

CHROMSYMP. 271

DETERMINATION OF FAULT GASES IN TRANSFORMER OILS

K. TORKOS* and J. BOROSSAY

Eötvös Loránd University, P.O. Box 323, Budapest 1445 (Hungary)

and

Á. SZÉKELY

Ganz Electrical Works, P.O. Box 63, Budapest 1525 (Hungary)

SUMMARY

A method was developed for the determination of incipient faults in oil-insulated transformers. It involves the determination of so-called fault gases (C_1 - C_3 hydrocarbons, CO and CO_2) formed upon thermal degradation of the insulator oil and of the insulating materials on the cellulose base by gas chromatography, using a flame ionization detector. The carbon oxides are converted into methane using a nickel catalyst at $400^\circ C$. The reproducibility of the method is better than $\pm 5\%$ relative. Examples of three types of application of the method are presented.

INTRODUCTION

The trouble-free operation of systems supplying electrical energy is of fundamental importance because of the extremely high investment costs and the requirement to save energy. Operational problems in high voltage transformers are due mostly to damage to the insulation, therefore continuous observation of the insulation in these high efficiency units is of major importance. The qualitative and quantitative analysis of the so-called fault gases appearing in insulator oil enables the detection of faults at a stage when they are not revealed by changes in the electric parameters.

It is well known that operational problems such as discharges and local overheatings cause a partial decomposition of the insulation which always leads to the development of gases. The gases formed upon decomposition of insulating oil and of insulators on a cellulose base, H_2 , CH_4 , C_2H_6 , C_2H_4 , C_2H_2 , C_3H_6 , CO and CO_2 , are considered as fault gases.

From the early 1960s, investigations in this field were published in the United States of America^{1,2}, whereas in Europe Dörnenburg *et al.*³ were the first to deal with this problem. At the plenary session of the Conférence Internationale des Grand Réseaux Électriques à Haute Tension (CIGRE) at Paris in 1970, several studies were reported and recommendations made for further investigations^{4,5}. In the United States the procedures and methods of measurement are regulated by ASTM standards^{6,7}. The recommendations published by the International Electrotechnical Commission (IEC) are very similar⁸.

The determination of the gases dissolved in the oil involves sampling of oil, vacuum extraction and measurement by gas chromatography (GC).

EXPERIMENTAL

The sampling of oil from the transformer was carried out by means of a flow-through type metal container. The vacuum extraction of the gases dissolved in the oil and the introduction of the sample was performed using the equipment shown in Fig. 1. The sample inlet system including the loops of the gas sampling valve is evacuated to 0.5–1.0 Pa after purging with helium of high purity. A 25-cm³ volume of oil is allowed to drop into the vessel E in about 3 min. The extracted gases are sampled in the flask M by opening and closing appropriate valves. The pressure in the sampling flask (M) is increased by addition of helium to the inlet pressure of the column (0.2–0.5 bar). The resulting sample then enters the evacuated loop.

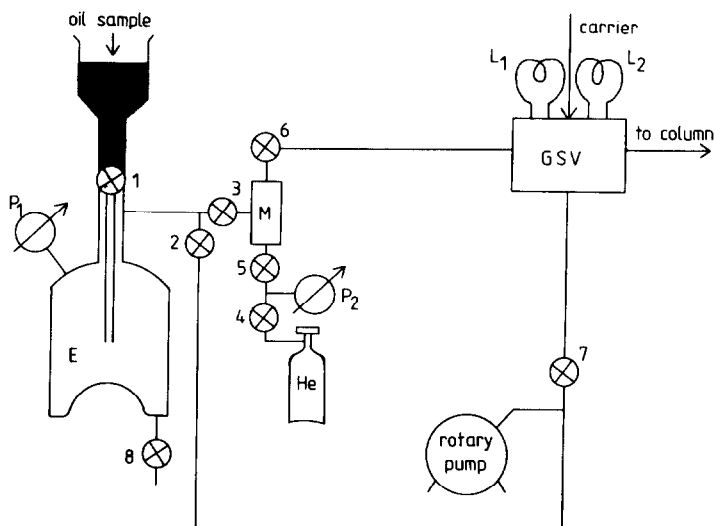


Fig. 1. The vacuum extraction and sample inlet system. E = Extraction flask (≈ 200 cm³); P₁ = Pirani gauge (0.1–30 mbar); P₂ = pressure gauge (0–4 bar); M = sampling flask (≈ 10 cm³); 1–8 = vacuum stopcocks (PTFE); GSV = 8-port gas sampling valve; L₁, L₂ = sample loops (0.5 cm³).

