



Editorial

# New Trends in Catalytic Reaction for High-Temperature and Low-Emission Combustion Technologies

Baiqian Dai <sup>1,\*</sup> , Xiaojiang Wu <sup>2</sup> and Lian Zhang <sup>1</sup> 

<sup>1</sup> Department of Chemical & Biological Engineering, Monash University, Wellington Road, Clayton, VIC 3800, Australia; lian.zhang@monash.edu

<sup>2</sup> School of Mechanical Engineering, Shanghai Jiao Tong University, Dongchuan Road, Minghang, Shanghai 200240, China; wuxiaojian@sjtu.edu.cn

\* Correspondence: bai-qian.dai@monash.edu

## 1. Introduction

With the continuous rise in global energy demand and the increasing awareness of environmental protection, high-temperature low-emission combustion technology has become a research hotspot in the field of combustion science. As a sustainable and economically efficient alternative, the combustion technology of mixed solid fuels demonstrates significant potential in reducing dependence on fossil fuels and meeting the demand for low-carbon energy [1,2]. This technology not only helps improve energy utilization efficiency, but also plays a positive role in mitigating environmental pollution. In this context, catalytic reactions in oxy-fuel combustion are particularly critical. The composition of mixed fuels and the oxy-fuel combustion environment may significantly affect combustion characteristics, ash deposition, corrosion phenomena, and pollutant emissions. However, systematic research on catalytic reactions in oxy-fuel combustion remains insufficient [3], and scholars are further exploring these processes to optimize them and enhance their efficiency.

High-temperature low-emission combustion technology aims to maintain high-temperature combustion while significantly reducing the emission of pollutants such as nitrogen oxide (NO<sub>x</sub>). This technology is of great importance for improving energy utilization efficiency and reducing environmental burden. During high-temperature combustion, the intense reaction between fuel and oxygen releases a large amount of thermal energy. However, traditional high-temperature combustion processes are often accompanied by high concentrations of NO<sub>x</sub> emissions, primarily due to the reaction between nitrogen and oxygen in the air at high temperatures [4]. To achieve this goal, researchers have proposed various technical solutions. The introduction of catalysts is considered an effective strategy. Catalysts can lower the activation energy of combustion reactions, allowing the fuel to react at lower temperatures and thereby reducing NO<sub>x</sub> formation under high-temperature conditions [4]. Additionally, optimizing the design of the combustion chamber and the organization of the flow field can promote the uniform mixing and complete combustion of fuel and oxygen, effectively reducing NO<sub>x</sub> emissions.

## 2. Overview of the Published Articles

This Special Issue highlights the latest trends in high-temperature low-emission catalytic combustion, focusing on the following research areas: the characterization of pyrolysis due to the catalytic reaction in oxy-fuel co-combustion; the clarification of synergistic reactions in oxy-fuel co-combustion; and ash sintering, slagging, fouling, deposition, and tube corrosion in oxy-fuel co-combustion. These topics have been explored in various research and review studies conducted by renowned scientists from around the world, including Australia, China, Poland, and the Czech Republic, achieving significant results. A detailed overview of this Special Issue is illustrated in Figure 1.



**Citation:** Dai, B.; Wu, X.; Zhang, L. New Trends in Catalytic Reaction for High-Temperature and Low-Emission Combustion Technologies. *Catalysts* **2024**, *14*, 398. <https://doi.org/10.3390/catal14070398>

