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British Standard

# Water cooling towers

## Part 2. Methods for performance testing

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Tours de refroidissement par l'eau  
Partie 2. Méthodes d'essai de fonctionnement

Wasserkühltürme  
Teil 2. Funktionsprüfung

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| Confirmed<br>December 2011 |
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## Foreword

This Part of BS 4485, which has been prepared under the direction of the Civil Engineering and Building Structures Standards Committee, deals with the performance testing of industrial mechanical draught and natural draught water cooling towers. This Part of BS 4485 is a revision of BS 4485 : Part 2 : 1969 which is withdrawn.

The principal difference between this Part of BS 4485 and the 1969 edition is the introduction of the option of using a computer to do the calculation of thermal performance capability rather than carrying it out manually.

The performance of a cooling tower is dependent upon a number of factors, such as conditions of the atmosphere, conditions of the cooling water flow, conditions of equipment and conditions of the site, and the object of this Part of BS 4485 is to describe methods for the accurate determination of thermal performance. In addition, methods are described for the functional testing of equipment necessary for the satisfactory operation of a cooling tower.

This Part of BS 4485 also includes a description for the performance test procedure, the computation and evaluation of results, and the appendices provide worked examples for establishing the  $L/G$  ratio for natural draught cooling towers, and also the cooling tower characteristic  $KaV/L$ .

The other Parts of BS 4485 are as follows.

Part 1 Glossary of terms

Part 3 Code of practice for thermal and functional design

Part 4 Code of practice for the structural design of cooling towers

Where necessary, definitions have been included in the revisions of BS 4485 : Parts 2, 3 and 4 so that when they have all been published BS 4485 : Part 1 can be withdrawn.

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# Methods

## 1 Scope

This Part of BS 4485 describes methods for the determination of the performance of industrial mechanical draught and natural draught water cooling towers.

This Part of BS 4485 can also be applied to other forms of cooling towers.

NOTE 1. The matters to be agreed between purchaser and supplier are listed in appendix A.

NOTE 2. The titles of the publications referred to in this standard are listed on page 33.

## 2 Definitions

For the purposes of this Part of BS 4485 the following definitions apply.

**2.1 air flow.** Total quantity of air, including associated water vapour flowing through the tower.

**2.2 ambient wet (dry) bulb temperature.** Wet (dry) bulb temperature of air measured windward of the tower and free from the influence of the tower.

**2.3 approach.** Difference between recooled water temperature and nominal inlet air wet bulb temperature.

**2.4 inlet water flow.** Quantity of hot water flowing into the tower.

**2.5 cold water basin.** Device underlying the tower to receive the cold water from the tower and direct its flow to the suction line or sump.

**2.6 cooling range.** Difference between the hot water temperature and the recooled water temperature.

NOTE. The term 'range' is also applied to this definition, but is regarded as a non-preferred term.

**2.7 drift loss.** Water lost from the tower as liquid droplets entrained in the outlet air.

**2.8 heat load.** Rate of heat removal from the water within the tower.

**2.9 hot water temperature.** Temperature of inlet water.

**2.10 inlet air wet (dry) bulb temperatures.** Average wet (dry) bulb temperatures of the inlet air; including any recirculation effect.

NOTE. This is an essential concept for purposes of design, but is difficult to measure.

**2.11 make up.** Water added to the circulating water system to replace water loss from the system by evaporation, drift, purge and leakage.

**2.12 nominal inlet air wet (dry) bulb temperatures.** Arithmetical average of the measurements taken within 1.5 m of the air inlets and between 1.5 m and 2.0 m above the basin kerb elevation on both sides of the cooling tower.

NOTE. See 5.2.2.

**2.13 purge.** Water discharged from the system to control concentration of salts or other impurities in the circulating water.

**2.14 recooled water temperature.** Average temperature of the water at the cold water basin discharge excluding the effect of any make-up entering the basin.

**2.15 recirculation.** Portion of the outlet air that re-enters the tower.

**2.16 fan drive assembly.** Components for driving the fan, normally comprising driver, drive shaft and transmission unit, and primary supporting members.

