DESIGN AND CONSTRUCTION OF A LARGE ULTRAVIOLET (UV) DISINFECTION FACILITY TREATING UNFILTERED WATER

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ABSTRACT

In the early 1990s, the Capital Regional District (CRD) in Victoria, B.C. identified the need for improvements to their water treatment system to protect public health. The CRD investigated various treatment strategies, and decided to implement UV disinfection. Added to its existing screening and chloramination systems, this treatment strategy would provide a multi-barrier approach.

Like many B.C. communities, the CRD has a high quality raw water source, so other treatment processes were not required. Ultraviolet irradiation has emerged as an extremely effective and economical treatment alternative for primary disinfection. However, UV disinfection applied to an unfiltered water supply would be a unique application.

This article presents the challenges for implementing a UV disinfection system on unfiltered water. Discussion includes design features, hydraulic considerations, and control implications for the 580 ML/d facility. Completed in 2004, the CRD UV disinfection facility is the largest in Canada and second largest in North America.

Keywords: ultraviolet, UV, disinfection, water treatment, drinking water, unfiltered water

INTRODUCTION AND BACKGROUND

The Capital Regional District (CRD) in British Columbia (B.C.) supplies drinking water to a population of about 310,000 in the Greater Victoria area. Victoria receives its water supply from Sooke Reservoir, located northwest of the City. The Reservoir is fed by a protected watershed, which is almost entirely owned by the CRD. Sooke Reservoir is a pristine lake with low turbidity and only moderate concentrations of naturally occurring organic material and color. Therefore, like many utilities in B.C., until recently, the CRD's treatment for its high quality raw water comprised only coarse screening followed by disinfection by chloramination.

In the 1990's, the CRD began planning for upgrades to its water treatment facilities. The CRD's 1994 Strategic Plan identified the need for improvements to their water treatment to protect public health. An outbreak of toxoplasmosis (a parasitic infection) in 1995 was linked to the water supply, and underscored the need to provide additional treatment barriers to pathogens.

Tests for the presence of Giardia cysts and Cryptosporidium oocysts indicated very low levels in the source water. However, the CRD recognized that chloramines alone provide a poor barrier if such organisms are present. In addition, during August/September each year, when water temperatures can exceed 20 degrees Celsius, chloramines alone provide insufficient protection against bacteria.

The CRD elected to follow a two-stage improvement strategy. Completed in 2001, Stage 1 included separating the chlorine and ammonia dosing points. The system now ensures that the free chlorine disinfection stage provides 4-log inactivation of viruses.

Stage 2 of the plan provided an additional disinfectant for treating protozoa. The CRD investigated various filtration and disinfection strategies, and originally anticipated using ozone as the primary disinfectant at an estimated cost of $23 million. In the late 1990's, ultraviolet (UV) disinfection emerged as an effective and economical treatment process for inactivating protozoa. Aware of the potential cost savings, the CRD evaluated UV disinfection for

Victoria. Results indicated that the UV disinfection strategy could be implemented at a cost of $14 million. As a result, the CRD selected UV disinfection combined with chlorination and chloramination as the preferred treatment technology. A unique application, UV would be applied on an unfiltered water supply.

DESIGN

Design Objectives

In British Columbia, the Drinking Water Protection Act (2003) identifies specific treatment requirements for surface water supplies as well as groundwater supplies under the direct influence based only on disinfection of bacteria. No specific treatment levels for the inactivation of Cryptosporidium oocysts, Giardia cysts or viruses have been included at this time.

The water quality objectives adopted by the Regional Water Supply Commission and approved by the Vancouver Island Health Authority were negotiated in advance of the present Drinking Water Protection Act. However, the CRD's approach is consistent with the Act as it relates to the design objectives, as shown in Table 1.

Detailed Design

In 2002, the CRD retained Associated Engineering to complete the detailed design of the UV facility based on equipment from Trojan Technologies (see Figure 1), which the CRD had pre-purchased. The UV facility is housed in a two-storey structure with the seventeen 600 mm diameter, medium pressure reactors and controls on the ground floor level. The large diameter pipe headers and other distribution piping are installed in the basement level.

