# Effect of Ambient Light on the SF6 Alternative Mixture and their Decomposition Products

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***Abstract*—With the ever-growing concern on emissions of greenhouse gases, insulating gaseous compounds and gas mixtures with low environmental impact are gaining importance. In addition to atmospheric gases and vacuum, selected synthetic gases show good electric insulation properties. These gases play an important role as insulant in gas insulated substations (GIS), gas insulated transmission line (GIL), and gas insulated busbar (GIB). With the potential increase in the usage of alternative gases, the effect of gases on the atmosphere and vice versa needs to be established as some leakage to the environment is unavoidable. The presented work studies the effect of ambient light on one such alternative gas mixture ($C_4F_7N/O_2/CO_2$). To study the effect of ambient light on the gas byproducts formed from the electric arc discharges, one batch of sample is subjected to multiple arcs and then exposed to the ambient light. The results show that the $C_4F_7N/O_2/CO_2$ mixture or its decomposition products are not affected by the ambient light when exposed for 30 calendar days. It was also observed that there were no solid byproducts formed during this process.**

***Keywords*—ambient light, byproducts, $C_4F_7N$ gas, GIS, $SF_6$ alternatives**

## I. Introduction

$SF_6$ has a very high global warming potential and is being phased out by developed economies as they plan to reduce greenhouse gas emissions by up to 95%, which is below the 1990s levels by 2050. This instrumental decision lead to the development of various low global warming potential (GWP) gases or mixtures that possess good dielectric and thermal properties. One such widely studied mixture is $C_4F_7N/O_2/CO_2$ that can potentially replace $SF_6$ due to their matching insulation properties and with an additional advantage of lower global warming potential (GWP).

Work has been carried out in [1, 2] to study the stability of various GIS build materials with the gas mixture. The gas is observed to be stable when brought in contact with copper, aluminium, silver, brass, nickel, steel, stainless steel at 120℃ for several months [2-7]. However, at high temperatures, the gas reacts with copper, decomposes itself and corrodes copper. However, the gas is found to be stable with aluminium even at high temperatures. The gas is also found to be stable with hard plastics and elastomers [2, 5]. The possible dissociation and recombination paths of the $C_4F_7N/O_2/CO_2$ mixture were also studied by researchers in [8-10] to explain the possible formation paths for byproducts. From the available literature, it is evident that the byproducts such as $C_3F_8$, $CF_3CN$, $C_3F_6$, $C_4F_{10}$, $C_2F_5CN$, $C_2N_2$, are formed when the gas mixture is subjected to thermal and/or electric stresses [10].

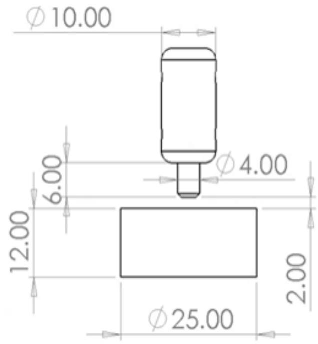
These byproducts may interact with the structural materials of gas insulated substations (GIS) and may lead to leakage of the mixture into the atmosphere. Also, leakage can also happen during the initial filling, retrofilling or decommissioning. Some of the decomposition products have longer atmospheric lifetimes and higher GWP than the original gases in the mixture [11-13]. This research focuses on studying the stability of such decomposition byproducts when subjected to ambient light. This research is based on the hypothesis that ambient light might be able to decompose these dangerous byproducts to molecules that are environmentally friendly. Therefore, there is a need to study the interactions of these state-of-the-art gas mixtures with atmosphere (light, temperature, humidity and other gases) as leakage of the gas from the GIS is inevitable. Due to the increase in use of these alternative gases, it is challenging to control the leakages into the atmosphere. This article presents a study on the effect of ambient light and temperature on the fresh and byproduct pervaded $C_4F_7N/O_2/CO_2$ gas mixture.

