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AMMONIA AND ZINC TREATMENT IN HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLANDS

BY

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يقدم هذا البحث التكنولوجيا البديلة لانظمة معالجة مياه الصرف الصحي التقليدية باستخدام اللأراضي الرطبة تحت السطحية أفقية السريان باستخدام نبات البردي في معالجة الامونيا والزنك. أجريت التجارب بإستخدام الزلط وقطع من المواسير البلاستيكية المموجة وقطع من المطاط.تنقسم الدراسة الي مرحلتين المرحلة الاولي وهي مرحلة الإعداد لاتزان المعالجة ثم بدأت المرحلة الثانية وهي مرحلة اتزان المعالجة بعد ثبات ملحوظ للمسامية للأوساط المستخدمة وأيضاً وصول النبات إلى كثافات منتظمة على مساحة الأحواض. في هذا البحث تم دراسة تأثير المسافة داخل الاحواض وزمن المكث ومعدل التحميل الهيدوليكي والتصرف علي كفاءة المعالجة في إزالة الامونيا والزنك. بناءاعلي النتائج المعملية والحقلية تلاحظ تأثير زمن المكث على كفاءة المعالجة حيث بزيادة زمن المكث تزداد.كفاءة المعالجة للامونيا والزنك. أثبتت الدراسة قدرة الأراضي الرطبة تحت السطحية على معالجة الامونيا والزنك بمختلف التركيزات وبتكلفة إنشاء وتشغيل وصيانة قليلة جدا بالمقارنة بالأنظمة التقليدية

Abstract

Investigation of wastewater treatment through horizontal subsurface flow constructed wetlands, (CWs) using three different treatment media (gravel, pieces of plastic pipes, and shredded tire rubber chips) was done. The experimental work could be divided in two stages, the set up one and steady stage. The study focused on the wetland steady stage. In this stage 13 water samples were taken weekly by applying five different average discharges (5.119, 3.482, 2.396, 1.696, and 1.263 m^3/day). The aim of this paper is to study the effect of media types and treatment distances along the channel on Ammonia (NH_3) and Zinc (Zn) effluent with respect to wetland hydraulic properties and obtaining NH_3 and Zn removal rates. Weekly water samples from inlet, intermediate of the Sedge bed were obtained at three distances along its length and outlet for wetland channel. The plastic channel has the highest retention time followed by the rubber and then the gravel channel. This is compatible with the porosity of the three media types. Plastic media has the greatest porosity while the gravel media has the smallest porosity followed by rubber media. At channels outlets, ammonia removal efficiency enhanced from 57 to 78.53% in plastic channel after moving from Q_{max} to Q_{min}, from 47.97 to 67.69% in gravel channel, and from 45.75 to 62.48% in rubber channel. From experimental results at channels outlets, plastic media gave average ammonia removal efficiency lower than gravel and rubber media by 8.56 and 11.84%, respectively. The Zinc removal efficiency for plastic media increased by an average value of 8.87 and 14.70% than gravel and rubber media, respectively. Wavy plastic pipes and shredded tires pieces have proved to be a good economical media for treating NH_3 and Zn. The empirical relationships developed in this study can be used in the

rational design of horizontal subsurface flow wetlands for conditions similar to the ones under which this study was conducted.

1. Introduction

Treatment of domestic wastewater in rural and urban is mostly carried out by activated sludge or by bacterial process. Constructed Wetlands (CWs) can be used as an alternative technology for the treatment of wastewater. In most part of the world especially in industrialized countries, it has been successfully applied for treatment of domestic sewage (Kivaisi, 2001, Brix et al., 2011: El Hamouri et al., 2007: Konnerup et al., 2009: and Trang et al., 2010). Constructed wetlands (CWs) are vigorous biological systems that can be applied for the treatment of several types of polluted water (Brix, 1994: Vymazal et al., 2006). A good designed constructed wetland should able to maintain the Hydrualic Retention Time and Loading Rates (Kadlec and Knight, 1996). CWs are considered the most promising technology to wastewater due to low cost simple operation and maintenance, and favourable appearance (Shutes, 2001).CWs for wastewater treatment may be classified according to the life form of the dominating macrophyte, into systems with free-floating, floating leaved, rooted emergent and submerged macrophytes (Brix, and Schierup, 1989). Further division could be made according to the wetland hydrology (free water surface and subsurface systems) and subsurface flow CWs could be classified according to the flow direction (horizontal and vertical) (Vymazal, and Kröpfelová. 2008).The wetland plants growing in CWs possess several functions in relation to the water treatment (Brix, 1997). The most common aquatic plants used in subsurface flow wetland are bulrush (Scirpus sp.), Cattail (Typha sp.), Reeds (Phragmites sp.), Cattail (Typha angustifolia L) is also widely used which is known to be highly tolerant to various types of wastewater (Koottatep et al., 2001a: Koottatep et al., 2005b). In the present study sedge was employed which is a local aquatic plant. Normally, local aquatic plant is chosen due to its natural adaptation with the local climate and availability as well as to mitigate the unnecessary introduction of foreign or new species to the local environment (Calheiros et al., 2008), it is normally used as a emergent plant because it forms extensive monoculture very rapidly through vegetative reproduction and maintain its dominance with formation of dense rhizome mats and litter which can used as a better to remove in wastewater treatment (Calheiros et al., 2008). The main objective of this study was to assess the ability of horizontal flow constructed wetland system. The objectives of the present study were to assess the ability of horizontal flow constructed wetland systems to treat ammonia and zinc present in wastewater, to evaluate the performance of system planted with sedge.

