ALTERNATIVE GASEOUS INSULATION FOR GITL USING N_20/N_2 GAS MIXTURES – DIELECTRIC PERFORMANCE OF 20/80% N_20/N_2 FOR VFT-STRESS

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ABSTRACT

The dielectric strength of different low N_2O content N_2O/N_2 gas mixture ratios have been investigated over a wide pressure rage from $p = 0.1 – 1.0$ MPa for transient voltage stress.

The authors propose low N_2O content N_2O/N_2 gas mixtures for large scale insulation systems, such as gas insulated lines. An admixture of 20 % – 40% N_2O to N_2 is most economical and ecological for high pressure applications above $p = 0.6 – 0.7$ MPa. The only limitation is that no switching operations are required for this gaseous dielectric.

INTRODUCTION

SF_6 is widely used as insulation media for gas insulated switchgears (GIS) and gas insulated transmission lines (GITL) [1] because of its excellent insulation properties such as high dielectric strength and arc quenching ability. Both properties let SF_6 be a very good universal gaseous dielectric. However since SF_6 is a potent greenhouse gas, its use and emission must be decreased, due to its large environmental impact.

SF_6/N_2 mixtures, especially low content SF_6/N_2 mixtures such as 10/90% SF_6/N_2 gas mixtures have been intensively investigated [2 - 7] in the recent years and found to be an appropriate alternative gaseous dielectric insulation media, especially for large scale gas insulated equipment, such as gas insulated transmission lines (GITL), which has been proven by various publications and large scale industry onsite tests [5 - 7]. Since 1999 systematic research for SF_6 free gaseous dielectrics has been performed at University of Darmstadt, besides research for low content SF_6/N_2 gas mixtures.

USE OF N_2O VERSUS CO_2

This section briefly discusses the use of both gases as an admixture component being a selection from a huge variety of insulation gases/gas mixtures. In order to limit the choice of possible gases for electrical insulation extremely an important specification requirement limitation was necessary, see also [8]. Therefore a big variety of insulation gases with their properties have been compiled. First of all, all gaseous dielectrics based on halogen-carbon insulation gases were avoided, because of their very high green house and toxicity potential, being both in partial much higher than that of SF_6 or at least in the same range, although dielectric strength and arc interruption capabilities may be tremendously higher in some extent. Second and most important, the capability to interrupt large currents does not necessarily meet the requirements of large scale insulation system [8]. Considering this important task, specification requirements concerning insulation gases are reduced. More details on this task will be discussed in [8].

Since N_2 is known to be a very inert insulation gas, it was first choice to use this gas a basis for an insulation gas mixture. Good electron buffer properties which enhance synergetic effects, when mixed with other insulation gases [9], small impact on most important non technical parameters, such as environmental aspects, price and availability etc. are characterizing this gas very positively.

As an admixture to N_2 the focus was, besides on the dielectric strength and the environmental impact, on strongly inertness, being from the molecular structure as simple as possible, having a low global warming potential, forming of no conductive decomposition by-products under partial discharge activity and of course being available for large scale industrial applications at low price.

A decision between CO_2 and N_2O had to be drawn [8]. Following shortly the pros and cons for N_2O versus CO_2 have been listed in **Table 1**:

N_2O	CO_2
critical pressure reduced electrical field strength / E/p_{crit}/ kV/(mm × MPa)	
40.7*[10]	32.1[11]
dew point [10, 12] T_d / degree celsuis	
-88.5	-78.5
thermal conductivity [11] λ / (W/ (m × K)) at 0° C	
0.0174	0.0142
GWP [11]	
310	1
Toxicity	
Concentrations larger than 80 %: lethal. hypoxia possible	Concentrations larger than 20 %: lethal. hypoxia possible

Conductive by-products	
no	Yes
Exothermic reaction (i.e. oxidation)	
Possible, prevent use of oils, grease, silane no mixture with CF Gases	possible
Temperature stability (degradation) / degree celsius	
Stable < 649	600 <
Thermal dissociation υ / degree celsius	
>1500 – 2500 °C	2000 <

Table 1: Pros and cons of pure N_2O versus pure CO_2
*pressure dependent, rising with gas pressure [10].