## II. Methodology

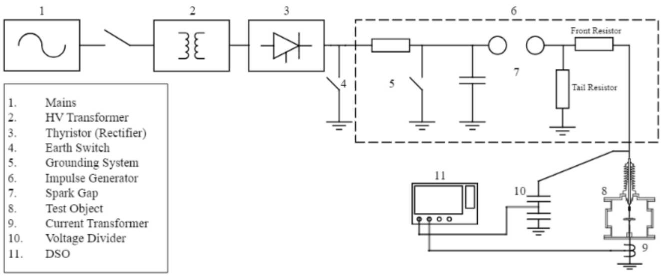
### *A. Preparation of Samples*

A mixture of fresh $C_4F_7N/O_2/CO_2$ gases in 5/13/82% composition is prepared and allowed to rest for one week for uniform mixing of the gases. Oxygen and carbon dioxide used were of 99.5% and 99.995% purity respectively. The preparation of the mixture was performed following the calculation processes recommended in [14]. The chambers for storage and testing were cleaned with isopropyl alcohol and dried in an oven at 50ºC for 3 to 4 hours. The chambers were also pressure tested at 4 bar absolute pressure with $N_2$ gas before being used. The chambers were found to hold pressure intact over a week. The pressure tested chambers are now used for testing.

The $C_4F_7N$ gas mixture is filled into two test chambers at 2.5 bar absolute pressure. One of the chamber has no internal fittings, the other chamber houses electrodes of dimensions shown in Fig. 1(a) that are used to subject the gas mixture to 400 lightning impulse breakdowns. The gap distance between the high voltage electrode and the plane at ground potential was set to 2 mm. The schematic circuit for carrying out the impulse breakdown tests is shown in Fig. 1(b). The impulse generator is Haefely made (SGSA 400-20). It has 4 stages and can generate impulse voltages up to 400 kV. The time gap between each breakdown is set to 2 minutes to let the mixture stabilize. The breakdown is monitored through a current transformer placed around the grounding wire to ensure the occurrence of desired number of breakdowns. After 400 impulse breakdowns, the second chamber will contain numerous decomposition products as determined from previous experimental work.



(a)



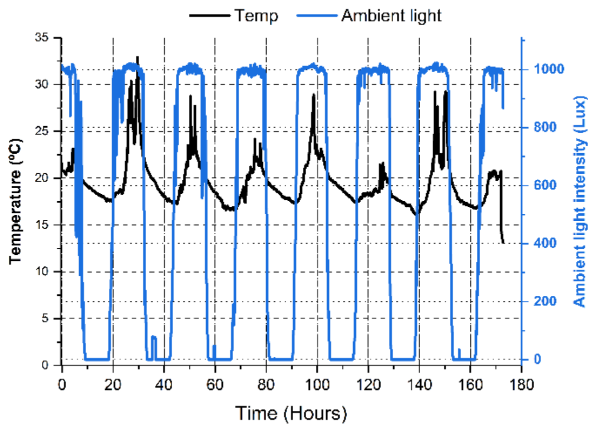
(b)

Fig. 1. (a) Schematic of electrodes for impulse breakdown testing, (b) schematic of the high voltage lightning impulse breakdown testing equipment.

## B. *Exposing the Samples to Ambient Light*

The two chambers, one containing unarced mixture and the other containing arced mixture have UV-grade Fused Silica (UVFS) glass on one of its sides that is capable of transmitting light of wavelengths as low as 200 nm with a transmittance >90% and which approaches 95% at 300 nm. Therefore, this glass enables the ambient light (including UV light) to enter the vessel and interact with the gas mixtures. These chambers are placed in an open area that is protected from the birds/animals. It is also unreachable to other people. The ambient light intensity and temperature are continuously monitored using sensors connected to an Arduino Giga R1 board. The Arduino and the sensors are powered by a 5 V power bank (20 Ah capacity). In addition to the ambient light intensity and the temperature, the setup is capable of monitoring the ambient UV index and humidity. The UV and ambient light sensors are placed in a waterproof box (IP 67) with a viewport. The viewport has a UV-grade Fused Silica glass that is similar to the one installed on the chambers. The temperature and humidity sensors are placed outside the box through a waterproof gland. All the monitored data is continuously stored in an SD Card attached to the Arduino and can be retrieved when the box is opened. This standalone system is shown in Fig. 2(a). The chambers and the monitoring system are placed together for accurate track of the ambient conditions. The collected ambient light intensity and temperature data over one week is presented in Fig. 2(b). The data only over a week is presented to make it legible. Some of the days were sunny, while some were cloudy over the one month test duration.


