Performance Characteristics of an Air-Cooled Condenser Under Ambient Conditions

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Abstract -- In this paper effects off air flow pattern as well as ambient conditions are studied. Unfortunately ACC becomes less effective under high ambient temperature and windy conditions. Fin cleaning plays a vital role in heat rejection. External surface cleaning improves air side heat transfer coefficient. Ambient conditions affect the steam temperature and heat rejection rate. It is observed that rise in wind velocity decreases thermal effectiveness of ACC up to considerable level. Ambient temperature not only affects performance of ACC at the same time turbine back pressure also increases with rise in ambient temperature. Skirts are effective solution to reduce the effect of wind on volumetric effectiveness. Hot air recirculation increases with wind velocity. Now a days wind walls are used to reduce this effect. Second option is to increase fan speed. It counter affects on electrical power consumption.

Index Terms -- Ambient temperature, Hot air Recirculation, Thermal effectiveness

I. INTRODUCTION

Due to the decreasing availability and rising cost of cooling water, dry-cooling towers or direct air-cooled condensers (ACC’s) are increasingly employed to reject heat to the environment in modern power plants incorporating steam turbines. Unfortunately, with an increase in the ambient temperature, the effectiveness of these cooling systems decreases resulting in a corresponding reduction in turbine efficiency. The reduction in turbine output during hot periods may result in a significant loss in income, especially in areas where the demand and cost for power during these periods is high.

II. DRY COOLING

As the availability of water required for wet-cooling systems becomes more limited, modern power plants are increasingly employing indirect dry-cooling towers or direct air-cooled steam condensers to condense steam turbine exhaust vapor. Direct air-cooled condenser units in power plants usually consist of finned tubes arranged in the form of a delta or A-frame to drain condensate effectively, reduce distribution steam duct lengths and minimize the required ground surface area.

A-frame direct air-cooled steam condenser units are normally arranged in multi-row or multistreet arrays. Each street consists of three to five main condenser units with a dephlegmator or secondary reflux condenser connected in series. The addition of the dephlegmator increases the steam flow in the main condenser units to such an extent that there is a net flow of steam out of every tube. This inhibits the accumulation of noncondensable gases in the tubes that may lead to corrosion, freezing or a reduction in the heat transfer capability of the system.

Unlike the thermal performance of wet-cooling systems, which are dependent on the wet bulb temperature of the ambient air, an air-cooled system’s performance is directly related to the dry bulb temperature. The ambient dry bulb temperature is normally higher than the wet bulb temperature and experiences more drastic daily and seasonal changes. Although air-cooled systems provide a saving in cooling water, they experience performance penalties during periods of high ambient temperatures.

III. CURRENT WORLD WIDE ACC SCENARIO

Selection of cooling technology for use in power plants is an economic decision which is frequently influenced by local environmental and political factors. In the early days, use of dry cooling methods was sometimes the only feasible option due to scarcity of water at otherwise attractive plant sites in arid and semi-arid regions of the world. However, the combined trends of increasing demands for power, more widespread scarcity of available water for cooling and increasing costs of water and tighter environmental restraints related to use of wet cooling systems served to broaden selection of the ACC option, in term of both number and size of units.

Fig. 1 Worldwide installation of dry cooled power plants.

Graph given above depicts the trends in installation of ACCs and indirect dry cooling systems on units >100MW since 1960. (Indirect designs employ water cooling of turbine condensate in a closed system arrangement with air-cooled exchangers used to reject the heat transferred to the cooling water during condensation.) From this figure it quickly
becomes apparent that increased interest started around the mid 1980s has generally continued to grow, particularly over the last 10 years.

IV. THE IMPACT OF AIR COOLED CONDENSER ON PLANT DESIGN AND OPERATIONS.

Air-cooled condensers were first introduced into the U.S. power industry in the early 1970’s, but only during the last decade has the number of installations greatly increased, largely in response to the growing attention being paid to environmental concerns. The rising importance of this rather different technology for the condensing and recovery of exhaust steam calls for a broader understanding of the associated design and application principles involved, as well as of the performance monitoring techniques and cleaning methods that have to be applied.

Over the past 30 years there has been a growing and competing demand for water for both domestic and industrial use and this has brought an increased interest in the use of air as a cooling medium in place of water. In the utility industry, the earliest applications for the air-cooled condensing of exhaust steam were modified air-cooled heat exchangers similar to those already in use by the process industries. Eventually, air-cooled condensers designed for the utility industry evolved into a configuration that recognized the special needs of condensing a large volume of low pressure vapor as well as the removal of non-condensable.

