flotek. g 2017- “Innovative Solutions in Flow Measurement and Control - Oil, Water and Gas”
August 28-30, 2017, FCRI, Palakkad, Kerala, India

MECHANICAL APPROACH TO FLOW MEASUREMENT IN AN INDUCED DRAFT EVAPORATIVE COOLING TOWER

MODIFIED HEAT EXCHANGER UNITS: COOLING TOWER

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Abstract:
The precise and accurate method to measure water flow in an Induced Draft Evaporative Cooling Tower is not an exact science however, experimental measures have been developed to insure accurate measurement and the instituted protocols set forth be followed precisely. The governing agency that institutes such procedures is the Cooling Technology Institute [CTI].

Brentwood Industries, has now developed testing expertise that follow, in detail, the flow measurement guidelines set forth by the Cooling Technology Institute. Brentwood's experienced test personnel maintain disciplined practice and insure proper test methodologies are carried out at each test site for each test as it mandates. With the successive results, the scope of expertise has now evolved to full project implementation. One being the water flow measurement and two, the complete thermal evaluation of a multiple cell tower to include test instrumentation set-up, operation, and disassembly.

The intent of the paper is to detail the precise mechanical methods to manage conventional flow measurement using a 6-foot stainless steel Simplex pitot tube in a single riser-single cell set-up and double riser-single cell set-up. Detailed in the paper will be the pre-measurement, amid measurement, and post measurement in-situ processes and practices followed in accordance with the Cooling Technology Institute standards set forth. Two current, ongoing case studies in India to highlight the benefits of mechanical flow measurement will be referenced periodically as well to help illustrate the mechanical method. In succession, we hope to educate experts on the benefits to this alternate approach on how to measure flow in large-size pipe diameter risers. The proper measurement of flow in a cooling tower to help determine the thermal performance of that tower is one of the most important factors in determining a power plant's efficiency. The correct methods to test become much more vital when a power plant looks to determine its overall annual output efficiency.

Key Words:
Experimental measures, instituted protocols, test methodologies, project implementation, water flow measurement, thermal evaluation, test instrumentation set-up, operation, disassembly, Simplex pitot tube, two ongoing case studies, large-size pipe diameters.

Part I- Scope/Purpose:

1.0 Purpose:

The precise and accurate method to measure water flow in an induced draft evaporative cooling tower is not an exact science however, experimental measures have been developed over the years to ensure accurate measurements are taken and the instituted protocols set forth followed precisely. The governing agency that institutes such procedures is the Cooling Technology Institute [CTI]. The need for such strict testing requirements is compounded by the fact that efficiency of a cooling tower [CT] is the number one problem witnessed in most of the power plants visited so far in India. With a constant demand to increase a Power Plant's overall efficiency, plant owners must look at alternatives to increase the cooling tower efficiency. The principle is simple and has been realized by most plant owners, that the more efficient or effective the thermal balance is within the cooling tower, the more efficiently the CT perform as designed. The end result will be a more efficient power plant.

2.0 Scope:

Brentwood Industries [BW], has developed testing expertise and has established a collaborative testing effort environment with India's leading cooling tower owners, operators and manufacturers alike. The test follows, in detail, the flow measurement guidelines set forth by the CTI. Brentwood's experienced test personnel maintain a disciplined practice and ensure proper test methodologies are carried out at each test site for each test as it mandates. Since BW's progression, the scope of expertise has now evolved to full project implementation. The scope entails the water flow measurement and the complete thermal evaluation of a multiple cell tower to include test instrumentation set-up, operation, and dis-assembly.

To run this program, calibrated test equipment is provided by BW test team performing the test. The responsibility of BW test team is to collect the data, evaluate the data to determine if test requirements are met, calculate the test result, and ultimately, conclude with an official test report. The thermal performance tests coincide with the flow measurements and two governing principles in accordance with CTI's "Acceptance Test Code for Water Cooling Towers," ATC-105 and "The Standard for Liquid Flow Measurement," CTI Standard 146.

3.0 Principal instrument and extraction method:

The primary instrument used to conduct water flow rate measurement is a pitot tube. It is an instrument designed to have one opening which is inserted into a flow channel facing upstream that senses the total pressure [PT] in a pipe [flow channel] and a second opening that senses the static pressure [Ps]. The total pressure [PT] consists of the static pressure [Ps] plus the velocity impact pressure [Pv] due to liquid flow. The differential pressure [ΔP], or the difference between the total pressure [PT] and the static pressure [Ps], is the direct measurement of the velocity pressure [Pv]. A differential pressure gauge or manometer connected between the total pressure [PT] and static pressure [Ps] taps of the pitot tube provides the measurable ΔP, or Pv, of the flowing water.

Part II- Test Objective and Test Type:

1.0 Test Objective

This section addresses the preparation for conducting a water flow performance test. The test can be further subdivided by test objectives. These tests in most cases are used to evaluate contractual performance guarantees and fulfill contractual terms of agreement and so, the contractually responsible parties work with BW in a collaborative effort to get a positive outcome. Due to greatly undersized and under-designed cooling towers witnessed by BW assessment teams throughout most power plants across much of India, the test and the witnessing of the test is done with respect to tower owners. Due to the sensitive nature of each test, it is imperative that tests be conducted with complete transparency. Flow measurement test are done in conjunction with third-party test teams wherever possible, especially in cases when the test is used to benchmark the performance of an existing tower. In all cases, all parties will detail the test objectives prior to the test and conduct pre-test meetings to discuss test plans and protocols. Data collection methods for performance tests and baseline tests are usually identical.

