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Investigation of the Supercritical Fluids as an Insulating Medium for High Speed Switching

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Abstract – The paper investigates the insulation properties of the supercritical CO_2 ($SCCO_2$) fluid as an insulating medium for electrical apparatuses. The insulating material is crucial for electrical apparatuses and SF_6 gas has been widely used for high power electrical apparatuses. There have been many research efforts to develop substituents for SF_6 gas because of high global warming potential. We obtained above 350 kV/mm insulation strength with 12.0 MPa $SCCO_2$. The positive and negative IEC standard pulses are applied between two 10 mm diameter spherical electrodes. The insulation strength of $SCCO_2$ is at least 2.5 times higher than that of CO_2 gas at 6.0MPa. The insulation strength of $SCCO_2$ fluid is about 10 times higher than that of SF_6 at 0.5MPa which is the ordinary operating pressure of electrical switchgears. Using the result, we expect that the time for switching and dielectric recovery could be reduced using $SCCO_2$ fluid as an insulating medium.

Keywords: Breakdown voltage, Supercritical state, CO_2, Insulation, Switchgear, Electrical apparatus

1. Introduction

Application research on Supercritical fluids become wide spread in the fields of extraction, solvent, chemical process, nano and micro particle formation, and power generation [1-5]. Supercritical fluids have the unique characteristics of the supercritical fluids such as high solubility, low viscosity, and high diffusivity. Especially, supercritical carbon dioxide ($SCCO_2$) has been widely used because it is nontoxic, nonflammable, low cost and low critical temperature of 304K. Using electrical discharge plasma inside supercritical $SCCO_2$ has been emerged as a useful chemical reaction tool which could be applied environment and biomedical fields [6-11].

Recently, based on the insulation strength [9] of supercritical fluid, there have been attempt to use it for the insulation medium for electrical apparatuses [12-13]. The reported breakdown voltage of $SCCO_2$ is greater than 350kV for 1mm gap distance according to the experiment in ref. 9. This corresponds to the breakdown voltage of SF_6 gas pressure greater than 5.0Mpa [14]. However, SF_6 gas is extremely potent greenhouse gas and is known to be global warming potential of 23,900 times that of CO_2. Therefore Great effort is devoted in the research of finding substitutes for SF6 gas all over the world. $SCCO_2$ could be a challenging candidate if the above results are confirmed.

In this paper, we will report our experimental results of breakdown voltages of $SCCO_2$ using pressure chamber. IEC standard impulse voltage over 100kV is applied to the chamber using facility in our institute. The experimental setup is described in section II. In section III, we report our experimental results for breakdown voltage of $SCCO_2$. Then we will conclude and mention the possibility of using $SCCO_2$ as an insulating medium.

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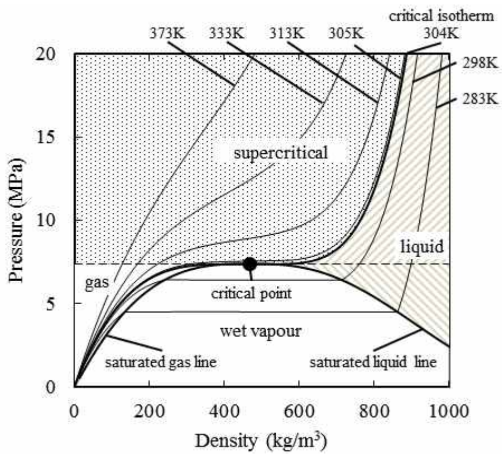


Fig. 1. Phase diagram of CO_2

2. Experimental Setup

The thermodynamic phase diagram of CO_2 fluid is shown in Fig. 1. The phase of CO_2 fluid is determined by temperature and pressure. The state of CO_2 is categorized classified into three states, gas, liquid, and supercritical states. The critical temperature and pressure of CO_2 is 304.1K and 7.38MPa, each. Above the critical temperature and pressure, the fluid becomes supercritical state.

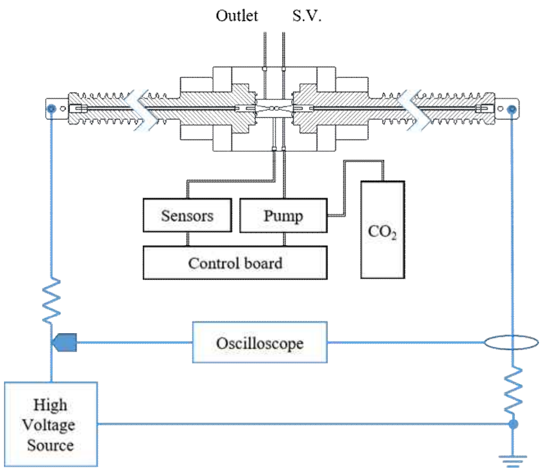


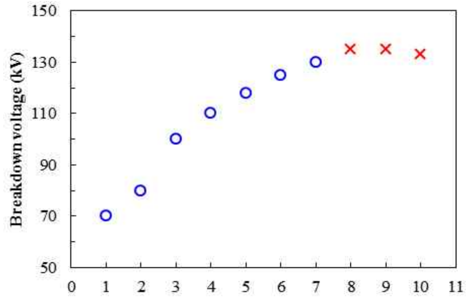
Fig. 2. Schematic diagram of the experiment

The schematic setup of our experiment is drawn in Fig. 2. The pressure chamber is made of stainless steel to withstand high pressure fluid inside the chamber. The electrodes are insulated with PEEK (polyether ether ketone) material. The temperature of CO_2 fluid in the chamber is monitored and controlled by sensors and heating system. The pressure of fluid is controlled by external pump. In order to pressurize the chamber, the external gas is cooled down to be liquefied and then pumped into the chamber. The pressure inside the chamber is controlled from 8MPa to 12MPa in order to maintain supercritical state.