V. THE ENVIRONMENTAL PROTECTION AGENCY AND DRY COOLING

In 2000, the U.S. Environmental Protection Agency conducted a comparative study of the environmental impacts of wet vs. dry cooling. Their conclusion was that the energy consumption per lb. condensate was higher for dry cooling than for wet cooling and that the atmospheric emissions associated with that energy consumption was also higher. These disadvantages are offset by the cooling water intake flow being reduced by 99% over that required by a once-through system; or 4-7% over a closed cooling water system. They also noted that dry cooling eliminates visual plumes, fog, mineral drift and water treatment and waste disposal issues. However, their conclusion was that, ‘dry cooling does not represent the “Best Technology Available (BTA) for minimizing environmental impact”.

Much of the E.P.A.’s concern is that ‘the high costs and energy penalty of dry cooling systems may remove the incentive for replacing older coal-fired plants with more efficient and environmentally favorable new combined-cycle facilities’, the latter presumably equipped with wet-cooling systems.

VI CORROSION PROBLEMS WITH AIR COOLED CONDENSERS.

Corrosion of the carbon steel components in these large systems has been a concern because of the impact of high iron levels and air in-leakage. The maximum corrosion has been observed at the entries to the A-frame ACC tubes. The mechanism of this corrosion is not fully understood and little work has been expended in trying to rectify this. Based on various analyses the actual corrosion appears to be a flow-accelerated corrosion (FAC) derivative where local indigenous magnetite is removed from the surface of the ACC tube leaving a very intergranular surface appearance. Adjacent to these areas where the local turbulence of the two-phase media is not as great, the magnetite deposits on the surface. There are clear boundaries between the regions where corrosion/ FAC takes place (white bare metal) and regions where deposition (black areas) occurs.

![Fig. 2 DHACI Indices 1-5 for upper ducts and tube entries.](image)

ACC Corrosion Index:

After inspecting a number of ACCs around the world, two of the authors developed an index for quantitatively defining the internal corrosion status of an ACC. This is known by the acronym DHACI (Dooley Howell ACC Corrosion Index). The index separately describes the lower and upper sections of the ACC, according to the following:

Upper Section

1. Tube entries in relatively good shape; possibly some areas with dark deposits in first few inches of tube interior. No corrosion or FAC.
2. Various black/grey deposits on tube entries as well as flash rust areas, but no white bare metal areas. Minimal corrosion/FAC.
3. Few white bare metal areas on a number of tube entries. Some black areas of deposit mild corrosion/FAC.
4. Serious white (bare metal) areas on/at numerous tube entries. Extensive areas of black deposition adjacent to white areas within tubes. Serious corrosion/FAC.
5. Most serious. Holes in the tubing or welding. Obvious corrosion on many tube entries.

VII. CLEANING TECHNIQUES FOR AIR-COOLED CONDENSERS

The three principal methods for cleaning the external surfaces of air-cooled condensers are as follows:
- Fire hose
- High pressure Handlance
- Semi-Automated cleaning machine
1) Fire Hose

While the volume of water consumed is high, a fire hose offers only a low washing effect because of the low pressure involved. The galvanized surfaces of the tubes and fins are not damaged by this method. Unfortunately, in order to perform cleaning the plant must be taken out of service and scaffolding erected. The process may also be time and labor intensive depending on unit design and accessibility. It has also been found that use of the fire hose only leads to small performance improvements even if the surfaces seem to be optically clean.

2) High Pressure Handlance

The high pressure handlance method offers low water consumption and a high water pressure. Unfortunately, the latter can cause the galvanized surfaces to become damaged or even cause the fins to be snapped off. Again, the plant must be taken out of service and scaffolding erected in order that cleaning can be performed. Unit accessibility will affect cleaning productivity. As with the use of a fire hose, this procedure only leads to small performance improvements and, once the fouling material has been compressed, it hinders heat transfer and obstructs air flow.

3) Semi-Automated Cleaning Machine

The semi-automated cleaning machine, an example of which is shown in Figure, uses a significant volume of water; but at a pressure that, while allowing for effective surface cleaning, avoids damaging galvanized surfaces and fins.

The main components of the system include a nozzle beam, a tracking system. The nozzle beam matches to the tube bundle geometry, with a constant jet angle. Optimizing the geometry of the nozzle beam involves determining the proper nozzle distance to the surface.

