International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:12, 2014

Low NOx Combustion Technology for Minimizing NOx

Sewon Kim, Changyeop Lee, Minjun Kwon

***Abstract*—**A noble low NOx combustion technology, based on partial oxidation combustion concept in a fuel rich combustion zone, is successfully applied in this research. The burner is designed such that a portion of fuel is heated and pre-vaporized in the furnace then injected into a fuel rich combustion zone so that a partial oxidation reaction occurs. The effects of equivalence ratio, thermal load, and fuel distribution ratio on the emissions of NOx and CO are experimentally investigated. This newly developed combustion technology showed very low NOx emission level, about 12 ppm, when light oil is used as a fuel.

***Keywords*—**Burner, low NOx, liquid fuel, partial oxidation, fuel rich.

I. Introduction

In combustion processes, various kinds of hydrocarbon liquid fuels such as light oil and heavy oil are used. Regarding liquid fuel combustion, due to increasing concerns over environmental pollutants such as carbon monoxide, unburned hydrocarbon and nitrogen oxides, development of low pollutant emission methods has become an imminent issue for practical application to numerous combustion devices. Nitrogen oxides (NOx) are known to be the most hazardous pollutants which are recognized as acid rain precursors that impose a significant threat to the environment. Therefore, their control is a major issue.

In most conventional liquid fuel burners, thermal NOx is reduced by decreasing a peak flame temperature using steam injection method or air and/or fuel staged combustion technique. However, the formation of fuel NOx in flame due to the nitrogen components in fuel is significant, especially in liquid fuels, and controlling fuel NOx is very difficult. Further, in conventional multi-staged burners, it is very difficult to divide the reaction region into fuel rich region and fuel lean region completely, making it difficult to prevent the formation of thermal NOx and fuel NOx. Therefore, the alternative combustion technologies with new concept of NOx reduction are needed to reduce NOx remarkably, and multi-staged burner adapting partial oxidation technique of liquid fuel can be one of good method to solve these problems.

Multi-staged combustion was demonstrated as a practical NOx reduction method in the late 1970s [1]. In the 1981, Takagi and Okamoto showed that the effect of swirl intensity and air ratio on thermal NOx [2]. Additional studies have been done to evaluate the effects of air/fuel staged combustion technology on suppression of NOx for various combustion cases [3], [4]. And a great deal of efforts has been exercised to examine it by changing its aerodynamic characteristics, swirl number or flow velocity [5].

Partial oxidation reaction methods have been extensive applied for thermal cracking of liquid fuels in oil refinery industry. It is well known that the main factors that affect the partial oxidization reaction are reaction temperature and oxidant/fuel ratio. In 2001, Ranzi et al. arranged the procedures in detail kinetic modeling of gasification, pyrolysis, partial oxidation and combustion of hydrocarbon mixture [6]. After two years, researches on cool flame partial oxidation and its role in combustion had been reviewed by Naidja et al. [7].

In this study, the effects of multi-staged burner with partial oxidation of secondary liquid fuel on NOx formation and reduction in diesel-air flame are examined. The aim of the present work is to show the design concept of ultra-low NOx burner using noble techniques for optimal NOx reduction.

II. Experimental Setup

A. Burner

The low NOx fuel oil burner of 500kW thermal capacity is designed so that both fuel and air are staged independently with secondary fuel injection causing partial oxidation reaction. The primary fuel is sprayed at the center through multi-hole nozzle, and the staged air is supplied to swirled primary air around the center nozzle and non- swirled secondary air is supplied at the annulus which is situated outside the primary air port. The primary air, around 60% ~ 80% of total air, is supplied through swirler while the secondary air, 20% ~ 40% of total air, is injected in axial direction without swirling. Additional secondary fuel, which is about 20% ~ 30% of total fuel, is preheated in fuel line installed inside the burner quarl and injected at several circumferential spud nozzles. In this experiment, 6 spud nozzles are used. The schematic diagram of the burner tested in this study is shown in Fig. 1 [8], [9].

B. Furnace

A horizontal cylindrical type furnace is used for this experiment. The volumetric heat release rate of this combustion chamber is 1,000 kW/m3. On the sidewall of the furnace, temperature measuring probes are installed axially to measure the temperature profile of the flame. The water jacket is installed outside the furnace to control the furnace wall temperature, and a window is installed to observe the flame. The schematics and picture of experimental furnace with experimental apparatus is shown in Figs. 2 and 3, respectively.