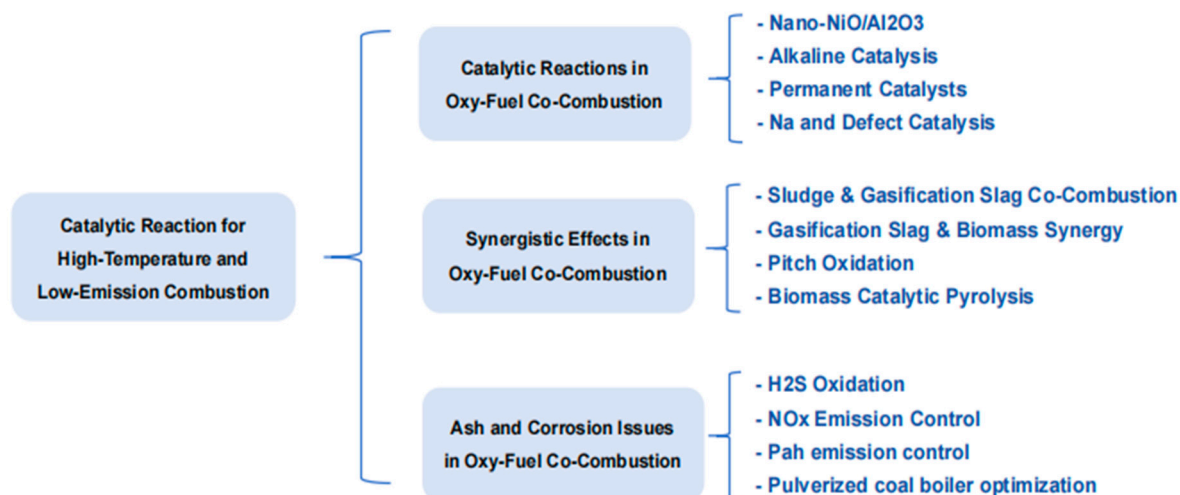
Received: 15 April 2024

Accepted: 21 June 2024

Published: 24 June 2024



**Copyright:** © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).



**Figure 1.** Main subjects included in this Special Issue.

In this Special Issue, there is a concentrated effort on enhancing oxy-fuel combustion with catalysts to optimize energy yield and environmental benefits. Zhonghua Du and Wu Li's investigation into the pyrolysis of tar-rich coal highlights the significant impact of alkali metals on tar formation and decomposition. Xuesen Kou et al.'s study elucidates the influence of sodium and carbon defects on NO adsorption on carbon surfaces and their thermodynamic properties. Błażej Gaze's research demonstrates the effectiveness of permanent catalytic systems in reducing SO<sub>x</sub> and NO<sub>x</sub> emissions from biomass boilers, ameliorating the environmental impact of combustion. Tao Xu's team has made strides with nano-NiO/Al<sub>2</sub>O<sub>3</sub> catalysts, achieving a 93% tar conversion rate and boosting H<sub>2</sub> and CO yields in the pyrolysis of pine sawdust. Collectively, these studies underscore the pivotal role of catalysts in advancing cleaner and more efficient energy production, particularly in mitigating emissions and enhancing hydrogen and carbon monoxide yields.

The clarification of synergistic reactions and the analysis of ash fusion phenomena in oxy-fuel co-combustion are also focal points of this Special Issue. In the study of co-combustion of sludge with gasification slag, Yang Guo and colleagues discovered that this approach not only enhances ignition and burnout performance, but also maintains combustion stability, exhibiting superior overall combustion efficiency with remarkably low activation energy ( $E_a = 81.6$  kJ/mol) and a strong synergistic effect ( $X_i = 0.36$ ). Additionally, through thermogravimetric analysis, Guo Yang and team observed the co-combustion behavior of a blend of bituminous coal (BC), gasification slag (GS), and bamboo residue (BR), noting a decrease in activation energy compared to the individual combustion of GS. These findings offer new perspectives for the sustainable development of energy conversion technologies.

In the context of oxy-fuel co-combustion technology, phenomena such as ash sintering, slagging, fouling, deposition, and tube corrosion are pivotal in influencing the efficiency of combustion and the longevity of equipment. This Special Issue attends to an array of innovative methodologies addressing these challenges, thereby refining the combustion process and mitigating equipment degradation. Pertaining to H<sub>2</sub>S oxidation, Yu and colleagues have reported the successful implementation of selective catalytic oxidation of H<sub>2</sub>S to sulfur, utilizing Co-doped LaFe<sub>x</sub>Co<sub>1-x</sub>O<sub>3</sub> perovskite catalysts. Wu and team have demonstrated a marked reduction in NO<sub>x</sub> emissions within a 75-ton/hour pulverized coal boiler framework, leveraging deep air staging integrated with the injection of ammonia solutions and pyrolysis gases. Such strategies for the mitigation of NO<sub>x</sub> and H<sub>2</sub>S emissions not only ameliorate the issues of slagging and corrosion, but also have the potential to augment combustion efficacy and protract the operational lifespan of machinery. These contributions are profoundly significant in the pursuit of concurrent environmental and economic advantages.

### 3. Conclusions

Through the collective findings presented in this Special Issue, several significant conclusions emerge:

- Catalytic pyrolysis, particularly under oxy-fuel co-combustion conditions, demonstrates remarkable potential for enhancing the efficiency of converting biomass and waste into energy resources. This technology holds the promise of more effective and sustainable energy production.
- Synergistic effects between various feedstocks in oxy-fuel co-combustion significantly improve combustion efficiency and stability. Notable progress has been made with combinations such as biomass/coal or coal slag, and sewage sludge/coal or coal slag. However, there is a need to explore additional mixtures and further develop co-combustion techniques that incorporate catalytic enhancements to fully leverage the benefits of these synergies.
- Through the judicious selection and design of catalysts, the phenomena of ash sintering and slagging can be effectively controlled during oxy-fuel co-combustion, leading to reduced fouling and deposition, consequently mitigating the risk of tube corrosion. While current studies have primarily focused on addressing issues of fouling and corrosion, the effective management of ash sintering, slagging, and fouling in oxygen-rich environments remains an area requiring further investigation.

