# Automation of Delivery Device for Chlorine Dioxide Disinfection

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## Introduction

The evolution of wastewater reclamation, recycling and reuse has its roots in the early water and wastewater system characteristics of the Minoan civilization in ancient Greece (Angelakis and Spyridakis, 1996). Although water reuse has been practiced to a small extent in many countries for centuries, renewed interest in water reuse is surging (Asano and Levine, 1996). Water reclamation and recycling have been prominently used or are being considered in the arid and semi-arid parts of the world such as West Asia (Al-A'ama and Nakhla, 1995), Mediterranean Europe (Kantanoleon et al., 2007), parts of Africa (Bahri and Brissaud, 1996), Australia (Eden, 1996) and countries such as China, where demand for clean water outstrips supply (Yang and Abbaspour, 2007). In the U.S., water reuse for non-potable or indirect potable purposes is being practiced in arid regions of Arizona, California, Colorado and Texas, and in humid regions of Florida, Georgia, Puerto Rico and the U.S. Virgin Islands, in which the surging water demands of rapidly growing human populations are threatening the water resources needed for agriculture and for natural ecosystems (Hartley, 2006).

In addition, there is an imperative need to prevent the fecal-oral transmission of pathogens by adequately disinfecting wastewater, as one of the highest priority health measures. Disinfection is the selective destruction of disease-causing microorganisms, as opposed to sterilization, which is the destruction of all living organisms (Crites and Tchobanoglous, 1998).

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Nevertheless, a disinfectant for treating wastewater must have sufficiently broad spectrum of action to destroy bacteria, viruses, protozoa and helminthes.

Chlorine is a widely used disinfectant (Winward et al., 2008). However, its limited ability to inactivate viruses and protozoan parasites and its role in the formation of carcinogenic by-products during the disinfection process (Kitis, 2004) spurred scientists to look for a better disinfectant. Chlorine dioxide has emerged as one of several viable options endorsed by USEPA because of the numerous advantages it offers. Some of these advantages are summarized, along with some challenges, by Gulian-Krishnaswamy and Mancl (2007). A portable delivery system for the dry media chlorine dioxide (dm$ClO_2$™), a proprietary product of Avantec Technologies, Inc., was developed by Gulian-Krishnaswamy and Mancl (2007). The purpose of this study was to further improve the Gulian-Krishnaswamy and Mancl portable dry media chlorine dioxide packet dispensing device by adding more features and making it automated and more user-friendly.

**System Configuration**

The chlorine dioxide dispenser is placed on top of a cylindrical vessel, the reaction chamber, as illustrated in figure 1. The reaction chamber is where the chlorine dioxide is generated when its precursors in the dry medium in the packet react in the presence of water, and where chlorine dioxide gas is dissolved in the wastewater.

The reaction chamber is held suspended inside a larger dosing tank, which contains the renovated wastewater being discharged from secondary treatment systems such as ponds or fine media bioreactors. The key issues in designing an automated disinfection system include the design of a packet-dispensing device and the ability to uniformly distribute the chlorine dioxide to facilitate the disinfection of the wastewater in the dosing tank. An irrigation pump is placed at the bottom of the dosing tank to pump the treated water out to a lawn or a garden. It is safe to discharge disinfected water on open lawns or gardens (Caldwell et al., 2007); however, wastewater discharge and reuse may be subject to local or state regulations.

The chlorine dioxide dispenser, as designed by Gulian-Krishnaswamy and Mancl (2007), consists of two parts: the stationary cartridge with compartments, and the rotating bottom plate with an open sector identical to the cross-section of a compartment, as shown in figure 2. The vertically oriented cartridge is closed at the top and on the sides and open at the bottom; and the sides are enclosed in an outer tube, which prevents the exposure of the packets to moist air (see Gulian-Krishnaswamy and Mancl, 2007). The cartridge is divided radially into 30 compartments, each holding one 5in. X 5in. water permeable pouch. The packets are held from falling down by the plate, which has a radial sector-shaped opening matching the size of a compartment on the cartridge. Though the cartridge has 30 compartments to store packets, only 29 of them can be utilized as one compartment is aligned with the opening in the plate at the time of installation. The dispenser, described later in the paper, is used to drop the packet vertically into the reaction chamber. The contents in the packet react with the renovated wastewater, releasing chlorine dioxide gas. After completion of the reaction, the spent packets remain at the bottom of the chamber, until they are removed when the cartridge is serviced after all the packets have been used. The spent packets are disposed of safely, and a fresh packet is placed in each compartment of the cartridge.