2. Material and Method

2.1 Wetland Channel

Experiments were carried out in three similar parallel field-scale horizontal subsurface flow constructed wetlands. All the units have a shape of a rectangular with identical dimensions of 10 m × 2.0 m × 0.65 m (length × width × depth). A small bed slope in wetland channels decreases runoff velocity. The channels of the model received primary treatment wastewater. The wetland channel was built from bricks and lined several times with impermeable fabricated liner material to avoid seepage and infiltration into groundwater to prevent groundwater from contamination. Each channel had an inlet zone, main treatment zone, and outlet zone. The wetland channel has an inlet zone, main treatment zone, and outlet zone. Inlet zone consists of three main parts as: 1) Flow control weir, which receives wastewater from the main distributing channel of plant, 2) Perforated distribution pipe, 4.00 inch diameter with length is 1.95 m, and 3) 40 : 60 mm diameter inlet gravel to limit the potential of clogging. The aim of the outlet zone is to control the depth of water in the wetland channels and to collect the effluent water. It consists of; perforated outlet collecting pipe 4.00 inch pipe, at the end bottom of wetland channels, coarse gravel to regulate the flow, and water level control sump, has a movable elbow. Three types of treatment media (rubber, plastic and gravel) were used in the main treatment zone to achieve its objective. The rubber was made from shredded tires. The rubber media was obtained and chipped into small pieces (about 30:60 mm length, 25:55 mm width, and 5:15 mm thickness). The second studied media was made of corrugated hollow plastic pipes 50 mm length and 19 mm diameter. Natural washed gravel was used as the third bed media. The gravel media of the 3rd channel was stratified by coarse gravel (40 to 60 mm diameter) layer at the bottom, medium gravel (20 to 40 mm diameter) at middle layer, and fine gravel (less than 20 mm diameter) layer at the top. Each layer had a thickness of 16.7 cm. The media was covered by wide plastic screens. A layer of gravel (10 cm depth) was then laid above these media to avoid floating. Also, 10 cm of gravel was placed on the top of the rubber and plastic media to hold plants, as well as for safety. The gravel channel was also covered with 10 cm coarse gravel for similarity. The treatment wetland system began to operate after experimental arrangements. The system was allowed to stabilize for about two months by flowing wastewater. After this stabilization period, the wetland channel was planted. The chosen plant was sedge (treatment plants that have high growth rates and can easily colonized), known popularly by common Sedge, and due to the availability of this plant in the surrounding areas of the experimental work. Water samples were collected manually in 500 ml sterile bottles from each inlet, outlet and every 2 meters in between. Water samples were stored in ice tanks, sent to laboratory. The collected water samples were analyzed for NH_3 and Zn (influent, intermediate from each channel and effluents).The effluent NH_3 and Zn was studied against distance from channel inlet, loading rate, and influent concentration. The variation of NH_3 and Zn removal efficiency with retention time and discharge was also determined.

2.2. Hydraulic Representations

Establishment of the horizontal subsurface wetland channels was done. These channels were tested for two stages; the first one is the set up stage (the system was in the start of operational state) and the other is the steady stage conditions (the system reached to the stability state of biofilm growth, plants maturation and uniform flow).For steady stage, five decreasing discharges are applied for each cell. Every discharge is utilized for five consequence weeks (cycles). The discharges were measured by a triangular weirs located at the start of wetland channels. The actual discharge (Q_{act}) is measured by means of measuring tank and stopwatch. The notch equation for computing discharge may be written as the follows (Anurita, 2005):

$$Q_{act} = \frac{8}{15} Cd\sqrt{2g}\tan\frac{\theta}{2} H_d^{5/2} \quad (1)$$

Where:
Q_{act} = Actual discharge, m3/d,
cd = coefficient of discharge,
g = Acceleration due to gravity, m/s^2,
H_d= Head over the notch, and
θ= Apex angle of V-notch.
The wetland channel was theoretically considered as four tanks 2.0 m width and surface areas of 4, 10, 16, and 20 m2.Equation (2) gives four corresponding values of loading rate at distances of 2, 5, 8, and 10 m measured from entrance (Kadlec and Wallace 1996):

$$q = \frac{Q_i}{A} \quad (2)$$

Where:
Q_i = discharge, m3/d,
A = surface area, m2, *and*
q = loading rate, cm/d.
The hydraulic time and removal efficiency at any distance could be calculated according to Equations (3) and (4), respectively, (Kadlec and Knight 2009):

$$T_r = \frac{V_{wx}}{Q_i} \quad (3)$$

$$RE = \frac{(C_i - C_o)}{C_i} \times 100 \quad (4)$$

Where:
T_r = hydraulic retention time, hr,
V_{wx} = volume of water at distance x, m^3,
RE = removal efficiency %,
C_o= effluent concentration, mg/l, and
C_i = influent concentration, mg/l,

The water volume at any distance inside the wetland channel is calculated as the media volume multiplied by the media porosity at the specified time from start of sampling given by the following equation:

$$V_{wx} = V_{cg} \times n_{cg} + V_m \times n_m \quad (5)$$

Where:
n_{cg} = = Porosity of coarse gravel,
V_{cg} = = Volume of coarse gravel,
V_m =Volume of media, and
n_m = = Porosity of media.

