Understanding Plume Dispersion

Predicting the External Aerodynamics of Cooling Towers using CFD

By Dr. Andrey Ivanov &
Dr. Svetlana Shtilkind

Figure 1. Natural Draft Wet Cooling Towers

Cooling towers are an integral part of power and chemical plants. Their primary function is to reject heat into the atmosphere as a relatively inexpensive and dependable means of removing low-grade heat from cooling water.

Cooling towers are characteristically tall, large, lightweight structures that are very sensitive to wind loads that can pose some problems to structural design. The design however, is not without purpose. In the case of Natural Draft Wet Cooling Towers (see Figure 1) these design features allow heated water to be evenly distributed through channels and pipes above the fill. As the water flows and drops through the fill sheets, it comes into contact with the rising cooler air. Evaporative cooling occurs and the cooled water is then collected in the water basin to be recycled into the condenser. The difference in density of the warm air inside and the colder air outside creates the natural draft in the interior. This upward flow of warm air leads to a continuous stream of fresh air through the air inlets into the tower.

Comparing Actual vs. Virtual

Following the collapse of three cooling towers at the Ferrybridge Power Station in Yorkshire, UK in 1966, these wind-sensitive structures have undergone numerous costly wind tunnel testing. These tests seek to identify those pressure distributions that lead to extreme key stress dominating the design of the tower. Wind tunnel tests and numerical investigations are generally used to obtain the wind-induced pressure coefficient distribution on outer and/or inner surfaces of cooling towers under specific surrounding or operating conditions.

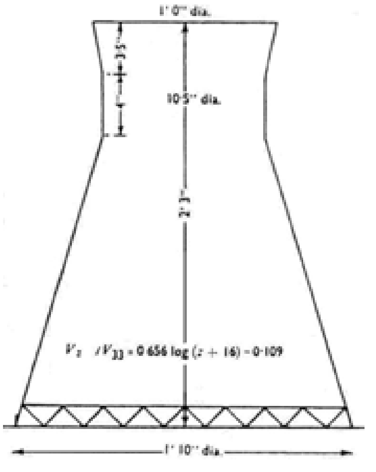

Figure 2. Cooling Tower Geometry

Geometrical Parameters	*Units*	*Value*
Overall height	in	27.0
Base diameter	in	22.0
Throat diameter	in	10.5
Top diameter	in	12.0
Cylindrical throat height	in	4.0
Upper truncated cone height	in	3.5
Air Flow Properties		
Temperature	K	293.2
Pressure	atm	1.0
Reference velocity V_{33}	m/s	103.9
Friction velocity U_*	m/s	7.86
Reynolds Number		≈ 6.0E6

Table 1. Cooling Tower Parameters and Flow Conditions

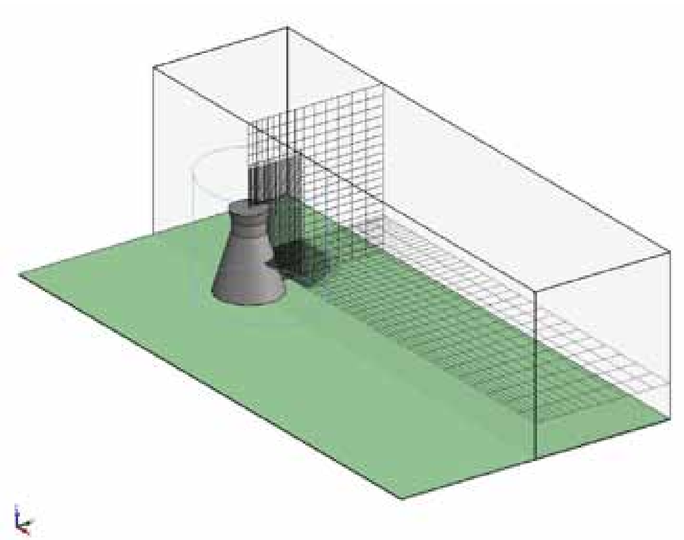

Figure 3. Computational Mesh Topology

In this given situation, the use of Computational Fluid Dynamics (CFD) can be regarded as an extremely useful tool in being able to predict cooling tower aerodynamic characteristics. Using a tool such as FloEFD™ to analyze the flow around the cooling tower could avoid costly wind tunnel tests and provide reliable data for practical structural design changes.

