

Original scientific paper/Izvorni naučni rad

NEW METHOD OF LEAK RATE MEASUREMENT IN SF₆ FREE MEDIUM VOLTAGE SWITCHGEAR USING HELIUM AND AMBIENT AIR

NOVI METOD MJERENJA STOPE CURENJA KORIŠTENJEM HELIJA I AMBIJENTALNOG ZRAKA U SREDNJE NAPONSKIM POSTROJENJIMA KOJA NE KORISTE SF₆ GAS

Ricardo Santa Ana¹, Marvin Muchametow², Manjunath Ramesh²

Abstract: The current medium voltage Gas Insulated Switchgears (GIS) predominantly use Sulphur Hexafluoride (SF₆) as insulation medium. The leakage tests performed on GIS use either SF₆ or Helium medium to ensure gas tightness. However, SF₆ has been strictly regulated for the last years due to the high global warming potential effect on the planet. As a response, new technologies are emerging using air as insulation medium. The present work establishes a basic comparison of the leakage rate in a medium voltage GIS using two different leak detection methods: Helium leak detector and Residual Gas Analyser (RGA). Both methods use Helium and additionally RGA using air as tracer gas.

Keywords: Leakage rate, Medium Voltage Switchgear, SF₆ Free, Air, Helium, RGA

Sažetak: Postojeća srednjenaponska metalom oklopljena postrojenja (MOP) dominantno koriste sumpor heksafluorid (SF₆) kao izolacioni medij. Kako bi se obezbijedila odgovarajuća zaptivenost, ispitivanje curenja gasa iz MOP-a se obično obavlja sa SF₆ gasom ili helijom. Međutim, SF₆ gas je posljednjih godina strogo reguliran zbog njegovog velikog potencijala globalnog zagrijavanja planete. Zbog toga nastaju nove tehnologije koje koriste zrak kao izolacioni medij. Ovaj rad daje osnovnu usporedbu stope curenja u srednjenaponskim MOP korištenjem dvije metode detekcije bazirane na: detektoru curenja helija i analizatoru zaostalih gasova (RGA). Obje metode kao gas za analizu koriste helij, pri čemu RGA dodatno koristi i zrak.

Ključne riječi: stopa curenja, srednjenaponsko postrojenje, SF₆ alternative, zrak, helij, RGA

INTRODUCTION

Designing a GIS includes different factors to be considered such as safety and performance. One of these criteria refers to the gas medium used. Traditionally the Medium voltage GIS predominantly used SF₆ or a mix of SF₆ with other gases as insulation medium. The advantages of using SF₆ are the excellent dielectric and arc-quenching properties. However, the usage of SF₆ signifies a higher damage to the planet since the SF₆ gas is considered a greenhouse gas with a Global Warming Potential of 22,800 rated by the European Parliament and the Council of the European Union [1]. Furthermore, the Kyoto protocol in its annex A established the SF₆ also as a potential greenhouse gas guiding the countries to reduce the usage [2].

The rigid SF₆ regulations are pushing the industry to develop new emerging technologies that allow the eco-friendly usage of GIS. One of the most promising is the development of GIS using dry air as insulation medium [3]. Nonetheless, as any new product, international acknowledged organizations such as, International Electrotechnical Commission (IEC) and Electrical and Electronic Engineers (IEEE) in their standards IEC 62271-1-2017 and IEEE C37.20.9-2019 with IEEE C37.100.1-2018 respectively, demand leakage tests to ascertain a suitable lifespan of at least 30 years in the case of Sealed pressure systems [4]. The leakage test in SF₆ GIS is commonly realized with Helium using a vacuum chamber or plastic foil depending on the equipment size and practicality. The test procedure and device must comply certain order of sensitivity. According to the IEC 62271-1-2017 the leak rate shall be in the order below of 10⁻⁷ mbarl/s [4].

This paper describes an analytical helium to air correlation of leakage rates calculation based on the mode of flows and a simple methodology to measure the leakage rate by using Helium leak detector based on mass spectrometry

¹ Technische Universität Berlin, Berlin, Germany

² Nuventura GmbH, Berlin, Germany

ricardo.santaana@nuventura.com

Paper submitted: June 2021 Paper accepted: September 2021

and the RGA. The RGA has an advantage over the Helium leak detector as it can measure partial pressure of Helium, as well as the partial pressure of Hydrogen, Oxygen, Nitrogen, and the ratio O_2/N_2 in percentage.

Based on data collected from the two leak detectors, the leakage rate curves against time show a variation with respect to the gas concentration released. On the contrary, the RGA curves with air show a steadier leakage rate.

The test object is a cubicle representing a GIS installed in a testing chamber with different concentrations of Helium in the testing chamber.

Helium is chosen as principal working fluid for both methods and as additional test, RGA uses air as working fluid. Yet, the Helium usage increments the capital investment, and it is ideal to perform the tests using air instead of Helium, which will have a beneficial economic impact.

1. STANDARDS FOR GAS INSULATED SWITCHGEARS

IEC and IEEE provide an important and helpful guidance when a GIS is being built, since both organizations specify parameters to be fulfilled by the manufacturers and end users. Among the different parameters, it is the tightness and leakage rate that the GIS must comply. Table I shows the principal standards to manufacture a GIS and the tightness sections.

