Journal of New Materials for Electrochemical Systems 21, 243-248 (2018)

Dichlorodifluoromethane (R_{12})/CO_2/Air Gas Mixtures a Competent Gaseous Insulator as Surrogate of SF_6

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Received: April 25, 2018, Accepted: December 08, 2018, Available online: January 25, 2019

Abstract: *This work encompasses testing and manufacturing of a unique composite gaseous insulating material alongside its various valuations with the properties of existing insulating materials. Main objectives include the development of novel composite insulating material with enhanced insulating properties, reduced cost and supplementary ecological traits. Sulphur hexafluoride (SF_6) is commonly used in current electrical insulation network but suffer sake recognized downside of having Global Warming Potential (GWP) 23,800 times larger than CO_2. This alarming metric prompted investigation for substitute gases with minor environmental influences. The emerging contenders substantiated were dichlorodifluoromethane (R_{12}) and its fusions with Carbon dioxide (CO_2.) at different pressure and density mix for high-voltage applications. Gaseous mixtures containing R_{12} gas demonstrate good dielectric properties with low-temperature usage possibilities. Dielectric strength underneath quasi-uniform field demonstrated results in descending order (e.g. SF_6> R_{12}> CO_2> Air) into direct current (DC) alternating current (AC) and impulse response examination. Density mixtures of (80:20%) for R_{12}:CO_2 reaches over 0.92–0.96 times to SF_6 at 50 lbs./in^2 keen on AC and (70:30%) for R_{12}:Air mixtures bestow 0.80–0.90 times of sole SF_6 properties. R_{12} offers wonderful self-recoverability and CO_2 is instantly good in arc-quenching capabilities. The optimal ratio established for surrogates to SF_6 gas is (70:30%) for R_{12}: Air and (80:20%) for R_{12}: CO_2. All establishment and analysis are based on the authors' experimental conditions and setup.*

Keywords: R_{12}/CO_2 mixtures; insulating material; dielectric properties; environment friendly

1. INTRODUCTION

Demand in the increase of efficient electrical energy has become a challenge, especially for developing countries since their demand increase is observed with minimum planning. This unplanned and unpredicted exponential rise in energy demand has increased the demand for deployment of better power protection systems which may withstand undue and unwanted system failures. For this purpose, protection equipmf ent should be installed with best and efficient insulation medium to overcome heating and quick faulty circuit isolation.

Their modern versions are often employing insulation with Sulphur hexafluoride SF6 gas [1]. SF_6 is a widely used as well as very prevalent choice in insulation medium for high voltage(HV) apparatus reminiscent ocompact circuit breakers gas insulated power lines as well as transformers and while also non-flammable comparatively to the insulating mineral oils particularly for interior environments. With such unique properties regrettably, SF6 is also very damaging greenhouse gas stated by the Kyoto Protocol that it is 23,800 times more harmful than CO2 [2-3], therefore it is included in the prohibited list for ecological safety. Even though it is nontoxic but as it's heavier than air, in any situation if it discharges at a facility area it can amass to ground level resulting in replacement of oxygen in facility which causes asphyxia to the on-site workers. Such critical matters have pointed the emphasis to improve the fidelity and adeptness of power transmission and distribution system around the world and also ensuring that for upcoming modern innovations and latest technologies not to be hazardous for atmosphere.

SF_6 decay products as well as moisture inside apparatus in facility can cause damages to materials one of them is alumina. Molecular filters are used for harmless exclusion and absorption purposes [4]. It is very significant aspects to reflect the universal ecology when planning electric power systems. Earlier investigations were carried out expand this gas mixture which can be used as a backup of SF_6 but these candidates have some disadvantages noted in Table 1[5-6] which depict some substitute candidate gases and their corresponding drawback.

