ENGINEERING STANDARD

FOR

PROCESS DESIGN OF COOLING TOWERS

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0. INTRODUCTION

"Process Design of Non-Combustion Type Heat Exchanging Equipment", are broad and contain variable subjects of paramount importance. Therefore, a group of process engineering standard specifications are prepared to cover the subject.

This group includes the following standards:

STANDARD CODE	STANDARD TITLE
IPS-E-PR-771	"Process Requirements of Heat Exchanging Equipment"
IPS-E-PR-775	"Process Design of Double Pipe Heat Exchangers"
IPS-E-PR-785	"Process Design of Air Cooled Heat Exchangers (Air Coolers)"
IPS-E-PR-790	"Process Design of Cooling Towers"

This Standard Specification covers:

"PROCESS DESIGN OF COOLING TOWERS"

Non-combustion type heat exchanging equipment are contained from various types from which the above mentioned have the most application in Oil, Gas, and Petrochemical (OGP) industries and each item will be discussed separately.

1. SCOPE

This Standard Specification covers the minimum process design requirements, field of application, selection of types, design consideration and thermal process design for cooling towers.

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor/Consultant:

IPS **(IRANIAN PETROLEUM STANDARDS)**

E-PR-190 "Layout and Spacing"
E-PR-771 "Process Requirements of the Heat Exchanging Equipment"
G-SF-880 "Water Pollution Control"

BSI **(BRITISH STANDARDS INSTITUTION)**

BS 4485 "British Standard Specification for Water Cooling Towers"
- Part 1: 1969, "Glossary of Terms"
- Part 2: 1988, "Methods for Performance Testing"
- Part 3: 1988, "Thermal Design Principles"
- Part 4: 1975, "Structural Design of Cooling Towers"

CTI **(COOLING TOWER INSTITUTE, USA)**

CTI Bulletin NCL-109 "Nomenclature for Industrial Water Cooling Tower"
- "Acceptance Test Code"

ASME **(AMERICAN SOCIETY OF MECHANICAL ENGINEERS)**

- "ASME Test Code"

3. DEFINITIONS AND TERMINOLOGY

In the preparation of this glossary care has been taken to standardize only suitable terms and definitions, dealing with the thermal design as mentioned by the British Standard Glossary and CTI of USA.

3.1 Air Flow

Air flow is total quantity of air including associated water vapor flowing through the tower.

3.2 Ambient Wet Bulb Temperature

Ambient wet bulb temperature is wet bulb temperature of air measured windward of the tower and free from the influence of the tower.

3.3 Approach

Approach is difference between recooled water temperature and nominal inlet air wet bulb temperature.

3.4 Basin Kerb

Basin kerb is top level of the retaining wall of the cold water basin; usually the datum point from which tower elevation points are measured.

3.5 Cell

Cell is the smallest subdivision of a cooling tower bounded by exterior walls and partition walls which can function as an independent unit as regards air and water flow.

3.6 Cell Height

Cell height is the distance from basin kerb to top of fan deck but not including fan stack.

3.7 Cell Length

Cell length is the dimension parallel to longitudinal axis and the plane where louvres are usually placed.

3.8 Cell Width

Cell width is the dimension perpendicular to tower longitudinal axis and usually at right angles to the louvre area.

3.9 Circulating Water Flow

Circulating water flow is the quantity of hot water flowing into the tower.

3.10 Cold Water Basin (Basin Pond)

Cold water basin is a device underlying the tower to receive the cold water from the tower, and direct its flow to the suction line or sump.

3.11 Column Anchor

Column anchor is a device for attaching the tower structure to the foundation; it does not include the foundation bolt.

3.12 Concentration

Concentration is the increase of impurities in the cooling water due to the evaporative process.

3.13 Concentration Ratio

Concentration ratio is ratio of the impurities in the circulating water and the impurities in the make-up water.

3.14 Cooling Range (Range)

Cooling range is the difference between the hot water temperature and the recooled water temperature.

3.15 Discharge Stack

Discharge stack is that part of the shell or casing of a forced draught tower, through which the outlet air is finally discharged. (See "fan stack" for induced draught towers and "shell" for natural draught towers.)

3.16 Distribution Basin

Distribution basin is the elevated basin used to distribute hot water over the tower packing.

3.17 Distribution Header

Distribution header is pipe or flume delivering water from inlet connection to lateral headers, troughs, flumes or distribution basins.

3.18 Distribution System

Distribution system is those parts of a tower beginning with the inlet connection which distribute the hot circulating water within the tower to the point where it contacts the air.

3.19 Down Spout

Down spout is a short vertical pipe or nozzle used in an open distribution system to discharge water from a flume or lateral on to a splash plate.

3.20 Drift Eliminator

Drift eliminator is a system of baffles located in the tower designed to reduce the quantity of entrained water in the outlet air.

3.21 Drift Loss

Drift loss is water lost from the tower as liquid droplets entrained in the outlet air.

3.22 Effective Volume

Effective volume is the volume within which space the circulating water is in intimate contact with the air flowing through the tower.

3.23 Fan

Fan is a rotary machine which propels air continuously. This is used for moving air in a mechanical draught tower and is usually of the axial-flow propeller type. The fan may be of induced draught or forced draught application.

3.24 Fan Casing

Fan casing is those stationary parts of the fan which guide air to and from the impeller. In the case of an induced draught fan, the casing may form the whole or part of the fan stack.

3.25 Fan Deck

Fan deck is surface enclosing the top of an induced draught tower, exclusive of any distribution system which may also form a part of the enclosure.

3.26 Fan Drive Assembly

Fan drive assembly is components for providing power to the fan, normally comprising driver, drive shaft and transmission unit, and primary supporting members.

3.27 Fan Duty (Static)

Fan duty (Static) is the inlet volume dealt with by a fan at a stated fan static pressure.

3.28 Fan Duty (Total)

Fan duty (total) is the inlet volume dealt with by a fan at a stated fan total pressure.

3.29 Fan Power

Fan power is the power input to the fan assembly, excluding power losses in the driver.

3.30 Fan Stack

Fan stack is cylindrical or modified cylindrical structure enclosing the fan in induced draught towers.

3.31 Fan-Stack Height

Fan-stack height is the distance from the top of the fan deck to top of fan stack.

3.32 Fan Static Pressure

Fan static pressure is the difference between the fan total pressure and the fan velocity pressure.

3.33 Fan Total Pressure

Fan total pressure is the algebraic difference between the mean total pressure at the fan outlet and the mean total pressure at the fan inlet.

3.34 Fan Velocity Pressure

Fan velocity pressure is the velocity pressure corresponding to the average velocity at the fan outlet, based on the total outlet area without any deductions for motors, fairings, or other bodies.

3.35 Film Packing

Film packing is an arrangement of surfaces over which the water flows in a continuous film throughout the depth of the packing.

3.36 Heat Load

Heat load is rate of heat removal from the circulating water within the tower.

3.37 Hot Water Temperature

Hot water temperature is temperature of circulating water entering the distribution system.

3.38 Inlet Air

Inlet air is air flowing into the tower; it may be a mixture of ambient air and outlet air.

3.39 Inlet Air Wet Bulb Temperature

Inlet air wet bulb temperature is average wet bulb temperature of the inlet air; including any recirculation effect. This is an essential concept for purposes of design, but is difficult to measure.

3.40 Louvres

Louvres is members installed in a tower wall, to provide openings through which air enters the tower; usually installed at an angle to the direction of air flow to the tower.

3.41 Make-Up

Make-up is water added to the circulating water system to replace water loss from the system by evaporation, drift, purge and leakage.