1.0 Test type:

Baseline/benchmark test- for our purposes is best identified as a test which considers a multitude of cells- each with its own specified thermal media for thermal performance purposes and each with separate water flow for flow measurement purposes. The measurement of flow is an in-situ test conducted on as-is tower conditions, within the first few months of operation with the newly installed media. The newly installed media must go through a period of what is referred as, “aging”, when the water passing through develops a film-like surface for optimal thermal performance. The premise behind it is to determine which media performs best thermally in relation to the content in the make-up water and environmental factors to help select the appropriate tower media for a tested tower.

In relation, a performance or status test involves the same principals with the exception being the performance results will prove definitively one media is more efficient-thermally superior over the other. This test quantifies existing thermal performance and may be used to evaluate thermal performance degradation which may have occurred since the tower was originally placed in service. This test is often performed either when tower retrofit is being considered, when there are problems with performance indicating the CT as a possible cause, or when an additional load will be put on the tower and new operating parameters are to be determined. For a complete performance evaluation, the retrofitted media get tested against pre-installed, original equipment manufacturer [OEM] media. The measure of flow in each designated cell is needed to determine how the flow compares to the design flow established by the tower manufacturer and agreed upon by the power plant owner before CT installation [performance curves are provided to owners by tower manufacturers]. If the flow is determined to be imbalanced, then the efficiency of the tower is negatively reflected. To help describe the water flow circuit, each cell has a flow path by means of main header pipe/s that get fed by a source point [i.e.: make-up]. The header pipe/s branch out to risers that channel water into a centralized header inside the cell whose primary function is to distribute the water evenly throughout the cell. The efficiency of the interaction of the water being distributed into the tower and the air moving inwards and upwards, through the tower, is what is most critical.

The required measurement parameters, recommended test limits, and frequency of readings are given in each applicable test code. Recommended test limits including stability requirements and maximum allowable deviations from the design specifications are provided for the measurement parameters and should be adhered to whenever possible. In practice, deviations from the recommended limits is allowed if agreed upon by the collaborating parties to the test. For baseline/benchmark tests, supplementary measurements may be required to achieve the objectives of the test.

Water flow measurements are an integral part of a thermal performance test and are conducted to determine the ability of the tower to cool water. Operating thermal parameters including inlet wet-bulb temperature, cold water temperature, hot water temperature, water flow rate, and fan motor power are measured and compared against design specifications each time a flow measurement is conducted.

As discussed prior, these design values are usually presented as performance curves in the form of cold water temperature versus inlet wet-bulb temperature as recommended by CTI. Alternately the design may be presented as a CTI characteristic curve. BW uses proprietary and CTI approved software to model cooling towers and give detailed analysis using design conditions provided by plant owners/operators. Flow measurement tests may be conducted on new or modified towers or in conjunction with ascertaining thermal performance of an older tower. Both tests are typically conducted in a collaborative effort and with the same caliber of instrumentation.

Part III- Flow Measurement Preparations and Test Activities: Modified Unit:

1.0 Pre-Test Activity & Pre-Flow Test Measurement: Modified Unit

BW case study example of pre-test preparation & scope of work for a modified unit: due to the collaborative nature on the scope of responsibility for flow measurement test, the contributing parties involved are: plant owner, vendor/contractor, and BW site project team.

Case Study Example [India Unit]:

The Scope of Work/s/Facilities includes: cutting & removing of the beams, removal of existing thermal component/s, assembly & installation of BW thermal component/s, and flow/performance test for thermal performance improvement in existing unit.

1. Contractor/Vendor/BW Scope:

A. Cutting & removing of the beams and removal of existing media:

- Safely cutting & removing of all Precast Beams [non-structural members] including shifting of the cut beams to designated locations offsite, necessary scaffolding, platform, manpower, tools-tackles, machineries, equipment etc. complete as per drawings, details & specifications and/or directed by EIC.
- Removal of existing media and mesh-grids, grid locks, SS wire etc. There are two support removal points; top beams and the other, bottom supported beam through SS wire.
- 20 number of cells/ per CT unit. During fill removal, the required cell/s will be isolated from water and fan turned off. Cooling tower will continue to remain in normal operation except the isolated cell(s). The cells for which the fill removal is to be carried out will have normal water levels in the cold-water basin.
- Necessary staging must be provided to ensure that no media debris enters cold water basin during the removal process.

B. Assembly & installation of new fills:

- Mechanical assembly [MA] of media to be staged under covered-tarp protection.
- $20\ nos.$ of cells per CT unit. During media installation, the required cell/s will be isolated from water and fan turned off. Cooling tower will continue to remain in normal operation except the isolated cell/s. The cells for which the media installation is to be carried out will have normal water levels in the cold-water basin.
- Work required for media support to be done by Contractor/Vendor.
- Necessary scaffolding/stage must be provided to ensure that no media debris enters cold water basin during the removal process.

C. Water Distribution System replacement without changing of pipes and hanging system:

- Removal of the existing nozzles, single branch arm, saddle and double branch arm.
- Cleaning of removed double branch arm and saddle.
- Installation of double branch arm with strapping, saddle with strapping, single branch arm, nozzles, etc.
- Re-arrangement [leveling] of existing distribution pipe if required.

