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Evaluation of three full scale sewage treatment plants for occurrence and removal efficacy of priority phthalates

Khalid Muzamil Gani*, Absar Ahmad Kazmi

Environmental Engineering Group, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttrakhand 247667, India

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ABSTRACT

The study focuses on evaluation of occurrence of four priority phthalates in sewage and their removal in sequencing batch reactor (SBR), activated sludge process (ASP) and up flow anaerobic sludge blanket (UASB) reactor based full scale sewage treatment plants (STPs). Mean concentration of total four phthalates in raw sewage and secondary sludge was in the range of 35.5–46.1 μg/L and 26.1–71.8 mg/kg respectively. The concentration of phthalates in anaerobic sludge was more (71.8 mg/kg) than aerobic sludge from SBR (26.1 mg/kg) and ASP (48.4 mg/kg). Overall removal of phthalates by biodegradation and adsorption was >75% in all STPs. However, biodegradation was the main removal process. A significant portion of incoming phthalates (18–31%) was removed in primary settling tanks as well. Phthalate removal and conventional performance of STPs showed positive correlation with value of spearman correlation coefficient in the range of 0.443–0.583. The study may act as a contribution to the understanding which is required to improve the removal of phthalates or similar organic micropollutants in wastewater treatment.

1. Introduction

Phthalates or phthalic acid esters (PAE) are used as plasticizers in polyvinyl chloride (PVC) products and additives in personnel care products. These compounds are also used in floorings, paints, food packaging, car coatings and wall coverings. Exposure of these compounds have harmful effects such as cancer and endocrine disruption. Other defects such as lethargy, imbalance and respiratory arrest can also occur on their exposure [1,2]. United States Environmental Protection agency (U.S. EPA) classified few phthalates such as Diethyl phthalate (DEP), Dibutyl phthalate (DBP), Benzylbutyl phthalate (BBP) and Diethylhexyl phthalate (DEHP) as priority pollutants for their potential harmful impact in environment [3].

Phthalates get leached from their parent product during manufacturing and during their use or disposal [4]. Past studies have reported the occurrence of phthalates in domestic untreated and treated sewage [5–7]. Gao et al. [8] reported occurrence of six phthalates at three domestic sewage treatment plants in China and the concentration reported in influent and effluent samples was 23.28–88.46 μg/L and 6.95–61.49 μg/L respectively. The concentration observed in sludge was in the range of 5.074–28.135 mg/kg with maximum concentration of DEHP. Roslev et al. [9] reported their occurrence at an activated sludge based sewage treatment plant in Denmark and the concentration of four phthalates in influent and effluent was 78.25–193.82 μg/L and 5.90–17.23 μg/L respectively. The mean concentration of four phthalates in sludge was 71.78 mg/kg.

Treated effluents from these sewage treatment plants is a major source of phthalates to aquatic sources which if not addressed may have eco toxicological effects on aquatic life [8,10]. Existing sewage treatment plants were designed for organic and nutrient removal or recovery, therefore removal of phthalate like micropollutants is generally poor in such treatment plants [11–13]. Nonetheless advance treatment technologies such as advance oxidation processes, activated carbon and ozonation are effective in removal of phthalates or such toxic compounds [14–16] but the higher costs associated with their implementation make them less preferable. Therefore as an alternative, existing STPs are to be optimized for removal of phthalate like trace organics which require fate investigation of phthalates in full scale STPs. Evaluation of existing STPs may led to generation of real field data and inferences which help in identifying efficient phthalate removal processes. Previous

* Corresponding author.
E-mail addresses: khalidmzml@gmail.com (K.M. Gani), absarakazmi@yahoo.com (A.A. Kazmi).

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studies have shown that removal of phthalates in full scale STPs can vary from 60% to 100% [8,17,18]. Fauser et al. [19] reported that there is approximately 70% and 48% of DEHP and BBP degradation in a full scale STP. Dargnat et al. [6] found DBP, BBP and DEHP are approximately removed by 80%, 97% and 78% respectively in a primary aeration nitrification based plant. Gao et al. [8] found removal of DEP, DMP and DBP as 90–100%, 63–100% and 53–85% respectively in three full scale nutrient removal based STPs.

