REQUIREMENTS FOR GASEOUS INSULATION FOR APPLICATION IN GITL CONSIDERING N_2, N_2O AND CO_2 WITH LOW CONTENT SF_6

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***Abstract*: This paper reviews briefly the requirements for gaseous insulation for application in GITL. Since a universal gas or gas mixture with comparable properties as SF_6 is not available, focus is on alternative gas mixtures with rather high dielectric strength and rather small environmental impact. Special focus is on N_2, N_2O and CO_2 gas mixtures.**

INTRODUCTION

SF_6 is widely used as insulation media for gas insulated switchgears (GIS) and gas insulated transmission lines (GITL) because of its excellent insulation properties such as high dielectric strength and excellent arc quenching ability. Because of the many and increasing uses of SF_6 there has been an increased demand for it. In turn, this has resulted in increased concentrations of SF_6 in the atmosphere. There are serious concerns about that development due to its large environmental impact. SF_6/N_2 Mixtures, especially with low content of SF_6 such as 10/90 % – 20/80 % SF_6/N_2 gas mixtures have been investigated intensively in the recent years and found to be an appropriate alternative gaseous insulation media, especially for large scale gas insulated equipment, such as gas insulated bus (GIB) or gas insulated transmission lines (GITL). Current research is focused on various other gas mixtures with low or no SF_6 content. Binary and ternary gas mixtures with low SF_6 content such as SF_6/N_2, SF_6/CO_2, SF_6/Air, $SF_6/CO_2/N_2$ [1 – 7] have been investigated recently, whereas $SF_6/N_2O/N_2$ has not been used until now. Numerous gas mixtures without SF_6 admixture have also been discussed theoretically and experimentally, i. e. O_2/N_2, CO_2/N_2 and N_2O/N_2 [8 – 11]. This paper is a contribution for systematic research of alternative gaseous insulation media, in particular for large scale gaseous insulation media.

SPECIFICATION REQUIREMENTS FOR GASEOUS INSULATION

In the following the most important requirements for insulating gases are summarized briefly:

electrical properties:

- high dielectric strength
- good arc quenching and gas recovery properties
- low sensitivity to surface roughness of the conductors
- good self healing properties
- low generation of decomposition products

physical and chemical properties:

- electronegative, electron moderation properties, formation of stable negative ions
- chemical inertness, which is no reaction with admixed gas components, decomposition products, equipment materials, very high stability
- high vapor pressure
- high thermal conductivity
- non-flammable

long term requirements:

- stable dielectric properties over time and temperature, no gas degradation
- no gas (mixture) liquefaction at low ambient temperature conditions
- no gas (mixture) separation
- insensitiveness to gas impurities (i.e. humidity, other gases)

important environmental boundary conditions:

- total environmental impact and toxicity has to be considered
- availability, price, easy and cheap storage possibilities
- easy recycling

Almost all of the above mentioned properties are fulfilled by using the "universal" unitary gas SF_6, except environmental impact due to the very high global warming potential of GWP=23900 and high price. Since both aspects are politically and cost driven, a intensive research for alternative gaseous insulation was initiated in the past years, as can be seen from international conferences since about 1998. Since a comparable universal gas or gas mixture as SF_6, which fully meets all of the above mentioned specification requirements for a gaseous insulation is not available until now [5], this paper wants to give a short summary of possible gases for admixture with SF_6 as well as with N_2 alone.

RESTRICTED REQUIREMENTS FOR GASEOUS INSULATION

One of the most contradictory requirements for gaseous insulation is the ability of high dielectric strength and additional good arc quenching properties. Since in large scale insulation systems such as GITL and GIBs no high current switching operations are required or may at least be prevented by appropriate apparatus design, the focus for such gas insulated equipment is primary on the dielectric strength. Aim of this paper is to propose admixture gases for N_2 and SF_6/N_2, in which the latter have a high or a rather high dielectric insulation performance, whereas the gas or gas mixture does not need to meet high current interruption or arc quenching requirements. The proposed method is to select a gaseous dielectric, dependant on its specific application, in order to perform best, keeping in mind not to have manifold gas admixture components, in order to save gas handling and recycling costs. Following this method, we can generally differentiate between two basic applications for gaseous dielectrics, on one hand arc interruption capabilities for switching devices, such as circuit breakers and on the other hand stand alone HV-insulation systems without current interruption requirements, in particular such as GITL or GIBs. Therefore the use of i. e. SF_6/CF_4 gas mixtures for circuit breaker units and using i. e. SF_6/N_2 gas mixtures for GITL, which is commonly accepted. With this limitation we can deselect following basic tasks from the specification requirement:

- good arc quenching and gas recovery properties
- very high thermal stability over 400 K

and in contrast we will select for future large scale application gases or gas mixtures:

- high dielectric strength

CHOICE OF GASEOUS ADDITIVES - BRIEF OVERVIEW OF IMPORTANT PROPTERIES

In order to prevent any possible impact with other gases or switchgear materials, the focus is set on inert gases, with best electrical properties, such as electronegativity, see also [10]. Properties of SF_6 are well known from multiple publications and shall not be reviewed in detail, see e.g. [12, 13].

