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Original research

Anaerobic digestion for treatment of polyester wastewater with different organic loading rates (OLRs)

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Abstract:

In this work, the performance of up-flow anaerobic staged reactor (UASR) was investigated for biogas production from polyester wastewater which are contaminated with heavy metals and 1,4-dioxane. three different values of average organic loading rates (OLRs) were applied 0.31±0.037, 0.71±.082, and 1.069±0.27 g COD /1.d, respectively at constant hydraulic retention time (HRT) of 96 h, in order to study their effects on biogas production, removal efficiency of 1,4-dioxane and COD. The results indicated that the biogas production obtained at three applied OLR were 14.7 ± 0.17 l/ d. at OLR 1.069±0.27 g COD /1.d., 7.5 ± 0.2 l/ d. at OLR 0.71±.082 g COD /1.d., and of 5.5 ± 0.11 l/d at low OLR, 0.31±0.037 g COD /1.d , respectively. Biogas is produced by the metabolism of acetic acid, lactic acid, and a small amount of propionic acid. Moreover, CODt and CODs removals efficiency were 79% and 80% at OLR 0.71±.082 g COD/l.d. The highest removal efficiencies were recorded at OLR 0.71 g COD/l.d. Effect of C/N ratio and heavy metals on biogas production were highlighted. Additionally, different HRTs were studied, to carefully describe the performance of UASR.

Keywords: up-flow anaerobic staged reactor, biogas, polyester, heavy metals, 1,4-dioxane, hydraulic retention times, organic loading rates.

1- Introduction

Many factories use chemicals in their manufacture in order to ensure the quality of their products, as they contain waste that contains some chemicals and is therefore difficult to treat. The treatment of organic waste has recently received great attention, due to the potential of energy generated from this waste as well as to prevent its harmful environmental effects. (Zupančič and Grilc, 2012).

One of these factories produces unsaturated polyester resins, which require a large amount of water use; producing large quantities of wastewater containing Mono-ethylene glycol (MEG), Di-ethylene glycol (DEG), and 1,4-dioxane.

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High levels of Chemical oxygen demand (COD) in wastewater range from 130 to 150 g COD/l.d and toxic contents, in addition to low pH of 3-5, complex composition, and rarity of nitrogen and phosphorus. If this effluent of wastewater is directly released into the environment without being treated, it will negatively affect the receiving water, harm the ecosystem, and maybe endanger human health (Rott and Minke, 1999). The primary cause of wastewater treatment process disruptions is frequently heavy metals, which can be found in considerable concentrations in certain industrial wastewater and sludge (Peng et al., 2011; Fang and Chan, 1997). Depending on their concentration, heavy metals can be poisonous, catalytic, or both in biological reactions. However, a little concentration of heavy metals is required to activate a large number of enzymes and co-enzymes (Demirel and Scherer, 2011). Furthermore, overindulgence may result in toxicity or inhibition (Vallee and Ulmer, 1972). Heavy metals are not biodegradable, in contrast to many other harmful compounds, and thus tend to accumulate to potentially toxic amounts (Sterritt and Lester,1980). 1,4-Dioxane is a byproduct of the polyester industry and can be found in wastewater made of polyester. Since it is very soluble, mobile, and stable, aquatic ecosystems are thought to be negatively impacted by it. 1,4-dioxane is difficult to remove from wastewater in the environment, and there is a significant chance that surface and groundwater will become contaminated (Zenker et al., 2003). 1,4-dioxane's presence can lead to a number of health issues. For instance, it can seriously harm a person's liver and kidneys (Klečka and Gonsior, 1986).

Numerous researchers have examined polyester wastewater, and numerous polyester wastewater treatment facilities have been constructed, utilizing a blend of anaerobic-aerobic biological processes and pre-treatment techniques (Rott and Minke, 1999). Utilizing combined processes to ensure wastewater satisfies discharge standards was the subject of numerous studies. One method used to treat polyester wastewater with COD influent concentrations of 10,000–12,000 mg/l is the up-flow anaerobic sludge blanket (UASB)–hydrolytic acidification–biological aerated filter (BAF) process, which results in COD effluent concentrations of 150 mg/l (Jun et al., 2007). Additionally, a COD removal rate of 98.7% was attained by treating a polyester wastewater with a COD range of 25,000 to 30,000 mg/l using the steam extracting, anaerobic, biological contact oxidation, and air flotation process (Aijun et al., 2010). examination of the interior microelectrolysis-anaerobic-aerobic process's ability to treat wastewater from polyester, along with a comparison between it and the anaerobic-aerobic process. Combining anaerobic and aerobic technologies with interior microelectrolysis has resulted in high COD removal efficiencies (Yang, 2009). Polyester wastewater was investigated for treatment using chemical oxidation with H_2O_2 and biological treatment of activated sludge process with low organic loading. The biological treatability study's findings showed that, if the system was fed with 1/100 diluted raw wastewater, 80% COD removal could be achieved with a 10-day retention period. 70% of COD was removed from raw wastewater by chemically oxidizing it with H_2O_2 in an acidic environment while utilizing ferric chloride as a catalyst. But in order to achieve this efficiency, roughly 1 kg of H_2O_2 per m^3 of wastewater was needed (Meric, 1999). Anaerobic treatment's pollution reduction contributes to environmental impact values that can be taken into account in cost-benefit analysis.

Heavy metal which came from industrial wastewater have a significant impact on anaerobic digestion (Huang et al.,2022). Anaerobic digestion is mainly used as initial treatment and thus has the highest exposure to heavy metals (Kadam et al., 2022). Additionally, heavy metals have significant effects on biochemical processes. Depending on their concentration, heavy metals can either stimulate or inhibit biochemical reactions, or even be toxic (Oleszkiewicz and Sharma, 1990). Metal ion toxicity in biological treatments can be quantified using a variety of techniques.

As well as the kinetics of bacterial activity, respiratory activity, enzymatic activity inhibition, and the dynamics of microbial community evolution (Mata-Alvarez et al., 2000; Bayer et al., 2007; Cirne et al., 2007). This is mostly because heavy metals chemically bind to enzymes and microbes, disrupting the structure and functions of the enzymes (Brady and Duncan, 1994; Li and Fang.,2007; Wani et al.,2012). They can form non-specific compounds at relatively high concentrations, which can have cytotoxic effects and change the ideal biochemistry and process performance (Kavamura and Esposito, 2010). Regarding, it has been demonstrated in earlier research that advanced oxidation techniques, such as the Fenton process, ozone, electrochemical oxidation, and others, can be used to analyze 1,4-dioxane in wastewater (Klečka and Gonsior, 1986). According to recent research, 1,4-dioxane can be biodegraded using both pure and mixed cultures. Lee et al, (2022) found that 1,4-dioxane could be broken down in a mixed biological culture cultivated on textile wastewater sludge using CSTR and PFR reactors. Moreover, biodegradation of 1,4-dioxane in bioreactors, biofiltration systems, and biosparging systems has shown that 1,4-dioxane bioremediation is feasible (Tag and Mao., 2023). Compared to other conventional techniques, biological approaches to treatment have a number of advantages, including being less costly, environmentally friendly, simple and safe to operate, and non-sludge producing (Singh et al., 2022).