D. CT flow measurement [BW test personnel]:

- BW is required to supply all instrument for measurement.
- BW test team will supply calibration certificate, calibration coefficient, and Reynolds number.

a. Calibration coefficient is given due to the magnitude difference between true pipe static pressure [Pst] and observed static pressure [Pso] at 95% confidence intervals. An ideal pitot tube would have a calibration coefficient of [1.0] but because of the discord, established code has a mean value of 0.793 calibration coefficient [$C0$] between 0.790 to 0.830 with a 95% confidence interval ± 0.029.

b. Reynolds number of the pitot tip in some cases gives an even more precise coefficient for variable pressure to a mean of $\pm .0260$ as ascertained in laboratory calibrations. It decreases the ratio of uncertainty but, because of a multitude of pressure annulis calculated [refer to the technical preparation section of paper] to compensate, that type of precision is not required in large diameter flow channels[riser].

c. Calibration certificate will include all the above data plus laboratory biodata, procedures, guidelines, and practices.

E. CWT Measurement [BW test personnel]:

- BW is required to supply all instrument for measurement.

F. Removal of existing pipes & hanging mechanism of WDS and installation of new WDS system:

- Removal of existing pipes and hangers.
- Installation of new system.

G. Owner’s Scope:

- Permit to work with cell isolation.
- Power supply at single location.
- Space for media assembly and storage of media nearby the CT area.
- Required crane/boom lift/scaffolding at each riser as needed.
- The power plant owner is responsible for ensuring that the cooling tower unit is operational to test.
- If a sub-unit/helper tower is involved, then the plant owner is responsible for ensuring it is operational.
- Pre-flow test, Owner to ensure test taps are installed properly at pre-specified location on risers
- Owner to adhere to pre-test checklist.
- Normal test preparation includes proper scaffolding is in place as it is required for safe access to elevated water flow measurement locations.
- Arrangements must be made for an electrician or other qualified technician/ operator to be available to take fan motor power readings as required during the test.

H. Tower Configuration:

If the heat load and/or water flow to a multi-cell tower is below the operating limits as established in test protocols, the number of cells in operation may be reduced prior to the test to meet equal flow to each cell provided by plant owner. In other words, the heat load and flow rates of the operating portion of the tower should meet protocol requirements for heat load/water flow rate on a per cell basis as opposed to an entire tower basis. The same shall be established if the tower has a helper tower. If the cell walls do not fully partition, proper accommodations will be made. The results of the operating portion of the tower are considered representative of the entire tower if the condition of the tested cells is representative of the aggregate tower. Any deviations from the limits recommended in the applicable test protocol should be mutually acceptable to the parties to the test.

I. Pre-flow test measurement:

1. Upon arrival at the test site, BW test team will meet with the collaborative test participants and discuss plans and requirements for the test. BW test team will conduct a perimeter inspection to examine excessive streaming and flow abnormalities within the rain zone. If issues are observed, an internal inspection will be made and the problem/issue rectified before the start of flow measurement.

2. Make-up water and blow-down water flow should be minimal as to avoid interference with the measurement of circulating flow. *It is recommended, both the make-up and blow-down be turned off during test as to provide consistent flow to each riser of each cell tested.*

3. BW test team to ensure every valve is completely open and in operating condition.

4. Scaffolding or boom lifter is required to reach the tap points for proper execution of flow measurement. BW on site team insures plant personnel have installation before execution.

5. BW test team makes sure every instrument is shifted to testing location safely and properly.

6. General Installation of Test Taps - The measurement of water flow rate is required for all of the cooling tower tests addressed in this paper [ex: baseline testing or performance testing]. Mechanical water flow measurements performed using a simplex pitot tube require the installation of pitot taps on the hot water pipes to the tower. Depending on the exterior design of tower and the pathway of the water lines, the pitot taps may be installed along a horizontal position or in a vertical position. Regardless, pre- existing taps for the measurement of thermal parameters [e.g. pump discharge pressure taps for cold water measurement] are usually sufficient as long as the pitot taps are in good, working condition. Additional taps beyond those required for the water flow measurement are not required [See Appendix: tap location/installation]. Pitot tube traverses of the hot water line/s/pipe/s to the tower with recently calibrated pitot tubes are the preferred water flow measurement technique. Installation of pitot taps is advised months before testing and calculations for sizing the openings are given in advance especially if third party testing is involved. [Figure 3] shows a typical installation of Pitot taps.

7. Specified Insertion Points- Two taps are placed $90°$ apart in the same cross-sectional plane of the same riser pipe in each liquid flow line the flow rate is measured. [Appendix A] shows a typical pitot tube installation in conjunction to the insertion taps. The mounting connections should be installed in a straight parallel free from obstructions. The pitot tap hole size should be the smallest hole size practicable, 50 mm for reinforced tubes. This minimizes erroneous flow readings from flow stream distortions, un expected turbulence, and vortices near the pipe wall at the insertion point. The flow measurement location will consider the following: locate Pitot taps in a straight section of pipe with a minimum of 10 pipe diameters downstream and 5 pipe diameters upstream from the nearest pipe fitting, valve, or other obstruction. In the absence of the total 15 diameters of straight pipe, the Pitot taps should be placed in the best $2/3 : 1/3$ ratio of straight pipe. BW test team will verify the Pitot tap installation location and any other unusual piping configurations during the test

preparation stage prior to arrival at the test site. Taps can be installed on either horizontal or vertical riser pipes dependent on tower construction. Scaffolding, or other means of access to elevated measurement stations is required.

