RESEARCH AND FINDINGS ON ALTERNATIVES TO PURE SF_6

Loucas G. Christophorou

National Institute of Standards and Technology, USA

- Best response to the concerns over the possible impact of SF_6 on global warming is to prevent the release of SF_6 into the environment

- A way to achieve this is the use of **alternative, environmentally more acceptable, gaseous dielectrics**

The Search for SF_6 Substitutes

- It traces back many years.

- Its aim has recently been shifted from finding gases "superior" to SF_6 to finding gases/mixtures which are comparable in dielectric properties and performance to SF_6, but are environmentally acceptable.

- Many electronegative gases have been identified with superior dielectric performance than SF_6, but they are not without problems.

- Non-electronegative gases which are benign and environmentally ideal, such as N_2, normally have low dielectric strengths and lack the fundamental properties for use by themselves in circuit breakers.

Nonetheless, such environmentally friendly gases might be used by themselves at higher pressures, or at comparatively lower pressures as the main component in mixtures with electronegative gases, including SF_6.

From: L. G. Christophorou, Nuclear Instruments and Methods in Physics Research **A268**, pp. 424-433 (1988).

Table 2
Relative dc uniform field breakdown strengths V_s^R of some dielectric gases [a)]

Gas	V_s^R [b),c)]	Comments
SF_6	1	Most common dielectric gas to date besides air
C_3F_8	0.90	Strongly and very strongly electron attaching gases, especially at low energies
n-C_4F_{10}	1.31	
c-C_4F_8	~1.35	
1,3-C_4F_6	~1.50	
c-C_4F_6	~1.70	
2-C_4F_8	~1.75	
2-C_4F_6	~2.3	
c-C_6F_{12}	~2.4	
CF_3H	0.27	Weakly electron attaching; some (CO, N_2O) are effective in electron slowing down
CO_2	0.30	
CF_4	0.39	
CO	0.40	
N_2O	0.44	
H_2	0.18	Virtually nonelectron attaching
Air	~0.30	
N_2	0.36	Nonelectron attaching but efficient in electron showing down
Ne	0.006	Nonelectron attaching and not efficient in electron slowing down
Ar	0.07	

a) Based on data in refs. [1,2,7–11].
b) Some of the values given are for quasiuniform fields and may thus be lower than their uniform field values.
c) The relative values can be put on an absolute scale by multiplying by 3.61×10^{-15} V cm^2, the $(E/N)_{lim}$ of SF_6.

PASCHEN'S LAW ($V_{BR} = f(Nd)$)

IS LIMITED TO CASES WHERE

- GAS PROPERTIES

DO NOT CHANGE WITH GAS

DENSITY

- GAS-MIXTURE PROPERTIES

DO NOT VARY WITH MIXTURE

COMPOSITION

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in Physics Research **A268**, pp. 424-433 (1988).