Table I: Switchgear Standards

Organization	Standard number	Year	Tightness sections
IEC	IEC 62271-1	2017	5.11, 6.2, 6.10, 6.16, 7.8 and 8.5
IEEE	IEEE C37.20.9	2019	6.13, 7.8, 8.5 and 11.3
IEEE	IEEE C37.100.1	2018	6.2, 6.15, 7.9, 8.5, and Annex G

The standards in the Table I, establish the minimum sensitivity that the device shall have, to detect the leakage rate. IEC 62271-1 also recommends the type of test procedure, tracer gas, and minimum requirements to perform such test. The test procedure may change whether the GIS is tested as Type test or routine test or for the purpose of revealing flaws in material or construction, which can be performed on site as well.

1.1. Tracer gases

A tracer gas is used to find leak paths, since it is detectable by using a leak detector along with the correct test procedure. The standards recommend the tracer gases such as SF_6 , Helium, mixture of SF_6 or the specified gas that the GIS is using in normal operations. However, Helium is used due to its excellent chemical behaviour, and

the industry experience working with it as well as the current instruments to measure its presence. Table II shows the molecular weight and the viscosity of the principal gases used in the present paper.

Table II: Physical properties of Helium and Air

Gas	Molecular weight (g/mol)	Viscosity at 25°C (Pa*s)
Helium	4.002	18.3×10^{-6}
Air	29.9	19.7×10^{-6}

2. GAS LEAKAGE TEST PROCEDURE AND METHOD

Standards recommend specific test procedures and methods that have traditionally been performed in the industry. In serial production terms, Helium leak detector (method) along with either pressurized system mode or pressurized enveloped mode (test procedure) is performed, as depicted in Figure 1. Such procedures and method can provide a leakage sensitivity of up to the order of 10^{-12} mbarl/s.

Yet, if the method and procedure are wrongly combined or performed, the leakage sensitivity will be highly diminished [5].

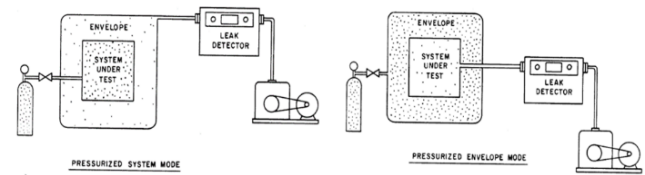


Figure 1: Test procedures Pressurized system or envelope mode [5]

2.1. Leakage sensitivity

The leakage sensitivity from the leak detector and leak test are different. According to William Marr there are other factors that may affect the leakage sensitivity when performing the test procedure [5]: Physical properties of the gas, vacuum pumping speed with respect to volume test and leak detector position.

2.2. Leakage rate

The equation (1) expresses the leakage rate of either liquid or gas, which is considered at standard conditions:

$$F = \frac{\Delta P \cdot V \cdot T_R}{\Delta t \cdot T} \tag{1}$$

ΔP represents the pressure difference in the system under test, V the test volume, T_R the standard temperature, Δt test duration and T the vessel or system temperature.

2.3. Leak rate using mass spectrometer

The Helium leak detector is based upon a mass spectrometer and counts with an inherent vacuum pump. In broad terms, the RGA is similar to the Helium leak detector, since it is also a mass spectrometer, although it does not count with an inherent vacuum pump. The vacuum pump is an important variable when calculating the leakage rate, either in RGA or Helium leak detector as the leakage rate (Q) is defined in the equation (2).

$$Q = PS \quad (2)$$

P is the gas partial pressure detected, and S is the pumping speed used to perform the test.

This equation shall be used only in the case of the RGA test procedure in order to know the leakage rate.

2.4. Gas to gas correlation of leakage rates and mode of flows

The gas-to-gas correlation allows the realization of test procedures using a different tracer gas than the actual gas used in the GIS. It is defined as follows:

$$\frac{Q_A}{Q_B} = \sqrt{\frac{T_A}{T_B}} \cdot \sqrt{\frac{M_B}{M_A}} \cdot \left(\frac{P_1^2 - P_2^2}{P_3^2 - P_4^2} \right) \quad (3)$$

Q_A denotes the known leakage rate of gas A , Q_B the unknown gas leakage rate of gas B , M_{A-B} the molecular weight of two different gases, P_1 and P_3 are the inlet pressure and P_2 and P_4 are the outlet pressure and finally T_A and T_B the absolute temperature of each gas.

The use of equation (3) is recommended if the mode of flow is molecular. The table III with the different mode of flows is taken as reference to identify the mode of flow.

Table III: Mode of flows [5]

Mode of flow	Leakage rate (mbarl/s)
Turbulent	$>10^{-2}$
Laminar	10^{-1} to 10^{-6}
Transition	10^{-4} to 10^{-7}
Molecular	$<10^{-7}$

2.5. Residual Gas Analyser

The vacuum industry contributes with specialized methods or devices to detect leakages in vacuum environments. The RGA is frequently used in vacuum environments under the order of 10^{-4} mbar to detect leaks of specific gases or air. The faster response from preventing such leakages can safeguard the vacuum environment integrity. The RGA, not only detects the partial pressure of gases like: Hydrogen, Oxygen, Nitrogen, and Air but also

detects H₂O [6]. By itself, the RGA is only able to detect partial pressure and not able to detect the leakage rate. Furthermore, RGA by its own is not capable to produce vacuum inside the test system and requires a vacuum pump system. If the test system has a large volume, it will need an auxiliary pumping line to reach the minimum vacuum of order 10^{-4} mbar. Otherwise, the RGA burns out. The RGA counts with an ion source that has a hot filament, this ion source can be either closed or open. If it is a closed ion source, the RGA is better protected, and it works at higher pressure order between 10^{-4} and 10^{-2} mbar. However, the selection of an open or closed ion source depends on test system working operation and vacuum pressure.

