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Integration of UASB and down flow hanging non-woven fabric (DHNW) reactors for the treatment of sewage water

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ABSTRACT

The present study introduces a new technique using combined up-flow anaerobic sludge bed (UASB) reactor followed by innovative downflow hanging non-woven fabric (DHNW) reactor for treating of sewage. The packing material used in this study could be produced from waste plastic bottles, thus huge part of solid waste can be reduced, recycled and reused in wastewater treatment plant to produce treated reusable effluent. Both packed and classical UASB reactors (in parallel mode) were used for the treatment of sewage. The UASB (packed and classical) were operated at two hydraulic residence time (HRT). The quality of the packed UASB (P-UASB) effluent was found to be better than that of the classical UASB reactor. Consequently, the effluent of the P-UASB reactor was fed directly to the DHNW reactor. The source of wastewater was the domestic wastewater from Zenein's wastewater treatment plant. The performance of the combined P-UASB/DHNW showed reduction of COD, BOD and TSS from 441, 309 and 187 to 41, 21 and 17 mg/l, and from 386, 293 and 192 mg/l to 45, 30 and 19 mg/l, at HRT 6 h and 5 h, respectively. While, the fecal coliform (FCs) count was reduced from 3.8×10^7 to 5×10^5 MPN/100 ml and from 3.6×10^7 to 7×10^5 MPN/100 ml at HRT 6 h and 5 h, respectively. Consequently, the effluent needs disinfection for safe reuse in irrigation. The results indicated that polyethylene terephthalate (PET) spun-bond non-woven fabric can offer a reliable and simple solution as well as efficient packing material for wastewater treatment.

Keywords: Sewage; Down flow hanging non-woven fabric reactor (DHNW); Packing materials; Waste plastic bottles recycling; UASB

1. Introduction

Recently, Egypt suffers a sharp shortage of water for different uses. This fact could be aggravated in the very near future as a result of constructing Al Nahda Dam of Ethiopia as well as drastic climatic changes [1]. Besides, the discharge of partially treated or even untreated sewage to the water resources is a serious public health and environmental risk problem. Therefore, the need to save water consumption in agriculture and during various industrial processes is inevitable. Non-conventional water resources exist to meet part of the country's water requirements [2]. Treated wastewater is one of the non-conventional water resources existed to decrease the gap between supply and demands [3]. Conventional wastewater treatment (activated sludge) has always been used worldwide, especially in developed or industrialized countries although these techniques are expensive and complicated. But for developing countries,

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economic aspect is critical to apply the sewage treatment system and its adoption as a national standard. In the developing countries, wastewater treatment getting low attention as the benefits are not directly appreciable and it does not have instant economical significance [4,5]. Low-cost as well as low-energy treatment has been proven as a suitable solution and considered as the basis of sustainable waste management for developing countries [6–10].

Anaerobic treatment of domestic wastewater saves and produces energy in addition, it produces a negligible amount of excess sludge. Consequently, operational costs compared with conventional domestic wastewater treatment could be reduced by these technologies [11]. During the past few decades the UASB (as low-cost and low-energy) technique attracted the attention of several researchers for the treatment of wastewater in tropical and sub-tropical developing countries, where financing is generally scarce. However, the quality of UASB effluent doesn't meet the discharge limits. Consequently, post treatment is considered as an option to get the benefits of that technology [9,12–14]. Low-cost post treatment techniques were used by several researchers [4,9,13,15]. The combined UASB/DHS system was found to be efficient for wastewater treatment [15–19].

The packing materials have been employed to improve the performance of both aerobic and anaerobic biological treatment techniques. It could be used for increasing the surface area suitable for attaching the microorganisms. The performance of the treatment systems could be optimized by retention of biomass which degrades the dissolved organic load [17–20]. Different types of packing materials (e.g. waste tire rubber and zeolite [21], wood charcoal (19), sponge or polyurethane) were used in previous studies [16–19].

The aim of this work is to provide environmentally acceptable solution for waste (solid or liquid) management. Valorization of such wastes will raise the growth rate of the national economy and sustainable development. The aim extended to reduce the discharging of sewage directly to the environment without treatment and in the consequence find a new non-conventional water resource.

