Preparation and Characterization of Amine Modified Activated Carbon from Corncobs for Carbon Dioxide Capture

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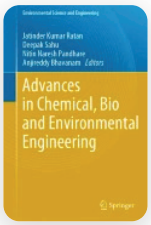

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Abstract

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Strategic implementation of integrated bioaugmentation and biostimulation for efficient mitigation of petroleum hydrocarbon pollutants from terrestrial and aquatic environment

Ipsita Dipamitra Behera [a], Manoranjan Nayak [b,c], Asmita Mishra [a], Bhim Charan Meikap [a,d], Ramkrishna Sen [b,e,*]

[a] Department of Chemical Engineering, Indian Institute of Technology Kharagpur, West Bengal 721302, India
[b] School of Energy Science and Engineering, Indian Institute of Technology Kharagpur, West Bengal 721302, India
[c] Biorefinery and Bioenergy Research Laboratory, Amity Institute of Biotechnology, Amity University Uttar Pradesh, Noida 201313, India
[d] Department of Chemical Engineering, School of Engineering, Howard College, University of KwaZulu-Natal, Durban 4041, South Africa
[e] Department of Biotechnology, Indian Institute of Technology Kharagpur, West Bengal 721302, India

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Keywords:
Petroleum hydrocarbon pollutants
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ABSTRACT

Release of petroleum hydrocarbon pollutants poses a serious problem to the terrestrial as well as marine ecosystem. This study investigated and compared the potency of different biodegradation strategies for mitigating total petroleum hydrocarbon (TPH) of petroleum refinery sludge by an integrated action of bioaugmentation and biostimulation vis-à-vis separate bioaugmentation and biostimulation approaches. The implementation of a concomitant bioaugmentation-biostimulation strategy (BABSS) involving the indigenously developed bacterial consortium and poultry litter extract showed the best performance by mitigating the TPH up to 90.3 ± 3.7% in 21 days. The GC-FID analysis confirmed the efficacy of different TPH degradation strategies. The kinetic study of TPH degradation of BABSS resulted first-order with rate 0.11 day^{-1}. Thus, the BABSS proved to be more efficient in degrading TPH in an eco-friendly manner and hence, may pave the way for better management of petroleum hydrocarbon pollutants, while providing a sustainable solution to the disposal of poultry wastes.

1. Introduction

Petroleum hydrocarbon pollutants pose a serious problem to the terrestrial as well as marine ecosystem (Kapsalis et al., 2021). A massive quantity of petroleum oily sludge is liberated to both terrestrial and marine ecosystems by the petroleum refineries due to the increased requirement of petroleum products for our routine life. Marine ecosystem is the final destination of various anthropogenic pollutants among which, oil spills are universal problematic situations which severely affect the marine environment along with the human populations nearby it (Liu et al., 2016; Mishra et al., 2019). A significant quantity of petroleum hydrocarbon pollutants released to the natural habitat, including terrestrial as well as aquatic environment during processing, transportation (oil spills), and by execution of the physico-chemical process of crude oil (Dellagnezze et al., 2014; Xu et al., 2018; Jasmine and Mukherji, 2019; Sayed et al., 2021). Indefinite handling of these petroleum refinery sludge (PRS) and petroleum hydrocarbons has adverse effects on human health besides environmental issues as it is recalcitrant and persistent in nature (Basak et al., 2020). Petroleum sludge is primarily composed of aliphatic hydrocarbons, including alkanes, alkenes, and alkynes, polyaromatic hydrocarbons, and toxic heavy metals (Cerqueira et al., 2014). Along with it also contains 5–85% of total petroleum hydrocarbons (TPH) based on its different processing techniques (Jasmine and Mukherji, 2015). Petroleum hydrocarbons have been found to be mutagenic and carcinogenic and cause respiratory and health issues to human beings, as well as endanger to aquatic life and terrestrial animals (Sayed et al., 2021). The toxic effects of petroleum hydrocarbon also caused damage to the phytoplankton and algae of the marine ecosystems, which imbalance the marine food chain (Mishra et al., 2019). As sequel to these negative effects, petroleum pollutants are considered as hazardous waste (USEPA, 2004; Cerqueira et al., 2014; Mishra et al., 2021).

