Cooling Tower Particulate Matter and Drift Rate Emissions Testing Using the Cooling Technology Institute Test Code – CTI ATC-140

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INTRODUCTION

Large utility and process cooling towers emit large volumes of low concentration particulate from multiple stacks that in aggregate are often significant mass emission sources. A significant number of regulatory authorities consider cooling towers as point emission sources and have required quantification of both particulate matter and constituent emissions from cooling towers containing high solids content or potentially hazardous constituents. The dissolved and suspended materials in the cooling water constitute the emissions.

Cooling tower emissions are very site specific. Small, localized gaps in the drift eliminator panels often introduce the most mass into the exit air stream. Because the local gaps are a function of the quality of the installation, maintenance, and operation, simply assigning a drift emission rate based solely on the drift eliminator design or performance guarantee is overly simplistic. Drift eliminator effectiveness decreases with age and thus the amount of emissions will increase as the drift eliminator panels shrink or become damaged due to wear, ultraviolet light exposure, ice damage or poor water distribution. In order to properly estimate the amount of emissions from a cooling tower, an emissions test is warranted.

The Cooling Technology's test code ATC-140 is designed to address the difficulties associated with collecting liquid droplet emissions above the cooling tower rotating equipment. The test code also incorporates operating and environmental limitations that minimize the variability in test results due to these parameters and ensures that the tower is not tested in an abnormal condition. The CTI test method has been accepted by various regulatory authorities to quantify the particulate emissions from cooling towers.

This paper illustrates the methodology for calculating particulate emissions from a cooling tower and discusses the conservatism applied when considering all particulate to be PM-10. The special characteristics of cooling tower emissions and the technology used for controlling cooling tower

emissions are explained. The methodology used in CTI ATC-140 is described and the assumptions and procedures used in the calculation of the drift rate and particulate emission rate are detailed. Recent test data are presented in order to illustrate the repeatability of the method and to demonstrate the site-specific nature of the cooling tower emissions.

Generation of Air-borne Particulate from Towers

In a conventional evaporative cooling tower, the circulating water is pumped to the top of the unit where the water is distributed through nozzles and allowed to fall over heat transfer media that either sheets the water or breaks the water into small droplets. The large surface area of the small droplets facilitates evaporation and cooling of the remaining circulating water. In the majority of systems, a fan on the top of the tower is used to induce an air stream against the water droplets. As the air is drawn through the tower, a small fraction of the water droplets are entrained in the airstream. Baffles, called drift eliminators, are placed between the nozzles and the fans to minimize (through inertial impaction) the amount of entrained water droplets that escape the cooling tower and discharged into the atmosphere. The escaping droplets are called drift. An important distinction between drift and the normally visible condensing plume is that the drift contains the same chemicals and solids present in the circulating water, whereas, the condensation is pure water vapor. Cooling tower emission rates are usually presented as a Drift Fraction Percentage which is defined as 100 times the ratio of the water exiting the tower as drift divided by the circulating flow rate. Particulate emissions result from the solids that exit the cooling tower in the liquid drift. As the liquid drift evaporates, the resultant crystals or salt solutions are dispersed into the atmosphere. The amount of drift and therefore the amount of emitted particulate is function of several items which vary from tower-to-tower. In a normal tower, the amount of drift is first a function of the quality of the drift eliminator installation. For a normal tower, the factors which influence the amount of drift (in order of influence) include:

1. the quality of the installation of the drift eliminators,
2. condition of the drift eliminators and water distribution system,
3. the type of drift eliminator,
4. the water and air loading and distribution, and
5. the water chemistry.

Thus the drift rate and the emission rate are very site specific. It is not uncommon for drift rates to vary from cell to cell by a factor of two, particularly in older towers.

Overview of Cooling Tower Emission Testing

The measurement of liquid droplet emissions leaving a cooling tower fan stack that may be up to 40 feet across, is problematic. The most accessible location for drift sampling downstream of the drift eliminators is the fan stack exit plane. The stack exit plane is often within ½ of the stack diameter of the rotating fan. The proximity to the fan creates non-parallel streamline vectors of varying pitch across the cross-sectional area of the stack plane, even to the point that near the middle of the stack there is usually a significant area with air coming back into the fan stack from above. The total tower elevation at the fan stack exit plans may be some 50-60 feet above grade and subject to elevated winds due to the influence of the tower itself. The effect of the wind is to skew the velocity profile and thus skew the emissions from the stack to the downwind side. Furthermore, because the fan blade pitch determines the amount of air flow through the tower, and because the amount of water delivered to the tower can impact the quality of the water distribution, these operating parameters can also influence the amount of drift emitted from a tower.