2. Materials and methods

2.1. UASB reactor

The primary treatment step used in this study was the UASB reactor (Fig. 1). The packing material was arranged vertically. Different hydraulic loading rates (HLR) of 6 and 5 h were examined during the study period. The height and the diameter of the UASB reactor were 2.0 and 0.25 m,

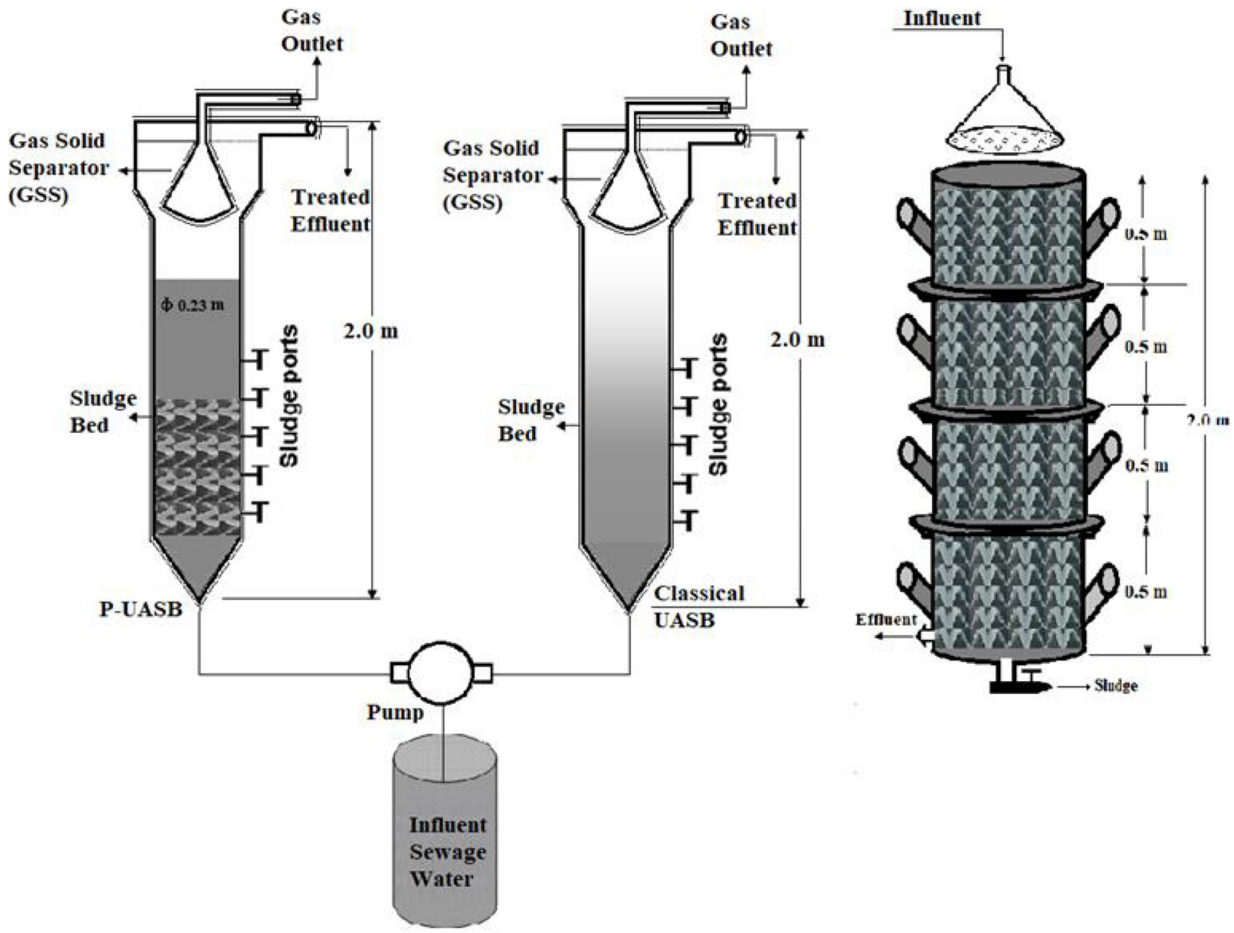


Fig. 1. Schematic diagram for the UASB and DHNW reactors.

respectively. The initial sludge concentration at the beginning of the study was about 20 g/l VSS. The height of the corrugated packing material was 80 cm and fixed at the bottom of the reactor.

