Acta Scientific Biotechnology

Volume 4 Issue 1 January 2023

Short Communication

Future Scope of Research on the Biodesulfurisation and Biodemineralisation of Petroleum and Coal for their Utilization in Environment Friendly Way for Sustainable Development

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Received: December 05, 2022

Published: December 21, 2022

Recent incidences of climate change have turned the attention of the world towards the sustainability issues on this terrestrial ball. There is no denying the fact that eco footprints may have to be brought down drastically to save the human life. Fossil fuels are lifelines of global economy and standard of living of the denizens. Thus the fossil fuels such as coal and petroleum may have to be cleaned and refined before using these in the environment friendly way. The carbon dioxide may have to be utilized to develop green and circular bioeconomy. Renewable energy sources alone may not be sufficient to meet the ever increasing load of global energy requirements. Extensive reserves of coal are available. Coal can be cleaned through physical and chemical cleaning and biochemical refining techniques [1-7]. However, these techniques are either not so effective for some coals or these involve the use of chemicals which are not so environment friendly.

Bioleaching and biodesulfurisation of coal

In the past attempts have been made to refine the coals through milder biorefining techniques such as bioleaching of nonsulfidic coaly matter [8-10] and biodesulfurization of coals [7,11]. These techniques remove not only inorganic and organic sulfur but even nonsulfidic inorganic mineral matter from coals. Bacteria such as *Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans, Leptospirrulum ferrooxidans, Sulfolobus acidocaldarius* etc. have been used to remove inorganic sulfur from coals and lignites [12]. These bacteria can also lead to the much desired biosequestration of carbon dioxide as these are chemoautotrophic bacteria. However, coals and lignites contain more than 50-60% organic sulfur. Therefore, bacteria such as *Rhodococcus erythropolis* H-2 *Mycobacterium* sp. G3, *Gordonia* sp. CYKS1 Pseudomonas putida etc. which have the potential of removing organic sulfur may be exploited for this.. Fungi such as *Aspergillus* sp., *Nocardia mangyaensis*, etc. have been used to remove organic sulfur from coals [10,13,14]. In fact Jain and Sharma [10] have suggested the use of bacteria such as *Arthrobacter* sp., *Bacillus megaterium*, *Paenibacillus polymyxa* etc. and fungi like *Aspergillus. niger, Penicillium* sp., *Coriolus versicolor, Streptomyces* sp. etc. for the removal of nonsulfidic inorganic matter from coal, lignite and other nonsulfidic ores. There is a great scope of developing integrated biorefining processes of firstly bioleaching of nonsulfidic inorganic mineral matter from coal by bacteria and fungi [10] followed by the biodesulfurisation using the bacteria and fungi [7].

Biodesulfurisation of petroleum

Removal of organic sulfur from petroleum and petroleum coke has been studied in the past by using *Pantoea agglomerans*

D23W3, *Rhodococcus* sp. IGTS8, *Rhodococcus erythropolis* H-2 *Mycobacterium* sp. G3, *Gordonia* sp. etc. [15-18]. Torkamani., *et al*. [19] used fungus such as *Stachybotrys* sp. for the removal of organic sulfur from crude oil. Linder [20] reviewed the research on the use of fungi in the biodesulfurisation of crude oil. *Fusarium proliferatum* and *Saccharomyces cerevisiae* have been found to result in the biodesulfurisation of crude oil.

Utilization of CO_2 along with biodesulfurisation and bioleaching of fossil fuels

Research work on the non - destructive pathway i.e., the 4 S - pathway for the biodesulfurisation of crude oil has been reported by Bhatia and Sharma [17]. The sulfones thus generated from oil derived benzothiophenes through biodesulfurisation following this process pathway may have good reactivity as sulfones have been reported to be highly reactive moieties with a large variety of reactive options [21] and thus their potential for reaction with CO_2 may be explored using nanozymes to produce valuable chemicals and products. Anaerobic conversion of sulfones to sulfide and biogas has also been reported [22]. There are options of the utilization of biomass wastes in these bioconversions where there may also be the possibility of hydrogen generation besides compressed biogas. Similar reactions of CO_2 with organic compounds and reactive inorganic products of desulfurization and demineralization of coals, lignites, petroleum coke etc. may also be studied. Research has been extended on the utilization of CO_2 in synthesizing several premium organic compounds and Liu., *et al*. [23] have also reviewed research work in this area.

Future scope of research

There is a need to extend research work in the area of systems biology to search for genomics and proteomics databases for the identification of novel and more promising biodesulfurizing, bio – nonsulfidic inorganic materials leaching microorganisms including biocatalysts (bacteria, fungi, etc.) from coal and petroleum. Some work in this direction has been pioneered by Bhatia and Sharma [24]. The same approach as followed for the bioinformatics research for the drug designing (Singh., *et al*. 2007) may be followed here. The use of not only genomics datamining but metabolomics, interactomics, bio-switches, reverse genomics, quorum sensing, quorum quenching etc. techniques should be employed for this research. There is also a wide scope of using nanozymes in catalyzing the biodesulfurisation and biodemetalation of petroleum and coal which may be explored as no work seems to have been done in this area.

Even the use of nanozymes, biocatalysts and nanocatalysts for the utilization of carbon dioxide through various biochemical and chemical reactions should be explored. Here the reaction of S-, N-. O- heterocyclic compounds recovered from the coal and petroleum with CO_2 may be studied to yield valuable chemicals and products. Research may be extended on promoting the growth of *Acidithiobacillus ferrooxidans* or *Sulfolobus acidicaldarius* etc. bacteria by genetic manipulations. There is a scope of transferring the CO_2 fixing (or rubisco enzyme genes) of *Acidithiobacillus ferrooxidans* bacteria to the faster growing bacteria such as *Vibrio natriegens*, *E.coli* etc.

Growth promoters for the carbon dioxide utilizing bacteria such as *Acidithiobacillus ferrooxidans and Sulfolobus acidocaldarius* should be found out through metabolomics studies involving bio-switches. Research on biodesulfurisation of petroleum and coal should be integrated with biosequestration of CO_2 [12]. The use of nanozymes along with enzymes may be extended in the further biodesulfurisation and bioleaching research. The S-, N- and O- heterocyclic compounds recovered from the bioleaching and biodesulfurisation (which are very reactive) may be reacted with carbon dioxide to yield newer polymeric and other nanomaterials. Utilization of carbon dioxide is important for the continuation of the use of fossil fuels. Recently it has been reported by Zhang., *et al*. [25] that the thiophenes (which can be derived from the biodesulfurisation of crude oil) can be carboxylated using CO_2 to yield value added chemicals through green catalytic reactions. Newer approaches for the biotechnological utilization of CO_2 have also been reported recently by Sharma [26]. Wang and Xi [27] have reported the cyclisation reactions of N-, O- and C- nucleophiles using CO_2 for the production of potential heterocyclic drug molecules. Therefore the attention of researchers should be drawn towards the research areas like biodesulfurization of petroleum and coal and utilization of organic chemicals thus recovered. These may be utilized through reactions with CO_2 where there is a scope of using even the inorganic mineral matter leached from the demineralization of coal as nanocatalysts or nanozymes. Thus this would afford the continued use of fossil fuels without harming the environment [28].

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