The leakage sensitivity can be considerably increased if the test system or component along with the RGA metal components are baked to get rid of residual moisture inside the test object, around 300°C [6]. It might not be possible to bake at such high temperatures considering the maximum operating temperature of the components of the test object such as switchgear, which is limited to 115°C . The outgassing phenomenon occurs when a system or RGA has been exposed during a considerable time at atmospheric pressure, and it may lead to a misreading. Yet baking the components entail the increase of capital cost and cycle time.

2.6. Test procedure with RGA and Helium leak detector

Pressurized envelope mode test procedure is used to perform the tests since the test object was designed to withstand the differential pressure of one bar. Therefore, pressurized envelope mode test procedure is suitable to perform RGA and Helium leak detector tests.

2.6.1. Gas concentration

The gas concentration is the amount of a tracer gas released inside the envelope/testing chamber, which is previously filled with ambient air and ambient pressure. In the present work, it is the Helium released in the testing chamber according to the test object volume ratio.

The test procedure was devised based on a volume ratio between test object and testing chamber. The volume of the test object (V_{to}) is 37.10 litres. The volume of the test chamber, when the test object is inside the test chamber (V_{tc}) is 115 litres. The volume of gas released in the testing chamber is proportional to the internal test object volume. Table IV denotes the test object and testing chamber ratio calculation to the different gas concentrations.

The air contains 5.222 ± 0.017 ppm of Helium by volume [7], in broad terms it is around 5×10^{-4} % of Helium in air. Therefore, the Helium background, before performing any Helium leak detector test, shall be removed. The Helium leak detector has a feature that allows the removal of Helium background. In the RGA case, Helium background removal is not possible. Therefore, in RGA tests Helium background will be considered as negligible.

Table IV shows 0% gas concentration implied by the removal of Helium background. 25% gas concentration refers to Helium background removal and then injecting 10 litres Helium in the testing chamber. The same applies for the rest of gas concentrations

Table IV: Gas concentrations

Test object internal volume (%)	Gas concentration in testing chamber (%)	Helium released (litres)
0	0	0
25	9.98	10
50	19.95	18.5
75	29.93	27.83
100	39.90	37.10

2.6.2. Test sequence

The test sequence used is similar to ASTM E1603/E1603M-11 [8], which recommends plotting the curves obtained from the data collected from the two devices. Such standard displays a theoretical curve, as it is depicted in Figure 2, which displays how the test should behave. The curve starts with low leakage rate measuring and then has a steady slope increasing the leakage rate and reaching a saturation leakage rate value. The test sequence considers signal response, time, steady leakage rate value or steady partial pressure as well as the Helium background level removal and ultimately, make the test repeatable.

Each test is repeated three times for each gas concentration. The first test defines the minimum test period. The minimum test period is used to perform the consecutive tests.

As a baseline, tests are performed without Helium gas concentration with the goal to compare the behaviour with the minimum gas concentration and with the highest gas concentration.

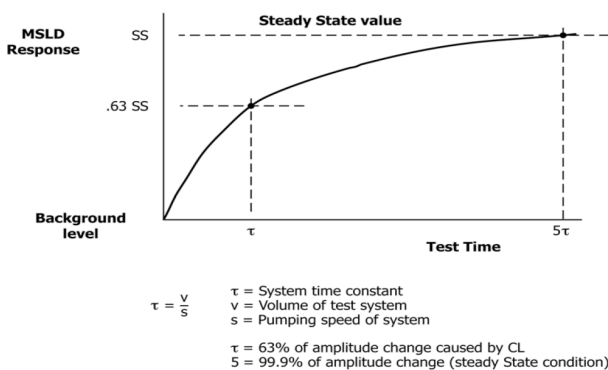


Figure 2: System time constant curve [8]

3. EXPERIMENTAL SETUP

The experimental setup is a modular design to use both devices without affecting the general setup when exchanging from one device to another.

The setup has a single connection to the devices, either RGA or Helium leak detector, which allows a modular connection. The gas concentration, its quantification and releasing in the testing chamber are carried out and controlled by using a thermal flow controller. The test object is directly connected to the leak detector devices. The gas inlet is supplied by a Helium bottle with the pressure regulator capable to provide until 10 bars of working pressure. The pressure regulator provides an inlet pressure to the thermal flowmeter of 5 bar and the flowmeter releases the Helium gas to the testing chamber with a pressure of 1 atm.

The testing chamber is provided with an internal seal to prevent leakages when Helium is released into the chamber. Furthermore, the chamber lid is latched with a clamp when the tests are being carried out, preventing leakages. On the other hand, a fan is placed inside the testing chamber to distribute the Helium uniformly and avoid gas concentration accumulation only at the top of the testing chamber.

