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Performance of a modified multi-stage bubble column reactor for lead(II) and biological oxygen demand removal from wastewater using activated rice husk

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ABSTRACT

The excessive release of wastewater into the environment is a major concern worldwide. Adsorption is the one of the most effective technique for treatment of wastewater. In this work activated carbon prepared from rice husk has been used as an adsorbent. In the present investigation a three phase modified multi-stage bubble column reactor (MMBCR) has been designed to remove lead and biochemical oxygen demand (BOD) from wastewater by means of its adsorption onto the surface of activated rice husk. The multi-staging has been achieved by hydrodynamically induced continuous bubble generation, breakup and regeneration. Under optimum conditions, maximum lead and BOD reduction achieved using activated rice husk was 77.15% and 19.05%, respectively. Results showed MMBCR offered appreciated potential benefits for lead removal from wastewater and BOD removal, even this extent of removal is encouraging and the MMBCR can be used a pretreatment unit before subjecting the wastewater to biological treatment.

1. Introduction

Environmental pollution due to development in technology is one of the most important contemporary problems. Industries have a large potential to cause lake, streams, sea and river pollution. It is very difficult to generalize the industrial wastes unlike the domestic sewage. The nature of pollution varies from industry to industry and also from plant to plant. The organic content of wastewater is traditionally measured using lumped parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC).

These parameters, as such, do not indicate the specific chemical identities of the organic contaminants. Biochemical oxygen demand of wastewater is a measure of the oxygen required for the bio-degradation of the organic substrate in the wastewater. Due to high pollutant concentration, its disposal without treatment in water bodies has became undesirable because if done so, it will be very dangerous for the water bodies and human health. So, before its final disposal in water bodies, it needs a proper treatment.

Rapid industrialization has led to increased disposal of heavy metals into the environment. Lead is one of the potentially toxic heavy metals when adsorbed into the body. The presence of high levels of lead in the environment may cause long-term health risks to humans and ecosystems. It is therefore mandatory that their levels in drinking water, waste water and water used for agricultural and recreational purposes must be reduced to within the maximum allowable concentrations recommended by national and international health authorities such as World Health Organisation. Its removal from wastewater prior to discharge into environment is there fore necessary.

Various treatment technologies were utilized for organics and toxic inorganic metal removal from wastewater. The physicochemical techniques are widely used to treat wastewater in various industries. These techniques include adsorption, chemical reaction, filtration, ion-exchange, coagulation/flocculation reverse osmosis, electrodialysis and so on [1–5]. The choice of treatment depend upon effluent characteristics such as concentration of lead, pH, temperature, flow volume, biological oxygen demand, the economics involved and the social factor like standard set by government agencies.

Based on the level of treatment provided, wastewater treatment processes are frequently classified as preliminary, secondary or tertiary treatments. Voluminous literature is available on the applications of physicochemical techniques. Physicochemical processes have a number of advantages versus the biological and other treatment processes. Physicochemical treatment processes remain unaffected by the presence of toxic substances such as metals whereas biological systems fail to operate in case of wastes predominantly inorganic or non-biodegradable in nature. In India, there are ~7500 industries of considerable pollution significance

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Nomenclature

C_{ef}	concentration of effluent (g/l)
C_{in}	concentration of influent (g/l)
C_p	inlet activated rice husk loading (g/l)
D	diameter of the bubble column (m)
D_l	diffusivity (g/m^2 s)
H	height of the bubble column (m)
H_R	height to diameter ratio (H/D)
Q_g	gas flow rate (m^3/s)
Q_l	liquid flow rate (m^3/s)
Re_g	superficial gas Reynolds number ($DV_g\rho_g/\mu_g$)
Re_l	superficial liquid Reynolds number ($DV_l\rho_l/\mu_l$)
Sc	Schmidt number based on activated rice husk loading (μ_l/D_lC_p)
V_g	gas velocity (m/s)
V_l	liquid velocity (m/s)

Greek letters

η	removal efficiency of pollutants experimental (%)
η_{BOD}	removal efficiency of BOD theoretical (%)
η_{Pb}	removal efficiency of lead theoretical (%)
η_T	removal efficiency of pollutants theoretical (%)
μ_g	gas viscosity (g/m s)
μ_l	liquid viscosity (g/m s)
ρ_g	gas density (g/m^3)
ρ_l	liquid density (g/m^3)

and ~4500 of them have put up effluent treatment plants [6]. There are several tens of thousands of other small industries, which contribute significantly to pollution load but escape attention. Considerable amounts of wastewater are also generated as human waste or sewage. Removal of these contaminants from wastewater to adequate levels is one of the fundamental goals in waste treatment using various available technologies. However, conventional treatment technologies implemented in the industrialized nations are expensive to build, operate and maintain in developing countries. Therefore, efforts are still going on to develop affordable treatment technologies for developing and underdeveloped countries. Various technologies to treat water/wastewater are very well documented but few studies are reported which use of low cost adsorbents to clean organic loads together with some toxic inorganic metal cations and anions from industrial wastewater/effluents.

