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Aerodinamic Calculations of Hyperbolic Cooling Tower

Technical paper

This paper analyzes the counter-current cooling tower of power plant. The basic relations for the buoyancy of air were shown. The coefficient of local drop pressure of air in some parts of the tower was defined. The velocity of air through the tower filling is determined for specific technical data.

Applying a filling for the film-drop water flow, drop pressure coefficients were determined for the air through the filling. The silhouette of hyperbolic cooling towers is defined.

Key words: *hyperbolic cooling towers, aerodinamic calculations*

Introduction

Cooling tower is essential element of the recirculation system of cooling water in power plant. Because of the reduction of operating cost, cooling towers are most commonly used with natural convection of air in direct contact with water. The water flow of air is proportional to the height of the tower and the difference in air density at the entrance and exit of the tower. The geometrical shape of the tower is usually hyperbolic because of aerodynamic reasons. Water and air flows are: counter-current, cross and combined. The construction of the hyperbolic shell is concrete or steel. Variety of cooling water filling are applied: film, film-drop, and drop.The aerodynamic calculation is very important part in designing of the tower. Overall dimensions of the tower were determined using this calculations.

Basics of the aerodinamic calculations

Air flow in natural cooling tower depends of the height of the tower and the density difference between air (inlet and outlet). Figure 1 shows the basic cooling tower dimensions required for aerodynamic calculation.

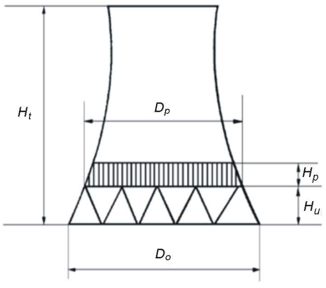

Figure 1. Basic overall dimensions of the tower

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The basic equations for the buoyancy (pressure) of air is [8]:

$$p_t = H_{uz}\, g(\rho_{v1} - \rho_{v2}) \tag{1}$$

where are: p_t [Pa] is the air pressure, H_{uz} [m] – the effective height of the tower, g [ms^{-2}] – the gravity, ρ_{v1} [kgm^{-3}] – the mean density of the surrounding air, and ρ_{v2} [kgm^{-3}] – mean air density at the exit.

Effective height of buoyancy is determined from:

$$H_{uz} \quad H_t \quad \frac{1}{2}(h_p \quad 0.5) \quad \frac{3}{4}h_u \tag{2}$$

where H_t [m] is the height of the tower, h_u [m] – the inlet height, and h_p [m] – the filling height.

Relation (2) takes into account the fact that in the inlet air (rain area) the exchange of heat is performed, *i. e.* this area is part of the filling. The total drop pressure on air side is:

$$p_v \quad \xi_t \frac{\overline{w_p^2}}{2} \bar{\rho}_v \tag{3}$$

where $\bar{\rho}_v$ [kgm^{-3}] is the medium density of air through the filling, ξ_t – the total pressure loss coefficient, and $\bar{w}_p$ [ms^{-1}] – the mean velocity of air through the filling.

The coefficient ξ_t is determined experimentally.

In the absence of experimental data, ξ_t is determined from the equation:

$$\xi_t = {}^{n}_{1}\,\xi_i \tag{4}$$

where ξ_i is the local pressure loss coefficients of air reduced to the average speed of air through the filling. By equating $p_t = p_v$ follows below:

$$H_{uz}\, g(\rho_{v1} \quad \rho_{v2}) \quad \xi_t \frac{\overline{w_p^2}}{2} \bar{\rho}_v \tag{5}$$

where in expression (5):

$$\bar{\rho}_v \quad \frac{\rho_{v1} \quad \rho_2}{2} [\text{kgm}^{-3}] \quad \text{and} \quad \bar{w}_p \quad \frac{q_{ma}}{S_{\rho_v}} [\text{ms}^{-1}]$$

Introducing tags:

(a) air number $\lambda = q_{ma}/q_{mw}$, q_{mw} [kgs^{-1}] – the water flow, and q_{ma} [kgs^{-1}] – the air flow, and
(b) surface flux of water (density of rain) $q_k = q_{mw}/S$ [kgm^{-2}s^{-1}], follows below:

$$\lambda q_k \quad \sqrt{\frac{H_{uz}\, g(\rho_{v1}^2 \quad \rho_{v2}^2)}{\xi_t}} \tag{6}$$

$$H_{uz} \quad (\lambda q_k)^2 \frac{\xi_t}{(\rho_{v1}^2 \quad \rho_{v2}^2) g} \tag{7}$$

where: H_{uz} [m], q_k [kgm^{-2}s^{-1}], ρ_v [kgm^{-3}], and g = 9,81 [ms^{-2}].

