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Assessment of deficiency of fish tank water ultraviolet disinfection and remedial measures

Key Messages

1. Better bacterial inactivation was observed with higher ultraviolet (UV) doses. There is a need for better tank configuration (hydraulic performance) to ensure proper water circulation or a need to suppress microbial recovery. Addition of titanium dioxide (TiO_2) during UV irradiation was effective in controlling microbial recovery.
2. Higher water temperature enhanced the fouling rate on quartz sleeves, revealing the need for more frequent cleaning of UV tubes to remove the fouling and enable higher UV transmittance for bacterial inactivation.
3. In a fish tank setup, better water circulation facilitates the UV disinfection system and minimises dead zones. This can be achieved by diagonal positioned inlets and the outlets, providing inlet baffles, and enabling better artificial mixing with oxygen diffusers.
4. UV system validation and maintenance practices need to be in place to secure the effectiveness.

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Introduction

Eliminating health risks associated with waterborne pathogen transmission through consumption of contaminated seafood has become an urgent issue. In particular there has been an explosion of several such infectious diseases including numerous incidences of *Vibrio cholerae*. Moreover, *V cholerae* and high concentrations of faecal coliform bacteria have been detected in wholesale and retail live seafood markets.[1,2] Since January 2004, the Hong Kong SAR Government has implemented a risk-based surveillance programme, which aims to educate relevant parties on preventive measures to improve the quality of fish tank water. In this programme, the normal frequency of testing for *Escherichia coli* at each premises remains at once every 8 weeks, while the actionable level was changed from 610 to 180 colony-forming units per 100 mL; any presence of pathogenic organisms also became actionable.[3] The Food and Environmental Hygiene Department licenses food premises and market stalls and requires that facilities used for keeping live marine or shell fish intended for human consumption should have properly installed water filtration and disinfection systems.[3]

To address this government policy on more stringent food safety standards, proper water disinfection systems must be installed in all fish tanks in wholesale and retail live seafood markets and restaurants. Various means of fish tank water disinfection include: ultraviolet (UV) disinfection, ozonation, copper-silver ionisation and photocatalytic disinfection (UV irradiation with titanium dioxide [TiO_2]). Due to their simplicity and lower costs, it is likely that UV disinfection achieved by inducing photobiological alteration of DNA (formation of lesions, typically *cis-syn* cyclobutane pyrimidine dimers, in the genomic DNA of organisms) will be preferred by most interested parties in Hong Kong. However, the success of UV disinfection is not necessarily guaranteed, as it relies on the system operating conditions; the presence of light scattering or absorbing reduces UV intensity reaching target pathogens. Fouling on the surface of quartz jackets and suspended particles in the water also reduce UV transmittance (UVT) and protect pathogens from irradiation. In addition, some organisms are able to repair UV-damaged DNA by photoreactivation and dark repair (or nucleotide excision repair). Furthermore, poor hydraulic conditions in fish tanks (mainly arranged for the convenience of operators) may engender many dead zones in the flow field, promoting pathogen reactivation and/or enabling escape from inactivation. Therefore, UV disinfection was selected as the target process for evaluation.

Aims and objectives

Factors causing defective UV disinfection of fish tank water were assessed by reference to both inactivation and reactivation of indicator organisms. Factors studied included: UV doses and sources, temperature, types of pathogens, modes of reactivation, presence of nutrients, seasonal fouling, seawater composition, and geometric and hydraulic configurations of fish tanks. We also evaluated remedial measures including the use of polychromatic UV lamps and using UV together with TiO_2. Our specific objectives were:

1. To establish the UV dose-response relationship for microbial inactivation and reactivation after exposure to conventional UV irradiation;

