

CHAPTER V

DESIGN OF WATER TREATMENT PROCESSES

A. INTRODUCTION

This chapter describes considerations involved in the design of water treatment processes. Through appropriate selection and design of individual processes and their integration into treatment sequences to suit the nature and quality of the raw water supply, and with good operating practices, it is possible to produce finished water for consumers that will comply fully with the biological, chemical, physical and radiological quality requirements of Kansas drinking water regulations. The National Primary Drinking Water Standards adopted by Kansas to date are referenced by the appropriate Kansas Administrative Regulation (KAR) designations. Those National Primary Drinking Water Standards that have not yet been adopted are referenced with the appropriate Code of Federal Regulations (CFR) designations, which will be superseded by the appropriate KAR designations as these standards are adopted.

The requirements of the drinking water regulations consist of MCLs and treatment techniques. These requirements and the analytical methods for measuring contaminant levels are summarized in KAR 28-15 and KAR 28-15a. Primary MCLs and treatment technique requirements are related to public health and are enforceable whereas secondary MCLs (SMCLs) address aesthetic qualities relating to the public acceptance of drinking water and are not enforceable. A treatment technique requirement is established instead of an MCL when routine monitoring of one or more contaminants is not economically or technologically feasible.

The USEPA designates best available technologies (BATs) for the purpose of: 1) demonstrating that a technology exists to achieve compliance with a particular MCL or treatment technique requirement; 2) providing a basis for estimating the cost associated with a particular regulation, thereby demonstrating that the costs are reasonable (relative to the benefits, at least for a typical large PWSS); and 3) to serve as a basis for granting variances (time extensions). PWSSs may use other treatment technologies to comply with an MCL or treatment technique requirement, if approved by the reviewing authority, but must use BAT or an equally effective technology when applying for a variance.

Kansas drinking water regulations are based on federal regulations promulgated by USEPA under the authority of the SDWA. KDHE will revise the Kansas regulations when the federal drinking water regulations are revised. Therefore, PWSSs should stay abreast with these changes, anticipate their impact on the ability of existing treatment facilities to comply with the primary drinking water regulations (i.e., both MCLs and treatment techniques), and plan to upgrade facilities when necessary. In undertaking this task, PWSSs should consider

alternate water sources and phased construction of process trains so that additions or changes can be made with minimal interruption to the treatment system and at a lower cost to the PWSS.

In some cases, a new treatment technology, for which KDHE has not developed specific design requirements, may be the best option for achieving compliance with a particular MCL or treatment technique, especially one that has been recently promulgated. Requirements for approval of such processes are described in Subsection A.5 of Chapter III.

B. OVERVIEW OF DESIGN REQUIREMENTS FOR MEETING THE PRIMARY DRINKING WATER REGULATIONS

1. GENERAL REQUIREMENTS – The design engineer generally has a number of treatment options to choose from, but at a minimum the treatment system must include those processes needed to produce water in compliance with the regulations. Treatment process requirements depend on:
 - a. The type of system and, in some cases, the number of customers served;
 - b. Whether the contaminants being removed are MCL- or treatment-technique-controlled (Section A); and
 - c. The requirements of the current drinking water regulations.
2. VOC REMOVAL
 - a. If the concentration of a VOC will exceed its MCL (KAR 28-15a-61) in the absence of treatment, a community or non-transient non-community system must implement the necessary treatment to reduce the concentration of the VOC to a level that is less than its respective MCL.
 - b. The BATs for all VOCs except vinyl chloride are packed-tower air stripping (Section P) and adsorption on GAC (Section Q). Packed-tower air stripping is the only BAT for vinyl chloride.
3. FLUORIDE CONTROL
 - a. The American Dental Association endorses fluoridation of community water supplies as being safe and effective for preventing tooth decay. The beneficial level of fluoride is known to be approximately 1 mg/L. Public water supply systems with a properly designed and operated fluoridation system (Section T) can readily comply with both the MCL and the SMCL for fluoride, 4 mg/L and 2 mg/L, respectively (KAR 28-15a-62)(40 CFR 143.3). Where the level of fluoride is excessive, treatment is required to meet the MCL and encouraged to meet the SMCL.

- b. A BAT has not been specified for fluoride removal. Central treatment using activated alumina adsorption (Rubel, 1984) or reverse osmosis (Section S) is an option for fluoride removal; and excess-lime softening (Section K) can be used to remove fluoride from hard waters containing an adequate concentration of magnesium. Design requirements for activated alumina adsorption are described in Section R; but due to the lack of experience with this process in Kansas, it will be treated in the same manner as a new process (Subsection A.5 of Chapter III).

4. FILTRATION AND DISINFECTION FOR PATHOGEN REMOVAL AND INACTIVATION – The treatment techniques of filtration (Section J) and disinfection (Section M) are used, in addition to the MCL for coliforms (KAR 28-15a-63), to ensure the microbiological quality of drinking water and to specifically address *Giardia*, *Cryptosporidium*, *Legionella*, HPC bacteria, viruses, and turbidity (KAR 28-15a-21, 70-76, 170-175)(40 CFR 141.400 et seq.)(40 CFR 141.600 et seq.)(40 CFR 141.700 et seq.).

- a. Disinfection is required for all PWSSs (KAR 28-15-19). All PWSSs that use surface water or GWUI must provide pathogen removal and inactivation by means of filtration and disinfection (KAR 28-15a-70), respectively.
- b. A conventional filtration system (KAR 28-15a-2) consists of coagulation (Section F), flocculation (Section G), sedimentation (Section H), and filtration (Section J) followed by protected storage (Chapter VI). A conventional filtration system can also include precipitative softening to remove hardness (Section K). Non-conventional filtration options include direct filtration, slow sand filtration, and membrane processes (Section S). The performance requirements for filtration are specified in KAR 28-15a-73.
- c. PWSSs using surface water or GWUI must achieve a 3-log removal and/or inactivation of *Giardia lamblia*, a 4-log removal and/or inactivation of viruses, and a 2-log removal of *Cryptosporidium*. Additional removal or inactivation of *Cryptosporidium* may be required, depending on the quality of the source water (40 CFR 141.700). Removal credits are assigned to various filtration processes, and the balance of the required removal must be achieved by disinfection. Residual disinfectant levels must meet both minimum (KAR 28-15a-72) and maximum (KAR 28-15a-65) values. (Maximum residual disinfectant levels are referred to as MRDLs.) If a MRDL can not be met because a higher dosage is needed to maintain the required minimum residual, additional treatment will be needed to reduce disinfectant demand. The disinfection process is monitored by measuring disinfectant residuals at the plant and in the distribution system (KAR 28-15a-74 and 28-15-19); by checking CT values (Section M); and by analyzing samples of finished water at the plant and in the distribution system for coliforms (KAR 28-15a-21).

- d. No variances from the total coliform, filtration, and disinfection requirements are allowed for PWSSs using surface water or GWUI. Exemptions are allowed for all requirements except total coliforms and disinfectant residual requirements at the point of entry to the distribution system.

5. CORROSION CONTROL FOR LEAD AND COPPER

- a. Community and non-transient, non-community PWSSs are required to comply with the lead and copper rule (KAR 28-15a-80 through 91). The lead and copper rule requires PWSSs to optimize corrosion control treatment to minimize lead and copper concentrations at the users' taps while ensuring that the treatment does not cause the system to violate another primary drinking water standard (KAR 28-15a-2)(KAR 28-15a-81 through 82). All PWSSs serving more than 50,000 customers are required to conduct corrosion control studies unless they can demonstrate to KDHE that corrosion control has been optimized. For smaller PWSSs, the requirement for corrosion control studies is triggered by lead and copper action levels.
- b. Treatment technique requirements are triggered when action levels for lead and copper are exceeded and they consist of optimized corrosion control, source water treatment, public education, and replacement of lead service lines under the direct control of the PWSS. Treatment processes able to remove particulate or dissolved lead and copper from source water include coagulation and filtration (Sections F and J), lime softening and ion exchange (Section K), and membrane processes (Section S). However, elevated lead and copper concentrations in the distribution system are generally attributable to corrosion rather than to elevated concentrations in raw water, and treating the raw water may only make the problem worse if the water is not properly stabilized. Therefore, stabilization (i.e., optimized corrosion control) is expected to be not only the most appropriate treatment process but also the only effective process. Stabilization is addressed in Section L.

6. IOC AND SOC REMOVAL

- a. Community and non-transient, non-community PWSSs are required to meet the MCLs for IOCs and SOCs (KAR 28-15a-11 and 62); but the MCL for fluoride applies only to community water systems. The MCLs for nitrate, nitrite, and the sum of nitrate plus nitrite also apply to transient non-community water systems.
- b. KAR 25-15a-61 and KAR 28-15a-62 list the BATs for all IOCs and SOCs except acrylamide and epichlorohydrin (for which specific dosage limitations are specified in KAR 28-15a-111) and fluoride (for which no BAT is listed). DBPs are not regulated as SOCs and are addressed in Subsection B.8.

- c. Numerous contaminants are regulated as IOCs or SOCs, and most of the processes addressed in later sections of this chapter are BATs for one or more of these contaminants. IOCs and SOCs present as particles, adsorbed onto particles, or able to be incorporated into floc particles formed during water treatment can be removed by coagulation and flocculation (Sections F and G), or softening (Section K), followed by sedimentation (Section H) and filtration (Section J). Membrane processes (Section S) effectively remove particulate contaminants, and reverse osmosis can also remove many contaminants present in dissolved form.

Adsorption on GAC (Section Q) is a BAT for most of the SOCs and for mercury; and packed-tower air stripping (Section P) is a BAT for the more volatile SOCs. Although a number of SOCs can be chemically oxidized using one or more of the chemicals used for disinfection (Section M), oxidation is specified as a BAT only for glyphosate. Oxidation of SOCs usually produces byproducts; and although the byproducts are generally expected to be less toxic than the parent compounds, there is rarely enough information available to fully assess the risks they pose to human health. Therefore, physical removal of SOCs is generally preferred over oxidation; however, oxidation is an effective way to address a number of organic chemicals that, in trace amounts, cause taste and odor problems (Section N) but are not toxic.

Other processes identified as BAT for selected IOCs include adsorption on activated alumina, ion exchange, and electrodialysis (Section R). KDHE considers these new processes (Subsection A.5 of Chapter III), but ion exchange systems must meet the applicable requirements for ion-exchange softening (Section K). Ion exchange and reverse osmosis are BATs for nitrate and nitrite; biological removal of nitrate and nitrite is not a BAT, but may be proposed as a new process.

Seven BATs and twelve “small system compliance technologies” have been identified for arsenic. These technologies are for removal of As(V), and pre-oxidation may be necessary to convert As(III) to As(V) (KAR 28-15a-62). A number of these technologies are new processes (Subsection A.5 of Chapter III); and some of the technologies for small systems involve point-of-use treatment, which is generally not favored over centralized treatment for a PWSS but may be economically justified for certain small systems. Additional information regarding these technologies, their removal efficiencies, and their design can be found in Section R, the final Arsenic Rule (USEPA, 2001) and in various other publications (e.g., USEPA 2000a, 2002, 2003a, and 2006b). Use of point-of-entry devices is subject to KDHE approval and the provisions of KAR 28-15a-100.

7. RADIONUCLIDE REMOVAL

- a. Community PWSSs are required to meet the MCLs for radionuclides (KAR 28-15a-66).
- b. KAR 28-15a-66 specifies BATs and small system compliance technologies for radionuclide removal. The BATs for radium 226 and 228 are lime softening (Section K), ion exchange (Sections K and R), and reverse osmosis (Section S). Radon (for which new regulations are pending) can be removed by air stripping (Section P) or adsorption on GAC (Section Q). The BATs for uranium are coagulation and filtration (Sections F and J), lime softening, ion exchange, and reverse osmosis. Reverse osmosis is the BAT for gross alpha particle activity (excluding radon and uranium); and reverse osmosis and ion exchange are the BATs for beta particle and photon activity.

Compliance technologies for small systems include the BAT processes as well as point-of-use ion exchange and reverse osmosis, electrodialysis and electrodialysis reversal, and adsorption on activated alumina or manganese-coated media (Subsection O.2 and Section R). Several of these will be considered by KDHE as new processes (Subsection A.5 of Chapter III); and use of point-of-entry devices is subject to KDHE approval and the provisions of KAR 28-15a-100.

8. DBP CONTROL AND PRECURSOR REMOVAL

- a. Community and non-transient, non-community PWSSs are required to meet MCLs for DBPs (KAR 28-15a-64); and Subpart H systems (those using surface water or GWUI) must meet treatment technique requirements for DBP precursors (KAR 28-15a-135). BAT processes for compliance with the MCLs for trihalomethanes (TTHMs) and haloacetic acids (HAA5) are enhanced coagulation and softening, adsorption on GAC (Section Q), nanofiltration (Section S) with a molecular weight cutoff of less than 1000 Daltons, and (for consecutive systems) improved distribution and storage tank management, to reduce residence time, and the use of chloramines for residual disinfection (KAR 28-15a-64).
- b. DBPs can be controlled by reducing the concentration of DBP precursors by means of source control or treatment, delaying the point of chlorine application, avoiding excessive use of chlorine and other disinfectants, using alternate disinfectants, removing DBPs after they form, using combined chlorine instead of free chlorine in the distribution system, improving distribution system and storage tank management to reduce residence time, and in some cases by adjusting pH. Practices potentially suitable for controlling precursors at the source include selective withdrawal from reservoirs, algae control, and using alternate water sources.

Treatment processes for removing precursors include coagulation (Section F), lime softening (Section K), filtration (Section J), adsorption on GAC (Section Q) or PAC (Section N), membrane processes (Section S), and chemical oxidation (Section M) followed by biological filtration (Subsection J.15). Alternate disinfectants include chlorine dioxide, ozone, and UV light (Section M). Removal of some byproducts can be accomplished using air stripping (Section P), adsorption on GAC (Section Q), and reducing or oxidizing agents.

C. DESIGN REQUIREMENTS FOR OPTIONAL TREATMENT PROCESSES

1. INTRODUCTION – Optional treatment processes may be used to meet the particular needs of a PWSS. Optional processes are those for which no regulatory requirement exists. They are most commonly used to remove contaminants for which SMCLs have been established (40 CFR 143.3).

Plans, specifications and a permit application for optional processes must be submitted to KDHE for review and approval prior to the start of construction and must:

- a. Identify the contaminants being removed, the treatment objectives, and the reasons for any differences between the treatment objectives and the SMCLs where the treatment objectives exceed the SMCLs;
- b. Include an appropriate basis of design (including pilot-plant data if necessary to demonstrate the effectiveness of an existing technology for a novel contaminant or the effectiveness of a new technology for a common contaminant); and
- c. Comply with all pertinent design requirements included in this document.

Considerations pertaining to several of the most commonly removed contaminants are presented in the following sections.

2. SOFTENING

- a. Softening is desirable for PWSSs where high levels of hardness are present. Softening may be accomplished by addition of lime alone where natural alkalinity will permit, or by addition of lime and soda ash where removal of non-carbonate hardness is desired (Section K). Softening may also be accomplished using cation exchange (Section K) and certain membrane processes (Section S).
- b. The processes used for softening also remove other contaminants, some of which are regulated and some of which are not. Fluoride, pathogens, heavy

metals (e.g., lead and copper), and certain IOCs, SOCs, and radionuclides are examples of regulated contaminants affected by softening. A number of contaminants for which SMCLs have been established are also affected by softening, including total dissolved solids, copper, zinc, aluminum, iron, manganese, and fluoride. Softening also influences pH and the stability of the water, which may need to be adjusted (Section L) following softening.

3. IRON AND MANGANESE REMOVAL

- a. Removal of iron and manganese is desirable for a PWSS when the source water contains iron or manganese in excess of their respective SMCLs.
- b. Common treatment processes include aeration (Section P) or chemical oxidation (Sections M and O) followed by filtration (Section J); lime softening (Section K) followed by filtration; and adsorption on manganese-coated media (Section O). Low concentrations of iron and manganese can sometimes be effectively sequestered (Section O).
- c. As in the case of hardness removal, other contaminants (especially certain IOCs) may be removed along with iron and magnesium depending on the process used.

4. HYDROGEN SULFIDE REMOVAL

- a. Removal of hydrogen sulfide is desirable for a PWSS when its odor would otherwise be present in the finished water.
- b. Treatment processes include air stripping (Sections N and P) and chemical oxidation (Sections M and N).

D. GENERAL DESIGN CONSIDERATIONS

1. GENERAL CRITERIA – Certain considerations should be addressed in the design of both optional and required treatment processes:
 - a. DEGREE OF TREATMENT PROVIDED – Required processes must achieve the required degree of treatment (based on applicable MCLs and treatment technique requirements) under the most stringent process constraints that can reasonably be anticipated. Optional treatment processes should be designed to meet the stated goals (e.g., SMCLs) under most or all anticipated water quality and operating conditions and must be designed such that the PWSS is able to provide an uninterrupted supply of potable water whether or not these goals are being met.

- b. **MINIMUM NUMBER OF UNITS** – There should be at least two units of each process so that one can be used if the other is inoperable; and this is mandatory for certain required processes, e.g., filtration and disinfection for PWSSs using surface water or GWUI.
- c. **PIPING** – Providing both series and parallel flow between units should be considered where doing so is practical and would beneficially increase the reliability of the treatment train. Where appropriate, a bypass should be provided to enable a unit to be removed from service.
- d. **FLOW RATE AND FLOW REGIME** – Internal or external flow control devices should be provided where necessary to control the rate of flow through the process. Baffling or mixing should be provided where needed to provide the desired flow regime of plug flow, complete mixing, or intermediate regimes.
- e. **CHEMICAL ADDITION** – Many treatment processes require the addition of chemicals. Both general and specific considerations are addressed in Chapter IX, Chemical Storage, Handling, and Application.
- f. **HYDRAULIC** – Head losses should be minimized to reduce energy costs but not to the point of affecting the desired flow regime or flow control; and the head requirements associated with anticipated future process additions and plant expansion should also be considered.
- g. **PROCESS CONTROL** – Automatic control of a process is often desirable, especially where it can relieve operators of mundane tasks, improve operational efficiency, improve process control, or where an operator's attention may be limited. Manual operation must always be possible where automatic controls are employed as the primary means of control.
- h. **MONITORING** – Monitoring of various water quantity and quality parameters is usually required for process control and regulatory compliance purposes. Provision should be made to collect samples and to measure and record the appropriate process and water quality variables.
- i. **CLIMATE AND WEATHER** – Many treatment units will be affected by seasonal and temporal variations in water temperature or weather conditions.
- j. **TRAINING AND SAFETY** – Operator and consumer safety must be given paramount consideration in process design. As with any existing or new technology, all necessary training for plant operators shall be provided prior to plant start-up.

- k. **ADJUSTABLE FEATURES AND FUTURE NEEDS** – The possibility of process modifications, expansions or other changes to the treatment system must be considered. These may be minor changes or adjustable features (such as alternate chemical feeding locations, adjustable mixing energy input, adjustable weirs, addition of baffles, or provisions for additional monitoring), that might improve treatment efficiency at minimal cost, or major changes such as future plant expansions involving large capital expenditures.
 2. **PERMIT APPLICATION** – A public water supply permit application and submission of plans and specifications to KDHE for review and approval prior to the start of construction are required for alterations or improvements involving a change in the treatment or the design capacity. A change in disinfection practice is also a change in treatment. Accordingly disinfection profiles and benchmarks (USEPA, 1999a), and CT ratio and log inactivation calculations for both the existing and proposed disinfection practice, must be submitted to KDHE for review. Changes in design capacity may be as simple as installing a larger capacity pump or as complex as addition of new infrastructure. Both would require submission of the above to KDHE for review and approval prior to the start of construction.
 3. **REMAINING CHAPTER ORGANIZATION** – The remaining sections in Chapter V review the design criteria for the various treatment processes used to accomplish contaminant removal or control. The sequence of processes does not follow any particular order except that those listed first are common to surface water treatment plants. Each plant will have its own unique sequence of processes depending upon site specific conditions and the preferences of the PWSS and its design engineer.
- E. PRESEDIMENTATION** – Source waters bearing gravel, sand, or silt, or with turbidity in excess of 1,000 NTUs, should have pretreatment. Presedimentation, with or without the addition of a coagulant, is recommended.
1. **BASIN DESIGN** – Presedimentation basins should have hopper bottoms or be equipped with continuous mechanical solids removal devices especially selected or designed to remove gravel, sand and/or heavy silt. They should include provisions for rapid draining and hydraulic flushing. Incoming water to non-circular types of basins, e.g., square or rectangular, shall be dispersed across the full width of the line of travel at the inlet end of the basin; short circuiting in all types of basins must be adequately controlled.
 2. **CHEMICAL ADDITION** – Provision should be made for adding chlorine and other chemicals for taste and odor control, color removal, and improved removal of turbidity. The formation of DBPs must be considered when selecting treatment chemicals. Also, removal of suspended solids by presedimentation may be enhanced by adding chemical coagulants and rapid mixing. Acrylamide and epichlorohydrin are impurities found in organic polymers used as coagulant aids. Each PWSS must certify annually that the chemicals it uses do not exceed USEPA specified levels of

acrylamide and epichlorohydrin based upon dosage and percentage of the compound in the coagulant aid (KAR 28-15a-111).

3. PRESEDIMENTATION CRITERIA

- a. **DETENTION TIME** – The recommended minimum detention time is 45 minutes, except for the Kansas and Missouri River sources, for which 2 and 3 hours, respectively, are recommended.
- b. **OVERFLOW RATE** – The recommended maximum surface overflow rate is 3,500 gpd/ft² (143,000 Lpd/m²); however, higher overflow rates (lower detention times) for basins equipped with inclined plate and/or tube sedimentation equipment may be allowed with prior approval from KDHE.
- c. **WATER DEPTH** – The recommended minimum side wall depth is 8 ft. (2.4 m).
- d. **WEIR RATE** – The recommended maximum weir rate is 20,000 gpd/ft (248,000 Lpd/m).
- e. **DRAIN LINES** – The recommended minimum diameter for drain lines is 8 inches (20.3 cm).
- f. **BYPASS** – Piping and controls for bypassing a single presedimentation basin shall be provided. Piping and controls for bypassing two or more presedimentation basins in parallel should be provided if appropriate.

F. RAPID MIXING AND COAGULATION – Rapid mixing is the rapid dispersion of coagulation chemical(s) throughout the water being treated, usually by violent agitation. Coagulation is the process of neutralizing the charges on suspended particles and colloids. The design engineer shall identify the basis for rapid mixing and coagulation in terms of the detention time and G values or other appropriate measures of mixing effectiveness for the expected water quantity and quality variations and the chemical(s) to be added. The following items should be among those evaluated when designing a rapid mix system: type(s) and dosages of coagulant(s) to be employed, other chemicals to be fed and the characteristics of each, raw water characteristics, design of chemical diffusers, available head loss, variations in plant flow rate and water temperature, the subsequent solids separation processes, and the quality and quantity of return flows and their potential impacts on coagulation, subsequent treatment processes, and DBP formation.

1. **REQUIREMENT** – Any of several types of mixers can be used to accomplish rapid mixing. These include mechanical mixers, diffusers, injectors, hydraulic mixers, in-line blenders (mechanical and static) and pumps. Baffled mixing chambers are not allowed to serve as the only means of mixing.

2. LOCATION – The rapid mixing and flocculation basins shall be as close together as possible. Typical velocities in conduits from the mixer to flocculation basins are 1.5 to 3.0 ft/s (0.46 to 0.9 m/s). Channels distributing water across the width of a flocculation basin or serving two or more flocculation basins are often tapered, either in width or depth, so as to maintain a constant velocity.
3. RAPID MIX CRITERIA – Inorganic coagulants destabilize colloids by adsorption and charge neutralization or by enmeshment. Polymers function using charge neutralization and/or interparticle bridging mechanisms. The mechanism of colloid destabilization will dictate the chemical dose and the rapid mix design criteria that should be used. Although the velocity gradient (G value) has been widely used as the primary design criterion for evaluating rapid mixers, recent studies have suggested alternate design parameters such as the total power input to the water per unit flow rate (e.g. hp/mgd or hp/cfs ($W/m^3\text{-d}$ or $W/m^3\text{-s}$)). Further, for in-line or pump-injection rapid mixing devices, G is difficult to calculate because the volume to be used in the calculation of G is uncertain. Design criteria utilized for a specific rapid mix system should be clearly identified and adequately justified by the design engineer.
4. MECHANICAL MIXERS – METAL SALT COAGULATION (FOR SYSTEMS NOT PRACTICING LIME SOFTENING)
 - a. DETENTION TIME – For conventional treatment plants, the required mixing time should not exceed 30 seconds at the maximum flow rate and should in most cases be less than 10 seconds. The optimal mixing time depends on the mechanism involved and other factors. Metal salt coagulation by adsorption and charge neutralization is thought to be most efficient at detention times less than 1 second, while enmeshment is relatively insensitive to mixing conditions.
 - b. VELOCITY GRADIENT (G VALUE) – For metal salt coagulation, the recommended minimum G value is 500 sec^{-1} . For coagulation using both a metal salt and a polymer, the recommended G value is 600 to 1000 sec^{-1} . Alternatively, the design engineer may submit the design basis which justifies the G value selected, considering the chemicals to be added and water temperature, color and other related water quality parameters.
5. pH CRITERIA – The optimum pH for coagulation depends on water quality and the treatment objectives. For DBP precursor removal, the optimum pH range for metal salt coagulants is typically about 5.5 to 6.0, whereas higher pH values (7.0 to 8.5) are typically optimal for particle removal. Optimum values for the proposed design can be determined by experimentation or from previous experience with the same source of water. Chemicals used to lower the pH should be added before the coagulant, although they can be added together. Chemicals used to raise the pH are typically added as part of the stabilization process; but if they are added during coagulation it

is better to add them after the coagulant, as the coagulant will typically be more effective when hydrolysis occurs at the lower pH.

6. MIXING REQUIREMENTS FOR LIME SOFTENING – When coagulation and lime softening are to occur simultaneously, whether in a process sequence of rapid mixing, flocculation and sedimentation or in a solids contact unit, mixing need not be particularly rapid, but the lime should be completely dissolved. Where rapid mixers are used, a G value of 300 sec^{-1} is typically adequate and a detention time greater than 30 seconds may be desirable to facilitate more complete dissolution of the lime. When solids contact units are used, the lime and coagulant may be added directly into the reaction zone, provided sufficient mixing is available to completely dissolve the lime, or the coagulant may be added ahead of the solids contact unit. The order of addition of lime, coagulant, and other chemicals (e.g., PAC) may significantly influence the properties of the solids, settled-water turbidity, and the removal of trace contaminants (e.g., IOCs and SOCs). Where full-scale experience is lacking, jar-test or pilot-plant data may be helpful in determining the optimum order of addition.
7. RECYCLE STREAMS – Plants using surface water or GWUI that recycle or have the capability to recycle filter backwash water, thickener supernatant, and liquids from dewatering processes must return these streams to a point in the treatment sequence prior to coagulant or lime addition (KAR 28-15a-76). Depending on the flow rates and solids concentrations involved, solids removal may be necessary to avoid adverse impacts on the effectiveness of coagulation and subsequent treatment processes. Equalization of recycle flows may be necessary to avoid disrupting the coagulation and flocculation processes. A constant recycle flow rate works best.

Recycling of filter wash water for water conservation is usually done using a recovery tank where the supernatant is recycled and the solids are handled separately. Recycling of filter wash water is not recommended where toxic materials or organisms may accumulate in the recycled water.

G. FLOCCULATION – Flocculation is the gentle agitation of water for extended time periods to facilitate the aggregation (or aggregation and growth in the case of lime softening) of smaller particles into larger particles suitable for settling by gravity. It follows rapid mixing for coagulation and is an integral part of both the conventional treatment sequence, as described in the SWTR, and the lime softening process.

1. REQUIREMENT – A mechanical unit is required in all new treatment plants and when existing plants are upgraded.
2. EXCEPTION – A separate mechanical unit will not be required where a solids contact basin with a reaction/mixing compartment is provided.

3. BASIN DESIGN

- a. Inlets and outlets should be designed to minimize floc destruction and short circuiting.
- b. Provision for adjusting mixing energies is required where compartments in series are used. Compartments in series in a single basin are recommended in preference to separate basins in series.
- c. Drains or pumps shall be provided to facilitate rapid dewatering of the unit and removal of accumulated solids.

4. DETENTION TIME – At maximum design flow, a minimum of 20 minutes is required for flocculation (to allow for good floc formation) and 30 minutes for softening (to allow adequate time for the softening reactions to approach equilibrium). Increased time is required where a series of separate flocculation basins is used (as apposed to compartments in series). It is important to note that the extra time will probably help only if it is provided in the last basin, since the primary problem here is floc fragmentation as the water travels between the basins. Detention times should be adjusted for temperature effects (and seasonal changes in flow rate) according to the guidelines in Table V-1.

TABLE V-1

**TEMPERATURE ADJUSTMENT GUIDELINES
FOR FLOCCULATOR DETENTION TIME (AWWA AND ASCE, 2005)**

Temperature, °C	Detention Time Factor
0	1.35
5	1.25
10	1.15
15	1.07
20	1.00
25	0.95
30	0.90

Many experts believe that flocculators should be designed on the basis of energy input per unit volume, which is not temperature dependent, rather than the G value. The premise for Table V-1 is that one must increase detention time, for a given energy input, in order to maintain the same G value. The values in this table reflect changes in the square root of the viscosity of water. The same result could also be realized by increasing the mixing energy, though this would significantly increase capital and operating costs. While the viscosity of the water is a factor in cold weather performance, many experts in the industry feel that the chemistry is a more important factor in that many cold-weather-related problems can be addressed by raising the pH 0.5 to 1.0 units to account for the temperature-related changes in the solubilities of Fe and Al and the ion product of water, pK_w .

