Performance Analysis of Air-Cooled Steam Condenser for Various Tube Heat Exchanger Configuration

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Abstract— Air-Cooled Steam Condenser is a heat exchanger consisting of an array of finned tube bundles. It consists of a primary heat exchanger, where major heat transfer takes place and secondary heat exchanger (dephlegmator) which is used to remove non-condensable from the system. The performance of an Air-Cooled Steam Condenser is influenced by the configuration of the finned tube bundles. It is significant to understand the mechanism of such influences to select the optimized configuration of the finned tube bundles. In this study Air-Cooled Steam Condenser is designed under two ambient conditions and for various finned tube bundle configuration. Finned tube bundle configuration means the number of tubes per bundle, fin density of tubes in each row, type of fins, length of the tubes and diameter of the tubes. The design calculations are targeted to a fixed power consumption for various configurations so that the relevant comparison is made for heat transfer area and flooding. The results show that flooding is intense in the lower ambient conditions hence heat duty distribution between primary heat exchanger and secondary heat exchanger is adjusted.

Keywords: Air-Cooled Steam Condenser, Tube Heat Exchanger Configuration

I. INTRODUCTION

Air-Cooled Steam Condensers are designed to service the cooling requirements of power plants using ambient air as the cooling medium. No water is directly consumed in the cooling process and the water consumption at an air-cooled plant is thus significantly less than at a wet cooled plant. Since air has a low density and specific heat, large volumes must be circulated to achieve adequate cooling. Fan power consumption in mechanical draft Air-Cooled Steam Condensers is therefore significant and expensive finned-tube heat exchangers are required to maximize the potential for heat transfer. In addition, to achieve adequate circulation, the air-side pressure drop across the ACC should be as low as possible and air velocities through the system need to be minimized. The dephlegmator facilitates additional vapor flow through the primary condensers, flushing them of non-condensable and preventing the formation of dead zones. The dephlegmator must be adequately sized to account for row effects, in the case of multi-row heat exchanger bundles, as well as the influence of transverse variations in tube inlet loss coefficients and non-ideal operating conditions [2].

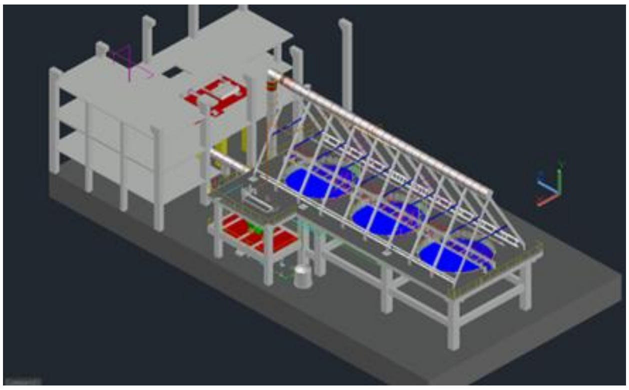

Fig. 1: AutoCAD 3-D model of Air-Cooled Steam Condenser

II. WORKING OF AIR-COOLED STEAM CONDENSER

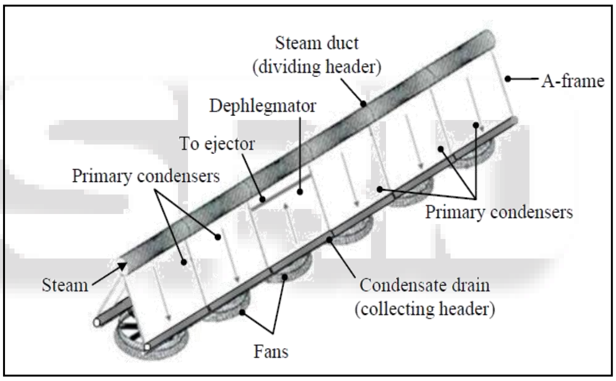

Fig. 2: ACC street with five primary condensers and one dephlegmator[2].

