The Prototype of Non-thermal Plasma After treatment System for Simultaneous Reduction of Nitrogen Oxide Emission in Flue Gas

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Abstract. Nowadays, global warming is the main environmental problems all over the world. The air pollutants mainly from the burning of fossil fuels and coal in power plants, transportation, and automobiles. There are release major point emission of the atmosphere. The nitrogen oxides are the most relevant for air pollution that contribute to the formation of photochemical smog and acid rain. Numerical methods have been studied to eliminate the nitrogen oxides such as the use low-nitrogen fuels technology, the selective catalytic reduction (SCR), wet scrubbing. The aim of this research is investigated non-thermal plasma (NTP) techniques offer an innovation to eliminate both nitrogen oxide (NOx) and soot emissions from combustion. This study is used to selectively transfer input electrical energy to electrons without expending this in heating the entire gas flow which creates free radicals in the flue gases. The simulated flue gas from combustion process is applied to the system. The results showed that the prototype of nonthermal plasma system is shown the highly efficient of NOx removal was achieved. However, the optimised of NTP operating conditions are required to enhance the NOx reduction activities.

Keyword. Non-Thermal plasma (NTP), Nitrogen Oxide, Flue Gas, Emissions

1 Introduction

Nitrogen oxides are toxic emissions produced from diesel combustion and consist of nitric oxide (NO) and nitrogen dioxide (NO₂). The nitrogen oxides from combustions are mainly air pollution generated by fuel combustion from stationary and mobile sources in the atmosphere. NO, emission can cause a series of health and problems such as eye and throat irritation and headache and environment issues such as toxic chemical smog and acid rain [1]. The post combustion technologies, selective catalytic reduction (SCR) has become dominant in controlling NOx emission from industries i.e., utility boilers and industrial furnace stacks [2-3]. However, there are many improvements aimed to reducing the SCR systems cost have been achieved, due to the space requirements and operating cost are still high cost [4]. The generation of ammonia emissions and the fouling of equipment with ammonium sulphate.

Given the health of diesel emission, power plant and combustion, there is an explicit to regard novel technologies to remove the tailpipe emissions. The highly traffic jam in urban areas is a big main problem of Nitrogen Oxide [5-6]. Thus, Non-thermal plasma (NTP) is an alternative chance for after treatment application to control emission [7]. Plasma is term that used to identify to fourth state of matter apart from the three well known states [8]. The three states are the state of matter that temperature increases which molecules are enormous energy and break down form solid, liquid, gas into plasma. Stage of plasma is more likely gaseous which its atoms and other free moving charge disassociated and collision between charges is observed. Commonly, plasma is involved electric and very conductivity greater than metal. There are two type of plasma that are thermal plasma and non-thermal plasma. Thermal plasma is normally affected very high power and reaction temperature from 10,000K to 100,000K. NTP offers lower implementation cost for system as it has better species selective characteristic with higher energy conversion efficiency. A novel power supply is used, which enables high voltage and high frequency operation for optimized electrical power input into the plasma. NTP can be operated at room temperature and atmospheric pressure [9].

Among the emerging technologies for post-combustion treatment, non-thermal plasma (NTP) is an advance oxidation method. During the NTP process, many active radicals, such as O, OH and O₃ are generated. These oxidize gaseous pollutants such as volatile organic compound (VOC), NOx and particulate matter (PM) at room temperature and atmosphere pressure [10]. NTP...
holds the advantages high oxidation efficiency, low floor area, no chemical addition, low initial cost, low temperature and at atmospheric pressure, and energy consumption [11].

Non-thermal plasma (NTP) as a useful method for NOx removal has been investigated in many years. It is almost primary pollution and has a good application prospect. This method is used to selectively transfer input electrical energy to the electrons without heating temperature the whole gas flow which generates free radicals through collisions and supports the preferred chemical changes in the exhaust gases. The created active species react with the pollutant molecules and followed by decomposition of pollutants.

This work is focused on the design of prototype of nonthermal plasma reactor for nitrogen oxide reduction in flue gas. The aim of the study is to obtain a high influence of applied voltage and electrode configuration parameters on the optical and electrical performance on the plasma reactor. In addition, the electrode configuration of plasma reactors is also investigated.

2 Experimental Apparatus and Procedure

The prototype NTP reactor was designed and developed in laboratory scale. The experiment schematic diagrams as shown in Fig.1 is composed of NTP reactor, a high voltage power supply, a high voltage probe, a digital oscilloscope, and a flue gas analyser. The simulated flue gas was feed under atmospheric pressure to nonthermal plasma (NTP) reactor which gas flow rate was controlled by a digital gas mass flow controller. Then the supernatant was analysed through flue gas analyser.

