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A comparison between extended aeration sludge and conventional activated sludge treatment for removal of linear alkylbenzene sulfonates (Case study: Kermanshah and Paveh WWTP)

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ABSTRACT

Linear alkylbenzene sulfonates (LASs) are anionic surfactants with extensive application as detergents. Discharge of wastewater containing these chemicals results in negative environmental impacts. In the present study, the process performance of an extended aeration activated sludge (EAAS) system in Paveh's wastewater treatment plant (WWTP) and a conventional activated sludge (CAS) system in Kermanshah's WWTP removing LAS and chemical oxygen demand (COD) were compared. The amounts of LAS removal in the CAS and the EAAS systems were calculated as 93.73 and 96.7%, respectively. It was concluded that EAAS system may be used for treating municipal wastewater with better LAS, COD, and total suspended solids (TSS) removal efficiency compared with CAS system.

Keywords: LAS; Wastewater treatment; Conventional activated sludge; Extended aeration

1. Introduction

Surfactants are used extensively throughout the world, with their application rising gradually; the worldwide production of surfactant in years 1984, 1987, 1995, 2007, and 2008 was 1.7, 1.8, 9.3, 10, and 13 million tons, respectively [1–3]. They constitute a diverse group of chemicals designed to have cleaning or solubilisation properties. They generally consist of a polar head group (either charged or uncharged), and a nonpolar hydrocarbon tail. Hence, surfactants combine hydrophobic and hydrophilic qualities in one molecule. With these properties, these chemicals are greatly used in household cleaning detergents, personal care products, textiles, paints, polymers, pesticide formulations, pharmaceuticals, mining, oil recovery, and pulp and paper industries [4]. They have the potential for broad-scale release into aquatic and terrestrial environments. There are two main ways for surfactants to enter the environment: (i) effluents from sewage treatment facilities which enter rivers and (ii) municipal sludge used on agricultural lands [5]. They have harmful impacts on human, fish, and vegetation; they give rise to foams in rivers and effluent treatment plants and reduce the quality of

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water. Moreover, they can be held responsible for short- and long-term changes in the ecosystem. For these reasons, many environmental and public health regulatory administrators have established firm and serious limits for surfactants as standard 0.5 mg/L for drinking water and up to 1.0 mg/L for other purposes [6]. Most of the surfactants consumed nowadays are anionic or nonionic surfactants [7]. Linear alkylbenzene sulfonates (LASs) are the most widely used anionic surfactants due to their excellent detersive properties and relatively low cost. Each year, about 2.5 million tons of LAS are produced worldwide, accounting for an estimated 28% of all synthetic surfactants [8]. Concentrations of LAS in raw wastewater (RW) have been reported in the range 2–21 mg/l [9–11]. Commercial LAS is composed of isomers and homologs, each containing an aromatic sulfonated ring attached to a linear alkyl chain consisting of 10–14 carbon atoms [12] (Fig. 1). LASs found in wastewater are removed in wastewater treatment facilities by sorption and aerobic biodegradation, hydrolysis, photolysis, and volatilization into the atmosphere [13].

Microbial activity is the main mechanism by which they are converted into completely inorganic products. This process produces CO_2, H_2O, inorganic salts, new microbial biomass, and organic compounds associated with the normal metabolic process of bacteria [14]. Biodegradation of LAS begins with oxygenation at the end of the alkyl chain; subsequently, the ring opens and the sulfonate group converts to inorganic sulfate. It is understood that aerobic systems will have an advantage over anaerobic systems, because the first stage of degradation requires oxygen [15].

In general, aerobic, anaerobic, and facultative methods or a combination of them are applied to treat the sewage. The activated sludge (AS) process is the most generally utilized biological wastewater treatment method. Depending on the design and the specific application, an activated sludge wastewater treatment plant (WWTP) can perform biological inorganic and organic substance removal [16]. Extended aeration is one of the modifications of activated sludge (AS) which has been widely used in many countries such as Iran [17], Chile [18], and Estonia [19]. This system is commonly used to treat wastewater from small communities and can accept periodic loadings without getting disturbed [17]. Table 1 shows typical design parameters of conventional activated sludge (CAS) and extended aeration [16].

