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Investigation of the Temperature Variation in Distribution Transformer Cooling System

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Abstract: **Temperature variation with in the transformer affects the life and efficiency of the distribution transformer. The top oil temperature in the transformer depends on the type of cooling and cooling ducts design and their layout. The present article investigates different methods of ONAN transformer cooling system by means of locating the cooling ducts at different spacing and inclinations, with the aim of increasing the heat transfer rate by disturbing the thermal boundary.**

Keywords: Distribution transformers, top oil temperature, cooling tubes, Life of transformer.

I. INTRODUCTION

A distribution transformer is a static device used to reduce the high voltage of the electrical power distribution system to the low voltage serving the customer by electromagnetic induction from one circuit to another at the same frequency. The voltage transformation generates heat in the core and windings due to eddy current and copper losses. The generated heat is collected by mineral oil flowing around core and windings and is dissipated through the transformer tank cooling system to the atmosphere.

The life time of transformers depends upon the transformer winding hot spot temperature. In the proper operating conditions the hot spot temperature of the winding coil is equal to the top oil temperature in the transformer tank. Transformer oil acts as both insulating material between the windings and tank material and as cooling medium in the transformer and Craft paper is used as an insulator between the conductors, because of its high dielectric strength. The stability of these insulating materials depends on the operating temperatures with the transformer tank. If the maximum designed temperature is exceeded for any length of time, the insulation lifetime may be reduced from the nominal level. As a thumb rule the life of transformer reduces by 50% if the hot spot temperature increases by 6°C above 80°C.

Overall network losses in the electrical transmission and distribution systems used to supply power to consumers can be as much as 6 to 9% of the total power supplied to the transmission and distribution networks by large power stations. Transformers, particularly in the distribution networks, make up about 30 to 40% of that network loss. High efficiency transformer means low losses and low hot oil temperature and result in less degradation of insulation and longer life of transformer.

The most important heat transfer mechanism in an oil immersed transformer is through the convection and radiation. Heat transfer by convection and radiation takes place from the tank surfaces and additional long vertical tubes / radiators are added to improve the heat transfer rate. These additional tubes/radiators increase the surface areas and increase the heat transfer rate. The rate at which heat is transferred from the tubular radiator to the atmospheric air depends on certain parameters like distance between the tubes, length of the tubes and movement of the air between the tubes.

Transformer cooling system improvement has been extensively studied through analytical or advanced numerical techniques by Miguel E. Rosillo(2). Eleftherios I. Amoiralis (3) and Ştefan D.L. ŢĂLU (1) developed a method for optimum transformer tank panels geometry for the cooling system.

The present paper investigates the effect of centre to centre distance between vertical tubes and their inclinations of the transformer cooling system on the top oil temperature. Experiments are conducted on an oil-immersed ONAN distribution transformer with different tubular radiators of different centre to centre distance and inclinations.

II. IMPROVEMENT OF TRANSFORMER COOLING SYSTEM

Generally the tubes/radiators are fixed to the tank of the transformer in vertical direction with different pitch. When the transformers are heated, heat transfer takes place by natural convection and radiation. Convection heat transfer occurs when the movement of the fluid is caused due to density differences, which are created by the temperature differences existing in fluid. Boundary layer develops due to the movement of the fluid upwards along the tube. Heat transfer within the boundary layer is by conduction only. As the boundary layer thickness increases, the heat transfer rate decreases and if the boundary layer thickness is more than tube diameter interference between boundary layers of air increases further and drop in heat transfer takes place.

