

2200 Cooling Tower Design Guidelines

Abstract

This section discusses key cooling tower design parameters, electrical facility installation, environment/safety/fire protection considerations, and forebay design.

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2210 Key Parameters

This section discusses the key design parameters that must be considered when purchasing or rating a cooling tower. The actual rating procedure is in Section 2300.

2211 Heat Load (Duty)

The tower duty is calculated using the following equation:

$$\text{Duty } Q \text{ MMBH} = m \cdot C_p \cdot (T_h - T_c) \quad (\text{Eq. 2200-1})$$

where:

m = Circulation water flow in pounds per hour.

C_p = Specific heat in Btu/lb·°F

T_h = Hot water to the tower, °F

T_c = Cold water from the cooling tower basin, °F

Converting pounds per hour to gallons per minute and using a C_p of 1,

$$Q \text{ (MMBH)} = 500 \cdot \text{GPM} \cdot (T_h - T_c)$$

The 500 comes from converting Item 1 from GPM to lb/hr: (8.33 lb/gal · 60 min/hr) = 500.

The calculated heat load is usually increased by a factor of 10 to 20% to obtain the design heat load.

2212 Circulating Water Rate (GPM)

Conversely, if we have the duty and we want to find the circulating water rate assuming a temperature range:

$$\text{GPM} = \frac{Q}{500(T_h - T_c)} \quad (\text{Eq. 2200-2})$$

The circulation rate and temperatures are developed by looking at:

1. All the heat exchanger duties in the cooling tower network.
2. The cooling water flow rates and temperatures to satisfy the design conditions for the heat exchangers.

By summing all the duties of the heat exchangers in the network and taking the weighted averages of all the inlet and outlet temperatures of the circulating water in GPM, T_h and T_c can be determined. For each circulating water rate there is a unique hot and cold water temperature combination.

2213 Wet Bulb Temperatures

Determining the design wet bulb temperature is an important decision, as investment costs are involved. Figure 2200-1 lists the ambient design wet bulb temperatures at a number of our operating centers.

Fig. 2200-1 Design Wet Bulb Temperatures at Several Company Locations

Location	Design Wet Bulb °F
Anchorage, Alaska	59
Bahamas, Freeport	79
Cedar Bayou (Bayport, Texas)	82
El Paso, Texas	70
El Segundo, California	70
Hawaii	73
Kaybob	61
Marietta, Ohio	77
Mt. Belvieu (Bayport, Texas)	82
Orange, Texas	80
Pascagoula, Mississippi	79
Philadelphia, Pennsylvania	76
Port Arthur, Texas	82
Richmond, California	65
Salt Lake, Utah	65
St. James, Louisiana	80
St. John, N. B.	65
Vancouver (Burnaby)	68

Considerations for Design Wet Bulb

1. Cooling towers should be oriented so that the longitudinal axis is aligned with (parallel to) the prevailing wind. If the plot plan will not accommodate this orientation, the wet bulb temperature shown in Figure 2200-1 may need to be increased by 1°F.
2. Cooling tower performance can be measurably affected by external influences on the wet bulb temperature of the air entering the tower. Examples of this are localized heat sources situated upwind, drift from adjacent cooling towers, recirculation of exit air caused by large structures adjacent to the tower, etc. For more information on recirculation, request a copy of CTI Bulletins PFM-110 and PFM-116. The external influences discussed here should be evaluated, and if appropriate, shown wet bulb design temperatures may need to be raised an additional 2°F.

If a cooling tower is being located where the Company has no experience, the design wet bulb temperature should be obtained from the local weather bureau or local airports. Industry's normal practice is to use the wet bulb temperature at the 5% level. This is the temperature that the wet bulb will be below over 95% of the time during the summer months.

2214 Optimizing Cooling Tower Costs

For a given heat duty and design wet bulb temperature, you can use the following three parameters to optimize the cooling tower cost.

1. The **temperature** of the water returning to the tower.
2. The **range**—the difference in temperature between the hot water returning to the tower and the cold water from the cooling tower basin. (Cooling ranges normally fall between the limits shown in Figure 2200-2.)
3. The **approach**—the difference in temperature between the cold water from the cooling tower basin and the ambient wet bulb temperature.

Fig. 2200-2 Acceptable Cooling Tower Temperature Range for Different Types of Plants

Type of Plant	Range, °F
Refineries	25-45
Power Plant Steam Condensing	10-25
Chemical Processes	15-25
Air Conditioning/Refrigeration	5-10

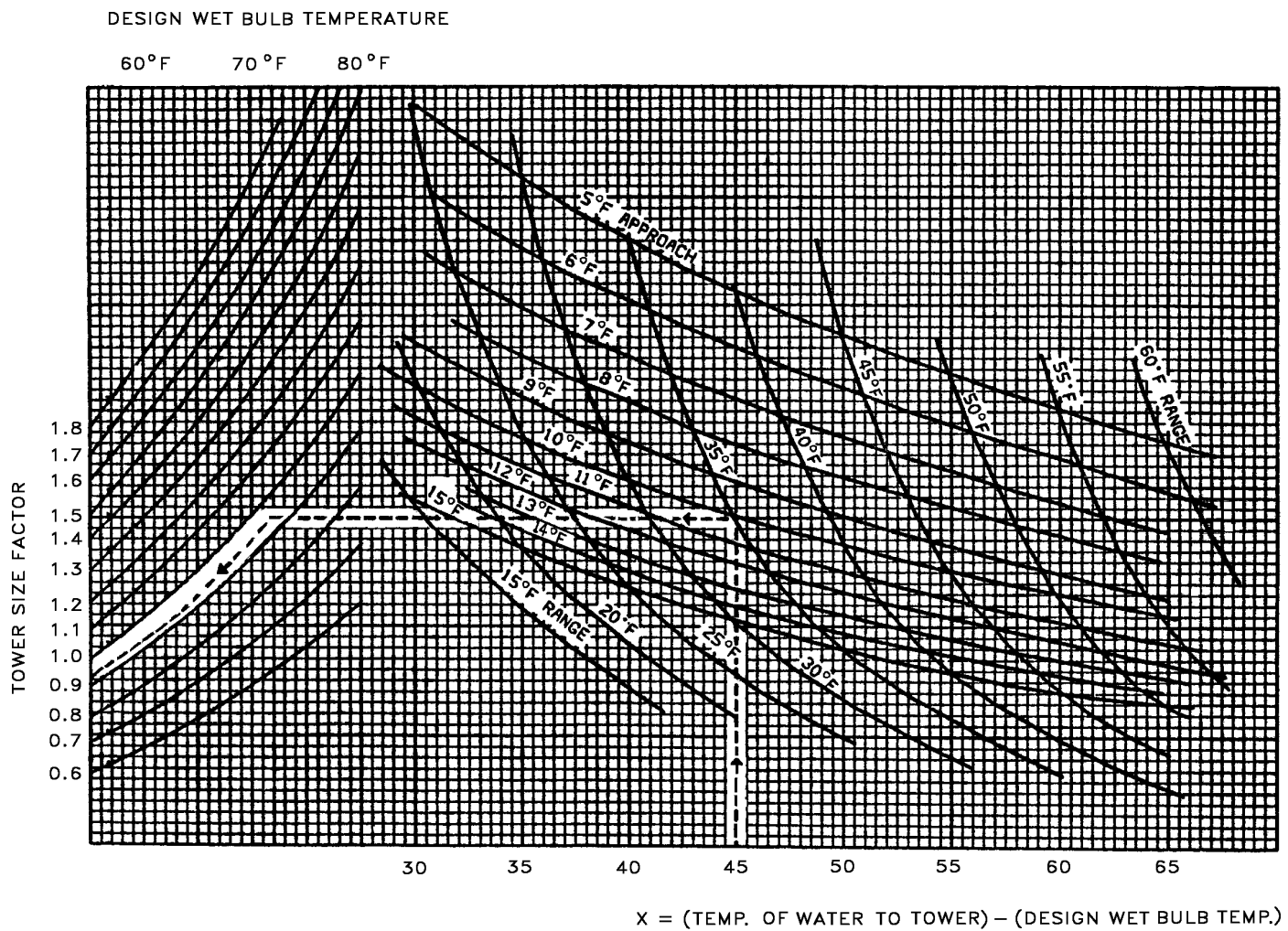
Tower Size Factor

The tower size factor is an empirical way of comparing various combinations of the parameters discussed above. Figure 2200-3 plots the "Tower Size Factor" for assumed returned water temperatures, known wet bulb temperatures, and resultant ranges and approaches. The return temperature, range and approach that satisfy the process and project limitations and result in the lowest "Tower Size Factor" will also result in the lowest cooling tower costs.

