Moisture Determination in Solid Transformer Insulation on the Basis of Capacitive Oil Sensors

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ABSTRACT

The moisture in the insulation system of power transformer in general and in the solid part in special is one of the most important factors for the aging processes. In this paper the causes for moisture occurrence and the conventional methods for the determination of moisture were reviewed. A new method to determine the moisture in the solid insulation system is presented. It is based on the results of the measurement with a capacitive oil sensor. A model for the calculation of the relative water content in the cellulose was developed. The basis of this model is the physical function of diffusion process by the law of Fick. The simulation model and laboratory tests were carried out and the results were compared and discussed.

Key words: capacitive sensor, diffusion model, moisture, transformer insulation system

1. MODEL OF MOISTURE DIFFUSION

If there is moisture in the transformer system several physical and chemical processes were present, which result in degradation of the insulation system. Aging of the solid and liquid worsens the condition of the transformer. The moisture can get into the transformer on several ways, mostly leakages in the tank, or sealings of the bushings were possible. But the moisture can also occur due to chemical effects e.g. hydrolysis, pyrolysis as well as oxidation in interaction of thermal load with the transformer oil. The most part of the so built moisture is present in the solid insulation system, the paper can keep some percent water in it. The moisture content in oil is much lower, only some ten ppm is a normal value. In dependence of the temperature, the water moves slowly from solid to liquid and vice versa. The physical background can be found in the theory of thermodynamic processes that a system always wants to get in the state of equilibrium. During this diffusion, the moisture moves at rising temperatures from the solid to the liquid insulation system because the humidity saturation level of mineral oil rises by temperature. The second law of Fick described this diffusion process [2]:

$$\frac{\partial c_p(x,t)}{\partial t} = D(T)\frac{\partial^2}{\partial x^2}c_p(x,t)$$

with c_p as the moisture content in paper in % at the place x and time t,
with D(T) as the diffusion constant

Solving the diffusion equation there were two possible arrangements:

- winding – paper – oil and
- oil – paper – oil.

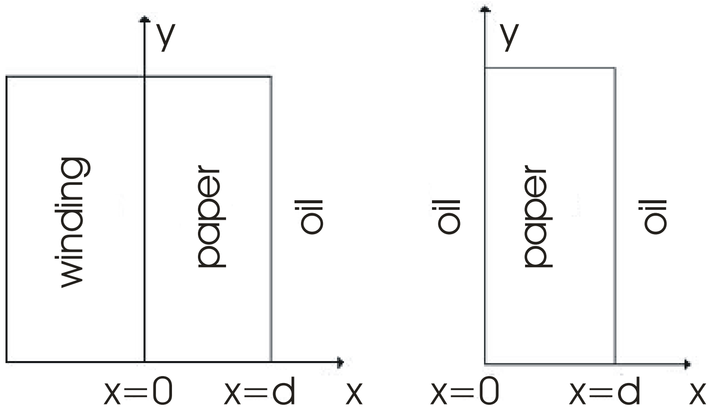

Figure 1: Arrangements for the diffusion model [1, 2]

Each arrangement affords different boundary conditions and results in other solutions. In [2] the calculations were demonstrated for these paper oil arrangements.

With the knowledge of the moisture content of oil and the equilibrium curves of paper and oil this diffusion equation can be solved in a balanced condition. Measuring the moisture content of oil and knowing the temperature of the system the humidity content of paper can be calculated. There were different models respectively equations to transform the oil moisture to paper moisture, in [3] a literature research was done and a historical overview is given. In following figure one possibility of the relation between oil and paper moisture is given.

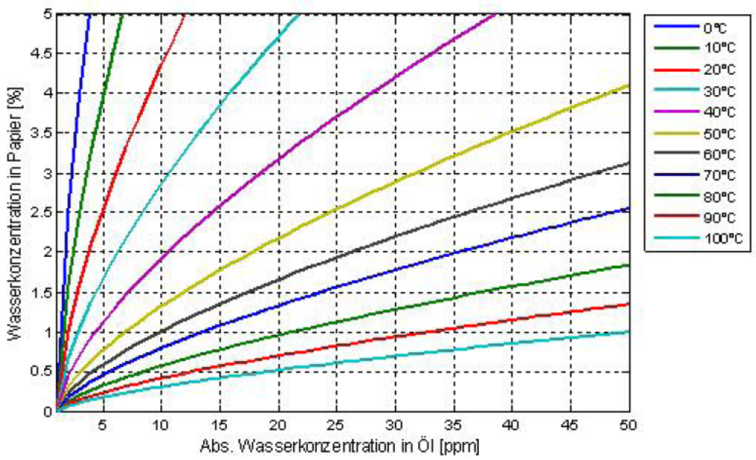

Figure 2: Equilibrium curves of moisture in oil and paper, calculated by the Ommen formula [1, 3, 4]

2. SIMULATION RESULTS

For the calculation of the diffusion process a was mathematical program was developed to calculate the moisture in the paper insulation system with following input data: temperature, relative oil humidity, mass of paper and oil and geometrical dimensions. The calculation algorithm can calculate systems in a stable state. It was not useful to do simulations about fast changing dynamic situations.

