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ORIGINAL ARTICLE

Batch growth kinetic studies of locally isolated cyanide-degrading *Serratia marcescens* strain AQ07

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Abstract

The evaluation of degradation and growth kinetics of *Serratia marcescens* strain AQ07 was carried out using three half-order models at all the initial concentrations of cyanide with the values of regression exceeding 0.97. The presence of varying cyanide concentrations reveals that the growth and degradation of bacteria were affected by the increase in cyanide concentration with a total halt at 700 ppm KCN after 72 h incubation. In this study, specific growth and degradation rates were found to trail the substrate inhibition kinetics. These two rates fitted well to the kinetic models of Teissier, Luong, Aiba and Heldane, while the performance of Monod model was found to be unsatisfactory. These models were used to clarify the substrate inhibition on the bacteria growth. The analyses of these models have shown that Luong model has fitted the experimental data with the highest coefficient of determination (R^2) value of 0.9794 and 0.9582 with the lowest root mean square error (RMSE) value of 0.000204 and 0.001, respectively, for the specific rate of degradation and growth. It is the only model that illustrates the maximum substrate concentration (S_m) of 713.4 and empirical constant (n) of 1.516. Tessier and Aiba fitted the experimental data with a R^2 value of 0.8002 and 0.7661 with low RMSE of 0.0006, respectively, for specific biodegradation rate, while having a R^2 value of 0.9 and RMSE of 0.001, respectively, for specific growth rate. Haldane has the lowest R^2 value of 0.67 and 0.78 for specific biodegradation and growth rate with RMSE of 0.0006 and 0.002, respectively. This indicates the level of the bacteria stability in varying concentrations of cyanide and the maximum cyanide concentration it can tolerate within a specific time period. The biokinetic constant predicted from this model demonstrates a good ability of the locally isolated bacteria in cyanide remediation in industrial effluents.

Keywords *Serratia marcescens* · Cyanide · Biodegradation · Kinetic models

Introduction

The physiochemical specification of cyanide makes it to be very toxic and harmful to the environment. It is used in industrial processes especially in the extraction of gold, zinc and silver from their ores (Gurbuz et al. 2009). Free cyanides such as hydrogen cyanide (HCN) and cyanide ion (CN^-) are considered to be among the most toxic cyanide forms due to their high metabolic inhibition potential (Potivichayanon and Kitleartpornpairoat 2010). Cyanide can lead to grave environmental catastrophes as a result of its toxicity and it is mostly aimed towards the aquatic biota. A leak at Colorado USA in 1990 led to the destruction of aquatic life along the 17 mile stretch of a river and in the same year, cyanide with an estimated amount of about 10 million gallons was spilled into the South Carolina River, killing thousands of aquatic biota

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(Gurbuz et al. 2009). Essentially, due to these reasons, it is very pertinent to treat cyanide-contaminated wastewater before it is released to the environment (Saravanan et al. 2009). Among the existing treatment techniques for cyanide pollution are alkaline chlorination, hydrogen peroxide method, ozonation and biological treatment. The biological treatment is a new process that seems to be promising as well as economical due of its advantages over the conventional chemical methods. It is considered to be a normal approach that has been overwhelmingly accepted by the public and regulatory agencies, since it could completely degrade waste volumes and easily reach the lowest level of wastewater more efficiently. It is reasonably cheap, since bacterial biomass can be made active by simple aeration. This procedure could degrade cyanide without creating a new waste such as sludge or other by-products. Besides, it does not contain any chemical risk, equipment handling risk and does not require expensive control; it produces no toxic by-products and is friendly to the environment (Dash et al. 2009). These promising and economic reasons made the biological method to become a more viable alternative (Dursun and Aksu 2000).