Example:

Assume this is Hawaii, with a temperature of water back to the tower of 118°F and a wet bulb temperature of 73°F ($118 - 73 = 45$). Move vertically up the chart at 45 to the range of 35°F, or an approach of 10°F, which is consistent mathematically. Move horizontally to the left to the design wet bulb temperature; then move down to the left, following the curves to the "Tower Size Factor." For our example, the Tower Size Factor is about 0.93.

Fig. 2200-3 Tower Size Factor



Determine If the Tower Meets Design Requirements

It is easy to determine if the tower meets design requirements because of the effort the CTI has put into resolving past problems that cooling tower manufacturers have had with their completed towers meeting design criteria.

Our Specification EXH-EG-1317 itemizes the following as the sole responsibility of the vendor:

1. Meet the operating conditions of the Data Sheet (EXH-DS-1317—CTI Bid Form).
2. Be certain that the tower is a CTI code tower.
3. Meet all applicable codes and ordinances.

In addition to these requirements, the purchase order should require the manufacturer to supply the appropriate data so that a CTI Acceptance Test under ATC-105 can be performed (with appropriate equations to financially penalize the manufacturer if the tower does not meet “design.”)

2215 Makeup Water

Water losses (and consequently makeup water rate) from a cooling tower are the sum of:

1. **Evaporation.** The cooling tower “cools,” mainly by evaporation. To approximate this loss, use 1% of the circulation rate for each 10 degrees Fahrenheit of cooling.
2. **Drift.** This is the water that leaves the tower with the air. In the past the maximum drift was specified at 0.2% of the water circulated. With modern advances in drift elimination, this has been significantly reduced. For towers purchased in early 1989 we have been receiving guarantees of 0.008% of the circulation rate for drift loss. This loss carries the impurities that are in the water and the chemicals added in the water treatment program. See Section 2230 for the environmental concerns for drift.

The rate of water through the fill material (“Water Loading”) for most of our towers is about 4 GPM/ft². Drift is not dependent on water loading. Increasing air velocity does result in greater drift. Typical air flows in cooling towers are 300 to 700 ft/min. Velocities in the stack are in the range of 1500 to 2000 ft/min.

3. **Blowdown.** This is the one water loss of the three that is adjustable, once the tower is running. It controls the “cycles of concentration.”

2216 Blowdown and Cycles of Concentration

Blowdown from a circulating water system is necessary to prevent scale-forming compounds from exceeding their respective solubilities. If water is not removed from the system, the dissolved solids present in the make-up will concentrate and

deposition will take place. A high total dissolved solids (TDS) level also increases the system corrosiveness. On the other hand, from an economic viewpoint, it is desirable to minimize blowdown in order to minimize water usage. **Cycles of concentration** is the term employed to indicate the degree of concentration of the circulating water as compared to the makeup. For example, two cycles of concentration indicate the circulation water has twice the solids concentration of the makeup water. Cycles are usually based on concentration of chloride (where water is not chlorinated) or magnesium and sodium ions (because they almost never precipitate under operating conditions). The chemical suppliers can also run soluble calcium concentration to determine cycles.

Blowdown Equations

Blowdown rates from a circulating water system can be calculated using the following equations:

$$M_u = E + B_d + W = E \cdot C / (C - 1) \quad (\text{Eq. 2200-3})$$

$$C = E + B_d + W / B_d = S_{tw} / S_{mu} \quad (\text{Eq. 2200-4})$$

$$B_d = E / (C - 1) \quad (\text{Eq. 2200-5})$$

where:

M_u = Makeup, GPM

E = Evaporation loss, GPM

B_d = Blowdown, GPM

W = Drift loss, GPM

C = Cycles of concentration (defined below)

S_{tw} = Solids concentration in tower water

S_{mu} = Solids concentration in makeup water

For each unit of total dissolved solids (TDS) added with the makeup, one unit of TDS must be removed as blowdown. We have:

$$S_{mu} \cdot M_u = S_{tw} \cdot B_d \quad (\text{Eq. 2200-6})$$

or

$$S_{tw} / S_{mu} = M_u / B_d = C \quad (\text{Eq. 2200-7})$$

Example of Blowdown and Cycles of Concentration Calculations

Given: Circulation rate = 13,000 GPM

Delta T = 120°F - 85°F = 35°F

Cycles of concentration = 5

Calculations:

$$E = 13,000 \cdot (0.1/10^\circ) \cdot 35^\circ = 455 \text{ GPM} \quad (\text{Eq. 2200-8})$$

Note Evaporation is usually 1% of circulation rate for each 10°F change across the tower.

$$M_u = \frac{C \cdot E}{C - 1} = \frac{5 \times 455}{4} = 569 \text{ GPM} \quad (\text{Eq. 2200-9})$$

$$B_d = M_u - E = 569 - 455 = 114 \text{ GPM.} \\ \text{Assuming } W = 0. \quad (\text{Eq. 2200-10})$$

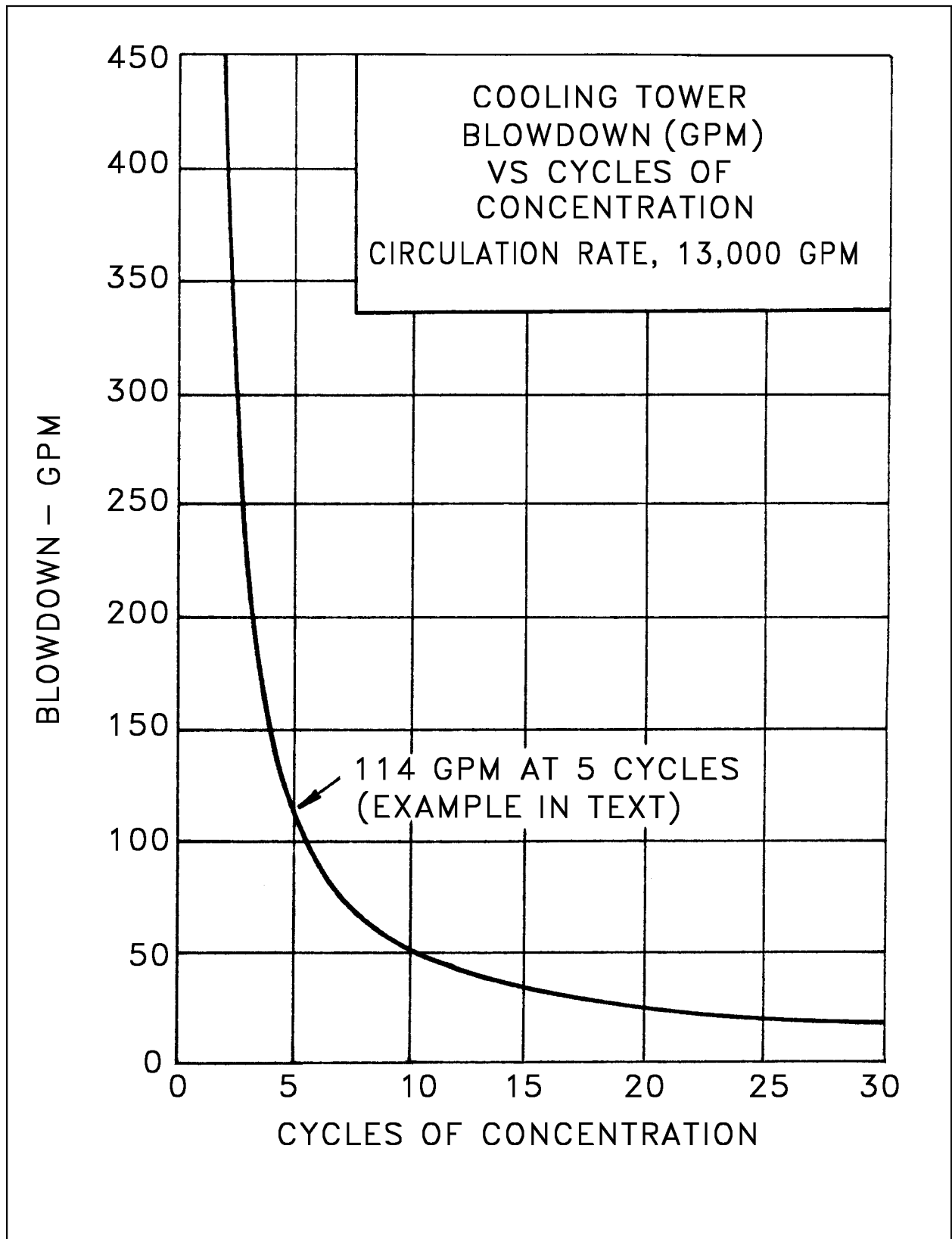
Figure 2200-4 shows the reduction of blowdown for the example above with increased cycles of concentration. The law of diminishing returns starts to apply at the higher cycles. However, minimizing the blowdown is very desirable in a zero effluent discharge location. Blowdown can also be expressed as a percent of the makeup flow rate. In this example,

