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EXPERIMENTAL STUDY OF WIND EFFECTS ON THE AIRFLOW OF NATURAL DRAFT WET COOLING TOWERS

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ABSTRACT

Natural draft cooling towers may enhance the overall performance of a thermal or a nuclear power station by providing coolant water to the condenser at a reduced temperature. The cooling tower thermal performance and its air flow inside the tower are influenced by the prevailing cross winds which in turn are amplified or damped by the flow-conditioning characteristics of surrounding structures, building and terrains in the relative proximity and orientation to the tower. These characteristics were investigated in the No-1 cooling tower at the Mount Piper Power Station near Sydney in Australia. The tower was instrumented using thermocouples and directional anemometers to measure air velocities and temperatures both inside and outside of the tower over three months period. The test results have indicated that surrounding structures and their relative orientations to the tower and wind directions affect on the air flow rate inside a tower and should be considered at the design stage..

INTRODUCTION

Natural draft cooling towers are large parabolic structures used in power stations, oil refineries and several other thermal installations to transfer large quantities of low grade heat from cooling water to the surrounding atmosphere in a direct-contact (the wet core), or indirect-contact (the dry core) arrangement. Authors have experimentally studied the performance of the natural draft cooling towers under the influence of a cross wind and concluded that cross wind have affected on the uniformity and flow rate of air inside the tower. [1-20]. Numerical investigation of natural draft cooling towers have mainly limited to dry-cores due to the complexity associated with the modelling of the coupling effects of mass, momentum and heat transfer between cooling water droplets and the non uniform incoming air flows [21]. There has also been a number of publications by other investigators on different aspects of wind effects on the performance of natural draft cooling towers and suggested that the prevailing cross wind significantly affected the tower performance and the overall efficiency of a power station [22-33]. However, most of the studies conducted on natural draft cooling towers have not considered the effect of adjacent plant buildings, structures and natural terrains or barriers. A detailed investigation on wind effects on the performance of these towers in vicinity of other structures and building is therefore conducted to further improve our understanding of the nature of the problem and to assist the designers, owners, and operators of cooling towers [22].

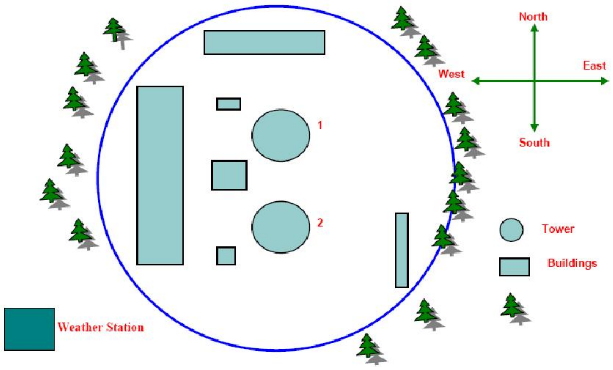

Figure 1: Layout of cooling towers and buildings at the Mount Piper power station.

This paper reports on the effects of a naturally blowing wind on a full scale prototype wet natural draft cooling tower (Figure1) in the Mount Piper power station at Sydney, which is operated by Delta Electricity the second largest power generation company at Australia. Delta Electricity was founded in March 1996 with four power stations located in NSW: Mount Piper and Wallerwang near Lithgow, and Vales Point and Munmorah on the Central Coast with a combined generating capacity of 4,240 MWe. The market share of the company is 13% in the power demand of South Australia, Queensland, New South Wales, Victoria and the ACT (www.de.com.au).

The company has been taking substantial steps in reducing the emissions from the coal fired power stations. The cooling tower project was one of the efforts aimed at increasing the power generation efficiency thereby assisting to minimise the emissions.

The tower-1 was selected because of its proximity and orientation relative to other tower and plant buildings. The wind speed and directions were measured at the inlet to the tower and relative to the surrounding structures. More specifically when the wind blows from particular direction, depending upon the type of obstructions, either buildings or another tower, the uniformity of the pressure distribution around the inlet of the tower may vary and result in peculiar effects on the tower performance.