<u>EPA Method 5</u>

Initial cooling tower emission tests were performed as particulate matter emission tests according to the general guidelines of EPA method 5. Typically, a total of 24 points, 6 per radii, were sampled in order to obtain a composite sample of the particulate exiting the fan stack. The EPA method 5 test utilizes an isokinetic approach where the sampled air is collected through a probe that is oriented into the air stream at the sampling location. The air is drawn through the probe at the same velocity (speed and direction), as the exiting air stream, thus the test is called isokinetic (IK). A vacuum pump is used to draw the air sample through the sampling train and flow measurement system. The method 5 sampling train consists of the sample probe, heated liner, heated filter box and filter, a series of impingers and a dry gas meter. Particulate drawn through the sampling train is deposited on a pre-weighed filter which is conditioned and reweighed at the conclusion of the test. Particulate which is deposited within the probe and on the sides of the tubing leading to the filter box is recovered through washing. The wash samples containing the

residue are placed in a pre-weighed crucible which is heated to evaporate the wash solution which leaves the collected residue mass. Knowing the total collected mass from the filter and the wash samples, the sampled air volume, and sampling time permits the calculation of the mass flux. The mass flux divided by the product of the water flow rate and the concentration of total solids in the circulating water, yields the fractional total solids emission rate. The implementation problems with the EPA method 5 approach include – difficulty in rotating the sampling train at each measurement point; difficulty in managing long sampling lines containing moisture laden air; and having to sample for an extremely long time to collect enough sample for gravimetric analysis.

In the late 1980's, the Cooling Tower Institute (CTI) began to codify a sampling technique that utilized isokinetic sampling to quantify the mass emission rate from cooling towers. In 1994, the CTI published the drift emission code ATC-140. This test code was developed by a cross section of cooling tower manufacturers, owner/operators and suppliers that were familiar with the difficulties inherent in cooling tower emissions tests and the influence of ambient and operating factors on the amount of the drift.

CTI Drift Test Code Overview and Test Instruments

Isokinetic drift testing is the process of collecting "drift emissions by drawing a portion of the cooling tower exit airstream into a collection apparatus at the same speed and direction (isokinetically) as the local velocity in the cooling tower." Instead of collecting particulate mass, the CTI test code ATC-140 is based on the isokinetic collection of composite mass sample of a tracer element (e.g., sodium, calcium or magnesium), leaving the tower. Most tests are conducted at the fan stack exit plane where the cross-sectional area is divided into 12 concentric rings of equal area. The midpoint of each of the 12 rings is sampled with apparatus suspended from ropes above the fan stack. After one diameter is sampled, the ropes and suspended equipment are rotated 90 degrees and a perpendicular diameter is sampled to obtain an integrated sample from the 24 locations. The primary collection apparatus in the CTI system is a cylindrical tube containing tightly packed glass beads. The outside of the tube is heated with high wattage heaters, that in turn, heat the glass beads. As water droplet laden air is drawn through the bead pack, the droplets strike the beads and evaporate, depositing salts from the droplets on the beads.

A “back-up” filter is placed immediately behind the glass bead pack to capture salts that escape the beads. The amount of salt deposited on the collection apparatus is a function of the amount of drift leaving the tower. The sampled air is drawn through the collection apparatus, and calibrated flow section by a large capacity vacuum pump. The collection apparatus is suspended from ropes over the fan stack. Lanyards tied to the sides of the collection assembly are used to rotate the assembly into the flow at each sampling point and to move the assembly from sampling point to sampling point. The sampling assembly contains a calibrated resistance device that measures the angle of rotation at each sampling station. The cosine of the measured angle is used to correct the sampling time at each point in order to maintain the sample proportionality. Adjusting the time is more convenient and mathematically equivalent to adjusting the area for the sampled component that is normal to the fan stack. Because of the proximity of the fan to the measurements made at the fan stack exit plane, the angle of the airflow at the sampling location often approaches 30 degrees from vertical.