(a)



(b)

Fig. 2 (a) ambient light and temperature measurement system, and (b) ambient light intensity and temperature measured during experimentation.

# III. RESULTS AND DISCUSSION

## A. *Comparison of arced and unarced gas mixtures*

The unarced and arced gases are studied using a gas chromatograph (GC) (Agilent 7890B) and a mass spectrometer (MS) (Agilent 5977A) for their composition. The gas is injected through an automatic gas sampling valve with Helium (CP grade N5.0 99.999% purity) as the carrier gas. The gas products are identified using National Institute of Standards and Technology (NIST) library. The GC is flushed with He gas to remove the traces of atmospheric air and humidity (if any) before letting the test sample. Each sample is tested three times.

The gas analysis results obtained for the unarced and arced mixtures are presented in Fig. 3. Figure 3(a) shows a full scale chromatogram of the samples, while Figures 3(b) and 3(c) show magnified regions within the same chromatogram where the byproducts are identified. In all the figures, the graph of unarced mixture is compared with the arced mixtures (200 and 400 breakdowns). The list of identified byproducts, their $LC_{50}$, molecular weight, atmospheric lifetime, and GWP are presented in Table I.

The peaks in Fig. 3(a) correspond to $O_2$, $CO_2$, and $C_4F_7N$ respectively. Since the mixture is composed principally of these compounds, the peaks have the high count for these gases. However, the byproducts formed do not show a very high count. Therefore, the chromatogram is magnified at certain regions to detect and classify the byproducts. Due to high concentrations of the base gases in the mixture, the peaks are very likely saturated and it is recommended that these peaks are not used for comparing the relative concentrations.