3.42 Motor Rated Power

Motor rated power is nameplate power rating of the motor driving the fan.

3.43 Nominal Inlet Air Wet Bulb Temperature

Nominal inlet air wet bulb temperature is 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.

3.44 Nominal Tower Dimensions

Nominal tower dimensions is dimensions used to indicate the effective size of cells, or cooling tower. In the horizontal plane, they refer to the approximate width and length of packed areas, and in the vertical plane to the height above basin kerb level.

3.45 Outlet Air

Outlet air is the mixture of air and its associated water vapor leaving the tower. (See Air flow.)

3.46 Outlet Air Wet Bulb Temperature

Outlet air wet bulb temperature is average wet bulb temperature of the air discharged from the tower.

3.47 Packing (Filling)

Packing is material placed within the tower to increase heat and mass transfer between the circulating water and the air flowing through the tower.

3.48 Plenum

Plenum is the enclosed space between the eliminator and the fan stack in induced draught towers, or the enclosed space between the fan and the packing in forced draught towers.

3.49 Purge (Blow Down)

Purge is water discharged from the system to control concentration of salts or other impurities in the circulating water.

3.50 Recooled Water Temperature

Recooled water temperature is average temperature of the circulating water entering the basin.

3.51 Recirculation (Recycle)

Recirculation is that portion of the outlet air which re-enters the tower.

3.52 Shell

Shell is that part of a natural draught tower which induces air flow.

3.53 Splash Packing

Splash packing is an arrangement of horizontal laths or splash bars which promotes droplet formation in water falling through the packing.

3.54 Splash Plate

Splash plate is used in an open distribution system to receive water from a down spout and to spread water over the wetted area of the tower.

3.55 Spray Nozzle

Spray nozzle is used in a pressure distribution system to break up the flow of the circulating water into droplets, and effect uniform spreading of the water over the wetted area of the tower.

3.56 Sump (Basin Sump or Pond Sump)

Sump is a lowered portion of the cold water basin floor for draining down purposes.

3.57 Standard Air

Dry air having density of 0.0011 kg/L, at 21°C and 0.7 atm (531 mm Hg).

3.58 Tower Pumping Head

Tower pumping head is the head of water required at the inlet to the tower, measured above the basin kerb to deliver the circulating water through the distribution system.

3.59 Water Loading

Water loading is circulating water flow expressed in quantity per unit of packed plan area of the tower.

3.60 Wet Bulb Temperature

Wet bulb temperature is the temperature indicated by an adequately and wetted thermometer in the shade and where applicable protected from strong ground radiation.

4. SYMBOLS AND ABBREVIATIONS

For the purposes of this Part, the symbols and units given in Table 1 shall apply (See BS 4485: Part 3: 1988, "Termal Design Principles").

TABLE 1 - SYMBOLS AND UNITS

SYMBOL	QUANTITY	UNIT
a	Area of effective transfer surface per unit of tower packing volume	m^2/m^3
A_s	Area of sound propagation	m^2
A_p	Total packing area normal to air flow	m^2
B	Width or length dimensions per-pendicular to tower axis	m
c	Specific heat capacity of water	kJ/(kg.K)
C	Concentration factor at equilibrium	
C_T	Concentration factor at time T	
C_1	Original make-up concentration of impurities	%
C_2	Stable state concentration of impurities in circulating system under continuous purge	%
D	Diameter	m
g	Acceleration due to gravity	
G	Mass flow of dry air per unit plan area of packing	$kg/(m^2.s)$
h	Enthalpy* of air-water vapor mixture	kJ/kg
h_m	Mean driving force	kJ/kg
h_G	Enthalpy* of air-water vapor mixture passing through the packing	kJ/kg
h_L	Enthalpy* of saturated air film in contact with and at the temperature of the water passing through the packing	kJ/kg
H	Height (vertical distance above or below basin kerb level)	m
H_e	Effective height of shell, normally taken as height from middle of packing to top of shell	m
K	Coefficient of mass transfer defined in terms of difference in absolute humidity	kg/[m.s.(kg/kg)]
L	Mass water flow per unit plan area of packing	$kg/(m^2.s)$
m_1	Mass of solute	kg
m_2	Mass of solvent	kg
M_1	Relative molecular mass of solute	
M_2	Relative molecular mass of solvent	
n	Mole fraction of solvent	
N	Number of velocity heads representing the system resistance	
P	Total pressure	Pa
P_2	Vapor pressure of pure solvent	Pa
P_3	Vapor pressure of solution	Pa
P_5	Sound pressure	N/m^2
P_0	Sound pressure reference datum	N/m^2
Q_1	Circulating water flow	m^3/s
R	Surface radius from sound source	m
S_w	Sound power level reading at a point source	dB
S_p	Sound pressure level reading some specified distance away from the source	dB
T	Time	h
t_b	Temperature of water with which boundary vapor is associated	°C
t_m	Mean water temperature	°C
t_{DB}	Dry Bulb temperature	°C

*** All enthalpies relate to 1 kg dry air and associated water vapor.**

(to be continued)

TABLE 1 - (continued)

SYMBOL	QUANTITY	UNIT
t_E	Temperature of mixture of recooled water and make-up leaving cold water basin	°C
t_{WB}	Wet bulb temperature	°C
t_1	Hot water temperature at inlet	°C
t_2	Recooled water temperature	°C
V	Effective packing volume per unit area of packing	m^3/m^2
V_b	Volume in cold water basin	m^3
v_e	Evaporation rate	m^3/h
v_P	Purge rate	m^3/h
V_s	Volume in system excluding pond	m^3
W_1	Atmospheric moisture content of ambient air condition	kg/kg
W_2	Atmospheric moisture content at mean water temperature saturated conditions	kg/kg
W_d	Fan driver power	kW
W_o	Sound power threshold	W
W_s	Sound power	W
x	Pond surface area	m^2
X	Spacing	m
ρ (rho)	Density of air	kg/m^3
Δh	Change in air enthalpy	kJ/kg
Δt	Cooling range	K
Δρ	Change in air density	kg/m^3
	Approach	K
	Power	W
K.a. V/L	Tower characteristic	
L/G	Water /air ratio	

5. UNITS

This Standard is based on International System of Units (SI) , except where otherwise is specified.

6. GENERAL

6.1 A water cooling tower is a heat exchanger in which warm water falls gravitationally through a cooler current of air. Heat is transferred from the water to the air in two ways:

a) by evaporation as latent heat of water vapor;
b) by sensible heat in warming the air current in its passage through the tower.

As a general measure, about 80% of the cooling occurs by evaporation and about 20% by sensible heat transfer. The transfer of heat is effected from the water through the boundary film of saturated air in contact with the water surface. This air is saturated at the water temperature. From this saturated air film, heat transfer occurs to the general mass of air flowing through the tower.

6.2 In the interests of efficiency, it is essential that both the area of water surface in contact with the air and the time of contact be as great as possible. This may be achieved either by forming a large number of water droplets as repetitive splash effects in one basic kind of tower packing, or by leading the water in a thin film over lengthy surfaces.

6.3 Air flow is achieved either by reliance on wind effects, by thermal draught or by mechanical means. The direction of air travel may be opposed to the direction of water flow giving counterflow conditions, or may be at right angles to the flow of water giving crossflow conditions. Although the methods of analysis may be different for counterflow and crossflow conditions, the fundamental heat transfer process is the same in both cases. In some designs mixed flow conditions exist.

