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Oxygen Enrichment DeviceUsingHall Effect

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---***ABSTRACT***---

A simple oxygen enrichment method was devised. The method use magnetic induction with Lorentz force and Hall effect. Paramagnetic oxygen molecules become subjected to force and are separated from air by the Hall effect. Many variables such as power, gap between electrodes and the number ofelectrodes affected oxygen separation. The variables were optimized separately through experimental studies. There was optimum number of sets of theelectrodesfor the oxygen separation although the oxygen concentration increased as the number of sets of electrode plates increased. It seems to be related to the power supplied to each electrode. The oxygen concentrations atthe O_2-rich outlet also increased as the output voltage to the electrodes increased. The oxygen enrichment was maximized through the device with 3 sets of electrodes and output voltage of 12.5V, showing the possibility of a simple and inexpensive oxygen separation device.

KEYWORDS:*oxygen, electric field, magnetic field, Lorentz force, Hall effect*

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I. INTRODUCTION

All animals cannot live without oxygen and the human body is in serious condition when oxygen is scarce or breathing air is contaminated. The air we breathe has been polluted more and more and theindoor air qualityhas becomemore serious sincebuildings are air-tightened forcontinuous cooling and heating. Recently, manyproductssuch as air purifier and oxygen generator have been produced and used for medical, industrial and household purposes to improve air quality or to supply purified oxygen. In order to spread the product distribution, we need low cost oxygen separation (or enrichment) device using a simple processsince the existing oxygen separation process is complex and requires high cost[1].

Conventional air separation methods include cryogenic air separation[2], PSA(pressure swing adsorption)[3] and membrane separation[4,5]: Cryogenic air separation liquefies air by cooling below the boiling point and separates oxygen and nitrogen from air. PSA method uses adsorbents which selectively adsorb oxygen in the air. Membrane separation uses permselective polymer membranes which separate oxygen and nitrogen fromair. Table 1 shows the characteristics of the oxygen separation methods.Each of the separation method has advantages and disadvantages. High purity oxygen can be obtained from the cryogenic method while the cost to liquefy air is quite high and large-scale equipment is required.PSA process is not expensive because it does not require heat exchangers.However, the entire process must be stopped when the adsorbent is required to replace and the purity of the separatedoxygen is not so high because argon gas is involvedduring

Table 1. The characteristics of oxygen separation methods

	Cryogenic	Non-Cryogenic	
Separation Method	Air Liquefaction	PSA	Membrane Separation
Heat Exchanger	O	X	O
Production Scale	100～2,000 ton/day	less than100 ton/day	variable
Process Temperature	Cryogenic (-200℃)	Roomtemperature	Medium temperature
Oxygen Purity	95～99.8%	90～95%	-

the process. Membrane process is simple and isoperated at moderate temperature, however, repeated membrane separation processes are required to obtain high purity oxygen. The membrane separation of oxygen has not been widely used compared to the other separation Methods.

In this research, a new and simple method using both electric field and magnetic field wasproposed to separate oxygen from air. The new method does not require heat exchangers and the process does not occupy large spaces. The method also does not require a compressor or fan to inject air since the oxygen movement creates natural convection during the process, and it is a semi-permanent system because the system does not require any adsorbents, filters or heating devices.

II. THEORETICAL BACKGROUND

Oxygen Similarity

The structural formula of an oxygen molecule is usually represented by O=O and the oxygen molecule combines valence electron pairs according to the octet rule. According to the Lewis electron-dot formula, all electrons in oxygen are paired so that the electrons become stable and consequently become neutral molecules or atoms.Nevertheless, the oxygen is paramagnetic. It had been found that liquid oxygen adheres to the magnet. Paramagnetic material has magnetic force when an external magnetic field is present, but it loses magnetic force when the external magnetic field disappears.Paramagnetic material is different from ferromagnetic material which retains magnetic force even when the magnetic field disappears. It is not possible to separate oxygen with normal magnetic force because the oxygen has high kinetic energy like other gases. However, it may be possible to separate oxygen using Halleffect due to both strong magnetic field and electric field rather than simple magnetic field.

LorentzForce

When a particle, of which charge is q and velocity is υ, receives force under an electric field E and a magnetic field B, the force(Lorentz force) can be expressed by the following equation[6].

$$F = q(E + v \times B)(1)$$

Thus, a charged particle is accelerated in the electric field E and moves in a spiral when the particle passes through the magnetic field Baccording to Fleming's right-hand rule (due to vector product) as shown in Fig.1.

