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A STUDY ON THE FROST SELF-PROTECTION OF COOLING TOWERS

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Abstract

The paper presents the results of an experimental research conducted using a climaxed stand on the griddle self-protection to frost of cooling towers. The parameters have been followed to influence the forming of ice curtains on the air access section into the tower and it is proposed an analytic relation for calculating the aerodynamic resistance of the self-protection system.

Keywords: cooling towers, frost self-protection, self-regulation system of the air flow, ice curtains.

1. Introduction

The present tendency towards increasing the installed power of electric and nuclear power plants imposes the realization of cooling devices of adequate capacities, and a significant increase in the investment costs (with approximately 25...30%). Therefore, there is a continuous preoccupation worldwide for the study of phenomena related to cooling towers.

In Romania the possibilities for reducing the energy consumption in cooling towers, have also been studied [6,7] by proposing a new type of cooling towers for nuclear plants, a tower with a natural ventilation and a reduced energy consumption. Its building conception relies mainly on the storing of cooled water next to the cooling layer, so disposing of the inferior dripping area which is characteristic to the classical models of cooling towers; this contributes to the decreasing of the pumping height and consecutively of the electric energy used for pumping.

Considering that the frost phenomenon is common in classical towers as well as in the new ones, and that the frost can appear in all cooling area, this study is aimed at making some experimental research, using a climaxed experimental stand of the griddle self-protection to frost of cooling towers. There are to be surveyed the parameters influencing the forming of ice curtains on the air access griddles of the tower in order to propose an analytical relation for determining the air resistance of the self-protection system.

2. Theoretical Consideration on the Cooling Towers and their Griddle Self-Protection to Frost

It is well-known that the cooling tower is a heat transfer device to join the thermo-energetic cycle and the environment. Its role is to evacuate in the surrounding atmosphere the heat not used in the cycle.

For big towers it is preferred the solution of natural ventilation, because it ensures an important energy saving as the air flow is provided by the difference in density between the outer air and the one heated and disposed through the exhaust pipe.

The air through the exhaust pipe can be expressed using the underneath given formula:

$$\rho_m(\rho_e - \rho_m) = \frac{K}{g}\left(\frac{q_t}{\Delta i}\right)^2 , \tag{1}$$

where: ρ_e, ρ_m represent the densities of the outer air and the average density of the air in the cooling tower, respectively; K – the air characteristic of the cooling tower; q_t – the specific thermic load of the tower's basis; Δi – the enthalpy difference of the air; g – gravitational acceleration.

Analyzing the relation (1), we notice the air flow of the cooling tower depends on the thermic load of the tower, the fresh air's density (which is independent from the tower), exclusively depending on the atmospheric air conditions and the aerodynamic resistance of the whole system (through the air characteristic).

Cooling towers with natural ventilation systems are characterized by the fact that the air flow through the tower can't be, practically, controlled. At negative temperatures and high atmospheric pressures, the air density (ρ_e) is high, leading to a significant increase in the air flow through the tower, and so inducing the partial or complete frosting of the tower. The system can then no longer work on low heat load, a condition essential to the security of nuclear plant.

The forming of external water curtains in the access section of the air in the directing blinds (which turn into ice shutters, sealing the access section) leads to the reduction of the air access section. The more lower the outer temperature, the more the access section is reduced, which creates a self-regulation system of the air flow.

Therefore it raises the problem of establishing the designing and execution parameters to help us use these phenomena to protect the cooling towers from freezing.

To this aim, an experimental study has been conducted (based on a research contract in collaboration with the ICEMENERG Institute from Bucharest) to design a poliethylene net system (the net being installed on a solid griddle and positioned in the way of the air flow in the dripping area).

