GUIDELINE

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WATER TREATMENT

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Rev	**Changes**	**Approved**	**Date**

1.0 PURPOSE

The guideline outlines the requirements and good practice for the design of water treatment facilities for typical process units.

2.0 SCOPE

This guideline applies to all CB&I process engineering groups responsible for the definition and specification of water treatment facilities.

3.0 RESPONSIBILITIES

The following personnel have key responsibilities defined in this guideline:

- Process Engineers

4.0 GUIDELINE

4.1 General

4.1.1 Water for most plant uses will need some form of treatment. This may range from clarification to complete demineralization.

4.1.2 Water treatment processes may be divided into two classes, namely physical treatment processes in which undesirable properties are removed and conditioning in which desirable properties are added to the water.

4.2 Physical Treatment Processes

4.2.1 Physical treatment involves treatment of water before it reaches its point of use in order to produce water, which is as pure as necessary for its particular application. Additional conditioning is normally required for complete protection of equipment. Examples of physical treatment include:

- Clarification/Filtration
- Desalination
- Water Softening
- Demineralization

4.2.1.1 Unit Sizing

1. Water treating equipment should be capable of treating all the necessary make-up water on a continuous basis. Stand-by equipment and treated water surge capacity should be installed to ensure continuity of supply at design rates.
2. For treating boiler feed water the treating plant capacity should be at least equal to the total capacity of the normally running feed water pumps minus the normal rate of condensate recovery. Where there are surface condensers this condensate should not be included with the recovered condensate for sizing purposes (since surface condensate is dumped at start-up).
3. To allow for start-up of the utility plant, the treating capacity should not be less than 120% of the rated capacity of a single boiler.
4. Note that these figures are net at the plant outlet. Higher gross flows may be required to cater for regeneration periods when the plant is off-line and backwash requirements, etc.

4.2.1.2 Clarification / Filtration

1. The removal of turbidity and suspended solids is effected by clarification and filtration.
2. Where solids levels are high, water may require several stages of treatment. Where solids levels are low, fewer stages are necessary. Coagulation and flocculation may also be required.
3. A summary of the various methods of solids, turbidity and color removal is given in Exhibit 7.2.

4.2.1.3 Coagulation

1. In the coagulation process finely divided particles, which are capable of remaining indefinitely in suspension, are combined into masses which are sufficiently large to effect rapid settling by means of the addition of coagulating chemicals.
2. For each coagulant there is an optimum range of pH values for good flocculation, which depends on both the coagulant and also the water quality.
3. The characteristics of suitable coagulants for different types of water are given in Exhibits 7.3 and 7.4.
4. Mixing is achieved by adding the coagulant, preferably dissolved in water to the raw water in a stirred vessel having a retention time of about one minute. Alternatively coagulant solution may be added to the bulk raw water flow at a point of turbulence, such as at pump suction.
5. The flocculation stage is carried out in baffled or stirred vessels. The retention time in the flocculation chamber is generally in the range 5 to 30 minutes using a peripheral stirring velocity of 0.1 to 0.5 ft/s (0.03 to 0.15 m/s).

4.2.1.4 Sedimentation

1. The complete sedimentation tank contains chambers for mixing and flocculation as well as for settling. Settling can be carried out either batch wise or continuously, the latter with either horizontal or vertical flow.
2. In batch tanks the settling time is proportional to depth.

4.2.1.5 Horizontal Flow Tanks

1. In horizontal flow tanks design is based on the formula:

$$t = \frac{AD}{F} = \frac{D}{V}, \text{ hence } A = \frac{F}{V}$$

Where:

t	=	Time taken to pass through the tank
A	=	Surface area of tank
D	=	Depth of tank
F	=	Volume Flow rate of water
V	=	Free falling velocity of a suspended particle which may be Determined using Stokes' Law or Exhibit 7.1.

2. A common figure for the depth is 10 ft (3m). Horizontal flow tanks are usually rectangular, though for a single tank a square layout is most economical.

3. The average rating for a tank handling unflocculated water is 18 gal/ft^2•h (0.73 m^3/m^2•h) though up to 30 gal/ft^{2}h (1.22 m^3/m^2•h) can be allowed.

4. Where the throughput is less than about 1.2 mm gal/day (4 550 m^3/day) a single settling tank is used. Several tanks in parallel are used for larger throughputs.

4.2.1.6 Vertical Flow Tanks

1. Vertical flow tanks often take the form of an inverted cone. The free surface area is given, as for horizontal flow tanks, by:

$$A = \frac{F}{V}$$

2. With inlet water velocities of about 2 ft/s (0.6 m/s) good clarification at throughputs of 30 – 120 gal/ft^2•h (1.22 and 4.88 m^3/m^2•h) are obtained. The retention time is usually only 1-2 hours as compared with 2-6 hours for the horizontal flow type.

4.2.1.7 High Rate Solids Contact Clarifiers

1. High rate clarifiers are available from several manufacturers under trade names such as Clariflocculators, Aero-accelerators, Reactor-Clarifiers, etc. These units effectively combine flocculation and clarification in one unit. The clarification basin is generally circular and is divided into 3 zones.

2. A central mixing well is used to mix raw water with coagulant and also with sludge, which is returned from the settlement zone.

3. A middle zone allows flocculation to occur under the influence of gentle agitation and the outer zone is where settling takes place and the water is decanted.

4. This type of unit can achieve very high settlement velocities and is hence much more compact than other units. The vendors should, however, be consulted on exact sizing.

4.2.1.8 Filtration (See Exhibit 7.5)

1. Slow gravity filters are used for treating domestic supplies but are rarely used in process plants. The filter medium is sand with a capacity of only about 2.5 US gal/ft^2•h (0.1 m^3/m^2•h).

2. Rapid gravity filters with capacities of about 184 gal/ft^2•h (7.5 m^3/m^2•h) are commonly used in industry. The depth of sand is usually between 1.3 – 2.5 ft (0.4 - 0.75m) supported on a layer of graded gravel or similar material 1 – 2 ft (0.3 - 0.6m) deep.

3. The filter material is cleaned by backwashing at daily to weekly intervals. Filters may be provided air scouring to agitate the sand during backwashing.

4. The addition of 1 to 2 ppm of chlorine to the feedwater often assists in preventing undesirable biological growth in the bed.

5. Pressure filters are the most widely used industrial water filters and comprise cylindrical vessels with a sand or anthracite bed in graded

layers. Water flow is reversed periodically to wash out accumulated material.