![Fig. 1. Schematic diagram of the experimental setup for the non-thermal plasma Non-thermal plasma (NTP).](image)

2.1. Experiment system and Conditions

A commercial grade nitrogen gas and oxygen-based nitrogen with a purity of 99.5 % and nitrogen oxide gas in nitrogen with 500 ppm concentration were use as simulated flue gas from combustion. The total simulated gas flow rate was controlled about 10 L/min via a mass flow controller to keep resident time constant. The simulated flue gas was passed in to NTP reactor. The flue gas was discharged by a high voltage (HV) power supply and plasma was generated at the same time. It flowed out of the reactor and according to the flue gas analyser’s measurement. Then the plasma power source is turned on to generate NTP. The output power of the power source was adjusted by input voltage and input current. And the concentrations of the reactor outlet gas at different powers were monitored. The input voltage of the plasma power source was controlled by the frequency adjustment knob of the plasma power source.

2.2 Non-thermal plasma (NTP) reactor

The non-thermal plasma reactor was designed in length 200 mm and width 100 mm as shown in Fig.2 (a) and (b). It consists of 40, 20, 10, 5 copper sheets of electrodes that was connected to HV electrode. The copper metal plate dimensions are the length (200 mm) and the width (100 mm) and the thickness (1 mm). The downstream region for measurement of the voltage variation and isolate form the ground. The dynamic variation of the metal-plate voltage was measured via oscilloscope and HV probe. The metal-plate voltage was monitored under ionization wave reaching to the metal plate. The high voltage input
of the metal plate was kept constant at the range of 10 kV, which implies the change of the space potential in the plasma jet under z-axis positions and discharge voltage conditions [12]. The effective discharge length is approximately 200 mm. The discharge gap in this study is 20, 40 and 60 mm.

Fig 2. (a) The non-thermal plasma reactor, (b) the non-thermal plasma drawing.

2.3 Electrodes

Electrode is an important part of the conductivity of a reaction. An electrode in an electrochemical cell is referred to as either an anode or a cathode [13-14]. It has both an anode and a cathode side. The copper material has been selected as electrodes due to the properties of copper has the low electrical resistance (1.93 x 10⁻⁸ Ωcm) that has the high current flow [15-16].

2.4 Electric measurements

The important key parameters to evaluate a pollution control system is the energy consumption. It was determined form simultaneous measurements of the discharge current and applied voltage. The DC Voltage applied to the electrode is measured by using an HV probe (Testec TT-HVP15 HF 500MHz 10 kV). The electrical wave form was monitored via a fast digital oscilloscope (Keysight Technologies DSOX1204).

2.5 Electric measurements

All experiments were conducted under ambient temperature and pressure. Space velocity is the ratio between gas flow rate through reactor and effective volume of the reactor as shown in Eq.1

\[ SV = \frac{Q_{gas}}{V_{eff}} \quad (h^{-1}) \quad (1) \]

Where \(Q_{gas} (m^3/h)\) is the exhaust gas volumetric flow rate and \(V_{eff} (m^3)\) is the reactor Volume. Increasing the space velocity results in high gas flow rate pass through the reactor lead to less time for reaction. The experiment conditions with NTP were designed to obtain results which affected by position electrode, reactor discharge gap and reactor high voltage input power as shown in Table 1.

Table 1. Electrode configuration parameters investigated in this work.

| Item Value No. | Number of copper | Discharge gap (mm) |
|----------------|------------------|--------------------|
| 1              | 40               | 20                 |
| 2              | 40               | 40                 |
| 3              | 40               | 60                 |
| 4              | 20               | 20                 |
| 5              | 20               | 40                 |
| 6              | 20               | 60                 |
| 7              | 10               | 20                 |
| 8              | 10               | 40                 |
| 9              | 10               | 60                 |
| 10             | 5                | 20                 |
| 11             | 5                | 40                 |
| 12             | 5                | 60                 |

2.6 Flue gas concentration measurements

Gas analysis model MEXA-584L from Horiba includes measurement of carbon dioxide, carbon monoxide and unburned hydrocarbons (NIDR-non-dispersive infrared), oxygen (magneto pneumatic sensor), and NOₓ (CLD-chemi-luminescence detection). In this work, the flue gas in each operating condition is measured and reported.

3 Result and discussion

The aim of this study to optimize the electrode position, which are the number of copper electrodes and discharge gap between electrode, to finding the best NOₓ reduction efficiency in NTP reactor. The power loss in system is also investigated. The reactor sizing to estimate the length and diameter of the reactor according to the empirical formula.

3.1 The effect of electrode configurations on the power input

This experiment was optimized the effective range of NTP reactor. The NTP power input are dependent on many parameters inclusive of the number of electrode copper sheets (5 sheets to 40 sheets), electrodes gap (40 mm to 5 mm) and fixed discharge gap at 20 mm. All electrode configurations are shown in Fig 3.