3. Description of the Experimental Stand and of the Measurement Equipment

The climaxed stand used in this research (*Fig. 1*) is formed by a closed circuit device and other necessary equipment's for taking over the heat for water freezing and measuring the systems working parameters, namely:

- a centrifugal mono-suction ventilator VS5, powered by an electric machine working in a continuous current of 5 KW at 3.000 rotations/minute, with variable rotation speed and using an electronic tiristor controlling device of rotation speed equipped with a measuring and rotation control device;
- an evaporation device, built from BRA 1350 × 840 – 8 with a cooling surface of 213.84 m^2, and an air flow section of 1.13 m^2;
- a group of compressors consisting of 3 gears of K 902 type, in parallel connection, with 2 90/90 cylinders each, and activated by 7.5 kW – 1.500 rot/min electric machines;
- a group of air condensers, consisting of 2 units in parallel connection, from Tehnofrig type heat pumps, cooled by air flow with axial electric activated ventilators of 1.1 kW – 1.500 rot/min;
- a distribution system for uniform water dripping flow in the superior division, with 2 water circulation pumps and an electric heat exchanging device of 12 kW provided with a thermostate for controlling the water temperature in the access section;
- a second water dispersion system, placed approximately at the middle height of the stand, supplied with a water circulation pump and a heat exchanger of 6 kW with a thermostat.

As measuring equipment, there were: manometers on the freezing circuit of high and low pressure level, pressure protection for the installations, a rotation measuring device for the ventilator, a micro–manometer with tilted tube for measuring the pressure drop in the ice curtain, a micro-manometer connected with a Prandtl–Pitot tube for measuring the air flow, a mercury thermometer for measuring the temperature of the cooled air, a thermostate thermometer for controlling the heating of water in the system, and rotation measuring devices for the water flow.

For determining the specific load from the ice, we used the volume measurement of the water quantity resulted from the melting of the ice curtain, by using a collecting vat.

Previously to starting, the stand has been secured by tightening and isolating it.

4. The Experimentation

The researched self-protection system consists of a polyethylene net with 14 × 14 mm meshes and a wire thickness of approximately 1.4 mm, settled on a metallic

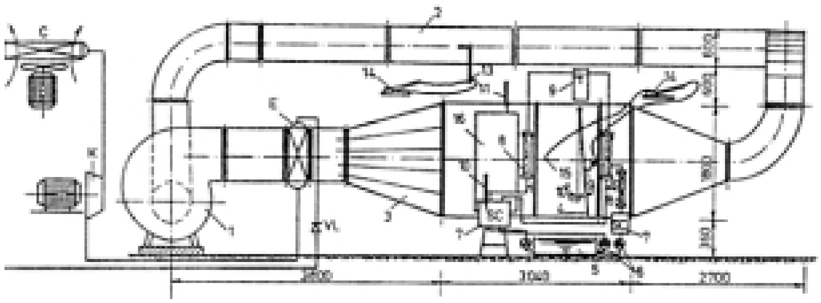

Fig. 1. Scheme of the experimental stand
C – Condenser; K – Compressor; E – Evaporation device; VL – Rolling valve;
1 – Centrifugal ventilator; 2 – Air channels made of iron sheet; 3 – Diffusing device with directing walls; 4 – Metallic net; 5 – Water basin;
6 – Pumps; 7 – Heat exchanger; 8 – Rotation measurement devices; 9 – Distribution basin; 10 – Water temperature measuring thermometer; 11 – Air temperature measuring thermometer; 12 – Water flow controlling clamps; 13 – Prandtl–Pitot tube; 14 – Tilted tube micro-manometer; 15 – Static pressure measuring plugs; 16 – A window for surveying and photographing the processes

wire support with 100×100 mm meshes. The diameter of metallic support's vertical bars is of $\phi 6$ mm; the diameter of horizontal bars is of $\phi 6$ mm.

The net wire system is placed under the dripping area of the superior distribution system, in two renderings: A) – with a double polyethylene net on the whole height of the air channel; B) – with a double polyethylene net only on the superior half of the air channel.

