ADVANCED TECHNOLOGIES AND POWER INSTALLATIONS FOR THERMAL AND ELECTRIC ENERGY GENERATION

6.4. Application of air condensers in power industry

6.4.2. Analyses of new design of air condensers

Klevtsov A.V., Pronin V.A.; MPEI (TU)

Analyses of experience in application of air condensers (ACs), produced by the leading world manufactures shows that development of their designs was focused on one direction - elimination of design defects. The published information on technical characteristics testifies that average heat transfer coefficient of various AC designs significantly differs. Considerable difference between them can't be explained only by exterior differences of AC designs of various manufacturers. Significant differences can be caused by other reasons, for example, various structure and thickness of an oxide film, formed on a metal surface. The available national and foreign data doesn't allow expecting further substantial increase in efficiency and reliability of functioning of the existing and operating ACs.

Non-uniformity of condensation with depth of a tube bundle can become a separate issue in designing and operating of ACs. Due to the fact that temperature difference goes down in a direction to outlet of air flow from a tube assembly; some rows of tubes condense less steam than those having lower temperature of cooling air. As a result, uniformity of pressure drop occurs on rows of tube bundle that leads to returnable movement of steam from the last outlet rows on cooling air to those rows of tubes, where condensation has already occurred. An absence of theoretical and experimental researches of this problem leaves an issue of development of the accurate AC calculation technique open.

When designing an AC, a correct choice of air under-heating to the exhaust steam saturation temperature is of a great importance. This is a technical and economic issue, as reduction of under-heating improves thermal efficiency of the installation, but leads to an increase in metal consumption and capital cost of ACs.

When estimating optimum parameters of a condenser installations or a low-potential complex of a power unit, including a low-pressure turbine, a condenser and a technical water supply system, some values required for an AC cooling surface calculation are to be found and for some of them a possible variation range is specified. Calculations are thus made for various options, and a definitive option is chosen with consideration of changes of total costs of the condenser and the elements of the power unit, connected with it.

It is clear that the estimation of a heat exchange surface should be made in a combination with development of a technology of its manufacturing, and thermo-physical and life time (including corrosion) tests should confirm thermal efficiency of the chosen surface and its technological effectiveness.

Thus, the analysis of air condensers, applied in power industry, and their operational characteristics, allowed to reveal the most essential drawbacks, holding wider implementation of ACs:

- possibility of overcooling and condensate freezing at low temperatures of air;
- necessity of heat exchange surface irrigation at high temperatures of a cooling air, aimed to vacuum deepening;
- tendency to snow drifts and icing of the bottom finned tubes;
- large area, occupied by AC;
- necessity of periodic clearing of a heat exchange surface from deposits on ribs and tubes (clearing by water or air);
- low-seismic resistance.

Substantial competitor of air condensers is a circulation cooling water system with evaporation cooling towers or cooling ponds. This system possesses the following disadvantages:

- poor quality and high temperature of cooling water;
- high capital costs in construction;
- harmful environmental influence, connected with high water steam emissions and moisture drops drift;
- need for a water treatment system to provide technical water supply system make-up;
- need for construction of expensive cooling towers (high capital and operational costs).

As it was noted earlier, according to experts of GEA company (Germany), cost of an AC makes 80 … 100 % of the total cost of a circulation water supply system with a surface condenser; power consumption for drives of fans and circulating pumps are about the same.

Thus, it is possible to accept cost of a circulation water supply system with an evaporation cooling tower as a basis for technical and economic indicators.

In comparison with a circulation water supply system with an evaporation cooling tower, AC application has the following advantages:

- independence of a power plant location from a water supply source;
- absence of environmental impact, caused by emissions of steam and moisture drops;
- absence of expensive cooling towers;
- decrease in scaling and bio fouling in a heat transfer equipment;
- increase in reliability of operation of power equipment and the power unit, as a whole;
- higher technological effectiveness due to modular delivery of an AC, factory assemblage of its elements;
- reduction of a power plant construction period due to AC unit delivery;
- practically total absence of a possibility of condensate injection into a flowing part of the turbine;
- possibility of an independent repair of any section of an AC without its complete shutdown that raises reliability of a turbine operation.

Implementation of air condensers in power industry

At the waste incineration plant (WIP-2) (“Spetszavod #2” State Unitary Enterprises “Ekotechprom”) turbine units P-1,2-13/6 with air condensers, made by OJSC “Kaluga turbine works” (KTZ) are in operation. Operation of the plant revealed faults in AC operation, connected with damage of tubes, i.e. there was a defrosting in condensing tubes in winter. Besides, failures of fans took place.

