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Application of low-cost fabricated column model for the adsorption analysis of pollutants from river water using coconut coir

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ABSTRACT

A simple fabricated column model of coconut coir was used to adsorb pollutants from polluted river water. This study proposes the application of this model that applied coconut coir to remove organic matter (OM), phosphate (PO_4^{3-}), and ammonia (NH_3) present in river Desa Bakti water. A mathematical model is also developed based on the experimental data as a prerequisite analysis to find out the affinity of adsorbent/adsorbate. The obtained mass transfer for OM was faster when compared to NH_3 and PO_4^{3-}. Resistance of mass transfer was verified based on the concentration of contaminant which usually depends on its environmental driving forces. The maximum growth rate observed for bacteria is 4.7756 g new cells/g cells·d, which proved that OM in water had contributed as food source for the growth of micro-organisms in the model. Thus, the developed treatment technology using coconut coir is able to be applied for effective adsorption of OM, NH_3, and PO_4^{3-}.

Keywords: Fabricated column model; Adsorption analysis; Coconut coir; Mass transfer; Organic pollutant removal

1. Introduction

In many countries, rivers act as a source of drinking water. It is undoubted that rivers are vital carriers of water and nutrients to all areas around the earth [1]. However, due to the presence of excess amount of nutrients in the river, it might cause a lot of problems, such as eutrophication, harmful algal blooms, dead zones, and fish kills [2]. Therefore, it is essential to remove the nutrients from water in order to achieve environmental sustainability. The adsorption and filtration techniques are commonly used to remove various types of pollutants from effluents. However, interaction of liquid/solid interface is still vital to be scrutinized for elucidating the adsorption mechanisms due to physical, chemical, and biological processes [3,4]. Till date, the resistance of mass transfer for adsorption processes to remove pollutants from water has been widely carried out with different types of activated carbon and not attempted using coconut

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coir. However, the potential use of coconut coir as treatment medium remains less comprehensive, and thus, it is crucial to verify the feasibility of coconut coir as a low-cost adsorbent material [5].

Coconut coir is a natural fiber present within the shell of coconut. It is produced during the separation process of the fiber from the coconut husk. It has been widely used for different purposes such as mattress, baskets, and erosion-control blankets in Malaysia [6]. Annual production of coconut coir worldwide is around 650 000 tonnes especially from India, Sri Lanka, Thailand, Indonesia, Malaysia, Vietnam, and Philippines [7]. Since coconut coir occurs abundantly and naturally being a low-cost material, the recycling of this material for pollutants adsorption is considered to be cost-effective and also environmentally friendly. Previous studies indicate that coconut coir has been scrutinized mostly for the pollutants removal such as dyes, heavy metals, pesticides, and metal anions [8–10]. However, limited research has been carried out to investigate the ability of coconut coir to remove organic matter and nutrients present in the river water.

The presence of high concentration of nutrients, such as nitrogen and phosphorus, has been observed in river Desa Bakti, Johor Bahru, Malaysia. The river is polluted such that it is most likely to exceed Class III (moderately polluted) of the Interims National Water Quality Standard (INWQS) set by the Malaysian Department of Environment (DOE) [11]. One of the reasons for this to occur may be attributed to the insufficient wastewater treatment facility located nearby the rivers. This provides an opportunity for the application of fabricated column model employing coconut coir as adsorbent material for pollutant removal such as organic matter (OM), phosphate (PO_4^{3-}), and ammonia (NH_3). The use of coconut coir for nutrient removal and river water treatment is considered as a competitive and effective treatment method due to the low cost, market availability, and simplicity of its application and operation. Therefore, the current study was undertaken with the following objectives: (1) to determine the pollutants removal efficiency of coconut coir for river water treatment, (2) to investigate the mass transfer between the relationship of adsorbate and adsorbent, and (3) to indicate biofilm activity via maximum growth rate of bacteria in coconut coir treatment after the final effluent discharge.

2. Materials and methods

2.1. Location

The study was conducted at river Desa Bakti in Johor Bahru, Malaysia. Samples of water were collected directly from the river and circulated in the fabricated column model established besides the river that was used in the experiment. There were four oxidation ponds located nearby which discharged the effluent to this river which is then flowing to a pond located near the recreational park (Fig. 1).

Fig. 1. Location of study area (solid circle indicates the sampling site and location of fabricated column model) [12].