The test object is a welded pipe with lids and bolts. The pipe at the bottom is gas tight welded, and Figure 3b shows the top with an internal groove to place an O-ring, while the lid has a bolt hole circle to fix it to the pipe. Additionally, the lid is designed to place valves and make the connection to the devices so that the vacuum pumps could evacuate the test object.

The connection between the test object and the devices was required to use vacuum technology accessories, which are suitable to the correct connection to the Helium leak detector and RGA. Figure 3a shows the test object with the accessories needed to connect the devices.

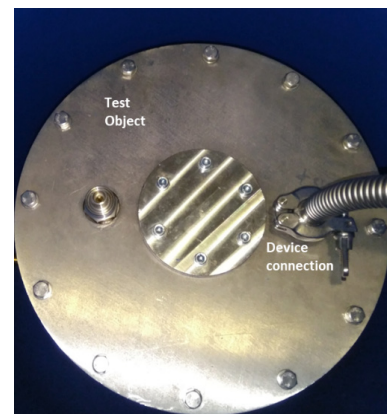


Figure 3.a: Test object

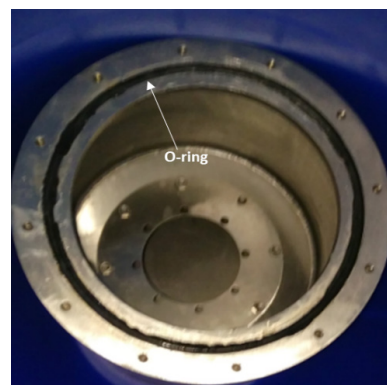


Figure 3.b: Test object without lid

Figure 4 shows the different arrangements, with RGA and Helium leak detector. In the RGA case, it counts with an external turbomolecular pump and needle valve which is manually activated when the test object reaches the vacuum pressure order of 10^{-6} mbar.

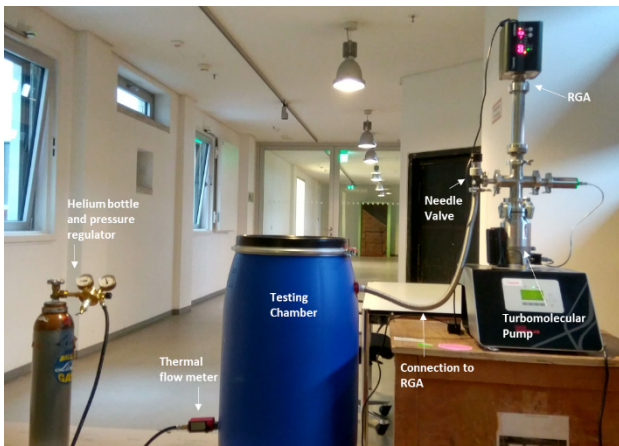


Figure 4.a: RGA arrangement [9]

Unlike the RGA, the Helium leak detector has an inherent turbomolecular pump, which activates the mass spectrometer when reaches the order of 10^{-4} mbar.

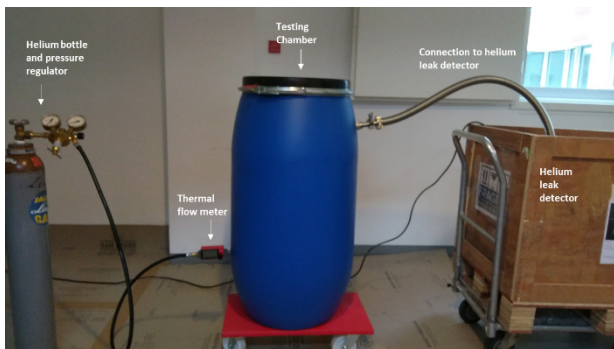


Figure 4.b: Helium leak detector arrangement [9]

4. RESULTS

4.1. Helium leak detector

The Helium leak detector has a display showing the Helium leakage rate, which varies constantly, in real time. The variations make it difficult to determine a constant value of leakage rate, as the leakage rate changes frequently but after certain time it states the order 10^{-8} mbarl/s. However, a constant value is difficult to determine when performing the test. This can be visualized at the end of each curve. Taking as reference Figure 6, the order is 10^{-8} mbarl/s, which is constant, but the constant value is varying in the time of 600 until 800 seconds having a value from 1×10^{-8} mbarl/s to 2×10^{-8} mbarl/s, which it may be considered as a constant value and stopping the test. Due to the aforementioned reason, the test duration was shorter than planned.

The Figures from 5 to 8 show the average of three Helium tests with different gas concentrations, as it is stated in table IV, during a test period of almost 900 seconds (15 min).

Figure 5 shows the 25% gas concentration curve with 0% gas concentration curve. In 0% gas concentration case the test duration was around 600 seconds (10 minutes).

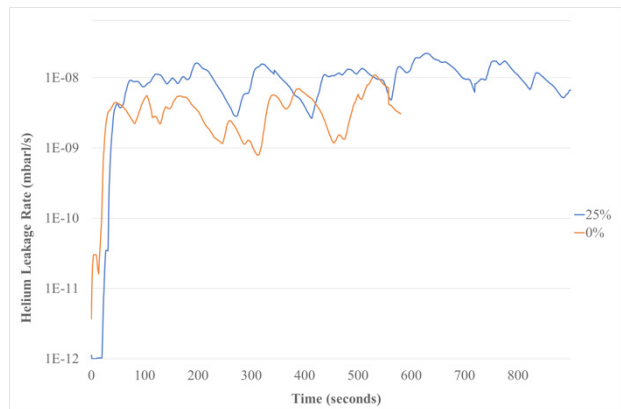


Figure 5: 0% with 25% gas concentration [9]

It is seen in the plot that both test behaviours are similar in the first seconds, however the 25% tests tend to have a higher peaks and fluctuations in the order of 5×10^{-9} mbarl/s until 1.5×10^{-8} mbarl/s order.