6. Anthracite is preferred to sand as a filter medium for pressure filters when pick-up of silica must be avoided, e.g., for boiler feed water. Anthracite also has a lower density than sand, thus requiring a lower backwashing rate.

7. Pressure filter sizes range from about 2'-6" to 10'-0" (0.76m to 3.05m) in diameter for the vertical types, giving capacities up to 14 200 US gal/hr (53.6 m^3/hr) at rates of 184 US gal/ft^2•h (7.5 m^3/m^2•h) or more. At similar rates horizontal pressure filters of 9'-0" (2.75m) diameter and 27'-0" (8.25m) long have capacities of around 43 600 US gal/h (165 m^3/h). Pressure drops range from 10 to 15 psi (0.7 to 1.0 bar) for a clean filter to 21 psi (1.5 bar) or more prior to backwashing. Backwashing rates are generally in the range 12.3 to 18.4 US gal/ft^2•min (0.5 to 0.75 m^3/m^2•min).

8. Pressure filter capacities and rates are being improved continuously by the specialist vendors and the figures given above are regarded as conservative. Specific projects should be referred to specialists, giving as much data as possible, or may be discussed with potential vendors with a view to preparing a suitable specification for tendering.

9. In cases where the turbidity or color of the raw water is low, it is possible to inject coagulant upstream of the filter without the need for flocculation. If this route is followed test work should be carried out wherever possible or a reputable vendor consulted.

4.3 Desalination

Desalination techniques are used for providing "fresh" water from seawater and brackish water. Many processes have been developed and are discussed at length in the literature; however, three processes are most commonly used, each in its own sphere of application, and are discussed briefly.

4.3.1 Multistage Flash Evaporation (MSF)

4.3.1.1 This process is based on flashing steam from preheated brine, in stages at progressively lower pressures and temperatures, and the collection of distillate from condensers, which carry the incoming brine stream to a heat input section, before entry to the flashing stages.

4.3.1.2 From seawater, flash evaporators yield high purity water with less than 10 ppm of dissolved solids in the distillate. Low-pressure steam is used to supply heat and the resulting condensate may be returned to the boiler feed water or may be added to the bulk distillate.

4.3.1.3 The most common use of this process is for obtaining large quantities of "fresh" water from seawater, and plants with capacity in excess of 6.6 million US gal/day (25 000 m^3/day) are in operation.

4.3.2 Electro Dialysis (ED)

4.3.2.1 The electrodialysis process is especially suited to the treatment of low salinity water up to the order of 5 000 mg/l Total Dissolved Solids (TDS). Thus, brackish well water is effectively treated and the process finds application in desert regions where suitable water may be supplied from bore holes.

4.3.2.2 The process is based on the removal of solute ions by their passage through permeable selective membranes under the influence of an electric potential. Hence, economics depend partly on power cost and availability.

4.3.2.3 Generally about 90% of solute ions are removed to the brine or concentrate, which must be disposed of, and about 10% of the solute ions remain in the "fresh" water to give a palatable drinking water and satisfactory cooling water after appropriate chemical dosing.

4.3.3 Vapor Compression

The vapor compression distillation process is best suited to restricted sites where its operational simplicity and compactness are its chief advantages. The process is used where relatively small quantities of fresh water are required from seawater, for example, on marine production platforms.

4.3.4 Reverse Osmosis (RO)

4.3.4.1 This process is based on the preferential transfer of water under an applied pressure through a semi-permeable membrane, which rejects a high proportion of dissolved solids and other large molecules.

4.3.4.2 There is theoretically no limit to the size and capacity of reverse osmosis plants, depending mainly on the membranes having suitable capacity, life and ruggedness at a satisfactory cost and requiring an acceptable pressure differential.

4.3.4.3 Membrane technology is improving rapidly and very large RO plants are in operation and operating reliably. In offshore situations where steam is not available to power evaporators, RO units produce the freshwater on the majority of platforms.

4.3.4.4 To increase membrane life it is advisable to use prefiltration upstream. Chemical treatment may also be required depending on the water analysis.

4.3.5 Other Desalination Processes

4.3.5.1 Vertical Tube Evaporation

This process is the most likely to replace the multistage flash process used for large capacity plants. Its main advantages are reduced size and lower pumping costs. Its competitiveness depends on the successful use of double-fluted piping that has three times the heat transfer performance of equivalent plain tube.

4.3.5.2 Freeze Desalination

No known commercial applications.

4.3.5.3 Solar Desalination

Not applied to process plants

4.3.6 Water Softening

4.3.6.1 Water softening processes are used for reducing the calcium and magnesium salts, which constitute the hardness in water. Water softening is primarily used to treat water feeding low-pressure boilers or for conditioning make up water for cooling systems.

4.3.6.2 Water softening plants will normally be specified as package plants to be purchased from a specialist vendor.

4.3.6.3 Lime-Soda Softening

1. This process causes the calcium and magnesium salts, which cause hardness, to be precipitated as sludge. This is affected by adding lime and soda ash and may be carried out at either normal raw water temperatures (cold process) or at around 212°F (100°C) (hot process). The reaction is more rapid and complete in the hot process.
2. Lime-soda softening is an economic process for use with very hard water but not very effective for water containing less than 100 to 150 ppm $CaCO_3$. The residual hardness of a filtered sample is in the range 5 to 15 ppm for the hot process and 15 to 30 ppm for the cold process.
3. These processes are rarely used nowadays.

4.3.6.4 Ion-Exchange Softening

1. The ion exchange process used for water softening is that of base exchange in a cation exchanger. The softening of water by ion exchange is by the substitution of sodium from the resin for the hardness cations, calcium and magnesium. The anions are unaffected in these reactions.
2. The process is reversible, so when the ion exchange resin is saturated with hardness salts, it is regenerated by rinsing with a solution of sodium chloride. The residual hardness of water softened by Base Exchange usually averages less than 5 ppm and is often less than 2 ppm.
3. Ion exchange plants operate batch-wise. The complete cycle of operation consists of the following four stages:
   a. Softening stage, i.e. Exchange of ions
   b. Backwashing
   c. Regeneration
   d. Rinsing
4. Manufacturers offer ion-exchange units in standard capacity ranges. Units are available for typical water throughputs of 132,000 – 13.2 million US gal/hr (500 to 50 000 m^3/h). The pressure drop across a unit is about 24.7 psi (1.7 Bar).
5. Since the units do not soften continuously, it is often necessary to provide dual units with common regeneration facilities; control of the plant may be fully automatic. Flow integrators are required at the inlets and outlets; a brine mixing and storage tank is required and a brine-metering tank must be provided for use with each regeneration.
6. When large volumes of water must be softened, large tonnages of sodium chloride must be handled and it is often preferable to locate the dissolving and storage tank below ground to facilitate the handling of salt.
7. Ion exchange is the method most commonly used for water softening. Small units may be used for domestic supplies while large industrial units are used for:
   a. Treating boiler feed water.
   b. Treating make-up for recirculating cooling water systems.
   c. Treating process water.

