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Research article

Effect of Organic Loading Rates on biodegradation of linear alkyl benzene sulfonate, oil and grease in greywater by Integrated Fixed-film Activated Sludge (IFAS)

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A B S T R A C T

In this study, performance of Integrated Fixed-film Activated Sludge (IFAS) system in treatment of Linear Alkylbenzene Sulfonate (LAS), and oil & grease in synthetic greywater and effect of Organic Loading Rates (OLRs) on removal efficiency within a period of 105 days were investigated. Present study was carried out in a pilot scale under such conditions as temperature of 30 ± 1 °C, dissolved oxygen of 2.32 ± 0.91 mg/l, pH of 8.01 ± 0.95 and OLRs of 0.11–1.3gCOD/L.d. Also, Scanning Electron Microscopy (SEM) images were employed to specify rate of the biofilm formed on the media inside the reactor IFAS. The best removal efficiency for COD, LAS and oil and grease were respectively obtained as 92.52%, 94.24% and 90.07% in OLR 0.44gCOD/L.d. The assessment of loading rate indicated that with increased OLR to 0.44gCOD/L.d, removal efficiency of COD, oil and grease was increased while with increased OLR, removal efficiency was decreased. In doing so, based on the statistical test ANOVA, such a difference between removal efficiencies in diverse OLRs was significant for COD ($p = 0.003$), oil and grease ($p = 0.01$). However, in terms of LAS, with increased value of OLR to 0.44gCOD/L.d, the removal efficiency was increased and then with higher OLRs, removal efficiency was slightly decreased that is insignificant ($p = 0.35$) based on the statistical test ANOVA. The SEM images also showed that the biofilm formed on the media inside IFAS reactor plays a considerable role in adsorption and biodegradation of LAS, and oil & grease in greywater. The linear relation between inlet COD values and rate of removed LAS indicated that the ratio of inlet COD (mg/L) to removed LAS (mg/L) was 0.4. Therefore, use of IFAS system for biodegradation of LAS, oil and grease in greywater can be an applicable option.

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1. Introduction

Nowadays, with quick growth of population and industrialization and thereby increased water consumption and also lack of natural water resources, alternative water resources have been considerably paid into attention (Blanky et al., 2015; Umapathi et al., 2013). One of the most important alternative water resources to cope with water scarcity is seawater desalination and reuse of unconventional water resources such as wastewater (Liberman et al., 2016). Reuse of wastewater can play an important role in maintenance and control of available water resources, environmental protection and public health (do Couto et al., 2015; Lopez et al., 2015). Nowadays, an important issue in reuse is treatment and reuse of greywater (Fountoulakis et al., 2016). Greywater includes the wastewater produced at homes including kitchen, shower, bath, wash basin and laundry (do Couto et al., 2013; Leal et al., 2011; Sanchez et al., 2010) which composes 50–80% of domestic wastewater (Li et al., 2009) and is considered as an alternative water resource for non-potable uses (Ghaitidak and Yadav, 2013). Consequently, purification and reuse of greywater currently are paid into attention as an alternative resource for decreased water consumption at home due to lower pollution

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compared to municipal sewage (Ghunmi et al., 2010; Gilboa and Friedler, 2008).

Treatment and reuse of greywater have been adopted by several countries including Australia (Pinto and Maheshwari, 2010), Japan (Fountoulakis et al., 2016), the US (Yu et al., 2013), Jordan (Halalsheh et al., 2008) and Egypt (Kossida et al., 2015) due to safety, health and economic aspects as well as environment protection. However, in terms of quality, the greywater contains such chemical compounds as soap, detergents, oil and grease, metal salts, chemical dyes and microbial pathogens (Chong et al., 2014). Linear Alkylbenzene Sulfonate (LAS) is a conventional anionic detergent which is used in about 80% of household detergent and can be considerably found in greywater (Belanger et al., 2016). LAS can be very toxic for marine life and result in foam formation in water resources (Asok and Jisha, 2012). Oil and grease are also considered as pollutants available in greywater so that in case of reuse of greywater, improper treatment of oil and grease can prevent passing through organic materials and water into the soil pores and intercept oxygen transfer from air to water resources (Travis et al., 2008). Therefore, if the greywater containing chemical compounds and detergents are not properly purified, reuse of them can be harmful for human and organisms (Bani-Melhem et al., 2015). So far, several methods have been used for treatment of the greywater including physical approaches such as filtrations (Katukiza et al., 2014; March et al., 2004) as well as chemical methods including photochemical oxidation (Sanchez et al., 2010) and electrochemical process with iron oxides (Barışçı et al., 2016) and biological methods such as constructed wetlands (Saumya et al., 2015), membrane bioreactors (MBR) (Santasmasas et al., 2013), Sequencing Batch Reactor (SBR) (Gabarró et al., 2013) and Rotating Biological Contractors (RBC) (Eriksson et al., 2009).

