A study on negative oxygen ions shunting based on direct current pulsating co-frequency coupled electric fields method

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Abstract. This paper aims to explore the feasibility and stability of negative oxygen ions (NOI) shunting based on direct current (DC) pulsating co-frequency coupled electric field method, and the safeness under a high anion concentration. Negative oxygen ions were obtained under corona electric discharge from high negative voltage, a shunting method which was employed to detach the negative ions and neutral gas was executed with an uncoupled and a coupled electric field. In coupled field, the negative ions were exported with the same electric field derived from the ion emission polar as a guiding polar, while neutral gas was exported from another outlet; In uncoupled electric field, the purity of NOI from guiding polar powered separately is employed as a control group. Safeness test was approached with 2 rats under a normal cage system. The purity(separate) ratio of NOI between the guide outlet and the neutral gas outlet is 8.5, while the separate ratio is 163636.4 in the coupled electric field respectively. The purity of NOI is 18 million per cm³ in coupled electric field and 9.8 million per cm³ in uncoupled electric field. The purity of NOI is 180 million/cm³ under a voltage of -26 kV. The purity and separate ratio of NOI could be improved significantly after using the coupled electric field compared to uncoupled electric field.

1. Introduction
It has been proved that negative oxygen ions (NOI) are effective for chronic pulmonary diseases [1, 2], cervical spondylopathy and some skin diseases. The mechanism is to neutralize the oxygen free radicals from metabolism, activate the natural killer (NK) cells [3] and repair the damaged basement membrane, thus the ions play a key role in repairing pathological tissues and organs, so as to achieve the treatment of some chronic or acute inflammatory diseases. In addition, the NOI could regulate the angiotensin (5-HT) which could induce the abnormal (higher) diastolic pressure [4].

The NOI could be produced by ionizing humid air with lightning in nature [5, 6], and is negative correlated with wind speed [7], so, the ions have obvious season character, regional feature and low purity (<50000/cm³) [8]. Honglin Yang and Jianyuan Feng found that the NOI could be obtained through cotton and polyurethane, but the intensity of the ions is only about 2050/cm³, furthermore, the purity would be lower after being washed [9, 10]. And Hanlin Gui reported that the ions could be obtain by some radioactive gas such as radon through radioactive ray, which could not be approached for human [11].

Compared to other gas (N₂, etc.) in air, the oxygen (O₂) is easier to be ionized, meanwhile, H₂O is easier to be detached as H₂ and O₂ in an ionized environment and O₂ could be ionized again. The ionized environment is usually formed under a high negative charge as -20 kV, and the purity of NOI...
could be up to $10^{13}$-$10^{15}/m^3$ ($10^7$-$10^9/cm^3$) by the avalanche effect of ions [12]. As a result, NOI could not be used effectively for health care considering there are lot of other neutral gas, it is necessary to extract the NOI from the ionized air or make the NOI shunt to a special path. In view of this, this paper aims to explore the feasibility and stability of NOI diversion based on direct current (DC) pulsating co-frequency coupled electric fields, and the purity of NOI in an uncoupled field would be measured as a control group.

2. Work flow

2.1. Design of the NOI shunting system
Uncoupled and coupled electric fields were employed to explore the diversion effect of NOI, based on the co-frequency of the negative voltage gain amplifier. Two negative voltage gain amplifiers were employed for ionization and guiding of NOI (Figure 1), while only one amplifier was used both for ionization and guiding (Figure 2).

2.2. Safeness test
Two rats were put into the high NOI (NOI purity>20 million per cm3) environment, the living state such as electric shock, sleeping, breath would be observed and recorded. Safeness would be evaluated according the times of electric shock, sleeping time and breath difficulties.

3. Materials and methods
This research was started from a set of instruments (Section 2.1) which were used to produce pure negative oxygen ions and designed and tested in Section 2.2. Details were demonstrated as following.