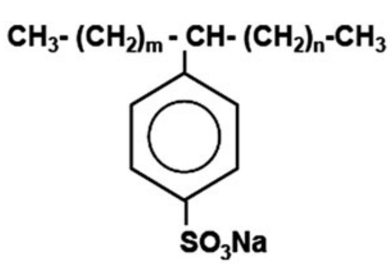


Fig. 1. Structure of 3-(4-sulphophenyl) dodecane (3-C12-LAS).

Numerous studies have addressed the efficiency of AS plants in removal of LAS; the results indicate that LAS removal in this system has been found to be mostly in 95–99.9% range [20–23]. In one study, concentrations of LAS in three types of treatment facilities in 10 US states were sampled and analyzed. The removal of LAS from four AS and five trickling filter wastewater treatment facilities averaged 99.5 and 82.9%, respectively, and the removals obtained by a rotating biological contactor were similar to those observed in the AS wastewater treatment facilities [23].

The present study was conducted in order to compare the performance of Paveh WWTP with extended aeration activated sludge (EAAS) and Kermanshah WWTP with conventional activated sludge (CAS) systems in terms of removing LAS from municipal wastewater.

2. Material and methods

2.1. Wastewater treatment plants

This study was carried out at two full-scale municipal WWTPs located in Kermanshah and Paveh (Iran) which operate with CAS and EAAS, respectively. The capacities of WWTPs in Kermanshah and Paveh are around 60,000 and 4,730 m^3/d, respectively, treating wastewater from approximately 400,000 and 20,566 inhabitants, respectively. The hydraulic residence times (HRT) are 8 and 25 h in Kermanshah and Paveh plants, respectively. The reasons for choosing these two systems with different capacities are as follows:

(1) Climatic and cultural similarities in the regions two plants are located.
(2) The influent concentration of LAS in these two plants was in the same range.

The process carried out in Kermanshah plant starts with a pretreatment (screening, aerated grit chamber, and primary settling) and followed by biological reactors (aeration tanks with plug flow), secondary settling, and chlorine contact basin. The treatment units in Paveh plant include screening, grit chamber,

Table 1
Typical design parameters of conventional activated sludge and extended aeration

Process name	Type of reactor	SRT (day)	*F/M (gCOD/gMLSS)	MLSS (mg/l)	Total, hour	**RAS (%)
Conventional plug flow	Plug flow	3–15	0.2–0.4	1,000–3,000	4–8	25–75
Extended aeration	Plug flow	20–40	0.04–0.1	2,000–5,000	20–30	50–150

*F/M = food/microorganism.
**RAS = (Return activated sludge).

biological selector, aeration tanks, secondary settling, and chlorine contact basin. Figs. 2 and 3 depict the complete process configuration of these two plants.

2.2. Wastewater samples and measurement

In the CAS system, samples were obtained from the influents of the plant (RW) and from the effluents of the primary and secondary sedimentation tanks; and in the EAAS system, samples were taken from the influent of the plant and the effluent of the sedimentation tank. Water samples were taken on a weekly basis from March 2009 to February 2010 and were analyzed for chemical oxygen demand (COD), total suspended solids (TSS), and LAS according to standard methods [24].

Grab samples were taken from the aeration tank in both systems for mixed liquor suspended solid (MLSS) sampling. The sampling was made taking into account the hydraulic retention time (HRT) of the CAS system and the EAAS system, to ensure effluent samples correspond to the same influent sample. For LAS sampling, 200 ml glass bottles previously washed with tap water were used for wastewater collection and were rinsed three times with the wastewater prior to sampling.