The collection assembly also contains a calibrated propeller anemometer to measure the local air speed and a temperature probe to measure the local stack temperature. The differential pressure across the calibrated orifice, the static pressure and the local temperature at the orifice are used to set the flow control valve to match the inlet velocity at the sampling probe to the local air velocity in the stack measured with the propeller anemometer. Barometric pressure is also measured to correct for the density difference between the air at the inlet to the sampling probe and the air flowing the orifice.

The solids collected on the glass beads and the filter are recovered by acid wash and repeated rinses with ultra-pure (metals analysis grade) water. The quantities of the tracer collected are generally so small that only constituents present in concentrations above 100mg/l are acceptable trace elements. Sodium, magnesium and calcium are the most commonly used tracer elements. Sample analyses are made by flame atomic absorption or inductively coupled plasma techniques.

Another difference between the EPA method 5 and the CTI Heated Glass Bead Isokinetic (HGBIK) sampling equipment is in the size of the sampling probe and pumps. Because of the high stack velocities (2500 fpm peak velocity) and the air volume limit of the typical method 5

vacuum pump, the sampling probe nozzle might be limited to approximately ¼ inch in diameter in order to reach the desired nozzle inlet velocity. In contrast, the HGBIK sample probe has an inlet diameter of approximately 1 inch. The larger area of the nozzle means that a much larger sample is collected in a given amount of time which reduces the overall duration of the test. Of course, in order to reach isokinetic velocities, the HGBIK vacuum pump must be much larger than the method 5 pump.

Drift Rate Calculation

The test apparatus is used to collect an integrated sample of the exiting tracer mass from across the stack. This mass be expressed as:

$$M = \left(M_{GB} - M_{GB_B}\right) + \left(M_F - M_{F_B}\right) \qquad \text{(Eq. 1)}$$

Where:

M = the net mass recovered from the glass bead pack and the back-up filter for the selected tracer element, (e.g. µg calcium);

M_{GB} = mass recovered from the Glass Bead pack for the selected tracer element, (e.g. µg calcium);

M_{GB_B} = mass recovered from the glass bead field blank for the selected tracer element, (e.g. µg calcium);

M_F = mass recovered from the back-up filter for the selected tracer element, (e.g. µg calcium); and

M_{FB} = mass recovered from the back-up filter field blank for the selected tracer element, (e.g. µg calcium).

The total emission of circulating water as drift is calculated by

$$Q_E = \frac{M}{C \times t} \frac{A_S}{A_N} \qquad \text{(Eq. 2)}$$

Where:

Q_E = the liquid emission rate of circulating water as drift; (m^3/s)

t = the total sampling duration (s);

C = the concentration of the tracer element (e.g. ppm calcium) in the circulating water

A_N = the area of the sampling nozzle. (m^2); and

A_S = the total area of the fan stack exit plane corrected for the hub seal disk area (m^2)

The total mass emission rate is a function of the solids in the circulating water, this is expressed by

$$Q_{PM} = Q_E C_{TS} \quad \text{(Eq. 3)}$$

Where:

Q_{PM} = Particulate matter mass emission rate (g/s); and

C_{TS} = the concentration of total solids in the water (g/m^3);

Finally, the drift rate for the tested cell is calculated by:

$$D\% = 100 \frac{Q_E}{Q_{CW}} \quad \text{(Eq. 4)}$$

where

Q_{CW} = the circulating water flow rate for the tested cell (m^3/s)

Although the equations above are listed for a single element, in normal practice multiple elements are used. The use of different elements for parallel drift rate calculations is beneficial as a quality assurance step, because an unexpectedly high blank concentration in a clean filter or bead pack for one element may be absent for the other elements.

The amount of each trace element collected in the sampling train is proportional to the concentration of the element in the circulating water. Thus for elements with similar detection limits, the duration of the test is a function of the concentration of the element in the circulating water. In most cooling towers, the elements sodium, calcium and magnesium are present in the

highest concentration and thus are used for analysis. The sampling times are chosen such that collected mass of at least one of the tracer elements, at the anticipated drift rate, will be at least 10 times the analytical detection limit for the tracer. Sampling times vary from 3 to 16 hours, depending on the expected drift rate and the tracer concentration.

In some situations where the circulating water is exceptionally clean or where the ambient concentrations in the air are unusually high, the circulating water may be spiked with a target analyte. This is usually practical only for small systems.