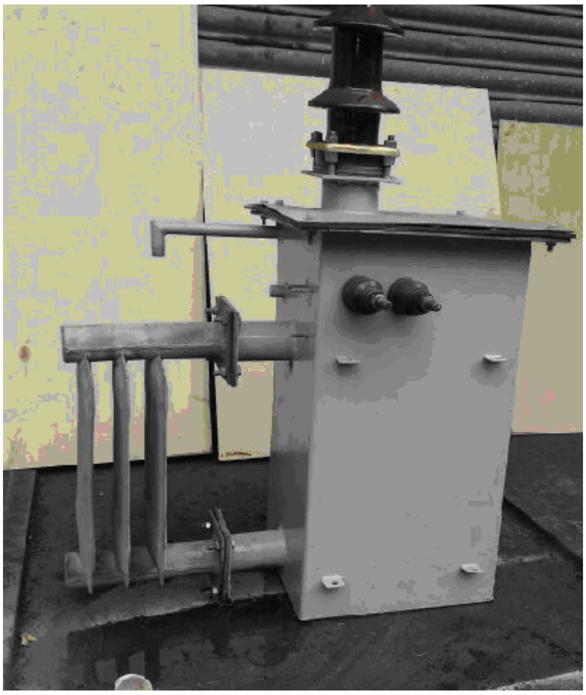

Fig.1. Distribution transformer with radiator

Fig.2. Cylindrical tubes with 1.5 D spacing

Fig.3. Radiator with 50mm spacing

When the tubes are inclined, there is a component of the buoyancy force acting normal to the flow direction, and can disturb the boundary layer and increase heat transfer rate. Investigation on inclined cavities was carried out by D. Henderson (13). Experimental data are not available for free convection from vertical tube for different pitches and inclinations.

The surface temperatures of cooling tubes at different lengths and top oil temperature in the tank are recorded for the different centre to centre to distance and for different inclinations of the tubes.

III. EXPERIMENTAL SETUP

The aim of this paper is to present the experimental results for flow over vertical tubes of a distribution transformer for different pitches and inclinations. The test is conducted on 16 KVA ONAN transformers. The transformer tank has the provision to connect the cooling tube bundles and radiators at different pitches as shown in Fig. 1.

In a typical test, the bundles of radiator tubes with a pitch of 1D (D diameter of the tube) are connected to the tank. The thermocouples are placed inside the transformer and within the tube bundles to record the temperatures.
Eight thermocouples record the temperature along the tube length for the different centre to centre to distance of the tube arrangement and for different inclinations of the tubes.
Two thermocouples record top oil temperature in the transformer and the room temperature. The data acquisition system with 12 channels continuously records the thermocouple readings

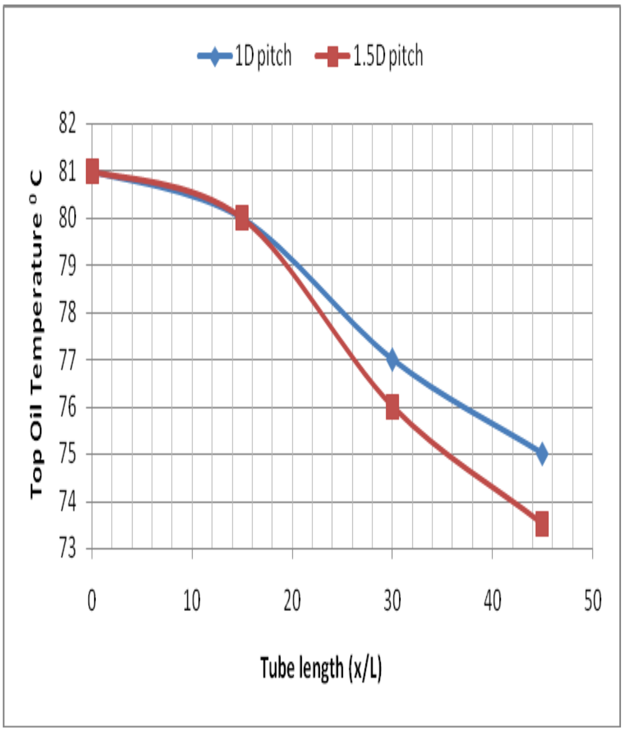

Fig.4. Top oil temperature variation for different tube Spacings (1D and 1.5 D)

