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"CFD SIMULATION ON THERMAL COOLING TOWER"

***Rajeev Ranjan* [1] *, Dr Rajneesh Kumar Gedam* [2]**

[1] *Research Scholar, Dept. of Mechanical Engineering, Bhabha University, Bhopal, MP, India*

[2] *Professor, department of Mechanical Engineering, Bhabha University, Bhopal, MP, India*

ABSTRACT

This research delves into examining temperature fluctuations, pressure alterations, and turbulence characteristics across distinct tower regions. Initially, the inlet air temperature stands at 300K, surging sharply as it encounters hot water in the rain zone. Near the tower center, where air thickens due to high heat, both air and water particle temperatures remain elevated. The primary heat exchange unfolds in the fill zone, where air temperature notably increases. Pressure experiences a sudden drop upon entering the fill area at 20 meters, followed by a slight ascent with altitude. Thermal conductivity peaks near the axis due to intense heat and low density, contrasting with its weaker conductivity near the wall where density is higher. Turbulence intensity fluctuates unpredictably until reaching the fill zone, after which it stabilizes. Post-rain zone, thermodynamic features undergo substantial shifts, with temperature reaching its zenith along the central axis and decreasing toward the wall. Pressure declines from maximum to zero at the fill zone, then gradually ascends with elevation. The highest thermal conductivity is noted near the axis. Turbulent intensity and viscosity display diverse patterns across various zones. The stream function remains consistent along the axis but diminishes in the middle and near the wall with increasing height.By comparing two design approaches at different flow rates and constant temperatures, the study concludes that the second design consideration yields superior performance outcomes.

Keyword*: Turbulent intensity ,viscosity, cooling tower*

I. INTRODUCTION

A cooling tower serves as a specialized heat exchanger essential for extracting surplus heat from industrial processes or systems. It finds widespread application in industrial setups, power generation plants, and other large-scale operations where dissipating heat generated during various processes is crucial to prevent equipment damage and maintain operational efficiency.

The fundamental operation of a cooling tower revolves around leveraging water evaporation to cool down a fluid, typically water, which has absorbed heat from a process. This process involves allowing a fraction of the heated water to evaporate, thereby carrying away the heat and reducing the overall temperature of the remaining water. The cooled water can then be circulated back into the process for further cooling.

Natural Draft Cooling Tower: These towers utilize the natural airflow resulting from temperature and density

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disparities to facilitate air circulation within the tower. They often feature imposing structures with a characteristic hyperbolic shape.

Natural draft cooling towers are renowned for their ability to efficiently dissipate substantial heat quantities without relying on energy-intensive mechanical fans. However, they typically entail larger and taller constructions compared to necessity generating a significant temperature and density contrast to drive airflow.

These cooling towers are prevalent in power plants and large-scale industrial setups where the removal of substantial heat loads from processes is imperative. While offering advantages in terms of energy efficiency, natural draft cooling towers demand meticulous design and engineering to ensure optimal air circulation and effective cooling.

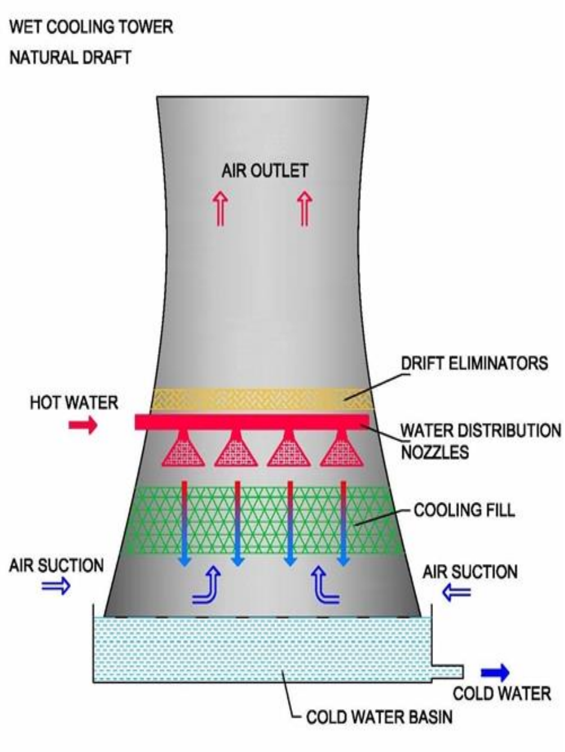


Fig. 1 Natural Draft Cooling Tower

Cooling towers, as noted by an anonymous source in 2013, function as devices aimed at dissipating heat, transferring undesired thermal energy to the surrounding atmosphere. These towers employ the evaporation of water as a means to expel excess heat and cool fluids. In the case of dry cooling towers, which operate within closed circuits, air alone is utilized for fluid cooling. Available in various shapes and sizes, cooling towers can tower up to heights of 200 meters for larger configurations, as reported by the same anonymous source. Conversely, smaller cooling towers serve as components for releasing heat from buildings' air conditioning systems.