6.4 The cooling range of the tower corresponds to the difference in temperature of the air-water film between entry to and exit from the tower. Air enters the tower having wet and dry bulb characteristics dependent on the ambient conditions. It is generally in an unsaturated state and achieves near-saturation in passing through the tower. It may be considered saturated at exit in all but very dry climates.

6.5 Performance Characteristics

6.5.1 The performance characteristics of various types of towers will vary with height, fill configuration and flow arrangement crossflow or counterflow. When accurate characteristics of a specific tower are required the cooling tower manufacturer should be consulted.

6.5.2 Performance tests on a cooling tower should be done in accordance with the Cooling Tower Institute (CTI) Acceptance Test Code and the American Society of Mechanical Engineers (ASME) test code.

7. TYPES OF COOLING TOWERS

There are many types of tower used in evaporating cooling, generally they tend to be divided into two groups depending upon the method used for moving air through the tower:

a) natural draught;
b) mechanical draught.

7.1 Natural Draught Towers

7.1.1 Atmospheric tower

7.1.1.1 General

Air movement through the tower is almost entirely dependent upon natural wind forces. Water falls in a vertical path through a packing while the air moves in a horizontal path, resulting in a crossflow arrangement to achieve a cooling effect. Wind speed is a critical factor in the thermal design and should always be specified. This type of tower is infrequently used in practice.

7.1.1.2 Advantage

The advantage is that there is no mechanical or electrical maintenance.

7.1.1.3 Disadvantages

The disadvantages are as follows:

a) Narrow construction results in considerable length of tower.
b) There is high capital cost due to low thermal capacity.
c) Unobstructed location broadside on to prevailing wind is required.
d) The recooled water temperature varies widely with changes in the wind speed and direction.
e) The drift loss may be substantial under high wind conditions.

7.1.2 Hyperboloidal tower * ♣ (see Fig. 1a)

7.1.2.1 General

Air flow is affected by the reduction in density of the column of warm saturated air within the tower shell. Secondary effects of wind velocity may influence air flow but are not normally taken into consideration in tower design.

Notes:

*** See BS 4485: Part 4 for shell geometry.**
♣ Commonly known as hyperbolic tower.

The choice of counterflow, mixed flow or crossflow arrangements is dictated primarily by site and economic considerations.

7.1.2.2 Advantages

The advantages are as follows:

a) It is suited to large water flow rates.
b) High-level emission of plume virtually eliminates fogging at ground level and recirculation.
c) It occupies less ground space than multiple mechanical draught towers for large thermal duty.
d) It is independent of wind speed and direction when compared with atmospheric towers.
e) There is no fan noise.
f) There is no mechanical or electrical maintenance.

7.1.2.3 Disadvantages

The disadvantages are as follows:

a) The chimney effect of the shell diminishes as the humidity decreases and this may be a disadvantage in hot dry climates.

b) Close approach is not economical.

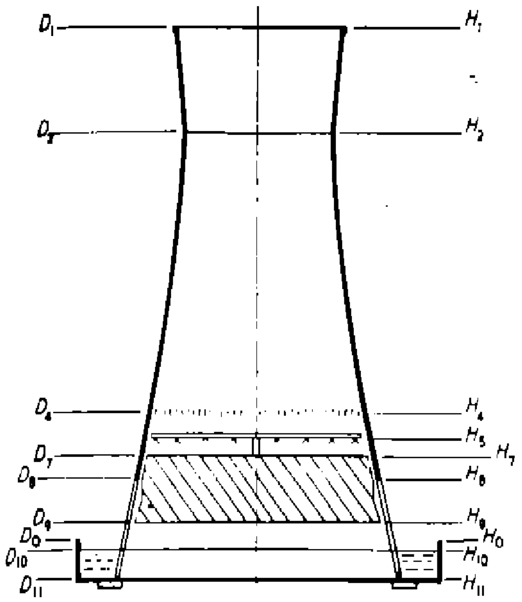
c) The considerable height of shell frequently arranged in multiple installations presents an amenity disadvantage.

7.2 Mechanical Draught Towers (see Figs. 1b, c and d)

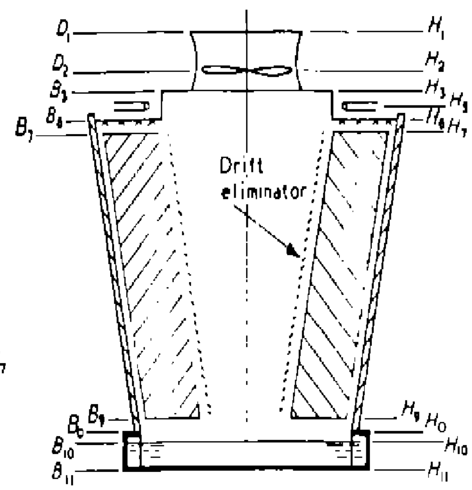
7.2.1 General

Fans are used to produce air movement through the tower. This enables the air flow to be determined independently of other process conditions. Correct quantities and velocities of air may be selected to satisfy various design demands.

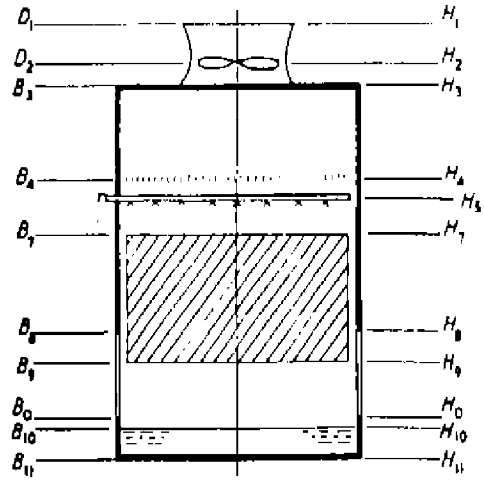
Several alternative ways of locating the fans in relation to tower structure are used to obtain specific advantages; also there are two basic flow arrangements for air-water flow, the counterflow and the crossflow.



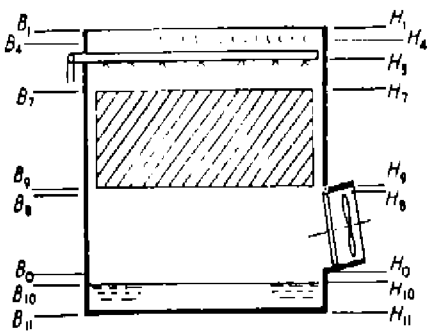
a) Natural draught, mixed or counterflow cooling tower



b) Induced draught crossflow cooling tower



c) Induced draught or counterflow cooling tower



d) Forced draught mixed or counterflow cooling tower

ILLUSTRATIONS OF BASIC TYPES OF COOLING TOWER
Fig. 1

Note:

A standard reference sheet for physical dimensions is given in Table 2.