Previous literatures reveal that cyanide was bioremediated by various microorganisms (bacteria, fungi and algae) in free and immobilised forms under aerobic and anaerobic conditions (Karamba et al. 2015b). In Portugal in 2006, immobilised form of *Fusarium oxysporum* utilised in a packed bed reactor was reported to degrade 1–7 mM cyanide at pH 8, 25–30 °C with a removal efficiency of 96% (Campos et al. 2006). Free and immobilised cells of *Klebsiella oxytoca* were reported to biodegrade 5 mM of potassium cyanide at pH 7 and 30 °C with a removal efficiency ranging from 0.224 to 0.192 nm/h (Kao et al. 2003). In Turkey, free cells of *Scenedesmus obliquus* were reported to remove 92.3% of 77.9 mg/L weak acid dissociable (WAD) cyanide at pH of 10 and temperature of > 20 °C (Gurbuz et al. 2009). Meanwhile, in Spain, free cells of *Pseudomonas pseudoalcaligenes* CECT5344 were reported to degrade 2 mM potassium cyanide with a removal efficiency of 2.31 mg/CN/L/O.D/h at a temperature of 30 °C and pH of 9.5 (Huertas et al. 2010). Furthermore, in Thailand, free cells of *Agrobacterium tumefaciens* SUTS 1 were reported to bio-remove 97.9% of 150 mg/L KCN at a temperature of 30 °C and pH 7.2 (Potivichayanon and Kitleartpornpairoat 2010). In Malaysia, Maniyam et al. (2011) reported the biodetoxification of 64% potassium cyanide ranging from 3 to 15 mM by free cells of *Rhodococcus* UKMP—5 M at pH 7 and temperature of 30 °C. These microorganisms utilise various enzymes in carrying out processes such as cyanide hydratase, cyanide dihydratase, cyanide oxygenase and cyanide dioxygenase following hydrolytic or oxidative reactions in carrying out these detoxifications, converting cyanide to ammonia, formate or formamide and carbon dioxide (Ebbs 2004).

Thus, to monitor the growth of microorganisms, their performance towards different levels of substrates (cyanide) and the role they play in the general efficiency of a process requires evaluation via kinetic studies (Sivakumar et al. 2002). Different types of models were described in the literature; thus, a brief description of the models used in this study is given in Eqs. (1–5).

Monods model 1949

This model relates the growth rate of bacteria to the concentration of a particular growth-controlling substrate as shown in Eq. (1) (Monod 2012). It is one of the most extensively used models for growth kinetics. However, it has its demerits in certain instances where unusual Km values can be obtained owing to multi-S-limitation endogenous metabolism, internal transport and ionic strength limitations, high cell concentration, non-stationery processing, product inhibition and biosorption (Moser 1985).

$$\mu = \mu_{\max} \frac{S}{K_s + S}, \tag{1}$$

where μ is the specific growth rate (h^{-1}), $\mu_{\max}$ is the maximum specific growth rate (h^{-1}), S is the half-saturation coefficient (ppm) at time t and K_s is the half-saturation coefficient (ppm).

Haldane model 1930

This model is the foremost and most accepted model for substrate inhibition kinetics due to its impact that makes it to be well-used by most researchers (Saravanan et al. 2009; Arif et al. 2013; Ahmad et al. 2015). Haldane uses the equation to explain the inhibition of enzyme via the formation of a sedentary complex of enzyme with dual substrate molecules. This equation of Haldane has been established by quite a few researchers to deliver a suitable fit of μ plot against S for growth at high levels of substrate. As substrate inhibition constant (K_i) approaches infinity, Eq. (2) approaches the accustomed quadrilateral hyperbola of the Monod relationship (Luong 1987):

$$\mu = \mu_{\max} \frac{S}{S + K_s + \frac{S^2}{K_i}}, \tag{2}$$

where K_i is the substrate inhibition constant (ppm).

Luong model 1987

Luong proposed the application of substrate inhibition to the microorganisms' growth, describing butanol inhibition on yeast growth (Carrera et al. 2004). This model is significant

in the kinetics of substrates inhibition. Nevertheless, this model is the widespread Monod's model, which deduces substrate stimulation at its low and high concentrations. The model could envisage the value of the maximum substrate concentration (S_m,), when the exceeded growth is totally inhibited (Luong 1987). It is as shown in Eq. (3).

$$\mu = \mu_{max} \frac{S}{K_s + S} \left(\frac{1 - S}{S_m} \right)^n. \quad (3)$$

Aiba model 1968

This model was proposed by Aiba to propose a model for microbial growth as shown in Eq. (4) (Dey and Mukherjee 2010). It is an exponential kinetic model, which correlates the growth inhibition data with cyanide degradation.

$$\mu = \mu_{max} \frac{S}{K_s + S} \exp(-K_p P). \quad (4)$$

Teissier model 1942

The assumption of diffusion-controlled substrate leads Teissier to derive Eq. (5). It is an exponential kinetic model.

$$\mu = \mu_{max} \left(1 - \exp \left(-\frac{S}{K_s} \right) \right). \quad (5)$$

