Private Water Supplies

Disinfection by UV Radiation

Technical Guidance

This is designed to be a short guide to Ultraviolet Irradiation (UV) used in the treatment of drinking water for those responsible for monitoring private water supplies and the owners and users of such supplies. The main text is aimed primarily at technical practitioners involved in the management and regulation of water supplies and covers basic principles, design, operation and maintenance. It also includes a checklist for maintenance and a Frequently Asked Questions section, which can stand alone and may be more appropriate for the non-technical user .

Introduction

Ultraviolet irradiation (UV) uses ultraviolet light in order to deactivate a wide range of pathogens found in drinking water supplies. Unlike chlorine, UV can also have the advantage of being effective against protozoa, including *Cryptosporidium*. The process relies on UV light being able to pass through the whole column of water requiring treatment with sufficient energy to inactivate the pathogens. Effectiveness is significantly impaired if water is coloured or contains particulate material. It is often the disinfectant treatment of choice for private water supplies, especially small ones. UV treatment can be located centrally at the source of the supply or at individual properties immediately before the water is consumed, or both. Unlike chlorine, UV does not have any residual disinfectant effect in the water.

UV light will also photo-oxidise some organic compounds, breaking them down into smaller molecules. This has some application in the treatment of compounds causing tastes and odours, pesticides and algal toxins. The shorter wavelengths of UV, around 185 nm, tend to be more effective in this application.

Strengths of UV

- Cheap and effective disinfection
- Chemical free
- Relatively simple to install, operate and maintain
- Inactivates *Cryptosporidium*
- Compact footprint
- Minimal concerns over by-products

Weaknesses of UV

- No lasting disinfectant residual
- Cannot operate without power
- Requires water to have low levels of colour and turbidity
- Is ineffective if the dose and contact time are not correct
- Hard to verify water has been adequately disinfected

Principles of UV Disinfection

UV radiation inactivates microorganisms by penetrating cell walls and disrupting vital cell functions. If sufficient energy reaches the cell it results in the death or impairment of that cell, and consequently the organism itself. The most effective wavelength of UV radiation for damaging cell DNA is 254nm, although in practice wavelengths between approximately 200 – 300 nm are generally considered biocidal. As with chlorine disinfection, some organisms are more susceptible than others. Bacteria are more susceptible than larger protozoan parasites such as *Cryptosporidium* and Giardia, although with a sufficient dose and contact time UV can be considered effective at deactivating these. There is less agreement on vulnerability of viruses, although UV undoubtedly has some effect. Sometimes UV is used in combination with other treatments such as ozone or hydrogen peroxide.

Generation of UV Radiation

Special lamps are used to generate UV radiation, and these are enclosed in a reaction chamber made of stainless steel or, less commonly, plastics. Low pressure mercury lamps, which generate 85% of their energy at a wavelength of 254 nm, are most commonly used; their wavelength is in the optimum germicidal range of 250 to 265 nm. These lamps are similar in design, construction and operation to fluorescent light tubes except that they are constructed of UV-transparent quartz instead of phosphor-coated glass. The optimum operating temperature of the lamp is around 40 °C so the lamp is normally separated from the water by a ‘sleeve’ to prevent cooling by the water. The intensity of UV radiation emitted decreases with lamp age; typical lamp life is about 10 to 12 months after which the output is about 70% of that of a new lamp, and lamp replacement is required.

The usual UV reactor configuration is a quartz-sleeved low pressure mercury lamp in direct contact with the water; water enters the unit and flows along the annular space between the quartz sleeve and the wall of the chamber. Other configurations include lamps separated from the water, for example lamps surrounded by ‘bundles’ of PTFE tubes through which the water flows.

Other Applications

Several new treatment technologies have been developed for inactivation of *Cryptosporidium*. These include pulsed UV or white light systems and combined filtration-irradiation or adsorption-irradiation techniques that increase exposure to UV, for example by trapping the micro-organisms on a filter then subjecting them to UV irradiation. Pulsed UV and pulsed white light devices that generate high intensity, short duration, pulses of radiation are reported to give more effective inactivation of oocysts than conventional UV systems.