Table 1 shows the operating conditions of the classical and P-UASB reactors that used as the primary treatment step. The period of study extended from July 2017 to January 2018.

2.2. DHNW reactor

The effluent of the P-UASB reactor was fed directly to the post (secondary) treatment step using the DHNW reactor. The reactors design is shown in Fig. 1. The treatment units were installed in Zenein wastewater treatment plant. The design of both UASB and DHNW reactors were described by El-Khateeb et al. [22].

Table 1
Operating conditions for the UASB reactor

Parameter	Value	
Length, m	2.0	
Diameter, m	0.25	
Hydraulic loading rate	5 h	6 h
(HLR), DT $m^3/m^3/d$	4.8	4.0
Organic loading rate (OLR), COD $kg/m^3/d$	1.853	1.764

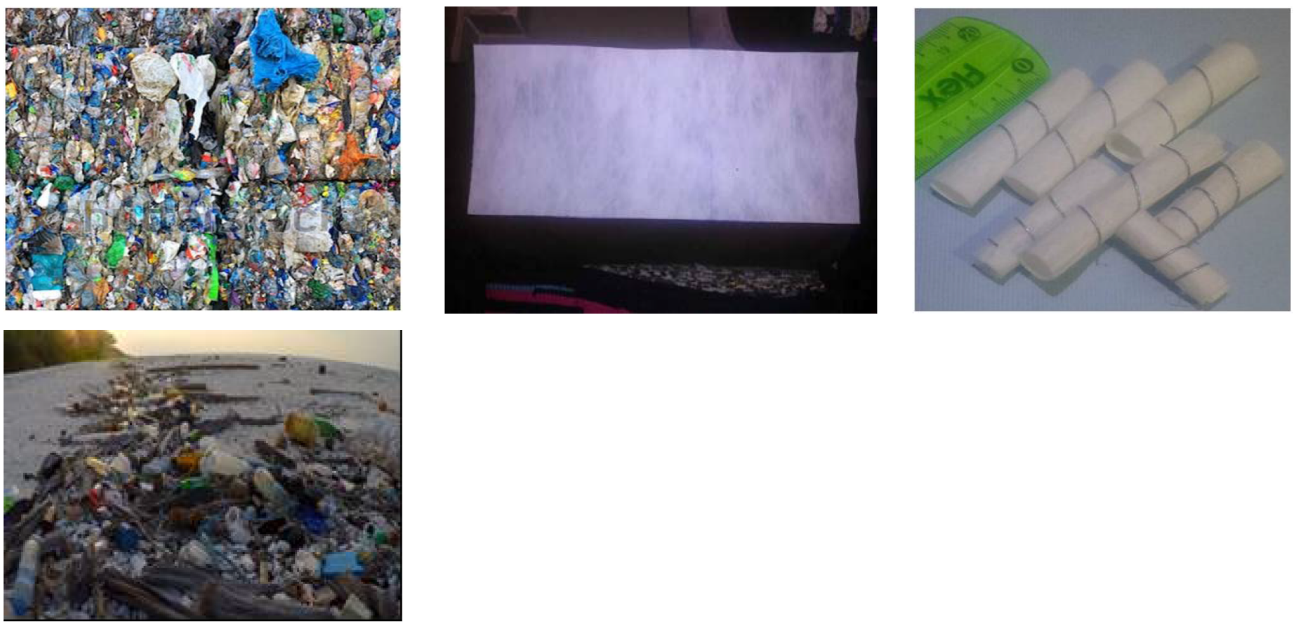
2.2.1. Characterization and shaping of the packing materials

Non-woven fabrics were produced as sheets of different thicknesses, densities and porosities. In this study the chosen shape of non-woven fabric for DHNW reactor was Bakelite hair rollers shape.