TABLE 2 - STANDARD REFERENCE SHEET FOR PHYSICAL DIMENSIONS (see Fig. 1)

ITEM	NATURAL DRAUGHT (Fig. 1a)		CROSS-FLOW (Fig. 1b)		INDUCED DRAUGHT (Fig. 1c)		FORCED DRAUGHT (Fig. 1d)	
Top of air outlet	D_1	H_1	D_1	H_1	D_1	H_1	B_1	H_1
Throat	D_2	H_2	D_2	H_2	D_2	H_2	—	—
Fan deck	—	—	B_3	H_3	B_3	H_3	—	—
Eliminator screen	D_4	H_4	—	—	B_4	H_4	B_4	H_4
Distribution pipes	—	H_5	—	H_5	—	H_5	—	H_5
Distribution basins	—	—	B_6	H_6	—	—	—	—
Top of packing	D_7	H_7	B_7	H_7	B_7	H_7	B_7	H_7
Top of air inlet	D_8	H_8	B_8	H_8	B_8	H_8	B_8	H_8
Bottom of packing	D_9	H_9	B_9	H_9	B_9	H_9	B_9	H_9
Cold water basin	D_0	H_0	B_0	H_0	B_0	H_0	B_0	H_0
Water level	D_{10}	H_{10}	B_{10}	H_{10}	B_{10}	H_{10}	B_{10}	H_{10}
Bottom of cold water basin	D_{11}	H_{11}	B_{11}	H_{11}	B_{11}	H_{11}	B_{11}	H_{11}

7.2.1.1 Advantages

The advantages are as follows:

a) There is positive control of the air supply.

b) Minimum capital costs makes it appropriate for low load factor applications.

c) High water loadings can be maintained regardless of the size of tower.

d) Difficult duties (long range combined with close approach) are more easily attainable than in natural draught.

e) It has a low height structure.

7.2.1.2 Disadvantages

The disadvantages are as follows:

a) Power is required to operate the fans.

b) It requires mechanical and electrical maintenance.

c) Warm, moist discharge air may recirculate into the air intakes.

d) For large multi-tower installations, the total ground area required is greater than for natural draught hyperboloidal towers for equivalent duty. This is due to the spacing of towers to minimize recirculation.

e) Fogging and drift may create problems at low levels.

f) Fan noise may be a nuisance.

7.2.2 Forced draught tower (see Fig. 1d)

7.2.2.1 General

A forced draught tower is a mechanical draught tower having one or more fans located in the air intake, normally limited to capacities of up to 9.3 m^3/s.

7.2.2.2 Advantages

The advantages are as follows:

a) There is low vibration due to rotating components being located near the base of the tower.

b) Fan units are placed in a comparatively dry air stream; this reduces the problem of moisture condensing in the motor or gearbox.

c) Fan units located at the base of the tower facilitate inspection and maintenance.

d) Fans moving ambient air will absorb less power than in induced draught towers (but see 7.2.3.2b).

e) See also 7.2.1.1.

7.2.2.3 Disadvantages

The disadvantages are as follows:

a) It may be more subject to recirculation than induced draught towers for equivalent duties.

b) Ice may form on fan inlets during operation in winter. This can be minimized by arranging the fan ducts at a slight angle for draining any water back into the storage basin.

c) See also 7.2.1.2.

7.2.3 Induced draught tower (see Figs. 1b and c)

7.2.3.1 General

An induced draught tower is a mechanical draught tower having one or more fans at the air discharge.

7.2.3.2 Advantages

The advantages are as follows:

a) It has the ability to handle large water flow rates (but see 7.1.2).

b) It is suitable for larger cell sizes and fan sizes as compared with forced draught. Larger fan sizes may result in greater efficiency and consequently lower power and sound levels.

c) It uses a more compact ground area than a forced draught tower of equivalent capacity due to the absence of fans on one side.

d) Fan equipment in warm exhaust air is less liable to icing up in winter operation.

e) See also 7.2.1.1.

7.2.3.3 Disadvantages

The disadvantages are as follows:

a) Protection is required for mechanical equipment against corrosion and internal condensation.

b) Inspection and maintenance of mechanical equipment is relatively difficult due to fans being located 5 m to 20 m above the base.

c) See also 7.2.1.2.

7.2.4 Counterflow tower (see Figs. 1c and d)

7.2.4.1 General

A counterflow tower is a mechanical draught tower in which air and water flow in opposite, mainly vertical directions.

7.2.4.2 Advantages

The advantages are as follows:

a) Normally it is an economical choice for difficult duties (long range combined with close approach).
b) It is less prone to icing than crossflow towers (see 10.1).
c) See also 7.2.1.1.

7.2.4.3 Disadvantages

The disadvantages are as follows:

a) With induced draught arrangement the water distribution system (generally piping or troughs with spray nozzles) cannot be easily inspected and cleaned unless the tower is shut down.

b) See also 7.2.1.2.

7.2.5 Crossflow tower (see Fig. 1b)

7.2.5.1 General

A crossflow tower is a mechanical draught tower in which air flow is normally horizontal, in contact with falling water drops. It is normally associated with an induced draught arrangement.

7.2.5.2 Advantages

The advantages are as follows:

a) It may be an economical choice for large water flows.

b) The plan area at basin level and the total power for fans and pumps can be less than for other mechanical draught towers.

c) The water distribution system of the open pan type is easy to clean without shut-down.

d) It may be designed to suit low-silhouette applications for small duties.

e) See also 7.2.1.1.

7.2.5.3 Disadvantages

The disadvantages are as follows:

a) Prevention of icing during extreme weather conditions generally demands more care from the operator.
b) The exposure of water distribution basins to sunlight promotes growth of algae.
c) See also 7.2.1.2.

8. DESIGN CONSIDERATIONS

A typical inquiry and suggested tender information for cooling towers is given in Appendix A herein.

8.1 Design Parameters

The parameters involved in the design of a cooling tower are:

a) ambient wet bulb temperature;
b) approach;
c) cooling range;
d) circulating water flow;
e) altitude (considered if more than 300 m above sea level).

An additional parameter in the case of natural draught towers is ambient dry bulb temperature or, alternatively, ambient relative humidity.

8.2 Ambient Air Temperatures

It is important that the correct design ambient conditions are chosen with care. Generally the hottest period of the year is selected as the critical area to be studied. For climatic conditions the atmospheric information covering the average five hot months period Ordibehesht to Shahrivar inclusive, i.e., two last months of spring and summer months (May to September inclusive) are analysed and presented in the form of wet and dry bulb temperature isotherm maps for the different localities.

In general the tower shall be designed for a wet-bulb temperature that will not be exceeded more than 2.5% of the time in five hot spring and summer months.

8.3 Approach

Approach is a very sensitive design parameter. Closer approaches are limited by practical difficulties such as minimum water loading on the packing.

The cooling tower supplier should be consulted before consideration is given to approaches closer than 3 K for mechanical draught towers or 7 K for natural towers.

At these levels an increase of 1 K in approach may result in a reduction of 20% in tower size and is therefore of considerable economic significance.

A 5.5°C approach between cold water temperature and wet bulb temperature shall be used unless otherwise specified.

8.4 Cooling Range and Water Quantity

Cooling range and water quantity variations are usually considered in relation to a fixed heat load and are selected in conjunction with other plant conditions.

8.5 Effect of Altitude

Cooling tower calculations involve the use of published tables of psychrometric data that are generally based on a barometric pressure of 1000 mbar*. Barometric pressure falls at a rate of approximately 1 mbar for each 10 m increase in altitude and, although this may be ignored for locations up to 300 m above sea level, appropriate corrections should be applied when designing for sites at higher altitudes.

8.6 Packings

The function of a packing in a cooling tower is:

a) to increase the duration of contact between the air and the water;
b) to cause fresh surfaces of water to be formed, thus increasing the rate of heat transfer per unit volume.

8.6.1 Types and selection

Packing may be of the two types namely splash packings and film packings. The intended situation of a tower should be considered in deciding on a particular type of packing. In general, the film packings will be more susceptible to fouling by suspended solids, fats and oils, biological growth or other process contamination. Where fouling may become a problem, the spacing and configuration of the packing elements should be considered regarding the potential for cleaning.