The objectives of this research are to: (1) evaluate the effectiveness of anaerobic treatment as modeled by the up-flow anaerobic staged reactor (UASR) for treating wastewater containing polyester; (2) examine the impact of heavy metals and the C/N ratio on the rate at which biogas is produced; (3) examine the impact of the loading rate of 1,4 dioxane on the removal efficiency of 1,4 dioxane; and (4) Examining UASR's performance at various HRT.

2. Materials and methods

2.1 Characteristics of polyester wastewater

In the fourth industrial zone of Borg El Arab, Alexandria, wastewater made of polyester is collected from the chemical industry and used to produce unsaturated polyester resin. Polyester wastewater is categorized as soluble and high strength wastewater, and Table 1 shows its characteristics.

2.2 Lab scale UASR reactor

A schematic diagram for UASR is shown in Fig. 1. The UASR has a 42 L volume. The material used to manufacture the UASR reactor was Perspex, and it had a pyramid-shaped bottom. The UASR measured 90 cm in height, 22.5 cm in width, and 22.5 cm in length. The first sludge to be added to the UASR came from the EL Ajami wastewater treatment plant in Alexandria. Sludge concentrations for TS and VS were 45 g/l and 33 g/l, respectively. 15 L, or roughly 33% of the reactor's total volume, of sludge were initially added to the UASR reactor. The reactor had inclined baffles along its height to allow increasing contact time between bacteria and influent substrate. There were five ports along the height.

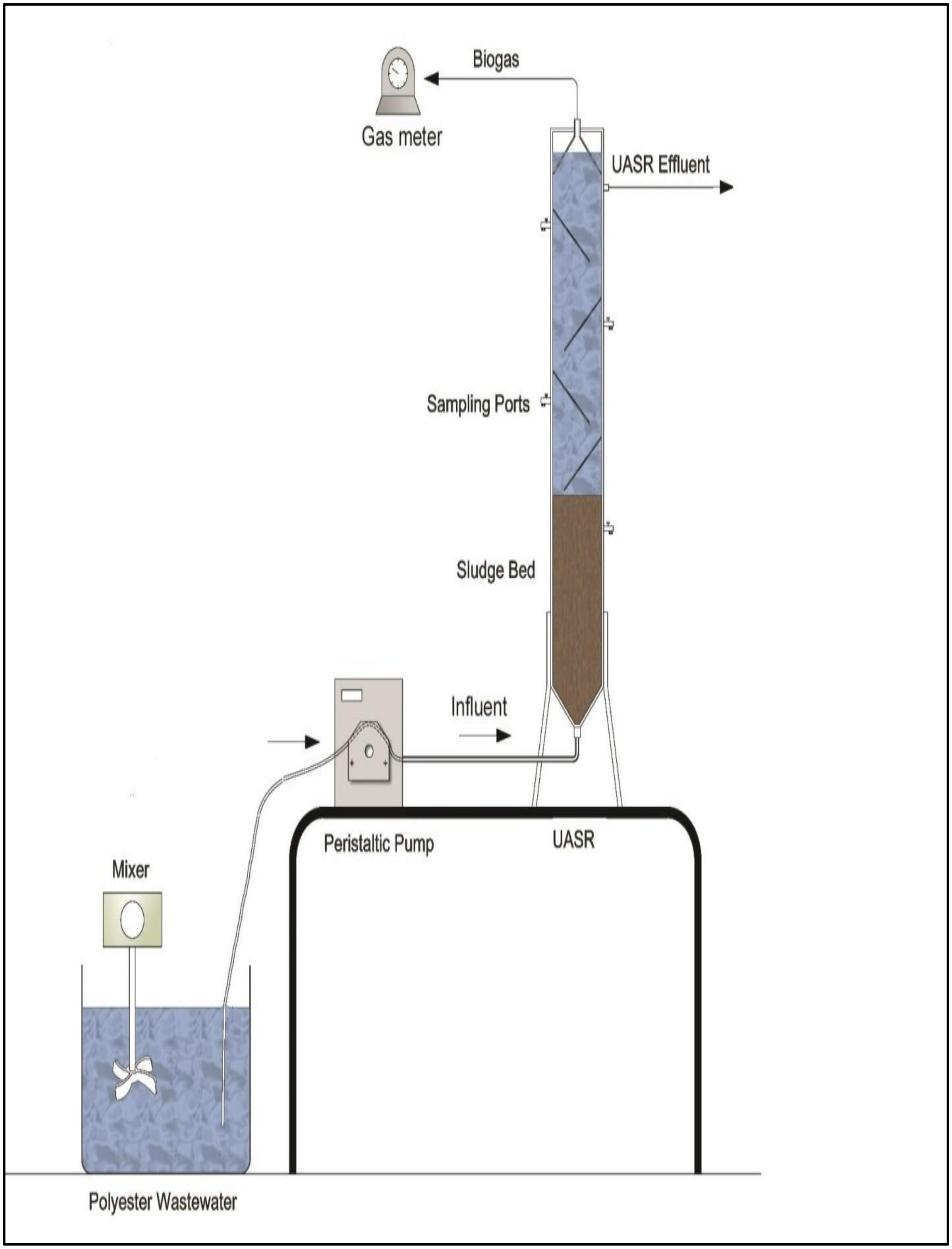


Fig. 1. Up-flow anaerobic staged reactor schematic diagram (UASR)

Table. 1 Main characteristics of polyester wastewater

Polyester wastewater	Values
pH	2.33 ± 0.25
COD_t (mg/l)	142666.67 ± 11015
COD_s (mg/l)	141990.33 ± 14199
Carbohydrate (mg/l)	5472.08 ± 464.65
Ammonia (mg/l)	660.28 ± 40.002
TKN (mg/l)	1597.42 ± 240.13
TSS (mg/l)	830 ± 26.45
VSS (mg/l)	750 ± 15.28
1,4-Dioxane (ppm)	100.4715 ± 12.06
OLR 0.3 g COD/l.d	
pH	6.99 ± 0.61
COD_t (mg/l)	1205.75 ± 147.32
COD_s (mg/l)	1160.33 ± 160.77
Carbohydrate (mg/l)	51.89 ± 15.11
Ammonia (mg/l)	6.33 ± 1.92
TKN (mg/l)	13.44 ± 3.77
TSS (mg/l)	9.85 ± 2.89
VSS (mg/l)	7.83 ± 2.55
1,4-Dioxane(ppm)	1.17 ± 0.14
OLR 0.7 g COD/l.d	
pH	6.93 ± 0.66
COD_t (mg/l)	2839.17 ± 328.78
COD_s (mg/l)	2744.33 ± 320.41
Carbohydrate (mg/l)	132.64 ± 28.26
Ammonia (mg/l)	16.49 ± 2.17
TKN (mg/l)	36.45 ± 2.94
TSS (mg/l)	16.30 ± 3.74
VSS (mg/l)	13.80 ± 3.65
1,4-Dioxane (ppm)	2.03 ± 0.18
OLR 1.1 g COD/l.d	
pH	7.62 ± 0.19
COD_t (mg/l)	4275.62 ± 228.09
COD_s (mg/l)	4187.01 ± 149.83
Carbohydrate (mg/l)	333.38 ± 18.86
Ammonia (mg/l)	31.89 ± 1.92
TKN (mg/l)	81.27 ± 4.62
TSS (mg/l)	48.20 ± 11.35
VSS (mg/l)	42.30 ± 7.19
1,4-Dioxane (ppm)	4.54 ± 0.49

2.3 Operation condition

In order to lessen the harmful effects of the high COD (150g/l) and the toxicity of the polyester wastewater, the UASR system was continuously run and fed with wastewater made of polyester at constant HRT for four days. Average OLR of 0.31, 0.71, and 1.069 g COD /1.d were adjusted by using tap water. A 300:5:1 COD: N: P ratio had been used to supply potassium dihydrogen phosphate (KH_2PO_4) and ammonium chloride (NH_4CL) (Aiyuk et al., 2004). Supplementing nutrients is crucial for improving bacterial growth (Sreethawong et al., 2010) due to a low PH Prior to feeding the wastewater made of polyester, the PH was adjusted using $NaHCO_3$. Table 2 lists the operational conditions.