Integrated Fixed-film Activated Sludge (IFAS) is a modified process of activated sludge which, by adding a fixed media to a suspended growth pond, causes to increase microbial population and enhance degradation speed of organic compounds (Kim et al., 2010). IFAS system is an integrated process containing the microorganisms with suspended and attached growth (Mehrdadi et al., 2006), thereby it provides much more advantages compared to conventional processes of activated sludge. This system has higher resistance to organic and hydraulic loading shock compared to conventional activated sludge. Besides, it has higher flexibility and purification power (Regmi et al., 2011; Rosso et al., 2011). Also, IFAS has lower retention time and lower basin volume compared to conventional activated sludge process (Andreottola et al., 2003).

Ultimately, given the importance of separation, treatment and reuse of greywater due to water resources scarcity and also importance of selecting the proper method for treatment and removal of pollutants from the greywater, present study was carried out to remove and biodegrade LAS, oil and grease from greywater by integrated fixed-film activated sludge system, investigating effects of diverse OLRs on efficiency of this system.

2. Materials and method

2.1. Synthetic greywater composition

The synthetic greywater was used as an influent to IFAS system. Chemical and commercial compositions used for preparation of greywater are mentioned in Table 1.

2.2. Pilot plant set-up and operation

IFAS reactor was composed of the material transparent Plexiglas with a thickness of 6 mm and an aeration basin followed by a sedimentation unit which is shown in Fig. 1. The aeration basin with a rectangular form was designed in length, width and height of 30, 20 and 15 cm, respectively, as well as free height of 5 cm and usable volume of 9 lit. The sedimentation tank of IFAS system has such dimensions as length of 20 cm, width of 20 cm on surface as well as 10 cm on floor and a height of 15 cm. In the aeration basin, was used of fixed media which is composed of PVC material with a specific surface area of 350 m^2/m^3 which occupies 25% of aeration reactor volume. The temperature was controlled by an aquarium heater embedded in the aeration basin at temperature of 30 ± 1 °C. The required air of the aeration reactor was supplied by the pump AIR-8000 with an airflow of 9 L/min. This pump was embedded on the reactor floor. The influent greywater is injected into reactor by a peristaltic pump (made by ETATRON in Italy) with a flow of 20 L/d.

In order to set up the system, initially the sludge entering into the aerobic digester of Yazd Wastewater Treatment Plant was used. This sludge has such specifications as MLSS = 5000 mg/l, MLVSS = 4510 mg/L and SVI = 160 mL/gr. Following 25 days and formation of biofilm on the fixed media of the aeration reactor, initially the greywater with a COD of 50 mg/L and OLR of 0.11gCOD/L.d was injected into the system and then at the succeeding steps, the greywater with CODs of 100, 200, 400 and 600 mg/L were injected into the IFAS system with OLRs of 0.22, 0.44, 0.88 and 1.3 gCOD/L.d, respectively, and hydraulic retention time of 8.1 h. The total operation time was 105 days.