5. EQUIPMENT

- a. Agitators are to be driven by variable speed drives. For vertical, low energy and horizontal, paddle-type flocculators, blade tip speeds in the range of 0.5 to 3.0 ft/sec (0.15 to 0.9 m/s) are appropriate for maximum floc growth and settleability. The tip speed for vertical, high energy flocculators should not exceed 10 ft/sec (3 m/s).
- b. Where three compartments in series are used, G values from 40 to 60 sec^{-1} in the first compartment down to 15 to 25 sec^{-1} in the last compartment are suggested. Higher values are used for softening in order to prevent solids deposition. Vertical, high energy flocculators typically have G values of 50 to 75 sec^{-1} compared to 20 to 45 sec^{-1} for vertical, low energy and horizontal paddle-type flocculators.
- c. External, non-submerged drive equipment is recommended.
- d. A superstructure over the flocculation basins may be appropriate.

6. PIPING

- a. The flocculation and sedimentation basins shall be located as close together as feasible.
- b. The velocity of the flocculated water through pipes, flumes, or effluent ports leading to the settling basin should not exceed 1.5 ft/sec (0.46 m/s) to avoid floc shear and should not be less than 0.5 ft/sec (0.15 m/s) to prevent settling before entering the basin. Most flocculators have an end baffle between the flocculation zone and the clarifier to prevent residual energy of the flocculation process from being transferred to the clarification stage.
- c. Allowances must also be made to minimize turbulence at bends and changes in direction.

H. SEDIMENTATION – Sedimentation shall follow flocculation except where dissolved air flotation (Section I) or direct filtration (Section J) has been approved.

1. **GENERAL REQUIREMENTS** – The requirements for effective clarification depend on basin design and raw water quality (turbidity, color, colloidal matter, taste and odor causing substances, or other material to be removed). The character of the floc formed is a major consideration. Sound engineering judgment is required to produce a good cost-effective design.
 - a. **BASIN DESIGN** – Conventional or solids contact units may be used. Conventional units can be circular, square, or rectangular. Solids contact basins are upflow units that utilize a zone where previously formed and settling floc interacts with incoming particles.
 - b. **INCLINED SETTLERS** – Plate or tube settlers may be used and a reduction in detention time is allowed with their use.
 - c. **DETENTION TIME** – Calculations for detention time requirements should be based on the maximum design flow.
 - d. **INLETS** – Inlets for square or rectangular shaped horizontal flow units should be designed to distribute the flow uniformly across the cross section of the basin. Balanced energy inlets, biased gates, baffle walls or similar entrance arrangements are recommended. A baffle should be constructed across the basin close to the inlet end or between the flocculation and sedimentation basins to dissipate inlet currents and provide uniform flow across the basin. Baffle walls are more effective than target baffles. Circular basins may have a center feed with radial flow, or a peripheral (rim) feed with radial flow. Regardless of the basin geometry, the design should provide a proper flow pattern with minimal floc breakup.
 - e. **OUTLET AND OVERFLOW DEVICES** – Means for controlling the maximum water level in the filters and basins shall be provided. Outlets, when used, should be designed to maintain velocities suitable for settling in the basin and to minimize short circuiting. Weirs or submerged orifices can be used on effluent troughs to minimize short circuiting; but submerged orifices should not be located more than three feet below the water line. An overflow weir installed to establish the maximum water level on top of the filters shall discharge by gravity, with a free fall, at a location where the discharge will be seen.

Weirs should be easily accessible for cleaning and maintenance. Each trough section should have sufficient drain holes in the bottom to relieve loadings when the basin is drained or filled. When lime softening is practiced,

overflow weirs and troughs will tend to become encrusted with CaCO_3 . Using troughs with submerged orifices may lessen this problem.

- f. DRAINAGE – Basins should be provided with the means for rapid dewatering. Basin bottoms should slope toward the drain. Drainage facilities shall not be physically connected to the sanitary sewer system except where proper cross-connection protection is provided such as an air-gap separation between the basin and the sanitary sewer connection.
- g. SOLIDS COLLECTION – Mechanical solids collection equipment shall be provided. Rakes and drive units should be designed to restart at the expected solids concentration after a 24-hour shutdown (especially in solids contact basins used for softening), and provision should be made for reversing the motor to assist in freeing the rake after shutdown.
- h. SOLIDS REMOVAL
 - 1) Solids withdrawal pipes shall be not less than 4 inches (10.2 cm) in diameter for clarification and not less than 6 inches (15.2 cm) in diameter for softening with the designer having the latitude to select larger diameter withdrawal pipes as deemed appropriate for the design to facilitate routine flushing and cleaning.
 - 2) Entrances to solids withdrawal pipes shall be designed to prevent clogging.
 - 3) Valves shall be located outside the tank for accessibility.
 - 4) The operator shall be able to observe and sample solids being withdrawn from the unit.
- i. SOLIDS DISPOSAL – Facilities are required for the proper disposal of solids.
- j. CROSS CONNECTIONS
 - 1) Solids blow-down outlets and solids withdrawal lines and drains must be designed to prevent backsiphonage.
 - 2) Cross-connection control must be included when potable water is used to back-flush solids withdrawal lines.

2. CONVENTIONAL BASIN CRITERIA

a. MINIMUM DETENTION TIMES

1) When no inclined settlers are used:

a) Kansas, Missouri, and Neosho Rivers:

(1) With presedimentation – 3 hours.

(2) Without presedimentation – 4 hours.

b) All other surface supplies – 3 hours.

c) Precipitative softening facilities treating only groundwater sources – 2 hours.

2) When inclined settlers are used:

a) Missouri and Kansas Rivers – designer must justify reduced detention times.

b) Neosho River – 2 hours.

c) Others – 1.5 hours.

b. OVERFLOW RATE

1) The recommended maximum surface overflow rate for horizontal flow basins is 600 gpd/ft² (24,400 Lpd/m²).

2) When effluent weirs are used in lieu of a ported outlet wall, the rate of flow over the outlet weir should not exceed 20,000 gpd/ft (248,000 Lpd/m) of weir length for horizontal flow basins. The surface overflow rate should not exceed 2,160 gpd/ft² (88,000 Lpd/m²) for the surface area covered by the trough system. Weir coverage should extend one-third to preferably one-half from the end of the basin toward the inlet end. The performance of circular basins greater than 50 to 60 ft. (15 to 18 m) in diameter may be improved by the use of inboard circumferential effluent troughs. A double-sided weir trough mounted inboard at least 15 percent of the tank radius is recommended.

3) Submerged exit ports used as an alternative for overflow weirs should be located no more than 3.0 ft. (0.9 m) below the water line at

maximum flow with loading rates equivalent to the weir loading rate in Subsection H.2.b.2 above.

c. **BASIN DIMENSIONS**

- 1) Minimum depth – 8 ft. (2.4 m).
- 2) The minimum length to width ratio for rectangular settling basins shall be 2.5:1. Ratios of 4:1 or more are recommended.

d. **INCLINED SETTLERS** – Where existing basins are adequate structurally and hydraulically, their capacities may be increased by installing approved inclined settlers (tubes or plates) provided that the new detention time is not less than the standards listed above and the following criteria are met:

- 1) Application Rate – A maximum rate of 2,880 gpd/ft² (117,000 Lpd/m²) for tube or plate settlers based on 2 foot (0.6 m) long 60° tubes or 39.6 inches (101 cm) long 7.5° tubes. Higher rates are not permitted unless successfully shown to be appropriate through pilot or in-plant demonstration studies.
- 2) Protection from Freezing – Outdoor installations must provide sufficient freeboard above the top of the settlers to prevent freezing in the units. A cover or enclosure is strongly recommended.
- 3) Drainage – Drain piping from the settler units must be sized to facilitate a quick flush without flooding other portions of the plant.
- 4) Flushing Lines – Flushing lines shall be provided to facilitate maintenance and must be protected against backflow and backsiphonage.

3. **SOLIDS CONTACT BASIN CRITERIA** – Solids contact units are acceptable for clarification or precipitative softening where water characteristics are not highly variable and flow rates are reasonably uniform.

- a. **INSTALLATION AND START-UP OF EQUIPMENT** – A manufacturer's representative should supervise the installation and initial operation of all mechanical equipment.
- b. **OPERATION OF THE EQUIPMENT** – The following should be provided by the manufacturer for routine plant operation of mechanical units.
 - 1) A complete set of tools and accessories.

- 2) Identification of process control procedures and suggested test equipment.
 - 3) Sampling taps located so as to permit the collection of samples which will allow process control and monitoring requirements to be satisfied.
- c. CHEMICAL FEED – Chemicals should be applied at such points and by such means as to ensure their satisfactory mixing with the water that is treated. (Also see Chapter IX on Chemical Storage, Handling, and Application.)
- d. MIXING
- 1) Mixing devices should be so constructed that the raw water or partially treated water is thoroughly mixed with the previously formed suspended particles.
 - 2) The mixing blade tip speed should generally not exceed 10 ft/sec (3 m/s) to avoid shearing the floc, but the mixer speed must be fast enough to prevent deposition of solids in the mixing zone.
 - 3) Mixers shall be adjustable for variable speed and be able to produce G values of 20 to 70 sec⁻¹.
 - 4) Softening units should be capable of maintaining solids concentrations in the mixing/reaction zone of at least one percent by weight (or about 5% by volume depending on settling time and specific gravity).
 - 5) A recirculation ratio of 10 to 1 at design flow is recommended. The mixing device should be able to thoroughly mix the recirculated stream with the primary stream at maximum plant flow.
- e. MIXING VOLUME – The volume of the mixing compartment is measured to the bottom of the skirt (mixing zone wall).
- f. DETENTION TIME – The detention time shall be established on the basis of the raw water characteristics and other local conditions that affect the operation of the unit. Based on the maximum design flow rate, the detention time should be:
- 1) Two to four hours for solids contact clarifiers and softeners treating surface water.

- 2) One to two hours for solids contact softeners treating only groundwater.
 - 3) The flocculation and mixing zone detention time shall be not less than 30 minutes nor greater than 40 minutes at maximum design flow for clarification and not less than 20 minutes for softening units. A minimum detention time of 15 minutes will be considered for softening units where adequate justification is provided.
- g. OVERFLOW RATES – Unless supporting data are submitted to KDHE to justify alternative values, the following overflow rates are required:
- 1) The overflow rate for clarification units shall not exceed 1.0 gpm/ft² (41 L/min-m²) at the solids separation line.
 - 2) The overflow rate for softening units shall not exceed 1.75 gpm/ft² (71 L/min-m²) at the slurry separation line.
- h. SOLIDS CONCENTRATORS
- 1) Either internal or external solids concentrators shall be provided to permit solids concentration and to minimize water loss.
 - 2) Large units should have at least two solids-collecting sumps, located below the central flocculation/reaction zone.
 - 3) Solids must be able to be drawn off frequently and for short durations, such that the desired slurry concentration can be readily maintained.
- i. WATER LOSSES
- 1) Units shall be provided with suitable controls for solids withdrawal.
 - 2) Total water losses should not exceed:
 - a) Five percent for clarifiers.
 - b) Three percent for softeners.
- j. OUTLETS
- 1) Solids contact units may be equipped with troughs employing overflow weirs or submerged orifices. Water at the surface of the

unit must not travel horizontally over 10 ft. (3.0 m) to a collection trough.

- 2) The maximum weir loading rate is 10 gpm/ft (14,400 gpd/ft, 125 L/min-m or 180,000 L/d-m) for clarification and 20 gpm/ft (28,800 gpd/ft, 250 L/min-m or 360,000 L/d-m) for softening.
- 3) Weirs shall be adjustable, at least equivalent in length to the perimeter of the tank if the tank is circular, and constructed so that they will produce a uniform rise rate over the entire area of the tank. When submerged orifices are used the loading rates per foot of launder should be no greater than the maximum allowable weir loading rates.
- 4) Other high-rate clarification processes may be approved if it is satisfactorily demonstrated to KDHE, by means of on-site pilot or full-scale demonstrations involving the same or similar water quality conditions, that they perform well and meet all applicable regulatory requirements. Reductions in detention times, increases in overflow rates and weir loading rates, and other exceptions to the relevant portions of Subsections 1 through 3 above shall be adequately justified. Examples of such processes include floc-blanket clarification (with or without pulsing), ballasted flocculation, contact flocculation, contact clarification, and helical-flow solids contact clarifiers. Subsection A.5 of Chapter III (New Processes, Methods, Chemicals and Equipment) may also be pertinent.

I. DISSOLVED AIR FLOTATION – Dissolved air flotation has found limited application in the clarification of waters typical of those found in Kansas. It is best suited for treating waters for which coagulation produces a light, slowly settling floc, e.g., those laden primarily with algae or organic matter (color) rather than turbidity. Design of DAF units must be based on pilot or in-plant demonstration studies approved by KDHE. Typical DAF units are rectangular with a depth of 10 ft. (3 m), a surface overflow rate in the range of 4 to 5 gpm/ft² (163 to 204 L/min-m²) and a nominal detention time in the flotation tank of between 5 and 15 minutes.

J. FILTRATION – Rapid rate gravity sand filters are recommended for all PWSSs treating surface water or GWUI. Rapid rate refers to the hydraulic loading on the filter. Filtration technologies other than rapid-rate gravity sand filtration are subject to approval by KDHE and proposals to employ them should be discussed with KDHE prior to submittal of a permit application. Filters used for PWSSs must be designed to meet the filtration requirements specified in KAR 28-15a-73, as well as those specified in KAR 28-15a-173 and 174 (if serving 10,000 or more people) or KAR 28-15a-550 through 553 and KAR 28-15a-560 through 562 (if serving fewer than 10,000 people). PWSSs using surface water or GWUI as

a source of supply must also comply with the provisions of KAR 28-15a-76, which regulates recycle flows, including filter backwash water.

GAC filter-adsorbers may be used for taste and odor control and may in some cases be appropriate for the removal of SOCs. Typical GAC bed lives are one to five years for taste and odor control, but laboratory and/or pilot-plant studies are recommended to confirm GAC requirements, especially for SOC removal, since naturally occurring organic matter can greatly reduce adsorptive capacity. GAC may be used in post-filter adsorbers (Section Q), as a replacement or topping medium in existing filters, or in new filter-adsorbers. See Subsection 5.b.4 for design requirements pertaining to GAC filter-adsorbers.

Pressure filters for treating groundwater or GWUI will be considered for approval on a case-by-case basis. Pressure filters have two significant disadvantages: an increased likelihood that particles (perhaps including pathogens) will be dislodged by hydraulic surges, and designs that interfere with the ability of the operator to observe the filter during filtration and backwashing and to physically inspect the media. For these reasons, gravity filters are preferred for PWSSs. See Subsection 13 for design requirements pertaining to pressure filters.

Bag or cartridge filter systems may be approved for treatment of groundwater or GWUI, but for GWUI the effectiveness of the proposed system for removal of *Giardia lamblia* and *Cryptosporidium* cysts and for complying with turbidity requirements must be established as required by KAR 28-15a-73. Appendix M of the USEPA's *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (USEPA, 1991) presents various approaches that can be utilized to demonstrate the effectiveness of alternate filtration technologies such as bag or cartridge systems. A bag or cartridge system physically removes particles by trapping them on specially designed material such as microporous ceramic elements or polypropylene woven fabrics. The bag or cartridge is installed in a cylindrical housing unit (canister) and is removed from the housing unit and replaced when buildup of particulate matter results in excessive pressure drop across the unit. Engineering considerations include evaluating the necessity for pretreatment, pumping requirements, and the number, size, and arrangement of filter units necessary to treat a particular source. See Subsection 14 for additional design requirements pertaining to bag and cartridge filtration systems.

The design criteria presented in Subsections 1 through 12 below apply specifically to rapid rate gravity filters, but many of them are also applicable to other types of filters. Design criteria pertaining specifically to pressure filters, bag and canister filters, and biofiltration are presented in Subsections 13, 14, and 15, respectively. Design criteria for GAC filter-adsorbers are presented in Subsection 5.b.4 and in Section Q. Design criteria for deep-bed mono-media filters are presented in Subsection 5.b.5. Design criteria for membrane processes, including microfiltration and ultrafiltration, which are increasingly being considered as alternatives to rapid rate gravity filtration, are presented in Section S (Membrane Processes). Design criteria for slow sand filtration, diatomaceous earth filtration, and direct filtration are not presented herein, since these filtration technologies are typically

not employed in Kansas. Proposals to employ these technologies, or any filtration technology other than rapid rate gravity filtration, should be discussed with KDHE prior to submittal of a permit application.

1. PRETREATMENT AND NUMBER

- a. PRETREATMENT – Pretreatment is required ahead of all rapid rate gravity filters.
- b. NUMBER – At least two units shall be provided. Where only two units are provided, each shall be capable of meeting the maximum design flow at the approved filtration rate. Where more than two filters are provided, the filters shall be capable of meeting the maximum design flow with one filter removed from service. Where declining rate filtration is provided, the variable nature of the filtration rates must be considered when determining the number of filters required.

2. STRUCTURAL AND HYDRAULIC DETAILS

- a. FILTER BOX DEPTH – The minimum depth of the filter box shall be 10 ft. (3.0 m).
- b. MINIMUM WATER DEPTH – The minimum water depth over the surface of the media shall be 3 ft. (0.9 m).
- c. MAXIMUM WATER VELOCITY – The maximum velocity of the water in the pipes and conduits leading to the filters shall be 2 ft/sec (0.6 m/s).
- d. WALKWAYS – Walkways around the filters shall be not less than 2 ft. (0.6 m) wide and not more than 3.5 ft. (1.1 m) below the top of prefabricated filters. An access walkway is required for prefabricated filters so that filter operation, especially backwashing, can be easily observed.
- e. OTHER CONSIDERATIONS – The filter system should be designed with the following structural and hydraulic features:
 - 1) Vertical walls within the filter with no protrusion of the filter walls into the filter media;
 - 2) Cover by a superstructure with roof drains that shall not discharge into the filters or any basin preceding or following the filters;
 - 3) Head room to permit normal inspection and operation;
 - 4) Trapped effluent to prevent backflow of air to the bottom of filters;

- 5) Curbs at least 4 inches (10.2 cm) high around the filters to prevent drainage into the filters;
 - 6) Prevention of flooding by providing an appropriately sized overflow;
 - 7) Cleanouts and straight alignments for influent pipes or conduits where solids loading is heavy, or following precipitative softening;
 - 8) A washwater drain with capacity to carry maximum flow;
 - 9) Backwash piping located below the media;
 - 10) Safety handrails between the filter and the walkways even if one or more filters are walled from the general gallery aisle;
 - 11) Materials contacted by wetted GAC to be resistant to corrosion and abrasion;
 - 12) Inlet design with provisions to mitigate turbulence and noise due to falling water where elevation of filter inlet is higher than the elevation of the water level in the filter box; and
 - 13) Prevention of cross-connections and common walls between filtered and unfiltered water, including on-site sources of groundwater, and between potable and non-potable water. A dry well to separate filters from prior treatment steps will be required when there would otherwise be only a common wall between them.
- f. APPURTENANCES – The following items should be provided (shall be provided, where regulatory requirements are referenced) with every filter:
- 1) Provisions to sample the influent and effluent streams;
 - 2) Provisions to measure head loss across the filter;
 - 3) Indicating and recording flow rate controller;
 - 4) Provisions to drain the filters to waste when treating surface water or GWUI, with appropriate measures to prevent backflow;
 - 5) Effluent turbidimeter for the combined filter effluent and, if treating surface water or GWUI at a treatment facility serving more than 10,000 people (KAR 28-15a-174) or serving fewer than 10,000 people and using conventional filtration (KAR 28-15a-560) or having more than two filters, an individual filter effluent turbidimeter for

each filter, capable of meeting the analytical requirements described in KAR 28-15a-74 and recording the effluent turbidity reading at least once every 15 minutes;

- 6) An alarm connected to the turbidimeter to signal unacceptable turbidity levels in the water being delivered to the distribution system with an option to shut down the service pumps; and
 - 7) A properly sized pressure hose (with storage rack) that will provide an adequate quantity of water at the pressure needed to wash filter walls.
3. FLOW CONTROL – Any of several different kinds of flow control systems can be employed. Designers should identify and validate the basis for their choice of control system.
4. UNDERDRAINS – Block or false bottom underdrain systems, with or without gravel, are acceptable. Porous plate underdrains are not recommended due to their potential to clog over an extended period of time, especially where precipitation or deposition of aluminum, iron, manganese, silica, calcium, phosphate, organic matter (including polymers used for treatment), or other substances may occur. Changes in chemical feed or water quality must be taken into consideration in evaluating them for use even if they are “compatible” with a given water under one set of operating conditions. Underdrain design should minimize loss of head while ensuring an even distribution of washwater and an even rate of filtration over the entire area of the filter. The maximum underdrain loading rate for the collection of filtered water and the uniform distribution of backwash water shall not be less than 20 gpm/ft² (814 L/min-m²) of filter surface area.
5. FILTER MEDIA
- a. QUALITY – Media quality shall conform to applicable AWWA standards for filtering material (i.e., B100 for granular media and supporting gravel and B604 for GAC).
 - b. CRITERIA FOR COMMON BED TYPES
 - 1) Single Media Beds – Silica sand is the approved filter material. Anthracite coal will be considered for approval only under special conditions.
 - a) For rapid sand filters, the minimum depth is 27 inches (0.7 m) for sand and 42 inches (1.1 m) for anthracite coal.

- b) For rapid rate filters, the sand or anthracite coal shall have an effective size of 0.45 to 0.55 mm with a uniformity coefficient of 1.65 or less.
- 2) Dual Media Beds – Coal-sand filters shall consist of a coarse anthracite coal layer above a layer of fine sand. Some mixing of coal and sand at their interface is acceptable.
- a) The minimum total depth of filter media should be at least 30 inches (76 cm).
 - b) The coal layer should be at least 18 inches (46 cm) thick.
 - c) The fine sand layer should be 12 inches (30.5 cm) minimum thickness. If 3 inches (7.6 cm) of fine gravel support media having an effective size of 0.8 to 2 mm and a uniformity coefficient no greater than 1.7 is used, a 9 inch (22.9 cm) minimum thickness of fine sand will be approved.
 - d) The sand and coal effective sizes shall be 0.4 to 0.55 mm and 0.8 to 1.1 mm with uniformity coefficients no greater than 1.65 and 1.7, respectively. The effective size of anthracite coal when used as a cap shall be 0.8 to 1.2 mm with a uniformity coefficient of 1.85 or less.
- 3) Mixed Media Beds – Filter beds of this type typically contain a layer of anthracite coal, a layer of silica sand, and a layer of garnet sand or ilmenite. After backwashing with water, the relative size and density of the particles will result in a filter bed with filter media and pore spaces graded progressively from coarse to fine in the downward direction of filtration.

A typical 30 inch (76 cm) bed consists of 16.5 inches (41.9 cm) of anthracite coal, 9 inches (22.9 cm) of silica sand, and 4.5 inches (11.4 cm) of garnet or ilmenite sand. Typical effective sizes are 0.8 to 1.1 mm, 0.35 to 0.5 mm, and 0.15 to 0.35 mm for the coal, sand, and garnet, respectively. Use of other bed depths and media distributions must be approved by KDHE.

- 4) GAC Filter Adsorbers – A GAC filter-adsorber can be made by replacing a medium in an existing filter with GAC, by capping an existing filter, or by constructing a new filter-adsorber. The sand can be replaced in a single media filter or the coal in a dual or mixed media filter. Additional information pertaining to GAC contactors and their design can be found in Subsection Q, Adsorption with GAC.

A 30 inch (76 cm) layer of 12 x 40 mesh GAC (effective size of 0.55 to 0.65 mm) is typically employed when replacing the coal or anthracite in a single-media filter; and a 12 to 18 inch (30.5 to 46 cm) layer of 8 x 30 mesh GAC (effective size of 0.80 to 1.0 mm) is typically employed for capping or to replace the coal in a dual or mixed media bed.

A filter adsorber must meet all applicable filter performance and design criteria. The GAC used must be compatible with the filtration and backwashing systems employed; and, when two or more filter media are used, care must be taken to be sure that they fluidize and re-stratify properly, relative to one another, during backwash.

Since bacteria can grow on and slough off from GAC, and since GAC reacts with chlorine, provision must be made for a post-GAC free chlorine residual and adequate contact time to prevent the growth of nuisance organisms or opportunistic pathogens in subsequent portions of the treatment sequence and the distribution system. Provision must also be made for periodic treatment of the filter media to control bacterial and other growths and for replacement or regeneration of the GAC.

- 5) Deep Beds – Rapid rate gravity filters with media depths equal to or greater than 48 inches (1.2 m) are referred to as “deep-bed” filters. Both mono-media and dual-media designs are employed, with a larger grain size being used to reduce head loss and a deeper bed being used to give the contaminant particles approximately the same opportunity to be removed as in a conventional filter. Careful attention shall be paid to the design of the backwash system, which usually includes simultaneous air scour and water backwash at subfluidization velocities.

Deep bed filters may be considered based on pilot studies pre-approved by KDHE. The final filter design shall be based on the pilot studies and shall comply with all applicable portions of Subsections 1 through 12 and 15.

c. FILTER MEDIA PLACEMENT

- 1) Prior to the placement of filter material, the filter basin shall be cleaned thoroughly by means of a high-pressure water jet, scrubbing, or equally effective means. The filter media shall be placed in the filter basin, backwashed and prepared for service in accordance with AWWA Standard B100. After all work related to placement of media has been completed, and before the filter is placed into service,

the entire filter shall be disinfected in accordance with AWWA Standard C653. Special disinfection procedures apply to GAC, since it reacts with chlorine. These procedures are described in AWWA Standard B604.

- 2) When a medium is first installed, as many as ten backwashes may be necessary before the filter effluent is void of media fines.

6. UNDERDRAINS AND SUPPORT GRAVEL – Many filters use underdrain systems with graded gravel layers to support the media and to prevent its entry into the underdrain openings. The following guidelines should be followed to establish the gradations of the adjacent layers:

- a. Each gravel layer should be as uniform as possible, preferably retained between sieve openings that differ by a factor of two or less.
- b. The bottom-layer fine size should be 2 to 3 times the orifice diameter of the underdrain system.
- c. The top-layer fine size should be 2 to 4.5 times the effective size of the media to be retained.
- d. From layer to layer, the fine size of the coarser layer should be less than or equal to 2 times the fine size of the adjacent finer layer.
- e. Each layer should be at least 2 inches (5.1 cm) thick or 3 times the coarse size of the layer, whichever is greater.

7. RATE OF FILTRATION – The rate of filtration shall be determined through consideration of such factors as raw water quality, degree of pretreatment, filter media, water quality control parameters, competency of operating personnel, and other factors as required by KDHE.

- a. NEW FILTER SYSTEMS – The following filtration rates are approved for new treatment plants that clarify, soften or remove hydrogen sulfide, iron and manganese, taste and odor, or trace organics:

Single Media	3.0 gpm/ft ² (122 L/min-m ²)
Dual Media	4.0 gpm/ft ² (163 L/min-m ²)
Mixed Media	5.0 gpm/ft ² (204 L/min-m ²)

- b. EXISTING FILTER SYSTEMS – For existing filter systems, the above listed filtration rates may be used provided the following conditions are met:

- 1) Pre-filtration treatment facilities meet applicable KDHE requirements;
 - 2) The filter system including support media, underdrain, and hydraulic controls is in satisfactory condition and meets applicable KDHE requirements; and
 - 3) KDHE approval to increase beyond the previously permitted rates of filtration is obtained.
- c. HIGHER FILTRATION RATES – Higher filtration rates will be considered for approval, if justified by the design engineer and shown to be satisfactory to KDHE by pilot or in-plant testing.
- d. POLYMER USAGE – Polymeric filter aids are typically helpful or necessary for meeting today’s more stringent turbidity limits, especially at higher filtration rates. Thus, the use of polymeric filter aids should be evaluated for all rapid-rate filters.
8. BACKWASH – Provisions should be made for backwashing, including:
- a. Filtered water provided at the required rate by washwater storage (tanks and/or clearwells), washwater pumps, from the high service main, or a combination of these. Use of water from high pressure mains is not recommended except for standby service; but this alternative may be approved under special conditions. Duplicate washwater pumps are required unless an alternate means of obtaining water is available.
 - b. A washwater regulator or valve on the main washwater line at a minimum to obtain the desired filter backwash water flow rate when the valve on any one individual filter is wide open. The system design shall include provisions to prevent rapid changes in backwash water flow.
 - c. A rate-of-flow indicator, preferably with a totalizer, on an operator console that is located so that the backwash water flow rate can be easily read by the operator during the backwashing process. In small plants, where an operator console is not used, a flow gauge must be installed in the washwater line.
 - d. Means to prevent accumulation of air in the filter washwater supply piping and pump between backwashes.
 - e. Provisions for filtering to waste with appropriate measures for backflow prevention.

- f. Proper disposal of the backwash water and/or its supernatant, in compliance with KAR 28-15a-76.

9. BACKWASH RATE AND DURATION

- a. The minimum rate of flow for filter backwashing without air scouring shall be 15 gpm/ft² (611 L/min-m²); however, a minimum rate of 20 gpm/ft² (814 L/min-m²) is recommended. These rates correspond to water temperatures of 68°F (20°C) and 86°F (30°C), respectively. A reduced rate may be acceptable for full depth, single-media anthracite or GAC filters.

Water temperature must be taken into account when selecting the minimum rate of flow as each degree Celsius increase in temperature requires roughly a 2 percent increase in the backwash flow rate to maintain the same degree of bed expansion.

- b. The minimum duration of a filter backwash without air scour, for design purposes, is 15 minutes at the design rate of flow.
- c. Requirements for backwash water storage tanks are described in Chapter VI, Subsection A.5.a.

10. BACKWASH EQUIPMENT

- a. Filter bottoms shall be designed to distribute the washwater evenly over the entire filter area and to withstand all imposed hydraulic and structural stresses.
- b. The bottoms of the washwater troughs should be above the maximum level of the expanded media during backwashing.
- c. The top edge of each washwater trough should be level, and all the troughs should be at the same elevation.
- d. Washwater troughs should be spaced so that each serves an equal amount of filter surface area. The maximum horizontal travel of suspended solids to reach a washwater trough shall not exceed 3 ft. (0.9 m).
- e. Washwater troughs should have a 2 inch (5.1 cm) freeboard at the maximum backwash rate.