2.2. Fabrication of column model

The fabricated column model, in this study, is the combination of three prefabricated cylindrical columns of 51 mm diameter which accommodates the treatment medium (i.e. coconut coir), storage tank, and water pump. The polluted river water to be treated was collected and stored in the storage tank with a volume of approximately 0.35 m. Prior to this, 45 grams of coconut coir was prepared which then equally divided into three portions to be installed in each of the cylindrical columns. The coconut coir before being installed to the cylinder was submerged in distilled water for 24 h in order to remove possible dust and other impurities attached to it. The treatment process lasted for 9 days whereby the water in the storage tank was consistently circulated with the help of defragmented pump with an approximate flow rate of 0.125 L/s. The conceptual diagram of the fabricated column model for pollution adsorption study is illustrated in Fig. 2.

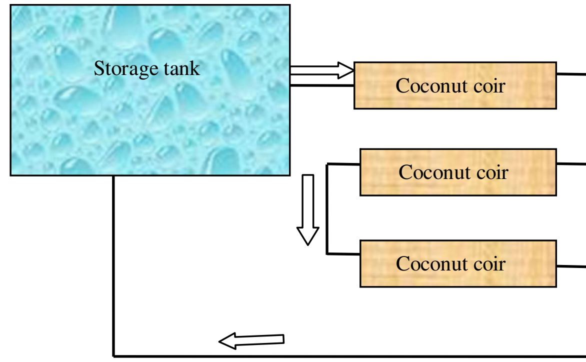

Fig. 2. An illustration of fabricated column model accommodating the coconut coir for pollutant adsorption study.

2.3. Methodology

The study was conducted in relation to treatment efficiency and feasibility of coconut coir function which includes chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), and phosphate (PO_4^{3-}). The COD was used to indentify OM in water, NH_3-N was used to measure NH_3, and PhosVer3 method was used to identify by PO_4^{3-} [13]. All the methods used for measurements were according to the standard methods for the examination of water and wastewater [13].

2.4. Mathematical model development

The mathematical model development was carried out in order to analyze the adsorption ability of coconut coir in reducing pollutants concentration present in water. This provides an understanding in the adsorption rate change due to the physical, chemical, or biological processes. Physical adsorption and chemical reaction typically depend on adsorbate molecule and the porosity of the adsorbent [14]. However, in biological reaction, it is normally focused on biofilm activity of selected growth-limiting nutrients present in the treatment and the micro-organisms that influence the organic-pollutant removal from water [15].

2.4.1. Rate expression

Metcalf and Eddy (2003) stated in their works that the changes in physical, chemical, and biological reaction of coconut coir to pollutants are rate-dependent [16]. A simple mass balance method was used for pollutant adsorption by coconut coir, and it was found that the effect of pollutant reduction time is crucial in determining the reaction rate, via first-order rate.

$$q_t = \frac{(C_0 - C_t) \times Q \times t}{m} \tag{1}$$

Table 1
Sample calculation of accumulation mass of COD concentration in coconut coir

t (d)	Q (L/s)	Q (m^3/d) (×10^3)	m (g)	C_o (g/m^3)	C_t (g/m^3)	C_o−C_t	$R = Q$ (C_o−C_t), (g/d)	P = R × t, (g)	$q_t = P/m$, (g/g)	q_t accumulates
0	0.125	10.8	45	37		0	0	0	0	0
1					33.00	4.00	43.20	43.20	0.96	0.96
2					10.00	27.00	291.60	583.20	12.96	13.92
3					36.50	0.50	5.40	16.20	0.36	14.28
6					22.25	14.75	159.30	955.80	21.24	35.52
7					17.00	20.00	216.00	1512.00	33.60	69.12
8					28.50	8.50	91.80	734.40	16.32	85.44
9					27.25	9.75	105.30	947.70	21.06	106.50

The accumulation of organic pollutant mass adsorbed per mass of coconut coir (in g/g) vs. time (in d) is crucial in order to identify different reactions that will affect the reduction of organic pollutant in water, since the water is circulated through the fabricated column model. As the initial flow rate (Q_o) was kept constant operated for nine consecutive days, the contamination can be reduced significantly. The sample of the calculation can be expressed as in Table 1.