Such investigation helps to formulate these two targets. Firstly, the development of an insulating medium that is technically and

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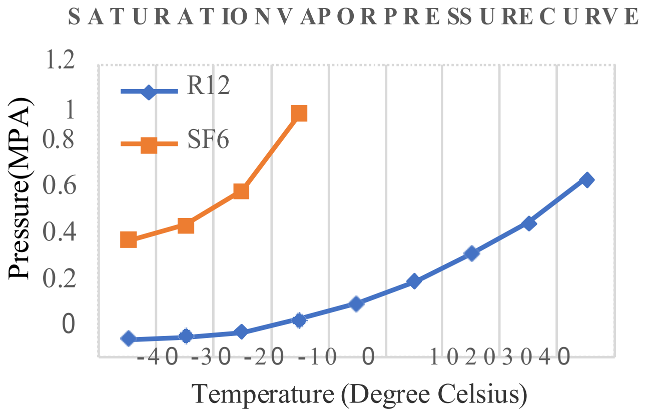

Figure 1. Vapor Pressure curve of R_{12} vs SF_6 in Saturation.

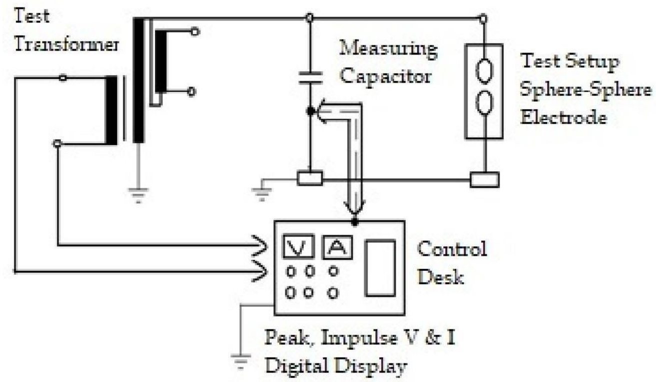

Figure 2. Experimental set up to examine R12–Air, R12-Co2 Breakdown voltage by Sphere-Sphere Electrodes.

economically attractive. Secondly, a better understanding of the characteristics of R_{12}:CO_2 mixtures and their breakdown mechanisms. After experimental verifications in this writing it is deliberated that insulation strength for these mixtures are larger than weighted entirety sum of these constituent gases. So, these composite novel mixtures can be shortlisted as likely substitution for Electric insulation in high voltage applications.

2. PROPERTIES OF SF_6 AND R_{12}/ CO_2. GAS MIXTURES

R12 is "Dichlorodifluoromethane (CCl_2F_2)" so its empirical formula shows that it consists of one carbon atom, two atoms of Chlorine and two atoms of Fluorine is recognized as Freon-12, a chlorofluorocarbon halo methane (CFC) and commonly used in refrigeration appliances and in aerosol sprays with properties in compliance with the Montreal Protocol [9]. R_{12} have several qualities which make it an effective gas to use in field e.g. it is harmless, non-explosive and nonflammable, all these features makes it popular for domestic as well as industrial usage. Another major benefit of R_{12} as compared to SF_6 is its effect on global warming and its ratio for contribution to greenhouse effect is minor. Global warming potential rate of R_{12} is 8500 over a century period. One of its characteristics resembles that of SF_6 as it maintains its chemical structure and do not fall to pieces even under unfriendly working condition. Precautions are to be taken while dealing with R_{12} it is advised to put all the flames off and keep the doors open so that it can get away to the open air [10.] Some other common features of R_{12} are (a) less global warming potential as compared to SF_6 (b) Minimum atmospheric lifetime, it causes depletion of ozone as it contains chlorine. In thisresearch, R_{12} is used along with the mixtures of CO_2 and air that consequence to less depletion of ozone layer.

The curve of saturation vapor pressure for R_{12} and SF_6 is shown in Figure 1 and Table 2 shows comparison of R_{12} gas with SF_6.

3. LABORATORY EXPERIMENTAL SETUP, TECHNIQUEAND ASSEMBLY OF TEST ELECTRODES

This section describes the details of test setup and test main unit in the high voltage laboratory.