In various biotechnological procedures, higher substrate concentrations or products often result in inhibitory effects, which most of the times lead to poor substrate utilisation. It also decreases the products' yield and rate of fermentation. Besides, it also affects the metabolic process of the microorganisms, if administered at a sufficiently high level (Sivakumar et al. 2002). However, kinetics modelling of bacteria using cyanide as substrate for degradation was not readily available in the literature. Thus, the objective of this study is to evaluate the kinetic model that fits the degradation potential of this bacterium. Biodegradation kinetics of ferrous II cyanide complex ions by *Pseudomonas fluorescens* immobilised in a packed bed column reactor has been reported (Dursun and Aksu 2000). Moreover, cyanidase degradation kinetics using immobilised enzyme preparations in powdered form fitted in a batch reactor and modelled with the help of simple Michaelis–Menten equation have been reported (Basheer et al. 1992). There is no further available literature reported in respect to inhibitory growth kinetics of bacteria utilising cyanide as substrate. The aim of this research was to study the potential of these bacteria in biodegrading cyanide utilising shake flasks as batch reactor with a vision to upgrade the process. A cyanide-degrading bacterium *Serratia marcescens* strain AQ07 which was isolated from soil sampled at Universiti Putra Malaysia was used for this study. The bacterium was isolated and identified fit for cyanide degradation, since it has the capacity of removing 200 mg/L KCN in 72 h (Karamba et al. 2016). This bacterium can be beneficial in the removal of cyanide devoid of producing toxic by-products in the process.

Materials and methods

Bacteria and culture conditions

Serratia marcescens strain AQ07, which has the potency of degrading cyanide, was isolated and characterised from the soil samples obtained from Universiti Putra Malaysia. The processes of isolation, characterisation and identification have been reported (Karamba et al. 2015a). Buffer medium composed of K_2HPO_4—3.5 g, KH_2PO_4—7.2 g, trace salts (10 mL) ($MgCl_2 \cdot 6H_2O$—180 mg/L, $FeSO_4 \cdot 7H_20$—300 mg/L, $CaCl_2$—40 mg/L, $Co(NO_3)_2 \cdot 6H_2O$—130 mg/L, MoO_3—20 mg/L $ZnSO_4$—40 mg/L,) and yeast extract—0.5 g in 1 L of distilled water (Potivichayanon and Kitleartpornpairoat 2010) was used for the study. It was sterilised using autoclave at 121 °C (23.3975 psi) for 15 min. Filter-sterilised glucose—5 g/L, which was autoclaved independently from the medium to prevent caramelisation, was incorporated to the medium. Filter-sterilised KCN was added in different concentrations ranging from 200 to 700 ppm. It was then incubated on an orbital shaker at 150 rpm, 32.5 °C for 72 h.

Flask culture experiment

The experiments were conducted in 250 mL screw cap Schott bottles containing 50 mL buffer medium incorporated with filter-sterilised potassium cyanide in an array of 200–700 ppm. Each batch experiment was carried out in triplicate. Each flask was inoculated with 20% free cells that were used as the inoculum size (Karamba et al. 2016). This was accomplished by direct transferring under aseptic conditions in the laminar flow hood resting cells of bacteria into the buffer medium containing KCN at various concentrations and incubated on an orbital shaker at 150 rpm for 72 h at 32.5 °C. Bacterial growth and cyanide biodegradation assay was carried out by drawing 1000 µL samples at regular intervals. It was used to measure the growth by OD_{600nm}, while the other part was centrifuged at 1000×*g* for 10 min and the supernatant was then analysed for residual cyanide concentration. The results obtained from triplicate samples were analysed and reported. Error bars represent mean ± STDEV.

Analytical method

Cyanide biodegradation assay was carried out to determine the residual cyanide, using modified ɤ-Picoline and barbituric acid method (Nagashima 1977). The modification and technique have been reported before (Karamba et al. 2015a).

Results and discussion

Extensive investigation on the existing literature reveals that the kinetic modelling for *S. marcescens* has not yet been reported in relation to cyanide degradation. It is designed to determine the suitable mathematical model for degradation and inhibitory growth kinetics in batch shake bottles using free cells of locally isolated *S. marcescens* strain AQ07 and cyanide as the substrate. Appropriate substrate inhibition models reported in the literature were related to the experimental data to determine the biokinetic constants. These models were used to compute the impact of substrate (cyanide) inhibition on specific growth rates. It considers the possibility that substrates will behave as inhibitors at a higher concentration and serve as the enhancers at lower concentration. The kinetic data obtained for the growth of *S. marcescens* strain AQ07 on cyanide and the degradation data have been utilised to evaluate the applicability of the models.

