



Overview of UV Disinfection for the Drinking Water Industry

An Online Continuing Education Course for Engineers

Course Number: EN-3032

Credit: 3 Hours / 3 PDH / 3 CPD

Overview of UV Disinfection for the Drinking Water Industry

This course provides an overview of UV disinfection. This overview includes discussion of basic chemical and physical principles, the components of UV equipment, and performance monitoring for UV facilities.

1 History of UV Light for Drinking Water Disinfection

UV disinfection is an established technology supported by decades of fundamental and applied research and practice in North America and Europe. Downes and Blunt (1877) discovered the germicidal properties of sunlight. The development of mercury lamps as artificial UV light sources in 1901 and the use of quartz as a UV transmitting material in 1906 were soon followed by the first drinking water disinfection application in Marseilles, France, in 1910. In 1929, Gates identified a link between UV disinfection and absorption of UV light by nucleic acid (Gates 1929). The development of the fluorescent lamp in the 1930s led to the production of germicidal tubular lamps. Considerable research on the mechanisms of UV disinfection and the inactivation of microorganisms occurred during the 1950s (Dulbecco 1950, Kelner 1950, Brandt and Giese 1956, Powell 1959).

Although substantial research on UV disinfection occurred during the first half of the 20th century, the low cost of chlorine and operational problems with early UV disinfection equipment limited its growth as a drinking water treatment technology. The first reliable applications of UV light for disinfecting municipal drinking water occurred in Switzerland and Austria in 1955 (Kruithof and van der Leer 1990). By 1985, the number of such installations in these countries had risen to approximately 500 and 600, respectively. After chlorinated disinfection byproducts (DBPs) were discovered, UV disinfection became popular in Norway and the Netherlands with the first installations occurring in 1975 and 1980, respectively.

Because of the susceptibility of *Cryptosporidium* to UV disinfection and the emphasis in recent regulations on controlling *Cryptosporidium*, the number of public water systems (PWSs) using UV disinfection is expected to increase significantly over the next decade.

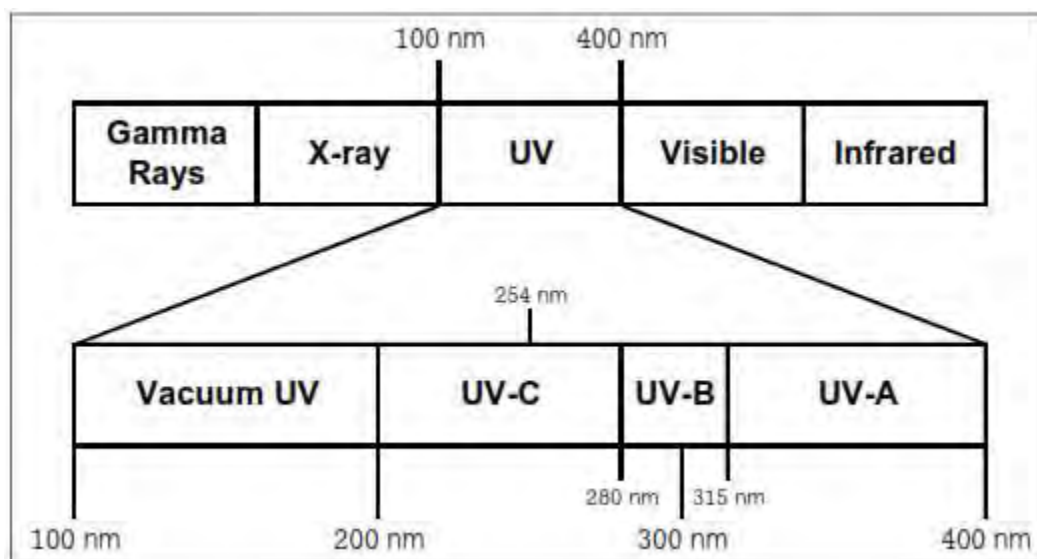
UV Light Generation and Transmission

The use of UV light to disinfect drinking water involves (1) generating UV light with the desired germicidal properties and (2) delivering (or transmitting) that light to pathogens. This section summarizes how UV light is generated and the environmental conditions that affect its delivery to pathogens.

Nature of UV Light

UV light is the region of the electromagnetic spectrum that lies between X-rays and visible light (Figure 1). The UV spectrum is divided into four regions: vacuum UV [100 to 200 nanometers (nm)]; UV-C (200 to 280 nm); UV-B (280 to 315 nm); and UV-A (315 to 400 nm) (Meulemans 1986). UV disinfection primarily occurs due to the germicidal action of UV-B and UV-C light on microorganisms. The germicidal action of UV-A light is small relative to UV-B light and UV-C light; therefore, very long exposure times are necessary for UV-A light to be effective as a disinfectant. Although light in the vacuum UV range can disinfect microorganisms (Munakata et al. 1991), vacuum UV light is impractical for water disinfection applications because it rapidly dissipates in water over very short distances. For the purposes of this course, the practical germicidal wavelength for UV light is defined as the range between 200 and 300 nm. The germicidal range is discussed in more detail later in the course.