The ACC of a direct air-cooled power plant is made up of several "streets" of A frame condenser units or cells, as shown in Figure 1. Steam is fed via a distributing manifold to the dividing header of the primary condenser units which are connected in parallel in a street. Partial condensation takes place in a co-current vapour/condensate flow arrangement in the primary condenser cells. Excess vapour leaving these cells is condensed in the secondary reflux (counter-current vapour /condensate flow) condenser, or dephlegmator. The dephlegmator is connected in series with the primary condenser units. The steam is condensed and collected in the collecting headers then to the condensate tank. This condensate is reused and fed to the boiler again.

III. CONFIGURATIONS OF TUBE HEAT EXCHANGER BUNDLE

The tube bundle consists of 3 parallel rows of finned tubes. The arrangement of the tubes is staggered.

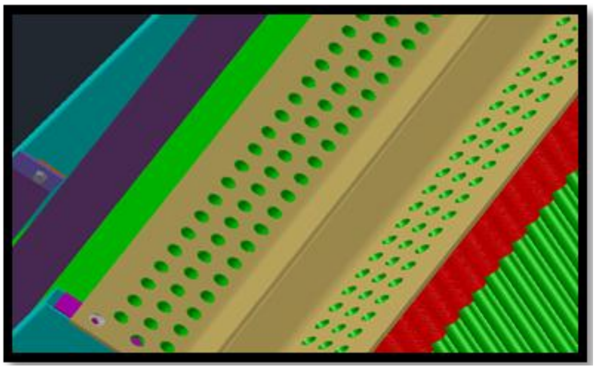

Fig. 3: Staggered arrangement of tubes in tube bundle

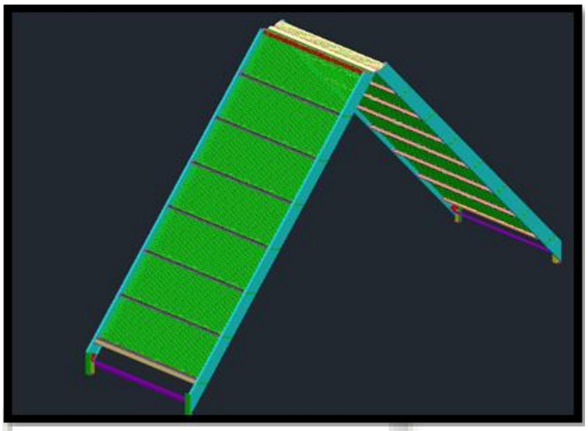

Fig. 4: 3-D model of tube heat exchanger bundle (A-frame)

1) Number of tubes per bundle: The number of tubes per bundle depends upon the size of fan, number of bundles per module and longitudinal pitch of tubes. e.g. for 36 feet fan and 8 number of bundles per module (fan) and for 75 mm pitch 38.1 mm diameter tube maximum of 52 tubes per row can be used.
2) Diameter of tubes: There are two varieties of tube diameter used (31.8 mm and 38.1 mm)
3) Length of the tubes: Length of the tube depend upon the size of fan used. e.g. for a 36 feet fan min of 10 m and maximum of 12 m.
4) Type of finned tubes: There are two types of fins used i) Knurled ii) Extruded. Extruded type of fins are expensive but has higher heat transfer coefficient. For the best performance of Air Cooled Steam Condenser Extruded type of fins are recommended.
5) Fin density: Fin density is the number of fins per unit length of the tube. Generally fin density is measured in fpi (fins per inch). Set of various combinations of fin densities is taken under this study.

Fig. 5: Knurled finned tube (Aluminium)

IV. ANALYSIS

To find the optimum design configuration for tube heat exchanger bundle of Air-Cooled Steam Condenser, sizing calculations are targeted to one fixed power consumption and various parameters are compared. Following two cases are taken under study.

