Disinfection of purified sewage effluent with monochloramine

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Abstract

The inactivation of faecal coliforms in purified sewage effluent by monochloramine was investigated using batch tests. For comparative purposes the data obtained were fitted to various published disinfection models. The series-event kinetic model was found to be the most suitable and was used in conjunction with tracer experiments to compare the predicted and observed inactivation of faecal coliforms in two continuous-flow systems. The value for the apparent kinetic constant K, was found to vary between 0.23 and 2.18 min^{-1} for monochloramine concentrations in the 1 to 5 mg/ℓ range and pH values between 6 and 8. The model was able to predict the behaviour of the continuous-flow systems. A design example for the determination of the monochloramine concentration required for a specific inactivation of faecal coliforms in an existing contact tank is given.

Background

The South African General and Special Standards stipulate that treated sewage effluent should comply to a standard of nil faecal coliforms/100 mℓ (Act 96 of 18 May 1984 No. 9225, Regulation 991). This standard can only be achieved by disinfection. Various methods of disinfection are available including physical (e.g. ultraviolet radiation) (Carnimeo et al., 1994) and chemical processes (e.g. chlorine, bromine and ozone) (Aieta et al., 1980; Jacangelo et al., 1989). According to White (1992) the most prevalent practice of disinfection is free chlorine ($HOCl + OCl^-$). This is also the practice in South Africa as was confirmed by a recent survey (Unpublished data, Univ. of Pretoria, 1996). Chlorine is a very reactive chemical and does not only disinfect, but also rapidly reacts with contaminants such as NH_4^+, NO_2^-, H_2S, Fe^{++}, Mn^{++} and organic compounds (Yamamoto et al., 1988; Teefy and Singer, 1990). These compounds create a chlorine demand so that chlorine is applied until the demand is met and free chlorine appears. This practice is called breakpoint chlorination and is wasteful in that it consumes more chlorine than is required for disinfection alone. The reaction of free chlorine with certain organic compounds present in wastewater leads to the formation of a group of compounds called trihalomethanes (THMs) (Johnson and Jensen, 1986), which have associated health risks (Reynolds et al., 1989). This is a concern in South Africa where treated sewage effluent is often reused as drinking water.

Some of the problems associated with free chlorine can be overcome by using chloramines for disinfection. Benefits of using chloramines include a reduction in the formation of THMs as reported by Reynolds et al. (1989) and greater disinfectant stability resulting in a reduction in disinfectant demand. Disadvantages of chloramines are their relatively long lifetime (compared to free chlorine) after discharge to the receiving environment, possibly with toxicity problems (Yamamoto et al., 1988) and their detrimental effect on kidney dialysis patients (Kreft et al., 1985).

The chloramines are formed by the reaction of free chlorine with ammonia. The reaction produces three main compounds, monochloramine (NH_2Cl), dichloramine ($NHCl_2$) and trichloramine or nitrogen trichloride (NCl_3). Palin (1974) showed that the dominant species formed in the reaction is dependent on the chlorine to nitrogen mass ratio (Cl_2:N). A low ratio (up to 5:1) favours the formation of NH_2Cl and higher ratios (up to 7.6:1) favour the formation of $NHCl_2$ and NCl_3. Ward et al. (1984), found that the three species also vary in their disinfectant power, with monochloramine being less effective than dichloramine. Studies have shown that free chlorine is a more effective disinfectant than the chloramines (Berman et al., 1992; Kouame and Haas, 1991; Rice et al., 1993; Ward et al., 1984) while some field reports (that observe naturally occurring bacteria and water with a chlorine demand) have shown that chloramines are adequate, and in some cases superior to free chlorine in terms of indicator organism reductions (Dice, 1985; Shull, 1981; Reynolds et al., 1989; ASCE, 1986).

Disinfection with chlorine and chloramines is influenced by five major factors, i.e. initial indicator organism concentration, disinfectant concentration, contact time, temperature and pH. Batch inactivation studies, performed in the laboratory to observe the efficiency of a disinfectant, are usually performed with pure culture bacteria, distilled water and well defined contact times (Ward et al., 1984). This is not the case in practice, where a complex mixture of bacteria and chemical species is present, and the contact time is dependent on the mixing regime (Teefy and Singer, 1990). The design of a full-scale disinfection process would be enhanced if the results of batch inactivation studies performed on real sewage effluents in the laboratory could be matched with the hydraulic behaviour of a real continuous-flow contact chamber.

The aim of this work was to evaluate the disinfection efficacy of monochloramine under operational conditions and to show how this information may be used in the design calculations of a chloramine disinfection system.

Theoretical

Kinetic models for batch inactivation

Since the turn of the century various mathematical models have been developed to describe the inactivating action of a disinfectant on micro-organisms. The main inactivation models found in the

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