The use of activated carbon is still very popular and different grades are available, but are quite expensive and the regeneration of the carbon is not always possible. Activated carbon has been chosen as an adsorptive media for removal of lead and BOD by many researchers [7,8]. Activated carbon is a black solid substance resembling granular or powder charcoal and are carbonaceous material that have highly developed porosity, internal surface area of more than 400 m^2 g^{-1} and relatively high mechanical strength. They are widely used as adsorbents in wastewater and gas treatments as well as in catalysis. The increasing usage and competitiveness of activated carbon prices, has prompted, a considerable research work has been done in the search of inexpensive adsorbents especially developed from various agricultural waste materials i.e. the usage of agricultural by-products such as fruit stones, coconut shell, bagasse, nutshells, coirpith and rice husk as raw materials to prepare activated carbon [9]. These solid wastes are not only cheap and easily available but also are considered as wastes that contribute to the disposal problems. In this study, rice husk has chosen as an adsorptive media.

The process of adsorption has been carried out mostly in packed bed, fluidized bed and moving beds. However, operational complexity and the limitation of the efficiency of removal have led to search for new and efficient equipment which can give better removal efficiency without additional mechanical complications. Simple bubble columns [10,11] and airlift reactors are drawing increased attention as possible alternatives to these devices. Simple bubble column, in their various forms and manifestations belong to the category of buoyancy induced flow reactors in which the compressed air is used to simultaneously aerate and agitate the liquid with controlled recirculation. Thus, simultaneous gas–liquid (or gas–liquid–solid) mixing and liquid recirculation is achieved by using only compressed air.

It may further be appreciated that a simple bubble column operates in one stage only and cannot achieve high efficiency except for highly soluble gas in chemically reactive systems. In order to achieve high efficiency of mass transfer, bubble columns must be operated in series or in multiple stages. In commercially available bubble columns, multistage operation has been achieved by the use of perforated multi-orifice plates. Thus in such columns, high efficiencies can be achieved only with high energy dissipation and mechanical complications. In the present investigation a bubble column, operating in three stages has been designed—the staging effect being achieved through hydro dynamically induced bubble generation and breakup through bubble rupture and regeneration. The staging effect is produced using contraction and expansion elements a 2 mesh sieve acts as the contraction element and a 4 mesh sieve acts as the expansion elements. A multi-orifice antenna type sparger produces fairly uniform bubbles of 3–5 mm in the first stage of the column. Bubbles which are generated by the sparger in the first stage of the column, rupture and reforms at these sieves, hence starting a cycle of bubble breakup, coalescence and regeneration [12]. The continuous generation of new surface area coupled with high turbulence achieved due to bubble breakup was expected to lead to very high interphase mass transfer. The modified multistage bubble column reactor (MMBCR) can therefore, prove to be a very important contacting system for the liquid phase adsorption of trace pollutants using powdered activated carbons, because of their basic advantages like: a simple construction without moving parts, an excellent heat transfer capacity, a reasonable interphase mass transfer and good mixing properties at low energy consumption, as the gas phase serves the dual function of aeration and agitation.

The lead metal adsorption characteristics of activated carbon are quite well known. The interesting part of the investigation is how far the activated carbon treatment is successful in reducing BOD levels of the wastewater. Even a fractional of BOD means encouraging results because this comes over and above the lead metal abatement and the apparatus can be used as a pretreatment unit before subjecting the wastewater to biological remediation.

2. Experimental set-up and technique

2.1. Reagents

All the chemicals used in the study were from Merck (India) Ltd. and Qualigens Glaxo (India) Ltd. analytical grade.

2.2. Adsorbent

The rice husk collected from a nearby rice mill was washed with distilled water to remove the water-soluble impurities and surface adhered particles and then oven-dried at 60 °C to get rid of the moisture and other volatile impurities. Then, the dried rice husk was soaked in concentrated H_2SO_4 in an amount sufficient to cover