นวัตกรรมการร่วมเครื่องปฏิกรณ์กวนชีวภาพแบบฟลูอิไดซ์เบด ด้วยแบบจำลองทางคณิตศาสตร์

An Integrated Fluidized Bed Bioreactor (iFBBR) by Mathematical Models

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บทคัดย่อ

งานวิจัยนี้มีจุดมุ่งหมายเพื่อการร่วมเครื่องปฏิกรณ์กวนชีวภาพแบบฟลูอิไดซ์เบด (Integrated Fluidized Bed Bioreactor; iFBBR) ซึ่งระบบการทำงานนั้นจะทำงานร่วมกับบ่อเติมอากาศและถังทรายกรอง ในการเพิ่มประสิทธิภาพการกำจัดสารอินทรีย์ได้รับการพัฒนาโดยใช้แบบจำลองทางคณิตศาสตร์ของเครื่องปฏิกรณ์แบบท่อไหลเวียน (RPFR) และเครื่องปฏิกรณ์ถังกวนแบบกวนผสมไหลเวียน (RCSTR) การประเมินและทำนายประสิทธิภาพการบำบัดน้ำเสียนั้นใช้เครื่องปฏิกรณ์ชีวภาพแบบฟลูอิไดซ์เบดกับถ่านกัมมันต์แบบเม็ด (FBBR-GAC) และบ่อเติมอากาศ จากการศึกษาครั้งนี้ได้นำน้ำเสียชุมชนโดยใช้ค่า BOD ในการทดสอบกับแบบจำลอง RPFR และ RCSTR ที่พัฒนาขึ้นพบว่าอัตราการหมุนเวียนที่เหมาะสม (R) มีค่าเท่ากับ 936 และอัตราความเร็วที่เหมาะสมของเครื่องกวน (N_B) คือ 26 รอบต่อนาที เกิดปฏิกิริยาแบบจำลองจลน์อันดับที่ 2 (k_{2nd}) ของเครื่องปฏิกรณ์ FBBR-GAC และบ่อเติมอากาศโดยมีค่า k_{2nd} ของ RPFR และ RCSTR เท่ากับ 1.543 และ 14 602 day^{-1} จากการเปรียบเทียบประสิทธิภาพของการกำจัด BOD ระหว่างเครื่องปฏิกรณ์ชีวภาพแบบฟลูอิไดซ์เบดกับถ่านกัมมันต์แบบเม็ด (FBBR-GAC) และ การร่วมเครื่องปฏิกรณ์ชีวภาพแบบฟลูอิไดซ์เบด (iFBBR) เพิ่มขึ้นจาก 83.64% เป็น 95.46% ใช้เวลาการหมุนเวียน (HReT) 0.0417 วัน ทั้งสองรุ่นมีความสำคัญต่อการออกแบบระบบบำบัดน้ำเสียในพื้นที่ชุ่มน้ำที่สร้างขึ้น

คำสำคัญ: เครื่องปฏิกรณ์ชีวภาพแบบฟลูอิไดซ์เบดกับถ่านกัมมันต์แบบเม็ดในอุดมคติ, การพัฒนาแบบจำลองทางคณิตศาสตร์, ถังปฏิกรณ์แบบไหลเวียน, ถ่านกัมมันต์แบบเม็ด, น้ำเสีย

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ABSTRACT

This study aimed to develop integrated fluidized bed bioreactor (iFBBR). The oxidation pond and sand filter were added for more treatment efficiency of this system. The organics substance removal efficiency was developed by using mathematical models of a novel recirculation plug-flow reactor (RPFR) and recirculation completely-mixed stirred tank reactors (RCSTR). The evaluated and predicted of wastewater treatment performance was conducted by a fluidized bed bioreactor with granular activated carbon (FBBR-GAC) and oxidation pond. On-site domestic wastewater was used in this study. The developed RPFR and RCSTR model can precisely predict the effluent BOD of wastewater at the optimum rate of recirculation (R) 936, and optimum rate of the bed's stirrer speed (N_B) 26 rpm. The kinetic results showed that the rate of BOD removal of wastewater used with FBBR-GAC reactors and Oxidation pond followed 2nd order kinetic models, with k_2^{nd}, RPFR and RCSTR values of 1.543 and 14.602 day^{-1} for treated sewage effluent, respectively. Additionally, it was found that the RPFR model and RCSTR model were more suitable for describing the behavior of the FBBR-GAC and oxidation pond system. The efficiency of BOD removal of FBBR-GAC was increased from 83.64% to 95.46% when compared with iFBBR. FBBR-GAC used the hydraulic recirculation time (HReT) of 0.0417 day. Both models are important to use for designing the waste water treatment system as constructed wetland.

Key words: integrated fluidized-bed bioreactor, development mathematical models, recirculation bioreactor, granular activated carbon (GAC), wastewater

INTRODUCTION

In the current years, as the community growth and industrialization have more and more increased consequential in resources and water crisis. Especially industrial department, agriculture and household, the water resource was use un appreciably used. These factors can cause wastewater and environmental damage (Suksomboon and Junsiri, 2018; Suksomboon *et al*., 2019a; Suksomboon *et al*., 2019b). The amount of wastewater has been influenced by water consumption. Thus, the wastewater treatment plant could support the organics loading in wastewater before release the treated water through public place but the high value of organics substance in wastewater such BOD and COD in wastewater cause the expensive treatment cost. Many sectors are concern about these issues.