Considering the toxicity of petroleum hydrocarbons, it is essential for

* Corresponding author at: Department of Biotechnology, Indian Institute of Technology Kharagpur, West Bengal 721302, India.
E-mail address: rksen@bt.iitkgp.ac.in (R. Sen).

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Enhanced biodegradation of total petroleum hydrocarbons by implementing a novel two-step bioaugmentation strategy using indigenous bacterial consortium

Ipsita Dipamitra Behera [a,1], Manoranjan Nayak [b,c,1], Subrata Biswas [a], Bhim Charan Meikap [a,d], Ramkrishna Sen [b,e,*]

[a] Department of Chemical Engineering, Indian Institute of Technology Kharagpur, West Bengal, 721302, India
[b] School of Energy Science and Engineering, Indian Institute of Technology Kharagpur, West Bengal, 721302, India
[c] Biorefinery and Bioenergy Research Laboratory, Amity Institute of Biotechnology, Amity University Uttar Pradesh, Noida, 201313, India
[d] Department of Chemical Engineering, School of Engineering, Howard College, University of KwaZulu-Natal, Durban, 4041, South Africa
[e] Department of Biotechnology, Indian Institute of Technology Kharagpur, West Bengal, 721302, India

ARTICLE INFO

Keywords:
Petroleum refinery sludge
Bacterial consortium
Two-step bioaugmentation strategy
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ABSTRACT

In the present study, a two-step bioaugmentation strategy (TSBS) was implemented by using indigenous bacterial consortium to enhance the degradation of total petroleum hydrocarbons (TPH) from petroleum refinery sludge (PRS). A bacterial consortium was developed using four indigenous isolated strains, Dietzia sp. IRB191, Dietzia sp. IRB192, Staphylococcus sp. BSM19 and Stenotrophomonas sp. IRB19 from PRS. The optimum conditions of pH, temperature, and sludge concentration were 7, 34 °C, and 2% (w/v), respectively, for maximum TPH degradation, obtained using one variable at a time approach. Under the optimal culture conditions, the developed consortium was inoculated twice to the culturing medium, at the beginning (0^{th} day) and again on the 10th day for implementing a novel TSBS. The maximum TPH degradation of 91.5 ± 2.28% was found with TSBS, which was 1.18 times higher than that of SSBS (77.3 ± 2.6%) in 15 days of incubation. GC-FID study also confirmed that the TPH present in the PRS was effectively degraded by the bacterial consortium with TSBS. The TPH degradation by using TSBS proceeded according to the first-order kinetics with a rate constant of 0.155 d^{-1}. Hence, biodegradation using a TSBS can be considered an effective and eco-friendly process for safe disposal of petroleum refinery sludge.

1. Introduction

The growing demand of petroleum products has led to the generation of a huge amount of petroleum hydrocarbon pollutants through refineries and petrochemical industries to the environment (Koolivand et al., 2019; Varjani, 2017). Mainly, oil refineries generate petroleum sludge during the crude oil production, pre-treatment, processing, the oil-water separation system, and from the bottom of storage tanks (Gholami-Shiri et al., 2017; Jasmine and Mukherji, 2015; Varjani and Upasani, 2019). Petroleum refinery sludge (PRS) is a complex mixture of hydrocarbons, water, and toxic heavy metals. Organization for Economic Co-operation and Development (OECD) countries, United States Environmental Protection Agency (US-EPA), USA, and India have recognized and stated oily waste as hazardous material due to their mutagenic, carcinogenic, and toxic properties (USEPA, 2004). Improper disposal of these pollutants may cause mutation or death of plants as well as animals (Poddar et al., 2019). Moreover, the accumulation of these pollutants to the environment represents a hazardous to human health, aquatic life and decreases soil fertility (Basak et al., 2020; Poddar et al., 2019; Poi et al., 2018; Varjani and Upasani, 2019). Therefore, hydrocarbon rich sludge requires effective treatment and proper disposal to ensure environmental safety.