The trace salts used in the composition of the buffer medium contain some heavy metals such as cobalt and zinc, which could work synergistically to exert toxic effect on the bacterium. This has been clarified by testing the effect of ten different types of heavy metals at 1 ppm concentration on cyanide biodegradation by resting the cells of *S. marcescens* strain AQ07. The bacterium has been observed to stand the toxicity of all the heavy metals, including cobalt and zinc, with the exception of mercury, which had a grave effect on it (Karamba et al. 2014). Zinc has been reported to have a good impact on the cellular activities of bacteria, but has high cytotoxicity when applied at higher concentrations (Pandiyan and Mahendradas 2011).

The effect of various concentrations of potassium cyanide on biodegradation

Figures 1 and 2 illustrate the time profile for cyanide degradation and growth of the bacteria. It was observed that the biodegradation of cyanide and the growth of bacteria depend on the varying cyanide concentrations, if given the same time period. The degradation of 200 ppm KCN and higher growth of the bacteria were achieved in a period of 72 h, while lower or less degradation and growth was observed for 700 ppm within the same time period. Even though there was a slight cyanide depletion observed at 700 ppm, it could be the result of abiotic factors such as air stripping or volatilisation (Patil and Paknikar 2000; Gurbuz et al. 2009), considering there is virtually no growth observed by the bacteria (Fig. 3). It can be concluded that the higher the concentration of cyanide is, the lower the growth rate and degradation will be. This shows the effectiveness of various cyanide concentrations that affect the biodegradation capacity of bacteria.

Effect of initial cyanide concentration on the growth of bacteria

When the time period in which the bacteria-biodegraded cyanide is monitored at its various initial concentrations, it can be observed that the bacterial growth follows the same pattern. This is evident in Figs. 1 and 2, where the substrate degradation and bacteria growth were plotted against time for various cyanide concentrations in the buffer media. It is apparent

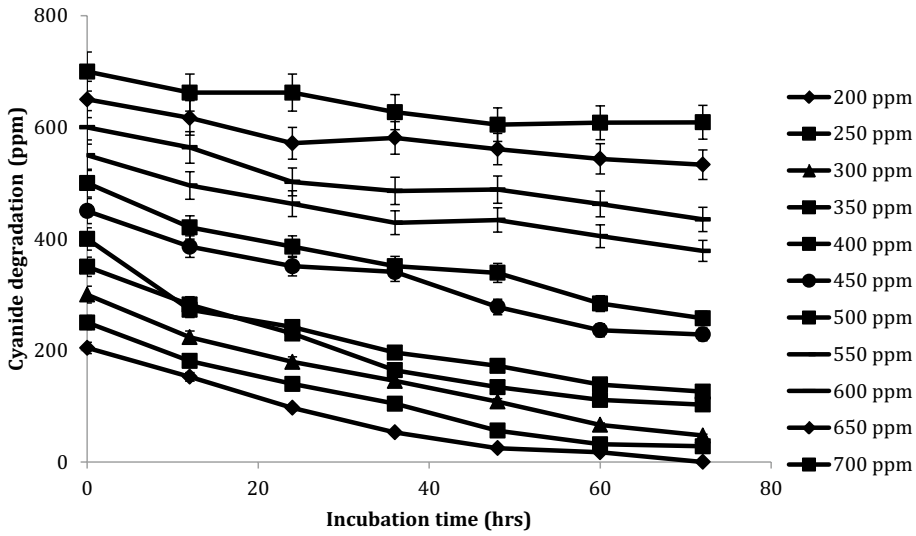

Fig. 1 Effect of varying cyanide concentrations on the biodegradation of cyanide by *Serratia marcescens* strain AQ07. Data represented as mean ± STDEV, $n = 3$

