INTRODUCTION

Ultraviolet (UV) irradiation is a powerful technology that has been successfully deployed in several diverse industries such as pharmaceutical, semiconductor, power generation, food and beverage, cosmetics, aquaculture, health care, etc. for several decades. While the most common application of UV radiation in water treatment is disinfection, its powerful energy can also be harnessed for other applications such as TOC (Total Oxidizable Carbon) reduction, ozone destruction, and chlorine destruction.

The use of UV technology for water treatment has several inherent advantages. UV radiation does not 'add' anything to the water stream such as undesirable color, odor, chemicals, taste or flavor, nor does it generate harmful by-products. It only imparts energy to the water stream in the form of ultraviolet radiation to accomplish the process of disinfection, TOC reduction or ozone destruction. UV disinfection produces no residual disinfectant to the finished water.

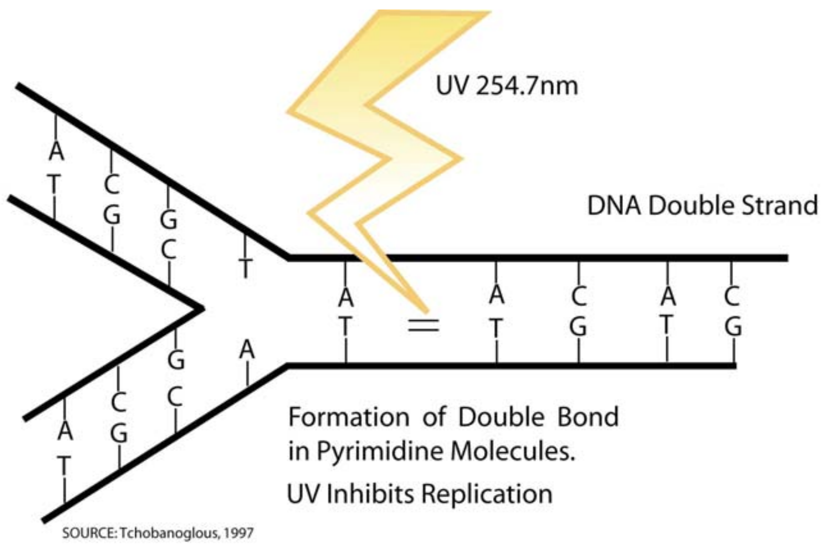

Figure 1: Germicidal Inactivation by UV Radiation

Two different UV wavelengths are employed in water treatment, the 254 nm and the 185 nm. The 254 nm (1 nm = 10-9 m = 10 Å) UV light (also called the 'germicidal light' due to its unique ability to destroy microorganisms) is employed in disinfection and ozone destruction applications. The UV radiation penetrates the outer cell wall of the microorganism, passes through the cell body, reaches the DNA (deoxyribonucleic acid) and alters the genetic material. The microorganisms are thereby destroyed in a non-chemical manner (Figure 1). The 254 nm UV light is also used to destroy residual ozone present in a water stream. The 185 nm UV light, utilized in TOC reduction applications, decomposes the organic molecules. The 185 nm light carries more energy than the 254 nm light. The 185 nm light generates hydroxyl (OH•) free radicals from water molecules.

INDUSTRIAL CASES

Ultraviolet light obeys all the laws of electromagnetic radiation, including the de Broglie's principles and Einstein's laws.

When a molecule absorbs incident UV radiation, it gains energy. The extent of energy absorption depends upon the wavelength of the radiation: the lower the UV wavelength, the greater the gain in energy. The gain in energy can be expressed by the following equation:

$$\Delta E = h\nu = hc/\lambda$$

or

$$\Delta E \ \alpha \ \lambda^{-1}$$

Where h is the Planck's constant, c is the velocity of light, ν is the frequency of the light and λ its wavelength.

Therefore, the energy carried by a light beam is inversely proportional to its wavelength. This is why, the 185 nm light carries more energy and is more powerful than the 254 nm light.

DEFINITION OF UV DOSAGE

Mathematically, UV dosage can be expressed as a product of UV intensity and exposure (residence) time. The most commonly used units of UV dosage are microwatt-seconds per square centimeter (μW-sec/cm2):

$$\text{UV Dosage } (\mu\text{W-sec/cm}^2) = \text{UV Intensity } (\mu\text{W/cm}^2) * \text{Time (sec)}$$

UV dosage is also often expressed in mJ/cm2 where 1 mJ/cm2 = 1000 μW-sec/cm2.

MECHANISM OF UV DISINFECTION

As noted above, the 254 nm UV radiation penetrates the outer cell-wall of the microorganism, passes through the cell-body, reaches the deoxyribonucleic acid (DNA) and alters the genetic material, thereby destroying microorganisms in a non-chemical manner. The process of disinfection by UV light is governed by the following equation, which is referred to as the **Chick's Law:**

$$N = N_o \, e^{(-kIt)}$$

where N = surviving bacterial population post-UV

N_o = initial bacterial population

k = rate constant

I = UV intensity

t = exposure time

Therefore, as the equation shows, the degree of reduction in the bacterial population is directly dependent upon the applied UV dosage.