- 11. SURFACE WASH OR SUBSURFACE WASH – Surface or subsurface wash facilities are required except for filters used exclusively for iron and manganese removal. Air scouring may be approved in place of surface wash based on experimental data and operational experience. A surface wash system of fixed

nozzles or, preferably, nozzles affixed to revolving arms may be used to apply the washwater to the media surface. All surface wash devices should be designed with:

- a. Provision of a water pressure of at least 55 psi (380 kPa).
- b. A vacuum breaker or other acceptable device installed at least 1 foot (0.3 m) above high water level in the filter or other device to prevent backsiphonage.
- c. Spacing of 2 to 3 ft. (0.6 to 0.9 m) for fixed nozzles and 4 to 8 inches (10.2 to 20.3 cm) for those on revolving arms, with the nozzle orifices about 2 inches (5.1 cm) above the unexpanded media.
- d. Rate of flow of 2.0 to 4.0 gpm (7.6 to 15.1 L/min) and 0.5 to 1.0 gpm (1.9 to 3.8 L/min) per square foot of filter area for fixed and revolving arms, respectively.

12. AIR SCOURING – Air scouring can be used in place of surface wash.

- a. Air flow and concurrent washwater rates must be matched to fit the media type and size used. Typical air flow is 3 to 5 scfm/ft² (0.9 to 1.5 m³/min-m²) when the air is introduced in the underdrain; a lower air rate must be used when the air scour distribution system is placed above the underdrains. Generally, concurrent backwash water rates are in the range of 4 to 7 gpm/ft² (163 to 285 L/min-m²).
- b. The backwash system must be capable of delivering washwater at a minimum rate of 15 gpm/ft² (611 L/min-m²); however, when air scour is provided the washwater rate must be variable and should not exceed 8 gpm/ft² (326 L/min-m²), unless operating experience shows that a higher washwater rate is necessary to remove particles scoured from the surfaces of the filter media.
- c. Air scouring can be followed by a fluidization wash sufficient to restratify the media if this is desirable.
- d. A method for avoiding excessive loss of filter media during backwashing must be provided. Some systems are equipped with a baffle arrangement; other systems use a lower washwater flow rate during periods of concurrent air flow.
- e. Air must be free of contamination, e.g., dirt, dust, fumes, oil, etc.
- f. Air scour system designs for new filters shall directly deliver air to underdrains designed to evenly distribute the air. When air distribution piping is required, the piping shall be sufficiently strong and rigid, shall not

- be subject to erosion at orifice openings due to the passage of air at high velocities, and shall be securely anchored and supported.
- g. Consideration shall first be given to designs that deliver air directly to the underdrain at or below the support/filter media interface when retrofitting existing filters for air scour.
 - h. Where existing filter underdrains are inaccessible, KDHE will consider, on a case-by-case basis, designs that locate air scour systems in filter boxes, according to the following:
 - 1) Air scour distribution systems shall introduce air at an elevation no greater than that of the interface between the filter media and the support media or underdrain;
 - 2) Designs for placement at the interface shall prevent media from clogging orifices and diffusers, and from entering the air scour distribution system;
 - 3) Air scour piping shall be constructed of stainless steel, be of sufficient strength and rigidity to withstand the operational cycles of a filter, support the filter load without collapse, and not be subject to erosion at orifice openings;
 - 4) Anchoring and support systems shall be constructed of the same material as the piping; and
 - 5) The full depth of filter media shall be determined as measured from the elevation of the top of the air scour system.
 - i. KDHE will on a case-by-case basis consider designs where air delivery piping must out of necessity pass downward through the filter media, according to the following:
 - 1) Drop pipes shall be constructed of the same type of stainless steel material used for air scour piping, anchors and supports;
 - 2) Drop pipes shall be single, jointless lengths of seamless stainless steel pipe with a wall thickness that precludes short circuiting resulting from failures such as breaks, cracks and/or corrosion;
 - 3) Drop pipe/lateral tee connections shall be factory welded and pressure tested; and
 - 4) Drop pipes may not pass through backwash water troughs.

- j. Consideration shall be given to maintenance and potential replacement of the air scour system piping and related appurtenances.
 - k. Neither the air scour system design nor the filter design shall allow for a cross-connection between the applied unfiltered water and the filtered water.
13. RAPID RATE PRESSURE FILTERS – The normal use of these filters is for iron and manganese removal. Pressure filters shall not be used in the filtration of surface water (including GWUI) or following lime-soda ash softening.
- a. GENERAL – Minimum criteria relative in part to rate of filtration, structural details, hydraulics and filter media provided for rapid rate gravity filters also apply to pressure filters where appropriate.
 - b. RATE OF FILTRATION – The rate shall not exceed 4 gpm/ft² (163 L/min-m²) of filter area except where in-plant testing as approved by KDHE has demonstrated satisfactory results at higher rates.
 - c. DETAILS OF DESIGN – The filters shall be designed to provide:
 - 1) Loss of head gauges on the inlet and outlet pipes of each battery of filters;
 - 2) An easily readable meter or flow indicator on each battery of filters, preferably a flow indicator on each filter;
 - 3) The ability to operate each filter individually, in either a filtration or backwashing mode, with a piping arrangement as simple as possible to accomplish these purposes;
 - 4) A minimum side wall shell height of five feet, except where a corresponding reduction in side wall height is acceptable to KDHE based on use of a proprietary underdrain that permits reduction of the gravel depth;
 - 5) At least 18 inches (46 cm) between the top edge of the backwash water collectors and the surface of the media;
 - 6) An underdrain system to efficiently collect the filtered water and to uniformly distribute the backwash water at a rate not less than 15 gpm/ft² (611 L/min-m²) of filter area;
 - 7) Backwash flow indicators and controls that are easily readable while operating the control valves;

- 8) An air release valve on the highest point of each filter;
 - 9) Manholes, at least 24 inches (61 cm) in diameter where feasible, to facilitate inspection and repairs of filters 36 inches (91 cm) or more in diameter, and sufficient handholds for filters less than 36 inches (91 cm) in diameter;
 - 10) Means for the operator to directly (visually) observe the wastewater produced during backwashing; and
 - 11) Construction that prevents cross connections.
14. BAG AND CARTRIDGE FILTERS – Proposals to use bag or cartridge filters should be discussed with KDHE prior to submittal of a permit application. Such proposals will be evaluated based on site-specific and other considerations, including the following:
- a. The filter housing and bag/cartridge filter must demonstrate a filter efficiency of at least 2-log reduction in particles 1 micron in size or larger. Demonstration of higher log removals may be required by KDHE depending on raw water quality and other treatment steps to be employed. Bag or cartridge filters used for compliance with 40 CFR 141.700 et seq. (LT2ESWTR) must meet the definition of bag or cartridge filtration (40 CFR 141.2) and their removal efficiency must be established as described in 40 CFR 141.719(a).
 - b. For applications involving GWUI, the necessary log reductions of *Giardia lamblia* and *Cryptosporidium* cysts and for complying with the turbidity requirements established by KAR 28-15a-73 must be demonstrated using procedures acceptable to KDHE. Acceptable procedures include: evaluation of *Giardia* and *Cryptosporidium* surrogate particles in accordance with NSF International's ANSI/NSF Standard 53 or equivalent (conducted by NSF International or by another third party acceptable to KDHE); and the "Particle Size Analysis Demonstration for Giardia Cyst Removal Credit" procedure in Appendix M of USEPA's *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (USEPA, 1991).
 - c. The demonstration of filter efficiency is applicable only to a specific housing used in combination with a specific bag or cartridge filter. Any other combinations of different bags, cartridges, or housings will require additional demonstration of filter efficiency.
 - d. KDHE will decide whether or not a pilot demonstration is necessary for each installation.

- e. System components such as housing, bags, cartridges, membranes, gaskets, and O-rings should be evaluated under NSF International's ANSI/NSF Standard 61 or equivalent, for leaching of contaminants.
- f. The source water or pretreated water turbidity should be less than 5 NTU.
- g. The flow rate through the treatment process shall be monitored with a flow valve and meter. The flow rate through the bag/cartridge filter must not exceed the maximum flow rate at which the applicable removal efficiencies were demonstrated.
- h. Pretreatment using pressure filters or bag or cartridge filters with larger openings is recommended when it will provide more constant water quality to the bag/cartridge filter and will extend bag or cartridge life.
- i. A filter to waste component is strongly recommended for pressure filters used for pretreatment. At the beginning of each filter cycle and/or after every backwash of the pre-filters, a set amount of water should be discharged to waste before water flows into the bag/cartridge filter. Filter to waste shall be provided for the final filter(s) and a set amount of water shall be discharged to waste after changing the filters.
- j. If pressure filters are used for pretreatment they must be designed according to Subsection 13.
- k. It is recommended that chlorine or another disinfectant be added at the head of the treatment process to reduce/eliminate biological growth on the filters, taking into consideration possible impacts on DBP formation.
- l. A sampling tap shall be provided ahead of any treatment so a source water sample can be collected.
- m. Pressure gauges and sampling taps shall be installed before and after the bag or cartridge filters and before and after any pretreatment filters.
- n. An automatic air release valve shall be installed on top of the filter housing.
- o. Frequent start and stop operation of the bag or cartridge filter should be avoided. The following options are recommended:
 - 1) Install a slow opening and closing valve ahead of the filter to reduce flow surges.
 - 2) Reduce the flow through a bag or cartridge filter to as low as possible to lengthen filter run times.

- 3) Install a recirculation pump that pumps treated water back to a point ahead of the bag or cartridge filter. Care must be taken to make sure there is no cross-connection between the finished water and raw water.
- p. A minimum of two bag or cartridge filter housings should be provided for water systems that must provide water continuously.
 - q. A pressure relief valve should be incorporated into the bag or cartridge filter housing.
 - r. Complete automation of the treatment system is not required, but KDHE may require continuous monitoring of finished water quality and may further require that the plant be designed to automatically shut down when the finished water does not meet applicable regulations. It is important that a qualified operator be available to operate the treatment plant. A plan of action should be in place should the water quality parameters fail to meet applicable regulations.
 - s. Bag or cartridge filters must be replaced when a pressure difference of 30 psi (210 kPa) or other pressure difference recommended by the manufacturer and acceptable to KDHE is observed. It should be noted that the pressure drop is not expected to increase linearly. KDHE may require continuous monitoring of the operating and/or differential pressures or other parameters such as instantaneous and total flows, and may establish other criteria for establishing the end of a filter run.
 - t. Maintenance (O-ring replacement) shall be performed in accordance with the manufacturer's recommendations.
 - u. Sterile rubber gloves and a disposable face mask covering the nose and mouth shall be worn when replacing or cleaning the cartridge or bag filters.
 - v. The filter system shall be properly disinfected and water shall be ran to waste each time the cartridge or bag filter vessels are opened for maintenance.
 - w. The following parameters shall be routinely monitored and recorded: instantaneous flow rate, cumulative flow through a given bag or cartridge, instantaneous operating pressure, differential pressure, and finished water turbidity.
 - x. The operational and maintenance cost of bag and cartridge replacement must be considered when designing a system.

15. BIOLOGICALLY ACTIVE FILTERS – Biologically active filtration (or biofiltration), as used herein, refers to a filtration process that includes establishment and maintenance of biological activity within the filtration media. Treatment objectives may include: removal of biodegradable organic matter (naturally occurring or produced during treatment, e.g., during ozonation) to increase the stability of the finished water or to reduce DBP formation; oxidation of iron and manganese; removal of synthetic organic chemicals; and oxidation of ammonia nitrogen.

Biological activity can adversely impact removal of turbidity, particles and pathogens; disinfection practices; head loss development; filter run times; and taste and odor. Design and operation should ensure that aerobic conditions are maintained at all times. Biologically active filtration often includes the use of ozone as a pre-oxidant/disinfectant which breaks down natural organic materials into biodegradable organic matter and granular activated carbon filter media which may promote denser biofilms.

Biologically active filters may be considered based on pilot studies pre-approved by KDHE. The study objectives must be clearly defined and must ensure the microbial quality of the filtered water under all anticipated conditions of operation. The pilot study shall be of sufficient duration to ensure establishment of full biological activity, which may require three months or longer; and seasonal effects on water quality and temperature must be adequately addressed. The pilot study shall establish empty bed contact time, loading rates, backwash frequency and duration, backwash disinfectant residual level, and/or other parameters necessary for successful operation, as required by KDHE. The final design shall be based on the pilot-plant studies and shall comply with all applicable portions of Subsections 1 through 12 above.

K. SOFTENING

1. GENERAL CONSIDERATIONS – Softening should be considered for a raw water having a total hardness exceeding 300 mg/L as CaCO₃ and may be a desirable way to treat waters having lower concentrations of hardness. The decision of a PWSS to soften (or to not soften) is typically based on economic and aesthetic considerations, including detergent costs, scaling of water heaters and other appliances, and the needs of local industries. The alkalinity of the softened water should be at least 40 mg/L as CaCO₃ and preferably about 50 to 60 mg/L as CaCO₃. In general, softening process selection is based upon the mineral qualities of the raw water (hardness, concentration and relative amounts of calcium, magnesium, and alkalinity), the desired finished water quality, requirements for disposal of solids or brine wastes, capital and O&M costs, and plant location. The applicability of the process chosen shall be demonstrated.
2. RELATED CRITERIA – The applicable design criteria for presedimentation, rapid mixing, flocculation, sedimentation, and filtration are included in Sections E to H and

J, respectively. For surface water and GWUI, the criteria are the same for lime softening and coagulation; but shorter minimum detention times are specified for sedimentation basins and solids contact basins used for lime softening of groundwater (Section H).

- a. Softening chemicals and recycled softening solids should be fed at the rapid mix basin along with the coagulant and/or coagulant aid as required for effective treatment when using conventional softening basins. Solids return flow rates vary depending on raw water quality, solubility equilibria, the physical and chemical properties of the solids produced by the softening process, and desired hardness levels.
 - b. Softening chemicals may be added directly to the mixing compartment of solids contact units.
3. LIME SOFTENING – Process variations include: conventional lime softening (addition of lime to remove calcium carbonate hardness); lime-soda ash softening (with sodium carbonate also added, to remove non-carbonate hardness); excess-lime softening (with extra lime added to raise the pH high enough to remove the desired amount of magnesium hardness); two-stage treatment (a term that can refer to softening followed by two-stage recarbonation or to softening followed by or preceded by coagulation); and split-treatment (a term that can refer to treatment of a portion of the flow using excess-lime softening and the remainder of the flow with conventional softening or coagulation, or to treatment of a portion of the flow with softening while bypassing the remainder of the flow, typically to use the alkalinity in the bypassed flow to partially stabilize the softened water).
- a. The CO_2 concentration in the raw water should be accurately determined based on field measurements. If the concentration exceeds 10 mg/L, the possibility of CO_2 removal by aeration rather than by adding lime should be considered (Section P).
 - b. Consultation with KDHE is required before proceeding with split-treatment. When split-treatment is used to reduce the chemical costs associated with magnesium removal, the magnesium concentration of the finished water should not exceed the values shown in Table V-2. When split-treatment is used to partially stabilize the treated water by using alkalinity in the bypassed flow to adjust the pH and alkalinity of the treated water, facilities to complete the stabilization process must be provided. For either type of split-treatment, the bypass line should be valved, metered, and sized to carry the total plant flow in case the need should arise to bypass the first stage of treatment, e.g., during an emergency.

TABLE V-2

APPROXIMATE MAXIMUM ALLOWABLE MAGNESIUM HARDNESS
CONCENTRATIONS TO PREVENT PRECIPITATION
IN 140 °C HOT WATER (AWWA, 1971)

pH @ 25 °C	Mg ⁺² , mg/L as CaCO ₃
9.0	65
9.2	57
9.4	51
9.6	45
9.8	40

- c. Stabilization of water that has been softened by treatment with lime is required (Section L). When two-stage recarbonation is used, settling must be provided between the first and second stages. The minimum settling basin detention time is 45 minutes, with a maximum overflow rate of 1,500 gpd/ft² (61,100 Lpd/m²) and a maximum weir loading of 15,000 gpd/ft (186,000 Lpd/m).
- d. Beneficial use of softening solids should be considered as an alternative to disposal.

4. CAUSTIC SODA SOFTENING

- a. Using caustic soda in place of lime results in consumption of only half as much alkalinity which can reduce or eliminate the need to use soda ash to soften low-alkalinity water.
- b. Other advantages of using caustic soda include its ease of storage, handling, and feeding along with much lower solids production.
- c. Disadvantages of using caustic soda include its higher cost (relative to lime) and increases in total dissolved solids and sodium in softened water. Additionally, if use of caustic soda results in higher softened water alkalinity concentrations this may increase the amount of carbon dioxide required to adjust finished water pH.

- d. Proposals to employ this process should include an analysis of the costs and benefits relative to those associated with the most applicable lime-softening process variation.
5. CATION EXCHANGE – Cation-exchange softening will only be approved on a case-by-case basis and the residual sodium and dissolved solids concentrations will be an important factor in this consideration. Silica gel resins should not be used for waters having a pH above 8.4 or containing less than 6 mg/L silica, and should not be used when iron is present. Iron, manganese, or a combination of the two, in the oxidized or unoxidized states, should not exceed 0.3 mg/L in the hard water treated by other cation exchange materials. Pretreatment for iron or manganese may be necessary and should be carefully evaluated. Water having 5 NTU or more turbidity should not be applied directly to the ion exchange softener. When the applied water contains a chlorine residual, the cation exchange resin shall be a type that is not damaged by residual chlorine. Phenolic resins should not be used. See Section R for design requirements pertaining to ion exchange systems used for IOC removal.
- a. DESIGN – The units may be pressure or gravity type, either upflow or downflow, and with automatic or manual regeneration. Automatic regeneration based on volume of water softened should be used unless manual regeneration is justified and approved by KDHE. A manual override shall be provided on all automatic controls. Units having a pipe that supplies water to the regeneration solution container also serving to siphon the solution to the softening unit will not be approved.
 - 1) Exchange Capacity – The design exchange capacity for hardness removal should be selected to minimize the resin regeneration and brine disposal requirements for the system.
 - 2) Depth of Media – The depth of the exchange material should not be less than 3 ft. (0.9 m).
 - 3) Flow Rates – Typical service flow rates for softening are 1 to 5 gpm/ft³ (134 to 670 L/min-m³) although higher rates are possible. The backwash rate should be selected to produce a bed expansion of no more than 100 percent.
 - 4) Freeboard – The freeboard will depend mainly upon the need for expansion of the resin during backwashing. Generally, the bottom of the washwater collector should be 2 ft. (0.6 m) above the top of the resin on downflow units.
 - b. BYPASS – A bypass should be provided for blending softened with unsoftened water to produce water of a desirable hardness. Totalizing meters must be installed on the bypass line and on each softener unit. The bypass

line must have a shutoff valve and should have an automatic proportioning or regulating device. In some installations, it may be necessary to treat the bypassed water to obtain acceptable levels of iron and/or manganese in the finished water.

- c. UNDERDRAINS AND SUPPORTING GRAVEL – These components should conform to applicable criteria for rapid rate gravity filters (Section J).
- d. CROSS-CONNECTION CONTROL – Backwash, rinse, and air relief discharge pipes should be installed in a manner that is appropriate to their intended use and prevents backsiphonage.
- e. SAMPLING TAPS – Smooth-nosed sampling taps shall be located to provide samples of softener influent, effluent, and blended water. The sampling taps for blended water should be located at least 20 ft. (6.1 m) downstream from the point of blending. Sampling taps should be provided on the brine tank discharge piping.
- f. BRINE DISTRIBUTION – Facilities should be included for even distribution of the brine over the entire surface of the upflow or downflow units.
- g. BRINE PUMP OR EDUCTOR – An eductor may be used to transfer brine from the brine tank to the softeners. If a pump is used, a brine measuring tank or means of metering should be provided to verify the volume of brine used.
- h. SALT AND BRINE STORAGE TANKS
 - 1) Salt dissolving (brine) tanks and wet salt storage tanks must be covered and corrosion resistant.
 - 2) The make-up water inlet must be protected from backsiphonage. Water for filling the tanks should be distributed over the entire surface by pipes above the maximum brine level in the tank. The tanks should be provided with an automatic declining level control system on the make-up water line.
 - 3) Wet salt storage basins must be equipped with manholes or hatchways for access and for direct dumping of salt from truck or railcar. Openings must be provided with raised curbs and watertight covers having overlapping edges similar to those required for finished water reservoirs.

- 4) Overflows, where provided, must be protected with corrosion resistant screens and must terminate with either a turned-down bend having a proper free fall discharge or a self-closing flap valve.
 - 5) Two wet salt storage tanks or compartments designed to operate independently should be provided.
 - 6) The salt shall be supported on graduated layers of gravel placed over a brine collection system.
 - 7) Alternative designs that are conducive to frequent cleaning of the wet salt storage tank may be considered.
- i. **SALT AND BRINE STORAGE CAPACITY** – Total salt storage should have sufficient capacity to store in excess of 1.5 truckloads or carloads of salt and provide for at least 30 days of operation.
 - j. **WASTE DISPOSAL** – Suitable disposal must be provided for brine waste. Where the volume of spent brine must be reduced consideration may be given to using a portion of the spent brine for a subsequent regeneration.
 - k. **CONSTRUCTION MATERIALS** – Pipes and contact materials must be resistant to the aggressiveness of salt. Plastic and red brass are acceptable piping materials. Steel and concrete must be coated with a non-leaching protective coating that is compatible with salt and brine.
 - l. **HOUSING** – Bagged salt and dry bulk salt storage shall be enclosed and separated from other operating areas in order to prevent damage to equipment.

L. STABILIZATION – An unstable water is one that changes significantly in quality during treated water storage or in the distribution system. A chemically unstable water may form scales in the distribution system (e.g., due to precipitation of CaCO_3 or other solids), corrode the distribution system or its components (which may increase lead and copper beyond acceptable levels), or become turbid or discolored (e.g., due to precipitation of iron or manganese). A biologically unstable water is one that supports the growth of bacteria, which can cause corrosion, taste and odor problems, high heterotrophic plate counts, loss of chlorine residual, and other adverse effects. A water may be naturally unstable (e.g., a source water may contain elevated levels of CO_2 or H_2S) or it may become unstable as a result of treatment (e.g., chemical addition may raise or lower the pH, and the use of a strong oxidant, such as ozone, may produce organic acids that are biodegradable). Water that is unstable, naturally or as a result of treatment, shall be stabilized. The expected quality of treated water shall be evaluated to determine what, if any, treatment is needed.

1. THE CaCO₃ SATURATION INDEX (SI) – The SI (often referred to as the Langlier Index) is widely used, especially in the Midwestern U.S., to indicate whether a water has a tendency to precipitate or dissolve calcium carbonate. Waters having a negative SI tend to dissolve CaCO₃ and to be corrosive, while those with a positive SI tend to precipitate CaCO₃ and to be scale forming. Instructions for calculating the SI can be found in *Standard Methods* (APHA *et al.*, 2005). The SI is imperfect, in that various factors affecting precipitation of CaCO₃ are ignored, e.g., the concentrations of phosphate and natural organic matter present in the water; but it is a useful reference point for the design of stabilization facilities and for monitoring and controlling water quality in a distribution system.

In general, waters having a slightly positive SI tend to be the most stable; but caution must be exercised lest too much CaCO₃ be deposited in the distribution system. Instructions for calculating the CaCO₃ precipitation potential of a water (or CCP) can also be found in *Standard Methods*. A positive CCP of 4 to 10 mg/L is typically recommended, but higher values may be needed to prevent corrosion, especially for water supplies high in TDS. To better resist changes in quality, it is also recommended that the water in the distribution system have concentrations of both calcium and alkalinity of at least 40 mg/L as CaCO₃ and low concentrations of chloride and sulfate (Merrill and Sanks, 1977). Furthermore, pH values associated with minimum buffer intensity (e.g., pH 8.0 to 8.5 for water at 68 °F (20 °C)) should also be avoided, as noted by Schock (1999). In order to produce a stable finished water, it may be necessary to adjust the pH and alkalinity of the finished water or to add chemicals, such as polyphosphates, that help stabilize the water.

2. STABILIZATION OF SOFTENED WATER – Lime softening is normally followed by stabilization, with carbon dioxide or sulfuric acid being added to reduce the pH; typically to 8.5 to 9.0, resulting in a slightly positive SI. When carbon dioxide is used, this process is typically referred to as recarbonation. When excess-lime softening is employed to remove magnesium, two-stage recarbonation is sometimes used. In the first stage, carbon dioxide is added to reduce the pH to 10.0 to 10.6, precipitating additional CaCO₃ that is removed by sedimentation. In the second stage, additional carbon dioxide is added to reduce the pH to a lower value, typically 8.5 to 9.0. If sulfuric acid is used, consideration should be given to its impact on finished water alkalinity and on the bicarbonate to sulfate ratio and its potential effect on copper corrosion (Schock, 1999). Submerged gas burners are not approved for new installations, and on-site generation of carbon dioxide is discouraged. Gas (under vacuum) or solution feed systems are recommended; but sulfuric acid may also be used (except in the first stage of two-stage recarbonation).
 - a. Recarbonation basin design should provide:
 - 1) A total detention time of 20 minutes;
 - 2) A mixing/dissolution compartment; and

3) A reaction compartment.

The mixing/dissolution compartment for carbon dioxide gas diffuser feed systems should provide at least 3 minutes of contact time and have a diffuser submergence depth of at least 7.5 ft. (2.3 m) but not a depth greater than what is recommended by the manufacturer. Other appropriate means of dissolution, e.g., direct injection into a pressurized pipe or the use of a solution feed system, may be proposed.

- b. Adequate precautions must be taken to prevent carbon dioxide used in the recarbonation process from accumulating to dangerous levels, especially in enclosed spaces.
 - c. Provisions should be made for draining the recarbonation basin and removing accumulated solids.
 - d. Split-treatment for partial control of stability may be feasible, but the treated water, including bypass flows, must be properly filtered and disinfected as described in Subsection B.4 of this chapter; and facilities to complete the stabilization process must be provided.
 - e. Due consideration must be given to diffuser design and location, pressure, flow, flow ratio, submergence, reaction and control times, temperature (solubility), and precipitation potential where direct injection or solution feed systems are employed. Consultation with the feed system supplier early on in the design process is strongly recommended to identify any special requirements.
3. CORROSION CONTROL FOR LEAD AND COPPER – As noted in Subsection B.5 of this chapter, all PWSSs are required to optimize corrosion control treatment to minimize lead and copper. This may involve adjusting pH and alkalinity, depositing a thin film of CaCO_3 on pipe surfaces (by adjusting the SI to a slightly positive value), or feeding chemicals such as orthophosphate, zinc orthophosphate, and blended phosphates (Schock, 1999; USEPA, 2003b).
4. CHEMICAL ADDITION – Many different chemicals may be used for stabilization, including: acids (usually carbon dioxide or sulfuric acid, to lower pH); bases (usually lime, soda ash, or caustic soda, to increase pH and/or alkalinity); calcium carbonate or sodium bicarbonate (to increase alkalinity, though this is rarely, if ever, necessary for water supplies in Kansas); antiscalants (usually polyphosphates); and chemicals used as corrosion inhibitors or sequestering agents (e.g., orthophosphate, sodium silicate, blended phosphates, and zinc orthophosphate).
- a. Chemicals used for stabilization must be appropriate for use in the production of drinking water (Subsection A.4.a.(1) of Chapter IX).

- b. Any proprietary compound must be approved by KDHE prior to use.
 - c. Chemical feeders must be approved by KDHE (Chapter IX on Chemical Storage, Handling, and Disposal).
 - d. Stock phosphate and polyphosphate solutions should be covered and disinfected by carrying a free chlorine residual of approximately 10 mg/L. Phosphate solutions having a pH of 2.0 or less may be exempted from this requirement by KDHE.
 - e. Polyphosphate may be added for treatment purposes, e.g., to prevent encrustation of filter media, to sequester iron, or to reduce corrosion or scale formation in the distribution system. The dosage and point of application must be carefully selected to achieve the desired purpose and to avoid unintended consequences. For example, adding polyphosphate prior to filtration can cause a significant increase in filtered-water turbidity. In this case, it may be necessary to use other means to reduce filter encrustation and to add the polyphosphate after filtration.
5. CARBON DIOXIDE REMOVAL BY AERATION – The carbon dioxide content of aggressive waters may be reduced by aeration (Section P).
6. INSTABILITY DUE TO BIOCHEMICAL ACTION IN THE DISTRIBUTION SYSTEM – Unstable water resulting from the bacterial decomposition of organic matter, biochemical action within tubercles or other deposits, oxidation of ammonia (nitrification), and reduction of sulfate can usually be prevented by maintaining an adequate chlorine residual throughout the distribution system. When a combined chlorine residual is maintained in the distribution system, optimizing operating practices, e.g., maintaining proper chlorine-to-ammonia ratios and monitoring free ammonia and chloramine residuals within the distribution system, will help ensure that nitrifying conditions do not develop. If ozonation or another strong oxidation process is used, it may be necessary, depending on the concentration and characteristics of organic matter in the raw water and on the oxidant dosage employed, to provide additional treatment to reduce the concentration of biodegradable matter entering the distribution system, e.g., to employ biological filtration (Subsection J.15) following the oxidation process or to remove more of the precursor materials using enhanced coagulation or adsorption on GAC.
7. OPERATIONAL CONTROL OF STABILITY – Laboratory equipment shall be provided for determining the effectiveness of stabilization.

M. DISINFECTION

All drinking water supplied to the public by a public water supply system must be disinfected (KAR 28-15-19(a)). Disinfection requirements depend upon the source and quality of the

supply. PWSSs using surface water or GWUI must use a treatment approach based on credits for removal and/or inactivation of *Giardia lamblia*, Cryptosporidium, and viruses (KAR 28-15a-70). PWSSs using groundwater must comply with the requirements of the Ground Water Rule (GWR), which under certain conditions may require virus removal and/or inactivation for PWSSs having fecally contaminated source waters or having significant deficiencies (40 CFR 141.400 et seq.). All PWSSs employing chlorination must maintain a specified level of chlorine in the distribution system (KAR 28-15-19(b)). These requirements are described in greater detail in Subsections 1 through 4 below.