Test Influences and Repeatability

Although the primary contributor to the amount of drift that is emitted from the tower is the quality of the installation of the drift eliminators, the type of drift eliminator, water distribution, water quality, airflow rate and the air distribution all contribute to the amount of drift. Calm winds also facilitate more symmetrical velocity distributions at the fan stack exit plane and repeatable distribution of drift at the sampling locations. Towers with small localized gaps in the drift eliminators may have large amounts of drift coming from a very small area. Gusty or variable winds shift the localized drift within the sampling plane leading to scatter in the calculated drift emission rate between repeated tests of the same stack. Since the drift rate is highly dependent on the quality of the installation and this may vary from cell to cell, it is not unusual for the drift rate to vary by up to 50 percent from cell to cell in the same cooling tower. This occurs even when the repeat runs on the same cell are very repeatable.

Although the test code requires the sampling of the ambient air to determine the concentration of the tracer element(s) in the ambient air, no correction is applied for the ambient concentration. This leads to the potential for positively biased test results as ambient concentrations are drawn through the tower air inlets and exhausted through the tower stack and into the sample train. The ambient concentration of the tracer elements at some locations is a function wind blown dust and thus, more repeatable tests may be performed during days with relatively calm winds. The CTI test code also specifies that the waterflow rate and fan motor input power should be within 10% of the design specifications. These limits minimize the effects of the changes in tower operation on the amount of drift.

The following table presents a summary of a recent cooling tower emissions test.

TABLE 1 : ISOKINETIC TEST SUMMARY

Drift Rate as a Percentage of Test Water Flow Rate

Test Number	Calcium %	Magnesium %	Sodium %	Average %
1 West Cell	0.0020	0.0017	0.0013	0.0017
2 West Cell	0.0015	0.0019	0.0018	0.0017
Avg. West Cell	0.0018	0.0018	0.0016	**0.0017**
1 East Cell	0.0011	0.0009	0.0006	0.0009
2 East Cell	0.0011	0.0010	0.0007	0.0009
Avg. East Cell	0.0011	0.0010	0.0007	**0.0009**
Overall Average				**0.0013**

For this three cell cooling tower, two cells were evaluated for emissions. Two tests were performed of each of the cells. The repeat runs on the same cell yielded identical drift rates, but the drift rate for the two cells differed by almost a factor of 2. The agreement between drift rates calculated based on the different tracers and the repeatability of the test runs indicates that contamination was not a problem.

SUMMARY OF RECENT TEST RESULTS

A summary of selected HGBIK test results performed by the authors is presented in Table 2.

TABLE 2: Summary of Test Results

Cooling Tower	Test Type	DE Type	Tested Drift Rate %Flow	Guaranteed Drift Rate %Flow
A	Status	ME	0.008	
B	Status	HE	0.004	
C1	Acceptance	HE	0.0009	0.002
C2	Acceptance	HE	0.0013	0.002
D	Acceptance	HE	0.0006	0.002
E1	Status	ME	0.025	
E2	Acceptance	HE	0.0007	0.001
F1	Acceptance	HE	0.007	0.002
F2	Acceptance	HE	0.007	0.002
G	Status	LE	0.019	
H	Status	LE	0.009	
I	Status	LE	0.008	
J	Acceptance	HE	0.001	0.002
K	Acceptance	HE	0.0002	0.001
L	Acceptance	HE	0.0004	0.0005
M	Acceptance	HE	0.0007	0.002
N	Acceptance	HE	0.0008	0.005
O1	Acceptance	HE	0.0006	0.0005
O2	Acceptance	HE	0.0005	0.0005
P1	Acceptance	HE	0.0036	0.002
P2	Acceptance	HE	0.0052	0.002
Q	Status	HE	0.001	0.005
R	Status	HE	0.006	0.005
S	Status	HE	0.001	0.001
T	Status	HE	0.0006	0.001
U	Status	HE	0.001	0.001
V	Status	HE	0.001	0.0005
W	Status	HE	0.0005	0.0005
X	Status	HE	0.001	0.0005
Y	Acceptance	HE	0.0004	0.0005
Number of Tests			30	
Average Drift Rate			0.004	
Maximum Drift Rate			0.025	
Minimum Drift Rate			0.0002	

LE = low efficiency drift eliminators; wood lathe
ME = medium efficiency drift eliminators; chevron type
HE = high efficiency drift eliminators; wave form

Status tests are done at the request of the owner usually based on a perceived problem or after modifications have been made to a tower that do involve contractual guarantees. Towers Q-X had been recently rebuilt but were not evaluated for contractual acceptance. Emission problems are usually manifested by excessive salt deposition around the cooling tower. Cooling towers G, H, and I are different designs of 40 year old wooden cooling towers with wood lathe drift eliminators. They are in reasonably good condition considering their age. Note that the drift rates from these older towers are lower than for cooling tower E1.