Setting the Parameters in CFD

To create the model in FloEFD the following parameters were set; the hyperbolic shape of a cooling tower shell is approximated by a short cylindrical throat joined onto two truncated cones, as can be seen in Figure. 2. Considering the structure is symmetrical,boundary conditions were used to mesh half of the tower. The shell surface is relatively smooth and the cooling tower base aperture was treated as sealed. The cooling tower was defined by the geometrical parameters given in Table 1. All presented parameters as well as experimental data were taken from the wind tunnel experiments of Cowdrey and Neil; Salter and Raymer; and Zdravkovich [1-3].

The kinetic energy of turbulence and its dissipation rate profiles in the approaching flow correspond to those of the neutral atmospheric conditions. Figure 3 below shows the computational mesh topology in FloEFD.

The Results

It is worth noting that all calculations presented below were performed as stationary ones. Usually this took 500-600 iterations to get to the converged solution. Figures 4 and 5 demonstrate the comparisons of predicted and measured *Cp* distributions at Z/H=0.79 and at Z/H=0.43, respectively.

From almost all angles it can be concluded that the predicted results compare very well with the experimental. Predicted *Cp* distribution with elevation in the rear side of the structure also show excellent correlation with the experimental data (see Figure 6 overleaf).

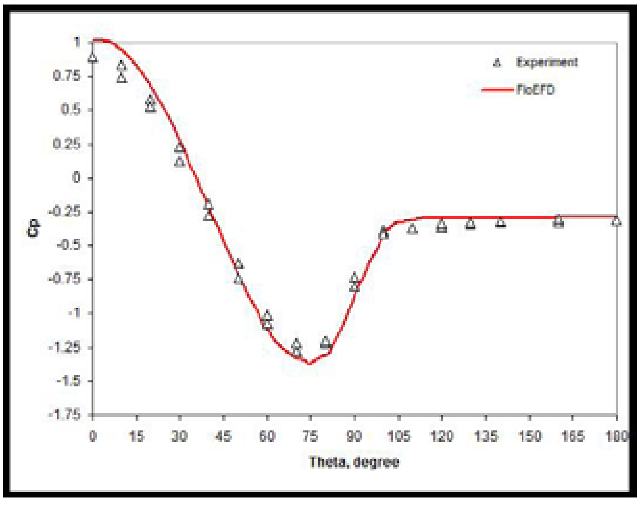

Figure 4. *Cp* distributions at elevation Z/H=0.79

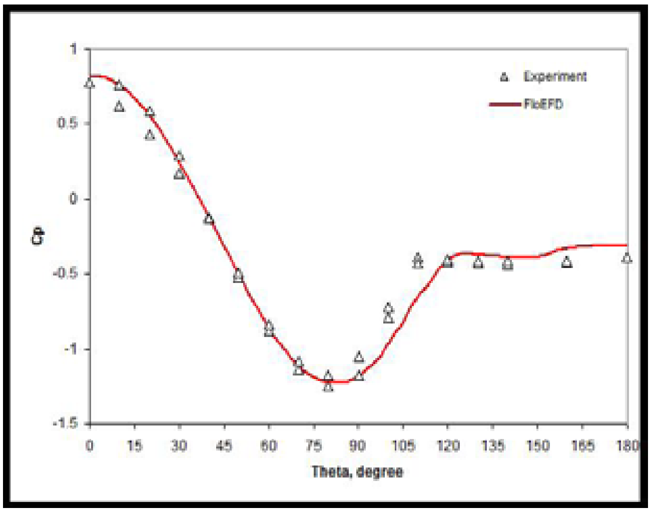

Figure 5. *Cp* distributions at elevation Z/H=0.43

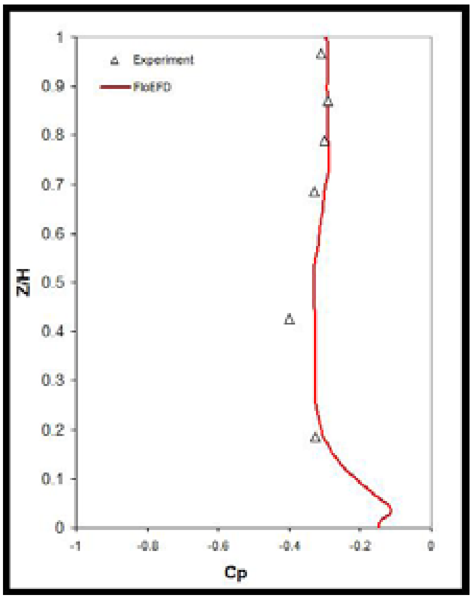

Figure 6. *Cp* distributions with elevation in rear side of the cooling tower (theta=180)

FloEFD can be used for complex multi-physics calculations including water vapor plume dispersion along with condensation and evaporation processes. Figures 8 – 10 demonstrate the results of the predicted visible saturated vapor plume formations complicated by a number of interesting associated physical processes.

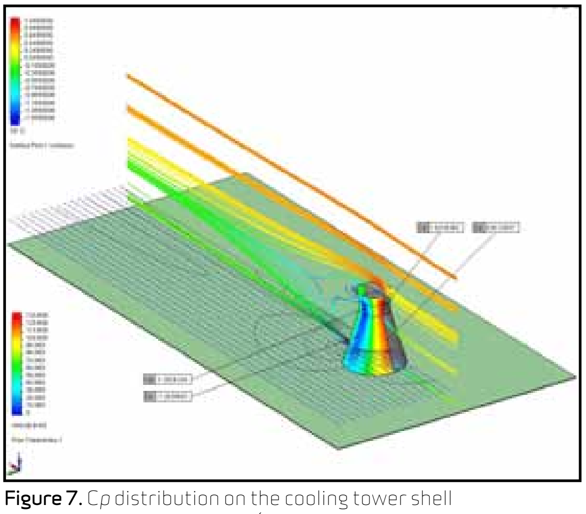

Figure 7. *Cp* distribution on the cooling tower shell along with flow trajectories (colored by velocity magnitude) in symmetry plane

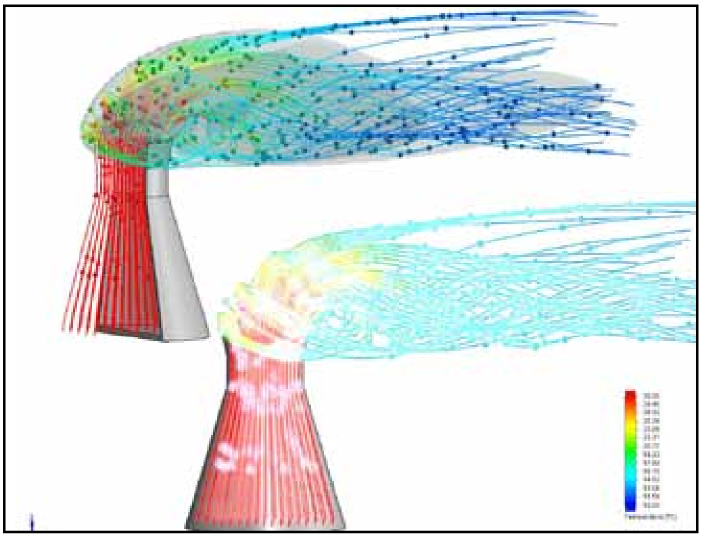

Figure 8. Condensate mass fraction isosurface with a value of 10-4 (wet plume visibility limit) with flow trajectories colored by temperature magnitude