The input voltage is generally related to the ionization degree to reaction with feed gas in NTP reactor. In additions, the electrical energy, discharge gap and number of coppers of the plasma reactor are all parameters that affect the number of energetic electrons [12]. The increasing input plasma power may effectively
cooper sheets is increasing power input (high power consumption) under the same reaction zone (200 cm²) as seen in Fig.4. To increasing the resistance with higher cooper sheets. In addition, the higher number of cooper sheets are requiring high level of energy source to generate plasma beam. The applied voltage supply is required to overcome the electrical impedance with high resistant (high amount of cooper sheets). The plasma per reaction area has not work full efficiency, thus optimization of number of sheets for operating conditions was found to be crucial in enhancing plasma beam efficiency and applications. The 20 copper sheets with 10 cm electrode gap were selected in this experiment due to the power output is suitable to for NOx reduction application. The input power for 40 copper sheets with 5 cm electrode gap has slightly higher than 20 copper sheets due to the small electrode heat losses.

### 3.2 The effect of discharge gap on input power

The influence of discharge gap on plasma beam performance has been studied to the optimum energy utilization in normal thermal plasma beam generation. The electrode configurations are following; discharge gap is 20, 40 and 60 mm with fixed cooper 40 sheets.

Fig. 3. Schematic diagram of the amount of copper (a) 40 sheets (electrodes gap 5 mm) (b) 20 sheets (electrodes gap 10 mm) (c) 10 sheets (electrodes gap 20 mm) and (d) 5 sheets (electrodes gap 40 mm)

Fig. 4. Effect of electrode to apply input power

**Fig. 5. Side view of plasma beam layer under different discharge gap (a) discharge gap 20 mm, (b) discharge gap 40 mm and (c) discharge gap 60 mm**

Fig.5 shows the various discharge gap on plasma beam and the input power under atmospheric conditions (without simulated gas feed). The plasma beam density was dependent on the discharge gap due to its different power input and followed the general trend: discharge gap...
20 mm > discharge gap 40 mm > discharge gap 60 mm as shown in Figure 5. The plasma beam in atmospheric condition show phenomena similar with uniform electric field under atmospheric condition as seen in Fig.5. The high electric field density occurring under the voltage lower than break down voltage. In additions, the electric field density was reduced under the increasing discharge gap because the ionization reaction between two electrodes is decreased. During begin, the discharge inception of semiconductor to produce external plasma beam is controlled by the specific conductivity of electrode. Thus, the capacity per electrode area unit, also called effective capacity, are very important for plasma density. Therefore, the voltage drop across the high gas gap leads to high electrical breakdown [18].

![Graph](image_url)

**Fig. 6.** Effect discharge gap of electrode to apply input power

The discharge gap is an important factor affecting electrical power input. The electron field behavior generally moves from a higher potential pole to a lower potential pole. The free electron can be move easily to lower potential pole under small discharge gap thus, the maximum electric field with small power input as shown in Fig.6. The highest power is 167.2 watts at 40 electrodes, discharge gap 60 mm and the minimum power is 19.8 watts at 5 electrodes, discharge gap 20 mm. The results can analyze that number of electrodes and the discharge affect to power consumption. In additions, the power generated is less than the other discharge gap in all cases. The discharge gap can have a significant influence on the number of micro-discharges. Therefore, the discharge gap can generate significant influence on the optical and electrical characteristics of the plasma reactor [19-20].

Furthermore, the number of electrodes and discharge is a very important factor to power consumption. The high number of electrodes will affect to higher power input. The input power is related to the electrode material resistance. Therefore, the high number of electrodes with high electric resistance are required the higher power to overcome electrodes resistant.

3.3 The influence of NOx, NO, NO2 removal activity over NTP reactor

This section presents the prototype of NTP reactor activities on NOx, NO, NO2 removal efficiency. The prototype configuration was selected as following; discharge gap 60 mm, 40 sheet of copper electrode sheets and approximate 168 watt of input-power that is the maximum condition for NTP reactor in this study. The simulated flue gas was feeding rate at 10 L/min. The result found that NTP reactor can be NOx removal of approximately 78% and consist of nitric oxide (NO) removal 99% and nitrogen dioxide (NO2) production 93% as shown in Fig.7.

![Graph](image_url)

**Fig. 7.** NOx, NO, NO2 reduction activities over NTP reactor

Reactor with NTP has increase the electric filed strength and electron density and provides more energy to electrons consequently leads to high NOx removal efficiency, supports high removal efficiency in this reactor [21]. In addition, the plasma reaction can reduce NO as the main component of NOx pollution, which then transforms to NO2 > 99% that are active in a discharge zone.

4 Conclusion

The preliminary study of prototype non-thermal plasma reactor design for NOx reduction presents a solution to the current challenge of air pollution over the combustion. The influencing working parameters such as the applied voltage, discharge length, interval between adjacent outer electrodes and electrode width were all considered to obtain a further and deeper understanding of the discharge characteristics of the multi-electrode plasma reactor. The efficient length and fringe effect were found to be the two significant reasons for the change of the optical and electrical performance. In additions, the prototype of NTP reactor could significantly enhanced 78% of NOx reduction activity. This benefit could be utilized with the nonthermal plasma technology to purpose continuous NOx reduction. Moreover, contribute to an improved post
treatment (e.g., SCR, Lean-NOx trap) aiming to achieve future emissions regulations that include control of NOx.

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