A Study on Technical Research and Model Establishment of Co-firing Ammonia with Coal

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1. Background

Achieving net-zero emissions by 2050 has become a global issue driven by the intensifying effects of global warming and the consequent need for substantial carbon dioxide reduction. Taiwan also focuses on expanding its renewable energy generation to align with global decarbonization trends. However, the inherent intermittency of renewable energy due to weather conditions necessitates integrating energy storage solutions and enhanced grid management capabilities, thus limiting its ability to replace thermal power generation fully in the short term.

To reduce emissions from thermal power plants, a key decarbonization strategy, utilizing low-carbon alternative fuels presents a viable approach. Emerging technologies such as hydrogen combustion in gas-fired units and ammonia combustion in coal-fired units show promise. However, due to its extremely low boiling point (-253℃), hydrogen poses substantial transportation and storage challenges. Ammonia, with its higher boiling point (-33 ℃) and carbon-free composition, offers a more practical alternative. Ammonia co-firing with coal in existing coal-fired units is expected to reduce carbon dioxide emissions substantially. While ammonia has historically been utilized as an agricultural fertilizer and chemical feedstock, its application in the energy sector is still being researched and developed. This effort includes the exploration of both direct ammonia combustion as a fuel and its decomposition technology for hydrogen production. Due to the carbon-free nature of ammonia combustion, its application as a carbon reduction pathway is being explored in various sectors, including coal-fired power generation, fuel cells, and marine fuels (Fig. 1). This study focuses on the application of ammonia in coal-fired units to reduce carbon emissions.

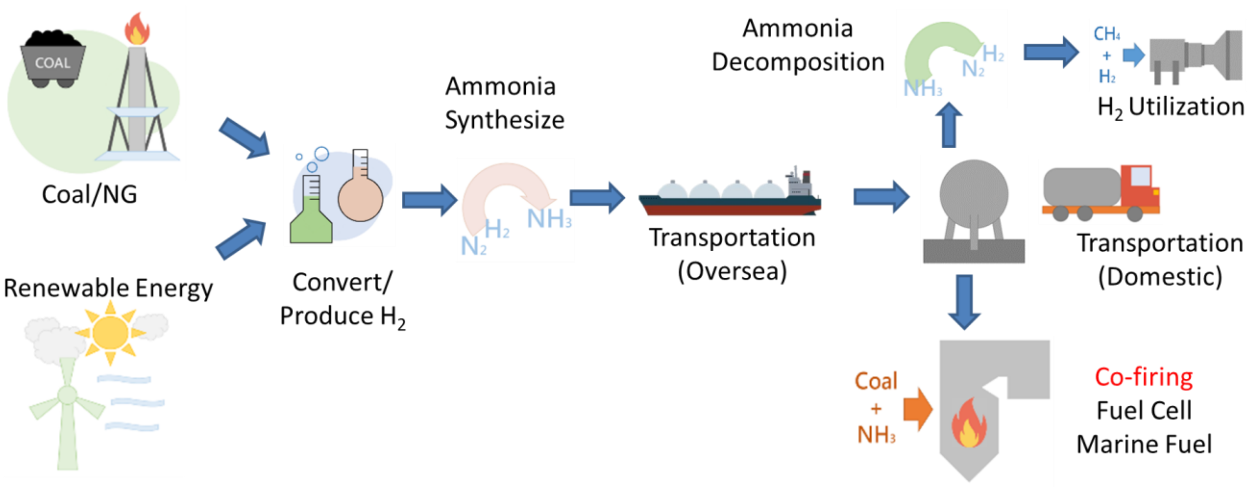
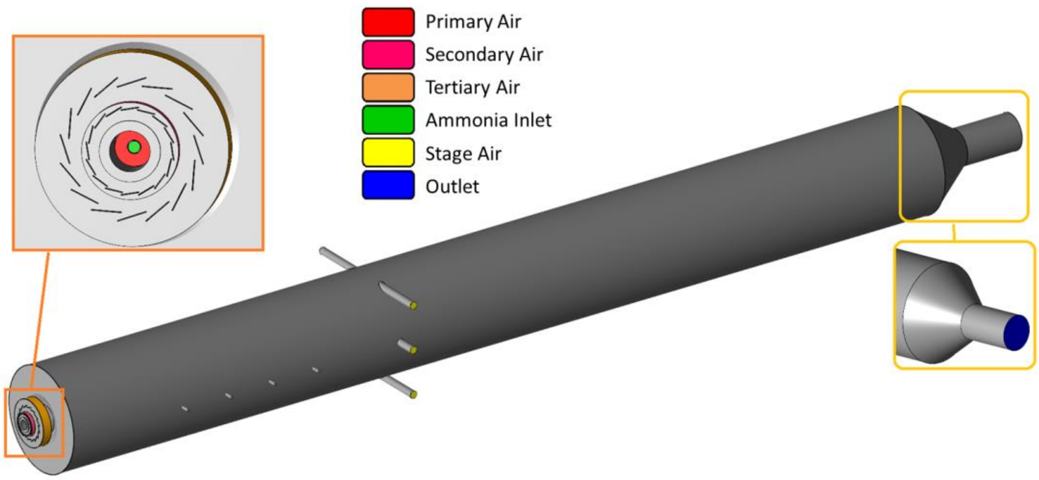