The nets are placed with a tiny tilt from the vertical (approximately $10°$) in order to improve the uniform dripping.

The experiments are realized in two stages; in the first stage it is studied the forming of ice curtains on a single system, working with only one water temperature at access for the cases A) and B), in the second stage it is studied the forming of ice curtains on two systems of serial connected curtains, working with two water access temperatures for case A).

The experiments are directed towards obtaining the aerodynamic resistance of the ice curtain which forms in various conditions, according to the variation of the following parameters: the dripping intensity (q), water temperature (t) and air temperature (θ), air speed (v).

In the first stage, various regimes of dripping intensities are realized: 2, 3.75, 4.5, 6.25 $m^3/(m^2.h)$, and water temperatures of 10, 15, 20 °C, at air temperatures between -4 °C and -9 °C and air speeds between 1 and 1.8 m/s.

In the second stage, 2 regimes of dripping intensities are realized: total dripping intensity $q = 3.75\ m^3/(m^2.h)$ and $q = 6.25\ m^3/(m^2.h)$; partial dripping intensity of the superior area $q_1 = 1.25\ m^3/(m^2.h)$ and partial dripping intensity of the inferior area $q_2 = 2.5$ m^3/(m^2.h) and respectively (for $q = 6.25$ m^3/(m^2.h)) $q_1 = 2.5$ m^3/(m^2.h) and $q_2 = 3.75$ m^3/(m^2.h). Water temperatures for the upper area (t_1) are of 10 °C and 15 °C, for the minor area (t_2) of 15, 20, 25 and 30 °C; air temperatures (θ) have varied between -3 °C and -8 °C; air speed (v) was of 1.2 m/s.

5. Experimental Results Processing and Interpretation

The air speed in the working section, in m/s, can be calculated using relation (2); the specific load from the ice, in kg/m^2, is calculated by relation (3):

$$v = \frac{S_1}{S_2} t \sqrt{\frac{2}{\gamma} p_d} \, , \tag{2}$$

$$G = \rho_w \frac{S_c}{S_2} (H_f - H_i) \, , \tag{3}$$

where: S_1/S_2 is the rapport between the measure section of air dynamic pressure and the working section; p_d – dynamic pressure, measured using a Prandtl–Pitot tube, in mm H_2O; γ – specific weight of the air, in N/m^3; ρ_w – the density of water from melted ice, in kg/m^3; S_c – vat's surface; H_i, H_f – water heights, in m, before and after the melting of the ice curtain.

The system's aerodynamic resistance can be determined with relation (4):

$$\xi = \frac{2}{\gamma v^2} h_r = \frac{1}{\left(\frac{S_1}{S_2}\right)^2} \frac{h_r}{p_d} \, , \tag{4}$$

where h_r is the loss head, measured in mm H_2O.

The studied phenomenon is a dynamic process that requires a time period stabilization of air parameters, period of about 30...90 minutes; the recordings during the working period of a regime are made at 10 minutes intervals.

Diagrams in *Fig. 2* represent the experimental results for the studied regimes of the system with simple self-protecting ice curtain, case A).

As the figure shows, the ξ coefficient increases in time, and at a certain time tends towards a constant value, depending on the dripping intensity, water temperature, air temperature and speed.

For the same system and case A), *Fig. 3* shows the results obtained for the specific load from ice (G). It can be seen that for a given dripping intensity and air speed, the specific load increases with the lowering of water and air temperature. In the above mentioned experimental conditions, the range of specific load varies between 10 and 20 kg/m^2, and the ice curtain's thickness is between 10...20 mm.