4.3.7 Demineralization (See Exhibit 7.8)

4.3.7.1 Mineral salts, including silica, are removed from water by ion exchange. Demineralization involves at least two ion-exchange stages. The cations, such as calcium, magnesium and sodium, are removed in a cation exchanger. The anions, such as chloride and sulfate, are removed in an anion exchanger.

4.3.7.2 Various arrangements of equipment are used, in the simplest form the two exchangers are replaced by one mixed bed exchanger; in a more complex form separate cation, anion and mixed bed units are provided, the last being used only for polishing.

4.3.7.3 Demineralized water quality is frequently expressed as specific conductance and one micromho/cm indicates a dissolved solids content of 0.5 to 0.6 ppm. Completely pure water has a conductance of approximately 0.04 micromho/cm.

4.3.7.4 Mixed bed units readily produce demineralized water having a specific conductance of 2 micromho/cm, which is suitable as make-up water to high-pressure boilers and for most process uses.

4.3.7.5 Exhibits Exhibit 7.6 shows the water quality that can be produced from the various demineralization processes.

4.3.7.6 The equipment and operating procedures used are similar to those for water softening by ion exchange. The feed water flow will usually be in the range 491 to 736 US gal/ft^2·h (20 to 30 m^3/m^2·h) of bed cross section. Backwash rates are normally set to provide a 50° 100% expansion of the beds and require flow rates in the same range, depending mainly on the resin density. Regeneration flow rates are low, being about 73.6 US gal/ft^2·h (3 m^3/m^2·h). Regeneration chemicals are usually mineral acids (HCl, H_2SO_4) and caustic soda solutions used in equivalent quantities to give an approximately neutral bulked effluent.

4.3.7.7 The detailed specifications for water demineralizing and softening plants will normally be prepared by Mechanical Engineering with liaison at an early stage with the specialist vendors. The process specifications need only therefore be brief, containing:

- Analysis of raw water with temperature and pressure.
- Specification of treated water required.
- Required average output rate from the process.
- Chemicals to be used.
- Standby equipment required.
- Effluent treating facilities required.

4.3.7.8 At times it may be desirable to purchase a complete water treating plant as a single package; additional specifications covering, for example, pretreatment facilities (clarification, etc.) and chemical dosing equipment, etc. should then be appended.

4.4 Chemical Treatment

4.4.1 Chlorine gas or chlorine compounds such as hypochlorites are added to water for sterilization of domestic water supplies and for the control of slime and algae in cooling water systems and for the control of marine growths in sea water systems.

4.4.1.1 Potable Water Treatment

1. The effectiveness of chlorine as a biocide is much reduced if it is in a form where it is combined with other substances. In treating

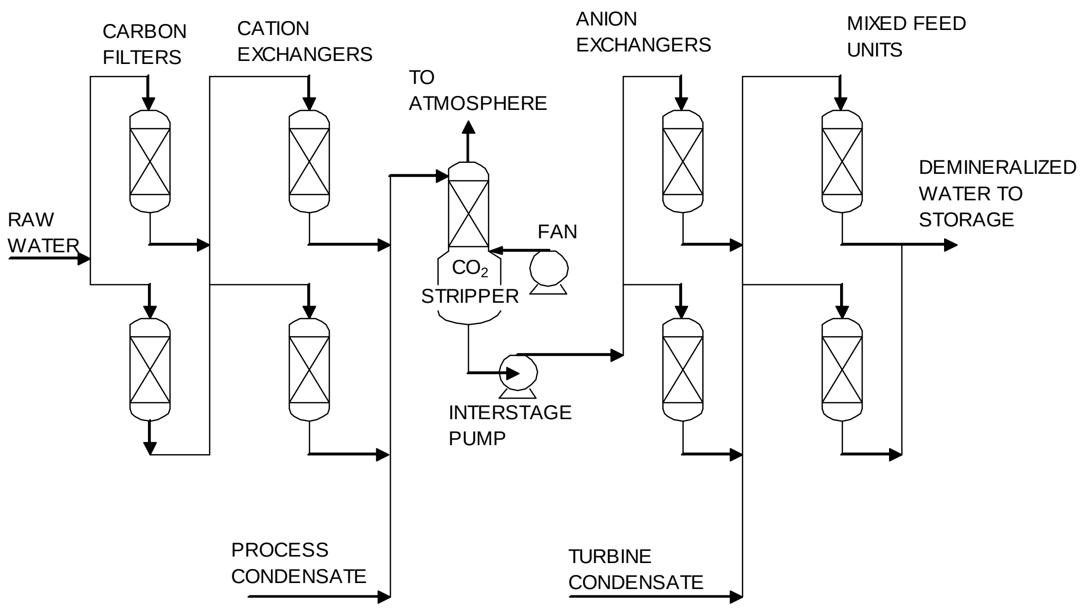
potable water the aim is to add sufficient amount to produce a residual chlorine level, which will ensure the effective killing of bacteria.

2. Normally a residual chlorine content of 0.2 to 0.5 ppm is satisfactory for drinking water after a minimum contact period of 10 minutes at or above 68°F (20°C). Higher residual values after 10 minutes may be required if the chlorine exists as a combined residual, the pH of the water exceeds 7.0 or the temperature is below 68°F (20°C).

4.4.1.2 Algae and Slime Control in Fresh Cooling Water Circuits

A residual chlorine level of 0.3 to 1.0 ppm will usually destroy most micro-organisms in cooling water. The amount of chlorine required is governed by numerous factors such as:

Quality of make-up water, e.g. organic content, suspended solids, nitrates, nitrogen, etc.
Water temperature.
Air to water ratio of the system.



4.5 The chlorine feed may be either continuous or intermittent. Continuous chlorination is expensive and it is usually possible to control equipment fouling adequately by using a fixed program of intermittent shock dosing at say 4 ppm for a number of hours. The frequency of shock dosing is best established during plant operation to give the desired results.

4.5.1 Shock injection has the advantage that it can kill slimes that become resistant to continuously maintained low levels of residual chlorine.