Several physicochemical methods, such as incineration (Zhou et al., 2009), froth flotation (Ramaswamy et al., 2007), solvent extraction (Taiwo and Otolorin, 2009), pyrolysis (Qin et al., 2015) and ultrasonic treatment (Sivagami et al., 2019), chemical treatment by addition of

* Corresponding author. Department of Biotechnology, Indian Institute of Technology Kharagpur, West Bengal, 721302, India.
E-mail addresses: rksen@yahoo.com, rksen@bt.iitkgp.ac.in (R. Sen).
[1] The authors contribute equally to this paper.

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Effect of superficial gas velocity and ratio of bed volume to reactor volume of inverse fluidized bed biofilm reactor on the removal of ammonia-nitrogen from wastewater

Anup Kumar Swain*, Abanti Sahoo, Hara Mohan Jena & Satish Chandra Bhuyan
Chemical Engineering Department, National Institute of Technology, Rourkela, Odisha 769 008, India
E-mail: anup.k.swain@gmail.com

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Hydrodynamic parameters of an inverse fluidized bed biofilm reactor (IFBBR) have been studied using spherical polypropylene (PP) particles having average diameter and density of 5.63 mm and 920 kg/m^3 respectively. Gas-phase holdup (ε_g) was analyzed for various ratios of settled bed volume to reactor volume (V_b/V_r) and superficial gas velocities (U_g) with a liquid recirculation velocity (U_l) of 0.0021 m/s. The ε_g values were found to increase with V_b/V_r ratios up to a certain limit and then decrease with further increase of V_b/V_r ratios. The effect of U_g, V_b/V_r ratios, and initial concentration of ammonia-nitrogen (NH_4^+-N) on the removal of NH_4^+-N from synthetic wastewater were studied. The optimal values of V_b/V_r ratio and U_g were found to be 0.380 and 0.0085 m/s respectively for all initial NH_4^+-N concentrations. Complete removal of NH_4^+-N was achieved in 8 to 44 hours for different initial NH_4^+-N concentrations. It was also observed that with the increase in initial NH_4^+-N concentrations, the nitrification decreases.

Keywords: Ammonia-nitrogen, Biofilm reactor, Inverse fluidization, Nitrification, Wastewater treatment

The detrimental effects of NH_4^+-N present in wastewater are eutrophication; reduction of dissolved oxygen (DO) level; and toxicity to human, animal, and aquatic species[1]. Its removal from wastewater can be achieved by chemical, physical, combined chemical-physical, or biological treatment methods[2]. Among these methods, the biological treatment methods are widely used for the removal of NH_4^+-N from wastewater due to its high efficiency and low operating costs[3]. The biological method of converting NH_4^+-N to unstable nitrite-nitrogen (NO_2^--N) and then to less toxic nitrate-nitrogen (NO_3^--N) is known as nitrification. The conversion of NH_4^+-N to NO_3^--N proceed faster due to which at any instance the level of NO_2^--N in the system is usually low[4]. The basic nitrification reactions[2] can be written as:

$$NH_4^+ + 1.5\ O_2 \xrightarrow{Nitrosomonas} 2\ H^+ + H_2O + NO_2 \quad \ldots (1)$$

$$NO_2^- + 0.5\ O_2 \xrightarrow{Nitrobacter} NO_3^- \quad \ldots (2)$$

The nitrification steps are dependent on *p*H; temperature; alkalinity; DO level; concentrations of NH_4^+-N, NO_2^--N, and NO_3^--N; presence of heavy metals and toxic substances; and concentration of organic substrate[3,5]. The nitrification steps are carried out by two different growth conditions of bacteria: suspended and attached (as biofilm) growth conditions. The reactors based on attached growth condition have several advantages such as minimum wash off of the microorganisms, ease of handling, better stability, and capability to withstand shock loading[6]. These reactors require less floor area for erection and the separation of solids is easier[5]. Furthermore, the growth of the nitrifying bacteria is slow and can easily be swept away from the treatment systems. Therefore, it is essential to use such type of biofilm reactors which can hold the biomass inside the reactor for long duration and can also facilitate their growth[3].

In the fluidized bed biofilm reactors biomass can be hold for long duration as well as their growth can easily be facilitated due to which these reactors were in use for the removal of NH_4^+-N from wastewater[7-11]. Though the use of fluidized bed biofilm reactors is advantageous, the use of IFBBRs has emerged in recent times for the treatment of wastewaters generated from a wide variety of industries[12,13].

