Atmospheric pressure plasmas and their application for Nitrogen fixation

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Abstract: The influence of plasma characteristics on nitrogen fixation (NF) efficiency of a magnetic field stabilized atmospheric-pressure plasma is investigated. The gas temperature and electric field of the plasma can be independently adjusted. Such characteristics make it suitable for investigations of the effect of plasma characteristics on NF.

1. Introduction

Nitrogen (N) is an essential building block for life, forming crucial components of amino acids, proteins, and nucleic acids. However, plants and animals are unable to take nitrogen directly from the air due to the strong triple bonds of nitrogen molecules (N_2).The Haber–Bosch (H–B) nitrogen fixation (NF) process, developed over the past century, accounts for 40% of the world's population but consumes 1%–2% of global energy consumption, 3%–5% of the worldwide natural gas output.

Plasma NF process, which can quickly adapt to the intermittent characteristics of renewable electricity, allowing for small scale, decentralized production to reduce carbon emissions during transportation, attracts lots of attentions recently.

2. Methods

Figure 1 shows the schematic of the plasma device for NF, which consists of two 3 mm thick brass diverging blade electrodes, this is similar to gliding arc discharge. The minimum gap between the two electrodes is 1 mm, and the angle of two electrodes is 40°. A high-voltage DC power supply is connected to one of the electrodes through a 100kΩ ballast resistor, and the other electrode is grounded. Two 2 mm thick quartz glass plates are closely attached to both sides of electrodes to ensure that the gas can only flow through the space between the two electrodes. The air flow, controlled by a mass flow controller, is injected into the gap between the two electrodes. In addition, a permanent magnet is placed beside one of the quartz plate severing as a source of magnetic field B. The direction of the magnetic field is perpendicular to the electrode plane (along Z-axis).

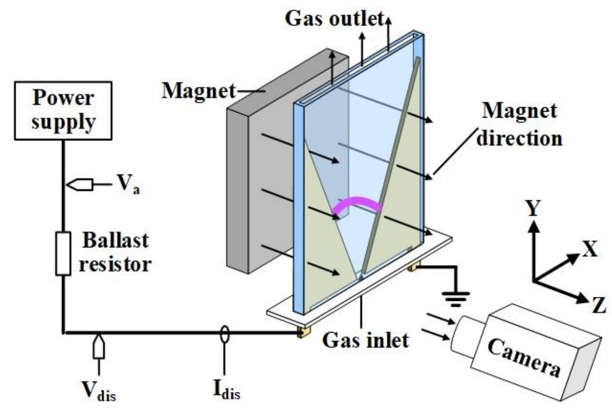

Fig. 1. Schematic of the experiment setup

3. Results and Discussion

With the increase of the discharge current, the average electric field varies significantly but the gas temperature remains at about 2250 K. The electric field is about 0.75 kV/cm for current of 55 mA, it decreases to only 0.55 kV/cm when the current increases to 100mA. With the increase of the current from 55 mA to 100 mA, the concentration of NOx decreases from 19500 ppm to 15600 ppm, while the energy cost increases from 2.76 MJ/mol to 3.44 MJ/mol.

Increasing the flow rate from 3 L/min to 6 L/min caused the gas temperature to decrease from 2637 K to 1474K, while the electric field remained relatively constant at around 0.67 kV/cm. Although the introduction of more air dilutes the product and reduces the NO_x concentration, the total amount of NO_x produced by the plasma increases. As a result, the energy cost decreased from 3.07 to 2.62 MJ/mol with the increased flow rate.

4. Conclusion

With the increase of the discharge current, the average electric field of plasma channel decreases from 0.75 kV/cm to 0.55 kV/cm, which is beneficial for the production of NOx and the energy cost is reduced by about 20 %. The decrease of gas temperature is beneficial for obtaining a lower nitrogen fixation energy cost, which is reduced by about 15 % when the air flow rate increases . In addition, the best NF effect is achieved when the discharge current is 55 mA, the gas flow rate is 6 L/min, and the O_2 fraction is 40%. The lowest energy cost is 2.29 MJ/mol and the corresponding NOx concentration is about 15925 ppm.

Future studies could explore methods for further reducing gas temperature or rapidly cooling the plasma after leaving it by applying extra cooling methods.

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