The difference in drift rate that can be achieved by rebuilding an existing cooling tower is illustrated by cooling towers E1 and E2. Cooling tower E1 had chevron type drift eliminators that had been seriously damaged by icing. Cooling tower E2 is the same cooling tower after the internal components, including the drift eliminators, had been replaced.

Cooling tower A was in good repair but had serious water chemistry problems. Foam covered the cold water basin as well as the drift eliminators. Large pieces of this foam were continuously being emitted. Since the drift eliminators cannot function properly in the presence of foam, foam control is required to minimize the amount of emissions. Excessive foam can usually be controlled through pH control.

Of all the cooling towers tested, only E1 exceeded the 0.02% drift rate specified by EPA emissions guideline AP-42. The maximum and minimum drift rate for cooling towers tested differed by a factor of 167. Considering only the acceptance tests (for which the cooling towers were new or recently rebuilt), the difference between the high and low drift rates was a factor of 47. With this degree of variability, the concept of an average drift rate of all cooling towers seems to have little meaning. Testing of the specific cooling tower in question is necessary in order to quantify the specific emissions from that tower. When tested, all of the new cooling towers tested had emissions levels much lower than that specified by AP-42.

Special Characteristics of Cooling Tower Emissions

Cooling tower drift has several special characteristics. The size of the drift droplet is usually very large with a typical mass mean diameter of 100-300 microns. The large size is partially due to

the limited collection efficiency of the drift eliminators for small droplets. The drift droplet size distribution is also a function of the mechanisms which causes the drift to occur. One of the primary factors for the amount of the drift and the distribution of the liquid droplet size is the quality of the installation of the drift eliminators. The drift eliminators must be installed around structural members. Small gaps around these structural members or between drift eliminator panels act as essentially uncontrolled emission sources. Another source of large diameter droplets is the collection and re-entrainment of drift by structural members, the fan stack and even the fan blades. Finally, circulating water can be re-entrained from the trailing edge of the drift eliminators if the drift eliminators are overloaded. Overloading occurs when the drift incident on the drift eliminators exceeds their drainage capacity. This can happen when the drift eliminators are installed too close to the water distribution system or when there are broken nozzles in the water distribution system.

Drift Droplet Size

Figure 1 illustrates a droplet size spectrum determined by PGT for a high efficiency drift eliminator utilizing a Sensitive Paper technique in a test cell. The drift rate associated with a test cell evaluation usually represents the lowest achievable liquid drift rate for the tested configuration because of the care with which the drift eliminator panels are installed and because most test cells are small enough that only one panel of drift eliminators are tested at a time. Furthermore the size of the test cell dictates that additional cross members for structural support and other penetrations in the drift eliminator plane are not required.

Two droplet size distributions from two full scale cooling towers are presented in Figures 2 and 3. The drift elimination system in both cooling towers were certified by the manufacturer to be ready for test and both, in fact, passed their drift guarantee.

