# Recent Trends in NOx Reduction Techniques from Gas Turbine Combustion

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*Abstract*— Fossil fuels are non-renewable energy resources and its rapid depletion is of widespread concern whereas at the same time global warming has prompted researchers to develop technologies to increase the combustor performance without any harmful impact on our environment.$NO_x$ Formation mechanisms have been discussed. Classification of $NO_x$ reduction techniques has been done. Important works related with swirling air injection into the combustion chamber for distributed combustion reactions have been discussed.

***Key words:*** $NO_x$, Fossil fuels, swirling air injection, global warming

## I. INTRODUCTION

Combustion is defined in Webster's dictionary as "rapid oxidation generating heat, or both light and heat; also, slow oxidation accompanied by relatively little heat and no light"[1].It has become very essential for the existence of humans on this planet. Ranging from house lighting, house heating, food cooking, motor vehicles, to spacecraft, many things shows the importance of combustion in our daily life. In a larger scale, industrial processes rely even more heavily on combustion. To give a few examples, iron, steel factories, cement manufacturing industry, transportation system rely almost entirely on combustion. It is estimated that, at present, approximate 90% global energy use comes from combustion processes, and the global energy need increase by 3% per year [2]. By seeing its enormous uses and applications it can be said that in the coming years, combustion will remain the main source of energy provider. The combustion process typically burns fuel in a device to create heat and power. Most fuels are mixtures of hydrocarbons, e.g. gasoline and diesel fuels, which are compounds that contain hydrogen and carbon atoms. In 'perfect' combustion, oxygen in the air would combine with all the hydrogen in the fuel to form water and with all the carbon in the fuel to form carbon dioxide. Nitrogen in the air would remain unaffected. In reality, the combustion process is not 'perfect', and combustion devices emit several types of pollutants as combustion byproducts. Pollutants generated by combustion include particulate matter [1] suchas fly ash, soot, various aerosols, etc.; the sulphur oxides, $SO_2$and $SO_3$; unburned andpartially burned hydrocarbons (UHC); oxides of nitrogen,$NO_x$,which represents thecombination of $NO$ and $NO_2$; carbon monoxide, $CO$; and greenhouse gases, particularly $CO_2$ [3].These pollutants affect our environment and human health in many ways.$NO_x$is an unwanted product of combustion process and can cause health and environmental impacts like ground-level ozone, acid rain, particles, water quality deterioration, climate change, toxic chemicals and visibility impairment [4].

The present paper reviews of recent works in the development of new technology on the reduction of $NO_x$ emission in gas turbine combustion. The concentration of $NO_x$ and hydrocarbon in the gas turbine combustion get increase due to the local non-uniform mixing of air and fuel. Conventional mixing methods yield the non-uniformity of the fuel concentration, which causes a non-uniform temperature distribution. As a result of the non-uniformity of the temperature, difficulties arise in controlling the exhaust gases. Thus, the uniform distribution of fuel concentration in the combustor is essential to enhancing the mixing with air, which plays a significant role in the improvement of combustion efficiency and control of exhaust gases. In the recent years a significant amount of work has been done in the reduction of $NO_x$ emission in gas turbine combustion. This paper discusses different ways implemented to reduce $NO_x$ emission over the years.

## II. $NO_x$FORMATION MECHANISM

There are mainly twochemical mechanisms for the formation of nitrogen oxides during combustion, thermal and prompt mechanism.

### *A. Thermal $NO_x$*

Thermal $NO_x$ is formed by the high temperature reaction of nitrogen with oxygen and consists of two chain reactions [5].

$$N_2 + O_2 \rightarrow NO + N \quad (2.1)$$

$$N + O_2 \rightarrow NO + O \quad (2.2)$$

Thermal $NO_x$increases exponentially with temperature as shown in Fig. 1, and it is generally the predominant mechanism in combustion processes where temperature reaches above 1100 °C.