In conventional three-phase fluidized bed biofilm reactors (FBBRs), the particle density is higher than

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Analysis of iron ore pellets properties concerning raw material mineralogy for effective utilization of mining waste

Kashinath Barik [a,b], Pallishree Prusti [c,d,*], Shatrughan Soren [a,**], B.C. Meikap [d], S.K. Biswal [c]

[a] Department of Fuel, Minerals and Metallurgical Engineering, Indian Institute of Technology (ISM), Dhanbad 826004, Jharkhand, India
[b] Department of Chemical Engineering, Indira Gandhi Institute of Technology, Sarang 759146, Odisha, India
[c] Mineral Processing Department, CSIR-Institute of Minerals and Materials Technology, Bhubaneswar 751013, Odisha, India
[d] Department of Chemical Engineering, Indian Institute of Technology, Kharagpur 721302, West Bengal, India

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ABSTRACT

The value addition in iron ore mining waste generated from washing or beneficiation plants is a challenging task. The iron ore slimes, which contain low iron content with high gangue minerals like kaolinite, gibbsite, and quartzite, cannot be used directly for iron production. The present study focuses on utilization of iron ore slimes without beneficiation by blending with high-grade fines for making iron ore pellets. The pellets were prepared by adding slimes in different weight proportions (0, 10, 20, 30, 40, and 50%) with high-grade iron ore fines. The high-grade iron ore fines contain 64% Fe, 2.25% LOI, and Blaine number 2975 cm^2/g, whereas iron ore slimes contain 52.45% Fe, 5.60% LOI, and Blaine number 7046 cm^2/g. Pellets were produced without using bentonite as the binder. The pellet properties, such as drop number, green and dry compressive strength and moisture content of green pellet, cold compressive strength, porosity, swelling index, reduction degradation index, and reducibility index of fired pellet, have been investigated. The pellet mineralogy was analyzed using x-ray diffraction and optical microscope. The empirical correlation has been developed incorporating feed mineralogical data based on kaolinite and goethite to predict the physical and metallurgical properties of pellet.

1. Introduction

The demand and supply of iron ore and steel production are allied to each other. According to the new National Steel Policy 2017, the Ministry of Steel, Govt. of India has set up a target to produce 300 million tonnes per annum (MTPA) of crude steel making by 2030–31 [1]. For the production of 300 MTPA, around 450 MTPA of high-quality iron ore is needed in the form of calibrated ore, sinters, and pellets. High-grade iron ore resources are depleting day by day. To achieve the given target, there is a pressing need to utilize the low and lean grade iron ore resources and rejected mining waste material found from sources like washing or beneficiation plant called "iron ore slimes". During the washing and size reduction of the iron ore, around 15–25% of the mined ore is lost as slimes with a size less than 45 μm. Around 25–30 MTPA is discarded as slimes into the slimes pond, which are stockpiled at different mine heads and create a massive environmental problem in the locality of mines [2,3]. Hence, the optimal use of currently available low and lean-grade iron ore resources like slimes with particular emphasis on preserving high-grade ores has to be always encouraged. Slimes are associated with mineral phases like hematite, goethite, gibbsite, kaolinite, and quartzite. Kaolinite contributes the lion's share of alumina in the slimes. These slimes cannot be utilized directly in iron production through a blast furnace, DRI, and Corex processes due to their high silica, alumina content, and ultra-fine particle size distribution. Therefore, there have been many attempts to produce high Fe content concentrate from iron ore slimes using conventional beneficiation techniques.

Desliming with hydrocyclone followed by high-intensity magnetic separation and flotation of iron ore slimes could enrich the Fe content from 49.86% to 66.36% Fe in the concentrate with a 25% yield [4]. It has also been reported that it is possible to enrich Fe content to 66.97% from 37.86% Fe with a yield of 14.4% by the conventional beneficiation process [5]. To improve the magnetic susceptibility of goethite and hematite particles, an advanced technique, i.e., selective coating of magnetite nano-particles through dispersing in anionic reagent and then followed by low-intensity magnetic separation, was used to enhance Fe content from 59% to 65.9% [6]. In another instance, through simple classification by hydrocyclone and followed by reverse flotation, Fe content in the concentrate could be achieved 64.64% Fe from a feed of

* Corresponding author at: Mineral Processing Department, CSIR-Institute of Minerals and Materials Technology, Bhubaneswar 751013, Odisha, India.
** Corresponding author.
E-mail addresses: pprusti@immt.res.in (P. Prusti), ssoren@iitism.ac.in (S. Soren).