PROPERTIES OF N_2

Physical and chemical properties: Under normal conditions N_2 is colourless, odourless, non-toxic, non-flammable, non-combustible very cheap and durable against aging. N_2 is approximately as heavy as air. Under normal atmospherical conditions N_2 can hardly displace oxygen in air, due to its rather low specific weight. Pure N_2 is only a simple asphyxiant. In closed rooms N_2 may displace oxygen in air and can cause symptoms of oxygen deprivation (asphyxiation) when present in high concentrations and for significantly lower oxygen concentrations than normally are contained in air. Air normally contains approximately 78 % nitrogen and 21 % oxygen. The oxygen content shall not fall below 18 % otherwise harmful effects will result. N_2 is an inert gas, which is characterized by its non reactive behaviour with other gases or material, except lithium which reacts with N_2 at room temperature to form lithium nitride [15] Lithium will burn in nitrogen [16]. N_2 has a very low dew point temperature at $\vartheta_d = -195°$ C (**Fig. 1**). Therefore N_2 is suitable to reduce the dew point temperature of a gas mixture significantly. N_2 is not electronegative. During electrical discharge electrons are effectively moderated by N_2 e.g. by means of vibrational excitation [17]. Electron moderation in combination with a strongly electronegative gases, e.g. SF_6, is the clue for synergetic effects e.g. for SF_6/N_2 gas mixtures. Therefore N_2 is generally accepted as a superior additive in insulation media. Considering the good overall properties, N_2 is the basis of a binary or ternary gas mixture, having a minimum environmental impact.

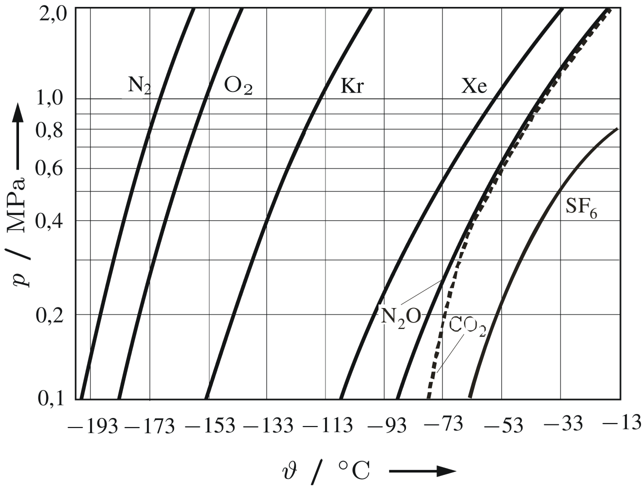

Figure 1: Vapor pressure of N_2 and N_2O [8] and CO_2 [19].

PROPERTIES OF N_2O

Physical and chemical properties: Under normal conditions colourless gas with a slightly sweet odour, non-flammable, non-combustible, non-self igniting. Simple asphyxiant. Can displace oxygen from air. N_2O is about 1.5 times heavier than air. Its dew point is at $\vartheta_d = -88.8°$ C (see **Fig. 1**) and is significant lower than that of SF_6 ($\vartheta_d = -63.8$ ° C).

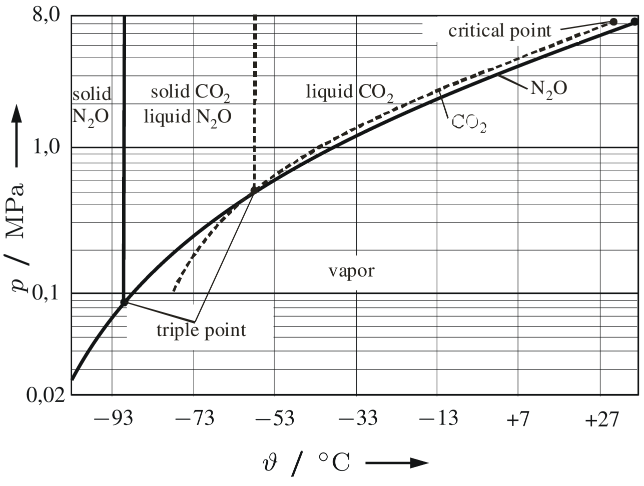

Figure 2: Phase diagram of N_2O [18] and CO_2 [19].