Single or multiple disinfectants can be used to meet the inactivation requirements. Approved disinfectants include free chlorine, combined chlorine, chlorine dioxide, ozone and ultraviolet (UV) light. Combined chlorine is not permissible for primary disinfection. Chlorine dioxide is not permissible as a residual disinfectant. The use of heat, extremes in pH, metals, surfactants, potassium permanganate, hydrogen peroxide, iodine, or bromine for the purpose of disinfection is not permissible. Other disinfecting agents will be considered if they are proven safe and effective, reliable application equipment is available, and a testing procedure suitable for determining an effective dose and/or residual is recognized in the most recent edition of *Standard Methods* (APHA *et al.*, 2005). Public notification must be given, especially to hospitals, kidney dialysis facilities, and fish breeders, before changing the residual disinfectant from free chlorine to combined chlorine.

Design considerations for gas chlorination facilities and for feeding chemicals (including disinfectants, such as sodium hypochlorite, and chemicals used to form disinfectants, such as sodium chlorite and anhydrous ammonia) are addressed in Chapter IX. Design considerations for chlorine dioxide, ozone, and UV installations are addressed in Subsections 5, 6 and 7, respectively.

1. CT REQUIREMENTS

- a. One basis for determining the acceptability of disinfection is to evaluate the composite CT (inactivation ratio) for the system under two extremes of operation. These are summer and winter operations at maximum hourly flow. For new treatment plants, CTs are calculated for these temperature and flow extremes using the design values of detention times and disinfectant residuals. For upgrading existing facilities, CTs are calculated using existing plant data and design values for new or modified treatment units. Before significant changes in disinfection practice are made to an existing system, a system is required to develop a disinfection profile (if the system has an annual average TTHM or HAA5 concentration \geq 80 percent of the MCL) (USEPA, 1999a), establish a disinfection benchmark, and consult with KDHE to obtain its approval prior to proceeding with the changes (40 CFR 141.172, 141.542 and 141.709).

For both new and existing facilities, the calculated CT values are compared with USEPA's CT requirements to determine if the required log inactivations

for *Giardia lamblia* and viruses will be achieved (USEPA, 1991)(40 CFR 141.74). The CT values for pH 9 and for a free chlorine residual of 3 mg/L must be used for a sample pH greater than 9 or a free chlorine residual greater than 3 mg/L, respectively.

b. Design of treatment facilities to achieve the required CT values must also take into consideration the contact time that needs to be provided and the location of the contact basin.

1) Minimum Contact Time – The contact time needed to meet CT requirements depends on several factors including the disinfectant residual concentration, temperature, pH and water quality. The minimum disinfectant contact time in straight-run pipelines is calculated based on the assumption of plug flow (i.e., by dividing the internal volume of the pipeline by the maximum hourly flow through the pipeline). Contact times for mixing basins, treatment basins, storage reservoirs, looped pipe networks, or other types of contact structures shall be determined by tracer studies or an equivalent demonstration. Since ozone residuals decay rapidly and are strongly dependent on water quality, the contact time required for ozone inactivation of microbes must be determined by pilot or in-plant studies (Subsection M.6). Basins used for disinfection should be designed to minimize short-circuiting. Baffling can be added to existing basins to minimize short-circuiting and to increase the effective contact time.

Credit for contact time in water storage structures (e.g., elevated and ground storage tanks, or standpipes) will only be granted for those located prior to the point of entry to the distribution system (or first customer) (KAR 28-15a-2). No credit will be granted for contact time in storage structures that have a single inlet/outlet line and/or where at any time only a portion of the total treated water volume flowing to the distribution system enters the storage structure.

2) Contact Basin Location – A contact basin used for CT credit may be located before or after filtration. In determining the location of the basin,

a) Adequate consideration must be given to the increase in DBP formation associated with disinfection of unfiltered water, the detrimental effects of particulate matter on the disinfection process, and short-circuiting associated with the concurrent use of process equipment in basins used for CT credit when a contact basin is located prior to filtration.

- b) Provisions must be included in the treatment sequence to ensure that both iron and manganese are adequately oxidized and their precipitated forms removed through sedimentation or filtration when a contact basin is located after filtration.
- c) The design of a post-filtration contact basin must ensure adequate contact time regardless of the manner in which transfer and high service wells and pumps are operated.
- d) The design of a post-filtration contact basin must ensure that post-filtration treatments do not adversely impact finished water quality.
- e) Post-filtration contact basins shall be enclosed, irrespective of being located inside a structure or out-of-doors, to preclude degradation of finished water quality by sources of contamination external to the contact basin.

2. GROUNDWATER (EXCLUDING GWUI)

- a. KDHE must determine if a groundwater resource is not GWUI (i.e., if it is exempt from the SWTR).
- b. All supplies shall be disinfected before delivery to the distribution system. Under certain conditions, the requirements of the GWR may require PWSSs having fecally contaminated source waters or having significant deficiencies to achieve at least a 4-log removal and/or inactivation of viruses (40 CFR 141.400 et seq.). As a minimum at plants treating groundwater, provisions shall be made for applying the disinfectant to the disinfection contact basin inlet and to the treated water entering the distribution system.
- c. Water from several wells may be combined to facilitate the disinfection process. However, if any well is determined to be GWUI, the combined flow must be filtered and disinfected in accordance with KAR 28-15a-70 unless such treatment is provided for the water deemed to be GWUI prior to the point where the flows are combined.
- d. A sampling tap shall be provided to collect a sample of the disinfected water before it enters the distribution system. The sampling tap shall be located at least 10 pipe diameters downstream from the point of disinfectant addition or at a location downstream of where the mixing of the disinfectant and treated water is complete.

3. SURFACE WATER AND GWUI – Disinfection of these sources can be accomplished using filtration in combination with one or more disinfectants at one or

more points in the treatment, storage, and distribution systems. The choice of disinfectant(s) and application point(s) will depend not only on microbial inactivation requirements but also on the need for predisinfection or preoxidation, the need to control DBP formation, the need to provide sufficient operational flexibility to deal with variations in water quality and temperature, and the need to maintain a minimum disinfectant residual throughout the distribution system. PWSSs using surface water or GWUI as a source of supply and using chlorine as the primary disinfectant should consider maintaining a combined chlorine residual throughout the distribution system in order to control DBP formation.

- a. **PREDISINFECTION AND PREEOXIDATION** – Predisinfection (the application of a disinfectant prior to clarification) has historically been practiced by Kansas PWSSs to enhance disinfection and to control problems associated with biological growths, such as slime formation and production of taste and odor causing substances. Preoxidation may be necessary when treating waters containing elevated levels of substances such as iron, manganese, and hydrogen sulfide, or to oxidize naturally occurring or synthetic organic chemical contaminants. Due to increasingly stringent regulatory limits on DBPs, predisinfection or preoxidation with free chlorine is no longer a viable option for many systems. Thus, other disinfectants and/or oxidants, some of which also produce DBPs, may need to be considered. Proposals to practice chlorine-free predisinfection or preoxidation will be evaluated by KDHE on a case-by-case basis. And approval of CT credit for such proposals will also be evaluated by KDHE on a case-by-case basis. Relevant factors for evaluating such proposals include:
 - 1) The impact on DBP formation in a particular source water and whether the PWSS will be able to comply with all applicable regulatory limits on DBPs.
 - 2) The purpose of chlorine-free predisinfection or preoxidation and whether other alternative chemicals, processes, or operational measures can achieve the desired objective while producing significantly lower levels of DBPs.
- b. **PRIMARY DISINFECTION** – Primary disinfection is the inactivation of pathogenic microorganisms, the effectiveness of which is evaluated by performing the CT calculations described above. PWSSs using surface water or GWUI must achieve at least a 3-log (99.9%) removal and/or inactivation of *Giardia lamblia* and a 4-log (99.99%) removal and/or inactivation of viruses (KAR 28-15a-70). Filtration is required for removal of *Cryptosporidium* (KAR 28-15a-170 or KAR 28-15a-500), but additional treatment for removal or inactivation of *Cryptosporidium* may be required, depending on the system's bin classification (40 CFR 141.700 et seq.). At plants treating surface water, a disinfectant is typically added ahead of the

filters to control biological growth on the filter media, and after filtration, prior to storage in the clearwell, to protect the water during storage and to produce the desired residual entering the distribution system. To provide operational flexibility at plants treating surface water, especially during emergencies or episodes of unusual water quality, provisions shall be made for applying the disinfectant to the raw water, settled water, filtered water, and water entering the distribution system.

Chlorinator capacity for primary disinfection should not be less than 10 mg/L at maximum flow. Depending on raw water quality and the level of treatment provided, higher capacities may be needed to ensure adequate disinfection at all times. The chlorinator capacity shall be such that a free chlorine residual of at least 2 mg/L can be maintained in the water, once all demands are met, after a contact time of at least 30 minutes when maximum flow coincides with maximum chlorine demand.

- c. SUPPLEMENTAL DISINFECTION – Regardless of the primary disinfectant used, chlorination facilities may be required for repumped storage reservoirs and booster pump stations in the distribution system. Other chlorination stations may be required to maintain satisfactory chlorine residuals in some distribution systems.

4. CHLORINE RESIDUALS AND USE OF CHLORAMINES

- a. Chlorine residuals at distant points in the distribution system shall not be less than 0.2 mg/L for free chlorine or 1.0 mg/L for combined chlorine (KAR 28-15-19(b)). Higher residuals may be needed, depending on water quality, temperature, and pH, to control undesirable growths of organisms (e.g., nitrifying bacteria) in the distribution system. If ammonia is present in the raw water, as is sometimes the case for groundwater supplies, its concentration must be considered in the design and operation of the chlorination process, and the monitoring method used to measure the residual must be capable of distinguishing between free chlorine and combined chlorine.
- b. Guidelines for treatment using chloramines (as a residual disinfectant in the treatment plant and/or in the distribution system) are:
 - 1) Sufficient ammonia or an ammonium compound should be added to convert free chlorine to the combined form at a location beyond the point where primary disinfection has been completed and where adequate mixing occurs. A $\text{Cl}_2:\text{NH}_3\text{-N}$ applied weight ratio of 3:1 to 5:1 is generally considered to be the optimum range for the formation of monochloramine under common chloramination treatment conditions. Lower ratios may promote nitrification in the distribution

system; higher ratios favor the formation of di- and trichloramine that can potentially cause taste and odor problems. Where applicable (e.g., GWUI drawn from a typical alluvial aquifer), the $\text{NH}_3\text{-N}$ in the raw water must be taken into account in controlling the $\text{Cl}_2\text{:NH}_3\text{-N}$ ratio. Ammonia or an ammonium compound should be fed after the chlorine but before the treated water enters the clearwell.

- 2) Careful consideration must be given to the adequacy of mixing and pH control (to minimize loss of chlorine and formation of di- and tri-chloramine); to the chloramine decay rate and the average residence time in the distribution system (to maintain an adequate residual throughout the distribution system); and to the need to control biological growths in the distribution system. The combined form of chlorine is much less efficient than free chlorine as a disinfectant, and a correspondingly higher concentration must be maintained to accomplish the desired degree of protection from pathogens and to prevent biological growths in the distribution system. This is reflected in the larger required CT value for chloramine disinfection as compared to free chlorine at the same pH and water temperature to achieve a desired level of inactivation of *Giardia lamblia* or viruses (USEPA, 1991)(40 CFR 141.74).

5. CHLORINE DIOXIDE

- a. **GENERATORS** – Chlorine dioxide generators shall be factory assembled pre-engineered units producing a minimum chlorine dioxide purity of 95 percent. Excess free chlorine (if used) shall not exceed three percent of the theoretical stoichiometric concentration required. The generators (and the associated storage and handling equipment) must be designed to prevent the occurrence of explosive levels of chlorine dioxide (approximately 8 percent and higher in air or in the head space over the solution).
- b. **OTHER DESIGN REQUIREMENTS**
 - 1) The design shall comply with the applicable portions of Subsections 1 through 4, above.
 - 2) Provision must be made for systems to comply with the MRDL for chlorine dioxide (KAR 28-15a-65) and the MCL for chlorite (KAR 28-15a-64). While it is important that chlorine dioxide be consumed prior to the finished water entering the distribution system, it is important to note that it can also be regenerated in the distribution system through the reaction of residual chlorite with free chlorine. The concentration of chlorate (which can be present as an impurity in chemical feed

stocks or produced by the generator, by sunlight, or by reactions with other oxidants) should be minimized.

- 3) Since chlorine dioxide (like free chlorine) is volatile, provision must be made to prevent the accumulation of chlorine dioxide in enclosed areas.
- 4) Since chlorine dioxide is photochemically degraded, KDHE strongly recommends that contact basins used for CT credit ahead of filtration be shielded from sunlight. Contact basins after filtration must be enclosed; thus they will be shielded by design.
- 5) Due to the highly reactive nature of chlorine dioxide and the chemicals typically used to generate it, careful attention must be given to safety and to the materials used in construction and maintenance of the generators, storage facilities, and piping runs. See Chapter IX (Chemical Storage, Handling, and Application), Gates (1998), and White (1999) for more detailed information.

c. **PUBLIC NOTIFICATION** – Notification of a change in disinfection practices and the schedule for the change shall be made known to the public, particularly to hospitals, kidney dialysis facilities, and fish breeders, as chlorine dioxide and its byproducts may have effects similar to those of chloramines.

6. **OZONATION** – The ozonation process consists of four primary components: ozone generator, feed-gas supply, ozone contactor and ozone destruct system. The ozone generator is the heart of the ozone process and is in general unique to each manufacturer. The feed-gas supply, ozone contactor and ozone destruct systems are not necessarily manufacturer specific; but, for new installations they are generally supplied by the manufacturer that provides the ozone generator.

Up until the early to mid 1990's, ozone systems were generally air- or oxygen enriched air-fed designs; however, the systems of choice are now oxygen-fed designs as a result of advances in ozone generator design that have reduced energy consumption and increased ozone generator efficiency (Rakness, 2005). The choice should be made after due consideration of energy and equipment costs. Ozone production is an energy intensive process and substantial economies in electrical usage, reduction in equipment size, and waste heat removal requirements can be obtained by using oxygen-enriched air or pure oxygen, and by operating at increased electrical frequency.

Ozone contactors have historically been constructed as over-under baffled basins with ozone gas introduced into the leading compartment through a bubble-diffuser grid. Sidestream ozone dissolution injection systems are more common today in new installations because they are more efficient in their delivery of ozone to the contactor as compared to gas-fed, bubble-diffuser feed systems (Rakness, 2005).

Ozone destruct systems treat off-gases collected from the ozone process. Ozone in the collected off-gases is destroyed by catalytically converting it to oxygen prior to discharge to atmosphere.

As a minimum, bench-scale studies shall be conducted to determine the minimum and maximum ozone dosages for disinfection, for taste and odor control (Section N), or oxidation of chemical contaminants, unless sufficient data are available from tests performed on the same water source. Pilot-plant studies shall be conducted when necessary to document ozone's potential benefits (e.g., lower concentrations of certain DBPs (KAR 25-15a-64), lower coagulant demand, and increased biodegradability of organic compounds in conjunction with biologically active filters), costs, or potential disadvantages (e.g., formation of bromate and biodegradable organic matter). The effects of variations in water quality must be adequately addressed; and the effect of pH should be carefully evaluated, since ozone's reactivity (and therefore its residual concentration, used to calculate CT) is strongly pH dependent. Consideration shall be given to multiple points of ozone addition. Special care must be taken during bench and pilot-scale studies to ensure accurate results. Particularly sensitive measurements include gas and water flow rates and the ozone concentrations in both the gas and the water. The following items shall be addressed in the design:

a. AIR FEED SYSTEM

- 1) General – Air handling equipment on conventional low pressure air feed systems shall consist of an air compressor, water/air separator, refrigerant dryer, heat reactivated desiccant dryer, and filters. Some package ozonation systems for small plants may work effectively operating at high pressure without the refrigerant dryer and with a heatless desiccant dryer. In all cases the designer must ensure that the maximum dew point of -76 °F (-60 °C) will not be exceeded at any time.
- 2) Air Compression
 - a) Air compressors shall be of the liquid-ring or rotary lobe, oil-less, positive displacement type or dry rotary screw compressors. Generally, dry rotary screw compressors are utilized by large systems. However, liquid ring compressors have been installed on some large systems.
 - b) The air compressors shall have the capacity to simultaneously provide for maximum ozone demand, provide the air flow required for purging the desiccant dryers (where required) and allow for standby capacity.

- c) Air feed for the compressor shall be drawn from a point protected from rain, condensation, mist, fog, and contaminated air sources to minimize the moisture and hydrocarbon content of the air supply.
- d) A compressed air aftercooler and/or entrainment separator with automatic drain shall be provided prior to the dryers to reduce the water vapor.
- e) A back-up air compressor must be provided so that ozone generation is not interrupted in the event of a breakdown.

3) Air Drying

- a) Dry, dust-free and oil-free feed gas must be provided to the ozone generator. Dry gas is essential to prevent formation of nitric acid, to increase the efficiency of ozone generation, and to prevent damage to the generator dielectrics. Sufficient drying to a maximum dew point of $-76\text{ }^{\circ}\text{F}$ ($-60\text{ }^{\circ}\text{C}$) must be provided at the end of the drying cycle.
- b) Drying for high pressure systems may be accomplished using heatless desiccant only. For low pressure systems, a refrigeration air dryer in series with heat-activated desiccant dryers shall be used except with a chilled water aftercooler. In the latter case, the chilled water system serves as the cooling water supply for the ozone generators and for the compressed air aftercoolers.
- c) A refrigeration dryer capable of reducing inlet air temperature to $40\text{ }^{\circ}\text{F}$ ($4\text{ }^{\circ}\text{C}$) shall be provided for low pressure air preparation systems. The dryer can be of the compressed refrigerant type or chilled water type.
- d) For heat-reactivated desiccant dryers, the unit shall contain two desiccant filled towers complete with pressure relief valves, two four-way valves, and a heater. In addition, external type dryers shall have a cooler unit and blowers. The size of the unit shall be such that the specified dew point will be achieved during a minimum adsorption cycle time of 16 hours while operating at the maximum expected moisture loading conditions.
- e) Multiple air dryers shall be provided so that the ozone generation is not interrupted in the event of dryer breakdown.

- f) Each dryer shall be capable of venting dry gas to the atmosphere, prior to the ozone generator, to allow start-up when other dryers are on-line.

4) Air Filters

- a) Air filters shall be provided on the suction side of the air compressors, between the air compressors and the dryers and between the dryers and the ozone generators.
- b) The filter before the desiccant dryers shall be of the coalescing type and be capable of removing solid or liquid particles larger than 0.3 microns in diameter. The filter after the desiccant dryer shall be capable of removing all particles greater than 0.1 microns in diameter, or smaller if specified by the generator manufacturer.

- 5) Air Preparation Piping – Piping in the air preparation system can be common grade steel, seamless copper, stainless steel, or galvanized steel. The piping must be designed to withstand the maximum pressure in the air preparation system.

b. HIGH PURITY OXYGEN FEED

- 1) General – High-purity oxygen is most commonly obtained by evaporating high-purity liquid oxygen (LOX), but it can also be generated on-site using pressure swing adsorption (PSA), vacuum swing adsorption (VSA), thermal swing adsorption (TSA), or cryogenic separation. The designer should justify the method employed, taking into consideration system cost and performance for the specific application involved. Noise attenuation may be necessary when using PSA, VSA, or cryogenic systems.

Major components of LOX systems are storage tank(s), vaporizers and a supplemental high pressure air supply. The design of LOX storage tanks and vaporizers is addressed in the subsections immediately below. LOX feeding facilities are commonly provided on a lease basis from the LOX supplier. Bulk LOX storage facilities shall comply with all Federal, State and local requirements. Specifications for LOX used in the generation of ozone may be found in AWWA Standard B304.

Of particular importance in the design of high-purity oxygen systems are design and construction, location, operation, placarding, safety and security.

2) LOX

- a) Tanks can be either vertical or horizontal depending on capacity and site limiting conditions. Typical vertical and horizontal storage tank sizes are 3,000 to 13,000 gallons (11,400 to 49,200 L) and 10,000 to 40,000 gallons (37,900 to 151,400 L), respectively. Tanks are typically sized for 15 days of storage at the minimum operating capacity.
- b) The daily rate at which oxygen can be vented during periods of minimum usage must also be considered. During minimum oxygen usage, tank warming can boil off oxygen at a rate of about 0.3% to 0.5% of the storage tank capacity each day. Oxygen will be vented to the atmosphere through the tank's pressure relief valve when the boil off rate exceeds the oxygen usage rate (Rakness, 2005).
- c) Tanks, piping and related appurtenances should be appropriately insulated to minimize temperature rise and boil-off.
- d) Tanks must be adequately protected from over pressure and vacuum conditions.
- e) Provisions to protect tanks from collision due to normal traffic or during deliveries shall be included.
- f) Bulk storage tanks and related facilities shall be properly located to ensure safe operation.

3) Liquid Oxygen Vaporizers

- a) A minimum of two vaporizers must be provided. Each must be capable of meeting the maximum oxygen usage rate with the other vaporizer either defrosting or on standby. Where there are more than two vaporizers, the maximum oxygen usage rate must be met with the largest vaporizer either defrosting or on standby.
- b) Vaporizers may be vertical or horizontal, and single or multiple staged.
- c) Ambient air vaporizers are recommended. Water-bath vaporizers are discouraged as they are subject to failure during freezing conditions.

- d) Designs for colder climates should include at a minimum trim heaters and vaporizer covers to assist with deicing during winter operations.
 - e) Delivery pressure of gaseous oxygen shall be controlled to ensure proper flow and protect all downstream equipment. Mechanical and pilot-operated valves are common types of pressure-reducing valves.
 - f) Gaseous oxygen must be filtered to remove particles greater than 0.1 microns in diameter, or smaller if specified by the generator manufacturer.
- 4) Supplemental High-Pressure Air Supply
- a) A high-pressure supplemental air supply system is typically included as the presence of nitrogen in the appropriate balance can, depending on the liquid oxygen technology, increase the efficiency of a LOX-fed ozone generator by 10-20% (Rakness, 2005).
 - b) The high-pressure air provided must be clean and dry. The steps necessary to achieve this are similar to those for air-fed ozone systems in Subsection 6.a above.
 - c) High-pressure air is typically injected into the gaseous oxygen supply header line downstream of the pressure control valve and ahead of the filters.
- 5) Safety – The facility shall be properly located to ensure its safe operation. Of particular importance is placarding which prohibits smoking and open flames. Additional warning placards or other signage shall be posted as is deemed necessary.
- 6) Security – The site must be adequately secured to prevent vandalism and unauthorized entry.

c. OZONE GENERATOR

1) Capacity

- a) The production rating of the ozone generators shall be stated in mass per unit time (lbs/day or kg/day) and energy per unit mass (hp-hr/lb or Wh/kg) at a maximum cooling water temperature and maximum ozone concentration.

- b) The design shall ensure that the minimum concentration of ozone in the generator exit gas will not be less than one percent (by weight), unless the system is specifically designed to operate at less than one percent.
 - c) Generators shall be sized to have sufficient reserve capacity so that the system does not operate at peak capacity for extended periods of time. This can result in premature breakdown of the dielectrics.
 - d) The production rate of ozone generators will decrease as the temperature of the coolant increases. If there is to be a variation in the supply temperature of the coolant throughout the year, then curves or other data shall be used to determine production changes due to the temperature change of the supplied coolant. The design shall ensure that the generators can produce the required ozone at maximum coolant temperature.
 - e) Appropriate ozone generator backup equipment must be provided.
- 2) Electrical – The generators can be low, medium, or high frequency type. Specifications shall require that the transformers, electronic circuitry, and other electrical hardware be proven, high quality components designed for ozone service.
 - 3) Cooling – The required water flow to an ozone generator varies with the ozone production. Normally, unit design provides a maximum cooling water temperature rise of 5 °F (2.8 °C) except where a chilled water cooling system is used. The cooling water must be properly treated to minimize corrosion, scaling, and microbiological fouling of the water side of the tubes. A closed loop cooling water system is often used to ensure that proper water conditions are maintained. Where cooling water is treated, cross-connection control shall be provided to prevent contamination of the PWSS.
 - 4) Materials – To prevent corrosion, the ozone generator shell and tubes shall be constructed of 316L stainless steel.
- d. **OZONE CONTACTORS** – The selection or design of the contactor and method of ozone application depends on the purpose for which the ozone is to be used.

1) Contactors

- a) When disinfection is the primary purpose, a minimum of two contact chambers, each equipped with baffles to prevent short-circuiting and induce countercurrent or cocurrent flow, shall be provided. A larger number of contactors may be warranted to improve hydraulic efficiency (T_{10}/T value, where T_{10} is the time required for 10 percent of the influent water to pass through a series of contact basins having an overall contact time of T).
- b) The minimum contact time shall be 10 minutes. A shorter contact time may be approved by KDHE if justified by appropriate design and CT considerations.
- c) For ozone applications in which precipitates are formed, such as with iron and manganese removal, porous diffusers should be used with caution.
- d) Where taste and odor control is of concern, multiple application points and contactors shall be considered.
- e) Contactors should be separate closed vessels. The contactor must be kept under negative pressure and sufficient ozone monitors shall be provided to protect worker safety. Placement of the contactor where the entire roof is exposed to the open atmosphere is recommended. The ozone process shall at a minimum be housed in a separate room. In no case shall the contactor roof be a common wall, whole or in part, with a separate room above the contactor, except the room used to house ozonation and related equipment; nor should the roof covering the contactors extend over adjacent rooms. Entrances and climate and noise reduction control systems shall be separate.
- f) Large contact vessels should be made of reinforced concrete. All reinforcement bars shall be covered with a minimum of 3.0 inches (7.6 cm) of concrete to insulate the reinforcement bars from ozone. Smaller contact vessels can be made of stainless steel or other material which will be stable in the presence of residual ozone and ozone in the gas phase above the water level.
- g) Where necessary a system shall be provided between the contactor and the off-gas destruct unit to remove froth from

the air and return it to the contactor or another location acceptable to KDHE. If foaming is expected to be excessive, then a potable water spray system shall be placed in the contactor head space.

- h) All gasketed openings into the contactor shall be properly sealed using welds or ozone resistant gaskets such as PTFE, expanded PTFE or chlorosulfonated polyethylene (Rakness, 2005).
- i) Multiple sampling taps shall be provided to enable sampling of each compartment's effluent water and determination of CT credit.
- j) A pressure/vacuum relief valve shall be provided in the contactor and piped to the destruction unit in a manner that will not damage the destruction unit.
- k) The contactor may work on either a countercurrent or cocurrent basis with respect to the ozone and water feeds. In either case, uniform distribution of ozone and adequate mixing of gas must be provided; and supplemental air may be needed to maintain the minimum flow needed to achieve these objectives, e.g., when the ozone concentration in the feed gas is high and the applied dosage is low.
- l) The contactor design shall facilitate cleaning and maintenance of the structure and internal piping, and drainage of the contactor. Each contactor compartment shall also be equipped with an access hatchway. Access hatchways must be gasketed, tightly sealed, and self draining. Hatchways (interior or exterior) located on top of the contactor must be curbed to an elevation of at least 4 inches (10.2 cm) above the deck. Hatches formed into the side walls of a contactor should be made self draining, i.e., with the ledges sloped to drain water away from the hatch.

2) Bubble Diffusers

- a) The depth of water in bubble diffuser contactors should be a minimum of 18 ft. (5.5 m) unless a smaller depth is justified by transfer efficiency considerations; and depths greater than 18 ft. (5.5 m) may be needed to achieve a transfer efficiency greater than 90 percent. The contactor should also have a minimum of 3 ft. (0.9 m) of freeboard to allow for foaming.

- b) Ozone shall be applied using porous-tube or dome diffusers spaced to achieve good distribution of gas bubbles over the floor area of the contactor. Gaskets shall be made of material suitable for use with the ozone concentration employed as gaskets are susceptible to deterioration (Rakness, 2005). Viton is in general considered to be a competitive alternative to expanded PTFE and chlorosulfonated polyethylene. Expanded Teflon is new to ozone service and is relatively expensive. Chlorosulfonated polyethylene performs well in applications where ozone concentrations are low, but performs poorly in applications where ozone concentrations are high. Aeration diffusers shall be fully serviceable for either cleaning or replacement.

3) Sidestream Dissolution Injection

- a) Sidestream dissolution injectors use pump/eductor units to mix a sidestream of water from the non-ozonated mainstream flow with highly concentrated ozone gas (10-12% by weight) and to then inject the resultant ozonated sidestream water solution into the non-ozonated mainstream flow upstream of the ozone contactor (Rakness, 2005).
- b) At least two sidestream pump/eductor units must be provided, to provide a standby. Additional units may be advisable to minimize operating costs at turndown water flow rates.
- c) Ozonated sidestream water may be degassed in a degassing vessel prior to injection into the mainstream flow or injected directly into the mainstream flow. Off-gas from the degas vessel or alternatively from the head space of the ozone contactor must be routed to the ozone destruct system for destruction.
- d) Optimum ozone transfer efficiency in the sidestream water is achieved differently in injector-degas-vessel and injector-only systems. Temperature, pressure, ozone concentration, and gas-to-liquid ratios are critical to each. Optimal transfer efficiency should be > 90%. Typical gas-to-liquid ratios for sidestream injector/degas vessels and sidestream injector only feeds are 0.1 or lower and 0.3 to 0.7, respectively (Rakness, 2005). The type of sidestream dissolution system employed must be factored into the contactor design to account for differences in mass transfer efficiency.