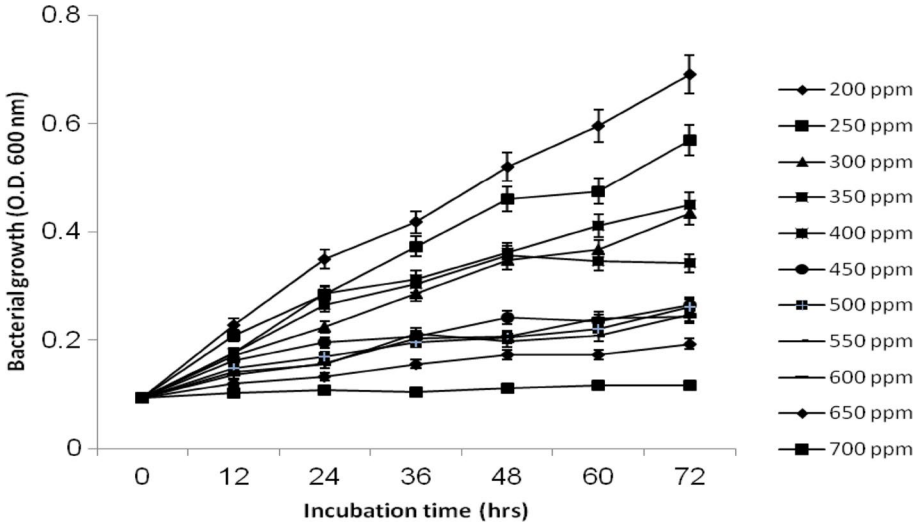

Fig. 2 Effect of varying cyanide concentrations on growth by *Serratia marcescens* strain AQ07. Data represented as mean ± STDEV, $n = 3$

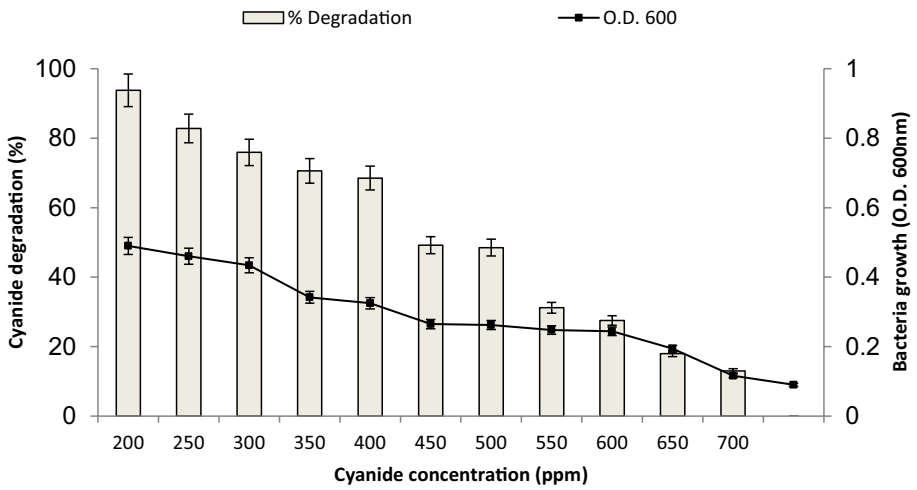

Fig. 3 Effect of different cyanide concentrations on biodegradation of cyanide by *Serratia marcescens* strain AQ07 in 72 h. Data represented as mean ± STDEV, $n = 3$

in these figures that cyanide concentration between 200 and 300 ppm showed a better growth ability of above 0.4 and degradation of above 90% of cyanide. However, concentrations higher than the said values have resulted in poor growth and degradation of bacteria that could be attributed to the toxicity of the cyanide. Furthermore, as cyanide concentration increases in the media, the bacterial growth and degradation decreased. To establish the relationship between cyanide concentration and growth of the bacteria, specific growth rates of the bacteria at various cyanide concentrations were considered as per Eq. (6). This illustrates a nonlinear analysis of the experimental data. The Luong model of inhibitory growth kinetics was considered as the most suitable mathematical model for the present work:

$$\frac{dx}{dt} = \mu x, \tag{6}$$

where x is the O.D. 600 at time t (hours) and μ is the specific growth rate (h^{-1}) (Kovárová-Kovar and Egli 1998).

Other models illustrate low coefficient of determination value, which is less than 0.8 with some as low as 0.3. Several models have considered both sides simultaneously with some performing inadequately, and one was very poor. The relationship between μ and cyanide concentration indicates that μ increases only in the first two concentrations within the free cells (100 and 200 ppm), but it declined with an increase in cyanide concentration above 150 ppm. This is a clear illustration for cyanide inhibition on the growth of bacteria that has been shown in the previous reports (Yan et al. 2006; Bai et al. 2007). Furthermore, specific substrate degradation rate (q, h^{-1}) was observed according to Eq. (7) that illustrates specific substrate removal rate:

$$\frac{dS}{dt} = -qx. \tag{7}$$

where x and S are the bacterial growth and cyanide concentrations in ppm at time (h^{-1}) (Hao et al. 2002). The comparison was carried out between the specific degradation rate and growth rate per hour at different initial cyanide concentrations in the media (Fig. 4). It has been illustrated that the rates corresponded with each other, indicating that the bacteria have the capacity of utilising cyanide from the media. Nevertheless, both rates declined after an early rise in activity, which indicates substrate inhibition attributes in the system (Yan et al. 2006; Bai et al. 2007). To envisage the model of cyanide degradation and bacterial growth in the media, kinetics from the two visible facts were examined by in-putting the data into substrate inhibition models (Saravanan et al. 2009).