This work introduces an innovative design of DHNW reactor which is inspired by the design of DHS reactor. This reactor was packed with innovative packing material prepared from waste plastic bottles. The packing material wasn't studied before as packing material for wastewater treatment with Bakelite hair rollers shape (Fig. 2). This material is inert since it is prepared from PET (plastic bottles).

2.2.2. Methods

The performance of the treatment system was evaluated during the study period. Complete physico-chemical characteristics and fecal coliform (FC) analyses of the influent sewage and effluents from different treatment steps was carried out. The physico-chemical analyses covered pH, organic loads (chemical oxygen demand (COD), biological oxygen demand (BOD)), Nitrogenous load (ammonia-nitrogen (NH_3) and total Kjeldahl nitrogen (TKN)), oxidized nitrogenous compounds (nitrates (NO_3) and nitrites (NO_2)), total suspended solids (TSS) and volatile suspended solids (VSS). The analyses were extended to determine fecal coliform. The analyses were carried out according to the American Public Health Association for Examination of Water and Wastewater [23].



Waste plastic bottles (Waste)* **Non-woven fabric (Intermediate)** **Shaped non-woven fabric as Bakelite hair rollers shape (Useful Packing material)**

*Sources: https://www.shutterstock.com/image-photo/compressed-plastic-bottles-background-1151862329
http://plastic-pollution.org/

Fig. 2. The packing material.

3. Calculation of cod and bod fractions

The soluble COD (COD_{sol}) was determined using filtrate of 0.45 µm filter paper, while the suspended COD (COD_{sus}) was determined by the subtraction of the total COD (COD_{tot}) from the COD_{sol}. The colloidal COD (COD_{col}) was determined by subtracting the COD of the filtrate of 4.4 µm filter paper from COD_{sol}.

3.1. Scanning electron microscopy (SEM)

The morphology of the packing material samples was investigated by scanning electron microscope (SEM) using JEOL JXA-840A electron probe microanalyzer (Tokyo, Japan). The samples were coated with a thin layer of gold before SEM with an S1SoA Edward, sputter coater (Crawley, UK).

3.2. Mechanical properties of the prepared composites

Different samples of the packing material were stored in water at pH 3, 7 and 10 for one month. Another sample of the packing material was boiled (100°C) in water for four hours/day for one month (five days/week). The mechanical properties (Tensile strength, Young's modulus, Stiffness and maximum load) of the samples were tested according to ASTM D638-91 standard using a universal testing machine LK10k (Hants, UK) fitted with a 10 kN load cell and operated at a rate of 10 mm/min.

3. Results and discussion

3.1. Morphological investigation via scanning electron microscopy (SEM)

The morphological properties of the packing material before and after subjecting to the different conditions are revealed in Fig. 3. The blank of non-woven fiber (packing material) before treatment was in a good fibril structure and the fiber was clear and smooth. After treatment with different conditions (boiling water and different pH values) the fiber was not degraded. It could be noted that, there were no effects on the fibers of the packing material at different environmental conditions. It could be noted that, the material has 4 pores/mm.

3.2. Mechanical properties

The mechanical properties of packing material were investigated before and after treatment with boiling water, low, high pH and at room temperature (blank) to study their resistance for different operating conditions.

Table 2 represents the dependence of mechanical properties (maximum load, strain %, stiffness and young's modulus) of the packing material fibers at different conditions. The treated samples have relatively higher young's modulus compared with the blank one (without any treatment) which increased by increasing the pH of solution or by soaking in boiling water. This is because Young's modulus was higher for the treated fibers than that for untreated one. Otherwise, it was shown that a slight decrease in each property of maximum load, stain%, st. at max load and stiffness for all treated samples compared with blank (Table 2).

The maximum loads at which the materials can be elongated without any deformation were more affected in case of acid media than alkali media and also in case of boiling water. The same trend for stiffness and strain % property which indicates the deformation of material per unit length of samples was observed. However, the Young's modulus gives the relationship between stress and strain (proportional deformation) in the tested material. It was found that, it is increased with all treatment in comparison with the blank materials for all different conditions.