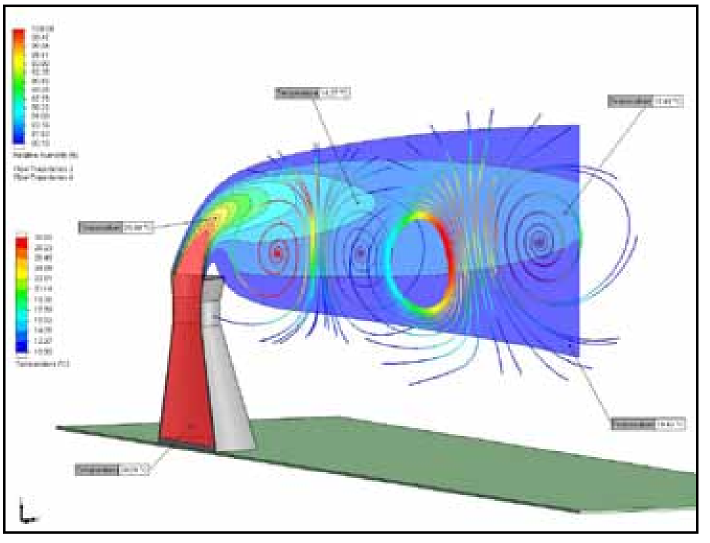

Figure 9. Temperature distribution in vertical symmetry plane with flow trajectories drawn in two lateral downstream sections and colored by relative humidity magnitude

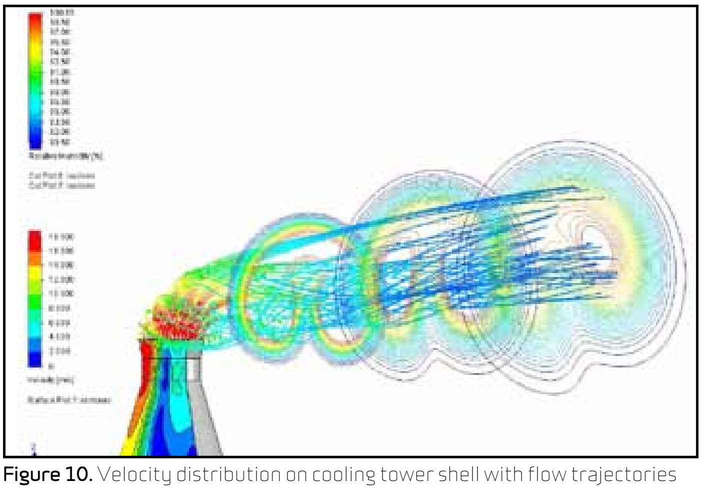

Figure 10. Velocity distribution on cooling tower shell with flow trajectories colored by temperature magnitude and relative humidity contours in three downstream cross-sections

Conclusions

Whilst it is clear that FloEFD has successfully validated the problem of predicting the external aerodynamics of cooling tower structures. This article also demonstrates its capability to accurately simulate complex multi-physics processes that occur in wet cooling tower plume. FloEFD's numerical approach can be used as a very cost effective method of evaluating cooling tower environmental impact before very costly wind tunnel or nature experiments are carried out.

References:

[1] Cowdrey, C.F. and O'Neill, P.G.G. Report of tests on a model cooling tower for CEA: pressure measurements at high Reynolds numbers. Nat. Phys. Lab., Aero. Rep. 316a, 1956.
[2] Salter, C. and Raymer, W.G. Pressure measurements at high Reynolds number on a model cooling tower shielded by second tower. Nat. Phys. Lab., NPL Aero. Rep. 1027, 1962.
[3]Zdravkovich, M.M. Flow around circular cylinders. Vol. 2: Applications. Oxford University Press, 2003.