The test time without gas concentration was not enough to conclude a tendency, but its last data is indicating a fall in the leakage rate and in addition most of the data is showing a leakage rate within the order 5×10^{-9} mbarl/s with a typical data above 1×10^{-8} mbarl/s.

Figure 6 shows the average of three Helium tests with 50% gas concentration. Unlike the 25% gas concentration, 50% shows the theory curve described in section 2.6.2, where it starts with low gas concentration and after certain time increases the leakage rate until it starts to normalize in the order of 2×10^{-8} mbarl/s.

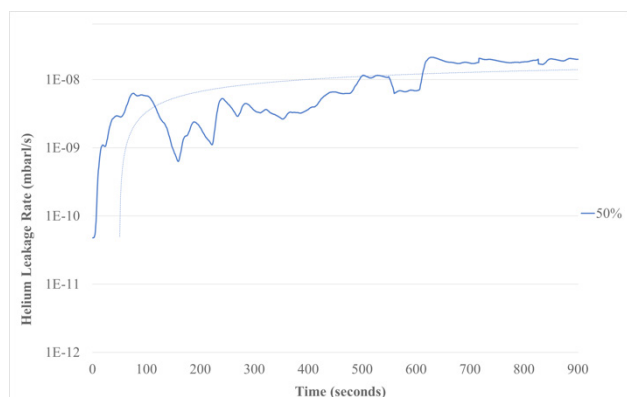


Figure 6: 50% gas concentration [9]

Figure 7 depicts the average of three Helium test with concentrations of 75%.

The 75% curve shows a better resemblance to the theory curve stated in ASTM E1603/E1603M-11 [7], it starts with low leakage rate and increases after some time. The slope is visible and starts to normalize to become a steady leakage rate above 3×10^{-8} mbarl/s.

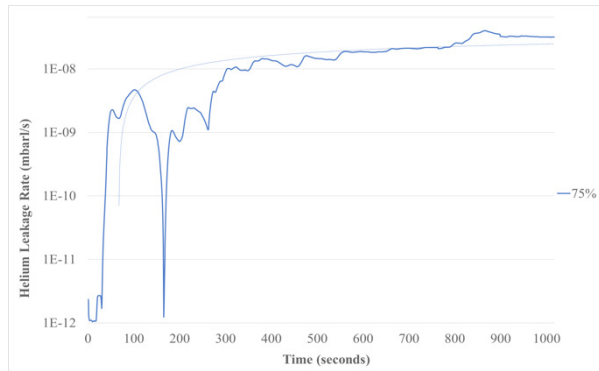


Figure 7: 75% gas concentration [9]

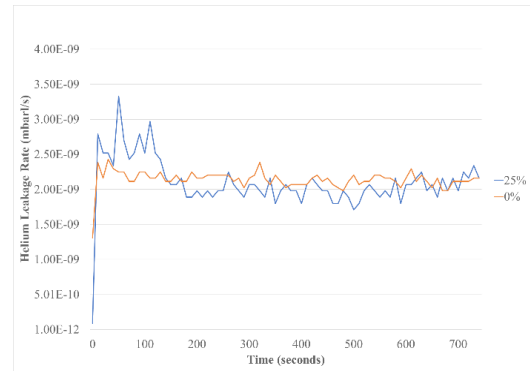


Figure 9: 25% and 0% gas concentration [9]

Figure 8, like the last Figure shows a curve with average of three Helium test with 100% gas concentration.

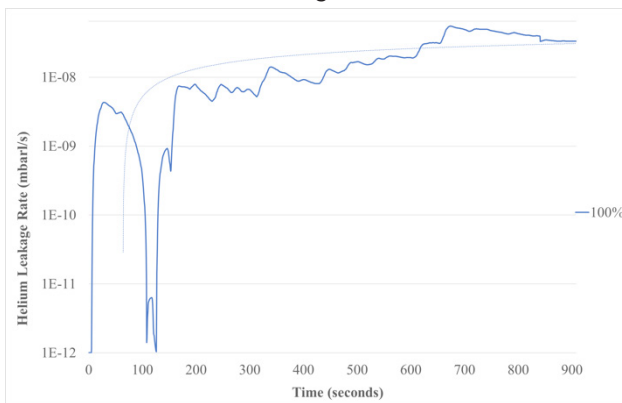


Figure 8: 100% gas concentration [9]

The 100% gas concentration also shows a tendency as in the Figures 7 and 6. It starts with low leakage rate and then has an increment. However, the duration of the test time was not enough to turn the end of the curve into a steady value leakage just above 3×10^{-8} mbar/s.

4.2. RGA - Helium

For the RGA as it is mentioned in section 2.5, it is recommended to bake the test object and some RGA components to have a more precise measurement, although it includes an additional cost and the cycle time increases. It is still worth performing the test without baking to observe the differences to the results of the Helium leak detector. Unlike the Helium leak detector, the RGA needs an additional step to calculate the leakage rate, as shown in equation (2), since the RGA only detects the partial pressure.