II. LITERATURE REVIEW

P. Chandra Shekhar and colleagues (2022) investigated the utilization of cooling towers in automotive, chemical, and other industrial plants to dissipate heat from water into the atmosphere. They highlighted the potential enhancement of cooling tower performance through water modeling and energy consumption analysis. Their research reviewed prior studies aimed at assessing the effectiveness of cooling towers under various operational conditions. The study presented analytical equations alongside experimental data to evaluate and improve cooling tower performance.

Ahmed Aboulmagd and team (2022) emphasized the critical role of cooling towers in large-scale process applications and the significant impact of any decrease in their efficiency on underlying processes to examine components contributing to cooling tower performance. Their study included a numerical analysis of performance at and tower above the ground, revealing both negative and positive effects of wind speed and a positive effect of tower height on performance.

Guangjun Yang and co-researchers (2020) discussed conflicting findings regarding the impact of wind speed on cooling tower performance and highlighted potential issues in dry-cooling towers under poor working conditions, leading to severe corrosion.

Asvapoositkul et al. (2012) predicted cooling tower performance through a mass evaporation rate equation and evaluated acceptance tests for new towers while monitoring changes in performance.

Lemouari et al. (2009) analyzed heat and mass transfer during air/water contact in cooling towers, observing two regimes: Pellicular Regime (PR) and Bubble and Dispersion Regime (BDR). They found BDR to be more efficient in achieving higher evaporation rates and heat transfer coefficients.

Muangnoi et al. (2008) identified heat and mass transfer properties of water and air in cooling towers and calculated energy based on a mathematical model.

Qi et al. (2008) derived heat and mass transfer characteristics of Shower Cooling Towers (SCT) without assumptions, focusing on optimization through proper water distribution to improve efficiency. Smrekar et al. (2006) optimized heat transfer rates and cooling tower packing to enhance the efficiency of natural draught cooling towers by reducing entropy generation and minimizing exergy destruction.

Kloppers et al. (2005) derived heat and mass transfer equations for cooling towers and compared results from various methods such as the Poppe method, Merkel method, and effectiveness-NTU method, providing insights into their suitable applications for different cooling towers.

III. METHODOLOGY, RESULTS AND DISCUSSION

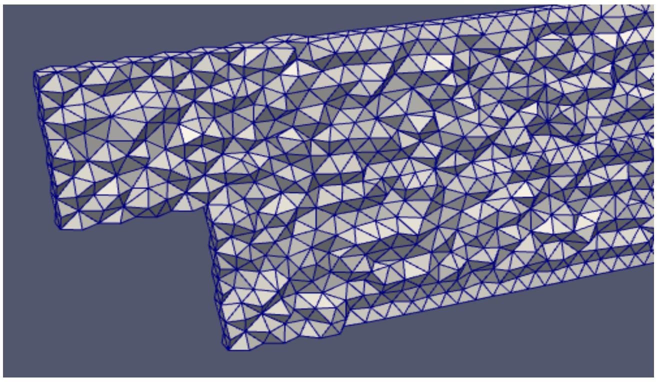


Fig. 2 Tetrahedral Mesh

1. Water Inlet temperature (T1): 329K, Mass flow rate of water (Mw): 0.055kg/s, Mass flow rate of air (Ma): 0.0404kg/s
2. Water Inlet temperature (T1): 329K, Mass flow rate of water (Mw): 0.099kg/s, Mass flow rate of air (Ma): 0.077kg/s

