The Nucleus, **46** (3) 2009: 213-218

The Nucleus
A Quarterly Scientific Journal of Pakistan Atomic Energy Commission
NCLEAM, ISSN 0029-5698

EFFECT OF PROCESS PARAMETERS AND INJECTOR POSITION ON THE EFFICIENCY OF NO_X REDUCTION BY SELECTIVE NON CATALYTIC REDUCTION TECHNIQUE

*A.HAMID, M.A.MEHMOOD, N.IRFAN, K.WAHEED[1] and M. T JAVED

Department of Chemical and Material Engineering, PIEAS, P.O. Nilore, Islamabad, Pakistan

[1]Department of Nuclear Engineering, PIEAS, P.O. Nilore, Islamabad, Pakistan

An experimental investigation has been performed to study the effect of atomizer pressure dilution of the reducing reagent and the injector position on the efficiency or the NOx reduction by a selective non-catalytic reduction technique using urea as a reducing agent. Experiments were performed with a flow reactor in which flue gas was generated by the combustion of methane in air at stoichiometric amount of oxygen and the desired levels of initial NO_x (400-450 ppm) were achieved by doping the flame with ammonia. The work was directed to investigate the effect of atomizer pressure, dilution of urea reagent and the injector position. The atomizer pressure was varied from 1 to 3bar and 20-25% increase in efficiency was observed by decreasing the pressure. Effect of dilution of urea solution was investigated by varying the strength of the solution from the 8 to 32% and 40-45% increase in the efficiency was observed. Effects of injector position was investigated by injecting the urea solution both in co current and counter current direction of the flue gases and 20-25% increase in the efficiency was observed in counter current direction.

Keywords: SNCR, NO_x, NO_x reduction, Urea dilution, Non stoichiometric ratio

1. Introduction

NO_X is a generic term for used the various nitrogen oxides produced during combustion. They are believed to aggravate asthmatic conditions, react with the oxygen in the air to produce ozone, which is also an irritant, and eventually form nitric acid when dissolved in rain. When dissolved in atmospheric moisture the result can be acid rain which can damage both trees and entire forest ecosystems

Generally, three primary sources of NO_X formation in combustion processes are documented:

- Thermal NO_X
- Prompt NO_X
- Fuel NO_X

Thermal NO_X formation, which is highly temperature dependent, is recognized as the most relevant source when combusting natural gas. Fuel NO_X tends to dominate during the combustion of fuels, such as coal, which have significant nitrogen content, particularly when burned in combustors designed to minimize thermal NO_X. The contribution of prompt NO_X is normally considered negligible. A fourth source, called feed NO_X is associated with the combustion of nitrogen present in the feed material of cement rotary kilns, at between 300° to 800° C, where it is also a minor contributor.

NO_x create many problems in the environment. Sulfur dioxide and NO_X are the two key air pollutants that cause acid deposition (wet and dry particles and gases) and result in the adverse effects on aquatic and terrestrial ecosystems, materials, visibility, and public health. A high level of nitrate in drinking water is a health hazard, especially for infants. NO_X emissions contribute directly to the widespread accelerated eutrophication of coastal waters and estuaries. Atmospheric nitrogen deposition onto surface waters and deposition to watershed and subsequent transport into the tidal waters has been documented to contribute from 12 to 44 percent of the total nitrogen loadings to coastal water bodies. In addition, emissions of NO_X lead to

---

* Corresponding author : Adnan@pieas.edu.pk

the formation of tropospheric O_3, which is another greenhouse gas. NO_X compounds react with other compounds in the atmosphere to form nitrate particles and acid aerosols. So NO_X posses a serious threat to the atmosphere so it is needed to be controlled [1].

There are two types of techniques used to control the effluent that are pre combustion control technique and other is post combustion control technique. In post combustion control two techniques are mostly used that are selective catalytic reduction and the other one is selective non catalytic reduction.