### *B. Prompt $NO_x$*

Prompt $NO_x$ is formed by the relatively fast reaction between nitrogen, oxygen, and hydrocarbonradicals. It is denoted by overall reaction. This process is more complicated than thermal $NO_x$ as it consists of a large number of reactions [5].

$$CH + N_2 \rightarrow HCN + N \quad (2.3)$$

$$N + O_2 \rightarrow 2NO \quad (2.4)$$

## III. $NO_x$ REDUCTION TECHNIQUES

For reducing $NO_x$emissions from combustion processes, there aretwo main procedures, named primary and secondary measures. When emission is reduced by modifying combustion devices to minimize the amount of $NO_x$ generated in the first place is called primary measures while secondary measures deals with the treatment of flue gases by some attachments like catalytic converters.

### *A. Pre-Treatment*

Flue gas recirculation is the method for the pre-treatment of flue gases which comes under primary measures.In this method, adding inert gas to the flame zone in combustion can lower the overall flame temperature. The inert gas requires heat from the combustion process, whichlowers the overallcombustion temperature. 70 % reduction of $NO_x$ can be obtained by applying external flue gas recirculation [6]. Internal furnace gas recirculation and external flue gas recirculation are methods of flue gas recirculation for reducing $NO_x$ [7]. An example of external flue gas recirculation is shown in fig. 2.

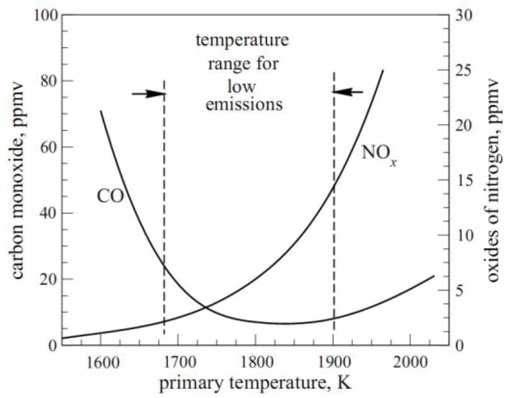


Fig. 1: Influence of temperature on CO and NOx emissions [8]

### B. Post-Treatment

In the secondary measures or post treatment, $NO_x$ is removed from exhaust gases after it has already been formed in gas chamber. Most common way to post treat the exhaust gases is to use catalytic converter [9-10]. The $NO_x$ emissions from catalytic combustion can be as low as 1 ppm [11].

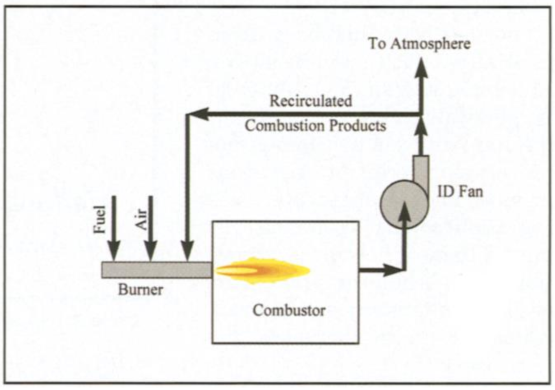


Fig. 2: External flue gas recirculation system [7]

## IV. MECHANISM TO REDUCE $NO_x$ EMISSIONS

Swirling flows are defined as a flow undergoing simultaneous axial–tangential and vortex motions. From the application of a spiralling motion, a swirl velocity component (tangential velocity component) being imparted to the flow by the use of swirl vanes, axial-plus-tangential entry swirl generators or by direct tangential entry into the chamber [12].The degree of swirl or rotation is defined by a non-dimensional number called swirl number. The swirl number S, [13] can be written as

$$S = \frac{G_\theta}{G_x r} \quad (4.1)$$

Where $G_\theta$ is the axial flux of swirl (angular) momentum, $G_x$ is the axial flux of axial momentum and r is a characteristic radius such as the burner radius.

Swirl increases the mixing of fuel and air and has been shown to increase combustion efficiency. It also decreases NOx emissions in industrial burners and gas turbine engines. Swirl can accomplish these benefits by optimizing the time that the products of reaction stay within the reaction zone. The preliminary experiments suggested that induced swirl flows might have the potential to achieve some reduction in pollutant formation and improvement in efficiency as found in swirl stabilized combustion [14].

