Adverse Effect of Wind Loads on the Cooling Capacity of an Evaporative Cooling Tower and a Device for its Reduction

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Abstract. An external wind has an adverse effect on the thermal efficiency of a cooling tower. At the top of the tower, the wind effect is manifested by the interaction of the incoming wind flow with the rising steam–air torch. Here a partial closing of the exit section of the cooling tower occurs, which reduces the free convective thrust and as a consequence reduces its cooling capacity. To reduce the adverse wind effect, a new aerodynamic method is developed for decreasing the negative wind impact on the thermal efficiency of the cooling tower through the use of its own kinetic energy. On the basis of the experimental studies on a laboratory model of the evaporative cooling tower, an optimal variant of a passive wind tip is created. Its optimal parameters under which the cooling capacity of the model with a wind load is maximum are determined.

1. Introduction

The work of cooling towers is significantly influenced by climatic conditions and, in particular, by the external wind. The effect of wind at the level of the air inlet windows of cooling towers is manifested in a change in the initial conditions at the entry of cooling air and its distribution in the sprinkling space, which adversely affects the cooling of the circulating water. In this area, significant progress has been made in the description of the aerodynamics of cooling towers and in the elaboration of special technical solutions to reduce the adverse wind effect [1–3].

The influence of wind in the upper part can be considered a permanent factor, since at the height of modern cooling towers (from 60 m and more) wind currents are present almost throughout the year due to stratification of the surface layer of the atmosphere. The wind speed at the height of the cooling tower is about 5 m/s or more, which is comparable to the average convection speed of the steam–air flow leaving the cooling tower. As this takes place, partial cluttering of the outlet section of the cooling tower occurs with the formation of detached vortices, a reduction in free convective or forced thrust (for fan cooling towers), an increase in the hydrodynamic resistance, a decrease in the cooling air flow passing through the cooling tower, and, as a consequence, a decrease in its cooling capacity.

In general, the effect of the wind is described by the interaction of an ascending steam–air torch (axisymmetric flooded jet) with a stream flowing around the cooling tower (the body of rotation is hyperbolic, conic or cylindrical) and represents a complex conjugate mathematical problem. Some particular solutions of such problems can be found in [4, 5]. However, information on the speed and pressure distributions of the flow around the tower allows us to obtain some results on the use of the flow energy to increase the cooling capacity of the cooling towers. The energy of the wind flow can be directed to additional ejection of the steam–air torch from the cooling tower and to an increase in the...
volume flux of the cooling air. Moreover, it can be used to twist a steam–air torch over a cooling tower. In this case, the steam–air flow emerging from the cooling tower should become more resistant to the influence of the wind load, which will allow stabilizing the convective thrust of the cooling tower.

To solve the problems associated with the effect of wind loads on the cooling capacity of evaporative cooling towers, it is preferable to use a complex approach, confirming theoretical studies by experimental results, as done, for example, in [6]. In the present work the authors present experimental results obtained on a laboratory model of an evaporative cooling tower, equipped with various structural elements, in the study of its cooling capacity under wind conditions.

2. Laboratory model

It can be considered that the wind energy is low potential, because its use to increase the thrust from the cooling towers presents significant technical difficulties. Thus, the proposed design solutions for the use of wind energy are very limited [7–9]. Similar designs of wind tips are installed, resting on the exhaust tower of the cooling tower. Therefore, the drawbacks of such solutions include the complexity of their installation at high height, and the thrust of the cooling tower increases, mainly because of the increase in the effective height of the exhaust tower. Nevertheless, all proposed designs of wind tips should be of a circular symmetry, which will allow using the energy of the wind flow blowing from different directions.

Investigation of the processes of heat and mass transfer, hydrodynamics and aerodynamics of the steam–air mixture flow in the intra tower space and outside the natural cooling tower is associated with great technical difficulties arising from the non-stationary nature of these processes during the daily observations. Therefore, laboratory modeling in such a situation is a reliable and relatively inexpensive method of accumulating initial experimental data. Figure 1 shows a part of the experimental stand with a model of the evaporative cooling tower and wind simulators which are an aerodynamic pipe with an open working part. At the section of the cooling tower, various design versions of wind tips were installed.

![Diagram of a laboratory model of evaporative cooling tower](image)

**Figure 1.** Diagram of a laboratory model of evaporative cooling tower: 1, 2 – simulators of the wind flow; 3 – cooling tower; 4 – water distributor; 5 – panel sprinkler; 6 – catching basin; 7 – underlying surface.