The Figures from 9 to 12 show Helium curve tests one test per respective gas concentration. The test duration is approximately 720 seconds (12 min).

The Figure 9 depicts the RGA readings of 25% and 0% gas concentration.

As Helium leak detector curves (Figure 5), in the Figure 9 both curves behave similar and steady within the order of 2×10^{-9} mbar/s. Yet, 25% plot shows some high peaks at the beginning and after certain time it behaves even below 0% with some higher peaks at the end.

In the case of Figure 10, the 50% gas concentration curve has low leakage rate when it starts and increases after few minutes in the order just below 3×10^{-9} mbar/s. Nevertheless, the time was not enough to allow the data collection to reflect a steady value at the end of the curve.

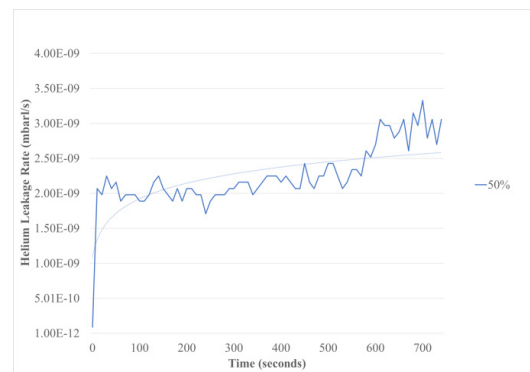


Figure 10: RGA 50% gas concentration [9]

Figure 11 reflects a similar tendency as Figure 10. The 75% gas concentration starts higher than in the middle of the test. Nonetheless, after several minutes a slope is visible tending to increase, and it starts to normalize. Once again test time was not enough to have a better visual reference.

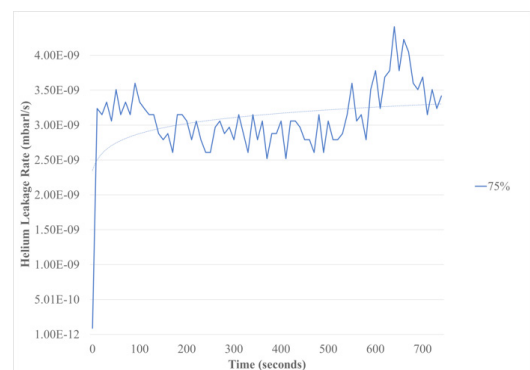


Figure 11: RGA 75% gas concentration [9]

The reading shown in Figure 12, unlike the Figures from 9 to 11, reflects the theoretical curve tendency mentioned in section 2.6.2., 100% gas concentration curve shows peaks at the beginning, then falls, and increases after several seconds. Time was not sufficient to define a tendency at the end of the test.

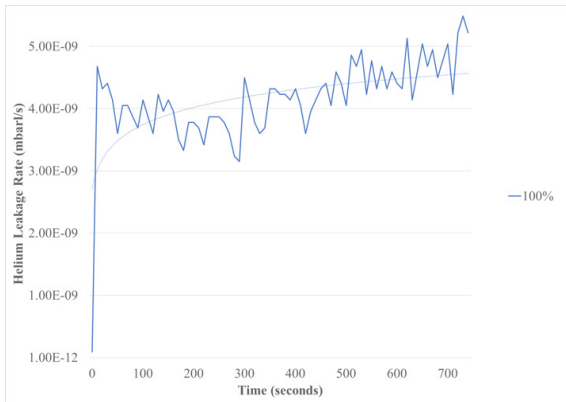


Figure 12: 100% gas concentration [9]

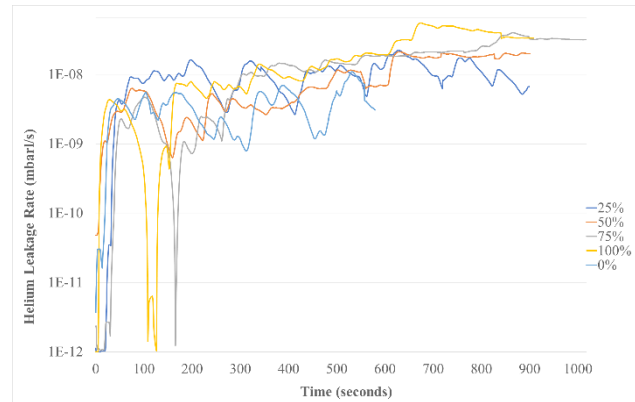


Figure 14: Helium leak detector tests [9]

4.3. RGA - Ambient Air

Considering the RGA – Helium results and Helium leak detector, it is of interest to know and compare how the RGA – ambient air curve behaves.

Two tests with ambient air were performed. The duration time is the same as the RGA – Helium tests. Also, as in RGA – Helium, the test object was not baked.

Figure 13 shows a steady leakage rate at the beginning and at the end reflects a high peak from near to 8.5×10^{-5} mbarl/s until just below 8.7×10^{-5} mbarl/s. The test time was not enough to determine a clear tendency of a steady value.