## Turning and indexing the dispenser

In the chlorine dioxide dispenser designed by Gulian-Krishnaswamy and Mancl (2007), the plate was rotated by a shaft, coupled to a motor. While redesigning the mechanism, the following features were considered necessary:

- Precision in the rotation of the plate such that its open sector comes to rest precisely beneath the next compartment in the cartridge to enable the packet to drop into the reaction chamber.
- The mechanism should not be energy-intensive.
- It should be easy to retrofit a hand-powered mechanism on the existing system to accommodate varying infrastructural and economic circumstances of the users.

After considering several options, a Geneva mechanism was chosen to index the dispenser due to the simplicity of the mechanism, in both design and construction, and its precise positioning motion (Hasty and Potts, 1966). Historically first used in watches and then in movie projectors, the Geneva mechanism translates a continuous rotation into an intermittent rotary motion. It consists of two components: a *drive pin*, which is a small rotating disk with a pin, and a *Geneva wheel*, which is a larger rotating disk with slots (usually four to eight) into which the pin slides. The drive pin also has a raised circular blocking disc that locks the Geneva wheel in position between steps. In the most common arrangement, the Geneva wheel has four slots and thus advances by one step of $90^{o}$ for each rotation of the drive wheel. If the Geneva wheel has $n$ slots, it advances by $(360/n)^{o}$ per full rotation of the drive pin. The Geneva mechanism is placed above the dispenser, and the Geneva wheel secured to the top of the cartridge through a circular shaft, fixed to the plate as shown in Figure 3. The nature of the design problem required a Geneva wheel with 30 slots. This number was chosen to match the number of compartments within the cartridge, as designed by Gulian-Krishnaswamy and Mancl (2007). The number of compartments and the number of slots on the Geneva wheel can be modified based on the frequency of disinfection and size of the packets. The Geneva mechanism can be operated in two modes.

### Manual Mode

In the manual mode, a minimal hand torque is applied on the drive pin, and the Geneva wheel rotates due to the interlocking mechanism, until the pin makes its way out of the slot. At this point, the Geneva wheel stops turning, while the drive pin is rotated until it comes back to its original position. This way, one full rotation of the drive wheel causes a $1/30^{th}$ rotation of the Geneva wheel. The plate, connected to the Geneva wheel through a keyless bushing, rotates by an equal amount, thus positioning the open sector of the plate directly under the adjacent compartment of the cartridge to allow the packet to drop into the reaction chamber.

### Automated Mode

The automated mode uses a motion controller and a DC stepper motor (NEMA Size 23) to actuate the drive pin of the Geneva mechanism. The stepper motor is placed above the Geneva mechanism using a specially designed mounting fixed on the cartridge and is connected to the drive pin using a setscrew. The motion controller can store programs and is programmable through the USB port of a computer.

## Design Dimensions of the Geneva Mechanism

The procedure for designing a Geneva wheel has been adequately described (Hasty and Potts, 1966; Lee, 1998; Figliolini and Angeles, 2002). However, most published descriptions present the design procedure for a six- or eight-slotted Geneva wheel; although Hasty and Potts (1966) state that their design concept can be extended to Geneva wheels with any number of slots. The 30-slot Geneva wheel was, thus, based on the design procedure described in Hasty and Potts (1966). Due to space constraints, the design details are omitted from this paper.

