Thermal Performance Analysis of the 3-φ Distribution Transformer Radiator with and without Fin Arrangement

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By

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Approval

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It is hereby declared that this thesis has not been submitted elsewhere for the award of any degree or diploma.

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Abstract

Transformer plays a significant role in providing a reliable and useful electricity supply. It is one of the most critical equipment in electric power transmission and distribution systems. Transformer losses are occurred by the current passing through resistance on the winding conductors. These losses are converted to heat energy. The majority of high voltage transformers are filled with liquids that work as an electrical insulation as well as a heat transfer medium. The most commonly used liquid in power transformers is mineral oil due to its low cost and good properties. The winding temperature must be kept within a limit so that the temperature dependent properties of the mineral oil do not hamper the performance of the transformer. Therefore, an air cooled radiator is generally fixed with the transformer to maintain the temperature of the mineral oil to its tolerable limit. In this study, heat transfer enhancement is investigated for different types of radiator filled with mineral oil. The thermal performance of conventional radiator and modified radiator with and without fin arrangement are analyzed through simulation and experimental results. A 200 kVA, 11 kV Oil Natural Air Natural (ONAN) cooled 3-φ distribution transformer is used for experiment. The simulation is performed using Solid Works 3D CAD Design and ANSYS 2016 version Software. A critical analysis is done with the experimental results for the transformer radiator with and without fin arrangement. The thermal performance of the radiator of 14 oval pipes with fin arrangement increases 3.45% as compared to the radiator of 14 oval pipes without fin arrangement. The cost of the radiator of 14 oval pipes with fin arrangement reduces 20.89% as compared to the conventional radiator without fin arrangement. The results obtained through simulation and experiment play vital role in the economical design of transformer radiator so that fabrication of transformer is cost effective.

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Chapter 1

Introduction

In power system, transformer plays important role during production, transmission and distribution of power. The power at high voltages is generated in power plants with the help of power transformers and then it is transmitted to electrical substations. The distribution transformers distribute power in the distribution lines by stepping down the high voltage to low voltage that is used by customer. Transformer is electrical device where at constant frequency AC electrical energy is transformed with altering voltage level as per requirement. The transformers rely on the principle of Faraday's law of electromagnetic induction. There are two types of losses occur in the transformers such as copper and core losses. Copper losses occur in transformer windings which is also called I^2R loss. Core losses occur in the core which is called Hysteresis loss and eddy current loss and both losses are responsible for increasing the temperature of the active part. Since the active part which formed of the windings and the core becomes hot hence cooling is required to cool the active part. As per cooling modes there are two types of transformers such as oil-immersed transformers and dry type transformers. In dry-type transformers air cools the transformer with the help of fans where air is directly pushed into the active part. In oil-immersed transformers the active part is cooled through transformer oil. From the active part the heat transferred to the transformer oil which moves into transformer radiators. There are conduction, convection and radiation heat transfer take place in the radiator. The radiator rejects the heat to the surrounding largely by convection. The thermal performance of conventional radiator is perfect for cooling the 200 kVA, 11 kV distribution transformer but conventional radiator is costly. That's why, the thermal performance of modified radiator with fin arrangement will be observed for cost effective with enhanced thermal performance.

1.1 Background of the project

The temperature of the active part increases for the total loss in the transformer converts as heat. With a view to defend the active part this rising temperature has to be confined under the definite limit. For this reason, to cool the active part an excessive heat dissipation mechanism required. For cooling the active part various cooling method used such as Oil Natural Air Natural (ONAN), Oil Natural Air Forced (ONAF), Oil Forced Air Forced (OFAF) and Oil Directed Air Forced (ODAF). Because of buoyancy effects natural convection produces both the oil flow in the cooling circuit and the air flow in the radiator fins in (ONAN) Oil Natural Air Natural transformers. It is very crucial to have a detailed knowledge for the transformer manufacturer about how the heat is conducted and dissipated in the radiators. This comprises the main bottlenecks in the heat dissipation process to improve the design of identified components. A better design enables to reduce the size, weight and the manufacturing cost of the machine for a required amount of heat to be removed. Thus improving the machine efficiency and lifetime.