A relatively unique feature of the design is the arrangement of the 17th reactor as a validation reactor. The 17th reactor piping includes extra components to allow this line to be used for onsite or Tier 2 validation. The extra components include:

- Double check valve assembly – to prevent bio-assay back-feeding into the piping system.
- Removable spools – to provide positive breaks
- Inline mixer - for mixing the bio-assay and UVT modifiers into the water stream.
- Validation water discharge line – to discharge validation water to a nearby creek.

Design Challenges

UV disinfection systems are generally included in water systems at the latter part of an existing series of treatment processes. One of the most unusual features of the plant is that the UV process is the first stage in the water treatment system. The UV system is also the only barrier to Cryptosporidium and is an important part of the multiple barrier defense to other pathogens. The importance of the UV system and its unique arrangement led to a number of design challenges.

1. UV Transmittance.

Ultraviolet transmittance or UVT is a key parameter in determining the suitability of UV treatment for a particular water supply. The UVT value has a direct relation to the sizing of the UV equipment required for satisfactory disinfection. The higher the UVT value, the greater capacity any given UV disinfection equipment will have. Depending on the reactor, an increase in UVT from 85% to 90% will typically increase the treatment capacity of the reactor by 70%. Selecting the correct UVT value is, therefore, essential. In a conventional treatment facility, where the UV system is downstream of a number of treatment processes, these treatment processes will typically provide a water stream with a more stable UVT value and the opportunity to increase the UVT if desired. There will be small fluctuations and, partly because of this, a 95 percentile UVT value is often used. For Victoria, the 95 percentile UVT is 85%. But, because there is no upstream treatment except for coarse screening, the UVT values vary considerably from season to season. These relatively

Table 1: Design Objectives

Parameter	Water Quality Objective
Giardia	3-log inactivation
Cryptosporidium	2-log inactivation
Viruses and bateria	4-log inactivation
Total coliforms	Not detected in 95% of monthly samples. No more than 10 coliforms per 10 mL square
Fecal coliforms	None
Disinfection by-products	Less than 0.080 mg/L total trihalomethanes Less than 0.060 mg/L sum of 5 haloacetic acids

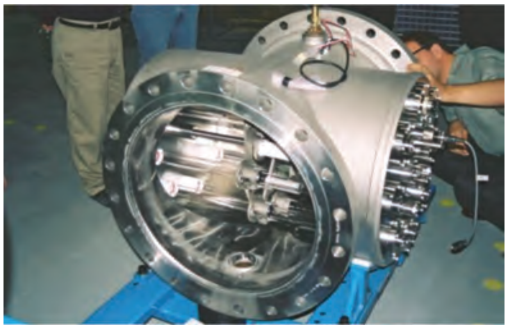

Figure 1: A Trojan reactor being inspected at the manufacturing facility

large fluctuations make it a challenge to deliver the required UV dose efficiently.

Victoria experiences its greatest water demands in July and August. At these times, however, the UVT in the lake is generally higher. This is significant, as UV equipment is usually selected on the basis of maximum flow and the 95 percentile UVT. For Victoria, it was finally determined that the UV equipment would be selected on this basis. However, further work is justified to determine if the 95 percentile approach is appropriate for all scenarios. A possible alternative would be to develop an optimum design UVT rate depending on seasonal water quality and seasonal water demands.

2. Hydraulics.

In any UV disinfection system, it is necessary to consider the hydraulic design. An issue that is often a concern is the anticipated hydraulic losses through the UV equipment and associated piping. This is particularly the case where the UV disinfection equipment is being retrofitted into an existing process stream.

For the Victoria UV facility, hydraulic friction losses were not a major concern as the system is a pressured system operating at approximately 700 kPa. Although it may seem that such a high operating pressure would be a problem, this is not the case. The quartz sleeves and lamps in UV systems typically have good compressive strength and are, therefore, very resilient to high pressures. UV equipment manufacturers often provide a pressure limit of 1030 kPa. This limit is often a function of the reactor strength rather than the lamp strength.