The samples used for the analysis of surfactants were preserved with 3% (v/v) formalin (37% formaldehyde) at the time of collection and stored for a maximum of 10 days at 4˚C until further analysis. The samples for other parameters were kept at 4˚C until analyzed (within 24 h) [24]. The statistical analysis was carried out using IBM SPSS Statistics 21.0 software package [25]. One-way analysis of variance (one-way ANOVA) was used for comparing means of LAS, COD, and TSS in two systems and bivariate correlation utilized in evaluating the degree of relationship between LAS and COD and TSS.

3. Results and discussion

As expected, sludge production was strongly increased in warmer seasons when the temperature rose in both systems. Temperatures of wastewater in

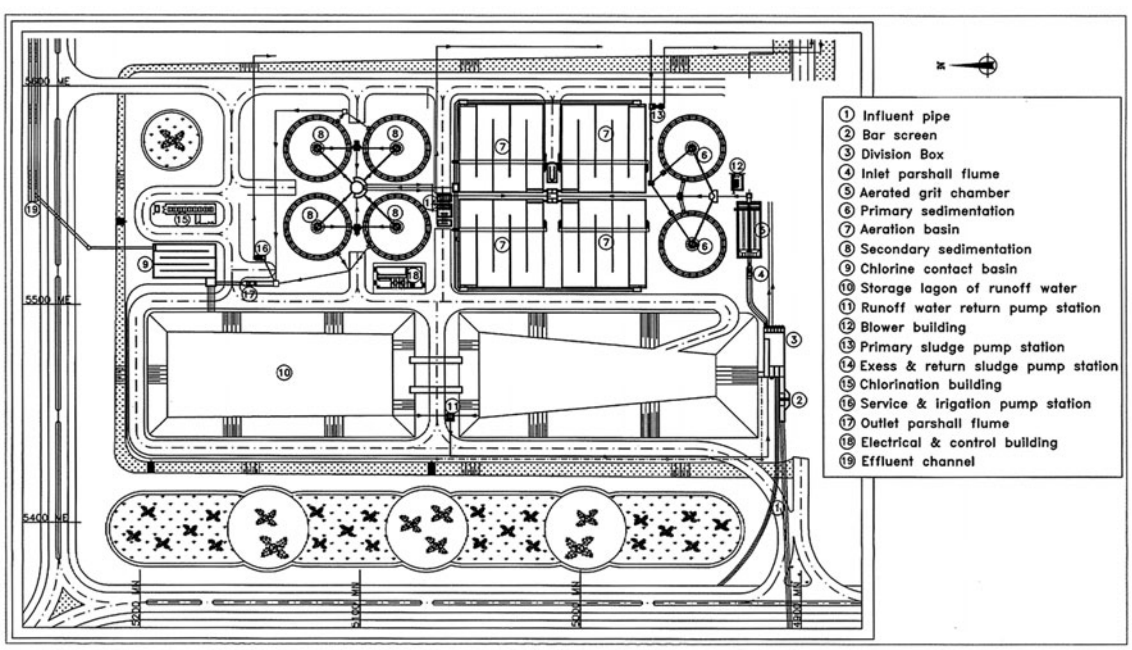


Fig. 2. Wastewater treatment in CAS plant.