2.4.2. Resistance mass transfer

In order to identify the process of pollutants reaction with coconut coir, resistance mass transfer method was used for analyzing the experimental data. This study implemented the developed mathematical models as proposed by Fulazzaky which is capable to determine the mass transfer for the adsorption of pollutants onto coconut coir [17].

$$q = B + \frac{1}{\beta} \times \ln t \tag{2}$$

where

$$B = \frac{\ln([k_{\mathrm{L}}a]_{\mathrm{g}}) - \ln(\ln C_0/C_t)}{\beta} \tag{3}$$

As per theoretical analysis, mass transfer rate is the transfer rate of pollutant from higher concentration to lower concentration. The concept of transfer is similar to the osmotic pressure system that will concurrently affect the level of contamination reduction by normal ambient pressure. Both fluid flow and separation unit operations are the predominant activity in segregation method and mass transfer rate. The amount of mass transfer can be calculated using mass transfer models. The experimental data can be further established with the mathematical kinetics of reactive pollutant adsorption onto any other kind of material. For example, coconut coir as adsorbent has been investigated for removal rate, which is strongly related to the properties of coconut coir, concentration, and properties of pollutants present in water. However, this is only able to be implemented once the adsorbates attached to the adsorbent.

2.4.3. Organic substrate utilization rate

The study describes bacterial growth rate through utilization of organic matter present in the fabricated column model. Theoretically, the organic matter is possible to be subtracted in biofilm, but it is very low compared with aqueous solution phase concentration of organic matter [18]. Therefore, the utilization rate of organic matter in biofilm can be described as follows:

$$r_{su} = \frac{\mathrm{d}C}{\mathrm{d}t} = \frac{\mu_{\max}}{Y}\left(\frac{CX}{K_C + C}\right) = -\frac{kXC}{K_C + C} \tag{4}$$

where

$$Y = \frac{\text{g biomass yield}}{\text{g substrate utilized}} = \frac{\mathrm{d}X}{\mathrm{d}C} \tag{5}$$

It is proposed by Monod where micro-organisms are able to grow in limiting substrate available in the fabricated column model [19]. In fact, the Eq. (4) is suitable to be used in order to find the specific growth of bacteria, and it is also being recognized as a saturation kinetic equation [16]. However, plotting the correlation of r_{su} vs. C in Eq. (4) will engender a curve. Therefore, basic integration is needed to develop a linear mathematical equation as followed:

$$\frac{1}{t}\ln\left(\frac{C_0}{C_t}\right) = -\frac{1}{\mathrm{k}X}\left(\frac{C_0 - C_t}{t}\right) + \frac{\mathrm{k}X}{K_c} \tag{6}$$

The particular rate of expression equation employed to classify kinetics involved in organic substrate utilization are based on the possibility of the experimental data to fit the kinetic equations and kinetic model [16]. Table 2 shows the calculation of COD in kinetic model.

There are several assumptions that need to be made. The system consist of coconut coir is assumed as a "black box". This is relevant in modeling the mechanisms of mass transfer and in achieving maximum growth rate of bacteria due to organic matter

Table 2
Calculation of COD to determine kinetic rate

T	C_o (mg/L)	C_t (mg/L)	$1/t \ln (C_o/C_t)$	$(C_o-C_t)/t$
0	37		0	0
1		33.00	0.114410	4.000000
2		10.00	0.654166	13.50000
3		36.50	0.004535	0.166667
6		22.25	0.084763	2.458333
7		17.00	0.111101	2.857143
8		28.50	0.032627	1.062500
9		27.25	0.033985	1.083333

utilization. In order to further explain the empirical model and coefficients, the hypotheses were made based on the following: (1) circulated water flow from the closed plug-flow fabricated column model and storage tank; (2) quantity of water flow was same for inlet and outlet; (3) surface area of coconut coir is fixed throughout the experiment.

