QUALITIES OF PRODUCTS OF THE BTS TRANSFORMER OIL DECOMPOSED BY ELECTRIC ARC[1])

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The paper presents the solution of problems involved in determining the chemical composition of products of mineral oil decomposition by electric arc, as well as the calculation of their thermodynamic behaviour. Comparison of calculation results considering hydrogen dissociation and without considering it is dealt with.

СВОЙСТВА ПРОДУКТОВ, ВОЗНИКАЮЩИХ РАСЩЕПЛЕНИЕМ ТРАНСФОРМАТОРНОГО МАСЛА БТС В ЭЛЕКТРИЧЕСКОМ РАЗРЯДЕ

В работе приведено решение проблем, связанных с определением химического состава продуктов реакции разложения минеральных масел при помощи электрической дуги, а также вычисление их термодинамических характеристик. Проводится сравнение вычисленных результатов с учетом и без учета диссоциации водорода.

I. INTRODUCTION

Processes that occur near the current zero and after arc extinction should be considered from the viewpoint of the oil circuit breaker extinguishing chamber reliability. The dependences that affect a successful operation of the extinguishing chamber such as e.g., the dependence of the electrical strength of gases flowing out of the extinguishing chamber on their pressure and temperature, on the relationship of the electrical strength to the recovery voltage rise, on the relationship of thermal conductivity of gasses to the action upon the arc, etc., can be solved only on the basis of an analysis of thermochemical and thermophysical processes occurring in the oil circuit breaker extinguishing chamber during arcing. The calculation of the C-H-S-O-N system is relatively complex and its results depend primarily on the transformer oil composition which varies with the type of the crude oil used.
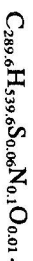
II. CALCULATION OF THE CHEMICAL COMPOSITION OF PRODUCTS OF THE TRANSFORMER OIL DECOMPOSITION

For the calculation of products of the transformer oil decomposition by electric arc the total-free-system-enthalpy-minimization method has been selected. The calculation was made assuming that an equilibrium state had been established and that the complete gaseous phase behaved as ideal gas. This assumption is physically justified since no corrections for gaseous phase nonlinearity can be introduced into the calculation at temperatures from 1000 to 4000 K and pressures from 0.1 to 3 MPa. The calculation of the summary formula of the system was based on an elementary analysis of the BTS oil and on the fact that, in addition to oil, air is also present. While respecting the relative molecular weight 288 of the oil the following summary formula for the further calculation of the gaseous phase was applied

$$C_{289.6}H_{539.6}S_{0.06}N_{0.1}O_{0.01}.$$

The selection of components for the calculation of decomposition products was made in two stages. In the first case it was based on the analysis of samples of the gaseous phase obtained from the experimental apparatus operation and from some theoretical studies, and the influence of atomic components was not considered [1]. In the second case the constitutional matrix was extended from the original twelve to twentyfour components, atomic ones included. In both cases the calculation was carried out for the range of temperatures within 1000 K to 4000 K (and/or 6000 K
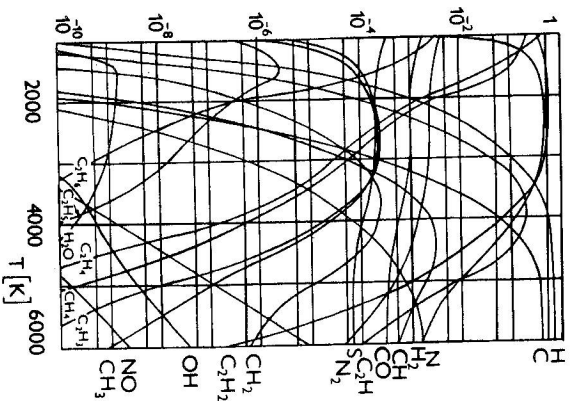
Fig. 1. Temperature dependence of the composition of mineral oil gas products.

y-axis: 1, 10^{-2}, 10^{-4}, 10^{-6}, 10^{-8}, 10^{-10}
x-axis: $T\,[K]$ — 2000, 4000, 6000
Component labels: H, C, N_2, H_2, CO, CH, C_2H, N_2, CH_2, C_2H_2, OH, NO, CH_3, C_2H, H_2O, CH_4

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in the second case) and for pressures from 0.1 to 3 MPa. The results are presented in Fig. 1.

III. DETERMINATION OF THE THERMODYNAMICAL QUALITIES OF PRODUCTS OF TRANSFORMER OIL DECOMPOSITION

For the determination of the thermodynamical qualities of products of transformer oil decomposition a technique was applied based initially on data on the molar fractions of decomposition products and also the approximation coefficients of standard thermodynamical functions and other thermodynamical data. An ideal behaviour of the individual components in the system is assumed, as in the calculation of equilibrium composition. 11 components are considered in the calculation since comparison calculations have shown that the thermodynamical properties of our interest have been determined with a sufficient accuracy ($\approx 0.05\,\%$) if only the prevailing components are considered in the calculation ($x_i \geq 10^{-3}$).