Figure 2 Shows Experimental Set up. Experiment method is based on IEC60270 standard [11-12]. Furthermore explanation about the test setup which consists of control desk (HV-9103). This control desk comprises of peak voltmeter (HV 9150) and built-in variable voltage supply. Power Supply output is 0 to 230 Volts and the voltmeter peak range is 100 to 1000 kilo Volt. Control desk consists of measuring instruments such as Impulse, Peak, Trigger devices and

Table 2. Contrast between physical and chemical properties of SF_6 vs R_{12} [11].

Properties	SF6	R12
GWP	22,800	2400
Atmospheric life	3200	12
Boiling point	−64°C	−29.8°C
Molar mass (g/mol)	140.6	120.914
Appearance	Colorless	Colorless
Permittivity	1.002	2.0
Electronegativity	2.5	2.42
Price/kg	28–30$	15 $
Water Solubility	Slightly Soluble	0.286g/l

Table 1. Association of SF_6 replacement. [1][5].

Gases	Drawbacks and problems
Dry air, Nitrogen and carbon dioxide	-Momentous expansion in Pressure -Momentous expansion in size of equipment -Momentous send regrets in endure voltages in the results of failure and fault. [6]
Mixtures of Trifluoroiodomethade (CF_3I/ CO_2. or N_2)	-Boiling point large rather than of CF_3I is (-22.5 °C) at (0.1 MPa). Classified as a perilous, mutagenic and venomous for facsimile (Type-3)[7].
Mixtures of Per-fluorinated Ketones ($CSF_{10}O$,$C_6F_{12}O$/Technical air or CO_2.)	-Superior smallest operating temperature than SF6 [8]. -Far above the ground boiling point (24 °C, 49 °C)at (0.1 MPa) for the reason that elevated molecular mass.
HFO 1234 zeE	-Carbon grime dump on electrodes owing to high spark voltage -Superior operating temperature than of SF_6 as unpolluted (constained at -15°C)

(a) **(b)**

Figure 3. Test equipment used: (**a**) Control and measurement unit; (**b**) Testing vessel (HV-9134) for AC setup.

DC Voltmeters. Figure 3(a) manifests the control and measuring unit. Using Voltage Doubler Circuit the rectification of AC can be done in case of DC voltage application and DC voltage can be developed up to 140 kilo Volt.

As the Breakdown occurs; Voltmeter measures the Breakdown Voltage across Measuring Capacitor. Prior to start the tests, [13] AC Voltage of identified value was applied to voltmeter and measuring devices for calibration purposes to minimize errors and improve precision.

Testing Vessel for gas and vacuum is mass-produced by Steel and equipped with Pressure meter to measure pressure up to 6bars. Manufacturing material of electrode was Aluminum and has coating of metal nickel. The Electrode diameter is 20 millimeters and gap in-between both electrode can be varied from 0 to 30 centimeters. The experiments were carried out in steel vessel shown in Figure 3(b). The vessel contains a cylinder made of Plexi-glass which is sandwiched with flanges top and bottom and are linked with high voltage (HV) and ground potential correspondingly. Bottom cover is furnished with essential apparatus such as inlet, outlet valve, measuring gauge for vacuum and pressure. The specifications of test vessel provided from the manufacturers are briefly described in Table 3.

Prior to start testing, both electrodes are cleaned with alcohol dumped silk textile stuff to eliminate wetness and impurities to minimize errors and maximize accuracy in all experiments.

Tests were carried in dried up and moisture free zone at 20–25°C room Temperature. To attain maximum vacuum the vessel was filled and evacuated from gas after every 20 minutes.

Increase in temperature raises the probability of errors in experiments so the time span has been restricted to 15-20 minutes of each test. To mix the gas appropriately 30–45 minutes were allocated [12]. Entire experiments have been completed under conditions specified in Table 4.

Dichlorodifluoromethane (R12) is one of an electro-negative gas and all negative ions come into existence by gaining electrons of neutral molecules and on losing of electrons neutral molecule becomes positive ions. Gaining and losing of electron could occur depending on the field applied.