8.6.2 Height of packing

The height of cooling tower packing will vary considerably even within the various types of packing according to the design economics relating to any specified requirements. In general, however, it can be stated that for equivalent duties and fan power requirements the film or extended surface packings will be of lower height than the splash bar type of packing.

8.7 Water Loadings

The maximum water loading on a packing is determined largely by the increase in resistance to air flow and by the risk of excessive drift.

Somewhat higher water loadings can in general be used in a crossflow cooling tower irrespective of the type of packing.

Cooling tower water loadings do not approach the level at which flooding takes place. The only problem with high water loadings is in obtaining adequate air flow and crossflow towers will often therefore be found advantageous.

Water loading shall not exceed 407 L/m^2 per minute (10 gpm/ft^2) of tower cross section area in the horizontal plane.

*** 1 mbar = 100 N/m^2 = 100 Pa.**

8.8 Drift Losses

Drift losses shall not exceed 0.01 percent of design flow rate. (For further information reference is made to BS 4485: Part 3: 1988, Clause 7.2.)

8.9 Windage Losses

Typical windage losses, expressed as percentages of the total system water circulation rate, for different evaporative equipment are as follows:

Spray ponds	1.0 to 5.0%
Atmospheric draft towers	0.3 to 1.0%
Mechanical-draft towers	0.1 to 0.3%

8.10 Recirculation

The percentage of air recirculating on the leeward side of the cooling tower can vary between 3% and 20%. However, the higher figure is normally associated with installations of one or more large multi-cell mechanical draught cooling towers.

In general, therefore, recirculation of the warmed air discharged from the cooling towers is relatively insignificant in mechanical draught cooling towers under 0.5 m^3/s capacity. For other cases allowance should be made for the maximum anticipated recirculation.

8.11 Hydrocarbon Detection System

Hydrocarbon detection facilities to be located in cooling tower basins, should be provided to account for probable hydrocarbon leakage.

9. WATER QUALITY

For the proper use of water resources, the consumption of high quality fresh water in an industrial cooling context should be discouraged, particularly if the quantities concerned are large as is usually the case in OGP industries. Any installation should use the lowest quality water suitable for the process concerned.

9.1 Make-Up Water

A full mineral and biological examination of the make-up supply is essential. A typical analysis data sheets provided by the Company is shown in Table 3.

Pre-treatment for larger systems is usually limited to suspended solids removal by sedimentation and possibly flocculation. In the case of smaller systems, however, instances arise where base exchange softening of the make-up is economically favourable by virtue of enabling operation at a higher concentration factor with consequent savings in water charges and chemical treatment costs.

TABLE 3 - TYPICAL MAKE-UP WATER CHARACTERISTICS

SOURCE	
- Availability over use (dm^3/s) - Value (cent/1,000 dm^3) - pH - Total hardness as $CaCO_3$ (mg/kg) - CALCIUM as $CaCO_3$ (mg/kg) - MAGNESIUM as $CaCO_3$ (mg/kg) - Total ALKALINITY as $CaCO_3$ (mg/kg) - SODIUM as $CaCO_3$ (mg/kg) - POTASSIUM as $CaCO_3$ (mg/kg) - SULFATE as $CaCO_3$ (mg/kg) - CHLORIDE as $CaCO_3$ (mg/kg) - NITRATE as $CaCO_3$ (mg/kg) - SILICA as SiO_2 (mg/kg) - Total IRON (mg/kg) - Suspended SOLIDS (mg/kg) - Dissolved SOLIDS (mg/kg) - COD (as MANGANESES) (mg/kg) - Others	

9.2 Circulating Water

An economical cycle of concentration, (with the concent of the Company) shall be selected and quality of circulating water should be maintained by making provisions for control of pH, hardness, biological growth, corrosion, etc.

10. COLD CLIMATE DESIGN CONSIDERATIONS

10.1 General

The necessity for anti-icing devices to be incorporated in the tower design should be considered at the pre-tender stage, and the means to be employed preferably discussed between the Company and the prospective suppliers.

The methods available for providing anti-icing facilities, and the need for such facilities, depend largely on the following factors:

a) The severity of weather conditions at the cooling tower site.

b) The thermal design conditions. For example, a close approach tower will mean a relatively higher air flow and a greater tendency to icing conditions in the air inlet.

c) The type of cooling tower used. A counterflow tower will normally have the packing protected by the tower shell, with a lesser tendency to icing on the packing than a mixed flow tower when part of the packing may be exposed.

When the tower is designed to be drained down in winter the system and tower should be designed so that no water pockets remain. In these circumstances anti-icing devices are unnecessary.

10.2 Avoidance of Icing by Air Control

As the air temperature drops, so does the recooled water temperature. It is often the case that below a certain temperature no further economic benefit occurs.

In such circumstances, in a mechanical draught tower, some fans may be stopped allowing the water temperature to rise sufficiently to keep the tower free of ice. A further refinement would be reducing fan speed in suitable circumstances, particularly where the saving in power has significant economic effect.

In extreme conditions (about-20°C) it may be desirable to provide for reversed air flow as an effective means of clearing air inlets partially blocked by ice. In crossflow towers, anti-icing may be brought about by reducing the fan speed so that a curtain of warm water is formed in front of the packing, falling from louvre to louvre down the face of the tower.

10.3 Avoidance of Icing by Control of Water Load

The most commonly used device is a bypass of the tower producing a warm water curtain outside the exposed packing face. For efficient operation it is important that such a curtain should consist of jets of water rather than small particles which might themselves become frozen.

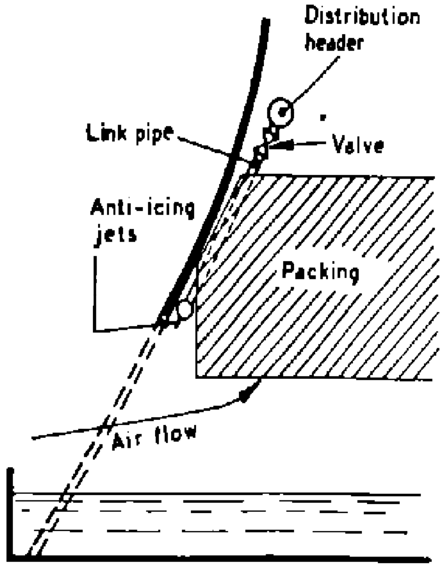
Generally the bypass should operate under a pressure head of not less than 2.0 m (having allowed for friction losses), the nozzles should be of a diameter not less than 12 mm, and the total bypass flow should be about 25% of the circulating water flow. Fig. 2 shows typical bypass pipe locations.

It is helpful, when combating a tendency to form ice, to reduce the number of cells working, which will increase the water loading and the temperatures of the water on the remaining cells.

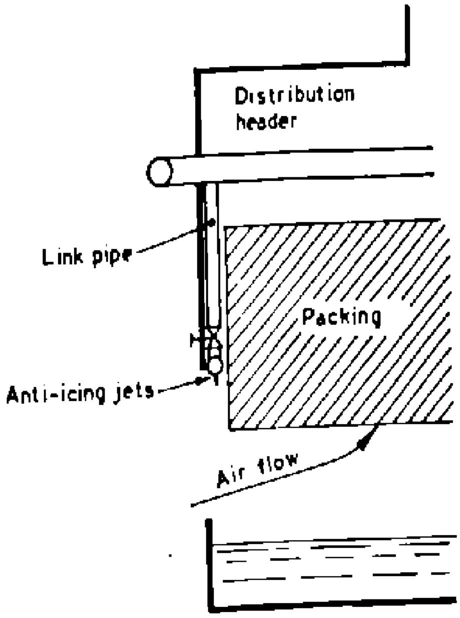
It should be noted that complete isolation has to be attained as the persistence of minor water leaks on to the packing can lead to a major ice build-up. Precautions should also be taken to avoid any static water in sections of pipework.

