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# NANOCAPILLARIES IN INSULATING OIL IMPREGNATED ELECTROTECHNICAL PRESSBOARD

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**Abstract** - Paper presents measurement bench for oil absorption speed during the impregnation of electrotechnical pressboard or other porous materials. The station allows for record of a measuring cylinder images, filled with insulating oil with the pressboard sample placed there in, and thus precisely record the volume of the absorbed oil and the time it was absorbed. It was foundthat the time to complete the pressboardimpregnationprocess was approximately $2{\cdot}10^6$ s. During this time, pressboard absorbs insulating oil in a volume of about 25.6% of the pressboard volume. This means that the free space occupies in pressboardabout 25.6% of its volume. Research of press board free surfaces howedthatit was about 10 $m^2$ per $cm^3$ of pressboardvolume. On the basis of this data, it was determinedthat the meancapillarydiameter of pressboard was about 25.6 nm.

**Keywords** - Electrotechnicalpressboard, insulatingoil, freesurface, capillary.

## I. INTRODUCTION

Cellulose in form of paper and electrotechnical pressboard for almost a century have been the most widely used insulating material for construction of high-voltage power transformers. In order to improve the insulation parameters, resistance to aging processes and to block moisture absorption by cellulose, so-called liquid-solid insulation is used. After the transformer is manufactured, it is usually vacumlly dried to a moisture level of less than 0.8% by weight.

The transformer is then filled in vacuum with an insulating oil with a moisture content of several ppm. During this period, cellulose impregnation with insulating oil takes place. In the course of many years of use, moisture content in the composite cellulose - mineral oil is gradually increasing. Increasing of moisture content significantly reduces the quality of paper and oil insulation and the reliability of power transformers. This means that level of power transformers solid insulation moisture content should be determined as precisely as possible.

For moisture content determination in paper-oil insulation of hermetic power transformers most often are used non-invasive electrical methods. These methods belong to two basic groups - time-related measurements such as RVM (Return Voltage Measurement) [1,2] and PDC (Polarization Depolarization Current) [3,4] methods, and measurements in the frequency domain FDS (Frequency Domain Spectroscopy) [5,6].

The dependencies defined by RVM, PDC and FDS can be used to estimate the moisture content of paper and oil insulation. However, the use of analysis based on these results requires a reference relationship for different levels of cellulose moisture and temperature. For this purpose, laboratory tests are carried out on previously moistened and then oil impregnated paper and electrotechnical pressboard.

In this case vacuum impregnation, which is use in industrial, cannot be used. It is possible that impregnating in a vacuum will contribute to uncontrolled evaporation of moisture from the sample, as there will occur so-called vacuum drying in this case. The impregnation of cellulosic materials with insulating oil takes place through the penetration of oil into the free spaces (capillaries) located in the structure of cellulose.

The purpose of the work was to develop a new method for determining speed of electrotechnical pressboard oil impregnation process, to make measurements and to determine the structure of the free spaces (capillaries) inside the pressboard.

## II. DETAILS EXPERIMENTAL

The NOVA 2200 (Quantachrome Corp. USA) measuring bench was used to investigate the capillary structure in the electrotechnical pressboard, which allows to determine the capillary surface inside the porous materials to which cellulose is undoubtedly included.

For the observation and registration of impregnation process, designed and made in Department of Electric Devices and High Voltage Technology measurement station, shown in Figure 1, was used. The test bench is based on a modified standard measuring cylinder with a volume of 250 $cm^3$ and with a graduation of 2 $cm^3$.

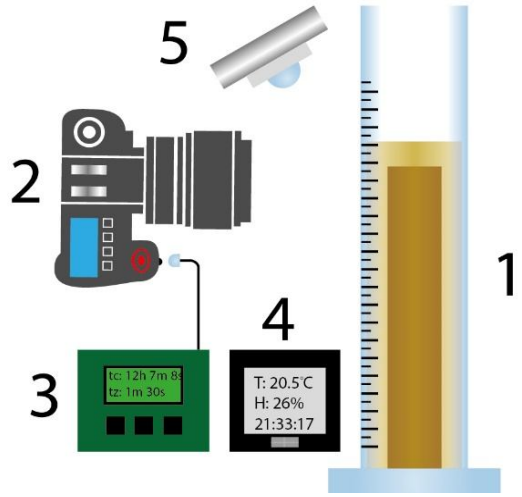


**Figure 1. Scheme of measurement stand: 1 - measuring cylinder, 2 - digitalcamera, 3 - microprocessorcontroller, 4 - weatherstation, 5 - LED lighting.**

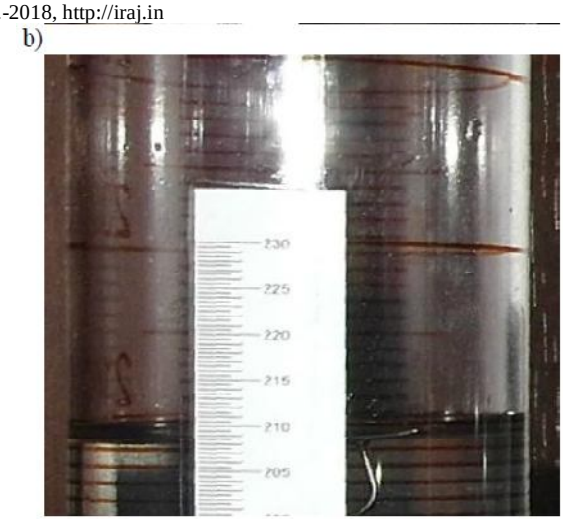


**Figure 2. Fragments of the measuringcylindersimages, containinginsulatingoil and pressboard: a - at the moment of pressboardimmersion; c - after 20 days.**