**Author Contributions:** B.D.: Conceptualization, Writing, Supervision; L.Z.: Reviewing, visualization, and supervision; X.W.: Data analysis, resources, and methodology. All authors have read and agreed to the published version of the manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

#### List of Contributions

1. Xu, T.; Zheng, X.; Xu, J.; Wu, Y. Hydrogen-Rich Gas Production from Two-Stage Catalytic Pyrolysis of Pine Sawdust with Nano-NiO/Al<sub>2</sub>O<sub>3</sub> Catalyst. *Catalysts* **2022**, *12*, 256. <https://doi.org/10.3390/catal12030256>.
2. Gaze, B.; Knutel, B.; Jajczyk, M.; Němček, O.; Najser, T.; Kielar, J. Influence of the Use of Permanent Catalytic Systems on the Flue Gases Emission from Biomass Low-Power Boilers. *Catalysts* **2022**, *12*, 710. <https://doi.org/10.3390/catal12070710>.
3. Yu, X.; Tao, X.; Gao, Y.; Ding, L.; Wang, Y.; Yu, G.; Wang, F. Oxygen Vacancy-Mediated Selective H<sub>2</sub>S Oxidation over Co-Doped LaFe<sub>x</sub>Co<sub>1-x</sub>O<sub>3</sub> Perovskite. *Catalysts* **2022**, *12*, 236. <https://doi.org/10.3390/catal12020236>.
4. Wu, X.; Guo, X.; Li, Z.; Zhang, Z.; Bai, H.; Fan, J.; Zhu, Z. Effects of Ammonia Solution and Pyrolysis Gas on NO<sub>x</sub> Emission from a 75 t/h Pulverized Coal Boiler. *Catalysts* **2022**, *12*, 141. <https://doi.org/10.3390/catal12020141>.
5. Chen, L.; Guo, F.; Wu, J.; Li, P.; Zhang, Y. Research on Coal Tar Pitch Catalytic Oxidation and Its Effect on the Emission of PAHs during Co-Carbonation with Coal. *Catalysts* **2021**, *11*, 1428. <https://doi.org/10.3390/catal11121428>.
6. Guo, Y.; Wu, J.; Jia, W.; Guo, F.; Qiu, G.; Wang, R.; Zhang, Y.; Dai, B. Evaluation of the Thermal Behavior, Synergistic Catalysis, and Pollutant Emissions during the Co-Combustion of Sewage Sludge and Coal Gasification Fine Slag Residual Carbon. *Catalysts* **2021**, *11*, 1142. <https://doi.org/10.3390/catal11101142>.
7. Zhang, Y.; Jia, W.; Wang, R.; Guo, Y.; Guo, F.; Wu, J.; Dai, B. Investigation of the Characteristics of Catalysis Synergy during Co-Combustion for Coal Gasification Fine Slag with Bituminous Coal and Bamboo Residue. *Catalysts* **2021**, *11*, 1152. <https://doi.org/10.3390/catal11101152>.
8. Du, Z.; Li, W. The Catalytic Effect from Alkaline Elements on the Tar-Rich Coal Pyrolysis. *Catalysts* **2022**, *12*, 376. <https://doi.org/10.3390/catal12040376>.

9. Kou, X.; Jin, J.; Wang, Y.; Li, Y.; Hou, F. The Catalysis Effect of Na and Point Defect on NO Heterogeneous Adsorption on Carbon during High-Sodium Zhundong Coal Reburning: Structures, Interactions and Thermodynamic Characteristics. *Catalysts* **2021**, *11*, 1046. <https://doi.org/10.3390/catal11091046>.
10. Xu, T.; Xu, J.; Wu, Y. Hydrogen-Rich Gas Production from Two-Stage Catalytic Pyrolysis of Pine Sawdust with Calcined Dolomite. *Catalysts* **2022**, *12*, 131. <https://doi.org/10.3390/catal12020131>.

## References

1. Glushkov, D.O.; Paushkina, K.K.; Shabardin, D.P. Co-combustion of coal processing waste, oil refining waste and municipal solid waste: Mechanism, characteristics, emissions. *Chemosphere* **2020**, *240*, 124892. [[CrossRef](#)] [[PubMed](#)]
2. Nandhini, R.; Berslin, D.; Sivaprakash, B.; Rajamohan, N.; Vo, D.V.N. Thermochemical conversion of municipal solid waste into energy and hydrogen: A review. *Environ. Chem. Lett.* **2022**, *20*, 1645–1669. [[CrossRef](#)] [[PubMed](#)]
3. Koohestanian, E.; Shahraki, F. Review on principles, recent progress, and future challenges for oxy-fuel combustion CO<sub>2</sub> capture using compression and purification unit. *J. Environ. Chem. Eng.* **2021**, *9*, 105777. [[CrossRef](#)]
4. Asghar, U.; Rafiq, S.; Anwar, A.; Iqbal, T.; Ahmed, A.; Jamil, F.; Khurram, M.S.; Akbar, M.M.; Farooq, A.; Shah, N.S.; et al. Review on the progress in emission control technologies for the abatement of CO<sub>2</sub>, SO<sub>x</sub> and NO<sub>x</sub> from fuel combustion. *J. Environ. Chem. Eng.* **2021**, *9*, 106064. [[CrossRef](#)]

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.