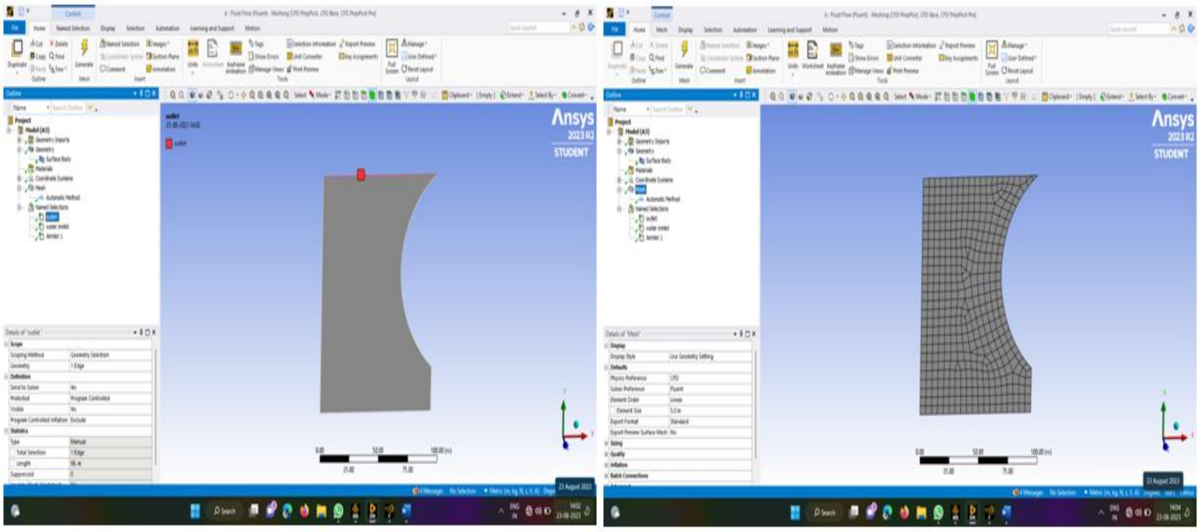


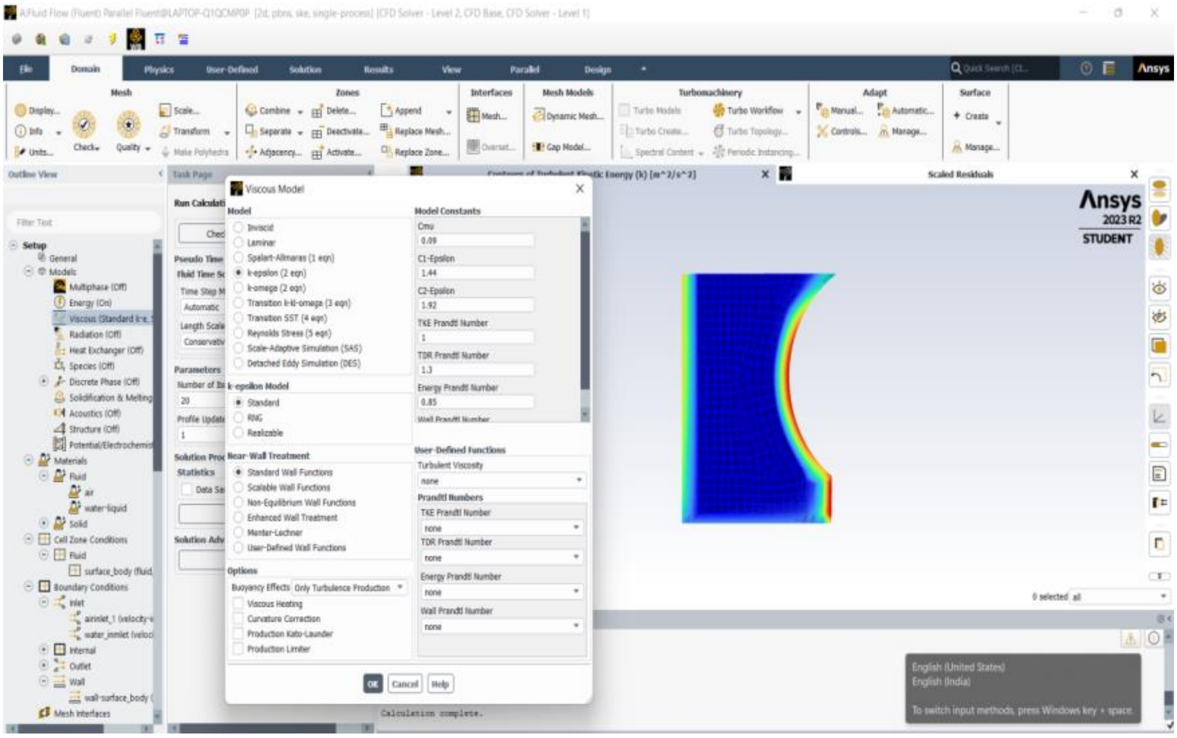
Fig. 3 Cooling tower outlet boundary condition and Cooling tower meshing applied

Following the geometry creation, the mesh is generated, a process that demands careful attention to mesh quality as recommended in FLUENT 19.2.