Figure 1. UV Light in the Electromagnetic Spectrum



Typically, UV light is generated by applying a voltage across a gas mixture, resulting in a discharge of photons. The specific wavelengths of light emitted from photon discharge depend on the elemental composition of the gas and the power level of the lamp. Nearly all UV lamps currently designed for water treatment use a gas mixture containing mercury vapor. Mercury gas is advantageous for UV disinfection applications because it emits light in the germicidal wavelength range. Other gases such as xenon also emit light in the germicidal range.

The light output from mercury-based UV lamps depends on the concentration of mercury atoms, which is directly related to the mercury vapor pressure. In low-pressure (LP) UV lamps, mercury at low vapor pressure [near vacuum; 2×10^{-5} to 2×10^{-3} pounds per square inch (psi)] and moderate temperature [40 degrees centigrade ($^{\circ}\text{C}$)] produces essentially monochromatic

(one wavelength) UV light at 253.7 nm. In medium-pressure (MP) UV lamps, a higher vapor pressure [2 – 200 psi] and higher operating temperature (600 – 900 °C) is used to increase the frequency of collisions between mercury atoms, which produces UV light over a broad spectrum (polychromatic) with an overall higher intensity. The characteristics of LP and MP lamps are and summarized in Table 1 later in the course.

2.2 Propagation of UV Light

As UV light propagates from its source, it interacts with the materials it encounters through absorption, reflection, refraction, and scattering. In disinfection applications, these phenomena result from interactions between the emitted UV light and UV reactor components (e.g., lamp envelopes, lamp sleeves, and reactor walls) and also the water being treated. When assessing water quality, UV absorbance or UV transmittance (UVT) is the parameter that incorporates the effect of absorption and scattering. This section briefly describes both the phenomena that influence light propagation and the measurement techniques used to quantify UV light propagation.

Absorption is the transformation of light to other forms of energy as it passes through a substance. UV absorbance of a substance varies with the wavelength (λ) of the light. The components of a UV reactor and the water passing through the reactor all absorb UV light to varying degrees, depending on their material composition. When UV light is absorbed, it is no longer available to disinfect microorganisms.

Unlike absorption, the phenomena of refraction, reflection, and scattering change the direction of UV light, but the UV light is still available to disinfect microorganisms.

Refraction (Figure 2) is the change in the direction of light propagation as it passes through the interface between one medium and another. In UV reactors, refraction occurs when light passes from the UV lamp into an air gap, from the air gap into the lamp sleeve, and from the lamp sleeve into the water. Refraction changes the angle that UV light strikes target pathogens, but how this ultimately affects the UV disinfection process is unknown.

Reflection is the change in direction of light propagation when it is deflected by a surface (Figure 3). Reflection may be classified as specular or diffuse. Specular reflection occurs from smooth polished surfaces and follows the Law of Reflection (the angle of incidence is equal to the angle of reflection). Diffuse reflection occurs from rough surfaces and scatters light in all directions with little dependence on the incident angle. In UV reactors, reflection will take place at interfaces that do not transmit UV light (e.g., the reactor wall) and also at UV transmitting interfaces (e.g., the inside of a lamp sleeve). The type of reflection and intensity of light reflected from a surface depends on the material of the surface.

