


Chapter 4


Experimental Approaches to Fuel Desulphurization: Catalysts, Conditions, and Performance

Subhraraj Panda

 <https://orcid.org/0000-0003-4224-4663>

Centurion University of Technology and Management, Bhubaneswar, India

Niharika Das

 <https://orcid.org/0009-0008-4524-5198>

Centurion University of Technology and Management, Bhubaneswar, India

Rajalaxmi Panda

S.K.C.G. Autonomous College, Paralakhemundi, India

ABSTRACT

Desulphurization of fossil fuels has emerged as a critical area of research in energy science and environmental engineering due to increasingly stringent environmental regulations. Sulphur compounds in fuels are precursors to SO_x emissions, which contribute to acid rain, smog formation, and adverse health effects. This chapter provides an in-depth exploration of experimental approaches to fuel desulphurization, with a primary focus on catalysts, process conditions, and performance outcomes. Emphasis is placed on hydrodesulphurization (HDS), oxidative desulphurization (ODS), adsorptive desulphurization (ADS), biodesulphurization (BDS), and emerging nanocomposite-based methods. Comparative analysis of catalyst design, experimental methodologies, and operating conditions is presented alongside discussions on

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reaction mechanisms and performance indicators. The chapter concludes by highlighting the future perspectives of nanostructured catalysts in achieving ultra-deep desulphurization under mild operating conditions.

1. INTRODUCTION

Sulphur-containing compounds are inherent in petroleum and its fractions, which creates significant challenges in both refining and environmental management. Song 2003; Stanislaus et al., 2010 The structural complexity of these compounds—from thiols and sulphides to complex cyclic structures like thiophenes, benzothiophenes, and multi-ring dibenzothiophenes—translates into differences in reactivities and removal efficiencies. Low molecular weight thiols and simple sulphides can be relatively easily removed from low sulphur streams using conventional refining methods; however, the more aromatically thiophenic species exhibit far greater chemical stability because of extensive electron delocalization within their ring structures. DBT and, in particular, its alkyl-substituted derivatives, especially 4,6-DMDBT, are considered among the most refractory species because of steric hindrance of the sulphur atom, limiting access to catalytic sites even under rigorous HDS conditions. Marafi & Stanislaus, 2008 Oxidation of thiophenic compounds to sulfoxides and sulfones, usually formed in the ODS process, represents another way of removal. Due to the higher polarity and elevated boiling points of these oxidized species, their separation by extraction or adsorption is possible. Since these species are seldom present in 'as-received' fuels, their controlled formation during experimental processes is of great importance in understanding reaction mechanisms and testing catalytic activities Campos-Martin et al. (2010); Otsuki et al. (2000). The proper characterization of sulphur compounds before and after treatment is crucial for process optimization. Advanced analytical techniques, such as GC–SCD, GC–MS, XPS, FT-IR, and ultraviolet fluorescence-based total sulphur analysers (ASTM D5453), now allow for the accurate quantification, structural elucidation, and oxidation state assessment of sulphur species (Hsu & Robinson, 2019; Lee et al., 2009). These data provide input to catalyst design through its correlations of molecular structure with desulphurization efficiency.

The persistence of refractory sulphur species has major implications for technology selection and fosters the development of nanocomposite catalysts, hybrid oxidative systems, and low-temperature processes suitable for ultra-low sulphur fuel production. Basically, other main reasons for this interest are linked with the environmental and operational impact caused by the sulphur oxides; in fact, combustion converts fuel sulphur to SO_2 and SO_3 , contributing to acid rain, particulate pollution, and material corrosion (EPA, 2023; WHO, 2021).

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