temperature, so that heat transfer is optimal during the most challenging operational period. Alternatively, immediately following seasonal events where fouling dust, insect or plant material is at its peak may be the preferred time to clean, or an additional cleaning may be advisable. Each plant needs to evaluate the extent of fouling and its impact on performance (backpressure) in order to devise cost-benefit scenarios for maximum benefit. Special circumstances may dictate special actions; for example, birds nesting in the piping of the air removal system have required more frequent cleaning of dephlegmator cells.

Implementing the Cleaning Process

There are two basic approaches to carrying out water-washing of finned ACC tubes. The preferred option is to have a permanently-installed pressurized spray system on each street, with a single accompanying pump and water supply system. Having this arrangement in place increases the likelihood that cleaning will take place, since the only significant requirement for carrying out the cleaning is to provide personnel to accomplish the task. The work can be accomplished by a single person if convenient (employee or contractor), albeit at a relatively slow pace (Figure 20).

Alternatively, a contractor may be hired to bring in cleaning equipment and carry out the cleaning process. While there are not necessarily any inherent technical problems with this approach, it is possible that fluctuating budget concerns and timing conflicts will result in less than optimal cleaning timing and frequency.

The cleaning itself may take anywhere from a week to two months, depending on the size of the condenser, the rate of nozzle movement (perhaps two to twenty feet per minute, depending on the flow rate), whether cleaning is done in one, two, or more passes at each location, the number of people assigned to the job, the length of the workday (single-shift vs. two shifts or round-the-clock), and any delays with the process such as pump failure, nozzle clogging, mechanical failure, operational priorities, etc. As mentioned previously, the fan in the cell being cleaned must be off, and perhaps the fans in adjacent cells as well. While it would be best to clean fins before the Summer season of high power demand, if cleaning is necessary in hot weather, it may be best to plan on doing the cleaning at night, when temperatures are more bearable for the cleaning crew and taking fans off-line with reduced load generation is not as critical.

Each unit / station should develop appropriate procedures for carrying out the cleaning on its own condenser.

Conclusions

Cleaning the exterior of finned ACC tubing must be undertaken periodically to maintain optimal unit performance. Well-designed approaches for timing and implementing the cleaning must be determined and enacted. ACC operators must be diligent to optimize heat transfer by addressing manageable issues that degrade performance.

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] Rettke, D. “ACC Condition-Based Maintenance.” 5th annual meeting of the air-cooled condenser users group, Summerlin NV, 2013. http://acc-usersgroup.org/wp-content/uploads/2013/10/ACC-MECHANICAL-MAINTENANCE-2013-presentation.pdf

[2] Montemayor, M.C., personal communication, 2018

[3] Hubregtse, H., personal communication, 2018

[4] Maultbetsch, J., personal communication, 2018

Figures

Figure 1: Typical heat exchange tubes in a single-row design, carbon steel tube with aluminum fins and external coating.

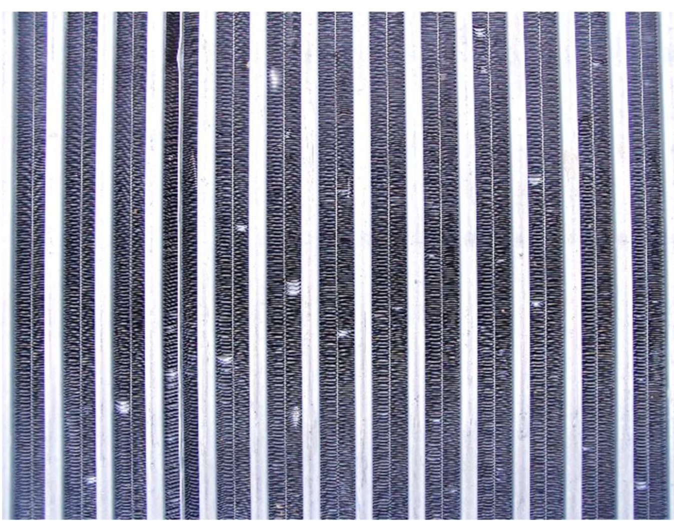

Figure 2: Tubes in an ACC viewed from the exterior (airside).

Figure 3: ACC heat exchange tubes viewed from inside the upper duct (steamside).

Figure 4: Large ACC fan viewed from beneath; air is typically forced upward through the finned heat exchange tubes.

Figure 5: ACC fans in operation.

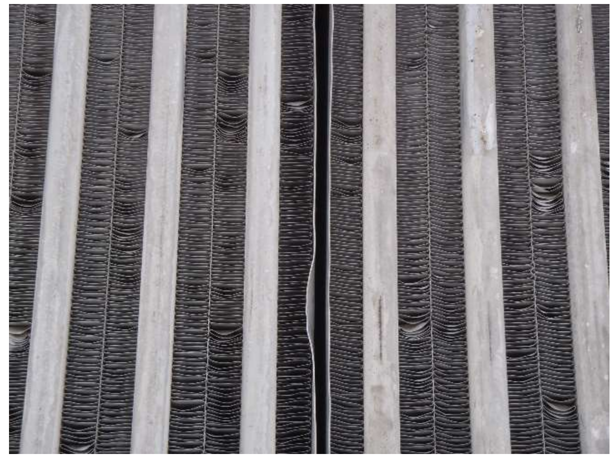

Figure 7: Gap between sets of tube bundles, allowing air to bypass cooling tubes.