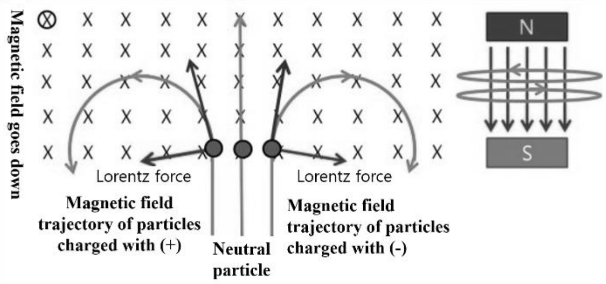

Fig. 1. Lorentz force

Here, the Fleming's right-hand rule is a law indicating the direction of the electric current generated in the wire when a wire (a metal or a string which the current can pass through) is moved in a magnetic field, and is refers to the principle of a generator. When a conductor moving with a velocity v passes through the magnetic field with a magnetic flux density of B under the conditions of a conductor length ℓ and an angle θ between the magnetic field and the conductor, the electromotive force E generated can be expressed by the following equation.

$$E = B \times v \times \ell \times \sin\theta(2)$$

Hall Effect

When a magnetic field is applied in the direction perpendicular to the moving direction of electric charges flowing inside the conductor or semiconductor, a potential difference is generated in the direction perpendicular to thecharge flow. The phenomenon is called Halleffect and the potential difference generated is called Hall voltage.The magnetic field acing in the direction perpendicular to the wire through which the current flows makes thechargesin the wire bent to one side, so that negative charges are accumulated on that sideandbecome negatively charged and the other side become positively charged. Accordingly, an electric field would come into existence across the wire, which is calledHall electric field(E). The Hall electric field forms a potential difference V=Ed across the wire. Fig.2 shows how the oxygen can be separated by the Hall effect. When incoming air passes through the electromagnetic field, paramagnetic oxygen is subjected to force and is bent to F directionand nitrogen not subjected to Hall effect goes out to the other direction.

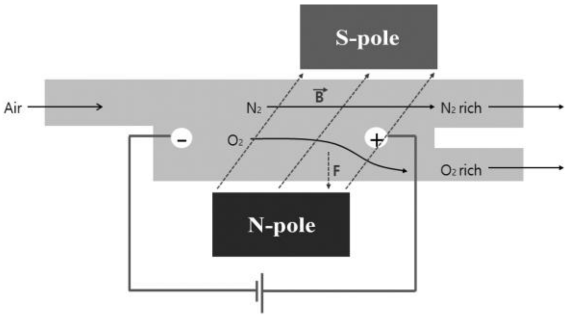

Fig. 2. The flow of oxygen and nitrogen due to Hall effect

III. EXPERIMENTAL

The oxygen separation system devised here is eco-friendly and low cost. The system is shown in Fig. 3. It consists of power supply, high voltage module (high voltage generating boost), neodymium magnets with a strength of 3,800G and electrode plates made of aluminum or copper. Table 2 to Table 5 shows the specification of the components of the system.

Power Supply

It is a device that generates voltage and current and sends the power to the high voltage module (Table 2).

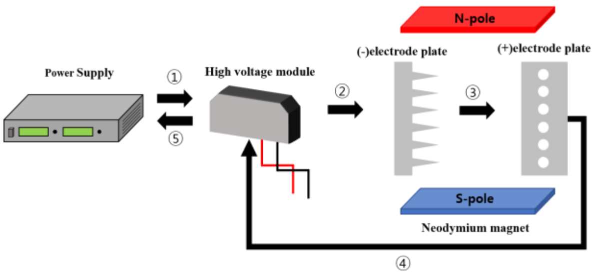

Fig.3. Schematic diagram of the oxygen separation system

Table 2. The specification of power supply

Model	Output Ripple (rms, 300kHz)		Output Noise (p-p :20MHz)
	Voltage	Current	
XG 100-15	8mV	35mA	80mV

High Voltage Module

It is a module that controls thevoltage and current generated bythe power supply.