3. Results and discussion

3.1. Level of OM, NH_3, and PO_4^{3-} concentrations

The effects of contact time, initial concentration of adsorbate and adsorbent dose were studied at the beginning of experiment. Typical contaminants, such as OM, NH_3, and PO_4^{3-}, were in specific interest for the whole process of pollutant removal by coconut coir. In existing condition, the level of pollutants were recorded as 37 mg/L COD, 5.15 mg/L NH_3-N and 0.473 mg/L PO_4^{3-}. Domestic wastes from nearby residential area, water runoff from landscape area and low efficiency of wastewater treatment system has caused river quality deterioration such that it contains too high nutrients and lead to algae bloom and death of fishes in the river [20]. Although the river water is not intended for drinking purposes, but the results showed that it does not meet the INWQS under Class III category, where maximum permissible limit for COD is less than 25 mg/L and for NH_3-N is less than 0.3 mg/L. According to INWQS, the water can be used only for recreation purpose. In fact, there is no phosphate concentrations proposed in INWQS [21]. However, according to Environmental Protection Agency, EPA in 1976, phosphate concentration that exceeded 0.025 mg/L will cause excessive growth of algae and other aquatic plants [21]. Figs. 3–5 show the quality of water obtained after coconut coir treatment was carried out for consecutive nine days. It shows that there exists a greater potential for coconut coir to be used as an adsorbent for reducing high-nutrient concentrations present in the water.

From Figs. 3–5, the maximum COD removal is depicted up to 73% during the second day of treatment. However, the COD removal recorded was found to be as unstable trend after day one. This might be due to the accumulation of organic content in the coconut coir within fixed volume of water which had contributed to the concentration of OM after the second day of experiment. This also indicates that carbonaceous COD would have leached out from the coconut coir into the water during the early stages of the experiment (three days), as stated by previous study where the COD value on second week in the experiment increases 50% and was found to be more than the 1st week of experiment [22]. There are also other researchers reporting that about 25 g COD/kg of coconut husk will be leached out during the experiment [23]. As for the second-day testing, the result shows only 24% of PO_4^{3-} removal and 62.13% of NH_3-N removal. But the percentage of PO_4^{3-} and NH_3-N obtained showed significant reduction up to 85 to 99%, respectively, after nine days of the experiment. The results showed that coconut coir can be comparable with other available market adsorbents for water treatment because of its reliability, relatively cheap and being an eco-friendly material.

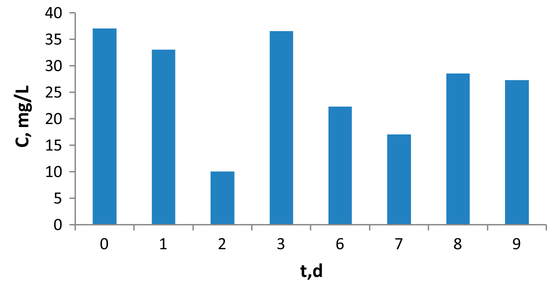

Fig. 3. Relation between chemical oxygen demand (COD) concentrations (mg/L) vs. time (d).

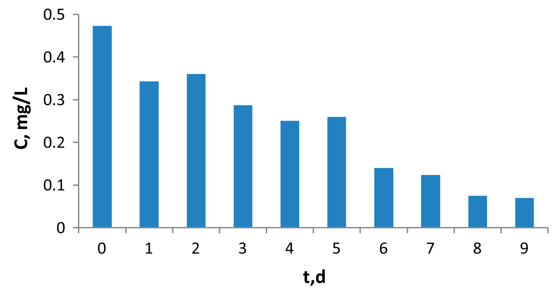

Fig. 4. Relation between phosphate (PO_4^{3-}) concentrations (mg/L) vs. time (d).

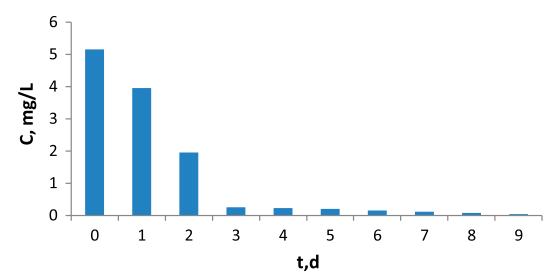

Fig. 5. Relation between ammonia Nitrogen (NH_3-N) concentrations (mg/L) vs. time (d).

3.2. Performance of coconut coir based on accumulation rate

The accumulation of pollutants mass onto coconut coir in a day (q_t accumulated) was calculated based on Eq. (1), and the results are shown in Table 1. A polynomial regression equation was developed by plotting the correlation result of q_t accumulated (q_t acc) vs. time (t) as shown in Figs. 6–8.