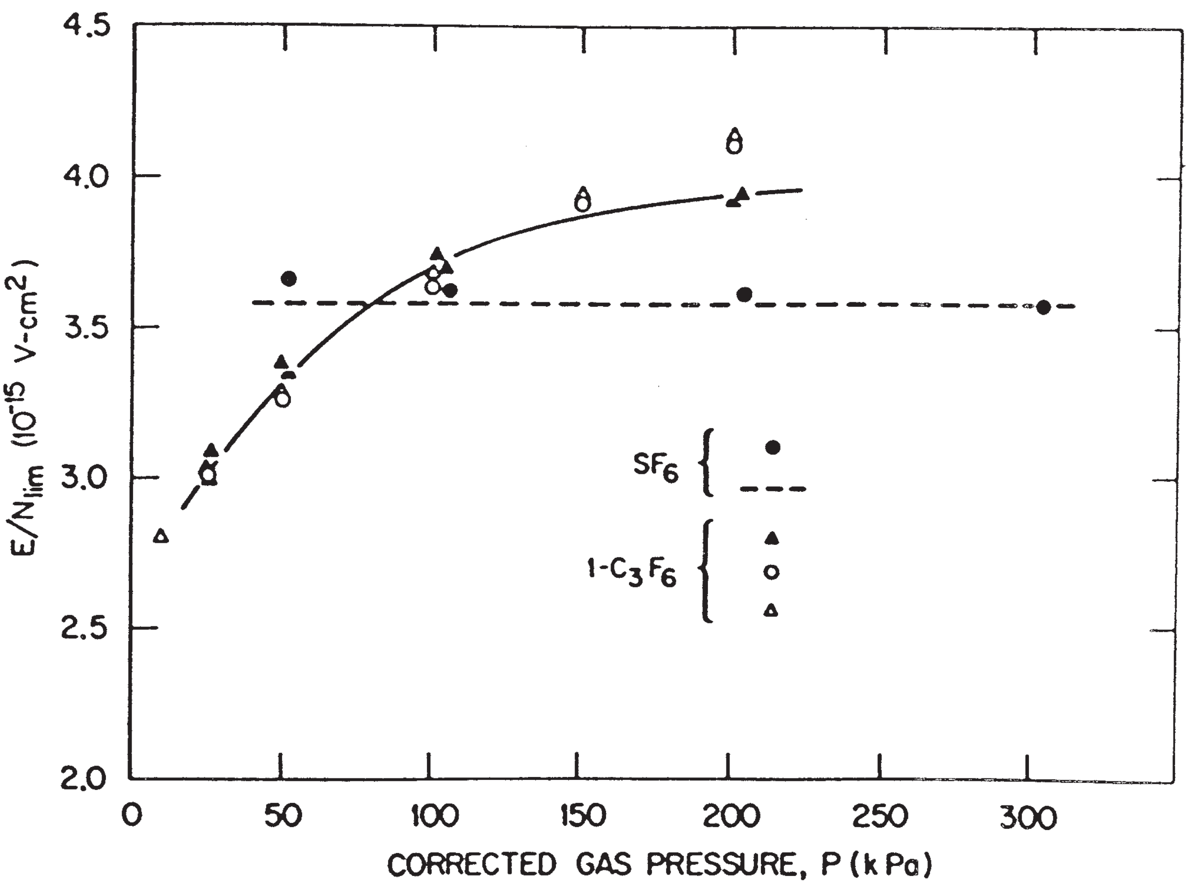

Fig. 5. $(E/N)_{lim}$ versus P (corrected for compressibility) for SF_6 and 1-C_3F_6 [8,18].

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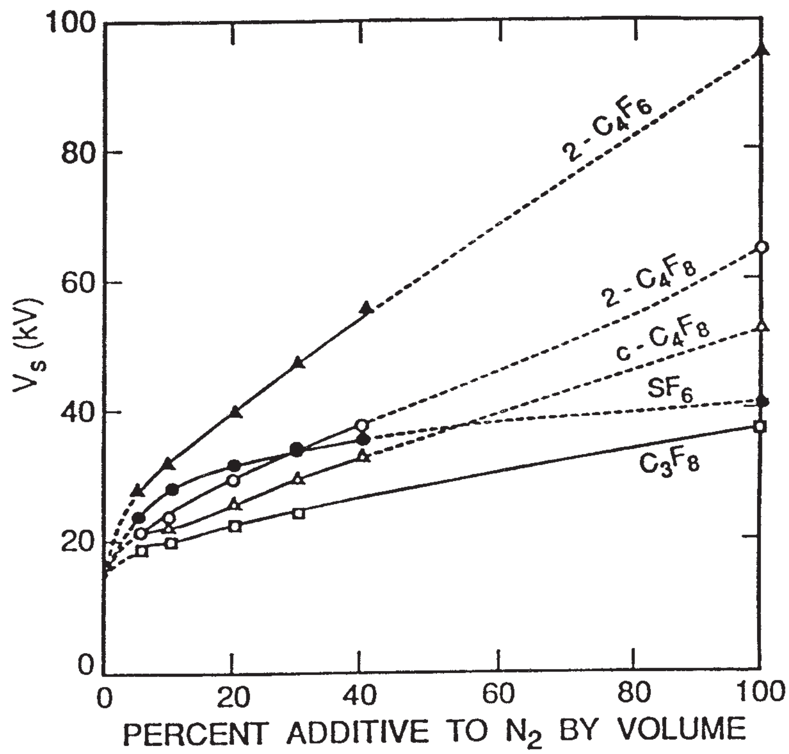

FIG. 4. DC breakdown voltage as function of electron attaching additive to nitrogen (uniform and quasi-uniform electric fields; the total gas pressure is 66.66 kPa and the electrode gap is 7 mm). The broken curves are extrapolations (from [35, 36]).