In this study, the moving fluidized bed bioreactor with granular activated carbon (MFBBR-GAC) (Suksomboon and Junsiri, 2018; Suksomboon *et al*., 2019b) was category in bioreactor type of fluidized bed reactor as previous study (Fluidized bed bioreactor - Granular Activated Carbon, FBBR- GAC) (Patel *et al*., 2006; Lohi *et al*., 2008; Xing *et al*., 2010; Suksomboon *et al*., 2019b). The integrated fluidized bed bioreactor (iFBBR) plays a row model in side of remove the high organic substances by using the speed of stirrer bed (N_B) and recirculation ratio as the condition (Suksomboon and Junsiri, 2018; Suksomboon *et al*., 2019a; Suksomboon *et al*., 2019b). It was reported that many supporting media have been used in FBBR such as granular activated carbon (GAC), sand, perlite, zeolite, lava rocks with considerably successful application (Yu and Luo, 2002; Fernandez *et al*., 2007). With the combined adsorptionbiodegradation process using a fluidized bed bioreactor, an FBBR-GAC system offers high performance with a small footprint. It was found that GAC had a specific biofilm surface area approximately 1,600-2,000 m2/m3 (Qasim *et al*., 2000; Suksomboon *et al*., 2019a) leading to high growth rate of microorganisms on the biofilm surface and in internal pores, and high tolerance of organic loads during adsorption-biodegradation.

In this research study, the development of fluidized bed bioreactor granular activated carbon bioreactor (FBBR-GAC) to became the integrated fluidized bed bioreactor (IFBBR) for use in preliminary treatment processes (PTSE). The FBBR-GAC reactor consists of highly acrylic cylindrical, which inside has the wheel fixed system design from 24 nozzles to 8 nozzles for optimum rate of recirculation (R) and optimum rate of the bed's stirrer speed (N_B) as period study (Suksomboon and Junsiri, 2018; Suksomboon *et al*., 2019a; Suksomboon *et al*., 2019b).

The development of recirculation plug flow reactors (RPFR) and recirculation completely-mixed stirred tank reactors were use to predict the removal efficiency of organics substance (RCSTR) (Benefield, 1980; Tchobanoglous and Schroeder, 1985; Suksomboon *et al*., 2019b). In a iFBBR-GAC, fluid flow has two components, a rising flow and a rotational flow. Effectively, the fluid flows in an upward spiral (Suksomboon and Junsiri, 2018). Since the FBBR-GAC reactor is a cylindrical acrylic tank containing GAC that uses a high degree of recirculation, hydraulic recirculation time (HReT) is very important design criteria for this system (Saravanane and Murthy, 2000; Suksomboon and Junsiri, 2018; Suksomboon *et al*., 2019a; Suksomboon *et al*., 2019b). Thus the aeration pond (Oxidation ponds) in which wastewater is exposed to the air as much as possible in order to increase the growth of bacteria after the primary treatment process (PTSE). Filter clear water through a filtered sand tank (Yu and Luo, 2002; Fernandez *et al*., 2007).

This research focuses on developing mathematical model's reaction as the First order (n = 1) and second order (n = 2) of the reactor FBBR-GAC and pond aeration (Oxidation. Pond), over-current the hydraulic retention time (HReT) and the concentration are minimal, but no less than (background concentration: C*) for the reaction rate constant (k) to monitor precision and compare the efficiency of wastewater treatment reactor. FBBR-GAC with iFBBR.

MATERIALS AND METHOD

1. Developing mathematical models

The fluidized bed bioreactor-granular activated carbon (FBBR-GAC) was developed from the fluidized bed bioreactor (FBBR) concept. However, its operation combines the processes of a plug flow reactor (PFR) and a completely mixed stirred tank reactor (CSTR), which are classified as ideal reactors. Therefore, this study employed mathematical models of these two ideal reactors (Suksomboon *et al*., 2019b) to develop two new mathematical models for predicting the performance of a FBBR and then determining which model is the most suitable.

From the studied found that the hydraulic retention time (HRT) is the important factor to design the reactor. However, the hydraulic retention time value is difficult to calculate. Therefore, this study was using the area of reactor (Ar), the height of water and the hydraulic recirculation time (HReT) instead. Moreover, the background concentration (C*) was used (Kadlec, 2009). To complete mathematical model for the constant changes reaction rate constant (k) to check the accuracy of reactor two ideal types (Reynolds, 1982).

1.1 Development Recirculation plug-flow reactor (RPFR)

When the recirculation plug-flow reactor: RPFR is operating in steady state.

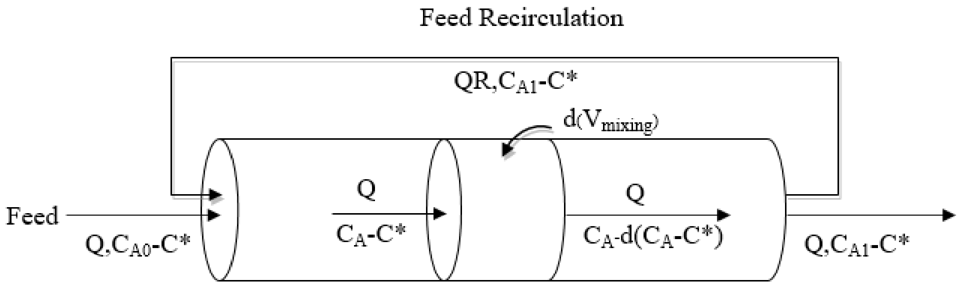

Figure 1 Recirculation plug-flow reactor (RPFR)

Figure 1 shows the thermodynamic principle of the conservation of mass. From such a principle can create the continuity equation for each component of the substance to study the changes within Control volume as shown in Eq. (1).

$$[\text{Input}] = [\text{Output}] + [\text{Decrease due to recirculation reaction}] \tag{1}$$

The development of ideal plug-flow reactor (PFR) to be recirculation plug flow reactor (RPFR) such a piston pattern as shown in Figure 1.