The accumulated adsorption quantity can be expressed by the capacity of proposed media toward the contaminant present in water. The results showed exponential trend for adsorption quantity of pollutants onto coir. It is also confirmed that the results obtained deviated significantly from a quadratic line, $y = ax^2 - bx + c$. Correlation for q_t and t was high ($R^2 > 0.9$) indicating that quadratic regression analysis is reasonable for studying the adsorption accumulation mechanism rate of coir onto the contaminants in water. This describes that recirculation of water sample might have caused the effectiveness of adsorption of mass pollutants onto the coir, therefore increased by time. The reason for accumulation of mass pollutant onto coconut coir can be described further based on the mathematical model of mass transfer as stated by Fulazzaky [5]. A further study on the closed-loop relationship between adsorbate and adsorbent is needed for analyzing the different properties of pollutants to coconut coir which will lead to different mass pollutant accumulation rate onto coconut coir. The aging or stability of pollutants might cause the saturation kinetics rate in the treatment and the different initial concentration and molecular weight of pollutant in water also influences the adsorption ability of coconut coir for the pollutants [24].

3.3. Development of mathematical model

A previous study by Fulazzaky in 2011 has proposed the resistance mass transfer approach

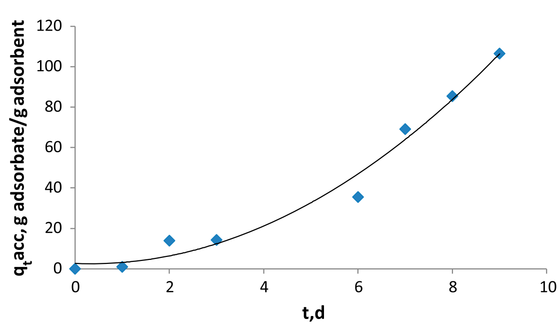

Fig. 6. Effect of q_t acc vs. t for OM accumulation in coconut coir, represented by quadratic equation q_t acc = $1.3784t^2 - 0.8835t + 2.653$ and $R^2 = 0.9804$.

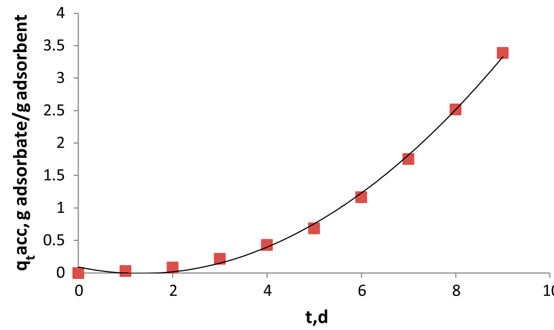

Fig. 7. Effect of q_t acc vs. t for PO_4^{3-} accumulation in coconut coir represented by the equation of q_t acc = $0.0566t^2 - 0.1498t + 0.0892$ and $R^2 = 0.9971$.

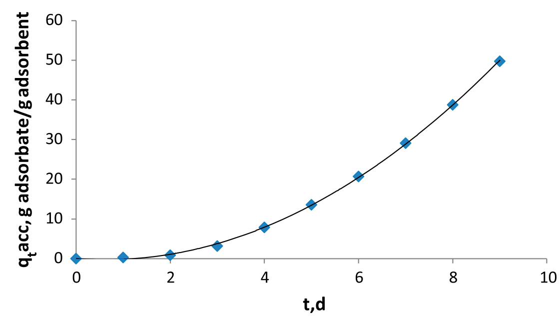

Fig. 8. Effect of q_t acc vs. t for NH_3 accumulation in coconut coir represented by the equation of q_t acc = $0.7167t^2 - 0.8957t + 0.0122$ and $R^2 = 0.9997$.

stated in Eqs. (2) and (3) as to assess the impacts of physiochemical sorption of the adsorbate to the adsorbent [17]. In this study, the conceptual model was developed using assumptions as follows: (a) progressive increase in mass of OM, NH_3, and PO_4^{3-} accumulated in the coconut coir pursuant to time (t), (b) the concentration of OM, NH_3, and PO_4^{3-} not only depends on the properties of coir mass but also due to the degradation effect of micro-organisms present in water or on the attached coir since water is being recirculated constantly within the fabricated column model.