**2.17 fan power.** Power input to the fan drive assembly, excluding power losses in the driver.

**2.18 tower pumping head.** Total head of water required at the inlet to the tower, measured above the basin kerb, to deliver the inlet water through the distribution system.

**2.19 water loading.** Inlet water flow expressed in quantity per unit of plan packing area of the tower.

**2.20 wet (dry) bulb temperature.** The temperature indicated by an adequately ventilated and wetted (non-wetted) thermometer in the shade and (where applicable) protected from strong ground radiation.

## 3 Symbols and units

For the purposes of this Part of BS 4485, the symbols and units given in table 1 apply.

## 4 Conditions of validity of tests

### 4.1 General

In determining the performance and thermal efficiency of mechanical and natural draught cooling towers, the conditions of validity specified in 4.2 to 4.5 shall be fulfilled.

NOTE. These conditions may also form the basis for contractual agreement between the purchaser and the supplier.

### 4.2 Conditions of site

Any variations in the conditions of the site from those of the design shall be recorded.

### 4.3 Conditions of equipment

At the time of test all equipment and systems shall be in proper operating condition, and the following checks shall be made.

(a) The water distribution system shall be clear and free from foreign materials which may clog or impede the normal water flow.

(b) Mechanical equipment shall be in good working order and set for the design duty (see 6.1).

- (c) Drift eliminators shall be clear and free from algae and other deposits which may impede normal air flow.
- (d) Packing shall be free from foreign material, such as oil, tar, scale or algae, and shall have been in use for such a period (as recommended by the supplier) to ensure adequate wetting.
- (e) The water level in the cold water basin shall be at normal operating elevation immediately prior to the test.

NOTE. Wherever possible the make-up and purge should be shut off during the test in the interest of simplicity and accuracy.

In the event of the equipment not being in a satisfactory operating condition, such adjustment or changes as may be required to place it in proper operating condition shall be made. However, no adjustments shall be made which are not practical in continuous commercial operation, other than the initial setting.

**Table 1. Symbols and units**

| Symbol        | Quantity                                                                                                        | Units                                                               |
|---------------|-----------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| $a$           | Area of effective transfer surface per unit of tower packed volume                                              | $\text{m}^2/\text{m}^3$                                             |
| $c$           | Specific heat capacity of water                                                                                 | $\text{kJ}/(\text{kg} \cdot \text{K})$                              |
| $G$           | Mass flow of dry air per unit plan area of packing*                                                             | $\text{kg}/(\text{m}^2 \cdot \text{s})$                             |
| $h$           | Enthalpy† of air-water vapour mixture                                                                           | $\text{kJ}/\text{kg}$                                               |
| $h_G$         | Enthalpy† of air-water vapour mixture passing through the packing                                               | $\text{kJ}/\text{kg}$                                               |
| $h_L$         | Enthalpy† of saturated air film in contact with and at the temperature of the water passing through the packing | $\text{kJ}/\text{kg}$                                               |
| $K$           | Coefficient of mass transfer defined in terms of difference in absolute humidity                                | $\text{kg}/[\text{m}^2 \cdot \text{s} \cdot (\text{kg}/\text{kg})]$ |
| $L$           | Mass water flow per unit plan area of packing                                                                   | $\text{kg}/(\text{m}^2 \cdot \text{s})$                             |
| $n$           | (Constant)                                                                                                      | —                                                                   |
| $Q_I$         | Inlet water flow                                                                                                | $\text{m}^3/\text{s}$                                               |
| $Q_M$         | Make-up water flow                                                                                              | $\text{m}^3/\text{s}$                                               |
| $Q_P$         | Purge water flow                                                                                                | $\text{m}^3/\text{s}$                                               |
| $t_{DB}$      | Dry bulb temperature                                                                                            | $^{\circ}\text{C}$                                                  |
| $t_E$         | Temperature of mixture of recooled water and make-up leaving cold water basin                                   | $^{\circ}\text{C}$                                                  |
| $t_M$         | Make-up water temperature                                                                                       | $^{\circ}\text{C}$                                                  |
| $t_P$         | Purge water temperature                                                                                         | $^{\circ}\text{C}$                                                  |
| $t_{WB}$      | Wet bulb temperature                                                                                            | $^{\circ}\text{C}$                                                  |
| $t_1$         | Hot water temperature                                                                                           | $^{\circ}\text{C}$                                                  |
| $t_2$         | Recooled water temperature                                                                                      | $^{\circ}\text{C}$                                                  |
| $V$           | Effective packed volume per unit area of packing                                                                | $\text{m}^3/\text{m}^2$                                             |
| $V_B$         | Average water volume in cold water basin during the test                                                        | $\text{m}^3$                                                        |
| $W_h$         | Fan horsepower                                                                                                  | W                                                                   |
| $\lambda$     | (Constant)                                                                                                      | —                                                                   |
| $\rho$        | Density of air                                                                                                  | $\text{kg}/\text{m}^3$                                              |
| $\Delta h$    | Change in air enthalpy                                                                                          | $\text{kJ}/\text{kg}$                                               |
| $\Delta t$    | Cooling range                                                                                                   | K                                                                   |
| $\Delta \rho$ | Change in air density                                                                                           | $\text{kg}/\text{m}^3$                                              |
| $KaV/L$       | Tower characteristic                                                                                            | —                                                                   |
| $L/G$         | Water/air ratio                                                                                                 | —                                                                   |
| Subscripts    |                                                                                                                 |                                                                     |
| d             | design                                                                                                          | —                                                                   |
| t             | test                                                                                                            | —                                                                   |