So, the losing or detachment coefficient is symbolized by η [12-13]. When a single electron travels for one centimeter and the number of electron come into existence during this path which called Townsend first ionization coefficient designated by α.

$$dN = N(\alpha - \eta)\,dx(1) \qquad (1)$$

Where N is the quantity of electron in the start, dN denotes the electron travelled and dx is the distance. When $\alpha > \eta$ (1) it demonstrates exponential rate growth and hereafter breakdown these gases mixture happen.

Gap distance in-between both electrodes too effects dielectric strength of gas. When distance between the electrodes is larger results rises. Equation (2) complete detailed breakdown voltages areconfirmed from gap flanked by electrodes as it is enlarged then it requires disdainful potential to sustain in electric field. [14]

Table 3. Test Setup Specification.

Specifications	Standards
Impulse Voltage (DC)	140 kilovolts
Voltage (AC)	100 kilovolts
Pressure (p)	0 to 6 bars
Diameter of Sphere Electrodes	20 millimeters
Vertical Height	800 millimeters

Table 4. Experimental constraints.

Configuration of Electrodes	Spherical - Spherical
Length of Spark Gap	6mm/0.6cm
AC voltage	0-100 kV (AC)
DC voltage	0-140 kV (DC)
Material of Electrode	Aluminum Ni Plated Steel

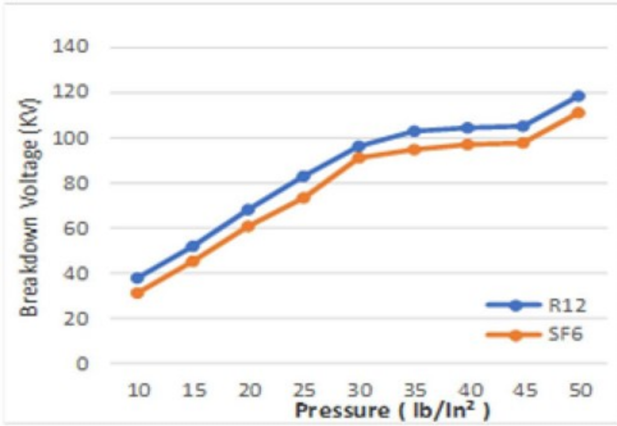

Figure 4. Breakdown curve characteristic of SF6 and pure R12 (8 mm gap between electrodes).

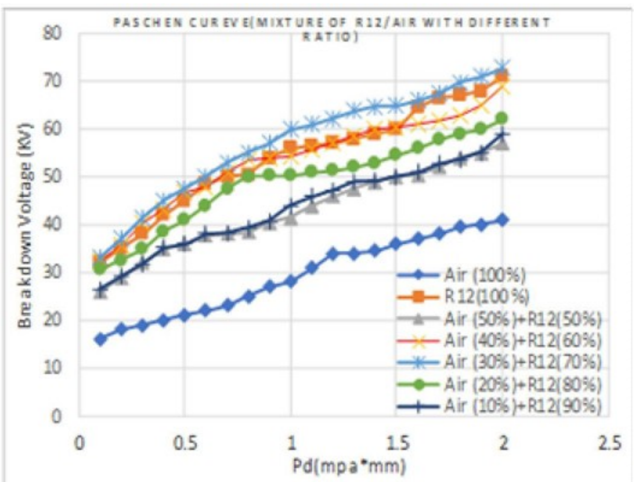

Figure 5. Shows Paschen curve intended for variant ratio (R12 and Air)

$$E = f \times V/D \quad (2)$$

Where as constant *f is* demonstrating non-uniformity, *V* is applied voltage and *D* is distance in between two electrodes.Synergy effect depicts non-linear behavior of combination of two gases.