For methane and natural gas burners, it was found [15] that the major source of NOx production was related to the residence time at high temperature. Thus, one means to reduce NOx emissions is to decrease the amount of time that fluid particles remainat high temperatures.

Hatami [16] discussed the effect of swirl on $NO_x$production in a combustion chamber by first allowing air entry without and then with swirl.It was seen that the maximum amount of NO produced was 10ppm without swirling flow. Whereas, in case of swirling flow,$NO$concentration was very low and $NO_2$concentration also diminished rapidly. Swirling flow caused the strong recirculation in the combustion chamber and lead to the combustion temperatures and the oxygen partial pressure got lowered and therefore swirl type of combustor was found to be more advantageous than parallel flow diffusion type burners.

Zhou et al. [17] worked on “Studies on the effect of swirl on NO formation in methane/air turbulent combustion” and their findings are as followings.

Both predictions and experiments shown, indicated the increase in swirl number from 0 to1, the thermal NO at first increased and then decreased. In contrast, the fuel NO at first decreased and then increased. This studies also shown that the increase in swirl number first lead to a rapid decrease and then decrease of temperature near the exit. Spangelo [18] Worked on “Experimental and Theoretical Studies of a Low NOx SwirlBurner” and his findings are as followings.

A novel low$NO_x$swirl stabilized gas burner concept, the swirl burner, has been studied experimentally, theoretically and numerically. Flame stabilization, rapid air and fuel mixing and internal flue gas recirculation had been provided by a strongly swirling flow generated in this patented burner concept. $NO_x$emissions had been measured below 25 and 45 ppmv dry corrected to 3% $O_2$ in the flue gases usingmethane and propane as fuel respectively. Studying the effect of varying geometricalparameters on the emissions of $NO_x$, fuel and air supply pressure and flame stability, haveresulted in an optimized burner design. Meier et al. [19] worked on “Reaction zone structuresand mixing characteristics of partially premixed swirling CH4/air flames in a gas turbinemodel combustor” and their findings are as followings.

The mixing, reaction progress, and flame front structures of partially premixed flames had been investigated in a gas turbine model combustor using different laser techniques comprising laser Doppler velocimetry for the characterization of the flow field, Raman scattering for simultaneous multi-species andtemperature measurements, and planar laser-induced fluorescence of CH for the visualizationof the reaction zones. Swirling CH4/air flames with Re numbers between 7500 and 60,000had been studied to identify the influence of the turbulent flow field on the thermochemicalstate of the flames and the structures of the CH layers. The results found indicate that the flames exhibit more characteristics of a diffusion flame (with connected flame zones) than of a uniformly premixed flame.

Swirl combustors with tangential air entry have shown to exhibit high swirl intensity, which helps reduce NOx emission and enhance flame stability [20].The role of swirling air injection into the combustion chamber for distributed combustion reactions had been explored by injecting air tangentially into the combustion chamber at high air velocity to form swirling motion. A cylindrical combustor incorporating tangential air injection had been used in this study. The experimental results obtained depicts to achieve near zero pollutant emissions at gas turbine operational conditions where even higher pressures were attributed, which would allow the combustor to sustain flame at even lower equivalence ratios, where much lower NO (near zero) emissions were produced without suffering from incomplete combustion and high CO emissions [21].Some works [22-23] have also been reported for ultra-low emissions of $NO_x$ and CO and significant improvement in pattern factor, low sound emission levels greatreduction in emission had been achieved.

## V. CONCLUSION

For a cleaner environment, low levels of pollutants emission (such as,$NO_x$, CO, unburned hydro- carbons and soot) from gas turbine combustors need to be achieved which leads to the motivation to develop novel combustion techniques. Swirl mixing of fuel creates recirculation zone which provides high and uniform temperatures in the combustion zone. This hot mixture provides the ignition energy for the fuel to ignite and stabilize the flame. Study of important literatures show that the use of swirl combustor greatly improves the emission of $NO_x$.

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