Study the Performance and Efficiency of Air Coolers in Power Plants

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Abstract —Due to the importance of removing the heat generated when operating various devices in industrial and various other applications, air coolers are usually used, as are the cases in cooling air in gas or steam turbines, to cool heat transfer fluids in various thermal cycles. Mathematical models and complex mathematical equations have been developed to study the performance and efficiency of heat exchangers as well as study the behavior of changing temperature properties with no full or partial mixing of the heat transfer fluid. An annular vacuum conveyor movement technique was used with parallel connection of the pass sections. An attempt was made to improve the efficiency of air coolers depending on the number of sections used in each unit, as well as the effect of parameters number of heat transfer units (NTU2) and ratio of water equivalents of heat transfer fluids (R). The heat exchange rate and heat transfer fluid mass flow rate were studied. It was concluded that the heat exchange rate has an incomprehensible effect on the efficiency of air coolers in general. When studying air coolers, it is necessary to focus on the rate of heat transfer as well as its efficiency, as well as the study of the effect of the arrangement of heat exchange surfaces and operating factors (pollution, deposits, etc.). The complexities related to one section were studied separately, as well as with the layout schemes of other sections.

Keywords —*Cooling Ai,R Steam Mass Flow Rate,* Number Of Heat Transfer Units**,** *Ratio Of Water Equivalents Of Heat Transfer Fluids, Power Plant, Gas Turbine.*

I. INTRODUCTION

Air coolers are widely used in installations for various technological purposes: for the production of compressed air and other gaseous substances, in gas-filling, gas and oil pumping stations, for cooling air in compressors of gas turbine units, as well as for cooling various gaseous and liquid media. These devices are the basis of the cooling system of stationary internal combustion engines, most of which it is used as power units for diesel generator power plants [1]. The main purpose of these devices is to dissipate heat into the environment. The cooling medium is ambient air, which is usually supplied by a fan. In the pipes of the apparatus, gaseous, liquid substances or their mixtures are cooled without changing their state of aggregation or with condensation of the gaseous medium. For the purpose of air cooling, as a rule, devices from the standard series are used with a finned surface area of up to 20,000 m2, a finning coefficient of up to 22 and designed for pressures up to 31.4 MPa [2]. Despite the difference in design, all standard air coolers have common features: the heat exchange surface is mono- or bimetallic finned tubes with rolled or wound fins, as well as fins formed by pressing plates. The tube sheet is basically a staggered bundle broken down along an equilateral triangle. The tube bundle is a separate section, which consists of 4 to 8 rows of tubes. Rows of tubes are arranged from 1 to 8 passes through the tube space generally in counterflow [3]. In air coolers, the most common parallel connection for cooling air (see Fig. 1), since it has a lower aerodynamic resistance and requires less fan power. In each section, there is not absolute or partial mixing of the cooling air that moves crosswise in the annular space. The degree of mixing depends on the fin structure and the number of fins per unit length of the pipe. Inside a separate row of pipes there is a mixed movement of the medium to be cooled, and in general along the section there is a partially unmixed movement of this medium along separate rows (from 4 to 6). Between sections, the medium to be cooled is mixed in intermediate bypass chambers [4,5].