2.3. Chemical analysis

The parameters COD, LAS, oil and grease as well as pH, DO and temperature were measured. The sampling was conducted on both inlet and outlet of the system and for each parameter; at least 5 samples were measured in each OLR. The measurements were carried out as follows: COD in Dichromate method (Closed Reflux, 2550 B, Colorimetric method, Spectrophotometer Milton Roy Company 2OD), LAS in Methylene Blue Active Substances (MBAS) method using Spectrophotometer in a wavelength of 652 nm, oil and grease in gravimetric method with a standard number of 5520 and also pH, DO and temperature by a portable YSI device accordance with the standard (APHA, 2005). Also, Scanning Electron Microscopy (SEM) with the model TESCAN VEGA3 (made in Czech Republic) was used to prepare image from biofilm.

2.4. Data analysis

The indicators mean and standard deviation and also ANOVA statistical test were employed to compare removal efficiencies of LAS and oil and grease in diverse OLRs.

3. Results and discussion

Biological system monitoring at all OLRs within the 105 days of operation are shown in Fig. 2. The mean temperature was 30 ± 1 °C, dissolved oxygen was 2.32 ± 0.91 mg/L and pH was 8.01 ± 0.95.

3.1. COD removal efficiency

Fig. 3a shows the mean inlet and outlet values of COD in OLRs 0.11–1.3gCOD/L.d. As it can be seen, the mean inlets and outlets values of CODs were 55.32–610.48 mg/L and 9.2–120.23 mg/L, respectively. Also, Fig. 3b shows mean COD removal efficiency in diverse OLRs. The highest removal efficiency of COD (92.5 ± 1.45%) was obtained in OLR of 0.44gCOD/L.d. Friedler et al. (2005) carried out a study on greywater treatment with integrated process of RBC and sand filter and indicated that COD removal was in a rate of 70–75% (Friedler et al., 2005). Abdel-Shafy et al. (2014) conducted a study on treatment of greywater by a hybrid system where COD

Table 1
Chemical compositions of synthetic greywater (Hourlier et al., 2010; Zhu et al., 2014).

Chemical substance	Amount per liter	Commercial products	Amount per liter
Secondary effluent	20 mL	Deodorant	10 mg
H_3BO_3	1.4 mg	Shampoo	720 mg
$C_6H_{12}O_6$	28 mg	Laundry	150 mg
Na_2HPO_4	39 mg	Sunscreen or moisturizer	10-15 mg
Na_2SO_4	35 mg	Toothpaste	32.5 mg
$NaHCO_3$	25 mg	Vegetable Oil	7 mg
Clay (Unimin)	50 mg		

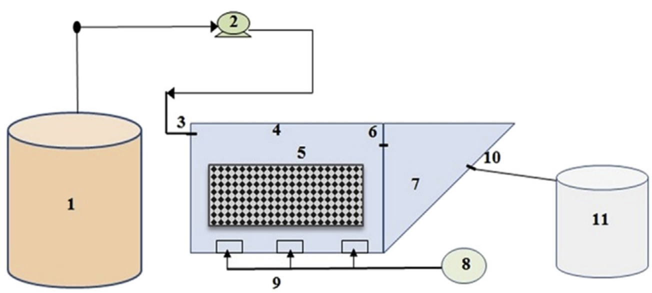

Fig. 1. Schematic of the IFAS pilot system (1. feed tank, 2. injection pumps, 3. Inlet of IFAS aeration reactor, 4. aerated reactor, 5. Media, 6, aeration reactor outlet, 7. settling basin, 8. air pump, 9. air inlet pipes, 10. effluent, 11. effluent storage tank).

removal efficiency was 63.1% (Abdel-Shafy et al., 2014). In Fountoulakis et al. (2016), COD removal efficiency in greywater treatment by Submerged Membrane BioReactor (SMBR) was 87% (Fountoulakis et al., 2016). The comparison of COD removal results in similar studies indicates that in present study, COD removal efficiency was higher than that of similar study. The reason is that IFAS is an integrated system with attached and suspended growth which has higher efficiency compared to other systems and in fact, a consortium of the micro-organisms with attached and suspended growth have been able to enhance efficiency of organic materials removal (Mahendran et al., 2012). As it can be seen in Fig. 3b, COD removal efficiency was initially enhanced by increased OLR to 0.44gCOD/l.d and then with increased OLR, the removal efficiency was decreased. Also ANOVA statistical test indicated that the difference between diverse removal efficiencies was significant ($p = 0.003$). With increased contact time of greywater with microorganisms and their more and more adaptation and with increased amount of inlet COD and required organic materials for microorganisms, the removal efficiency was increased. However, the system efficiency was decreased in high OLRs due to increased amounts of xenobiotic compounds in greywater and their negative impacts on microbial population (Jabornig and Favero, 2013).