10.4 Effects of Anti-Icing Flow on Tower Capacity

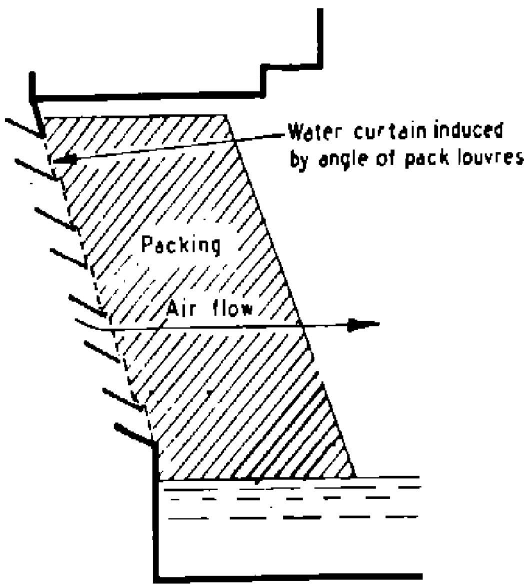
When the anti-icing pipe is in use, the effect on tower capacity is the equivalent of a bypass equal to the anti-icing flow as the cooling effect on the bypass flow will not be substantial. At the time of the year when such a system is in use, unless the towers serve generating plant, the maximum capacity of the tower is not usually required and no disadvantage is to be expected from the use of an anti-icing facility.



a) Natural draught mixed flow



b) Mechanical draught mixed flow



c) Mechanical draught crossflow showing induced water curtain

ANTI-ICING ARRANGEMENTS
Fig. 2

11. SITING, SPACING AND ENVIRONMENTAL CONSIDERATIONS

11.1 General

The siting and spacing of a cooling tower installation should be considered from economic, thermal and environmental aspects.

11.2 Siting

11.2.1 Tower levels

The cooling tower should be located at a suitable site and due consideration should be given to the question of drainback from the system resulting in loss of water and flooding.

11.2.2 Air restrictions

On small industrial tower installations, due to aesthetic reasons or sound attenuation requirements, enclosures or barriers are sometimes built to shield the towers. These barriers or enclosures should be spaced and designed to achieve the minimum of air restriction with the maximum maintenance working area.

The exclusion of birds and bird droppings may also necessitate the provision of barriers which should be subject to the same considerations. The total flow area in the barrier or enclosure should be a minimum of twice the area of the tower inlet openings on that side.

11.2.3 Recirculation

The extent of recirculation depends mainly upon wind direction and its velocity, tower length and atmospheric conditions. Further factors that may exert some influence are spacing, topography or geographical situations with respect to downdraught, exit air speed, tower height and the density difference between exit air and ambient temperatures.

11.2.4 Orientation of cooling towers

The orientation of cooling towers should be as follows:

a) Towers with air inlets on one side should be oriented so that the air inlets face the prevailing wind.

b) Towers with air inlets on opposite faces of the cooling tower should be oriented so that the air inlets face at 90° to the prevailing wind.

c) Large mechanical draught towers should preferably be divided into banks, each of which should have a length-to-width ratio of about 5 to 1.

d) The wind loading on any tower within a group will be affected by the grouping and spacing and should be considered in their structural design (see BS 4485: Part 4).

Note:

The prevailing wind direction, determined by the local topography, should be taken as that obtained during periods of maximum duty.

11.3 Spacing

11.3.1 The spacing of cooling tower banks should be based upon the recommendations in 11.3.2 to 11.3.5.

11.3.2 When the long axis of one bank is perpendicular to the prevailing wind direction (see Fig. 3a), the influence on another bank will be minimized when the distance, X, between the banks is greater than their average length. The long axes of the tower banks should be in line.

11.3.3 When the long axis of the existing tower is parallel to the wind direction (see Fig. 3b), the influence of the existing tower on the new will be minimized if the distance, X, is greater than their average length.

11.3.4 When the long axis of the existing tower is at 45° to the wind direction (see Fig. 3c), the influence of the existing tower on the new will be minimized if the distance, X, between the towers measured normal to the wind direction is greater than their average length.

11.3.5 Spacing of large natural draught cooling towers is considered to be adequate if adjacent cooling towers are spaced so that the distance between the towers is equal to or greater than half the base diameter of the large tower (see Fig. 3d). Should a tower be sited in close proximity to large buildings such as the turbine and boiler houses, the nearest point of the tower relative to the buildings should be at least one tower diameter away (see Fig. 3d).

11.3.6 Further consideration should be given to spacing and layout by making reference to IPS-E-PR-190.

11.4 Environmental Considerations

11.4.1 General

The effects of drift, blow-out, fogging and noise are further contributing factors that may need consideration when siting a tower installation.

11.4.2 Drift

When towers are sited adjacent to high-voltage electrical equipment, drift may cause flashover and icing problems. Drift can also constitute a hazard, particularly under icing conditions, on public footpaths and roadways and may also create a nuisance in adjacent residential areas.

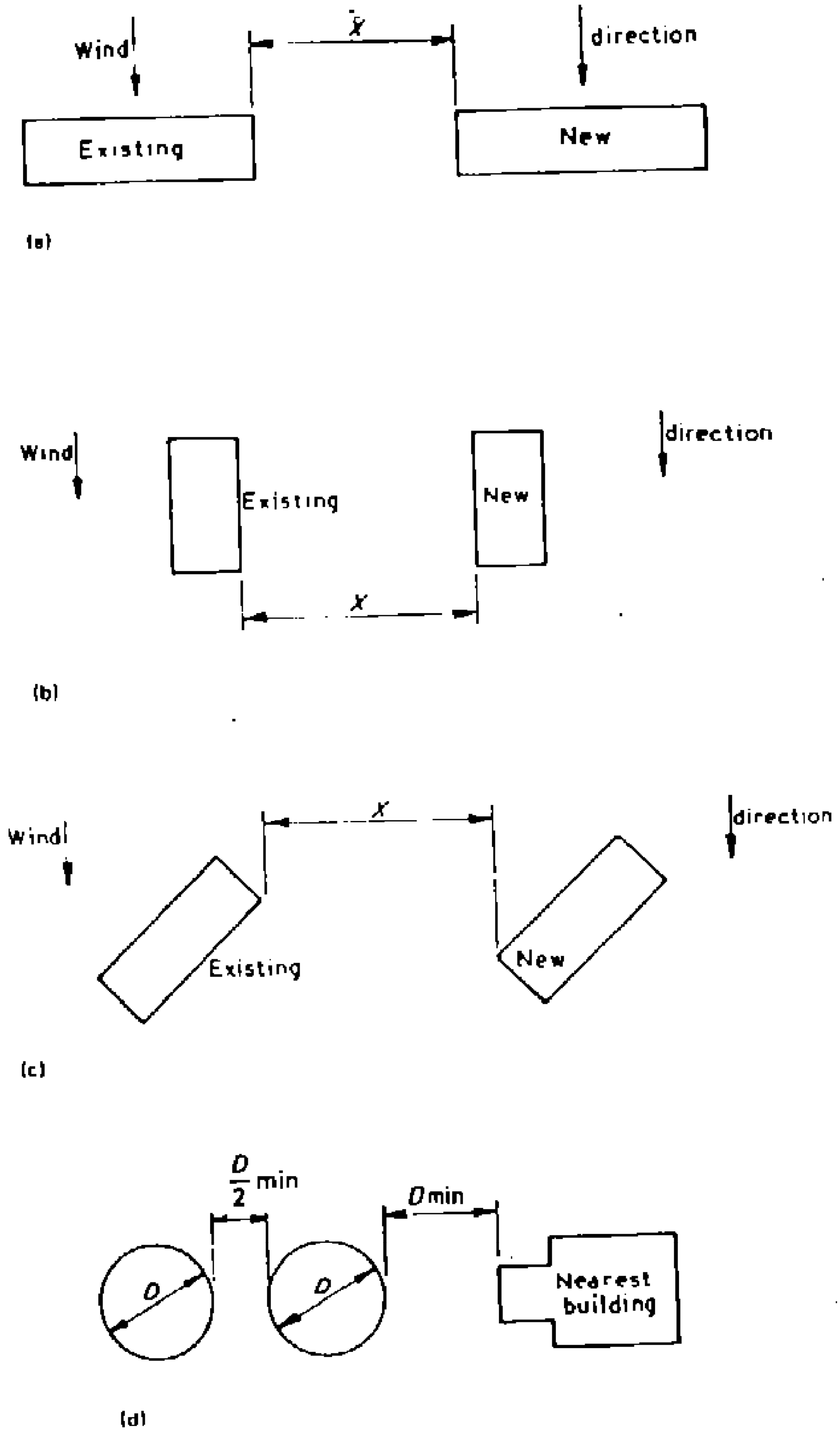
Drift may also create a health hazard by virtue of its bacterial population and towers should be sited so as to avoid drift into open windows and re-entrainment of cooling water droplets in the intake air to ventilation equipment. Effective eliminators at the tower discharge should be capable of reducing the drift to an acceptable level (see 10.4 and also Table 4 of BS 4485: Part 2: 1988).