1.2 Motivation

In General Electric Manufacturing Company Limited, the transformers are manufactured with the radiator of multiple oval pipes. The welding of the oval pipes causes various problems and also the scrap materials of circular shape from the transformer tank, the radiator vertical plate, the conservator, and the cover are not used. Being an employee of General Electric Manufacturing Company Limited, it is realized that the effective thermal management is very crucial for cooling of transformer radiator oil as well as fabrication of the radiator can be cost effective. Therefore, a modified radiator is proposed with circular fin arrangement. The main purpose is to reduce the number of oval pipes of conventional radiator by introducing cooling enhancement through fins. Thus, materials cost and radiator fabrication processing time will also be reduced. Moreover, welding and welding leakage testing time will be saved because arc welding of oval pipes with net plate is difficult. Also repairing the leakage after welding test can be minimized.

1.3 Research objectives

The main goal of this research is to carry the study of the transformer radiator in order to reduce the cost of the transformer with enhancement thermal performance of the transformer radiator. The specific objectives are:

1. To study the thermal performance of conventional transformer radiator through simulation and experiment for the 200 kVA, 11 kV three phase distribution transformer.
2. To study the thermal performance of the transformer radiator with fin arrangement through simulation and experiment for the 200 kVA, 11 kV three phase distribution transformer.
3. To compare the results of the transformer radiator with and without fin arrangement.
4. To study the cost analysis of the transformer radiator with fin arrangement.

1.4 Organization of the report

The research paper is decorated into six chapters. The significance and objectives of project are introduced in chapter 1. Previous research works are narrated in chapter 2 which helps to specify the research direction. In chapter 3, conventional radiator geometry and modified radiator geometry of different types of model are described. Temperature distributions with temperature at inlet and outlet of conventional radiator as well as modified radiator with and without fin arrangement are discussed. In chapter 4, experimental set up of conventional radiator and modified radiator with and without fin arrangement are described. The simulation and experimental results are presented in chapter 5 with discussion about simulation and experimental result. The report is concluded in chapter 6 with further recommendations.

Chapter 2

Literature Review

2.1 Introduction

There are different types of transformer radiator such as fin type, corrugated type, circular pipe type, panel type, oval pipe type etc. are used all over the world. In oil-immersed transformer the radiator play vital role for cooling the transformer oil. The transformer oil protects the transformer active part from excessive heating which save the transformer from short circuit and finally explosion. If fabrication time and quantity of materials of the transformer radiator can be shortened then quantity and quality of production of the transformer will increase and thus production of the transformer will be cost effective. Besides cost effective of production of the transformer, concentration should be focused on enhancement of thermal performance of the transformer radiator. That's why, previous research works are narrated in this chapter in order to specify the direction of the present work.

2.2 Previous research works

In recent years, many research works had been performed in order to reduce the cost as well as enhance the thermal performance of the transformer radiator. Therefore, for cost effective and enhancement of thermal performance of the transformer radiator the theoretical studies are provided below.

2.2.1 Theoretical studies

Numerical investigation of oil flow distribution and temperature distribution was performed by Zhang et al. [1] for a disc-type transformer winding in an oil natural (ON) cooling mode. It was shown that for increasing of 6 ˚C the paper thermal ageing rate will be double [2, 3]. To improve the performance of network models as well as to calibrate the correlations related with network models CFD results could be employed [4-6]. There were important flow and temperature features of CFD simulations for transformers in oil natural (ON) cooling modes [7, 8].

For ONAN cooling modes in the winding it was proven experimentally in [9] and theoretically in [10], the total oil flow rate was proportional to the square root of the total power loss and the square root of the thermal head which was the height difference between the centreline of the radiator and the centreline of the winding. Therefore, for the same total oil flow rate it was required to do double the height difference while there was halved power loss. In the winding for ensuring high enough liquid flow rates the design of the circulation loop was crucial factor to obtain a low-pressure drop loop with high thermal head.

The transformer cooling oil movement inside the tank was studied by Baidak et al. [11] in the form of Navier-Stokes differential equation in software environment COMSOL Multiphysics Femlab 3.0 in the Fluid Dynamics. It was found that reliability and regulatory insulation durability and therefore regulated by the transformer manufacturer operating conditions, in general, depended on the exact choice of the transformer electromagnetic load in terms of current density in the windings and magnetic induction in the magnetic circuit. The impact of the physical process of braking that occurred when the coolant contacts with the wall due to viscous forces gradually extended to the whole cross section of the pipe, which leaded to uneven distribution of velocity and temperature of the coolant in section of pipe (parabolic in laminar flow).