The calculation results are represented in Figs. 2 to 4. Dependences of specific enthalpy h, specific weight ϱ and molar weight M_m on temperature are presented in Fig. 2. Dependence $h = f(T)$ determined from the calculations in the first stage is represented in the same Figure in dashed lines. It can be seen that a more accurate input of thermochemical data and respecting further components (H, C_2H) in the second stage of the calculation lead to substantial variations in the course of the specific enthalpy. The specific enthalpy linear growth within the range from 2000 to 4000 K is not present due to a great stability of the $H_2 + C_2H_2$ components as in the first case. The relationship $M_m = f(T)$ indicates in good accord with the calculation of the composition (course H_2 and C_2H_2) the stability of the whole system within the range of temperatures 2000—2500 K. Figure 3 represents temperature dependences of specific heat c_{pf}, sound velocity a_f and equilibrium specific heat c_{pe}. Extreme values c_{pe} characterize in the given temperature range the maximum gradient of decay of the molecular compound of the system. The first value is conditioned by dissociation of CH_4 and C_2H_4 in molecular hydrogen and C_2H_2. At temperatures of 2000 to 2500 K the system is stable, dissociation of higher molecules is finished. A further increase of temperature causes dissociation of molecular hydrogen, which is indicated by an extreme value of T 3800 K ($p = 0.1$ MPa).

The dependence of the main thermodynamic values in pressure is given in Fig. 4 for the temperature of 2500 K. Within the following range of pressure both the specific enthalpy and the molecular weight of the system vary little. Thermodynamic properties of the system are determined by two components only — $H_2 + C_2H_2$ — their share reaches 97.5 % and does not vary with the change of pressure. Differences increase for lower and higher temperatures because in these

Fig. 2. Temperature dependence of the main thermodynamic properties of mineral oil gas products.

Fig. 3. Temperature dependence of the specific heat and sound velocity of mineral oil gas products.
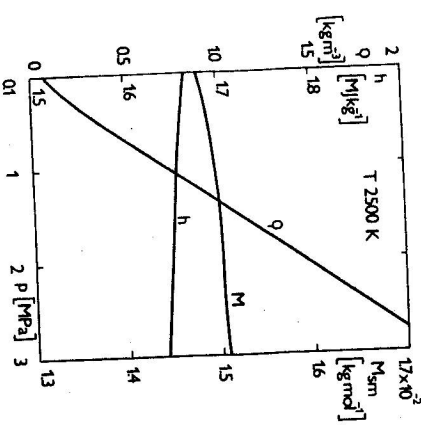
Fig. 4. Pressure dependence of the same thermodynamic properties of mineral oil gas products.

regions extreme values can be found (see Fig. 3) as a consequence of maximum gradients of decomposition reactions. From the mutual comparison of the two systems considered (without considering dissociation H_2 and considering it), a great effect of atomary hydrogen on the thermodynamic properties of the system is evident. Nevertheless, it is necessary to take into consideration that, in the second case, newer input data from 1978 and 1979 were applied and another constituent C_2H was considered in the system. The supposed values are for orientation since the existing calculations were realized with the 500 K temperature step. Nevertheless, it is possible to consider the two above mentioned variants of calculation as limit cases which give a basic conception of the properties of products of transformer oil decomposition by electric arc.

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[1] Bartl, J., Fidler, A., Gregor, P., Vávra, Z.: Contribution to the Determination of the Effectivness of the Oil-breakerextinguishing chamber. Publications of Technical and Scientific Papers of the Technic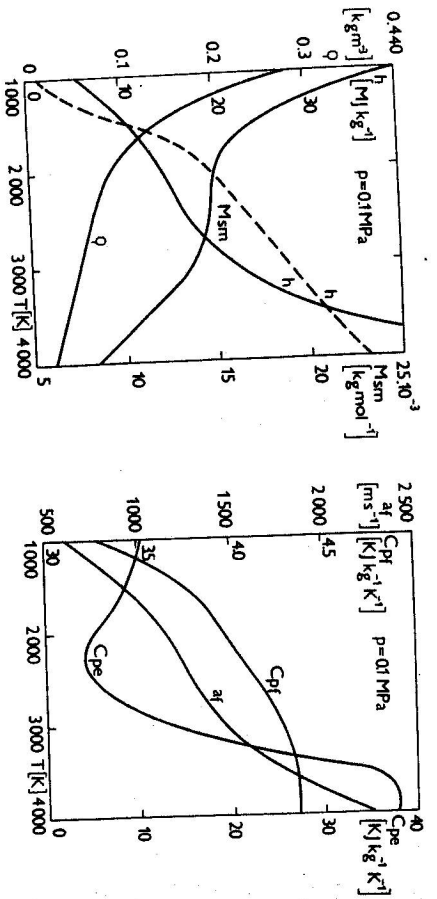al University in Brno 1980, Vol. B-89.