3.3. Performance of the packed and classical UASB reactors

Table 3 reflects the main characteristics of raw sewage as well as the effluents of packed and the classical UASB

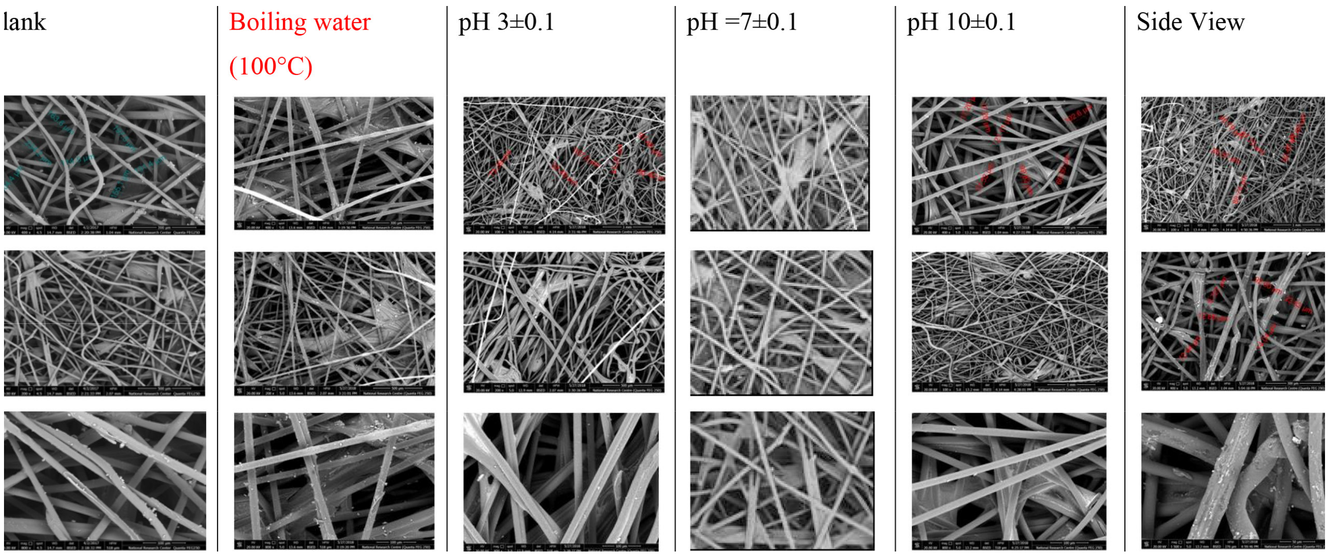


Fig. 3. SEM for the non-woven fiber at different conditions.

Table 2
Mechanical properties of PET and sponge as affected by different operating conditions

Sample	Max. load (N)		Strain %		Stiffness		Young's modulus (MPa)	
	PET	Sponge	PET	Sponge	PET	Sponge	PET	Sponge
Untreated PET	76.5	14.9	250.9	61.3	19325	19854	715.9	780.9
At pH = 3	61.9	8.56	139.8	39.9	17523	15151	2215	1450
At pH = 7	71.3	8.96	155.3	44.2	17892	16122	200	2888
At pH = 10	75.6	9.87	225.9	52.6	18498	17995	1925	2998
Boiling water (100°C)	69.9	11.95	156.8	47.8	19098	18135	2192	3278

Table 3
Main characteristics of sewage water and the effluents of packed and classical UASB reactors*