Due to the inlet is Q+QR which give the influent equal to C_{A0}-C* and effluent equal to C_{A1}-C* (Kadlec, 2009; Suksomboon *et al.*, 2019b). Therefore, the mass of component A travel in perpendicular with flow direction from the start and the concentration was evenly decreased during the time flows. The component A is becoming to Vmixing as show in the pattern of partial differential equation. Which can indicate the fluctuating of the concentration per the area of reactor (A_r), The hieht of water (h), and the hydraulic recirculation time (HReT) as the equation below.
Considering as a first order (n=1).

$$(Q+QR)(C_A - C^*) = (Q+QR)((C_A - C^*) - d(C_A - C^*) + r_A d(V_{mixing})). \tag{2}$$

Given $r_A = -k_1 st_{RPFR}(C_A - C^*)$, Arrearage for integrating results in

$$(Q+QR)d(C_A - C^*) = -k_1 st_{RPFR}(C_A - C^*)d(V_{mixing}), \tag{3}$$

integration yields

$$\int_{C_{A0}}^{C_{A1}} \frac{d(C_A - C^*)}{(C_A - C^*)} = \frac{-k_1 st_{RPFR}}{(Q+QR)} \int_0^{V_{mixing}} d(V_{mixing}). \tag{4}$$

$$\ln\left(\frac{(C_{A1} - C^*)}{(C_{A0} - C^*)}\right) = -k_1 st_{RPFR} \frac{V_{mixing}}{(Q+QR)}. \tag{5}$$

$V_{mixing} = Qt_{PFR} + Qt_{\text{Re}}$ is Volume of mixing

$$\ln\left(\frac{(C_{A1} - C^*)}{(C_{A0} - C^*)}\right) = -k_1 st_{RPFR} \frac{(Qt_{PFR} + QRt_{\text{Re}})}{(Q+QR)}. \tag{6}$$

From which

$$\ln\left(\frac{(C_{A1} - C^*)}{(C_{A0} - C^*)}\right) = -k_1 st_{RPFR} \frac{(t_{PFR} + Rt_{\text{Re}})}{(1+R)}. \tag{7}$$

Given $t_{PFR} = \frac{(1-f)Ah}{Q_{in}}$; f= specific gravity of media, A= area of Reactor, and h= height of Water

$$k_1 st_{RPFR} = -\frac{\ln\left(\frac{C_{A1}-C^*}{C_{A0}-C^*}\right)}{\frac{\left(\frac{(1-f)Ah}{Q_{in}}+Rt_{\mathrm{Re}}\right)}{(1+R)}}, \tag{8}$$

from which

$$C_{A1} = C^* + (C_{A0}-C^*)e^{-k_1 st_{RPFR}\frac{\left(\frac{(1-f)Ah}{Q_{in}}+Rt_{\mathrm{Re}}\right)}{(1+R)}}. \tag{9}$$

Considering as the second order (n=2)

$$(Q+QR)d(C_A-C^*) = r_A d(V_{mixing}), \tag{10}$$

Given $r_A = -k_2 nd_{RPFR}(C_A-C^*)^2$, Arrearage for integrating results in

$$(Q+QR)d(C_A-C^*) = -k_2 nd_{RPFR}(C_A-C^*)^2 d(V_{mixing}), \tag{11}$$

integrate

$$\int_{C_{A0}-C^*}^{C_{A1}-C^*} \frac{d(C_A-C^*)}{(C_A-C^*)^2} = \frac{-k_2 nd_{RPFR}}{Q+QR}\int_0^{V_{mixing}} d(V_{mixing}), \tag{12}$$

$$\frac{1}{C_{A0}-C^*} - \frac{1}{C_{A1}-C^*} = -k_2 nd_{RPFR}\left(\frac{V_{mixing}}{Q+QR}\right), \tag{13}$$

$V_{mixing} = Qt_{PFR} + Qt_{\mathrm{Re}}$ is Volume of Mixing

$$\frac{1}{C_{A0}-C^*} - \frac{1}{C_{A1}-C^*} = -k_2 nd_{RPFR}\left(\frac{Qt_{PFR}+QRt_{\mathrm{Re}}}{Q+QR}\right). \tag{14}$$

From which

$$\frac{1}{C_{A0}-C^*} - \frac{1}{C_{A1}-C^*} = -k_2 nd_{RPFR}\left(\frac{t_{PFR}+Rt_{\mathrm{Re}}}{1+R}\right), \tag{15}$$

Given $t_{PFR} = \frac{(1-f)Ah}{Q_{in}}$; f= specific gravity of media, A= area of Reactor, and h= height of Water

$$k_2 nd_{RPFR} = \frac{\left(\frac{1}{C_{A1}-C^*} - \frac{1}{C_{A0}-C^*}\right)}{\frac{\frac{(1-f)Ah}{Q_{in}}+Rt_{\mathrm{Re}}}{1+R}}. \tag{16}$$