Process Data	Case 1 (Low Ambient)	Case 2 (High Ambient)
Steam Mass Flow Rate	15.566 kg/s	21.667 kg/s
Turbine Back Pressure	199 mbar	196.3 mbar
Steam Enthalpy	2491.1 kJ/kg	2512.1 kJ/kg
Design Ambient Temperature	35°C	45°C
Maximum Ambient Temperature	35°C	48°C
Minimum Ambient Temperature	30°C	4.5°C
Design Relative Humidity	60%	60%
Site Altitude	0.1 m	446 m
Air Density	1.132 kg/m^3	1.0152 kg/m^3

The guaranteed shaft power of fan for low ambient case is targeted to 296 kW (±2kW) and for high ambient case it is targeted to 570 kW (±2kW) from the reference of previous projects of similar design conditions so that the relevant comparison is made for below parameters:

– Heat Transfer Area
– Flooding

This study compares the parameters for following set of design configuration for two cases to get better clarity.

1) Primary Bundle Tube Diameter 31.8 mm and Secondary Bundle Tube Diameter 38.1 mm
2) Primary Bundle Tube Diameter 38.1 mm and Secondary Bundle Tube Diameter 38.1 mm
3) Primary Bundle Tube Diameter 38.1 mm and Secondary Bundle Tube Diameter 38.1 mm

each of the above case is designed for fin densities 8/8/8, 8/9/10, 9/10/10, 9/10/11, 9/11/11, 10/11/11. 8/8/8 means 8 fpi for all the rows. 8/9/10 means 8 fpi for first row, 9 fpi for second row and 10 fpi for third row.

Air cooled sizing calculations are divided into three stages. First stage of calculations are performed to get process data for primary heat exchanger bundle sizing. Second stage of calculations are performed to get process data for secondary heat exchanger bundle sizing. Third stage of calculations are performed to match the design parameters.

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V. RESULTS AND DISCUSSION

Air cooled sizing calculations are divided into three stages. First stage of calculations are performed to get process data for primary heat exchanger bundle sizing. Second stage of calculations are performed to get process data for secondary heat exchanger bundle sizing. Third stage of calculations are performed to match the design parameters. Second and Third stage calculations are performed in the HTRI software.

In this paper the graphs for Case 1 (low ambient case) with knurled type of fins are shown. This study has conducted for number of combinations varying the type of fins and pitch of tubes, graphs are plotted for all the cases to get the idea of which combination can be efficient under two ambient conditions. Fig. 6, Fig. 7 and Fig. 8 are the graphs of differential heat transfer area, differential flooding and differential power are plotted to find out the most optimized case. This study aims to minimize the heat transfer area and flooding, hence from each graph optimized configuration can be identified. Fig. 6 shows 8/8/8 configuration has the least heat transfer area and 9/10/10 configuration has the least flooding. For all the cases in Fig. 6 flooding is well below the permissible limit (<90%) hence the deciding factor is heat transfer area. 8/8/8 configuration is most efficient for case A. Similarly, for case B and C we find the same configuration is efficient. Fig. 9 shows the combined graph for case A, case B and case C. It is found that though the case B and case C gives the same efficient configuration, flooding in these cases exceeds the limiting value (90%) hence, it concludes the combination of Primary Bundle Tube Diameter 31.8 mm and Secondary Bundle Tube Diameter 38.1 mm with 8/8/8 configuration is the most efficient.

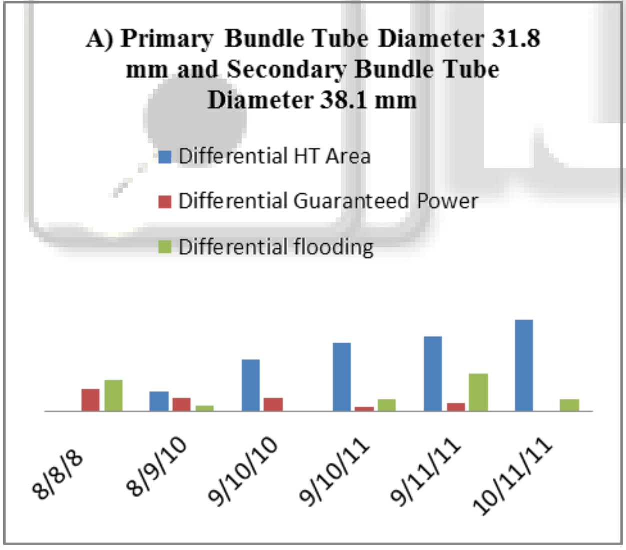

Fig. 6: Differential graph for Case 1 (A)