Application and Design of Systems

Design and Installation

Careful consideration needs to be given to the design a UV system, and this should be done in the context of the whole water supply system, from source to tap. The production of a draft Drinking Water Safety Plan, or management plan, for the system may be helpful at this stage to highlight actual or potential risks and to try to minimise them through good design.

One of the key things to remember about UV is that there is no lasting residual disinfectant effect imparted to the water, unlike chlorine disinfection where a residual concentration remains. Consequently, there remains the risk that UV disinfected water may become re-contaminated post-treatment before it is supplied to the user. Ingress of contaminants is a particular risk if the integrity of any tanks and pipework is not satisfactory. Additionally, long retention times in storage tanks or long lengths of pipework in buildings can lead to biological activity and present a risk. This is particularly the case where water is allowed to heat up, perhaps due to pipes running in close proximity to hot water pipes. One option is to install UV treatment at the point of use, as close to the tap as possible. On a larger supply, consideration could be given to installing UV treatment at a central point on the whole supply to minimise microbiological growth in the system, with further small UV units to ensure continued disinfection at the point of use.

Pre-treatment

Although relatively simple to operate, UV disinfection will only be effective if certain constraints are met. The ideal water for use with UV has minimal dissolved substances, is free from turbidity an suspended solids and low in organic compounds and colour. Few raw water supplies, certainly in the North of the UK, meet these criteria without pre-treatment and such treatment should be considered a pre-requisite otherwise UV disinfection will not be consistently effective.

The exact pre-treatment required will depend on the quality of incoming water and the specific requirements of the UV system in use. Cartridge filters are the most common and, probably, the simplest treatment solution for preparing water for UV disinfection. It is common for a sequence of filters, decreasing in pore size, to be used in series so that the first filter removes coarse material and each successive filter removes increasingly fine particles. The use of too fine a filter can result in filters blocking or needing to be changed at an impractically high frequency. Filter pore sizes of 20 micron, 10 micron and 5 micron are common, but specialist advice should be sought. When choosing filters it should be remembered that incoming water can vary significantly, especially after heavy rainfall.

Where organic and coloured compounds are a problem, ordinary cartridge filters are unlikely to help and filters containing activated carbon or another adsorbant substance may be required. Where colour is particularly high, even these may struggle to be effective and more complex treatment may be needed, on specialist advice.

Selection of UV System

The choice of UV system will depend on the circumstances of each individual supply, and professional advice should be sought. Any product intended for use should have been proven to be effective via an accredited validation method. This is often undertaken by the manufacturer.

Common validation schemes are:

Austrian : ÖNORM M 5873
Part one of this standard covers low pressure mercury lamp units. Part two covers medium pressure.

German: DVGW Standard W294
Products are tested at the DVGW's testing facility in Germany and issued with a certificate if they meet the standard.

American: NSF. 2004. NSF/ANSI 55 Ultraviolet Water Treatment Systems
This standard has two classes: Class A covers equipment capable of providing full disinfection of micro-organisms including Cryptosporidium. This standard is most appropriate to most PWS applications. The Class B standard is designed for supplementary disinfection, where the water has already been thoroughly treated.
Further information and a maintained list of accredited equipment may be found here:

http://www.nsf.org/services/by-industry/water-wastewater/residential-water-treatment/residential-drinking-water-treatment-standards

Incoming Water Quality

As with any treatment process, a comprehensive knowledge of the raw water quality is important when considering the choice and design of a UV system. Multiple quality samples, for a range of parameters and taken over a suitable time period to capture varying water quality should always be taken prior to designing a new system. Two issues need to be considered with respect to the quality of water entering the UV reactor:

UV Transmittance (UVT)

Firstly, the quality of water can inhibit the ability of the UV radiation to pass through it. The ability of the water to allow the propagation of UV is known as the UV Transmittance (UVT) and is measured as the percentage of UV at a wavelength of 254nm that is passed across a 1cm distance. Metals such as iron and manganese, anions such as sulphite and nitrate and natural organic material such as humic and fulvic acids can greatly reduce the UVT of the water and must be controlled by pre-treatment. Many upland waters are highly coloured and therefore contain large quantities of organic compounds that will absorb UV. Suspended solids and turbidity in the water will physically prevent the transmission of UV and could shield microbes from the radiation, leaving the water undisinfected.