Following equation demonstrates connection between the synergistic effects

$$Vm = V2 + \frac{K(V1 - V2)}{K + (1 - K)C} \text{ where } V1 > V2 \quad (3)$$

Above equation shows the synergy effect of combined gases where 'Vm' is the breakdown voltage for pure gases while V1and V2 presenting for both mix gases, k denote mixing ratio while C in this equation illustrate synergistic effect indexing.

4.1. Pure R12 and SF6

Dichlorodifluoromethane R12 gas is 0.90 times supplementary

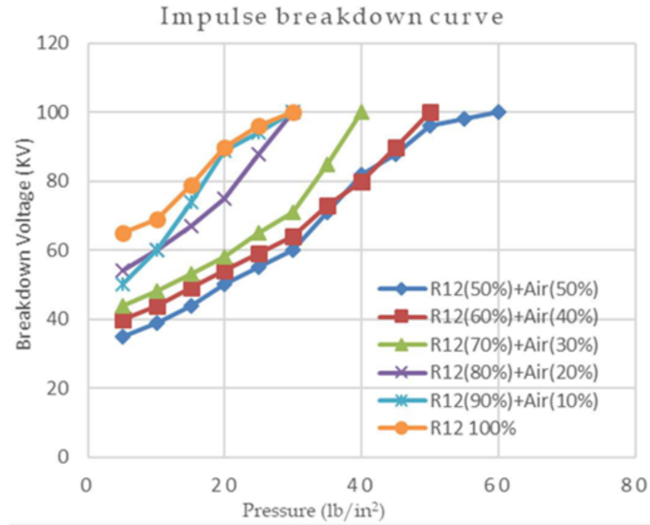

Figure 6. Impulse breakdown Characteristics for R12 and Air (8 mm gap betweenelectrodes)

Dielectric strength of pure SF6gas Figure. 4 expressions that by ever-increasing gap distance among electrodes the dielectric strength as well increases. Following figure below also present a contrast of R12 with SF6 gas in Alternating Current (AC) environment.

4.2. Mixture of R_{12} and air

Experiments have been performed on pure as well as different ratios of R_{12} and Air such as (a) Pure R_{12} (b) Pure Air (c) Air 50% with addition of R_{12} 50%(d) Air 40% with addition of R_{12} 60% € Air 30% with addition of R_{12} 70% (f) Air 20% with addition of R_{12} 80% and (g) Air 10% with addition of R_{12} 90%. Figure 5 expresses that by addition of pure R_{12} 50% with air increases breakdown strength abruptly. Though increasing the ratio of pure R_{12} gas, further breakdown voltage strength does not fetch analogous variation. Paschen curves intended in favor of different ratios shown in Fig 5. Air and R_{12} in Pressure * Distance (PD) series regarding (0.2–2.5 Mpa*mm) where pressure denoted by P and gap Distance between denoted by D for both electrodes [15]. Breakdown voltage boost with boosting of pressure, On the other hand, in case of sphere–sphere electrodes there is gradually slope decreased in curve. Breakdown characteristics features of pure R_{12} with air at impulse situation have shown these effects In Figure. 5 deviations from Paschen's law. Impulse Generator created Impulse voltage shown in Figure. 6. When Positive impulse was applied then with augment in pressure breakdown voltage increasing at certain level of pressure value Pm.

Following figure shows that the paramount and finest Dielectric strength of R_{12} and Air with ratios (70/30%) has been achieved in impulse.

Table 5 displays insulation characteristics R12 and Air amid at different ratios. Comparatively most excellent Dielectric Strength of (R12: Air) ratios (70:30%) has attained in alternating Current (AC) with impulse Voltages grounded on our experimental test setup conditions. Mixture of R12 and Air has higher dielectric strength than the pure R12 which is called Positive Synergistic effect as the nonlinear behavior on the mixing of two gases described