- Different parts undergo meshing with varying element sizing.
- The fill zone receives a finer meshing treatment.
- Employing mapped face meshing, the model is created with appropriate element sizing.
- Subsequently, the cooling tower's different parts are named.

CASE I: DESIGN 1

Design 1



Viscous Model

Model
○ Inviscid
○ Laminar
○ Spalart-Allmaras (1 eqn)
● k-epsilon (2 eqn)
○ k-omega (2 eqn)
○ Transition k-kl-omega (3 eqn)
○ Transition SST (4 eqn)
○ Reynolds Stress (5 eqn)
○ Scale-Adaptive Simulation (SAS)
○ Detached Eddy Simulation (DES)

k-epsilon Model
● Standard
○ RNG
○ Realizable

Near-Wall Treatment
● Standard Wall Functions
○ Scalable Wall Functions
○ Non-Equilibrium Wall Functions
○ Enhanced Wall Treatment
○ Menter-Lechner
○ User-Defined Wall Functions

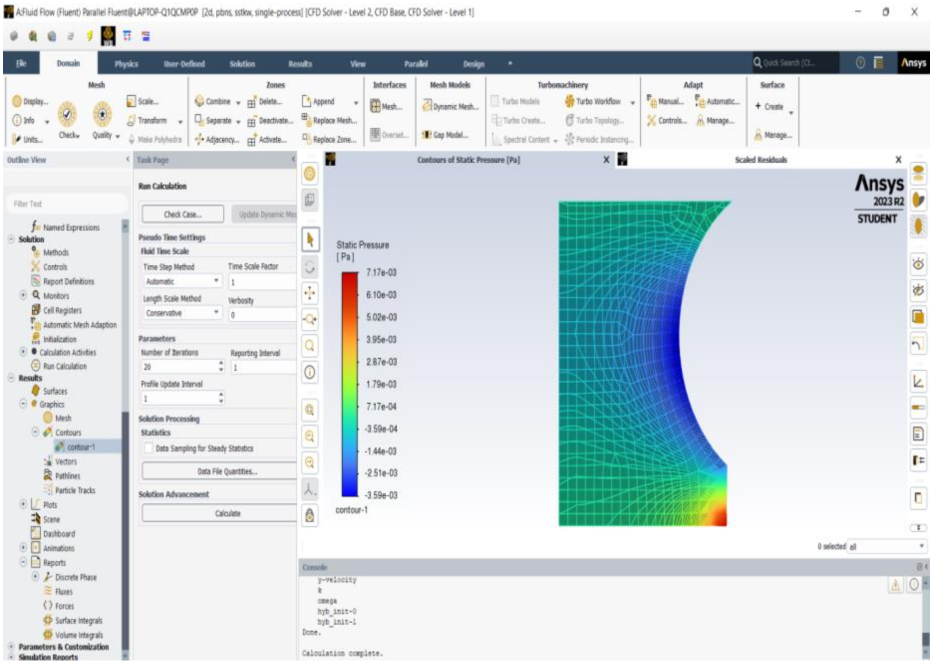
Options
Buoyancy Effects: Only Turbulence Production
☐ Viscous Heating
☐ Curvature Correction
☐ Production Kato-Launder
☐ Production Limiter

Model Constants
Cmu: 0.09
C1-Epsilon: 1.44
C2-Epsilon: 1.92
TKE Prandtl Number: 1
TDR Prandtl Number: 1.3
Energy Prandtl Number: 0.85

User-Defined Functions
Turbulent Viscosity: none
Prandtl Numbers
TKE Prandtl Number: none
TDR Prandtl Number: none
Energy Prandtl Number: none
Wall Prandtl Number: none

```
Calculation complete.
```