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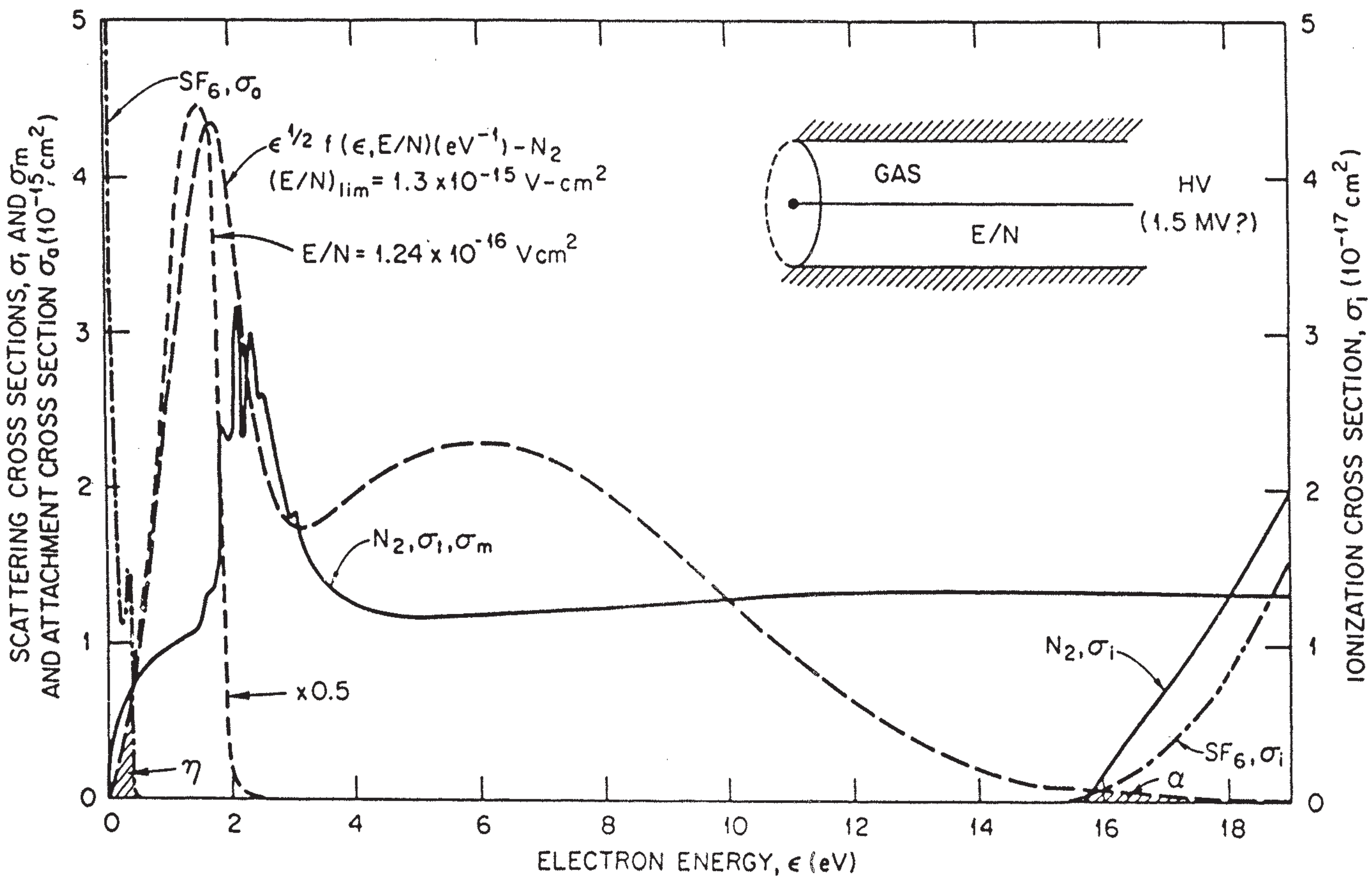

Fig. 1. Ionization cross sections $\sigma_i(\epsilon)$ for N_2 and SF_6 close to the ionization onset I. Electron scattering cross section as a function of electron energy ϵ for N_2, and electron attachment cross section $\sigma_a(\epsilon)$ for SF_6. Normalized electron energy distribution function $\epsilon^{1/2} f(\epsilon, E/N)$ as a function of ϵ for N_2 at two values of E/N (see text) [8].