11.4.3 Blow-out

Blow-out is water blown out from the air inlet and occurs to a greater extent on natural draught towers of counterflow design than on mechanical induced draught towers. It can produce a nuisance factor with similar detrimental effects to drift, although the radius of area affected would be smaller. Where blow-out creates a nuisance, it may be reduced by the following means:

a) diagonal partitions or a central division situated so that the prevailing winds are prevented from blowing across the tower basin;

b) inclined louvre boards positioned around the air opening at the base of the tower, sections of which may be removable to permit access.



SPACING
Fig. 3

11.4.4 Fogging

Fogging arises from the mixing of the warm moist air discharged from the tower with cooler ambient air, which lacks the capacity for absorbing all the moisture as vapor. This mixing results in the excess moisture condensing as fog.

When fogging exists, it is a nuisance factor that could create visibility and icing hazards. It is an intrinsic feature of any evaporative cooling tower and is worst during periods of low ambient temperatures and high relative humidity. The dissipation of fog, where it occurs, depends mostly on the characteristics of the prevailing atmosphere.

Measures may be taken to reduce fogging, but these add substantially to the capital and operating costs of the tower. For example, heating the moist air discharge reduces the fog as does an increase in the volume of air through the tower.

Fan stacks discharging warm vapors at a high elevation can be a partial solution, although this may be expensive depending on the stack diameter and the height required to derive some benefit. This problem is solved far more easily if the tower installation is sited where the least possible nuisance may be caused. The high-level discharge of the vapor plume from a natural draught tower generally prevents this from being a hazard.

11.4.5 Discharge of cooling water

Discharge of cooling tower purge directly to the environment will be subject to Department of Environment Regulations (see IPS-G-SF-880). Discharge temperature restrictions and the elimination of navigation hazards may necessitate auxiliary cooling or pre-dilution of the discharge by further abstracted water. The said Regulations will almost certainly place limitations on the type of water treatment which may be used. Chromates are now almost universally banned and restrictions on the use of a range of other inhibitors and biocides are becoming increasingly widespread. Discharge to sewers may also entail consent subject to conditions. These conditions should also be observed when draining the system for maintenance.

11.4.6 Noise

11.4.6.1 General

The likely noise level from fans and falling water in a cooling tower installation should be considered in the context of the existing noise level at the proposed site.

It is necessary that the noise aspect be given early prominence in that to effect a significant reduction in noise may need a design of tower quite different from and possibly less economical than that which may have been suitable in a position of no noise restriction. For data on noise level requirements reference should be made to the Company's project specification.

11.4.6.2 Noise abatement

If noise is to be a minimum at any point of sensitivity, the following recommendations are made:

a) The basic noise level should be as low as possible. Fan power should be low and the water noise reduced to a minimum.

b) The towers should be sited the maximum distance from the point of sensitivity.

c) If a multi-cell mechanical draught unit is to be installed, the fans should be in line with the point of sensitivity and the air inlets in the broadside on position.

d) Motors should be located behind the fan flares when viewed from the sensitive point.

e) In forced draught towers the fan axis should be away from the sensitive point.

f) It may be possible to analyse the sound spectrum, locate and abate discrete frequencies and thereby reduce the general noise level.

g) Antivibration mounting may be necessary to minimize the transfer of vibration from a tower to a supporting building. In certain cases the fan and driver may be independently supported on antivibration mountings and flexibly connected to the tower which may then be rigidly mounted. This has the advantage of eliminating the need for flexible circulating water connections, make-up lines and drains.

h) Silencers on fan intakes or discharge stacks are possible aids in the reduction of noise, but may introduce prohibitive additional air resistance.

i) The use of multi-speed drives for the fan provides for a reduction in noise level when operated at reduced speed.

j) Employment of centrifugal fans in the case of forced draught cooling towers may contribute to a reduction in noise level.

k) As fan noise is roughly proportional to fan driver power, the air flow directly influences the degree of noise. Towers that operate at high L/G ratio may therefore be less noisy than their most economical equivalent where there is a noise problem to be solved.

l) If fan noise is to be reduced on an existing tower, it may be possible to reduce the fan capacity and therefore fan power by operating at an increased water flow and a different heat balance. If the tower is small and of the forced draught kind, then a change from axial to centrifugal fans may be possible.

12. GUARANTEES

12.1 The Vendor shall give the predicted performance of the tower over a range of atmospheric conditions.

12.2 The Vendor shall guarantee that the cooling tower and its appurtenances and accessories shall perform successfully and satisfactorily in continuous operation over the entire range of duty, without undue noise or injurious vibration, or sagging of the Redwood wood members due to the temperature involved.

12.3 The Vendor shall guarantee that the tower shall perform as specified in Clauses 12.3.1 through 12.3.7 below and as specified in the design condition.

12.3.1 The tower shall be designed for a wet bulb temperature that will not be exceeded more than 2.5% of the time in five hot spring and summer months (Ordibehesth to Shahrivar inclusive) as per Clause 8.2.

12.3.2 A 5.5°C approach between cold water temperature and wet bulb temperatures shall be used as stated in 8.3 unless otherwise specified.

12.3.3 There shall be no leakage of water from sides or ends of the tower.

12.3.4 The manufacturer shall furnish curves showing performance of cooling tower over a considerable range of atmospheric wet bulb temperatures, for various heat loads and water qualities.

12.3.5 The field performance of the tower shall be determined by CTI standard testing procedures and as specified by 6.5.2. If tower does not meet the performance specifications, Vendor shall be obligated to make the corrections without charge until performance specifications are met.

