Mathematical Modeling and Analysis of Cooling System of Electrical Transformer Dipped into Polymerized Resin

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Abstract— **This paper presents an analysis of the cooling system of electrical transformer dipped in polymerized resin with the help of mathematical modeling. It represents that the temperature at the measurement points for both cooling systems are closed.**

Keywords— Mathematical modelling, transformer, temperature etc.

I. INTRODUCTION

Now-a-days, electrical transformers are commonly used to provide an appropriate electric supply for many machines used in industry. In many cases, these transformers operate in quite rigorous condition, which result in difficulties in cooling their coils below an acceptable temperature level. Typically, all devices must be fire resistant and impervious to high humidity. For this reason transformers have to placed in hermetic container, which make their cooling very challenging. Heat transfer problem in electrical transformers has been analyzed for more than seventy years. The preliminary result of this project has shown that it is necessary to improve the earlier model of heat dissipation controlled by natural convection within the environment. The main objective is analysis of the cooling system efficiency, if the cooler is attached to the bottom and then a top wall of transformer casing. Additionally, this project considers the heat exchange between the transformer casing with a water cooling system and the calm ambient air using CFD (computational fluid dynamics).

The organization of the paper is as follows: next section discusses the geometry and discretization followed by the discussion of a mathematical model in the third section. In the fourth section result and discussion are presented and then in the last section present the conclusion of the work.

II. GEOMETRY AND DISCRETIZATION

The geometrical models in this consist of two sub-regions. The first is the transformer and other is cooler. Due to complicated shape of three phase transformer, a three dimensional model is created. The dimension of transformer is (0.194m x 0.102m x 0.1525m).it components are such as coil, core, transformer, base and mounting steel container, etc. are kept in their original shapes and dimensions, but some other element of lesser importance to the heat transfer problem, are neglected. The cooling systems consist of a steel cooling coil dipped into an aluminium block.

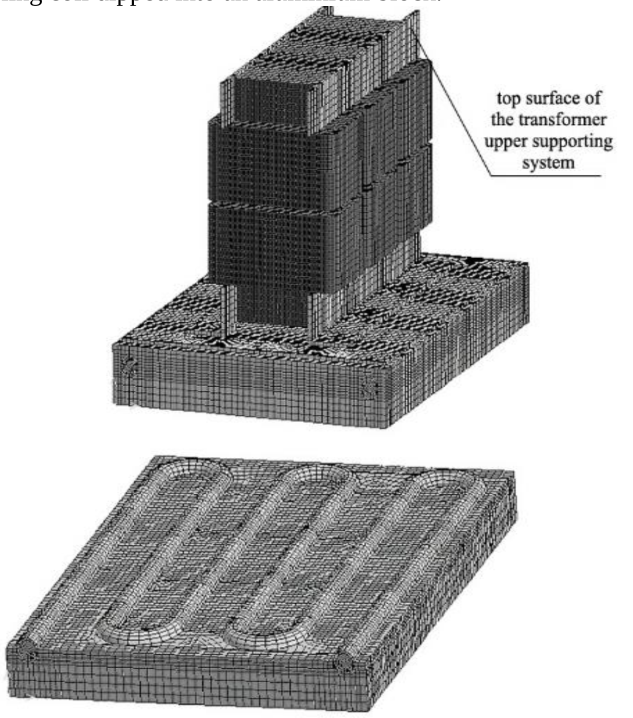

Fig 1.Geometrical model of selected elements of the analyzed transformer with the lower cooling system: core with coils and supporting system (top), half of the cooler (bottom).

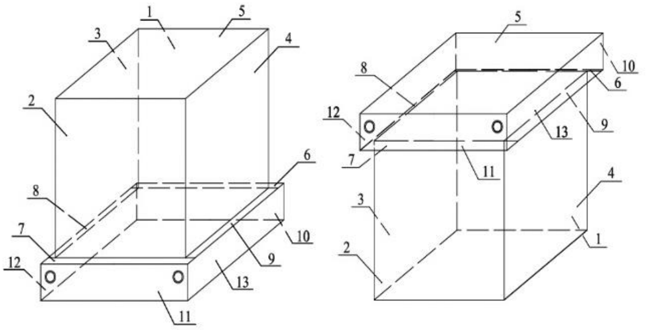

Fig 2. Geometrical model of the transformer casing with cooling system:, wall labels are listed in Table 4