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Gases for Electrical Insulation and Arc Interruption: Possible Present and Future Alternatives to Pure SF_6

L. G. Christophorou, J. K. Olthoff, and D. S. Green

HIGH-PRESSURE GASEOUS DIELECTRICS

N_2 AND N_2/SF_6 MIXTURES

- High-pressure (≳1 MPa) N_2 and low-concentration (<20% SF_6) mixtures of N_2 with SF_6 can be used for insulation

- Higher SF_6 concentrations (40% to 50%) in N_2 can be used for arc quenching, current interruption, and transformers (see Refs. [3], and [6]).

A Program on Gaseous Dielectrics

- Presently there is *no* program looking *systematically* and *comprehensively* for substitutes

- There is a need for one to:

- *Evaluate possible substitutes for their physical, chemical, thermal, and electrical properties and requirements;*
- *Conduct the required basic, applied, and industrial testing and quantify their performance under various test voltages;*
- *Study their decomposition under prolonged electrical stress, corona, breakdown, and arc, as well as their aging, and influence on spacers and other materials;*
- *For gaseous dielectric mixtures, address industry's concerns with regard to difficulties in handling, mixing, maintaining constant composition, and reclamation of the mixture's components.*

- The establishment of a comprehensive program on substitutes to address these and other issues relating to alternative gaseous dielectrics is a ***collective responsibility.***

Two Aspects of an Effort to Find Viable Substitutes Require Immediate Attention

- *Full Characterization of SF_6/N_2 Mixtures*

- *New Gas(es) for Insulation*

Full Characterization of SF_6/N_2 Mixtures

- There must be an in-depth investigation of the overall properties of these mixtures, especially:

  - **Low-concentration (10-20%) SF_6/N_2 mixtures for high voltage insulation (transmission); and**

  - **40% to 50% SF_6/N_2 mixtures for arc and current interruption and transformers.**

- Major issues to be addressed include:

  - **Behavior at high pressure (0.6-1.2 MPa) under laboratory and under industrial-type conditions;**

  - **Recycling/recovery;**

  - **Implications for design of new equipment with alternative gases; and**

  - **Byproduct formation, identification, and characterization.**

With regard to the last issue, there is a need to answer the question: ***What are the discharge byproducts which are formed in SF_6/N_2 mixtures as compared to pure SF_6, and what are the mechanisms of their formation and their properties?*** The answer to this question is needed both for health and environmental reasons, but also for handling, recycling, and diagnostic purposes.

