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Review

Biodegradation of dibenzothiophene and its application in the production of clean coal

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ABSTRACT

In the current era, the alarming rate at which coal is being burned as a fuel is causing concern with regard to the release of sulphur oxides. According to reports, global coal consumption has increased by 0.4% in 2014. While countries like UK, Ukraine etc. have witnessed a decline in coal consumption, some others like India, China, Africa and North America have increased their use of coal to meet the energy requirements of the growing human population. The increasing use of coal has led to extensive investigations for finding an ecofriendly clean coal technology. Dibenzothiophene (DBT) and some of its alkylated derivatives present in the form of organic sulphur in coal have received a great deal of attention in the past few years because of their recalcitrant nature. Considering the economic and environmental prospects, biodesulphurization is being regarded as an effective tool for the degradation of DBT, with concomitant application towards sulphur removal from coal. Owing to the importance of microbial applications towards production of clean coal, the present review discusses some of the recent findings in the area of DBT biodegradation. In addition, current advances in coal biodesulphurization are reviewed, concluding with a consideration of future prospects for the rapidly growing energy sector.

Contents

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1. Introduction

With the continuing increase in the human population, the world energy consumption is growing rapidly. According to the United States Energy Information Administration (EIA), the world energy consumption reached upto 5.6×10^{20} J in 2012 [1]. Coal has become an indispensible source of energy industrially, and its use is growing. Coal reserves are widely distributed (over 891 billion tonnes) globally and are mined in >100 countires [2]. Table 1 presents a list of recoverable coal reserves existing at the end of 2014. Based on a recent analysis provided by the Global Energy Statistical Yearbook, China was the leading producer as well the leading domestic consumer of coal and lignite in 2014. The coal and lignite consumption in China, however, dropped by 2.9% in the year 2014 as compared to the previous year. A detailed analysis of global coal and lignite production and domestic consumption during the years of 2000 to 2014 has been presented in the Global Energy Yearbook [3]. Coal has found application in various industrial sectors such as the aluminium and steel industries, iron industries etc. Bituminous coal is employed in the production of coke, which is used in the manufacture of steel. Gasified or liquefied coal is also employed in the production of synthetic fuel. Apart from these uses, heat generated from the burning of coal is needed for the manufacture of cement. Unfortunately, the sulphur present in coal detracts from its usefulness as a fuel because it creates pollution when the coal is burned. Strict government regulations to reduce sulphur emission (SO_2) from coal combustion have compelled researchers to explore ways of reducing the sulphur content of coal. Around 43% of the global SO_2 emissions come from Asia, which is responsible for serious environmental pollution, health disorders and the corrosion of several historic monuments [4]. Hence, the Environmental Protection Agency has limited the sulphur emissions from different mobile and non-mobile sources to 15 mg/L, which has led to the combining of pertinent technologies to lower the sulphur content of coal [5].

Table 1
World's total proven coal reserves by 2014 [2].

Coal reserves in	Country	Anthracite & bituminous (in million tones)	Sub-bituminous & lignite (in million tones)	Total (in million tones)	% of the world's total
North America	United States	108,501	128,794	237,295	26.6
	Canada	3474	3108	6582	0.7
	Mexico	860	351	1211	0.1
South and Central America	Brazil	–	6630	6630	0.7
	Columbia	6746	–	6746	0.8
	Venezuela	479	–	479	0.1
	Others South & Cent. America	57	729	786	0.1
Europe and Eurasia	Bulgaria	2	2364	2366	0.3
	Czech Republic	181	871	1052	0.1
	Germany	48	40,500	40,548	4.7
	Greece	–	3020	3020	0.3
	Hungary	13	1647	1660	0.2
	Kazakhstan	21,500	12,100	33,600	3.8
	Poland	4178	1287	5465	0.6
	Romania	10	281	291	<0.05
	Russain Federation	49,088	107,922	157,010	17.6
	Spain	200	330	530	0.1
	Turkey	322	8380	8702	1.0
	Ukraine	15,351	18,522	33,873	3.8
	United Kingdom	228	–	228	<0.05
	Uzbekistan	47	1853	1900	0.2
	Other Europe & Eurasia	1389	18,904	20,293	2.3
Middle East and Africa	South Africa	30,156	–	30,156	3.4
	Zimbabwe	502	–	502	0.1
	Other Africa	942	214	1156	0.1
	Middle East	1122	–	1122	0.1
Asia Pacific	Australia	37,100	39,300	76,400	8.6
	China	62,200	52,300	114,500	12.8
	India	56,100	4500	60,600	6.8
	Indonesia	–	28,017	28,017	3.1
	Japan	337	10	347	<0.05
	New Zealand	33	538	571	0.1
	North Korea	300	300	600	0.1
	Pakistan	–	2070	2070	0.2
	South Korea	–	126	126	<0.05
	Thailand	–	1239	1239	0.1
	Veitnam	150	–	150	<0.05
	Other Asia Pacific	1583	2125	3708	0.4
	World's total	403,199	488,322	891,531	100

Several different types or varieties of coal are recognized [6]. In general, sulphur which is an important constituent of coal exists in organic and inorganic forms [7,8]. A major portion of coal contains organic sulphur (70%), of which dibenzothiophene (DBT) is the most recalcitrant sulphur-containing compound, which calls for invasive methods to remove the sulphur [9,10]. For many decades, sulphur has been removed from coal by several methods, including physical, chemical, and biological processes [9]. Physical methods are useful in the removal of pyritic sulphur, but they are ineffective in the removal of organic sulphur. By contrast, chemical methods that are applied at high temperature and pressure have been found effective in removal of both pyrite and organic sulphur [9]. In these processes, the high temperature and pressure break certain chemical bonds, which enable the release of sulphur from organic combination. The chemical methods release large amounts of carbon dioxide, and they are also associated with high operating costs, all of which detracts from the use of chemical methods. Considering the aforementioned disadvantages, biological methods of desulphurization, which are ecofriendly, have been examined on a laboratory and industrial scale. Biodesulphurization is emerging as an effective tool for removal of sulphur from coal. In this process, microbes metabolize sulphur for their growth. In bacteria, sulphur contributes 0.5–1.0% to cell dry weight. It is contained in the structure of some amino acids, proteins and enzyme cofactors [11,12]. The use of microbes as biodesulphurizing agents of fossil fuels continues to gain interest [9].

Owing to the recalcitrance of DBT, an important constituent of coal, many attempts have been made to remove the sulphur from coal. In this review, biodesulphurization of coal is examined. An overview of microbes with potential application to biodesulphurization is presented. Several aspects of DBT degradation and their importance are discussed. Recent progress in scale-up of coal biodesulphurization is summarized. The applicability of microbial coal desulphurization and future challenges are considered.

2. Dibenzothiophene (DBT): a model compound for biodesulphurization studies

DBT, an organo-sulphur compound, has been used as a typical model for desulphurization studies because of its high occurrence in fossil fuels. It has a high boiling point and is refractory to conventional sulphur removal methods [9,13]. Structurally, DBT has two benzene rings fused to a thiophene ring at the centre. It has a molar mass of 184.26 g/mol