Fig. 4 Cooling tower turbulence FEM results



Run Calculation

Pseudo Time Settings

Fluid Time Scale

Time Step Method: Automatic

Time Scale Factor: 1

Length Scale Method: Conservative

Verbosity: 0

Parameters

Number of Iterations: 20

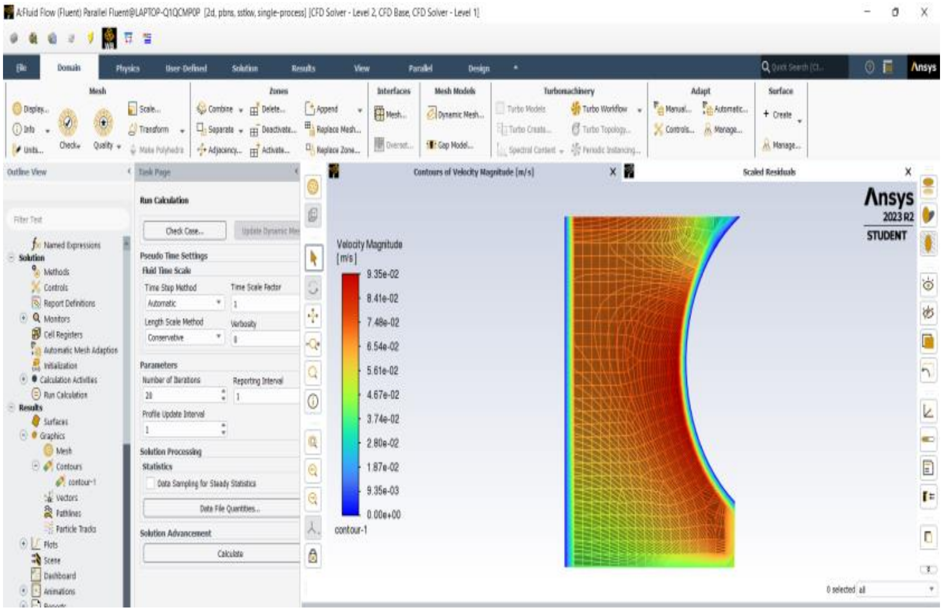
Reporting Interval: 1

Profile Update Interval: 1

```
    y-velocity
    k
    omega
    hyb_init-0
    hyb_init-1
Done.

Calculation complete.
```