From **Fig. 2** one can see, that until ambient temperatures as low as $\vartheta = -33°$ C, pure N_2O still remains in its vapor phase up to pressures as high as $p = 1$ MPa. Since N_2O is a very stable gas, it is considered to be a greenhouse gas too. Compared with SF_6, the greenhouse potential of N_2O is 77 times lower (GWP_{N2O}= 210). Its life time in the atmosphere is about 150 to 170 years [18]. N_2O is thermal absolutely stable until $\vartheta = 650$ °C [18, 20] and decomposes thermally (dissociation) at temperatures of above 1500 K to 2000 K [21].

PROPERTIES OF CO_2

Physical and chemical properties: Under normal conditions colourless, odourless, non-flammable, non-combustible, non-self igniting. Used as a fire-extinguishing agent. Simple asphyxiant. Can displace oxygen from air. CO_2 is about 1.5 times heavier than air. Its dew point is with $\vartheta_d = -78.5°$ C (see **Fig. 1**) roundabout $d\vartheta = 10°$ C higher than that of N_2O. The phase diagram in **Fig. 2** shows similar physical properties of CO_2 compared with N_2O. It shall only briefly be summarized here, that various properties of N_2O and CO2 are related. Since CO_2 is a very stable gas, it is also considered to be a greenhouse gas. Compared with SF_6, the greenhouse potential of C_2O is 23900 times lower (GWP_{CO2}= 1). Its life time in the atmosphere is about 50 to 200 years. CO_2 is thermal absolute stable until $\vartheta = 650$ °C and decomposes thermally at temperatures of above 2200 K.

CONCLUSIONS

- Specific selection for the application of gaseous dielectrics is necessary:

Make a clear decision between best performance in dielectric strength or switching capabilities. The use of a "universal application" gas mixture for electrical insulation and switching purposes will allow an economic solution with low environmental impact.

- Regarding N_2O or CO_2 admixture to N_2 respectively SF_6/N_2 one must consider, that N_2O has advantages for low content admixtures in between 10 – 30 % to N_2 or SF_6/N_2, see also the compilation according to **Table 1**:

-higher dielectric strength.
-no formation of conductive carbon possible due to PD or other gas degrading discharge processes of the gas.
-larger thermal conductivity .
-limited amount of Oxygen given admixture rates, in order to limit the possible catalysation process during arcing. During arcing N_2O as well as CO_2 decompose thermally. Free Oxygen will conduct oxidation, whereas CO_2 has double amount of oxygen than N_2O.

- N_2O/N_2, $SF_6/N_2O/N_2$ and CO_2/N_2, $SF_6/CO_2/N_2$ gas mixtures may be considered as future gas mixtures for large scale and high pressure applications, such as GITL, with minimized contribution to the greenhouse effect.
- The new proposed insulation gases N_2O/N_2, $SF_6/N_2O/N_2$ should be investigated more intensively.

parameter	conditions	SF_6	N_2	N_2O	CO_2
dielectric strength relative to SF_6		1	0.37 [31, 33]	0.46 [25] 0.50 [33]	0.35 [25] 0.32 [33]
pressure reduced critical fieldst. E/p_{crit} / (kV mm^{-1} MPa^{-1})	$\vartheta = 20 – 25$ °C	88.4 [38]	33.0 [23]	40.7 [35]	32.1 [39]
GWP100	ref. to CO_2	23900 [39]	-	310 [39]	1
dew point ϑ_d / ° C	$p = 0.1013$ MPa	-63.9 [22, 33]	-195.8 [33]	-88.5 [30, 33]	-78.8 [30, 33]
thermal conductivity λ / (W m^{-1} K^{-1})	$p = 0.1013$ MPa, $\vartheta = 25$°C	0.0155 [27, 39]	0.0238 [39]	0.0174 [39]	0.0142 [27]
specific heat cp/ (kJ kg^{-1} K^{-1})	$p = 0.1013$ MPa, $\vartheta = 20$°C	0.657 [39]	1.038[26]	0.873 [29]	0.837 [26]
gas densitiy relative to air ρ / (kg m^{-3})	$p = 0.1013$ MPa, $\vartheta = 20$°C	6.07 [30]	1.250 [31]	1.948 [30, 39]	1.977 [27, 34]
relative molar weight M / (g mol^{-1})		146.06	28.01	44.01	44.01
Velocity of sound c_s/ (m s^{-1})	$p = 0.1013$ MPa, $\vartheta = 0$°C	138 [24]	336 [2]	263	258 [26]
critical pressure p_c / MPa		3.755 [23, 31, 36]	3.394 [22, 26, 29]	7.236 [29, 39]	7.380 [29, 37]
critical temperature T_c / K		318.72 [22, 26, 36]	126.04 [31]	309.4 [29]	304.1 [31, 39]
critical density ρ_c / (kg m^{-3})		735 [39]	311 [39]	450 [39]	460 [39]
first ionization energy E_I / eV		15.32 [22]	15.58	12.89	13.78 [32]

Table 1: Compilation of the relevant data for the most promising gas additives for N_2 or SF_6/N_2, for gas mixtures with low content of SF_6 .

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