Table. 2 The UASR's operational state

Parameters	UASR
Up-flow velocity. m/h	0.0095.
Flow rate (Q) m^3/d	0.00048
Organic loading rate (OLR), g COD/l.d	0.31,0.71,1.069

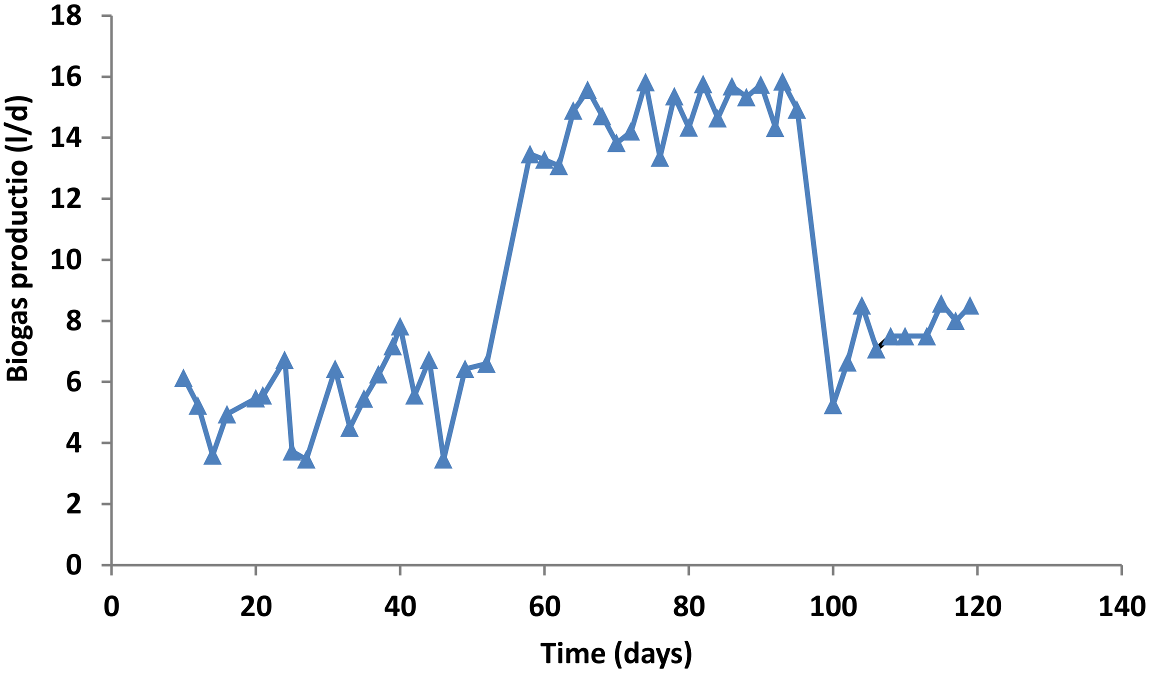
2.4 Analytical methods

Analysis was performed three times per week on raw wastewater samples and effluent from the UASR system: Analysis included pH, COD total, heavy metals, and volatile fatty acids (VFAs) in terms of acetate (HAc), butyrate (HBu), and propionate (HPr). Raw samples were used to determine CODtotal and 0.45μm membrane filtered samples were used for the determination of CODsoluble and heavy metals. All analytical procedures were measured according to APHA (APHA,1998). High performance liquid chromatography was used to analyze VFAs in terms of acetate (HAc), butyrate (HBu), and propionate (HPr) (LC-10AD, Shimadzu, Japan). The column oven had a temperature of 40°C. 4 mM H_2SO_4 was used as the mobile phase, with a flow rate of 0.5 ml min^{-1} for 22 min and 0.4 ml min^{-1} for 8 min. A wet gas meter was used to measure the produced gas during the study period. The HPLC and GC analysis processes were carried out in accordance with Nasr and Elsamadony's prior descriptions (Nasr et al., 2015; Elsamadony et al., 2015). A PerkinElmer Model Analyst 200 atomic absorption spectrophotometer (AAS) was used to measure the concentrations of heavy metals which included in polyester wastewater as (Cr, Cu, Fe, Mn, and Ni). In order to prevent metal precipitation and adsorption onto surfaces, liquid samples were first filtered through a 0.45 μm cellulose acetate syringe filter (Sigma Aldrich, USA). The filtrate was then acidified with concentrated nitric acid (pH < 2) and examined for residual heavy metals.

3. Results and discussion

3.1. Biogas production and COD removal efficiency

Biogas production at various organic loading rates (OLRs) is displayed in Fig. 2a. According to the available data, the average biogas production value increased significantly from 7.5 ± 0.2 to 14.7 ± 0.17 l/d, while the OLR decreased from 1.1±0.3 to 0.7±.03 g COD /1.d., respectively. At 1.1±0.3 g COD/1.d, the hydrogen consortium bacterium was predominant. Nonetheless, UASR yielded an average biogas production of 5.5 ± 0.11 l/d at low OLR of 0.3±0.04 g COD /1.d. As the OLR increased from 0.3±0.04 to 0.7±.01 and from 0.7±0.01 to 1.1±0.3 g COD/1.d, respectively, the organic removal rate (ORR) increased from 0.15 ± 0. 1 to 0.6 ± 0.1 g COD/l.d. and decreased from 0. 6 ± 0.1 to 0.03 ± 0.02 g COD/l.d. However, on day 100, the presence of high concentrations of heavy metals in the influent wastewater and a high concentration of 1,4 dioxane in the influent caused a significant drop in the rate of organic removal and biogas production.



The removal efficiency of CODt and CODs at different OLR are depicted in Fig. 2c and d. CODt and CODs removal efficiency was 49.2±10. 7 and 50 ± 11.6% respectively at OLR of 0.31±0.04 g COD/l.d., and increased up to 79.3 ± 5.5% and 80.1 ± 5.6 % with increasing the OLR up to 0.7±.09 g COD/l.d. However, the removal efficiency of CODt and CODs dropped dramatically to the minimum value of 2.3±3.21% and 2.6 ± 0.33% at OLR of 1.069 ± 0.27 g COD /1.d.