C. Gas Analyzer

The exhaust gas are measured using NDIR gas analyzer with heated sampling probe and water trap, and the concentrations of CO, CO_2, NO, NO_2 and O_2 are recorded throughout the

Sewon Kim is with the KITECH, Korea (corresponding author to provide phone: +82-41-8535; fax: +82-41-8323; e-mail: swkim@kitech.re.kr).
Changyeop Lee is with the KITECH, Korea (e-mail: cylee@kitech.re.kr).
Minjun Kwon is with the Hanyang University, Korea (e-mail: mjk@kitech.re.kr).

experiments.

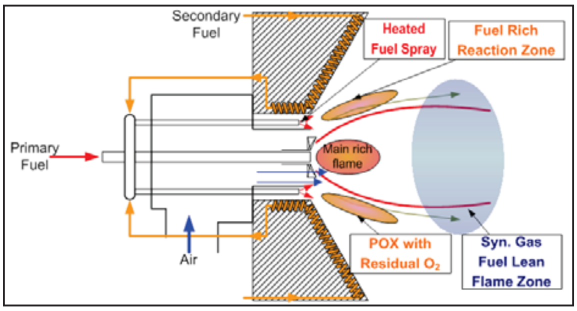

Fig. 1 Schematic Diagram of Burner

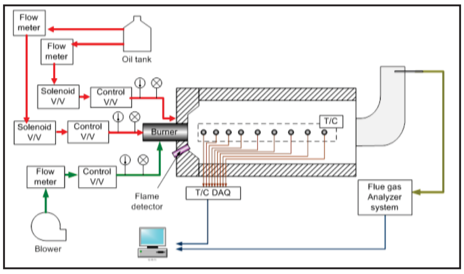

Fig. 2 Schematics of Experimental setup

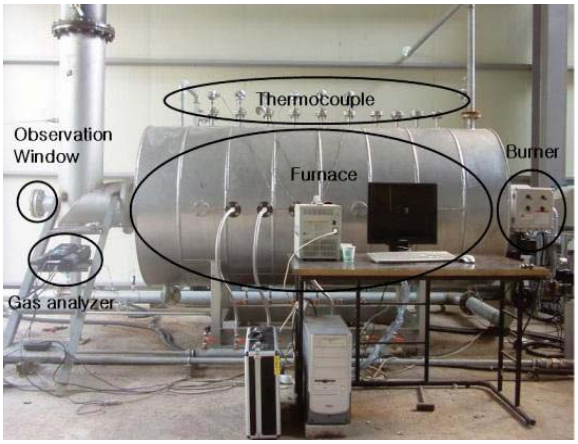

Fig. 3 Photograph of Experimental setup

III. Results and Discussion

For this study, diesel oil with 0.02 wt % nitrogen is used. Experiments are carried out for wide ranges of air/fuel ratios at various heat input conditions.

The primary fuel and air are operated at fuel rich condition in the primary reaction zone to lower fuel NOx formation and also to promote the NOx reduction reaction, while the secondary swirled air is supplied at fuel lean condition. The secondary fuel is preheated through fuel line installed inside the quarl. The injected preheated fuel is instantaneously vaporized in the combustion chamber, and then it reacts with the remaining oxygen in the combustion gas, causing partial oxidation reaction in extremely fuel rich condition.

Fig. 4 shows the reaction pathways of hydrocarbon fuels. As shown in figure, hydrogen cyanide (HCN) is converted to nitrogen through several reduction reaction sequences in fuel rich condition. On the other hand, HCN is easily converted to NO through other oxidation reaction pathways in fuel lean zone with O, OH radicals present in the reaction regime. That's why fuel rich condition should be kept in the primary zone and partial oxidation reaction zone to accomplish low NOx combustion, as shown in Fig. 5.