A more subtle hydraulic consideration is the behavior of the lamps and sleeves with respect to pressure transients. UV lamps and sleeves do not have good tensile strength. This makes them prone to failure under partial vacuum conditions. The most probable cause of a partial vacuum is a transient event (see below).

3. Lamp Breakage.

For a UV disinfection system, lamp breakage is the mode of failure that is of most concern. In such a failure, mercury, glass and quartz is released into the water system. The glass and quartz, which will typically be four times heavier than water, will immediately settle. The glass and quartz can then be removed at a location of known low flow velocity.

The mercury release, however, is more subtle. If the lamp were operating prior to the break, the mercury would be in a vapor form. As the lamp breaks, the mercury can be expected to partly condense into the fluid state and partly combine with the water stream as dissolved mercury. Liquid mercury is heavy and can be expected to collect at locations of low flow velocity. This mercury is likely possible to recover. The dissolved mercury, however, will be lost into the water supply system.

As part of a UV disinfection system design, it is necessary to consider the amount of mercury that could be released into the water supply system. Depending on flow conditions, it is likely that the loss of a few lamps will not be a problem. However, in a transient event, the partial vacuum could lead to the failure of a significant number of lamps. Such a loss of lamps could lead to unacceptable quantities of mercury being released into the water system.

4. Transients.

For the Victoria facility, transients were a concern as, under certain conditions, a partial vacuum could be developed. Early in the design, Komex International conducted a transient analysis to investigate the possible scenarios that could lead to a partial vacuum. The simulations identified a number of key valves that, under certain opening or closing conditions, could lead to the development of transients. During design, particular attention was paid to selecting and arranging these valves, which significantly reduced the likelihood of a transient event.

For UV disinfection systems involving pressurized flow, the designer should consider the impacts of a transient event. A transient analysis may be required to identify if transient mitigation is required. The designer should also consider the impact of a single lamp break and the quantity of mercury that could be released into the water stream.

5. Control

Most UV disinfection systems are designed around a constant or controlled water throughput. This concept is well suited to a UV system installed between the filters and a clearwell in a treatment plant. In this scenario, the individual reactors experience constant flow and when flow

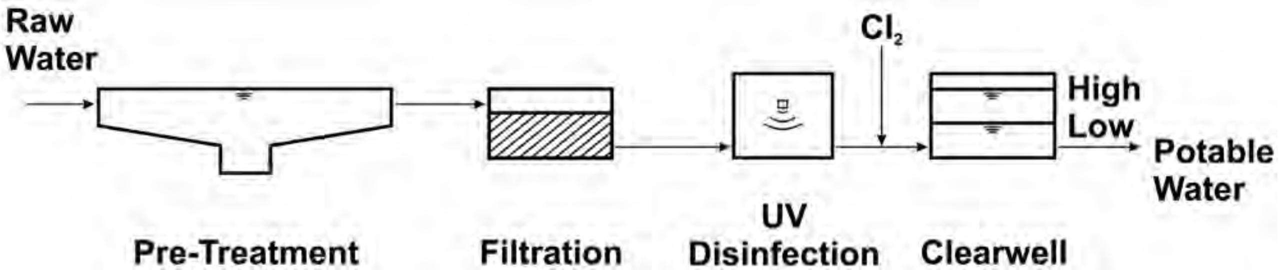

Figure 2. Typical Arrangement of a Plant Flow System

changes are made, it is in response to a controlled process variable. Rapid variations in demand are normally satisfied by a changing level in the clearwell. Figure 2 shows a typical arrangement of a set plant flow system.

A more complicated operating regime is where the UV disinfection system is placed after the water storage, such as at Victoria. In the Victoria scenario, the UV disinfection system experiences a constantly changing flow. Figure 3 shows the demand-based flow system as installed at Victoria.