Figure 2. Refraction of Light

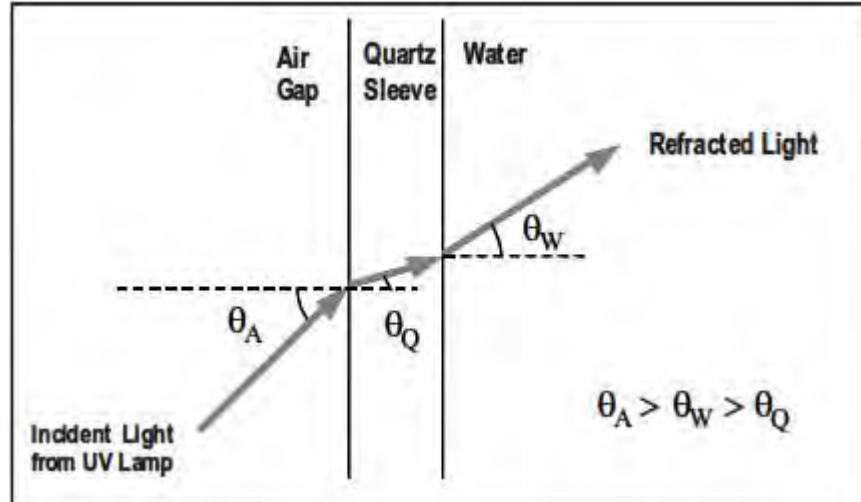
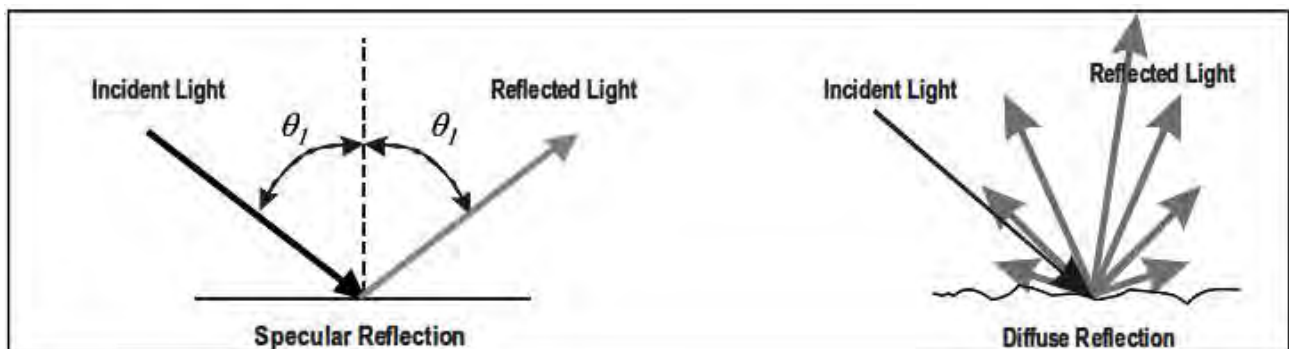


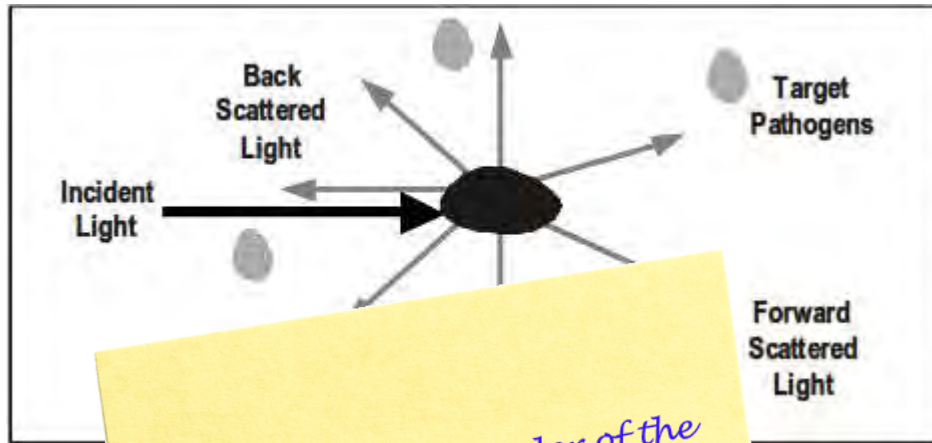
Figure 3. Reflection of Light



Scattering of light is the change in direction of light propagation caused by interaction with a particle (Figure 4). Particles can cause scattering in all directions, including toward the incident light source (back-scattering). Scattering of light caused by particles smaller than the wavelength of the light is called Rayleigh scattering. Rayleigh scattering depends inversely on wavelength to the fourth power ($1/\lambda^4$) and thus is more prominent at shorter wavelengths. Particles larger than the wavelength of light scatter more light in the forward direction but also cause some backscattering that is relatively independent of wavelength.

UV absorbance (A) quantifies the decrease in the amount of incident light as it passes through a water sample over a specified distance or pathlength. UV absorbance at 254 nm (A_{254}) is a water quality parameter commonly used to characterize the DBP formation potential of the water (e.g., specific UV absorbance calculations). In UV disinfection applications, A_{254} is used to measure the amount of UV light passing through the water and reaching the target organisms. A_{254} is measured using a spectrophotometer with 254 nm incident light and is typically reported on a per centimeter (cm^{-1}) basis.

Figure 4. Scattering of Light



Standard Method
0.45-μ m membrane
applications, however
samples should be ana
defines this measurem
latter term is widely us

UV Transmittance (U
describing the behavior
material (e.g., a water s
calculated using Beer's

sample through a
ance. For UV disinfection
treated. Therefore, water
igh Standard Methods
of absorbance because the

To view the remainder of the course material and to take the quiz for PDH credit, you must purchase the course.
Close this window and click "Add to cart" on the product page.

when
g through
T can be

$$(1)$$

I_0

Where

UVT = UV transmittance at a specified wavelength (e.g., 254 nm) and pathlength (e.g., 1 cm)

I = Intensity of light transmitted through the sample [milliwatt per centimeter squared (mW/cm^2)]

I_0 = Intensity of light incident on the sample (mW/cm^2)