III. MATHEMATICAL MODEL

The temperature distribution within the device and its surrounding can be determined by solving the energy equation.

$$\nabla(k\nabla T)+q_v=\rho_o c\frac{dT}{dt} \qquad \text{….. (1)}$$

Where T is the temperature [K], k stand for thermal conductivity [W/mk], q_v represents the source term rate [W/m^3]. The density ρ was assumed to be constant [Kg/m ^{3}], c is the specific heat [J/kgK], and t is time[s]. The derivative on the right hand side is the substantial derivative.

$$\frac{dT}{dt}=\frac{\partial T}{\partial t}+\omega_x\frac{\partial T}{\partial x}+\omega_y\frac{\partial T}{\partial y}+\omega_z\frac{\partial T}{\partial z}=\frac{\partial T}{\partial t}+\nabla T\bullet\omega \qquad \text{……. (2)}$$

Where w_x, w_y, w_z are the velocity components of vector W in the x-, y-, z-direction [m/s], respectively and x, y & z represents the Cartesian coordinates.
Energy sources can be calculated from the following equation:

$$q_v=\frac{P}{V} \qquad \text{……… (3)}$$

Where, p= power, v= volume.
For the fluids (i.e. water and air) considered in the analysis, the energy equation should be completed by the continuity and the momentum equations.

$$\nabla.\omega=0 \qquad (4)$$

While the momentum equation can be expressed as:

$$\rho_o\frac{d\omega}{dt}=F-\nabla p+\mu\nabla^2\omega, \text{……… (5)}$$

Where p is the pressure [N/m^2], F represents a body force term, Fz = ρ g in the z-direction, g is gravity acceleration and μ is the dynamic viscosity.

The Bonssinesq approximation was adopted in the buoyancy terms in equation 5. Thus the density takes the usual form:

$$\rho=\rho_o(1-\beta(T-T_o)), \text{……….. (6)}$$

Where β is the thermal expansion coefficient [1/K], T_o and ρ_o represents that so called operating parameters.

The following boundary condition was prescribed:

A. External boundary condition

The pressure boundary condition was prescribed on all external walls of the surrounding air. This is a typical boundary condition for flows that can reverse direction at the boundary. It requires the specification of a static pressure, temperature of backflow at the outlet boundary parameter of the flowing water at the inlet were set to temperature 286k and velocity 0.6m/s

A standard k-e model was used to model turbulence within cooler. (R_e=4500)

B. Internal boundary condition

Along each interface in the problem, including the interface between the transformer and surrounding air, standard continuity boundary condition were prescribed (i.e. both temperature and heat fluxes have to be same on each side of the interface)
The continuity condition at the interface between the two subdomains (the transformer and the surrounding air) where enforced through iteration process. This process can be summarized as follows:
The starting boundary temperature profile was calculated using an average heat transfer coefficient h on each transformer wall. Its value was determined by using a formula for the Nusselt number, as explain in equation 7. The temperature profile obtained was then prescribed to the second sub region (the surrounding air).
A FLUENT analysis of the air sub region provides the heat flux boundary profile within the air, which was then prescribed back to the transformer. The next step was to calculate the interface temperature again by analyzing the transformer. This iteration process is continued in succession until the temperature and heat flux profile in two subsequent steps were sufficiently close. The convergence criterion was 0.01%.

$$\delta_T=\frac{T_i-T_{i+1}}{T_i}\bullet 100\% \qquad (7)$$

$$\delta_T=\frac{q_i-q_{i+1}}{q_i}\bullet 100\% \qquad (8)$$

The errors δ_T and δ_q were defined as

Where,
$T_i, T_{i+1}, q_i, q_{i+1}$ was the average temperature and heat fluxes on the container top wall in two subsequent steps.

IV. RESULTS

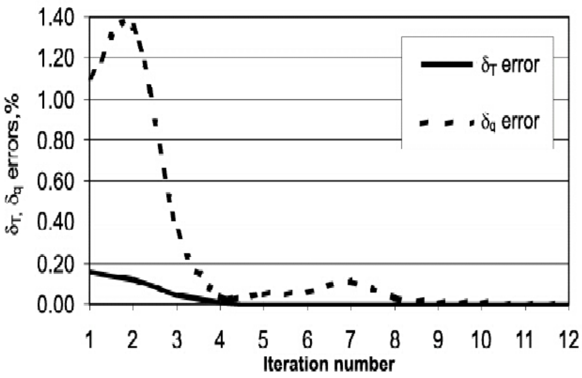

Fig 3. Convergence rate versus number of iterations

The temperature field in the prior equation7 was mainly verified based on experimental measurement at the selected point (see figure 4). Values of temperature at these points were also used to compare the efficiency of the cooling system being attached to the bottom or to the top wall of the transformer casing (column 1 and 2) in table 3.