\*The quantity defined for  $G$  applies to counterflow; for crossflow see appendix C.

†All enthalpies relate to 1 kg of dry air.

#### 4.4 Conditions of atmosphere

The tests shall be carried out during stable weather conditions and within the following limitations.

(a) Wind velocity readings averaged over the test period shall not exceed 5.0 m/s, with readings averaged over 1 min not exceeding 7.0 m/s, when measured at a height of 1.5 m to 2.0 m above local ground level.

(b) The inlet wet bulb temperature shall be within  $\pm 5$  K of the design wet bulb temperature, but shall not fall below 3 °C.

Readings may fluctuate but the rate of change in average wet bulb temperature shall not exceed 1 K/h.

(c) In the case of natural draught towers, the relative humidity shall not fall below 40 %.

(d) Natural draught towers shall not be tested under conditions of atmospheric inversion. Where doubt exists as to the presence of a normal 'lapse rate', additional readings of air temperature shall be taken at a height of 8 m to 10 m to confirm a positive lapse (see 5.2).

The tests shall be carried out during daylight hours for reasons of safety and accuracy of measurements except that under certain circumstances it may be necessary to carry out noise tests at night.

#### 4.5 Conditions of inlet water

The total dissolved solids in the inlet water shall be within 500 mg/L of the design value and oil, tar or other fatty substances shall not exceed 10 mg/L.

#### 4.6 Variation from design conditions

The following variations of average test readings from design conditions are permissible.

(a) Inlet water flow not more than 10 % below or 10 % above the design value.

(b) Cooling range not more than 20 % below or 20 % above the design value.

(c) Heat load not more than 20 % below or 20 % above the design value.

During the hour selected in accordance with 7.3.1 as being representative of the test conditions, the difference between maximum and minimum readings of the inlet water flow, cooling range and heat load, shall not exceed 5 %.

### 5 Instruments and methods of measurement

#### 5.1 Measurement of wind velocity

Instruments shall be calibrated before use. Measurement shall be made in an open and unobstructed location to the windward of the equipment at a horizontal distance sufficient to eliminate the influence of the upstream effects of the equipment, and, where possible, a vertical distance of 1.5 m to 2.0 m above local ground level.

NOTE 1. The instrument recommended for the measurement of wind velocity is either the rotating cup or rotating vane anemometer.

NOTE 2. If such a location is inaccessible, a suitable location for wind measurement should be agreed between the test personnel (see appendix A).