It must be noted that UV treatment, just as Chlorination or Ozonation, is a disinfection mechanism. Disinfection is a 3- to 6-log reduction in the influent microbial levels. Disinfection is not a sterilizing mechanism, which would, by definition, require the complete absence of all viable microorganisms. Most of the common waterborne pathogenic microorganisms can be inactivated using an UV dosage of less than 15,000 μW-sec/cm2. Absorption of the adequate UV dosage by the microorganisms at the 254 nm wavelength results in a greater than 99.9% reduction in influent microbial population. A minimum of greater than 4-log reduction is required for influent viral population. Figure 2a and 2b (Ref: EPA815-D-03-007) shows the modeled results of UV dose required to inactivate Cryptosporidium and Giardia from various research studies.

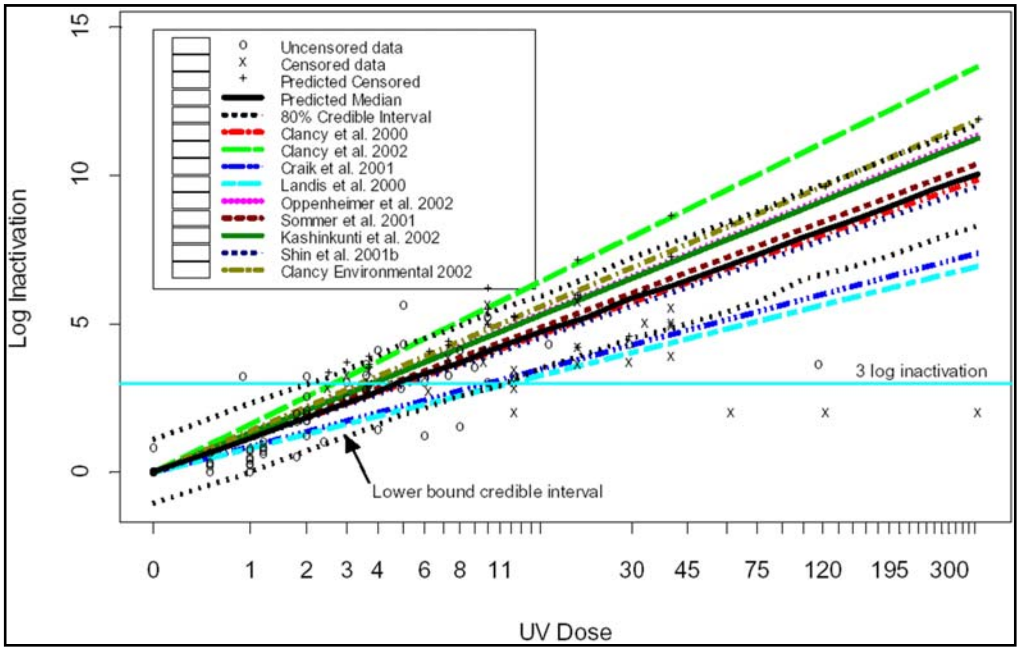

Figure 2a: Cryptosporidium Modeled Data and Predictive Credible Intervals