Table 1 Hydraulic calculation for steady stage for the three media

Cycle No.	H_d (cm)	Gravel Channel			Rubber Channel			Plastic Channel		
		Q (m^3/d)	Q (cm/d)	T_r (day)	Q (m^3/d)	Q (cm/d)	T_r (day)	Q (m^3/d)	q (cm/d)	T_r (day)
1	4.2	5.037	25.19	0.714	5.119	25.60	0.916	4.814	24.07	1.410
2	3.6	3.426	17.13	1.050	3.482	17.41	1.347	3.275	16.38	2.073
3	3.1	2.357	11.79	1.527	2.396	11.98	1.957	2.253	11.27	3.013
4	2.7	1.669	8.35	2.156	1.696	8.48	2.765	1.595	7.98	4.256
5	2.4	1.243	6.22	2.895	1.263	6.32	3.713	1.188	5.94	5.715

3. Results and Discussion

3.1 Ammonia Treatment

Influent and outlets effluent samples were analyzed in steady stage. The effluent ammonia was studied with both loading rate and influent concentration. The variation of pollutant removal efficiency and both retention time and sewage load are discussed.

3.1.1 Inlet and Outlet Ammonia Relationships

Figure 1 gives the relationship between effluent and influent concentrations (Co and Ci) of ammonia for the three media at outlets.

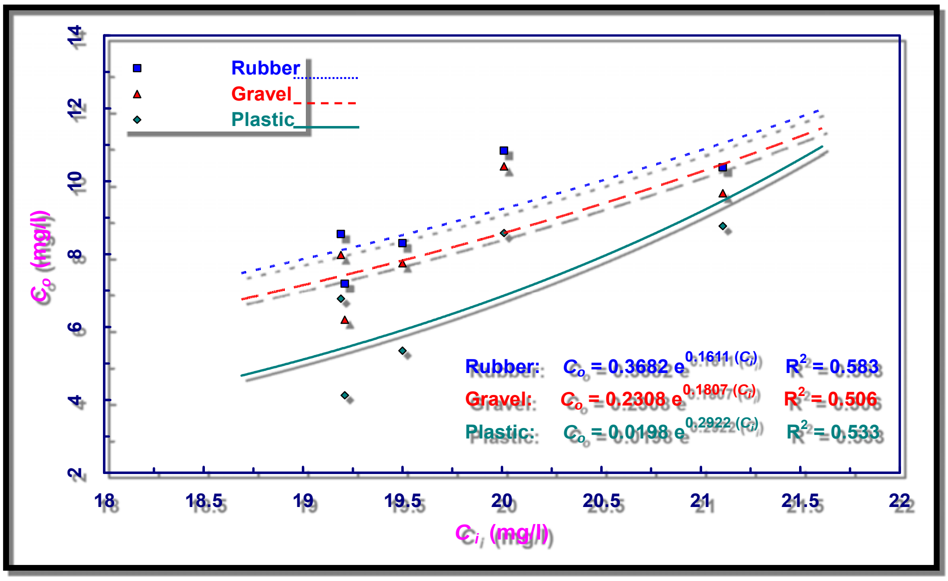

Figure 1 Variation of influent and effluent ammonia concentrations

From fig 1, through steady stage, the effluent ammonia concentration of plastic media is smaller than the other media (better ammonia treatment) at outlets, followed by the gravel media. For plastic, gravel, and rubber media, the outlet concentrations of ammonia at outlets are in the allowable limit (less than 10:12 mg/l) of Law No. 48 of 1982 (NAWQAM, 2002) for discharge lower than 4.814, 5.037, 5.119 m^3/d with loading rates equal 24.07, 25.19, and 25.6 cm/d, respectively. Effluent and influent ammonia relationship for the three media is varying according to an exponential function as the best fit. The exponential equations at outlets are as follows:

$$Plastic: \quad C_o = 0.0198\, e^{0.2922\, C_i} \qquad R^2 = 0.533 \tag{6}$$

$$Gravel: \quad C_o = 0.2308\, e^{0.1807\, C_i} \qquad R^2 = 0.506 \tag{7}$$

$$Rubber: \quad C_o = 0.3682\, e^{0.1611\, C_i} \qquad R^2 = 0.583 \tag{8}$$

Where:

C_o = ammonia outlet concentration, mg/l

C_i= ammonia inlet concentration, mg/l

3.1.٢ Impact of Loading Rate on Ammonia Treatment

Table 2 illustrates the average inlet and outlet ammonia concentrations with discharge, and q values at the end of channels. Figure 2 represents the variation of average effluent ammonia concentration and the loading rate at distance of 10 m from inlet.

Table 2 Influent and effluent ammonia concentrations and q values for channels.