NOTE 3. The frequency of readings taken should increase with wind speed and gust effect, in order to arrive at a representative average result.

#### 5.2 Measurement of air temperature

**5.2.1 General.** The number of stations at which measurements are to be taken depends upon the size of the cooling tower and the existence of neighbouring influences. In the case of multi-cell mechanical draught and natural draught cooling towers, a minimum of three stations shall be used, whereas one station may suffice for a single-cell cooling tower.

##### 5.2.2 Measurement of nominal inlet air temperatures.

The nominal inlet wet bulb and dry bulb temperature shall be determined as the arithmetical average of the measurements taken within 1.5 m of the air inlets and between 1.5 m and 2.0 m above the basin kerb elevation on both sides of the cooling tower so as to bracket substantially the air flow to the tower.

In the case of natural draught towers, it is likely that the ambient and nominal inlet air temperatures will be identical, in which case the tests can be carried out using the ambient temperature measurements only in accordance with 5.2.3.

**5.2.3 Measurement of ambient temperatures.** The ambient wet bulb and dry bulb temperatures shall be determined as the arithmetic average of measurements taken, where possible, approximately 1.5 m to 2 m above ground level, and not less than 15 m or more than 100 m to windward of the equipment, and equally spread along a line substantially bracketing the flow of air to the equipment.

NOTE. If such a location is inaccessible, or the area surrounding the equipment contains elements which can affect the ambient wet bulb and dry bulb temperatures, a suitable location for these measurements should be mutually agreed (see appendix A).

##### 5.2.4 Measurement of wet bulb and dry bulb temperatures.

The instrument for the measurement of the wet bulb and dry bulb temperature shall be a mechanically aspirated psychrometer complying with the following.

(a) The temperature-sensitive element shall be in accordance with 5.3.1.

(b) Temperature-sensitive elements shall be shielded from the direct rays of the sun or from any other sources of radiant heat. Shielding devices shall be substantially at the dry bulb temperature.

(c) The wick covering the bulb of the wet bulb thermometer shall be kept clean at all times and maintained in a saturated condition. It shall be a snug fit over the bulb and at least 25 mm in length.

(d) The temperature of the distilled water used to wet the wick shall be at approximately the wet bulb temperature to be measured.

NOTE 1. This can be obtained in practice by allowing adequate ventilated wick between the water supply and the temperature-sensitive element.

(e) The air velocity over the temperature-sensitive elements shall be between 3.0 m/s and 6.0 m/s.

At least three successive readings, separated by 10 s, shall be taken at any given location and averaged after the psychrometer has reached equilibrium.

NOTE 2. The instrument will usually reach equilibrium in 2 min.

### 5.3 Measurement of water temperature

**5.3.1 General.** The method used to measure water temperature shall be accurate to  $\pm 0.05^\circ\text{C}$ .

NOTE. The instrument preferred for water temperature measurement is the mercury in glass thermometer with divisions etched on the glass at intervals not greater than  $0.1^\circ\text{C}$ . Other officially calibrated instruments may be used by mutual agreement (see appendix A).

The instrument used for the test shall have been checked against a reference thermometer calibrated by an approved calibrating authority prior to the test, but not more than 6 months before the test in the case of a first calibration of the same instrument. Certificates of examination shall be made available for inspection.

The locations of the temperature measuring instruments shall be such that the average temperature of the hot and the recooled water flows are determined. Where various streams of different temperatures combine, the point of measurement shall be located to ensure complete mixing without stratification.

If stratification is evident, the weighted average water temperature shall be determined by a survey of a selected section using simultaneous temperature and water flow measurements at each point.

**5.3.2 Hot water temperature.** A suitable location for the measuring instrument for hot water temperature is the common supply conduit to the tower.

**5.3.3 Recooled water temperature.** The recooled water temperature can be measured directly at the point where the water is discharged from the basin, the average cold water temperature being determined by simultaneous test readings, where possible, across the selected section.

Where stratification is evident, a suitable point of measurement is at the outlet of the circulating water pump. Allowance shall also be made for the rise in temperature due to energy losses in the pump (see 8.4).