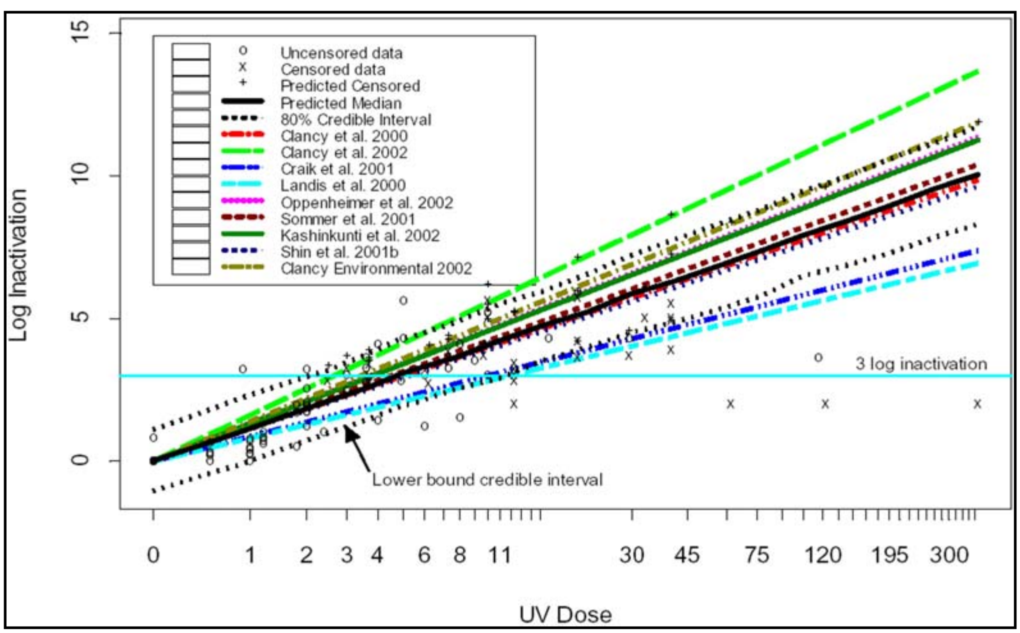

Figure 2b: Giardia Modeled Data and Predictive Credible Intervals

MICROBIAL AND VIRAL EFFICACY OF UV SYSTEMS

UV radiation can produce a greater than 4-log reduction even in not-so-clear feed water streams. The testing conducted by major soft drink Company in Atlanta, Georgia, produced an almost 5-log reduction in influent microbial levels on a feed-water stream exhibiting a UV transmission of only 51% (Figure 3). Clearer feed-water streams exhibit even better UV transmittance (95% in the soft drink example), producing a LRV of almost 6.

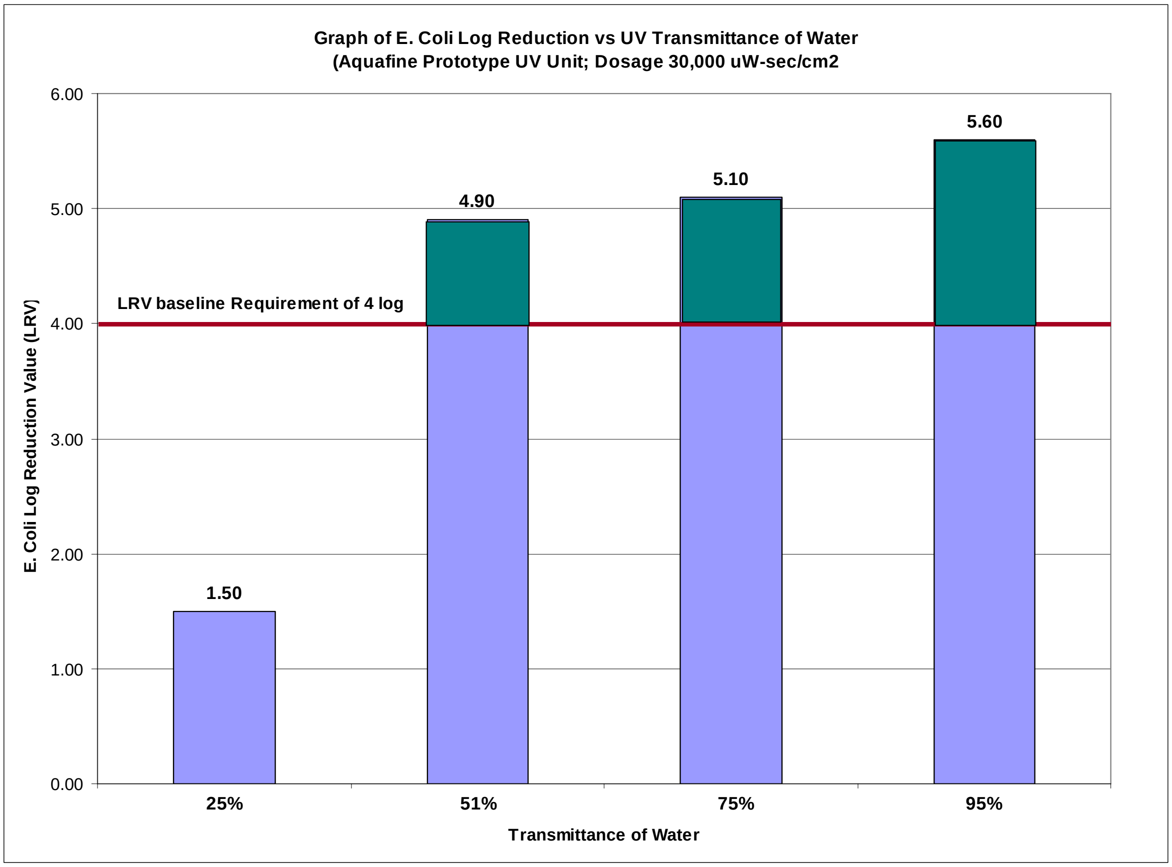

Figure 3: E. Coli Reduction Testing at the Major Soft drink Company (1995)

It is also very pertinent to mention that if sterilization of the water stream is required, then a suitable method of sterilization (such as filtration by a 0.2 µm absolute-rated filter) needs to follow the UV disinfection process.