Conventional activated sludge process, sequencing batch reactor (SBR) and up flow anaerobic sludge blanket (UASB) with natural process as post treatment are among commonly adopted sewage treatment technologies [20,21]. Among aerobic suspended growth processes, ASP is the most promising technology designed usually for carbonaceous removal. Cyclic activated sludge process in the form of SBR is a modified form of ASP which operates in a fill and draw manner. Among anaerobic processes of wastewater treatment UASB has been recognized as appropriate technology for its simplicity in construction and operational costs [22]. However, the effluent of UASB reactor usually does not met the discharge standards and are therefore coupled with post treatment of final polishing units [21]. Conventional ASP and SBR based treatment plants exist in developing as well as developed countries while as UASB with polishing units as post treatment is mostly adopted in developing countries like India [23]. These sewage treatment technologies have been well studied for organic and nitrogen removal. But little is known about fate of phthalates in these technologies. Therefore the objective of this research was investigation of occurrence level, and removal of phthalates in SBR, ASP and UASB technology based STPs. Samples in between the sewage treatment line were analyzed to determine the removal efficiency of phthalates in various treatment units. Mass balance approach was used to determine the contribution of removal mechanisms involved in removal of phthalates. The phthalates selected for the study were DEP, DBP, BBP and DEHP which are enlisted as priority phthalates by U.S. EPA. Their properties and structures are shown in Table S1.

2. Material and methods

2.1. Chemicals

All standard solutions of phthalates were purchased from Sigma Aldrich (Germany) with purity 99.5%. Solvents (*N*-Hexane, Dichloromethane and acetone) used for the extraction of phthalates were purchased from Merck (Mumbai, India). Distill water from Milli-Q Advantage A10 system (Millipore, USA) was used for cleaning of glassware.

Table 1
Design and operational parameters of 27 MLD SBR, 18 MLD ASP and 38 MLD UASB.

Parameter	Details
27 MLD SBR	
Design capacity ($m^3 d^{-1}$)	27000
Operating capacity ($m^3 d^{-1}$)	27000
Dimensions of primary clarifier (m)	24 Diameter × 3 m Depth
Number of primary clarifiers	2
Basin size (m) and number	Area – 39 × 19.5; Side water depth (SWD) – 4.1 m and 4 in number
HRT (hours)	11
MLSS of basin ($mg L^{-1}$)	5205 ± 1807
MLVSS of basin ($mg L^{-1}$)	1641 ± 515
Cycle time (hours)	3
Filling and aeration time	1.5 h per cycle
Settling time	0.75 h per cycle
Decanting time	0.75 h per cycle
Effluent disposal	River Ganga
18 MLD ASP	
Design capacity ($m^3 d^{-1}$)	18000
Operating capacity ($m^3 d^{-1}$)	18000
Dimensions of primary clarifier (m)	15 m Diameter and 0.785 m Depth
Number of primary clarifier	3
Aeration tank size (m) and number	Area – 15 m × 15m; SWD – 4.8 m and 3 in number
HRT in aeration tank (hours)	4.3
MLSS of Aeration tank ($mg L^{-1}$)	3228 ± 276
MLVSS of Aeration tank ($mg L^{-1}$)	1516 ± 166
Return sludge recycle ratio	0.5–0.6
Dimensions of secondary clarifier	Diameter – 19.5 m; Depth – 3.5 m
Number of secondary clarifier	3
Dimension and number of sludge thickener	Diameter – 11.4 m; Depth – 3 m and 02
Number of Sludge digesters	2
Number of Gas collectors	4
Dimensions of sludge drying beds and numbers	Area – 35 m × 24 m; Depth – 0.25 m and 12
Sludge Disposal	Agricultural land
Effluent Disposal	River Ganga
38 MLD UASB	
Design capacity ($m^3 d^{-1}$)	38000
Operating capacity ($m^3 d^{-1}$)	38000
Dimensions of UASB and number	28 m × 24 m × 6.05 m and 4 numbers
HRT of UASB (hours)	10.2
Volume of Polishing pond and number	38000 m^3 total and 2 numbers,
HRT of Pond (hours)	24
Dimensions of sludge drying beds and numbers	25 m × 14 m each and 20 numbers
Disposal of treated sludge	Agricultural land
Treated effluent disposal	River Dhamola