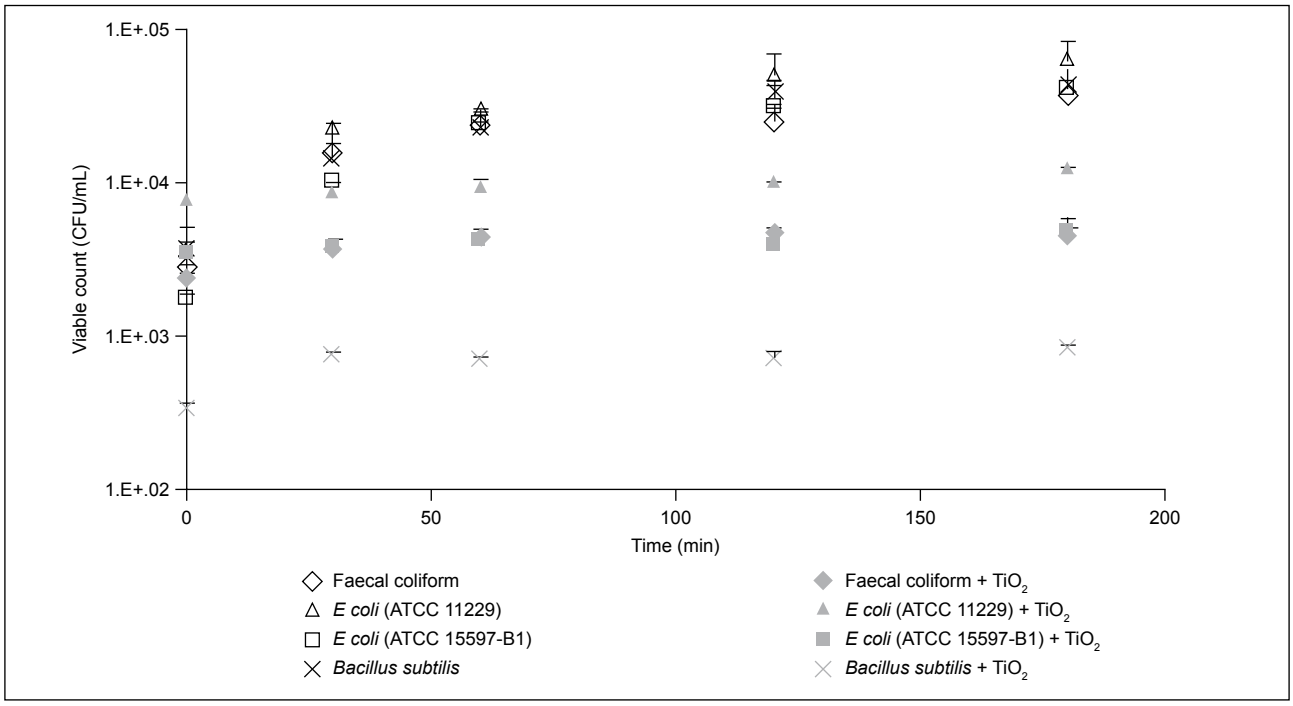

Fig 1. Time-dependent viable count of bacteria (colony-forming unit [CFU]/mL) after low-pressure (LP) UV irradiation alone (open symbols) and LP UV-plus-TiO_2 (in suspension) irradiation (filled symbols in grey) followed by allowing photoreactivation under fluorescence light up to 3 hours

TiO_2 denotes titanium dioxide and UV ultraviolet; UV doses were 12 mJ/cm^2, TiO_2 concentrations were 1 mg/L, if present, and initial bacteria concentrations were approximately 10^7 CFU/mL. Experimental conditions were 22ºC, pH 7, and in 3.5% phosphate-buffered saline. Data presented at time zero represent the bacteria counts right after the completion of UV or UV-TiO_2 exposure and the starting bacteria counts before the occurrence of photoreactivation

2. To study and characterise the hydraulic conditions in fish tanks arranged to simulate actual usage, to evaluate potential pathogen harvest zones and microbial reactivation;
3. To assess the reduction of UVT in seawater and the responsible causative constituents;
4. To investigate the fouling behaviour in UV lamp reactors, and characterise the chemical composition of fouling materials, to establish the cleansing frequency needed; and
5. To evaluate the enhancement of inactivation and prevention of reactivation by polychromatic UV irradiation or using UV radiation combined with TiO_2.