Fig. 2a. Biogas production by UASR at different OLR

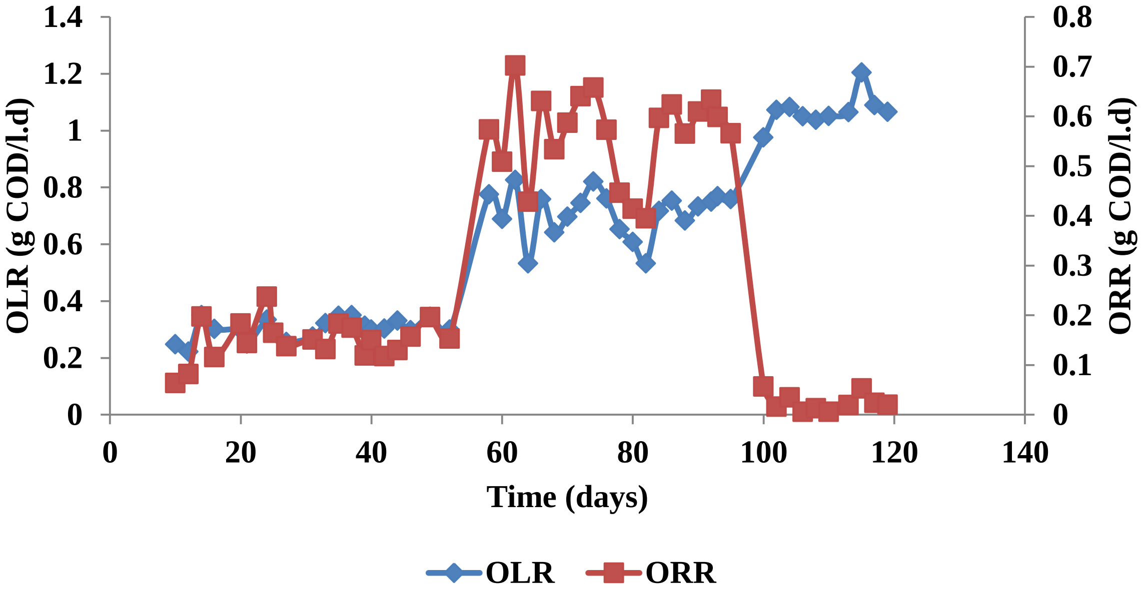


Fig. 2b. Organic loading versus removal rate

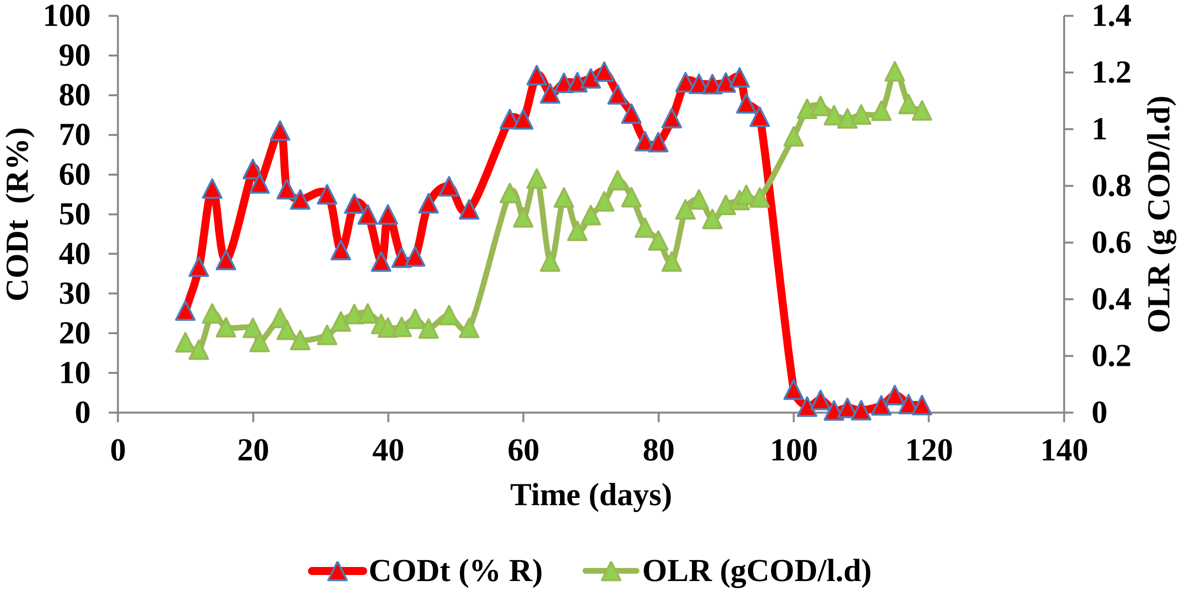


Fig. 2c. CODt removal efficiency at different OLRs

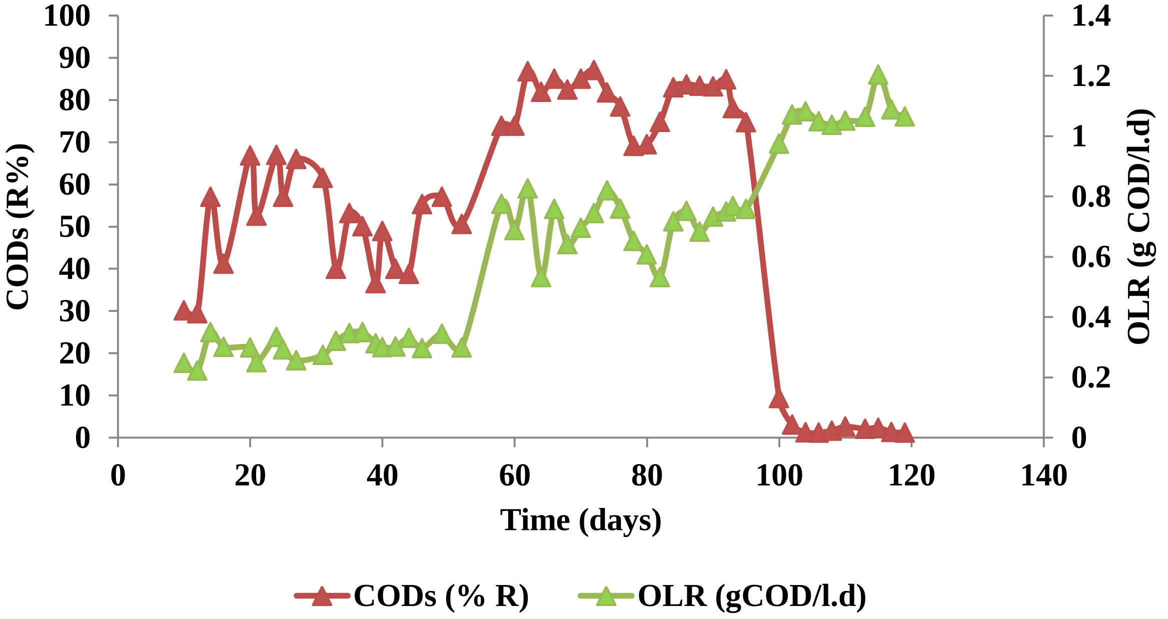
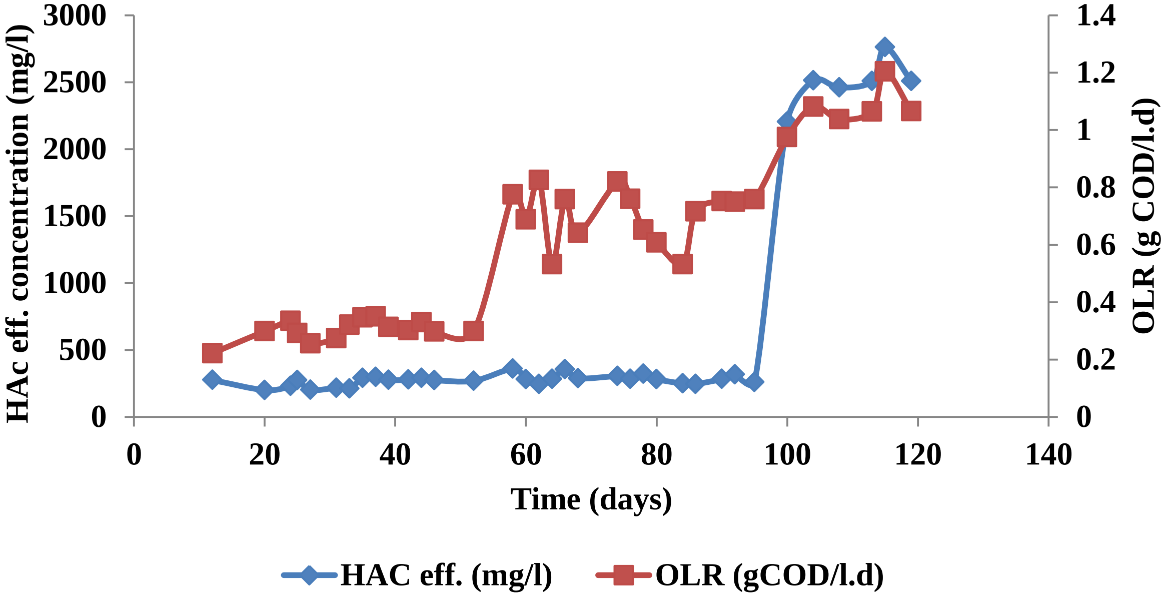
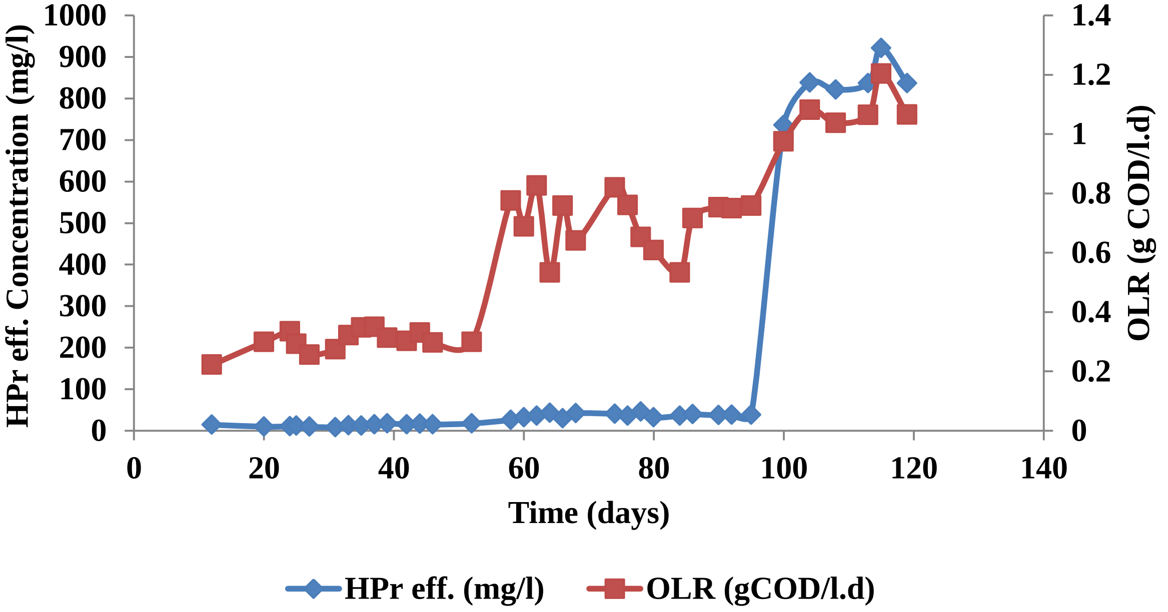


Fig. 2d. CODs removal efficiency at different OLR

The results presented in Figs. 3 shows the effect of OLR on the conversion efficiency of VFAs as., HAc, HPr, and HLa. The data revealed that increasing the OLR from 0.31±0.037 to 0.71±.082 gCOD /1.d., positively affected the conversion efficiency of HAc, where the removal efficiency was increased from 57.96 ± 1094% to 78.81 ± 11.56%, respectively. Nevertheless, increasing the OLR from 0.71±.082 to 1.069±0.27 g COD/l.d., provided an accumulation of HAc in the treated effluent. Similar trends were observed for the consumption of HPr. The HPr conversion efficiency was substantially increased from 63.6 ± 6.65% to 69 ± 9.85%, by increasing the OLR from 0.31±0.037 to 0.71±.082 g COD/l.d. Further increasing the OLR up to 1.069±0.27 g COD/l.d., leads to accumulate the HPr concentration in the treated effluent. An amount of 42.51 ± 8.77% of HLa was removed at OLR of 0.31±0.037 g COD/l.d. Also, increasing the OLR from 0.71±.082 to 1.069±0.27 g COD/l.d., led to increase of removal efficiency from 46.9 ± 7.62% to 72.1 ± 2.34%. This indicates that the conversion efficiency of the mixtures of VFAs strongly depends on the imposed OLR. Moreover, each organic acid had its optimal OLR. Similar findings were reported by Lo et al., (2011).