3.2. LAS removal efficiency

As it can be seen from Fig. 4a, the mean values of inlets and outlets of LAS in the IFAS system in diverse OLRs were 1.61–14.25 mg/L and 0.18–3.85 mg/L, respectively. Removal efficiency of LAS in diverse OLRs is also shown in Fig. 4b. As it can be seen, the best LAS removal efficiency was 94.24 ± 1.75% which was obtained in 0.44gCOD/L.d. Also, removal efficiency was somewhat decreased in higher OLRs but such variations were insignificant according to the statistical test ANOVA ($p = 0.35$). Ramprasad and Philip (2016) conducted a study on surfactants removal from greywater by constructed wetlands system where surfactants removal efficiency in diverse operation conditions was reported 89% (Ramprasad and Philip, 2016). In Carosia et al. (2014), LAS removal efficiency from greywater in Anaerobic Fluidized Bed Reactor (AFBR) was obtained 48 ± 10% (Carosia et al., 2014). The comparison of LAS removal efficiency in similar studies show that

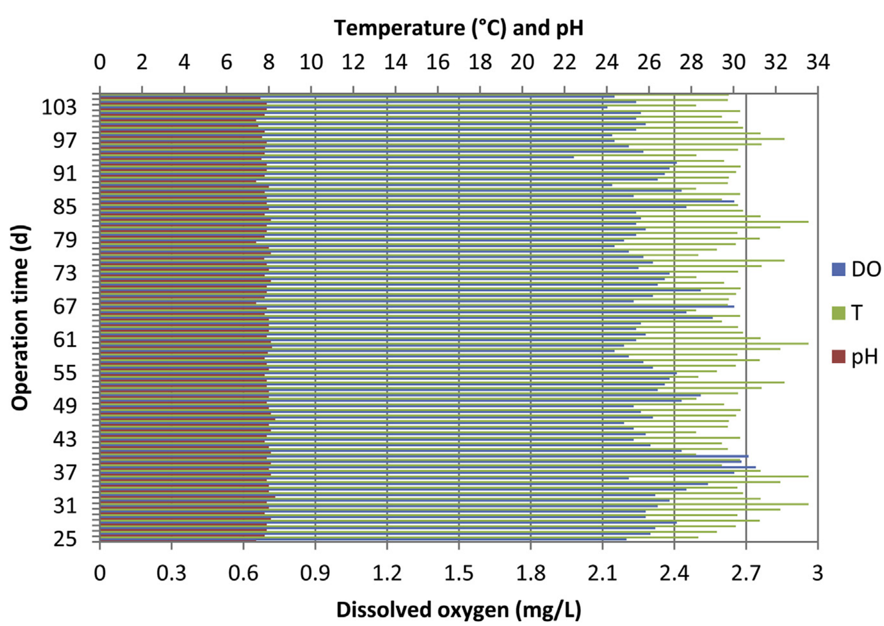

Fig. 2. Biological system monitoring in days of operation by pH, Dissolved oxygen and temperature parameters.