Therefore, the mathematical model was developed with the following assumptions: (1) many phenomena need to be taken into consideration such as driving force and affinity adsorbate/adsorbent to make accurate and reliable prediction. (2) $q = \log q_t$acc is defined as the accumulation of mass pollutant to coir due to the circulation of water in model pursuant to ln t. The resulting plot of q vs. ln t for OM, NH_3-N, and PO_4^{3-} are shown in Fig. 9.

3.4. Analysis of adsorbate/adsorbent affinity

From the Eq. (2), the coefficient β and intercept B can be determined using Fig. 9. The coefficient β is the affinity adsorbate and adsorbent related to molecular weight, molecular structure, solubility/polarity, and properties of adsorbent, while B is the potential mass transfer related driving force of the pollutant concentration in water to the adsorbent due to physical, chemical, and biological process (as mention in Eq. 3) [5]. Experimental data validations showed that the value β for OM adsorption (1.2055 gd/g) was higher than PO_4^{3-} (0.9314 gd/g) and the circulation would create a better chance for the biodegradability of organic matter in polluted water. It can be assumed that coconut coir can serve as a base medium for biological growth in order to develop microbial film and utilize all organic and nutrient contaminants as food sources [25]. In addition, the molecular weight of PO_4^{3-} (94.97 g/mol) is greater than NH_3 (17.031 g/mol) and shows that greater molecular weight of adsorbate increases adsorption by the formation of Van der Waals force between adsorbate and adsorbent [26]. Hence, the molecular weight of organic pollutants to attract the force between adsorbate to adsorbent is considerably significant. However, the different value β obtained between PO_4^{3-} (1.0491 gd/g) and NH_3 (0.9314 gd/g) remains negligible which is only 0.1177 gd/g. This is because ammonia molecule has the shape of trigonal pyramid which makes the molecule polar and readily dissolves in water when being recirculated through the adsorbent [27].

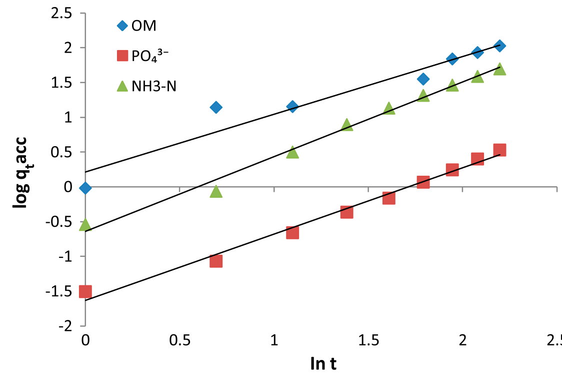

Fig. 9. Plot of q vs. ln t for accumulation mass of OM (q = 0.8295ln t + 0.2136, R = 0.9328), NH_3 (q = 1.0736ln t −0.6392, R^2 = 0.9905) and PO_4^{3-} (q = 0.9532 ln t -1.6352, R^2 = 0.9881) onto coconut coir.

3.5. Analysis of mass transfer

The effects of concentration, granulometric size distribution and hydrodynamic condition on the mass transfer for the adsorption of solute onto coconut coir in aqueous solution has been identified by index B and β [17]. Similarly, in this study, the effect of pollutant concentration influencing the mass transfer rate was analyzed for the adsorption of OM, PO_4^{3-} onto coconut coir. It was found that higher concentration of pollutant in water induces strong C_t, thereby increases the potential mass transfer, and the pollutant adsorption present in water for OM was also found to be highest, followed by NH_3, and PO_4^{3-} since the initial concentration before adsorption study of OM was 37 mg/L, while NH_3 is 5.15 mg/L and PO_4^{3-} is 0.473 mg/L. Therefore, increase in mass transfer was observed along with the increasing mass of pollutants adsorption onto coconut coir (Table 3).

It was found that $[k_L a]_g$ was in the order of OM ≫ NH_3 ≫ PO_4^{3-} (Figs. 10–12) indicating that the mass transfer rate for OM was significantly higher compared to NH_3 and PO_4^{3-}. The presence of multivarious existing pollutants in feed water can decrease the mass transfer due to the competition in same adsorption sites. A close relationship between biodegradability and mass transfer may arise due to the circulation of sample water in the fabricated column model involving the attachment of micro-organisms onto the surface groups of coconut coir [28]. In fact, it can be concluded that $[k_L a]_g$ for OM is higher than NH_3 and PO_4^{3-}, because the types of micro-organism present in the water may be more favorable to consume organic matter when compared to NH_3 and PO_4^{3-}. The same was reviewed by Qureshi and his researchers in the year, 2005 where the micro-organisms occurring naturally are able to produce biofilms and reduce the COD simultaneously in the water [29].