8. Obstruction Specifications- Sufficient clearance for the insertion of the pitot tube is required. Insertion of the pitot tube into the pitot tap requires unobstructed access for a distance of the pipe diameter plus $1.0 - 1.2$ meters [$3 - 4$ feet]. The edges of the insertion holes must be clean and rounded slightly, free from burrs, wire edges or other irregularities. Care must be taken to ensure that scaffolding, walls, cross members and other obstructions are not in a direct line with the pitot tap for a distance of the pipe diameter plus the required clearance.

9. Hot Water Temperature Measurement - Hot water temperature needs to be measured in a bleed stream from the hot water line to the tower, thermal well, or by immersion in the hot water distribution system. The location selected should have a well-mixed uniform temperature. If different temperatures are delivered to the tower, a flow weighted average temperature will be used. Pitot tube taps are usually sufficient for hot water temperature taps. The hot water temperature tap can be located in an adjacent cell using the same insertion taps made for flow rate measurement. If the CT is built with two hot water flow pipes/cell, then two bleed streams should be used to accommodate hot water temperature readings on both sides of tower.

10. Technical Preparations:
1. Determine the flow channel pipe diameter.
2. Determine the conventional method; mechanical traverse method.
3. Calculate equal internal annuli, usually of ten or more equal increments along the same cross-sectional plane [a, b]. Amount of equal increments is based on flow channel inside diameter [I.D.]

where for station $N = 1$ through $N = \frac{n}{2N}$:

$f = 0.5 - \sqrt{n - 2N} + \frac{1}{4n}$

[**equation 1**]

and for stations $N = \frac{n}{2} + 1$ through $N = n$:

$f = 0.5 + \sqrt{2N - 1} - \frac{n}{4n}$

[**equation 2**].

$n =$ number of points in the diameter traverse

$N =$ the specific station number; numbered from point $N_{\circ}$ on pipe inside wall

$X^{N} =$ distance from reference point $N_{\circ}$ to station N

$f =$ diameter factor from table of annuli

$D =$ pipe I.D. along traverse line

[nomenclature]

11. General Assembly/ Meetings Pre-Test- Once the tower is deemed ready for testing, a general meeting will be held to discuss the actual test procedures, and assignments will be made for those participating in test data collection. If necessary, the BW test team will instruct other test personnel in the proper procedures and techniques of instrument reading and data recording. If operating or test conditions are outside of recommended test limits, the test will be delayed unless the authorized test parties agree to proceed with the test. The flow test shall then be conducted in the presence of all collaborative parties.

2.0 Primary Test Activity & Flow Measurement: Modified Unit//reinforced pitot tube

Flow measurement test activity is generally conducted by the trained BW test team or in collaboration with a third-party affiliate or in conjunction directly with Plant Owner personnel. In all cases, the parties involved must agree with the test procedures and methods and both are made transparent outlining a clear, concise test.

Determine the internal velocity profiles; obtained by traversing a Pitot-static head mounted at the end of a cylindrical rod [ex: Simplex Pitot tube] cantilevered into the pipe at two insertion taps along the same cross-sectional plane, situated 90˚ apart.

A. Primary and Secondary step-by-step flow activity: Procedure for Mechanical measurement.

1. Drain each tap point of water by opening the valve tap fully for few seconds until the water flow is devoid of mud/debris/brownish discoloration.
2. Insert the pitot tube, simplex side [←] into the valve.
3. Adjust/tighten connector bushings/pipe fittings accordingly.
4. *Always ensure the pitot tube is extended out completely but remains securely tightened to the valve before opening the main pressure ball valve. If opened while pitot tube is fully/partially inserted, damage would occur to the pressure ports at the tip of tube and subsequent replacement of pitot tip needed.*
5. Place the manometer in a vertical position with pressure port knobs facing downward [↓] at a suitable location close to the tap point.
6. Check the orientation of pitot tube, arrow pointing in the upward location [↑], to confirm the alignment of pressure ports.
7. Connect the high-grade plastic pipe tubes first to the Pitot tube end pressure ports.
8. Connect the other end of the high-grade plastic pipe tubes to the manometer pressure ports watchful to avoid any gas [air] pockets restricting the flow area.
9. Open the main pressure ball valve attached to tap point [insertion valve].
10. Wait until the manometer pressure is leveled at eye-level.
11. Adjustments can be made to the pressurized water level by releasing the air from manometer slightly at the top end of manometer.
12. Insert the Pitot tube in the flow channel riser until the pitot tip touches the far end wall of flow channel [riser].
13. Make markings of the calculated location of ten-point I.D. annuli position onto wooden stick attached $25-50$ mm distance parallel to pitot tube.
14. Verify, mark, and record, if needed, $11th$ point-center point [C.P.] for flow validation purposes. BW will validate the C.P. in case of changes in flow.
15. Tighten wooden stick to rod assembly attached to pitot header clamp by Allen wrench.
16. Loosen the pitot tube fitting by Allen wrench and move the tube towards the far end wall to take it to the first point. Tighten with Allen wrench firmly at first point.
17. Let the manometer pressure levels balance then stabilize for $5-10$ seconds and take the difference in deflection also known as the dynamic pressure [differential pressure[ΔP]] between the two water columns at first annuli point with measuring tape [record deflection point number one on record sheet].
18. Continue to extend outward one annuli position point at a time, measuring the deflection between the two water columns, until you reach tenth annuli point at the near wall position point [record each deflection point until all ten annuli are recorded].
19. Take center point [C.P.] if needed.
20. Continue same traverse procedures along same axis for second tap location $90°$ apart on the same flow channel [riser].
21. Total of 20 traverse points must be tabulated for each flow channel [riser] for each cell tested.
22. If two flow channels [risers] are attached to one cell, repeat the same primary test activity procedure.
23. Minimum [2] maximum [3] person test team is recommended for a proper flow measurement.