## Water Take-Off

Chlorine dioxide is effective as a disinfectant when it dissolves completely in water. Dropping the chlorine dioxide packet in water by itself does not guarantee full dispersion of the dissolved gas. Mixing is needed to ensure complete dispersion. A pump could be used to achieve mixing; however, the mixing pump would be in addition to the irrigation pump needed to pump out the disinfected wastewater. To minimize equipment cost, a concept of water take-off is used. Similar to the concept of Power Take-Off (PTO), the irrigation pump is used to deliver part of the water from the dosing tank up to the reaction chamber (fig. 1). The pump is connected to an irrigation controller, which treats the reaction chamber and the outside lawn as two separate zones that can be programmed to run at different times and for different durations. Both "zones" are regulated using solenoid valves. It has been shown that the best time to irrigate the lawn is early morning (Cathey, 2001). A functional prototype of the automated delivery device is shown in figure 4.

## Discussion and Future Work

Automation of the delivery device for chlorine dioxide disinfection was achieved using the Geneva mechanism and the water take-off. It was shown to be operable in two modes - manual and automated. It is envisaged that in the automated mode, solar or waste-powered batteries could be used in the future to power the stepper motor and controller. However, the manual mode still remains an attractive option for places where electricity may not be available around-the-clock to keep the irrigation controller running all day and for people who may not be willing to invest additional money in the motor and associated control equipment. Using the water take-off mechanism is likely to allow for uniform distribution of chlorine dioxide within the water in the dosing tank. Future work will focus on safety and additional maintenance aspects.

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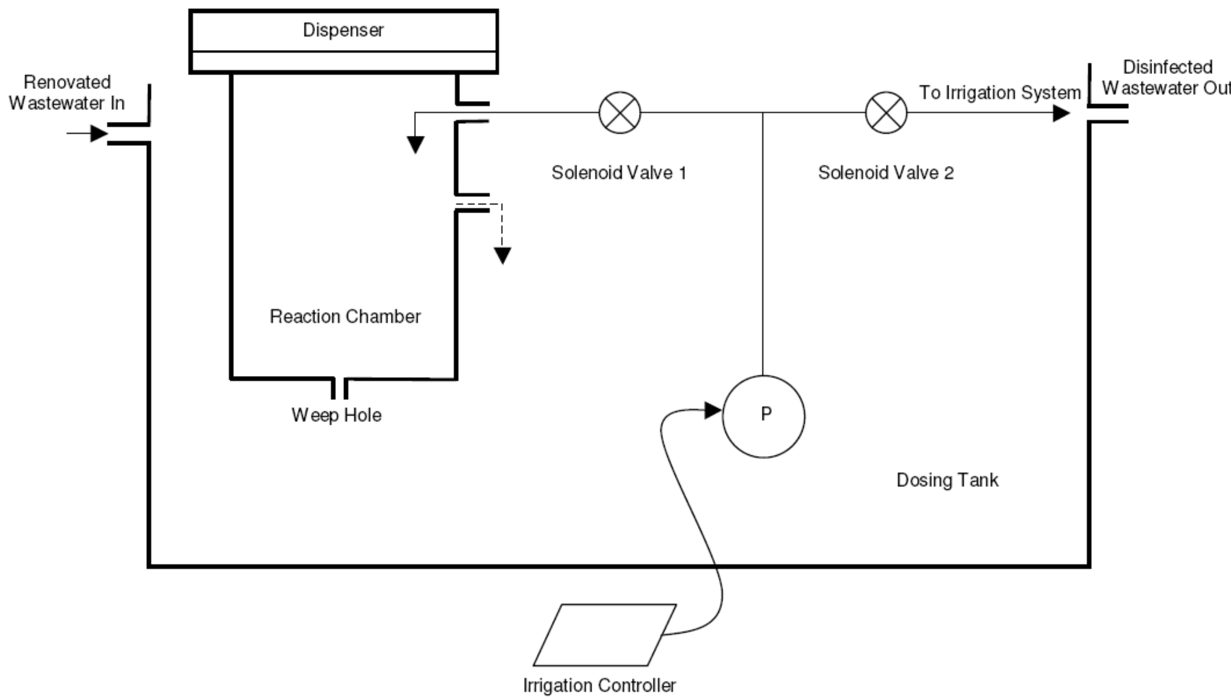