3.1. Materials
Negative voltage gain amplifier (Input voltage: AC 220V, 50Hz; export: DC -20 kV, 5w, Shanghai Yitao Electronic Commercial Co. Ltd, China);
   Metal net: aluminium net;
   Negative air ions detector (AES-60, Shenzhen Elsen Environment Co., Ltd, China).
Figure 3 depicts the design of NOI generating and separating device.
Figure 3. Diagram of NOI generating and separating device: (a) schematic diagram of the device for NOI generating and shunting in uncoupled electric field; (b) schematic diagram of the device for NOI generating and shunting in coupled electric field (1- insulating case; 2- exhaust fan; 3- arc metal mesh; 4- negative ion emitter; 5- 1st outlet; 6a, 6b- 2nd outlet; 7- wire; 8- negative voltage gain amplifier; 9a, 9b- negative guide polar).

Figure 4. The process and devices of NOI emission and shunting: (a) the schematic diagram of uncoupled electric field; (b) the device of emission and shunting of NOI in uncoupled electric field; (c) the schematic diagram of coupled electric field; (d) the device of emission and shunting of NOI in uncoupled electric field.
3.2. Methods

3.2.1. Designation of the devices. The velocity of air import should not only be matched with ionization speed but also has a minimized effect of the migration of anion. In this study, the velocity is less than 20cm\(^3/s\) which could supply air enough and has a least effect to the movements of the ions. The ions guiding is relay on another negative voltage gain amplifier which has a different pulse from the emission polar, while in coupled electric field, the guiding polar is coupled with the amplifier which has a same pulse as emission polar. Figure 4 shows the process and devices of NOI emission and shunting.

Input voltage: 220V, corona electric discharge: -20 kV, frequency:2000 Hz. After the air is ionized by corona electric discharge, the oxygen molecules are decomposed into NOI. The arc-shaped aluminium mesh receives the negative electric field with the same pulse coupling as the emission polar. The electric field potential is introduced into the 2\(^{nd}\) outlet through a conductive wire. The electric field is converted into the voltage by carbon brush and forms the same frequency coupling electric field with the aluminium mesh at the 2\(^{nd}\) outlet. The double coupling electric field with the same frequency in the emission polar, the aluminium mesh and the 2\(^{nd}\) outlet electrodes (Figure 1) are formed. Electronegativity of electric field leads NOI to 2\(^{nd}\) outlet and flows out at high speed. Non-ionized neutral gases such as nitrogen and carbon dioxide are discharged through 1\(^{st}\) outlet, thus achieving the goal of NOI shunting.

In this study, the amplifier with -26 kV was used to obtain more NOI and the purity of the ions would be measured in a chamber with the guiding polar on the top.

3.2.2. Measuring the purity of NOI. Negative oxygen ion purity (cm\(^-3\)) was measured at 10 cm, 20 cm, 30 cm, 40 cm and 50 cm away from neutral gas outlet (1\(^{st}\) outlet) and NOI outlet (2\(^{nd}\) outlet) in windless natural environment, respectively, and recorded when fluctuation of the number was less than 10% in 3 seconds.

3.2.3. Measuring the migration velocity of NOI. Migration velocity is an important index for the diameter of negative ions, and is mainly affected by voltage, if the diameter is less than 10nm, the velocity is more than 0.4cm\(^2/Vs\). In this paper, the detector was put at 2m away from the guiding polar (2\(^{nd}\) outlet) after the emission polar was shut down, when the negative oxygen ion generator is turned on, the spending time for the negative oxygen ion purity to rise is recorded.

