Measuring Methods for Solubility of Gases in Insulation Liquids

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Since 2003 he is with ABB AG, Transformer Service in Halle, Germany, where he has hold different national and international positions. Since 2010 he is the general manager of the Transformer Service Workshop in Halle with more than 200 employees. He is member of VDE, IEEE, DKE K 182 insulation liquids and CIGRÉ as liason officer A2 - IEC TC 10 and active in different working Groups. He is the author or co-author of more than 100 publications and owner of more than 20 patents in Asset Management, Diagnostic Methods, Monitoring and High Voltage Testing.

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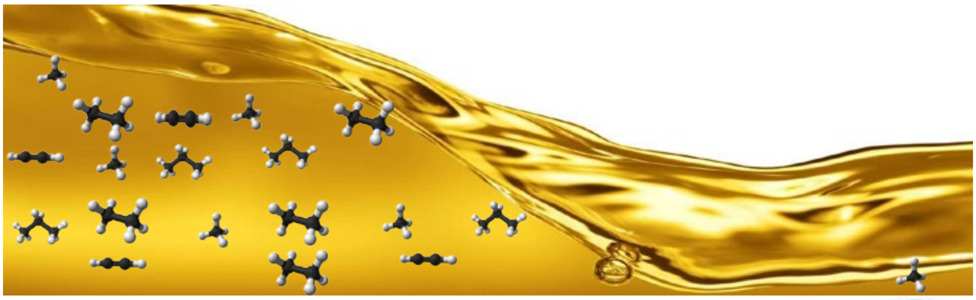

International Transformer Life Management Conference
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TLM

Motivation

- Knowing the gas solubility in insulating fluids is needed, because
  - it is applied for DGA Headspace method
  - it governs the gas diffusion into the liquid phase or vice versa in hermitic sealed transformers
  - enables a comparison of the undissolved trapped gases in the transformer Buchholz relay and those dissolved in oil, which could deliver information about transformer health condition
- No standardized method to quantitatively determine the gas solubility in liquid insulations

ASTM D2780-92 being already withdrawn!

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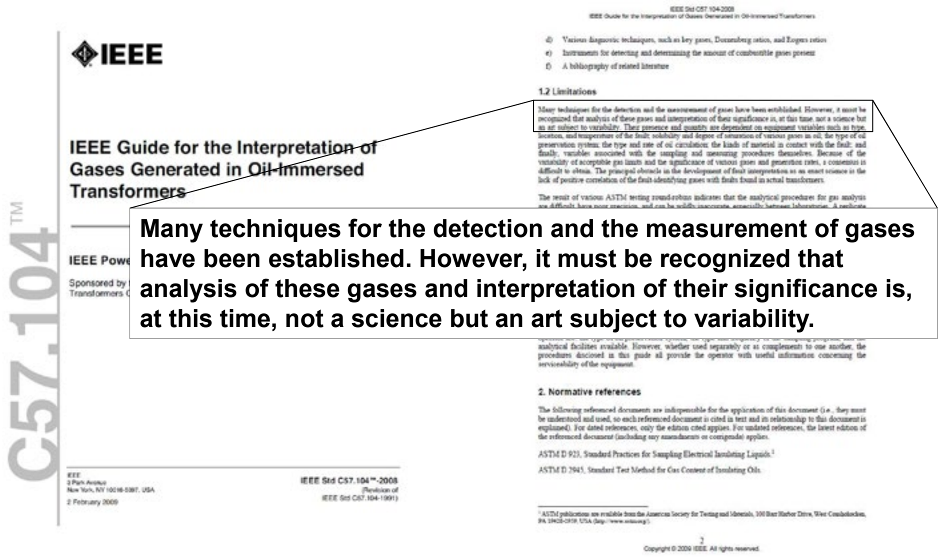
Motivation



IEEE

IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers

C57.104™

1.2 Limitations

Many techniques for the detection and the measurement of gases have been established. However, it must be recognized that analysis of these gases and interpretation of their significance is, at this time, not a science but an art subject to variability.

2. Normative references

IEEE Std C57.104™-2008

Motivation

- Gas solubility coefficients provided by IEEE C57.104 and IEC 60599 are inconsistent resulting in misleading DGA interpretations

Gas	k (IEC 60599)	k (IEEE C57.104)	Difference in %
N_2	0.091	0.0745	22.1
H_2	0.056	0.0429	30.5
O_2	0.172	0.138	24.6
CO	0.132	0.102	29.4
CO_2	1.09	0.9	21.1
CH_4	0.429	0.337	27.3
C_2H_6	2.82	1.99	41.7
C_2H_4	1.84	1.35	36.3
C_2H_2	1.24	0.938	32.2