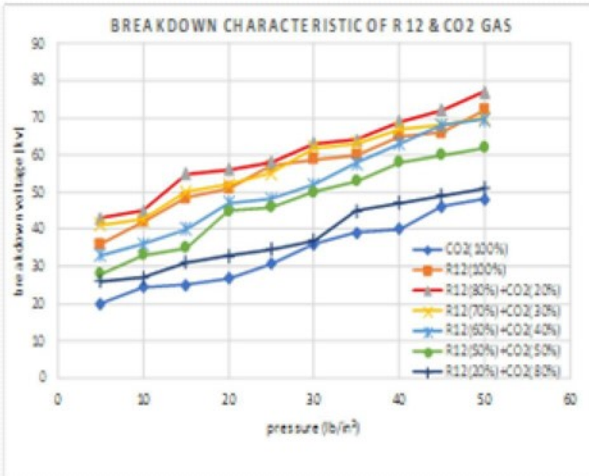

Figure 7. Breakdown Characteristics: R12 along with CO2 gas (6mm gap between electrodes).

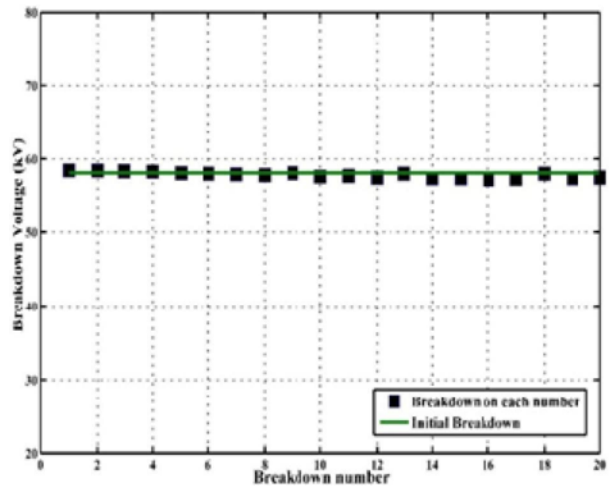

Figure 9. Insulation self-recoverability

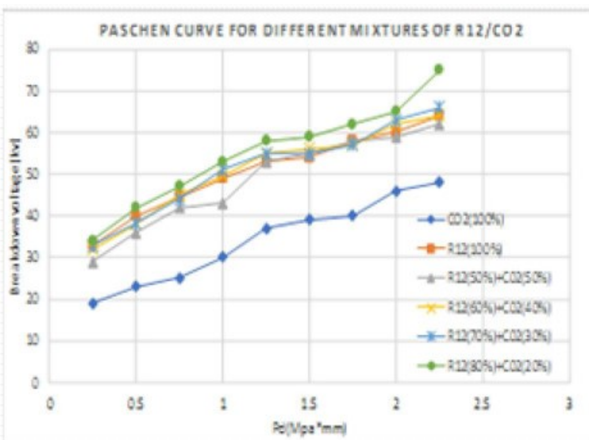

Figure 8. Paschen Curves on different ratio: R12 along with CO2

as Synergistic Effects. This benefit of mixing air make use for reducing its Boiling temperature point as well sound effects on GWP. Global Warming Potential of R12 ten (10) times less than peril SF6 gas so consequently R12 is finest surrogate of SF6 gas.

4.3. Mixture of R_{12} and CO_2 gas

CO2 has been chosen over Nitrogen and Air for its superior arc quenching ability to produce the mixture appropriate for Circuit Breaker and Disconnect Switch applications CO2 has an advanced thermal interruption capability comparative to Nitrogen gas and Air. Mixture of R12 and CO2 has fewer GWP and Boiling Point [18]. Experiment expresses that mixing a slight quantity of this R12 will drastically augment with CO2 gas dielectric strength as well as auxiliary adding up did not give similar hasty outcome [14]. It's the result of low down energy electrons attachment because lofty energy electrons attachment is extremely problematic. In Figure .7 shows breakdown strength of this R12 and CO2among mixture of different ratios. Figure. 8 displays that superior dielectric strength can be attained of R12 and CO2 ratios 80% and 20% respectively on (50 lb/in2) which one is 0.96 times of this peril SF6 gas. Figure. 8 presents Paschen curve of R12 and CO2 on changeable ratios at given pressure.