4.5.2 Wooden cooling tower packing are attacked by residual chlorine levels above 1 ppm.

4.5.3 Control of Marine Growths in Sea Water Systems

Sea water cooling systems are usually of the once-through type which require shock-dosing to keep chlorine consumption within acceptable limits.

4.5.4 Chlorine Dosing Equipment

4.5.4.1 Several proprietary units for dosing chlorine are available from specialist vendors. The most common type, for chlorine gas is the V-notch chlorinator, which is supplied with liquid chlorine from a cylinder or drum.

4.5.4.2 Essential components include drum handling equipment, chlorine leak detectors and alarms and a water spray system, which is commissioned automatically in the event of a leak being detected. The dosing equipment consists essentially of a chlorine vaporizer and regulating system for preparing a strong chlorine solution, which is fed into the main stream using a suitable distributor. The equipment is installed in a weather-proof housing.

4.5.4.3 Sodium hypochlorite solution may be injected using conventional solution tanks and dosing pumps. Equipment should be of lined carbon steel or stainless steel generally as the solution is strongly corrosive to mild steel.

4.5.4.4 Sodium hypochlorite solution may be produced at the required rate for dosing by using proprietary equipment for electrolysis of sea water or brine. This type of equipment is generally suitable for dosing only at continuous rates unless bulk storage for the prepared solution is provided. Cheap electricity is required to make this system competitive with the above.

4.5.5 Chemical Conditioning

4.5.5.1 Many chemicals may be added to water to improve its properties for specific uses. Many proprietary compounds may be used, for which it is advisable to consult the vendors regarding equipment for handling and injecting the required quantities.

4.5.5.2 In addition to chlorination, Section 4.4.1 above, some of the more important chemicals encountered include:

- Flocculating agents (See Exhibit 7.3)
- Corrosion inhibitors: sodium chromate, zinc-chromium complex, zinc phosphates, etc.
- Scale inhibitors: phosphates, calgon, etc.
- Oxygen scavengers: hydrazine, sodium sulfite, etc.
- Acids and alkalis for pH control.
- Algaecides and biocides.

4.5.6 Corrosion Inhibitors

4.5.6.1 In the past corrosion inhibitors were based primarily on the chromate ion and its derivatives. Chromate ion is, however, highly toxic and it is rarely used these days except in some third world countries, which do not have access to more sophisticated treatment programs.

4.5.6.2 Modern systems are typically organophosphorus compounds with additional zinc or polyphosphates added depending on the vendor selected to supply the chemicals.

4.5.7 Scale Inhibitors

Complex phosphates have been widely used to prevent scaling in cooling water systems. Phosphates are also used to prevent scale forming in boilers (See Section 4.5, CMS-830-02-80095 “Boiler Feed Water”).

4.5.8 Combined Programs

Nowadays, chemicals used to treat cooling water generally constitute part of a consolidated treatment program to cater with corrosion and scale prevention and often solids deposition as well.

4.5.9 Oxygen Scavengers

These compounds are added to boiler feed water to remove small amounts of oxygen remaining after mechanical deaeration. (See Section 4.4.3, CMS-830-02-80095 “Boiler Feed Water”).

4.5.10 pH Control

Control of the pH of circulating cooling water, boiler feed water and aqueous effluent streams is effected by injection of suitable acids or alkalis. Acid is sometimes required for adjusting the alkalinity of water treated by ion exchange. Rate of addition of acid or alkali may be controlled from a pH meter.

4.5.11 Algaecides and Biocides

Algaecides and biocides are used primarily to inhibit the growth of slimes and other organisms in circulating, open cooling water systems.

4.5.12 Equipment for Chemical Dosing

4.5.12.1 A variety of methods are used for injecting chemicals into water systems. These are summarized in Exhibit 7.7 and may be purchased as package units.

4.5.12.2 The most common type of equipment comprises a suitable mixing or dilution tank with an agitator for preparation of the solution. The injection pump takes suction directly from the tank and feeds the injection chemical into the water stream. Variable capacity proportioning pumps are usually specified. If several injection points have to be supplied simultaneously with the same chemical a multi-headed pump may be used, each head having a variable capacity which may be reset automatically or manually.

4.5.12.3 The capacity of suitable pumps usually ranges up to about 12 US gal/hr (0.05 m^3/hr). Injection systems include:

1. Shot Feed Systems

   - Pot type feeders suitable for up to 4 shots per day
   - Water jet eductors, for capacities to about 528 US gal/hr (2 m^3/hr)
   - Automatic shot feeders using timer controlled gear pumps

2. Constant Rate Feeders

   - Controlled volume pumps to about 12 US gal/hr (0.05 m^3/hr)
   - Drip Feeders (rarely used)

3. Proportional Feed Systems

   Based on flow ratio control valves

4. Dry Feeders

   Usually used when quantities of additives exceed 11 lb/hr (5 kg/hr). Volumetric Feeders have an accuracy of around 5% and are cheaper than gravimetric feeders, which have an accuracy of about 2%.

4.5.13 Steam Generation Pressure

4.5.13.1 The water quality specified should be consistent with the requirements of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems as well as the quantity of blowdown used.

4.5.13.2 In turn, the blowdown rate depends on the type of water treatment used.

4.5.13.3 Use of a small blowdown rate is desirable because it reduces the size of the blowdown piping, which can be especially significant for large plants.

4.5.13.4 The percent blowdown is computed as a percentage of the feedwater to the steam generation unit. This feedwater includes recycle condensate and condensed stripping steam. Hence, for the treated water specification to be rigorously correct, the quality of the recycle condensate and condensed stripping steam must be assumed to be the same as the treated makeup water. This is a convenient assumption since it permits the required water quality to be estimated without the necessity of a heat-and-material balance. It also provides a conservative basis that we would normally want to keep as a design margin. However, if it becomes important, the treated water specification can be based on the actual heat-and-material balance, using the actual makeup water quantity in relation to the actual blowdown used.

4.5.13.5 Exhibits 7.8 through 7.15 present common specifications for required water quality for various pressure steam systems as a function of blowdown rate.