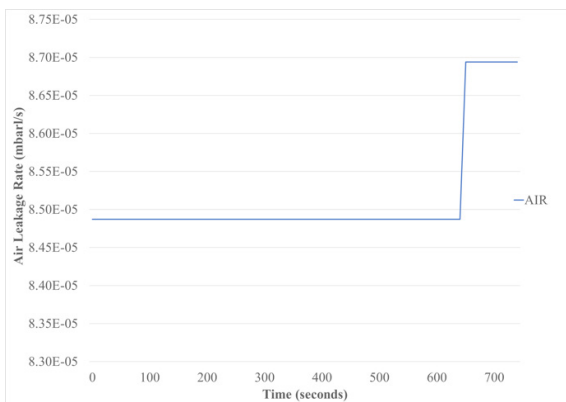


Figure 13: RGA – 100% ambient air [9]

The goal was to determine the leakage rate with a change in Helium gas concentration. The data plotted in Figure 15 was collected after the leakage rate has stabilised (after 800s).

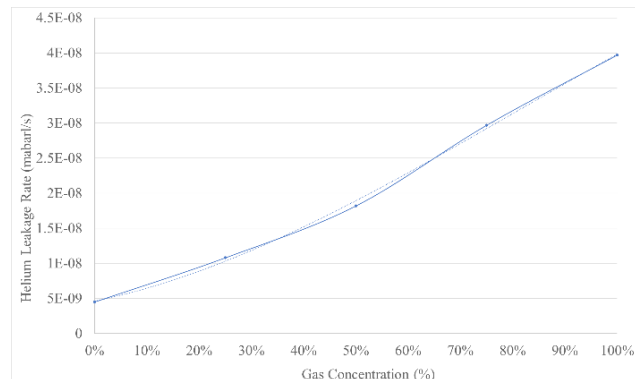


Figure 15: Helium leak detector tests, leakage rate – Gas concentration [9]

Figure 15 shows a linear correlation between tracer gas concentration and leakage rate. Those results can be used as a preamble for future test setup designs for GIS. This enables the use of less Helium for each test iteration and thus saving valuable resources. However, the test duration time and the point of leakage rate stabilisation should be treated with a higher accuracy in the future in order to improve the reliability of the results. Thus, a higher accuracy of the correlation between tracer gas concentration and measure leakage rate can be determined.

5. CONCLUSIONS

5.1. Helium leak detector

Using the Helium leak detector with different Helium concentrations as tracer gas shows a leakage rate of the order of 10^{-8} mbarl/s. Figure 14 shows all tests performed with varying Helium concentrations and the measured leakage rates.

On the other hand, the plots showed molecular behaviour and it is possible to use equation 3 in the case that if it is interest of knowing the correlation from Helium leakage rate to Air leakage rate. This correlation may help to develop the new test equipment design. This present work is not showing such correlation as it is not within the scope.

5.2. RGA - Helium

The tests using the RGA showed that the leakage rates with different gas concentrations were in the order of $x10^{-9}$ mbarl/s. Figure 16 shows all the RGA tests with leakage rates from 0% to 100%. It is visible that the leakage rate only increases significantly beyond 50% gas concentration.

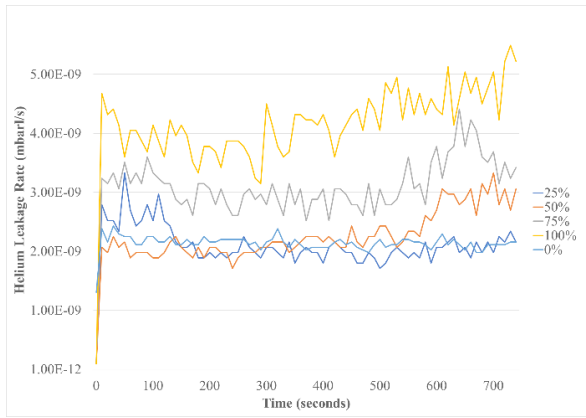


Figure 16: RGA tests [9]

To compare the graphs, the leakage rate must be collected after the trendline has stabilized. Figure 17 depicts such behaviour. The data plotted was collected from the last data from the RGA single curves when the leakage rate starts to stabilize.

Figure 17 shows an approximately linear behaviour similar to Figure 15 (using the Helium leak detector). However, the slope lies in the order of 10^{-9} mbarl/s in comparison with the curve of the Helium leak detector (10^{-8} mbarl/s). It is worth noting that the steepness increases significantly after an increase of 50% gas concentration.

In order to improve the accuracy of the test using the RGA extending the test duration, as well as removing the background Helium before performing the test is important. However, the RGA can be a good reference to be used as preamble to design future test setups.

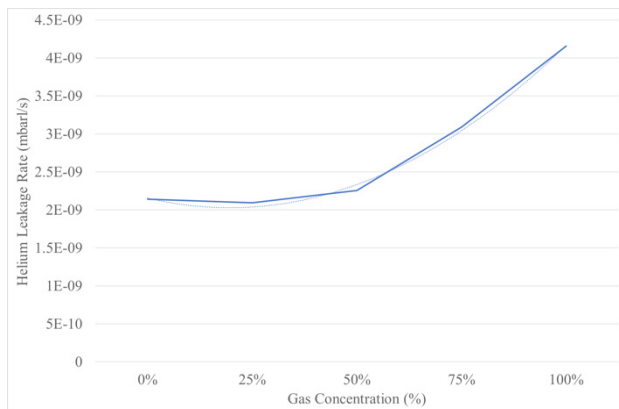


Figure 17: RGA tests, leakage rate – Gas concentration [9]

5.3. Helium leak detector and RGA

Both devices have their own advantages and disadvantages, yet the devices can be used for the same purpose. RGA shows a good sensitivity and fulfils the IEC and IEEE standards sensitivity requirements ($<x10^{-7}$ mbarl/s).