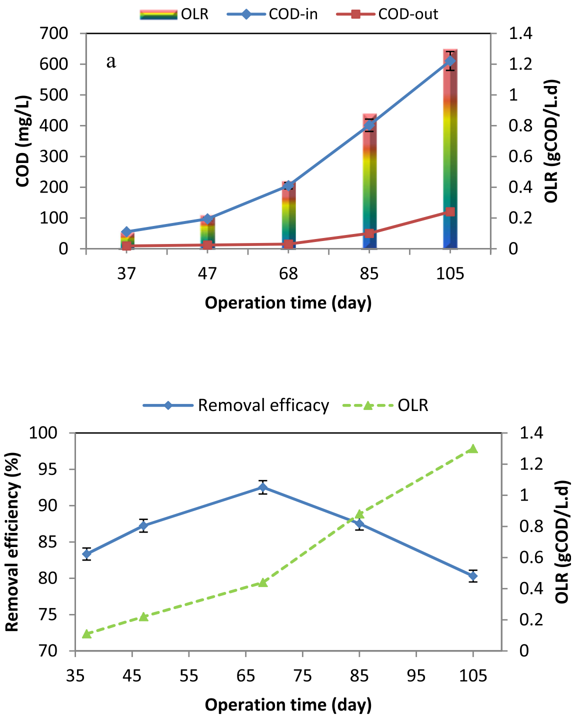

Fig. 3. Removal efficiency of IFAS system in different OLRs, a) the mean inlet and outlet COD and b) COD removal efficiency.

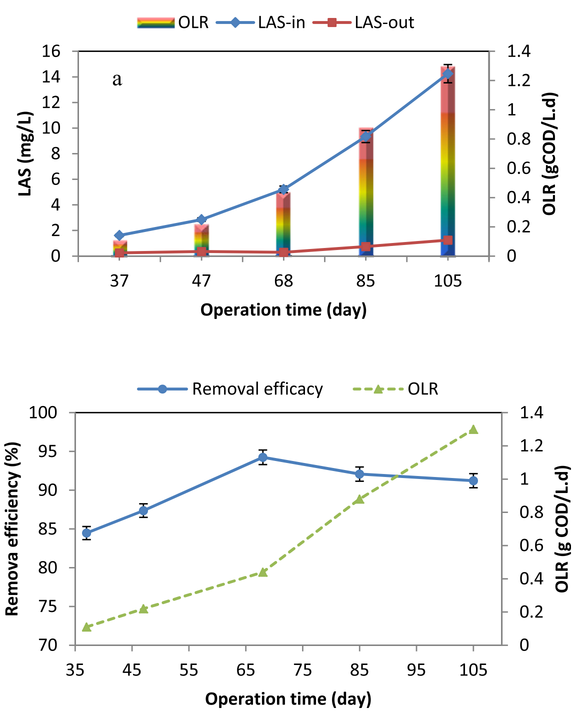

Fig. 4. Removal efficiency of LAS in diverse OLRs during the operation time a) the mean values of inlet and outlet LAS and b) LAS removal efficiency.

in present study, IFAS system has provided a suitable efficiency on LAS removal. LAS removal in a biological system can be influenced by three important factors including biodegradation by microorganisms, adsorption on biofilm surface in the systems with attached growth such as IFAS as well as adsorption on biomass or the sludge exiting from reactor (Carosia et al., 2014; de Oliveira et al., 2010). Therefore, it can be argued that the biofilm formed on IFAS media plays a substantial role in adsorption and the microorganisms grown in LAS biodegradation from the greywater. Also, Fig. 5 shows SEM images from the media within IFAS reactor before biofilm formation (Fig. 5 a and b) and media after biofilm formation (Fig. 5 c and d) on the surface media inside the IFAS reactor. As it can be seen, the mentioned biofilm has a suitable thickness and porosity which cause to increase biological surface area per unit volume ratio. In this case, the contact surface between degrading microorganisms and LAS was increased and thereby gave rise to improve biodegradation process as well as LAS adsorption on biofilm (Massol-Deyá et al., 1995).

3.3. The relationship between inlet COD and removed LAS

Fig. 6 shows the relationship between inlet COD and removed LAS using linear regression model. As it can be seen, determination coefficient (R^2) is 0.9987 which indicates a direct and reasonable relationship between the COD values entering to IFAS reactor and amount of removed LAS from the reactor. In this regard, the ratio of inlet COD (mg/L) to removed LAS (mg/L) was 0.4. Therefore, the LAS degrading microorganisms are argued to be along with consuming inlet organic materials, using LAS as auxiliary carbon resource.