C_i (mg/l)	Plastic channel			Gravel channel			Rubber channel		
	Q (m^3/d)	q (cm/d)	C_o (mg/l)	Q (m^3/d)	q (cm/d)	C_o (mg/l)	Q (m^3/d)	q (cm/d)	C_o (mg/l)
20.01	4.814	24.07	8.58	5.037	25.19	10.41	5.119	25.60	10.84
21.11	3.275	16.38	8.77	3.426	17.13	9.67	3.482	17.41	10.38
19.19	2.253	11.27	6.78	2.357	11.79	7.98	2.396	11.98	8.55
19.50	1.595	7.98	5.35	1.669	8.35	7.75	1.696	8.48	8.30
19.21	1.188	5.94	4.13	1.243	6.22	6.20	1.263	6.32	7.19

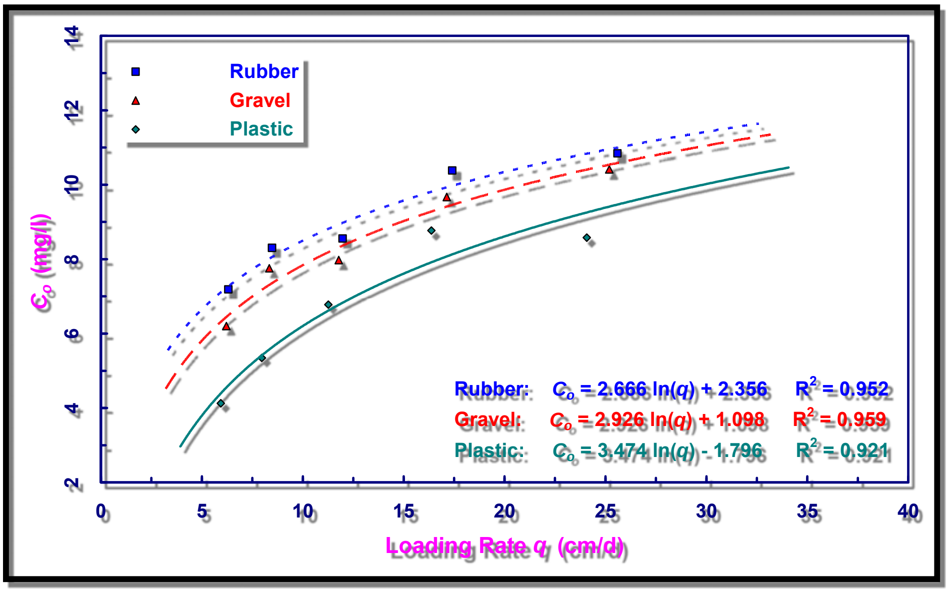

Figure 2 Variation of C_o with hydraulic loading rate for ammonia pollutant

From Table 2 and Figure 2, it is noticed that the ammonia outlet concentration decreases with the decrease of loading rate which means, the enhancement of the treatment for the three media at outlets with smaller q. For cycle number one (Q_{max} = 4.814, 5.037, and 5.119 m^3/d), the ammonia influent concentration is 20.01 mg/l and the q values are 24.07, 25.19, and 25.6 cm/d for plastic, gravel, and rubber channels produce corresponding outlet concentrations of 8.58, 10.41, and 10.84 mg/l, respectively. For cycle number five (Q_{min} = 1.188, 1.243, and 1.263 m^3/d), the ammonia influent concentration is 19.21 mg/l and the q values are 5.94, 6.22, and 6.32 cm/d for plastic, gravel, and rubber channels which produce corresponding outlet concentrations of 4.13, 6.2, and 7.19 mg/l, in the same sequence. At low loading rate, the difference between outlet ammonia values for plastic, gravel, and rubber media are big and these differences decrease at high values of loading rate. Plastic channel gives ammonia outlet concentration lower than other channels followed by gravel. The ammonia effluent concentration is directly proportional to the loading rate according to a logarithmic function. The logarithmic equations at outlets are as follows (q ranges from 5.94 to 25.6 cm/d):

$$Plastic: \quad C_o = -1.796 + 3.474 \ln q \qquad R^2 = 0.921 \quad (9)$$

$$Gravel: \quad C_o = 1.098 + 2.926 \ln q \qquad R^2 = 0.959 \quad (10)$$

$$Rubber: \quad C_o = 2.356 + 2.666 \ln q \qquad R^2 = 0.952 \quad (11)$$

3.1.3 Impact of retention time on Amonia Removal Efficiency

Table 7.41 gives the retention time which corresponds to the used discharges at outlets for the three media and ammonia removal efficiency for steady stage cycles. Figure

7.54 illustrates the relationship between ammonia removal efficiency and retention time at outlets for plastic, gravel, and rubber channels.

Table 3 Ammonia removal efficiency and retention time for the used media.

Cycle No.	NH_3 Removal Efficiency (%)			Hydraulic Retention Time (hr)		
	Rubber	Gravel	Plastic	Rubber	Gravel	Plastic
1	45.75	47.97	57.00	21.98	17.16	33.84
2	50.77	54.26	58.55	32.30	25.20	49.73
3	55.59	58.46	64.64	46.97	36.65	72.31
4	57.55	60.18	72.64	66.34	51.74	102.12
5	62.48	67.69	78.53	89.09	69.48	137.11