$$\% B_d = (114/569) \cdot 100 = 20\% \quad (\text{Eq. 2200-11})$$

Sizing Acid and Inhibitor Systems

The above equations can also be used when sizing inhibitor and sulfuric acid pumps. In both cases, it is necessary to know the makeup water rate to the system. This rate, together with cycles of concentration, is used to calculate the inhibitor and acid consumption. For calculation purposes, the amount of corrosion inhibitor required to be added to the makeup water is the total inhibitor level desired in the system divided by the cycles of concentration. For example, if 50 ppm are recommended for the circulating water, then 10 ppm are added to the makeup water if the system is cycled five times.

Multiplying this makeup dosage in ppm by the millions of pounds of makeup per day will result in the pounds of inhibitor requirements. In the above example, the daily makeup rate is 569 gallons per minute or 6.8 million pounds/day. Multiplying this by 10 ppm, the daily inhibitor requirement amounts to 68 pounds.

Fig. 2200-4 Example: Blowdown vs. Cycles of Concentration

2220 Electrical Installations

Cooling towers present special problems for the installation of electrical facilities. Moist, corrosive conditions normally exist; hence, moisture-and-corrosion-resistant materials are required. In addition, because flammable gases or vapors may be present under some conditions, equipment suitable for the appropriate hazardous area classification is required.

Standard Drawing GD-P1011 shows the typical area classification requirements and installation details and lists recommended materials.

2221 Area Classification

Leaks in water-cooled heat exchangers will normally result in leakage of process fluid into the cooling water. If the process fluid is a gas or a hydrocarbon liquid with a flash point lower than the cooling water temperature, gas or vapor will be released from the cooling water at the tower. In case of a tube rupture in a high-pressure gas heat exchanger, large quantities of gas will be entrained in the water. This gas may cause pressure surges in the cooling water return line that may rupture the cooling water piping on the tower. Thus, it is possible for flammable gases or vapors to be released at the cooling tower, sometimes in large quantities.

However, an abnormal condition involving equipment failure must exist—i.e., a leak in a heat exchanger—in order for flammable gases or vapors to be present at a cooling tower. Thus, the appropriate classification is Class I, Division 2.

2222 Materials

Because of the corrosion problem, aluminum conduits and fittings should be used. Electrical equipment enclosures should be aluminum or corrosion-resistant materials. For corrosion resistance, all aluminum materials should have a copper content of less than 0.4%.

Typical Class I, Division 2, wiring methods should be used. Conduits should be of rigid metal with threaded connections. Fittings should have threaded hubs and cast gasketed covers. Push buttons should be explosionproof, and vibration switches should be hermetically sealed (mercury type) in cast enclosures, or explosionproof. Receptacles should be explosionproof, of the arc-tight type designed so that arcs will be confined within the case of the receptacle. Lights should be enclosed and gasketed. Conduit seals should be provided as normally required in classified areas.

2223 Installation

Installation details shown on Standard Drawing GD-P1011 should be used. Wherever practical, conduits should be routed on the exterior of the tower. However, the conduit may be run below the upper deck if required. Conduit runs across the upper surface of the deck can be ramped over. **In all cases, the conduits should be routed away from any cooling water piping that might move during upset conditions and cause damage to conduits and fillings.**

2230 Environmental/Safety/Fire Protection Considerations

2231 Effluent Quality

Chromate vs. Nonchromate Corrosion Inhibitors

Environmental regulations are forcing drastic limitations on or elimination of the chromium in waste water. The National Pollution Discharge Elimination System (NPDES) and the Environmental Protection Agency (EPA) limit the discharge of total and hexavalent chromium from our process plants.

Cooling tower blowdown constitutes a large portion of a typical plant's waste water. The alternatives are either chromium removal from cooling tower blowdown or the use of an alternative ultra-low or nonchromate treatment. Chromate removal/recovery equipment on cooling tower blowdown streams is usually more expensive than nonchromate inhibition. However, automatic control of chemical concentrations and an excellent microbiological program are a must for a nonchromate program to perform successfully.

Nonchromate treatments can be expected to reduce corrosion on mild steel only down into the range of 3 to 5 mils per year. Even with higher corrosion rates, the cost of nonchromate treatments run from 1.5 to 2.0 times the cost of a chromate-based treatment program.

The selection of the proper corrosion inhibitor should be made by the process plant on an individual basis based on economics and operational reliability. Section 2400 and Appendix J give guidelines on the various corrosion inhibitor systems.

Minimizing Blowdown

Minimizing blowdown makes sense from both an economic and environmental standpoint. Depending on the location, makeup water costs can range from 40 cents to \$4.00 per 1000 gallons.

Normally, the plant effluent systems are capable of handling cooling tower blowdown streams. However, if large volumes of cooling tower blowdown must be disposed of and the blowdown contains high levels of total dissolved solids (TDS) and metal-based water treating chemicals, this practice may be unsatisfactory. Possible future Best Available Technology (BAT) Effluent Regulations may also require a reduction in effluent flow rate. For these reasons, methods of minimizing cooling tower blowdown are being investigated.

Typically, cooling tower blowdown is composed of less than 0.5% by weight of dissolved solids. The cost of disposal by such means as solar ponds, evaporation plants, and deep well injections depends on the volume discharged. Other blowdown treating methods, such as chrome removal processes (which the Company has not used to date) are also dependent on the volume. Therefore, every effort should be made to minimize the amount of water going to ultimate disposal. Other special processes are side stream softening or side stream softening combined with an elec-

troodialysis or reverse osmosis unit. The clean effluent from these processes can be recycled to the tower to reduce the amount of cooling tower blowdown.

Blowdown is discussed in detail in Section 2216 and Section 2422.

Use of Biocides

In some areas, effluent must meet fish toxicity requirements. Biocides can be toxic to fish and must be used with care. They should be chosen so that a minimum amount is used with a maximum potential for degradation in the effluent system. Biocides may also have an adverse effect on the water treatment systems. A rough indication of this can be obtained by comparing the biological oxygen demand (BOD) for a sample of normal effluent water and a sample of effluent containing biocide at the concentration expected in the effluent. A low BOD result in the presence of biocide indicates a potential toxicity problem. These tests should be conducted before a new biocide is used.

Impounds Around Chemical Areas

As discussed in Section 2530, all chemical injection facilities should be contained by berms. The impoundage should be large enough to hold the contents of the largest container in case of a rupture.

2232 Air Quality

Drift

The drift off the cooling tower contains solids and other additives in proportion to the level of solids and additives in the recirculating water. The most significant contaminant is hexavalent chromium (Cr^{+6}) if it is being used as a corrosion inhibitor. Hexavalent chromium emissions can be controlled by:

1. Limiting the average chromate concentration in the recirculating water (presently 13 ppm maximum in the petroleum and chemical industries).
2. Eliminating chromate-based chemical completely from the water treating programs.
3. Retrofitting towers with higher efficiency drift eliminators.
4. A combination of 1 and 3 above.

Minimizing Drift

Manufacturers claim they can guarantee drift rates from 0.02% down to 0.001% of the recirculation rate. To achieve the lower drift numbers requires some additional investment and 3% to 5% added fan horsepower. These low numbers are difficult to measure. The measuring techniques vary and several different sampling train configurations have been developed. The drift rates have not given consistent results.

2233 Safety

Chemical Handling

The safety considerations for handling water treatment chemicals and chlorine are discussed in Section 2500.

