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Separation of Bio-Butanol

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Abstract

Research to develop an alternative to fossil fuels is the interest of research. Bio-fuels produced from a fermentation process are the alternative to petroleum based fuels. Bio-fuels will decrease the release of carbon dioxide into the atmosphere and it is the major merit of using bio-fuels. Butanol can be directly used as a fuel in vehicles having 30% higher energy content than that of ethanol. The fermentation is not efficient due to the great cost associated with the separation of butanol from the fermentation broth. In present paper, various separation techniques were reviewed briefly and membrane based methods are more promising than others.

Key words: Analytical techniques, Bio-fuels, Butanol, Bio-butanol.

1. Introduction

The development for utilization of renewable energy sources are more attracting now-a-days due to environmental issues and depletion of petroleum sources [1]. Bio-fuels produced by fermentation are the alternatives for petroleum based fuels. Bio-ethanol has been used as a bio-fuel which has certain disadvantages. Bio-butanol has emerged as a new type of bio-fuel overcoming the disadvantages of bio-ethanol. Due to low vapour pressure of butanol, it can be directly used without any modifications in engine. Butanol has energy content of 29.2 MJ/L which is close to the gasoline (0.0438 kJ/kg) and higher than the ethanol (19.2 MJ/L) [2] and which is accounted for 30% more energy than that of ethanol. The Butanol has four isomers (n-butanol, 2-butanol, iso-butanol, tert-butanol) and the properties of bio-butanol resembles as n-butanol. Bio-butanol is competing with synthetic butanol as a superior bio-fuel and will have great contribution to fulfil the demand of fuel [3].

Bio-butanol has better properties as compared to the bio-ethanol such as high heating value, high viscosity, low volatility, high hydrophobicity and less corrosive [1]. Apart from the application of bio-butanol as bio-

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fuel, it has several applications as a solvent in chemical and allied industries. Butanol can be produced by Oxo-synthesis [4] and aldol condensation. Bio-butanol is mainly produced in acetone–butanol–ethanol (ABE) fermentation by bacteria *Clostridium acetobutylicum* [5]. Lignocellulosic feedstock (bagasse, straw, corn stover, switch grass etc.) is the main source for bio-butanol fermentation [6].

The major challenges facing in the commercialization of bio-butanol is the end product toxicity to the microbes which inhibits the growth and stops the fermentation and second is simultaneous separation. Butanol is toxic to the microbes at a low concentration (normally > 10 g/L) [7]. There is a major problem with butanol fermentation that butanol (normally > 10 g/L) inhibits its production. The toxicity of butanol is attributed to passive proton flux by butanol causing membrane leaking, disruption of the lipid structure in cell membranes that alters the membrane-bound enzyme activity and membrane fluidity in the presence of butanol [8]. High cost of bio-butanol separation from fermentation broth makes fermentation process inefficient. Butanol solubility is around 7% by weight [9]. In bio-butanol production, mainly *in-situ* continuous recovery by separation process is very important [10]. There are number of separation processes studied and few have been patented and also implemented such as distillation, extraction, gas stripping, membrane based separation, adsorption etc.

2. Distillation

Distillation is one of the oldest, conventional and well proven separation techniques. It may be considered for butanol separation from water but it is highly energy intensive. The boiling point of bio-butanol (118^{o}C) is higher than the water hence energy needed is very high [11]. In butanol-water system distillation, there is a formation of an azeotrope at 101.3 kPa with 55.5 wt% butanol which increases the energy cost [12]. The separation of butanol by distillation from the fermentation broth accounted up to 40% cost of the total production costs [13]. Hence, distillation is not economical [1]. Also the main difficulty is low solubility (maximum 7.7 wt %) of butanol in water. Almost 12 t of steam is needed for 1 t of butanol [14]. The desired purity may be achieved with multiple columns. In conventional distillation, improvements may be possible to reduce energy using non-conventional ways [3].

3. Adsorption

Bio-butanol can be easily adsorbed on adsorbent in fermenter from the bulk aqueous fermentation broth. Hydrophobic adsorbent may have high selectivity for butanol [15]. In adsorption, butanol is transferred from the aqueous feed of butanol to solid adsorbent may be physically, chemically or both [12]. Silicalite is silica with a zeolite-like structure with hydrophobic properties was used for adsorption of bio-butanol [16]. Adsorption may not be suitable on industrial scale due to low adsorption capacity [1]. Also it may not be suitable at large scale or for high throughput.

