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The effect of HRT on biohydrogen production from acid hydrolyzed waste wheat in a continuously operated packed bed reactor

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ABSTRACT

Biohydrogen production in a continuously operated up flow packed bed reactor was investigated at different hydraulic retention time (HRT) varying between 2 h and 13 h scouring sponge pad. The substrate was sugar solution obtained from hydrolysis of waste wheat at pH = 2 and 90 °C in an autoclave for 15 min. Experimental results indicated that hydrogen production volume and yield increases with decreasing HRT. The highest volumetric hydrogen production rate and yield were obtained as VHPR = 1.75 L H_2/L d and Y_{H2} = 1.6 moL H_2/mol TS, respectively, at HRT = 2 h. Yields and rates at HRT = 2 h were almost two times of that obtained at HRT = 13 h. It can be concluded that metal mesh covered plastic scouring sponge pad is a suitable microorganism support particle to obtain high hydrogen yield and rate at short HRTs by dark fermentation.

Introduction

Hydrogen is a non-toxic, renewable, securely storable and transportable energy sources of future. It has got a high specific energy on a mass basis. The energy content of 9.5 kg of hydrogen is equivalent to that of 25 kg of gasoline. Apart from all these advantageous of hydrogen, it can be generated by different technologies and from various sources. The biological production of hydrogen is considered as an important key sustainable world energy supply and it is currently being seen as the versatile fuel of the future, with the potential to replace fossil fuels.

Two main biological hydrogen production methods are dark and photofermentation. Dark fermentation is more common due to high hydrogen production rates and yields, requirement of simple operation conditions and controls over other biological methods. The studies about dark fermentation concentrated on the effect of substrate, microbial culture type and environmental condition on hydrogen gas production [1–9]. Substrate type was the major concern to make the process economical and sustainable. It was realized that carbohydrate rich waste materials should be the first choice instead of pure sugars [1,3]. Using lignocellulosic waste materials to obtain carbohydrate source for biohydrogen production by dark fermentation is the recent challenge and

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Abbreviations

VSS	Volatile Suspended Solid
CSTR	Continuously Stirred Tank Reactor
WP	Wheat Powder
HRT	Hydraulic Retention Time h
VHPR	Volumetric Hydrogen Production Rate L/ L d
OLR	Organic Loading Rate g/L d
ORP	Oxidation reduction potential mV
TS	Total Sugar g/L
V_{H2}	Hydrogen Volume, ml
Y_{H2}	Hydrogen Production Yield mol H_2/mol substrate
COD	Chemical Oxygen Demand mg/L

investigations on low cost, efficient pretreatment method to obtain pure 5C and 6C sugars and on fermentation conditions of these sugars are the research subjects [10–14].

The recent studies have been devoted to investigation of biohydrogen production potentials of dark fermentative, continuously operated different immobilized or suspended growth bioprocess technologies [4–8,17–22]. Type of bioprocess used for dark fermentative biohydrogen production are continuously stirred tank reactor [4] and hybrid bioreactor as CSTR with immobilized biomass [15,16], the membrane bioreactor [5], packed bed bioreactor (fixed/packed-bed) [6,20], fluidized bed bioreactor [7,20], up-flow anaerobic sludge bed bioreactor [8,21] and trickling filter bioreactor [9]. The main parameters that have been studied so far are comparison of immobilized and suspended culture systems, selection of microorganism support particle type for immobilized bioprocesses and also determination of best operation conditions such as hydraulic retention time (HRT) and organic loading rate (OLR) to obtain high yields and rates. The studies indicated that immobilized systems are superior over suspended growth systems for dark fermentative hydrogen production [22].

Immobilized systems have certain advantages over suspended ones such as higher biomass holding capacity, operating the system at low retention times without washout of organisms, longer biomass retention times, resistance to high organic loading rates, the high rate of substrate conversion to product [22,23]. However, improper mixing, mass transfer limitations, efficient gas retrieving and biomass accumulation are the major shortcomings of immobilized systems to be solved [22–24]. Wu & Chang (2005) reported that mass transfer limitation was more substantial in entrapped cells compared to surface attachment and self flocculation type immobilization which affected operation condition and hydrogen productivity of the system [25]. On the other hand, it was stated that an appropriate growth environment is provided by the entrapment of microorganisms and stability of the cells is increased [26]. Peixoto et al. (2011) conducted a hydrodynamic assay for long term operated packed bed reactor and it was observed that HRT was 3 times less than the initially adjusted HRT due to biomass accumulation [6]. The immobilization techniques used in the bioreactor for hydrogen production has a substantial role in the productivity. Entrapment into a gel matrix, for instant, has been widely used for biohydrogen production. Although biomass loss is minimum in this immobilization method, the long term stability of the matrix and substrate diffusion limitations were the problems. Immobilization on a solid surface, especially on porous support particle, relatively eliminates these problems [27]. Support particle characteristics also affect the operation conditions such as organic loading rate, HRT and gas retrieving. High yields were obtained at low HRTs in some studies and relatively longer HRTs in others [21]. It was observed that porous support particles could be more advantageous than non-porous ones regarding to gas retrieving, biomass holding capacity. Si et al. (2015) suggested that although hydrogen gas is almost insoluble in water and it would escape from aqueous medium, insufficient liquid-to-gaseous phase component transport may take place in packed bed reactor [28]. HRT is a factor in controlling homoacetogenesis and methanogenesis which are two hydrogen consuming pathways in dark fermentation. It has been reported that these two pathways can be suppressed by reducing HRT [28].

Some of the support particle types used in immobilized bioreactors for hydrogen production are coir [29], polyethylene pellets [30], polyurethane foam [21], polyethylene rings [28], ceramic ring [31], ceramic beads [33], clay beads [34], alginate beads with a solid surface such as activated carbon or chitosan [15]. Porous support particles used for hydrogen production are plastic scouring sponge pad, plastic nylon sponge, black porous sponge, plastic scouring sponge pad with metal mesh, plastic nylon sponge with metal mesh [2], stainless steel scrubber, volcanic stone, tulle, polyester fiber, loofah sponge, plastic bath sponge, sea sponge, aquarium biological sponges [32] and pumice stone [31]. The problems observed in packed bed reactor are performance losses in the short term because of the negative effects of operational factors, such as biomass accumulation and inadequate pH conditions [23]. pH proved to be a key factor for obtaining continuous hydrogen production, and the optimal results were observed in a pH range from 5.1 to 5.2. Long term operation of the reactor resulted in slight decline in hydrogen production. This result was explained as, most likely, biomass aging, which was characterized by the proliferation of non-hydrogen producing bacteria. Moreover, it was stated that the low porosity of particle caused by the random arrangement of support media in packed-bed reactors hinders the removal by bottom discharge of interstitial acidogenic biomass that accumulates in the bed, which could affect the biomass retention. In addition it was reported that hydrogen production is related with the bed porosity rather than support particle type used in the packed bed reactor. Low porosity causes of the accumulation of biomass which decreases HRT [23].

The aforementioned studies in immobilized continuously operated biohydrogen production bioprocesses indicated that there is a strong relationship between support particle type, HRT, hydrogen yield and rate. Therefore, the operation conditions in an immobilized bioprocess should be determined depending on the support particle type used in a process. In our previous study, different porous microbial support particles were used in hydrogen production by repeated batch

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