# EXPERIMENTAL STUDY ON CHARACTERISTICS OF $CO_2$ AND ITS GAS MIXTURES WITH $SF_6$ FOR HIGH VOLTAGE GAS CIRCUIT BREAKERS

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## ABSTRACT

To develop environmentally friendly $SF_6$-free gas circuit breakers, it is necessary to study characteristics of the alternative mediums. In this work, $CO_2$ which has lower global warming potential, together with its gas mixtures with $SF_6$, is investigated. Based on a 126 kV puffer-type circuit breaker, a series of experiments at different concentrations of $SF_6$ is carried out. Analysis is performed on arc voltage, arc conductance and puffer pressure which are vital factors to estimate the arc-quenching property of the gaseous working mediums. It is found that with the increase of concentration of $SF_6$, arc voltage, extinction voltage and arc resistance increase either. And adding $SF_6$ gas to $CO_2$ gas leads gas blow to be more intense and therefore enhance arc-quenching capability of gases.

## 1. INTRODUCTION

Owing to its outstanding insulation and arc-quenching capabilities, $SF_6$ is widely used in high-voltage gas circuit breakers (GCB) and gas-insulated switchgears (GIS). However, $SF_6$ is found to be a strong greenhouse gas and its emission is strictly limited by regulation. In the past decades, many researchers have made efforts to find appropriate alternative mediums of $SF_6$ [1-6]. $CO_2$ has a relatively high arc-quenching capability and lower global warming potential, and therefore is regarded as a potential substitute for $SF_6$.

However, compared with $SF_6$ gas circuit breaker, $CO_2$ gas circuit breaker is much larger and its interruption performance is not satisfactory. Further studies on characteristics of $CO_2$ still need to be done, including interaction between gas pressure field and arc, property differences between $CO_2$ and $SF_6$, and interaction between $CO_2$ arc and nozzle. Recently, some fundamental research has been conducted on $CO_2$ and its gas mixtures as candidates of $SF_6$ [6-10]. Toshiyuki Uchii measured puffer pressure rise of $SF_6$ gas and $CO_2$ gas with the same puffer-type interrupter and interruption current 28.4 kA, concluding that $CO_2$ is preferable for a short arcing time condition and $SF_6$ is suitable for a long arcing time condition. Meanwhile, there is little investigation on interaction between gas pressure field and arc [8] [11].

In this paper, based on a 126 kV puffer-type circuit breaker, an experimental study on characteristics of $CO_2$ and its gas mixtures with $SF_6$ for high-voltage gas circuit breakers is carried out. Pivotal parameters including arc voltage and current and gas pressure at the upstream of the nozzle during current interruption are measured at different concentrations of $SF_6$. Characteristics of arc voltage, arc conductance and puffer pressure are analysed eventually.

## 2. EXPERIMENTAL SETUP

A new circuit breaker with a simplified nozzle is designed on the basis of a 126 kV puffer-type circuit breaker prototype. Longitudinal cross section of the arc-quenching chamber is shown in Fig. 1. Pressure transducer is located at the upstream of the nozzle. Length of the arc-quenching chamber is 1000 mm, its radius 320 mm, maximum clearance between open contacts 150 mm, overtravel 25 mm, solid contact radius

20 mm, length of the nozzle 45 mm, nozzle throat radius 22 mm, nozzle inlet radius 34 mm, nozzle outlet radius 38 mm.