From the condition to be satisfied this relation we get the basic overall dimensions of the tower, where are:

$$\xi_t \quad f(D_p, H_{uz})$$

Therefore, it is necessary first to adopt the values depending on variables in the above eq. (9), and then perform iterative procedure to get the actual size.

Air drop pressure coefficient

The total drop pressure coefficient of air depends on the constructive solution of the tower and density of rain. The best and most reliable way of determining this ratio is a measure of derived objects or by using models. In lack of experimental data, the overall ratio of air drop pressure is defined as the sum of local coefficients.

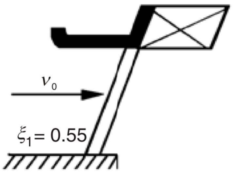
Systematic reviews of these ratios for towers with natural convection is given in [8]. The paper [2] gives the drag coefficient for the hyperbolic tower in the form:

$$\xi_t \quad 0.117 \; \frac{\mathrm{D_p}}{h_\mathrm{u}}^{2} \quad 0.33 \; \frac{\mathrm{D_p}}{h_\mathrm{u}} \quad 2.48 \quad \xi_\mathrm{ost} \tag{8}$$

where ξ_ost includes resistance in parts of the tower: the restoration, construction of wearing a filling, drops eliminator, water distribution system, and the influence of wind.

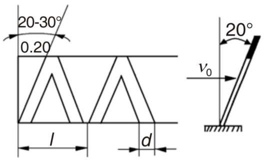
Local resistance coefficients for the cooling tower with natural convection [8] are:

(1) The entrance to the tower



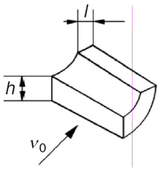
With editorial
Without editorial $\xi_1 = 0.35$

(2) Poles mantle



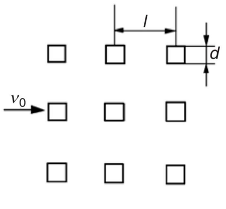
d/l		0.1		0.15	
ξ_2	0.21		0.40		0.64

(3) The shift of the air flow



l/h	1	2	≥3
3	0.79	0.55	0.50

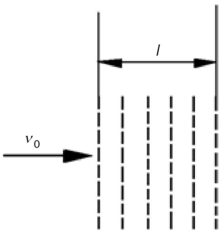
(4) Pillars point



d/l	0.05	0.10	0.15
ξ_4	0.08	0.13	0.19

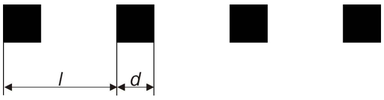
$\xi \quad n\,\varsigma \quad = 10$

(5) Rain



$\xi_5 = l\,(0.1 + 0.09\,q_k)$
$\xi_5 = 8\,(0.1 + 0.09\;2{,}5) = 2.6$

(6) Beamsto carry the filling



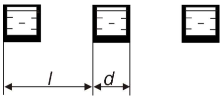
d/l	0.05	0.10	0.15
ξ_6	0.07	0.17	0.27

(7) Filing (the calculation for the filling [8]) ξ_7

(8) Drop eliminators $\xi_8 = 5\text{-}6$

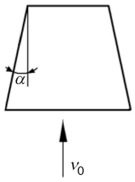
All coefficients are related to speed v_o. When budgets need to be translated into $\overline{w}_p$.

(9) The system for distributing water (canals or pipes)



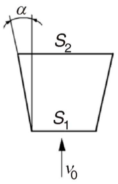
d/l	0.10	0.15	0.20
ξ_9	0.17	0.38	0.60

(10) Conffuser



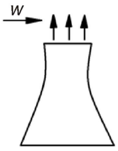
α	5°	10°	20°	30°
ξ_{10}	0.16	0.20	0.28	0.32

(11) Diffuser



$$\xi_{11} \quad \sin\alpha \; \frac{S_2}{S_1} \quad 1^{\;\;2}$$

(12) Output from the tower and the impact of wind



	ξ_{12}			
Wind speed: w[ms^{-1}]	0	2	4	6
	1	1.5	2	2.5

Calculation ξ_t of the local resistance in the above table presents the results only slightly higher than the values surveys, so that the obtained value can be considered as upper. Relation (9) gives slightly lower values.