5.0 REFERENCES

CMS-720-01-FM-00020	Business Glossary
CMS-720-01-FM-00021	Technical Glossary

6.0 TERMINOLOGY

None

7.0 EXHIBITS

Exhibit 7.1	Settling Time for Particles of Water
Exhibit 7.2	Characteristics of Methods for Suspended Solids, Turbidity and Color Removal
Exhibit 7.3	Coagulation
Exhibit 7.4	Typical Coagulants for Some Typical Water Sources
Exhibit 7.5	Characteristics of Granular Media Filters
Exhibit 7.6	Water Quality from Demineralization Plants
Exhibit 7.7	Methods of Feeding for Common Treatment Chemicals
Exhibit 7.8	Water Quality Requirements for 0 to 300 Psig (0 To 21 Barg) Steam Systems
Exhibit 7.9	Water Quality Requirements for 301 to 450 Psig (21 To 31 Barg) Steam Systems
Exhibit 7.10	Water Quality Requirements for 451 to 600 Psig (31 To 41 Barg) Steam Systems
Exhibit 7.11	Water Quality Requirements for 601 to 750 Psig (41 To 52 Barg) Steam Systems
Exhibit 7.12	Water Quality Requirements for 751 to 900 Psig (52 To 62 Barg) Steam Systems
Exhibit 7.13	Water Quality Requirements for 901 to 1000 Psig (62 To 69 Barg) Steam Systems

EXHIBIT 7.1 **SETTLING TIME FOR PARTICLES OF WATER**

Particle Diameter* Microns	Approximate time to settle 1 ft (0.3m) in still water at 50°F (10°C)	Typical Material
10,000	0.5 seconds	Gravel
1,000	2 seconds	Coarse Sand
100	1 minute	Fine Sand
10	1 hour	Silt
1	100 hours	Bacteria
0.1	500 days	Clay
0.01	150 years	Colloids

* Particle density is assumed to be 165.43 lb/ft ^{3} (2.65 g/cm ^{3}), e.g. approximate average for sand and silt

EXHIBIT 7.2 **PAGE 1 OF 1**

CHARACTERISTICS OF METHODS FOR SUSPENDED SOLIDS, TURBIDITY AND COLOR REMOVAL

Method	Effect	Quality of Water Produced	Remarks
Coagulation / Flocculation	Small particles and colloidal material coagulate into larger particles	If followed by settlement and/or rapid filtration can give color < 10 Hazen units and turbidity < 5 ppm expressed as silica	Water must Usually be filtered to remove last traces of flocculation. Chemical dosage must be carefully controlled.
Settlement	Removes coarse suspended solids of size >0.01mm. Prolonged storage may remove finer particles and bacteria.	Still colored. Turbidity may be reduced by 90%	Preliminary prior to settlement coagulation is common for river waters.
Filtration	Rapid filters remove small particles but not colloidal materials unless coagulant has been used. Slow filters remove small particles and some colloidal material and can affect the nature of the dissolved solids.	Varies with fineness of filter material and whether coagulation has been used. Turbidity reduced. Color removal depends upon coagulant used.	Generally used after coagulation.
Treatment with Active Carbon	Organic coloring matter adsorbed from the water.	Color reduced. Taste and odor removed. Little direct effect on turbidity.	If powered material used, treated water must be filtered. Granular material must be reactivated and sterilized at intervals. Sometimes used after coagulation and filtration.
Oxidation	Organic coloring matter destroyed chemically.	Color reduced. Taste and odor often removed. Little effect on turbidity.	Too expensive for general use. May be used for removing residue color after coagulation and filtration. Some color removal accompanies sterilization with chlorine.

EXHIBIT 7.3 **COAGULATION**

Coagulant	Purpose	Normal Dosage ppm	pH Range	Charge	Precipitate Produced	Remarks
Aluminum sulfate (Filter alum)	Main coagulant. To assist coagulation with sodium aluminate	5 to 50 2 to 20	5.5 to 8.0 optimum 6 to 7	Positive	Hydrated alumina	Floc is relatively light and will generally not settle against an upward flow greater than about 3 ft/hr. Higher rates obtainable, however, in sludge-blanket type plant.
Sodium aluminate	Main coagulant. To assist coagulation with aluminum sulfate	5 to 15 2 or 0.1-0.05 of alum dosage	4.0 to 7.0	Negative	Hydrated alumina	Floc formed by double coagulation usually coarser than that from filter alum alone. Aluminate should be added about 2 minutes before alum. Sometimes useful as main coagulant for surface waters of variable compositions.
Ferrous sulfate	Main coagulant	5 to 50	4.0 to 11.0	Positive	Hydrated ferric oxide	At low pH values oxidation to ferric state may not be complete and treated waste may contain residual iron. Floc heavier than that of alumina and settles faster. Rarely used.
Ferric chloride	Main coagulant	5 to 50	4.0 to 11.0	Positive	Hydrated ferric oxide	Floc heavier than that of alumina and settles faster. Rarely used.
Ferric chloride / ferric sulfate	Main coagulant	5 to 50	4.0 to 11.0	Positive	Hydrated ferric oxide	Floc heavier than that of alumina and settles faster. Reagent solution prepared as required by passing chlorine into ferrous sulfate solution. Rarely used.
Activated silica gel	To assist coagulation with alumina sulfate	1 to 15 (as SiO_2)	5.5 to 8.0	Negative	Hydrated silica	Used as a coagulant aid in conjunction with aluminum sulfate. Rapidly produces strong coarse floc which settles quickly. May give effective treatment during periods of spate and at low temperatures
Bentonite or other clays	Main coagulant or to assist coagulation with aluminum sulfate	2 to 12	-	-	-	Increases density of loc formed from filter alum and thus gives faster settling. Should be added to water before filter alum.
Calcium carbonate	To assist coagulation with aluminum sulfate	-	-	-	-	Increases density of floc formed from filter alum and thus gives faster settling. Should be added to water before filter alum.
Proprietary Poly electrolytes	Main coagulant Or in conjunction with alum.	1 0.5 to 1	-	-	-	Improves stability of flocculation. Should be used with inorganic flocculants for removal of low solids/turbidity.

