

Nitric Oxide Generator Based on Pulsed Arc Discharge

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Nitric oxide (NO) is increasingly being used in medical applications. Currently, a gas cylinder of N₂ mixed with a high concentration of NO is used in the NO inhalation system. However, this arrangement is potentially risky due to the possibility of accidental leak of NO from the cylinder. The presence of NO in air leads to the formation of nitric dioxide (NO₂), which is toxic to the lungs. Therefore, an on-site generation of NO would be very desirable for patients with acute respiratory distress syndrome and other related illnesses. Previously, our group reported the production of NO using a pulsed arc discharge. In this work, the prototype of the on-site NO generator was developed and the performances of the NO generator were demonstrated for medical applications.

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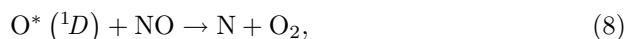
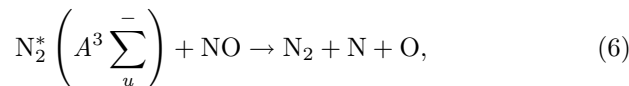
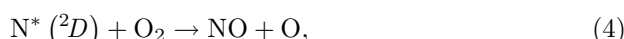
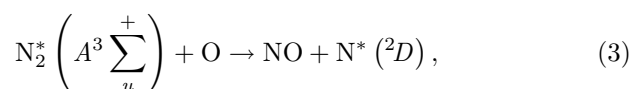
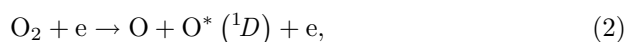
1. Introduction

It is well known that nitrogen oxide (NO_x) is produced by nitrogen fixation of bacteria, combustion of fossil fuel, natural lightning stroke and so on. Bacteria produces nitric dioxide (NO₂), and the others generate nitric oxide (NO). In the atmosphere, NO is immediately oxidized to NO₂ by oxygen (O₂) or ozone (O₃). Because NO_x is toxic for human being, many researchers have studied about its removal [1–3]. On the other hand, NO is well known as one of the most important molecules within the living human body in the medical field. It is well known that NO is related to the memory, the attack of pathogens and the vessel relaxation. Especially, the blood vessel relaxation effect found by Ignarro et al. in 1987 [4] has had a lot of attention from the medical doctors. In the literature [4], NO was introduced as endothelium-derived relaxing factor (EDRF) within the living body. From the discovery, many medical doctors and researchers started the investigation of applications of NO into a medical treatment. As a result, NO inhalation therapy has been developed and used for some lung diseases such as acute respiratory distress syndrome (ARDS) or persistent pulmonary hypertension of the newborn (PPHN), in these days. Currently a system of NO inhalation has a gas cylinder of nitrogen (N₂) mixed with a high concentration of NO. NO from the gas cylinder is introduced to patients after attenuation by air or O₂. However, this system is potentially risky due to the possibility of accidental leak of NO from the cylinder. In addition, gas cylinder is too heavy to carry and is very expensive to

use for long time. Therefore, an on-site production of NO with low cost would be highly desirable for patients and medical doctors. We have reported the production of NO based on a pulsed arc discharge [5–7]. In the present work, NO generator based on a pulsed arc discharge was developed and it was evaluated as the medical device.

2. NO generation by pulsed arc discharge

Air mainly consists of N₂ and O₂ and these molecules could be an origin of NO. NO is produced and decomposed in a mixture of N₂ and O₂ via following equations [8]:



Under high temperature plasma, the reaction starts with a decomposition of O₂ to O atoms and NO is mainly generated through a collision of N₂^{*}(A³∑_u⁺) and O atoms, Eq. (3). NO₂ is also produced by a reaction of NO and O₃, Eq. (9), or O₂.

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3. Performance of developed NO generator

The developed NO generator consists of the point to plane type electrode as a discharge chamber, the capacitor (190 pF) discharge circuit with the control board, an air pump and a particle filter. The air pump introduced the ambient air at 300 mL to the discharge chamber and the particle filter trapped the metal particle from the arc discharge. In this time, the distance of the point to plane electrodes and the charging voltage of the energy stored capacitor are fixed at 5 mm and 10 kV, respectively. (Fig. 1 shows waveforms of the applied voltage to and the discharge current in the electrode.)

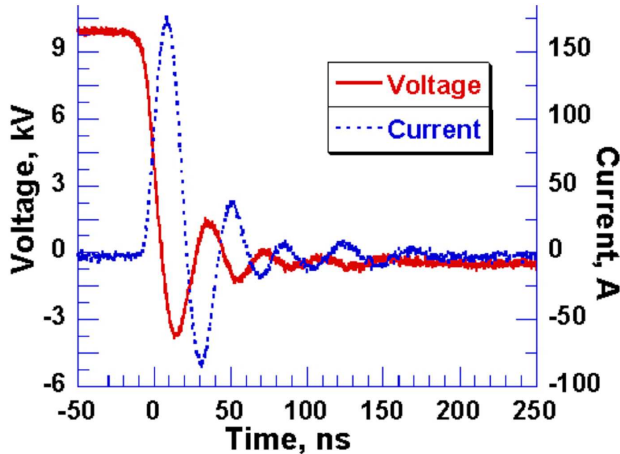


Fig. 1. Typical waveforms of applied voltage to and discharge current through discharge chamber.