Wood Deterioration

Wood deterioration in platforms and stairs has been a problem. Decay organisms also affect the nonwater wetted areas of the cooling tower. All cooling towers should be inspected regularly for any signs of cracking or deterioration. This is particularly critical for towers where pressure-treated Douglas fir and non-heartwood redwood are the principal materials of construction. These two types of wood have a history of deterioration and therefore higher maintenance costs.

Fan Vibration

Excessive fan or gearbox vibration has caused many fan failures. Obviously, this can be a significant personnel hazard. The primary purpose of cooling tower vibration switches is to detect high fan/gearbox vibration and shut down the fan motor before a failure occurs. A secondary purpose of the switch is to allow surveillance of machine condition in operation so that failures can be predicted ahead of time and preventive maintenance performed. While mechanical switches have proven inadequate in meeting the primary purpose and incapable of providing the second purpose, electronic monitor/switches can meet both requirements.

Mechanical vs. Electronic Switches. After tests in 1987 comparing the commonly used mechanical switch (Metrex 5175-01) and an electronic switch (PMC Beta Model 440), Richmond Refinery is now recommending the use of electronic switches for cooling tower fans. For more information on this testing, please contact the Richmond Refinery IMI group and request the 1/31/89 report entitled "FCC Cooling Tower Electronic Vibration Switches."

Previously, cooling tower fans at Richmond Refinery have been equipped with mechanical vibration switches (Metrix Model 5175-01 or Robertshaw Model 365 Vibraswitch). Recent experience has shown these mechanical switches provide inadequate protection against catastrophic failures of cooling tower fans. Alternatively, electronic switches provide all of the following essentials for protective shutdowns:

- Good sensitivity and repeatability at generated vibration frequencies (especially low frequencies, 3 to 30 Hz)
- Transducer mounted on gearbox housing for good signal detection (not on auxiliary piping or cooling tower structure where the vibration signal is attenuated)
- Testing capability with fan running
- Time delay or shutdown bypass for startups
- Remote reset capability

Mechanical switches cannot be mounted on the gearbox and are not testable on-the-run because mechanical switches do not have a remote test function. Furthermore, bench tests have shown that, even with new mechanical switches, sensitivity and repeatability are inadequate to detect destructive vibrations.

In addition to the above vibration switch essentials, electronic switches provide the following features to meet the secondary purpose of applying predictive maintenance techniques:

- AC output for monthly surveillance
- 4 to 20 mA output for remote vibration monitor/recorder

Mechanical switches are self-contained and are not designed to have these capabilities.

Installation. Richmond Refinery now uses the PMC Beta Model 450 (see Figure 2200-5 for the specifications and settings Richmond uses for these switches.) Other manufacturers offer similar switches.

Switch electronics are mounted on the cooling tower in explosionproof housings. Four of 14 switches mounted at Richmond had corrosion problems on PC boards attributed to moisture intrusion during installation. Long term reliability of electronics in this environment has yet to be proven. Currently, the PMC Beta switches are fully operational and are providing continuous protection and gearbox vibration data via the DC Plus data collector.

Maintenance. Perform periodic maintenance (every 3 months) in conjunction with monthly vibration monitoring functions.

Change Corrosion Inhibitor Packet. Due to the moist environment, corrosion inhibitors are installed in the housings of the transformer/power supply, vibration switch, and transducer. Corrosion inhibitor: Hoffman Corrosion Inhibitor, Part No. A-HCI-1DV, size 0.25" × 1.25" × 3".

Relubricate Housing Threads with Grease. Housing cover threads corrode and must be coated with Crouse-Hinds Anti-Seize Screw Thread Lubricant Sealer, Part No. STL-2.

Reference—Johnson, C. W., "FCC Cooling Tower Electronic Vibration Switches," 1/31/89, IMI, Richmond Refinery.

Safety Considerations

1. When working on mechanical equipment (like the fan), utilize the electrical lock-out feature.
2. Cooling tower fill and drift eliminators are not safe working surfaces. They should be evaluated from existing access walkways, from air inlet openings, or from temporary planking that spans column lines.
3. A "buddy" system should be used whenever entering any part or hatch on a cooling tower. Only qualified people familiar with the mechanical components and understanding the safety hazards should inspect the tower.

Fig. 2200-5 FCC Cooling Tower Vibration Switches, Specifications and Settings**Manufacturer:**

PMC Beta Corporation
 4 Tech Circle
 Natick, MA 01760
 (617) 237-6920

Model: PMC Beta, Model 450 D-R supplied with:

- 480 VAC input transformer (L1 & L2 of 480 V System)
- 480 VAC 3 Amp Relay for Shutdown Circuit
- 0.1 to 1.5 in/sec range
- AC output on BNC Connector on Switch Panel
- AC output sensitivity = 278 MV/in/sec

Starting Lockout Terminals

3/4 FNPT connections drilled at right, left, bottom

Model 160 E transducer

Field-Configurable Settings for Cooling Tower Gearboxes:

Shutdown setpoint = 0.4 to 0.5 in/sec

Alarm Setpoint = 60% to 80%

Shutdown Relay = Normally closed (NC)

Alarm Relay = Not used

Shutdown Relay Time Delay = 3 seconds

Alarm Relay Time Delay = 3 seconds

Remote Reset = Not used

4. Always replace coupling guards before putting any cooling tower cell back into service.
5. In cold climate locations, ice formation can damage tower components and be a safety hazard. Icing procedures should be available and in good working condition, anytime the temperature drops to around 40°F.

2234 Fire Protection

Nearly all of our cooling towers are made of wood and, because we are cooling hydrocarbons in most of the exchangers, have wooden splash fill. Cooling towers are fire hazards, particularly when idle. Recommendations for fire protection are as follows:

1. Prohibit smoking, open lights, and warm-up fires anywhere near the tower.
2. Supervise closely any welding or cutting operations.
3. Locate new cooling towers remote from any equipment that produces sparks.

4. Provide hydrants with adequate pressure and hoses to reach all sections of the cooling tower.
5. Install fire sprinkler systems that automatically deluge any fire source.

2240 Cooling Tower Forebay Design

This section provides basic concepts and guidelines for cooling tower forebay design. Past experience has shown that a poorly designed cooling tower forebay will severely impact cooling tower operation and pump life because of the following associated problems:

- Pump cavitation
- Pump vibration
- Pump equipment damage
- Reduced pump efficiency
- Excessive noise

Good design is especially important when large pumps (over 300,000 GPM) are used; large pumps are more susceptible to rough running and vibration, and thus require “better” forebay conditions for satisfactory performance.

Accordingly, the following standards are applicable to forebays equipped with either horizontal or vertical pumps of the following capacities:

- 3000 to 300,000 GPM
- 300,000 GPM and greater

These standards do not apply to facilities with pump capacities less than 3000 GPM, because small pumps are not usually used in cooling tower forebay applications.

These design guidelines may also apply to facilities with the same function as a forebay, e.g., pumping station sumps. For facilities with pump capacity less than 3000 GPM, facility design should follow the pump manufacturer’s recommendations.

The information in this section is based on research conducted by the Hydraulic Institute and British Hydromechanics Research Association. Forebay designs should be analyzed using a hydraulic model; most models are efficient, relatively inexpensive, and reliable.

2241 General Information

The forebay is an intake structure that collects and supplies a flow of water to the suction point of the circulation pumps. The flow conditions that govern pump performance are a function of the hydraulic design and upstream approach flow. A “good” forebay design results in a uniform, steady, single phase flow and satisfactory pump performance.

Conversely, inadequate design may cause adverse flow conditions and hydraulic problems such as uneven flow distribution and large scale turbulence. The most damaging conditions, however, are vortices near the pump column (vertical pumps) and in the corners and along the walls and floor of the forebay. Even a small amount of air entrained in the vortices will cause pump cavitation and vibration and may lead to severe pump damage.

To avoid these above problems, the forebay design should achieve and maintain the following conditions:

- Uniform distribution of flow entering the forebay
- Minimal circulating flows in the forebay
- Filled zones of separation
- Minimal significant fluid rotation

The following design standards provide an initial design basis. Note that these standards are subject to variation with individual applications. Hydraulic model testing will physically analyze the preliminary design and may suggest structural modifications toward the development of the final design.