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    **In most all cases, it must be noted that to complete a thorough evaluation of a cooling tower, thermal performance testing in conjunction with mechanical flow measurement be conducted with a reinforced [SS] pitot tube.*

3.0 Post-Test Activity & Post-Flow Measurement: Modified Unit/ Reinforced Pitot Tube

1. Record all 10 deflection points onto a record sheet.
2. Make sure the pitot tube is completely extended out from tap.
3. Close the water flow by closing the main valve of tap.
4. Loosen pipe fittings and connector bushings with Allen wrench.
5. Disconnect the high-grade plastic tubing from pitot tube and then disconnect tubing from manometer.
6. Unfasten the pitot tube from pitot tap.
7. Repeat the same for adjacent tap [$90°$ on the same axis].
8. If two flow channels [risers] are attached to one cell, repeat the same procedure for post-test activity.
9. Calculate then tabulate total flow rate onto an excel spreadsheet.
10. Traverse and flow rate calculations as described in technical preparation section of paper:

Part IV Instrumentation for Test Measurement:

A. Water Flow Test Measurement– BW test personnel will provide sufficient calibrated instrumentation for all test data collection accompanied with calibration certificates of all instrumentation involved. A discussion of specific test measurements and measurement frequency is included. Any equipment not provided by the approved test personnel on site must not be considered for official test.

1. Flow test instruments-typical water flow test instrumentation will consist of: Simplex Pitot Tube, inverted, air-over-water manometer, tubing, fittings, bushings, and counter-weight brass rod tips [used for directional insertion of pitot tube].
2. Supplemental Equipment- carrying case for pitot tube, Allen wrench, extra high-grade, plastic pipe tubing, tape [variety], water-proof flow rate data collection sheets, water-proof pen/pencil, iron wrench, steel coil, measurement tape, protective gloves with grip, and cotton cloth.
3. Wet bulb instruments for measurement of inlet wet-bulb temperature and/or dry-bulb temperature.
4. Vane anemometers are used to measure wind speed. Wind speed is a crucial component to determine ideal test conditions pre-determined following protocol and must be met before official testing commence.
5. Data acquisition system with multi-plexer card equipped with precision, 4-wire temperature probes will be used to measure hot water, cold water, wet-bulb and dry-bulb temperatures.
6. Clamp-on watt-meters are used to measure the fan motor power for systems with motor voltages less than 600 V. If the cooling tower is equipped with fan motors greater than 600 volts or if the system is equipped with a variable frequency drive [VFD], collaborate to source alternate fan motor power measurement techniques.
7. The data acquisition system is an instrument highly recommended to be used to collect thermal and wind speed data.

Part V Test Calculations:

A. **Flow rate calculations** – The basic pitot tube mechanism only senses the fluid velocity pressure at one point [local velocity] in a flow stream such as a flow channel. In order to establish the average velocity of a flow channel, the entire I.D. must be traversed taking ΔP measurements at the centroid of each of several equal area annuluses [ex:10-point traverse]. A flow velocity needs to be calculated at each of these points and then the average taken to get the total flow rate.

1. **Flow rate formula**:

$$V = c\sqrt{2gH}$$
$$Q = VA$$

[**equation 3**]

When the above equation is simplified; we get, $Q = 1592.6 \times C \times A \times \sqrt{d}$

[**equation 4**]

and; $\sqrt{d} = \frac{D1 + D2}{2}$

$$D = \frac{[d(a) + d(b)]}{2}$$

$$A = \frac{[\pi \times D \times D]}{4},\ C = 0.783$$

where; A = Area of flow in m^2.

c = pitot coefficient dimensionless.

d = dynamic pressure.

and, calculate water flow rate [$m^3/hr.$]

2. **Calculate equal internal annuli**:

where for station $N = 1$ through $N = \frac{n}{2}$:

we get, $f = 0.5 - \sqrt{n - 2N} + \frac{1}{4n}$

[**equation 5**]

and for stations $N = \frac{n}{2} + 1$ through $N = n$:

we get, $f = 0.5 + \sqrt{2N - 1} - \frac{n}{4n}$

[**equation 6**]

where; n = number of points in the diameter traverse

N = the specific station number; numbered from point $N_{\circ}$ on pipe inside wall

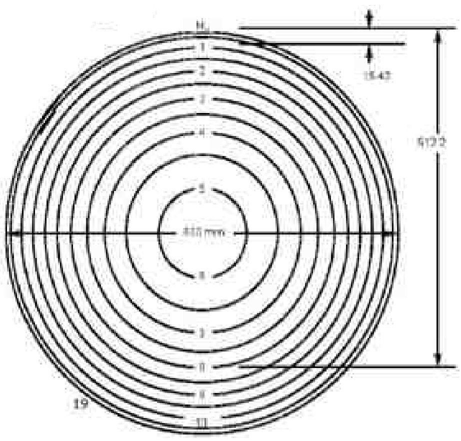
X^{N} = distance from reference point $N_{\circ}$ to station N

f = diameter factor from table of annuli

D = pipe I.D. along traverse line

[nomenclature]

$$X^{N} = f \times D$$



[**diagram 1**]

3. **Calculate for inverted air-over-liquid manometer**:

a. The manometer fluid [mf] is less dense than the flowing fluid [ff]. The density of air is very minute in comparison to fluid density in fact, it is negligible.