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Review

Graphene, Graphene-Derivatives and Composites: Fundamentals, Synthesis Approaches to Applications

Dibyani Sahu [1], Harekrushna Sutar [1,*], Pragyan Senapati [2], Rabiranjan Murmu [1] and Debashis Roy [3]

[1] Department of Chemical Engineering, Indira Gandhi Institute of Technology, Sarang 759146, India; sahudibyani006@gmail.com (D.S.); rabiranjan_murmu@rediffmail.com (R.M.)
[2] Department of Mechanical Engineering, ITER, Siksha 'O' Anusandhan Deemed to be University, Bhubaneswar 751030, India; pragyansenapati@soa.ac.in
[3] Department of Chemical Engineering, Jadavpur University, Kolkata 700032, India; deebie_roy@yahoo.com
* Correspondence: h.k.sutar@gmail.com; Tel.: +91-8594845698

Abstract: Graphene has accomplished huge notoriety and interest from the universe of science considering its exceptional mechanical physical and thermal properties. Graphene is an allotrope of carbon having one atom thick size and planar sheets thickly stuffed in a lattice structure resembling a honeycomb structure. Numerous methods to prepare graphene have been created throughout a limited span of time. Due to its fascinating properties, it has found some extensive applications to a wide variety of fields. So, we believe there is a necessity to produce a document of the outstanding methods and some of the novel applications of graphene. This article centres around the strategies to orchestrate graphene and its applications in an attempt to sum up the advancements that has taken place in the research of graphene.

Keywords: graphene; grahene-derivatives; composites; synthesis; applications

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1. Introduction

Graphene is an allotrope of carbon which has a two-dimensional structure. It is in the form of a hexagonal lattice (see Figure 1) that resembles honeycomb structure [1]. It has some unique properties that have interested the researchers since its discovery by Geim and Noveselov [2]. Due to its high versatility and relatively huge specific surface region [3], graphene is sought as a good option in sensing applications [4]. Main advantages of graphene are: (a) it is the finest and toughest material known; (b) it has carbon monolayered atoms that are both flexible and transparent in colour; (c) it is an excellent thermal and electrical conductor; (d) its main usage is in the manufacture of high-speed electronic gadgets; (e) explosives detection through chemical sensors; (f) membranes for more proficient separation of gases and is produced using sheets from which nanoscale pores have been made; (g) for manufacturing of transistors operating at high frequencies; (h) it has boosted the manufacture of low-cost display screens of cell phones replacing the indium-based electrodes in organic light emitting devices (OLED); (i) to produce lithium-ion batteries that use graphene on the anode surface and these batteries recharge faster; (j) stockpiling hydrogen for cars powered by fuel cells; (k) cheaper water desalination techniques by using graphene films with nanoscale holes to separate water from ions in brine; and (l) Graphene condoms are produced to increase the sensation and is thinner than conventional latex condoms.

The very first examinations on exfoliated graphene done by Schedin et al. [5] have showcased graphene's capability on identifying single gas particles based on estimations under Hall effect. The basic guideline behind the usage of graphene in gas sensors is the transfer of charge between the molecule adsorbed to its surface and the material [6]. The carrier concentration of graphene is changed by the absorbed particles which cause the electrical properties to change and the concentration of particles is determined. The response of the

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ORIGINAL PAPER

Development of chitosan-based hybrid membrane modified with ionic-liquid and carbon nanotubes for direct methanol fuel cell operating at moderate temperature

Rabiranjan Murmu[1,2] · **Debashis Roy**[1] · **Subhasmita Jena**[2] · **Harekrushna Sutar**[2]