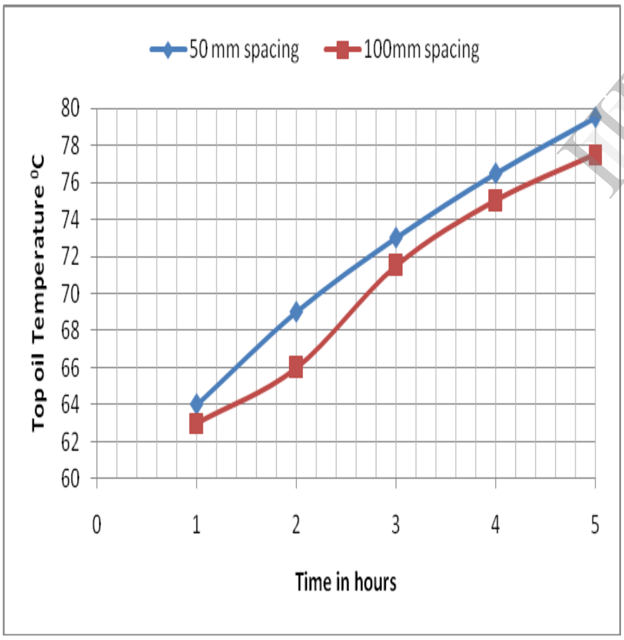

Fig.5. Top oil temperature of the transformer with radiators of different pitch

IV. TESTING PROCEDURE

Tests were carried out for a heat flux of 250W/m^2 and are maintained constant for all the setups. Initially the tube bundles are arranged at a spacing of 1D (D diameter of the tube).

Experiments were carried out for different inclinations and all the temperature readings are recorded. The experiments were repeated for 1.5D and 2D pitches. Similarly radiators with 50 mm and 100 mm pitch are connected to the tank and top oil temperatures were recorded for 6 hours duration. Each test is carried out until the system reaches thermal equilibrium. At the end of a test, the data is transferred to the excel software for plotting the graphs.

V. RESULTS AND DISCUSSIONS

For the purpose of comparing the results the tube length in vertical distance is normalized by the total length of the tube. During the top oil temperature test, constant heat flux was maintained in the tank tested for 6 hrs and temperatures were recorded every fifteen minutes. When the temperature of the top oil rise reached a constant value, the temperature is recorded. Fig.4 shows the variation of top oil temperature for different inclinations (0, 15, 30 and 45^0) for different spacing (1D and 1.5D). For a given arrangement as the inclination angle of the tube bundle increases, the top oil temperature decreases and drops drastically after 15 ^{0} inclination angle. This behavior is due to the disturbance of the thermal boundary layer, which exposes the surface of the tube for

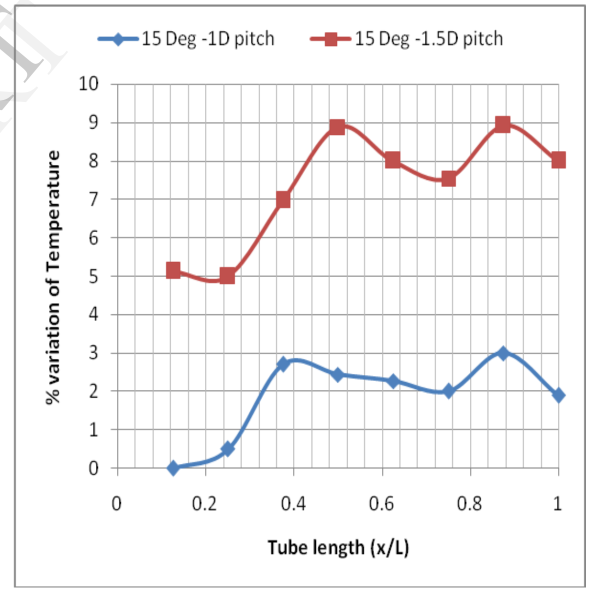

Fig.6. Percentage variation of temperature along the tube for 15 ^{0} inclination for 1D and 1.5 D Spacings