Table 3. The specification ofhigh voltage module

Model	Input	Output	Dimensions
Boost High Voltage Generator	3V DC	7kV	41x24x17mm

Electrode Plate

A set of electrode platesconsists of a (+)electrode plate(a perforated plate) and (-)electrode plate (a triangular plate). Equally spaced 7 holes were perforated on the 10cm length of (+)electrode plate. (Only 6 holes were shown in Fig. 3 because the drawing of 7 holes was very difficult). The diameter of each hole was 0.5cm.The width of each triangular pin of the (-) electrode plate was varied between 2.2cm and2.6cm. The center points of the (-)electrode plate and the (+)electrode plate were aligned in the vertical direction as shown in Fig. 3. Aluminium or copper were used as electrode plates.

Neodymium Magnet

Neodymium magnet is the most powerful magnet on the earth and generates a magnetic field to cause the Hall Effect in the system.

Table 4. The specification of Neodymium magnet

Material	Size	Magnet Strength
Neodymium Magnet	10x2cm	3,800G
	5x5cm	-

Oxygen Concentration Meter

It is a device used to measure the oxygen concentration.

Table 5. The specificationof oxygen concentration meter

Model	Detection range	Measurement error	Indication	Operating temperature
Digital Oxygen Meter	0~25vol%	0.5%	4-digit	-10~40℃

Experimental Procedure

The experimental sequence starts from the power supply, voltage emission from the high voltage module, movement of electrons from the (-)electrode plate, receiving the electrons from the (+)electrode plate, and the electronsback to the power supplyas shown in Fig. 3.When incoming air passes sequence ③ in Fig. 3paramagnetic oxygen molecules are affected by the Hall effect and are subjected to force and are bent to one side as shown in Fig. 2.

Detailsof the typical setting of the electrode plates in Fig. 3is shown in Fig. 4, in which 3 sets of electrode plates are used. The top picture in Fig.4 is the upper view, and the bottom picture is the side view for the 3 sets of electrode plates, each of which is covered with neodymium magnets.The top of the magnet is N-pole and the bottom is S-pole.The number of sets of electrode plates was changed from 1 set to 4 sets and their effects on oxygen enrichment were investigated.

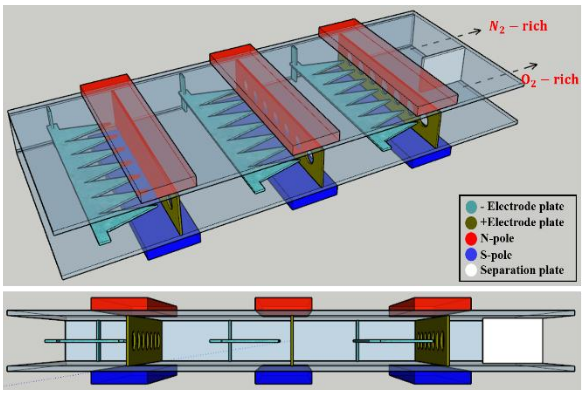

Fig.4. Threesets of electrode plates covered with neodymium magnets

IV.RESULTS AND DISCUSSIONS

Thepower, gap between the electrodes, and width of the pin of the (-)electrode plate are important variables to affectoxygen separation.The oxygen concentration increased as the power supplied to the electrode increased, which would be discussed later. The measurement of oxygen concentrations was also made with the change in the gap between (-)electrode plate and (+)electrode plate at the fixed output voltage. When the distance between (+)electrode plate and (-) electrode plate was closer to a certain distance(0.1cm) or more, a short-circuit occurred and the life of the high voltage module was shortened while the shorter the gap between the electrodes the higher the efficiency was.Thereafter, all the experiments had been carried out with the attention to maintain the gap wider than the limiting distance. The moststable and optimum distance between the two electrodes was 0.5-0.7cm.For the electrode plate, aluminium was mostlyusedasanelectrodeplateinsteadofcopperbecausethecopperhad highconductivitybutitdeformed easilyandshowed lowdurability. In addition, the dependence of the width of the triangular pins of (-) electrode plate was compared and analyzed.The optimumwidth of the pins was 2.6cm and was mostly used thereafter. The size of mostly used neodymium magnet was 10x2cm.

