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EVALUATION OF MULTIDIMENSIONAL EFFECT OF NATURAL DRAFT WET-COOLING TOWER FLOW

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Abstract: *The computational study of the flow fields inside the natural draft wet-cooling tower has been done. Obtained results allow evaluating the influence of particular parts on the flow field inside cooling tower. The effect of rain zone, fill zone and flue gas injection are studied. It is shown that the flow field above the fill zone is mainly influenced by minor losses in cooling tower fill and by the controlling of the flow direction in this zone. This effect is leading to practically uniform velocity field just above the fill zone even though the flow field in the rain zone is multidimensional. The impact of flue gas injection is studied by using momentum and kinetic energy flux coefficients. The system of Euler equations for quasi-one-dimensional flow is generalized using momentum and kinetic energy flux coefficients. It is shown that the flow field inside cooling tower excluding rain zone can be considered as quasi-one-dimensional in the case where the flue gas injection is not taken into account. The effect of flue gas injection slightly deviates the character of the flow, which is still very close to quasi-one-dimensional flow in the whole domain excluding rain zone.*

Keywords: natural draft wet-cooling tower, momentum flux coefficient, kinetic energy flux coefficient

1. Introduction

Natural draft cooling tower of rotational hyperboloid shape with

$$A(z) = \frac{\pi}{4}(0.006977z^2 - 1.2764z + 131.61)^2 \qquad (1)$$

is selected. The tower is 150m high with fill zone placed at the height of 11.5m. Fill height is assumed to be 2 m. Water inlet mass flow rate is 17200 kg/s. Inlet water temperature is 34.9°C. Air inlet temperature is 22°C, and specific humidity is 7.622 g/kg. The atmospheric pressure is 98100 Pa. Fill Merkel number is assumed to be 0.815 and Lewis factor is 0.9. Loss coefficient per meter of the fill zone is 12 m^{-1}. The flue gas mass flow rate is 350 kg/s and the temperature is 59°C. The heat and mass transfer is solved together with quasi-one-dimensional flow model in the first step by using model (Hyhlík, 2015-1). Dry air mass flow rate of 16393 kg/s is obtained in the case without flue gas injection, and 15576 kg/s is obtained with flue gas injection. Water temperature decreases to 26.4°C without flue gas and to 26.5°C with flue gas injection. Mentioned results are used as an input to the multidimensional flow field study.

2. Generalized quasi one-dimensional flow model

The system of governing equations can be written in the case of quasi-one-dimensional flow as

$$\frac{\partial(\boldsymbol{W}A)}{\partial t} + \frac{\partial(\boldsymbol{F}A)}{\partial z} = \boldsymbol{Q}, \qquad (2)$$

where $A(z)$ is cross-sectional area of the cooling tower, z is spatial coordinate, and t is temporal coordinate. Vector of conservative variables $\boldsymbol{W}$ and vector of fluxes $\boldsymbol{F}$ are

$$\boldsymbol{W} = \begin{bmatrix} \rho \\ \rho v \\ \rho e \end{bmatrix}, \quad \boldsymbol{F} = \begin{bmatrix} \rho v \\ \rho v^2 \beta + p \\ \left\{\rho\left(u + \gamma \frac{v^2}{2}\right) + p\right\} v \end{bmatrix}, \qquad (3)$$

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where ρ is density, v is velocity, p is pressure, u is internal energy, and e is sum of internal energy and kinetic energy. The first equation is continuity equation, the second is momentum equation, and the third is equation of energy. The system of governing equations is generalized by using momentum coefficient β and by using kinetic energy coefficient γ taking into account the non uniformity of velocity field

$$\beta = \frac{A \int_A v^2 dA}{\left(\int_A vdA\right)^2}, \quad \gamma = \frac{A^2 \int_A v^3}{\left(\int_A vdA\right)^3}. \tag{4}$$

Coefficient β is analogous to Boussinesq momentum correction coefficient which is a ratio of momentum flux based averaged velocity and mass flux based averaged velocity. Similarly, the kinetic energy coefficient is a ratio of kinetic energy flux based averaged velocity and mass flux based averaged velocity. These coefficients can modify momentum flux and kinetic energy flux with respect to non-uniformity of the velocity profile in the quasi-one-dimensional computation (Hyhlík, 2015-2) and, on the other hand, they allow to quantify nonuniformity of velocity profile.

