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Radiotracer investigation and modeling of an activated sludge system in a pulp and paper industry

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HIGHLIGHTS

- A radiotracer investigation was carried out in an activated sludge process system.
- RTDs of an aeration tank and secondary clarifier were measured.
- Mean hydraulic residence times and dead volumes were determined.
- The measured RTDs were simulated using suitable models.

ARTICLE INFO

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Mean hydraulic residence time
Bypassing
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Axial dispersion model

ABSTRACT

A radiotracer investigation was carried out in an activated sludge process (ASP) system of an effluent treatment plant in a pulp and paper industry. The system consists of an aeration tank and a secondary clarifier connected in series. The primary objective of the investigation was to measure mean hydraulic retention times (MHRTs) of wastewater and investigate the hydraulic performance of the ASP. Residence time distributions (RTD) of the wastewater were measured in an aeration tank and a secondary clarifier of the system using Iodine-131 as a radiotracer. The measured RTD data was treated and MHRTs were estimated. No bypassing was found to exist in the aeration tank and the secondary clarifier. However, the dead volume in the aeration tank and the secondary clarifier was found and estimated to be 2.34% and 4.6%, respectively. The treated curves were further simulated using suitable hydraulically representative mathematical models and detailed flow patterns in the aeration tank and the secondary clarifier were deciphered.

1. Introduction

Pulp and paper industry is a water intensive industry that uses water for most of its processes. Water is used in all stages of the paper production, including washing of raw materials, pulping, bleaching and operation of various machines. Water is also used for cooling of equipment, cleaning of systems and generation of steam for process use and on-site electricity production. Although most of the process water is recycled, still a significant amount of wastewater is generated during the pulp washing. The quality and quantity of wastewater generated vary according to the process adopted by specific industry (Kamali and Khodaparast, 2015; Thompson et al., 2001). The untreated effluent or wastewater contains a considerable amount of organics and toxic pollutants, which when discharged in the open atmosphere or water bodies, causes an adverse effect on human health and the environment. The adverse impact such as excessive solid accumulation, eutrophication, oxygen depletion in the receiving bodies and chemical accumulation in aquatic food web caused by discharge of wastewater from the pulp and paper industries on aquatic system has been studied and reported by many researchers (Afroz and Singh, 2014; Ali and Sreekrishnan, 2001; Andersson et al., 1988; Owens, 1991). Over the years the growing concern about the environment has led water intensive industries such as pulp and paper industry to implement necessary treatment processes to treat wastewater to predefined standards before final disposal in the open atmosphere.

Various wastewater treatment technologies comprising of a combination of primary, secondary and tertiary treatment processes are applied depending on the degree of treatment required (Bajpai, 2001). As

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the wastewater produced in the pulp and paper industry contains a substantial amount of organics, biological treatment becomes an essential part of the treatment process. Activated sludge process (ASP) developed in early 1900 remains one of the most widely used and efficient process for biological treatment of wastewater produced in the pulp and paper (Metcalf & Eddy et al., 2003). The process involves mixing and aeration of suspended microbe culture in a tank to maintain the aerobic conditions to breakdown the dissolved organic pollutants in the effluent wastewater into biomass. The biomass formed is separated from the treated effluent in a secondary clarifier (Peavey et al., 2013; Metcalf & Eddy et al., 2003). The system (aeration tank and secondary clarifier) in which the process is carried out is called as activated sludge process (ASP) system. The aeration tank used in an ASP consumes around 45–75% of the total energy required to operate a wastewater treatment plant (WWTP) in a pulp and paper industry resulting in high operating cost (Karpinska and Bridgeman, 2016; Rieger et al., 2006). Therefore, the optimum functioning of an ASP is essential both from the environmental and economic point of view.

The efficient operation of an ASP depends upon parameters of the wastewater i.e. mean hydraulic retention time (MHRT), degree of mixing (flow pattern) and occurrence of flow abnormalities within the system such as bypassing, channeling, recirculation and dead volume etc. Measurement and analysis of residence time distribution (RTD) of wastewater in the ASP can provide insight to its hydrodynamic performance. Conventional tracers such as dyes, salts and chemicals have been used to measure the RTD of wastewater and investigate flow characteristics of various systems in WWTPs (Bode and Seyfried, 1985; Burrows et al., 1999; Gresch et al., 2011; Makinia and Wells, 2005; Kjellstrand et al., 2005). However, there are many disadvantages are associated with the use of conventional tracer, such as cumbersome and manual offline monitoring of tracer data and relatively higher degree of inaccuracy in measurement and analysis. All these disadvantages are overcome by using radiotracer techniques (IAEA, 2008, 2011). Several authors have used these techniques for measurement of RTD in various systems in wastewater treatment plants (Ambrose et al., 1957; Burrows et al., 1999; Farooq et al., 2003; Debien et al., 2013; Jung et al., 2004; Kim et al., 2005; Kasban et al., 2010; Kumar et al., 2012; Makinia and Wells, 2005; Pant et al., 2000, 2009, 2012; IAEA, 2008, 2011). Although radiotracer experiments have been performed on various systems in wastewater treatment plants but the results obtained in a particular system cannot be generalized as every single system uses different raw material and process, design parameters and operating conditions. The available literature also indicates that no activated sludge process of wastewater treatment plant in pulp and paper industry has been investigated using radiotracer technique. The present paper describes a radiotracer investigation for measurement and analysis of RTD of wastewater in an ASP of a wastewater treatment plant in a pulp and paper industry with a primary objective to examine its hydraulic performance.

