

# A Numerical Analysis of the Cooling Effect in a Ferrofluid Immersed Power Transformer using the Finite Element Method

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This paper presents a thermal-fluid-magnetic analysis based on the 3D finite element method to investigate the cooling efficiency inside a power transformer. A 400/230V 3D power transformer with a non-axisymmetric ferromagnetic core is modeled. Two concentric copper windings are wrapped around the central leg of the ferromagnetic core. The whole system is immersed in a steel tank filled with cobalt ferrite nanoparticles-based Midel vetagetable oil. Investigation of the heat transfer associated to the motion of a magnetizable ferrofluid requires modeling with Navier-Stokes equations coupled with temperature and magnetostatic equations. The magnetization of ferrofluid is connected to the applied magnetic field by Langevin's law for linear magnetic material:  $\mathbf{M} = \chi(T)\mathbf{H}$ ,  $\chi(T) = \frac{\phi\mu_0\pi d^3 M_{s,p}^2(T)}{18K_B T}$  (S. Nasser El Dine et al., "Impact of magnets on ferrofluid cooling process : Experimental and numerical approaches", in IEEE Transactions on Magnetics, vol. 56, pp. 1–4, 2020). The impact of the magnetic field on the ferrofluid is modeled by the Helmholtz force  $f_H = -\mu_0 \frac{\mathbf{H}^2}{2} \nabla \chi(T)$ . We use a tetrahedral mesh for this model with 1049891 elements. The time step varies from 0.01 s to 0.5 s. The magnetic field, velocity and temperature are numerically computed using Comsol Multiphysics in a quarter of the model in order to save computational resources. The time evolution of the temperature is recorded whether the Helmholtz magnetic force is activated or not. For these two cases, the temperature curves computed at two sensors localized at the top of each winding are shown in Fig. 1. Comparing both time series, one can note a decrease of the local temperature of the two sensors by 10°C approximately when the magnetic force is activated. In this case, a snapshot of the velocity field at  $t = 15000$  s is shown in Fig. 2. The convection cells are localized in the gap between the two windings, as well as at the top of their surface. The fluid circulation is therefore modified between the core and the internal winding and amplifies the heat removal from the inside of the tank. This proves the beneficial effect of the thermomagnetic convection phenomenon.

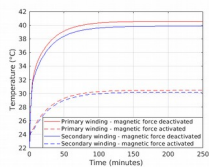


Fig.1. Temperature curves

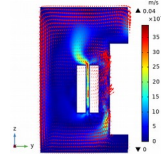


Fig. 2. Velocity field and streamlines ( $t = 15000$  s) in (y, z) plane