$H = \delta \div 1000 \times \rho ff - \frac{\rho mf}{pff}$

[**equation 7**]

simplified, we get;

$H = \delta \div 1000$

[**equation 8**]

Example;

b. If the pitot DP measurement is taken when the fluid has a density similar to or greater than water than the deflection can be calculated as;

$Q = 140 \times C_{\circ} \times A \times \sqrt{\delta}$

[**equation 9**]

where, Q = flow rate [L/s]

$C_{\circ}$ = pitot calibration coefficient

A = flow area [m^2]

[nomenclature]

δ = manometer deflection [mm]

where, δ [manometer deflection [mm]] = velocity pressure of a column of head [H] of net differential density

$\boldsymbol{\rho}$ = pressure

$\boldsymbol{ff}$ = flowing fluid

$\boldsymbol{mf}$ = manometer fluid

[nomenclature]

where, the value of the constant 140 is derived from

$$4428 \times \frac{\sqrt{1}}{1000} = 140.05 \approx 140$$

[**equation 10**]

we find, 40 is a convenient rounded value with less than 0.1% introduced error.

Please note: with large-size diameter flow channels and mid to high flow velocities [$\geq 2\,m/s$], it is not uncommon to have vibrations of the pitot tube. Slight vibrations do not seem to affect the velocity head but large vibrations will have influence. It is therefore recommended to use a reinforced pitot tube with pipe diameter $\geq 1.2\,M$ to minimize vibration and prevent excessive tube deflection.

In some cases, the area occupied by the pitot tube may not be taken to consideration in the calibration of the tube. BW test team ensures, with a calibration certificate comprised with calibration coefficient [$C_{\circ}$] that the correction blockage factor will be determined for the blockage area of the pitot tube before each and every flow measurement.

Part VI Summary:

It is important to note that mechanical flow measurement with a Simplex tip pitot tube is not an exact science. In fact, a measurement accuracy factor of $\pm 3\%$ the true value of liquid flow is possible. Minimizing the percent error and ensuring more precise measurement depends on the professional conduct of the test personnel performing measurement, the correct location and installation of tap points, the precision of equipment calibration, the accuracy of the readout device, the conduct of collaborative parties involved, and the ambient weather conditions. Factors must be made for each in order to obtain best results.

It is also important to state that the mechanical method using a Simplex pitot tube is not the only method to determine flow profiles in mid to large size pipe diameter at mid to high flow velocities. Accuracy values for other pitot tube types have not yet been established. There are a variety of instruments that are used today, all with their own advantages and disadvantages: orifice plate/Venturi tube/flow nozzle [differential pressure type flow meters], multiport averaging flow meter, vortex shedding meter, turbine meter, magnetic flow meter, transit time ultrasonic flow meter, and tracer injection measurement method also known as dye dilution method. The use of these instruments seems to be subjective and very site dependent outside the US but the BW test team has adopted the recommendation from a leading US Institute [CTI] which still recommends the use of a mechanical pitot traverse method.