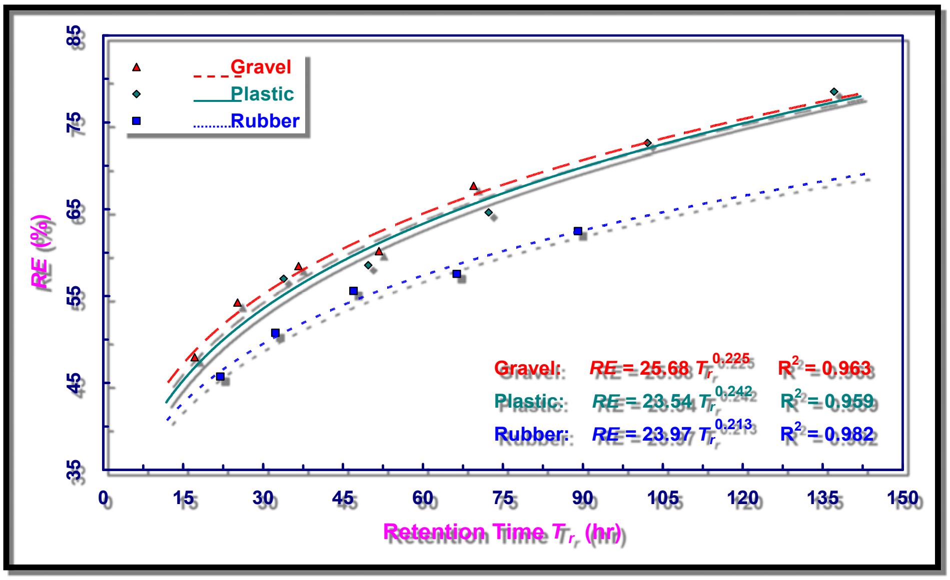

Figure 5 Variation of Amonia removal efficiency with retention time.

From Figure, it is noticed that the gravel channel gives the highest removal efficiency for ammonia treatment followed by plastic channel. The ammonia removal efficiency increases with the increase of retention time through steady stage for the three media at outlets. The treatment improves with the increase of T_r for each media. For example for plastic channel at T_r value equals 33.84 hr, the removal efficiency is 57%, while at T_r value equals 137.11 hr, the removal efficiency is 78.53%. The difference between removal efficiency of ammonia for gravel and plastic channels is small but it becomes bigger between these two channels and rubber. At low retention time, the difference between rubber and both gravel and plastic channels is small and increases as T_r increases. The ammonia removal efficiency for the three media is directly proportionate to retention time according to a power function. The power equations at outlets are:

$$Plastic: \quad RE = 23.54\, T_r^{0.242} \qquad R^2 = 0.959 \quad \text{..} (١٢)$$

$$Gravel: \quad RE = 23.54\, T_r^{0.225} \qquad R^2 = 0.963 \quad \text{(١٣)}$$

$$Rubber: \quad RE = 23.97\, T_r^{0.213} \qquad R^2 = 0.982 \quad \text{(١٤)}$$

3.1.4 Impact of Discharge on NH_3 Treatment Efficiency

This study focuses on the effect of changing discharge on treatment. Figures 6 show the relationship between NH_3 removal efficiency and the corresponding changing discharge on treatment.

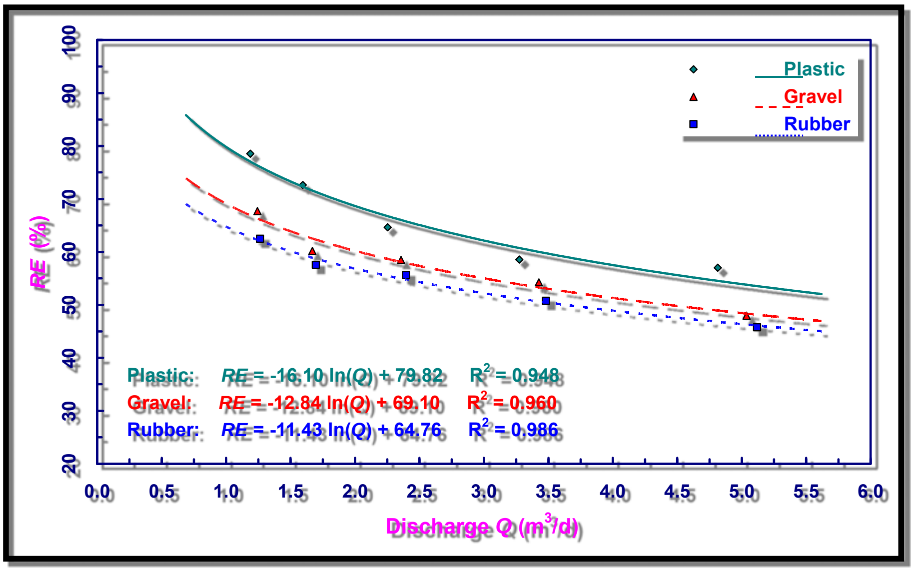

Figure 6 Relationship between ammonia removal efficiency and discharge

From Figure 6, it could be concluded that as the discharge increases, the removal efficiency of ammonia decreases for the three media, indicating deterioration of treatment performance. The plastic channel has the highest removal efficiency followed by the gravel. This may be because of the higher surface area (high amount of attached biofilm) of plastic media than the other media. At the biggest Q (4.814, 5.037, and 5.119 m^3/d), the ammonia removal efficiency values are about 57, 47.97, and 45.75% for plastic, gravel, and rubber channels, respectively. While these values are 78.53, 67.69, and 62.48% for the smallest Q (1.188, 1.243, and 1.263 m^3/d). The ammonia removal efficiency for plastic media increases by an average value of 8.56 and 11.84% higher than gravel and rubber media. While in gravel channel the ammonia removal efficiency is higher than rubber channel by about 3.28%. The ammonia removal efficiency gradually decreases with the increasing discharge value for the three media, according to a logarithmic function. The logarithmic equations at outlets are written as:

$$Plastic: \quad RE = 79.82 - 16.1 ln Q \qquad R^2 = 0.948 \quad \text{(1٥)}$$

$$Gravel: \quad RE = 69.1 - 12.84 \ln Q \qquad R^2 = 0.960 \quad \text{...} (1٦)$$

$$Rubber: \quad RE = 64.76 - 11.43 \ln Q \qquad R^2 = 0.986 \quad \text{...............................} (1٧)$$

Where:

3.2 Zinc Treatment

The influent Zinc was analyzed with both loading rate and effluent concentration. The variation of pollutant removal efficiency and both retention time and sewage loads were studied.