- e) Injection into the mainstream flow shall ensure that the concentrated ozone solution is thoroughly mixed into the mainstream flow before it enters the contactor. Mixing-enhancement nozzle injectors are typically utilized.
 - f) The ozone generator must be protected from backflow of water or water vapor. A fail-to-close ball valve operated by a high pressure switch, a liquid trap and a check valve, in that order, should be included the ozone gas line. Outlet valves for non-operating ozone generators should be closed.
 - g) Flow of ozone to each contactor must be controlled.
 - h) Pressure gauges must be provided along gas and liquid piping to facilitate trouble shooting.
 - i) A degas vessel may be necessary where the DO level in the ozonated water or bubbles entering the ozone contactor must be kept to a minimum.
 - j) Alternatively, stripping oxygen from ozonated water by the introduction of clean, compressed air into the last compartment of the contactor to reduce DO may be considered.
 - k) Detention time in the degas vessel and sidestream piping must be taken into account in order to properly adjust the applied ozone dose to off-set ozone decay.
 - l) Capital and operating costs may differ for the injection-degas-vessel and direct-injection options.
- 4) Other Ozone Dissolution-Injection Contactors – Other contactors, such as those that utilize a sidestream venturi injector with downflow tube (J-tube), or a static mixer, may be approved by KDHE provided that adequate ozone transfer is achieved and the contact times and residuals required for disinfection can be met and verified.
- e. OZONE DESTRUCT UNIT
- 1) A system for treating the final off-gas from each contactor must be provided in order to meet applicable safety and air quality standards. Acceptable systems include thermal destruction and thermal/catalytic destruction units.

- 2) In order to reduce the risk of fires, the use of units that operate at lower temperatures is encouraged, especially where high purity oxygen is the feed gas.
- 3) The maximum allowable ozone concentration in the destruct unit's discharge is 0.1 ppm (by volume) based on the maximum recommended limit for worker exposure for eight hours or more.
- 4) At least two units shall be provided which are each capable of handling the entire gas flow.
- 5) Exhaust blowers shall be provided in order to draw off-gas from the contactor into the destruct unit.
- 6) Catalysts must be protected from froth, moisture, and other impurities which may harm the catalyst. Demisters are typically used to provide this protection.
- 7) The catalyst and heating elements shall be located where they can easily be reached for maintenance.

f. CONTROL OF RESIDUAL OZONE AND HYDROGEN PEROXIDE

- 1) Since residual ozone decays rapidly, removal or quenching of residual ozone is often not necessary. However, when high dosages of ozone are employed (especially at lower pH values) or when water having a measurable ozone residual flows into an enclosed space (e.g., a filter building), it may be necessary to remove or quench the residual ozone to avoid exposing people to unsafe levels of off-gassing ozone. Options include: adding an additional contactor or a detention basin to provide sufficient time for the ozone to dissipate; increasing pH to accelerate ozone decay; air stripping (with the air vented to the ozone off-gas destruct unit); adding hydrogen peroxide to catalyze ozone decomposition (e.g., as part of an advanced oxidation process); and quenching the residual ozone with sodium bisulfite or calcium thiosulfate. Adequate safeguards must be in place to prevent overdosing of quenching agents, since any excess will interfere with subsequent disinfection processes.
- 2) If hydrogen peroxide is used in combination with ozone or UV radiation in an "advanced oxidation process" designed to remove organic contaminants, the residual hydrogen peroxide will exert a significant chlorine demand. Therefore, excess hydrogen peroxide must be quenched prior to chlorine addition (or the chlorinators must be adequately sized to meet the added demand associated with the

hydrogen peroxide). Overfeeding of a quenching agent such as sodium bisulfite or calcium thiosulfate will also exert a significant chlorine demand, so adequate safeguards (including appropriate analytical methods for process control) must be provided to ensure the integrity of subsequent disinfection processes.

g. PIPING MATERIALS – Only low carbon 304L and 316L stainless steels shall be used for ozone service with 316L the preferred.

h. JOINTS AND CONNECTIONS

- 1) Connections on piping used for ozone service are to be welded where possible; otherwise, flanged connections shall be used.
- 2) Connections with meters, valves, or other equipment are to be made with flanged joints with ozone resistant gaskets, such as PTFE or chlorosulfonated polyethylene. Screwed fittings shall not be used because of a tendency to leak.
- 3) A positive closing plug or butterfly valve plus a leak-proof check valve shall be provided in the piping between the generator and the contactor to prevent moisture reaching the generator.

i. INSTRUMENTATION

- 1) Pressure gauges shall be provided at the discharge from the air compressor, at the inlet to the refrigeration dryers, at the inlet and outlet of the desiccant dryers, at the inlet to the ozone generators and contactors, and at the inlet to the ozone destruction unit.
- 2) Electric power meters should be provided for measuring the electric power supplied to the ozone generators. Each generator shall have a trip which shuts down the generator when the wattage exceeds a certain preset level.
- 3) Dew point monitors shall be provided for measuring the moisture of the feed gas from the desiccant dryers. Because it is critical to maintain the specified dew point, it is recommended that continuous recording charts be used for dew point monitoring which will allow for proper adjustment of the dryer cycle. Where there is potential for moisture entering the ozone generator from downstream of the unit or where moisture accumulation can occur in the generator during shutdown, the installation of post-generator dew point monitors should be considered.

- 4) Flow meters shall be provided for measuring inlet gas at the application point to each contactor. Additional recommended flow monitoring points include air flow from the desiccant dryers to each of the ozone generators and purge air flow to the desiccant dryers.
 - 5) Temperature gauges shall be provided for the inlet and outlet of the ozone cooling water and the inlet and outlet of the ozone generator feed gas, and, if necessary, for the inlet and outlet of the ozone power supply cooling water.
 - 6) Water flow meters shall be installed to monitor the flow of cooling water to the ozone generators and, if necessary, to the ozone power supply.
 - 7) Ozone monitors shall be installed to measure ozone concentrations in both the feed-gas and off-gas from the contactor and in the off-gas from the destruct unit. For disinfection systems, monitors shall also be provided for monitoring ozone residuals in the water. The number and location of ozone residual monitors shall be such that the amount of time that the water is in contact with the ozone residual can be determined.
 - 8) A minimum of one ambient ozone monitor shall be installed in the vicinity of the contactor and a minimum of one shall be installed in the vicinity of the generator. Ozone monitors shall also be installed in any areas where ozone gas may accumulate.
- j. **ALARMS** – The following alarm/shutdown systems should be considered at each installation.
- 1) Dew Point Alarm/Shutdown – This system should shut down the generator in the event the system dew point exceeds -76 °F (-60 °C).
 - 2) Ozone Generator Cooling Water Flow Alarm/Shutdown – This system should shut down the generator when cooling water flow decreases to the point that generator damage could occur.
 - 3) Ozone Power Supply Cooling Water Flow Alarm/Shutdown – This system should shut down the power supply when cooling water flow decreases to the point that damage could occur to the power supply.
 - 4) Ozone Generator Cooling Water Temperature Alarm/Shutdown – This system should shut down the generator if either the inlet or outlet cooling water exceeds a certain preset temperature.

- 5) Ozone Power Supply Cooling Water Temperature Alarm/Shutdown – This system should shut down the power supply if either the inlet or outlet cooling water exceeds a certain preset temperature.
- 6) Ozone Generator Inlet Feed-Gas Temperature Alarm/Shutdown – This system should shut down the generator if the feed-gas temperature is above a preset value.
- 7) Ozone Generator Inlet Feed-Gas Flow Alarm/Shutdown – This alarm should sound when the feed-gas flow to the generators is less than a preset value.
- 8) Ambient Ozone Concentration Alarm/Shutdown – The alarm should sound when the ozone level in the ambient air exceeds 0.1 ppm (by volume) or a lower value chosen by the water supplier. Ozone generator shutdown should occur when ambient ozone levels exceed 0.3 ppm (or a lower value) in either the vicinity of the ozone generator or in the vicinity of the contactor.
- 9) Ozone Destruct Temperature Alarm – The alarm should sound when temperature exceeds a preset value.

k. SAFETY

- 1) The maximum allowable ozone concentration in the air to which workers may be exposed must not exceed 0.1 ppm (by volume).
- 2) Noise levels resulting from the operating equipment of the ozonation system shall be controlled to within acceptable limits by special room construction and equipment isolation.
- 3) High voltage and high frequency electrical equipment must meet current fire and electrical codes.
- 4) Emergency exhaust fans must be provided in the rooms containing the ozone generators to remove ozone gas if leakage occurs. Self-contained breathing apparatuses should be located in hallways outside rooms subject to ozone hazards.
- 5) A portable purge air blower that will remove residual ozone in the contactor prior to entry for repair or maintenance should be provided.
- 6) A sign shall be posted indicating “No Smoking, Oxygen in Use” at all entrances to the treatment plant. In addition, no flammable or combustible materials shall be stored within an oxygen storage or

ozone generator area. Materials of concern include oil, grease, paper, PAC and GAC, organic solvents, petroleum products, and paint. Additional warning placards and/or other signage shall be posted as is deemed necessary.

- 7) The facility shall be properly located to ensure safe operation.

1. CONSTRUCTION CONSIDERATIONS

- 1) Prior to connecting the piping from the desiccant dryers to the ozone generators, the air compressors should be used to blow the dust out of the desiccant.
- 2) The contactor should be tested for leakage after sealing the exterior. This can be done by pressurizing the contactor and checking for pressure losses.
- 3) Connections on the ozone service line should be tested for leakage using the soap-test method prior to placing the ozone facility into service.

7. ULTRAVIOLET (UV) DISINFECTION – UV light may be used to treat surface waters (including GWUI) to achieve compliance with the disinfection requirements of the LT2ESWTR (40 CFR 141.700 et seq.) and to achieve inactivation of *Giardia lamblia* as part of complying with the log removal and/or inactivation requirements of the SWTR. Although it is relatively inefficient for virus inactivation, there may be circumstances under which it could be considered as a treatment to achieve at least a 4-log inactivation of viruses if required by the GWR (40 CFR 141.400 et seq.). It may also be used to provide supplemental disinfection beyond that required by State or Federal regulations.

In support of the LT2ESWTR, the USEPA has developed the *UV Disinfection Guidance Manual* (UVDGM) (USEPA, 2006a) which provides detailed technical information regarding the application of UV disinfection by PWSSs. This document focuses on surface water supplies, but much of the information presented also pertains to groundwater supplies. This document should be reviewed and KDHE should be consulted prior to submittal of a preliminary engineering report proposing installation of a UV disinfection system.

UV light can also be used alone or in combination with chemicals such as hydrogen peroxide to oxidize chemical contaminants (regulated or unregulated, and synthetic or naturally occurring). A decision to use such a process should be made only after its suitability for treating a potable water supply and its technical and economic feasibility have been adequately demonstrated, and after consultation with KDHE. For UV systems employing chemical addition, special validation protocols may be required for

disinfection credit. Some requirements described below (e.g., biosimetry-based validation testing) are not applicable to UV systems for which no disinfection credit is claimed; but many of the considerations and requirements described below are applicable to such systems, and other site-, contaminant-, and process-specific requirements may apply. For systems employing a very high UV dose ($>200 \text{ mJ/cm}^2$) or using chemicals in conjunction with UV light, the engineer must satisfactorily demonstrate that the process does not introduce significant levels of chemical byproducts (including biodegradable organic matter) or chemical residuals into the water. Quenching of residual hydrogen peroxide may be necessary to control chlorine demand (Subsection 6.f).

The output of a UV lamp can vary significantly with temperature, but most lamps are mounted in quartz sleeves that provide insulation, allowing the lamps to reach an adequate temperature even when the water is very cold. Furthermore, UV lamp output is typically controlled to a specified level by a power supply linked to a UV sensor. Water temperature does not appear to influence UV disinfection at a given UV dose (fluence); but it may affect UV oxidation of chemical contaminants, and this possibility needs to be adequately addressed in the design of a UV oxidation system.

Since UV disinfection and UV oxidation are relatively new technologies for PWSSs, and since technological developments are occurring at a rapid pace, portions of Subsection A.5 of Chapter III may be applicable.

a. WATER QUALITY AND PRETREATMENT REQUIREMENTS

Particles (turbidity), chemical species that absorb UV light, and chemical constituents that foul lamp sleeves can significantly and adversely influence the effectiveness of UV disinfection. In properly pretreated water, the effects of these substances on UV disinfection can be adequately addressed by using UV intensity sensors and adjusting the output of the UV lamps as water quality fluctuates. Nevertheless, since experience with UV disinfection in Kansas is limited, KDHE will determine pre- and post-treatment requirements for UV disinfection on a case-by-case basis. The following water quality parameters are of particular concern:

- 1) Turbidity – The turbidity of the influent water must be controlled to less than 1 NTU. In surface water applications, UV disinfection must be preceded by filtration. Note that the UV dose requirements listed in Table 1.4 of the USEPA's *UV Disinfection Guidance Manual* (USEPA, 2006a) and LT2ESWTR (40 CFR 141.720(d)(1)) apply only to post-filter applications, in systems that filter under Subpart H, and to systems meeting filtration avoidance criteria, which are not applicable in Kansas.

For unfiltered groundwater supplies (excluding GWUI), a 5- μm pre-filter shall be provided, as a minimum, ahead of each UV reactor if the peak turbidity exceeds 1 NTU. For low-turbidity groundwater supplies (not requiring a pre-filter), removable screens should be installed upstream of the UV reactors if it is possible that large debris might enter the system (e.g., due to failure of a well screen or pump impeller).

Particles, even those in filtered water, will accumulate on the surfaces of the lamp sleeves over time. Therefore, an appropriate means of cleaning the lamp sleeves must be provided.

- 2) UV Transmittance (UVT) And Total Organic Carbon (TOC) – UVT, a measure of the ability of UV light to pass through the water, is influenced by turbidity, natural organic matter (typically measured as TOC), color, iron and manganese, ozone, permanganate, and other chemicals that may be present in the water or added during treatment. The UVT of the influent water must be well characterized and controlled to a level that ensures that an adequate level of disinfection can be achieved at all times. Validation testing must be done with water having a UVT equal to or less than the water to be treated.
- 3) Iron (Fe) And Manganese (Mn) – Fe(III) strongly absorbs UV light, Fe and Mn can precipitate to form particles that block UV light, and Fe and Mn can form scale on the lamp sleeves. Fe and Mn must be below the secondary MCLs (0.3 and 0.05 mg/L, respectively) prior to UV application.
- 4) Scale-Forming Constituents – Scale formation on the lamp sleeves reduces the amount of UV light entering the water column. Scales promoted by an increase in water temperature are of particular concern, since the lamp sleeves are warmed by the lamps. Scale compounds of concern include: CaCO_3 , Mg(OH)_2 , CaSO_4 , Al(OH)_3 , Fe(OH)_3 , FeCO_3 , BaSO_4 , oxides of Mn, SiO_2 , and various silicates, phosphates, and sulfides. The potential of water to form scale on the lamp sleeves must be adequately evaluated and, if necessary, controlled. This is typically accomplished by performing solubility calculations (based on adequate water quality data and taking into consideration the effects of temperature as well as chemical species added to or removed from the water by treatment prior to UV disinfection) and/or conducting pilot-, demonstration-, or full-scale testing on the water to be treated or one similar in quality with respect to scaling potential.
- 5) Ozone – Ozone strongly absorbs UV light, but also acts synergistically in concert with UV light to promote disinfection and oxidation. If residual ozone may be present as the water enters the UV reactor, this

must be taken into consideration in the design and operation of the system and in validation testing.

b. DESIGN CONSIDERATIONS AND REQUIREMENTS

- 1) Reactor Number, Configuration, And Layout – The number of UV reactors provided, including critical system components, shall be sufficient to assure a continuous water supply when one unit is out of service. Closed-channel reactors mounted in parallel shall be used, unless circumstances merit consideration of other configurations. The proposed layout should include reactor dimensions, inlet and outlet configurations, any devices used to modify flow upstream or downstream of the reactors, individual flow meters, individual vent valves, and the locations of control panels, electrical panels, off-line cleaning systems, and other appurtenances. When flow through a series of UV reactors operating in parallel is not individually controlled, all upstream and downstream piping arrangements shall ensure equal flow through all of the UV reactors. Where validation is conducted at an off-site testing facility, the UV reactor/piping layout shall be designed based on the validated inlet and outlet conditions as outlined in the UV reactor's validation report. The inlet and outlet hydraulics shall be designed according to manufacturer recommendations and to accommodate any site-specific constraints where on-site validation or custom off-site validation is planned. Additional discussion of UV reactor and piping layouts can be found in the USEPA's *UV Disinfection Guidance Manual* (USEPA, 2006a).
- 2) Lamp Type, Number, Arrangement, And Orientation – The lamp type, manufacturer, performance characteristics, and emission spectrum shall be specified. Low-pressure (LP), low-pressure high-output (LPHO), and medium-pressure (MP) lamps are typically used in PWS applications. A proposal to use MP lamps must include a description (graphical or numerical) of the spectral variations that occur as the lamps age, along with technical documentation (from the manufacturer or an independent source) regarding the impact of spectral shifts on germicidal effectiveness and the safety factors used to address such shifts. Other types of ultraviolet lamps will be considered on a case-by-case basis. Lamp orientation may be parallel, perpendicular, or diagonal to the flow or ground. The number of lamps in each reactor, including their arrangement and orientation, shall be specified.
- 3) UV Dose Requirements – The UV dose (or fluence, typically expressed in units of millijoules per square centimeter, mJ/cm^2) required to achieve a specified level of inactivation depends on the nature of the organism, the characteristics of the reactor, and water quality.

The UV doses required to achieve various levels of inactivation of *Cryptosporidium*, *Giardia lamblia*, and viruses (adenovirus) have been tabulated by the USEPA in the UVDGM (USEPA, 2006a) (40 CFR 141.720(d)(1)). These UV doses are applicable only to post-filter applications of UV in filtered systems for UV light at a wavelength of 254 nm as produced by a low pressure mercury vapor lamp. As outlined in the USEPA's *UV Disinfection Guidance Manual* (USEPA, 2006a), the validated dose is determined by applying a validation factor to these values to quantitatively account for various key uncertainties such as reactor hydraulics, measurement uncertainties, and variations among lamps.

The UV dose effectively delivered to the water by a full-scale reactor can not be directly measured, but is determined (during validation testing) by comparing the inactivation of challenge microorganisms achieved by the reactor to the organisms' dose-response curve obtained in a collimated-beam test (USEPA, 2006a). UV doses thus determined are referred to as "reduction equivalent doses" (REDs) (USEPA, 2006a).

- 4) Hydraulic Considerations – The flow rate through each reactor must be limited (reliably controlled) to the maximum flow rate for which reactor performance has been validated; and the hydraulic characteristics of the inlet and outlet of each reactor must be identical to (or demonstrably more conservative than) those used during reactor validation testing.

Since UV reactors must flow full during operation (to avoid lamp damage and for proper flow distribution), they should be placed below the hydraulic grade line. Air release valves or combination air/vacuum relief valves may be needed to prevent air pockets and negative pressures; and water-level sensors may be needed, in some systems, to warn the operator that the reactor is not full.

Reactor operating pressure must be limited to the maximum for which the reactors are designed; and pressure surges (including negative pressures) and vibrations (e.g., from pumps and motors) sufficient to damage the lamps, lamp sleeves, or other components must be eliminated.

Any product water bypassing UV disinfection must be piped to waste (or a suitable recovery basin) unless provision is made for another means of providing the required level of disinfection before the water enters the distribution system.

Drains (designed to allow rapid and complete draining) and isolation valves must be provided to facilitate inspection, maintenance and repair activities. A clean (potable) water supply should be readily available for use in cleaning and maintenance activities.

- 5) Power Supply – The potential for power fluctuations to shut down or dim the UV lamps, or to damage them by causing excessive lamp on/off cycling, must be evaluated and, if necessary, reduced, e.g., by installing such devices as alarms, automatic shut-off valves that direct inadequately disinfected water to waste, and uninterruptible power supply (UPS) units. Although power quality problems may not cause a PWSS to produce off-spec water, they can increase costs, reduce operational flexibility, and adversely affect lamp life and lamp operation (Cotton *et al.*, 2005).

All UV-system electrical and electronic components should be UL approved and, since they could potentially be exposed to high-pressure water, ground-fault circuit interruption (GFCI) circuitry is required and a water-proof enclosure (NEMA 4 or better) is recommended. Ballasts must be properly mated with the lamps being used, adequately ventilated, and thermally protected.

Careful attention should be paid to the electrical wiring of the UV systems to avoid electrical hazards, component failures, and fires. Wiring should be properly sized and, where appropriate, wire coverings should be UV resistant.

Reactor housings shall be constructed of stainless steel (314 or 316L). All components of the system exposed to UV light shall be UV resistant, and components that come into contact with the water shall not impart toxic constituents into the water (either by leaching or as a result of exposure to UV light).

- 6) Instrumentation And Control – The instrumentation and control system must be designed to monitor reactor performance, flow rate, and influent water quality; to prevent damage to the reactor; to meet the O&M and monitoring requirements described below; and to prevent inadequately disinfected water from entering the distribution system. The instrumentation and control system should include an appropriate level of redundancy.

Instrumentation, including appropriate sensors and alarms, shall be provided to monitor the following in each reactor: flow rate, liquid level (if it is possible for air to enter the reactor when it is in operation), power status (on/off), reactor power setting (if applicable), UV intensity

(or dose), lamp temperature, cumulative number of on/off cycles, and, for each lamp, lamp status (on/off) and cumulative lamp operating time in hours. (Monitoring frequency requirements are described below.) The cumulative operating time and number of on/off cycles for each lamp must be recorded on non-resettable counters. Provision should also be made to monitor cumulative power consumption to help assign costs and to assess future energy conservation measures or the economic feasibility of alternative systems.

Suitable instrumentation must be provided to enable the operator to reliably monitor influent water quality. See Subsection 7.a, Water Quality and Pretreatment Requirements, above, and Table V-3, below, which summarizes monitoring and reporting requirements. Sampling frequency and the specific constituents monitored will depend on regulatory requirements and the nature and quality of the source water. UVT must be continuously monitored if this parameter is used for UV dose control. Sampling taps suitable for collecting representative influent and effluent samples must be provided.

Each reactor must have a UV intensity sensor system (including one or more stable, reliable, and appropriately located UV intensity sensors) suitably integrated into the control system and included in validation testing. During validation testing and plant start-up, each UV intensity sensor must be individually calibrated to an absolute standard. Appropriate documentation (obtained from the manufacturer or an independent source) must be provided to: verify that the sensor characteristics (measurement range, angular response, spectral response, linearity, and stability) are suitable for monitoring and controlling the UV dose for disinfection credit; describe the measurement standards and the uncertainty of each measurement; describe the quality control and quality assurance procedures used to calibrate the sensors to NIST-traceable standards; and demonstrate that the sensors reliably meet specifications over an extended period of time.

Sensor location must be compatible with the UV dose monitoring approach and sensors must monitor the sections of the lamps that experience the greatest decrease in UV output with aging (USEPA, 2006a). If each lamp is not fitted with an individual UV intensity sensor, the control system and operating procedures must be designed to ensure an adequate level of disinfection when unmonitored lamps burn out or produce less UV light than those lamps which are being monitored. Sensors whose readings are sensitive to their orientation must be oriented to the point of minimum intensity or keyed such that

their orientation is fixed. The lamp monitoring strategy must ensure compliance with regulatory requirements for UV dose.

The control system must be fail-safe, i.e., in the event of a power outage, inadequate UV intensity or dose, exceedance of the maximum flow rate or of an influent water quality limit, or major system malfunction, an audible alarm shall sound and the water system shall automatically shut down (or the water shall automatically flow to waste) until the problem is corrected, thereby ensuring that inadequately disinfected water does not reach a consumer. (Use of a backup disinfection system able to meet all applicable disinfection requirements will be considered in lieu of an automatic shutdown or pipe-to-waste approach.) Alarms must also be provided to indicate: lamp or ballast failure, high reactor temperature, low flow, production of off-specification water, and (if applicable) wiper failure.

LT2ESWTR requires validation of UV reactors (40 CFR 141.720(d)). The results of the validation testing establish the conditions under which UV reactors must be operated to ensure the required UV dose delivery and to ensure that at least 95% of the water delivered to the public during each month is treated by UV reactors operating within their validated limits (40 CFR 141.720(d)(3))(USEPA, 2006a). Proposals that would allow up to 5% of the treated water delivered to the public during each calendar month to be “off specification” will be considered if safeguards that adequately protect public health are included. Factors KDHE will consider in evaluating such proposals include: annual *Cryptosporidium* risk (with the goal of the LT2ESWTR being less than 1 in 10,000); raw water quality; other disinfection processes used and the disinfection credit they are awarded; and the conditions under which off-specification water will be produced, i.e., how far outside the validation conditions the UV reactors will be operated before production ceases.

The control system must be designed to accommodate the start-up and shutdown requirements of the lamps without compromising the quality of the finished water or damaging the lamps. This may require installation of a bypass-to-waste line to carry off-specification water diverted by automatically operated diversion valves. The control system should be designed to avoid excessive on/off cycling of the lamps and overheating of the lamps, both of which reduce lamp life.

- 7) Operation And Maintenance (O&M) – O&M procedures, including those for system start-up and shutdown and for calibrating devices used to make critical measurements, such as UV dose (fluence), flow rate, UVT, and temperature (if applicable) must be developed based on the

manufacturer's recommendations and submitted in writing. The operating procedures should include contingency plans describing the actions to be taken following lamp breakage, major alarms (e.g., inadequate UV dose), failure of upstream processes, and power supply interruptions. System start-up plans must include a performance test as described in the USEPA's *UV Disinfection Guidance Manual* (USEPA, 2006a). The calibration of each UV intensity sensor must be checked at least monthly against a reference sensor, and a sensor whose readings do not fall within acceptable limits (USEPA, 2006a) must be replaced with another calibrated sensor. The reference sensor must be calibrated at least once annually at a qualified facility; and, if it is found to be out of calibration, the calibration interval must be shortened.

For routine operation, the intensity of each lamp shall be checked bimonthly and the lowest intensity lamp in a given reactor shall be placed in the position closest to the UV intensity sensor if one sensor monitors multiple lamps.

If UVT is used to control the UV dose, the calibration of the UVT monitor must be checked at least weekly unless data are available to support a less frequent calibration interval.

UV reactors must be designed to accommodate visual inspections, as well as physical inspection of internal surfaces, and to provide reasonably convenient access to lamps, lamp sleeves, sensors, sensor lenses or windows, lamp-wiper assemblies, and other system components to facilitate cleaning, calibration, repair, and replacement activities.

Appropriate means for routine in-place cleaning of the lamp-sleeve surfaces must be provided. The cleaning method(s) used may be physical, mechanical, or chemical, and may be done on-line or off-line; but the method or combination of methods used should be demonstrably effective. If lamp sleeves are to be cleaned chemically, the chemicals used must be approved for use in drinking water applications (KAR 28-15-18(h)) and provisions must be made to ensure that they do not contaminate the finished water (including cross-connection control) and that they are properly disposed of. UV reactors that are taken out of service for an extended period of time should be drained and stored in a dry condition.

The useful life of lamps, lamp sleeves, ballasts, UV intensity sensors, and other system components that will eventually require replacement should be considered in estimating operating costs (Subsection A.7 of Chapter III). The useful life of some components may be influenced by

raw water quality and the frequency and effectiveness of cleaning. Other factors to consider include experience with the same or similar components (especially when treating the same or similar water) and the supplier's performance guarantees.

Adequate provisions (procedures, equipment, and protective devices) shall be made for protecting the safety of operating staff and visitors from hazards, including those associated with UV light exposure, electricity, burns from lamps or equipment, broken lamps, and mercury exposure.

If the UV lamps contain mercury, an assessment of the vulnerability of the system (including storage) to lamp breakage and mercury release must be provided, and emergency response plans (for off-line and on-line breakage) and a waste disposal plan must be submitted for approval.

A recommended spare-parts inventory that reasonably enhances the reliability of the UV disinfection system should be included in the operating procedure. Replacement lamps must be the same as those used in validation testing. Use of alternative lamps must be approved by KDHE and may require reactor re-validation.

Adequate space must be provided for all O&M activities.

Operator training shall be provided prior to system start-up.

- 8) Monitoring and Reporting Requirements – The LT2ESWTR requires utilities to monitor their reactors to demonstrate that they are operating within the range of conditions that were validated for the required UV dose (40 CFR 141.720(d)). At a minimum, utilities must monitor each reactor for flow rate, reactor status (on/off), lamp status (on/off), UV intensity (or dose), liquid level (if applicable), reactor power (if applicable), and selected measures of influent water quality where applicable. Monitoring and reporting of other parameters in addition to the above may also be required by the State at its discretion.

UVT must also be continuously measured where it is used in a dose control strategy. Systems must “regularly check the calibration of UV intensity sensors in accordance with a protocol provided by the manufacturer and approved by the State” (USEPA, 2006a).

The LT2ESWTR also requires “routine (i.e., monthly) reporting of the volume of water entering the distribution system that was not treated by UV reactors operating under validated conditions” (USEPA, 2006a).

UV systems used for disinfection credit must be continuously monitored for flow rate, reactor status (on/off), UV intensity or dose, cumulative number of reactor on/off cycles, water level (if applicable), reactor power setting (if applicable), lamp status, and cumulative lamp operating time. UVT must be continuously monitored if used for UV dose control; otherwise, it must be monitored at least weekly, and more often if necessary to ensure that the reactor is operating within the range of its validated operating conditions.

The following information must be reported monthly to KDHE: peak daily flow rate, maximum daily or weekly UVT, minimum daily UV intensity or dose, cumulative number of reactor on/off cycles, the percentage of treated water produced with the UV system operating outside its validated operating conditions, daily lamp status, monthly total operating time for each lamp, the date of each major alarm or unplanned system shutdown and its cause, and the date of each lamp replacement, sensor calibration, off-line chemical cleaning, and (where applicable) pre-filter replacement. Additional water quality monitoring may be required by KDHE, especially during system start-up. If so, the data must also be included in the monthly report to KDHE.

The minimum monitoring, recording, and reporting frequencies required and recommended by KDHE for parameters associated with UV disinfection are summarized in Table V-3. KDHE shall have access to both the UV disinfection system and the records associated with it.