When the temperature of the circulating water in the basin is the mixed temperature of both circulating water and make-up water, the recooled water temperature shall be determined indirectly by heat balance calculation taking into account the temperature and quantity of make-up and purge and other heat added or removed between the tower and the point of measurement (see 8.4).

**5.3.4 Make-up water and purge temperatures.** Temperature readings shall be taken at the spill over weir or in the piping immediately adjacent to the cooling tower.

### 5.4 Measurement of water flow

#### 5.4.1 Measurement

**5.4.1.1 Inlet water flow.** Measurements shall be made either:

- (a) in the piping leading to the cooling tower, and care shall be taken to ensure that during the test water is neither fed into nor taken away from the pipe system between the measuring points and the cooling tower; or
- (b) where it is not possible or practicable to measure the flow at the inlet to the cooling tower, a different location shall be selected and the necessary correction shall be applied to determine the actual flow into the cooling tower.

**5.4.1.2 Make-up water flow.** Measurement of make-up water flow shall be made in the make-up piping leading to the cooling tower or the system.

**5.4.1.3 Purge water flow.** Measurement of the purge water flow shall be made in the piping leading from the cooling tower or the system.

#### 5.4.2 Methods

**5.4.2.1 General.** The method to be employed for the measurement of inlet water flow will be dependent upon the layout of the pipe system, and shall be selected from those methods listed in (a) to (h) and detailed in 5.4.2.2 to 5.4.2.9.

- (a) Pitot-static tubes.
- (b) Orifice plates and nozzles.
- (c) Venturi tubes.
- (d) Notches, weirs and flumes.
- (e) Current meters.
- (f) Dilution methods (including the use of radioisotope techniques).
- (g) Heat balance.
- (h) Magnetic or sonar devices.

NOTE. The method to be employed should be agreed between the purchaser and the supplier.

**5.4.2.2 Pitot-static tubes.** The design and use of pitot-static tubes shall be as specified in BS 1042 : Section 2.1.

NOTE. This device is suited to a closed circuit where no permanent flow measuring device is installed.

**5.4.2.3 Orifice plates and nozzles.** The design and use of orifice plates and nozzles shall be as specified in BS 1042 : Part 1.

NOTE. These devices are suited to closed circular conduits running full. They are normally permanently installed and their inherent energy loss usually limits the use to small diameter pipelines.

**5.4.2.4 Venturi tubes.** The design and use of venturi tubes shall be as specified in BS 1042 : Part 1.

NOTE. The conditions for the measurement of water flow are the same as those for an orifice plate or nozzle but with the advantage that this type of device results in a lower permanent head loss.

**5.4.2.5 Notches, weirs and flumes.** The construction and installation of notches, weirs and flumes shall be as specified in BS 3680 : Part 4A.

NOTE. This method is suitable only when a system is designed to accommodate a notch, weir or flume as a permanent structure.

**5.4.2.6 Current meters.** Current meters shall be as specified in BS 3680 : Part 8A and their use shall be as specified in BS 3680 : Part 3A.

NOTE. This method is suitable for flow in channels having a free water surface.

**5.4.2.7 Dilution methods.** Flow measurement by chemical dilution shall be as specified in BS 3680 : Part 2A and by radioactive tracer dilution as specified in BS 3680 : Part 2C.

NOTE 1. This method is equally applicable to flow in open channels with free water surface and to conduits running full.

NOTE 2. It is important that the appropriate water authority and river authority are consulted.

NOTE 3. The requirements specified in 7.3.2 do not apply with the use of this method.

**5.4.2.8 Heat balance.** Application of this method shall be as specified in BS 752.

NOTE. This method can be employed in the case of power station cooling towers.

**5.4.2.9 Magnetic or sonar devices.** Several proprietary devices are available and have the potential for high accuracy.

## 5.5 Water analysis

When it is required to determine the concentration of dissolved solids, oil, tar and other fatty substances (see 4.5) samples of water shall be taken at the cooling tower inlet, and tests carried out in accordance with BS 2690 : Part 9 or Part 11, as appropriate.