Kim et al. [12] had also studied the conjugate heat transfer and fluid flow analysis by numerically simulating the distribution of velocity and temperature fields for the insulating oil inside the radiator as well as ambient cooling air outside the radiator and also the distribution of temperature field in the solid part of the radiator using the porous media model. If the heat generated by a transformer was not properly reduced to the environment, the insulation performance of the transformer might be reduced, the life of the transformer might be shortened, and the transformer malfunction or explosion might occur [13, 14]. For correct operation, it was needed to develop high performance cooling technology to maintain acceptable temperatures [15].

To reduce the size and number of radiators in order to reduce the production cost the design of a radiator with superior performance which was indispensable for realization of an optimum cooling system of the transformer. For low total heat loss of the transformer, the Oil Natural Air Natural (ONAN) cooling system was used for cooling the transformer. When the total heat loss of the transformer increased above a certain level, the Oil Natural Air Forced (ONAF) or Oil Directed Air Forced (ODAF) cooling system was used to cool the transformer. The characteristics of fluid flow and heat transfer of cooling air outside the radiator as a function of the oil flow rate flowing into the radiator cooling systems.

The transformer life dependency on the aging of cellulose-based insulation material in winding was studied by KAYMAZ [16]. For A Class insulation materials the temperature limit was 118˚C since the chemical process was function of temperature. In this study thermal characteristics of transformer oils were compared where natural ester oil had the best heat transfer and pressure drop. Corrugated tanks were frequently used for distribution transformers as cooling fins. Transformer losses were dissipated through the corrugated walls. However, corrugated walls suffered from excessive internal pressure and limit the transformer sizes due to their low mechanical strength.

The outlet temperature of radiators was the same which were simulated with natural ester and mineral transformer oil, respectively. On the other hand, pressure difference between inlet and outlet of the radiator simulated with natural ester transformer oil was more than mineral oil. Silicon transformer oil had the most pressure drop. Although mineral oil had the lowest pressure drop but could be replaced by natural ester transformer oils according to environmental concerns. The inlet velocity was increased while pressure difference was increased. Besides, temperature difference between inlet and outlet was decreased by increased velocity. Furthermore, temperature difference between the inlet and outlet of transformer winding had to be kept as low as possible. The difference between inlet and outlet temperature of the transformer winding could be kept minimum, if mass flow rate of radiator could be increased. This could be achieved by increasing value of pressure drop along a closed circulating loop.

Fonte et al. [17] stated that the hot-spot temperature could be reduced by as much 10˚C which had a strong direct impact on the transformer's lifetime. For CFD simulations ANSYS Fluent CFD solver used finite volume method where modeling and meshing works were specified as pre-processing and solution and results were defined as post-processing. CFD calculations were based on three main equations; continuity, momentum and energy equations. Especially in recent years, environmental issues had become more important at all around the world. Therefore, in the near future non-renewable transformer cooling fluids will be replaced with renewable alternative cooling fluids.

Veken et al. [18] had described the development of a thermo-hydraulic radiator model. Physically, the oil temperature entering the winding was determined by the external cooling capacity and the oil flow rate. Thus on the winding temperatures in the transformer the external cooling had a direct impact, but also on the total oil flow in ON cooling mode: (i) the pressure drop would be affected during the oil flow distribution over the radiators and (ii) the thermo-syphon pressure would be affected during the oil temperature distribution along the height of the radiator panels.

Although radiators were mechanically very simple, thermal modeling was quite complex because of the some reasons: (i) the oil temperature was not constant, but varied in function of the height and per radiator panel; (ii) this temperature variation was in its turn a function of the oil mass flow and local heat flux, the local heat flux was again dependent on the temperature difference between oil and air, and the local air velocity; (iii) the local air velocity was variable along the position in the radiator (certainly for forced air cooling); (iv) the oil mass flow per panel was not constant; (v) the oil mass flow was function of the driving thermo-syphon pressure and was thus on its turn temperature dependent. Therefore, to be able to model the radiator correctly it was necessary to model both the air and oil-side as well as the thermal and hydraulic behavior of the radiator simultaneously.