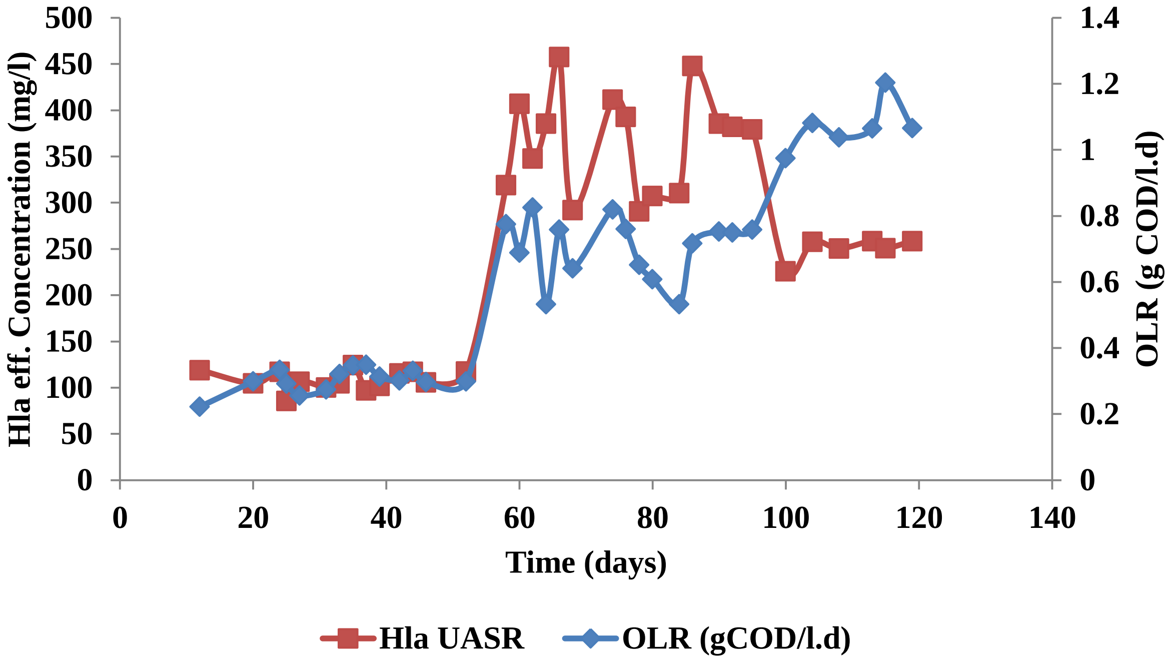


Fig. 3. Effect of organic loading rate on the production of volatile fatty acids

3.2. Effect of C/N ratio and heavy metals on biogas production

The C/N ratio was determined to be an important parameter for biogas production (Demirel and Scherer, 2011). The results in Figs. 4a show that the biogas production rate increased continuously until it reached its maximum peak 0.35 ± 0.03 l/l.d at C/N ratio of 78.31 ± 10.48 , followed by a constant decline, until production decreased completely at day 100 and a C/N ratio of 52.71 ± 3.29 (R^2= 0.9541). Similar findings were made by Nurliyana et al. (2015), who discovered that the effect of carbon to nitrogen (C/N) ratios towards facultative co-digestion of palm oil mill effluent (POME) and empty fruit bunches (EFB) increased with increasing C/N ration until C/N ratio 45, then decreased with increased C/N ratio (Nurliyana et al., 2015).