Modelling the degradation and growth kinetics of the bacteria

Given that both growth rate (μ) and cyanide degradation (q) were subjected to cyanide inhibition, the disparity of these two rates were modelled utilising appropriate deterministic models as previously reported (Ahmad et al. 2015). The model was explained using nonlinear regression method by MATLAB®2012b and was first applied to the experimental records on specific growth rate of bacteria at various cyanide concentrations. The deviation of specific cyanide degradation rate at every concentration was modelled via the same set of equations. Conversely, during the application of the models to values on specific degradation rate, the term μ has been changed to q and μ_{max} was replaced with q_{max} to represent specific substrate degradation and maximum specific substrate degradation rates within that order. The model fitness in envisaging the two rates is shown in Figs. 5 and 6.

The biokinetic constants of degradation and growth of the bacteria recorded from these models along with R^2 and RMSE among the experimental and expected rate standards are indicated in Tables 1 and 2. These tables illustrate the factors of μ_{max} (hr^{-1}), K (ppm), K_i (ppm), K (ppm), S_m (ppm) and n. All the models predicted the maximum specific growth rate per hour and half-saturation coefficient in ppm,

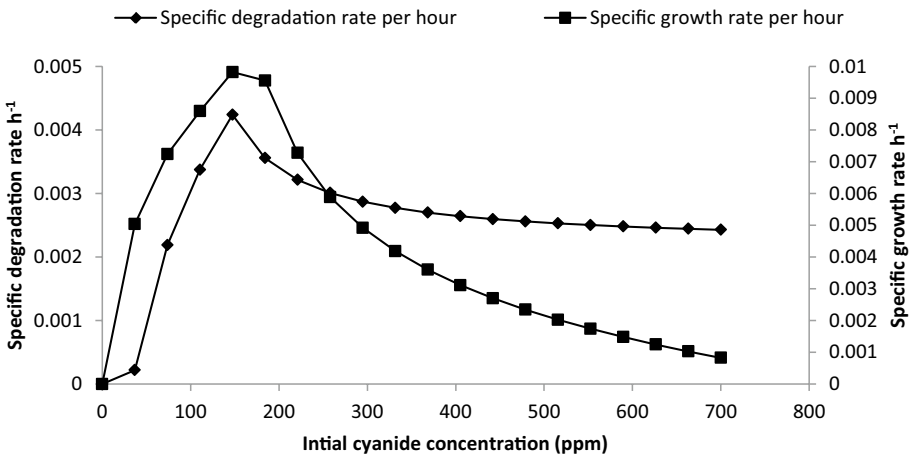

Fig. 4 Comparison between specific degradation and growth rates at varying initial cyanide concentrations

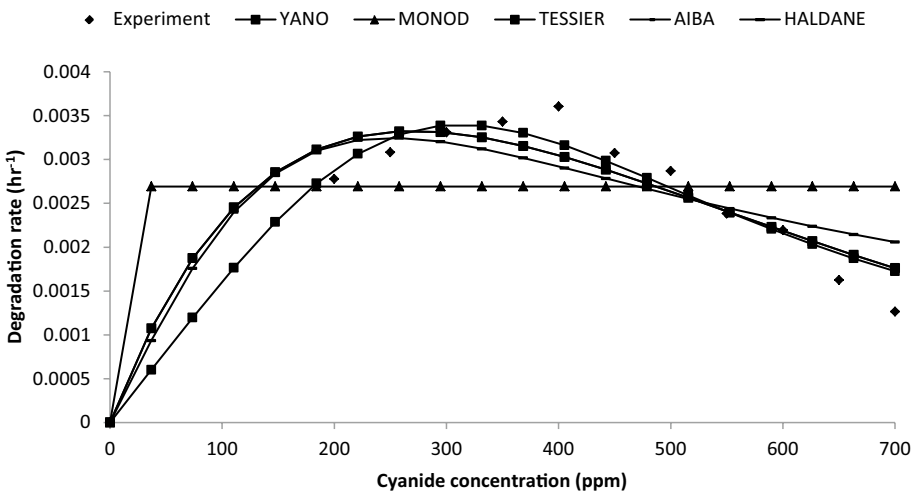

Fig. 5 Experimental and envisaged specific degradation rate (q) of the bacteria at different cyanide concentrations