4. Perstraction

It is one of the membrane based separation. In perstraction, membrane is used to separate the fermentation broth and extractant phase. Membrane provides the contact surface for exchange of butanol across two immiscible phase and toxicity can be avoided [16]. While in perstraction for butanol separation, higher concentration of substrate (lactose, 227 g/L) can be used as compared to 28.6 g/L in fermentation without perstraction [17].

5. Membrane Reactor

In membrane reactors, microorganisms can be immobilized in the membrane. The increase in productivity was observed using membrane reactor [18-19]. Still this suffers with the drawback of leakage of cells from the matrices and also poor mechanical strength and high mass transfer resistance [1].

6. Membrane Based Extractive Separation

Two phases of fermentation broth and extractant are separated by porous membrane in extractive fermentation assisted by membrane which acts as a passive barrier. Hydrophilic or hydrophobic membrane may be used with interface which immobilized one of the two phases depending on the membrane affinity by impregnation of membrane pores [20]. In this technique, the mass transfer occurs by diffusion due to a concentration gradient [21]. Glucose consumption was increased from 66% to 100% by using this approach by avoiding toxicity and inhibition for bio-butanol production [22]. This technique has advantages of prevention of contamination by diffusion of the solvent in the fermentation broth, also formation of emulsions and accumulation of cells in the interface is prevented [23].

7. Gas Stripping

Fermentation integrated with separation by gas stripping can be the promising option to avoid product inhibition and to increase the productivity and concentration [24]. Membrane or expensive chemicals are not needed in this process and it is free of emulsion formation [25]. In gas stripping, gas is bubbled in fermenter which captures the bio-butanol followed by condensation [1]. N_2 or CO_2 can be used for gas stripping which enhances productivity [26]. It is more selective towards butanol than acetone and ethanol and very efficient for more than 8 g/L butanol in fermentation broth [27-28].

8. Pervaporation

Pervaporation is one of the important membrane separation technique used specially to separate water-organic and organic-organic systems by sorption-diffusion mechanism. Pervaporation does not require heating energy and provides efficient separation and concentration in a single step. It maintains the productivity of the microorganism by preventing product inhibition [29]. It is more selective for butanol and best alternative to conventional distillation. In this membrane-based separation, selective removal is possible using membrane (polydimethylsiloxane and silicon rubber sheets) for removal of volatile compounds from fermentation broth. *In-situ* separation of bio-butanol is promising by pervaporation [12, 30]. The productivity and yield increased by 20% using poly (ether-block-amide) and 5% and 10% (w/v) of carbon nano tubes as compared to only poly (ether-block-amide) membrane [31].

9. Using Surfactant

Non-ionic surfactant may be used for recovery of bio-butanol with decrease in toxicity. It is carried out by the non-ionic surfactant micelle aqueous solution by cloud point extraction [32].

10. Liquid-Liquid Extraction

The water-insoluble extractant is used to remove bio-butanol from fermentation broth. Extractant is mixed in fermenter to form two phases. Bio-butanol can be selectively separated in extractant phase [33]. The solvent toxicity to the cells is the main problem in liquid-liquid extraction [16]. Also this technique has major limitations that extractant with high partition coefficient may tends to toxicity towards microbes due to direct contact of extractant with fermentation broth [22].

11. Using Ionic Liquids

Conventional solvents are volatile and toxic. Ionic liquids have negligible vapour pressure. Ionic liquids with a hydrophobic nature can be the promising solvent for separation of bio-butanol [9].

12. Commercial Methods for Separation

Green mentioned the few patented processes for butanol recovery [3]. DuPont patented use of oleyl alcohol for separation of isobutanol by extraction [34]. GevoInc developed GIFT^{TM} process in which distillation followed by phase separation has been performed for separation of butanol [35].

13. Conclusion

Bio-butanol is the emerging biofuel which may be the promising alternative to other bio-fuels and also other petroleum fuels. Major issue in production of bio-butanol is separation of bio-butanol from fermentation broth and also to avoid or decrease the inhibition and toxicity. Number of methods are available for separation such as improved distillation, gas stripping, membrane based separation, adsorption etc. It is observed membrane based separation have better opportunities than other separation techniques in terms of inhibition, toxicity, selectivity, and separation efficiency.

14. Conflicts of Interests

The author(s) report(s) no conflict(s) of interest(s). The author along are responsible for content and writing of the paper.

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16. References

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