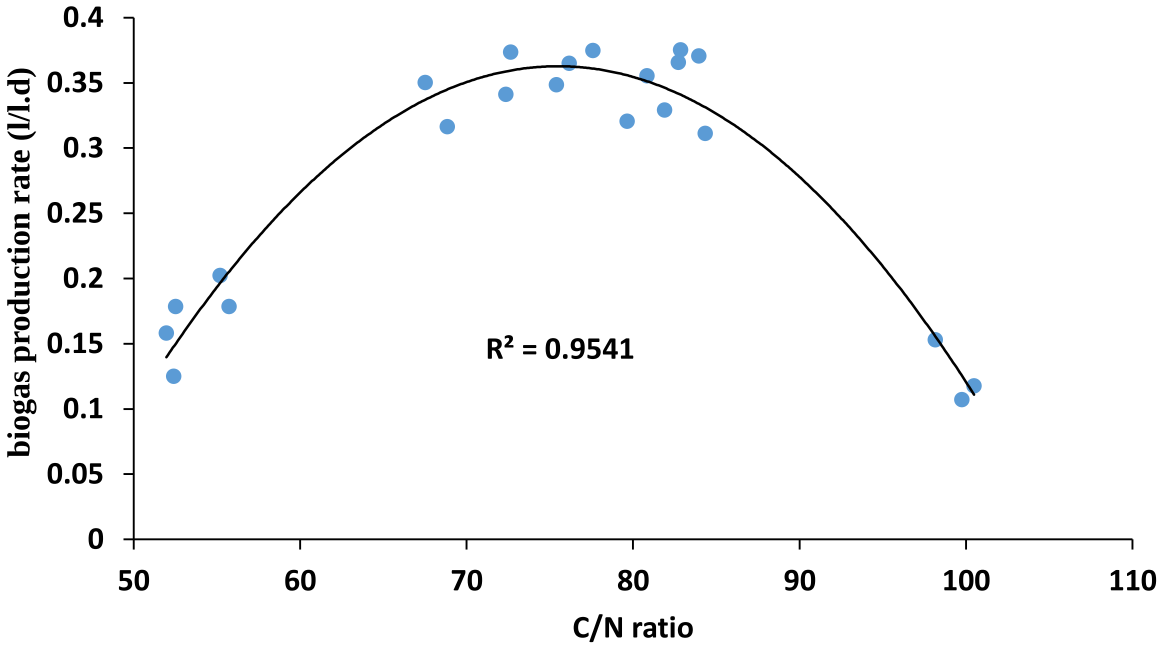


Fig. 4a. Coloration between C/N ratio and biogas production rate

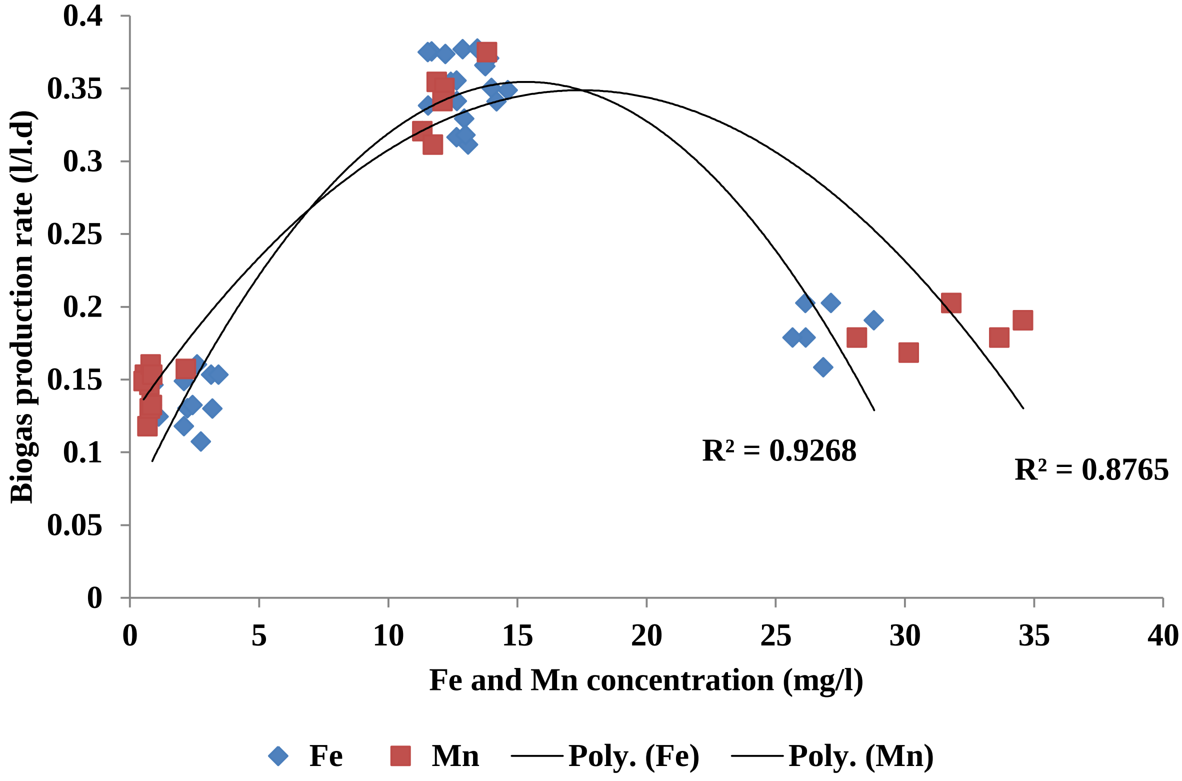


Fig. 4b. Effect of Fe and Mn concentration on biogas production rate

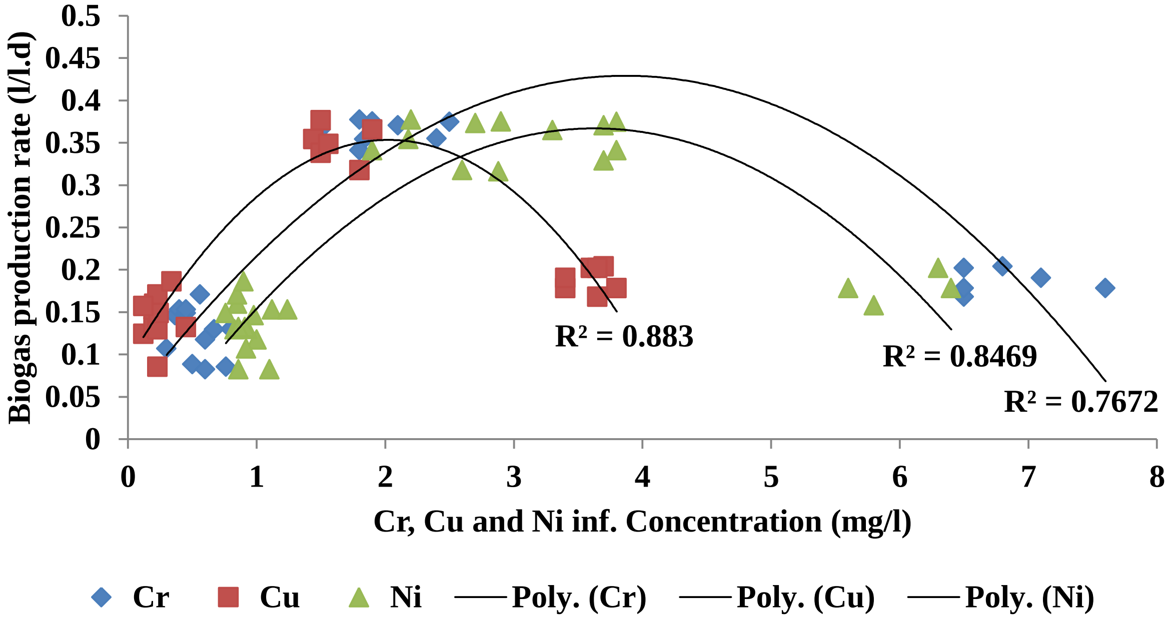


Fig. 4c. Effect of Cr, Cu and Ni concentration on biogas production rate

Figs. 4b and c display the biogas production rate at different concentrations of heavy metals (Fe, Mn, Cr, Cu, and Ni), respectively. The biogas production rate was noticeably increased from 0.132 ± 0.05 to 0.35 ± 0.03 l/l. d at increasing the concentration of heavy metals as, Fe from 2.23 ± 0.79 to 12.81 ± 1.04, Mn from 0.71 ± 0.11 to 5.34 ± 4.48, Cr from 0.536 ± 0.22 to 1.48 ± 0.72, Cu from 0.249 ± 0.12 to 1.36 ± 0.96, and Ni from 0.918 ± 0.15 to 3.18 ± 0.99 mg/l. This may be the result of numerous enzymes and co-enzymes activating or functioning in the presence of low concentrations of heavy metals (Demirel and Scherer , 2011). Nonetheless, there was a noticeable drop in the rate of biogas production rate from 0.35 ± 0.03 to 0.179 ± 0.02 l/l.d at increasing concentration of heavy metals by Fe from 12.81 ± 1.04 to 25.73 ± 2.58, Mn from 5.34 ± 4.48 to 27.07 ± 5.41, Cr from 1.48 ± 0.72 to 6.66 ± 0.98, Cu from 1.36 ± 0.96 to 3.82 ± 0.58 and Ni from 3.18 ± 0.99 to 6.92 ± 1.45 mg/l respectively, with correlation coefficients of R^2= 0.926 for Fe, R^2= 0.877for Mn, R^2= 0.767 for Cr, R^2= 0.883 for Cu and R^2= 0.847 for Ni .

3.3. Effect of 1,4-dioxane loading rate on 1,4-dioxane removal efficiency