2242 Forebay Design

General

Forebay design is based on the Hydraulic Institute Standards for sump design. Continuing research on rectangular, free surface wet pit sumps with 3000 to 300,000 GPM capacities has yielded guidelines in pump position and approach distance. All recommended distances are functions of the rated pump capacity at design head.

As pump capacities exceed 300,000 GPM, however, the casing wall thickness (and rigidity of support) increases disproportionately with the hydrodynamic loading on the pump. Consequently, large capacity pumps are more prone to vibration and demand better forebay design than smaller pumps. Using more stringent acceptance criteria to measure “satisfactory” performance, the British Hydromechanics Research Association has developed recommended dimensions based on the bell diameter of large pumps.

The following sections contain general forebay design guidelines according to pump type (i.e., horizontal or vertical pumps) and suggested forebay dimensions according to pump capacity (i.e., 3000 to 300,000 GPM or pumps larger than 300,000 GPM).

Guidelines for Horizontal and Vertical Pumps

The following general guidelines are applicable to forebays with capacities exceeding 3000 GPM and either horizontal or vertical pumps.

1. Ideally, a straight channel approaching the pump suction point(s) will deliver uniform flow to the pump(s). Avoid any obstructions and/or turns that will

cause abrupt changes in flow direction; e.g., sharp corners and rapidly diverging passages may induce eddy currents and vortices.

2. Unavoidable obstructions such as columns and cross braces should be streamlined to reduce the trail of alternating vortices; these vortices form in the wake of the obstructions as water flows past.
3. Maximum velocity of the flow approaching the pump(s) should be 1.0 foot per second. Straightening vanes and/or a longer forebay length may reduce velocities; if properly located near the mouth of the forebay inlet, trash screens may also function as straightening vanes.
4. A longer forebay length may also be necessary to dissipate the kinetic energy associated with steeply sloped floors, weirs, and steps, and therefore prevent aeration.
5. “Dead pockets” of the forebay which contain stagnant water (e.g., corners behind the suction point) may be eliminated via simple fillets or complex formwork.
6. The inlet to the forebay should be below the normal operating water level to avoid aeration.
7. In multiple-pump installations, water should not flow past one pump suction point to reach another; i.e., pumps should not be placed in line with the flow of water. To maintain even flow distribution, the water stream entering the forebay should be normal to the line of pumps and along the line of symmetry.
8. For suction bells that must be placed in line of flow, an open front cell around each intake may induce a more uniform flow into the pumps. Cells may be unnecessary if both the longitudinal distance between intakes and the ratio of forebay to pump size are quite large.
9. In multiple pump installations, rounded or “ogived” separating walls may be beneficial if pumps operate simultaneously. Otherwise, separating walls should be avoided.
10. To avoid uneven flow distribution in multiple-pump installations, pumps should not be placed around the edge of the forebay.
11. To avoid upstream flooding, forebay volume should be sized to accommodate the maximum design flow during pump operation. When constant-speed pumps are used, volume must also be adequate to prevent short cycling (rapid “on-off” operation) of the pumps.
12. Double screens should be placed ahead of the suction of the cooling water pumps, particularly in new installations to screen out foreign materials. Screens should be removable, while in service, for cleaning.

Guidelines for Horizontal Pumps Only

The following general guidelines are applicable to forebays with horizontal pumps at capacities in excess of 3000 GPM; these standards should be used in conjunction

with the information of the preceding section. Refer to Standard Drawing GB-Q99594 for layout and piping details for horizontal pump suction lines.

1. Submergence for net positive suction head and minimal vortexing should be according to pump manufacturer's recommendations. On average, minimum submergence of the suction intake is as follows:
 - a. Two line diameters when the intake is located in the forebay floor
 - b. One line diameter when the intake passes through the forebay wall
2. Vortex prevention plates just below the water surface may also be necessary to prevent vortexing.
3. To mitigate any upstream flow disturbances, the minimum length of the suction line should be ten line diameters.
4. An expansion joint and pipe anchor may be installed between the forebay wall and pump to prevent overloading of the pump case.
5. Under suction lift conditions, suction piping should maintain an upward slope to the pump; this slope helps prevent air entrainment and cavitation.
6. Under flooded suction conditions, the following conditions should be maintained:
 - a. Suction piping should be level or maintain a gradual downward slope to the pump; the piping should not extend below the pump suction flange.
 - b. Diameter of the intake mouth should not be smaller than the diameter of the suction piping.
 - c. A gate valve should be installed in the suction piping between the forebay wall and expansion joints. The pump may then be "disconnected" from the forebay during inspection and maintenance.

Guidelines for Vertical Pumps Only

The following general guidelines are applicable to forebays with vertical pumps at capacities exceeding 3000 GPM; these standards should be used in conjunction with the guidelines above for both horizontal and vertical pumps.

1. Submergence for net positive suction head and minimal vortexing should be according to pump manufacturer's recommendations. Typically, minimum submergence is two times the suction bell diameter.
2. Necessary changes in floor elevation should occur at least three suction bell diameters upstream of the pump column(s).
3. In multiple pump installations where pumps must be placed in line of flow, turning vanes under each suction bell may deflect the flow upward and directly into the pump. Vanes may be unnecessary if both the longitudinal distance between intakes and the ratio of forebay to pump size are quite large.

4. In multiple pump installations where flow distribution is skewed and pumps do not operate simultaneously, flow splitters may redirect the flow to the suction bells. Flow splitter lengths should be greater than four bell diameters.

Recommended Dimensions: 3000 to 300,000 GPM Capacity

The recommended forebay dimensions and layouts as shown in Figures 2200-6 through 2200-8 are applicable to facilities with either horizontal or vertical pumps in the 3000 to 300,000 GPM capacity range (see also Standard Drawing GB-Q99594). All dimensions are based on the rated capacity of each pump at design head.

Dimension C is the distance between the bottom lip of suction bell and the forebay floor. It is an average value subject to changes suggested by the pump manufacturer.

Dimension B is the recommended maximum distance between the centerline of the suction bell and the forebay back wall. If actual Dimension B exceeds the suggested length for structural or mechanical reasons, a “false” back wall may be installed.

Dimension S is the recommended minimum center-to-center distance between suction bells. In single pump installations, it is the minimum forebay width.

Dimension H is the suggested “normal low water level.” It is **not** the minimum submergence required to prevent vortexing; submergence is normally defined as the quantity H minus C .

Dimension Y is the minimum distance between the bell centerline and the first upstream obstruction inside the forebay. For most bell designs, Dimension Y is approximately three bell diameters.

Dimension A is the minimum overall forebay length when the average flow velocity in the forebay is less than 2.0 feet per second.

Recommended Dimensions: Pumps Larger Than 300,000 GPM

The recommended forebay dimensions and layouts as shown in Figures 2200-9 through 2200-11 are applicable to facilities with either horizontal or vertical pumps in the 300,000 GPM-plus capacity range. Dimensions are based on the intake or suction bell diameter; unless noted otherwise, dimension symbols are identical to those previously noted.

Dimension D is the diameter of the pump intake or suction bell.

Dimension X is the recommended distance between the edge of the bell and the back forebay wall.

Dimension d is the diameter of the suction line or pump column.