Appendix A: Figures

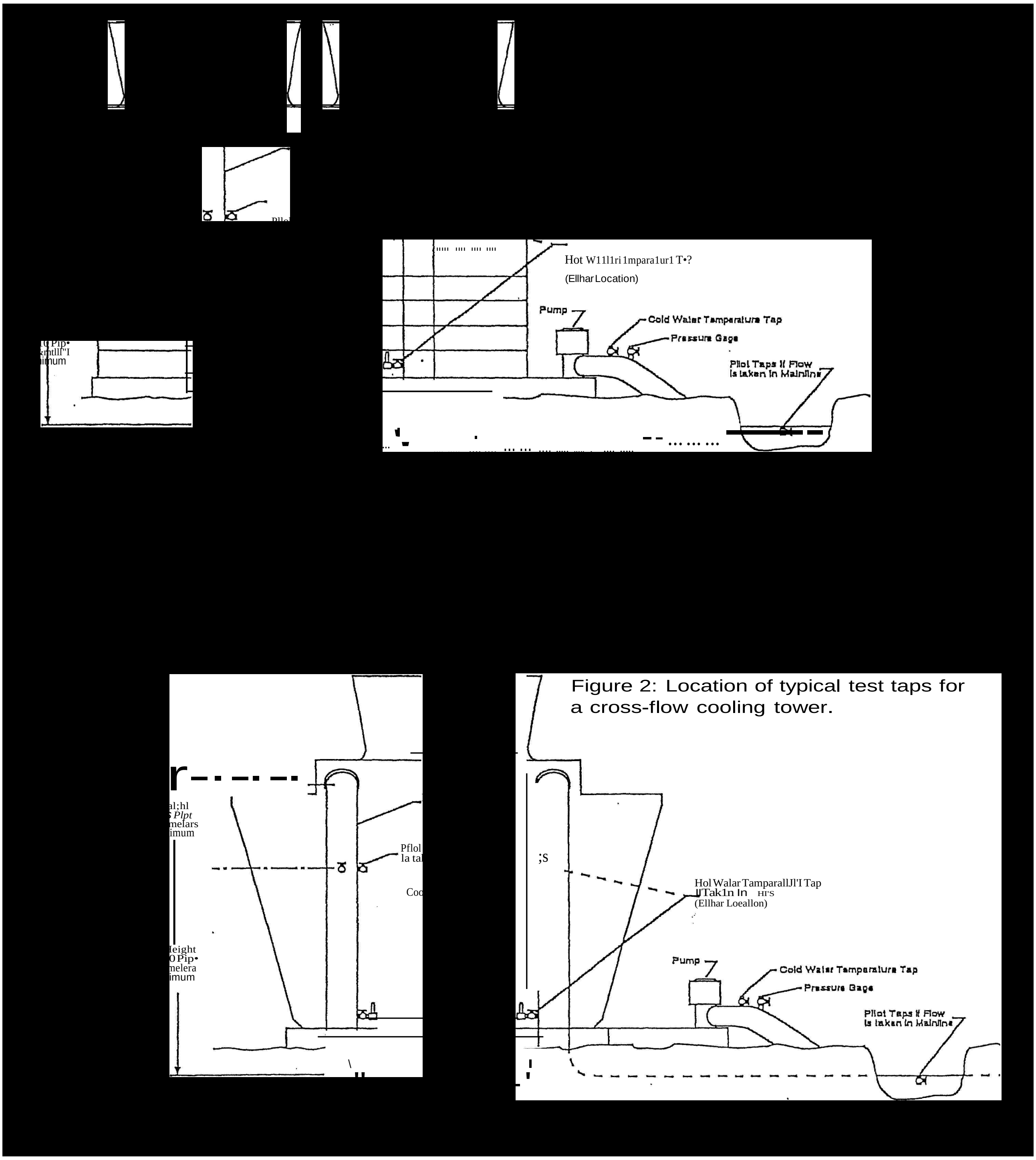


Figure 2: Location of typical test taps for a cross-flow cooling tower.

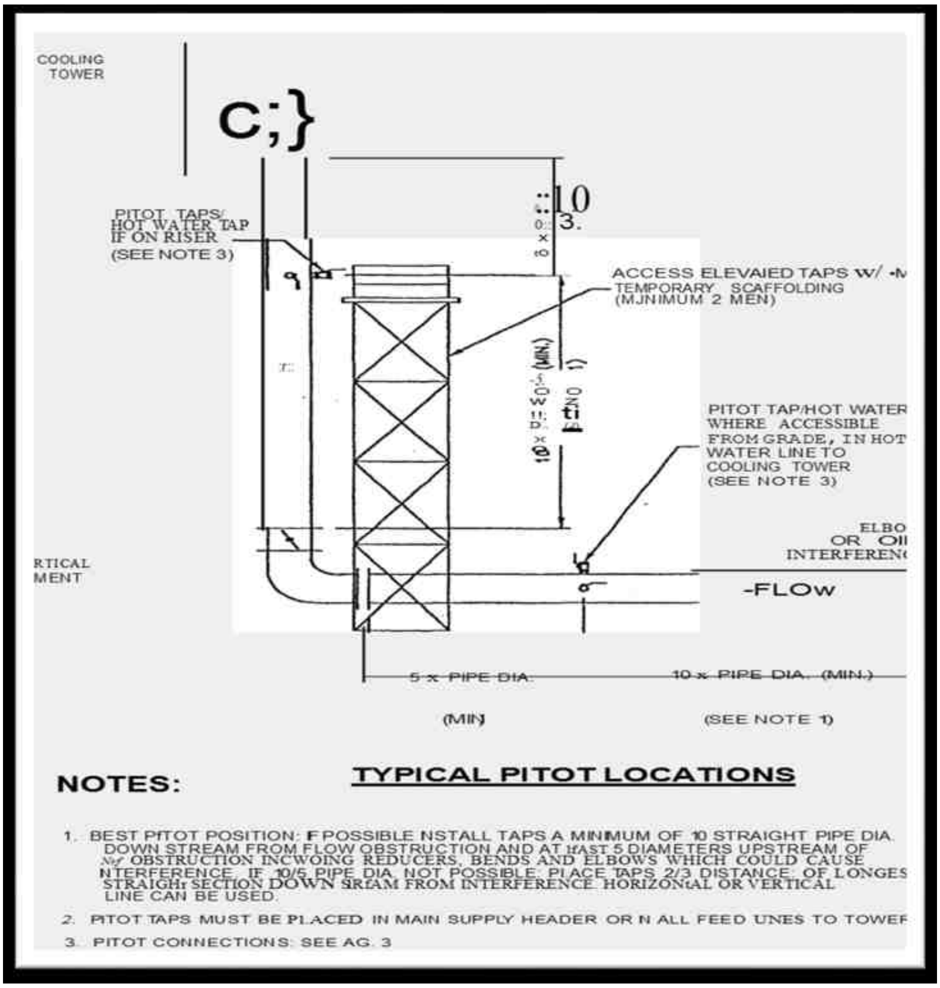


Figure 3: Pitot vertical insertion point

PITOT TAP INSTALLATION

Gate Valve or Equal For Pitot Taps			
Pitot Tap	Pipe Size	Water Velocity	Valve and Nipple Opening
Standard	150 mm – 1500 mm (6 in – 60 in)	< 3 m/s (<10 ft/s) recommended	≥ 32 mm* (≥ 1 1/4 in)
Reinforced	900 mm – 3660 mm (36 in – 144 in) Consult CTI if larger	Higher velocities may be tolerated Contact CTI	≥ 50 mm* (≥ 2 in)