## 5.6 Measurement of tower pumping head

The following measurements shall be taken in order that the pumping head may be evaluated.

- (a) Static pressure above atmosphere measured at the centreline of the water inlet to the tower and immediately adjacent to the termination of supply.

NOTE 1. This may be a connecting flange or another termination of supply agreed between the purchaser and supplier.

- (b) The height above basin kerb level of the point at which the above static pressure is measured.

- (c) The cross section of the inlet conduit at which the above static pressure is measured.

NOTE 2. This may be most conveniently taken from the design drawings and an observation taken to confirm that the size and shape of the inlet corresponds to the design.

## 5.7 Measurement of power input to the fan driver

The electrical power input of three-phase a.c. electric motors shall be determined from measurements of voltage and current in each phase in conjunction with the power factor quoted by the motor manufacturer.

When voltage measurements cannot be made at the motor terminals, due allowance shall be made for voltage drop in the cable between the points of measurement and the motor terminals.

## 5.8 Measurement of drift loss

The assessment of the nuisance created by drift loss from a cooling tower shall be obtained by the method described in appendix B.

NOTE. The amount of drift loss can be estimated by taking the difference between the quantity of make-up water flow and the sum of the purge flow and evaporation loss. The accuracy of the measurement of the various quantities concerned should be taken into account. This measurement should preferably be carried out under conditions of no-heat-load.

## 5.9 Measurement of tower noise

When it is necessary to measure the free-field sound level of a cooling tower, the instrument used shall be an industrial grade sound level meter, complying with BS 5969, fitted with an 'A' weighting network and capable of measurements at least over the range 30 dBA to 90 dBA.

The instrument shall have its acoustic calibration checked immediately before and after the test.

The microphone of the sound level meter shall be located out of doors, at least 1.5 m above local ground level.

NOTE 1. The microphone positions should be agreed between the purchaser and the supplier.

The values recorded shall correspond to the free-field noise of the cooling tower (water and fans) and exclude noise due to wind, electrical interference and other sources of noise.

The total noise inclusive of the tower under full water and fan load shall be measured and also the background noise measured immediately before the test and exclusive of fan and water noise.

Measurements shall be made under conditions representative of the guaranteed conditions.

NOTE 2. Evaluation of the results obtained is covered by appendix B of BS 4485 : Part 3 : 1988.

# 6 Test checks and readings

## 6.1 Functional test

**6.1.1 General.** In order to establish that the cooling tower is fully operational and that the mechanical equipment is functioning in accordance with the design requirements, check the equipment in accordance with 6.1.2 to 6.1.4.

**6.1.2 Fans.** Check the following:

- (a) that the fan blades are set to the correct pitch for design duty;
- (b) that the fan is centralized in the fan casing to ensure uniform tip clearance within the specified tolerances;
- (c) that the fan rotates in the correct plane;
- (d) that the direction of rotation of the fan is correct at all speeds.

**6.1.3 Fan drive assembly.** Check the following:

- (a) that the fan drive is aligned within the specified tolerances;
- (b) that the lubrication is in accordance with the manufacturer's recommendations;
- (c) that the fan power observed under no-heat-load conditions is within the capacity of the driver;
- (d) that there is no excessive mechanical noise or vibration.

**6.1.4 Water distribution system.** Check the following:

- (a) that all valves are operating freely;
- (b) that the system is regulated for even distribution;
- (c) that the water levels are correct with sufficient freeboard;
- (d) that on an approximate assessment, the inlet water flow is in accordance with 4.6(a).

**6.2 Performance test**

**6.2.1 General.** For the performance test take the readings detailed in 6.2.2 and make the check detailed in 6.2.3.

**6.2.2 Thermal performance test.** To conduct a full thermal performance test, take readings of the following quantities:

- (a) wet bulb temperature;
- (b) dry bulb temperature;
- (c) hot water temperature;
- (d) recooled water temperature;
- (e) inlet water flow;
- (f) make-up water flow and temperature;
- (g) purge water flow and temperature;
- (h) fan power;
- (i) wind velocity.