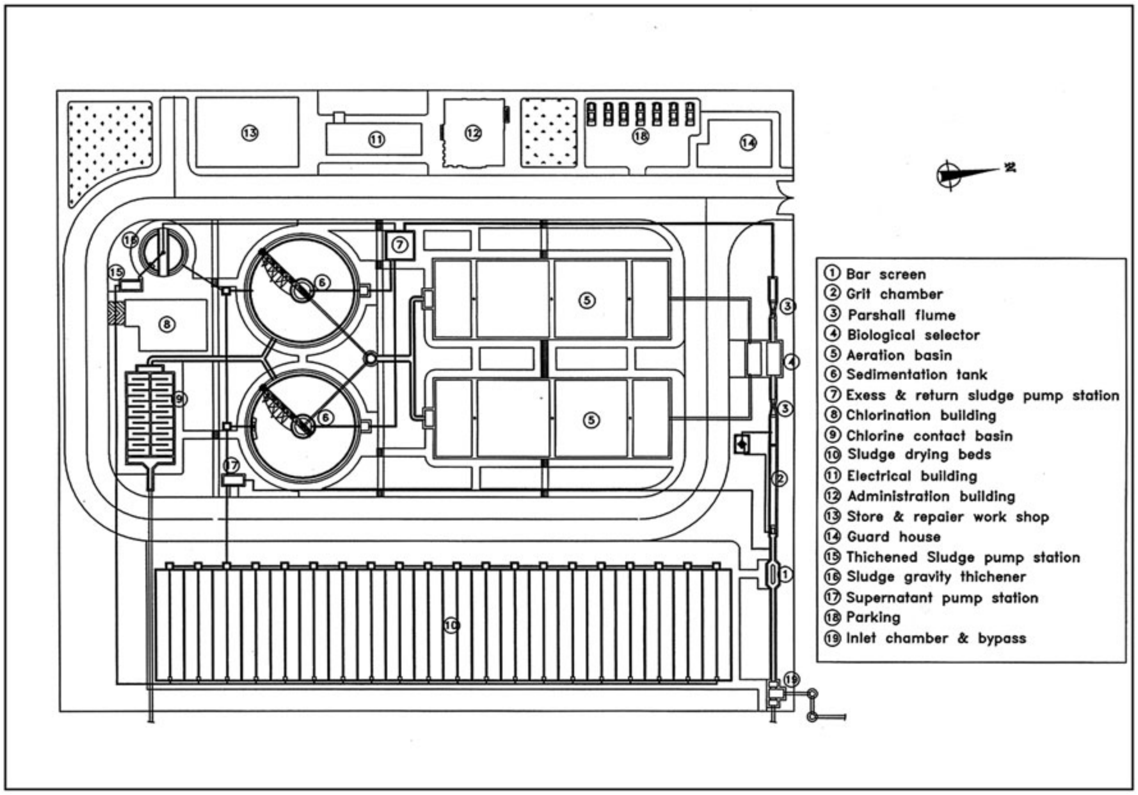


Fig. 3. Wastewater treatment in EAAS plant.

these two systems range from 12˚C in winter to 26˚C in summer. The range of mixed liquor suspended solids (MLSS) in the EAAS system was higher than the CAS system. The average and maximum values of MLSS concentration were 1,547 and 1,836 mg/L, respectively, in the CAS system, and 2,869 and 3,488 mg/L, respectively, in the EAAS system. It has been reported that in the EAAS system F/M ranged from 0.06 to 0.13 gCOD/gMLSS with an organic loading rate (OLR) 0.41–0.72 kg COD/m^3 d, while the values obtained for the CAS system were 0.13–0.21 gCOD/gMLSS and 0.37–0.54 kg COD/m^3. In this study, the average concentrations of LAS, COD, and TSS were lower in the influent of the CAS system compared with the EAAS system. The long wastewater collector (more than 10 km) in CAS system might account for this observation. Moreover in the CAS system, the primary settling have an important role in the elimination of some amount of COD, TSS, and LAS from the system. The concentrations of LAS in the influents and effluents of Kermanshah and Paveh plants in different months are presented in Figs. 4 and 5. The average values of influent LAS in Kermanshah and Paveh plants were obtained as 15.76 ± 1.59 and 16.59 ± 1.14 mg/l, respectively. The influent concentration of LAS in this study was in the same range as previous studies: 2–21 mg/l [9–11]. Elimination averages of LAS were 93.73 ± 3.41% and 96.78 ± 2.13% for CAS and EAAS systems, respectively. The amount of LAS eliminated in the primary settling through precipitation in CAS system ranging from 9 to 16% of all LAS load to the primary settler. In previous studies, the physical removal of LAS during primary settling was obtained at the range of 15–35% [21]. Other studies indicated based on mass balance: 80–90% of LAS degraded, 10–20% adsorbed onto