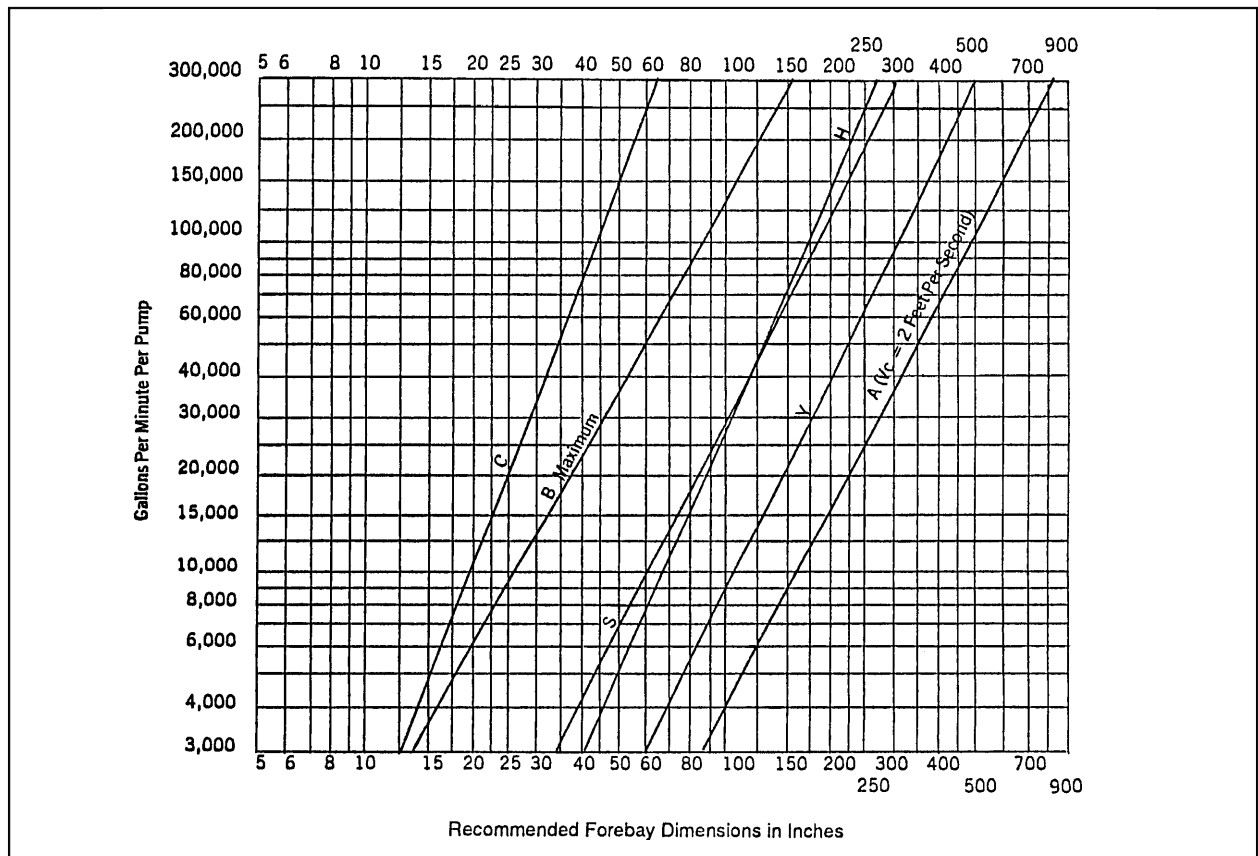
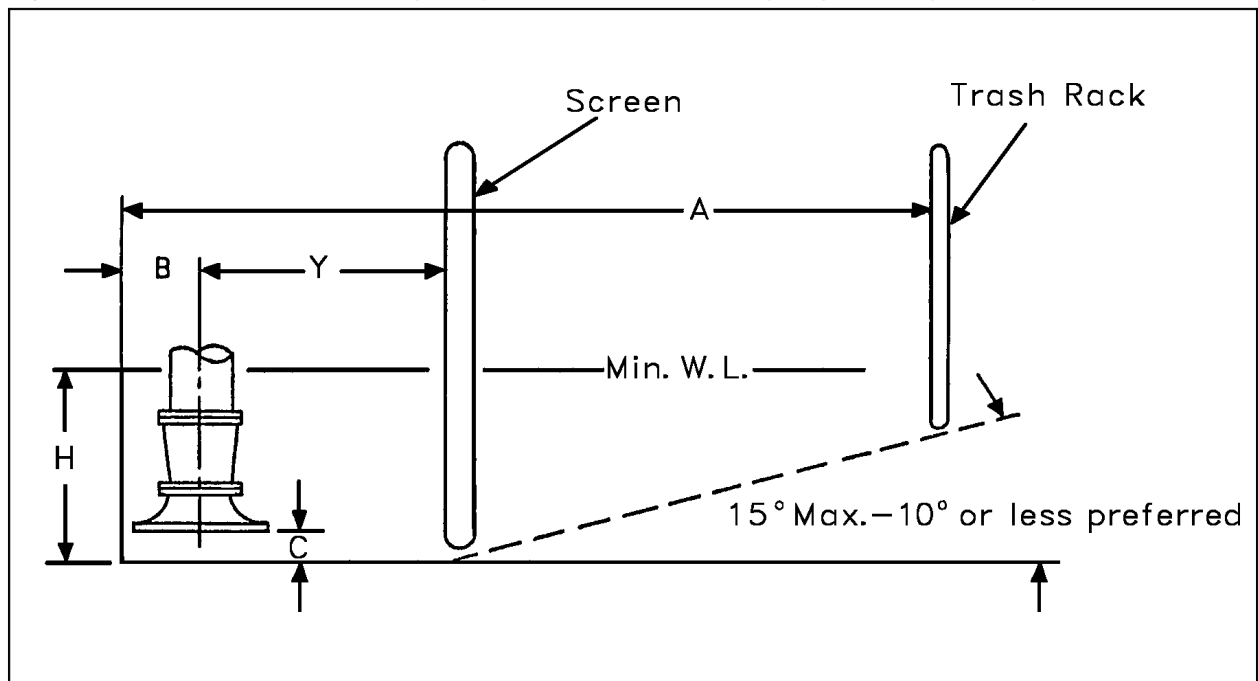
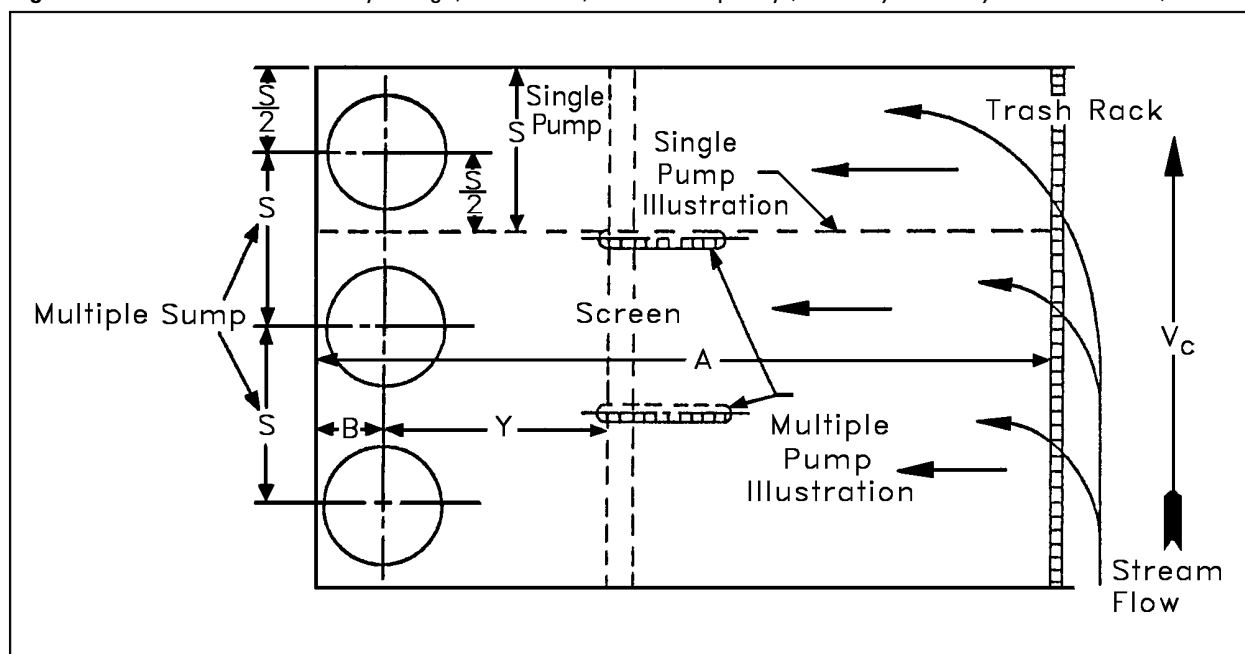
Fig. 2200-6 Sump Dimensions vs. Flow, 3000 to 300,000 GPM Capacity (*Courtesy of the Hydraulic Institute*)**Fig. 2200-7** Elevation of Basic Forebay Design, 3000 to 300,000 GPM Capacity (*Courtesy of the Hydraulic Institute*)

Fig. 2200-8 Plan of Basic Forebay Design, 3000 to 300,000 GPM Capacity (*Courtesy of the Hydraulic Institute*)

2243 Hydraulic Model Testing

Because the hydraulic problems associated with forebay design are functions of many variables, analysis of expected flow conditions is difficult. Unfortunately, outside circumstances often force the designer to deviate from the design standards—and expected resulting flow conditions—described herein. On these occasions, scaled hydraulic model testing may be the best method to analyze the preliminary design.