Parameter	HRT of 6 h					HRT of 5 h				
	Sewage water	P-UASB	Removal (%) by P-UASB	Classical UASB	Removal (%) by classical UASB	Sewage water	P-UASB	Removal (%) by P-UASB	Classical UASB	Removal (%) by classical UASB
pH	7.3–7.4	7.1–7.2	–	7.1–7.2	–	6.9–7.4	6.8–7.3	–	6.8–7.3	–
COD, mgO_2/l	441 (21)	141 (12)	68 (4)	182 (15)	59 (5)	386 (20)	150 (13)	61 (7)	166 (16)	57 (7)
BOD, mgO_2/l	309 (17)	90 (9)	71 (3.5)	120 (11)	61 (4)	293 (17)	100 (10)	66 (8)	108 (13)	63 (8)
TSS, mg/l	187 (21)	48 (7)	75 (6)	62 (8)	67 (6)	192 (23)	61 (9)	68 (9)	69 (9)	64 (9)
VSS, mg/l	150 (18)	33 (4)	78 (5)	53 (6)	64 (5)	129 (17)	48 (8)	63 (8)	50 (8)	60 (9)
Ammonia, mg/l	25 (6)	28 (4)	–	28.5 (5)	–	27 (7)	28 (5)	–	27.5 (6)	–
TKN, mg/l	32 (7)	29.5 (5)	9 (2)	30.2 (6)	6 (1)	32 (7)	30 (6)	6 (1.0)	30.3 (7)	5 (1)
Nitrates, mg/l	0.07 (0.01)	0.02 (0.006)	81.0 (8)	0.02 (0.009)	81.55 (9)	0.06 (0.01)	0.02 (0.003)	70.98 (12)	0.02 (0.004)	69.13 (12)
Nitrites, mg/l	0.004 (0.001)	0.002 (0.0007)	62.4 (7)	0.002 (0.0008)	57.512 (8)	0.004 (0.001)	0.002 (0.0007)	60.667 (11)	0.002 (0.0008)	53.75 (10)
Org. nitrogen, mg/l	7.0 (1.1)	1.5 (0.35)	71 (8)	1.7 (0.4)	–	5.250 (1.0)	2.2 (0.7)	–	2.75 (0.8)	–
Fecal coliform, MPN/100 ml	3.8×10^7 (8×10^6)	3.6×10^6 (7×10^5)	89 (12)	5.1×10^6 (7×10^5)	85 (10)	4.6×10^7 (8×10^6)	4.8×10^6 (6×10^5)	88 (12)	6.6×10^6 (7×10^6)	84 (11)

* Standard deviation between brackets, number of samples were 32

reactor at different HRT. Sewage used in this study is considered as medium strength [24]. Two different HRT (6 and 5 h) were examined by using UASB reactors (packed and classical) for the treatment of sewage. At HRT of 6 h for the P-UASB reactor, the levels of COD, BOD and TSS were decreased from 441, 309 and 187 to 141, 90 and 48 mg/l with corresponding removal rates of 68%, 71% and 75%, respectively. While, the levels of COD, BOD and TSS for the effluent of the classical UASB were 182, 120 and 62 mg/l with the removal rates of 59%, 61% and 67%, respectively. By reducing the HRT to 5 h the level of COD, BOD and TSS for the effluent of the P-UASB reactor, were reduced from 386, 293 and 192 to 150, 100 and 61 mg/l with corresponding removal rates of 61, 66 and 68%, respectively. While, in the classical UASB, the level of COD, BOD and TSS were reduced to 166, 108 and 69 mg/l with corresponding removal rates of 57%, 63% and 64%, respectively. The removal of organic loads during the anaerobic treatment was carried out in four successive steps namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis [25].

It can be noted that, the reduction in the concentrations of COD, BOD and TSS may be due to settling of suspended solids, agglomeration and flow down the surface of the non-woven fabric, while the treated effluent is conducted upwards [26]. These results revealed that the use of the packing material improved the removal efficiency of the organic materials [26]. The performance of the reactor was higher than that obtained by Picanco, et al., [27] and Abou-Elela et al., [28] although they operated the UASB at relatively higher hydraulic loading rate. The TKN was reduced by 11% and 10.1% for both UASB reactors (packed and classical), respectively. This may be attributed to particulate nitrogenous compounds removal, and/or conversion to ammonia [29].

On the other hand the levels of ammonia, TKN and organic nitrogen were 28, 29.5 and 1.5 mg/l for the effluent of P-UASB and 28.5, 30.2 and 1.7 mg/l for classical

UASB reactor at 6 h HRT, respectively. It was noted that the level of organic nitrogen in the effluent of P-UASB reactor was slightly lower than that of the level in the classical UASB effluent. This may be attributed to the entrapment of washed sludge in the P-UASB reactor. The presence of packing material increases the solid residence time consequently, enhancing the biodegradation of organic loads [26]. The efficiency of the UASB reactor was not affected greatly by HRT reduction from 6 to 5 hours. The level of organic nitrogen in the effluent of the P-UASB reactor was lower than that of the classical UASB reactor.