Table 6 shows the oxygen concentrationsat the outlet of the system forblank runs. The blank run was carried out in the oxygen separation systemwith no electric power to the system after setting the system. The measurements were repeatedfor 15 minutes and thedata were noted in Table 6. The oxygen concentration in the atmosphere is 20.9±0.1. The oxygen concentrations in Table 6 were almost constant, except for slight fluctuations due to air convection.

The effect of the number of sets of the electrode plates on the oxygen separation is shown in Table 7. The set of (-)(+) electrodes was varied between 1 set and 4 sets. The output voltage was fixed at 12.5V, and the gap between the electrodes and the length of the pins of (-) electrode were fixed at the optimum values as mentioned previously. Air was not separately supplied to the system and utilized natural convection due to the Hall effect. All the oxygen concentration values in Table 7 reached steady state values at least 6 minutes after starting each set of runs. The oxygen concentrations at the O_2-rich outlet increased upto about 0.2% for the 1 set of electrode plates compared to the blank run and the oxygen concentrations at the O_2-rich outlet increased gradually as the number of sets of electrode plates increased as shown in Table 7. The oxygen concentrations at

Table 6. The oxygen concentration for blank runs

	Oxygen concentration (%)		
Time (minute)	Day 1 (temp: 15℃, humidity:25%)	Day 2 (temp: 11℃, humidity:25%)	Day 3 (temp: 12℃, humidity:25%)
0	20.9	21.0	21.0
1	20.9	21.0	21.0
2	20.9	21.0	21.0
3	21.0	21.0	20.9
4	21.0	21.0	20.9
5	21.0	21.0	20.9
6	21.0	21.0	20.9
7	20.9	21.0	20.9
8	20.9	21.0	20.9
9	20.9	21.0	20.9
10	20.9	21.0	20.9
11	20.9	20.9	20.9
12	20.9	20.9	20.9
13	20.9	20.9	20.9
14	20.9	21.0	20.9
15	20.9	21.0	20.9

Table 7. The effect of the sets of electrode plates on the oxygen concentration(%)

	1-set		2-sets		3-sets		4-sets	
Time(min)	O_2-rich outlet	N_2-rich outlet	O_2-rich outlet	N_2-rich outlet	O_2-rich outlet	N_2-rich outlet	O_2-rich outlet	N_2-rich outlet
0	20.97	20.97	20.90	20.90	20.93	20.93	20.97	20.97
1	20.97	20.97	21.00	20.80	21.03	20.83	21.00	20.80
2	21.03	20.90	21.13	20.67	21.13	20.73	21.13	20.67
3	21.07	20.87	21.23	20.57	21.20	20.67	21.23	20.57
4	21.10	20.83	21.30	20.50	21.33	20.53	21.30	20.50
5	21.10	20.83	21.33	20.47	21.43	20.43	21.33	20.47
6	21.10	20.83	21.37	20.43	21.53	20.33	21.37	20.43
7	21.10	20.83	21.37	20.43	21.57	20.30	21.37	20.43
8	21.13	20.80	21.37	20.43	21.57	20.30	21.37	20.43
9	21.13	20.80	21.37	20.43	21.57	20.30	21.37	20.43
10	21.13	20.80	21.37	20.43	21.57	20.30	21.37	20.43
11	21.13	20.80	21.37	20.43	21.57	20.30	21.37	20.43
12	21.13	20.81	21.37	20.43	21.57	20.30	21.37	20.43
13	21.13	20.81	21.37	20.43	21.57	20.29	21.37	20.43
14	21.13	20.81	21.37	20.43	21.57	20.29	21.37	20.43
15	21.13	20.81	21.37	20.43	21.57	20.29	21.37	20.43
Maximum difference	0.16		0.47		0.64		0.47	

the O_2-rich outlet showed a little decreasefor the 4-sets of electrode plates.It seemed that more oxygen molecules were subjected to force as the number of sets of electrode plates increased, which would make more oxygen molecules bent to one sideand increase the oxygen concentrationsat the O_2-richoutlet.However, the oxygen enrichmentappears to be maintained or decreased as the number sets of electrode plates exceed a certain number. The electrode plates with a parallel structure sharedthe output voltage,thus, each set of electrode plates get less power from the module as the number of sets of electrode plates increased. That would be a reason for the decrease in O_2 concentration for the 4-sets of electrode plates. Conclusively, the number of sets of electrode plates with optimum efficiency was 3-sets, whichmade the highest oxygen enrichment.