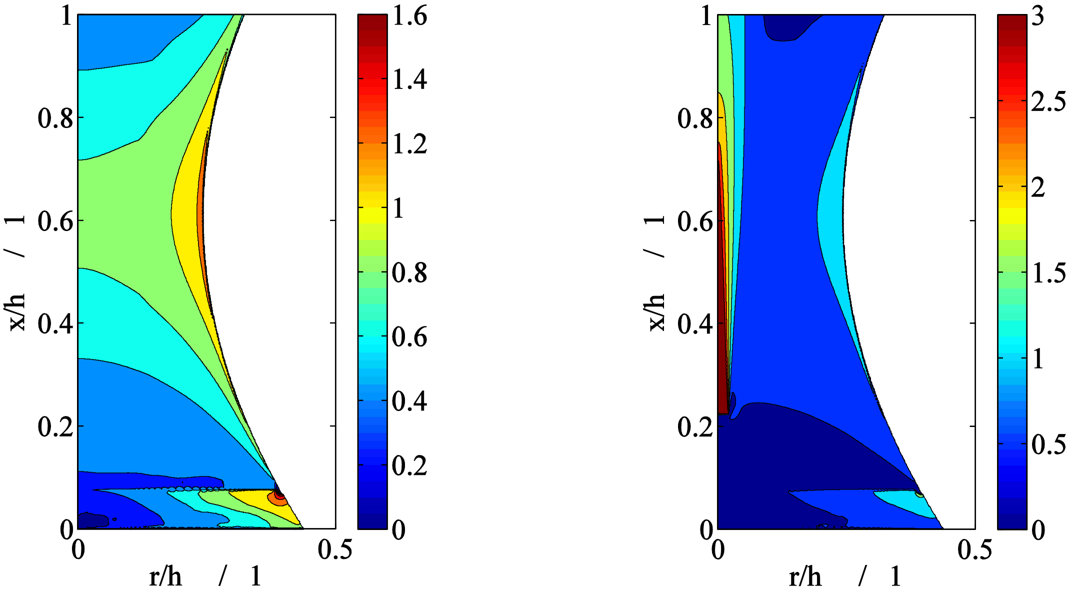

Fig. 1: Contours of velocity (non-simplified model); without flue gas injection (left) and with flue gas injection(right) .

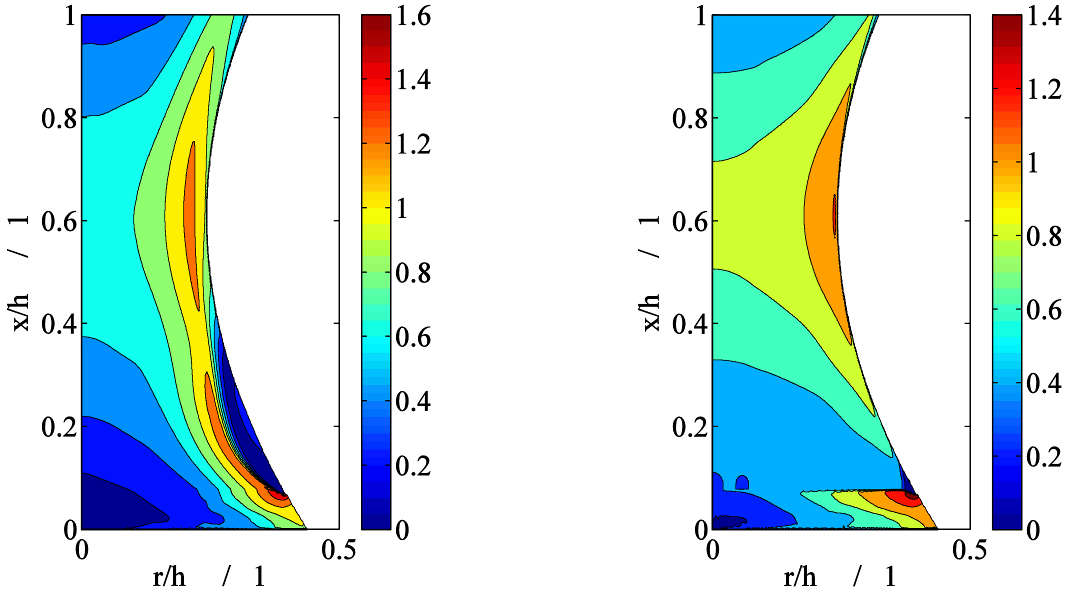

Fig. 2: Contours of velocity (simplified model); there are no minor losses in the fill (left);there are minor losses only in radial direction in the fill (right)