The number and frequency of the readings to be taken shall be in accordance with 7.3.2.

Water samples shall be taken when there is reason to believe that the water does not comply with 4.5.

**6.2.3 Pumping head.** Check that the total head at each tower inlet is correct for design conditions.

**6.2.4 Amenities.** If tests on tower noise and drift nuisance are required, they shall be carried out in accordance with 5.9 and appendix B respectively.

**7 Performance test procedure**

NOTE. Recommendations for the test personnel are given in appendix A.

**7.1 Preparation for test**

**7.1.1 Programme.** The programme for the test shall include particulars of the following items:

- (a) number of cooling towers to be tested;

- (b) number of cells per cooling tower to be tested;
- (c) extent and duration of the test;
- (d) methods of measurement and measuring equipment;
- (e) personnel required;
- (f) communications, transport and signals;
- (g) temporary power and water supplies, and other facilities;
- (h) preparation and circulation of test records.

**7.1.2 Inspection.** Inspect the cooling tower before the tests to ascertain that the conditions of the equipment have not changed since the functional tests carried out in accordance with 6.1.

**7.1.3 Measurements.** Prepare test record sheets, in advance, clearly indicating the items to be recorded at the various observation points for the observers.

The test record sheets shall record the following:

- (a) the serial number of each cooling tower, and of the instruments and any other essential information to identify the instruments and measuring points;
- (b) all readings made at each observation point and the exact time at which each was taken, together with any circumstances deserving attention;
- (c) the name of the particular observer(s) and the date of test.

**7.1.4 Instruments.** Prior to the test, arrange for a recognized authority to calibrate instruments used in this test over a range covering the test conditions.

Ensure that all necessary instrument corrections and calibration curves are available, so that adequate preliminary calculations can be made and all errors eliminated or accounted for before the tests are terminated, and the test instruments removed.

If any doubt arises about the accuracy or reliability of an instrument, replace it and/or check it by a recalibration as soon as practicable.

**7.2 Preliminary tests**

It is permissible to run preliminary tests in order to determine whether the equipment and measuring instruments are in suitable condition for the conduct of a performance test, to acquaint the personnel with the test procedure and to determine whether any adjustments or modifications are required.

NOTE 1. The supplier should be allowed to make preliminary tests and to carry out any adjustments or modifications that may be necessary. The supplier should be limited, by written agreement, as to the time to be taken for these preliminary test adjustments and modifications, so that the acceptance tests are not unduly delayed.

NOTE 2. A preliminary test may, if mutually agreed, be considered as an acceptance test, provided it has complied with all the requirements for an acceptance test.

### 7.3 Test procedure

**7.3.1 Duration of test.** Ensure that the duration of the test is such as to enable steady state conditions to be achieved within the limits specified in 4.6. Take the readings (at the intervals specified in 7.3.2) during the hour in which conditions are steadiest, as the test readings.

Increase the period of 1 h by a period equivalent to the thermal lag of the system, as specified in 8.6, provided this exceeds 15 min.

If the test run is undertaken with the make-up water and purge shut off, the water level in the basin will drop and the concentration of dissolved solids in the circulating water will increase. Therefore, limit the duration of the test run so that the corresponding rise in pumping head will not decrease the inlet water flow by more than 5 % and the increase in the concentration of dissolved solids does not exceed the concentration specified.

**7.3.2 Frequency of readings** (see note 3 to 5.4.2.7). Take readings:

- (a) at regular intervals over the same period of time, at each measuring point;
- (b) accurately, even for preliminary tests, so as to be repeatable and to serve as a reliable basis for calculating the test results;
- (c) at the frequencies given in table 2.

**7.3.3 Test records.** Prepare complete test record sheets in accordance with 7.1.3.

NOTE. The test records should be signed by the Chief of Test (see appendix A) and by representatives of both the purchaser and the supplier.

**7.3.4 Preliminary results.** Work out a preliminary assessment of results during the test in order to investigate irregularities, to eliminate detectable faults and errors, and to ensure that the test points are suitable in number and position for determining the final results.