Figure 1 Production, Transportation, and Application of Ammonia [1]

2. Research Content

A single burner of the test furnace from Japan's Central Research Institute of Electric Power Industry (CRIEPI) was chosen for simulation and verification, with a coal combustion flow rate of approximately 100 kg/h. Designed as a cylindrical chamber (Fig. 2), the diameter of the furnace is 0.85 m, and its length is 8 m. A pulverized coal burner, located in front of the furnace, supplies fuel and air, including fuel-carrying primary air and separate secondary and tertiary air inlets. Ammonia is injected through a pipe inserted into the center of the primary air, while flue gas emissions are discharged from the furnace's end. Six intake ducts, positioned 3m downstream from the burner, introduced stage air. This burner configuration served as the basis for combustion simulations of coal and a 20 cal.% ammonia co-firing (coal co-firing with 20 cal.% ammonia).

Figure 3 shows coal-fired combustion (left) and 20 cal.% ammonia co-firing (right) of the simulation results, including axial velocity, temperature, and gas concentration distribution (O_2, CO_2, NO, and H_2O) along the central cross-section of the test furnace. Due to the cyclonic airflow from the burner, Figure 3(a) shows air spreading radially after entering the furnace. The temperature distribution between the two cases is similar, and the combustion occurs in the axial distance of 0-1m from the outer ring of the burner due to the cyclonic effect, as shown in Figure 3(b). However, the ammonia co-firing case exhibits a lower temperature in the initial 0.5m region near the burner due to ammonia injection with ambient temperature. The concentration distribution of O_2 (Fig. 3(c)) is comparable, showing near-zero oxygen before stage air injection. The CO_2 concentration distribution (Fig. 3(d)) is generally lower in the ammonia co-firing case compared to the coal-fired case. The NO concentration distribution (Fig. 3 (e)) is higher than the coal-fired case, except for the initial combustion zone. The concentration distribution of H_2O (Fig. 3 (f)) is higher before and lower after the stage air injection. Figure 4 shows the comparison between the measured and simulated results of the coal-fired and ammonia co-firing test furnace, including the temperature, O_2 concentration, and NO concentration. The agreement between simulation and measurement validates the feasibility of the coal/ammonia co-firing combustion model developed in this study.