Figure 1. A schematic of the automated delivery device for chlorine dioxide disinfection

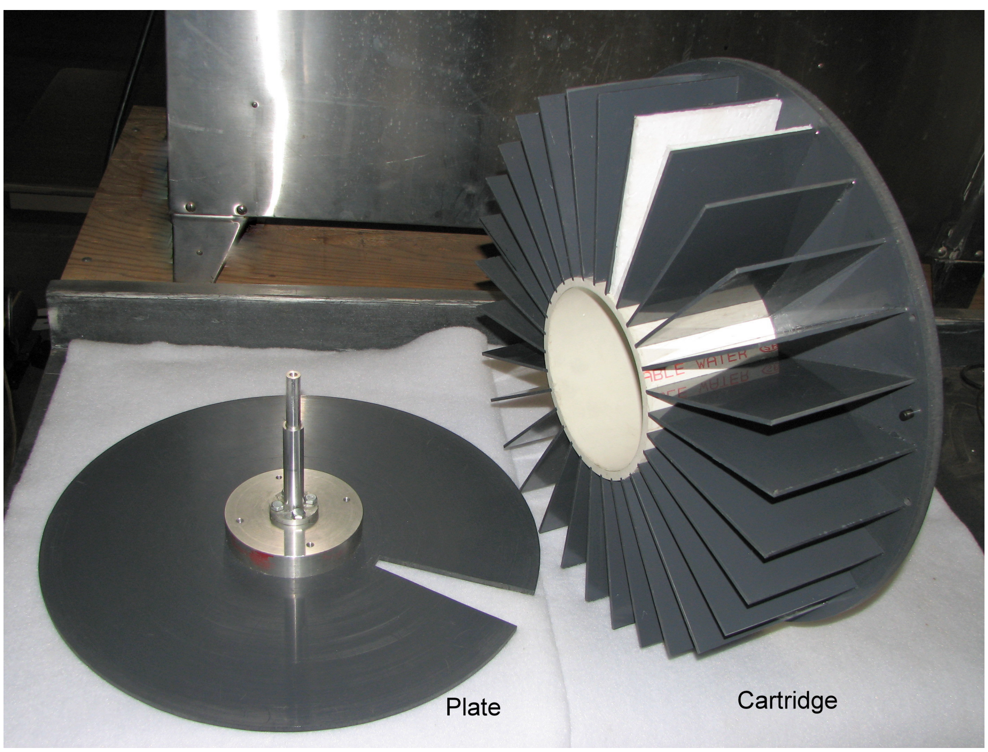


Figure 2. Chlorine dioxide dispenser

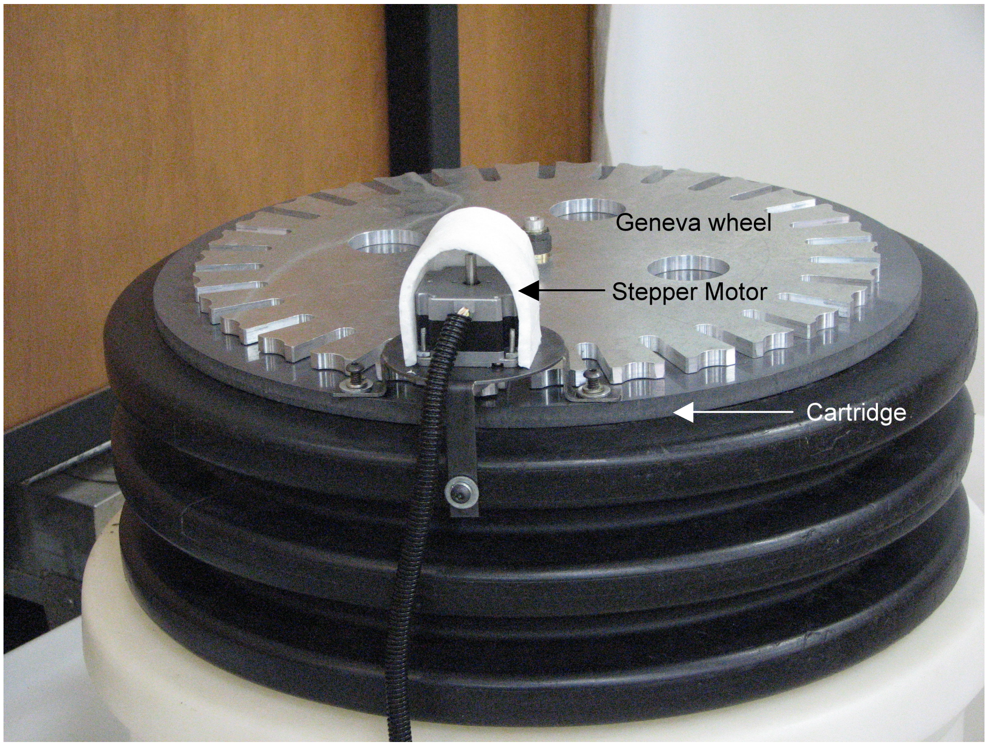