3.2.1 Inlet and Outlet Ammonia Relationships

Table 3 presents the average inlet and outlet Zinc concentrations and the corresponding removal efficiency for plastic, gravel, and rubber media at outlets. The influent and effluent Zinc concentrations at outlets are presented as clustered columns in Figure 7 for the three media.

Table 3 Zinc concentration and removal efficiency for wetland channels.

Cycle No.	Influent (mg/l)	Effluent Concentration (mg/l)			Zn Removal Efficiency (%)		
		Rubber	Gravel	Plastic	Rubber	Gravel	Plastic
1	1.85	1.12	1.04	0.90	39.35	43.54	51.32
2	1.64	0.91	0.80	0.60	44.58	51.41	63.21
3	1.54	0.77	0.65	0.48	49.51	57.47	68.76
4	1.73	0.66	0.59	0.48	61.73	65.59	72.17
5	1.58	0.49	0.40	0.29	68.65	74.91	81.83

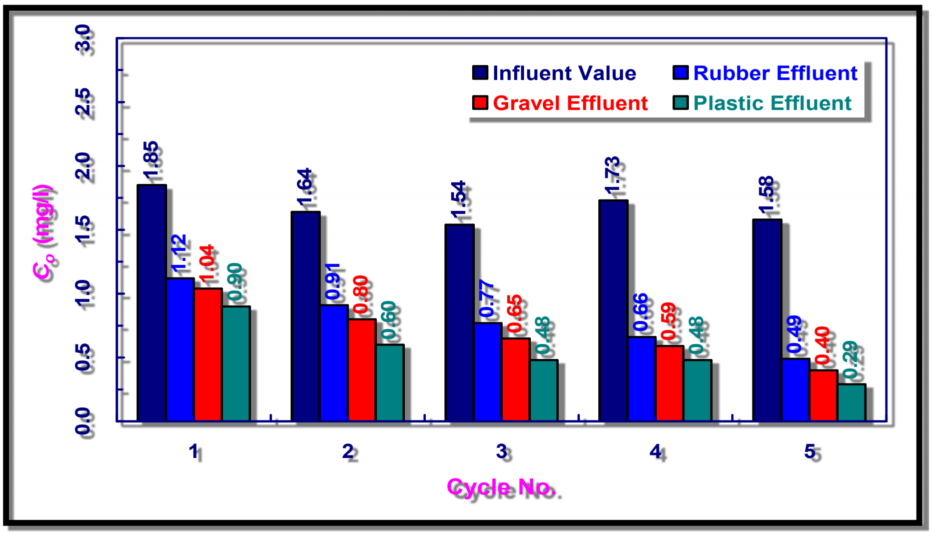

Figure 7 Influent and effluent Zinc concentrations of used media for various cycles

Table 3 and Figure 7 demonstrate that, Zinc effluent concentrations are in the allowable limit (less than 5 mg/l) of law No. 48 of 1982 (NAWQAM, 2002) at discharge lower than 4.814, 5.037, 5.119 m^3/d (q equal 24.07, 25.19, 25.6 cm/d) for plastic, gravel, and rubber media at outlets, respectively.

3.2.2 Impact of *q* on Zinc Treatment

Figure 8 represents the variation of Zinc outlet concentration and loading rate at outlets for plastic, gravel, and rubber media.

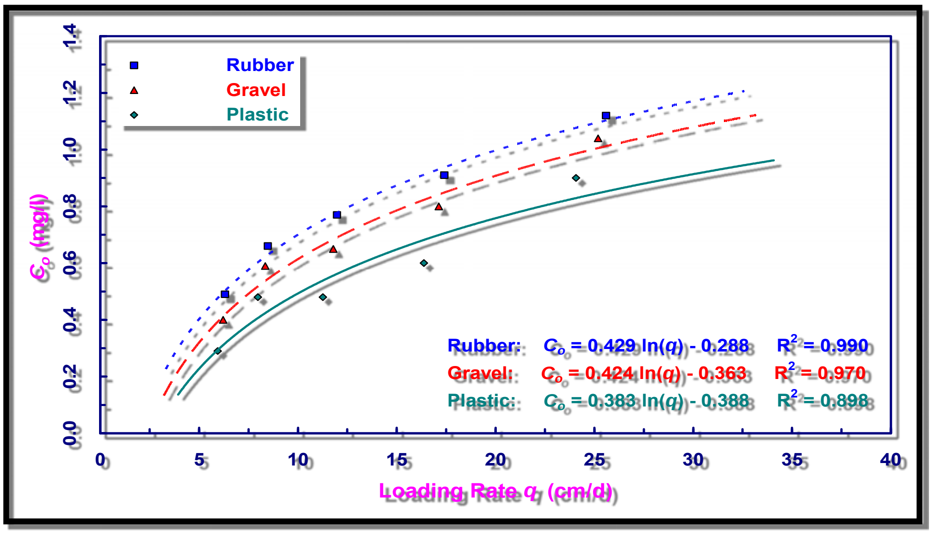

Figure 8 Relationship between C_o and hydraulic loading rate for Zinc element.