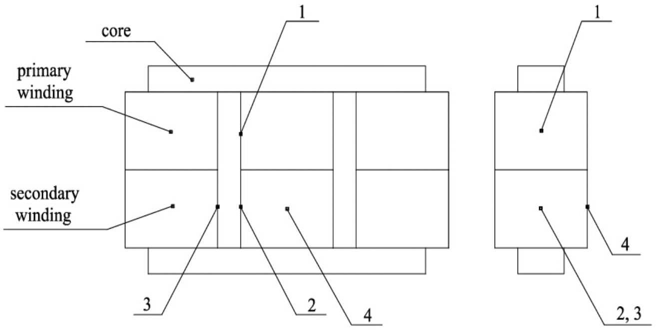

Fig 4. Schematic layout of thermocouples on the transformer coils and core.

Now, in the considered case the air temperature was in the range 292k to 311k, as shown in figure 5, but warmer air occurred only near the casing side wall. Obviously, in the region the maximum velocity (0.18m/s) occurred. It seems that the dimension of the artificial external boundaries of the air sub model was appropriately determined from the velocity field at the bottom and top wall were less than 0.014m/s & at the side walls they were less than 0.01m/s. The flow field of the air around the transformer is shown in Figure 6

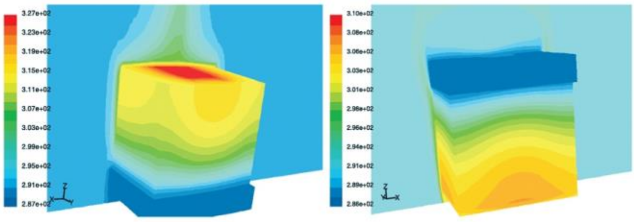

Fig 5. Temperature field within the transformer with cooling system and the surrounding air; the lower cooler is in the left, and the upper one in the right.

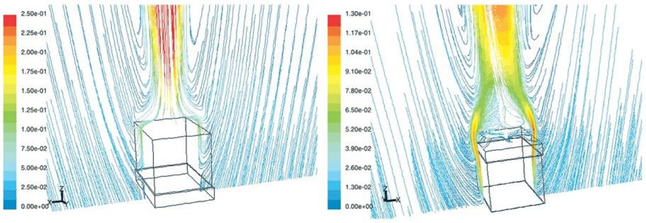

Fig 6. Path lines colored by velocity within the surrounding air; the lower cooler is in the left, and the upper one in the right.

V. CONCLUSION

This paper considers the heat dissipation process in an electrical transformer dipped in polymerized resin. The transformer was cooled using both natural convection (from the ambient air) and forced convection (from the water cooling system attached to the bottom and top wall). The following conclusion can be drawn from this research.

- The temperature at the measurement point for both cooling systems are close.
- The energy balance indicates the significance of the applied cooler to the total heat flow. In the consider cases reverse heat transfer can occur on the external wall of the model.
- An analysis of the heat flow rates confirms that the surrounding air was adequately modeled.