Selective non catalytic reduction is a method for reducing nitrogen oxide emissions in conventional power plants that burn biomass and coal. The process involves injecting either ammonia or urea etc. into the fire box of the boiler at a location where the flue gas is between 850 - 1150^{o}C. NO_X emissions in the flue gas are converted into elemental nitrogen and water by these nitrogen-based chemical reagent, most commonly urea (CH_2CONH_2) or ammonia (NH_3; either anhydrous or aqueous) [2].

SNCR is an ideal retrofit technology and is compatible with other techniques (i.e., low-NO_X burners, OFA, FGR, gas reburning, etc.) as part of a combination technology approach to even higher NO_X reduction. Selective non Catalytic Reduction may be used in any industry with effluent gas at sufficient temperature and residence time such as Power, Petrochemical, Steel, Metal production, Pulp and Paper, Cement, Waste to Energy, Glass, Nitrous Acid Production etc.

2. Experimental Setup

The experimental set up under discussion was simulation of the modern fossil fuel fired power plant on laboratory scale. This experimental setup was used to perform experiments to testify the different technology for the emission control. This setup consists of six main parts that were burner, combustion section, temperature control section, injection section, reaction section and the exhaust section as shown in Figure 1.

There are some supply systems attached to the rig that are air supply system that supplies the air for the burning, gas supply system that supplies the methane gas to the burner for burning, ammonia supply system which was used to artificially simulate the NO_x in the rig, water supply system to cool the injector and the sampling probes and chemical injection system which was used to inject the chemical to control the NO_x.

3. Combustion Rig

Fuel was burnt with air with the help of a 150 KW burner in the combustion section. Combustion section was made of mild steel with the insulation of fire bricks, gas kits made of asbestos were used to join combustion section with the other sections.

Next to the combustion section was temperature control section. The main purpose of this section was to control the temperature of the flue gases being generated in result of combustion. The temperature was controlled by changing the position of the coils with in the section or by adjusting the flow rate of the water. The material of construction for this section was mild Steel, and that for the cooling coils was copper with the covering of Kao wool. Thick insulation was provided for this section so that the surface temperature was bearable. The thickness of insulation in this section was 275mm. The flow area of this section was 250mm x 250mm.

Third section was the chemical injection section where reducing reagent was injected. For this purpose an entrance was given for the injector from the side of the section. Injector was cooled by water jacket so that it can bear the intense thermal condition inside the furnace. Thick insulation was provided for this section so that the surface temperature was bearable. The thickness of insulation was this section was 300mm. The flow area of the flue gases in this section was 250mm x 250mm.

In the fourth section i.e. reaction section injected chemical was given sufficient time to reduce the NOx generated in the flue gases. Holes were provided in this section for the injection of the thermocouple so that the temperature inside the reaction section can be found. Moreover, from these holes suction pyrometer can be inserted to check the exact flue gas temperature. Due to high temperature thick insulation was also provided here. The thickness of the insulation in this section was 300mm and the flow area was increased to 500mm x 500mm.

The fifth and last section of the combustion rig was exhaust section. The purpose of the exhaust section was to provide the space to flue gases to exit from the furnace. There was also thick insulation provided to maintain the surface temperature to the bearable limits. The thickness of the insulation in this section was 300mm and flow area was 500mm x 500mm.

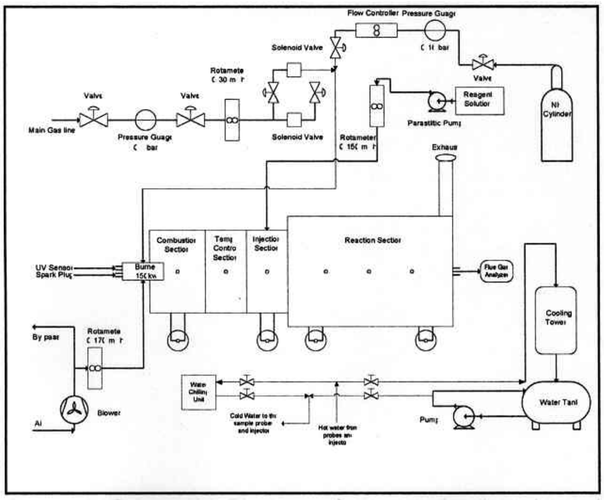

Figure 1 Schematic Diagram of the combustion rig and associated supply systems.