Fig. 4 shows the correlation between the resistance coefficient and the water temperature at a dripping intensity of 6.25 m^3/(m^2.h), an air temperature of -5°C

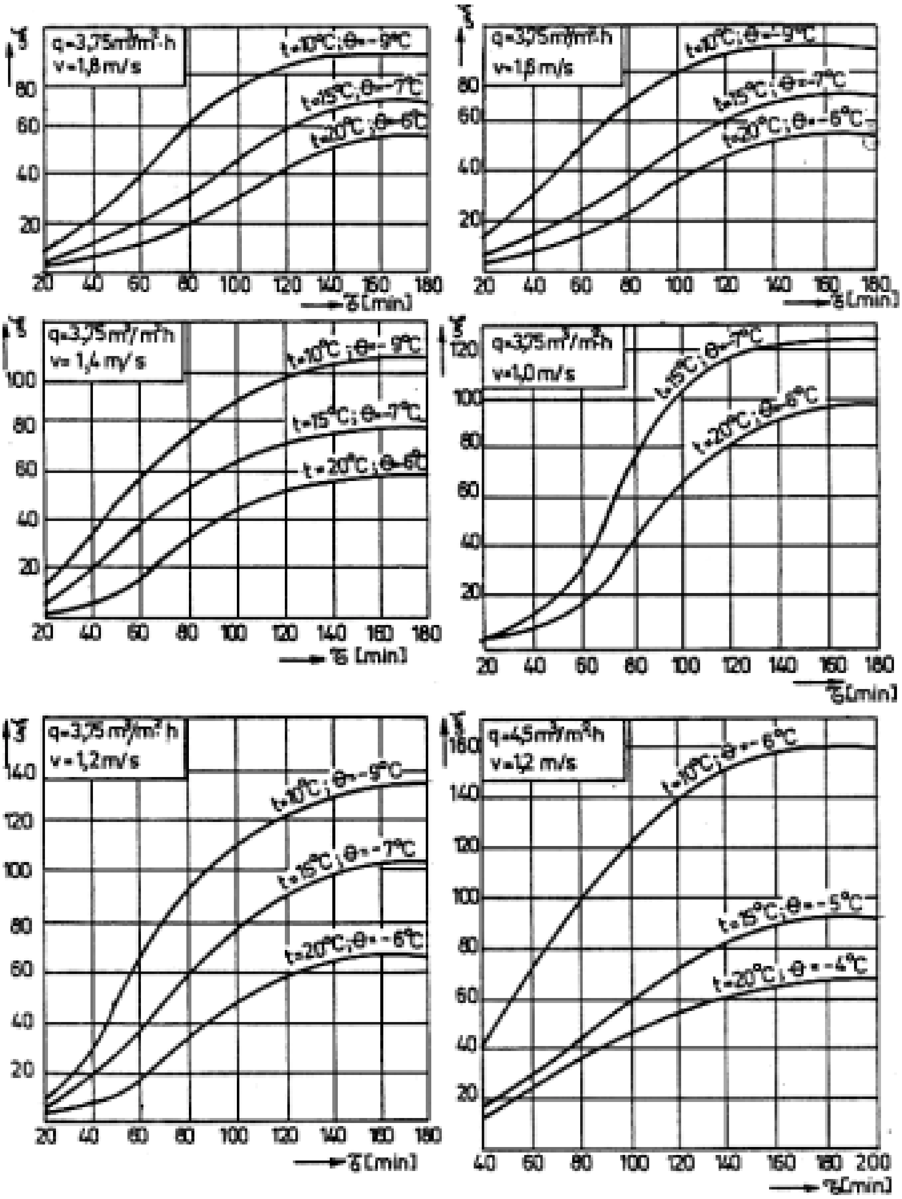

Fig. 2. The variation of aerodynamic resistance coefficient (ξ) for the simple ice curtain system

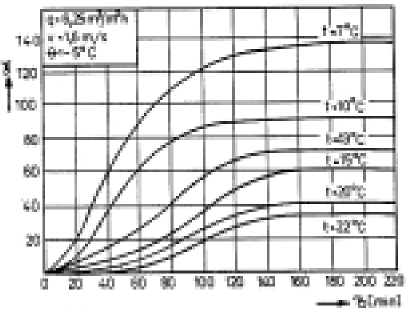

Fig. 2. continued

and an air speed of 1.6 m/s for cases A) and B) of the simple frost self-protecting system.