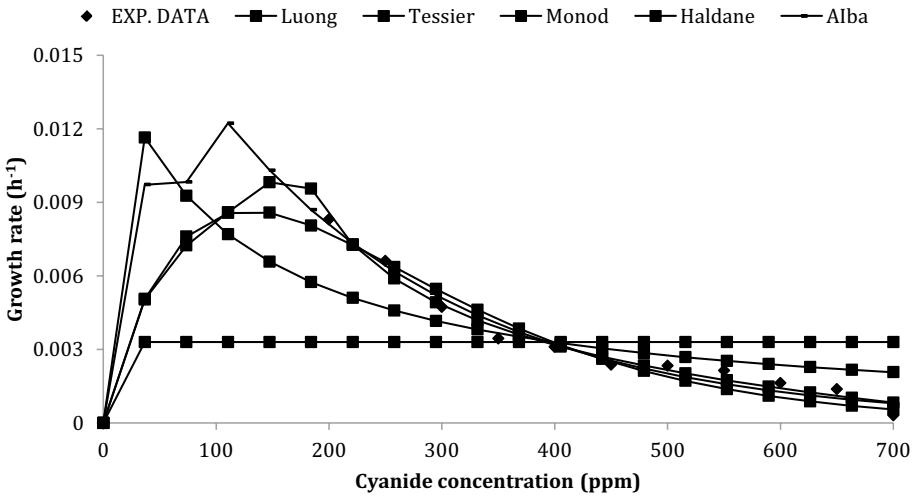

Fig. 6 Experimental and envisaged specific growth rate (μ) of the bacteria at different cyanide concentrations

Table 1 Specific biodegradation rate kinetic parameters acquired for various models through biodegradation of cyanide by *Serratia marcescens* strain AQ07 in batch screw cap shake flask

S/no	Model	μ_{max} (h^{-1})	K_s (ppm)	K_i (ppm)	S_m (ppm)	n	R^2	RMSE
1	TESSIER	0.999	248.1	250.5	–	–	0.8002	0.0006
2	LUONG	0.005355	174.7	–	713.4	1.516	0.9794	0.000204
3	AIBA	0.02056	577	380	–	–	0.7661	0.000649
4	HALDANE	0.01396	351.2	124.4	–	–	0.6742	0.000602
5	MONOD	0.002516	66.23	–	–	–	0.3999	0.000986

Table 2 Specific growth rate kinetic parameters acquired for various models through biodegradation of cyanide by *Serratia marcescens* strain AQ07 in batch screw cap shake flask

S/no	Model	μ_{max} (h^{-1})	K_s (ppm)	K_i (ppm)	S_m (ppm)	n	R^2	RMSE
1	TESSIER	0.9997	285.7	294.2	–	–	0.9338	0.001148
2	LUONG	0.0479	801	–	937.9	1.301	0.9582	0.001
3	AIBA	0.05698	491.6	422.1	–	–	0.9098	0.0013
4	HALDANE	0.02828	214.5	253	–	–	0.7861	0.002065
5	MONOD	0.008254	32.04	–	–	–	0.3834	0.003246

This research discloses the potential of locally isolated bacteria in the treatment of wastewater containing highly toxic compounds including cyanide μ_{max}, K_s, K_i, and S_m

while Luong and Monod models did not predict the substrate inhibition constant. Only the Luong model managed to predict the critical substrate concentration value in ppm and empirical constant (n).

The substrate degradation and specific growth have perfectly declined and tallied with the experimentally achieved value of 200 ppm. The Luong model calculated the critical substrate concentration (S_m) value, which declined to zero at ~ 700 ppm and was observed to be similar with the experimental value. The substrate degradation rate illustrated by the bacteria is similar to the value obtained in the experiments, which affirms that the behaviour of substrate inhibition and cyanide degradation was efficient in relation with the bacterial growth in the culture media (Yan et al. 2006). It is pertinent to note that while comparing with the other model parameter values in this research, there are no other related studies on cyanide and *S. marcescens* conducted by the other researchers established in the literature.