2. Experimental

2.1. Activated sludge process

The schematic diagram of the ASP system is shown in Fig. 1. The system consists of an aeration tank connected in series with a secondary clarifier. The aeration tank is 76 m long, 18 m wide, 4 m deep with a capacity of 5472 m^3. The effluent from a primary clarifier enters into the aeration tank with a flow rate of 5.21 ± 1% m^3/min. The aeration tank contains a predefined population of active microorganisms. These microbes consume the organic pollutants in the wastewater as a food and convert them into biomass under aerobic conditions. Dissolved oxygen (DO) concentration is maintained between 1.5 and 2.0 mg/l with the help of diffused aeration system fitted with fine bubble membranes connected to a centrifugal blower. Six mechanical surface aerators are installed in the tank to homogenize and ensure adequate

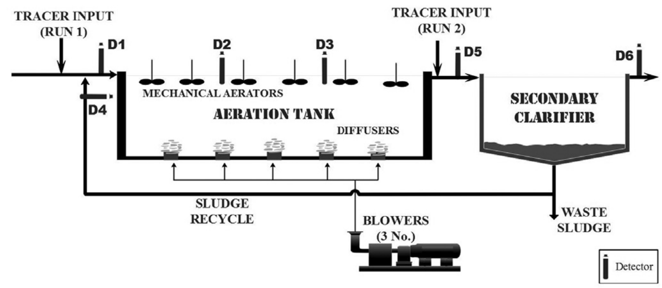

Fig. 1. Schematic diagram (front view) for radiotracer experiment in ASP system.

mixing of wastewater and air in the aeration tank. The secondary clarifier is a circular settling tank having a diameter of 18 m, height of 3.71 m and capacity of 944 m^3 with a peripheral feed mechanism. The treated wastewater from the aeration tank flows into the secondary clarifier which acts as a settling tank where biomass settles at the bottom. About 20% (1.04 m^3/min) of the under flow from the secondary clarifier is recycled back to the aeration tank to maintain the mixed liquor suspended solids (MLSS) concentration of 3500 mg/l in the aeration tank. A part of settled biomass is subsequently removed from the bottom of the clarifier and used as organic manure. The treated wastewater is obtained from the secondary clarifier overflow.

2.2. Radiotracer experiments

The radiotracer experiments were performed in an ASP meant for wastewater treatment at M/s Shreyans Paper Ltd, Ahemedgarh, India. The experimental setup is shown in Fig. 1. Stimulus-response approach was used to measure the RTD of the wastewater in the aeration tank and the secondary clarifier. Iodine-131 (half-life: 8 days, gamma energy: 0.36 MeV) as NaI aqueous solution supplied by Board of Radiation and Isotope Technology (BRIT) Mumbai, India,was used as a radiotracer to measure RTD of the wastewater. Although, Bromine-82 (half-life: 36 h and gamma energies: 0.55, 0.62, 0.70, 1.48 MeV) and Technitium-99 m (half-life: 6 h, gamma energy: 0.14 MeV) are more suitable radiotracers for tracing the wastewater in WWTPs, but in the present investigation, Iodine-131 was used because of its easy availability, ease of transportation and relatively longer half-life thus facilitating the measurements at a far remotely located wastewater treatment plant (~1700 km) from the nuclear reactor. Two different RTD runs were carried out and about 1 GBq of the radiotracer was used in each run. In first run, the radiotracer (activity: 1 GBq in volume 5 ml) was diluted in about 2 l of wastewater and instantaneously injected at the inlet of the aeration tank as shown in Fig. 1. The radiotracer was monitored at the several locations along the aeration tank and the secondary clarifier using NaI (TI) scintillation detectors D1, D2, D3, D4, D5 and D6 as shown in Fig. 1. Whereas, in the second run, the radiotracer was injected at the inlet of the secondary clarifier and monitored at the inlet and outlet of the secondary clarifier. Since monitoring locations were quite far from each other and therefore it was not possible to connect all the detectors to one common data acquisition system (DAS) due to the limited length of the detector and DAS connecting cables. Thus, the detectors were connected to two independent DASs and set to record the radiotracer concentration with a sampling time of 5 min. Both the DASs were synchronized and started at the same time to acquire the data. The background radiation levels were measured prior to conducting each run.

3. Data treatment and analysis

The measured radiotracer concentration data usually contains many undesired influences and thus needs to be treated before drawing any useful information and modeling the data. The data treatment involved, zero-shift, background correction, tail correction and normalization