2.2.2 Experimental studies

Rodriguez et al. [19] had presented semi-analytical calculations, computational fluid dynamic simulations and experimental measurements accomplished on a typical 30MVA power transformer. For solving the thermo-hydraulic equations governing the transformer thermal performance an iterative coupled 3-D model was used using FEM (Finite Element Method) [20], while to study the relationship between the radiator characteristics and its cooling capacity for a power transformer working in ONAN mode, 3-D CFD simulations were used.

A recirculation zone at the end of the radiator pipes, which prevented the oil to flow into the cooling channels of the last radiator panel, was found in [21] as the explanation of low cooling efficiency. On the other hand, analytical and experimental studies about cooling performance of radiators used in power transformers working both in (ONAN) Oil Natural Air Natiral and (ODAN) Oil Directed Air Natural modes were presented in [22]. On a power transformer radiator block working in ONAF mode the effects of blowing direction and offset of fans on the thermal performance were studied by means of 3-D simulations [23].

The calculations presented with the reduced model were shown that the heat transfer coefficient in the oil was almost ten times higher than that in the air. Even if the oil flow rate were greatly increased the heat dissipated would not increase that much, as it was verified. It was thought that although there was turbulence in the air flow between the panels, this was not enough for improving the mixing of fresh air with the hot air within the thermal boundary layer in contact with the panels.

In recent years, researches had been performed about modification, optimization and economical design. Therefore, for modification, optimization and economical design of the transformer radiator the studies are provided below.

2.2.3 Modification, optimization and economical design

Paramane et al. [24] had done the experimental and numerical studies that were reported on radiator–fan assembly, for Oil Natural Air Natural (ONAN) and Oil Natural Air Forced (ONAF) cooling configurations. For the radiators, oil and air domains hexahedral elements were used and for meshing of the fans and rotating domain tetrahedral elements were used due to the complexity of fan blade profile. Heat dissipation predicted from the present numerical than the experimental results was found to be less, by 17.9% for ONAN and 16.8% for ONAF (vertical air flow) configurations. There was a significant effect of the direction (horizontal or vertical) of air flow on the temperature field for the oil inside the radiators. Variation of oil temperature along the height of the radiator was not linear (as often assumed) but showed an exponential decay for ONAN and ONAF (vertical and horizontal flow) configurations than the theoretical expectation for heat exchanger. In order to reduce the weight of the system without compromising on the thermal performance, transformer manufacturers were keen to reduce the number of radiators and fans.

Thermal Management was an important aspect for efficient and reliable functioning of transformers [25]. For optimal thermal design, transformer manufacturers were interested to reduce the number of radiators and fans. A radiator was mechanically a simple object, but from thermo-hydraulic point of view the heat transfer characteristics of the radiator was influenced by different parameters such as air velocity around the radiator panels, temperature difference between oil and air, oil velocity inside the radiator panels which relied on pump pressure or thermo-syphon pressure, hydraulic resistance of the radiator panels and hydraulic circuit and oil distribution over the different radiator panels. The radiators worked as a kind of open chimney, air heated up in between the radiator fins and this hot air tended to move upwards due to buoyancy forces. For optimal design, accurate heat dissipation from radiators could be known for various cooling configurations.

Liang et al. [26] had used CFD software to simulate when group panel-type radiator quantity, space, and how temperature distribute on the radiator. For saving transformer costs and extending the life of transformer, improving the group of panel-type radiator cooling efficiency and enhancing its cooling capacity was of great significance. But to improve the cooling capacity of the radiator became a real problem where forced cooling could not be used in residential areas and places had some special requirements for noise level and energy using. With the panel-type radiator space increasing, the overall heat transfer efficiency showed an upward trend, but rise rapidly at first and then slowly. The results through simulation the influence on the heat transfers efficiency while changed the group panel-type radiator quantity and space showed that: (1) Group panel-type radiator flow resistance and heat transfer characteristics was the best when the quantities of radiator were 25-26. (2) The internal resistance of the radiator distributed uniformly, maximum heat exchange with the outside world as panel-type radiator space was 45-50 mm.

Steve Zeng, P. Eng. [27] had presented an innovative cooling method by Rayleigh-Bénard convection and the transformer structure with tank-top radiators. A tank-top radiator was included in the new method and had the advantages of higher heat dissipation efficiency and land area occupation reduction. The radiator had higher heat dissipation efficiency in about 15 percent, and the transformer complex reduced the land area in about 50 percent was showed in a 3400 kVA prototype and its temperature test.