VIII. ULTRATECH AIR-COOLED CONDENSER DETAILS

ACC transfers exhaust steam into condensate, then gives condensate to water circulation. Exhaust steam comes from turbine gets into ACC steam collection header through steam pipe. In the steam collection header, steam falls down in fin tubes in “A”frame of air cooled condenser due to vacuum.

The steam in tubes is condensate by air come from fan. The condensate will be collected in the steam collection header and gets the bottom of “A” structure; then goes to CRT (hot well).

We use two condensate pumps. They pump condensate water to condensate water header, gland seal cooler and LPH, at last, gets to deaerator. The un-condensate is exhausted by

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<th>No.</th>
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<td>3</td>
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<td>Distance of fin</td>
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The steam in tubes is condensate by air come from fan. The condensate will be collected in the steam collection header and gets the bottom of “A” structure; then goes to CRT (hot well).
steam ejector. For any condenser condensation of steam as well as removal of dissolved gases are important. Each condenser contains six fans. Fan no. 1, 3, 4 & 6 are for the condensation of turbine outlet steam. Fan no. 2 & 5 are for dephlegmator section. Dephlegmator section is connected with steam ejector system. For this particular plant being at sea shore ambient temperature playing effective roll.

Due to sea shore it is not going as higher as compared to interior regions. As shown in the sketch dephlegmator section is just like sandwich form. A-Frame air cooled condenser is shown in the sketch.

IX. RESULTS AND DISCUSSION

1) Effect of Wind Velocity on Hot Air Recirculation

From the above results, it is found that the HAR of the ACC system is extremely serious when the wind blows normal to the boiler house.

![Graph showing heat recirculation at different wind velocities](image)

In order to the further understand the impact of the unfavorable wind condition on the HAR, twelve wind speeds are selected for the numerical calculation. The curve shows that the HRR varies with the wind speeds. It is clearly seen that HRR maintains the growing trend with the increase of wind speed. With the increase of the wind speed, the interaction and disturbance between hot exhausted air and weak flow of leeward side of the boiler house and turbine room are gradually enhanced, and in the addition of intensive suction of axial flow fans, a lot of hot exhausted air involves into the fan-inlet of the edge of the ACC platform. However, when the wind speed reaches up to very high level reduction is possible of the HAR of the ACC system. The main reason that causes this reduction trend is that under the strong wind conditions, the forced convection action of oncoming wind and hot exhausted air are evidently reinforced, therefore most of the heat quantity are transferred and diffused to the downwind of the ACC platform.

2) Hot air recirculation at different fan speeds:

The ambient wind field around the ACC system is one of major factors that cause the HAR, and the variation of fan rotational speed will inevitably lead to the changes of wind fields, so the fan rotational speed is also an indirect factor affecting the HAR. In the current calculations, four rotational speeds of 800 to 1400 r/min are considered for the comparison and analysis.

![Graph showing heat recirculation as a function of fan speed](image)

According to the relation that the volume flow rate is proportional to the rotational speed, in the ACC cells around the edge of ACC platform shown in the graph. The temperature of the fans boundary and the ambient temperature are both 30˚C. The ambient wind speed is in between 6 to 9 m/s. The graph shows that how the HRR varies with the increases of rotational speed. It is concluded that the HRR gradually reduce with the acceleration of rotational speed. The reasonable explanations causing this phenomenon are that accelerating the rotational speed of the edge fans leads to the increment of fan flow rate, which makes inlet and outlet wind speed of the ACC both increase correspondingly, thus aggravating the convective heat exchange between the cooling air and the finned tubes. The temperature of the hot air exhausted from the ACC has aggrandized, but the kinetic energy along the vertical direction will increase, which can weaken the entrainment phenomena of flow-field around the ACC on the hot exhaust air. Finally, the hot air involved into fan-inlet is to reduce and its temperature is to lower.

3) Effect of wind velocity on effectiveness:

As the wind speed increases inlet flow distortion experienced. The thermal effectiveness decreases as the wind velocity increases as shown in the graph. The flow distortion and regarding low pressure region at the upstream region of the fan contributes in the decrease of ACC performance. The wind itself has positive impact on certain fans also.