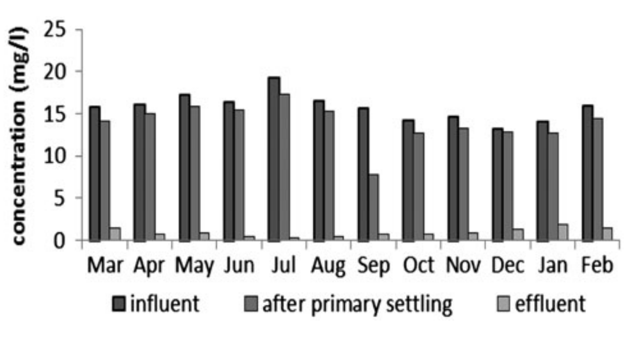


Fig. 4. Average concentrations of LAS in CAS systems in different months.

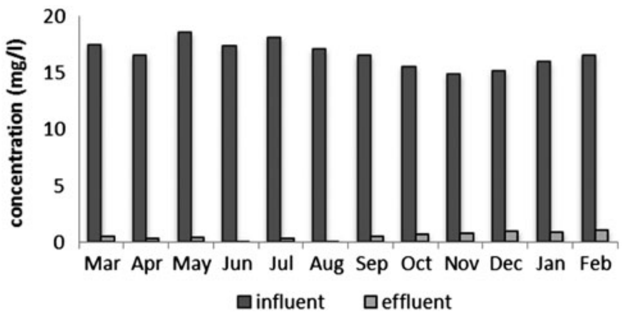


Fig. 5. Average concentrations of LAS in EAAS system in different months.

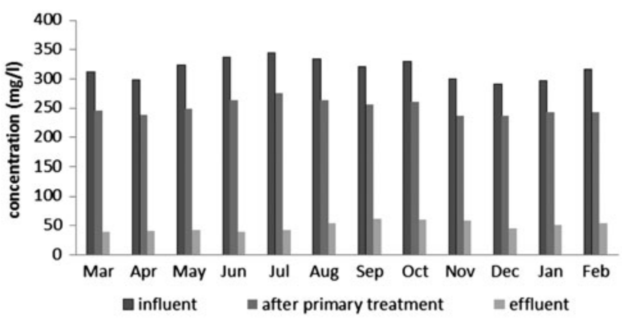


Fig. 6. Average concentrations of COD in CAS system in different months.

sludge (in primary and secondary settling), and about 1% released to surface waters [26,27].

The concentrations of COD in influent of CAS and EAAS systems were 317.33 ± 17.6 and 502.41 ± 29.49 mg/l, respectively, and the average effluent concentrations of COD for these two systems were 49.25 ± 8.11 and 52.66 ± 6.42 mg/l, respectively (Figs. 6 and 7). In addition, the removal of COD during the overall CAS and EAAS plant operation were 84.4 ± 2.6% and 89.4 ± 1.5%, respectively. In the CAS system the removal of COD in primary sedimentation was 18–23% which was in the similar range as in the previous studies [16].

The concentration of TSS is plotted in Figs. 8 and 9. The average concentrations of TSS in influent and effluent of CAS system were 138.7 ± 9.01 and 35.1 ± 4.1 mg/l, respectively. For the EAAS system, these values were 250.8 ± 12.7 and 30 ± 4.04 mg/l, respectively. Moreover, Fig. 9 illustrates the average concentration of TSS after primary settler in CAS system. The percent removal of TSS after primary sedimentation was 50–56%. The total percent removal of TSS in CAS and EAAS plants were 74.6 ± 3.1% and 87.9 ± 1.8%, respectively. Most of the amount of TSS in CAS system was removed in primary settling.