As one of the performances of the developed NO generator, the concentration of NO increased linearly with the pulse repetition rate. This is because the input energy to the discharge plasma increased with the repetition rate. The demand of NO concentration in medical applications is over 1000 ppm at flow rate of 300 mL. The pulsed repetition rate of 280 pps is suitable for the NO generator. Of course, the NO concentration is controllable by the adjustment of the pulse repetition rate.

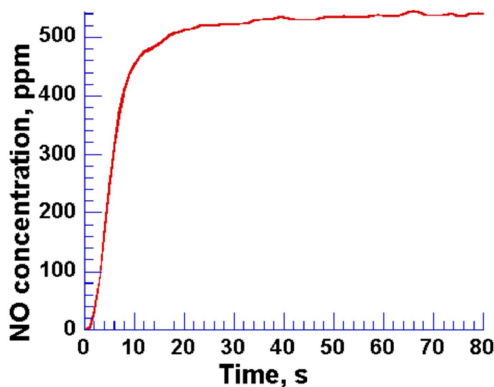


Fig. 2. Approach time to required NO concentration.

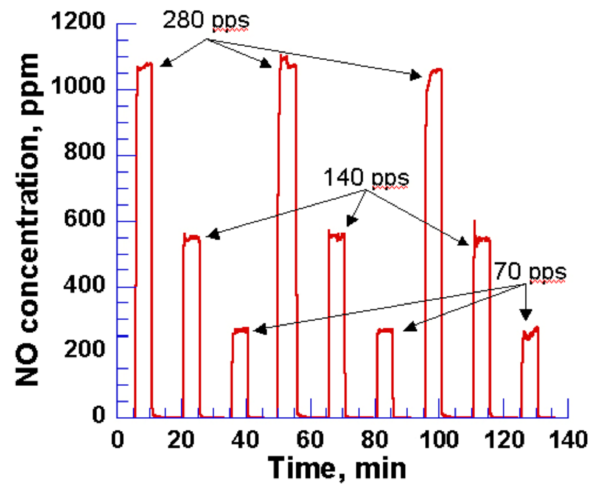


Fig. 3. NO concentration reproducibility of developed generator.

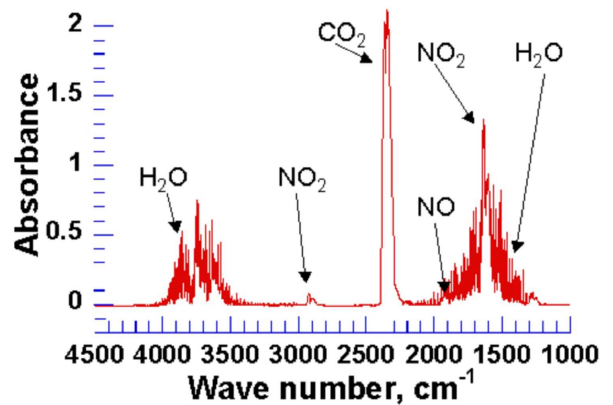


Fig. 4. FT-IR spectrum of output gas from developed generator.

The NO inhalation therapy is sometimes needed for emergency case. The warm-up time of a medical device should be short. Figure 2 shows the warm-up time of the developed NO generator. From Fig. 2, the time to achieve the required concentration of NO is less than 30 s. It should be sufficient for medical applications.

The reproducibility of and the lifetime of medical device are also important factors. Figure 3 indicates the result of the confirmation test of the generator's reproducibility. In the test, three concentrations were required for three times. From the results, the reproducibility of NO concentration was less than 2.0% for 1061 ppm. As the result of the lifetime test, the 75 h operation with no maintenance was demonstrated. After 75 hours, the discharge became gradually unstable and NO concentration decreased with operation time. However, the discharge and the NO concentration could be stable by re-setting of the discharge parameters. This means that the NO generator needs the feed-back control from NO concentration to the discharge parameters for long time operation.

The Fourier transform infrared (FT-IR) spectrum of the output gas from NO generator is shown in Fig. 4. It can be observed from Fig. 4 that the output gas included only NO, NO₂, CO₂ and H₂O. NO and NO₂ are from the reactions in the discharge plasma discussed in Sect. 2. Meanwhile, CO₂ and H₂O might come from the ambient air. It is also well known that ozone is produced by the discharge. However, the NO generator has no ozone. This might be because all ozone generated by the discharge reacted with NO immediately after the generation. As a result, it must be considered that the developed NO generator needs the device or the function for NO₂ removal from the output gas.

4. Conclusions

In this paper, the detailed performances of a prototype device of NO generator based on pulsed arc discharge has been demonstrated. The followings are summary of the performances of the developed NO generator:

- The discharge treated gas includes NO, NO₂, CO₂ and H₂O.
- The concentration of NO is controlled by the pulse repetition rate.
- The warm-up time of the generator is less than 30 s.
- The reproducibility of NO concentration is less than 2.0% at 1061 ppm.
- The lifetime of the generator is 75 h under no maintenance condition.
- The generator needs the removal unit of NO₂.

Acknowledgments

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