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Abstract

Remarkable progress has been made to develop proton exchange membrane for direct methanol fuel cell to achieve higher power density. However, the higher methanol cross-over and poor water management are the two major obstacles of fuel cell which significantly reduces its performance. In this work, we have developed a highly performance Ionic Liquid (IL) modified chitosan based composite membrane and characterized by different experimental technique. The incorporation of IL in the chitosan composite introduces cationic acid which increases the ion exchange capacity and proton conductivity. Although the hydrophilic base of IL enhances water uptake capacity of the composite, the water is strongly attached with the polymer chain via hydrogen bonding thereby reducing free water content. The incorporation of Carbon Nanotubes (CNT) and bulky pendant group of IL in the chitosan composite reduces methanol cross-over and the methanol cross-over reported for CPCN@IL-4 composite (5.58×10^{-8} cm^2sec^{-1}) is significantly lower than the commercial N117 membrane (2.74×10^{-6} cm^2sec^{-1}). The IL modified composite membrane provides higher proton conductivity and membrane selectivity which is desirable for fuel cell design. At 70 °C, the maximum proton conductivity was achieved in CPCN@IL-3 composite (21.52×10^{-4} Scm^{-1}) and the proton transport was controlled by bound water regulated Grotthus mechanism. The polarization curve obtained for CPCN@IL-3 composite at 70 °C and 2 M methanol feed in a single cell of fuel cell provides the maximum power density of 82 mW/cm^2 at a current density of 370 mA/cm^2. The modification of chitosan based composite membrane with CNT and IL significantly reduces the methanol cross-over and provides higher membrane selectivity which will attracted a possible candidate for DMFC application.

Keywords Methanol cross-over · Ionic liquid · Multiwall carbon nanotubes · Membrane selectivity · Polarization curve · DMFC

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BRIEF COMMUNICATION

A New Perspective on the Green Strategy of Close Cycle Dissociation of H_2S

Bachcha Lal[2] · Dan Bahadur Pal[3] · Chandradhwaj Nayak[4] · Amit Kumar Gupta[5] · Arvind Singh[1]

Received: 15 October 2021 / Accepted: 12 March 2022

Abstract Extremely toxic H_2S gas is produced in huge quantities across the world as a byproduct of the desulfurization of hydrocarbon fuels. This H_2S gas is further converted into sulfur in sulfur recovery units. However, the valuable hydrogen content is lost as water vapour. It emphasizes the importance of proper exploitation of this resource. A continuous two-steps cyclic process for producing H_2 and sulfur simultaneously has been derived in this study. The first well-studied photocatalytic step generates hydrogen by water splitting in the presence of sulfide (S^{2-}) and sulfite (SO_3^{2-}), the sacrificial agents. Here, these sacrificial agents are converted into thiosulfate ($S_2O_3^{2-}$). In the second step, this $S_2O_3^{2-}$ reacts with hydrogen sulfide (HS^-) to form elemental sulfur, along with generation of S^{2-} and SO_3^{2-}, which are again reused in the first step. The kinetics of the reaction involved in the second step ($HS^- + S_2O_3^{2-} + OH^- \rightarrow S + S^{2-} + SO_3^{2-} + H_2O$) were studied in the present work. The reaction was found to be non-elementary with a rate law of $k[HS^-]^{1/2}[S_2O_3^{2-}]^{3/2}$. The observed rate law is of the order of 1.5 with respect to thiosulfate and 0.5 with respect to HS^- ions. A reaction mechanism for the second step consistent with the kinetics was also proposed. The rate constant was observed to be $1.075 \times 10^{10} e^{-62280/RT}$/M/s. This new proposed close cycle may simultaneously achieve green and renewable H_2 production along with H_2S removal.

Keywords H_2S · Dissociation · Sulfur · Kinetics

Introduction

Hydrogen sulfide (H_2S) is a very poisonous and corrosive gas with a rotten egg stench [1]. H_2S is often produced by natural processes such as microbial metabolism in the absence of oxygen or volcanic eruptions. However, in current civilization, the major sources of H_2S are ascribed to human need based industries such as crude oil refineries (desulfurization), coal industries, and natural gas production. A quantity of H_2S in the air exceeding 320 ppm might cause pulmonary edema and mortality [2]. Therefore, H_2S must be properly eliminated from these industries and associated human activities. H_2S is made up of two hydrogen atoms. As a future energy carrier, H_2 may play a pivotal role [3]. The Claus process, which produces sulfur and water via a high-temperature oxidation phase followed by a low-temperature reduction step, is the standard and well-known technique for H_2S removal (Eqs. 1, 2) [4, 5].

$$2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O \quad (1)$$

$$2SO_2 + 4H_2S \rightarrow 6S \downarrow + 4H_2O \quad (2)$$

Due to the requirement of higher temperature, the energy consumption of this process is rather significant.