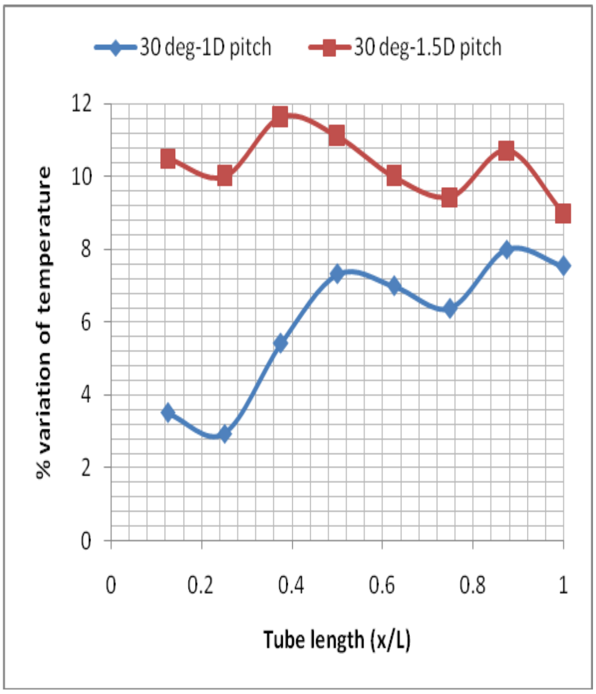

Fig.7. Percentage variation of temperature along the tube for 30 ^{0} inclination for 1D and 1.5 D Spacings

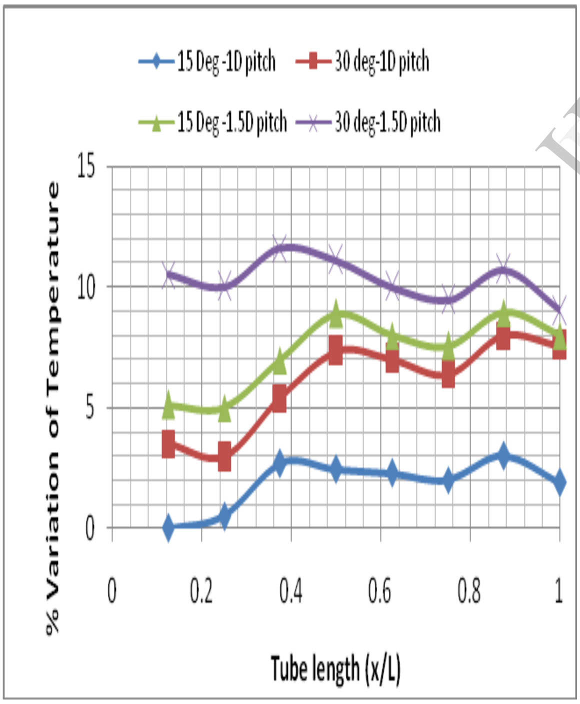

Fig.8. Percentage variation of temperature along the tube for 15^0&30^0 inclination for 1D and 1.5 D Spacings

low temperature ambient air. As the temperature difference (T tube surface- T ambient) increases the top oil temperature decreases.

Figure 5. illustrates the variation of the hot spot temperature in the distribution transformer with radiators of different pitches.

It is observed that 100 mm pitch radiator experiences 2^0C drop in top oil temperature compared to 50 mm pitch radiators, a drop of 2.6% in hot oil temperature.

Fig. 6 and 7 shows the percentage variation of temperature along the tube length. For a given inclination angle15^0 the percentage decrease of surface temperature along the tube with 1D pitch is 2 to 2.5% and for 1.5D is 8 to 9%. As per the free convection heat transfer the thermal boundary develops along the tube in vertical position and the thermal boundary layer thickness increases. The heat transfer within the boundary layer is by conduction only. By increasing the spacing and inclination of the setup, the boundary layer gets disturbed and creates a low pressure, which in turn allows more fresh air onto the surface of tube. The temperature drop decreases at the top of the tube due to the effect of interface boundaries. Fig. 8 shows the percentage variation of temperature for different pitches and inclinations.