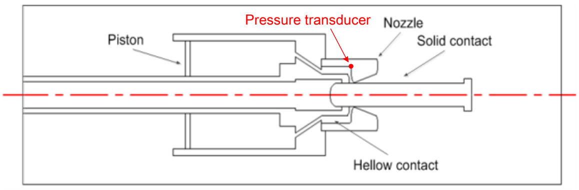


*Fig. 1 Longitudinal cross section of the arc-quenching chamber*

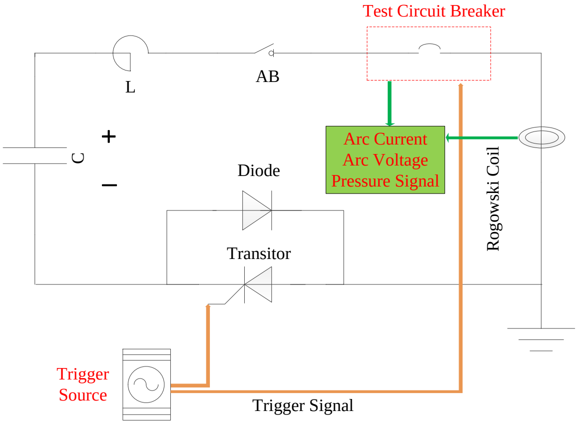


*Fig. 2 Sketched diagram of the equivalent electrical circuit*

To obtain the short-circuit current we need, a high-capacity oscillation circuit is utilized. The equivalent electrical circuit is shown in Fig. 2. A diode is parallel to the transistor to prevent the reversal current from being chopped. In the beginning, auxiliary breaker AB is closed. After the capacitor is charged to an assigned value, signals controlling operation of the mechanism and the moment to load the current are send sequentially by the trigger source, decoupled with a solid state relay and an optical fiber respectively. Sinusoidal current with frequency around 50 Hz is generated by capacitor C resonating with reactor L.

Arc voltage is measured by a high-voltage probe, arc current by a Rogowski coil, gas pressure at the monitoring point by a pressure transducer. These signals are recorded by a digital oscillograph. Prospective short-circuit current and filling gas pressure are defined as *I* and *P* respectively and $i_a$ represents arc current.

## 3. RESULTS AND DISCUSSION

Arc voltage and current is measured and analysed below for pure $CO_2$, $80\%CO_2/20\%SF_6$ and $50\%CO_2/$ $50\%SF_6$. Variation of arc voltage and current with time of 5 tests for pure $CO_2$ gas under the same conditions ($P$=0.6 MPa, $I$=10 kA) is shown in Fig. 3. It can be seen that experimental results are reliable for they are good in repeatability.

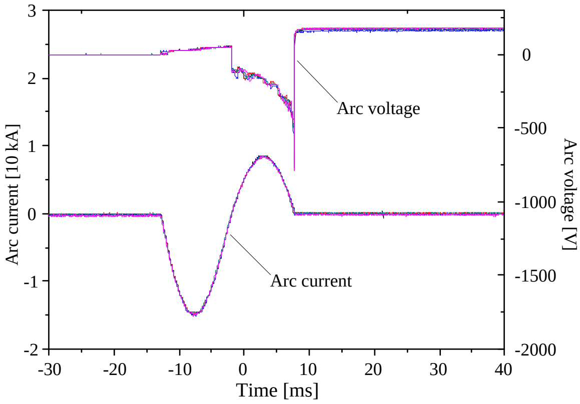


*Fig. 3 variation of arc voltage and current with time of 5 tests for pure $CO_2$ gas under the same conditions (P=0.6 MPa, I=10 kA)*

Fig. 4 shows variation of arc voltage and current with time for pure $CO_2$, $80\%CO_2/20\%SF_6$ and $50\%CO_2/50\%SF_6$ gas ($P$=0.6 MPa, $I$=10 kA). As can be seen, arc voltage for $CO_2$ and $80\%CO_2/20\%SF_6$ is approximate to each orher, whereas arc voltage for $50\%CO_2/50\%SF_6$ is much higher than that for other two mediums. Higher arc voltage is beneficial to limitation of $di_a/dt$ and thus arc current crosses current zero earlier. Besides, Fig. 5 shows that extinction voltage for $CO_2$ gas is around 720 V, 770 V for $80\%CO_2/20\%SF_6$ and 950V for $50\%CO_2/$ $50\%SF_6$. Extinction voltage reflecting dielectric recovery in the gap rises nonlinearly as concentration of $SF_6$ increases, explaining why $SF_6$ has better arc-quenching performance.

