A wet atmospheric pressure plasma scrubber

S. Seethamsetty\textsuperscript{1}, S. K. Dhalli\textsuperscript{1}, Bakul Dave\textsuperscript{1}, and R. Carty\textsuperscript{2}

\textsuperscript{1}Southern Illinois University, Carbondale, Illinois 62901
\textsuperscript{2}Illinois Clean Coal Institute, Carterville, Illinois

Abstract

A regular barrier discharge is modified by flowing water through the reactor. The flowing water changes the electrical characteristics of the discharge. The results of removal of SO\textsubscript{2} with such a discharge are discussed.

I. Introduction

The use of non-thermal plasma for pollution control is an active research area. To name only a few, non-thermal plasmas have been used for flue gas treatment \cite{1}, \cite{2}, volatile organic compound (VOC) removal \cite{3}, and car exhaust pollution control \cite{4}, \cite{5}.

At atmospheric pressures, there are two popular methods of generating plasmas: (1) Corona in DC or pulsed form, and (2) Barrier discharge with AC sources. Corona discharges are due to inhomogenous electrode geometries such as a point electrode and a plane. Although corona discharges have found numerous applications \cite{6}, \cite{7}, they are limited due to the low active volume available for processing the gas.

The barrier discharge, also known as a silent discharge or a partial discharge, is widely used in commercial voltage periods when the discharge is "on".

We have modified the dielectric barrier discharge to create a discharge in a gas, liquid and solid medium. The electric discharge takes place in the gas bubbles formed in this mixture. Having water in the discharge has several advantages: (1) It improves the removal efficiency and (2) It prevents the fouling of the dielectric surface due to contaminants. Atmospheric pressure plasma is generated in medium containing dielectric beads, water and gas. The

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{Fig_1}
\caption{A modular section of plasma-assisted wet scrubber.}
\end{figure}

3129
discharge behaves like a partial discharge in voids. It is excited with a 2-5 kHz high voltage source. In this paper, we present some basic characteristics of the wet plasma scrubber followed by removal of SO₂.

2. Plasma Reactor

The schematic of the wet-plasma reactor is shown on Fig. 1. The configuration is a cross flow reactor with the water coming down and the gas moving up. It consists of a glass dielectric (1.6 cm) with the inside filled with glass pellets. The size of the glass pellets can be varied (4-5 mm). The inner electrode is a 6mm stainless steel rod and the outer electrode is a conducting film on the outer surface of the dielectric. The plasma is created in the gas, liquid and solid mixture between the beads. This produces a heterogeneous medium and enhances the removal rate considerably.

3. Results

Shown in Figure 2 is a simplified picture of the reactor in presence of water. The glass beads are lumped as uniform glass dielectric, the water drops are lumped as a layer of water dielectric, and the air gaps between the beads and water drops are lumped as the gas gap. The addition of water increases the dielectric constant, which increases the overall capacitance of the reactor. The oscilloscope trace of the discharge voltage and current for the wet plasma reactor is shown in Fig. 2. The current shown is primarily due to the capacitance of the reactor. When no water is passed through the system, the capacitive current is slightly lower.

![Figure 2: Simplified schematic of the gap when water is added.](image)

![Figure 3: Discharge voltage and current with a 140 ml/min flow of water at 2 KHz.](image)
The amount of power deposited to the discharge changes significantly with the addition of water. The discharge power, $P$, in a dielectric-barrier type discharge is given by [10]

$$P = 4 f V_e [ c_g V_p - (c_g + c_d) V_e ] = 4 f V_e c_d [ V_p - \frac{(c_g + c_d)}{c_d} V_e ]$$  \hspace{1cm} (1)

Where $f$ is the power frequency, $c_g$ and $c_d$ are the gap and dielectric capacitance respectively, $V_p$, $V_e$, and $V_e'$ are the peak to peak applied voltage, the critical gap voltage required to sustain a discharge, and the critical voltage at which the gap breaks down, respectively. The voltages $V_e$ and $V_e'$ are nearly equal, however we have observed that $V_e'$ tends to be lower than $V_e$ [10]. When water is added to the discharge, $c_g$ and $c_d$ change significantly: As shown in Figure 2, the dielectric capacitance which consists of the glass and water in series, decreases due to addition of water. However the addition of water reduces the gas gap volume and thus increases the gas gap capacitance, $c_g$. Shown in Fig. 4 is the discharge power as a function of the applied voltage. Clearly, the power input to the discharge reduces with water flow. Water flow causes a decrease in $c_d$ and an increase in the term $(1 + c_g/c_d)$ causing power to decrease according to equation 1.

The removal efficiency of SO$_2$ was studied under various conditions. It was found to work better compared to dry plasma techniques [11]. The power requirements were less by a factor of 5 compared to dry reactors [11]. The addition of water in the reactor causes enhanced production of OH radicals, which improves the removal efficiency. In addition, the water removes H$_2$SO$_4$ from the discharge and prevents regeneration of SO$_2$. A typical removal study on water flow is shown in Fig. 5.

There two sets of plots for a starting concentration of 3000 ppm of SO$_2$: (1) Concentration of SO$_2$ in the exhaust as a function of discharge energy and (2) removal of SO$_2$ per kWh of energy. Removal studies were done for no water flow and with different water flows through the reactor. There is an initial removal of SO$_2$ when water is passed through the discharge without the plasma. This depends on the water flow and can be significant. When the discharge is turned on, there is further removal due to the plasma. With increasing flow of water, the fall in the concentration is steeper with respect to power. The flow of water has several important functions in the discharge: (1) SO$_3$ formed is quickly dissolved and removed before the plasma can dissociate it back to SO$_2$. (2) The discharge operates much cooler than dry reactors. Lower temperatures favor most removal reactions. (3) In dry reactors, aerosols on the dielectric foul the reactor, which causes intense microdischarges with
reduced efficiency for radical production. Clearly, the process under investigation with water flow in the plasma is superior to the dry systems being currently investigated by other investigators.

The heterogeneous conditions have been used to demonstrate effective removal of pollutant from gases. One of the most effective active species for the stimulations of a wide range of oxidation reactions is negative ion in the liquid phase [12]. Exothermic ion-molecule reactions require no activation energy; therefore negative ions can be effective chain carrier even in conditions when there are no radical chain reactions.

4. Conclusions

Due to the relative changes in gas and dielectric capacitance, it was found that the power coupled to the discharge decreases due to water flow. In addition, with water flow in the reactor, the removal efficiency is enhanced and the reactor fouling was non-existent.

5. Acknowledgements

This research was supported by grants from Illinois Clean Coal Institute and The National Science Foundation.

6. References