In the first try a temperature change from 25°C to 70°C and down to 30°C again was calculated. The results were shown in following figures:

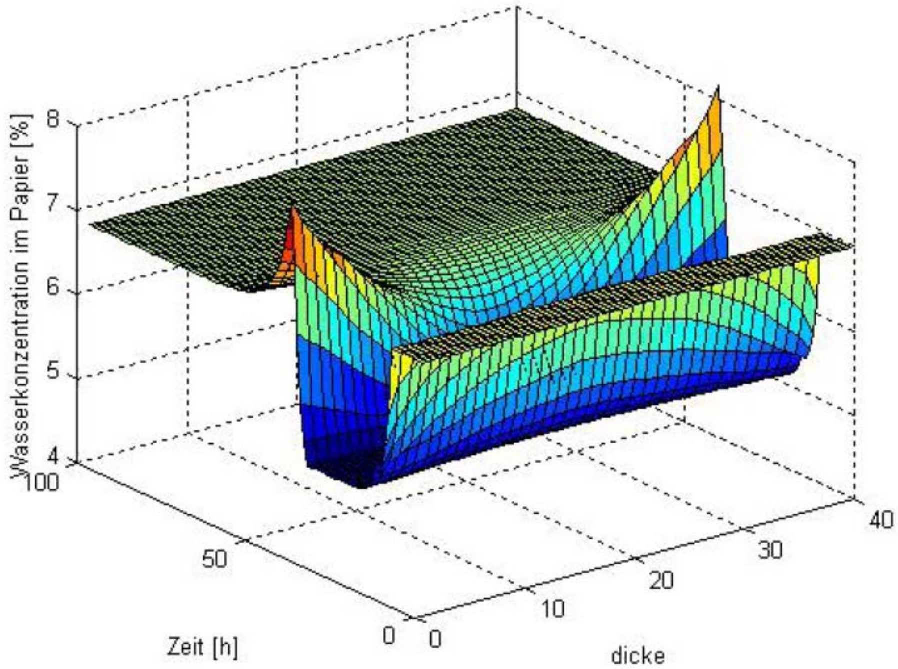

Figure 3: Results of simulation: temperature change from 25 to 70°C [1]

3. MEASUREMENT RESULTS

To verify the calculation model a test arrangement was developed. A hermetic encapsulated test vessel with a paper oil arrangement with a volume of ca. 10 l was constructed. The oil moisture was measured with a capacitive sensor and the temperature was measured with a PT100.

Before the measurements were started the pressboard and oil were dried in a vacuum chamber to guarantee ideal measurement conditions.

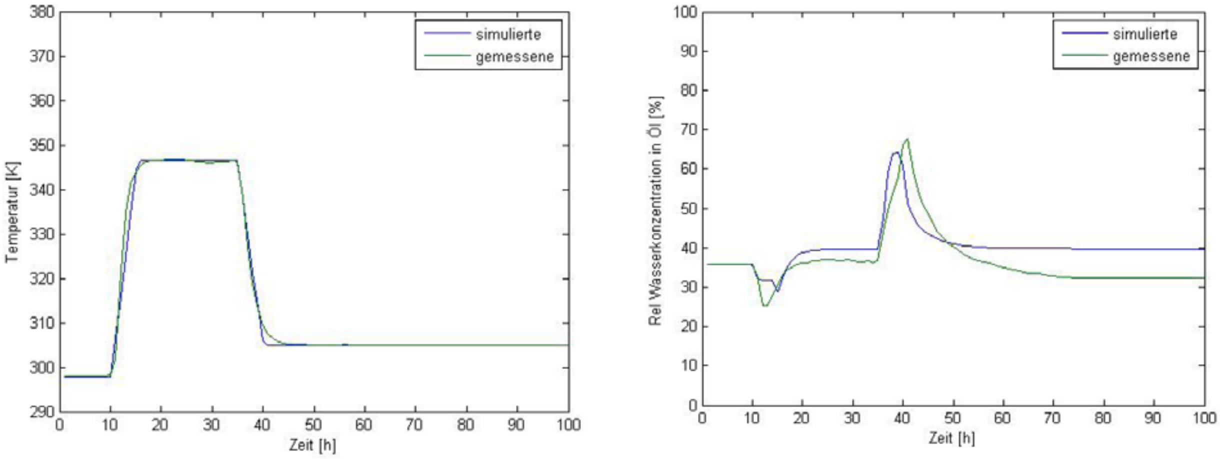

Figure 4: Comparison of simulation and measurement: temperature change from 25 - 70 - 30°C [1]

4. CONCLUSION

In this research work a mathematical model was developed to simulate the diffusion process of moisture in transformer insulation systems. First a simulation was done to calculate the moisture content in paper at a defined temperate changes. In a next step the model was verified by a practical measurement.

This investigation showed that the developed model meets the reality good, the test and simulation results were in very good accuracy. The developed model can be applied at simple insulation models. For the calculation of complex insulation arrangements as power transformers the temperature gradient in the solid insulation system should to be taken into account.

5. REFERENCES

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