In-situ simulation, while another possible alternative, is usually impractical. A scaled model is more efficient because the system geometry can be quickly and easily modified. The forebay size may be adjusted, various screen blockages modeled, and instrumentation located in all areas of interest to measure momentum, velocity distribution, and velocity changes at obstructions. Model forebay walls are usually constructed of Plexiglas so that modelers and engineers may observe flow patterns throughout the model.

The model should encompass all forebay components likely to influence the flow entering the pump(s). Model boundaries should be located in areas where flow pattern control has minimal boundary effects on the system. Models normally use either equal Froude numbers or velocities; no significant scale effects occur in 1:2 and 1:4 models.

When conducted by an independent laboratory or the pump manufacturer, hydraulic models are relatively inexpensive, reliable tools to analyze the hydraulic performance of a preliminary design. Modifications suggested by models may also result in substantial savings in later forebay construction, operation, and maintenance. Since 1986, hydraulic models have been used to analyze the Richmond Refinery's

Fig. 2200-9 Elevation of Basic Forebay Designs, Pumps Larger than 300,000 GPM (*From Hydraulic Design of Pump Sumps and Intakes by Prosser. © 1980 by the Construction Industry Research & Information Assn., London. Used with permission.*)

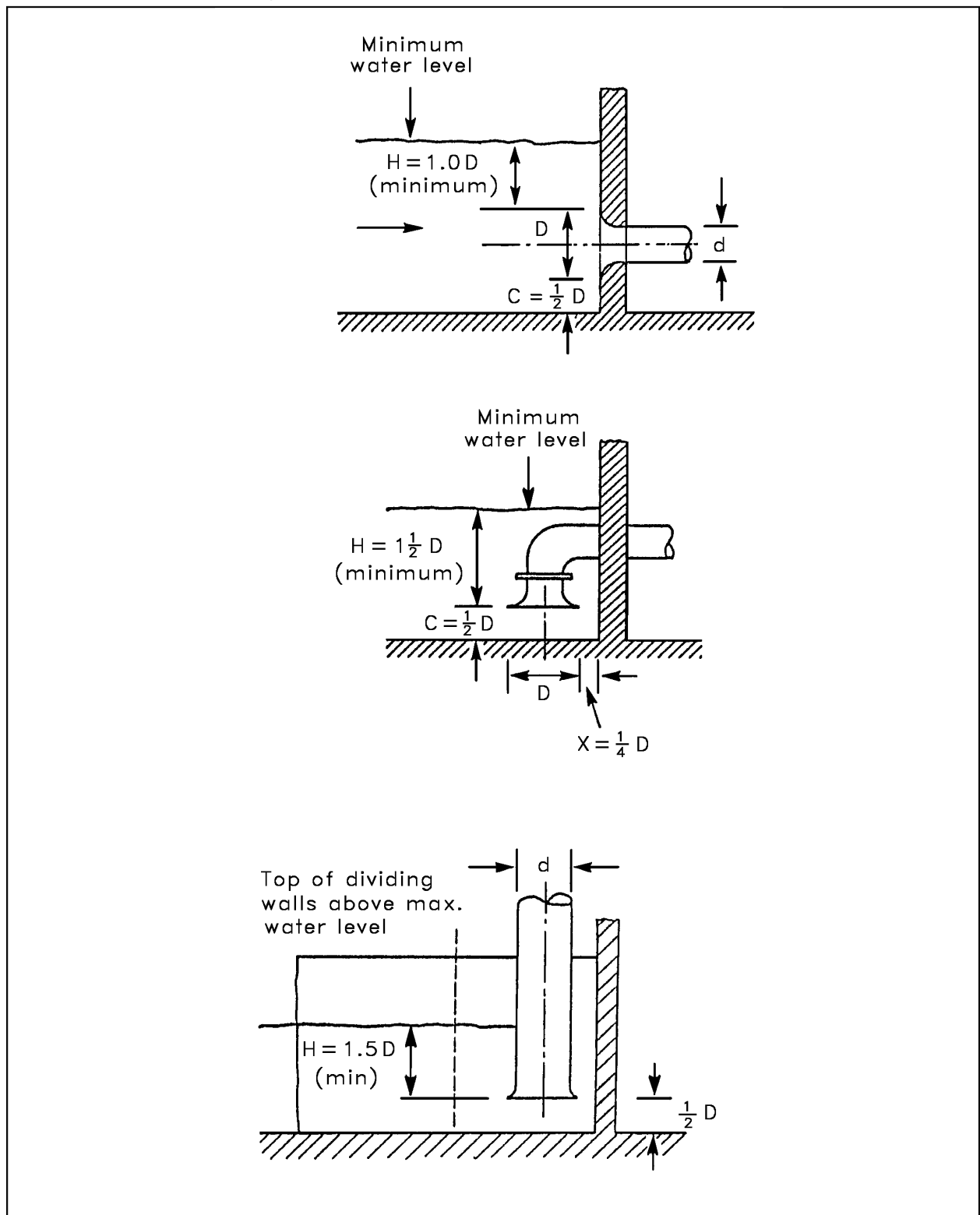


Fig. 2200-10 Plan of Basic Forebay Design, in Plane of Uniform Flow Approaching the Pumps, 300,000 GPM - Plus Capacity (From Hydraulic Design of Pump Sumps and Intakes by Prosser. © 1980 by the Construction Industry Research & Information Assn., London. Used with permission.)