ORIENTATION OF THE MOUNT PIPER COOLING TOWERS IN RELATION TO SURROUNDING PLANT BUILDINGS AND WIND DIRECTIONS

The layout of the cooling towers and plant buildings at the power station is shown in Figure 1. In this study, tower 1 has been instrumented and tested which has a water treatment building and other small structures (not shown here) in front, a second cooling tower at the back and a large building block section housing turbines and both boilers on the western side. A mountain terrain surrounds the power station area. The plant records suggest that the prevailing wind in the power station area is predominantly from either north or west directions with occasional gusts from the south. In this study, data was collected from certain days when the wind direction was fairly constant during the test duration and the plant was working on full load. The wind in the power station blows predominantly from the northern and western directions and occasionally comes from south or east directions. The wind was found to be blowing from west (250 - 270^{o}) between 00:00 and 6:00 and north (0/360^{o}) between 6:00 to 00:00. The wind direction has been fairly constant from north after 6:00 to mid night. During this time the plant operates on its full load capacity and the data for studying the wind effects was taken from this period of time.

EFFECT OF WIND ON AIR VELOCITY INSIDE THE TOWER

The performance of natural draft cooling towers can vary significantly with changes in the airflow inside the tower. Since water flow rate in most of the power station installations remain fairly constant, any decrease in the airflow inside the tower will eventually decrease the cooling efficiency of a natural draft cooling tower. An uneven air distribution may cause a reduction in the heat exchange process. Hassan [28] reported on the basis of an analytical and experimental study that uneven air distribution in a cooling tower will significantly affect the cooling water temperature drop. There will be other factors associated with the natural draft cooling towers which may affect airflow inside the tower such as pressure loss across the tower fill and the tower drift (Klopers and Kroger [26], Meroney [30].

In a study conducted on the energy and mass transfer in natural draft cooling towers of a 350 MWe unit, Sirok et al [33], divided the cooling tower section above the drift eliminator into four quadrants. A mobile robot unit with an anemometer and a thermocouple was used for recording data. They found that the velocity profile varied between 1.4 to 1.9 m/s for the test duration. The study did not took any account of wind in the plant area and also the time the mobile unit had taken while moving from one measuring point to another in the selected four quadrants. The wind effect on the air velocity inside the tower is further investigated by taking the data from specific wind directions. As buildings surround the cooling towers so the wind can affect the airflow inside the tower depending upon the building type and size and height as the wind is obstructed before it reaches the inlet of the tower. It may therefore have a different effect at the exit of the tower.

The air velocity inside the tower is measured by number of anemometers installed inside the tower along four selected diameters, as shown in Figure 2. These were marked as zone 1 at 30 meter diameter, zone 2 at 56 meter diameter, zone 3 of 72 meter diameter, and zone 4 of 86 meter diameter measured from the centre line of the tower extending towards the outer wall.

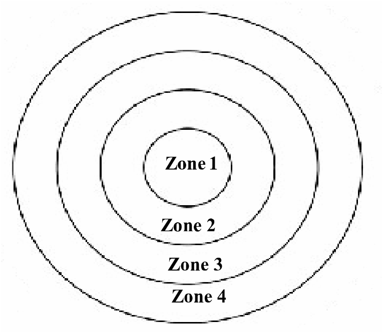

Figure 2: Cooling tower data collection zones

The air velocity profile has been found to vary in each zone as shown Figure 3. It has been found that the air velocity was higher in zone 1 (centre) compared to that recorded in the other three zones. As the measurement points, which are symmetrically related to the centre, are taken further away from the centre of the tower, the air velocity tends to drop slightly towards the outer wall of the tower. The average zone velocities were found to be 2.1 m/s in zone 1, 1.95 m/s in zone 2, 1.7 m/s in the Zone 3 and the 1.4 m/s in the zone 4. The wind speed in this case was predominantly from the northern side which has few buildings in front of the tower.