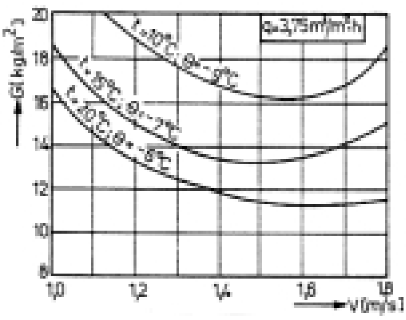

Fig. 3. The correlation of specific ice load of the self-protecting curtain

In *Fig. 5* is presented the correlation between the resistance coefficient with air temperature for dropping intensity 6.25 $m^3/(m^2.h)$, a water temperature of 15 °C and an air speed of 1.6 m/s in case A).

It can be noticed that in the case in which the used polyethylene net is doubled for the whole height of the air access section, higher values for the ice curtain's final resistance are obtained, compared with the situation when the net is doubled only for a half of the air access section's height, for the same water temperature. The difference increases with the lowering of the water temperature.

The results of the experiments for the self-protecting system with two ice curtains in serial connection are presented in diagrams in *Fig. 6*; it can be noticed that the final resistance of the ice curtain increases with the lowering of the ratio between the dripping intensity in the upper and lower area for the same water and air temperatures and air speeds in the two areas.

Using the experimental results a formula has been established for calculating the final aerodynamic resistance of the self-protecting simple ice curtain system, as

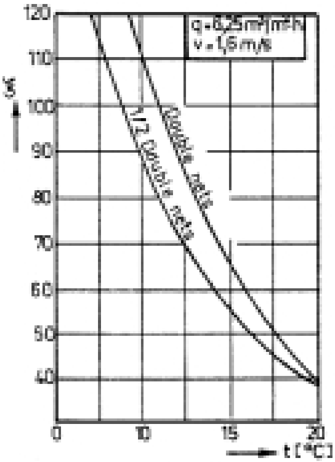

Fig. 4. The correlation between the aerodynamic resistance coefficient and the water temperature for cases A) and B) of the self-protecting system

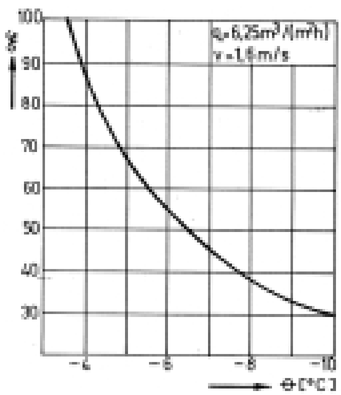

Fig. 5. The correlation between the resistance coefficient and air temperature in case A).

follows:

$$\xi_c = e^{\frac{57.2-t}{10.01}} \cdot \left(\frac{v_0}{v}\right)^{0.5} \cdot \left(\frac{\theta_0}{\theta}\right)^{1.2} \cdot \left(\frac{q_0}{q}\right)^{1.04}, \tag{5}$$

where: v_0, θ_0, q_0 are the reference parameters for which the correlation between the resistance coefficient and the water temperature have been established in the following experimental conditions: $q = 2 \ldots 6.25$ m^3/(m^2.h), $t = 5 \ldots 20$ °C, $\theta = -1 \ldots -10$ °C, $v = 1 \ldots 1.8$ m/s.

