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Fungi solubilisation of low rank coal: Performances of stirred tank, fluidised bed and packed bed reactors

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ABSTRACT

Coal biosolubilisation was investigated in stirred tank reactor, fluidised bed and fixed bed bioreactors with a view to highlight the advantages and shortcomings of each of these reactor configurations. The stirred aerated bioreactor and fluidised bioreactor represent slurry reactor systems enabling a comparative study. Direct comparison between these and the fixed bed bioreactor could not be carried as the corresponding particle sizes will result to a pressure drop in the fixed bed reactor.

Coal solubilisation showed a higher coal weight loss in the stirred tank slurry bioreactor in comparison to the fluidised bed slurry bioreactor at 5% (w/v) coal loading and 600–850 μm coal fractions. Higher aeration is required in the fluidised bed bioreactor than in the stirred tank slurry bioreactor at constant coal loading and particle size because in fluidised bed bioreactor aeration was also used for mixing.

Coal biosolubilisation in the packed bed bioreactor was minimal. The low performance was attributed to the large coal particle size fraction (1.5–2 mm) used. Minimal damage to the fungal culture was observed. However, clogging of bed by fungi resulted in channelling or misdistribution that ultimately leads to poor and unpredictable internal mass transport.

1. Introduction

Biosolubilisation of coal has been reported over the past two decades [1]. However, current research efforts on this subject have focussed on solubilisation potential of microbes and nutrients and/or bioreaction conditions for maximum solubilisation [2–5]. Although prospects for scale-up have been suggested by some authors [1,6,7], current studies are limited to laboratory-scale study using Petri dishes or Erlenmeyer flasks of moderate volume [8,9]. Large scale designs for coal biosolubilisation bioreactors are constrained by several problems encountered in the control of parameters such as pH, temperature, aeration, mass and oxygen transfer and agitation. Therefore, the design of an appropriate reactor configuration should take into account biocatalyst concentration, mass transfer between interacting phases and, ultimately, economic feasibility.

The proposed bioreactor configuration for coal bioprocessing, according to Scott [6], should comprise a multi-phase interacting system in which there is a particulate solid phase consisting of coal particles, a liquid phase comprised of nutrients, a biomass phase of suspended catalyst and solubilized products, and a gas phase containing reactants such as oxygen or products such as CO_2. Extensive literature survey revealed that limited references on scale-up studies involving application of bioreactors to coal biosolubilisation, also, parameters describing hydrodynamic behaviour including overall gas hold and volumetric gas–liquid mass transfer coefficient, k_La, for relevant bioreactors have not been reported.

In this article, coal biosolubilisation in fluidized bed bioreactor was investigated with a view to compare the bioreactor performance with other reactor configurations. Coal biosolubilisation was carried out in an aerated stirred tank bioreactor, a fixed bed bioreactor and a fluidized bed bioreactor. The aerated stirred tank and fluidized bioreactors represent slurry reactor systems enabling a comparative study. Direct comparison between these and the fixed bed bioreactor could not be made since small coal particles (150–300, 600–850 μm) required for the slurry reactor systems cannot be used in the fixed bed bioreactor due to the large pressure drop. A recent study has shown that particle size is a critical operating variable in coal biosolubilisation [3], hence direct comparison of rate and extent of solubilisation is inappropriate. However key data is presented in this study to allow feasibility of the packed bed system to be assessed for later comparison in terms of compromise between biosolubilisation rate, efficiency, energy input and communition required.

2. Experimental

2.1. Coal

Sub-bituminous coal from SASOL (SA) was used. Coal samples were dry sieved into 1500–2000 μm, 600–850 μm and 150–300 μm size

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fractions using laboratory sieves. The dry coal samples were autoclaved at 120 °C for 20 min. No further pretreatment was performed.

2.2. Microorganisms

The fungal strain, *Trichoderma atroviride* (ES 11) was obtained from the Institute for Microbial Biotechnology and Metagenomics (IMBM), Department of Biotechnology at the University of the Western Cape, South Africa. This fungal strain was isolated from soil samples. It was maintained on 3% malt extract agar plates at 4 °C for up to 6 months. These plates were used for inoculum preparation.

2.3. Inoculum preparation and propagation

The pre-inoculum was prepared by cutting five plugs of fungal culture from the stock plates with a 5 ml sterile Pasteur pipette tip and inoculating these into 100 ml sterile growth media. The growth medium contained 0.1% (w/v) coal of 150–300 μm size fractions. Ten glass beads (6 mm diameter) were added and the culture was incubated for 4 days at 28 °C in an orbital incubator shaker at an agitation rate of 120 rpm. The inoculum was prepared by transferring a 10 ml aliquot of the pre-inoculum culture into 100 ml fresh growth medium. The inoculum was cultured for 2 days at 28 °C with agitation at 120 rpm.