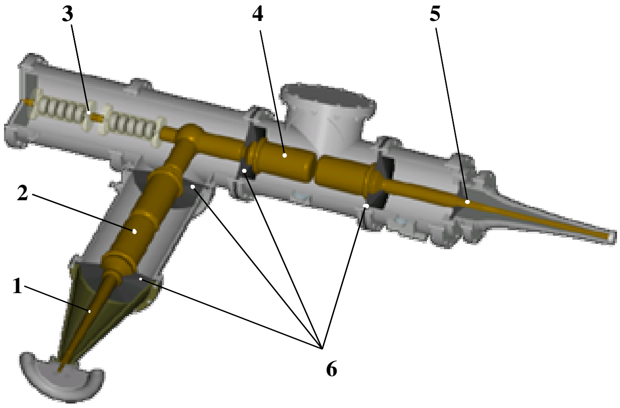

Figure 1: Experimental gas insulated set-up

It is of practical importance, that N_2O and CO_2 are generally related in sense of electrical (i.e. Buffer gas properties, electron attachment and detachment processes), physical and chemical behaviour (inert, similar molecular size, vapour point etc.). Only in some few aspects significant differences between both gases are given (see **Table 1**).

Another important task, is that due to medical application of N_2O, N_2O seems to be peculiar in sense of impact to human health, but besides weak narcotic indication without influence on consciousness, main risk for human health is, that with increasing amount of N_2O, e.g. in a closed room, its application entails a hypoxia. Hypoxia is defined by an absence or deficiency of oxygen from the respiratory system, not reaching human tissues. The air to breath is more or less displaced under such conditions.

This behaviour is well known for gases which have a larger specific weight than air, e.g. SF_6, N_2O and CO_2 etc. and serious care has to be taken, similar to the safety standards to those of SF_6 switchgear used in closed rooms, if such gases are applied in gas insulated equipment. More than 20 % admixture to usual air and inhalation of such gases must be avoided to prevent hypoxia. A more precise discussion on further pros and cons to N_2O and CO_2 will be published [8].

The focus has also to be set on oxidation potential in case of a malfunction, e.g. an earth fault where arcing can cause serious damage to the enclosing tube of the gas encapsulation, therefore low content admixtures of N_2O or CO_2 are generally recommended [8].

Increasing critical pressure reduced electrical field strength E/p_{crit} of N_2O with increasing pressure promises good dielectric insulation performance due to synergetic effects. Long term live time consideration leads to the result that a disadvantageous formation of conductive by-products must be prevented in any case, and therefore we decided to proceed with the investigation of binary and tenary [8] N_2O gas mixtures.

EXPERIMENTAL SET-UP

Fig. 1 shows the applied test set up. The investigational set up is designed as a gas insulated system. All measurements have been performed using a high frequency sinusoidal voltage superimposed to a steep fronted voltage step.

The test voltage is generated by feeding an external DC voltage over a SF_6 insulated bushing (1) to a pressurized switching gap (2). By firing the switching gap a high voltage oscillation is initiated. The oscillation frequency is tuned by a very low inductive ceramic capacitor cascade C_X (3) and an external and variable HV-inductor L_X. The applied resonance frequency was $f_{\text{VFTO}} = 1$ MHz, because it was found to be most critical and of practical relevance [4, 13, 14] as testing frequency. Test voltages up to $V_{\text{VFTO}} = 600$ kV can be generated with this test circuit. The test voltage is applied to a point to plane configuration in the test vessel (4). The test gap has a point to plane configuration, with a free gap width of $d = 30$ mm and a needle shaped protrusion with a length of $l = 10$ mm. The tip of the needle has a diameter of $Ø = 1\text{ mm} = 2r_c$ and is made of stainless and hardened bearing steel (100CrMn6). With these dimension the test gap has a degree of homogeneity (field utilisation factor) according to "Schwaiger" of $\eta = E_{\text{hom}}/E_{\text{inhom}} = 5{,}5$ %. The test gap was coupled to an exponential HV-resistor. The value of the HV-resistor applies to the characteristic impedance of a standard GITL system. All gaseous volumes have been separated by spacers (6).

DIELECTRIC STRENGTH OF VARIOUS N_2O/N_2 GAS MIXTURES

In order to evaluate the best admixture rate of N_20 to N_2, various practical relevant mixture ratios have been investigated. displays a three dimensional graph, in order to get a rough but broad overview of the performance of the dielectric strength, the 50% breakdown voltage $V_{\text{bd-50}}$ respectively, in dependence of the pressure p and additional in dependence of the N_2O/N_2 mixture ratio.