Figure 4 on the following page, illustrates the summary results of lab tests performed on four Aquafine UV models. The efficacy of UV irradiation is best illustrated in Figure 5. A 3-log reduction is easily achieved by all 4 models, while a greater than 5-log LRV is achieved by models CSL-6R, SL-1, and MP-2-SL.

Daylin Laboratories
Test Report K13475
Model Tested: CSL-6R

Inoculated Control—Standard
Plate Count 140,000 organisms per ml
Effluent Samples—After UV
Flow Rate: 70 GPM

	S.P.C. per ml
Sample 1	–1
Sample 2	1
Sample 3	–1
Sample 4	–1
Sample 5	–1

Griffin-Hasson Laboratories
Test Report R6390
Model Tested: SL-1

Inoculated Control—Standard
Plate Count 120,000 organisms per ml
Effluent Samples—After UV

Flow Rate	*S.P.C. per ml*
5 GPM	–1
10 GPM	–1
15 GPM	9

Model Tested: MP-2-SL

Inoculated Control Std.
Plate Count 130,000 organisms per ml
Effluent Samples—After UV

Flow Rate	*S.P.C. per ml*
10 GPM	–1
20 GPM	–1
30 GPM	–1

Griffin-Hasson Laboratories
Test Report S10250
Model Tested: SL-10A

Inoculated Control—Standard
Plate Count 2,500 organisms per ml
Inoculated Control—Coliforms per ml 16+
Effluent Samples—After UV

Flow Rate	*S.P.C. per ml*	*Coliforms per ml*
1 GPM	1	–1
2 GPM	2	–1
3 GPM	–1	–1
4 GPM	–1	–1
5 GPM	1	–1

Figure 4: Summary of Lab Test Results for 4 Different UV Modes

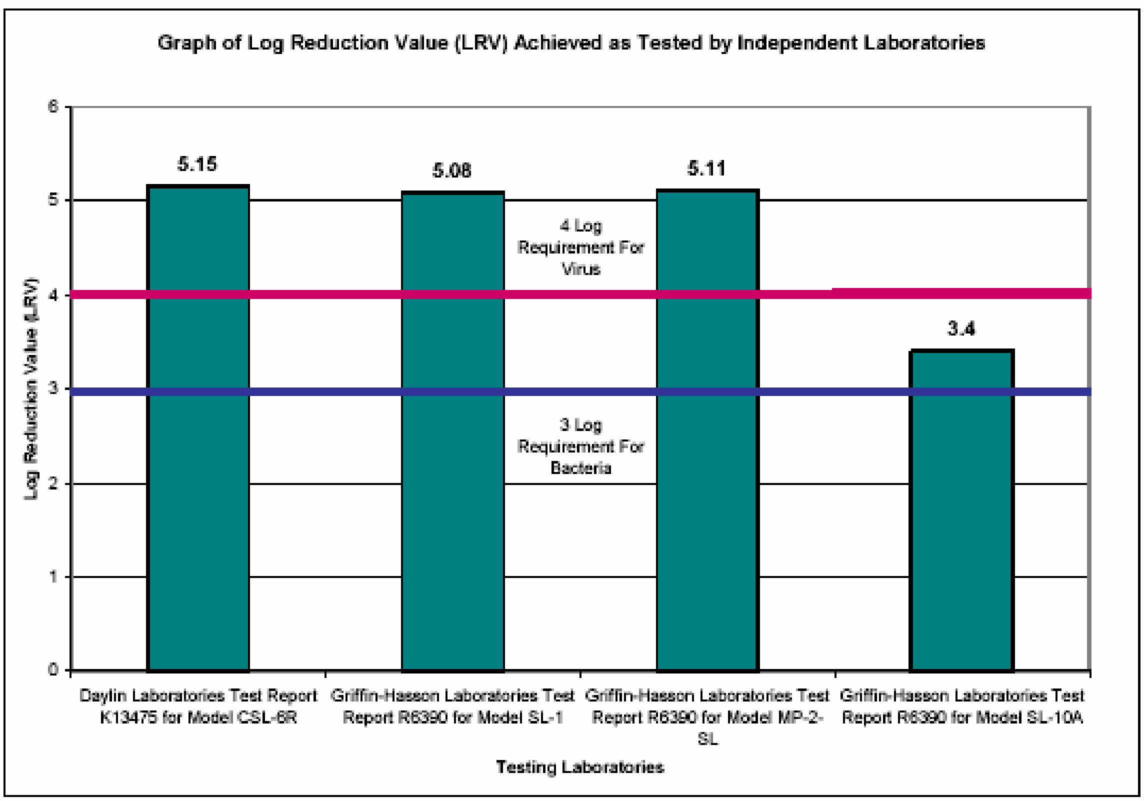

Figure 5: Graph of Log Reduction Value Achieved Using UV Irradiation