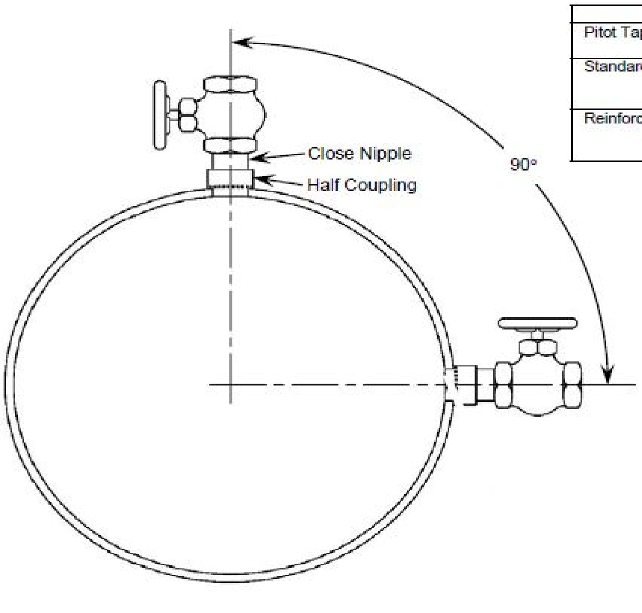


Figure 4: Pitot tap location [plan view]

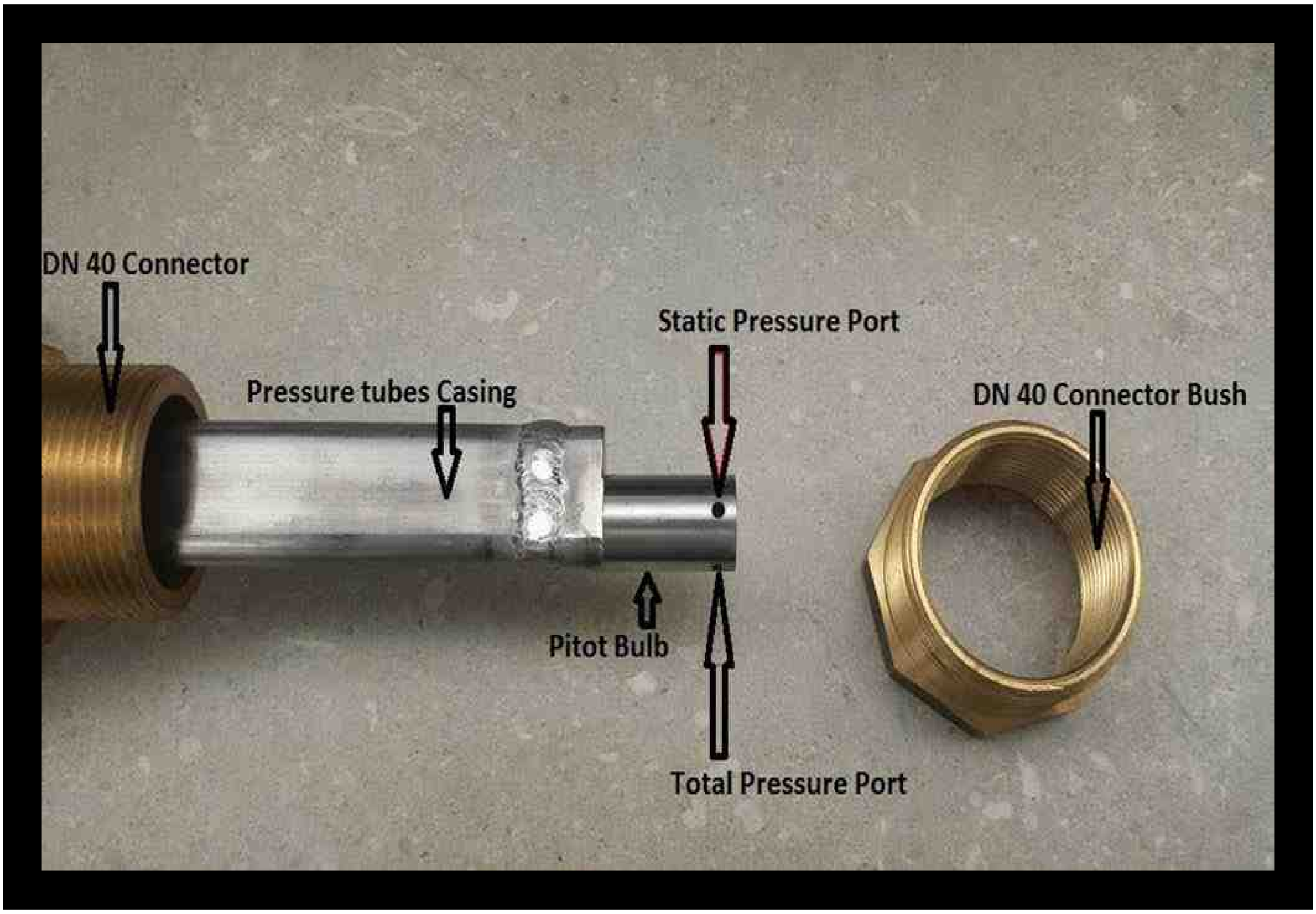


Figure 5: Pitot tube and accessories

Appendix B:

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Number of Papers Published in Conferences:

[1]. Aull, Rich M.E., Upadhyaya, Vardan. "A Case Study: Improving Efficiency of Coal Based Thermal Power Plants by Retrofitting Outdated Fill and Water Distribution Systems with Modern High Efficiency and Low Fouling Fill System."

Reference No: fg 17025