With a demand-based system, any imbalance in treatment capacity and water demand can lead to a restriction to system flows. For this type of system, additional control logic is required to ensure that there are always enough UV reactors on-line to satisfy the instantaneous water demand. This type of varying flow system generally does not fit in with the standard product available from UV disinfection equipment manufacturers.

For the Victoria facility, the design team developed a specific operating philosophy to control the UV reactors. The control system needs to ensure that the number of reactors on-line would always meet demand and not influence it. The solution was to start and shutdown reactors as required to meet the demand, but to ensure that there is always one more reactor in operation than the flow through the facility required. This concept was developed into a control philosophy that would automatically determine when a reactor is needed, and when a reactor could be shut down, as demand fluctuated. By always having one more reactor on-line than required, the UV system would not influence the flow and could tolerate an increase in demand of as much as the capacity of one reactor over the 10 minutes required to bring an additional reactor on-line. Thus, a high-energy efficiency would be achieved while still allowing for a rapid increase in demand.

The flow permitted through each reactor would normally be determined initially based on the manufacturer's validated capacity at a particular UVT and the measured UVT. When considering using a demand-based control system, the designer should consider the extra control logic programming that will be required.

GENERAL INSTALLATION CONTRACT

In December 2002, the CRD tendered the general installation contract, which was awarded to Knappett Construction Limited. During construction, the key scheduling constraint was the requirement to maintaining the water supply to Victoria. As a result, all major tie-ins had to be completed after the summer peak demand period.

CONCLUSION

Many communities in B.C. are considering the improvements they can make to their existing treatment facilities to provide multi-barrier treatment. UV primary disinfection is well suited to the typically pristine lake water sources in B.C. The lakes generally have low turbidity and low hardness. Watersheds are also often protected and owned by the water provider.

In March 2004, the CRD commissioned the 580 ML/d UV disinfection facility (see Figure 4). The facility is the largest of its type in Canada and, most importantly, improves the drinking water for 310,000 people.

Figure 4. UV reactors and headers installed

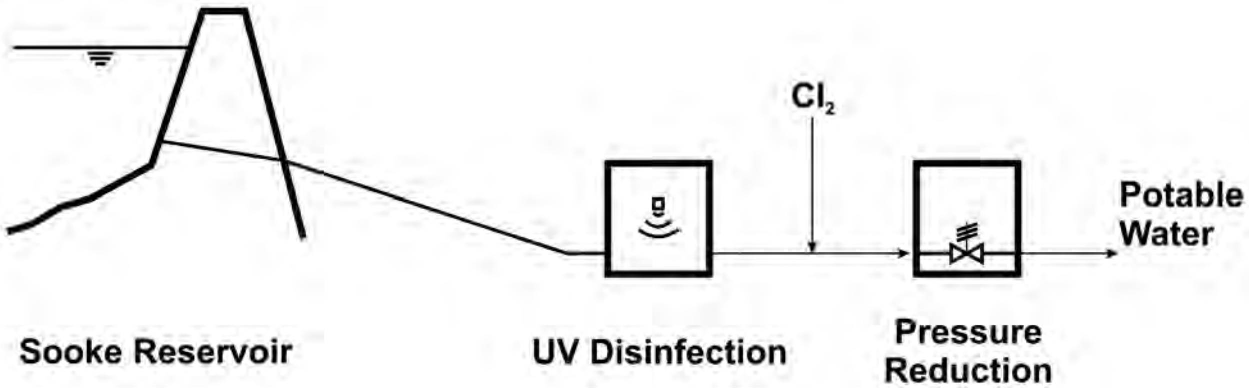

Figure 3. Victoria's Demand-based Flow System

The treatment scheme is relatively unique; there is no treatment prior to the UV disinfection. When applying UV disinfection treatment in this way, there are a number of issues that must be addressed. Firstly, the appropriate value for UVT must be used. Secondly, particular care must be taken in regard to the hydraulic design of the facility. Finally, system control is likely to be more complicated, especially if the point of storage is upstream of the treatment.

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