Figure 3. The Geneva mechanism placed above the dispenser

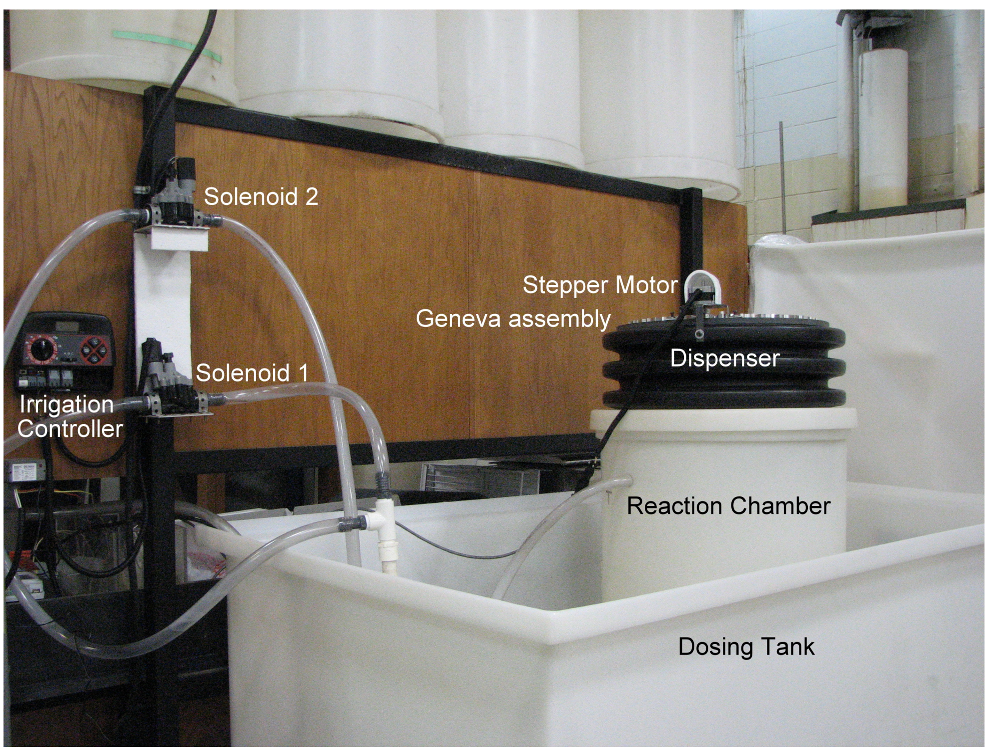

Figure 4. A functional prototype of the automated delivery device for chlorine dioxide disinfection