Figure 1: Test Cell Droplet Size Distribution

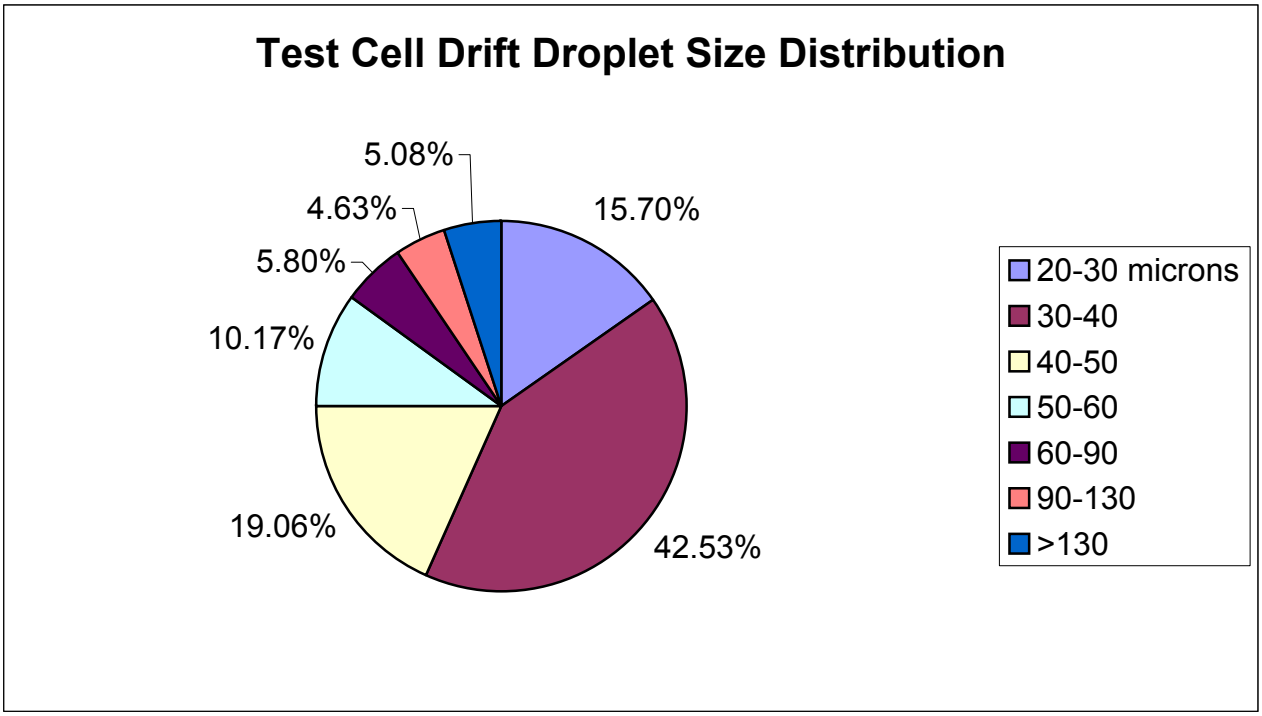


Figure 2: Droplet Size Spectrum For Full Scale Cooling Tower 1

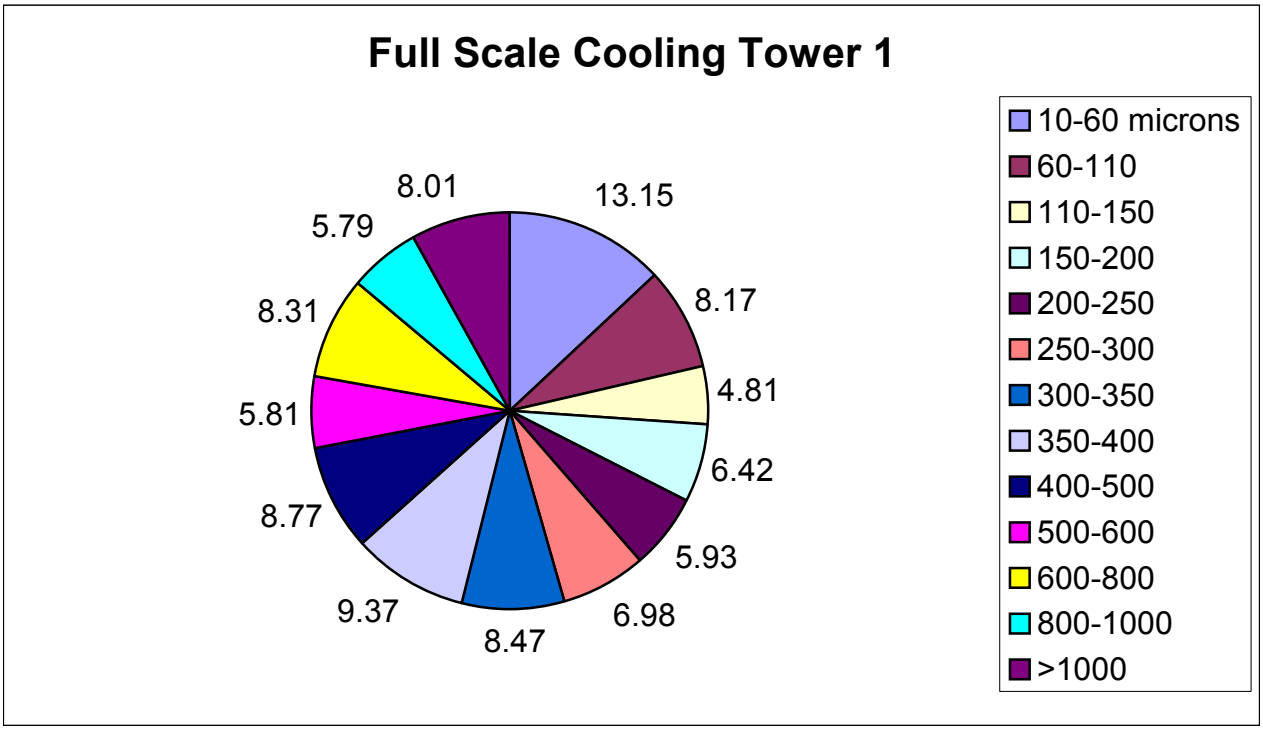
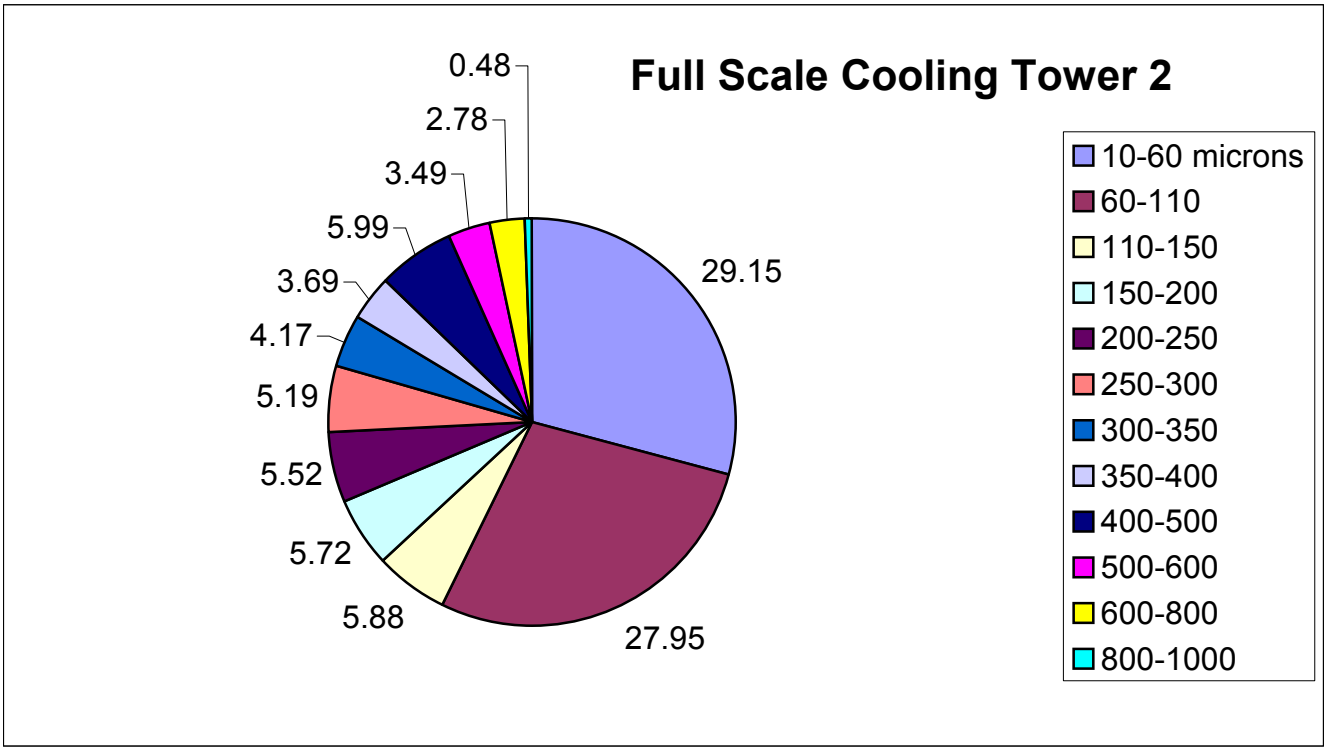


Figure 3: Droplet Size Spectrum For Full Scale Cooling Tower 2



While care in installation can minimize the drift rate, some gaps are unavoidable in the installation. For this reason, cooling tower manufacturers guaranteed drift rates are often higher than typical of drift eliminators when tested in test cells.