4.4. Insulation Self-Recoverability of Gas mixtures

Due to any fault if breakdown occurs which will produce a surge and will rise the temperature of these gases mixtures have a capability to quench the breakdown surge and restore to its original form and this is called Insulation self-recoverability. This mixture has insulation self-recoverability properties as that of SF6 gas because CO2 also have arc quenching properties [17]. Breakdown tests of Power AC frequency were carried out in testing circuit exposed above in Fig. 2. Test has been intended for each one minute, twenty shots for this breakdown was tested to this insulation gases. By-products gained after the putrefaction of these gases alike), Hydrogen Fluoride (HF), Hydrogen Chloride (HCl) and also carbon dioxide (CO2) Diminutive quantity of carbon was observed lying on electrodes consequently this one bridges the capability of insulation for the reason that carbon is very well conductor for electricity Although few drawback occurred, that can be eliminated by specific techniques of preventing carbonization available in literature [18]. By and large, self-recoverability of this gases mixture mi is excellent. Figure.9.

Table 5. R12 and Air (Insulation characteristics).

BASE GAS-R12 MIXED GAS Air						
RBG	50%	60%	70%	80%	100%	0%
SD	9.18	9.3	11.3	9.0	10.8	8.25
M	44.3	53.8	58.9	51.2	55.3	29.6
C.V	0.21	0.16	0.20	0.12	0.19	0.28
Max.Kv	59	69.1	73	63	71.6	42

RBG: Ratio of base gas; SD: standard deviation; M: mean; C.V: coefficient of variation

Table 6. R12 and Air (Insulation characteristics).

BASE GAS-R12 MIXED GAS CO_2						
RBG	50%	60%	70%	80%	100%	0%
S.D	11.2	12.3	5.21	10.2	10.9	9.18
M	46.1	51.6	59.7	57.3	55.3	32.1
CV	0.23	0.25	0.08	0.17	0.19	0.29
Max Kv	60	69.8	70.1	73	71.6	45.2
Min Kv	26	4	49.8	43	35.6	18.7

RBG: Ratio of base gas; SD: standard deviation; M: mean; C.V: coefficient of variation

5. CONCLUSIONS

This work concludes with merit altogether the dielectric characteristics of R12 gas mixtures as potential replacement for SF6 gas in insulation of high-voltage equipment.These gas mixtures were experimentally investigated underneath power frequency plus quasi-uniform electric field breakdown characteristics of formed gases in different pressure ratios are noted under several configurations leading to prime candidate mixes of R12/air (70/30%) and R12/CO2. (80/20%) at a pressure of 50 lb/in2 which show good key values and demonstrate voltages up to 140 kV moreover this composite mixtures demonstrate excellent self-recoverability potential. This indeed promises usage as a prime alternative in high voltage insulation mediums. The breakdown experimental tests results acquire which designate the acceptable insulation aptitude of these proposed anticipated gases mixture. Furthermore these formulated mixtures have cost effectiveness of 49%, and a 65% reduced amount of GWP as compared to pure SF6with auxiliary tendency to also subdue the spark generated during HV switching and quenching scenarios. In reflection of these performance measures, it's concluded to be a novel composite surrogate gas for electrical insulation in particularly high voltage applications.

6. THE FUTURE OF THIS INVESTIGATION

The liquefaction temperature required for R12 gas is high that is a shortcoming of R12.This affects the insulating properties of electrodes .However, a substitute to these concerns is a gas from Freon family, the Tetrafluoroethane R134 with associated low GWP to SF6 so it can primarily be the forthcoming candidate for analysis, mixture formulation and testing.

7. ACKNOWLEDGMENTS

The authors thank HEC Pakistan for financial support to this work's commencement. A statement of graceful acknowledgment is to our most respectful Prof. Dr. Rasheed (late) COMSATS Pakistan for his guidance and project work support.

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