The affiliation that exists between specific growth rate (μ) of bacteria and concentration of substrate (S) is an important factor in the field of biotechnology (Othman et al. 2013; Ahmad et al. 2014; Ibrahim et al. 2016).The kinetics of cyanide degradation and growth by Strain AQ07 were applied to different types of models which are indicated in Eqs. (1)–(5). Among these models that were tested for degradation and growth, three models (Tessier, Luong and Aiba) have fitted the data well with coefficient of determination (R^2) values greater than or equal to 0.93 (Tables 1, 2). These models may perhaps be considered as the more appropriate models, as they incorporated both kinetics of cyanide degradation and bacteria growth (Saravanan et al. 2009). For both growth and degradation by the bacteria, the Luong model illustrates

good performance with R^2 of 0.9582 and 0.9794, respectively, with root mean square error (RMSE) of 0.000204 and 0.001. It has a maximum specific growth rate (μ_{max}) for degradation of 0.0054 and 0.048 h^{-1} for growth. Half saturation coeficient (K_s) was given as 174.7 ppm for the cyanide degradation and 801 ppm for bacterial growth by Luong model. Luong model did not predict substrate inhibition constant (K_i) as predicted by other models (Table 1 and 2), it is the only model that predicts the maximum substrate conentration (S_m) of 713.4 ppm for cyanide degradation and 937.9 ppm for bacterial growth with an emperical constant (n) of 1.516 and 1.301, respectively. Meanwhile, the Teissier model illustrated good performance next to Luong model. It has a R^2 value of 0.8002 for degradation and 0.9338 for growth with root mean square values of 0.0006 and 0.001148, respectively. It predicted the maximum specific growth rate (μ_{max}) of 0.999 h^{-1} for degradation and 0.9997 h^{-1} for growth. The half-saturation coefficient (K_s) was shown to be 248.1 ppm for degradation and 285.7 ppm for growth, respectively. The model predicted substrate inhibition constant (K_i) of 250.5 ppm and 294.2 ppm for degradation and growth, respectively. This model did not envisage the maximum substrate concentration (S_m) and empirical constant (n). The Aiba model followed suit with R^2 values of 0.7661 and 0.9098 for degradation and growth, respectively. It predicted the maximum substrate concentration (μ_{max}) of 0.02056 h^{-1} for degradation and 0.05695 h^{-1} for growth. Half-saturation coefficient (K_s) was deduced to be 577 ppm for degradation and 491.6 ppm for growth. Substrate inhibition constant (K_i) was found to be 380 ppm for degradation and 422.1 ppm for growth. The model did not predict the maximum substrate concentration (S_m) and empirical constant (n), whereas the Haldane model was able to illustrate R^2 values of 0.6742 and 0.7861 for degradation and growth, respectively. It indicated root mean square values of 0.000602 and 0.002065 for degradation and growth in that order. The model illustrated a maximum substrate concentration (μ_{max}) of 0.01396 h^{-1} for degradation and 0.02828 h^{-1} for growth. It demonstrated 351.2 ppm half-saturation coefficient (K_s) for degradation and 214.5 ppm for growth. It also pointed the substrate inhibition constant (K_i) of 124.4 ppm for degradation and 253 for growth, respectively. Meanwhile, Monod model illustrated very poor performance among the models as it illustrated R^2 values of 0.3999 and 0.3834 for degradation and growth, respectively. Root mean square values of 0.000986 and 0.003246 were recorded for the degradation and growth. The model predicted maximum substrate concentration (μ_{max}) of 0.002516 h^{-1} for degradation and 0.008254 h^{-1} for growth, respectively. It indicated only 66.23 ppm half-saturation coefficient (K_s) for degradation and 32.04 ppm for growth and did not predict substrate inhibition constant (K_i). A better fitness data for these models to the experimental values also illustrates that cyanide degradation in this study is a growth-dependant phenomenon, since the degradation cannot be achieved without bacterial growth. It is crucial to note that growth and degradation by bacteria is always in two phases: initial lag phase and active degradation phase (Saravanan et al. 2009).

Conclusions

The evaluation of kinetic models for the biodegradation of cyanide by *S. marcescens* strain AQ07 was studied in batch screw cap Schott bottles. A non-deterministic and three half-order kinetic models were discovered to explain the complete biodegradation outline at various cyanide concentrations, somewhat precisely. The calculated specific growth and degradation rates are well tallied with one another through the experimented concentration ranges, illustrating that the bacterial culture could effectively proliferate and biodegrade cyanide. This bacterial strain could be further studied for its utilisation on industrial wastewater treatment.

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