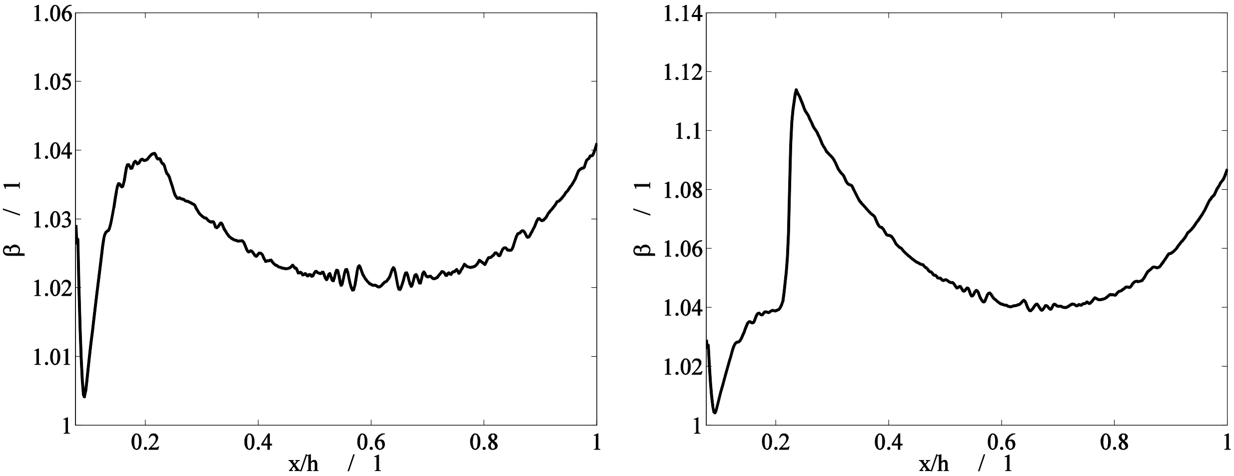

Fig. 3: Momentum coefficient (non-simplified model); without flue gas injection (left) and with flue gas injection(right).

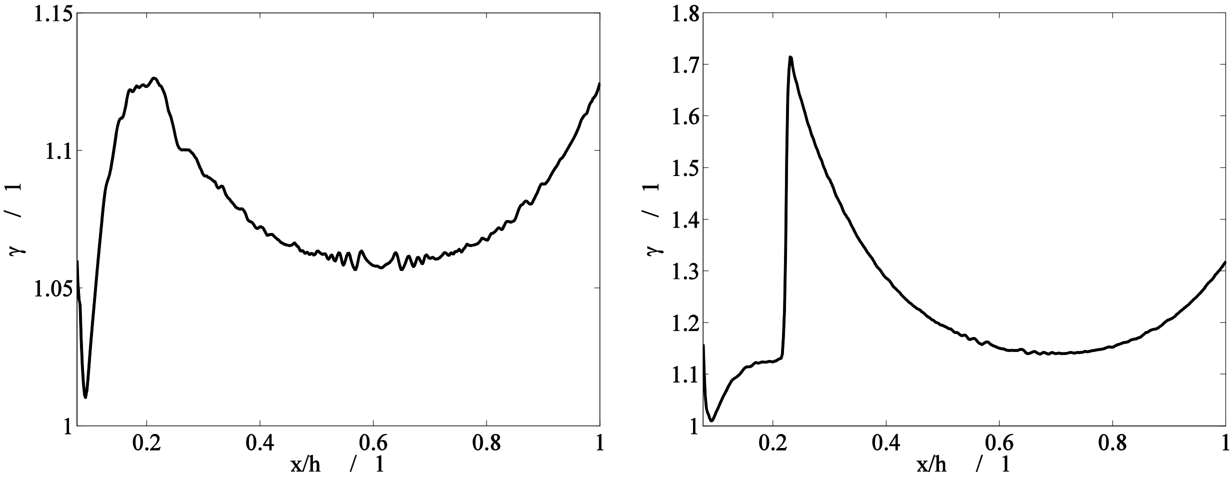

Fig. 4: Kinetic energy coefficient (non-simplified model); without flue gas injection (left) and with flue gas injection(right).