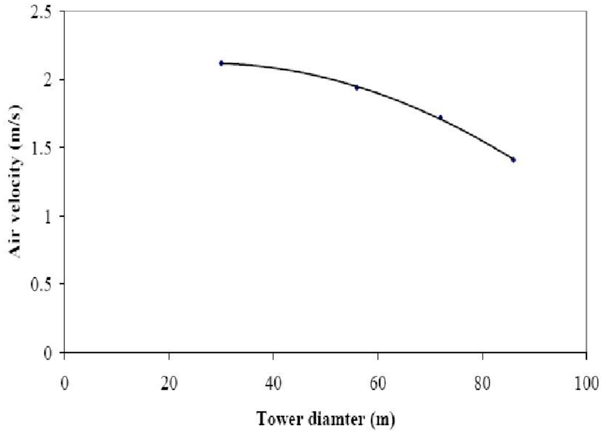

Figure 3: Air velocities inside the cooling tower at different diameters

As shown in Figure 4, while the wind increased, the air velocity inside the tower at zone 1 and zone 2 also increased; however, not much variation can be noticed at zones 3 and 4. The velocity in zone 1 increased from 1.7 m/s to about 2.5 m/s and that in the zone 2 increased from 1.6 to 2.2 m/s when the wind speed increased from 0 to about 5 m/s. Further away from zones 1 and 2, at zones 3 and 4 there is no significant change in the air velocity with an increase in the wind speed as it remained fairly constant around 1.7 m/s and 1.4 m/s respectively in both cases. The higher air velocity near the centre of the tower can be attributed to the increased tower draft in this region. Hence it can be understood that the tower draft has a major suction intensity in the centre region due to the difference in the diameter of the chimney and that at the measurement points above the drift eliminator. Due to the smaller diameter at the tower outlet section, the suction effect can have a slightly higher intensity along the centre line of the tower and its nearby surroundings; however, it may decrease thereafter at the measurement points located along the outer diameters inside the tower.

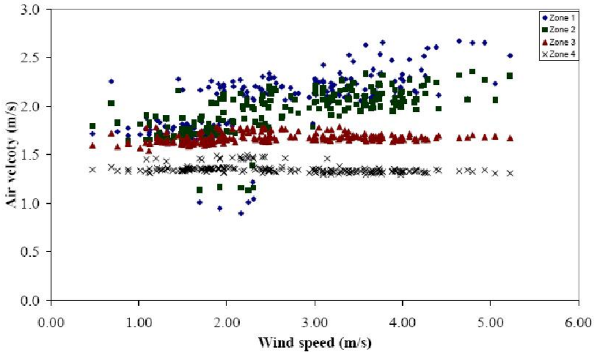

Figure 4: Effect of wind on air velocity in selected zones inside the tower

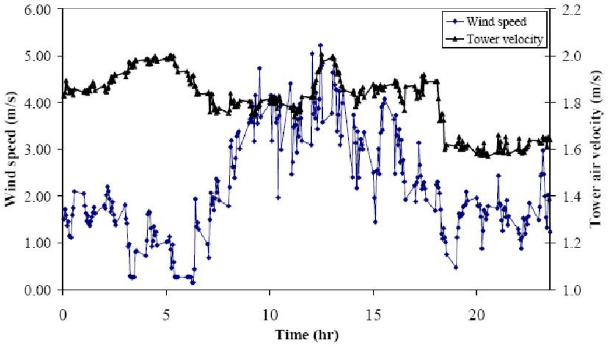

Figure 5: Variation of wind speed and the air velocity inside the tower. Wind direction: North

The variation of the wind speed and the air velocity is shown in Figure 5 for the wind predominantly blowing from the north building sides. The meteorological station, which records the wind speed and other measurements, is located in an open area in the power station vicinity. It is considered here that the wind speed measured at this point is similar to that at the up stream of the plant buildings. The wind speed is lower between 0:00 and 5:00 hrs and varies somewhere between 0 to 2 m/s, the air velocity inside the tower during this period varying from 1.8 to 2.0 m/s. It can be noticed that during this period, as the wind speed tends to drop, the air velocity inside the tower increased in the period from about 2:00 to 5:00 hrs. The improvement in the wind speed with reduction in air velocity can be partly attributed to the variation in the power during that period as between 0:00 and 2:00 hrs the plant operates normally; however, it works at part load between 2:00 and 5:00 hrs due to lower demand, operating at 50 percent of its capacity as can be seen in Figure 2. After that time, the power demand increased and from around 6:00 hrs onwards, the plant worked on full load capacity.

