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SO_x/NO_x Removal from Flue Gas Streams by Solid Adsorbents: A Review of Current Challenges and Future Directions

Fateme Rezaei,*[,†] Ali A. Rownaghi,[†] Saman Monjezi,[†] Ryan P. Lively,[‡] and Christopher W. Jones*[,‡]

[†]Department of Chemical and Biochemical Engineering, Missouri University of Science and Technology, 1101 North State Street, Rolla, Missouri 65409, United States

[‡]School of Chemical & Biomolecular Engineering, Georgia Institute of Technology, 311 Ferst Drive, Atlanta, Georgia 30332, United States

ABSTRACT: One of the main challenges in the power and chemical industries is to remove generated toxic or environmentally harmful gases before atmospheric emission. To comply with stringent environmental and pollutant emissions control regulations, coal-fired power plants must be equipped with new technologies that are efficient and less energy-intensive than status quo technologies for flue gas cleanup. While conventional sulfur oxide (SO_x) and nitrogen oxide (NO_x) removal technologies benefit from their large-scale implementation and maturity, they are quite energy-intensive. In view of this, the development of lower-cost, less energy-intensive technologies could offer an advantage. Significant energy and cost savings can potentially be realized by using advanced adsorbent materials. One of the major barriers to the development of such technologies remains the development of materials that are efficient and productive in removing flue gas contaminants. In this review, adsorption-based removal of SO_x/NO_x impurities from flue gas is discussed, with a focus on important attributes of the solid adsorbent materials as well as implementation of the materials in conventional and emerging acid gas removal technologies. The requirements for effective adsorbents are noted with respect to their performance, key limitations, and suggested future research directions. The final section includes some key areas for future research and provides a possible roadmap for the development of technologies for the removal of flue gas impurities that are more efficient and cost-effective than status quo approaches.

1. INTRODUCTION AND MOTIVATION

The reliance of the energy sector on fossil fuels for electricity generation is still growing to address rising electricity demands. According to the U.S. Energy Information Administration (EIA),[1] coal-fired power generation is expected to increase by an average of 0.2% per year from 2011 through 2040, and coal remains the largest source of electricity despite the growing interest in natural gas as a fuel, as can be seen from Figure 1. This is primarily the case because natural gas prices are projected to increase more rapidly than coal prices over the next 30 years, which will keep coal as a significant fuel for power generation for decades to come.

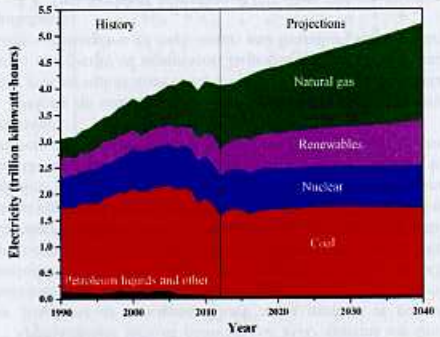

Figure 1. Electricity generation by fuel for the time period of 1990–2040 (10^{12} kwh). Reprinted from ref 1.

SO_x and NO_x impurities are emitted into the atmosphere from both stationary and mobile combustion sources, including fossil fuel combustion in heating and thermal power plants, petroleum refineries, and on-road transportation vehicles. Flue gas streams from fossil-fuel-fired power plants alone are responsible for 87% of SO_x and 67% of NO_x emissions.[1,2] Among various sulfur and nitrogen oxide species, SO_2, NO, and NO_2 are considered the most toxic and harmful gases emitted into the atmosphere. These acidic gases are primary sources for atmospheric pollution and are believed to be causing increasingly serious environmental problems, mainly through the formation of acid rain and photochemical smog as well as ozone layer destruction. Furthermore, high concentrations of these undesirable contaminants in air pose serious health threats to human beings by contributing to a broad range of health issues, including respiratory diseases such as asthma, bronchitis, emphysema, and throat inflammation, among others. In particular, these acid gases highly contribute to the formation of secondary organic aerosols (SOAs), which have an impact on the climate as well.[3,4] These emissions stem from various sources, including the combustion of fossil fuels in power plants and petroleum refineries as well as in transportation vehicles.

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