Electrical-Discharge-Induced Chemical Decomposition of SF_6/N_2 Mixtures

- Only limited measurements from corona discharges

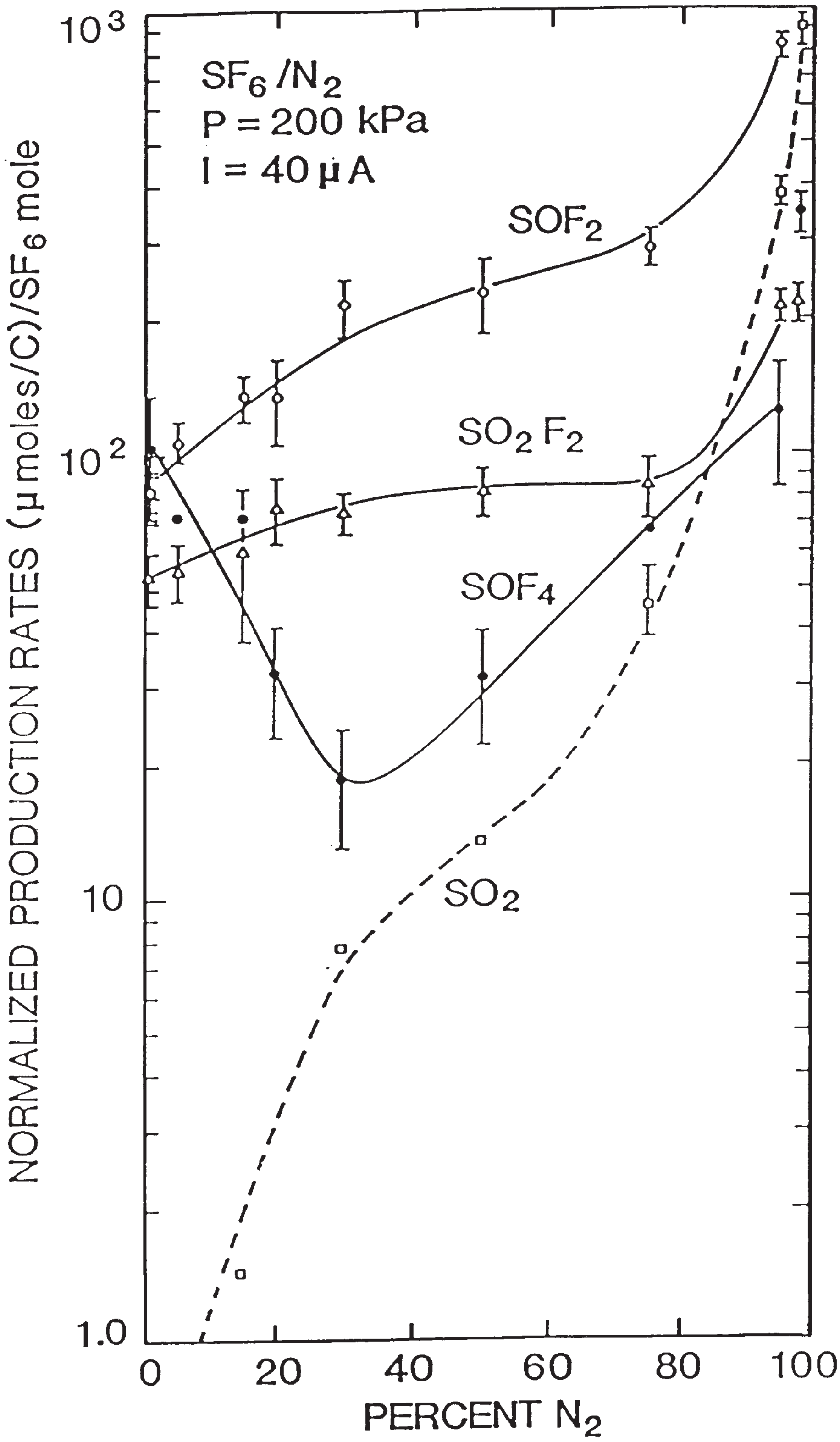
- Little chemistry between SF_6 and N_2 in discharges

- Predominant oxidation byproducts are those seen in SF_6 (e. g., SO_2, SOF_2, SO_2F_2, and SOF_4)

- Nitrogen oxides and fluorides are formed, but in minor amounts

- The yields of certain oxyfluorides (e. g., SO_2) are much larger in dilute SF_6/N_2 mixtures compared to pure SF_6. This would make diagnostic techniques based on the detection of such byproducts more sensitive for the mixtures than for pure SF_6

R. J. Van Brunt, see IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 2, 952-1003 (1995).



New Gas(es) for Insulation

A search for new dielectric gases may include:

- Investigation of nonelectronegative high-pressure dielectrics - - high-pressure (1.0-1.5 MPa) nonelectron attaching (N_2) and weakly electron-attaching (CO_2) gases;

- Search for suitable gaseous dielectrics with an infra-red window;

- Chemical synthesis of a new dielectric gas;

- Design of high-pressure equipment for higher-pressure dielectrics.

Some Basic Questions

- Chemistry and Destruction of SF_6 in Upper Atmosphere

- Characterization of SF_6/N_2 Mixtures

- High-Pressure Gaseous Dielectrics

- New Gases with New Equipment

- Gaseous Dielectrics in Light of Such Issues/Prospects as
    - EMF Effects
    - Expanded Transmission Lines