Table 3
Values of $[k_L a]_g$ determined by graphical method

Parameters/percentage of outflow	2	5	8	10	20	50
OM (day^{-1})	0.043075	0.032996	0.027826	0.025372	0.017747	0.007668
NH_3 (day^{-1})	0.004507	0.003591	0.003121	0.002897	0.002204	0.001288
PO_4^{3-} (day^{-1})	0.003676	0.002852	0.002429	0.002228	0.001604	0.000779

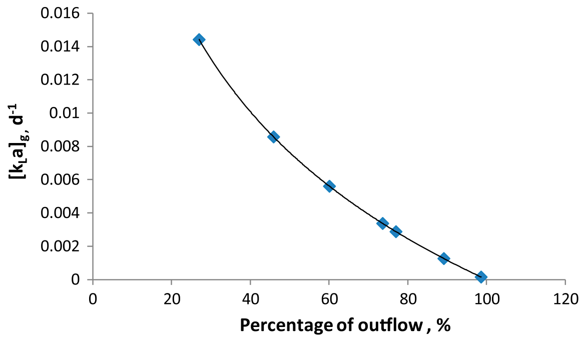

Fig. 10. Variations of $[k_La]_g$ pursuant to percentage outflow for OM.

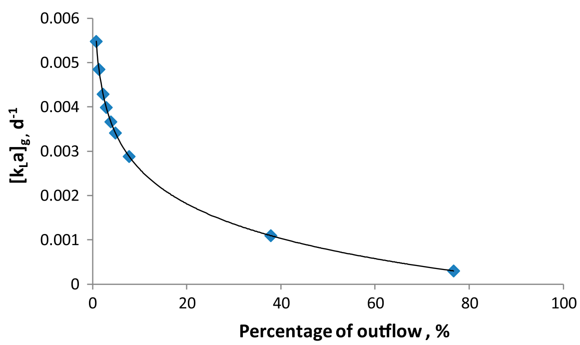

Fig. 11. Variations of $[k_La]_g$ pursuant to percentage outflow for NH_3-N.

3.6. Analysis of biological adsorption

In actual experiment, the assessment of laboratory analysis can be utilized for fabricated column model performance as critical capability of treating wastewater containing high organic content. The adsorption of solute onto coconut coir in aqueous solution due to affinity of adsorbent/adsorbate is one of the key for organic pollutant treatment. However, biofilm activity in the fabricated column model also acts as an indicator for nutrient utilization by the micro-organisms in water and coconut coir. In this study, the circulation of aqueous solution in the fabricated column model boosts to increase the contact of liquid with coconut coir and deliver oxygen to the water. The saturation reaction of OM is shown in Fig. 13.

The performance of biological process used for wastewater treatment depends on the dynamic of substrate utilization and microbial growth. It is noted that the expression of saturation rate for OM utilization showed higher correlation coefficient R^2 = 0.9854, and the correlation regression seemed to be good. From Fig. 13, $1/K_c$ and kX/K_c can be estimated from the linear-regression line of $(1/t) \times \ln (C_0/C_t)$ vs. $[(C_0/C_t)/t]$. The slope and intercept of the graph can be represented as $1/K_c$ and kX/K_c, respectively. By using Eqs. (4)–(6), the maximum bacteria growth rate can be obtained.

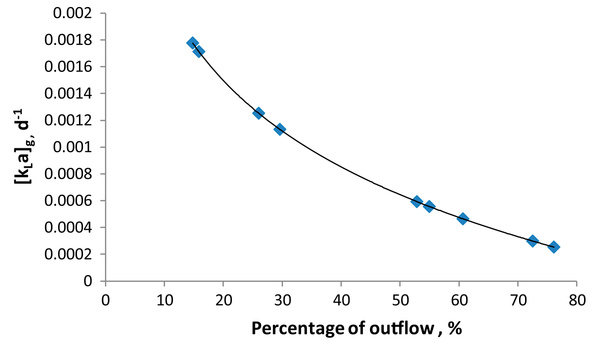

Fig. 12. Variations of $[k_La]_g$ pursuant to percentage outflow for PO_4^{3-}.