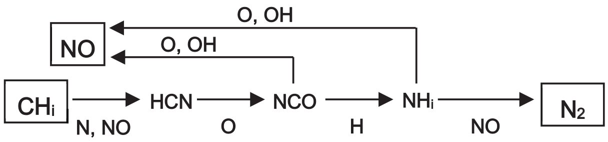

Fig. 4 Reaction pathways of hydrocarbon fuel

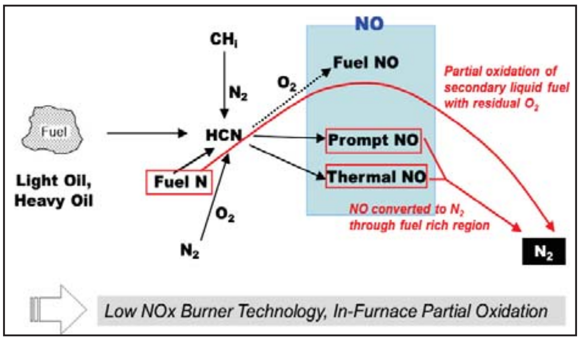

Fig. 5 Formation and Reduction of NO

The formation of fuel NOx attributable to the oxidation of nitrogen components can also be suppressed by partial oxidation as shown in (1). Nitrogen element in liquid fuel is converted to nitrogen gas molecule through gasification reaction in reduction condition. Thus nitrogen compounds become more stable and large amount of fuel NOx formation is restrained.

$$CxHyNz + O_2 \rightarrow CO + H_2 + N_2 \quad (1)$$

At downstream of flame, the fuel lean flame zone is established to complete the combustion.

The detailed flame temperature profiles and pollutant emission characteristics are measured at various burner operating conditions. That is, the effects of equivalence ratio, thermal load, injection distance, and fuel distribution ratio of burner are experimentally investigated. As both the fuel and air are staged, especially fuel oil is individually sprayed by main and spud nozzles, the distinct staged flame structure is observed when an appropriate injection pressure, in which a main fuel rich flame and secondary fuel rich flame is established in near burner outlet, then fuel lean flame zone is formed in downstream of main reaction zone, as shown in Fig. 6.

Fig. 7 shows the effect of fuel distribution ratio on NOx emission level. Fuel distribution ratio, QR is defined as the percentage of fuel injected to the secondary fuel nozzle over total amount of fuel. As shown in the graph, NOx levels

International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:12, 2014

decreases as the fuel distribution ration increases, but NOx remains constant as fuel distribution ratio increase over 30%. It is believed that the partial oxidation reaction at the secondary injection nozzle saturates at 30% and excess fuels react with secondary air in oxidation condition.

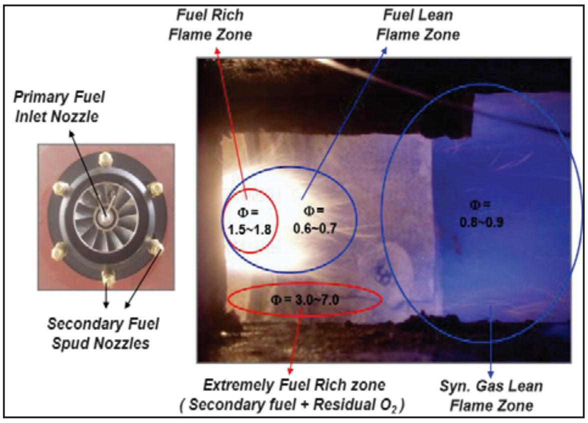

Fig. 6 Picture of experiment

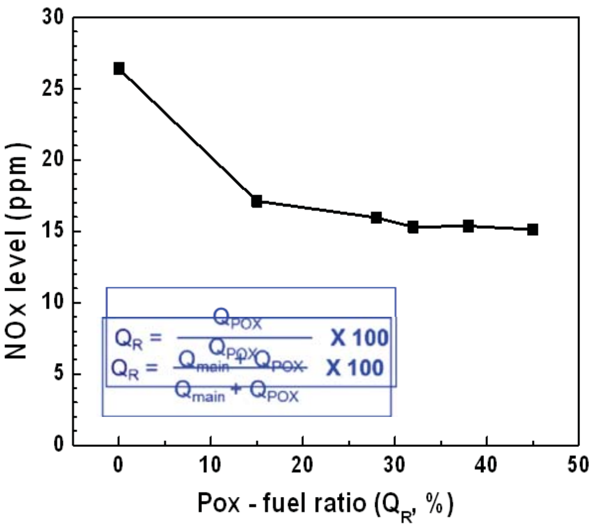

Fig. 7 NOx level on Q_R (Equivalence ratio: 0.82)

Fig. 8 shows the flame temperature profiles in the furnace. As shown in the data, the peak temperature region is situated around center of the flame, which is around 1200°C. And the flame temperature is relatively low in the entire region of the flame. That means thermal NOx formation is fully suppressed in this combustion condition.