The deviation of most values of aerodynamic resistance coefficient calculated using relation (5) compared to the measured values falls in the range of $\pm 15\%$; so,

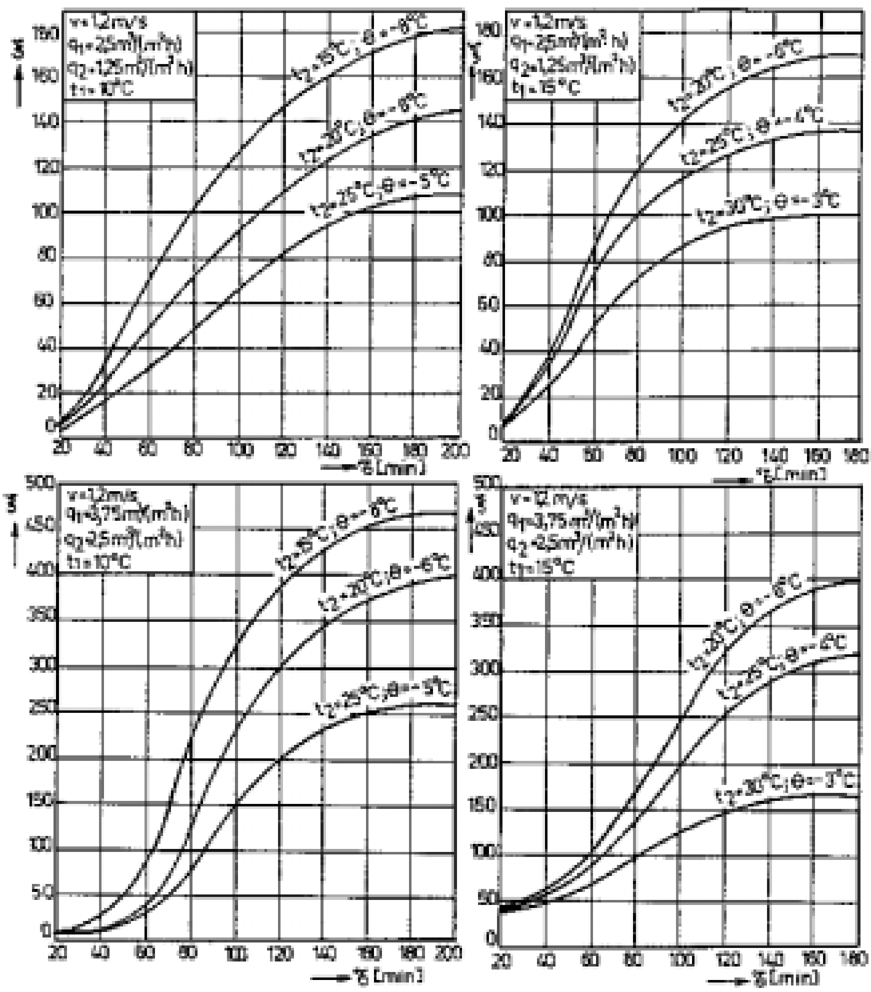

Fig. 6. The variation of aerodynamic resistance coefficient (ξ) for the serial connected ice curtain system

we could appreciate that relation (5) has a good precision level for practical use.

6. Conclusions

The dripping of water in cooling towers contributes to the frosting of these towers in cold weather.

Experimental results have confirmed that during the process of ice curtain forming occurs a self-controlling phenomenon characterized by the stabilization of the system's resistance at a constant value to define a series of parameters: q, t, θ, v, net type, etc.

In order to obtain a self-controlled process according to the tower's diagram, two systems of serial connected ice curtains can be realized, systems which are to function with two water access temperatures; the upper area is to be supplied with cooled water and the lower area with a mixture of cooled and warm water.

For protecting the cooling towers against freezing can also be taken into consideration the solution of using ice 'shutters' with griddles for support and providing the system with a separate water flow pipeline or a system to use the cooling water.

The results of the study on the controlled forming of ice curtains using a climaxed experimental stand have led to the founding of general relation (5); it is necessary to check the practical use of this formula in real situation, using functional cooling towers, in order to enable further studies on the frost phenomena on cooling towers and the testing of other protecting wire systems.

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