GC

A Hewlett-Packard 5720 A type gas chromatograph equipped with a flame ionization detector, a Spectra Physics System I computing integrator and a Hewlett-Packard 7123 A chart recorder were used. The C₁–C₃ hydrocarbons were separated at 200°C on a 80 cm \times 1/8 in. stainless-steel column containing Carbosieve B (60–80 mesh) (Supelco), with nitrogen as carrier gas (30 cm³/min). The order of elution was methane, acetylene, ethylene, ethane, propyne (methylacetylene), propadiene (allene), propylene and propane.

Carbon oxides were converted into methane with the use of a nickel catalyst at 400°C, and detected also by flame ionization detection (FID)⁹. The carbon oxides were separated at 55°C on a 2.5 m \times 1/8 in. stainless-steel column containing Po-

rapak N (80–100 mesh), with hydrogen as carrier gas (30 cm³/min). The stainless-steel catalyst tube (10 cm × 1/4 in.) was inserted between column and detector. It contained Ni on Chromosorb P (60–80 mesh) and was heated by an externally controlled supply unit. The efficiency of the catalyst decreases with time, therefore calibration was carried out prior to each series of measurements. This is however not necessary in the case of hydrocarbons provided the measurements are carried out under identical conditions.

Calibration for hydrocarbons and carbon oxides was carried out on the basis of peak height using mixtures of known composition. The data are given in units of ppm ($V_{\text{gas}}/V_{\text{oil}}$). The limits of detection are 1.0 ppm for C₁–C₂ hydrocarbons, 5.0 ppm for C₃H₄ isomers and 10 ppm for C₃ hydrocarbons and carbon oxides. A complete analysis requires less than 20 min.

RESULTS

Over the period from 1978 to 1980 the operation of nine power station transformers was observed. The results of our investigations showed that the amount of fault gases fluctuated but definite trends could not be distinguished. Of the investigated transformers, no failure occurred in eight cases, and the transformers are still operating to day. The transformer taken as the example in Table I was used as a reserve, and therefore it was switched off and on very frequently; the oil space in the high voltage oil switch was in direct contact with the insulator oil of the transformer.

The main decomposition products (acetylene, ethylene and propylene) of the arc discharge formed during these switchings are present in relatively high concentrations. Owing to deterioration in the condition of the insulator oil, the loss factor (loss due to decrease of the breakdown voltage of insulator oil) of the transformer

TABLE I
CONTINUOUS OBSERVATION OF AN ACTIVE TRANSFORMER (NO. 102894)

Date		Concentrations in ppm ($V_{\text{gas}}/V_{\text{oil}}$)							
		CH ₄	C ₂ H ₂	C ₂ H ₄	C ₂ H ₆	C ₃ H ₆	C ₃ H ₈	CO	CO ₂
1978	March	41.0	13.2	108	28.0	134	36.0		
	April	78.0	34.0	230	5.7	28.0	83.0		
	May	3.6	2.2	7.6	1.4	3.0	—		
	June	21.0	12.1	40.0	5.6	15.2	—		
	Sept.	26.5	14.3	56.0	50.0	—	—		
	Oct.	33.0	18.8	64.0	10.0	21.0	—		
1979	May	117	15.5	183	23.0	61.0	—		
	June	91.0	24.0	280	32.0	185	—	20.0	4410
	Aug.	44.0	16.9	167	29.0	66.0	48.0	30.0	9900
	Oct.	46.0	14.2	215	30.0	85.0	11.0	—	6240
1980	April	92.0	9.8	109	29.0	—	—	20.0	9590
	June	50.0	16.0	187	29.0	≈10.0	—	50.0	9500
	Sept.	39.0	11.0	170	27.0	37.0	≈10.0	100	11,300
	Oct.	53.0	9.5	198	33.0	—	≈10.0	≈10.0	4700

increased. Since changing the oil in 1981 the transformer has operated without failure. The measurement of CO and CO₂ was carried out from June 1979 on wards. It should be noted that the values obtained for CO are not unusual; in the case of transformers operating without failure, no carbon monoxide could be detected in the majority of cases. Hydrogen was measured by a mass spectrometric method.

In the course of our investigations severe failures were recorded in some cases. These occurred mostly with transformers operating in industrial plants or in smaller distributor sites. Even these units should be monitored regularly because the cost savings which can thereby be made.