Methods

This study was conducted from January 2005 to December 2006.

Faecal coliform bacteria, *E coli* (ATCC 11229 and ATCC 15597), *Bacillus subtilis* (ATCC 6633) and coliphage MS-2 (ATCC 15597-B1) were used as the surrogates. Buffer solutions with different salt contents and artificial and/or natural seawater were used as the water matrices. Batch studies were conducted using collimated UV irradiators with variations in testing conditions to develop UV dose-response relationships for inactivation and reactivation of the surrogates. Both physical and mathematical models were assembled for hydraulic study of fish tanks. Two flow-through UV units were installed and fed with filtered natural seawater to study how seasonal variations in seawater quality affects fouling.

Results

The inactivation of bacteria in seawater by UV disinfection was rapid; a dose of 12 mJ/cm^2 can yield over 3-log inactivations but against coliphage MS-2 it was much slower (60 mJ/cm^2 was needed to yield 3-log inactivation). However, photoreactivation of bacteria yielded more than 1-log recovery within 1 hour of fluorescence light exposure under all experimental conditions (Fig 1). Dark repair also yielded more than 1-log recovery but required more than 3 hours after UV disinfection. Ultraviolet disinfection with polychromatic UV lamps reduced but did not arrest recovery in seawater. Additions of TiO_2 in suspension during UV disinfection repressed bacterial recovery under all conditions tested (Fig 1). The repressive effect was also achieved by providing TiO_2 in the attached phase during UV disinfection, regardless of nutrients being present (Fig 2).

The composition of seawater on UVT had a negligible effect, as more than 94% persisted if it was properly filtered. The fouling rate on the quartz sleeves of UV lamps changed with the seasons and depended on the temperature; higher temperatures lead to faster fouling. According to this study,

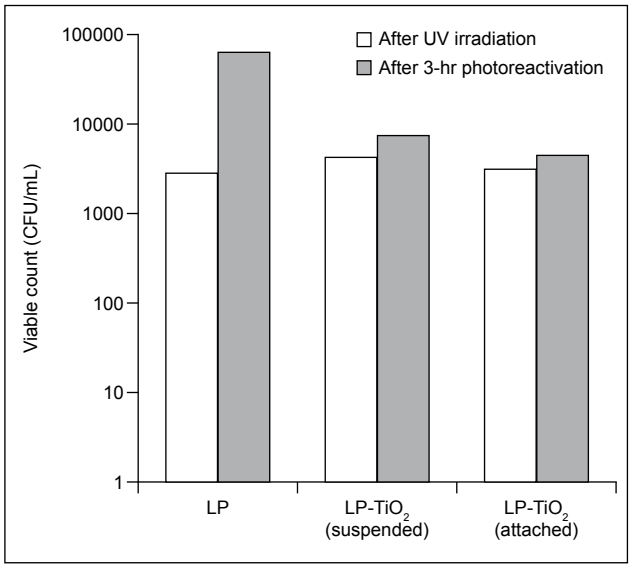

Fig 2. Effect of phases of titanium dioxide (TiO_2) in 3.5% phosphate-buffered saline on viable counts of local wastewater-isolated faecal coliform bacteria (CFU/mL) after low-pressure (LP) UV irradiation alone and LP UV-plus-TiO_2 irradiation (right after UV irradiation (open bars) and after photoreactivation under fluorescence light for 3 hours (filled bars)

UV dose=12 mJ/cm^2, TiO_2 concentration=1 mg/L (in suspension) and 1.44 mg/cm^2 (in attachment), if present

the cleansing frequency of at least once per month (as per guidelines) seemed insufficient[4]; twice a month seemed more appropriate. The fouling materials mainly consisted of precipitates of metal ions, corresponding to the major ions present in seawater and from corrosion.

