

論文 / 著書情報
Article / Book Information

題目(和文)	希硫酸と接触する大気圧プラズマを用いた炭素材料スルホン化の改善
Title(English)	Improvement of the Carbon Sulfonation via Atmospheric Pressure Plasma Contact with Dilute Sulfuric Acid
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学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

(博士課程)
Doctoral Program

論文要旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	電気電子 電気電子	系 コース	申請学位 (専攻分野)： Academic Degree Requested	博士 Doctor of	(工学)
学生氏名： Student's Name	Deng Siqi		審査員主査： Chief Examiner	竹内希	

要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

This dissertation, titled *"Improvement of the Carbon Sulfonation via Atmospheric Pressure Plasma Contact with Dilute Sulfuric Acid,"* is written in English and consists of seven chapters.

Chapter 1: Introduction

This chapter provides a comprehensive overview of the research background, emphasizing the importance of biomass energy, sulfonated carbon catalysts, and plasma-assisted sulfonation techniques. It discusses the need to mitigate climate change and reduce dependence on fossil fuels, highlighting the role of biomass energy as a sustainable alternative. The chapter underscores the necessity of improving biomass conversion processes and the development of highly efficient catalysts for biomass hydrolysis.

Chapter 2: Research Trends and Literature Review

This chapter presents an extensive review of current research trends related to plasma technology, reactive oxygen and nitrogen species, plasma-liquid interactions, material science, and catalysis. Special attention is given to active species, including sulfate radicals, which play a crucial role in modifying carbon materials. Additionally, the broad applications of plasma technology in environmental and agricultural fields are summarized. The gas-liquid interfacial plasma technology employed in this study is a promising technique for removing organic pollutants, heavy metals, and microorganisms from wastewater. It also has significant applications in soil purification, nitrogen fixation, and fertilizer enhancement in agriculture. Plasma technology offers an environmentally friendly and energy-efficient process, contributing to the realization of a sustainable society.

Chapter 3: Plasma Sulfonation via Atmospheric Plasma Discharge

This chapter explores the sulfonation of carbon materials using atmospheric plasma and examines the reaction processes in which active species modify carbon surfaces with functional groups. Optical emission spectroscopy (OES) confirmed the generation of OH radicals, and rotational temperature estimations indicated that the gas temperature in the plasma exceeded 1000° C. Fourier-transform infrared (FTIR) spectroscopy of the exhaust gases from the plasma reactor detected SO₂ and sulfuric acid vapor. Based on these findings, a reaction mechanism was proposed: plasma irradiation leads to the thermal decomposition of evaporated sulfuric acid, forming SO₃ and SO₂, while OH radicals generated from evaporated water react with SO₂ to produce HOSO₂ radicals. These active species are suggested to contribute to the modification of carbon materials with sulfonic (-SO₃H), hydroxyl (-OH), and carboxyl (-COOH) groups.

Chapter 4: Mechanism of Plasma Sulfonation in the Liquid Phase

This chapter experimentally demonstrates the role of sulfate radicals (SO₄·⁻) in plasma-assisted sulfonation through plasma-sulfuric acid interactions. Carbon materials were suspended in a solution containing persulfate ions, and UV irradiation or thermal activation was used to generate sulfate radicals, confirming the feasibility of sulfonation. The study focused on the reaction between bisulfate (HSO₄·⁻) ions and OH radicals in sulfuric acid solutions, estimating the amount of OH radicals generated during plasma irradiation. The results indicated that a sufficient quantity of sulfate radicals was produced in the liquid phase, playing a crucial role in plasma-induced carbon sulfonation.

Chapter 5: Mechanism of Sulfonation in the Gas Phase

To verify the sulfonation mechanism proposed in Chapter 3, experimental studies were conducted. Argon gas bubbles containing 1% SO₂ were introduced into a sodium chloride solution with suspended carbon materials, and plasma was generated within the bubbles. The presence of sulfate ions in the solution confirmed the oxidation of SO₂ gas, leading to the formation of SO₃ or HOSO₂ radicals. Furthermore, sulfonation of the carbon materials was confirmed, demonstrating the feasibility of sulfonation through these active species. The catalytic performance of the plasma-sulfonated carbon

materials was evaluated in cellulose hydrolysis, showing improved catalytic efficiency. These results validate the effectiveness of plasma technology in synthesizing sulfonated carbon catalysts.

Chapter 6: Improving Carbon Treatment through DBD Plasma

This chapter investigates the application of dielectric barrier discharge (DBD) plasma for carbon material sulfonation and demonstrates its effectiveness. The carbon catalysts obtained through this process exhibited high catalytic performance in cellulose hydrolysis. Compared to conventional sulfonation methods, DBD plasma treatment significantly reduced the use of chemical reagents, making it a more environmentally friendly and energy-efficient technique. Additionally, the study highlights key challenges for future research, including process scalability, long-term stability, and optimization of treatment conditions.

Chapter 7: Conclusion

The final chapter summarizes the conclusions drawn from this study and outlines future research prospects.

In summary, this research has developed an efficient method for synthesizing carbon catalysts using plasma technology, which is critical for enhancing biomass-to-biofuel conversion processes. The findings contribute to expanding the utilization of biomass energy while also providing valuable insights into plasma-liquid interactions. The study offers significant engineering and industrial contributions, making this dissertation a valuable work worthy of a doctoral degree in engineering.

備考：論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

Note: Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1 copy of 800 Words (English).

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