4. Results

4.1. The efficiency of NOI shunting in -20 kV uncoupled field

Table 1 depicts the purity of NOI at 10cm, 20cm, 30cm, 40cm and 50cm away from outlet1 and 2\(^{nd}\) outlet as well as the ratio between the two outlets. (temperature: 26\(^{\circ}\)C, humidity:65%, one standard atmospheric pressure).

| Distance(cm) | 1\(^{st}\) outlet purity(10\(^4\)/cm\(^3\)) | 2\(^{nd}\) outlets purity(10\(^4\)/cm\(^3\)) | Ratio (2\(^{nd}\) / 1\(^{st}\)) |
|--------------|------------------------------------------|------------------------------------------|-------------------------------|
| 10           | 110                                      | 935                                      | 8.5                           |
| 20           | 75                                       | 380                                      | 5.07                          |
| 30           | 45                                       | 220                                      | 4.89                          |
| 40           | 30                                       | 120                                      | 4                             |
| 50           | 22                                       | 75                                       | 3.41                          |

*1\(^{st}\) outlet is the exit of N\(_2\), CO\(_2\) and other neutral gas while 2\(^{nd}\) outlets are the exit of O.
As Table 1 shows, the purity of NOI which is separated in uncoupled electric field is 9.35 millions/cm$^3$ at 2$^{nd}$ outlet, 1.1 millions/cm$^3$ at 1$^{st}$ outlet respectively. The ratio of the NOI purity between 2$^{nd}$ and 1$^{st}$ is 8.5 at 10 cm away from the outlets.

According Table 1, a cubic equation was used to fit the measured values: 'x(cm)' is the distance and 'y$_i$' is the purity, based on parameters from [13], Equation (1) is the fitting result.

$$y_i = -283.3x^3 + 33210x^2 - 1330000x + 19560000$$

Where $y_i$ represents the purity (/cm$^3$) of NOI in 2nd outlet under -20 kV uncoupled electric field, $x$ is the distance from the 2nd outlet (cm), while the R-square is 0.9968, adjust R-square is 0.9873, Root Mean Square Error(RMSE) is 3.944e+05.

### 4.2. The efficiency of NOI shunting in -20 kV coupled field

Table 2 depicts the purity of NOI at 10cm, 20cm, 30cm, 40cm and 50cm away from 1$^{st}$ outlet and 2$^{nd}$ outlet as well as the ratio between the two outlets. (temperature: 26°C, humidity:65%, one standard atmospheric pressure).

| Distance(cm) | 1$^{st}$ outlet purity(/cm$^3$) | 2$^{nd}$ outlets purity($10^4$/cm$^3$) | Ratio (2$^{nd}$/1$^{st}$) |
|--------------|---------------------------------|-------------------------------------|--------------------------|
| 10           | 110                             | 1800                                | 163636.4                 |
| 20           | 150                             | 1200                                | 80000                    |
| 30           | 160                             | 650                                 | 40625                    |
| 40           | 200                             | 400                                 | 20000                    |
| 50           | 1000                            | 300                                 | 3000                     |

*1$^{st}$ outlet is the exit of N$_2$, CO$_2$ and other neutral gas while 2$^{nd}$ outlets are the exit of O.

![Figure 5](chart.png)

**Figure 5.** The splines of equations (Equation (1) and Equation (2)) in -20 kV uncoupled and coupled electric fields: the filled dots represent the purity values in coupled electric field and the dashed spline is the simulation of Equation (2), while the empty dots represent the values in uncoupled field and the solid spline is the simulation of Equation (1).
As Table 2 shows, the purity of NOI which is separated in coupled electric field is 18 millions/cm$^3$ at 2$^{nd}$ outlet, 110/cm$^3$ at 1$^{st}$ outlet respectively. The ratio of the NOI purity between 2$^{nd}$ and 1$^{st}$ is 163636.4 at 10 cm away from the outlets.

According Table 2, a cubic equation was used to fit the measured values: ‘$x$(cm)’ is the distance and ‘$y_2$’ is the purity, based on parameters from [13], Equation (2) is the fitting result.

$$y_2 = 83.8x^3 + 1786x^2 - 740500x + 25200000$$ (2)

Where $y_2$ represents the purity (/cm$^3$) of NOI in 2$^{nd}$ outlet under -20 kV coupled electric field, $x$ is the distance from the 2$^{nd}$ outlet (cm), while the R-square is 0.9985, adjust R-square is 0.9942, RMSE is 4.781e+05.