For N_2O admixtures up to 30 % to N_2 and a maximum (critical) pressure of $p_c = 0.55$ MPa a significant area of corona stabilisation can be seen. Additional the breakdown voltage of SF_6 is added to the graph in **Fig. 2**. The most interesting information from the

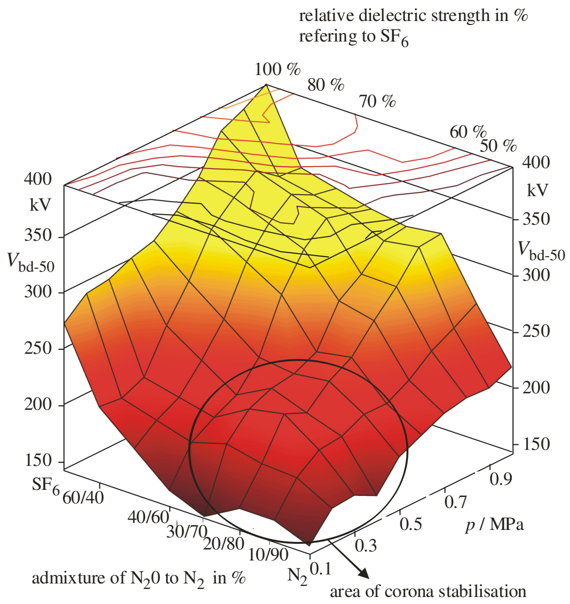

Figure 2: Dielectric strength of various N_2O/N_2 gas mixtures

graph are the isoclines, which indicate the relative breakdown voltage, referring to the breakdown voltage of pure SF_6. The largest gradient of the breakdown voltage is of interest, because it indicates clearly a large breakdown voltage drop or rise. As can be easily seen from **Fig. 1**, the 60 % isocline separates two characteristic areas. The first area, where the breakdown voltage drops distinctively with decreasing gas pressure and lower N_2O admixture and a second area. The second area is a plateau of the dielectric strength for high gas pressures above $p = 0.8$ MPa and for N_2O admixture to N_2 of more than 20 %. In other words: already a 20/80 % N_2O to N_2 admixture provides nearly 60 % insulation performance compared with pure SF_6 for the same gas pressure, only considering high gas pressures above $p = 0.6 – 0.7$ MPa. This is indeed a hint, that already low content N_2O/N_2 gas mixtures exhibit a significant synergetic behaviour considering the dielectric strength.

DIELECTRIC STRENGTH OF VARIOUS 20 % N_2O/N_2 GAS MIXTURES COMPARED WITH 10 % SF_6/N_2 GAS MIXTURES

Fig. 3 shows the influence of synergetic behaviour of N_20/N_2 mixtures on the dielectric performance distinctively and more detailed than **Fig. 2**. For 20/80 % N_2O/N_2 gas mixtures at a pressure of $p = 0.3$ MPa, the dielectric strength in the area of corona stabilisation is already significantly higher than for pure N_2. Surprisingly the dielectric strength of 20/80 % N_2O/N_2 rises nearly linear with increasing pressure, after passing the critical pressure at $p_c = 0.4$ MPa. For a pressure of greater than $p = 0.8$ MPa the dielectric strength of 20/80 % N_2O/N_2 is nearly equivalent to the dielectric strength of 10/90 % SF_6/N_2 at the same pressure. At pressures above $p = 0.9$ MPa dielectric strength reaches saturation. Considering 40/60 % N_2O/N_2 and larger N_20 admixtures, however, corona stabilisation process seems to be suppressed or at least it is not as extended as for 20/80 % N_2O/N_2 gas mixture. This behaviour may be clarified by means of further electro-optical investigations. Similar to 20/80 % N_2O/N_2, for 40/60 % N_2O/N_2 the dielectric strength is rising significantly for gas pressures above $p = 0.4$ MPa and reaches a similar intrinsic dielectric strength as 10/90 % SF_6/N_2 gas mixtures at $p = 0.55$ MPa. Moreover there is the tendency, for increasing amount of N_2O to N_2, that the slope of the traces of the pressure dependent dielectric strength increase for gas pressures greater than $p = 0.4 - 0.5$ MPa. This indicates a distinct high pressure dielectric performance property of low content N_2O/N_2 gas mixtures in general.