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Ostwald Coefficient

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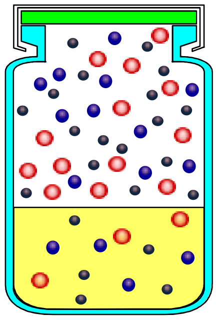
- **Henry's law:**
  - **The ratio of partial pressure to mole fraction of gas in solution is a constant**
- **Ostwald coefficient**
  - **The solubility of a gas is the volume of gas dissolved per volume of liquid when the gas and liquid are in equilibrium at the specified partial pressure of gas and at the specified temperature**



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Ostwald Coefficient

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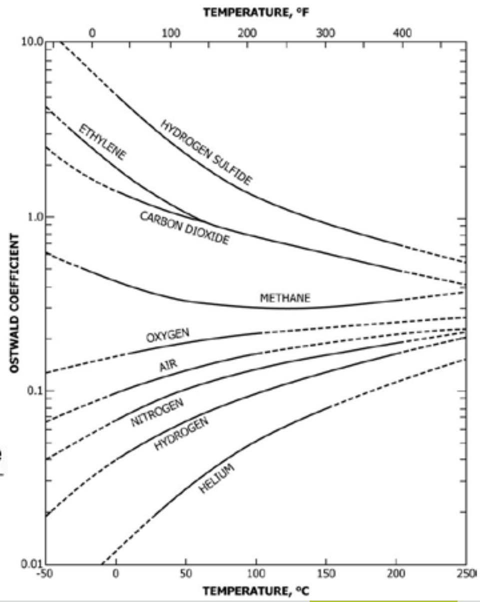
- **Ostwald Coefficient dependencies**
  - **Pressure**
  - **Temperature**
  - **Moisture**
  - **Solvent and solute compositions**
  - **…?**

$$k = \frac{\text{concentration of gas in liquid phase}}{\text{concentration of gas in gas phase}}$$



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Glass Syringe Method

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- Measurement procedure
  - A 50ml glass syringe filled with 30ml insulation liquid
  - Residual gas volume decreased to less than 0.3%
  - 20ml pure key gas was injected
  - The syringe kept in a heating chamber at 25°C for 72h
  - And subjected to the periodical shaking

- Dilemma
  - Gas leakage at elevated temperature (75°C)

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Measuring of Dissolved Gases

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- Full-Vacuum degassing using TOGA GC
  - Establishment of vacuum ranging from 2 to 200mbar for app. 2min
  - Complying with the standard IEC 60567
  - Detection of extracted gases through Thermal Conductivity Detector (TCD) and a Flame Ionization Detector (FID)

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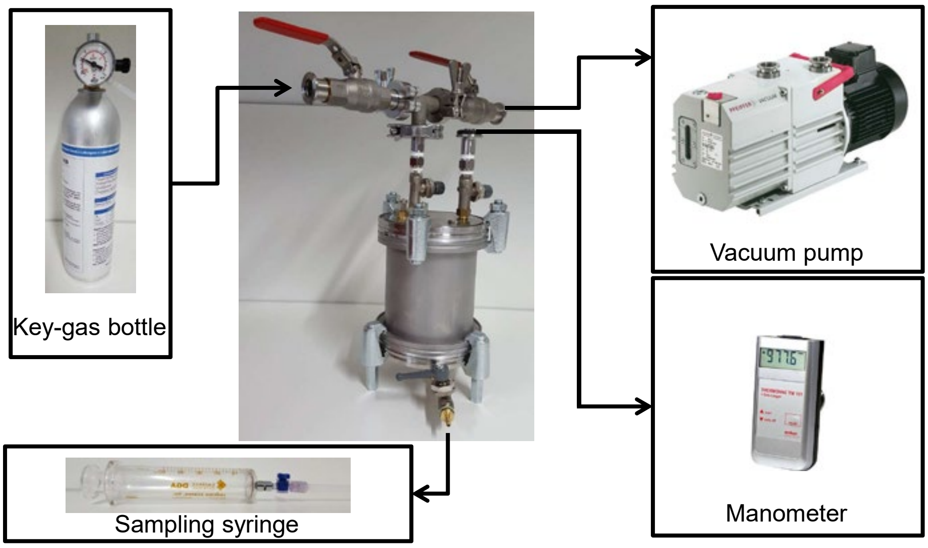
New Method

- Test set-up for gas saturation in liquid
  - The vessel was filled with 150ml of mineral insulating fluid
  - Liquid was treated at room temperature again at a vacuum level of 0.05mbar for 180min to ensure the removal of gas traces dissolved in the investigated oil
  - The pressure of the key gas was regulated at 1020mbar at the temperature of 25°C for 72h
  - Measuring the dissolved gases using a full vacuum degassing unit connected to the GC