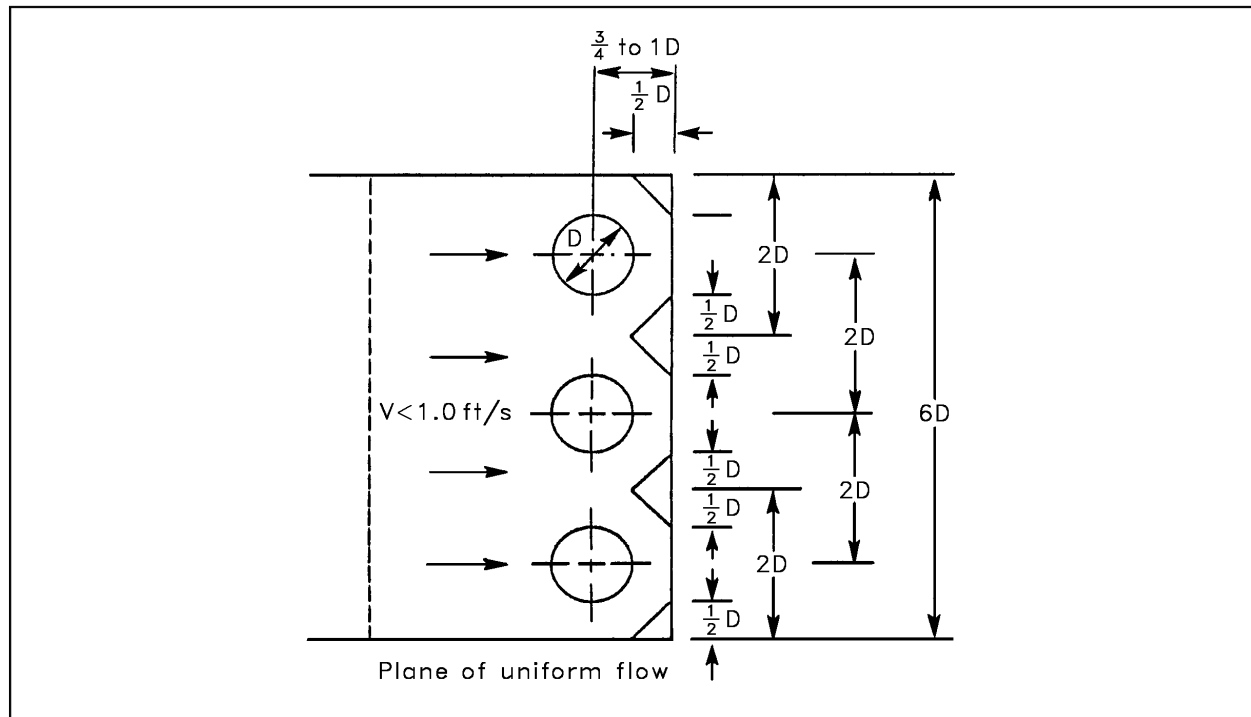
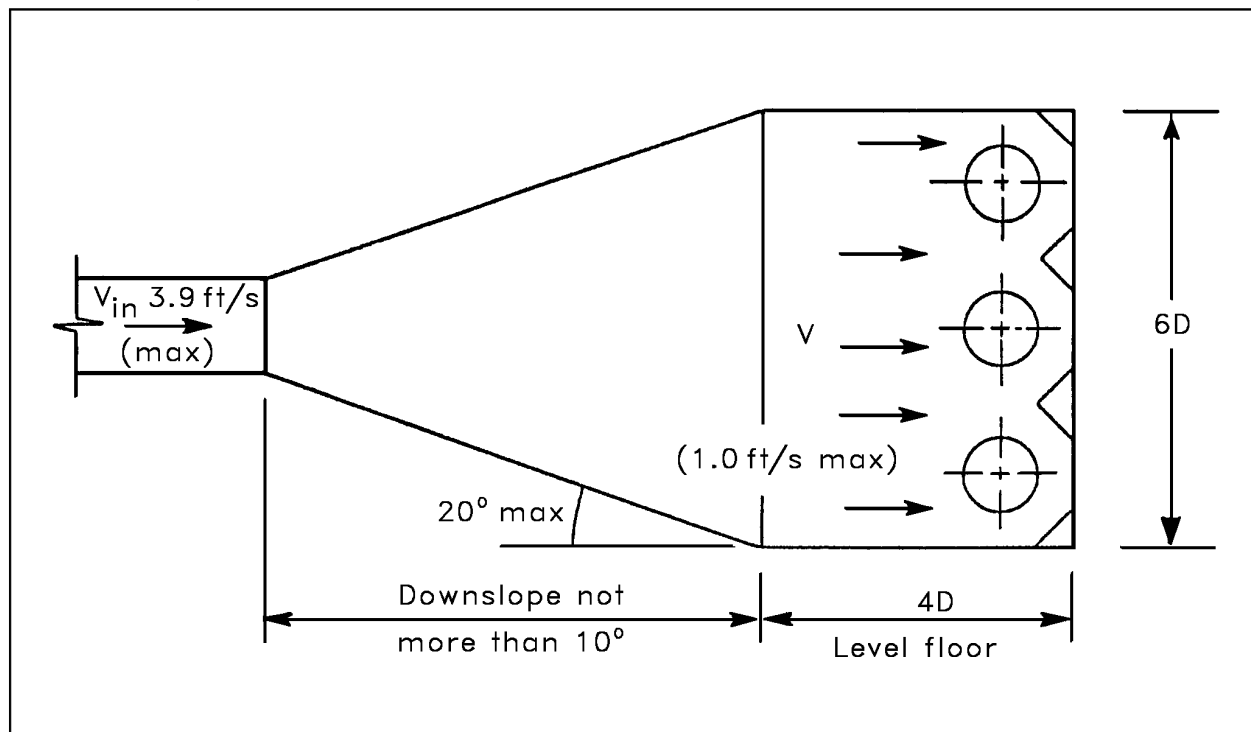


Fig. 2200-11 Plan of Basic Forebay Design, 300,000 GPM - Plus Capacity (From Hydraulic Design of Pump Sumps and Intakes by Prosser. © 1980 by the Construction Industry Research & Information Assn., London. Used with permission.)



flow splitter box of the 1A and 2A Separators, pump station of the Deep Water Outfall, and No. 13 Separator.

In addition to developing possible structural modifications to improve flow conditions in preliminary forebay design, models may also be used to correct conditions in existing forebays. These improvements, the usual basic recommendations of a model, are:

Increase the “normal low water level”. Usually, to simultaneously increase the “normal low water level” and accommodate the desired operating forebay volume, the forebay must be deepened. This change may increase excavation and engineering costs.

Install antivortex devices. Devices such as cones, splitters, grids, and extension plates may prevent or reduce vortexing in the forebay. The devices shown in Figures 2200-12 and 2200-13 should also be selected in consultation with the pump manufacturer.

Reshape the approach flow. Modifications may occur in the existing piping that supplies the forebay and/or the inlet to the forebay.

2244 Standard Drawings

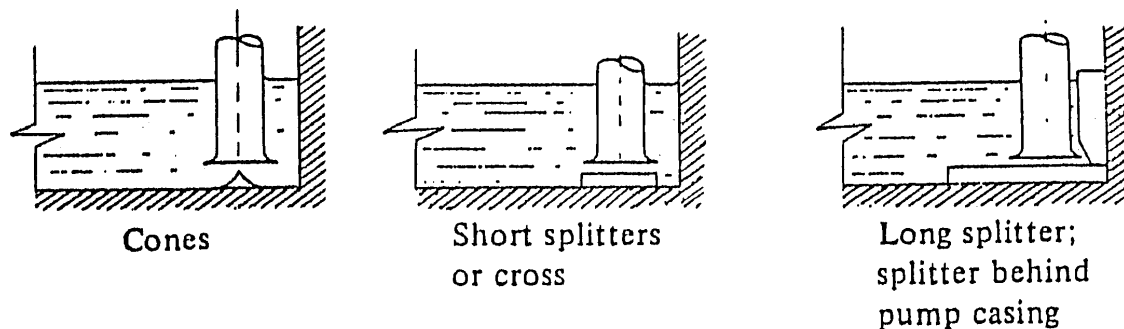
The following standard drawing is included in the Standard Drawings and Forms section of this manual.

- GB-Q99594 Piping and Screen Details, Suction Pit for Cooling Tower Basin.

2245 References

1. *Hydraulic Institute Standards for Centrifugal, Rotary & Reciprocating Pumps*, 14th Edition, Hydraulic Institute, 1983.
2. Nystrom, James B., et al., “Modeling Flow Characteristics of Reactor Sumps,” *Journal of the Energy Division*, ASCE, Vol. 108, No. EY3, November 1982.
3. Padmanabhan, M., and G. E. Hecker, “Scale Effects on Pump Sump Models,” *Journal of Hydraulic Engineering*, ASCE, Vol. 110, No. 11, November 1984.
4. Prosser, M. J., *The Hydraulic Design of Pump Sumps and Intakes*, British Hydromechanics Research Association/Construction Industry Research and Information Association, 1980.
5. Sweeney, Charles E., et al., “Pump Sump Design Experience: Summary,” *Journal of the Hydraulics Division*, ASCE, Vol. 108, No. HY3, March 1982.

Fig. 2200-12 Modifications to Intake Design to Reduce Vortices (From Hydraulic Design of Pump Sumps and Intakes by Prosser. © 1980 by the Construction Industry Research & Information Assn., London. Used with permission.)



For *some* conditions. (Pump manufacturers may not approve of these devices particularly for axial or bowl type pumps.)

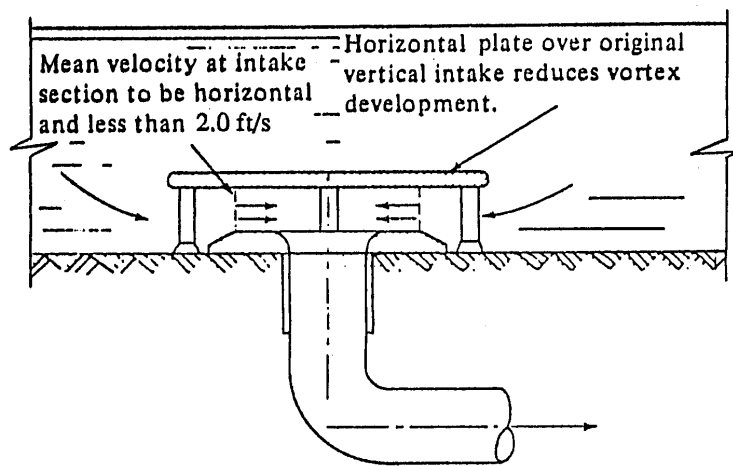


Plate over vertical intake

Fig. 2200-13 Other Modifications to Intake Design to Reduce Vortices (*From Hydraulic Design of Pump Sumps and Intakes by Prosser. © 1980 by the Construction Industry Research & Information Assn., London. Used with permission.*)