REFERENCES

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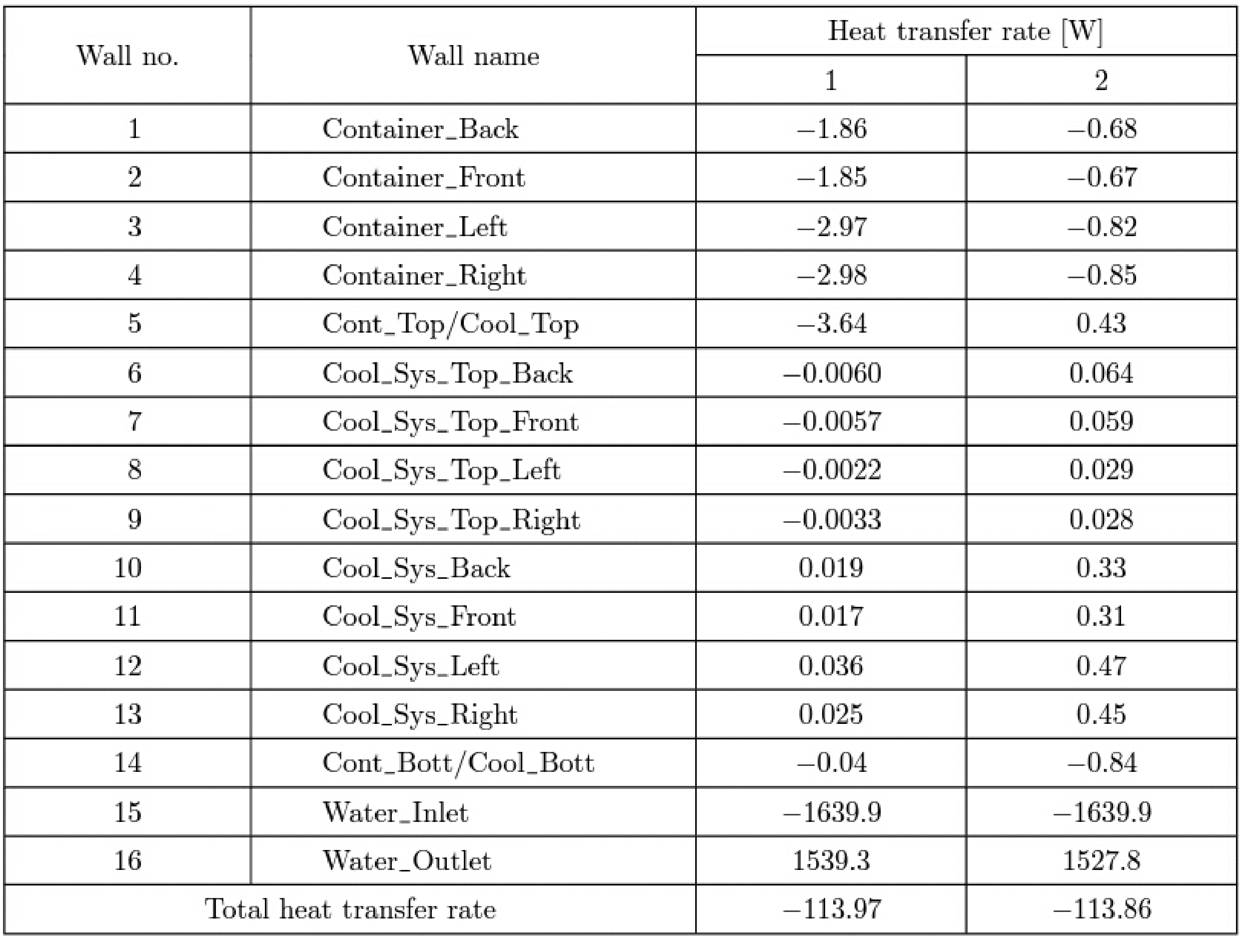
Table 3 Temperature field in the transformer within cooling system: 1 – transformer with the lower cooler, 2 – Transformer with the upper cooler, 3 – Transformer with the upper cooler (partly ideal connection between the transformer casing and its upper cooler).

Measurement point	Measured temperature [K]	Calculated temperature [K]		
		1	2	3
Point 1	331.95	328.20	326.40	311.60
Point 2	332.35	326.85	327.65	313.30
Point 3	328.00	327.30	327.90	313.70
Point 4	323.35	326.45	327.40	312.70

Table 4. Energy balance : 1- transformer with the lower cooler , 2- transformer with the upper cooler



Wall no.	Wall name	Heat transfer rate [W]	
		1	2
1	Container_Back	−1.86	−0.68
2	Container_Front	−1.85	−0.67
3	Container_Left	−2.97	−0.82
4	Container_Right	−2.98	−0.85
5	Cont_Top/Cool_Top	−3.64	0.43
6	Cool_Sys_Top_Back	−0.0060	0.064
7	Cool_Sys_Top_Front	−0.0057	0.059
8	Cool_Sys_Top_Left	−0.0022	0.029
9	Cool_Sys_Top_Right	−0.0033	0.028
10	Cool_Sys_Back	0.019	0.33
11	Cool_Sys_Front	0.017	0.31
12	Cool_Sys_Left	0.036	0.47
13	Cool_Sys_Right	0.025	0.45
14	Cont_Bott/Cool_Bott	−0.04	−0.84
15	Water_Inlet	−1639.9	−1639.9
16	Water_Outlet	1539.3	1527.8
Total heat transfer rate		−113.97	−113.86