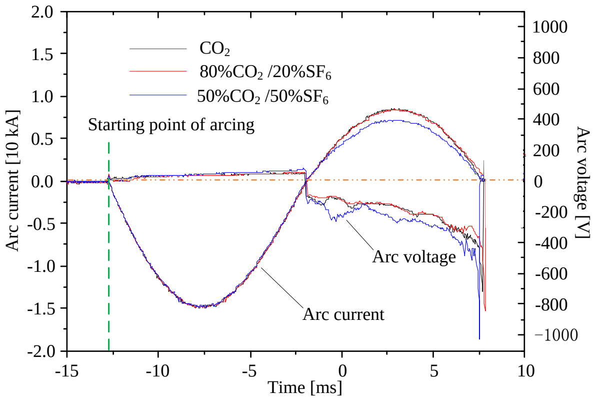


*Fig. 4 Variation of arc voltage and current with time for pure $CO_2$, $80\%CO_2/20\%SF_6$ and $50\%CO_2/50\%SF_6$ gas (P=0.6 MPa, I=10 kA)*

Fig. 6 shows dependence of extinction voltage on concentration of $SF_6$ ($P$=0.6 MPa, $I$=10 kA). Arc conductance for $CO_2$ is approximate to that for $80\%CO_2/20\%SF_6$, whereas arc conductance for $50\%CO_2/50\%SF_6$ is much lower, partially as a result of the fact that thermal dissipation capability of $SF_6$ is better than that of $CO_2$.

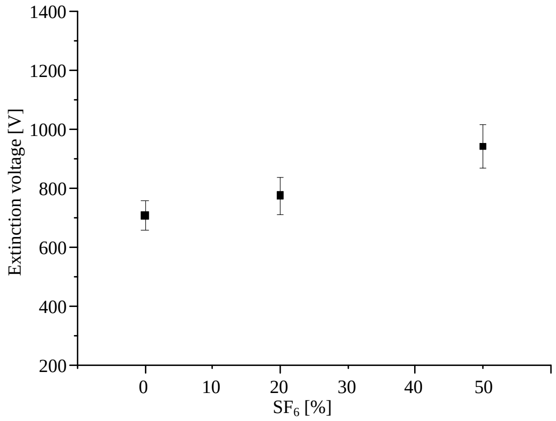


*Fig. 5 Dependence of extinction voltage on concentration of $SF_6$ (P=0.6 MPa, I=10 kA)*

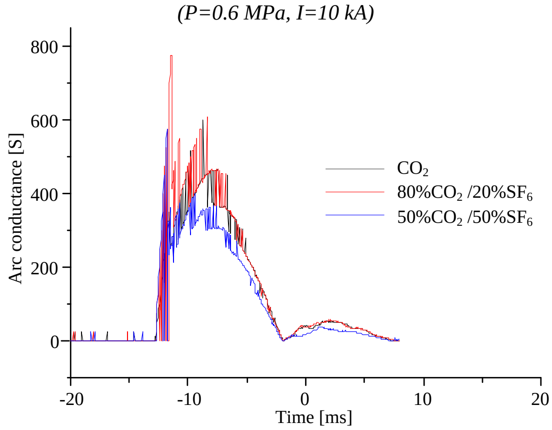


*Fig. 6 Variation of arc conductance with time for pure $CO_2$, $80\%CO_2/20\%SF_6$ and $50\%CO_2/50\%SF_6$ gas (P=0.6 MPa, I=10 kA)*

Once the breaker is operated and gas in the cylinder is compressed, gas blow field in the nozzle is generated. Fig. 7 depicts variation of gas pressure increment at upstream of the nozzle with time for pure $CO_2$, $80\%CO_2/20\%SF_6$ and $50\%CO_2/50\%SF_6$ (*P*=0.6 MPa, *I*=10 kA). Fig. 8 shows dependence of maximum gas pressure increment during arc burning phase on concentration of $SF_6$ (*P*=0.6 MPa, *I*=10 kA). Rising rate of gas pressure for $CO_2$ is 0.0062 MPa/ms, 0.0077 MPa/ms for $80\%CO_2/20\%SF_6$ and 0.0101 MPa/ms for $50\%CO_2/50\%SF_6$. Puffer pressure and its rising rate for $50\%CO_2/50\%SF_6$ is higher than that for other two mediums apparently, implying that gas blow effect of $50\%CO_2/50\%SF_6$ is better. This phenomenon may be caused by more decomposed products and higher arc voltage of hot $SF_6$ gas. In addition, dip occurring in the beginning results from electromagnetic coupling just when the current is loaded.