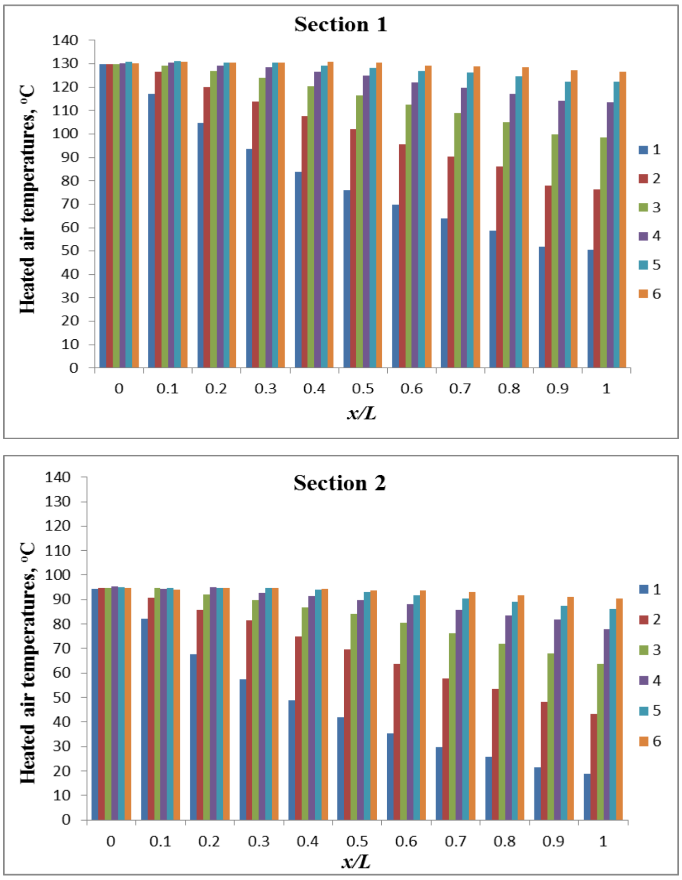


Figure 1: Detailed diagram of a single-pass three section air-cooled devices with parallel connection of sections.

II. FORMULATION OF THE PROBLEM

In internal combustion engines, the power consumption for the maintenance of the cooling system is usually 3-10% of the effective power. Therefore, ensuring high efficiency of the air cooling apparatus of the internal combustion engine cooling system is an urgent task. Traditionally, much attention of designers and researchers of such heat exchangers is paid to increasing the heat transfer rate from the side of the coolant, which has a lower heat transfer coefficient. For this, a more perfect finning of the outer surface of the pipes is being developed [6,7]. However, the efficiency of such devices with cross-flow will depend not only on the heat transfer rate, but also on the switching circuit sections, their number, the number of rows of pipes in one section and their arrangement along the paths, the degree of mixing during the coolant in each section [8]. In this study, the task is set on the basis of a mathematical model of such heat exchangers to develop relationships that make it possible to obtain the distribution of temperature characteristics by elements and in the apparatus as a whole. With these relationships, it is possible to analyze the effectiveness of both newly developed and operating devices, taking into account the operating factors (pollution, deposits, contact thermal resistances, etc.).

$$\left(\frac{t_{c1}-t_c(x)}{t_{c1}-t_{h1}}\right)_i = f_i \quad , \qquad (1)$$

$$f_i = (A_i - B_i - C_i).exp^{-\bar{x}};$$

$$A_i = exp^{-\bar{x}} - 1;$$

$$B_i = \sum_{i=1}^{i-1}\left[\binom{i-1}{l}(\bar{a})^l(1-\bar{a})^{i-1-l}.\frac{(\bar{x})^l}{li}\right];$$

$$C_i = \bar{a}.\sum_{j=1}^{i-1} B_j \quad ,$$

where "c" cooled medium;
"h" - heated medium (cooling air);
"1" - input,
"2" - exit;
i - the current number of a pipe rows (from the inlet of the medium, moving in the annular space);
l, j - current indices;
fi - the current degree of cooling in the i-th row of pipes;
$\bar{x}$ - relative coordinate, $\bar{x}$=Rax/L;
x - current coordinate from the entrance to the pipe in one section along the length L;

$$a = n.\left(1 - exp^{\frac{-NTU_2}{n}}\right), \qquad (2)$$

$$\bar{a} = \frac{a}{n};$$

n - the number of rows of pipes in one section;
R - ratio of water equivalents of heat transfer fluids;

$$R = \frac{C_{P_h}.G_h}{C_{P_c}.G_c} \qquad (3)$$

NTU2 - number of heat transfer units,

$$NTU_2 = \frac{K.F}{C_{P_h}.G_h} \quad , \qquad (4)$$

K and F - coefficient and area of heat transfer, W/(m2.K) and m2;
G and C_p – mass flow rates and heat capacities of the media within one section, kg/s and J/(kg.K).

The cooling efficiency PR in one section will be determined as follows:

$$(PR)_j = \left(\frac{t_{c1}-t_{c2}}{t_{c1}-t_{h1}}\right)_i = \frac{1}{n}\left(\sum_{i=1}^{n} f_i\right)_j \qquad (5)$$

It should be noted that a particular case of these relationships only for the parameter $(PR)_j$ is given in [9,10], but they have a different formulaic form. However, when comparing the results of calculations by the developed formulas with the nomograms given in [11,12], it turned out that they practically coincide. Similar dependencies were developed for the opposite case, where a heated medium moves inside the pipes, and a cooled (heating) medium moves in the annular space, which is relevant, for example, for gas turbine regenerators, but they are not presented in this work. If assume that the thermophysical properties of substances for all sections are the same, then based on the obtained dependences with parallel connection of sections, the final cooling efficiency for the entire apparatus will be:

$$PR = \frac{t_{c1}-t_{c2}}{t_{c1}-t_{h1}} = 1 - \left(1-(PR)_j\right)^{nc} \qquad (6)$$