3.4. Oil and grease removal efficiency

Fig. 7a shows the mean oil and grease amounts in diverse OLRs within the operation time. The mean inlets and outlets oil and grease values were 1.41–22.23 mg/L and 0.18–3.85 mg/L, respectively. The best efficiency of oil and grease removal was 90.07 ± 1.21% which was obtained in OLR of 0.44gCOD/L.d (Fig. 7b). As it can be seen, removal efficiency was decreased in the OLRs higher than 0.44COD/L.d and ANOVA test indicated that such an efficiency reduction was statistically significant ($p = 0.01$). Abdel-Shafy et al. (2014) conducted a study on greywater treatment in a hybrid system where oil and fat removal efficiency was 63.5% (without adding Effective Microorganisms (EM) to the system under normal conditions) which was 96.1% in case of adding effective microorganisms (Abdel-Shafy et al., 2014). The studies show that such bacteria as *Stenotrophomonasrhizophila*, *Sphingobacterium* sp., *Pseudomonas libanensis*, *Pseudomonas aeruginosa*, and *Pseudomonas poae* are the main oil and grease degrading bacteria (Nzila et al., 2016). Such bacteria which are more efficient in attached growth phase can lead to degrade and break large molecules of oil and grease by secretion of the lipases and esterases enzymes (Ma'an et al., 2015; Wan et al., 2013). Therefore, the microorganisms and the lypoltic enzymes secreted from them can play a very important role in oil and grease removal from greywater. However, in high OLRs, the removal efficiency is decreased due to increased oil and grease amounts and the corresponding negative impacts on transmission of oxygen to bacterial cells (Brooksbank et al., 2007).

4. Conclusion

In this study, the efficiency of IFAS system in biodegradation of LAS, oil and grease from greywater and impact of OLR on efficiency of this system within a period of 105 days were investigated. The best removal efficiency for COD, LAS and oil and grease were 92.52, 94.24 and 90.07%, respectively, which were found in an OLR of 0.44gCOD/L.d. The assessment on OLRs showed that initially with increased OLR to 0.44gCOD/L.d, efficiency of COD and oil and grease removal was enhanced while with increased OLR, removal efficiency was decreased. The statistical test ANOVA showed that the difference between removal efficiencies in diverse OLRs were significant for both COD ($p = 0.003$) and oil and grease ($p = 0.01$). In