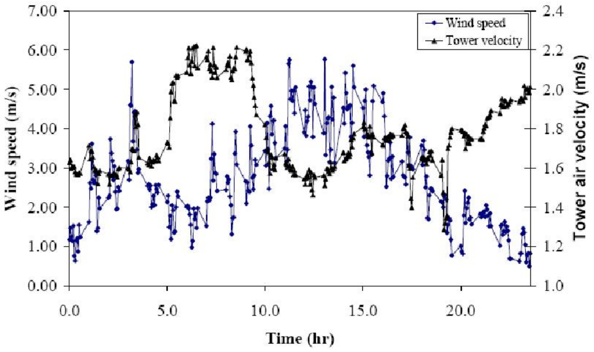

Figure 6: Variation of wind speed and the air velocity inside the tower. Wind direction: Northwest

The wind is calm around 6:00 hrs, after this it increases to around 5 m/s by the midday. During that period, the air velocity inside the tower can be seen to be 1.8 m/s between 6:00 hr and 11:00 hrs. After that, as the wind was approaching its peak around 5 m/s, the tower velocity increased from 1.8 m/s to about 2.0 m/s. As the wind speed then decreased to about 2 m/s, the tower velocity remained constant at 1.9 m/s until about 18:00 hr. The tower velocity then suddenly decreased to 1.65 m/s due to a decrease in the wind speed to 1 m/s.

The wind speed and tower velocity profile over a period of 24 hours is shown in Figure 7. In this direction, the prototype tower has boilers, turbines and other buildings in front of the tower the second tower at its right hand side and the other buildings on its left hand side, whereas there is open terrain on the leeward side of the tower.

The wind speed in this case was found to vary from 1 m/s to 8 m/s and the tower velocity was found to increase significantly with an increase in the wind speed. As the unit started working at the full power generation level, it could be observed that for a wind speed of about 3 m/s, the tower velocity was around 1.7 m/s. However, as the wind speed further increased to 8 m/s, between 10:00 and 15:00 hrs, the tower velocity was found to be about 2.1 m/s. As the wind decreased again from about 6 m/s to 2 m/s, between 18:00 to 24:00 hrs, the average tower velocity could be seen to have a value of about 2.0 m/s.

The above results clearly demonstrate that the wind has a significant impact on varying the tower velocity. In this case, even though the wind speed increased to 8 m/s, the tower velocity pattern can be seen to be higher compared to that at the low wind speed. It is interesting to note that although there is a high wind speed in the plant area at around 8 m/s, the tower velocity has also risen proportionally.

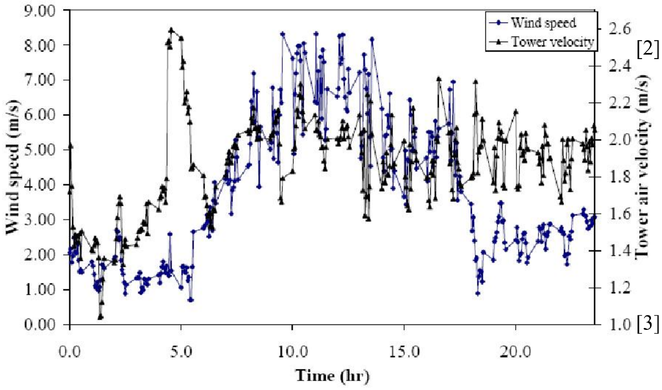

Figure 7: Variation of wind speed and the velocity inside the tower: West

CONCLUSION

It is concluded that

- wind velocity, direction, uniformity and distribution at the inlet to a cooling tower are influenced by the proximity of plant buildings, cooling tower structures, and natural terrains.
- the surrounding upstream structures may have flow-conditioning-(sheltering)-effects and can therefore alleviate the adverse effects of wind on the tower-performance, and improve cooling tower performance in the windy conditions.
- the thermal design of a cooling tower as a heat exchanger should include flow-conditioning-factors of its surrounding which may affect on its performance in both the design conditions (eg no-wind operations), and off-design (eg with wind operations).

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