3.1. Supply systems

There were five supply systems attached to the rig that were fuel supply system, air supply system, ammonia supply system, water supply system and the chemical injection supply system. Natural gas supply system was one of the basic supply systems because natural gas was burnt as a fuel in the furnace. This gas supplied was controlled and measured with the help of a Rota meter and two solenoid valves. Air supply system was started from the blower which takes air from the surrounding environment and pushes it through a globe valve to regulate the air supply to the furnace. A bypass was also provided to the air supply so that the excess air can be purged off. A Rota meter was used to measure the flow rate of the air. Since natural gas was burnt as a fuel which doesn't contain the NOx in it so NOx needed to be produced artificially for which ammonia was burnt with the fuel to simulate the NOx inside the furnace. The NOx produced can be controlled with controlling the flow rate of the ammonia [3] .

Since in the combustion rig temperature reaches above 1000^{o}C so the sampling probes and the injector needed to be cooled adequately. So sampling probes and the injector were cooled with cold water which was supplied either by chilling unit or by cooling tower .

Chemicals were injected in the injection section of the rig to reduce the NO_x. This chemical was injected inside the section through parastilitc pump alongwith a carrier gas i.e. air. Air was supplied through a compressor that takes the chemical with it and was injected through a water cooled injector inside the injection section.

3.2. Instruments and analyzer

For the measurement of the temperature K type and R type thermocouples were used. For the precise measurement of the temperature suction pyrometer was used. Suction pyrometer is a device used to take the precise temperature reading of the flue gas by aspirating the flue gas over the R type thermocouple with the help of a suction pump.

Analyzer used was Lancom III which was a compact, portable combustion and emissions analyzer for checking or testing a boiler system or pollutant process. The user friendly analyzer simply selects the gas types and options (from an extensive list) that were required for their specific application. This analyzer was attached to the sample probe which was made of three co axial water cooled pipes. The analyzer took the flue gases through these probes for the analyses.

3.3. Axial temperature profile in the combustion rig

The flow reactor in contrast to other experimental setups reviewed in the literature was a pilot scale facility and hence its reactor section was wider (500mm x 500mm). This design accommodates some features of hydrodynamics in addition to chemistry and therefore resembles more to an actual power plant duct. While the other investigators e.g. Muzio, Arand and Teixeira assume there set up to be an isothermal which was not an actual representation of full scale power plant facility. Hence one can only study the chemistry and not the hydrodynamics which was an important feature playing a vital role in real conditions. An investigation on temperature distribution in the reactor section was thus necessary to estimate the extent of reaction at various residence times. For this purpose axial and lateral temperature profiles were traced along the reactor section.

Figure 2 shows the axial temperature distribution in the reaction section at various injection point temperatures. The experiments were performed keeping the injection point temperature same and then measuring the temperature gradient along the length of the reaction section. It was found that the overall trend of the temperature variations remained the same in almost all injection temperature while the temperature gradient increases with increased injection point temperature. It can be seen that the temperature drop ΔT corresponding to injection point temperatures of 700^{o}C, 900^{o}C and 1100^{o}C are about 375, 475 and 575 respectively. This indicates that the more the difference between internal and room temperature, the greater are the heat losses and more was the temperature drop.