Therefore, the solution for the concentration of recirculation plug-flow reactor (RPFR) is given by

$$C_{A1} = C* + \frac{(C_{A0} - C*)}{\left(1 + (C_{A0} - C*)k_2 nd_{RPFR}\left(\frac{\frac{(1-f)Ah}{Q_{in}} + Rt_{\mathrm{Re}}}{1+R}\right)\right)}. \tag{17}$$

1.2 Development Recirculation completely-mixed stirred tank reactor (RCSTR)

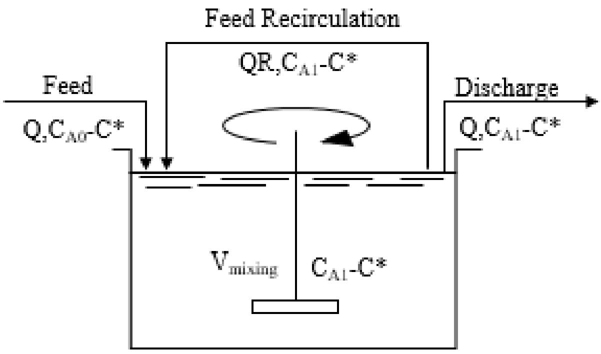

Figure 2 Recirculation completely-mixed stirred tank reactor (RCSTR)

This type of reaction has an integrated flow rate combined with the circulating flow rate (Q + QR). Constantly, with a constant rate of interaction occurring within the tank, the concentration of the flow into the tank is changed to a new concentration, which may be reduced (or increased). It depends on the reaction time within the tank from the principle of the water balance and the balance of the substance. The Wastewater treatment system of the water tank has the flow rate (Q) of the substance and the spinning flow rate (QR) of the existing original substances with the same existing processing as the same and equal (Q + QR).) (Suksomboon *et al.*, 2019b) and (Vmixing) is the volume of reactor and providing concentration influent as C_{A0}-C *. The concentration Effluent is C_{A1}-C * (Kadlec, 2009; Suksomboon *et al.*, 2019b) showing the changes in concentration per unit = The reactor area (area of Reactor, Ar), H = water level in the reactor (height of Water) and circulating time hydraulic (hydraulic recirculation time, HReT), since inside reactor, is equally concentrated at all points. Figure 2 the recirculation material balance for the processing of a time unit as the equation below:

Considering as the first order equation (n=1).

$$V_{mixing} d(C_{A1} - C*) = (C_{A0} - C*)(Q + QR)dt - r_A V_{mixing} dt - (C_{A1} - C*)(Q + QR)dt, \tag{18}$$

Given $r_A = -k_1 st_{RCSTR}(C_A - C*),$ Arrearage for integrating results in

$$V_{mixing} d(C_{A1} - C*) = (C_{A0} - C*)(Q + QR)dt - k_1 st_{RCSTR} V_{mixing} dt - (C_{A1} - C*)(Q + QR)dt. \tag{19}$$

For steady state, $\frac{d(C_{A1} - C*)}{dt} = 0.$

$$0=\left(C_{A0}-C^*\right)-k_1 st_{RCSTR}\left(C_{A1}-C^*\right)\frac{V_{mixing}}{\left(Q+QR\right)}-\left(C_{A1}-C^*\right), \quad (20)$$

$V_{mixing}=Qt_{RCSTR}+Qt_{\mathrm{Re}}$ is Volume of Mixing

$$0=\left(C_{A0}-C^*\right)-k_1 st_{RCSTR}\left(C_{A1}-C^*\right)\frac{\left(Qt_{RCSTR}+QRt_{\mathrm{Re}}\right)}{\left(Q+QR\right)}-\left(C_{A1}-C^*\right), \quad (21)$$

from which

$$0=\left(C_{A0}-C^*\right)dt-k_1 st_{RCSTR}\left(C_{A1}-C^*\right)\frac{\left(t_{RCSTR}+Rt_{\mathrm{Re}}\right)}{\left(1+R\right)}-\left(C_{A1}-C^*\right), \quad (22)$$

Given $t_{CSTR}=\frac{(1-f)Ah}{Q_{in}}$; f= specific gravity of media, A= area of Reactor, and h= height of Water

$$k_1 st_{RCSTR}=\frac{\left(\frac{C_{A0}-C^*}{C_{A1}-C^*}-1\right)}{\left(\frac{\frac{1-f)Ah}{Q_{in}}+Rt_{\mathrm{Re}}}{1+R}\right)}, \quad (23)$$

Therefore, solving for the concentration of recirculation continuously stirred tank reactor (RCSTR) is given by:

$$C_{A1}=C^*+\frac{C_{A0}-C^*}{1+k_1 st_{RCSTR}\frac{\frac{(1-f)Ah}{Q_{in}}+Rt_{\mathrm{Re}}}{1+R}}. \quad (24)$$

Considering as the second order (n=2).

$$V_{mixing}d(C_{A1}-C^*)=(C_{A0}-C^*)(Q+QR)dt-r_A V_{mixing}dt-(C_{A1}-C^*)(Q+QR)dt. \quad (25)$$

Given $r_A=-k_2 nd_{RCSTR}\left(C_{A1}-C^*\right)^2$, Arrearage for integrating results in

$$V_{mixing}d(C_{A1}-C^*)=(C_{A0}-C^*)(Q+QR)dt-k_2 nd_{RCSTR}(C_{A1}-C^*)^2 V_{mixing}dt-(C_{A1}-C^*)(Q+QR)dt. \quad (26)$$