Source: Made by author

Figure 2　Schematic diagram of small test furnace

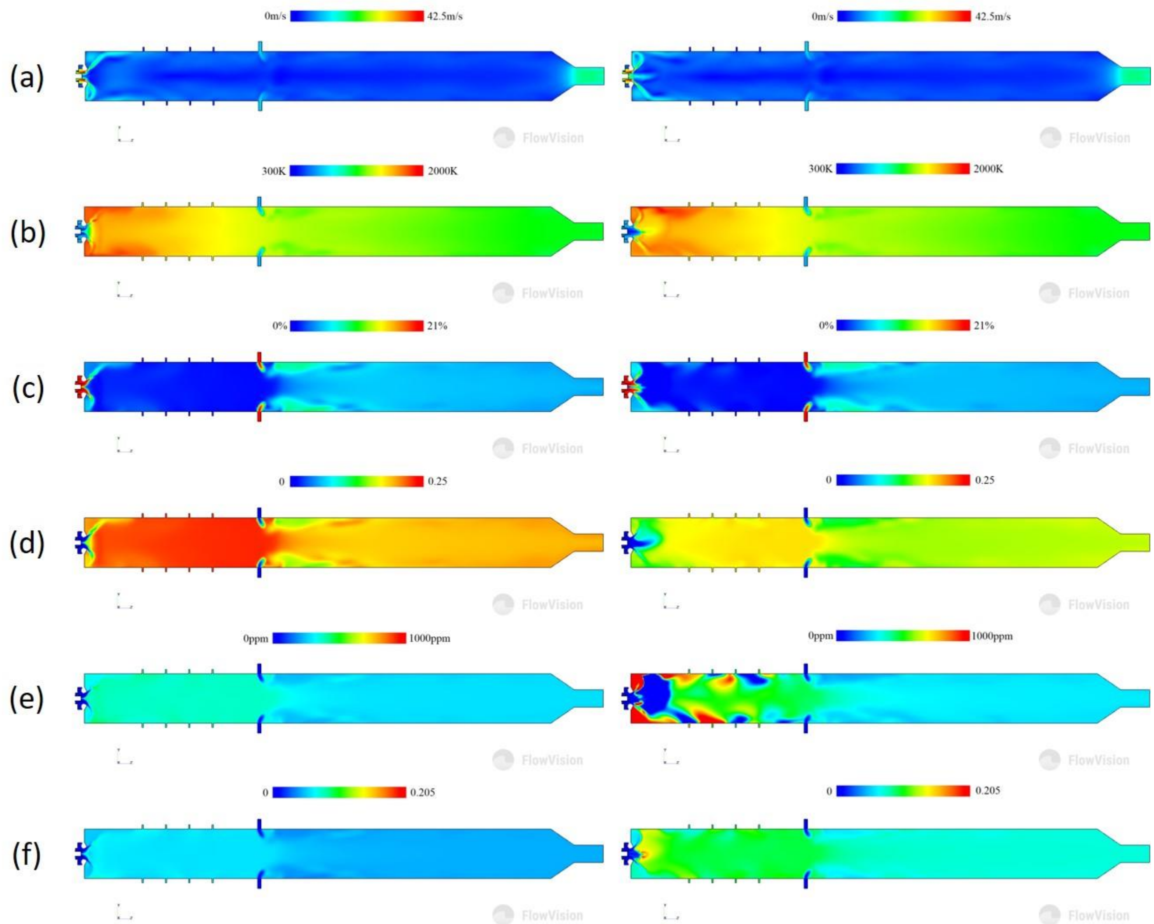


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Figure 3　The result of coal-fired (left) and 20 cal.% ammonia co-firing (right) cases