The percent removals of LAS, COD, and TSS in CAS and EAAS systems are illustrated in Figs. 10 and 11. Comparatively, the average removal efficiency of the mentioned parameters showed a statistically significant differences between the two treatment plants ($P_{\text{value}} < 0.05$).

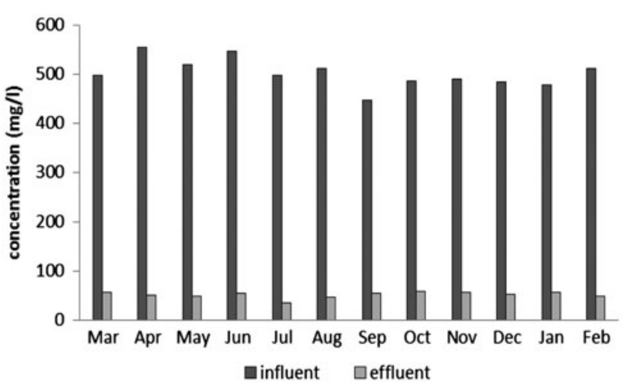


Fig. 7. Average concentrations of COD in EAAS system in different months.

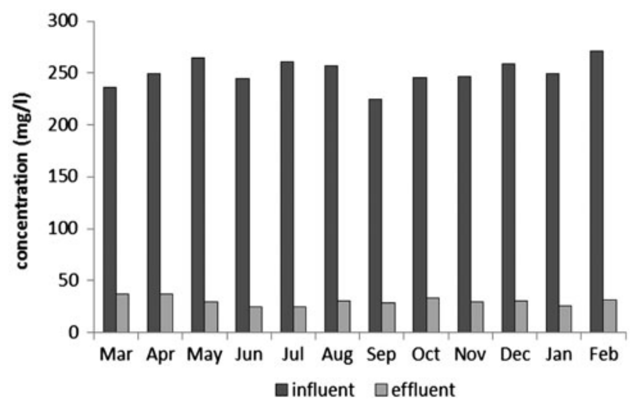


Fig. 8. Average concentrations of TSS in different months for EAAS system.

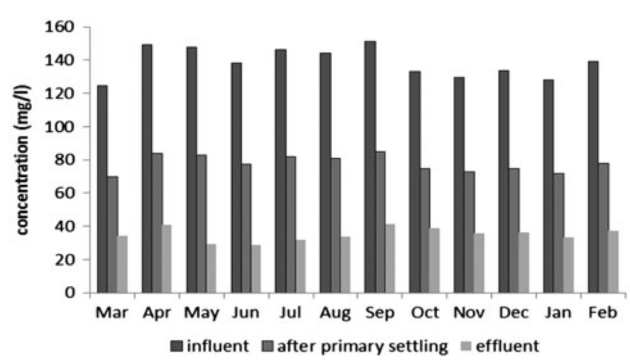
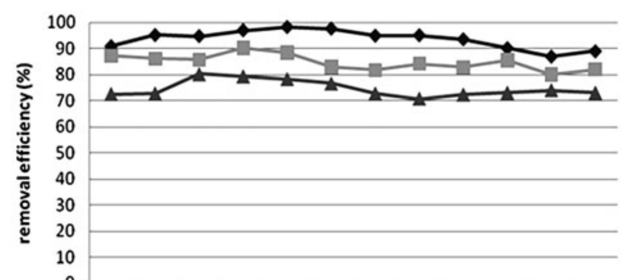


Fig. 9. Average concentrations of TSS in different months for CAS systems.