For steady state, $\frac{d(C_{A1}-C^*)}{dt}=0.$

$$0=\left(C_{A0}-C^*\right)-k_2 nd_{RCSTR}\left(C_{A1}-C^*\right)^2\frac{V_{mixing}}{\left(Q+QR\right)}-\left(C_{A1}-C^*\right), \quad (27)$$

$V_{mixing}=Qt_{PFR}+Qt_{\mathrm{Re}}$ is Volume of Mixing

$$0=\left(C_{A0}-C^*\right)-k_2 nd_{RCSTR}\left(C_{A1}-C^*\right)^2\frac{\left(Qt_{CSTR}+QRt_{\mathrm{Re}}\right)}{\left(Q+QR\right)}-\left(C_{A1}-C^*\right), \quad (28)$$

from which

$$0=\left(C_{A0}-C^*\right)-k_2nd_{RCSTR}\left(C_{A1}-C^*\right)^2\frac{\left(t_{CSTR}+Rt_{\mathrm{Re}}\right)}{\left(1+R\right)}-\left(C_{A1}-C^*\right). \quad (29)$$

Given $t_{CSTR}=\frac{(1-f)Ah}{Q_{in}}$; f= specific gravity of media, A= area of Reactor, and h= height of Water

$$k_2nd_{RCSTR}=\frac{\dfrac{\left(C_{A0}-C^*\right)-\left(C_{A1}-C^*\right)}{\left(C_{A1}-C^*\right)^2}}{\dfrac{\frac{(1-f)Ah}{Q_{in}}+Rt_{\mathrm{Re}}}{1+R}}. \quad (30)$$

From which

$$\left(C_{A1}-C^*\right)^2-\frac{\left(1+R\right)}{k_2nd_{RCSTR}\left(\frac{\left(1-f\right)Ah}{Q_{in}}+Rt_{\mathrm{Re}}\right)}\left(C_{A1}-C^*\right)=\frac{\left(1+R\right)}{k_2nd_{RCSTR}\left(\frac{\left(1-f\right)Ah}{Q_{in}}+Rt_{\mathrm{Re}}\right)}\left(C_{A0}-C^*\right) \quad (31)$$

Therefore, solving for the concentration of recirculation continuously stirred tank reactor (RCSTR) is given by:

$$C_{A1}=C^*+\sqrt{\left(C_{A0}-C^*\right)\frac{\left(1+R\right)}{k_2nd_{RCSTR}\left(\frac{(1-f)Ah}{Qin}+Rt_{\mathrm{Re}}\right)}-\left(\frac{1+R}{2k_2nd_{RCSTR}\left(\frac{(1-f)Ah}{Qin}+Rt_{\mathrm{Re}}\right)}\right)^2}-\left(\frac{1+R}{2k_2nd_{RCSTR}\left(\frac{(1-f)Ah}{Qin}+Rt_{\mathrm{Re}}\right)}\right). \quad (32)$$

where C_{A1} is the concentration Effluent (mg/L),C_{A0} is the concentration Inffluent (mg/L),
C^* is the background concentration (mg/L),Q_{in} is the inflow rate (m^3/day),
A is the area of Reactor (m^2),
h is the height of Water (m),
f is the specific gravity,
t_{Re} is the hydraulic recirculation time (day),
R is the rate of recirculation,
k_1st_{RPFR} is the 1st order kinetic models RPFR (day^{-1}),
k_2nd_{RPFR} is the 2nd order kinetic models RPFR (day^{-1}),
k_1st_{RCSTR} is the 1st order kinetic models RCSTR (day^{-1}),
k_2nd_{RCSTR} is the 2nd order kinetic models RCSTR (day^{-1}).

2. Kinetic experiments

2.1 Domestic wastewaters

This study is using the wastewater discharging from residences such as kitchen, toilet and from grease trap tank (package on site). These domestic wastewater revealed that the domestic wastewater was characterized by BOD only having concentrations in the range of 90-105 mg/L (Xing *et al.*, 2010). The pH values are generally between 6 and 9.

2.2 Experimental set-up of FBBR- GAC

Integrated fluidized bed bioreactor with granular activated carbon (iFBBR-GAC) was operated with ratio of 1 wide: 6.55 length and contain the granular activated carbon 4 kg. (dry weight) with an initial height of bed (h_0) about 0.55 m. The area of reactor (Ar) is 0.017 m^2 and the height of water is 0.95 m. The reactor was design to has volume of 15.68 Litter. Note that, the previous study uses 8 of fixed wheels (Suksomboon *et al*., 2019b).

The reactor (iFBBR-GAC) was connected with Oxidation pond by using the recirculation ratio,R to control the operate system as demonstrate in Figure 3. Note that, the oxidation pond was constructed by using the polyester tank with volume of 20 L, the area of the reactor (Ar) of 0.096 m^2 and the height of water in polyester tank of 0.23 m. The treated water is reusable by using sand filter to improve such a post-treatment (Yu and Luo, 2002; Fernandez *et al*., 2007) as shown in Figure 3.