✉ Arvind Singh
indian.arvi@gmail.com

[1] Chemical Engineering and Biochemical Engineering, Rajiv Gandhi Institute of Petroleum Technology, Amethi 229304, India

[2] TD College, Jaunpur 222002, India

[3] Chemical Engineering Department, BIT Mesra, Ranchi 835215, India

[4] Chemical Engineering Department, IGIT Sarang, Dhenkanal 759146, India

[5] Chemical Engineering Department, BIT Sindri, Dhanbad 828123, India

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ZnO/Bone-Char Hybrid Composite: Catalyst Preparation, Characterization, and Its Application

Damodhar, Ghime; Vijyendra, Kumar; Titikshya, Mohapatra; Neelam, Sonwani; Saket, Pradhan; Prabir, Ghosh*+

Department of Chemical Engineering, National Institute of Technology, Raipur (CG), INDIA

Sandeep, Dharmadhikari

Department of Chemical Engineering, Guru Ghasidas Vishwavidyalaya, Bilaspur (CG), INDIA

Sudip, Banerjee

Department of Chemical Engineering, Indira Gandhi Institute of Technology Sarang, Dhenkanal, Odisha, INDIA

ABSTRACT: *This study was aimed at the development of the ZnO/bone-char (ZnO/BC) hybrid composite and it was characterized by its suitability for the treatment of dye-containing wastewater. The Zn/BC composites were prepared using four different methods such as sol-gel, precipitation, hydrothermal and wet-impregnation methods. Various analyzing techniques such as X-Ray Diffraction (XRD), Fourier Transform Infra-Red (FT-IR), Brunauer-Emmett-Teller (BET) surface area, and Scanning Electron Microscopy (SEM) were performed to characterize the prepared photocatalysts. The photocatalytic activity of the ZnO/BC composite prepared from the sol-gel method was evaluated by the decolorization of brilliant green dye in an aqueous solution. The results of SEM analysis confirm the agglomeration of nano-ZnO particles and particles are evenly distributed on the surface of the bone char. Moreover, the influence of different experimental parameters like solution pH, H_2O_2 concentration, and photocatalyst dosage was studied to optimize the process efficiency. This study also shows that chicken bone waste can be used as a photocatalyst carrier for the synthesis of photocatalytic composites. It not only provides a better way to treat dye-containing wastewater but also offers an ideal solution to using chicken bone waste. From the kinetic analysis, it has been observed that the photocatalytic decolorization of BG dye with ZnO/BC photocatalyst follows pseudo-first-order kinetics.*

KEYWORDS: *Development of catalyst; Photocatalytic activity; Brilliant green dye; Environmental pollution; Wastewater treatment; Kinetics.*

INTRODUCTION

Water pollution is a global environmental issue among environmental pollutions. Industrialization and an increase in population density led to producing a large volume of wastewater, which contains a variety of refractory organic pollutants. The dye is a significant water contaminant, which has drawn the attention of

*To whom correspondence should be addressed.
+E-mail: prabirg.che@nitrr.ac.in
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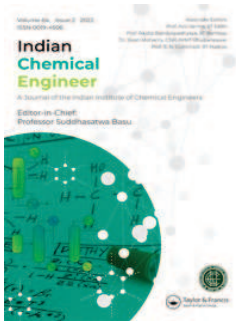

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A kinetic model and parameters estimate for the synthesis of 2-phenyloctane: a starting material of bio-degradable surfactant