The model of the cooling tower is made in geometric similarity to the actual cooling tower and has the following dimensions:

- Height of cooling tower is 850 mm.
- Diameter of the exhaust tower base is 680 mm.
- Diameter of the neck is 380 mm.
• Irrigation area is 0.32 m².
• The capacity of the catching basin is 32 l.

The main operating characteristics provided during operation of the experimental stand are as follows:

• Maximum flux of circulating water is 15 l/min.
• Maximum temperature of circulating water at the inlet to the water distributor at a flow rate of 12 l/min is 80 °C.
• Maximum wind speed from the upper simulator is 4.5 m/s.
• Maximum wind speed from the lower imitator is 2 m/s.

Reheating of circulating water in a thermostat with a capacity of 180 liters was carried out by electric heaters with a total capacity of 10 kW. To measure the speed of the steam–air mixture at the slit of the tower, as well as the wind speed created by the simulators, an electronic anemometer was used, which makes it possible to measure the wind speed in the range 0.8–12 m/s. The ability to set and maintain a constant circulating water temperature ensured a change in the speed of free convection $V_0$ of the steam–air flow from the cooling tower in the range from 0.47 to 0.9 m/s.

The construction of the wind tip created by the authors is formed by the lateral surface of a straight truncated circular cone. Rectangular plates are arranged along the surface perimeter along the cone generatrix with a certain step. The plates serve as structural stiffeners and simultaneously form guide channels, so that the incoming wind flow moving along them tilts up along the generatrix of the conical surface. Thus, the wind flow is directed to the cutoff zone of the tower where, interacting with the outgoing steam–air torch, creates an additional ejecting effect. The wind tip is installed directly at the level of the cooling tower cutoff and does not increase its height. The sketch and general view of the wind tip are shown in Figure 2.

![Figure 2. Wind tip in the form of a truncated cone with an angle at the base $\alpha=45^\circ$ and guide channels.](image)

The experimental studies were carried out with various designs of wind tip differed in a number of parameters:

• Angle $\alpha$ at the base of the truncated cone varied from 30° to 60°.
• Number of the guide plates varied from 18 to 36 (the width of the guide channel, from 40 to 80 mm).
- Dimensions of the guide plates varied in height (from 10 to 40 mm) and in length (from 40 to 80 mm).
- Angle of the installation of the guide plates changed: the plates were fastened along and at an angle to the generatrix of the conical surface.

The operation of each of the structures under consideration was studied with three different wind loads set in proportion to the speed of the free-convective flow, which made it possible to experimentally determine the optimal parameters of the wind tip at which the cooling capacity of the model is maximum. A control parameter that allows to judge the efficiency of using a specific design of the wind tip was the difference in the circulating water temperature in the cooling tower model; this value was compared with the water temperature difference for the model without a wind tip operating under the same regime parameters and wind load.

3. Experimental results
To verify the laboratory model, the experiments were conducted on the effect of wind on its thermal efficiency. The model with the help of a two-channel wind simulator was exposed to the wind velocity $W_{\text{down}}$ and $W_{\text{up}}$ at the levels of the air inlet windows and of the upper tower section, respectively. The value of $W_{\text{down}}$ ranged from zero to 0.8 m/s, while under all conditions of the wind influence the ratio of velocities $W_{\text{up}}/W_{\text{down}}=2$ was maintained. As a measure of the thermal efficiency of the cooling tower model, the relative temperature difference of water $\Delta T/\Delta T_{\text{calm}}$ was used, where $\Delta T$ and $\Delta T_{\text{calm}}$ are respectively the temperature drop of water in the cooling tower model when it operates under calm and wind load conditions. The obtained results were compared with a similar dependence for an industrial cooling tower. For this purpose, the full-scale tests of the Minsk thermal power plants No. 4 cooling tower with an irrigation area of 3200 m$^2$, a base diameter of 60 m and a height of 86 m were used. The results of the comparison are shown in Figure 3.

![Figure 3](image_url)

*Figure 3.* Dependence of the relative temperature drop of water on the surface wind speed $W_{\text{down}}$ for a laboratory model and a full-scale cooling tower: (a) – laboratory model of the cooling tower; (b) – cooling tower of Minsk thermal power plants No. 4.

The hydraulic load and the temperature of water, fed to the water distributor of the tower, were kept constant in the experiments, the temperature of the ambient air determined by dry and wet–bulb thermometers varied within small limits. Since the study of industrial cooling towers does not enable in action to set aside a statistically significant array of measurements in absolute calm, the wind speed at a height of 2 m from the Earth's surface equal to 1.0 m/s was taken as the basic mode for the full-scale tests under such conditions.