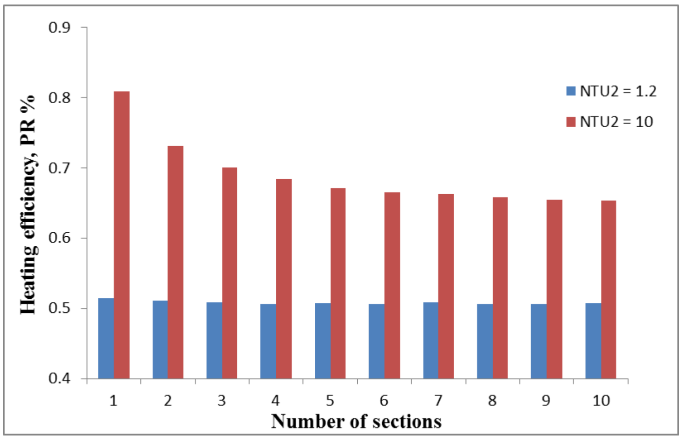
where nc - the number of sections;
j - the current section number (in this case, the efficiency (PR) j is the same for all sections).

If in air coolers there are zones with different properties or phase states of the media, it is necessary to apply the interval-iterative method for calculating the heat exchanger [13,14]. The distribution of temperatures and the efficiency of cooling in the apparatus substantially depend on the number of sections, rows of pipes in one section, the ratio of flow rates and heat capacities of heat coolant, and the number of heat transfer units NTU_2. The number of NTU_2 at constant flow rates of the heating medium depends on the product of the coefficient K and the heat transfer area F. The NTU_2 parameter with an unchanged arrangement of the apparatus reflects the intensification of heat transfer (which increases K) or an increase in the heat transfer area F, as well as operational factors (deposits, pollution, etc.) that reduce K [15,16]. The change in the flow rate of the cooling air supplied to the air coolers is reflected by the parameter R.

III. RESULTS AND DISCUSSION

Figure 2 shows the temperature distribution of a cooled single-phase medium in a three-section air cooling apparatus (see. Fig. 1). Each section has 6 rows of finned tubes with one stroke. The following parameters were adopted for the study:

R = 1, NTU_2 = 10; the temperature of the cooled medium tc1 = 120 C; cooling atmospheric air – t_{c1} = 20 °C.



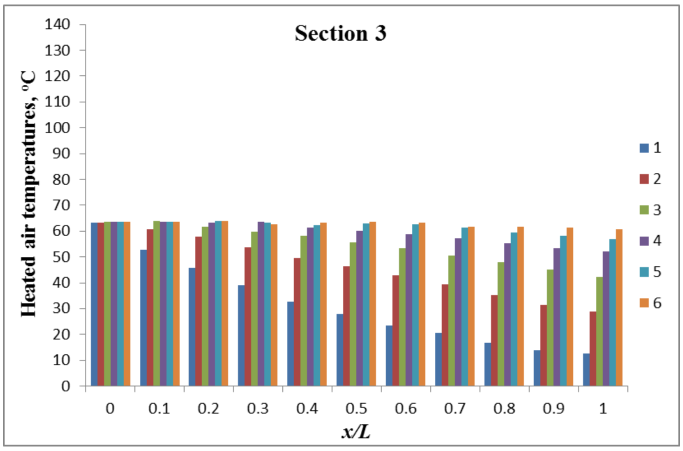


Figure 2. The distribution of temperature of heated air in a three section of air cooling apparatus, and the heating efficiency from number of sections.