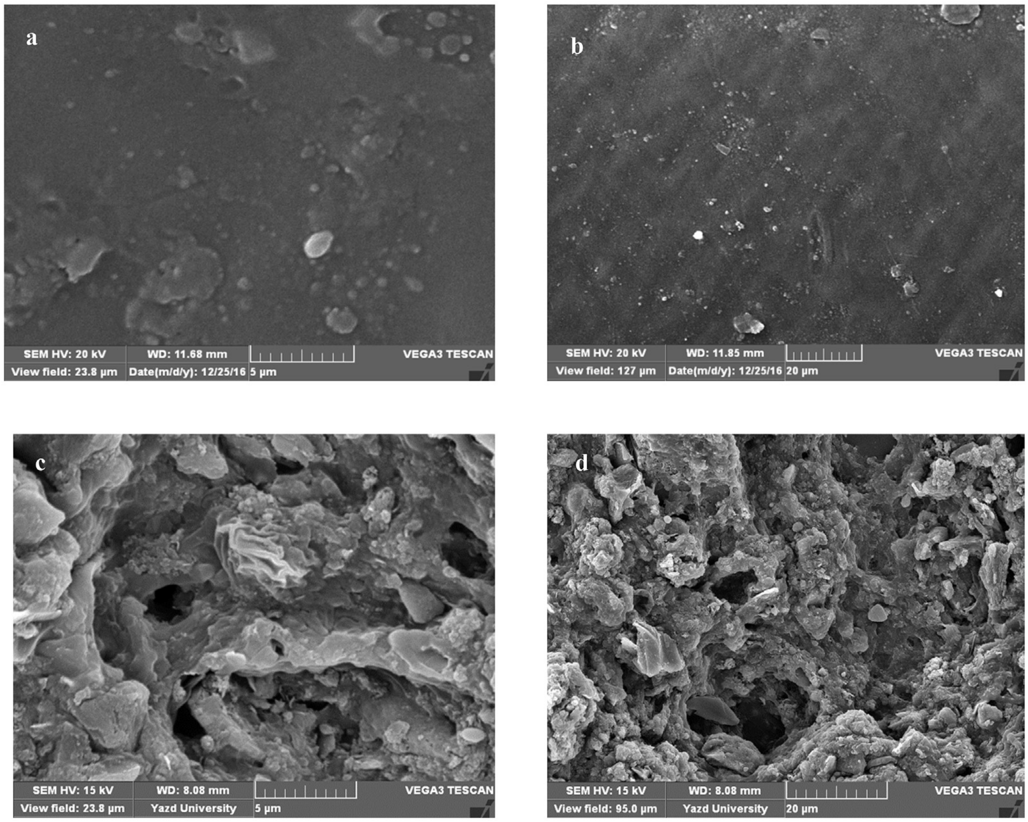

Fig. 5. SEM images from media in IFAS reactor, a) and b) before the biofilm formation, c) and d) after the biofilm formation on the surface media.

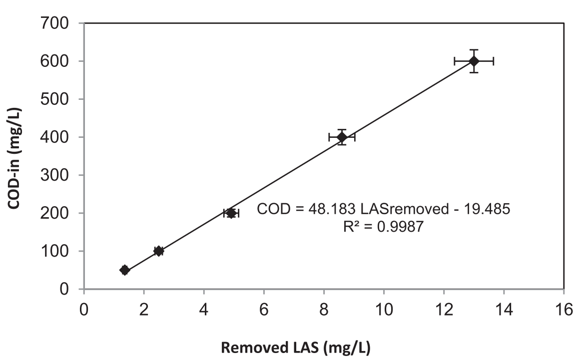

Fig. 6. The relationship between inlet COD and removed LAS based on the linear regression model.

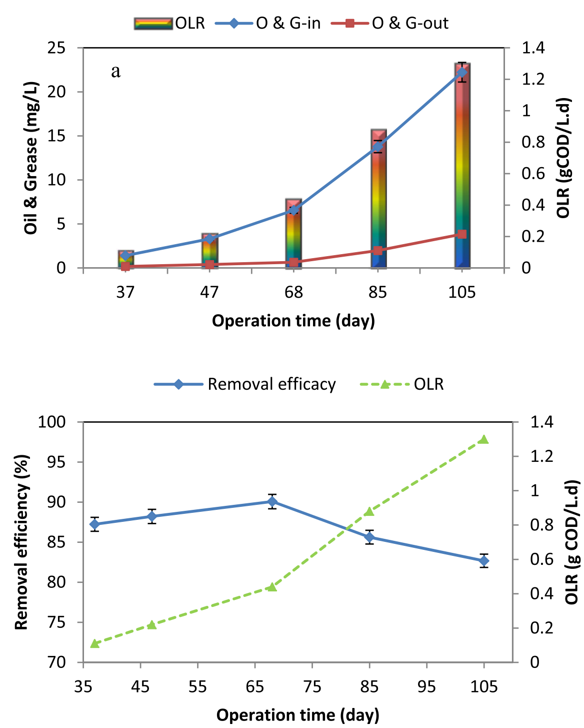

Fig. 7. Efficiency of IFAS system in removal of LAS from greywater, a) the mean inlet and outlet oil and grease and b) removal efficiency of LAS.

terms of LAS, the removal efficiency was enhanced by increasing OLR up to 0.44gCOD/L.d while it was somewhat decreased in higher OLRs. Such statistical variations were insignificant based on the statistical test ANOVA ($p = 0.35$). Also, SEM images indicated that the biofilm formed on the media inside the IFAS reactor plays a substantial role in adsorption and biodegradation of LAS and oil and grease from greywater. The linear relationship between inlet COD values and removed LAS indicated that the ratio of inlet COD (mg/L) to removed LAS (mg/L) was 0.4.

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