To compare the shunting efficiency of NOI, the splines to fit the measured number were plot in one figure, Figure 5 depicts the two splines of equation $s$ on NOI densities in uncoupled and coupled electric fields.

According Figure 5, the purity values of NOI from coupled field are higher than those from uncoupled field, the purity values approached gradually with the increase of distance. Furthermore, the purity ratio of NOI at 10 cm from 2$^{nd}$ outlet is 163636.4 in coupled field, while the ratio is only 8.5 in uncoupled field respectively.

4.3. The efficiency of NOI shunting in -26 kV coupled field

In this study, the amplifier with -26 kV was used to obtain more NOI and the purity of the ions would be measured in a chamber with the guiding polar on the top.

Table 3 depicts the purity of NOI at 10cm, 20cm, 30cm, 40cm and 50cm away from 1$^{st}$ outlet and 2$^{nd}$ outlet as well as the ratio between the two outlets. (temperature: 26°C, humidity:65%, one standard atmospheric pressure).

**Table 3.** The purity of NOI from 1$^{st}$ outlet and 2$^{nd}$ outlet in -26 kV coupled electric field.

| Distance(cm) | purity/cm$^3$ | First outlet | Second outlets (10$^9$/cm$^3$) | Ratio (2$^{nd}$/1$^{st}$) |
|-------------|----------------|--------------|-------------------------------|-------------------------|
| 10          | 110            | 18000        | 1636363.6                     |
| 20          | 150            | 4850         | 323333.3                      |
| 30          | 160            | 2700         | 168750                        |
| 40          | 200            | 1100         | 55000                         |
| 50          | 1000           | 560          | 5600                          |

*The 1$^{st}$ outlet is the exit of N$^2$, CO$^2$ and other neutral gas while the 2$^{nd}$ outlet is the exit of O.

As Table 3 shows, the purity of NOI which is separated in coupled electric field is 180 millions/cm$^3$ at 2$^{nd}$ outlet, 110/cm$^3$ at 1$^{st}$ outlet respectively. The ratio of the NOI purity between 2$^{nd}$ and 1$^{st}$ is 163636.4 at 10 cm away from the outlets.

According Table 3, a cubic equation was used to fit the measured values: ‘$x$(cm)’ is the distance and ‘$y_3$’ is the purity, based on parameters from [13], Equation (3) is the fitting result.

$$y_3 = -8283x^3 + 929600x^2 - 34460000x + 438300000$$ (3)

Where $y_3$ represents the purity (/cm$^3$) of NOI in 2$^{nd}$ outlet under -20 kV coupled electric field, $x$ is the distance from the 2$^{nd}$ outlet (cm). Figure 6 shows the relationship between the purity of NOI and the distance from the guiding outlet, while the R-square is 0.9918, adjust R-square is 0.967, RMSE is 1.31e+07.
Figure 6. The spline of Equation (3) in -26 kV coupled field: the empty dots represent the purity values measured from 2\textsuperscript{nd} outlet (temperature: 26°C, humidity:65%, one standard atmospheric pressure).

According to the spline, the highest purity (0 cm from the 2\textsuperscript{nd} outlet) of NOI in -26 kV coupled field could be $4.5 \times 10^8$/cm\(^3\) theoretically.

4.4. Migration velocity of NOI

Migration velocity of NOI is calculated with Equation (4).

$$Q = \frac{D^2}{|V|s}$$  \hspace{1cm} (4)

Where the Q represents the migration velocity, D represents the distance (cm) between the detector and 2\textsuperscript{nd} outlet, V is the emission voltage (-20 kV), and s (seconds) is the starting time of the ion purity rise in the detector after the emission was began. In this study, the starting time is 1 s with 2 m distance, the migration velocity is $2\text{cm}^2$/Vs, according the standard mentioned in [14] (>0.4$\text{cm}^2$/Vs), most of the NOI which were produced in this study are smaller diameter ions.

4.5. Safeness evaluation

4.5.1. Design of the rat cage with high concentration of NOI. The shunting system was fixed in a thin box which would be fixed on the top of a normal rat cage, Figure 7 and Figure 8 show the designation of the system and box.