The fluid flowed in an upward spiral direction toward a 15.68 L of wastewater/day. In oxidation pump and nozzle jet water of wheel fixed as showing in Fig.1 were used for pump wastewater to the range of 11-15 Lpm with the specific gravity (f) equal to 0.61. Its cause the speed of stirrer speed of bed (N_B) equal to 19, 23, 26, 29 and 32 rpm, respectively (Suksomboon *et al*., 2019b). This experiment collected the wastewater by hydraulic recirculation time (HReT) increased for 5 levels:0, 10, 20, 30 and 60 min. The standard method was used to analyze the treated water (samples) and the mathematic model was used to find k value. For the FBBR-GAC is using equations 8 and 16. Intended for Oxidation pond is using equations 23 and 30 to fitting the mathematics model. These equations are achieved by using Microsoft excel.

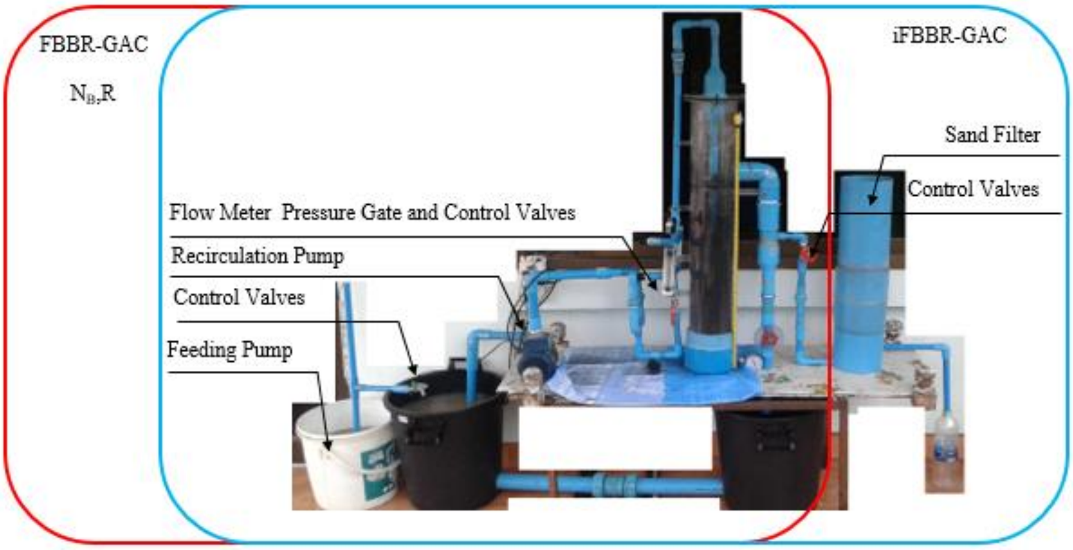

Figure 3 The integrate fluidized bed bioreactor–granular activated carbon (iFBBR-GAC)

RESULTS AND DISCUSSION

1. Calibration Kinetic studies of BOD removal using FBBR-GAC and Oxidation pond

The FBBR-GAC has the flow characteristics similar to recirculation plug-flow reactor (RPFR). Due to the flow rate of recirculation at Q_{Re} =13 L/min and Q_{in}=20 L/d (Suksomboon and Junsiri, 2018; Suksomboon *et al.*, 2019a; Suksomboon *et al*., 2019b) with ratio of width to length of 1:6.55, resulting in the initial concentration of BOD in a plane per pedicular to the flow is reduced along cylinder length. The oxidation pond has a flow characteristic nearly to recirculation completely-mixed stirred tank reactor (RCSTR) when combine with FBBR-GAC the BOD concentration in oxidation pond were decreased. So that it depending on hydraulic recirculation time of the reaction in oxidation pond (RCSTR) as shown in Table 1.

The develop mathematical models and identified which one among them is the most accurate. From Table 2, R values indicate that the calibration kinetics of

BOD reduction followed a pseudo 1st order and 2nd order reaction, as demonstrated in Figure 4.

Table 1 The quality of wastewater at different recirculation ration (R) and Hydraulic recirculation time, (HReT) in terms of organic loading rate

WW	Q_R (L/m)	R	N_B (rpm)	BODin (mg/L)	BODout of FBBR-GAC and Oxidation Pond (mg/L) — Hydraulic recirculation time,(HReT) of FBBR GAC and Oxidation Pond (min): 10	20	30	60	BODout of iFBBR (mg/L)
Domestic	11	792	19	104	53.47	39.62	35.18	24.66	13.64
	12	864	23	109	52.59	37.62	32.96	21.79	8.69
	13	936	26	110 ± 5.31	50.35 ± 1.08	35.9 ± 1.53	31.3 ± 1.47	18.0 ± 2.12	5.00
	14	1008	29	105	51.58	36.61	32.13	21.48	8.10
	15	1080	32	95	52.75	35.17	31.12	21.75	12.35
	11	792	19	104	53.47	39.62	35.18	24.66	13.64

BOD*= 5 mg/L (Kadlec, 2009)

Table 2 Calibration Kinetics models fitting 1st and 2nd order

Reactor	**Try**	**Models**	**Rate constant, k (day^{-1})**	**R^2**
FBBR-GAC	RPFR	1st order	27.353	0.966
	RPFR	2nd order	1.543	0.983
Oxidation Pond	RCMFR	1st order	132.087	0.933
	RCMFR	2nd order	14.602	0.996

* FBBR-GAC and Oxidation Pond For the data of HReT=0.0417 day and recirculation ratio, R = 936 that give the highest BOD removal efficiency