- c. **REACTOR VALIDATION** – The LT2ESWTR requires use of validated UV reactors for inactivation credit (40 CFR 141.720(d)) and reporting of validation test results (40 CFR 141.721). Recommended procedures are described in the UVDGM (USEPA, 2006a). Current procedures are based on biosimetry; but more accurate procedures (e.g., procedures based on actinometry) may become available and, if so, proposals to use improved methods will be considered. Specific concerns and requirements pertaining to validation of reactors used in Kansas are as follows:

- 1) Validation requirement – Each reactor design used for disinfection must undergo biosimetry-based validation testing prior to being approved for use. Validation testing may be done off-site or on-site, but scale up is not acceptable. A reactor used to obtain disinfection credit must be operated within the range of conditions (including flow rate, UV intensity or dose, power setting, UVT, and lamp status) for which it has been validated. Plans for on-site validation testing should be submitted to KDHE for approval prior to testing.

Validation is not strictly required for applications where disinfection is not required, i.e., where the disinfection credit associated with the UV system is not needed (and will not be claimed) to meet applicable disinfection requirements. However, it is recommended that a validated reactor design be used to facilitate compliance with future changes in treatment requirements. When a UV system is initially installed for reasons other than disinfection credit, but at a later date is proposed for such a purpose, the UV system as installed will be evaluated within the regulatory frame work that exists at the time disinfection credit is requested.

- 2) Third-party oversight – Third-party oversight is required to ensure that validation testing and data analyses are conducted in a technically sound manner and without real or perceived conflicts of interest. Validation testing should be overseen by a registered professional engineer who is both independent of the manufacturer and experienced in testing and evaluating UV reactors. KDHE will not require that the engineer overseeing the validation testing be registered in Kansas; however, a detailed report regarding the validation test and its results must be submitted with the engineer's report or with the plans and specifications, which must bear the seal of a professional engineer registered in the State of Kansas, thereby verifying the adequacy of the testing protocol and data analysis. Experts should be consulted if the engineer has limited experience in one or more pertinent areas (e.g., lamp physics, optics, hydraulics, microbiology, or electronics).
- 3) Test organism – Validation testing must be conducted with a test organism that is at least as resistant as the pathogens the system is designed to inactivate (if feasible) and whose dose-response characteristics have been quantified using a LP mercury-vapor lamp.
- 4) Lamp aging – Validation testing must take into account the effects of lamp aging, including reduced intensity, any spectral shifts that occur, blackening of the ends, and changes in intensity along the length of the lamps.
- 5) Other factors – Validation testing must also take into account uncertainties in measurements made using on-line sensors, the UV dose distribution associated with the velocity profile through the reactor, failure of the UV lamps or other critical system components, and inlet and outlet piping or channel configurations.
- 6) Revalidation – A reactor must be re-validated when any design or operational change is made that may affect its UV dose delivery characteristics. At this time, KDHE does not plan to approve any

alternative approaches, i.e., approaches not adopted by the UVDGM, e.g., use of CFD models or microspheres coated with a UV sensitive dye.

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TABLE V-3 MINIMUM MONITORING, RECORDING AND REPORTING FREQUENCIES REQUIRED AND RECOMMENDED BY KDHE FOR PARAMETERS ASSOCIATED WITH EACH UV REACTOR USED TO OBTAIN DISINFECTION CREDIT¹

Parameter	Monitoring Frequency	Recording Frequency	Include in Monthly Report ²	Notes
Flow Rate	Continuous	Every 4 hours	Max. Day & Mo. Avg.	Must be within validated range
Lamp Status (On/Off)	Continuous	Every 4 hours	Only if Off	Must be energized when water flowing
Reactor Power Setting	Continuous	Every 4 hours	Min. Day & Mo. Avg.	If applicable (must be in validated range)
UV Intensity	Continuous	Every 4 hours	Min. Day & Mo. Avg.	Must exceed validated set point
Calculated UV Dose	Continuous	Every 4 hours	Min. Day & Mo. Avg.	Only if used for control purposes
UVT	Continuous	Every 4 hours	Min. Day & Mo. Avg.	Daily if not used for control purposes
Volume Treated	Daily	Daily	Monthly Total	
Volume Off-Spec	Continuous	Each Event	Events & Mo. Totals	Must be <5% of volume treated
UV Sensor Calibration	Monthly	Monthly	All Results/Actions	Increase frequency if necessary
UVT Sensor Calibration	Weekly	Weekly	All Results/Actions	Increase frequency if necessary
Flow Meter Calibration	Monthly	Monthly	All Results/Actions	Increase frequency if necessary
Cum. Lamp On/Off Cycles	Continuous	Weekly	No	Use for O&M planning
Cum. Lamp On Hours	Continuous	Weekly	No	Use for O&M planning
Lamp Age	Monthly	Monthly	No	Use for O&M planning
Lamp Intensity	Bimonthly	Bimonthly	No	Locate lowest-intensity lamp next to the sensor
UV Sensor Age	Monthly	Monthly	No	Use for O&M planning
Ballast Age	Monthly	Monthly	No	Use for O&M planning
Sleeve Age	Monthly	Monthly	No	Use for O&M planning
Power Draw	Continuous	Every 4 hours	No	Use to assess energy use
Water Temperature	Continuous	Daily Max	No	Equipment limit not to be exceeded.
Reactor Water Level	Continuous	Every 4 hours	No	If applicable (to prevent lamp damage)
Influent Turbidity	Hourly	Hourly	Daily Average	Daily avg. must be ≤ 1 NTU
pH, Alk., Hardness, Fe & Mn	Weekly	Weekly	Monthly Average	Reduce in absence of fouling
Date of Last Chemical Cleaning	Monthly	Monthly	No	Use for O&M Planning

Notes:

1. Required frequencies and reporting information are shown in bold.
2. The monthly report must also include the date and cause of each major alarm, unplanned shutdown, and off-spec water event.

N. TASTE AND ODOR CONTROL

1. REQUIREMENT – All surface water supplies may have periodic taste and odor problems and means for their prevention and control should be provided. Attention should be given to these taste and odor problems in the management of the watershed, in the design of the treatment plant, and on the basis of past experience with the supply. Plants treating waters known to have taste and odor problems should be provided with equipment that allows several of the available control processes to be used so that the operator will have maximum flexibility in the plant's operation. Also, a pilot or in-plant study may be necessary to determine the best way to effectively deal with a severe taste and odor problem or to demonstrate the effectiveness of a proposed treatment technique. Selection of treatment processes used for taste and odor control, as well as their design basis, must be justified by the designer.
2. CHLORINE AND CHLORINE DIOXIDE – Historically, prechlorination has been used for controlling certain types of taste and odor problems. However, restrictions on DBPs often preclude this option. Chlorine dioxide is effective for treating certain types of taste and odor problems; but chlorine dioxide and its primary byproduct (chlorite) may need to be removed to ensure compliance with the MRDL for chlorine dioxide and the MCL for chlorite, or to prevent regeneration and volatilization of chlorine dioxide in the distribution system. It is also important to note that adding an oxidant (not only chlorine or chlorine dioxide, but also potassium permanganate or ozone) prior to clarification can exacerbate a taste and odor problem by lysing cells and releasing an additional amount of the offending chemical(s) into solution.
3. HYDROGEN SULFIDE REMOVAL – Hydrogen sulfide has a threshold odor concentration of less than 0.0001 mg/L (Cohn *et al.*, 1999) and at concentrations greater than 0.1 mg/L it can impart a very offensive odor to drinking water. Treatment methods commonly used to remove hydrogen sulfide include oxidation (using chlorine or other oxidants), aeration or air stripping (when more than traces of hydrogen sulfide are present), and filtration (to remove sulfur particles formed by the incomplete oxidation of hydrogen sulfide).
 - a. OXIDATION USING FREE CHLORINE – Chlorine reacts with hydrogen sulfide to form sulfate, but polysulfides and particles of elemental sulfur are also formed. These byproducts may be difficult to remove, may also contribute to taste and odor problems, and can react in the distribution system to create “black water” problems. If only traces of hydrogen sulfide are present (i.e., less than 0.3 mg/L) and a slight increase in finished water turbidity can be tolerated, plain chlorination may suffice. Higher concentrations can be effectively treated using aeration (to add oxygen to the water to impede reversion of sulfur and polysulfides to sulfide) or air stripping (to also remove a portion of the hydrogen sulfide, thereby reducing chlorine demand and minimizing formation of sulfurous byproducts),

followed by chlorine addition, a contact basin (to provide at least 2 hours detention time for chemical reactions and particle growth) and then filtration (to remove sulfur particles, as well as any particulate contaminants introduced by aeration or air stripping). White (1999) notes that colloidal sulfur and polysulfides can also be treated by adding sulfite to convert them to thiosulfate and then adding more chlorine to convert the thiosulfate to sulfate; but this treatment sequence will be considered as a new technology (Subsection A.5 of Chapter III). White also notes that polysulfide problems do not occur in lime softened water, presumably because sulfate formation is favored in the high-pH environment associated with lime softening.

- b. **OXIDATION USING OTHER OXIDANTS** – Other oxidants known to be effective for oxidizing hydrogen sulfide include ozone, potassium permanganate, hydrogen peroxide, and chlorine dioxide. Each of these oxidants can oxidize hydrogen sulfide to elemental sulfur and polysulfides, but an adequate dosage of chlorine dioxide (Gates, 1998) or ozone can carry the reaction to completion, leaving only sulfate as a byproduct. When chlorine dioxide is used, care must be taken to comply with the MCL for chlorite; and ozone can produce increased concentrations of bromate and biodegradable organic matter. Hydrogen peroxide reacts relatively slowly with hydrogen sulfide, so an adequate detention time must be provided; and it also exerts a significant chlorine demand, so careful control of the process is required to avoid overtaxing the disinfection process. Potassium permanganate reacts rapidly with hydrogen sulfide, but the reaction is typically incomplete and filtration must be provided to remove both elemental sulfur and manganese dioxide particles. Since hydrogen sulfide exerts a large oxidant demand, regardless of the oxidant used, air stripping should be considered when dealing with high concentrations of hydrogen sulfide. See Section M and Chapter IX for additional information regarding the design of facilities for feeding chemical oxidants.
- c. **AERATION AND AIR STRIPPING** – Forced draft air stripping should be considered for hydrogen sulfide concentrations exceeding 0.6 mg/L, and packed-tower air stripping for concentrations of 3 mg/L and higher (Section P). Air stripping can be used to reduce the concentration of hydrogen sulfide to a low enough level that the residual hydrogen sulfide can be readily removed by oxidation. Air stripping of hydrogen sulfide may require pH suppression, since above a pH of 7 more than half of the hydrogen sulfide will be present in ionized (non-strippable) form; and it may also require off-gas treatment to control odor. Aerators and air strippers introduce oxygen into the water, which stimulates the growth of sulfur oxidizing bacteria when a biocide is not present. These bacteria are in many cases responsible for a substantial amount of the hydrogen sulfide removal attributed to “aeration” and they are beneficial in that they reduce the oxidant demand associated with hydrogen sulfide and accumulate sulfur in forms that are easier to settle and

filter than the sulfur particles produced by chemical oxidation. However, these bacteria also contribute to increased turbidity and can pose other operational challenges; thus, if present, they must be properly managed.

- d. **FILTRATION** – Filtration may be needed following chemical oxidation or aeration to control turbidity by removing sulfur particles or sulfur oxidizing bacteria, respectively. Filtration is required following permanganate addition, to remove manganese dioxide solids (Section J).
 - e. **BENCH AND PILOT STUDIES** – KDHE may require bench and/or pilot studies to verify the adequacy of the proposed treatment system, especially when experience with the proposed system is limited. Treatment processes other than those listed above (e.g., biological processes and catalytic adsorption) will be considered as new technologies (Subsection A.5 of Chapter III).
4. **POWDERED ACTIVATED CARBON (PAC)** – PAC is commonly added as part of controlling taste and odor problems associated with naturally occurring organic contaminants, especially those produced by algae and bacteria. Tastes and odors can arise from a single compound, but they can also arise from a combination of compounds that may be difficult to quantify but is nonetheless amenable to removal using PAC. PAC is commonly added to control taste and odor problems associated with seasonal events such as algal blooms, reservoir turnover, or heavy rains.
- a. **POINT OF ADDITION** – In selecting the point of PAC addition, consideration should be given to the following:
 - 1) Selecting the primary point of PAC addition to maximize PAC contact time; for taste and odor, however, having more than one point of addition to provide flexibility is preferred.
 - 2) Enhancing contact between the PAC and the water being treated by providing adequate mixing.
 - 3) Allowing sufficient contact time for adsorption of the contaminant(s) of concern. The required contact time is a function of the characteristics and concentration of the molecule(s) to be adsorbed, the dosage of the PAC, and the presence of any competing organics in the water.
 - 4) Minimizing interference of other treatment chemicals with the adsorption process. Activated carbon will chemically reduce oxidants such as chlorine, chlorine dioxide, ozone, and permanganate. Such reactions not only increase oxidant/disinfectant demand, but in some cases can also reduce the adsorptive capacity of the carbon for the

compound(s) of interest. The chemicals used for coagulation and lime softening can form coatings on PAC particles, reducing their ability to adsorb contaminants; however, coagulation and softening can also enhance removal of trace contaminants by removing naturally occurring organic matter that would otherwise compete for adsorption sites. Jar tests may be needed to determine the optimum point of addition.

- 5) Providing flexibility regarding the point of addition of PAC. Generally recommended points of PAC addition include the pipeline carrying raw water to the plant and the inlets to the rapid mix basin, flocculation, and sedimentation basins. When PAC remains in the settled water or is applied after sedimentation, prior to filtration, it is important to recognize that the PAC in the water or captured on the filters may react with chlorine or other oxidants. Thus, an increased dosage of chlorine may be required to maintain an adequate residual in the treated water and additional steps (e.g., chlorine addition to the backwash water) may be needed to control bacterial growths in the filters. Furthermore, the PAC dosage must be carefully controlled lest PAC carried over to the filters breaks through, causing erroneously low filtered-water turbidity readings and contaminating the treated water with black particles.
- b. RATE OF APPLICATION – The required dosage of PAC depends upon the taste and odor problem involved; but the upper limit is usually controlled by the amount of carryover that can be handled by the filters. Provisions should generally be made for adding 1 to 40 mg/L, but higher doses may be needed to address a severe taste and odor problem.
- c. METHOD OF APPLICATION – PAC should be added as a slurry to the water being treated. This approach requires mixing to uniformly disperse the carbon throughout the stock slurry. A dry feeder is typically used to prepare the slurry, though the PAC can also be slurried upon delivery; and an agitator keeps the PAC in suspension. The PAC concentration in the slurry should not exceed 0.5 to 1.0 lb/gal (60 to 120 g/L) to reduce settling and to maintain fluid conditions suitable for handling. Once the PAC is wetted, the slurry can be pumped into feed lines with periodic water flushing or transferred by eduction to prevent caking. Slurry storage, sized to accommodate delivery of truck or railcar quantities, is recommended for larger PWSSs. Continuous agitation is necessary to keep the PAC from depositing in the slurry storage tank and to aid in wetting the PAC upon receipt.

Provisions shall be made to minimize dust. A separate room shall be provided for a carbon feed installation. PAC shall be handled as a potentially

combustible material and carbon feeder rooms should be equipped with explosion-proof electrical outlets, lights, and motors.

PAC, in dry or slurried form, adsorbs oxygen from the air. Therefore, enclosed spaces where PAC is stored must be adequately ventilated and equipped with oxygen monitors, alarms, and other appropriate safety features to avoid an oxygen deficient environment. See Chapter IX for additional information regarding PAC storage and handling.

5. GRANULAR ACTIVATED CARBON (GAC) – See Section J on Filtration and Section Q on Adsorption with GAC for related design criteria.
6. POTASSIUM PERMANGANATE – Application of potassium permanganate may be considered provided that permanganate and its end product, manganese dioxide, do not impart a visible color to the finished water in the clearwell and compliance with the SMCL for Mn (0.05 mg/L) is maintained. A residual Mn concentration of 0.02 mg/L or less entering the distribution system is strongly recommended. The application point should be at the rapid mix basin in conjunction with coagulant addition or upstream, e.g., at the raw water intake or before or after presedimentation, depending on water quality, the nature of the compound(s) responsible for the taste and odor problem, and the treatment provided.
7. OZONE – Ozonation can be used as a means of taste and odor control. Adequate dosage and contact time must be provided to complete the chemical reactions involved. Ozone is generally more feasible when treating water with severe taste and odor problems. See Section M on Disinfection for detailed information on the design of ozonation systems.
8. TASTE AND ODOR ARISING IN THE DISTRIBUTION SYSTEM – Taste and odor problems can develop after treatment in the distribution system as a result of chemical and/or biological reactions, e.g., corrosion, nitrification, sulfate reduction, and unmasking of taste- and odor-causing compounds as residual chlorine decays. Methods to alleviate such problems include maintaining a suitable free or combined chlorine residual, periodic maintenance of distribution system mains (e.g., by flushing, pigging, or shock chlorinating), and removing or oxidizing contaminants (at the treatment plant) that can be masked by residual chlorine.
9. OTHER METHODS – The decision to use any other methods of taste and odor control should be made only after careful laboratory and/or pilot-plant tests, and consultation with KDHE.

O. IRON AND MANGANESE REMOVAL

The control of iron and manganese usually requires the selection of one or more treatment processes designed specifically for this purpose, taking into account specific local conditions

as determined by engineering investigations. It may be necessary to conduct laboratory tests or operate a pilot plant to facilitate these investigations. Historically, pilot studies have been conducted to confirm design parameters and provide the basis for developing design parameters based on local conditions.

The filtration step of any iron/manganese removal processes shall be designed to treat the maximum day demand (or design rate) and to meet the effluent treatment objectives specified in the design at an individual filter loading rate of no more than 5 gpm/ft² (204 L/min-m²). A minimum of two filters is required. When only two filters are to be provided, each filter should be capable of treating the maximum daily demand. When more than two filters are to be provided, the filters should be capable of treating the maximum daily demand with one filter removed from service. In all cases, the filter design shall include provisions to facilitate complete isolation of individual filters from other filters. KDHE will on a case-by-case basis consider granting requests to operate at higher individual filter loading rates if the results of on-site pilot testing adequately support such requests. It is recommended that KDHE be given the opportunity to review and comment on the pilot testing protocol prior to beginning the testing. KDHE must approve the proposed treatment scheme.

1. REMOVAL BY OXIDATION, DETENTION, AND FILTRATION

- a. DESCRIPTION OF REMOVAL PROCESS – This approach involves oxidizing iron and manganese to insoluble forms, providing time for the precipitated iron and manganese to form particles, and then filtering out the particles. Ferrous iron, Fe²⁺, is oxidized to ferric ion, Fe³⁺, and precipitated as ferric hydroxide, Fe(OH)₃; and manganous manganese, Mn²⁺, is oxidized to tetravalent manganese, Mn⁴⁺, and precipitated as manganese dioxide, MnO₂. Oxidation may be accomplished using oxygen, provided by gravity, forced or induced draft aerators, or using free chlorine (but not combined chlorine), chlorine dioxide, ozone, or potassium permanganate.
- b. DETENTION TIME – Sufficient detention time must be provided, prior to filtration, using a separate detention basin, sedimentation basin, or solids contact reactor. The detention time needed to convert dissolved iron and manganese into filterable particles depends on the forms and concentrations of iron and manganese present, the type and concentration of oxidant employed, pH, temperature, and other water quality parameters, including the type and concentration of natural organic matter. Coagulants may need to be added to effectively remove colloidal iron and manganese.

The required reaction time for a particular system shall be determined, in consultation with KDHE, based on kinetic data and appropriate operating parameters. A minimum reaction time of at least 30 minutes shall be provided if oxidation is accomplished through aeration, unless a pilot study demonstrates that a shorter detention time will suffice. The detention basin should be designed with baffling to prevent short circuiting. Solids collection

is not required unless the detention basin is used as a sedimentation basin; but, provisions must be included in the design to flush solids from the detention basin when it is taken out of service for cleaning.

Oxidation of Fe^{+2} and Mn^{+2} with permanganate is quite rapid at pH 5.5 or higher. Oxidation of Fe^{+2} using free chlorine is quite rapid at pH 7 or higher, but oxidation of Mn^{+2} using free chlorine can be relatively slow. When using free chlorine to oxidize iron and manganese, residual Mn^{+2} can be removed using a stronger supplemental oxidant, e.g., permanganate, or by adsorption on manganese coated media (Subsection 2, below). Ozone and chlorine dioxide react rapidly with Fe^{+2} and Mn^{+2} , but can form small particles that can be difficult to filter. Iron complexed with natural organic matter reacts very slowly with oxygen, chlorine, and permanganate, and its removal may require additional treatment, e.g., coagulation or application of a stronger oxidant. Ozone can also oxidize manganese to permanganate, which can pass through a filter in dissolved form.

When oxygen is used as the oxidant, the reaction rate is very strongly dependent on pH, with oxidation of iron being very rapid above a pH of 7.5 and oxidation of manganese tending to be relatively slow below a pH of 9.5. Aeration alone may raise the pH to a high enough level (by removing CO_2); if not, a base (typically lime or sodium hydroxide) can be added to increase the reaction rate. Base addition may also be needed if there is not enough alkalinity present to counteract the acidity produced by the oxidation reactions. Since manganese oxidation is catalyzed by its own end product, manganese dioxide (a phenomenon referred to as autocatalysis), and since manganese is adsorbed by both iron hydroxide and manganese dioxide, a high pH is not necessarily needed for manganese removal, depending on the type of system employed and the concentrations of iron and manganese present. Residual manganese can also be removed by adsorption on manganese coated media, as described in Subsection 2, below.

- c. **DOSAGE CONSIDERATIONS** – The chemical feed system should be designed to provide at least the stoichiometric oxidant dosage for iron and manganese removal, assuming the highest anticipated influent concentrations and application of an appropriate safety factor that takes into consideration other possible sources of oxidant demand, e.g., sulfide, ammonia, and natural organic matter. However, the actual amount of oxidant required may be less than stoichiometric because ferric hydroxide and manganese dioxide can adsorb limited amounts of Fe^{+2} and Mn^{+2} .
- d. **SEDIMENTATION BASINS** – Sedimentation basins should be provided when treating water high in iron and/or manganese or where chemical coagulation is used to reduce the load on the filters. Provisions for solids removal must be made.

- e. FILTRATION – Filters shall be provided and shall conform to the requirements given in Section J on Filtration.

2. REMOVAL BY MANGANESE COATED MEDIA FILTRATION – In this process potassium permanganate or chlorine is fed, continuously or batchwise, to the influent of a manganese coated filter able to adsorb dissolved iron and manganese and to filter out particulate iron and manganese. This process is typically used primarily for manganese removal, since iron can be readily and less expensively removed by oxidizing it prior to filtration using oxygen or chlorine, as described in Subsection 1, above. Manganese is oxidized much more slowly by oxygen and chlorine, especially at the pH values typically employed, but residual manganese (and iron, if present) can be adsorbed on manganese coated media, provided that the coating is maintained in an oxidized state. This is accomplished by feeding permanganate or chlorine ahead of the media, usually continuously but also batchwise if necessary, e.g., during start-up or if desirable to extend the service cycle when regeneration is only intermittently required. The process must be carefully monitored to avoid underfeeding of permanganate or chlorine, which will impair process performance, or overfeeding of permanganate, which will impart a pink color to the finished water and cause black or brown manganese dioxide particles to form in the distribution system. The process is generally more efficient at pH values above 7.5 and is not practical for removal of iron complexed with natural organic matter (MWH, 2005). Neutral or slightly acidic pH values promote adsorption and subsequent oxidation of manganese, whereas alkaline pH values promote formation of manganese particles that must be removed using a filtration mechanism (Hargette & Knocke, 2001).

- a. Provisions should be made to feed the primary oxidant, typically oxygen, chlorine, or permanganate, to the raw water as far ahead of the filter as possible, and to feed permanganate or chlorine at a point immediately before the filter. The stoichiometric dosages for permanganate are 0.94 mg/L per mg/L of Fe^{+2} and 1.92 mg/L per mg/L of Mn^{+2} . When designing the feed system for permanganate addition (or any other oxidant) it is important to size the feeding capability to account for stoichiometric demand as well as demand exerted by other constituents in the water.
- b. Use of oxygen or free chlorine, in place of permanganate, to meet part of the oxidant demand is generally recommended as a cost-saving measure. If chlorine is used prior to filtration, a minimum free chlorine residual should pass through the filter in order to drive the reactions to completion. Post-chlorination may be necessary so that the required residual can be maintained in the distribution system. Oxidants that rapidly oxidize iron and manganese, e.g., ozone, chlorine dioxide, and permanganate, will convert them into particles that can be removed by filtration (Subsection 1 above) rather than by adsorption (Knocke *et al.*, 1988); but such particles may be more difficult to filter than those produced using oxygen or chlorine, especially if they are formed immediately prior to filtration.

- c. Sufficient capacity for the feeding of each oxidant being employed shall be provided.
 - d. The media may be natural greensand, anthracite, or silica sand having an effective size of 0.4 to 0.5 mm and a uniformity coefficient of 1.3 to 1.7. Other media types may be approved if their ability to develop and maintain a manganese oxide coating is demonstrated. A 6 inch (15.2 cm) cap of anthracite having an effective size of 0.8 mm and a uniformity coefficient no greater than 1.85 is recommended. The total filter media depth should not be less than 27 inches (70 cm). If an anthracite cap is used, the media depth should be 30 inches (76 cm), including the cap.
 - e. The filtration rate should not exceed 4.0 gpm/ft² (163 L/min-m²) and a design rate of 3.0 gpm/ft² (122 L/min-m²) is recommended. KDHE will on a case-by-case basis consider granting requests to operate at higher individual filter loading rates if the results of on-site pilot testing adequately support such requests.
 - f. The gravel support media must be of sufficient depth and size to uniformly distribute the backwash water. The backwash rate should be within the range of 15 to 18 gpm/ft² (611 to 733 L/min-m²). A means for maintaining proper backwash rates shall be provided. A backwash pump is recommended, in which case selection of the proper pump capacity and head is necessary. Where distribution system pressure and flow are used, a reliable flow indicator shall be provided. When using only water for backwashing, the backwash rate should be sufficient to fully fluidize the media when the water temperature is at its maximum value, typically about 15 to 18 gpm/ft² (611 to 733 L/min-m²) for conventional sand and greensand filters meeting the specifications stated in Subsection d above. However, it may be appropriate to specify lower backwash rates when employing air/water backwash systems, and such systems are now recommended to effectively clean the media. The designer must adequately justify the proposed air and water backwash rates. A means for maintaining proper backwash rates shall be provided. See Section J on Filtration for other pertinent design requirements for filters.
 - g. Sampling taps should be provided prior to application of the permanganate or chlorine, immediately ahead of filtration, and immediately following filtration. Also, sampling taps should be provided between the anthracite cap and the manganese coated media and halfway down the media.
 - h. Process wastes must be handled and disposed of as required by KDHE.
3. STABILIZATION BY SEQUESTRATION – Sequestration is a chemical treatment process used to keep iron and manganese in solution or suspension, thereby

eliminating or minimizing some of their adverse aesthetic effects. Sequestration is generally suitable only for concentrations of iron, manganese, or a combination of the two up to 1.0 mg/L for polyphosphate sequestration and up to 2.0 mg/L for sodium silicate sequestration. Sequestration may be less effective for manganese than for iron.

- a. POLYPHOSPHATES – Polyphosphates should be applied before chlorine is added for disinfection and after any other treatment for iron and manganese removal. Mixing in the water line should be thorough and complete before chlorination; and satisfactory chlorine residuals shall be maintained in the distribution system. Polyphosphate shall not be applied directly into the well for groundwater supplies, nor should water treated with polyphosphates be allowed to backsiphon into a well. Possible adverse impacts of polyphosphates on corrosion (and especially on lead levels at the tap) must be addressed when sequestration is proposed. Since polyphosphate may exert a dispersing action on accumulated deposits, frequent flushing of the system is recommended when polyphosphate treatment commences. The effectiveness of polyphosphate treatment may be adversely affected by calcium hardness (Klueh and Robinson, 1988).
 - 1) The phosphate chemicals employed must be appropriate for use in the production of drinking water (Subsection A.4.a.(1) of Chapter IX) and total phosphate applied shall not exceed 10 mg/L as PO_4 .
 - 2) Stock phosphate solution should be kept covered and disinfected by maintaining a free chlorine residual of about 10 mg/L. Phosphate solutions having a pH of 2.0 or less may be exempted from this requirement by KDHE.
 - 3) Polyphosphates shall not be applied ahead of iron and manganese removal treatment. The point of application shall be prior to any aeration, oxidation, or disinfection if no iron and manganese removal treatment is provided.
- b. SODIUM SILICATES – On-site pilot-plant tests are required to determine the suitability of sodium silicate sequestration, and the dosage needed, for the particular water being treated. This process is appropriate only for groundwater supplies prior to their contact with air (Recommended Standards, 2003). Rapid oxidation of the iron and manganese, e.g., using chlorine or chlorine dioxide, must accompany or closely precede sodium silicate addition. Injection of sodium silicate more than 15 seconds after oxidation may cause detectable loss of chemical efficiency. Dilution of feed solutions below 5 percent silica as SiO_2 should also be avoided for the same reason.