There was only one log unit reduction of FC count obtained for both HRT during the period of the study. But, the P-UASB reactor showed slightly higher performance than that of the classical UASB reactor for removal of FC as shown in Table 3.

These results are inconsistent with the results of Lew et al., [12] who reported no difference in performance of hybrid and classical UASB reactors.

3.4. Performance of the DHNW reactor

The DHNW was used as a secondary treatment step to improve the effluent of the P-UASB reactor. Table 4 shows the performance of the combined P-UASB (at 6 and 5 h HRT) and DHNW for the treatment of sewage. The HRT of DHNW corresponding to that of the UASB reactor (6 and 5 h) were 0.6 and 0.5 h, respectively. Outstanding COD removal was noted during operation. This may be attributed to the temporary adsorption of organic substances onto the fabric media [31]. At 6 h HRT, the levels of COD, BOD and TSS were reduced from 141, 90 and 48 to 41, 21 and 17 mg/l, respectively. While, at 5 h HRT the levels COD, BOD and TSS were reduced from 150, 100 and 61 to 45, 30 and 19 mg/l, respectively. Fig. 4 and Table 4 summarize the performance of the DHNW for the treatment of sewage during period of operation. The fecal coliform count was reduced by 86.1% and 84.4% in the final effluent (at 5 and 6 h), respectively. Mechanisms for the

Table 4
Characteristics of the effluents of the P-UASB and DHNW*

Parameter	6 h				5 h			
	P-UASB	Removal (%) by P-UASB	DHNW	Removal (%) by DHNW	P-UASB	Removal (%) by P-UASB	DHNW	Removal (%) by DHNW
pH	7.1–7.2	–	7.2–7.3	–	6.8–7.3	–	7.2–7.3	–
COD, mgO_2/l	141 (12)	68 (4)	41 (3)	71 (7.5)	150 (13)	61 (7)	45 (3)	68 (7)
BOD, mgO_2/l	90 (9)	71 (3.5)	21 (2)	76 (8)	100 (10)	66 (8)	30 (3)	70 (8)
TSS, mg/l	48 (7)	75 (6)	17 (2)	64 (6)	61 (9)	68 (9)	19 (2.5)	70 (8)
VSS, mg/l	33 (4)	78 (5)	11 (2)	66 (7)	48 (8)	63 (8)	13 (2)	74 (8)
Ammonia, mg/l	28 (4)		11.5 (2)	57 (6)	28 (5)		12.3 (3)	56 (7)
TKN, mg/l	29.5 (5)	9 (2)	12.0 (2)	49 (5)	30 (6)	6 (1.0)	13.0 (4)	54 (7)
Nitrates, mg/l	0.02 (0.006)	81.0 (8)	1.4 (0.4)		0.02 (0.003)	70.98 (12)	1.0 (0.3)	
Nitrites, mg/l	0.002 (0.0007)	62.4 (7)	0.3 (0.1)	–	0.002 (0.0007)	60.667 (11)	0.2 (0.03)	–
Org. nitrogen, mg/l	2.0 (0.35)	71 (8)	0.5 (0.07)	77 (8)	2.2 (0.7)	–	0.7 (0.05)	68.2 (7)
Fecal coliform, MPN/100 ml	3.6×10^6 (7×10^5)	90.5 (12)	5×10^5 (6×10^4)	86.1 (10)	4.8×10^6 (6×10^5)	90.2 (12)	7×10^5 (8×10^4)	84.4 (11)