(a)　Axial Velocity (b) Temperature (c) O_2 Concentration (d) CO_2 Concentration

(e) NO Concentration (f) H_2O Concentration

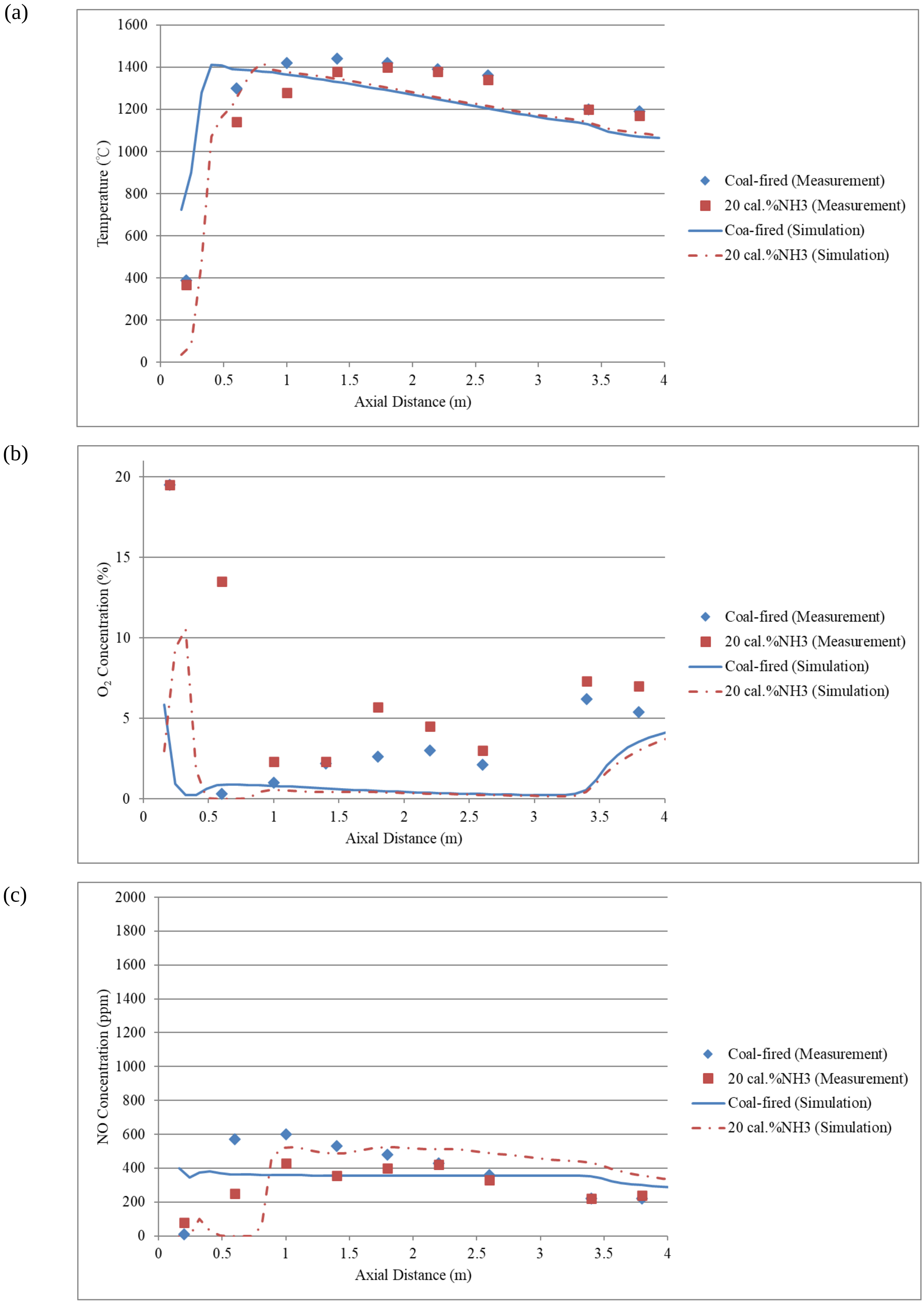

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Figure 4 The axial distribution between measurement and simulation with coal-fired and 20 cal.% ammonia co-firing cases[2]

(a) Temperature (b)O_2 Concentration (c)NO Concentration

3. Conclusions

Coal/ammonia co-firing technology is still under development, and Japan has made the most significant advancements. Therefore, this study gathered information from Japan to understand the evolution of technology and its potential challenges. With CRIEPI's test data and computational fluid dynamics software, a coal/ammonia co-firing combustion model was developed. The results demonstrated that NOx emission trends in 20 cal.% ammonia co-firing case were consistent with test data, which validate the feasibility of the developed combustion model. To explore the effects of the ammonia co-firing approach, location, and ratio on boiler combustion efficiency, combustion simulations of ammonia co-firing in large coal-fired boilers for power generation will be conducted in future studies.

4. References

[1] Aziz, M., Wijayanta, A. T., & Nandiyanto, A. B. D. (2020). Ammonia as Effective Hydrogen Storage: A Review on Production, Storage and Utilization. *Energies*, 13(12), 3062.

[2] 日本電力中央研究院, 既設火力発電所におけるアンモニア利用に関する検討, 2019.