- 1) Sodium silicate shall not be applied ahead of iron and manganese removal treatment.
 - 2) The amount of silicate added shall be limited to 20 mg/L as SiO₂, and the amount of added and naturally occurring silicate shall not exceed 60 mg/L as SiO₂.
 - 3) The liquid sodium silicate employed must be appropriate for use in the production of drinking water (Subsection A.4.a.(1) of Chapter IX).
4. REMOVAL BY ION EXCHANGE – Ion exchange softeners should not be used for iron and manganese removal for water containing more than 0.3 mg/L of iron, manganese, or a combination of the two. Ion exchange is not acceptable for iron and manganese removal where the raw water, regenerant, or rinse water contains dissolved oxygen.
 5. REMOVAL BY LIME-SODA ASH SOFTENING – Iron and manganese are readily removed by lime softening because they are simultaneously precipitated (as carbonates and hydroxides) and rapidly oxidized (if oxygen is present) due to the high pH values associated with lime softening (Section K).
 6. SAMPLING TAPS AND TESTING EQUIPMENT – Smooth-nosed sampling taps shall be provided, for control purposes, for each raw water source, each treatment unit influent, and each treatment unit effluent. Testing equipment shall be provided for all plants. The equipment should have the capacity to accurately measure iron and manganese concentrations in low concentration samples that do not require dilution or in higher concentration samples by means of sample dilution. The method detection limit should be less than or equal to 0.10 and 0.05 mg/L for iron and manganese, respectively and preferably less than 0.01 mg/L for manganese. Where polyphosphate or sodium silicate sequestration is practiced, appropriate testing equipment should be provided.

P. AERATION AND AIR STRIPPING

Aeration is the addition of air to water for the purpose of adding oxygen to the water, e.g., for oxidation and removal of iron and manganese (Section O). Air stripping is the use of air to strip volatile constituents, such as dissolved gases and VOCs, from the water. Groundwaters and hypolimnetic surface waters are more susceptible to these contaminants than are streams and epilimnetic surface waters.

Dissolved gases include carbon dioxide, which is corrosive and increases the lime dosage required for softening (Section K); hydrogen sulfide, which is highly corrosive and can cause taste and odor problems (Section N); methane, which is explosive in high concentrations and can serve as a food source for microbial growth; chlorine dioxide, used as an oxidant and

disinfectant; radon, a naturally occurring radioactive gas; and excessive amounts of oxygen and nitrogen, which are typically responsible for gas supersaturation problems. Most VOCs, like many taste and odor substances, can also be effectively removed by adsorption on GAC (Section Q), so both air stripping and adsorption are typically evaluated for treatment of VOC-contaminated water supplies; however, few taste and odor producing substances can be effectively removed by aeration.

Air strippers used to remove carbon dioxide and hydrogen sulfide also serve to aerate the water, thereby facilitating removal of iron and manganese. Carbon dioxide levels greater than 10 mg/L may be more economically removed by air stripping than by lime addition. Air stripping is commonly employed for hydrogen sulfide removal when the concentration is 0.6 mg/L or greater. Concurrent removal of carbon dioxide and hydrogen sulfide may not be practical because the loss of carbon dioxide, which is more volatile than hydrogen sulfide, may raise the pH sufficiently to convert a significant fraction of the hydrogen sulfide to the bisulfide ion, which is not strippable. (Approximately 50% of the sulfide will present as bisulfide, rather than hydrogen sulfide, at pH 7.) When aeration is used to remove hydrogen sulfide, it should be done prior to coagulation or softening.

1. METHODS – Natural draft aeration, forced or induced draft aeration, packed tower aeration, air stripping, and pressure aeration are approved methods. Spray aeration is not recommended by KDHE. Other methods may be used if applicable to the treatment needs. Such methods include but are not restricted to fine- and coarse-bubble diffusion, cascade aeration and air stripping, mechanical aeration, and membrane permeation. The method employed must be suitable to meet the particular needs of the water to be treated and is subject to approval by KDHE.
2. PROTECTION – All aerators and air strippers except those discharging to a lime softening or coagulation process followed by filtration shall be protected from contamination by birds, insects, wind-borne debris, rainfall, and water draining off the exterior of the aerator or air stripper.
3. DISINFECTION – Aerators and air strippers shall be disinfected according to AWWA Standard C653 before being placed into service.
4. STABILIZATION – The stability of the finished water following aeration should be determined and, if necessary, adjusted by additional treatment (Section L).
5. DESIGN CRITERIA
 - a. NATURAL DRAFT AND FORCED OR INDUCED DRAFT MULTI-TRAY AERATION SYSTEMS – Forced or induced draft systems are preferred over natural draft systems. Natural draft systems are typically used for aeration (especially for iron and manganese removal) and for stripping out carbon dioxide and methane. Forced draft systems are commonly employed for aeration and/or to remove dissolved gases, and may in some cases be

effective for VOC removal (e.g., for a highly volatile compound present at a relatively low concentration). Designs for these types of systems should provide:

- 1) Uniform distribution of water over the top tray.
- 2) Perforations in the distribution pan 0.2 to 0.5 inches (0.5 to 1.3 cm) in diameter, spaced 1 to 3 inches (2.5 to 7.6 cm) on centers to maintain a 6 inches (15.2 cm) water depth.
- 3) Discharge of the water through a series of trays. Natural draft systems should have three or more trays separated by not less than 12 inches (30.5 cm) between trays. Induced draft systems should have five or more trays separated by not less than 6 inches (15.2 cm) between trays.
- 4) Inert media, such as coke, ceramic balls, limestone, or (preferably) synthetic packing that will not disintegrate due to freezing cycles. Typical media depths range from 8 to 12 inches (20.3 to 30.5 cm); but trays without media can also be used. A slat-type design may be more appropriate than a design employing media or trays where there is significant potential for clogging and deposition.
- 5) Justification of the design loading rates.
- 6) Trays with slotted, heavy wire mesh (0.5 inch or 1.3 cm openings), or perforated bottoms.
- 7) Construction using durable materials and components acceptable for use in contact with potable water and resistant to the aggressiveness of water, dissolved gases, and potable-water-compatible cleaning materials.
- 8) Prevention of water loss from either type of system by wind carriage by enclosure with louvers sloped to the inside at an angle of approximately 45°.
- 9) Insect control using non-corrodible 24-mesh screen.

In addition, forced or induced draft systems shall be designed to:

- 1) Ensure that the water outlet is adequately sealed to prevent unwarranted loss of air.

- 2) Include a blower that is both adequately protected from the elements and properly screened. In some systems, electrical interconnection of the blower, disinfectant feeder, and well pump may be appropriate. A backup motor for the air blower must be readily available, particularly when necessary to maintain compliance with an MCL.
 - 3) Ensure adequate flow of air through the aerator or air stripper.
 - 4) Include a down-turned and screened (24-mesh) air inlet and a screened (4-mesh) outlet. The screens shall be composed of non-corrodible material.
 - 5) Ensure that the air introduced into the column is as free as possible from contamination such as fumes, dust, dirt and oil.
 - 6) Provide easy access to internal surfaces, components, and media for inspection, cleaning, maintenance, repair, and replacement. If removal of trays or other heavy parts will be necessary for maintenance, consideration should be given to installing a crane.
 - 7) Address potential plugging or fouling problems (e.g., those associated with precipitation of calcium carbonate, deposition of iron and manganese compounds, or biological growths, which may decrease air flow and adversely affect contaminant removal) by providing access (Subsection 6, above), suitable means for cleaning and/or replacing media, and appropriate pre- and post- treatment. Post-filtration for removal of precipitated solids or bacterial slimes may be necessary for installations treating groundwater, and disinfectant application points may be needed both before and after units in which biological growths may occur.
 - 8) Discharge the exhaust air directly to the outside atmosphere or, where applicable, into a treatment unit designed to remove contaminants from the air stream prior to discharge to the outside atmosphere. The applicant should contact KDHE prior to submission of a permit application to determine if a permit will be required under the Clean Air Act.
 - 9) Provide noise control, as needed, especially when located near residential areas.
- b. **PRESSURE AERATION** – Pressure aeration is aeration of water using compressed air and diffusers to release bubbles into the water. It may be used for oxidation purposes only if a pilot-plant study indicates the method is applicable. It is not acceptable for removal of dissolved gases. Filters

following pressure aeration must have adequate exhaust devices for release of air. Pressure aeration devices shall provide:

- 1) Thorough mixing of compressed air with the water being treated.
- 2) Screened and filtered air, free of fumes, dust, dirt, and other contaminants, supplied by an oil-less type compressor.

- c. **AIR STRIPPING** – Forced draft systems (Subsection 5.a) may be effective for air stripping of some constituents; but packed towers are generally used to remove less volatile constituents, including most VOCs, especially when a high degree of removal is required. In a packed tower, contaminated water is pumped to the top of the tower and distributed over the cross-sectional area of the tower, which is filled with a highly porous packing material. Typically, air is introduced at the bottom of the tower and flows upward, counter to the downward water flow; but cross-flow systems may be advantageous in some applications. The packing material serves to maximize the water surface area in the tower, since transfer of volatile contaminants from the water to the air occurs at the air/water interface.

Generally, packed towers are feasible for removing compounds with a Henry's constant greater than 100 atm-mol/mol. For compounds having a Henry's constant between 10 atm-mol/mol and 100 atm-mol/mol, packed tower air stripping may be feasible, but should be carefully evaluated using pilot studies. A two-stage packed tower system instead of a single-stage packed tower system may be required to obtain the necessary removals for compounds having Henry's constants in this range.

An air stripper should be designed to remove the target contaminants from the water to concentrations significantly below their respective MCLs and, preferably, to the lowest levels that are practical. The effect of temperature must be considered, since a drop in water temperature can result in a significant drop in removal of the contaminants(s) of interest. Unless an alternate source of supply is available, redundant capacity may be necessary to ensure compliance with applicable MCLs when the largest air stripper is down for cleaning, maintenance, or repair.

The mass transfer approach to packed tower design is well developed and computer models are widely available to facilitate preliminary design; but traditional forced draft systems and various other stripping systems have not been as extensively modeled in the literature as the packed tower, especially for VOC removal. For these systems, the initial design should be based on manufacturers' recommendations and confirmed through actual performance data from similar installations or through pilot studies.

KDHE recommends that small-scale pilot studies be conducted using the actual water to be treated to confirm both the effectiveness of the proposed air stripper design and the accuracy of the mass transfer coefficients used to estimate contaminant removal, preferably at the peak contaminant concentration(s) anticipated. Pilot studies could also evaluate various areal loading rates and air-to-water ratios so that the design can be optimized with respect to cost and performance. The ratio of the column diameter to the packing diameter should be at least 7:1 for the pilot unit, and the type and size of packing used in the full-scale unit should be the same as that used in the pilot study.

In cases where considerable performance data are available on the contaminants to be removed, at concentrations similar to those in the water to be treated, KDHE may approve the process design based on appropriate calculations and supporting data, without pilot testing. Proposals of this type should be discussed with KDHE prior to submission of a permit application.

Packed-tower air strippers shall be designed in accordance with the applicable guidelines provided in Subsection 5.a, above, for forced draft systems. Additional design requirements and considerations for packed-tower air strippers are as follows:

- 1) The applicant shall specify the flow pattern (countercurrent or crosscurrent) and provide justification for the design parameters selected, including tower height and diameter, air and water areal loading rates, Henry's constant(s), mass transfer coefficient(s), air pressure drop, and packing depth. The ratio of the column diameter to packing diameter shall be at least 10:1.
- 2) The minimum volumetric air-to-water ratio at peak water flow should be at least 25:1. The maximum gas and liquid loading rates must be selected such that "flooding" of the tower will be avoided by a reasonable margin of safety. A packed tower is said to be "flooded" when the gas and water loading rates are so high that an excessive gas pressure drop occurs and the passage of the water through the tower is impeded. This results in unstable operation, excessive energy use, impaired performance, and the possibility that water will be discharged out the top of the column (i.e., flooding in the common sense of the word).
- 3) The tower can be constructed of stainless steel, concrete, aluminum, fiberglass, or plastic. Uncoated carbon steel is not recommended because of corrosion. Towers constructed of light-weight materials shall be provided with adequate support to prevent wind damage.

- 4) Water should be distributed uniformly over the media at the top of the tower using spray nozzles or orifice-type distributor trays that prevent short circuiting. For multi-point injection, one injection point for every 30 square inches (194 cm²) of tower cross-sectional area is recommended.
- 5) A mist eliminator shall be provided above the water distributor system.
- 6) A redistribution ring shall be provided at least every 10 ft. (3 m) to prevent water channeling along the tower wall and short circuiting.
- 7) The effluent sump, if provided, shall have easy access for cleaning and be equipped with a drain valve. The drain shall not be physically connected directly to any storm or sanitary sewer. At a minimum an air-gap separation shall exist between the drain line and any sewer or receiving structure connected to a sewer.
- 8) A blow-off line should be provided in the effluent piping to allow for the discharge of water/chemicals used to clean the tower.
- 9) The design shall prevent freezing of the influent riser and effluent piping when the unit is not operating. Arranging the influent riser and effluent pipes so that they self-drain when the unit is not operating should be considered. If piping is buried, it shall be maintained under positive pressure.
- 10) The water flow to each tower shall be metered.
- 11) An overflow line shall be provided that discharges 12 to 14 inches (30.5 cm to 35.6 cm) above a splash pad or drainage inlet. Proper drainage shall be provided to prevent flooding of the area.
- 12) A suitable flow control valve should be used to control flow in the water effluent line and to minimize air entrainment.
- 13) Means shall be provided to prevent flooding of the air blower.
- 14) The water influent pipe should be supported separately from the tower's main structural support.
- 15) The air inlet shall be in a protected location.
- 16) An air flow meter shall be provided on the influent air line or an alternative method to determine the air flow shall be provided.

- 17) A positive air flow sensing device and a pressure gauge must be installed on the air influent line. The positive air flow sensing device must be a part of an automatic control system which will turn off the influent water if positive air flow is not detected. The pressure gauge will serve as an indicator of fouling or flooding.
 - 18) Tower effluent collection and pumping wells shall be constructed to clearwell standards.
 - 19) Provisions should be made for extending the tower height without major reconstruction.
 - 20) The packing support shall be adequate to prevent deformation of the media or column with deep packing heights while allowing the free flow of water.
 - 21) The foundation shall be designed to adequately support the tower and provide enough lateral support to prevent overturning due to wind loading. The design of the foundation as well as that of the tower shall take into account the possibility of the tower being liquid full, e.g., due to inadvertent flooding or to submergence of the media during cleaning.
 - 22) An access ladder with safety cage shall be provided to permit inspection of the tower including the exhaust port and mist eliminator.
 - 23) Monitoring devices (with alarms and, if needed, telemetry) should be provided to detect excessive fouling, flooding, overflow, significant pressure fluctuations, lack of positive air flow, and other operating conditions that could adversely impact contaminant removal.
 - 24) Air blowers should be housed to protect the equipment and related appurtenances and to help control noise. A standby blower will be required if necessary to ensure the availability of an adequate supply of potable water. Air blowers shall be of the oil-free type.
- d. BYPASS – A bypass should be provided for all aeration units except those installed to comply with MCLs, in which case no bypass shall be provided unless specifically approved by KDHE.
- e. SAMPLING TAPS, TESTING EQUIPMENT, AND MONITORING – Provide appropriate influent and effluent sampling taps and equipment to test for dissolved oxygen, pH, temperature, carbon dioxide, sulfide, and VOCs, as applicable. Sampling lines from the sampling taps located along the height of

the stripper shall be valved at an elevation that permits safe access and facilitates maintenance and drainage. Sampling lines shall be protected from freezing. After the air stripper is in service, regular monitoring for the target contaminant(s) in the influent and effluent of the stripper will be required.

Q. ADSORPTION WITH GAC

Activated carbon is available in powdered and granular forms (PAC and GAC). PAC usage is generally limited to taste and odor control or seasonal control of pesticides, and design of PAC systems is addressed in Subsection N.4. GAC is commonly used in filter-adsorbers (Subsection J.5.4), primarily for taste and odor control, but may also be used in adsorbers, following filtration, typically for the removal of trace organics, including taste and odor causing compounds and disinfection byproduct precursors. GAC can be also used to remove chlorine and certain inorganics such as radon and mercury, but these applications are limited.

Adsorption on GAC is also a BAT process for compliance with the MCLs for TTHMs and HAA5 (KAR 28-15a-64). Two alternatives are provided: GAC10, involving an empty bed contact time of 10 minutes and a carbon reactivation frequency of 120 days for Subpart V (locational running annual average) compliance and 180 days for Subpart L (running annual average) compliance; and GAC20, involving an empty bed contact time of 20 minutes and a carbon reactivation frequency of 240 days.

1. DESIGN BASIS – Predictive tools such as diffusion or mass transfer models, laboratory-scale column tests, and isotherm measurements can provide a basis for the preliminary design. Isotherm constants for numerous contaminants (organic and inorganic, toxic and potentially toxic) have been published, but care must be exercised in their interpretation and use (Randtke and Snoeyink, 1983). Depending on the complexity of a proposed installation, laboratory or pilot-plant column studies using the actual water to be treated may be required. Pilot studies, employing contactor conditions based on isotherm data or laboratory columns, can provide a valuable indication of performance at full scale. Also, pilot studies provide data that can be used to calibrate various widely used adsorption models. The design engineer should submit to KDHE a detailed proposal for a laboratory, modeling, and/or pilot-plant study appropriate for a particular project and seek KDHE approval prior to conducting the tests. The proposal should also identify the source(s) of the contaminants, their frequency of occurrence, and abatement schedules.

Major process design considerations for a GAC adsorber include the following:

- a. Design flow rate;
- b. Nature and concentration of the contaminants to be removed;
- c. MCLs or other regulatory limits pertaining to the contaminants of concern;

- d. Type, size, and adsorptive characteristics of the GAC to be utilized in the adsorber;
 - e. Adsorber type (e.g., steel or concrete, upflow or downflow, gravity or pressure, etc.), dimensions, number, and arrangement (series or parallel);
 - f. Location of the adsorber(s) in the water treatment process;
 - g. Superficial (approach) velocity (or areal loading rate);
 - h. Minimum empty bed contact time required for removal of the contaminants to concentrations significantly below their respective MCLs and, preferably to the lowest levels that are practical.
 - i. Bed depth of GAC in the adsorber(s);
 - j. Expected service time (bed life) of the adsorber(s); and
 - k. Identification of the parameters that will be monitored to evaluate process performance, and development of a corresponding process monitoring and control program.
2. CONTACTOR TYPE AND NUMBER – GAC adsorbers may be upflow or downflow, and can operate under pressure or by gravity. Upflow units can operate with packed or expanded beds. Downflow, gravity contactors are recommended for water treatment applications. Multiple adsorbers can be operated in series or in parallel. Adsorbers used for water treatment are typically operated in parallel; but operation in series may be justified if a high degree of removal is required, if adsorption is rapid (i.e., the mass transfer zone is small relative to the bed depth), and if adsorption is favorable (i.e., the adsorption front is non-spreading). Where only two units are provided, each unit shall be capable of meeting the maximum daily demand. Where more than two units are provided, the contactors shall be capable of meeting the maximum daily demand with one or more units removed from service, as determined in consultation with KDHE.
3. MEDIA REQUIREMENTS
- a. The GAC shall conform with AWWA Standard B604. Only Virgin GAC or GAC regenerated from this application is acceptable because of possible contamination of carbon from other sources.
 - b. GAC selection is based on head loss, backwash characteristics, hardness, rate and capacity for adsorption, and overall process cost. Both 8 x 30 and 8 x 20 mesh GAC are commonly used for filter adsorbers and 12 x 40 mesh GAC is commonly used for post-filter adsorbers. The head loss is less in the larger 8

x 30 mesh carbon but the rate of adsorption is slower as compared to the smaller 12 x 40 mesh carbon.

4. MATERIALS OF CONSTRUCTION – Since GAC is corrosive when wet, special attention must be given to the adsorber's construction. The columns should be constructed of non-corrosive material such as fiber glass or lined mild steel. The lining materials must be approved for use in potable water applications and be resistant to abrasion by GAC particles.
5. COMPETITIVE ADSORPTION – Analysis of the water should extend beyond the regulated compounds since other compounds, especially naturally occurring organic matter (typically measured as total organic carbon), may have a very significant impact on the design, operation, and performance of the adsorber. Competitive adsorption by natural organic matter may greatly decrease both the rate and extent of adsorption of regulated compounds, necessitating greater contact times and/or more frequent replacement of the GAC to comply with the applicable MCLs.
6. WATER STABILITY – The stability of both the treated and untreated water must be ascertained and adjusted if necessary (Section L). A depositing water may rapidly clog the pores of the GAC while an aggressive water could corrode valves, piping, and media supporting materials.
7. DISINFECTION AND BIOLOGICAL ACTIVITY – Disinfectants do not prevent biological growth from occurring on GAC because they react with GAC. Further, since GAC has the capacity to de-chlorinate water, disinfection should follow the GAC adsorbers. Disinfection requirements for start-up of filters (Section J and AWWA Standard C653) also apply to adsorbers and filter-adsorber vessels; however, the disinfection of the adsorber vessels must be completed prior to loading the vessels with GAC as residual chlorine reacts with GAC. AWWA Standard B604 recommends microbial testing of a GAC filter before it is placed in service. Biologically active GAC may improve removal of trace organics; but such activity must be controlled to avoid undesirable effects.
8. BACKWASHING – Provisions for backwashing must be made to remove carbon fines and particulate matter that may accumulate in the GAC bed and to restratify the media. Backwash water should not be chlorinated, or should be de-chlorinated to prevent loss of adsorptive capacity due to chlorine contact with the carbon surface. If the source of water for backwashing the adsorber is the public water supply, proper cross-connection protection must be provided. The backwash water drain line shall not be physically connected to any storm or sanitary sewer; at a minimum, an air-gap separation shall exist between the drain line and any sewer or receiving structure connected to a sewer.

The backwash system should be designed to accomplish the following:

- a. Expand the carbon bed for cleaning while avoiding excessive carbon loss or structural damage to the interior of the vessel.
- b. Settle the carbon bed in a stratified state so that the adsorptive wave front will be at least partially maintained, thereby reducing carbon usage.

Disposal of backwash water and spent GAC must be in a manner approved by KDHE.

9. REGENERATION OF SPENT GAC – On-site thermal regeneration is usually limited to larger PWSSs. Large and intermediate-sized plants may use off-site regeneration facilities but these plants and their transportation units must not use carbon that has been put to any other use. Small plants normally replace their spent GAC with virgin GAC.
10. RADON – When GAC adsorbers are used to remove radon, adequate shielding and other safeguards must be provided for both operators and visitors. The spent GAC may require disposal as radioactive waste in accord with Nuclear Regulatory Commission regulations and must be disposed of in a manner approved by KDHE.
11. SAFETY – GAC adsorbs oxygen from the air. Therefore, enclosed spaces where GAC is stored must be adequately ventilated and equipped with oxygen monitors, alarms, and other appropriate safety features. See Chapter IX for additional information regarding PAC storage and handling that may pertain to GAC storage and handling.

R. REMOVAL OF TRACE INORGANIC CONTAMINANTS AND RADIONUCLIDES

General regulatory and design requirements for inorganic contaminants (IOCs) and radionuclides are described in Sections B.6 and B.7 of this chapter, respectively. For inorganic contaminants and radionuclides not adequately removed by existing or proposed treatment processes, additional treatment(s) sufficient to meet the applicable MCLs is required. Depending on the particular contaminant(s) involved, it may be possible to accomplish this using a process described in another section of this chapter. This section presents general requirements for processes not described in other sections of this chapter, specific requirements for selected processes, and information regarding selected contaminants.

1. GENERAL REQUIREMENTS

- a. A process not described in detail elsewhere in Chapter V will in most cases be considered by KDHE to be a new process. See Chapter III, Subsection A.5 for general requirements for new processes.

- b. Data from laboratory studies, pilot-plant tests, or full-scale demonstrations may be required to justify the basis of design. The design engineer should consult with KDHE prior to conducting such tests or submitting a permit application.
- c. IOCs and radionuclides can accumulate in waste streams, rendering them hazardous and/or precluding the use of disposal methods that might otherwise be suitable for such wastes. Waste streams containing IOCs or radionuclides must, like wastes from any other process, be disposed of in a manner approved by KDHE; but special requirements may apply due to the nature of the contaminants being removed.
- d. Removal of trace contaminants can depend heavily on their physical state (e.g., dissolved or particulate), their oxidation state, and whether they are complexed with other constituents. For example, barium, radium, and arsenic can be present in a water supply in both dissolved and particulate forms; and the dissolved forms can typically be removed by ion exchange but not by filtration, whereas the opposite is true of the particulate forms. As(III) may need to be oxidized to As(V) before it can be adequately removed by some of the treatment processes listed in 40 CFR 141.62. A process suitable for removing Hg(II) may not work well for methylmercury or for mercury complexed with chloride ions or natural organic matter. In such cases, the nature of the contaminant must be adequately considered when selecting and designing a treatment process to remove it.
- e. Changes in pH can significantly influence both the nature of a contaminant (e.g., its physical state or the valence of its dissolved form) and the performance of a treatment process designed to remove it. Depending on the circumstances, the design engineer may be required to submit supporting data to show that process performance has been optimized with respect to pH or that the process performs well over the range of pH values that will be encountered. The effects of pH changes made to improve process performance and other impacts of the process on water quality (e.g., changes in hardness or TDS) must be adequately accounted for when assessing the stability of the finished water (Section L).

2. ION EXCHANGE, ADSORPTION ON ACTIVATED ALUMINA, AND OTHER ADSORPTIVE PROCESSES

- a. Ion-exchange softening (Section K) can effectively remove certain cationic IOCs such as Ba^{+2} and Ra^{+2} . Anion exchange resins can be used to remove anionic IOCs such as arsenic, chromium, and nitrate, as well as perchlorate, which may be regulated in the future. In some cases it may be advantageous to use an ion exchange resin tailored by the manufacturer to selectively adsorb a specific contaminant.

Activated alumina and other adsorbents (some of them proprietary in nature) can also be used to remove IOCs. In many cases the primary removal mechanism is ion exchange, but other mechanisms can be involved, e.g., oxidation or reduction, complexation, and precipitation. Activated alumina has been designated by the USEPA as a BAT for removal of arsenic, beryllium, and selenium, and it can also be used to reduce excessive levels of fluoride to achieve compliance with the SMCL for fluoride. A number of proprietary and non-proprietary adsorbents are available for arsenic removal. Radium can be removed using a radium selective adsorbent or manganese greensand filtration.

For additional information regarding ion exchange, adsorption on activated alumina, and removal of various IOCs by adsorptive processes, the reader is encouraged to consult Clifford (1999) and Gottlieb (2005).

- b. Important considerations in the design of these processes include:
- 1) The applicable provisions of Subsections 1 through 8 of Section Q (which specifically address adsorption on GAC but in many cases are broadly applicable to any adsorptive process);
 - 2) The capacity of the adsorbent for the contaminant(s) of interest (when used to treat the source water in question under conditions equivalent to those expected in the full-scale facility) and, for adsorbents that will be periodically regenerated, the capacity of the adsorbent after it has been repeatedly regenerated;
 - 3) The useful life of the adsorbent, recognizing that some adsorbents (e.g., anion exchange resins) tend to degrade over time while others may degrade physically (e.g., during backwashing) or chemically (e.g., during regeneration) or may become fouled by contaminants that are not completely removed during regeneration;
 - 4) The presence of other constituents in the water that may effectively compete for adsorption sites (reduce the capacity of the adsorbent for the contaminant of interest), especially those able to chromatographically displace (“dump”) the contaminant(s) of interest (e.g., displacement of nitrate or arsenic from an ion exchange column by sulfate), and variations in the concentrations of such constituents;
 - 5) The presence of constituents in the water that may foul the adsorbent because they are not adequately removed during regeneration (as can happen when natural organic matter binds to anion exchange resins) and variations in the concentrations of such constituents;

- 6) The potential for the adsorbent to leach constituents into the water (e.g., the odorous degradation products that can leach from anion exchange resins and the potential for aluminum to be released from activated alumina) and measures to monitor and control such leaching;
 - 7) The potential for the adsorbent to react with chemical oxidants or disinfectants and to produce byproducts or necessitate boosting of the residual disinfectant concentration;
 - 8) The possible need for pH control, a suitable means of controlling pH when needed, and stabilization of the finished water (Section L).
 - 9) A means of backwashing the adsorbent to remove accumulated solids and a means of measuring the pressure drop through the adsorbent bed;
 - 10) The frequency of regeneration, the chemicals used for regeneration (which are subject to approval by KDHE), regenerant loading rates and volumes, regenerant storage and feeding facilities (Chapter IX), the pros and cons of cocurrent versus countercurrent regeneration, rinsing requirements, and disposal of spent regenerant, rinsing solutions, and adsorbents; and
 - 11) Operating procedures, including protocols for ensuring compliance with the applicable MCL(s) and for protecting the quality of the finished water, especially when blending is required, as is often the case when removing nitrate or fluoride.
- c. Barium and radium adsorb more strongly than calcium and magnesium to the resins used for ion-exchange softening; but they are typically not well removed during regeneration. Therefore, the apparent adsorptive capacity of the resin for barium and radium will decrease after a number of regeneration cycles. Furthermore, the calcium and magnesium (hardness) ions will gradually push the barium and radium ions toward the effluent end of the column, which can potentially lead to exceedance of the MCL for barium or radium. Possible preventive measures include initiating a regeneration cycle when hardness begins to break through, employing countercurrent regeneration, or using a calcium-form cation exchange resin.
- d. Although some adsorbents are able to effectively remove As(III), anion exchange resins, activated alumina, and other resins adsorb As(V) much more strongly than As(III). In such cases, a preoxidation step should be included to convert all of the arsenic to As(V). Additional information on arsenic

removal has been published by Clifford (1999), USEPA (2003a), and Gottlieb (2005).

- e. Uranium can be effectively removed by strongly basic anion exchange resins operating at pH values between 6.0 and 8.2, but a relatively strong regenerant is needed to remove uranyl carbonate ions from the resin (Gottlieb, 2005).

3. ELECTRODIALYSIS (ED) AND ELECTRODIALYSIS REVERSAL (EDR)

ED and EDR are electrically driven membrane processes. The flow passes through a series of parallel channels separated by alternating anion and cation exchange membranes; and an electrical charge causes the ionic species present in the water to migrate through the membranes, leaving deionized water in one set of alternating channels and a more saline concentrate in the other channels. Each set of channels is manifolded together to produce a stream of deionized water and a stream of concentrate. EDR differs from ED in that the charge is periodically reversed. Reversing the charge reverses the deionized and concentrate streams and can reduce membrane fouling and scaling problems. For additional information, the reader is encouraged to consult Taylor and Wiesner (1999) and Bergman (2005).