2.4. Growth medium and culture conditions

The inoculated reactor used 900 ml of growth medium and 100 ml of 48 h inoculum. In shake flask experiments, 90 ml growth medium and 10 ml inoculum were used. The growth media used for agar plates, inoculum preparation and experimental studies contained (per litre): 1 g $NH_4(SO_4)$, 3 g malt extract, 0.52 g $MgSO_4 \cdot 7H_2O$, 7.6 g KH_2PO_4, 0.005 g $FeSO_4 \cdot 7\ H_2O$ and 0.003 g $ZnSO_4 \cdot 7H_2O$. The standard growth medium was supplemented with 10 g glucose per litre, unless otherwise stated. The growth medium was selected through optimisation studies at IMBM, Department of Biotechnology at the University of the Western Cape [10].

2.5. Equipment

2.5.1. The stirred tank reactor

Experiments were carried out in a 2 l jacketed Z61104CT04 Applikon autoclavable bioreactor made of borosilicate glass. The bioreactor had a height to diameter ratio (H/D) of 1.32 and working volume of 1 l. The bioreactor was maintained at constant temperature of 28 °C by circulating water from a Grant Y6 constant temperature bath through the bioreactor jacket (Fig. 1). The geometry of the reactor is shown in Table 1. The mixing and gas dispersion was achieved by a pitched (45°) six-blade turbine impeller rotating at 560 rpm, located 2 cm from the base of the bioreactor. The impeller was driven by a flexible coupling, linked to an Applikon P100 motor and Applikon 1012 stand-alone speed controller. Inlet gas was supplied by Peak Scientific OAG200DA oil-less air compressor. The flow rate was set at 350 ml min^{-1} by a Brooks model 5850S mass flow controller. The CO_2 concentration of the bioreactor off-gas was determined using a Hartmann & Braun Uras 4 NDIR (non-dispersive infrared) industrial photometer and the O_2 concentration was determined using a Hartmann & Braun Magnos 6G oxygen analyser.

2.5.2. The fluidised bed bioreactor

The fluidised bed reactor was 50 cm in length with an inner diameter of 10 cm and an outer diameter of 12 cm. The bioreactor design incorporated an internal gas–liquid–solid separation area to permit the settling of solids (microorganism and coal). Prior to its entering the fluidised bed, dry air was humidified by bubbling into sterile water. This humid air was used to fluidise the bed of coal at flow rates of 0.46 cm s^{-1} and 0.64 cm s^{-1}. The working volume of the fluidised bed reactor was approximately 2 l, with a solid loading of 5% (w/v) and 10% (w/v) used as specified for each experiment. A schematic diagram of the fluidised bed bioreactor is presented in Fig. 2.

2.5.3. The fixed bed bioreactor

The dimension of the fixed bed is the same as fluidised bed (Fig. 3). The lower plate used for coal packing has a sieve size of 6 mm diameter. The bed was packed with 50 g glass beads (5 mm) to increase the bed height and 200 g sub-bituminous coal (2–4 mm). Initially, 15 ml of inoculum (5-days old) was applied to the top of

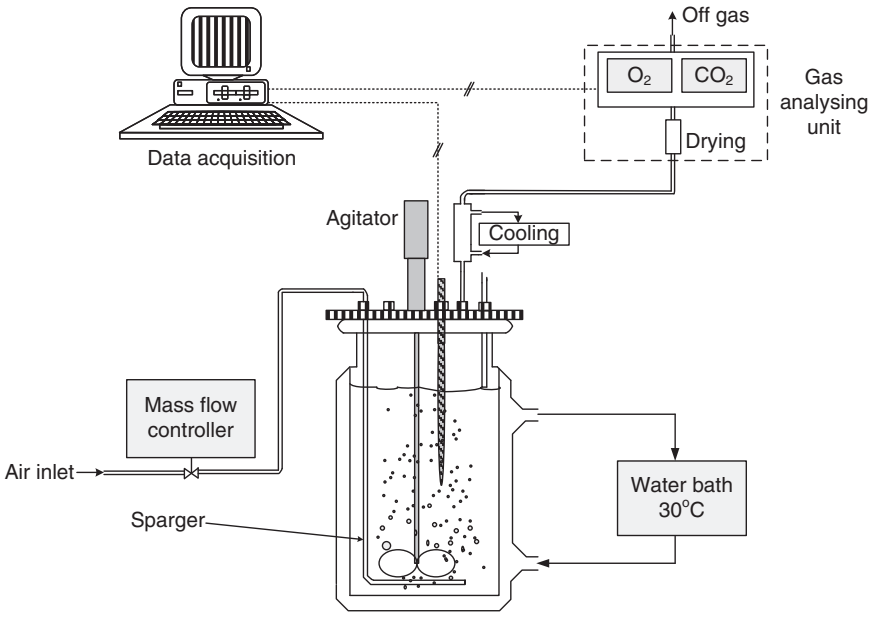

Fig. 1. Applikon bioreactor set-up used, including controlled air supply through the mass flow controller and on-line off-gas analysis. [adapted from Ojumu et al. [11].