Coefficient of local air resistance are usually expressed as:

$$\xi \quad (\xi_s \quad kq_k)h_p \tag{9}$$

where ξ_s is the coefficient of air resistance for dry filling, $k = 0.8\text{-}1.0$ – the coefficient of density of rain, and h_p [m] – the filling height.

For a concrete example of film-drop filling: $\xi \quad = (7 + 0.9$.

Basic project parameters for a cooling tower of a power plant of 300 MW

(1) Rated power block: $N = 300$ MW
(2) Type of cooling tower: natural counter-flow
(3) Cooling water flow: m/h
(4) Cold water temperature: 28 °C
(5) Hot water temperature: 38 °C
(6) Cooling range: 10 °C
(7) Air temperature: 35 °C
(8) Relative humidity: $\varphi = 33\%$
(9) Wet bulb temperature: $t_{WB} = 22$ °C
(10) Barometric pressure: $p_b = 980$ mbar
(11) Wind velocity: $v_v = 2$ m/s

Budget results

Air velocity through the filling

Based on the approved air number λ and water flow q_{mw}, we determine the air flow:

$$q_{mw} \quad \lambda q_{mw} \quad 0.7 \;\, 38000\frac{1000}{3600} \quad 7389 \;\; \text{kg/s}$$

The mean density of air through the filling:

$$\bar{\rho}_v \quad \frac{\rho_{v1} \quad \rho_{v2}}{2} \quad \frac{1.127 \quad 1.087}{2} \quad 1.11 \;\text{kg/m}^3$$

The parameters of the air on exit are:

$$t_{v2} \quad 34.2 \quad \text{C}, \;\; \rho_{v2} \quad 1.087 \;\text{kg/m}^3$$

Volumetric air flow is:

$$q_{vv} \quad \frac{q_{mw}}{\rho_v} \quad \frac{7389}{1.11} \quad 6657 \;\text{kg/m}^3$$

Cross-sectional area at the level of the filling:

$$S \quad \frac{q_{vw}}{q_k} \quad \frac{38000\frac{1000}{3600}}{2.5} \quad 4798 \;\text{m}^2$$

Diameter of the tower at the level of the filling is:

$$D_p \quad \sqrt{\frac{4S}{\pi}} \quad \sqrt{\frac{4 \;\; 4798}{3.14}} \quad 78.2 \;\text{m}$$

Adopted: D_p = 78 m.

Air velocity through the filling is:

$$\bar{w}_p \quad \frac{q_{vv}}{S} \quad \frac{6657\ 4}{78^2 \pi} \quad 1.40\ \mathrm{m/s}$$

Adopted height of the tower for film-drop type of the filling is H_t = 110 m. These are supposed tower height, obtained from historical data and current literature.

Coefficients of air drop pressure reduced to an average speed of air through the filling

Local air drop pressure is:

$$\Delta p_v \quad \xi \frac{w^2}{2} \rho_v \quad \bar{\xi} \frac{\overline{w_p^2}}{2} \bar{\rho} \tag{10}$$

where

$$\bar{\xi} \quad \frac{w}{\bar{w}_p}^{\;2} \quad \frac{\rho_v}{\bar{\rho}_v} \xi \tag{11}$$

Table 1. The values of local air resistance coefficient (*air drop pressure coefficient*) is reduced to an average speed of air $\bar{w}_p$ and secondary air density $\bar{w}_p$

Values \ Place		1	2	3	4	5	6	7	8	9	10	11	12
ξ	F-K	0.55	0.21	0.50	0.8	2.6	0.17	16.16	2.0	0.38	0.20	0.13	1.5
w [ms^{-1}]	F-K	3.35	3.35	3.35	1.40	1.40	1.40	1.40	1.40	1.40	1.40	3.58	3.10
ρ_v [kgs^{-1}]	F-K	1.123	1.123	1.123	1.123	1.123	1.123	1.110	1.087	1.087	1.087	1.087	1.087
$\bar{\xi}$	F-K	2.92	1.12	2.65	0.80	2.6	0.17	16.16	2.0	0.38	0.20	1.10	5.71

Table 2.Values of $\bar{\xi}_t$, H_{uz}, H_t and adopted tower height H_t

Filling type	$\bar{\xi}_t$	H_{uz} [m]	H_t [m]	H_t [m]
Film-drop	33.93	102.8	109.5	110

Cooling tower silhouette

Figure 2 shows the longitudinal (vertical) section of the tower – a silhouette, with relevant overall dimensions.