Sudip Banerjee, Md Aurangzeb & Amit Kumar

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Article

Dynamics of Drop Release from the Edge of a Spinning Disc

Kshetramohan Sahoo and Sanjeev Kumar*

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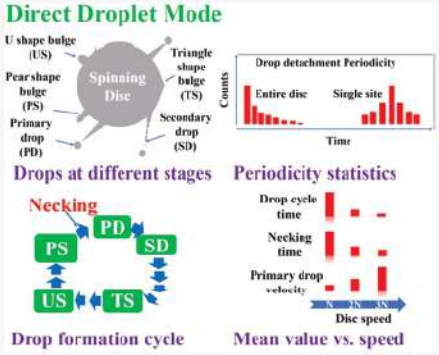
ABSTRACT: The direct formation of drops at the edge of a spinning disc is of fundamental interest. We use high-speed imaging to report here on the process of release of drops from a perfectly wetted disc at low inflow rates. A drop-detachment event begins by forming an incipient bulge on the disc edge, which grows into a series of shapes—triangle, inverted U, pear, and finally a nearly spherical bulge connected to the disc with an elongated neck. Neck pinching at the base of the bulge releases a primary drop followed by several secondary drops. The drop shape versus time plots show high variability under fixed conditions, which disappears on a single curve for time scaled with individual drop cycle time. The measurements at a different disc speed show the same scaled time evolution, pointing to a universal drop release process. The rapid stretching of the liquid thread as the bulge moves away before pinch-off follows a parabolic relationship with time but with only half the relative acceleration of a free object released from the disc edge. The mean values of cycle time and necking time follow a power-law decrease with disc speed. All of the drops generated in a single event move with the speed of the disc. There is no slip, which is not the case with the ligament mode of breakup. The intervals of quiescence between the successive release of drops from the entire disc follow the Poisson process.



1. INTRODUCTION

An incoming liquid jet spreads on a spinning disc as a thin film and emerges as fine drops. Spinning disc atomizers help produce agricultural sprays,[1] particles of controlled morphology by spray drying,[2,3] granulation of molten slags,[4−6] etc. A spinning disc can also mix two or more miscible liquid streams fed to it to facilitate chemical reactions[7,8] and synthesis of nanoparticles.[9] A recently developed contactor in our laboratory employs a spinning disc to generate drops of one liquid, which impinge on the rising film of another liquid on the cylindrical wall of a coaxially located rotating bowl.[10] The unidirectional flow on the bowl wall, driven by the centrifugal acceleration, sweeps away liquids to provide intense mixing with low back-mixing. We have synthesized sub-10 nm silver nanoparticles of narrow size distribution using a free impinging jet reactor and a spinning bowl spinning disc reactor.[11] The latter is easy to set up and operate. In this work, we focus on the process of drop formation from a spinning disc.

The flow rate and rotational speed are the two control parameters for a spinning disc. At a high flow rate, the incoming liquid leaves the disc edge as a thin sheet that disintegrates in the air to release drops. The sheet breakup mode[12] produces drops with poor control on polydispersity. At moderate flow rates, the liquid emerges as ligaments attached to the disc edge. The ligaments are of nearly fixed shape and orientation.[13−15] They release drops from the free end by the Rayleigh−Plateau instability. The drop formation in jetting mode from a capillary (away from the capillary tip by jet instability) is analogous. Peng et al.[15] have studied regime changes with flow rate and rotational speed using high-speed imaging. The improved control on drop release in ligament mode has led to studies on discs of different designs.[16−20] Guided drop formation in ligament mode is recently achieved by Wang et al.[21] using a stacked serrated disc. The authors suggest that pointed tips in their disc increase the frequency of drop formation by promoting jet formation for low-to-moderate viscosity liquids.

At low inflow rates, the drop formation occurs at the disc edge. To the best of our knowledge, there are no systematic studies on this mode of drop formation from a spinning disc. The drop formation from a capillary tube in dripping mode is analogous, for the tube end exposed to air or another immiscible liquid, stationary or coflowing. Microfluidic systems extensively use the latter to generate controlled size drops continuously. Drop formation from a hydrophobic disc is qualitatively different, as shown by the high-speed images of Wu et al.[22] and is not addressed in this study. Figure 1 schematically brings up the basic difference between direct drop and ligament modes of drop formation.

Perhaps the earliest study on drop formation from a capillary tube under gravity goes back to 1864 by Tate,[23] who argued

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