One of the very important applications of the analysis of fault gases is in the examination of new transformers. Such tests may provide useful data concerning faults in design or manufacture. In these measurements on the basis of the CIGRE recommendations, in normal cases low concentrations must be measured with high accuracy in order to obtain reliable results¹⁰. In Fig. 2 an example is shown of a transformer which sustained a loading test only for a few minutes, and safety devices then switched off the equipment. An investigation of the fault gases indicated a deficiency in the insulation which was later confirmed by subsequent tests. However, this is a very extreme case occurring only once during our series of investigations which lasted for several years.

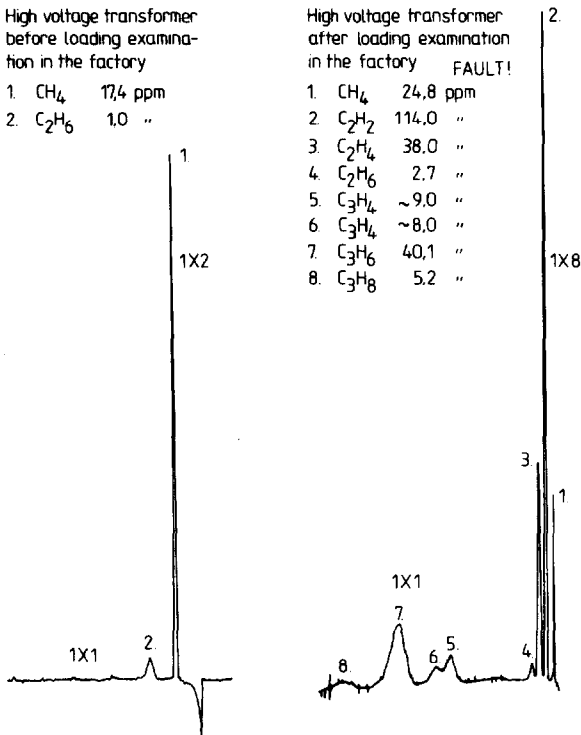


Fig. 2. Chromatograms indicating an extreme fault in a new transformer. Column: 80 cm × 1/8 in., stainless steel, packed with Carbosieve B (60-80 mesh). Oven temperature: 200°C. Carrier gas (nitrogen) flow-rate: 30 cm³/min.

CONCLUSIONS

The method of measurement developed by us was applied in three areas:

- (1) to increase the safety of operation by means of continuous observation of active transformers (nine power station transformers were investigated for 3 years)
- (2) to verify the type of fault in transformer breakdowns
- (3) to detect faults in manufacturing at the loading examination of new equipment

According to our experience the continuous measurement of hydrocarbons is most important for the characterization of the insulation of a transformer, and until acetylene is not formed the safety of operation is adequate. An increase in the concentrations of ethylene and propylene points to incipient faults. In our opinion the measurement of carbon oxides is necessary only in cases where the concentration of hydrocarbons increases significantly because in this case one must take into account also a thermal degradation of the insulators on a cellulose base.

REFERENCES

- 1 P. S. Pugh and H. H. Wagner, *IEEE Trans. Power Apparatus and Systems*, 80 (1961) 189.
- 2 J. P. Vora and L. C. Aichler, *IEEE Trans. Power Apparatus and Systems*, 83 (1965) 172.
- 3 E. Dörnenburg and O. E. Gerber, *Brown-Boveri Mitt.*, 54 (1967) 104.
- 4 R. Müller, K. Pothoff and K. Soldner, *Conférence Internationale des Grand Réseaux Électriques à Haute Tension, Paris, 1970*, Rep. No. 12-02.
- 5 B. Fallou, F. Viale, I. Davides and E. Dörnenburg, *Conférence Internationale des Grand Réseaux Électriques à Haute Tension, Paris, 1970*, Rep. No. 15-07.
- 6 *Annual Book of Standards*, Part 40, American Society for Testing and Materials, Philadelphia, PAD 3612-79.
- 7 *Annual Book of Standards*, Part 40, American Society for Testing and Materials, Philadelphia, PAD 3613-77.
- 8 IEC Standard, Publication 599, International Electrotechnical Commission, Geneva, 1st ed., 1978.
- 9 K. Porter and D. H. Volman, *Anal. Chem.*, 34 (1962) 748.
- 10 *Final Report of Working Group of Study Committee 12 (Conférence Internationale des Grand Réseaux Électriques à Haute Tension)*, *Electra*, 82 (1982) 33.