Fig. 5 Cooling tower static pressure FEM results



Run Calculation

Pseudo Time Settings

Fluid Time Scale

Time Step Method: Automatic

Time Scale Factor: 1

Length Scale Method: Conservative

Verbosity: 0

Parameters

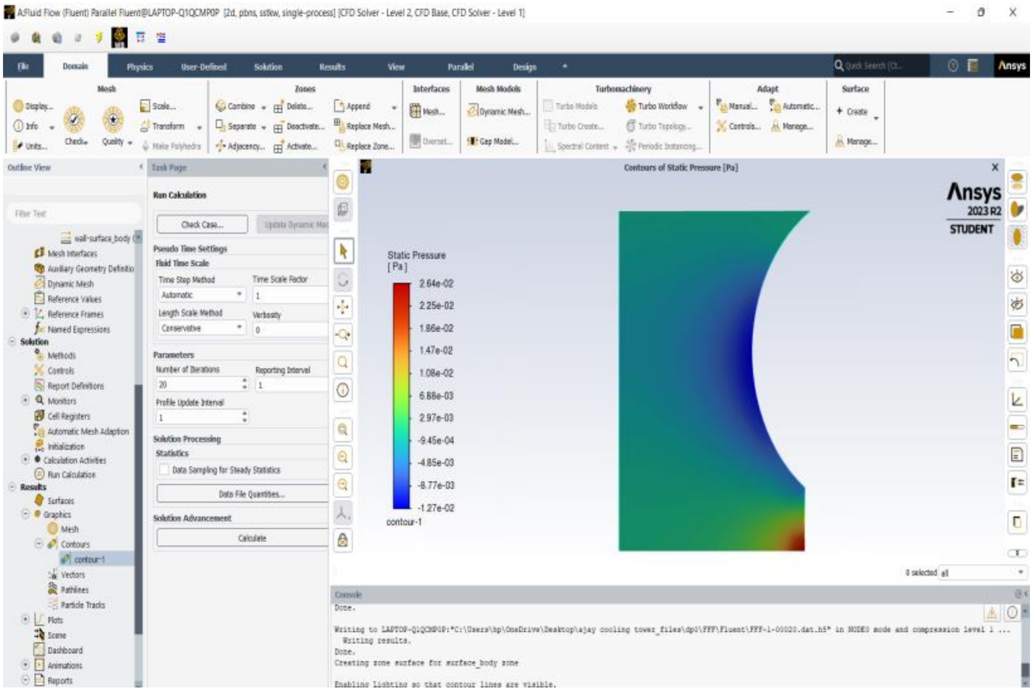
Number of Iterations: 20

Reporting Interval: 1

Profile Update Interval: 1

Fig. 6 Cooling tower velocity magnitude FEM results

CASE II: DESIGN 2



Run Calculation

Pseudo Time Settings

Fluid Time Scale

Time Step Method: Automatic

Time Scale Factor: 1

Length Scale Method: Conservative

Verbosity: 0

Parameters

Number of Iterations: 20

Reporting Interval: 1

Profile Update Interval: 1

Solution Processing

Statistics

☐ Data Sampling for Steady Statistics

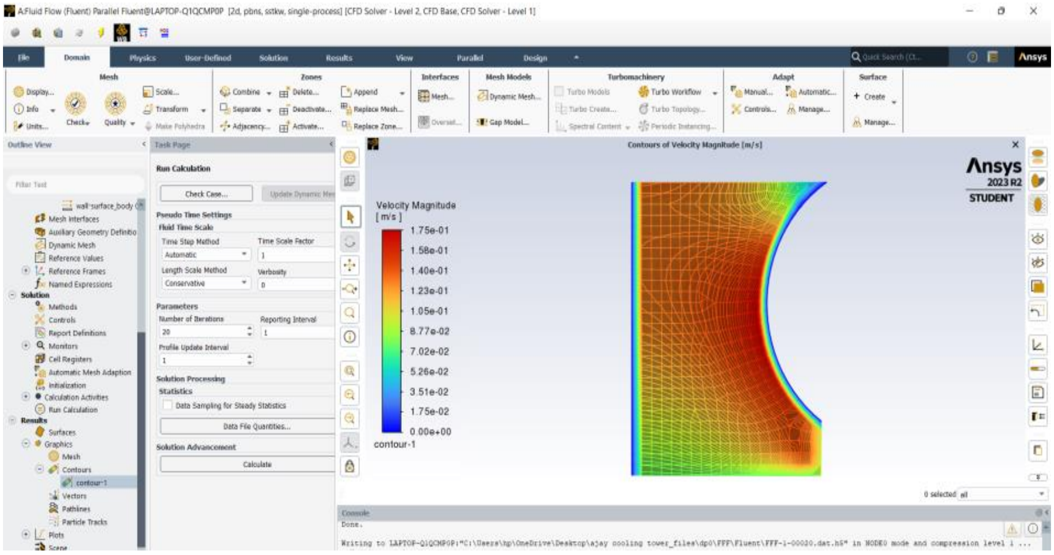
Console

```
Done.

Writing to LAPTOP-Q1QCMP0P:"C:\Users\hp\OneDrive\Desktop\ajay cooling tower_files\dp0\FFF\Fluent\FFF-1-00020.dat.h5" in NODE0 mode and compression level 1 ...
  Writing results.
Done.
Creating zone surface for surface_body zone

Enabling Lighting so that contour lines are visible.
```

Fig. 7 cooling tower static pressure FEM results



Run Calculation

Pseudo Time Settings

Fluid Time Scale

Time Step Method: Automatic

Time Scale Factor: 1

Length Scale Method: Conservative

Verbosity: 0

Parameters

Number of Iterations: 20

Reporting Interval: 1

Profile Update Interval: 1

Solution Processing

Statistics

☐ Data Sampling for Steady Statistics

Console

```
Done.
Writing to LAPTOP-Q1QCMP0P:"C:\Users\hp\OneDrive\Desktop\ajay cooling tower_files\dp0\FFF\Fluent\FFF-1-00020.dat.h5" in NODE0 mode and compression level 1 ...
```

Fig. 8 Cooling tower velocity ma FEM results

IV. CONCLUSION

The natural draft wet cooling tower experiences temperature changes throughout its structure. At the tower inlet, the ambient air temperature is 300K. Near the tower axis, where air chokes due to high temperatures, both air and water particle temperatures remain elevated. The most significant heat transfer occurs in the fill zone, leading to high air temperatures. Total pressure experiences a sudden decline upon reaching the fill area at 20 meters, followed by a slight increase with height.

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Thermal conductivity is highest due to temperatures, while it is poor near the wall where density is higher. Turbulence intensity fluctuates randomly until the fill zone, after which it stabilizes. Various thermodynamic characteristics change after the rain zone, with temperature peaking along the decreasing near the wall. From maximum to zero at the fill zone and then gradually rises with height. The highest thermal conductivity is observed near the axis, and turbulent intensity and viscosity exhibit varying patterns across different zones.

The stream function remains constant along the axis and decreases with height along the middle line and near the wall.

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