The efficiency of 1,4-dioxane removal in an up-flow anaerobic staged reactor (UASR) is displayed in Fig. 5. When the 1,4-dioxane loading rate was 0.00027 kg/m^3.day, the maximum 1,4-dioxane removal efficiency was noted. Comparatively, the location with the lowest 1,4-dioxane removal efficiency had a loading rate of 0.0011 kg/m^3.day for 1,4-dioxane. The removal efficiency for 1,4-dioxane loading rates of 0.00027,.00049, and 0.0011 kg/m^3.day was 51.83%, 35.9%, and 26.3%, respectively. When the 1,4-dioxane loading rate was lower, the removal efficiency was higher; when the loading rate was higher, it was lower. The findings demonstrated that the COD:1,4-dioxane ratio had an impact on the removal efficiency of 1,4-dioxane; at lower ratios, the removal efficiency was comparatively higher than those at higher ratios, which may have inhibited the degradation of 1,4-dioxane Similar results were achieved by (Han et al., 2012).

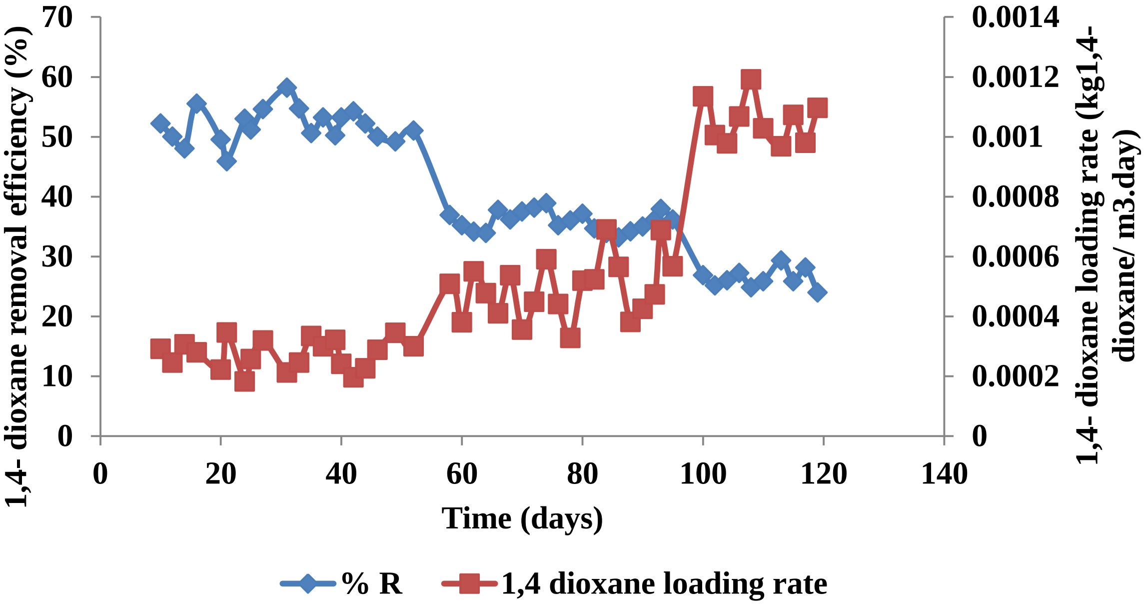


Fig. 5. 1,4-dioxane removal efficiency at different loading rate

3.4. Performance of UASR at different HRTs

The steady state COD removal efficiencies for the UASR at various HRTs and OLR 0.7 g COD/l.d. are displayed in Fig. 6, five different HRTs (96, 77, 58, 38 and 19 hrs, respectively) utilized to look into the impact of HRT. Furthermore, in accordance with the disposal regulations, the admissible HRT to be applied for optimal removal can be ascertained. The outcomes showed that reducing HRT from 96 to 19 hours had an important effect on the efficiency of COD removal, which decreased from 83.11 ± 2.97 to 16.51 ± 0.53 %. Additionally, the removal efficiency dropped gradually at the first three HRT 96, 77, and 58 hours to 53.66 ± 1.46 %. But at 38 hours of HRT, its value significantly declined by nearly 50% to 34.14 ± 1.27%. The accumulation of soluble microbial products (SMP) by acidogenesis was the cause of the specific decline in system removal efficiency at the lowest HRT of 19 hours (Langenhoff et al., 2000).