It is hard to specify concentrations and values for incoming water that would make it acceptable for UV disinfection, as interactions between substances can occur. It is therefore important to measure the UVT of the water directly when designing a UV disinfection process, always remembering that water quality can change considerably with time, especially where the source is a flashy surface water. As a general guide, if the water is compliant with the regulatory standards for iron and manganese (200μg/l and 50 μg/l respectively) it is likely to be acceptable for UV treatment. Turbidity is required to be below 1NTU. It is harder to provide definitive guideline values for colour and organic compounds. If there is any visible colour at all it is unlikely to be suitable for UV treatment, meaning that the colour needs to be a long way below the regulatory standard of 20 mg/l Pt/Co . Additionally, the absence of colour does not guarantee an acceptable UVT as some compounds that do not impart a colour to the water still absorb UV at 254nm.

Fouling

The other issue concerning the quality of water entering the UV contactor is fouling. Fouling occurs when substances accumulate on surfaces within the contactor, such as the lamp sleeves and the UV monitoring window. These accumulations can significantly reduce the amount of UV radiation reaching the water and the effectiveness of measurement. It is vital that cleaning forms part of a regular maintenance schedule. The frequency of cleaning will depend on the quality of water entering the contactor, and consequently, the effectiveness of any pre-treatment. Where frequent cleaning is required, automatic cleaning systems are available which physically or chemically remove any fouling deposits.

Hardness and alkalinity are key indicators of water that will cause fouling due to the precipitation of limescale. It may be necessary to install softening upstream of the UV contactor, with consideration given to the selection of the appropriate process as not all methods of softening are suitable for use in potable water. Most waters in Scotland are soft, and this type of fouling should not be an issue.

Iron and manganese are common metals that cause fouling of UV systems. This can be a particular problem with underground sources where the metals are originally in reduced, soluble, form, oxidising to the insoluble form when they reach the surface and precipitating on any surfaces.

Power

The adequacy of the power supply to any system is fundamental to any UV system. If the power fails, the water will be undisinfected and it may be worth considering some form of emergency

disinfectant or alternative supply for this eventuality. Fluctuations in voltage, even if power does not fail completely, can affect the intensity of the UV and shorten the life of both the bulb and the ballast (the module which regulates the electric current supplying the lamp). It should also be remembered that UV lamps can take time to warm up after being switched on, and water may not be effectively disinfected during this time, which could be up to ten minutes depending on the particular system.
In order to ensure a consistent power supply to the lamp, certain precautions such as the installation of an uninterrupted power supply (UPS) can be included. If power supply issues are present it is even more imperative to take the advice of a competent installer who is familiar with the specifications of the particular system being considered.

Installation location

Many factors need to be considered in deciding upon the optimal location for the installation of the UV unit. Again, a competent installer should be able to advise. The following are factors to consider – the list is by no means exhaustive:

- Desired location in the water supply system, including any pre-treatment;
- Availability of a suitable connection into the supply system (without creating excessive runs of pipe);
- Availability of a reliable power supply;
- Ease of access for maintenance, and storage for spare bulbs etc.;
- Adequate ventilation – both ballasts and the lamp units themselves generate heat;
- Protection from extremes of temperature, especially frost;

Water Flow Management

The passage of water through the UV contactor is of the utmost importance as the UV energy needs sufficient time in contact with every element of the water flow to achieve full disinfection. If water passes too quickly through the contactor it may not be properly disinfected. UV contactors are designed to treat a maximum flow of water and this should be listed in the product specification. When designing a UV system, careful thought needs to be given to the maximum demand required from that supply, and the equipment should be sized accordingly. Some means of restricting the flow through the unit should be installed to ensure that at times of peak flow water spends sufficient time in the unit. On larger systems some means of measuring flow would be a worthwhile consideration.