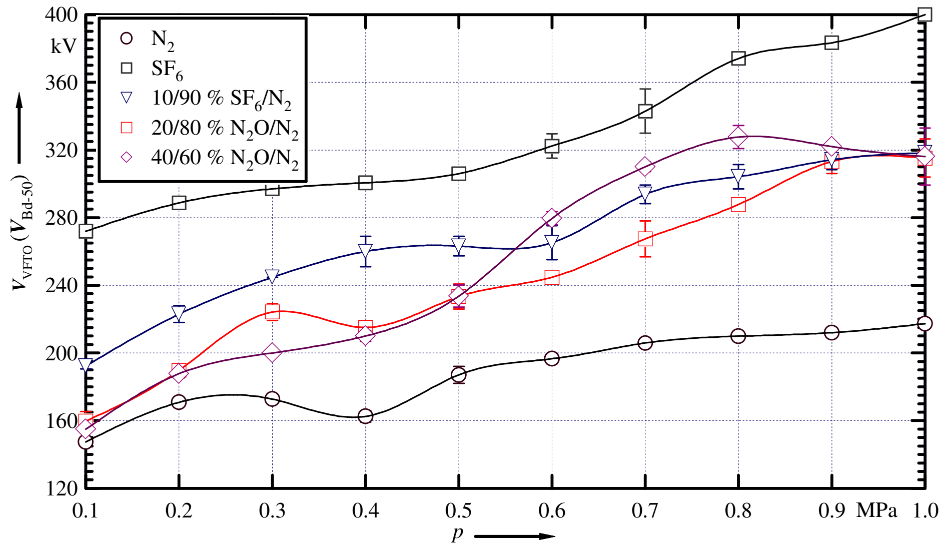

Figure 3: Comparing various N_2O/N_2 gas mixtures with a 10 % SF_6/N_2 gas mixture and pure SF_6. Values are given for: positive polarity voltage, $p = 0.1 – 1.0$ MPa, gap distance: $d = 30$ mm, protrusion length: $l = 10$ mm

DISCUSSION OF THE RESULTS

High pressure performance of N_2O/N_2 gas mixtures: Since both gases N_2 and especially N_2O are known to be good, respectively very good buffer gases, the effect of monotone rising slope of the traces for increasing dielectric strength with increasing gas pressure is a consequence of these properties. Additional pressure dependent (increasing) E/p_{crit} of N_20 affects the dielectric strength with rising pressure obviously very positive.

Due to the significant smaller electronegativity and high N_2 amount, low content N_2O/N_2 gas mixtures are in contrast to pure SF_6, less sensitive to electrode imperfections at the same intrinsic dielectric strength as pure SF_6 or SF_6/N_2 gas mixtures. For electronegative gases the figure of merit $M=(K/\beta)/(E/p_{\mathrm{crit}})$, which was introduced by [15], one can access the sensitivity of the gaseous dielectric to the effect of electrode defects, locally and significantly distorting the homogeneous field of a given gas insulated device with imperfections. The larger the figure of merit M is, the less sensitive a gas or a gas mixture is in tendency to electrode defects. **Table 2** shows, that pure N_2O has a significant larger figure of merit than, e.g. SF_6 or 10 % SF_6/N_2.

	SF_6	10% SF_6/N_2	N_2O
M/MPa × µm	3.8 – 6[16,17]	14,5[16]	40[16]

Table 2: Figure of merit for selected gases

The authors experienced during research work and considering independent research work of companies and other universities for low content SF_6/N_2, i.e. 10 % SF_6/N_2 gas mixtures, that dielectric stress with very fast overvoltages V_{VFTO} and LI (IEC60060-1) is decisive and may additionally be used to to estimate optimum gas mixture ratio and that insulation performance may be evaluated by applying such worst case voltage shapes to a homogeneous field configuration with applied electrode defects (i.e. needle shaped protrusion). Further it is expected, that low CO_2 content CO_2/N_2 gas mixtures exhibit a similar high pressure dielectric performance as low N_2O content N_2O/N_2, due to very close relationship of properties between N_2O and CO_2 molecules.

For future work binary gas mixtures such as N_2O/N_2, CO_2/N_2 and ternary gas mixtures such as very low SF_6 content $SF_6/N_2O/N_2$ and $SF_6/CO_2/N_2$ will be most interesting for large scale gas insulated equipment such as GITL and GIB's.

CONCLUSIONS

- Dielectric strength of various N_2O/N_2 gas mixtures for N_2O/N_2 mixture ratios between 10 – 60 % N_2O to N_2 have been investigated for a gas pressure in between $p = 0.1 - 1.0$ MPa. Results have been evaluated carefully and are compared with the dielectric strength of pure SF_6 and 10/90 % SF_6/N_2.
- Intrinsic dielectric strength of 20/80 % N_2O /N_2 is comparable with the dielectric strength of 10/90 % SF_6/N_2 for pressures above $p = 0.8$ MPa. Admixture of 20 % N_2O to N_2 is determined as the absolute minimum applicable gas mixture for low content N_2O/N_2 gas mixtures.
- The dielectric strength of 20/80 % – 40/60% N_2O/N_2 gas mixtures exhibit the best dielectric performance for high pressures above $p = 0.6$ MPa. Therefore 20/80 % – 40/60% N_2O/N_2 gas mixtures are promising to totally replace low content SF_6/N_2 gas mixtures for large scale gas insulated equipment, in order to significantly reduce SF_6 emissions.
- Nevertheless it seems to be promising, to add very small amounts of SF_6 to N_2O/N_2, to enhance electron attachment of the gaseous dielectric without loosing the superior high pressure dielectric properties of low N_2O content N_2O/N_2 gas mixtures, which may exhibit additional synergetic effects. Future research will focus on this task.

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