Puffer pressure at current zero crossing may provide direct evidence on arc-quenching performance of a certain medium. Dependence of gas pressure increment at current zero crossing on concentration of $SF_6$ (*P*=0.6 MPa, *I*=10 kA) is shown in Fig. 9. Higher gas pressure increment at current zero crossing indicates stronger gas blow effect and better dielectric recovery. It partially demonstrates why interruption capability of $SF_6$ circuit breaker is much better than that of $CO_2$ circuit breaker. Thus, if we intend to apply $CO_2$ to high-voltage gas circuit breakers, it's considerable to improve its gas blow effect by modifying the configuration of the arc quenching chamber.

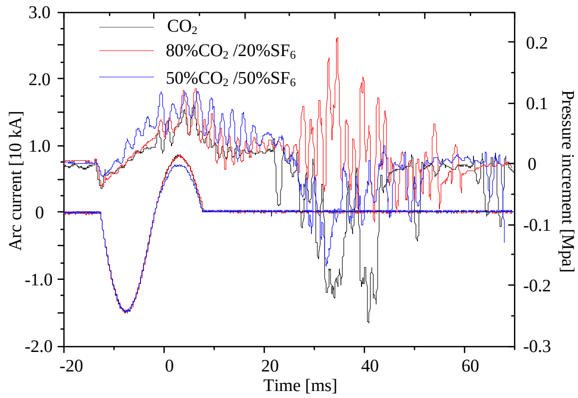


*Fig. 7 Variation of gas pressure increment at upstream of the nozzle with time for pure $CO_2$, $80\%CO_2/20\%SF_6$ and $50\%CO_2/50\%SF_6$ gas (P=0.6 MPa, I=10 kA)*

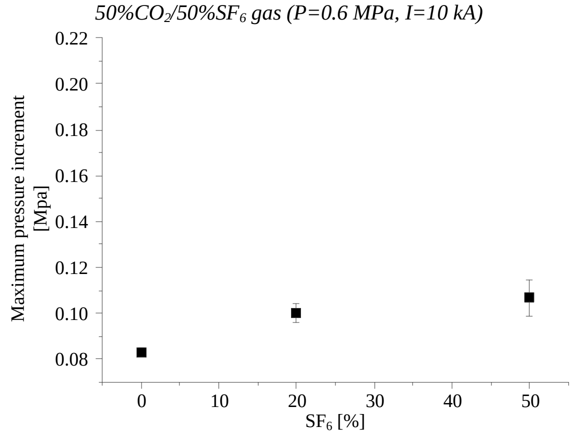


*Fig. 8 Dependence of maximum gas pressure increment during arc burning phase on concentration of $SF_6$ (P=0.6 MPa, I=10 kA)*

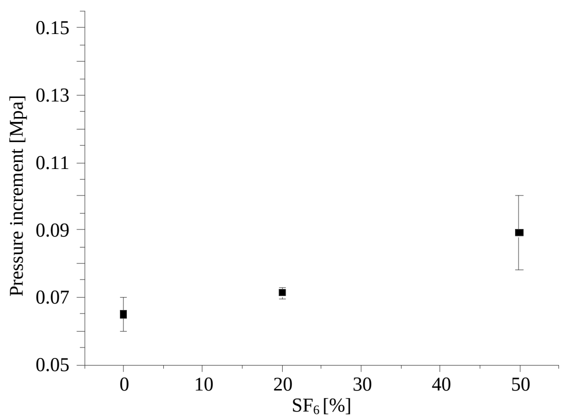


*Fig. 9 Dependence of gas pressure increment at current zero crossing on concentration of $SF_6$ (P=0.6 MPa, I=10 kA)*

## 4. CONCLUSION

This paper performs a preliminary analysis on characteristics of $CO_2$ and its gas mixtures with $SF_6$. Factors that are directly relevant to interruption capability of circuit breakers are investigated. Experimental results reveal that:

1) As concentration of $SF_6$ in $CO_2/SF_6$ gas mixtures increases, arc voltage, extinction voltage and arc resistance tend to increase, with dielectric strength in the gap rising nonlinearly.

2) Compared with $SF_6$, gas blow effect of $CO_2$ is relatively weaker, especially at current zero crossing. Therefore measures should be taken to improve gas blow effect of $CO_2$ when it is applied to high-voltage gas circuit breakers.

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