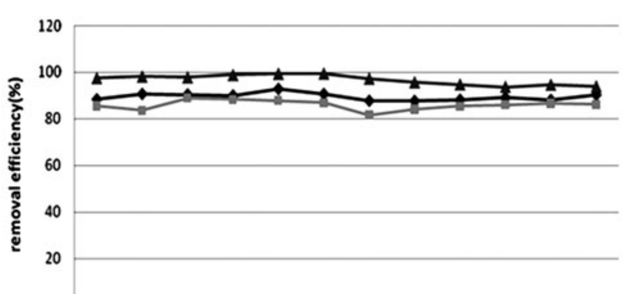
Figs. 12–15 demonstrate the correlations between the COD and TSS concentration with LAS. Significant associations were found between LAS with TSS and COD in two systems ($P_{value} < 0.05$). This may be due to adsorption of some amount of the surfactants on TSS; thus, when TSS increases, LAS and COD concentrations rise, as well. Pakou et al. stated surfactant products have a pronounced lipophilic character and are consequently absorbed onto solids readily [28]. It has been reported that 16–53% of surfactants in sewage treatment facilities adsorb onto suspended solids [29,5].

As Figs. 4–11 depicts the removal of COD, TSS, and LAS is more efficient in the EAAS system compared to CAS system. This might be due to its long sludge retention time (SRT) and high HRT. Most previous studies reported the efficiency of AS systems in LAS removal to be around 95–99% which is much higher compared with our findings [20–23].



	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
LAS	90.9	95.2	94.8	97	98.2	97.6	94.9	95.1	93.5	90.2	87	89
COD	87.2	86.1	85.7	90.2	88.4	83	81.7	84.2	82.8	85.6	80	82
TSS	72.5	72.7	80.2	79.4	78.3	76.6	72.7	70.7	72.3	73	74	73

Fig. 10. Average removal of LAS, COD and TSS in CAS system.



	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
COD	88.35	90.63	90.38	89.95	92.77	90.63	87.72	87.65	88.16	89.07	88.08	90.23
TSS	85.5	83.63	88.98	88.36	87.87	86.87	81.62	84.12	85.47	86.04	86.63	86.15
LAS	97.53	98.18	97.84	98.84	99.45	99.53	97.27	95.74	94.73	93.71	94.65	93.94

Fig. 11. Average removal of LAS, COD and TSS in EAAS system.

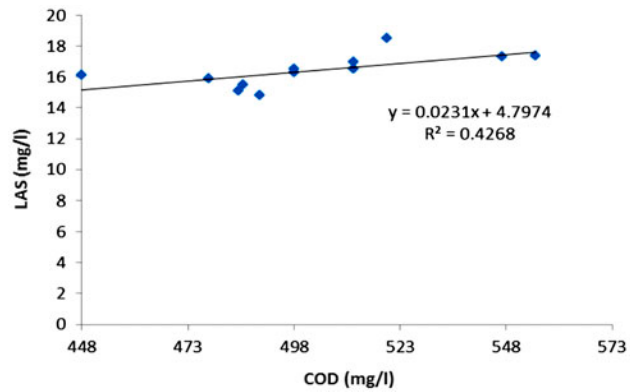


Fig. 12. Correlation between LAS and COD in CAS system.

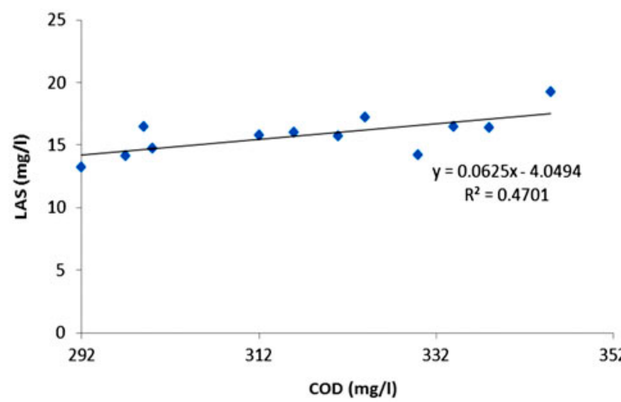


Fig. 13. Correlation between LAS and COD in EAAS system.