*R^2 = Explained variation

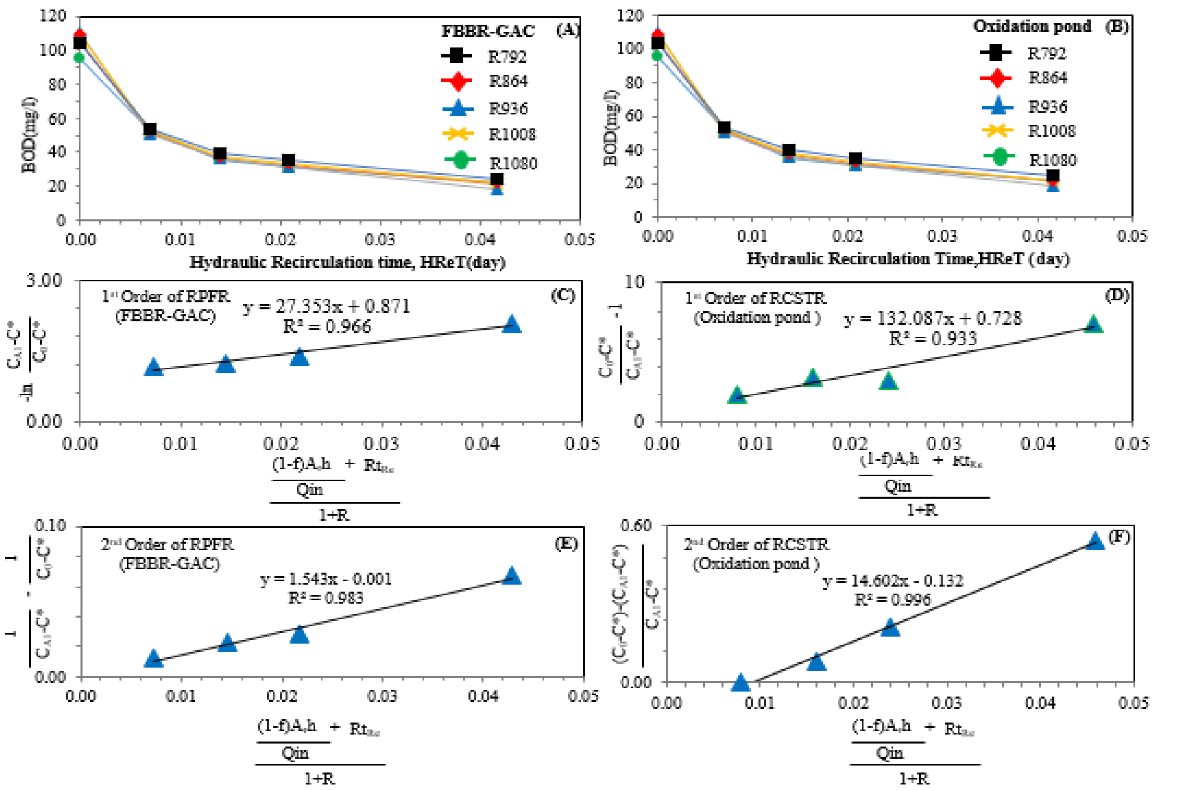

Figure 4 Prediction of Calibration kinetic reactions using 1st,2nd order models, (C)(E) kinetic study of BOD reduction from FBBR-GAC, (D)(F) kinetic study of BOD reduction from Oxidation Pond

2. Reactor modelling of FBBR- GAC and Oxidation pond

Respect to the objectives, the optimum recirculation (R) and kinetic rate coefficient rate, (k) were used to determine the performance of FBBR- GAC and Oxidation pond are BOD removal efficiency in order to identify which model is the most accurate to the result from actual treated wastewater by using equations 9 and 17 of RPFR and equations 24 and 32 of RCSTR for calibration

This present study used MS Excel for mathematical simulation of the RPFR and RCSTR models derived in Section 1 (Suksomboon *et al.*, 2019b). Figure 5 illustrate the predicted behavior of the FBBR-GAC and Oxidation pond reactors are the second order reaction (refer to the R^2 value), which indicate that the performance of system depending on initial concentration of substance. Figure 6 shows the flow charts of calculation process using mathematical models.

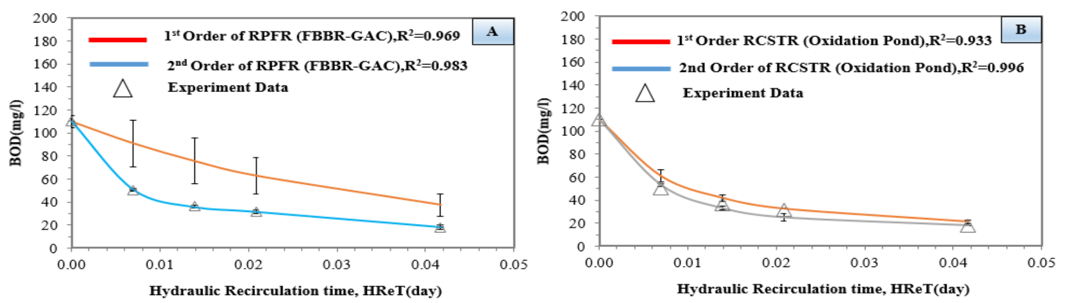

Figure 5 Model simulation of RPFR and RCSTR between FBBR- GAC and Oxidation pond (HReT=0.0417 day and R=936)