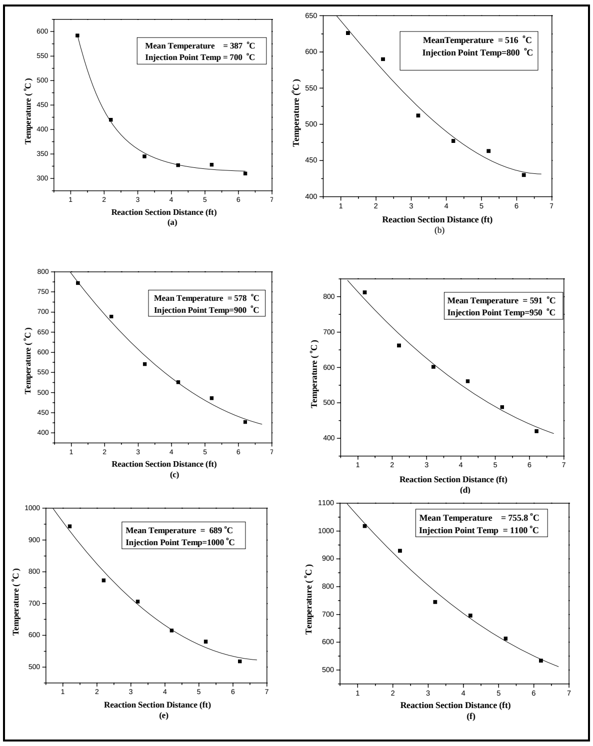

Figure 2. Axial temperature profiles along the reaction section.

4. Results and Discussion

4.1. Effect of atomizer pressure

Experiments were performed at different atomizer pressure varying from 1-3 bar keeping the temperature constant at the optimum value of 1050^{o}C. The reagent used for the reduction was the urea solution and NSR was kept at 4. For all runs, all the other parameters such as dilution, injection flow rate, background NOx value, injector type and position, residence time etc were maintained at identical values. Figure 3 shows the effect of the pressure on the efficiency. Figure 3 depicts a general and noticeable feature that with the increase of pressure the reduction efficiency is decreased. This can be explained on the basis that when pressure of the atomizer is increased the solution injected inside the rig makes a jet and is carried to a greater length before it get mixed and react with the NO_x

Considering the fact that there exist a temperature gradient of 35^{o}C per 10 cm length of the reactor section (Figure 2) Hence mixing and subsequent reaction starts at a lower temperature compared to the point of injection. It is well known that there exists a temperature window of maximum reduction for SNCR technique which is 1050-1150^{o}C in case of urea.

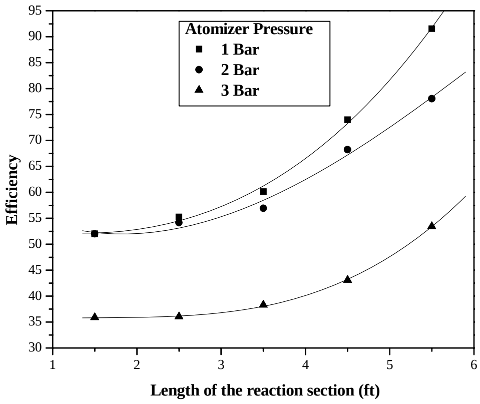

Figure 3 Effect of atomizer pressure on the Efficiency.

Due to increase in atomizer pressure, the jet penetrates to point where temperature is away from the window and hence after subsequent mixing the reaction may result in lesser efficiency. Thus it may be concluded that the greater the atomizer pressure, the greater will be the length of the jet, more will be the delay in mixing and reaction resulting in decrease in SNCR performance due to drop in temperature beyond the optimum efficiency window. As can be seen from Figure 3 when pressure is decreased from 3 bar to 2 bar the efficiency is improved by about 20%. Only a slight improvement i.e. about 3% is observed when it is further decreased to 1bar beyond which atomization is badly affected and droplets were observed. Hence it was inferred that the optimum atomization pressure is 1 bar for the simple injector design and position of the experiment.

4.2. Effect of urea dilution

More dilute solution necessitate the high flow rate to keep the NSR same i.e. the strength of the solution may be lesser while keeping the amount of the urea being injected per unit time as same by increasing flow rate. This would produce a denser spray with better penetration that could induce more mixing in the reaction section and may offer a potential for the improved NO_x efficiency. Based on this theme, various urea solutions with different strengths were injected keeping all other parameters at optimum values i.e. NSR is kept at 6, temperature at 1050°C and the atomizer pressure at 1 bar and the effect of dilution was studied systematically with decreasing solution strengths. Tuning the flow rate accordingly ensured that the amount of urea injected and hence the same NSR was maintained. In this case four urea solutions i.e. 8%, 12%, 16% and 32 %. were used.