Simplifying $1/K_c$ and kX/K_c from Fig. 13, it yields kX = 0.4898. The maximum growth rate can later be determined by substituting Eq. (5) in Eq. (4), where the expression kX as a result of the substitution is similar to that of the kX value from Fig. 13. The final calculated maximum growth rate marked a total of 4.7756 g new cells/g cells·d.

Basically, the maximum specific growth rate of bacteria is related to maximum specific organic matter utilization rate. Increasing maximum growth rate of micro-organism in the model reflects the ability of the organic matter to be broken down into simpler substances by the micro-organisms as their population increases [30]. It was proved that the organic matter present in the water not only adsorbed onto the coconut coir but also degraded by the micro-organism presence simultaneously in the water and coconut coir [29,31]. The treatment method used in the current model was an attempt to improve not only the physical and chemical nature of adsorption but also to

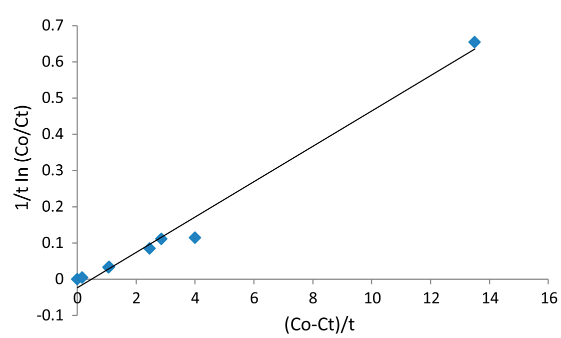

Fig. 13. Saturation order of COD designated $(1/t) \times \ln (C_0/C_t) = 0.0488 [(C_0/C_t)/t] -0.0239$, R^2 = 0.9854.

improve biodegradability determined to be more effective and efficient in treating polluted water.

4. Conclusions

The performance of the fabricated column model operated reduced COD to become stabilized at 26%. While PO_4^{3-} and NH_3-N levels were significantly reduced up to 85 and 99% at nine days, respectively. This study used mass transfer and bacteria growth rate analysis based on organic nutrient utilization rate to investigate the adsorption of organic matter, phosphate and ammonia onto coconut coir. The $[k_La]_g$ pursuant to the percentage outflow were traced separately to evaluate the properties of adsorbent and adsorbate that will influence the mass transfer either by physical, chemical, or biological process. The molecular weight, solubility/polarity of adsorbate for physical adsorption was significant and determination of the concentration of degraded adsorbate confirmed higher biodegradation of coconut coir in the treatment. The decrease of COD concentration in fabricated column model also proved the existence of biological and physical process in the model. The coconut coir in the fabricated column model along with circulating water showed biodegradability to be more effective and efficient.

Nomenclature

q_t	—	mass of organic pollutant adsorbed per mass of coconut coir in a day (g/g)
V	—	volume of water sample (m^3)
C	—	concentration of organic pollutant (g/m^3)
C_0	—	initial concentration of organic pollutant in river water (g/m^3)
C_t	—	concentration of organic pollutant in a day (g/m^3)
Q	—	flow rate of fabricated column model (m^3/d)
T	—	accumulation time of polluted water onto coconut coir (d)
M	—	mass of coconut coir used for the study (g)
R	—	load of pollutant in river water adsorbed by coconut coir per day (g/d)
P	—	load of pollutant in river water adsorbed by coconut coir (g)
q_t		acc
—		accumulation of organic pollutant adsorbed per mass of coconut coir (g/g)
$[k_La]_g$	—	mass transfer factor (d^{-1})
β	—	adsorbate–adsorbent affinity parameter (gd/g)
B	—	potential mass transfer index related to driving force and mass transfer (mg/g)
r_{su}	—	rate of organic pollutant concentration change due to utilization ($g/m^3 \cdot d$)
$_{max}$	—	maximum specific growth rate of bacteria (g new cells/g cells·d)
Y	—	biomass yield (g biomass/g COD removed)
X	—	biomass concentration (g/m^3)
K_c	—	saturation constant, when $r_{su} = 1/2$ of maximum r_{su} (g/m^3)
K	—	maximum specific organic pollutant utilization rate, (g/g·d)

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