* Standard deviation between brackets, number of samples were 32

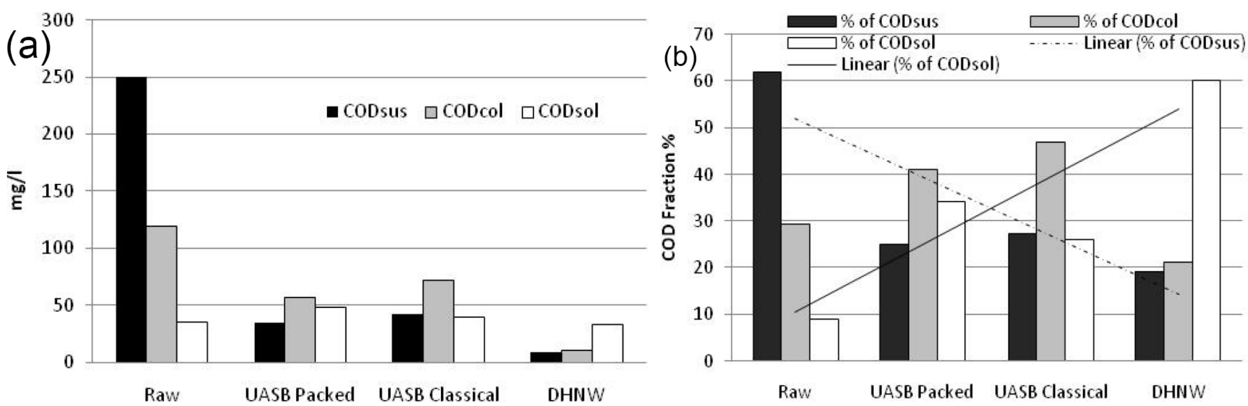


Fig. 4. Fate of COD fractions throughout the treatment steps.

removal of FC in DHNW can be suggested as entrapment or adsorption, predation, natural die-off and toxicity of oxygen, which is also described by Tawfik et al., [26]. Njenga et al. [31] also suggested that coliforms are unable to compete with other bacteria for nutrients in aerobic system. Hence, DHS exploits physical as well as biological interactions for coliform removal.

The high performance of the DHNW for the removal of organic loads (COD and BOD) could be due to the high specific surface area of the packing material and as a result, the low surface loading rate in the reactor [30]. The surface adsorption is the first step in the organic load degradation in the DHNW reactor [22]. In addition, the well developed biofilm (micro-organisms) on the surface of the packing material biocatalysts the degradation of the organic matter [30]. After that, hydrolysis of the substrate takes place on the surface of the non-woven fabric in the DHNW system due to the presence of the biofilm. This may increase the area of contact between wastewater and microorganisms, thus reduces the cost of the treatment processes. The fibers were not damaged and supported the biomass tightly on the surface [22].

In comparative work Mahmoud et al. [17] studied the treatment scheme consisted of hybrid UASB followed by DHS reactor. The study was continued for more than 5 months. The results revealed that the average removal values of organic loads (COD, BOD), TSS and TN were 90, 95, 96 and 72%, respectively. It was proven that the DHS reactor can withstand to higher organic loads. The DHS reactor efficiently removes both carbonaceous organic matter and nitrogenous compounds.

3.5. Fate of COD fractions

Excellent COD removal was rapidly established in all the reactors, which is one of the merits of combination between UASB and DHNW system. This is attributed to the biotransformation as well as the temporary adsorption of organic substances onto the fabric media's surface. The level of COD_{sus} was found to be less than 10 mg/l while the COD_{sol} gradually increased throughout the treatment steps. These results were in a good agreement was that obtained by Uemura, et al. [32].

4. Conclusions

The study examined the use of non-woven fabric as packing material for both UASB and DHNW reactors. The results indicated that, the proposed packing material has a promising capacity as efficient material that could be used for the treatment of wastewater. This material easily shaped as corrugated sheets or any other shape. The organic load expressed by COD, BOD and TSS were greatly reduced along the treatment steps. The reduction of FCs was from 3.8×10^7 to 5×10^5 and 7×10^5 MPN/100 ml at 6 as well as 5 h HRT. The reduction in FCs counts was not exceeding 2 log counts. Consequently, the disinfection step could be used to meet the unrestricted irrigation for safe reuse of the treated effluent. Applications of such simple technologies will reduce the risk associated with the discharge of partially treated sewage. The benefits of this technology will extend to the valorization of waste plastic bottles.

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