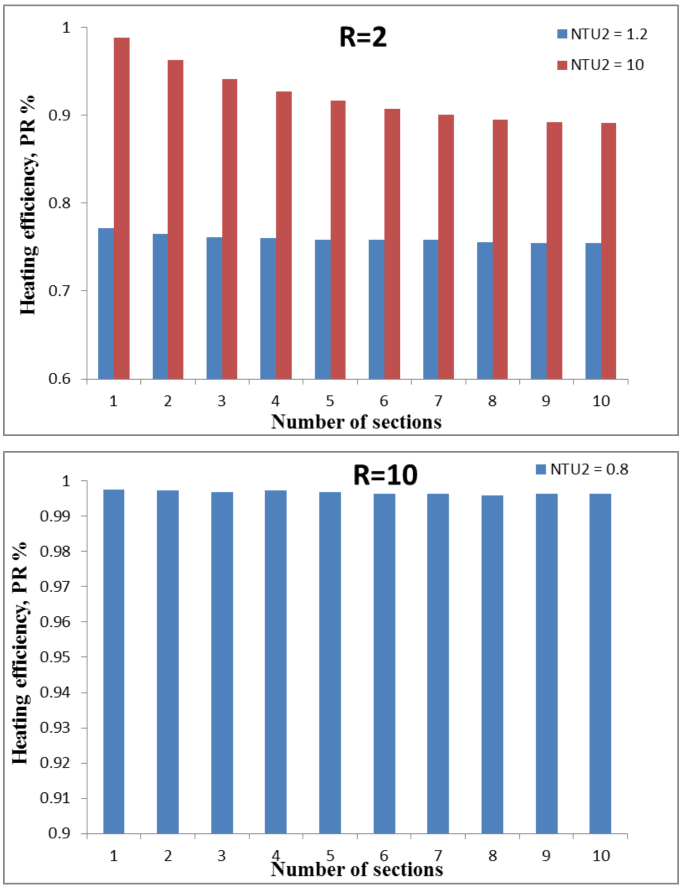


Figure 3: The efficiency of air coolers on the number of sections.

The figure shows that the least of all the medium is cooled in the last (sixth) row of pipes. The most uneven cooling of the medium is in the first section. Stirring the medium between the sections reduces the uneven distribution of the temperatures of the cooled medium through the rows. The more sections there are in the apparatus, the less unevenness. With an increase in the intensity of heat transfer (i.e. NTU_2), the unevenness increases.

As a result, the average temperature of the medium to be cooled was:

after the first section $t_{c21} = 87\ ^{o}C$,
after the second section – $t_{c22} = 65\ ^{o}C$,
after the whole apparatus – $t_{c2} = 50\ ^{o}C$.
Cooling air temperature: at the exit from the first section th21 = 118 ^{o}C,
from the second section - $t_{h22} = 86\ ^{o}C$,
from the third section - $t_{h23} = 64\ ^{o}C$,
average after air coolers - $t_{h2} = 90\ ^{o}C$.
Cooling efficiency PR = 0.7.

The same figure shows the dependence of the cooling efficiency PR on the number of sections in the apparatus and the number of NTU_2, where the parameter R = 1. At NTU_2 = 1.2, the efficiency is low and depends little on the number of sections (PR = 0.515 in a single-section air cooler and PR = 0.504 in a ten-section unit). In the apparatus with the best heat exchange rate (NTU2 = 10), the efficiency already strongly depends on the number of sections (PR = 0.806 in a single-section air cooler and PR = 0.651 in a ten-section air cooler). An increase in intensity from NTU_2 = 1.2 to NTU_2 = 10 affects an increase in efficiency by 29% (from PR = 1) in a single-section air cooler, by 17% in a five-section air cooler and by 15% in a ten-section air cooler. With a very large number of sections, the movement of the medium to be cooled tends to complete mixing with the limiting efficiency PR = 0.632 and $NTU_2 \rightarrow \infty$ (line A). Fig. 3 shows the dependence of the efficiency of cooling the medium in air coolers on the number of parallel connected sections for other values of R, different from 1. As can be seen from the presented graphs, the efficiency of single-section air coolers is the highest. With a significant increase in the consumption of cooling air (i.e., the heated medium, which is equivalent to an increase in the parameter R), even with NTU_2 = 0.8 and R = 10, the cooling efficiency approaches unity (i.e., the temperature of the medium to be cooled will be close to the ambient air temperature). At the same time, the efficiency will practically not depend on the number of sections. However, in this case, the consumption of supplying cooling air increases significantly.

CONCLUSION

The relationships have been developed for determining the temperature characteristics and efficiency of heat exchangers with partial or complete non-mixing of the media with parallel connection of one-pass sections relative to the heated medium, which moves in the annular space. Such relationships can be used to solve optimization problems in air coolers. The efficiency of air coolers is investigated depending on the number of sections, and generalized parameters NTU_2 and R, which reflect the intensity of heat exchange and the ratio of the flow rates of heat transfer fluid. It is shown that the intensification of heat transfer has an ambiguous effect on the efficiency of the entire apparatus as a whole. In the development of new and reconstruction of existing air coolers, it is necessary to carry out not only the intensification of heat transfer, but also to take into account the influence on their efficiency of the arrangement of heat exchange surfaces and operating factors (pollution, deposits, etc.). With some complication of the above relationships, it is possible to study multi-pass devices relative to the section and with other section layout schemes [17,18], as well as heat exchangers of this type or or other similar type designation.

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