Fig. 9 shows the effect of equivalence ratio and thermal heat input on NOx emission level. As shown in graph, this new type of burner has two major advantages in NOx reduction over other conventional burners. Firstly, as the fuel rich and lean zones are obviously separated, the thermal hot spots are almost diminished so that the formation of thermal NOx is restrained. Secondly, vaporization of secondary fuel droplets by heat transfer from primary reaction zone and partial oxidation with residual O2 around the main flame, result in formation of extremely rich reaction zone of secondary fuel, thus NOx reduction and prevention of the formation of fuel NOx condition are provided. Consequently, in this experiment, the NOx concentration shows minimum of 12 ppmv at full load, as shown in Fig. 9.

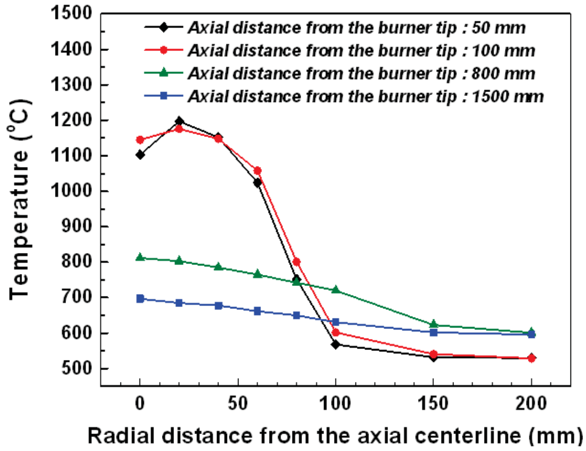

Fig. 8 Temperature Distribution along the Radial Direction

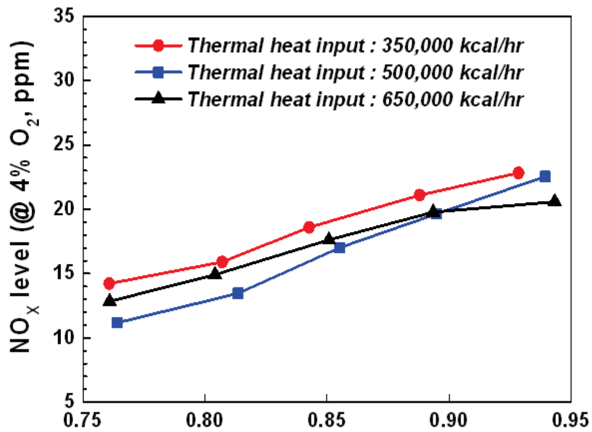

Fig. 9 NOx emission characteristics

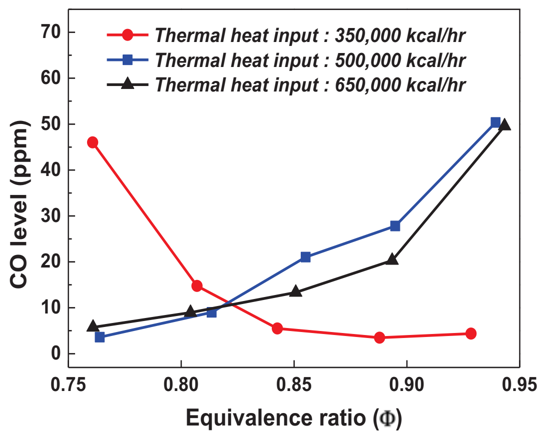

Fig. 10 CO emission characteristics

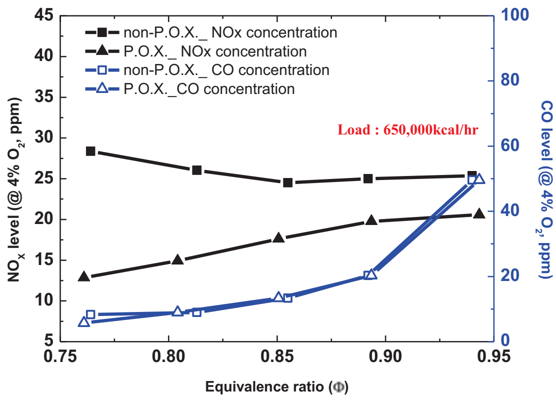

Fig. 11 Comparison of non-P.O.X. and P.O.X. condition

Fig. 10 shows the effect of equivalence ratio and thermal heat input on CO emission level. It shows the different characteristics as thermal input changes. When thermal input is low (350,000 kcal/hr), CO emission characteristic is contrary to other cases, that is, CO concentration increases with the increase of air/fuel ratio. It is believed that at low thermal input conditions, fuel and air mixing behavior is relatively low, so that a partial incomplete combustion phenomenon is occurred. However, in all experimental conditions, CO levels are lower than 50 ppmv which is still quite low compared to conventional liquid burners.

Fig. 11 shows the comparison of NOx & CO concentration in non-partial oxidation (non-P.O.X.) condition and NOx & CO concentration in partial oxidation (P.O.X.) condition. The experiments are performed such that all the fuels are injected to the main center nozzle in the non-partial oxidation reaction condition. As shown in the graph, the maximum concentration of NOx is about 28ppmv in the non-P.O.X. condition, which is much higher than 12 ppmv in P.O.X. condition. As equivalence ratio is increased the NOx concentration is decreased, but in the P.O.X condition, the NOx concentration is increased as equivalence ratio is increased. Thus, the effect of partial oxidation reaction is clearly shown that it is more effective in the low equivalence ration condition.