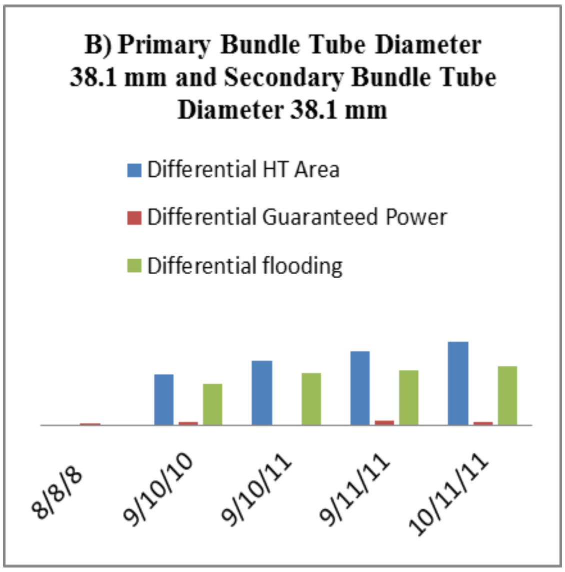

Fig. 7: Differential graph for Case 1 (B)

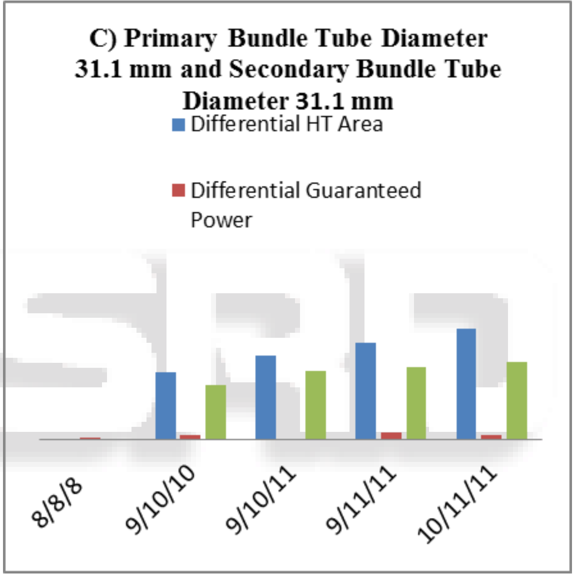

Fig. 8: Differential graph for Case 1 (C)

Fig. 9 shows the flooding increases in the case of combinations of B and C. It is highest for the combination C and lowest for the combination A, hence in the low ambient conditions, in most of the cases combination A is efficient. From the observations of graphs like Fig. 5 the efficient configuration for Air-Cooled Steam Condenser is found out.

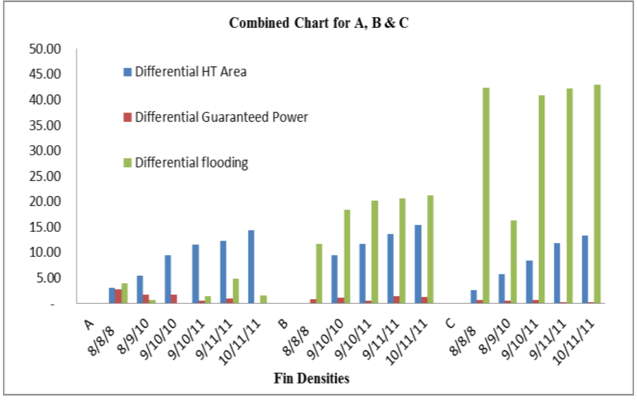

Fig. 9: Combined differential graph for Case 1 (A), Case 1(B) and Case 1 (C)

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