EXHIBIT 7.4 TYPICAL COAGULANTS FOR SOME TYPICAL WATER SOURCES

Types of Water	Characteristics of Water	Coagulants Generally Suitable	Recommended range of pH Values for Coagulation	Remarks
Upland surface waters	Hardness: low pH Value: 5.0 to 6.5 Alkalinity*: 50 ppm Color: high Turbidity low	Aluminum sulfate and alkali	5.0 to 7.0	Add sodium aluminate or activated silica sol to assist coagulation
River waters of pH value 6.2 to 7.4	Hardness: med to high Alkalinity*: to 200 ppm Color: medium Turbidity may be hi	Aluminum sulfate alone	5.0 to 7.0	Generally more difficult to treat than upland surface waters. Use activated silica gel to assist coagulation.
River waters of pH value 7.4 to 8.4	Hardness: med to high Alkalinity*: to 200 ppm Color: medium Turbidity may be hi	Aluminum sulfate after pretreatment with: i. Sulfuric acid or ii. Precipitated chalk or iii. Activated silica gel Alternately, use iron salts or aluminum sulfate alone	Aluminum sulfate: 6.0 to 7.0 Iron salts: 9.0	Generally more difficult to treat than upland surface waters. Use activated silica gel to assist coagulation.
Well waters	Hardness: med to high Alkalinity*: to 200 ppm or more pH: 7.0 to 7.8 Color: low Turbidity low	Aluminum sulfate in large doses with or without sulfuric acid. Alternately, use iron salts.	Aluminum sulfate: 6.0 to 7.5 Iron salts: 9.0	Use activated silica gel to assist coagulation.

EXHIBIT 7.5 **CHARACTERISTICS OF GRANULAR MEDIA FILTERS**

Characteristics	Gravity Filters		Pressure Filters
	Slow	Rapid	
Rate of filtration	2.56 gal/f^{t2}/hr (0.1 m^3/m^2hr)	5-10 gal/ft^{2}hr (0.2-0.4 m^3/m^2hr)	5-10 gal/ft^{2}hr or higher (0.2-0.4 m^3/m^2hr) or higher
Effective size of filter medium*	About 0.35mm	0.4-0.6mm when used with coagulants; 0.8mm when used as course strainers	0.4-0.6mm when used with coagulants; 0.8mm when used as course strainers
Uniformity coefficient of filter medium	2.5	1.7	1.7
Method of cleaning	Scraping	Backwashing	Backwashing
Frequency of cleaning	Occasionally	Every 1-7 days	Every 1-7 days
Water wash usage	-	1-5% of total filtered water	1-5% of total filtered water
Space occupied	Large	Much less	Least
Liability of "breakthrough" of suspended matter	Little or none	Appreciable, but less than with pressure filter	Appreciable, greater than with rapid gravity filter
Uniformity of production of highest quality water	Good, except just after scraping	Good	Not quite so good as rapid gravity filter
Suitability for:			
Use with coagulants	No	Yes	Yes
Operations under mains pressure	No	No	Yes
Easy addition of extra units	No	No	Yes
Insulation for use with hot water	No	No	Yes
Use without re-pumping	No	No	Yes
Visual observation of operation	Yes	Yes	No

EXHIBIT 7.6 **WATER QUALITY FROM DEMINERALIZATION PLANTS**

Property	Process				
	Raw Water	A	B	C	D
Conductivity (µs/cm)	540	25	17	0.5	0.1
Alkalinity (total) (mg/l)*	222	10	10	-	-
Bicarbonate (mg/l)*	222	3	-	-	-
Sulfate (mg/l)*	72	< 1	< 1	< 0.1	-
Chloride (mg/l)*	44	< 1	< 1	< 0.1	-
Nitrate (mg/l)*	4	< 1	< 1	< 0.1	-
Silica (mg/l)*	10	10	< 0.5	< 0.2	< 0.02
Calcium (mg/l)*	264	-	-	-	-
Magnesium (mg/l)*	48	-	-	-	-
Sodium (mg/l)*	30	< 5	< 5	< 0.2	< 0.02
Total Hardness (mg/l)*	312	< 1	< 1	-	-
Dissolved solids (mg/l)	376	< 15	< 5	< 1	-

*As $CaCO_3$

Processes

A Strong acid + weak base

B Strong acid + weak base + degassing tower + strong base

C Mixed Bed

D Strong acid + weak base + degassing + strong base + mixed bed

EXHIBIT 7.7 METHODS OF FEEDING FOR COMMON TREATMENT CHEMICALS

Chemical	Process Use	Type Feeders	Points of Application
Alum	Coagulation; Color removal	Dry Pot type Proportioning Double Orifice Decanting Pumps	Coagulation and sedimentation systems, prior to pressure filters for removal of suspended matter and oil.
Sodium Aluminate	Coagulation	Dry Decanting Pumps Shot Feeders	Usually added with soda ash to softeners. Used to some extent for internal boiler water treatment.
Polyelectrolytes	Coagulation	Pumps	As primary coagulants, to chemical mixing section. As coagulant aid, to flume after primary chemical mixing or to flocculation zone of clarifier.
Ferric Salts	Coagulation; Color removal; Oil removal	Dry Decanting Double Orifice Pumps	Prior to coagulation and filtration systems
Lime (Hydrated)	pH adjustment; Softening	Dry Decanting Special (slurry) pumps	Prior to coagulation systems; to softeners; to treated water lines for adjustment of pH.
Soda Ash (Crystalline)	pH adjustment	Pot Type proportioning	Prior to pressure filters.
Soda Ash (Anhydrous)	pH and alkalinity adjustment; Softening	All types of wet and dry feeders	To domestic systems. Feedline softeners, coagulation and filtration systems; boilers
Caustic Soda	pH adjustment; Alkalinity adjustment; Softening	All types of solution feeders	To softeners; oil removal systems; domestic water systems; boilers.
Acid Feed (Sulfuric Acid) (Phosphoric Acid)	pH adjustment; Reduction of alkalinity	Decanting Pumps Gravity Ejectors	Treated water lines, prior to degassifiers or deaerators; H3PO4 to phosphate softeners (for both softening and alkalinity reduction); tow sump or basin.
Surface Active Phosphates	Prevent calcium carbonate deposits; eliminate "red water"	All types of proportional solution feeders	Treated water lines
Orthophosphates (Monosodium Phosphate) (Disodium Phosphate) (Trisodium Phosphate)	Prevent scale in boilers	Pumps Shot Feeders	Added continuously to boiler drums; shot fed to drums or boiler feedlines.
Chelating Agents	Prevent scale in boilers and economizers	Pumps	Added continuously to feedline on pressure side of feed pump.
Sodium Sulfite	Prevent corrosion due to oxygen in boilers, feedlines, economizers	All types, continuous solution feeders	Storage section of deaerator; suction or pressure side of BFW pumps.
Sodium Nitrate	Inhibition of embrittlement	All types of solution feeders	Any point in boiler feedlines or directly to boilers.
Amines and related organic compounds	Prevention of return line corrosion	Shot feeders Pumps	Application depends upon material used. Some materials may be added to boilers and volatize with steam; others are added to steam line directly requiring pumps.