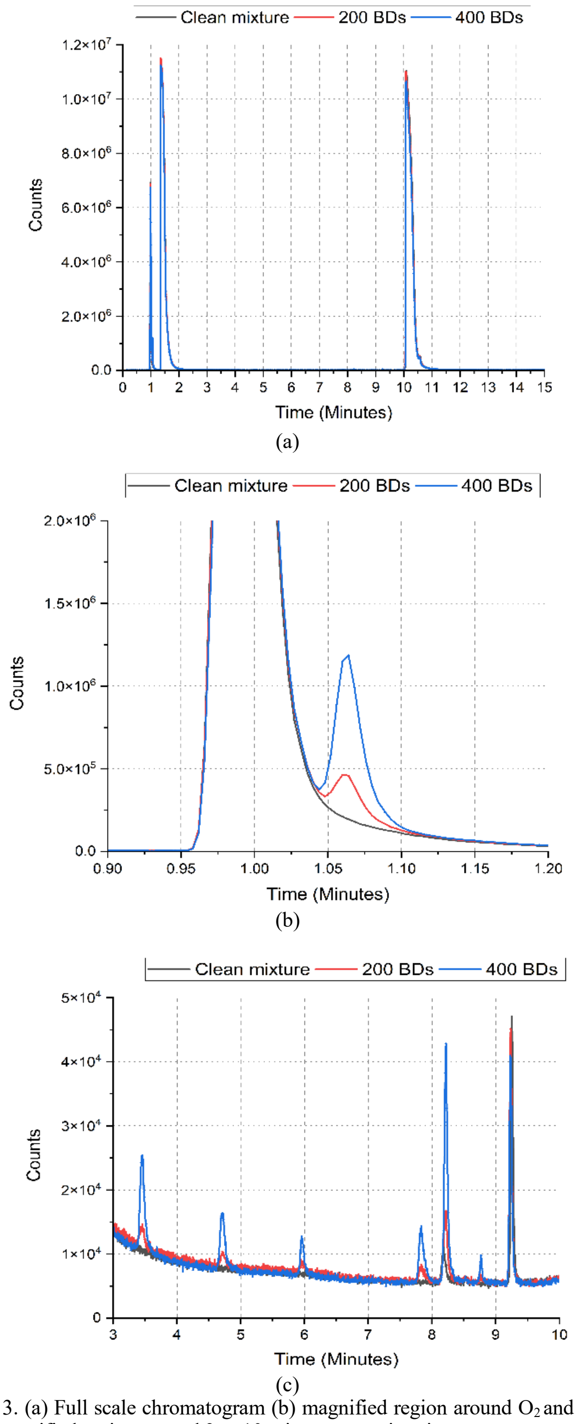



Fig. 3. (a) Full scale chromatogram (b) magnified region around $O_2$ and $CF_4$ (c) magnified region around 3 to 10 minutes retention time.

Fig. 3(b) shows the region around the $O_2$ and $CF_4$ peaks. Carbon monoxide (CO) is not detectable following the total ion chromatogram peak detection elutes very closely to molecular oxygen ($O_2$), and thus it is not possible to separate these peaks. CO is listed in Table I as it was detected using the deconvolution peak detection. $CF_4$ is observed to increase with increase in number of breakdowns. Figure 3(c) shows majority of the detected decomposition arcing by-products such as $C_3F_8$, $CF_3CN$, $C_3F_6$, $C_4F_{10}$, $C_2F_5CN$, $C_2N_2$ and $C_3HF_7$ which is a known impurity of the pure $C_4F_7N$. The content of all these compounds increases with the number of breakdown events. All the results obtained in this study are very much in agreement with previous findings [10].