As can be seen in Figure 3, the results of the model operation and the actual tests of the industrial cooling tower correlate well to one another. The thermal efficiency of both the model and the natural
cooling tower is markedly reduced with increasing wind load. In this case, the minimum relative temperature difference of water \( \Delta T/\Delta T_{\text{calm}} \) in both cases is \( \sim 0.85 \). Cooling of recycled water is reduced by approximately 15\%. It should be mentioned also that the minimum value of the thermal efficiency corresponds to the values of the wind speed \( W_{\text{down}} \) approximately equal to the speed of free convection \( V_0 \) of the steam–air flow.

After numerous experiments with different designs, the wind tip shown in Figure 2, was selected as the final version of the passive technical device to reduce the adverse impact of the wind on cooling water in the cooling tower. Figure 4 shows the experimental data on the effect of wind load \( W_{\text{up}} \) at the upper section level of the model tower on the efficiency of cooling water in a cooling tower model equipped with such a wind tip.

![Figure 4. Dependence of the cooling capacity \( \Delta T \) of the cooling tower model equipped with a wind tip with an angle at the base \( \alpha=45^\circ \) on the upper wind speed \( W_{\text{up}} \).](image)

The graphs in Figure 4 show that at low wind speeds from zero to 1 m/s, the presence of a wind tip in the model has practically no effect on the process of cooling circulating water in the cooling tower (the curves in the figure almost coincide). The ejecting effect begins to manifest itself when the wind speed becomes comparable with the speed of free convection of the steam–air torch and exceeds it. It should be noted that a similar effect was observed by the authors practically in all experiments on the study of various designs of wind tips (in all, more than seven different constructions were considered). The magnitude of the water temperature difference \( \Delta T \) in the model with a wind tip for large wind loads was higher by 0.2–0.5 °C than in the model of a conventional cooling tower. In our opinion, this is indicative of the correctness of such an approach to the choice of the wind tip design.

Simultaneously with the study of the thermal efficiency, optical visualization of the interaction of the steam–air torch from a cooling tower model with an incoming wind flow was carried out. The pictures of this visualization are shown in Figure 5.

As can be seen from Figure 5, the wind effect leads to a decrease in the outlet section of a conventional cooling tower, which is expressed in the formation of a stagnant zone in the upper part of the tower from the windward side. At the same time, the slope of the steam–air torch and the size of the stagnant zone on the conventional cooling tower increase with the external wind speed.

For a model with a wind tip, this effect is smoothed due to the deflection of the wind flow by the working surface of the guide channels. At the same time, the steam–air torch from the cooling tower with the wind tip is deflected through a smaller angle from the vertical, i.e. the outgoing flame is more stable and the filling of the outlet section with the steam–air mixture remains practically unchanged.
Figure 5. Flow pattern of the steam–air flow from the model of a conventional cooling tower and of a cooling tower with a wind tip for wind blowing of different intensity: (a) – wind speed $W_{up}=1.4$ m/s; (b) – $W_{up}=1.7$ m/s.

When flowing around the wind tip, the external wind partially changes the direction from horizontal to oblique (at an angle at the cone base), and the presence of the guide plates on the conical surface artificially "increases" the diameter of the exhaust tower near the mouth of the cooling tower. Thus, for the flow layers flowing around the outlet section of the cooling tower from above, an additional hydrodynamic resistance is created, which leads to a reduction in the pressure on the steam–air flare as it exits from the cooling tower outwards. As a result, the stagnant zones in the mouth of the cooling tower are reduced or completely disappear, and its thermal efficiency is increased.

4. Conclusions
When conducting the experimental studies on a laboratory model, the adverse effect of wind on the thermal efficiency of the tower evaporative cooling tower was confirmed. To reduce the adverse wind impact on the cooling of circulating water, it is proposed to use a truncated cone as a passive device installed at the section of the tower. On the lateral surface of the cone, the rectangular plates are arranged, forming separate guide channels along the cone perimeter. Such a device during a flow past it allows changing the direction of the wind flow in the zone of the cooling tower mouth, creating an additional ejecting effect, i.e., the wind energy is partially directed to an increase of the thrust of the cooling tower. This leads to deeper cooling the circulating water, especially with large wind loads. It has been shown experimentally that the temperature drop of water in the cooling tower model equipped with such a wind tip is, on average, by 0.2–0.5 °C higher than for a conventional cooling tower. This opens up possibilities for using such a technology for industrial cooling towers of thermal power plants and nuclear power plants, where the problem of cooling circulating water is urgent.

Based on the results of the experimental studies carried out, an application for a useful model of a wind tip for an evaporative cooling tower as a patent of the Republic of Belarus has been drawn up.

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