Table 3. Basic dimensions of cooling tower silhouette

Fillling type	H_t [m]	H_3 [m]	H_p [m]	h_u [m]	h_p [m]	D_{oo} [m]	D_p [m]	D_p [m]	D_o [m]	D_3 [m]	α [°C]	β [°]
F-K	110	24	76.2	8.0	1.8	84.15	78	79.12	49.33	52.87	72.5	8.1

Conclusions

The paper describes the aerodynamic calculation of hyperbolic cooling towers. Used by local pressure loss coefficients of air reduced the average speed of air flow through the tower fill. Procedure was used for the design of cooling tower power plant of 300 MW. The budget is taken into account the contribution of cooling zones meet changing rainfall below the effective height of the fill. Determined by the effective height of the tower, depending on flow conditions, air and water flow.

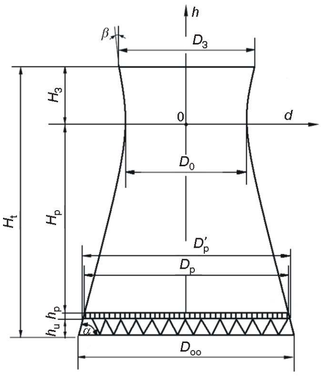


Figure 2. Geometric characteristics of hyperboloid cooling towers

References

[1] Benton, D., J., A Numerical Simulation of Heat Transfer in Evaporative Cooling Towers, Tennesse Valley Authority, Knoxville, Ten., USA, Report WR 28-1-900-110, 1983
[2] Берман, Л. Д., Испарительное охлаждениє циркуляционной воды, Госенергиздат, Ленинград, Россия, 1957
[3] Golubović, D, D., Improvement of Cooling Water in the Fillings of Power Plant's Hyperbolic Cooling Towers, M. Sc. thessis, Faculty of Mechanical Engineering, Belgrade, 2010
[4] Golubović, B. D., Golubović, D. D., Hyperbolic Cooling Tower's Fillings, The International Conference Mechanical Engineering in XXI Century, Faculty of Mechanical Engineering, Niš, Serbia, 2010
[5] Golubović, D. D., Golubović, B. D., Aplication of Modern Construction Packings in Hyperbolic Cooling Towers, 23, International Congress, *Proceedings*, 10, Tara, Serbia, 2010
[6] Golubović, D. D., Golubović, B. D., Water Cooling Efficiency in Power Plant Hyperbolic Cooling Tower, *Proceedings*, II International Conference IEEP, Zlatibor, Serbia, 2010
[7] Golubović, B. D., Golubović, D. D., Improvement of Water Cooling in the Hyperbolic Cooling Tower, 41. International Congresse KGH, Belgrade, 2010.
[8] Фарфоровский, В. С., Фарфоровский, В. Б., Охладители циркуляционной воды тепловых электростанций, *Енерīиа*, Ленинградское отделение, Россия, 1972
[9] Zemanek, I., Heat and Mass Transfer in Cooling Tover Packings, National Research Institute for Machine Design, Praha, 1989

Апстракт

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Аеродинамички прорачун хиперболоидног расхладног торња

У раду је анализиран противструјни расхладни торањ термоелектране. Приказане су основне релације струјања ваздуха. Дефинисан је коефицијент локалног пада притиска ваздуха у појединим деловима торња. Одређена је брзина ваздуха кроз испуну торња за специфичне техничке податке.

Применом филмско-капљичасте испуне, одређен је коефицијент пада притиска ваздуха кроз испуну. Дефинисана је силуета хиперболоидног расхладног торња.

Кључне речи: *хиперболичне куле за хлађење, аеродинамички прорачун*

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