Figure 8, it could be concluded that the Zinc effluent concentration decreases with the decrease of loading rate, which means the enhancement of the treatment performance for the three media at outlets. For cycle one (Q_{max} = 4.814, 5.037, and 5.119 m^3/d), the Zinc influent concentration is 1.85 mg/l and the q values are 24.07, 25.19, and 25.6 cm/d for plastic, gravel, and rubber channels, in the same order with corresponding outlet concentrations of 0.9, 1.04, and 1.12 mg/l. For cycle five (Q_{min} = 1.188, 1.243, and 1.263 m3/d), the Zinc influent concentration is 1.58 mg/l and the q values are 5.94, 6.22, and 6.32 cm/d for plastic, gravel, and rubber channels, respectively with corresponding effluent concentrations of 0.29, 0.4, and 0.49 mg/l. At low hydraulic loading rate, the differences between outlet Zinc concentrations for the used media are small and these differences increase at high values of loading rate. Plastic channel gives the lowest Zinc outlet concentration followed by gravel channel. The Zinc effluent concentration directly proportions with the loading rate according to a logarithmic function.

$$Plastic: \quad C_o = -0.388 + 0.383 \ln q \qquad R^2 = 0.898 \ \ldots\ldots \ (1٨)$$

$$Gravel: \quad C_o = -0.363 + 0.424 \ln q \qquad R^2 = 0.970 \ \ldots\ldots \ (1٩)$$

$$Rubber: \quad C_o = -0.288 + 0.429 \ln q \qquad R^2 = 0.990 \quad \text{.......................................} (٢٠)$$

3.2.3 Impact of T_r on Zinc Removal Efficiency

Figure 7.66 shows the relationship between Zinc removal efficiency and Tr for plastic, gravel, and rubber media at outlets.

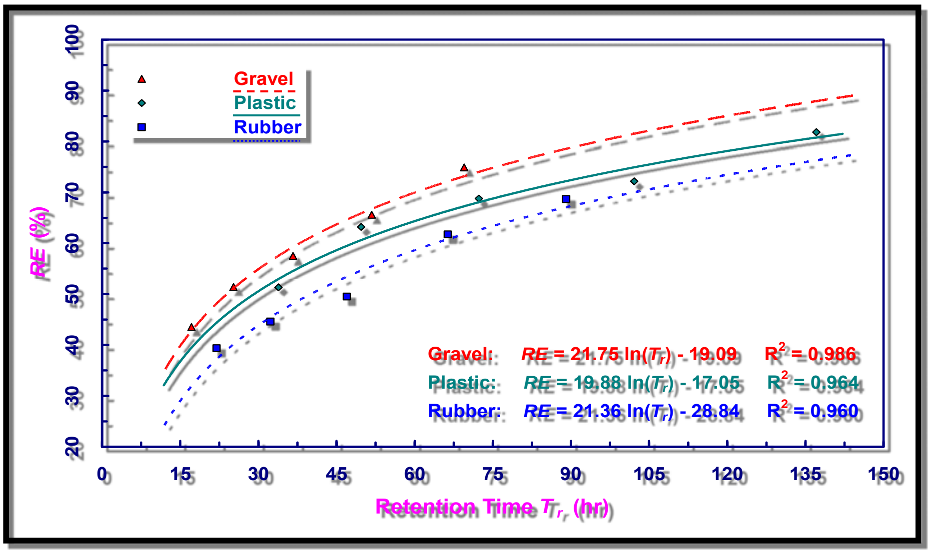

Figure 9 Relationship between Zinc removal efficiency and hydraulic retention time.

Figure 9, it is remarked that Gravel channel gives the highest Zinc removal efficiency followed by plastic channel. The Zinc removal efficiency increases with the increase of Tr values for the used media at outlets. The treatment improves with the increase of retention time for each media. For example for plastic channel at retention time equals 33.84 hr, the removal efficiency equal to 51.32%, while at Tr equals 137.11 hr, the removal efficiency becomes 81.83%.The difference between removal efficiency of Zinc for gravel and plastic channels is small at low retention time and increases with the increase of Tr values. The Zinc removal efficiency for the three media is directly proportional to retention time according to a logarithmic function as the best fit relationship.

$$Plastic: \quad RE = -17.05 + 19.88 \ln T_r \qquad R^2 = 0.964 \qquad (٢١)$$

$$Gravel: \quad RE = -19.09 + 21.75 \ln T_r \qquad R^2 = 0.976 \qquad (٢٢)$$

$$Rubber: \quad RE = -28.84 + 21.36 \ln T_r \qquad R^2 = 0.960 \qquad (٢٣)$$

3.2.4 Impact of Discharge on Zn Treatment Efficiency

Figure 10 shows the relationship between the discharges for the used media and the corresponding Zinc removal efficiency.