Calculation of Particulate Emissions from Drift Rate

Current designs for new cooling towers specify drift rates of 0.0005 to 0.002 percent of the circulating water flow. A typical design for a 250 MW combined cycle power plant would be an 8 cell cooling tower with 10 meter (33 ft) diameter fans and a water flow rate of 820 kg/s (13,000 gpm) per cell. At drift rate of 0.001 percent of the circulating water flow, such a cooling tower would emit:

$$\dot{m}_w = \frac{0.001}{100} 820 \frac{kg}{\sec cell} * 8\, cells * 1000 \frac{g}{kg} = 65.6\ g/\sec \qquad \text{(Eq. 5)}$$

of liquid water. At a total solids concentration of 5000 ppm in the circulating water, the total particulate emission rate would be:

$$\dot{m}_{pm} = 5000x10^{-6} * 65.6\frac{g}{\sec} = 0.327g/\sec = 11.4 \ \ ton/yr \qquad \text{(Eq. 6)}$$

AP-42 specifies that particulate emissions be calculated based emission factor equivalent to a drift rate of 0.02 percent of the circulating water flow. Using this emission factor, the cooling tower described above would have a PM10 emission rate of 4.58 g/sec, a factor of 20 higher than cooling tower previously described.

The diameter of the airborne particle which is produced by the evaporation of the liquid water from a drift droplet can be calculated by:

$$m_{salt} = \rho_w C_{TS} \frac{\pi}{6} d_d^3 = \rho_{salt} \frac{\pi}{6} d_p^3 \qquad \text{(Eq. 7)}$$

$$d_d = d_p \sqrt[3]{\frac{\rho_{salt}}{\rho_w C_{TS}}} \qquad \text{(Eq. 8)}$$

where

msalt	=	mass of salt particle, g
ρsalt	=	density of particle, g/cm3
ρw	=	density of drift droplet, g/cm3
C_{TS}	=	concentration of solids in circulating water, ppm
d_p	=	diameter of solid particle, microns
d_d	=	diameter of drift droplet, microns

For a circulating water concentration of 5000 ppm and assuming particle density of 2.5 gm/cm^3 , the maximum diameter of the drift droplet which would produce a salt particle of 10 microns would be:

$$d_d = 10\sqrt[3]{\frac{2.5}{1.0 * 5000x10^{-6}}} = 79 \, microns \qquad \text{(Eq. 9)}$$

For the drift droplet size distribution in Figure 2, over 78 percent of the particulate emission would be greater the 10 microns. For the drift droplet size distribution in Figure 3, over 42 percent of the particulate emission would be greater the 10 microns.

CONCLUSIONS

Cooling tower emissions are difficult to measure with traditional EPA methods. The proximity of the fan to the measurement plane coupled with the long sampling duration required for a gravimetric analysis makes the method 5 test difficult to perform. The CTI test code, ATC-140 is designed for cooling towers and utilizes a test sampling apparatus that can be employed above the rotating fan and can provide a sample suitable for emission rate calculation in a much shorter test. The test code also incorporates operating and environmental limitations that minimize the variability in test results due to these parameters and ensures that the tower is not tested in an abnormal condition.

Cooling tower emissions are very site specific. Small localized gaps in the drift eliminator panels often introduce the most mass into the exit air stream. Because the local gaps are a function of the quality of the installation, maintenance and operation, simply assigning a drift emission rate based solely on the drift eliminator design or performance guarantee is overly simplistic. Drift eliminators also age and thus the amount of emissions will increase as the drift eliminator panels shrink or become damaged due to wear, ultraviolet light exposure, ice damage or poor water distribution. In order to properly estimate the amount of emissions from a cooling tower, an emissions test is warranted. The Cooling Technology's test code ATC-140 is designed to address the difficulties associated with sampling a liquid droplet emission at various streamlines and low drift rate percentages.

The EPA emission factor guideline AP-42 is very conservative in the calculation of total PM10 from cooling towers. The emission factor of 0.02% of the circulating water is higher than all tested towers other than a single unit in serious disrepair. It is also apparent that a significant fraction of the cooling tower drift is larger than PM10. The amount of PM10 emitted is also site specific because these emissions are a function of the water chemistry, drift rate, tower components, tower condition and operation. A test cell droplet size distribution should be used

with great care when used to predict emissions from a full-scale field erected cooling tower. In practice, the emission levels predicted from a test cell should be considered the lower bound for total cooling tower emissions.

References

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