Either device requires a capital investment, the RGA can diverse to more than one or two specific gases but it will require more testing to find the correct leakage rate. Figure 18 shows both devices with their leakage rate in accord with their respective gas concentration.

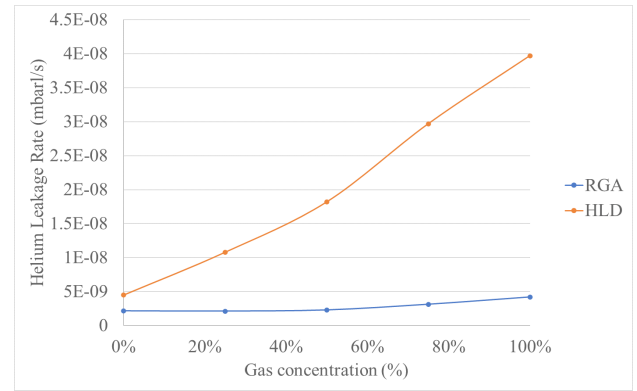


Figure 18: Helium leak detector and RGA [9]

The difference is remarkable, and it can be explained by the different vacuum pressures in the test. The RGA uses a turbomolecular vacuum pump with higher performance than the Helium leak detector. The Helium leak detector reached a vacuum pressure of $x10^{-4}$ mbarl/s and the RGA reached $x10^{-6}$ mbarl/s.

Other reason of having a remarkable difference between RGA and Helium leak detector could be the missing step of baking the object.

For now, the RGA - Helium usage is not feasible as it needs more test procedure development that involves baking and time efficiency. However, in the long term this can be feasible as next level to measure leakage rate with Helium.

5.4. RGA using ambient air as tracer gas in vacuum

By trying to use ambient air as a tracer gas and to detect a leakage in a vacuum environment, some remarkable differences are found, like higher leakage rate readings than Helium measurements. The high leakage rate measurement is due to the outgassing phenomenon that occurs when a body, which has been exposed to atmospheric pressure, is being evacuated. Small molecules of air are stored in walls surface and such molecules are detected by the RGA during testing. This leads to a significant experimental error, measuring the air molecules from the surfaces and not through the actual leakage. Therefore, it is essential for future research to bake the specimen as well as the components of the RGA before testing, to remove air molecules from the surfaces. Then ambient air can be used as a tracer gas and detected in a vacuum.

Once the RGA – Helium results are similar to Helium leak detector it could move to the next level, that is to make comparable RGA – Helium results with RGA – Air results. Hence the RGA usage at this stage is not feasible to apply it accurately.

REFERENCES

[1] European Union: Fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006, Official Journal of the European Union, no. 517/2014, pp. 195-230, 16.04.2014

- [2] United Nations: "Kyoto Protocol," 1998. [Online]. Available: <https://unfccc.int/resource/docs/convkp/kpeng.pdf>. [Accessed 27 October 2020]
- [3] "Nuventura," [Online]. Available: www.nuventura.com. [Accessed 20 May 2021].
- [4] IEC62271-1: High-voltage switchgear and controlgear - Part1: Common specifications for alternating current switchgear and controlgear, Switzerland: Geneva, 2017
- [5] J. W. Marr: Leakage testing Handbook, New York, Schenectady, 1969
- [6] "Leybold Products", 2021, [Online]. Available: <https://www.leyboldproducts.com/products/measuring-and-analysis-instruments/residual-gas-analysis/2941/leyspec-view-100s?c=16931>. [Accessed 21 May 2021]
- [7] B.M. Oliver, James G. Bradley, H. Farrar: Helium concentration in the Earth's lower atmosphere," *Geochimica et Cosmochimica Acta*, vol. 48, no. 9, pp. 1759-1767, 1984
- [8] ASTM E1603/E1603M-11: Standard practice for Leakage Measurement using the Mass Spectrometer Leak detector or Residual Gas Analyzer in the Hood Mode, USA: Pennsylvania, 2011
- [9] R. Santa Ana: Methodological test equipment design and prototyping to measure dry air / helium leakage rate in medium voltage gas insulated switchgear tanks, Berlin: Technische Universität Berlin, 2021

BIOGRAPHY

Ricardo Santa Ana was born in Queretaro, Mexico, in 1989. He received his B.sc. degree in mechanical engineering in 2012 at Instituto Tecnológico de Queretaro and currently he is on his M.sc. studies at Technische Universität Berlin. He has previous experience in the development of equipment for the Oil & Gas industry.

Marvin Muchametow was born in Berlin, Germany, in 1991. He received the B.sc. and M.sc. degrees in mechanical engineering from the Technische Universität Berlin in 2014 and 2018 respectively. He is currently Product Design Leader at Nuventura GmbH and developing SF₆-free medium voltage gas insulated switchgear.

Manjunath Ramesh was born in 1986 and has master's in electrical engineering from RWTH Aachen in 2011. He has experience in high and medium voltage switchgear. His interests are in dielectric breakdown, SF₆ free GIS, compact switchgears, DC breaking. Currently he is the founder of Nuventura GmbH.