### *B. Comparison of arced and unarced gas mixtures after subjecting to ambient light*

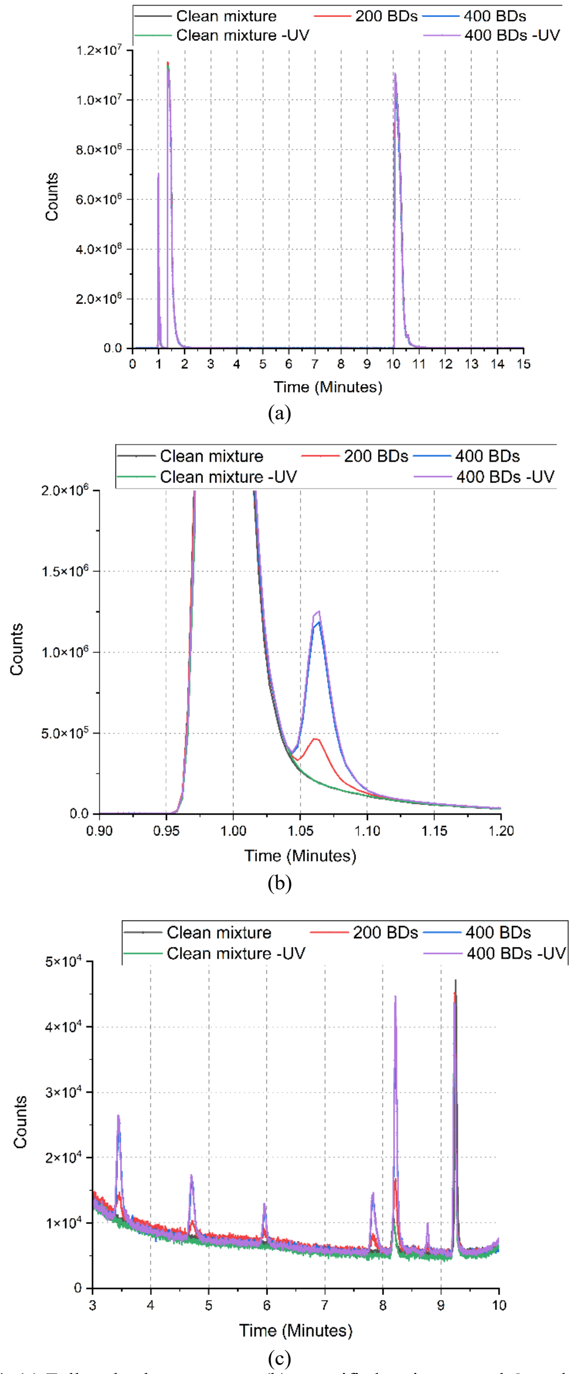



Fig. 4. (a) Full scale chromatogram (b) magnified region around $O_2$ and $CF_4$ (c) magnified region around 3 to 10 minutes retention time.

Both arced and unarced gas mixtures are placed in ambient light for 30 days and later their gas analysis is carried out using the GC equipment described in Section IIIA. The gas analysis results are presented in Fig. 4. The results show that there is no effect of the ambient light on the mixture or on the byproducts formed.

Although, there is a slight increase in $CF_4$ concentration, the increase is within the accuracy range of the instrument which may suggest that there is no significant change in the $CF_4$ concentration. The study concludes that there are no significant changes in the amount or number of gaseous by-products due to ambient light exposure over a period of one month. Moreover, the chambers are monitored once a week for formation of solid byproducts. Following a visual inspection, it was observed that there were no solid byproducts formed during this process.

Table I. List of detected by-products, corresponding LC50, Molecular weight, atmospheric lifetime, and GWP.

| Gas | LC50 | Molecular weight (g/mol) | Atmospheric lifetime (years) | GWP (100 years) |
|---|---|---|---|---|
| $O_2$ | - | 31.999 | - | 0 |
| $CO_2$ | 470000ppm–30min [15] | 44.01 | 5-200 [12] | 1 |
| $C_4F_7N$ | | 195.04 | 30 [11] | 2100 [11] |
| CO | >10000ppm – 4h [13] | 28.010 | - | 1.6-2 |
| $CF_4$ | 20000ppm – 4h [1] | 88.004 | 50000 [13] | 6630 [16] |
| $C_3F_8$ | 90000ppm – 4h [1] | 188.02 | 2600 [13] | 8900 [16] |
| $CF_3CN$ | 250ppm – 4h [2] | 95.02 | - | - |
| $C_3F_6$ | 3060ppm – 4h [1] | 150.02 | 3000 [16] | 9310 [16] |
| $C_4F_{10}$ | - | 238.03 | 2600 [16] | 9320 [16] |
| $C_2F_5CN$ | 2730ppm – 4h [1] | 145.03 | | - |
| $C_2N_2$ | 175ppm – 4h [1] | 52.03 | 1.2-24 [17] | 3.8-96 [17] |
| $C_3HF_7$ | 788698 ppm | 170.03 | 36 [16] | 3140 [16] |

## IV. Conclusion

In this work, the effect of natural ambient light on the fresh and byproduct pervaded gas mixtures subjected to multiple electric arcs is qualitatively assessed. The following conclusions are drawn from this study:

- Ambient light does not affect the fresh gas mixture on short term exposure upto one month.
- Ambient light does not have any significant effect on the byproducts formed from arcing when exposed for short term upto one month.
- The composition of the mixture did not change in unarced and arced mixture when subjected to ambient light for short term upto one month.

This work presents information to the regulatory committees and researchers working in this area about the effect of ambient light on the gas mixtures and their decomposition products. However, this work does not include the effect of ambient humidity. The future scope of this work includes studying the long term effect of ambient light on the gas mixtures and their byproducts with special focus on the ambient UV light. The authors are working towards carrying the above tests for longer duration, of a few months.

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