UV reactors will be designed so that they remain full of water, with no airspace, under all flow conditions. This is important to prevent the unit from overheating. The system should also be protected from the effects of water hammer which may cause breakage of the lamp. Where water has been stationary or flowing very slowly across the lamps for some time it may become warmed by the lamps. This warm water can be run to waste until the temperature decreases.

Ensuring Disinfection

Disinfection will only be effective provided that a sufficient dose of UV is applied. The 'dose' of UV radiation is expressed as an energy flux, in units of $mW.s/cm^2$ (milliwatt seconds per square centimetre), which is the product of the intensity given out by the lamp and the residence time of water in the reactor. The minimum dose required for disinfection depends on several factors, including the susceptibility of micro-organisms. For log 2 (i.e. 99%) inactivation of *Cryptosporidium* and Giardia, the USEPA consider that a dose of approximately 6 $mW.s/cm^2$ is required. Bacteriological pathogens such as *E.coli* should be inactivated at doses well below this. Inactivation of viruses to the same standard requires 100 $mW.s/cm^2$, however. These inactivation doses are still the subject of some scientific study, and values quoted have changed significantly over recent years. For this reason a biodosimetric approach to validation of UV systems is recommended. This uses laboratory trials to demonstrate that a particular UV system is capable of inactivating a surrogate micro-organism with similar characteristics to the main target pathogenic organisms.

A well designed and operated system will incorporate checks and monitoring to validate the process and the effectiveness of disinfection. These should be considered essential to any UV installation and not optional extras. As an additional safeguard, these could be linked to pump operation so that it is not possible to supply undisinfected water should process specifications be exceeded.

Monitors of UVT transmittance and lamp operation should be considered as essentials. These should be linked to an alarm so that it is obvious to the user when a lamp has failed or water quality has deteriorated to the point that UV disinfection can no longer be considered effective. Where no restriction on flow is present, water flow monitoring should also be installed, with an alarm where flow exceeds that for which the contactor is designed. Lamp life is another parameter worth monitoring, as UV intensity declines with bulb life and may require replacement after a certain number of hours of operation, even if the bulb still appears to be emitting light. Advice on this matter should be sought from the equipment manufacturers.

Operation and Maintenance

Provided the system has been sized and designed correctly, it should be simple to operate. UV systems do, however, require occasional maintenance and it is vital that users of systems are aware of this and understand what is required. As systems vary, the first source of reference should be the manufacturers' guidelines for the equipment concerned. Below are the main tasks that will be required. If the user does not feel competent to undertake these, specialist advice should be sought. Frequencies are indicative, and manufacturer's instructions should be followed.

<u>UV light can be harmful. When undertaking any maintenance activity, care should be taken to avoid exposure to UV by following manufacturers' guidelines.</u>

Cleaning - Approximately Monthly

Cleaning to remove fouling is one of the most important maintenance tasks required for UV systems. The frequency and method used will depend upon the quality of water being treated and the design of the UV treatment process. Typical cleaning tasks involve the removal and cleaning of quartz sleeves surrounding the lamps as well as any sensor windows. The inside wall of the reactor itself should also be checked for fouling and cleaned if necessary.

When cleaning, care should be taken not to break or scratch sleeves. Cleaning equipment and chemicals (if used) should be in accordance with manufacturers' specification. Ideally, the inside of the quartz sleeve should not be allowed to get wet, but if it does it this should be thoroughly dried before returning to use.

It may take some trial and error to arrive upon the correct frequency for cleaning – a sensible starting point is monthly where no automatic cleaning is installed. If no fouling is observed, cleaning intervals could be lengthened, always taking a precautionary approach. Where automatic cleaning is present, six monthly checks on performance and fouling could be implemented. It may be useful to record when cleaning is needed in a diary.

The opportunity should also be taken to check for any leaks or damage. O-rings and seals should be replaced as necessary.