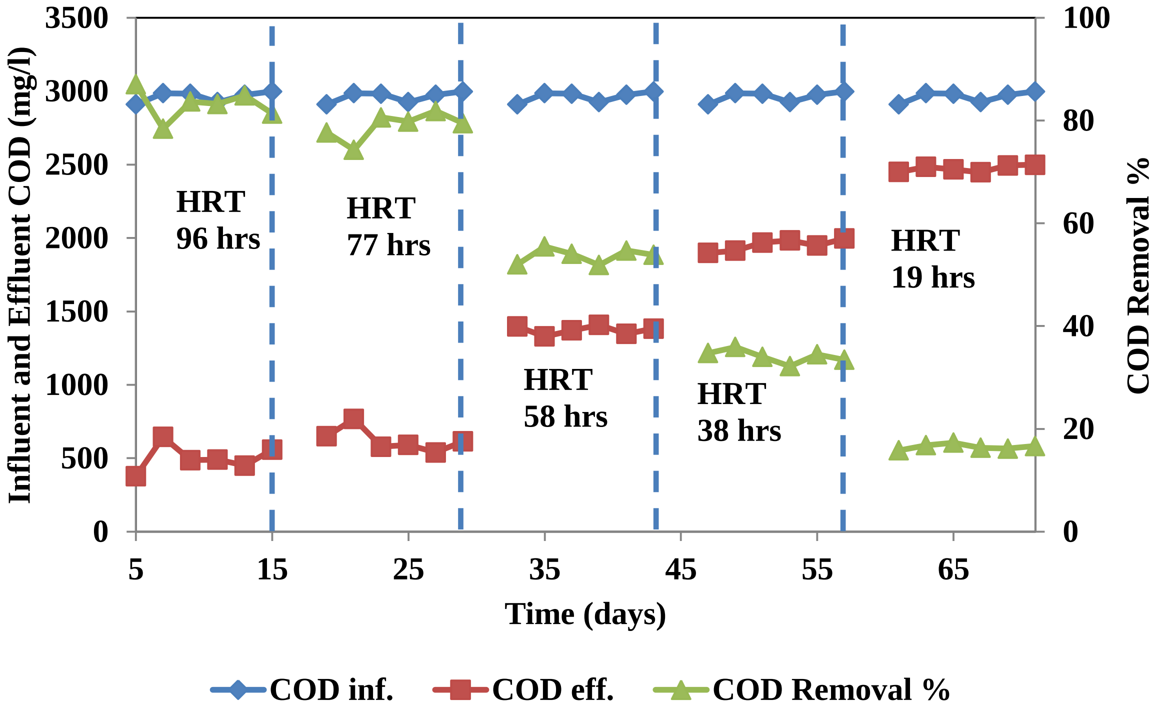


Fig. 6. Time course variation of COD versus HRT

According to Table 3 results, acetic acid, lactic acid, and a trace amount of propionic acid were the primary metabolic products of the methane production process. At the ideal HRT (96 hours), a low concentration of acetic acid was obtained, indicating effective methane production from VFA. Reduced HRT from 96 to 19 hours led to lower consumption of acetic acid and higher concentrations of lactic acid, which were correlated with higher concentrations of propionic acid. This outcome could be the result of the anaerobic digestion of lactic acid, which is typically thought to be a precursor of propionic acid (Min et al., 1993; Costello et al., 1991). The HRT 19 hours had the highest lactic acid concentration (578.77 mg/l), suggesting that lactic acid bacteria could proliferate and were more active there than at the other HRT. The efficiency of methane production was reduced by the fermentation system's lactic acid production. Lactic acid could break down the sludge granules' structure and further reduce the amount of specific methanogenic activity (Liu, 2001). An unwanted intermediate product of the methanogenesis process is propionic acid (Fang and Yu, 2002). This is because, in contrast to acetate and butyrate, propionate's methanogenesis during the anaerobic digestion (AD) process was slower. This is because the hydrogen partial pressure must be less than 103 Pa for propionate to convert to acetate, as per Gibb's free energy calculations. Practically speaking, though, the hydrogen partial pressure during the AD process typically rises above 103 Pa (Meng et al., 2013). As a result, propionate either does not convert to acetate at all or does so slowly. Furthermore, propionic acid prevents the growth of methanogenic bacteria (Barredo and Evison, 1991). As the HRT was lowered, the total VFA rose (Table 3).

Table. 3 VFAs compositions, in terms of acetic, propionic and lactic acid, variations with the different HRT

Parameter	Initial	HRT (19 h)	HRT (38 h)	HRT (58 h)	HRT (77 h)	HRT (96 h)
Acetic acid (mg/l)	1551.22 ± 30.31	987.16 ± 19.72	1005.67 ± 19.40	678.09 ± 30.37	395.13 ± 23.98	310.25 ± 19.62
Propionic acid (mg/l)	96.62 ± 3.94	68.43 ± 2.53	65.10 ± 2.41	53.82 ± 2.82	48.97 ± 1.81	44.35 ± 1.98
Lactic acid (mg/l)	684.83 ± 20.76	578.77 ± 16.71	337.19 ± 10.64	321.01 ± 8.50	303.42 ± 8.42	300.46 ± 17.55
Total VFA (mg/l)	2332.67 ± 80.11	1634.36 ± 90.35	1407.96 ± 83.49	1052.92 ± 63.72	747.52 ± 52.64	655.06 ± 38.61

4. Conclusions

In this research, an analysis of the up-flow anaerobic staged reactor's performance was conducted. The results showed that. The rate of organic removal and biogas production decreased significantly due to the increase of 1,4-dioxane above 4.21 ± 0.30 mg/l and heavy metals represented in (Cu, Mn, Cr, Fe, Ni) on 3.82 ± 0.58, 27.07 ± 5.42, 6.66 ± 0.98, 25.73 ± 2.58 and 6.92±1.45 mg/l, respectively in effluent wastewater, that matching to an OLR of 1.07 g COD/l.d. Additionally, the rate of biogas production was observed to be correlated with an increasing C/N ratio up to a C/N ratio of 78.31 ± 10.48, after which it decreased as the C/N ratio increased. The operation of varying HRT was conducted to examine its impact on the performance of UASR (in terms of COD). The COD removal efficiencies dropped dramatically with the reduction in HRT, from 83.11% at 96 hours of HRT to 16.51% at 19 hours of HRT. The obtained experimental results showed that uasr can effectively treat polyester wastewater at HRT of 96 hrs and an OLR of 0.71±.082 g COD/l.d.

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