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Modelling *Escherichia coli* concentration in a wastewater reservoir using an operational parameter MRT%FE and first order kinetics

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Abstract

The operational parameter MRT%FE, representing the mean residence time of different ages fractions of effluent within a completely mixed reactor, was evaluated and integrated with first order kinetics. The parameter was used to model *Escherichia coli* concentrations in a municipal wastewater reservoir managed under different operating conditions (continuous and discontinuous).

The study was conducted during 2004–2005 in a reservoir receiving effluents from the activated sludge treatment plant of Caltagirone (Eastern Sicily – Italy). The analytical approach is applied to the hydraulic state variables of the system (daily stored volumes, inlet and outlet flows), and the physical–chemical (pH, temperature, EC, TSS, BOD_5, COD) and bacteriological wastewater parameters (*E. coli*, FC, FS). In order to evaluate the reliability of the proposed approach, predicted *E. coli* concentrations within the reservoir were compared with measured ones by the correlation coefficient, *F*-test and Sperman's index. The study included the evaluation of die-off coefficient K_T (d^{-1}), light extinction coefficient K (m^{-1}) and their relationships with climatic factors.

Results of the study confirm that *E. coli* removal is related to the fractions of fresh effluent remaining each day within the reservoir with MRT%FE of about 5–8 d, significantly lower than the nominal detention time (about 27 d). The *E. coli* die-off coefficient (K_T) was higher during system discontinuous operations and correlated with incident solar radiation and water temperature.

Keywords: Bacteria removal; Mean residence time; Modelling; Operational parameters; PFE; MRT%FE; Wastewater storage

1. Introduction

Wastewater reservoirs (WWRs) are particularly suitable for storage and stabilization of treated effluents and they are key-elements in all reuse systems for agricultural purposes. These hypertrophic aquatic systems contribute to the removal of refractory pollutants and pathogens and release effluents of much better quality than other alternative treatment schemes, at lower O&M costs (Juanicó, 1993, 1999). The use of storage reservoirs to regulate and transfer winter wastewater volume, cope agricultural water needs and improve their bacteriological quality, requires the selection of appropriate operational procedures to combine the need for a continuous wastewater disposal with the natural removal processes dynamics (Friedler et al., 2003).

Most completely mixed sewage treatment reactors (i.e., aerated lagoons, activated sludge, waste stabilization ponds with long residence time, etc.) are assumed to be steady-state flow systems with constant flow rate, volume and mean hydraulic residence time. The dynamics of water quality changes of these reactors are, generally, modelled using first order kinetics by the Marais (1974) approach, with predicted pollutant concentration related inversely with die-off or removal coefficient (K_T, d^{-1}) and effluent residence time (t_d) within the system. However, these reactors do not actually fulfill the ideal steady-state flow assumption, because of differences in flow rate between day and night, weekdays and weekend, summer and winter, and because of impact of storm water discharges, etc. Juanicó and Friedler (1994) developed a mathematical

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tool to analyze the hydraulic age distribution in completely mixed reactors and demonstrated that the performance of these reactors is not determined by the whole volume of effluents within the reactor but by a small fraction of fresh effluents within it. These authors calculated this small fraction and called it PFE −percentage of fresh effluents. They concluded that the mean residence time (MRT) of the whole effluents can be used for the design of steady-state reactors because MRT and PFE have an absolute correlation under ideal steady-state conditions. The PFE is a measurement of the amount of fresh effluents within the reactor, where ‘‘fresh’’ is defined in time units, i.e., PFE5 is the percentage of fresh effluents having 5 or less days (or hours, or minutes) within the reactor. PFE itself is a timeless unit (a percentage) and thus it cannot be used to implement kinetic models.

In the present paper, a new parameter derived from classical MRT but involving the concept of ‘‘fresh effluents’’ used by PFE is developed. The procedure implies the definition of the operational parameter MRT%FE that represents the mean residence time of different freshest effluent percentages (FE).