Measurement of ultraviolet transmittance (UVT), the amount of UV that can penetrate through water, is useful as a drop off in UVT can indicate fouling, as well as a reduction in the lamp performance itself. If fouling causes an impractically frequent maintenance requirement, additional pre-treatment and automatic cleaning systems can be considered. Where cleaning of sleeves does not restore UVT to its original value, the quartz sleeve may be damaged and should be replaced. It is advisable to keep spares readily available.

UVT sensor check - Monthly

The sensor monitoring UVT is vital for ensuring UV systems are operating correctly. The sensor should be checked and/or calibrated according to manufacturer's instructions. Where a reference sensor is fitted, the performance of the duty sensor can be checked against this.

Lamp Replacement - Approximately Annually

Most low pressure UV lamps have a lifespan of approx. 9000 hours, which equates to roughly a year. Lamp usage hours should be monitored and the lamp replaced in accordance with manufacturers' guidance when the recommended hours have elapsed rather than waiting for the lamp to fail completely.

Other Maintenance Aspects

Other aspects which may require checking include the ballast (especially for overheating), circuit breakers and any pre-treatment upstream of the UV system. Additionally, it may be necessary to regularly disinfect any pipes and tanks in the water supply system using a chemical approved for drinking water use (it is important to take precautions to prevent accidental consumption by users on the system during cleaning). Chlorine-based disinfectants are commonly used for this, but other non-chlorine products are also approved for use. A list of approved products can be found at http://dwi.defra.gov.uk/drinking-water-products/approved-products/ .

A check list may prove useful to ensure that maintenance is done regularly and to record measurements taken from the process to monitor performance over time. Resource 1 contains a simple checklist template that may be used or adapted to suit individual requirements.

Further Reading

This is intended as a short guide to UV for those responsible for monitoring private water supplies and owners and users of such supplies. Further information is available from these sources, some of which were used as a reference for the production of this guide.

United States Environmental Protection Agency (USEPA)
Ultraviolet Disinfection Guidance Manual for the Final Long Term Surface Water Treatment Rule
EPA 815-R-06-007
November 2006
Comprehensive guidance document on all aspects of UV disinfection. Although primarily aimed at public water supplies it is also a useful document for those using UV on private water supply systems.
http://www.epa.gov/safewater/disinfection/lt2/compliance.html

Drinking Water Inspectorate, England and Wales
Guidance on the use of Ultraviolet (UV) irradiation for the Disinfection of Public Water Supplies
February 2010
Guidance for those using UV disinfection on public water supplies in England and Wales, aimed at securing compliance with the Water Supply (Water Quality) Regulations 2000.
http://dwi.defra.gov.uk/stakeholders/guidance-and-codes-of-practice/uvirradiation.pdf

New Zealand Ministry of Health
UV Disinfection and Cartridge Filtration – Resources for Drinking Water Assistance Programme
December 2010
Simple, practically based guidance for those operating UV disinfection, including small water supplies.
http://www.health.govt.nz/system/files/documents/publications/uv-disinfection-and-cartridge-filtration.doc

Supplementary Resources

1 – UV maintenance checklist template

A basic template checklist to enable the regular recording of basic maintenance of UV disinfection equipment, suitable for use by an owner or user. The template may be used as it is or modified to suit circumstances.

2 – UV disinfection – what you need to know

A simple FAQ style leaflet that may be given to owners and users without extensive technical knowledge who have recently installed, or are considering installation of UV disinfection on their private water supply.

UV Water Disinfection Unit Location:

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Date:												
Cleaning												
Extent of fouling before cleaning (Score 1- clean to 5 - filthy)												
Quartz sleeves cleaned (TICK)												
Sensors cleaned (TICK)												
Interior of chamber cleaned (TICK)												
UVT Sensor												
UVT sensor reading (before cleaning)												
Sensors cleaned (TICK)												
UVT sensor reading (after cleaning)												
Reference sensor reading (if applic.)												
Lamps												
Lamp hours run												
Lamp replaced? (TICK) Check Mfrs recommendations												
General												
O-rings replaced? (TICK)												
Other Maintenance / Comments												

Private Water Supplies

UV Disinfection – What You Need to Know - FAQ

What is UV?