The extensive experimental research was carried out for definition of parameters and characteristics of ACs under various options of fans connection and different steam flow rates. The analysis of possible reasons of "defrosting" of AC heating surface tubes and possible ways to increase reliability of their work were carried out.

The analysis of AC operation has shown that the AC design has a constitutional drawback, namely: the bottom ends of tubes of the whole heating surface or separate tubes are filled with air practically in all AC operational modes. It means that blowing-off modules of the AC and the ejector fail in removal of not condensed gases (air).

The results of the KTZ tests have shown:

1. A considerable non-uniformity of temperatures of AC heat exchange surfaces in a bottom part of modules is set both at a natural convection, and at partially included fans. In the bottom part of modules a temperature of a tube surface at the cooling air input at some AC operating modes is close to a cooling air temperature that can lead to condensate freezing in tubes at negative air temperatures;
2. The main reason of non-uniform distribution of thermal loading is the collector effect and a small share of a heat exchange surface, allocated in gas coolers.

The specified drawbacks cause undesirable consequences under AC operation at negative ambient air temperatures. This is one of the main reasons for conduction of further researches and development of technical measures for increase in AC reliability.

Operation of AC under different operational modes of the waste incineration plant was analyzed in MPEI (Moscow power engineering institute). Thermal aerodynamic analyses of the flow process and heat exchange in AC sections was performed based on measurements of temperature fields of external surface and air, fields of air speed at AC module outlet under their operation.

Analyses of the obtained data:

• considerable distortion of air temperature at the outlet from tube bundles in a cross-section and longitudinal directions is observed;

• in the top part of modules temperature of flue air is essentially higher, than in the bottom; for example:

$\bar{t}_{top} = 50{,}8\,^oC$ $\bar{t}_{bottom} = 37{,}6\,^oC$ (Fig. 6.23)

At the same time air velocity in the same places at the bottom part has higher values, than at the top (Fig. 6.24);

• along the edges of modules slit trenches are noticeable for air pass and possible overcooling of tubes in outer rows;

• in the module with a gas cooler, tube surface temperature is lower at the top than at the bottom. However, at the bottom part overcooling of separate tubes is observed that is obviously connected with condensate flowing down and its overcooling or with its subsequent possible freezing.

Measurements of air temperature and velocity fields in condensing modules and gas coolers of ACs at State Unitary Enterprises “Ekotechprom”of “Spetszavod № 2” have shown:

1) significant temperature non-uniformity of the flow and heat exchange surfaces at the tube bundles outlet. This corresponds well to the results, obtained earlier by KTZ. Besides, significant dissimilarity of air speed distribution in the cooled ACs is revealed. This can be a significant factor of discrepancy of parallel operation of condensing tubes;

2) absence of control and measuring means and regulating devices that doesn't allow to improve controllability and reliability of the considered ACs;

3) it is necessary to develop technical proposals and actions to provide operational controllability of ACs at State Unitary Enterprises “Ekotechprom” of “Spetszavod #2”.

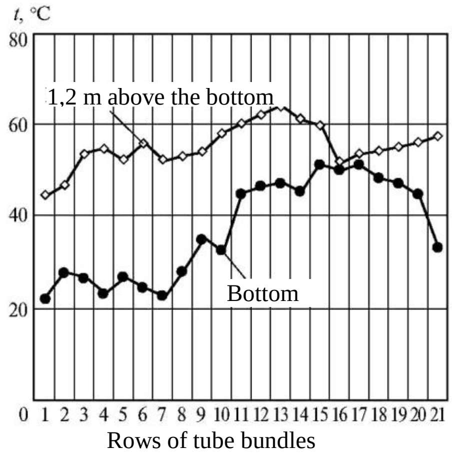

Fig. 6.23. Air temperature at the module outlet

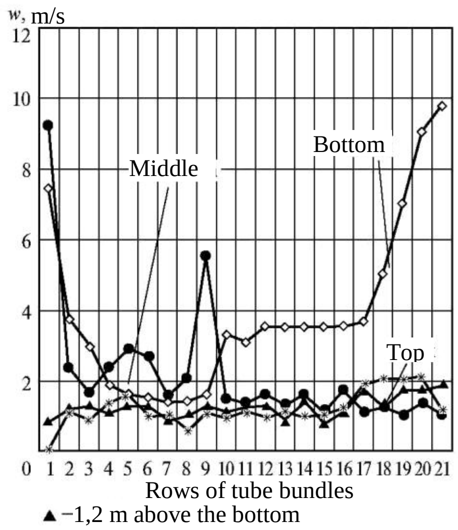

Fig. 6.24. Air speed at the module outlet

Technical suggestions

Condensation of water steam from a steam-air mix occurs at mix flowing from the top to the bottom in condensing tubes and from the bottom upward in a gas cooler. When the total surface (length of a tube) of condensation corresponds well to the distance of "completion" of condensation, ejector will suck away a steam-air mix with the small water steam content according to the AC pressure.