A 10 Mp digital camera was used to record oil level changes. Next to the measuring cylinder is a weather station, which displays date, time, minutes and seconds, pressure, temperature and humidity. The weather station image was also recorded with a camera. On this basis, the values of time when the oil level coincided with the next mark on the measuring cylinder scale, were read. In the experiments, pressboard strips made by one of leading companies Pucaro, with thickness of 1mm, length of 160 mm and width of 20 mm, was used. The total sample volume was about 70 $cm^3$. For the purpose of impregnation, a new transformer oil from one of the leading manufacturers - Nynas, type Nitro - Taurus with a moisture content of less than 5 ppm was used. The pressboard strips were vacuum dried at 80 °C for 8 h. After cooling the strips in a vacuum, the digital camera was started, and then strips of dried pressboard were placed in a measuring cylinder filled with oil.

## III. RESULTS AND DISCUSSION

By observing enlarged images, the times when the oil level is exactly the same as the scale line, were determined.

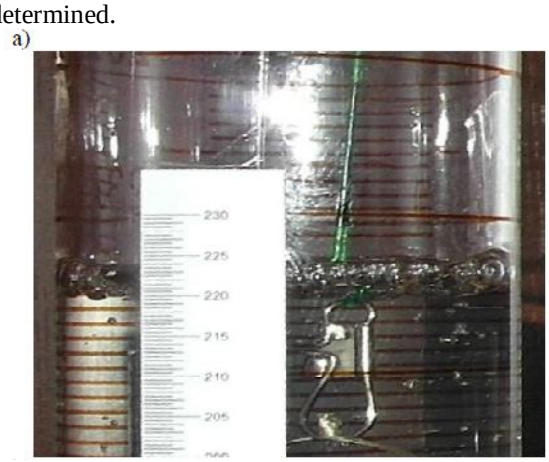


Figure 2 shows, that with the passage of time from the immersion of pressboard the oil level drops. This is related to the oil absorption by pressboard. On this basis, the time dependence of the volume of oil sinked by the pressboard, was depicted in Figure 3 on a semi-logarithmic scale. As canbesee from Figure 3, after a few seconds there is a change in oil level, related to its absorption by the pressboard. As the time of impregnation increases, the volume of oil absorbed by the pressboard grows. In addition, there are clearly visible growth stages.

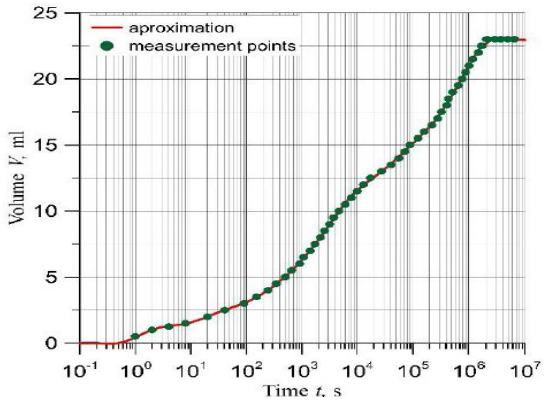


**Figure 3. The timedependence of the volume of oilabsorbed by the electricalpressboard.**

At an impregnation time of about $2 \cdot 10^6$ s, the volume of oil absorbed by the pressboard sample stabilizes. The volume of used in experiments pressboard was 70 $cm^3$, and in the impregnation process about 18 $cm^3$ of oil was absorbed. This means that the free spaces inside the pressboard occupy about 25.6% of the sample volume.

The capillary area inside the pressboard was determined by the NOVA 2200 (Quantachrome Corp. USA) measuring system. Studies have shown that the area of the capillaries within one cm3 of pressboard is 10 m2. Determining the volume of free space (capillaries) inside the pressboard and the free area of the capillaries will serve as a basis for determining the mean dimensions of the capillaries.

The area of the capillary free area inside the pressboard is:

$$S = \pi \cdot d \cdot l \quad (1)$$

Where: d - capillary diameter; l - total length of capillaries.

Total volume of capillaries inside the pressboard:

$$V = \frac{\pi \cdot d^2 \cdot l}{4} \quad (2)$$

By dividing the formula (2) by the formula (1) we obtain:

$$\frac{V}{S} = \frac{d}{4} \quad (3)$$

Or finally:

$$d = 4\frac{V}{S} \quad (4)$$

By substituting V = 0.256 $m^3$ and S = $10^7$ $m^2$ in one cubic meter of pressboard, the mean value of the capillary diameter, which is about 25.6 nm, was determined by the formula (4).

## CONCLUSIONS

A bench for measuring the oil absorption rate during the impregnation of the electrotechnical pressboard was developed and made. It was found that the time necessary to complete the impregnation process is about $2 \cdot 10^6$ s. At this time, pressboard absorbs insulating oil in a volume of about 25.6% of its initial volume. Measurements of free surface of the pressboard showed that its value is about 10 $m^2$ per $cm^3$ of pressboard volume. On the basis of these data, the mean value of the capillary diameter in the pressboard, which is about 25.6 nm, was calculated.

## ACKNOWLEDGMENTS

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