12.3.6 Drift losses shall not exceed 0.01 percent of design flow rate as per 8.8.

12.3.7 Water loading shall not exceed 407 liter per minute/m (407 L/min/m) of tower cross section area in the horizontal plane as per 8.7.

APPENDICES

APPENDIX A
ENQUIRY AND SUGGESTED TENDER INFORMATION FOR COOLING TOWERS

A.1 Information To Be Provided by The Purchaser

A.1.1 General

The information in A.1.2 to A.1.12 can be given by the Company for tendering purposes or in the form of a questionnaire supplied by the manufacturer to the purchaser.

A.1.2 Location of site ....

a) National grid ref. or equivalent ....
b) Height above ground level .... m.
c) Height above sea level .... m.
d) Maximum expected wind speed .... m/s.

A.1.3 Site details*

a) Available area: length .... m; width .... m.
b) Height limit: min. .... m; max. .... m.
c) Any other restrictions ....
d) Sketch of tower location giving direction of prevailing wind.

A.1.4 Type of tower required ♣

....

A.1.5 Restrictions on unit size*

a) No. of towers ....each of ....cell(s) ....
b) Max. lifting mass ♥ .... kg
c) Max. operating mass .... kg
d) Max. permissible size of largest section: length ....m;
width ....m;
height ....m;
e) Required with/without basins (delete as necessary).

*** Any restrictions, particular to the site, should be made clear. Particular attention is drawn to the following:**

a) restricted access for delivery vehicles;
b) restricted access for cooling towers into building;
c) building design restrictions to air movement;
d) details of adjacent chimneys, discharge ventilation fans or process discharges.

♣ If a particular type of tower, i.e., forced draught, induced draught, etc., is required by the purchaser, it should be indicated to minimize pointless alternative selections being made by the supplier.

♥ See 8.2 Consideration should be given to possible environmental heat gain which may increase the wet bulb temperature of the air at the intake of the cooling tower.

(to be continued)

APPENDIX A - (continued)

A.1.6 Duty of each tower .... L/s

Of water from ....°C to ....°C.

A.1.7 Ambient air conditions

a) Dry bulb temperature max. ....°C min. .... °C.
b) Wet bulb temperature .... °C.
c) Relative humidity .... % at dry bulb temperature.

A.1.8 Electricity supply .... V .... phase
.... Hz .... wire

A.1.9 Noise level

A design requirement of noise rating ....
is being sought at the points indicated on the sketch required by A.1.3(d).

A.1.10 Extras required

A.1.11 Details of water

a) Type ....
b) Analysis if known ....
c) Water supplier ....
d) Details of intended water treatment if known ....
....
e) Recommended purge rate .... L/s.
f) Mains pressure available for make-up .... kPa.
g) Head pressure available at tower inlet .... kPa.
h) Expected contamination ....

A.1.12 Additional information

(Including legislative and regulatory requirements at site.)

A.2 Information To Be Provided by The Supplier

A.2.1 General

The information in A.2.2 to A.2.4 is required for the assessment of compliance with the purchaser's requirements and to accommodate provisions required in structural design.

(to be continued)

APPENDIX A - (continued)

A.2.2 Specification ....

a) Type of tower*
b) No. of towers .... each of .... cells(s).
c) Max. lifting mass .... kg.
d) Max. operating mass .... kg.
e) Dry mass .... kg.
f) A mass distribution diagrams is enclosed YES/NO (delete as necessary).
g) Maximum size of largest section:
length ....m; width ....m;
height ....m.
h) With/without basin (delete as necessary).

A.2.3 Duty of each tower .... L/s

Of water from .... °C to .... °C.
At ambient air wet bulb temperature of .... °C.

A.2.4 Tower packing

a) Type ....
b) Material ....

A.2.5 Casing

a) Materials ....
b) Protective treatment(s)♣ . ...

A.2.6 Basin

a) Materials ....
b) Water quantity held:
i) At operating level .... m^3;
ii) at overflow level .... m^3.

A.2.7 Fans

a) Type ....
b) Air flow per tower .... m^3/s.
c) Fan static pressure .... kPa.

*** The type of tower being proposed by the supplier, i.e., forced draught, counterflow, induced draught crossflow, etc., should be stated.**

♣ Any particular treatments should be as recommended in BS 4485: Part 4.

(to be continued)

APPENDIX A - (continued)

d) No. of fans:

i) Per drive shaft ; ....

ii) per motor ....

e) Fan speed .... r/min.

f) Handling wet or ambient air ....

A.2.8 Motors

a) No. per unit ....

b) Absorbed power .... kW per motor.

c) Rated power .... kW per motor.

d) Speed(s) .... r/min.

e) Electricity supply .... V .... phase;
...................................Hz .... wire.

f) Frame size ....

g) Enclosure ....

h) Manufacturer ....

i) Inside wet airstream/outside wet airstream (delete as necessary).

A.2.9 Drive details

A.2.10 Distribution system

a) Type ....

b) Minimum pressure tower inlet .... kPa.

A.2.11 Eliminators

a) Materials ....

b) Expected drift loss .... %

A.2.12 Make-up

This includes recommended purge/excluding purge (delete as necessary) ....

A.2.13 Noise level

Noise level complies/does not comply with A.1.9.

(to be continued)

APPENDIX A - (continued)

A.2.14 Process requirements

A.2.14.1 Performance curves

The Vendor's proposal shall include three separate performance curve sheets, one each for 90%, 100%, and 110% design water quantity, showing tower temperatures versus ambient air wet bulb temperature. Curves shall cover cooling ranges corresponding to 60%, 80%, 100%, and 120% of design heat duty, at wet bulb temperatures ranging from 5.5°C (10°F) below to 1.6°C (3°F) above the specified ambient wet bulb temperature. Performance curves shall be based on constant fan power equal to the design power.

A.2.14.2 Characteristic curve

The Vendor's proposal shall include a tower characteristic curve showing K.a.V/L versus L/G.

A.2.14.3 Inquiry and bid form

The Vendor's proposal shall include a data sheet containing all applicable information listed in the A(2) and the followings:

a) Percent recirculation (design).

b) Air temperature leaving tower, °C.

c) Grade, dimensions, and other applicable specification for materials of construction.

d) Detailed description of deicing facilities, if required.

e) Cold water temperature when one cell is shutdown, and design duty and flow is distributed between remaining cells.

f) Description of Vendors standard practice for incising of lumber (if incising is proposed).

g) Recommended spare parts based on 2 years continuous operation.

A.2.14.4 Supplemental proposal data

A supplemental data sheet shall be submitted with proposals to include the following additional information:

Fan Data:

1) State whether the fans are multispeed and, if so, give air delivery per fan at all speeds, at inlet conditions.
2) State whether the fans are reversible and, if so, give qualifications for operating in the reverse direction.
3) Fan efficiency (including gear loss).

A.2.14.5 Polypropylene, polyethylene, or polyvinyl chloride fill shall be quoted as a base bid or as an alternative.

(to be continued)

APPENDIX A - (continued)

A.2.14.6 Operating and maintenance manuals

All manuals shall be written specifically for the equipment being furnished and shall contain (but not be limited to) the following information:

a) Mechanical data on fan, hub, coupling, and fan drivers, including shafts bore and keyway dimensions, design pitch for fan blades, type of lube oil recommended.

b) Sectional drawings of fan, hub coupling, fan drivers (including gears) showing location of parts, part numbers, and materials.

c) Instructions for installation, operation, and maintenance of the tower and mechanical equipment.

d) Instructions for fan hub and blade assembly, and recommended procedures for field dynamic balancing of the installed fan.

A.2.15 Additional information..

....

....