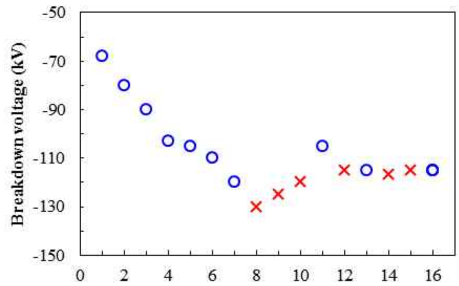
We applied high-voltage between two sphere-sphere electrodes using DC and impulse voltage generator. The DC power is connected to RC circuit and switched automatically by capacitor charge-discharge process. While the applied voltage pulse in ref. 9 is not IEC standard one, we applied the IEC 1.2*50μs standard lightning impulse voltage to compare the results with those of other insulating media. The results could be used to design the new electrical apparatus using $SCCO_2$. The radius of the sphere is 10mm each.

3. Experimental Results

We used high-voltage standard testing facility in our institute. The gap between the electrodes was 0.32mm. The pressure was 11.8~12.5MPa and the temperature was 35℃ during the experiment. The pressure was slowly decreased during the experiment because of sealing problem but the difference was smaller than 0.2MPa. The main test was accomplished after applying several aging pulse voltages. The results of impulse voltage breakdown are shown in Fig. 3. Fig. 3(a) is the result of positive pulses application and Fig. 3(b) is that of negative pulses. The pressures were 12.2MPa and 11.8MPa each. The temperature was maintained to be the same 35℃. The gap between electrodes was 0.32mm. The maximum voltage of



(a) Positive pulse application



(b) Negative pulse application

Fig. 3. The breakdown voltage of CO_2 supercritical states. (a) The pressure is 12.2MPa and temperature is 34.9℃; (b) The pressure is 11.8MPa and temperature is 34.9℃. The gap between electrodes is 3.2mm

(a)

(b)

Fig. 4. The voltage pulses of (a) without breakdown (applied voltage is 130kV), and (b) with breakdown (applied voltage is 135kV) for the case of the experiments in Fig. 3(a)

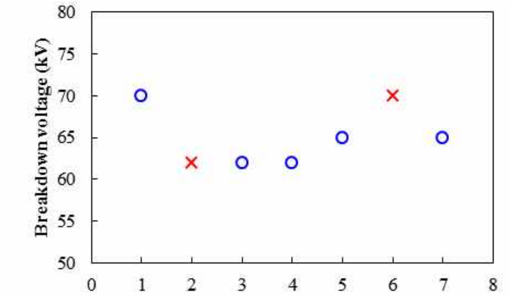


Fig. 5. The breakdown voltages of CO_2 gas. The pressure is 5.94MPa, the temperature is 23.1℃, and the gap distance is 0.53mm

breakdown for positive pulse was 130kV/0.32mm ~ 400kV/mm and for negative pulse was 115kV/0.32mm ~ 360kV/mm. The insulation strength of $SCCO_2$ in our experiment is nearly the same or greater than that of ref. 9 (~360kV/mm). We could obtain the excellent insulating characteristics of $SCCO_2$ even under higher voltages over 100kV.

The voltage pulses of the experiment are shown in Fig. 4. Fig. 4(a) is the voltage pulse without breakdown when the applied voltage peak is 130kV and Fig. 4(b) is the voltage pulse with breakdown discharge when the applied voltage is 135kV. The pulse waveform if Fig. 4(b) is the traditional insulation breakdown ones.

The breakdown voltage results for CO_2 gas state was obtained and shown in Fig. 5. The breakdown voltage of CO_2 gas state was about 70kV/0.53mm ~ 132kV/mm and much lower than that of the supercritical state. The breakdown voltage of CO_2 gas matches well with the results of ref. 9 (~140kV/mm).

4. Conclusion

We investigated the insulation properties of the supercritical CO_2 ($SCCO_2$) fluid as an insulating medium for electrical apparatuses. We applied greater than 100 kV to the gap between two spherical electrodes in our pressure chamber and obtained above 350kV/mm insulation strength for the pressure of 12.0MPa $SCCO_2$. The insulation strength of $SCCO_2$ is 2.5~3.0 times higher than that of 6.0MPa CO_2 gas. The insulation strength of 12MPa $SCCO_2$ fluid corresponds to the 5 ~ 6MPa SF_6 gas. The insulation strength of $SCCO_2$ was about 10 times higher than that of SF_6 at 0.5kPa which is the usual gas pressure of high power switchgear. This means that the insulation strength of $SCCO_2$ is enough to substitute SF_6 gas which has been used in electrical apparatus. Using the result, we expect that the time for switching and dielectric recovery could be reduced using $SCCO_2$ fluid as an insulating medium. Further research on the insulation characteristics of $SCCO_2$ for wide pressure range will be done in near future.

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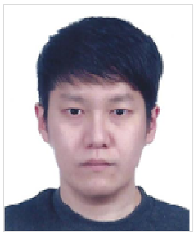

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