Table 8 shows the effect of output voltage on the oxygen separation. The voltage has been changed to 3, 6, 9, 12.5V. The oxygen concentrations were measured for the system with 3-sets of electrode plates with the other conditions fixed. All the oxygen concentration values in Table 8 are the steady state values. In Table 8, the oxygen concentration at theO_2-rich outlet increased as the output voltage increased irrespective of the number of measurements. The number of electrons generated at the negative electrode seemed to increase and move faster to the positive electrode as the output voltage increased, whichenhancedthe Hall effect. Greater Halleffect would draw more oxygen molecules to be bent, which result in higher oxygen concentration at the O_2-rich outlet. The highest oxygen concentration at the O_2-rich outlet was 21.8% at 12.5V of output voltage. Oxygen concentrations at the O_2-rich outlet are drawn as a function of voltage in Fig. 5. The higher the voltage, the higher the oxygen concentration. Fig. 6 shows the actual 3 sets of electrode plates and the highest oxygen concentration value measured.

Table 8. The effect of output voltage on the oxygen concentration(%)

	1^{st}time		2^{nd} time		3^{rd} time	
	O_2-rich outlet	N_2-rich outlet	O_2-rich outlet	N_2-rich outlet	O_2-rich outlet	N_2-rich outlet
3V	21.0	21.0	21.0	21.0	21.0	21.0
6V	21.3	20.7	21.2	20.8	21.3	20.7
9V	21.4	20.6	21.4	20.6	21.5	20.5
12.5V	21.8	20.2	21.7	20.3	21.8	20.2

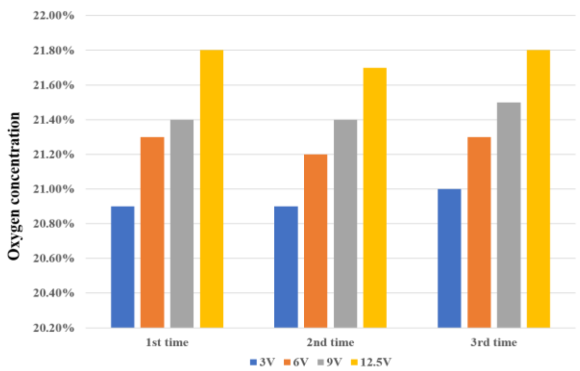

Fig. 5. The oxygen concentration as a function of output voltage

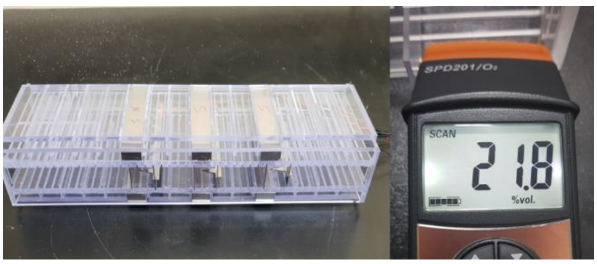

Fig. 6. The photograph of 3 sets of electrodes and thehighest oxygen concentration measured

V. CONCLUSION

A new method to enrich or separate oxygen from air was devised and the effect of variables to affect oxygen separation was investigated.The method uses Hall effect which generates electromagnetic force in the direction perpendicular to the electric field and the magnetic field. Paramagnetic oxygen is subjected to force by the Hall effect and become enriched or separated fromthe air.

As for the number of sets of electrode plates, the highest increase in oxygen concentration was obtained when 3 sets of electrode plates were used, butthe oxygen concentration tended to decrease when the number of sets electrodes was 4 sets. It seems that there exists a limit to the power delivered to each electrode plate as the number of electrode plates increases. The reduced power to the electrodes would weaken the Hall effect, which resultin the decrease in oxygen concentrations.It may be possible to connect additional power supplies to supply enough power to the electrodes, but it would not bean efficient way because the energy for oxygen separation is also increased. The effect of output voltage was also investigated. The oxygen concentrations at the O_2-rich outlet increased as the output voltage increased. Higher voltage to the electrode plates would generate higher power and enhance the Hall effect.

Through this study, it was confirmed that the oxygen in the atmosphere was able to be separated and concentrated by the Hall Effect, and the oxygen concentration increased upto 0.8% at the output voltage of 12.5V with 3 sets of electrode plates.

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