MRT%FE is herein applied to predict *Escherichia coli* concentrations in a municipal wastewater reservoir located in Eastern Sicily (Italy). The reactor was operated during the years 2004 and 2005 using different inlet/outlet flow modalities. The MRT%FE values were related inversely with microbial concentrations of treated wastewater using first order kinetics by the Marais (1974) model. In the study, the variability of die-off coefficient K_T (d^{-1}) for continuous and discontinuous reservoir operation modalities was evaluated and related to *E. coli* removal dynamics.

2. Methodology

2.1. Caltagirone reservoir

The reservoir is located at Caltagirone, a municipality of about 35,000 inhabitants in Eastern Sicily equipped with an activated sludge wastewater treatment plant (WWTP). Part of the flow, about 30 L s^{-1}, is pumped into the wastewater reservoir (WWR) and used for irrigation of citrus orchards. The WWR is built in concrete, has an area of about 2.0 ha (140 × 140 m) and maximum volume of 80,000 m^3 with a depth of 4.1 m. The system was equipped with a volumetric gauge at the inlet, an electronic flow meter with a data logger at the outlet, a refrigerated automatic sampler for composite sampling at the outlet and an integrated weather station for monitoring of air temperature, rainfall, solar radiation, air humidity, wind velocity and direction.

2.2. Measurements, sampling and analysis

Water samples were collected with a weekly or fortnightly frequency along a depth profile from 0.2 m below the reservoir surface to 0.5 m above the bottom. Sampling locations were at WWR inlet (P1), at each corner about 20 m far from the bank (P2, P3 and P4), at WWR centre (P5) and at WWR outlet (P6) (Fig. 1).

Wastewater samples at the outlet location (P6) were collected throughout 24-h with an automatic sampler, the other samples were grab. The following chemical−physical parameters were measured in laboratory according to Standard Methods (APHA, 1999): TSS (at 105 °C), BOD_5, COD, total phosphorus (TP) and total nitrogen (TN). Depth profiles of temperature, dissolved oxygen (DO), pH and electrical conductivity (EC) were measured at the selected locations (P1−P6) within the reservoir, with a portable instrument (Horiba U10). Microbiological analysis included total coliforms (TC), Faecal coliforms (FC), *E. coli*, Faecal streptococci (FC), *Salmonella* and helminth eggs (nematodes). The TC, FC, FS, and *E. coli* concentrations were analyzed according to Standard Methods (APHA, 1998); *Salmonella* according to Giammanco et al. (2002); helminth eggs according to Ayres and Mara (1996). Water samples for microbiological analyses were withdrawn at the same selected locations along the surface and the reservoir depth profile.

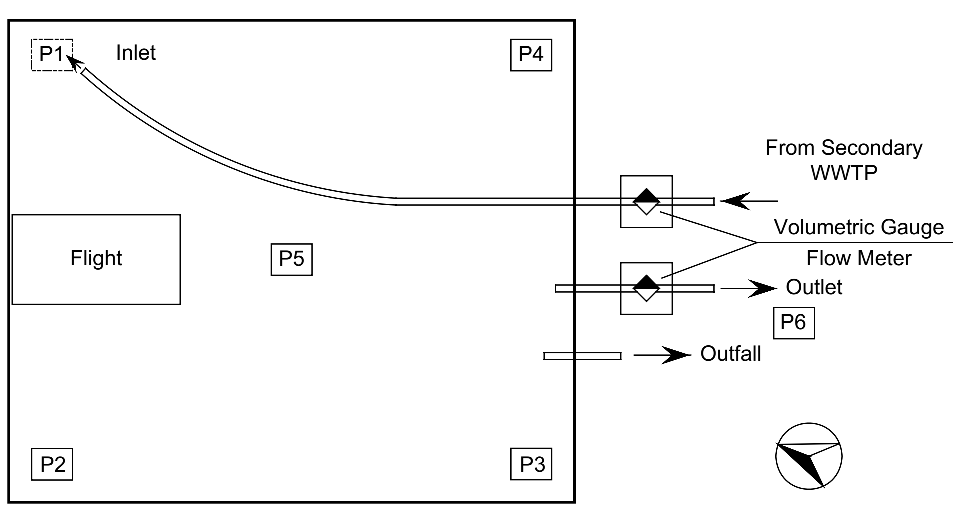

Fig. 1. Water sampling points (P1−P6) within Caltagirone WWR.