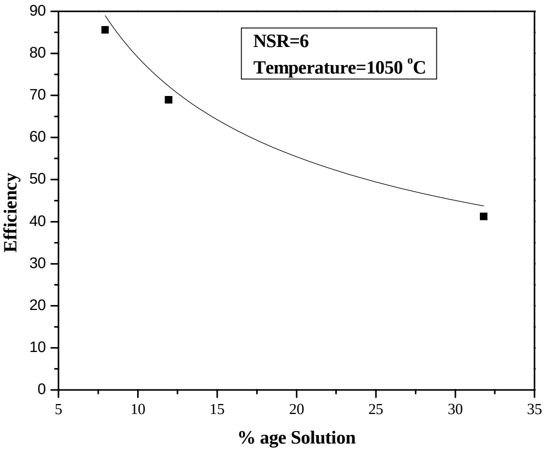

Figure 4. Effect of urea dilution.

Figure 4 shows the effect of dilution on the efficiency. In general it can be deduced that the dilution affects the efficiency positively as can be seen that denser solution (32%) gives a reduction efficiency of only 40% which increases to 67% for 12% urea solution which further increases to 85% for 8% solution. This can be attributed to the fact that urea may not begin to be released from the solution until the saturation is approached the initial evaporation of the water caused the urea to remain at 100°C which is below its dissociation temperature.

When the concentration of the urea reaches saturation it gets superheated leading to dissociation of reducing species. The evaporation process may be responsible for the delay in urea dissociation until it may well be dispersed with in the reactor section, such delay might be affected by varying the concentration of the urea solution. Lowering the urea solution strength increases the amount of water that must evaporate before the urea concentration in the solution reaches saturation.

Another aspect of dilution may be the consideration of increase in momentum of the injected spray i.e. for a given NSR, reducing the urea concentration would increase the mass of aqueous solution injected. This increases the momentum of the injected spray and its penetration and mixing within the reactor, resulting in better efficiency.

4.3. Effect of injector position

Experiments were performed to investigate the effect of injector position on the efficiency using the urea solution of NSR 4.

Figure 5 shows that the efficiency is about 20 to 25% higher when the chemical is injected in the counter current direction of the flue gases as compared to when it is injected in the direction of the flue gases. Obvious reason may be that counter current injection results in more turbulence and better mixing and hence better performance and efficiency.

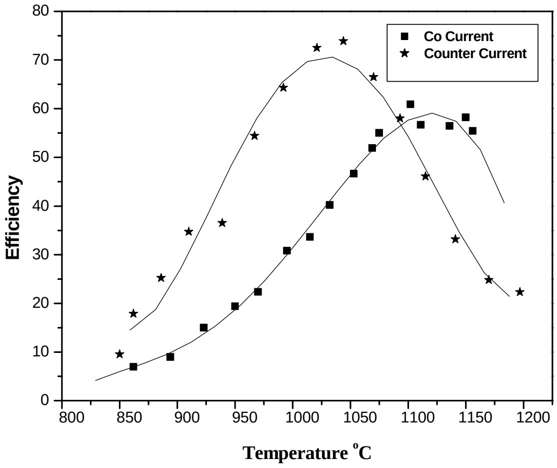

Figure 5. Effect of injector position on the efficiency.

5. Conclusions

Experimental runs were made to investigate the effect of three important parameters namely effect of the atomizer pressure, effect of dilution of urea solution and the effect of the injector position on the performance of percentage NOx reduction. It was noted that with the increase of atomizer pressure the efficiency decrease while with the increase of dilution NOx reduction performance was increased. The counter current flow of the injected reagent gave positive contribution to reduction efficiency.

References

[1] Alzueta, M.U. Alzueta, R. Bilbao, A. Millera, M. Oliva and J.C. Ibanez, Energ. Fuel **12** (1998) 1001.

[2] L.J. Muzio, J.K. Arand and D. P. Teixeira, Gas Phase Decomposition of Nitric Oxide in Combustion Products, 16th Symposium Combustion, The Combustion Institute (1976) 199-20.

[3] S.M. Banna and M.C. Branch, Mixing and Reaction of NH_3 with NO in Combustion Products, Combustion and Flame, **42** (1981) 173.