Application of computational fluid dynamics modelling to an ozone contactor#

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Abstract

Computational fluid dynamics (CFD) modelling has been applied to examine the operation of the pre-ozonation system at Wiggins Waterworks, operated by Umgeni Water in Durban, South Africa. A hydraulic model has been satisfactorily verified by experimental tracer tests. The turbulence effect induced by the gas injection was modelled by increasing the level of turbulence intensity at the ozone contactor inlet. The simulated tracer response corresponded closely to the experimental results. The framework of ozone reaction modelling was subsequently investigated using values of rate constants from the literature. The predicted profile of residual ozone concentration suggests the current operating strategy can be improved to optimise the ozone utilisation. The wide range of values found in the literature suggests that the ozone reactions are strongly dependent on site-specific characteristics of the water. Further experimental work is required to determine rate constants which are applicable to water from the Inanda Dam.

Keywords: ozone reaction kinetics, CFD modelling, disinfection, rate constants, residence time distribution

Nomenclature

C(t)	Concentration of tracer	kg·m^{-3} or g·ℓ$^{-1}$
C_i	Tracer concentration at time i	kg·m^{-4} or g·ℓ$^{-1}$
C_{O3}	Residual ozone concentration	mg·ℓ$^{-1}$
f(t)	RTD density function	-
k	Turbulent kinetic energy	m^2·s^{-2}
k_m	Disinfection rate constant for *Cryptosporidium parvum*	m^3·kmol·s^{-1}
k_r	Ozone consumption rate constant	m^3·kmol·s^{-1}
k_s	Ozone self-decomposition rate constant	ℓ·s^{-1}
N	Number of surviving micro-organisms at time t	-
N_0	Number of controlled micro-organisms at t = 0	-
T	Time	s or min
$\overline{T}$	Mean residence time	s or min
V	Mean velocity magnitude	m·s^{-1}

Greek letters

Δt	Time increment	s
α(t)	Average mass fraction of tracer	-
ε	Turbulent dissipation energy	m^2·s^{-3}

Introduction

Ozonation is used in drinking water treatment primarily to oxidise iron and manganese, to reduce odour- or taste-causing compounds, and to inactivate micro-organisms. The peripheral benefits include possible reduction in coagulant demand, enhancement of algae and colour removal. Ozonation of water is typically carried out by dispersing gas containing ozone into the liquid phase. The contact between the two phases accompanied by an ozone mass transfer takes place in ozone contactors (Bin and Roustan, 2000).

CT concept and the disinfection purpose of ozone

The most important hydraulic characteristic of an ozone contactor is its residence time distribution (RTD). Under the US EPA Interim Enhanced Surface Water Treatment Rule (IESWTR) the physical removal or the inactivation of waterborne pathogens during disinfection of drinking water is specified in terms of CT which is the numeric product of the residual ozone outlet concentration (C) and a characteristic contact time (T) (USEPA, 1999). The value of CT is dependent on the target species and the disinfectant. The effective contact time is taken to be T_{10} rather than the mean hydraulic retention time. T_{10} is the time required for 10% of a pulse of a tracer introduced at the disinfectant dosing point to have reached the residual sampling point. Thus T_{10} can be derived from the RTD of a contactor, which in turn, is affected by its geometry and operating conditions.

Cryptosporidium parvum is a parasitic protozoan which infects humans and may cause gastroenteric disease. Due to its relatively high resistance to free chlorine, its control is a particular problem for water treatment works. Several studies have reviewed the superior efficacy of ozone for control of *C. parvum* (Staehlin and Hoigné, 1985; Korich et al., 1990; Gyürék et al., 1999; Driedger et al., 2000; Rennecker et al., 2000). Because of the large CT value for *C. parvum* (up to 5 mg O_3·min·ℓ$^{-1}$) its reaction with ozone is chosen to indicate the disinfection performance of the contactor.

Ozone contacting system at Wiggins Waterworks

The pre-ozonation system at Wiggins Waterworks, operated by Umgeni Water in Durban, consists of four contactors. Each contactor is preceded by a static mixer so that every chamber can operate individually or in parallel with another contactor. The Sulzer static mixer is 1 m in diameter. An ozone-oxygen gas mixture is injected as a side-stream through the static mixer which

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