Figure 7. The design of high concentration anion rat cage system: A is an oxygen supplier, B is a high concentration anion generator, C is a rat cage and D is a conduct tube connected between the oxygen separator and the high concentration anion generator; the size of rat cage is 60×40×20 cm.
The concentration of NOI was detected under the guide pole as Figure 8 shows.

![Image](a)

![Image](b)

**Figure 8.** The anion concentrations which were detected under a fast measuring model at the breathing height of rats: the value is 12.2 million per cm³, while the concentration value near the cage is 756 per cm³ with the cage closed.

4.5.2. Living state of rats. Times of electric shock, which would occur during the process of drinking water, sleeping time were observed and recorded to evaluate the living state of rats. Figure 9 shows the living state and Table 4 shows the times of electric shock, sleeping time.

![Image](Figure 9. The rat was drinking water: red arrow shows the aluminum board under the cage.)
Two rats were put into the cage under a continuous NOI supply for 868 h, water and feeding were executed as ordinary condition.

Table 4. The times of electric shock, sleeping time of the rats.

|        | Electric shock(times) | Sleeping time(h) |
|--------|-----------------------|------------------|
| Rat1   | 0                     | 289              |
| Rat2   | 0                     | 291              |

As Table 4 shows, there was no electric shocks occurred in 868 hours after the rats were put into the cage, and the sleeping time is normal.

No breath difficulty had been observed during the test.

5. Discussion

The efficiency of NOI on human body is manly depends on its particle size and purity, world health organization (WHO) stipulates that the minimum concentration of NOI in fresh air should reach 250/cm³ [7], it could be better if the concentration arrives 2000 [6]. The purity of NOI could be more than 2000/cm³, but [9] does not indicate the distance, according to Table 1 in this paper, the purity of NOI could decrease sharply in practical applications if the distance is over 20 cm, which is a safe and applicable position for breath. As Table 2 shows, the purity of NOI has been improved to 12 million/cm³ at 20 cm and 3 million/cm³ at 50 cm in a coupled electric field, the ratio of shunting is 163636.4. Under the condition of low energy consumption (< 5w), the manufacturing purity and purity of NOI have been significantly promoted, which could open up a new direction for the application of NOI in medicine. In this section, the safety and the diversion effect of the coupled electric field for shunting NOI would be discussed.

5.1. Polyfit method for the relationship between the distance and the anion concentration

Polyfit is an effective way for concentration evaluation of the anion, the common method is linear and nonlinear. Considering the anion spread velocity in air, a three-power equation was employed in this paper. There may a better equation to simulate the relationship, but the results of three power equation fitted the measured value exactly as Tables 1~3 and Figures 5~7 show.

5.2. Safety of coupled electric field

The voltage to form the coupled electric field should be considered to produce a negative corona electric discharge zone maximally within the safe range-the distance from the air in the corona zone without breaking down. In general, air is an insulator, but when the electric field exceeds a certain intensity, the travelling speed of ions increases, and the electron avalanche effect occurs with the original ions in the air, which would lead to electrical breakdown of air [15]. As reported in the researches, the breakdown voltage has a linear relationship with the gap distance if the gap is less than 3 m. For rod-plate electrodes, the average breakdown voltage is 4.5 kV/cm for positive rods, and about 10 kV/cm for rods with negative polarity. In this paper, the coupled metal web is 4 cm away from the emission polar, and the negative voltage is -26 kV, which meets the safety standards.

In addition, the guiding voltage formed by the coupled electric field is significantly less than that directly connected with the power supply, and the safety around the guide port is also higher.