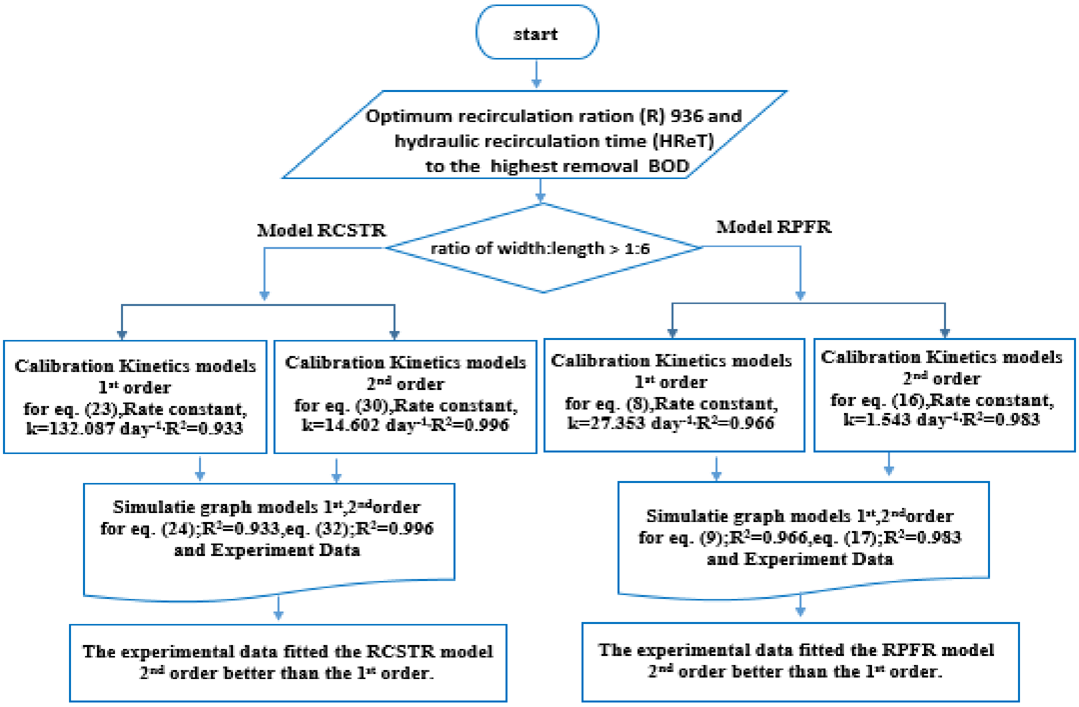

Figure 6 Flow charts of calculation processes using mathematical models

3. Effect of optimum recirculation ration (R) to the BOD removal efficiency

Table 1 illustrates the quality of water after treatment in a FBBR-GAC reactor over time in terms of its organic loading rate. Both models, RPFR and RCSTR, were used to predict the BOD in the effluent using the fitted kinetic rate constants (k). It was shown that optimum recirculation ratio (R)was 936 and optimum rate stirrer speed (N_B) was 26 rpm, resulting in the highest adsorption-biodegradation capacity in a FBBR-GAC process in terms of biological oxygen demand (BOD) removal efficiency is increase from 83.64% to 95.46%. Bioreactor treatment efficiency depended on the hydraulic recirculation time (HReT), 0.0417 days as shown in Figure 7.

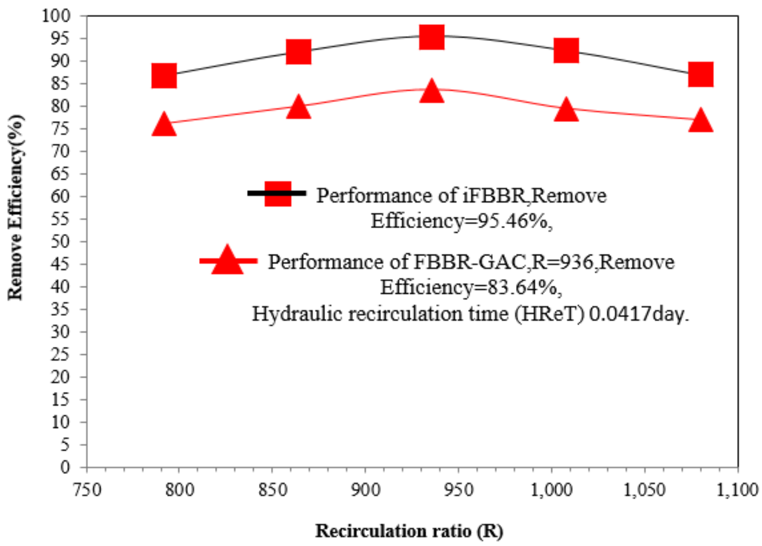

Figure 7 Relationship between removal efficiency vs. recirculation ratio (R)

CONCLUSION

From the experiment data, it was found that the suitable ratio for operate the reactor is using the stirrer speed of bed: N_B is approximately 26 rpm and using the recirculation ratio, R) of 936. The reaction kinetics for Fluidized bed biofilm reactors and Oxidation pond to BOD removal using treated sewage effluent followed the 2nd order kinetic models, with kinetic rate constants (k) of 1.543 and 14.602 day^{-1}, for the RPFR and RCSTR, respectively. Optimal recirculation RPFR and RCSTR for first and second order were successfully derived and validated with experimental data for treated sewage effluent. These models were developed to evaluate the kinetics of adsorption-biodegradation of bio oxygen demand (BOD) onto a granular activated carbon during a treatment process. The results of the study presented that these RPFR and RCSTR models can predict the BOD effluent precisely and found that the BOD removal efficiency was increase from 83.64% to 95.46% with using the hydraulic recirculation time of 0.0417 day.

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