New Method

- Test set-up for gas saturation in liquid



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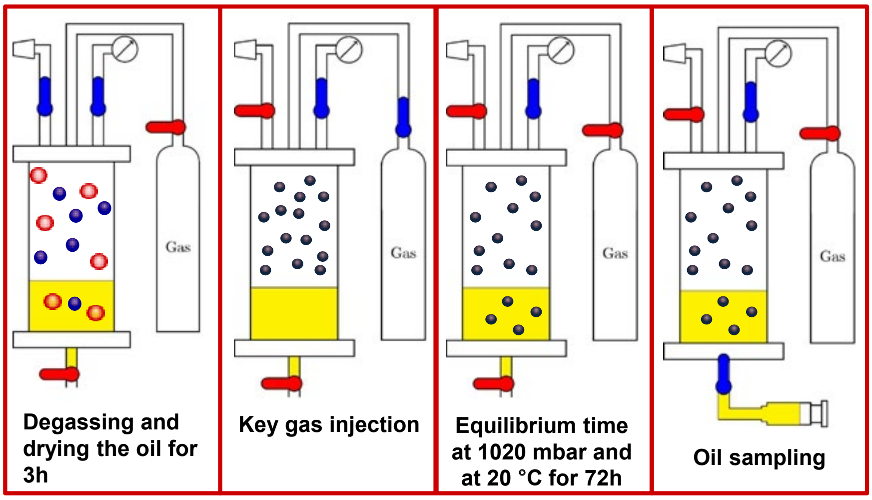
New Method

- Gas saturation process



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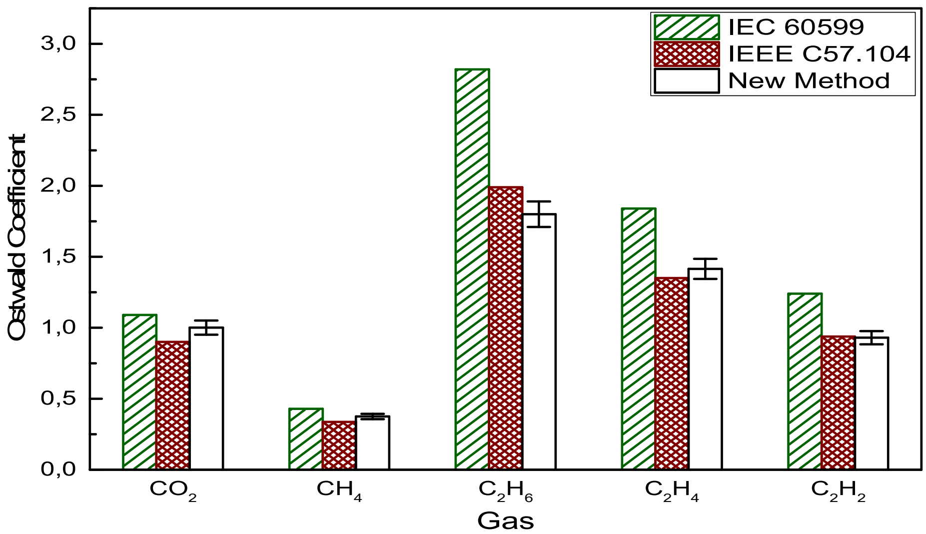
Results

- The measured results are in between IEC and IEEE standard, but more close to IEEE



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Results

- Ostwald coefficient values by IEEE C57.104 and IEC 60599 are inconsistent
- Measured Ostwald coefficients of key gases in mineral oil is comparable with those provided by IEEE C57.104
- Good reproducibility

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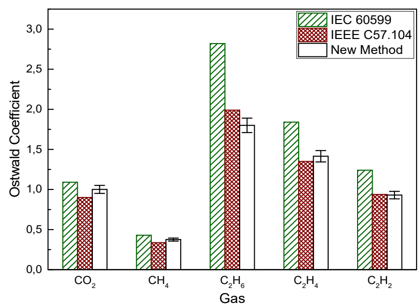
Gas	IEC 60599	IEEE C57.104	New Method
N_2	0,091	0,075	
H_2	0,056	0,043	
O_2	0,172	0,138	
CO	0,132	0,102	
CO_2	1,090	0,900	1,001
CH_4	0,429	0,337	0,375
C_2H_6	2,820	1,990	1,800
C_2H_4	1,840	1,350	1,415
C_2H_2	1,240	0,938	0,930



Ostwald coefficient of key gases in mineral oil S2 ZU-I at room temperature and at the pressure of 1020 mbar in comparison to IEC 60599 and IEEE C57.104

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Conclusion

- Gas solubility coefficients provided by IEEE C57.104 and IEC 60599 are inconsistent resulting in misleading DGA interpretations
- No standardized method to quantitatively determine this dynamic property of the binary gas-liquid system
- Gas solubility measurement on oil S2 ZU-I has verified the applicability of the new proposed method
- Establishment of a new standard method for determination of Ostwald coefficient to substitute ASTM D2780-92 being already withdrawn

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Outlook

- Verification of this approach should be subjected to a round robin test
- Influence of the following parameters should be investigated
  - Water content
  - Aging status of the oil (more importantly dispersed cellulose fibers)
  - Cross-influence of gases
- Ostwald coefficients for all important insulation liquids to be determined
  - Synthetic and natural esters
  - Silicone liquid
  - Etc.…