The observation of Figures 9-10 leads to the conclusion that as the pitch of the tube increases the percentage drop of tube temperature increases exhibiting better thermal performance and it is further enhanced by increase of inclination angle of the tubes

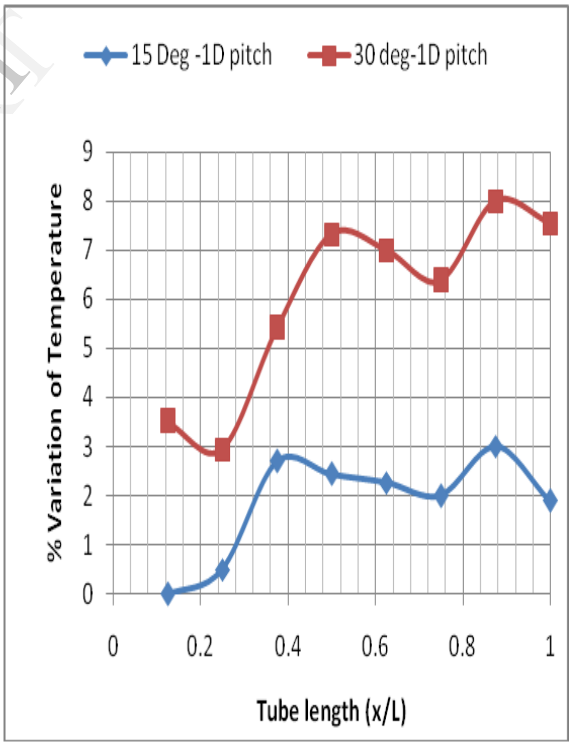

Fig.9. Percentage variation of temperature along the tube for 15^0&30^0 inclination for 1D spacing

It was also found that the minimum heat transfer is associated with the 15^0angle and 0.125 x/L tube length of 1D pitch. (fig.6.) Maximum heat transfer occurred at 0.38 x/L of 30^0 inclination angle for a pitch of 1.5D (Fig.7).

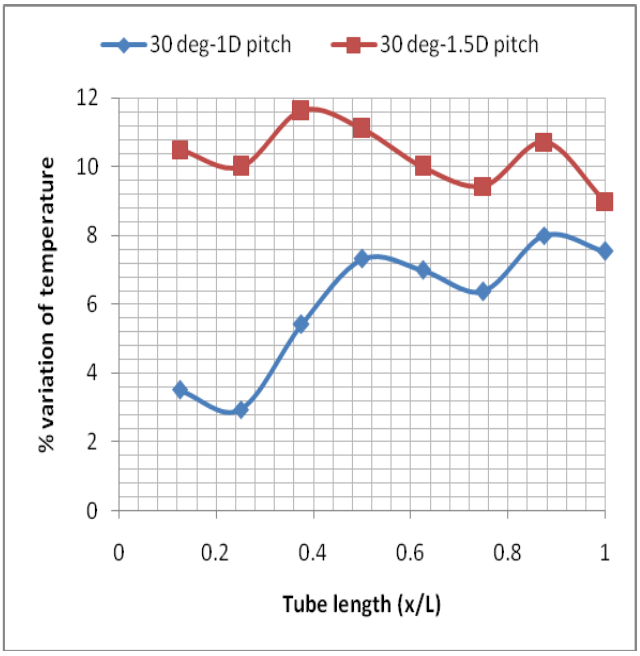

Fig.10. Percentage variation of temperature along the tube for 15^0&30^0 inclination for 1.5 D spacing

VI. CONCLUSION

In this paper, cooling system of a transformer is modified in terms of better layout of the tube / radiators, improving transformer thermal performance. In particular, increasing the pitch of the tubes/radiators improves the heat transfer rate and decreases the top oil temperature.

The investigation is carried out by increasing the pitch of the tubes/radiators. The experiments have shows that top oil temperature has reduced by 11.8% with 1.5D spacing at 30^0inclination, which enhances the life of the transformer.

Further research concerning higher pitches and disturbance of thermal boundary by turbulent generators will be done in later works.

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