Since ED and EDR involve the use of membranes to produce a concentrate stream, they are typically classified as membrane processes and they are, in some ways, similar to the pressure-driven processes described in Section S. However, there are some very significant differences between these two types of processes. ED and EDR membranes are relatively porous membranes that are not effective in removing particulate contaminants and natural organic matter. Furthermore, the water being treated does not travel through the membranes; instead, only the small ionic contaminants being removed move through the membranes. Thus, contaminants are removed on the basis of charge and not size. Accordingly, ED and EDR do not meet the definition of a membrane filtration process under 40 CFR 141.2 and are therefore not eligible for credit for removal of *Cryptosporidium* oocysts.

Important considerations in the design of ED and EDR processes include:

- a. Pretreatment requirements;
- b. Power requirements, limiting current density, current leakage, and proper handling of the water from electrode compartments (Bergman, 2005);
- c. Membrane life and fouling potential;
- d. The potential for scale formation on surfaces in contact with the concentrate;
- e. Temperature effects on process performance;

- f. Post-treatment requirements (Section L); and
- g. Proper disposal of brine and cleaning solutions.

S. MEMBRANE PROCESSES

A membrane is a thin layer of material that allows some constituents to pass through while rejecting (removing) others. Depending on the type used, membranes can be used to remove contaminants ranging in size from small ions to macromolecules (e.g., humic substances) to relatively large particles. Thus, membranes have numerous potential drinking water treatment applications.

Membrane processes may be classified on the basis of the driving force employed and the type of membrane used. Most membrane processes used for drinking water treatment are pressure driven, including reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF). Electrically driven processes, such as electrodialysis (ED) and electrodialysis reversal (EDR), employ ion exchange membranes and are used primarily to demineralize water. They effectively remove certain IOCs (Section R); but they do not effectively remove unionized contaminants or particles. Temperature and concentration driven membrane process, e.g., thermoosmosis and dialysis, are used primarily for laboratory and industrial purposes.

RO can effectively remove salts (small ions) and larger constituents from water. To overcome the osmotic pressure of the feed water, and to achieve a reasonable water flux (water flow rate per unit of membrane area) through a relatively “tight” membrane, RO processes typically operate at moderate to high pressures, e.g., 90 to over 1,000 psi (620 to 6,900 kPa), depending on the concentration of total dissolved solids (TDS) in the feed water and the desired recovery (percentage of the feed water passing through the membrane). RO is listed as a BAT for eleven inorganic compounds regulated in 40 CFR 141.62(b) as well as four radionuclides regulated in 40 CFR 141.66(b) through (e), and it is capable of effectively removing numerous regulated synthetic organic chemicals (40 CFR 141.61(c)).

NF membranes achieve only partial removal of salts but are particularly effective for removing divalent cations and natural organic matter (DBP precursors). Because they can remove calcium and magnesium they are sometimes referred to as “softening membranes.” Since they do not reject smaller ions, such as sodium and chloride, as well as RO membranes do, they are subject to much lower osmotic pressures and are typically operated at much lower pressures, e.g., 50 to 150 psi (345 to 1034 kPa). NF membranes are very effective for DBP precursor removal, and NF with a molecular weight cutoff of less than 1000 Daltons is a BAT process for compliance with the Subpart V (locational running annual average) MCLs for TTHMs and HAA5 (40 CFR 141.64).

UF membranes are used to remove molecules, especially organic molecules, larger than a specified size, usually expressed as an apparent molecular weight cutoff, which can vary from about 500 Daltons (atomic mass units) to greater than 150,000 Daltons. However, UF

membranes having molecular weight cutoffs in the 30,000 to 150,000 Daltons range typically exhibit little, if any, removal of dissolved organics that form disinfection byproducts. MF membranes remove particles, typically those larger than about 0.1 to 0.5 microns (micrometers); but they do not remove dissolved substances, including true color, unless the dissolved substances are first converted into particulate form (e.g., by precipitation or by adsorption on a solid adsorbent). MF membranes may be useful for removing protozoan cysts and other organisms when recovering filter backwash water.

Typical operating pressures are 5 to 40 psi (34.5 to 280 kPa) for UF and MF. UF and MF membranes may also be operated under vacuum or by gravity, since the required operating pressure for some applications may be significantly less than atmospheric pressure; and such membranes are commonly referred to as submerged (or immersed) membranes because they can be placed in an open basin rather than being confined in a pressure vessel.

Membranes may also be classified based on their composition and configuration. Membranes composed of cellulose acetate, cellulose acetate blends, cellulose triacetate, and polyamide have been available for many years; and membranes composed of many other materials, including polysulfone, polycarbonate, polyolefins, polyvinylidene fluoride, and ceramics, have more recently become commercially available. These materials exhibit a broad range of physical and chemical properties, which not only enable them to be tailored to individual applications but also give rise to differences in membrane life, fouling resistance, chemical and biological resistance, mechanical degradation, and pretreatment requirements. Manufacturers and suppliers should be contacted to identify all critical design issues applicable to the particular types of membranes being considered for a particular application (Bergman, 2005).

Virtually all membranes employed in drinking water treatment plants are either spiral wound or hollow fine-fiber. RO and NF membranes used for drinking water treatment are usually spiral wound, while hollow fine-fiber membranes are more commonly used for UF and MF applications and for applications involving membrane backflushing. Other configurations, including flat-sheet and tubular membranes, are used primarily for laboratory or industrial applications.

Individual membrane elements (or modules) are contained in housings (or vessels), with a typical RO or NF housing containing four to eight spiral-wound elements in series. Groups of housings are typically manifolded together in parallel, acting as a single unit (referred to as a bank or train), which simplifies process operation and maintenance. Redundancy can be achieved by placing an adequate number of banks in parallel, such that the desired flow can be achieved while one bank is out of service; and increased product water (permeate) recovery can be achieved by staging banks in series, e.g., by extracting additional product water from the concentrate leaving an earlier stage of a multistage (or multipass) system. It is also possible to deploy two different types of membranes in series (e.g., UF followed by RO, thereby reducing fouling of the RO membranes) or in parallel (e.g., UF and RO, thereby producing a water that is not completely demineralized).

RO, NF, UF, and MF membranes can effectively remove bacteria and protozoan cysts, and RO, NF, and UF membranes (but not MF membranes) can effectively remove viruses. However, membrane processes are not 100% effective in removing pathogens from drinking water due to membrane imperfections, leaking seals, bypass lines, and other factors. Therefore, safeguards must be in place to ensure that a treatment sequence which utilizes a membrane system consistently achieves the log removal/inactivation credits it has been recognized as being able to achieve; and careful consideration must be given to the disinfection requirements of the product water and to the residual disinfectant used to protect the quality of the water in the distribution system. KDHE will not grant 100% of the required log removal/inactivation credits for microbes to the membrane system alone. See Subsection 4.f, below.

Incorporation of a membrane treatment system into the treatment scheme will be approved by KDHE upon demonstration of feasibility by the design engineer and the submission of an acceptable plan for disposal of all wastes generated by the membrane process. Prior to initiating the design of a membrane treatment facility, KDHE should be contacted to determine if a pilot study will be required to demonstrate feasibility, i.e., to demonstrate such things as: membrane performance (water flux, product water recovery, and contaminant removal) for cold and warm water and after prolonged membrane use; the effectiveness of membrane cleaning procedures in preventing long-term fouling; and the adequacy of the proposed pre- and post- treatment processes. Since pilot plants are typically run only for a short period of time (e.g., several months) relative to the typical life of a membrane, and since raw water quality may vary during the expected life of the facility, appropriate safety factors must be applied to critical design parameters. At the conclusion of a pilot study, the membranes used in the pilot study should be subjected to non-destructive and destructive (autopsy) tests to characterize changes in performance and to better understand the reasons for any fouling that may have occurred.

Plans and specifications must address each of the items below, many of which will be included in the demonstration of feasibility. Additional information pertaining to the design and operation of membrane treatment systems can be found in USEPA's *Membrane Filtration Guidance Manual* (USEPA, 2005) and manuals of practice published by AWWA (AWWA, 1999c and 2005a).

1. RAW WATER QUALITY – To evaluate process performance, determine pre- and post-treatment requirements, estimate waste composition, and evaluate membrane cleaning requirements, the composition of the raw water must be well characterized. Both average composition and temporal (especially seasonal) variations in composition are important; and characterization must include not only the constituents targeted for removal, but also other substances that might significantly affect system performance, pre- or post-treatment requirements, the quality of the finished water, and waste disposal. Constituents of interest, in addition to the contaminants to be removed, include: pH, alkalinity, turbidity (or size-distributed particle counts), organic matter, color, coliforms, protozoan cysts, major anions and cations, iron and manganese, and dissolved gases. Seasonal changes in water

temperature must also be well characterized. For RO and NF processes, conductivity, total dissolved solids, and the concentrations of silica, barium, strontium, radionuclides, nutrients, and boron need to be known so that osmotic pressure, scaling potential, and waste composition can be properly evaluated.

2. MEMBRANE TYPE, CONFIGURATION, NUMBER AND ARRANGEMENT

- a. Membrane type, composition, driving force, and operating pH range
- b. Membrane configuration (e.g., spiral wound or hollow fine-fiber) and flow pattern (e.g., cross-flow or dead-end flow)
- c. Number of elements in each module, number of modules per bank, number and arrangement of banks and stages, flow schematics (including capacity and location of feed pumps, recirculation pumps, and backwash pumps), and operating pressure of each stage
- d. System redundancy (number of modules available to achieve the design flow rate when one or more groups of modules is out of service for cleaning, repair, or modification; and redundancy of other critical system components, including valves, air supply and controls)

3. PROCESS OPERATING CONDITIONS

- a. Flow rates of the feed water, product water, and concentrate
- b. Applied pressure, transmembrane pressure, osmotic pressure (if applicable), and pressure drop across each stage and across the entire membrane system
- c. Mode of operation (e.g., constant flux or constant pressure)
- d. Minimum water temperature, maximum water demand, and the minimum net membrane water flux required to meet the demand during each month or season, taking into consideration the strong influence of temperature on water flux for a system operating at a given pressure
- e. Operating pH and means of adjustment
- f. Recirculation rate for cross-flow membranes

4. PROCESS PERFORMANCE – The ability of the process to reliably meet treatment requirements and performance objectives must be thoroughly evaluated and adequately demonstrated.

- a. For each contaminant (or group of contaminants) to be removed by the membrane process, the designer must characterize the concentrations present in the raw water (and feed water, if partial removal is achieved by pretreatment); estimate the average and minimum removal that will be achieved by the membrane process, taking into consideration changes in water temperature, feed water quality, membrane age, operating pressure and other important factors; and provide supporting information to adequately establish the basis for estimates of contaminant removal. For trace constituents, it is especially important to demonstrate that removal results from rejection and not from adsorption on the membrane(s) over a short period of time.
- b. The overall log removal credit for a treatment sequence that includes membranes, and/or the log removal credit for the membrane treatment step by itself, shall be determined by KDHE on a case-by-case basis. When a pilot-plant study will be used to establish log removal credit, KDHE must be contacted prior to the study to establish the protocols to be followed. Pertinent data from pilot- or full-scale installations similar to the one proposed, as well as the results of challenge tests, may be presented in support of a particular level of log removal credit. Pertinent data may include turbidity measurements, microscopic particulate analyses, counts of particles in the appropriate size range, or the results of challenge tests using surrogate particles, surrogate organisms, or live organisms.
- c. In determining log removal credit, consideration will be given not only to the performance of new membranes but also to the performance of aged membranes, the potential for leakage through membrane imperfections and seals, the integrity testing protocols to be employed, the level of instrumentation provided, raw water quality, pre- and post-treatment, and other factors influencing the extent and reliability of pathogen removal.
- d. Regardless of the level of log removal credit allowed, a residual disinfectant will be required to protect the quality of water in the distribution system.
- e. The hydraulic performance of membranes as they age is a key factor in evaluating the economic feasibility of a membrane process. Membrane water flux and product recovery as a function of transmembrane pressure and membrane age should be adequately evaluated; and a reasonable estimate of membrane life (discussed below) is needed to properly estimate operating costs, particularly membrane replacement costs.
- f. KDHE will require post-membrane disinfection to achieve a minimum of 0.5-log inactivation of *Giardia lamblia* and 2-log inactivation of viruses for treatment sequences that employ membranes to treat surface water or GWUI.

5. PRETREATMENT REQUIREMENTS – Membrane performance, cleaning frequency, and useful life depend heavily on the quality of the feed water, which is determined by the quality of the raw water and the pretreatment provided. Acceptable feed water characteristics depend on the type of membrane and operating conditions.
- a. Pretreatment may be needed to remove particulate matter, to remove iron or manganese, to stabilize the water to prevent scale formation, to control microbial growths, to remove chlorine or other oxidants (necessary for certain types of membranes), to adjust pH, to eliminate dissolved gas supersaturation, or to prevent upstream spills of oil, grease, or solvents from entering the membrane system and damaging the membranes. To prevent fouling of RO and NF membranes with elemental sulfur, hydrogen sulfide must be removed by pretreatment, unless an airtight system prevents air from entering the water, in which case hydrogen sulfide may be removed during post-treatment. If hydrogen sulfide is removed using air stripping or degasifiers, the off-gas may require treatment to prevent odor problems.
 - b. In evaluating the stability of the feed water, consideration must be given not only to precipitation of calcium carbonate but also, for RO and NF membranes, to other substances (including silicates, fluoride and sulfate salts) that may precipitate as the concentrate reaches the far ends of the system. Any antiscalant chemicals or solutions (commonly fed prior to NF or RO systems) must be certified for direct or indirect use in the treatment of drinking water (Subsection C.2 of Chapter III). Changes in chemical or solution feed systems will be considered to be changes in treatment and as such must be approved by KDHE.
 - c. A filtration step is normally required ahead of RO or NF; and conventional filtration, MF, UF and cartridge filtration are acceptable for this purpose if compatible with site- and system-specific conditions. At a minimum, cartridge or bag filters should be provided to protect the membranes from excessive amounts of particulate matter; but cartridge or bag filters alone may not be suitable for raw waters having occasionally high levels of turbidity.
 - d. UF and MF membranes are less susceptible to particulate fouling than RO and NF membranes but must still be protected from exposure to large particles or excessive levels of smaller particles. Conventional filtration, presedimentation, roughing filters, and strainers or bag filters able to remove particles in the 100 to 500 μm size range (Bergman, 2005) may be suitable for this purpose, depending on site- and system-specific conditions.
6. POST-TREATMENT REQUIREMENTS – Additional treatment may be required for the product stream, including degasification (for carbon dioxide or hydrogen sulfide removal), alkali addition (for pH adjustment or alkalinity recovery, i.e., conversion of

carbon dioxide to bicarbonate), hardness addition (for corrosion control), hydrogen sulfide oxidation, chemical stabilization (Section L), control of bacterial growths, and final disinfection before the water enters the distribution system.

7. BYPASS WATER – Membrane systems may bypass a portion of the raw water or feed water around the membrane unit provided that treatment objectives and regulatory limits are met. Such a bypass may be necessary to produce a stable finished water, e.g., for an RO system that demineralizes the product water or an NF system that removes most of the hardness. However, the bypass water must be adequately filtered; and when a membrane process is used to obtain log removal credit, any bypass water must be disinfected using an appropriate means of disinfection.
8. CROSS-CONNECTION CONTROL – Cross-connection control must be incorporated into the design (KAR 28-15-18(f)). Consideration must be given not only to cross-connections between the finished water and non-potable water (e.g., the raw water, the feed water, or the concentrate), but also to any cross-connections that might be formed with chemical solutions and cleaning wastes.
9. MEMBRANE CLEANING – Membrane cleaning procedures are membrane and foulant specific. The manufacturer's recommendations as to cleaning solutions and procedures should ordinarily be followed (and may have to be followed to fulfill the terms of the warranty).
 - a. The cleaning method(s) and chemicals used must be approved by KDHE.
 - b. The components of the membrane cleaning system should be specified, including tanks, mixers, heating elements (if any), filters, pipes, valves, and the associated instrumentation and control systems.
 - c. The cleaning process must be designed and operated in a manner that prevents contamination of the raw water, feed water, and finished water.
 - d. A non-destructive method of assessing the membrane condition (e.g., water flux or transmembrane pressure) should be provided.
 - e. During the design a means of flushing membrane modules with high quality water (e.g., permeate, finished water or raw water, depending on the site-specific issues) after planned or unplanned system shutdowns should be considered.
10. INTEGRITY TESTING – Intact membranes achieve virtually complete removal of pathogens larger than the pore size of the membrane; but pathogen removal can be compromised by membrane imperfections such as, but not limited to, broken lumens, leaking seals, and faulty valves. Therefore, when a membrane process is used to

achieve log removal credit, an integrity testing program having direct and indirect integrity testing components is required to verify that the membranes are intact (40 CFR 141.719(b)). Indirect integrity testing must consist of continuously monitoring the turbidity in the effluent from each membrane bank with an appropriately ranged turbidimeter, regardless of the number of banks or arrays employed. Indirect integrity testing based on other water quality parameters, such as conductivity, will be considered for RO and NF membrane systems where turbidity is removed during pretreatment and is therefore not a suitable parameter for monitoring process performance. Off-line direct integrity testing must be performed at least once per day on each bank and the method used must be sensitive enough to verify the removal credit awarded by KDHE. Direct integrity testing methods include the air-pressure (vacuum) decay test, the diffusive airflow test, the water displacement test, and various marker-based integrity tests (USEPA, 2005). The integrity testing program must be approved by KDHE.

11. USEFUL LIFE OF MEMBRANES – Membrane life and replacement costs must be considered in assessing the overall cost of operating the treatment facility. Factors to consider in estimating membrane life include raw water quality, experience with same or similar membranes (especially when treating the same or similar water), the frequency and effectiveness of cleaning, membrane performance requirements (in regard to both water flux and contaminant removal), and the supplier’s performance guarantees. The proposed design should include recommended criteria for membrane replacement and a projected membrane replacement schedule.
12. WASTE VOLUME, COMPOSITION, AND DISPOSAL – Wastes generated by membrane systems include pretreatment wastes, membrane concentrate, cleaning wastes, and post-treatment wastes. Reasonable efforts should be made to minimize waste production without compromising the performance of the system. The system design must provide for management of all such wastes in compliance with KDHE requirements. Each waste stream must be fully characterized through appropriate analyses or modeling, and alternate disposal options must be fully evaluated. Potential disposal options include land application, surface water discharge, injection wells, evaporation (in ponds or using evaporators), and discharge to a wastewater treatment plant.
13. INSTRUMENTATION AND CONTROL – A minimum level of instrumentation and control is required to ensure fail-safe operation, to avoid potential damage to the membranes and pumps, and to prevent non-potable water from entering the distribution system. Instrumentation should include appropriate sensors, alarms, or other indicators of changes in finished water quality or in operating conditions (e.g., inadequate feed water quality, pressure or flow rate) that could potentially impair membrane performance or compromise finished water quality. Systems should be designed to automatically shut down when necessary to prevent damage to the system or introduction of non-potable water into the distribution system. Regarding RO, the system designer should consider whether a permeate drawback tank is needed to

prevent damage following feed pump shutdown. The manufacturer should be consulted regarding conditions for the specific project and potential risk of membrane damage. The instrumentation and control system should include an appropriate level of redundancy.

14. OPERATOR TRAINING AND START-UP – The ability to obtain qualified operators must be evaluated when selecting any treatment process, including membrane processes. The necessary operator training shall be provided prior to plant start-up.

T. FLUORIDATION

Detailed information regarding the design and operation of drinking water fluoridation facilities is available from a number of excellent sources, including manuals and handbooks published by the U.S. Department of Health and Human Services (Reeves, 1986, 1994 and 1999) and AWWA (2004c).

1. REQUIREMENTS – KDHE will approve the fluoridation of a PWSS under the following conditions:
 - a. An application has been submitted to KDHE for permission to fluoridate the water supply by the PWSS.
 - b. Plans and specifications covering the following items have been submitted to and approved by KDHE:
 - 1) Chemical to be used as a source of fluoride;
 - 2) Methods of storing and handling the chemical;
 - 3) Feeding equipment;
 - 4) Point of application;
 - 5) Rate of flow at point of application and flow characteristics;
 - 6) Automatic controls;
 - 7) Safety precautions; and
 - 8) Laboratory controls and equipment to be used for determination of dosage and fluoride content of water.
 - c. A copy of an ordinance from a city or a resolution from a rural water district, authorizing fluoridation of the water supply, must be submitted to KDHE.

- d. The owner of the public water supply system must provide to KDHE a written statement designating the operator or operators in responsible charge of the system or facility, or both, whose operator certification is recognized under KAR 28-16-36 as being Class II or higher.
2. APPLICATION PRINCIPLES AND CRITERIA – The following general principles will be used in promotion and administration of the program by KDHE.
- a. No fluoridation project should be undertaken without the full cooperation and approval of the city administration (or the rural water district board), the water department, and the local health department, as well as KDHE.
- b. In considering an application for approval of fluoridation, KDHE will consider the qualifications of the public water supply system’s operators to perform the control and maintenance operations required.
- c. Chemical forms of fluoride and corresponding methods of feeding are listed in Table V-4. The addition of sodium fluoride, sodium silicofluoride, or hydrofluorosilicic acid constitutes the practice of chemical addition in the production of drinking water and as such shall conform to applicable AWWA standards and NSF International’s ANSI/NSF Standard 60, or other equivalent (Subsection C.2 of Chapter III). Other types of fluoride compounds must have prior approval by KDHE.

TABLE V-4

FLUORIDE CHEMICAL FORMS AND FEEDING METHODS

Name	Form	Feeder Type	Remarks
Sodium Fluoride	Powder	Saturator	-
Sodium Silicofluoride (Sodium Fluorosilicate)	Powder	Dry	Low Solubility
Hydrofluorosilicic Acid (Fluorosilicic Acid)	Liquid	Solution	Corrosive

- d. Fluoride chemicals should be isolated from other chemicals to prevent contamination and mixing with other potentially reactive chemicals. Compounds shall be stored in covered or unopened shipping containers and should be stored inside a building. Unsealed storage units for

hydrofluorosilicic acid should be vented to the atmosphere at a point outside the building. Bags, fiber drums, and steel drums should be stored on pallets.

- e. When other chemicals are being fed, chemical compatibility must be considered. Fluoride compounds shall not be added before or during lime-soda ash or ion-exchange softening. Whenever possible, fluoride should be added after filtration. In surface water plants, the ideal location for fluoride addition is usually in the water line from the filters to the clearwell for constant rate filters, but this may not be the case for declining rate filters. In the latter case, if the fluoridation system cannot be flow paced by the filtered water flow rate, the addition may need to be at the high service pump station (ahead of the entry point sampling tap).

If the first customer's service line is located less than 100 ft. (30.5 m) from the fluoride point of application and there is no storage tank between the two points, an in-line mixer or a small mixing tank should be installed in the water line exiting the plant to ensure complete mixing.

For groundwater, the fluoride point of application should be far enough upstream of the entry point sampling tap to ensure complete mixing prior to the treated water entering the distribution system. In the absence of an adequate length of pipe to ensure complete mixing prior to the entry point sampling tap an in-line static mixer may be installed in the discharge pipe between the fluoride point of application and the entry point sampling tap to ensure complete mixing.

- f. Water used for sodium fluoride dissolution shall be softened if its hardness exceeds 75 mg/L as calcium carbonate, and a sediment filter should be installed in the make-up water line.
- g. Scales, loss-of-weight recorders or liquid level indicators, as appropriate, shall be accurate to within 5 percent of the average daily change in reading for the chemical feeders.
- h. Feeding equipment must be accurate within 5 percent, and facilities must be provided for accurately weighing the amount of chemical used. Solution feeders must be of the positive displacement type with a stroke rate of not less than 20 strokes per minute and must be provided with an accurate means for measuring the water used in making up the solution, except where hydrofluosilicic acid is fed directly. Where the point of application of hydrofluosilicic acid is to be in a horizontal pipe, it shall be in the lower half of the pipe.

The maximum design operating pressure of the feed pump should be at least one-third more than the expected operating pressure at the fluoride point of application.

Selection of the feed pump capacity so that the discharge rate is 30 to 70% of the maximum is important. If the pump operates at either extreme of the operating range the operator will have difficulty in matching flow changes. More importantly, oversized pumps should not be used because they increase the risk of a serious overfeeding event.

Metering pumps should be located on a shelf above the carboy, day tank, or solution container, but not more than 4 ft. (1.2 m) higher than the lowest normal level of liquid. A flooded suction line is not recommended for water fluoridation.

- i. Fluoride solutions shall not be applied at a point of negative pressure.
- j. The electrical outlet used for the fluoride feed pump should have a nonstandard receptacle and its electrical circuit shall be interconnected with the electrical circuit of the well or service pump.
- k. Anti-siphon devices shall be provided for all fluoride feed and dilution water lines. Two anti-siphon devices should be used on each feed line, one on the discharge side of the pump head and the other at the fluoride injection point. The dilution water pipe shall terminate at least two pipe diameters above the solution tank.
- l. Saturators should be of the upflow type and be provided with a meter and backflow protection on the make-up water line. The minimum depth of sodium fluoride in a saturator should be 12 inches (30.5 cm), and this depth should be clearly marked on the outside of the container. A maximum fill line should also be used, since the saturator should never be filled to the point that undissolved chemical is drawn into the pump suction line. Only granular sodium fluoride should be used in saturators, since powdered and very fine forms can cause plugging problems.
- m. A properly sized totalizing water meter is required in the water line to a saturator for all types of saturators as part of assuring that the addition of fluoride will be in proportion to the treated water flow rate. Since saturator make-up flows are very low, this typically requires a small (0.5 to 0.63 inch or 1.3 to 1.6 cm) positive displacement totalizing meter.
- n. Entrained air has a tendency to come out of solution forming bubbles in the feed lines. The air bubbles can interfere with the feed and should be bled from the lines whenever they appear.

- o. Secondary control systems for fluoride chemical feed devices may be required by KDHE as a means of reducing the possibility for overfeed. These may include flow or pressure switches or other devices.
- p. Special precautions must be taken to protect operators against possible injury from concentrated chemicals. A facial respirator with a rubber face-to-mask seal, rubber apron, and rubber gloves are needed, and if hydrofluorosilicic acid is used then splash-proof goggles, a full face shield and rubber boots are also needed. Acid systems should also have flushing water at the place where carboys are handled. Operators must be fully instructed in the proper handling of fluoride chemicals. An eye washer and an emergency shower should be provided.
- q. Provisions must be made for the transfer of dry fluoride compounds from shipping containers to storage bins or hoppers in such a way as to minimize the quantity of fluoride dust that may enter the room in which the equipment is installed. The enclosure shall be provided with an exhaust fan that places the hopper under a negative pressure. Air exhausted from fluoride handling equipment shall discharge through a dust filter to the outside of the building.

Provisions shall be made for disposing of empty bags, drums, or barrels in a manner that will minimize exposure to fluoride dusts. The best practice is to thoroughly rinse all empty containers with water until they are fluoride-free.

- r. Suitable laboratory space and equipment must be provided for the determination of the fluoride content of the water. Two commonly employed methods, the SPADNS (colorimetric) method and the ion-selective electrode method, are described in *Standard Methods* (APHA *et al.*, 2005). The SPADNS method, which employs a spectrophotometer, is often the best choice for small PWSSs. However, this method may require a preliminary distillation step should interfering ions be present at excessive levels. Testing laboratories and larger water plants typically use the electrode method mainly because of the ease of running a large number of samples and its greater tolerance of interferences. Operators appropriately designated by the PWSS to be in responsible charge of the system or facility must demonstrate their proficiency in performing such tests to KDHE's satisfaction prior to the initiation of fluoridation of the PWSS's water supply.

Immediately upon initiating the addition of fluoride, a PWSS must begin collecting paired samples, as described below, to further demonstrate its proficiency in performing fluoride analysis. Concurrently the PWSS must continue collecting samples and analyzing them for fluoride to demonstrate compliance with the MCL (KAR 28-15a-23) or alternatively the SMCL (40 CFR 143.3) for fluoride.

When a PWSS begins fluoridating, paired samples must be collected at least once per day at each affected entry point sampling tap. One sample of each pair must be submitted to KDHE for fluoride analysis and the other sample is to be analyzed by the PWSS for fluoride. A report summarizing the results of the fluoride analyses performed by the water system must be submitted to KDHE so that KDHE can compare both sets of results. The PWSS must continue to collect paired samples for analysis until such time that KDHE is satisfied with the consistency between the PWSS's results and KDHE's results.

After the PWSS has established its proficiency, it must continue to collect and analyze samples (though not paired samples, unless directed to do so by KDHE) to ensure proper operation and for compliance purposes. Samples collected for operational purposes must be collected at each affected entry point sampling tap on a daily basis and analyzed by the PWSS for fluoride using the method employed during the proficiency demonstrating period.

In order for the fluoride analysis to be meaningful, water samples must be collected after the fluoride has completely mixed with the water to which it is being applied. In some cases, a static mixer may have to be installed in the water line at a location sufficiently upstream of the sampling tap to ensure complete mixing. During sample collection from a sampling tap, the sampling tap must be thoroughly flushed prior to the collection of the sample in order to obtain a sample that is representative of the water in the main (Reeves, 1986). Additional discussion regarding this subject may be found in Subsections D.4.g.4 and D.5.d.6 of Chapter IV.

- s. Daily records shall be kept of the amount of chemicals fed, water pumped, and all fluoride determinations. Quarterly reports of the results of the fluoride analyses performed by the public water supply system must be submitted to KDHE – Bureau of Water, Public Water Supply Section, 1000 SW Jackson St., Suite 420, Topeka, KS 66612-1367.
- t. No fluoridation equipment shall be placed in operation until the installation has been inspected by a representative of KDHE and found to be in conformance with the plans and specifications approved by KDHE.

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