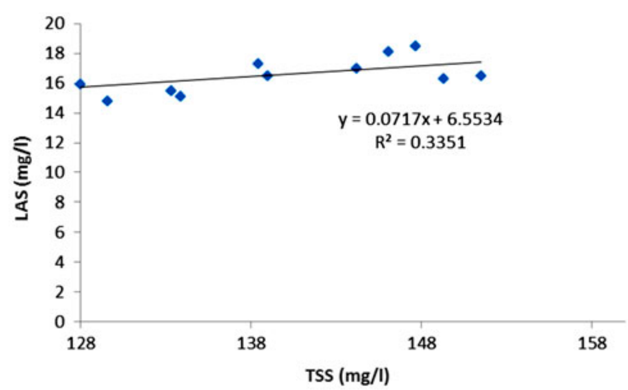


Fig. 14. Correlation between LAS and TSS in CAS system.

In one study, LAS removal in nine different sewage treatment plants averaged about 95.0–98% resulting in effluent concentration <0.2 mg/1 in domestic sewage [21]. The results of an extensive study by McAvoy showed that LAS was removed during AS (99.3 ± 0.6%), lagoon (98.5 ± 1.8%), oxidation ditch (98.0 ± 4.2%), and rotating biological contact

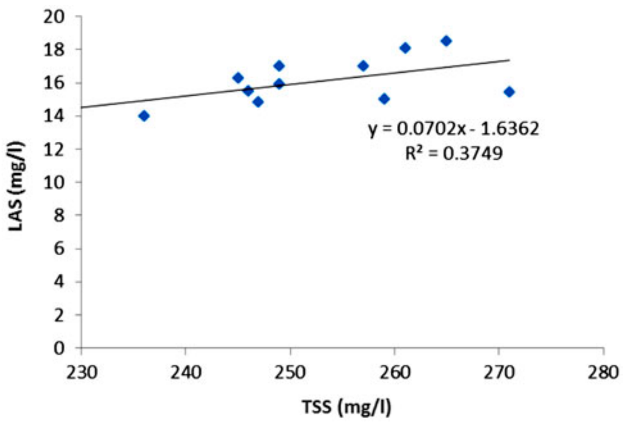


Fig. 15. Correlation between LAS and TSS in EAAS system.

(96.2 ± 6.1%) treatment with poorer removals observed at trickling filter (77.4 ± 15.5%) facilities [22].

The outcome of another study at an AS sewage treatment showed the removal of the organic load (measured as BOD) and LAS were both very high, 98% and 99.9%, respectively. Hence, very low concentrations of LAS were discharged to the treated effluent (average daily of 10.4 μg/L) [11].

Nevertheless, one study conducted in Spain reported the removal of LAS in AS system to be 92% which is lower than these two systems [30]. Although the efficiency of these two plants was not as high in most previous studies, the effluent concentrations of COD, TSS, and LAS were less than the standard values for effluent discharges made by Central Pollution Control Board (CPCB) [31].

4. Conclusion

In this study, the comparison of EAAS and CAS systems for treating municipal wastewater revealed that the EAAS system can produce an effluent with much better quality in terms of TSS and LAS. The average removal values of LAS, COD, and TSS in the CAS system were 93.73 ± 3.41%, 84.4 ± 2.6%, and 74.6 ± 3.1%, respectively, while in the EAAS system, the figures were 96.78 ± 2.13%, 89.4 ± 1.5%, and 87.9 ± 1.8%, respectively. We found statistically significant differences between the efficiency of these two systems for the removal of LAS, COD, and TSS. This investigation demonstrates that despite primary settling, the performance of Kermanshah plant (CAS system) for LAS, COD, and TSS removal was lower than that of Paveh plant (EAAS system). This might be due to long SRT and high HRT in the EAAS plant. However, further investigation is needed to generalize on the overall treatment performance of two systems (CAS and EAAS) for the removal of COD, LAS, and TSS.

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