Poorly designed fish tanks allow channelling effects to occur in the circulated water, leaving most of the water uncirculated and untreated. To reduce the channelling effect shown in Figure 3, positioning of the inlet and outlet was as important as the dimensions of tanks. Fish tanks should be designed with a longer distance for water to travel so as to enhance dispersion. Better mixing can also be accomplished by inlet baffles and/or strategically locating oxygen diffusers in the dead zones. However, if TiO_2 is not used, the total time for water to traverse tanks in series should be less than 30 minutes, in order to prevent bacterial recovery.

Discussion

An improved understanding of the science involved provides guidelines for designing and operating UV disinfection systems for fish tank water. The developed TiO_2-UV disinfection process provides extra security for controlling the transmission of waterborne diseases through fish consumption. However, since the concept of the modified TiO_2-UV disinfection system achieved suppression of microbial recovery only in the batch setup, a pilot study of this system is needed prior to its widespread application. Fouling and deactivation of the TiO_2 film should also be addressed. Another limitation of this project pertained to the evaluation of adsorption and desorption of pathogens on and from fishes. This topic was beyond the scope of this project but deserves further study.

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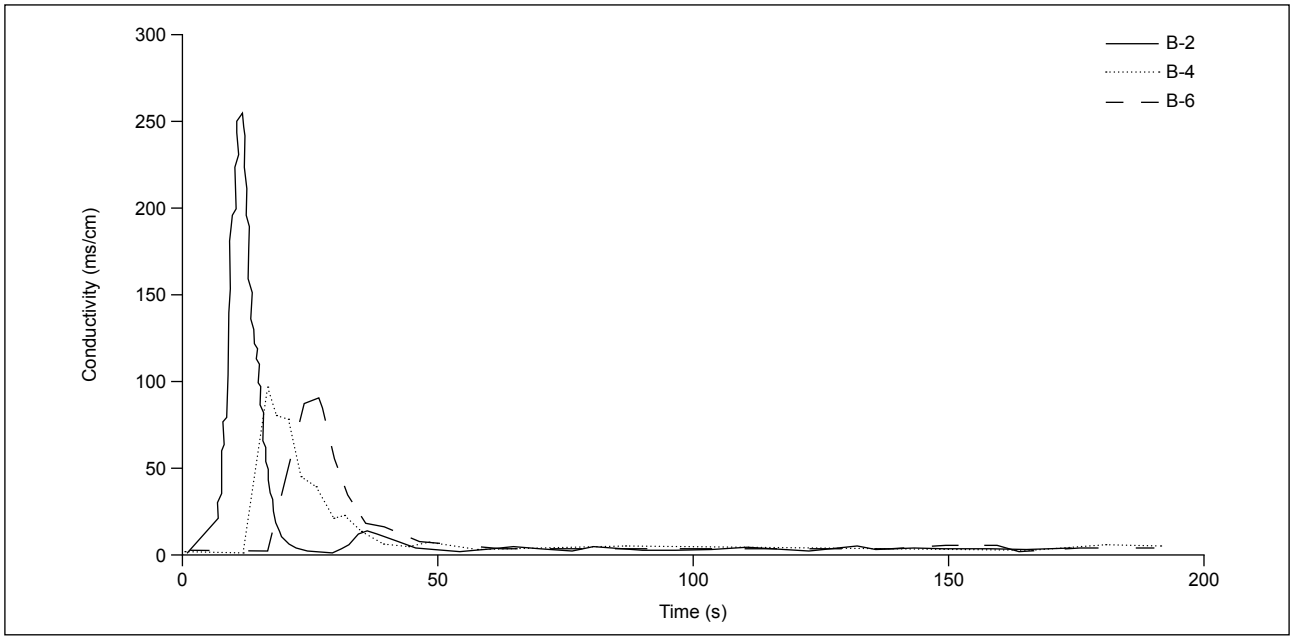

Fig 3. Time-dependent tracer concentrations in outlet position with combination of Inlet B and Outlets 2, 4, and 6

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