UV is invisible light radiation with a wavelength between 200-300 nanometres. It can be used to kill or damage organisms that cause disease in drinking water, including some that cannot be killed by chlorine such as *Cryptosporidium*. UV is therefore used to disinfect water supplies.

What does a UV disinfection unit look like?

A typical UV disinfection unit consists of a reaction chamber containing a number of UV lamps. The water flows through this and is disinfected. A typical unit for a small water supply is a metal cylinder about 1m long which can be mounted on wall.

Can I install a UV disinfection system on my water supply?

UV requires a reliable power supply – if the power fails, the system will not work and your drinking water will not be disinfected. It is also vital that the UV radiation is able to pass through the water. In much the same way as visible light, UV cannot pass through cloudy or coloured water. Other substances in the water such as iron and manganese can also reduce the ability of the UV system to work. Where the quality of water to be disinfected is not good enough, pre-treatment can be installed. The extent and cost of this will depend on the water quality, but typically consists of a series of cartridge filters. As with any water treatment system, it is recommended that you obtain advice from a suitably qualified professional (see below for details).

So all I need to do is zap my water with UV and it will be safe to drink?

Not quite – UV is an effective disinfectant, but it leaves no lasting residual disinfectant in the water. It is easy for a supply to become re-contaminated between the UV unit and the tap. For this reason it is important to make sure that all pipes and tanks are in good condition and nothing can get into or grow within the system. It may be necessary to periodically flush pipes and tanks with a chemical disinfectant. Small point of use UV disinfection units can also be installed, typically under sinks, to make sure the water remains safe at the point of consumption.

How much effort is required to maintain a UV system?

Some maintenance is required, but it is relatively simple. Fouling will reduce the efficiency of the unit, so regular cleaning is needed. This is typically monthly, but will depend on how clean the incoming water is. UV lamps will also need changing – they typically last about a year. It is a good idea to have some sort of safeguard built into the system so that an alarm is produced if the UV lamp stops working or the water quality deteriorates so that the UV is no longer able to pass through the water to kill pathogens.

How big does my UV system need to be?

This will depend on the volume of water produced by your water supply. UV disinfection units are rated for certain flows of water and it is important to remain within the stated ranges. If the system is undersized, water can pass through too quickly and the UV light will not have sufficient time to disinfect the water properly.

How do I go about finding a suitable contractor to install or work on a UV disinfection system?

A good place to start is the Watersafe website. Watersafe is a UK wide approvals scheme that provides a searchable database of plumbers and contractors with the necessary qualifications and experience to work safely on drinking water systems. The Watersafe scheme can be accessed here: https://www.watersafe.org.uk/ Some local authorities also maintain lists of contractors.

My UV system doesn't appear to be working – what should I do?

Firstly you should make sure no-one drinks the water unless it has been boiled until you are certain it is being disinfected. If necessary you may need to take advice on an alternative means of disinfection until the UV is operational. Here are some things to check:

- Are the UV lamps operating?
    - Replace faulty lamps
    - Is the power supply functioning?

- Has UV transmittance reduced?
    - Check the quality of incoming water and any pre-treatment
    - Check the condition of the quartz sleeves surrounding the lamps – do they need cleaning or replacing?
    - Check the operation of the UV sensor

My UV system appears to be working, but I am still getting failures – why?

There could be a number of reasons :

- Is the water supply becoming re-contaminated after the UV system?
- Is the UV system being adequately maintained and cleaned?
- Is the incoming water suitable quality for UV disinfection without pre-treatment?
- Is the water getting sufficient contact time with the UV (i.e. design flows not exceeded)?
- Are the taps themselves clean?

My UV system makes the water warm and I don't like it.

This can happen on first drawing water or if there is a low flow through the unit and it is incorrectly sized. Try flushing water through the system until cooler water appears.

Further advice on the safe treatment of private water supplies and the Private Water Supply Grant Scheme may be obtained from the Environmental Health Department of your local authority.