Figure 6: Aluminum fins on exterior of A-frame, damaged by hail.

Figure 8: Gaps between individual ACC tubes blocked with rubber strips to minimize air bypass.

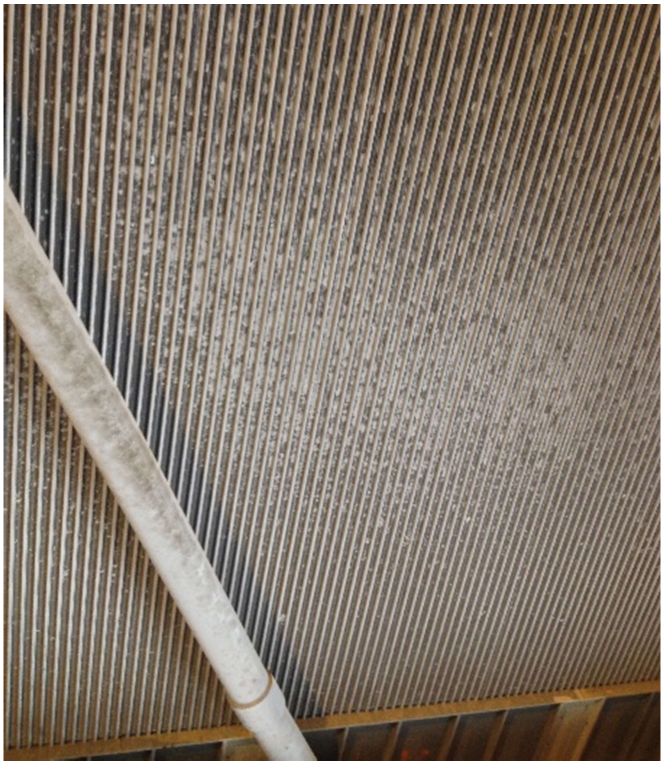

Figure 9: Underside (fan-side) of A-frame with significant debris blocking airflow through fins.

Figure 11: Gearbox oil splatter in fan bay.

Figure 10: Debris on fins; note plastic bag.

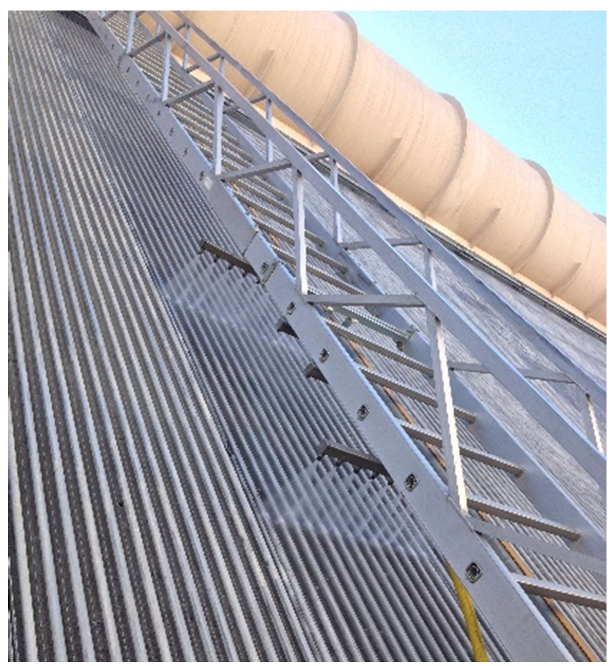

Figure 12: Water-spray washing with a permanently-mounted system.

Figure 13: External corrosion of finned tubes due to poor quality water supply.

Figure 15: Finned tube water-washing, fan bay interior.

Figure 14: Steamside tube entries with through-wall corrosion from exterior.

Figure 16: Water under ACC after finned tube cleaning.

Figure 17: Electrical equipment under ACC.

Figure 18: Fan motor/gearbox covered during water spray cleaning to protect from water.

Figure 19: Finned tubes after cleaning; sunlight showing clear path through fins where blockage is minimal.

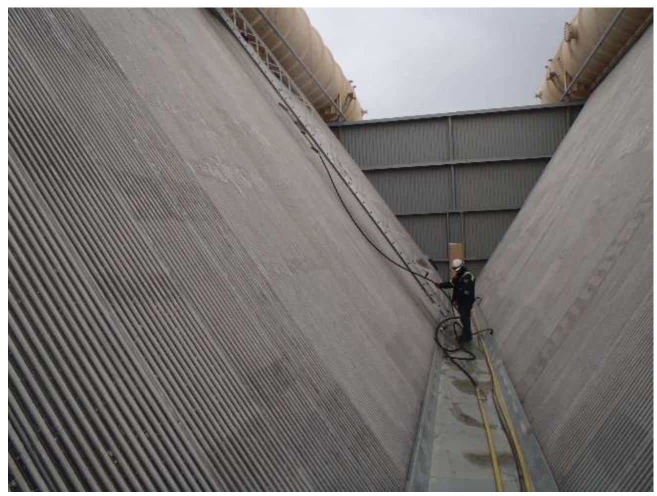

Figure 20: Semi-automated finned tube wash system operated by one person.

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 inleakage: 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.

dephlegmator: The section in an ACC that is designed to remove non-condensable gases from condensing steam.

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