IV. Conclusion

In this paper, detailed experimental studies are performed to examine the performance of this newly designed low NOx fuel oil burner with partial oxidation reaction on NOx and CO emission characteristics. The major findings are as follows.

A. Due to the obviously separated fuel rich and lean reaction zone and partial oxidation reaction, ultra-low NOx emission of the liquid fuel burner is achieved, the NOx concentrations are below 11~15ppmv at various thermal heat input conditions without FGR or any other after combustion treatment.

B. In line preheating the liquid fuel within the burner quarl is very effective method that achieves the preheating temperature around 400~500K. Then partial oxidation reaction is conveniently induced. In addition, the fuel rich condition for partial oxidation reaction is formed in recirculation zone using the oxygen in combustion gas without the external supply of air for this reaction.

C. In all experimental conditions, CO level is kept below 50 ppmv.

D. The new type multi-staged liquid burner with partial oxidation shows very good performance on pollutant formation and reduction. In future studies, more detailed chemical and fluid mechanical research is needed. In addition, slurry fuels, such as coal-water slurry and petroleum coke-water slurry, will be tested as a fuel for this noble low NOx burner.

Acknowledgment

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry and Energy.

References

[1] B. W. Gerhold, C. P. Fenimore and P. K. Dederick, Proc. Combust. Inst. 17 (1978) 703-713
[2] T. Takagi and T. Okamoto, Combust. Flame 43 (1981) 69-79
[3] J. P. Smart and R. Webber, Proc. Ins. Energy (1989), 237-245
[4] M.A. Toqan, J. M. Beer, P. Jansohn, N. Sun, A. Testa and J. D. Teare, Proc. Combust. Inst. 24 (1992) 1391-1397
[5] T. K. Terasaki and S. Hayashi, Proc. Combust. Inst. 26 (1996) 2733-2742
[6] E. Ranzi, M. Dente, A. Goldaniga, G. Bozzano and T. Faravelli, Prog. Energy Combust. Sci. 27 (2001) 99-139
[7] A. Naidja, C. R. Krishna, T. Butcher and D. mahajan, Prog. Energy Combust. Sci. 29 (2003) 155-191
[8] S. Kim: Development of Combustion System for Water Tube Boiler , Annual Report (KITECH, Korea 2009
[9] S. Kim: Combustion Control of Boiler System to Increase Efficiency , Annual Report (KITECH, Korea 2014