![Graph showing effectiveness at different wind velocities](image)

The volumetric effectiveness also can be increased. Relatively at low wind speeds effectiveness is higher. As the
wind velocity increases due to flow distortion and low pressure regions thermal effectiveness of ACC is reducing up to level of 61.5%. The favorable thing for ACC is that wind velocity improves volumetric effectiveness.

4) Ambient Temperature effect on heat rejection:
The magnitude of the vortex increases in the downstream direction due to increased air temperature. ACC becomes less effective when ambient temperature is higher.

![Fig. 8 Heat Rejection for various Ambient temperatures](image)

As ambient temperature increases from 22°C heat rejection rate decreases as its effect on LMTD. Up to large extent heat rejection rate depends on inlet (ambient) temperature and ambient temperature depends on the seasons. Normally in winter heat rejection rate is as per design. In summer as the ambient temperature increases it adversely affect on heat rejection because it decreases LMTD and ultimately heat rejection. Due to this reason in some of the areas of the world they are using water spray techniques to maintain heat rejection rate constant. Ultra tech power plant is situated at sea shore and where ambient temperature never exceeds 36°C. In countries like India ACC can work better nearer to sea shore.

5) Cleaning of an ACC.
Heat is rejected in the atmosphere and rejection rate is largely dependent on the surface condition of fins. Due to different weather conditions fouling occurs on the surface of exposed surfaces. Due to the deposition it decreases heat rejection rate and ultimately cleaning becomes inevitable. Thermal effectiveness increases even though mass flow rate of air decreases. By cleaning coefficient of heat transfer (air side) is increasing. For different values of coefficient calculations are made and plotted graph clearly indicates that as cleaning progresses less mass flow rate of air is required.

![Fig. 9 Effect of cleaning on Thermal Effectiveness.](image)

At the same time thermal effectiveness also increases. For different 5 values of heat transfer coefficients calculations have been made. As the cleaning progresses required mass flow rate decreases for the same heat rejection. Cleaning not only reduces mass flow rate of air but gives considerable savings in terms of rupees.

6) Ambient Temperature impact on Turbine Back Pressure:
Ambient temperature plays key role not only heat rejection but it also effects on turbine back pressure. As the turbine back pressure increases output of turbine decreases. Increased back pressure will reduce heat transfer rate and adversely affect on vacuum to be maintained. Increased ambient temperature reduces heat transfer rate due to that steam to condensation conversion rate is badly affected.

![Fig. 10 Turbine Back pressure Vs. Ambient temperature.](image)

This is the reason why turbine back pressure is increasing. In summer turbine back pressure rising occurs because of higher ambient temperature. As the ambient temperature increase turbine back pressure starts to increases. It increases from 0.78 to 0.9 Kg/cm² for the rise in temperature difference of only 14°C.

7) Skirt effect on volumetric performance of ACC:
The addition of skirt does increase the performance of an ACC measurably under windy conditions, by modifying the flow into the ACC and by reducing the hot air recirculation that exists at the downstream edge fans. The low pressure region at the inlet of the upstream edge fans is displaced away from the fan inlet, resulting in an increase in the volumetric effectiveness of the upstream edge fans and a corresponding increase in the volumetric effectiveness of the ACSC.

![Fig. 11 Effect of Skirt on Volumetric Effectiveness.](image)
At a relatively low wind speed (3 m/s) the volumetric effectiveness of the ACSC with a 3 m skirt is approximately 99%. Even though the volumetric flow rates of the upstream edge fans are below the ideal volumetric flow rate, the volumetric effectiveness of the downstream fans are increased to the windy conditions.

X. CONCLUSION
The primary focus of this study was to determine performance trends of an ACC under atmospheric parameters.

- Ambient temperature plays key role in the performance of ACC. Generally ACC is advisable where ambient temperature not rising much, especially at sea shore areas. More than that ambient temperature also effects on turbine back pressure which can reduce output power. In both these cases ambient temperature impact is considerable.
- After ambient temperature wind velocity is the secondary parameter which affects on ACC performance. As the wind velocity increases effectiveness (thermal and volumetric) decreases and hot air recirculation increases.
- Hot air recirculation is generally observed in so many plants. To minimize fan rotational speed to be increased. This is not the solution because electrical energy consumption by fan will increase. The optimum solution is wind wall on the sides of the radiator.
- Various techniques for cleaning are adopted to increase heat transfer rate. As the cleaning progresses for various heat transfer coefficients (air side) improves. Ultimately which accelerates heat rejection rate to atmosphere.

XI. REFERENCES