EXHIBIT 7.8

WATER QUALITY REQUIREMENTS FOR 0 TO 300 PSIG (0 TO 21 BARG) STEAM SYSTEMS

The quality of boiler feed water should be consistent with the standards of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems. Based on these standards, CB&I's estimate of the minimum water quality requirement for a 0 to 300 psig (0 to 21 barg) steam system is given below. The allowable concentration of some impurities depends on the blowdown percentage, as noted below.

Dissolved Oxygen (mg/L, max before oxygen scavenger addition)	0.040*
Carbon Dioxide (mg/L as free titratable CO_2)	none*
Total iron (mg/L Fe) maximum	0.100
Copper (mg/L Cu) maximum	0.050
Total Hardness (mg/L $CaCO_3$) maximum	0.30
pH range @ 77°F (25°C)	7.5 to 10.0
Non-volatile TOC (mg/L C) maximum	1.0
Oily matter (mg/L) maximum	1.0
Free chlorine (mg/L) maximum	below detectable limit
Sulfur	none

* after degasification

Blowdown percent	**5**	**3**	**2**	**1**	
Silica (mg/L SiO2) maximum	6.25	3.75	2.5	1.25	125 maximum in steam drum
Total alkalinity (mg/L $CaCO_3$) maximum	17.5	10.5	7	3.5	350 maximum in steam drum
Specific Conductance [micromho/cm @ 77°F (25°C)] maximum	175	105	70	35	3500 maximum in steam drum
Total Solids (mg/L) maximum	175	105	70	35	3500 maximum in steam drum
Suspended solids (mg/L) maximum	15	9	6	3	300 maximum in steam drum

WATER QUALITY REQUIREMENTS FOR 301 TO 450 PSIG (21 TO 31 BARG) STEAM SYSTEMS

The quality of boiler feed water should be consistent with the standards of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems. Based on these standards, CB&I's estimate of the minimum water quality requirement for a 301 to 450 psig (21 to 31 barg) steam system is given below. The allowable concentration of some impurities depends on the blowdown percentage, as noted below.

Dissolved Oxygen (mg/L, max before oxygen scavenger addition)	0.040*
Carbon Dioxide (mg/L as free titratable CO_2)	none*
Total iron (mg/L Fe) maximum	0.050
Copper (mg/L Cu) maximum	0.025
Total Hardness (mg/L $CaCO_3$) maximum	0.30
pH range @ 77°F (25°C)	7.5 to 10.0
Non-volatile TOC (mg/L C) maximum	1.0
Oily matter (mg/L) maximum	1.0
Free chlorine (mg/L) maximum	below detectable limit
Sulfur	none

* after degasification

Blowdown percent	5	3	2	1	
Silica (mg/L SiO2) maximum	4.5	2.7	1.8	0.9	90 maximum in steam drum
Total alkalinity (mg/L $CaCO_3$) maximum	15	9	6	3	300 maximum in steam drum
Specific Conductance [micromho/cm @ 77°F (25°C)] maximum	150	90	70	30	3000 maximum in steam drum
Total Solids (mg/L) maximum	150	90	70	30	3000 maximum in steam drum
Suspended solids (mg/L) maximum	12.5	7.5	5	2.5	250 maximum in steam drum

EXHIBIT 7.10

WATER QUALITY REQUIREMENTS FOR 451 TO 600 PSIG (31 TO 41 BARG) STEAM SYSTEMS

The quality of boiler feed water should be consistent with the standards of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems. Based on these standards, CB&I's estimate of the minimum water quality requirement for a 451 to 600 psig (31 to 41 barg) steam system is given below. The allowable concentration of some impurities depends on the blowdown percentage, as noted below.

Dissolved Oxygen (mg/L, max before oxygen scavenger addition)	0.007*
Carbon Dioxide (mg/L as free titratable CO_2)	none*
Total iron (mg/L Fe) maximum	0.030
Copper (mg/L Cu) maximum	0.020
Total Hardness (mg/L $CaCO_3$) maximum	0.20
pH range @ 77°F (25°C)	7.5 to 10.0
Non-volatile TOC (mg/L C) maximum	0.5
Oily matter (mg/L) maximum	0.5
Free chlorine (mg/L) maximum	below detectable limit
Sulfur	none

* after degasification

Blowdown percent	5	3	2	1	
Silica (mg/L SiO2) maximum	2	1.2	0.8	0.4	40 maximum in steam drum
Total alkalinity (mg/L $CaCO_3$) maximum	12.5	7.5	5	2.5	250 maximum in steam drum
Specific Conductance [micromho/cm @ 77°F (25°C)] maximum	125	75	50	25	2500 maximum in steam drum
Total Solids (mg/L) maximum	125	75	50	25	2500 maximum in steam drum
Suspended solids (mg/L) maximum	15	4.5	3	1.5	150 maximum in steam drum

WATER QUALITY REQUIREMENTS FOR 601 TO 750 PSIG (41 TO 52 BARG) STEAM SYSTEMS

The quality of boiler feed water should be consistent with the standards of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems. Based on these standards, CB&I's estimate of the minimum water quality requirement for a 601 to 750 psig (41 to 52 barg) steam system is given below. The allowable concentration of some impurities depends on the blowdown percentage, as noted below.

Dissolved Oxygen (mg/L, max before oxygen scavenger addition)	0.007*
Carbon Dioxide (mg/L as free titratable CO_2)	none*
Total iron (mg/L Fe) maximum	0.025
Copper (mg/L Cu) maximum	0.020
Total Hardness (mg/L $CaCO_3$) maximum	0.20
pH range @ 77°F (25°C)	7.5 to 10.0
Non-volatile TOC (mg/L C) maximum	0.5
Oily matter (mg/L) maximum	0.5
Free chlorine (mg/L) maximum	below detectable limit
Sulfur	none

* after degasification

Blowdown percent	5	3	2	1	
Silica (mg/L SiO2) maximum	1.5	0.9	0.6	0.3	30 maximum in steam drum
Total alkalinity (mg/L $CaCO_3$) maximum	10	6	4	2	200 maximum in steam drum
Specific Conductance [micromho/cm @ 77°F (25°C)] maximum	100	60	40	20	2000 maximum in steam drum
Total Solids (mg/L) maximum	100	60	40	20	2000 maximum in steam drum
Suspended solids (mg/L) maximum	5	3	2	1	100 maximum in steam drum

EXHIBIT 7.12

WATER QUALITY REQUIREMENTS FOR 751 TO 900 PSIG (52 TO 62 BARG) STEAM SYSTEMS

The quality of boiler feed water should be consistent with the standards of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems. Based on these standards, CB&I's estimate of the minimum water quality requirement for a 751 to 900 psig (52 to 62 barg) steam system is given below. The allowable concentration of some impurities depends on the blowdown percentage, as noted below.