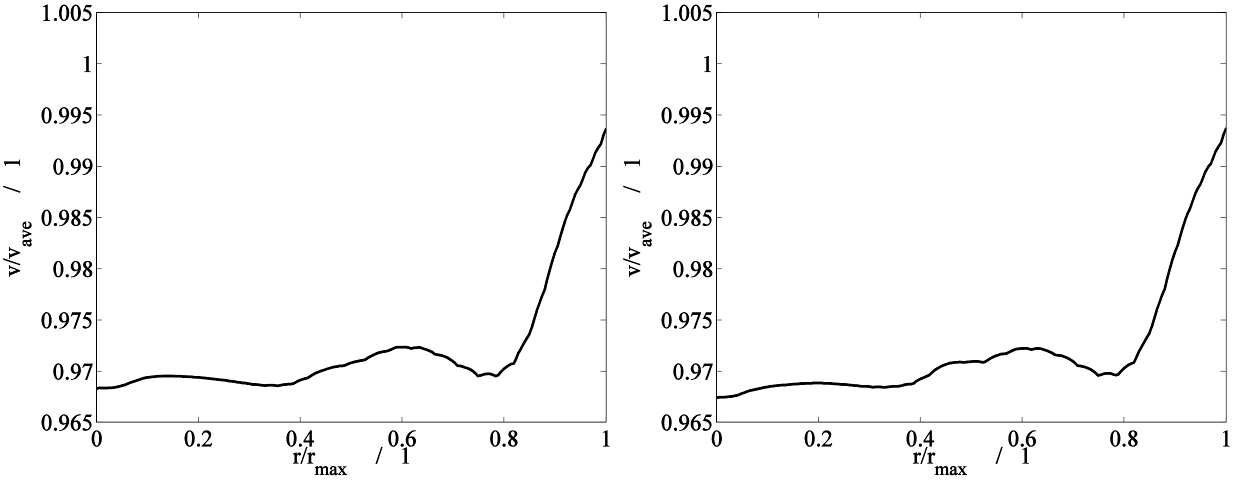

Fig. 5: Velocity distribution above the fill zone (non-simplified model); without flue gas injection (left) and with flue gas injection(right).

3. Results

The numerical solution of axisymmetric flow inside the cooling tower has been done by using ANSYS Fluent code, where air and water mass flow rates are prescribed as was mentioned in the introduction. Rain zone in the cooling tower is modeled by using discrete phase model which allowed modeling an interaction of flowing moist air and water droplets. Fill zone is prescribed by using both radial and axial direction minor loss coefficients, where radial loss coefficient is set to have very high value to prevent flow in the radial direction in this zone. There is the cooling tower cross section in figures 1 and 2, where the axis is on the left, the inlet is on the right down and outflow is on the top side. The velocity is normalized by area weighted velocity in the narrowest cross section of the cooling tower. Figure 1 shows the velocity field in the case of the flow without and with flue gas injection. The highest velocities are in the bottom part of the cooling tower close to the inlet. It is visible that the velocity field is strongly affected by flue gas injection, but the flue gas injection affects only limited region close to the cooling tower axis. The figure 2 documents importance of minor loses in the model. The left part of this figure shown the case, where minor loses in the fill zone are ignored, loses in rain zone are modeled correctly with discrete phase model. It is visible that this approach leads to the unrealistic flow field with a large separation zone. The right-hand side of figure 2 documents the case where the minor loses in the radial direction in the fill zone are included, and this approach leads to realistic flow field which in very close to the flow field in figure 1 despite the fact that the minor loses in the axial direction are ignored. From the engineering point of view is very important to evaluate the nonuniformity of the flow field because the design codes are mainly one-dimensional. Momentum and kinetic energy coefficients defined in section 2 are evaluated in figures 3 and 4 as a function of the nondimensional axial coordinate. Because the flow field in the rain zone is multidimensional, this zone is not included in figures 3 and 4. It is possible to see that the case of the flow without flue gas injection is almost one dimensional because the coefficients β and γ are very close to one. The values of momentum and kinetic energy coefficients are higher in the case of flue gas injection, but the flow field is not so far from the one-dimensional case. There is an increase in momentum and kinetic energy coefficient in the bottom part of the cooling tower above fill zone. The coefficients are decreasing in the middle of the cooling tower, and then there is an increase in the outflow part. The highest values of mentioned coefficients are connected with the place where the flue gas is injected. It is visible that the distribution of velocity above the fill is not affected by the flue gas injection as depicted in figure 5. Although the flow in the rain zone is multidimensional, the velocity above the fill is almost uniform. This effect is connected with loses in the rain zone and in the fill zone.

4. Conclusions

A computational study of the flow through the natural draft wet-cooling tower has been performed. It has been shown that the most important minor loss is the radial loss coefficient in the fill which significantly affects flow field as is documented in figures 1 and 2. The utilization of this coefficient allows flowing only in the axial direction in the fill. The character of the flow field deviates from the idealized quasi-one-dimensional flow especially in the case of flue gas injection, but the deviation is not strong. The flow field in the case without flue gas injection is almost quasi-one-dimensional. The obtained results allow being included in the model of quasi-one-dimensional flow in the section 2 which can improve the flow field prediction. Another possibility is to include presented momentum coefficient into so-called draft equation (Kröger, 2004) which is frequently used by cooling tower industry.

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