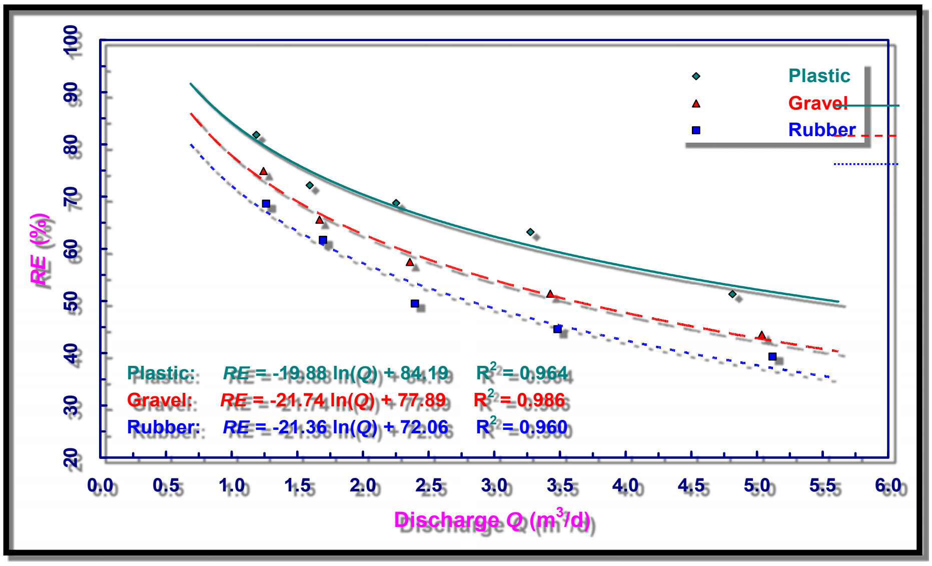

Figure 10 Relationship between Zinc removal efficiency and discharge for wetland channels.

Figure 10 it could be concluded that as the discharge decreases, the removal efficiency of Zinc increases for the three media and the treatment enhances. At the biggest Q equals 4.814, 5.037, and 5.119 m^3/d, the Zinc removal efficiency is about 51.32, 43.54, and 39.35% for plastic, gravel, and rubber channels. At the smallest Q equal to 1.188, 1.243, and 1.263 m^3/d the removal efficiencies are 81.83, 74.91, and 68.65%, respectively. The plastic channel has the highest Zinc removal efficiency followed by gravel channel. The Zinc removal efficiency for rubber media decreases by average values of 5.82 and 14.69% lower than gravel and plastic media, in the same order. Plastic channel gives Zinc removal efficiency higher than gravel channel by an average of 8.87%. The Zinc removal efficiency is gradually decreased by the increase of discharge for the used media according to a logarithmic function. The logarithmic equations at outlets are as follows:

$$Plastic: \quad RE = 84.19 - 19.88 \ln Q \qquad R^2 = 0.964 \quad \text{(٢٤)}$$

$$Gravel: \quad RE = 77.89 - 21.74 \ln Q \qquad R^2 = 0.986 \quad \text{(2٥)}$$

$$Rubber: \quad RE = 72.06 - 21.36 \ln Q \qquad R^2 = 0.960 \quad \text{(2٦)}$$

4. Conclusion

The conclusions which were reached from the previous analysis of the obtained results are as follow:

- At channels outlets, ammonia removal efficiency improved from 57 to 78.53% in plastic channel after moving from Q_{max} to Q_{min}, from 47.97 to 67.69% in gravel channel, and from 45.75 to 62.48% in rubber channel.
- From experimental results at channels outlets, plastic media gave average ammonia removal efficiency lower than gravel and rubber media by 8.56 and 11.84%, respectively.

- For plastic, gravel, and rubber media, the ammonia concentration (at outlet) was in the permitted limit (less than 10:12 mg/l) at loading rate lower than 24.07, 25.19, and 25.6 cm/d, respectively.
- At channels outlets, Zinc removal efficiency enhanced from 51.32 to 81.83% in plastic cell after moving from Q_{max} to Q_{min}, from 43.54 to 74.91% in gravel channel, and from 39.35 to 68.65% in rubber channel.
- The Zinc removal efficiency for plastic media increased by an average value of 8.87 and 14.70% than gravel and rubber media, respectively.
- Significant improvement in the characteristics of the wastewater as the wastewater flowed through the wetland channel and the quality of the effluent water enhanced along the treatment path of flow.
- The gravel channel has the lowest retention time followed by the rubber and then the plastic channel. This is compatible with the porosity of the three media types. The gravel media has the smallest porosity followed by rubber media, while plastic media has the greatest porosity.
- Wavy plastic pipes and shredded tires pieces have proved to be a good economical media for treating NH_3 and Zn.
- The empirical relationships which developed in this study can be used in the rational design of horizontal subsurface flow wetlands for conditions similar to the ones under which this study was conducted.

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APPENDIX NOTATION

The following symbols are used in this paper:

A = Wetland surface area, L^2
C_d= coefficient of discharge, D.L.
C_{i} = Influent concentration; M/L^3
C_o= Effluent concentration, M/L^3
H_d= Head over the notch, L
n = porosity, D.L
n_g = Porosity of gravel, D.L
n_{cg}= Porosity of course gravel, D.L
n_r= Porosity of rubber media, D.L
n_p= Porosity of plastic media, D.L
q = Hydraulic loading rate, L/T
Q = Discharge, L^3/T
Q_{act} = Actual discharge, L^3/T
Q_{avr}= Averagedischarge L^3/T
Q_i= Inlet flow rate, L^3/T

Q_{Th}= Theoretical discharge, L^3/T
R^2 = Determination coefficient, D.L.
RE = Pollutant removal efficiency, D.L.
T_r = Hydraulic loading rate, T
V_{Wx} =Volume of water inside channel at distancex, L^3
θ = Apex angle of V-notch, D.L.
CWS = Constructed Wetlands
NH_3 = Ammonia.
Zn = zinc