## 8 Computation of results

### 8.1 Reduction of test readings

In general, use the arithmetic mean of the quantities during the test period to derive the average values necessary for the final evaluation of the results. However, when conditions of stratification are known to exist compute the mean values of water temperatures in accordance with 8.2 to 8.7.

### 8.2 Computation of inlet water temperature

Derive the mean value of the inlet water temperature from the arithmetic mean of the individual readings at each measuring point weighted by the corresponding water velocities at these points to give average hot water temperatures.

### 8.3 Computation of recooled water temperature with make-up and purge flows shut off

**8.3.1** Derive the mean value of the recooled water temperature from the arithmetic mean of the individual readings at each measuring point weighted by the corresponding water velocities at these points to give the average recooled water temperature.

**Table 2. Frequency of readings**

| Quantity                                                 | Unit              | Recommended number of readings each hour |
|----------------------------------------------------------|-------------------|------------------------------------------|
| Wind velocity                                            | m/s               | 3 to 12 (see 5.1)                        |
| Wet bulb temperature                                     | °C                | 12                                       |
| Dry bulb temperature (for natural draught cooling tower) | °C                | 12                                       |
| Hot water temperature                                    | °C                | 12                                       |
| Recooled water temperature                               | °C                | 12                                       |
| Make-up water temperature                                | °C                | 2                                        |
| Purge water temperature                                  | °C                | 2                                        |
| Inlet water flow                                         | m <sup>3</sup> /s | 12 (see 5.4.2)                           |
| Make-up water flow                                       | m <sup>3</sup> /s | 2                                        |
| Purge water flow                                         | m <sup>3</sup> /s | 2                                        |
| Tower pumping head                                       | m                 | 2                                        |
| Fan power                                                | W                 | 1                                        |

**8.3.2** When the point of measurement for the recooled water temperature is taken at the discharge of the circulating water pump, determine the true recooled water temperature by subtracting the temperature rise of the water across the pump from the measured value.

#### 8.4 Computation of recooled water temperature with make-up and purge flows operating

Where make-up and purge flows exist up-stream of the point of temperature measurement, this point being taken before the circulating water pump, determine the true recooled water temperature readings by heat balance calculation as follows:

$$t_2 = \frac{Q_I t_E + Q_P t_P - Q_M t_M}{Q_I + Q_P - Q_M}$$

NOTE. This equation is based on the assumption that during the test there is no leakage and the make-up water only replaces the evaporation and purge loss (drift losses being neglected).

When the point of measurement for recooled water temperature is taken at the discharge of the circulating water pump, the value of  $t_E$  in the equation shall be reduced by the calculated temperature rise across the pump.

#### 8.5 Computation of tower pumping head

Compute the pumping head, which represents the total energy at the cooling tower inlet related to basin kerb level, as the sum of the measurements taken in accordance with 5.6(a) and (b) and add to this the velocity head, calculated on the basis of the measured water flow and the conduit cross section measured in accordance with 5.6(c).

#### 8.6 Computation of thermal lag

Calculate the thermal lag of the cooling tower as:

$$\frac{V_B}{Q_I + Q_P}$$

Where the thermal lag exceeds 15 min assume that the period of the recooled water temperature readings lags an equivalent time behind the period of the other readings.

#### 8.7 Computation of fan power

Compute the fan power from measurements of electrical power input to the motor, together with the efficiency quoted by the motor manufacturer.

### 9 Evaluation of thermal performance

The measure of the thermal performance of a cooling tower is its ability to fulfil guaranteed conditions in terms of fan power, water flow, range, approach and inlet air conditions.

This can be achieved by a direct comparison between the test results and the manufacturer's performance curves, or by reference of the test results to design conditions as described in appendix C.

The effect of measurement errors shall be taken into account when interpreting the results.

NOTE. The reproducibility of this evaluation is  $\pm 5\%$ . Therefore, the tower should be deemed acceptable if the evaluated result from the test equals or exceeds 95 % of the design capability.