Division of a surface length into two parts, i.e. on *descending* and *ascending*, leads to necessity of definition of exact proportion of these lengths. In actual conditions this proportion changes can lead to failure of condensation process. For example, for an infinitely long vertical air-cooled condensing tube at steam supply from above, steam is condensed on all surface of a pipe from the condensation start. The condensate which is flowing down on an internal tube surface, will overcool, saturation pressure will fall, the condensate temperature will decrease and come nearer to a cooling air temperature, the condensate can freeze at negative temperatures of the atmospheric air.

If to connect a number of these condensing pipes of infinite length from the top and bottom by general steam and condensate collectors, a balance (uniformity) of condensation will remain anyway even if the condensing pipes are cooled unequally. It is fair for infinitely long pipes.

If pipes have the limited length and cooled non-uniformly, then condensate with different temperatures will enter a condensing collector. Thus, pipes having lower condensate temperature, also have lower pressure of steam-air mix. In this connection steam together with air will be leaked from a common bottom collector to colder tubes, i.e. air slug (condensation blocking) will be formed. It is inadmissible.

In order to avoid a returnable current of a steam-air mix, it is necessary to shorten length of parallel condensing tubes, until the length when "flying" steam from the coldest pipe passes to the bottom collector. Thus, the flow rate of the passing steam will be different in different pipes, but pressure in the bottom condensation collector (and condensate temperature) will be identical. Air will be leaving together with stream, i.e. air slugs won't be formed.

Thus, for adequate operation of parallel tubes it is necessary to provide a certain surface of condensation (length of tubes) with a passing steam. In this case any restrains of heat exchange surfaces (jalousie, valves, etc.), washed by atmospheric air, can provide a necessary thermal mode with the passing steam. As at AC operation thermal modes will change together with change of atmospheric air temperature, hence, application of controllers, based on change of a cooling atmospheric air flow rate, temperature and speed, are obligatory.

For an ascending current, i.e. at movement of a steam-air mix from below upwards in gas coolers, steam and condensate overcooling can occur before outlet section of a tube. As this process is limiting and isn't defined by an exact border then the remained steam will arrive in an ejector and at intensive cooling by atmospheric air in tubes of a gas cooler condensate overcooling is possible. Thus, gas cooled tubes need to be protected from excessively cold atmospheric air.

Thus, to provide regular and effective operation of an air condenser, steam pressure and temperature should be measured and a thermal mode with the minimum pressure of steam in the condenser should be maintained. At atmospheric air temperatures above zero, it is necessary to provide the greatest air velocity. At lowered, i.e. negative temperatures of atmospheric air, it is necessary to limit a length of condensing pipes by means of a jalousie or valves. In this case, passing steam will arrive in each of parallel condensing pipes at the bottom collector input.

To provide variable operational modes at transition to negative temperatures of atmospheric air, three levels of control system are necessary:

1. Maintenance of cooling air temperature — air exchange at air recirculation: $p_{st\ min}$ without freezing at $t_{air} > 0$ °C;
2. Elimination of condensate freezing $p_{s\ min}$, $t_{condensate} > 0$ °C
3. Start-up of an air condenser in winter at any atmospheric air temperature: air exchange and warming up of the total volume, $t_{air} > 0$ °C.

Reliable operation of fans can be provided at reduction of a number of cycles at control of start-up and shut down of the drive engine.

Use of the adjustable asynchronous electric drive allows solving automation problems with high reliability and efficiency.

Frequency converters AP-140 are developed and serially manufactured by a scientific technological center "Privodnaya Technica", intended for transformation of a single- or three-phase voltage with a constant frequency of 50 Hz into three-phase voltage with a variable frequency in a range of 0,2 to 400 Hz. This feature of frequency converters yields their wide application for even regulation of speed of any asynchronous electric motors.