Dissolved Oxygen (mg/L, max before oxygen scavenger addition)	0.007*
Carbon Dioxide (mg/L as free titratable CO_2)	none*
Total iron (mg/L Fe) maximum	0.020
Copper (mg/L Cu) maximum	0.015
Total Hardness (mg/L $CaCO_3$) maximum	0.10
pH range @ 77°F (25°C)	7.5 to 10.0
Non-volatile TOC (mg/L C) maximum	0.5
Oily matter (mg/L) maximum	0.5
Free chlorine (mg/L) maximum	below detectable limit
Sulfur	none

* after degasification

Blowdown percent	5	3	2	1	
Silica (mg/L SiO2) maximum	1	0.6	0.4	0.2	20 maximum in steam drum
Total alkalinity (mg/L $CaCO_3$) maximum	7.5	4.5	3	1.5	150 maximum in steam drum
Specific Conductance [micromho/cm @ 77°F (25°C)] maximum	75	45	30	15	1500 maximum in steam drum
Total Solids (mg/L) maximum	75	45	30	15	1500 maximum in steam drum
Suspended solids (mg/L) maximum	3	1.8	1.2	0.6	60 maximum in steam drum

EXHIBIT 7.13

WATER QUALITY REQUIREMENTS FOR 901 TO 1000 PSIG (62 TO 69 BARG) STEAM SYSTEMS

The quality of boiler feed water should be consistent with the standards of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems. Based on these standards, CB&I's estimate of the minimum water quality requirement for a 901 to 1000 psig (62 to 69 barg) steam system is given below. The allowable concentration of some impurities depends on the blowdown percentage, as noted below.

Dissolved Oxygen (mg/L, max before oxygen scavenger addition)	0.007*
Carbon Dioxide (mg/L as free titratable CO_2)	none*
Total iron (mg/L Fe) maximum	0.020
Copper (mg/L Cu) maximum	0.015
Total Hardness (mg/L $CaCO_3$) maximum	0.05
pH range @ 77°F (25°C)	8.5 to 9.5
Non-volatile TOC (mg/L C) maximum	0.2
Oily matter (mg/L) maximum	0.2
Free chlorine (mg/L) maximum	below detectable limit
Sulfur	none

* after degasification

Blowdown percent	**5**	**3**	**2**	**1**	
Silica (mg/L SiO2) maximum	0.4	0.24	0.16	0.08	8 maximum in steam drum
Total alkalinity (mg/L $CaCO_3$) maximum	5	3	2	1	100 maximum in steam drum
Specific Conductance [micromho/cm @ 77°F (25°C)] maximum	50	30	20	10	1000 maximum in steam drum
Total Solids (mg/L) maximum	62.5	37.5	25	12.5	1250 maximum in steam drum
Suspended solids (mg/L) maximum	2	1.2	0.8	0.4	40 maximum in steam drum

WATER QUALITY REQUIREMENTS FOR 1001 TO 1500 PSIG (69 TO 103 BARG) STEAM SYSTEMS

The quality of boiler feed water should be consistent with the standards of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems. Based on these standards, CB&I's estimate of the minimum water quality requirement for a 1001 to 1500 psig (69 to 103 barg) steam system is given below. The allowable concentration of some impurities depends on the blowdown percentage, as noted below.

Dissolved Oxygen (mg/L, max before oxygen scavenger addition)	0.007*
Carbon Dioxide (mg/L as free titratable CO_2)	none*
Total iron (mg/L Fe) maximum	0.010
Copper (mg/L Cu) maximum	0.010
Total Hardness (mg/L $CaCO_3$) maximum	ND*
pH range @ 77°F (25°C)	9.0 to 9.6
Non-volatile TOC (mg/L C) maximum	0.2
Oily matter (mg/L) maximum	0.2
Free chlorine (mg/L) maximum	below detectable limit
Sulfur	none

* after degasification, ND=none detectable

Blowdown percent	**5**	**3**	**2**	**1**	
Silica (mg/L SiO2) maximum	0.1	0.06	0.04	0.02	2 maximum in steam drum
Total alkalinity (mg/L $CaCO_3$) maximum	5	3	2	1	100 maximum in steam drum
Specific Conductance [micromho/cm @ 77°F (25°C)] maximum	7.5	4.5	3	1.5	150 maximum in steam drum
Total Solids (mg/L) maximum	50	30	20	10	1000 maximum in steam drum
Suspended solids (mg/L) maximum	1	0.6	0.4	0.2	20 maximum in steam drum

WATER QUALITY REQUIREMENTS FOR 1501 TO 2000 PSIG (103 TO 138 BARG) STEAM SYSTEMS

The quality of boiler feed water should be consistent with the standards of the American Boiler Manufacturer's Association and the ASME Research Committee on Water in Thermal Power Systems. Based on these standards, CB&I's estimate of the minimum water quality requirement for a 1501 to 2000 psig (103 to 138 barg) steam system is given below. The allowable concentration of some impurities depends on the blowdown percentage, as noted below.

Dissolved Oxygen (mg/L, max before oxygen scavenger addition)	0.007*
Carbon Dioxide (mg/L as free titratable CO_2)	none*
Total iron (mg/L Fe) maximum	0.010
Copper (mg/L Cu) maximum	0.010
Total Hardness (mg/L $CaCO_3$) maximum	ND*
pH range @ 77°F (25°C)	9.0 to 9.6
Non-volatile TOC (mg/L C) maximum	0.2
Oily matter (mg/L) maximum	0.5
Free chlorine (mg/L) maximum	below detectable limit
Sulfur	none

* after degasification, ND=none detectable

Blowdown percent	5	3	2	1	
Silica (mg/L SiO2) maximum	0.05	0.03	0.02	0.01	1 maximum in steam drum
Total alkalinity (mg/L $CaCO_3$) maximum	5	3	2	1	100 maximum in steam drum
Specific Conductance [micromho/cm @ 77°F (25°C)] maximum	5	3	2	1	100 maximum in steam drum
Total Solids (mg/L) maximum	37.5	22.5	15	7.5	750 maximum in steam drum
Suspended solids (mg/L) maximum	0.5	0.3	0.2	0.1	10 maximum in steam drum