5.3. Effect of NOI shunting in coupled field

According Table 1, the shunting ratio of NOI at 10 cm of 2nd outlet and 1st outlet in uncoupled electric field is 8.5, while Table 2 shows that he shunting ratio of NOI is 163636.4 in coupled field, respectively. The diversion effect in the coupled field is obviously higher than that in the uncoupled field. As to the purity of NOI, the purity from 2nd outlet is 9.35 million /cm³ in uncoupled field, but the purity reaches 18 million/cm³ in the coupled field. The results show that in the same negative voltage, the number of NOI shunted in the coupled electric field is significantly higher than that shunted in the uncoupled electric field. The reason is that the coupled electric field synchronously resonates the
electric field A at the place where the negative oxygen ions ionized to the metal network to form the coupled electric field B, which is then extended to the 2nd outlet with a wire to form the electric field C. The negative oxygen ions are confined to the electric field A and B, and the electric field C is in the electric field A and the electric field gradients C₁, C₂, C₃... Cₙ are formed outside. Because it is a single power supply, the electric field pulses of A, B and C are synchronized/coupled in process. Under the action of resonant electric field, the NOI are effectively stored and guided, and eventually discharged from 2nd outlet along the electric field gradient. The other function of the coupled electric field is to expand the electric field of NOI, with the B field, the purity of NOI at 1st outlet is significantly reduced. It is the reason why purity of NOI at 1st outlet in Tables 2 and 3 is almost zero (110/cm³). After a further measuring of the densities at longer distance, the electric field A, B and C are ellipsoidal with a radius of about 4 m and the center deviating from the 2nd outlet forwardly. Figure 10 shows the electric field A, B, C and the gradients of field C.

**Figure 10.** The electric field and the gradient, the triple arrows represent the guiding (2nd) outlet: A is a high negative electric field formed by the emission polar, B is derived from A through metal web, and C is derived from B through a wire; A, B and C are coupled and resonance fields, the direction of electric field gradient is from C₁→Cₙ.

Because of the ionization effect at A, the oxygen molecule around A is consumed, and with the shielding effect of metal mesh on electric field A and C, an extremely low NIO zone is formed in the front and back regions of 1st outlet. In the uncoupled electric field, this shielding effect does not exist. In addition, there is no resonance effect between electric field A and electric field C, so the guiding effect on NOI is not effective, the purity and shunting ratio of NOI are obviously lower than those in coupled electric field, the purity of NOI at 1st outlet is still higher (1.1 million /cm³), and also the purity of NOI was also reduced at the 2nd outlet.

5.4. Improving the purity of NOI with -26 kV
In order to improve the purity of NOI, the third part of this study increased the negative voltage (from -20 kV to -26 kV) and released negative oxygen ions in a semi-enclosed silo environment. Table 3 shows that the NOI purity at 10 cm away from the 2nd outlet has increased 10 times, while the NOI
purity at 1st outlet has not changed significantly. The densities of NOI increased by 3-4 times at 30-40 cm, which significantly increased the densities of negative oxygen ions safely.

5.5. **Application value and safeness of the NOI separated from the coupled-electric field**

It has been reported that there are some harmful anions or ozone could be produced during the ionization process of air under a negative voltage. On the other hand, anion concentration with different distance are important to the application of the technology, if the distance is very short, the effective area of anion would be limited significantly. Equations (1) ~ (3) were used to demonstrate the relationship between the distance and the anion concentration. As Table 3 shows, the anion concentration is 5.6 million per cm$^3$ at the distance of 50 cm which illustrates that the effective distance is about 50 cm from the guide polar. According Table 4, the rats are normal as without NOI in sleeping time and breath. NOI after shunting from a coupled electric field is safe to the rats, after 868 hours under a continuous supply of NOI with 20 million per cm$^3$. A further animal experiment would be held to evaluate the therapeutic effect of NOI.

6. **Conclusions**

According to this paper, the purity and separative ratio of NOI could be improved prominently after using the coupled electric field compared to uncoupled electric field. The anion concentration could reach 100 million degrees without increasing the power significantly. And the NOI after shunting with a purity of 20 million per cm$^3$ is safe to rats both in electricity and biology. It is helpful to use this technology for health care and the treatment of pulmonary diseases such as interstitial pneumonia, asthma.

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