Xing et al. [28] had a method enhancing heat transfer of panel type radiators placed on the surface of the oil-immersed transformers. Heat transfer effect could get a certain degree of improvement when some turbulators added on the panel type radiators and chosen the location of them appropriately. Capacity of panel type radiator could be improved using the perfect heat transfer effect of heat pipe, with some necessary structural transformation. The effective heat transfer area was increased by new types of panel shape. Therefore, by changing many kinds of structure parameters, for instance, the panel oil passage number and non-uniform size distribution, inclination angle of up oil pipe and so on; optimization design with theory and simulation was a significant research field.

When the air was heated by panel groups and flow around groups; there could be small vortexes up near the turbulators, obstructed by turbulators. These vortexes, on the other hand, disturbed thermal boundary layer near the turbulators, which made convection in heat resistance lower and heat transfer coefficient larger. Because the oil viscosity was marked affected by temperature itself, oil flow was a variable property process. Thermal performance parameters optimization could improve the effect of heat transfer, such as table panel height, oil channel structure, oil channel position arrangement and so on. The main exploration was combining a variety of structure parameters to research optimization scheme.

Prototype of transformer radiator with different types of fin had been analyzed to study the thermal performance in Department of Mechanical Engineering, CUET by the undergraduate students. Experimental analysis of the cooling performance of elliptical tube radiator using fin had been performed by Tasnim [29]. It was found that by using annular fin the LMTD increased 120%, thus heat transfer increased. Also, the change of temperature along elliptical tube length increased about 8-11˚C but the value was 5-6˚C except fin. Another study was performed by Tasnim [30] to analyze the cooling performance of elliptical tube type transformer radiator with rectangular fin. It was found that the overall heat transfer coefficient increased to 6.65% through longitudinal fin array. Besides, heat transfer performance analysis of an elliptical tube type radiator with rectangular fin had been performed by Islam [31]. It was found that with the rectangular fin the overall heat transfer coefficient increased by 10.39%. The present project work is aligned with these research performed and to analyze the thermal performance of real-time 3-φ distribution transformer radiator with and without fin arrangement.

The comparative cost analysis for the manufacturing of the conventional radiator and the proposed radiator is another goal of this research.

2.3 Conclusion

The above review describes different methods and techniques to enhance the thermal performance and to reduce the manufacturing cost of transformer radiator. It is seen that in (ONAN) Oil Natural Air Natural cooling mode transformer, radiator fabrication is time consuming and costly. Therefore, it is aimed to fabricate a new design of transformer radiator using circular fins. The thermal performance of transformer radiator with fin arrangement will be analyzed through simulation and experiment. It is expected that the results of thermal performance of the radiator with fin will provide better enhancement and thus the manufacturing cost can be reduced. The proposed models are analyzed through simulation in Chapter 3.

Chapter 3

Simulation

3.1 Introduction

An approximate emulation of the actions of a method or system called simulation which requires a model is flourished first. Real-world problems are solved safely and efficiently through simulation modeling. An important method of analysis is provided by it which is easily verified, communicated and understood. In many sectors such as tuning or optimizing, safety engineering, testing, training, and education simulation is used. This chapter presents conventional radiator geometry and modified radiator geometry of different types of model. Furthermore, materials properties and boundary conditions are essential for simulation. For this reason, materials properties of the transformer such as naphthenic oil and mild steel are prescribed as well as boundary conditions of some properties are assumed. Also, temperature distribution in full radiator geometry, inlet zone, outlet zone, and fin zone of conventional radiator and modified radiator of different types of model are described.

3.2 Conventional radiator

For cooling transformer oil of 200 kVA, 11 kV; 3 phase distribution transformer the conventional radiator is being used at General Electric Manufacturing Company Limited. The conventional radiator raw materials are mainly mild steel oval pipes, mild steel sheets, and mild steel pipes. Figure 3.1 shows the conventional radiator geometry which is fabricated by 28 oval pipes without fin arrangement. Each oval pipe is 598 mm in length, major diameter is 45 mm, minor diameter is 18 mm, and thickness is 1.5 mm. From one oval pipe to next oval pipe space one is 15 mm of oil box lengthwise and another space is 13 mm of oil box widthwise. Oil box is 470 mm in length, 130 mm in width, and 70 mm in height of one side. Two connection pipes used which are 130 mm in length, diameter is 51 mm and thickness is 3 mm. One connection pipe is used as inlet i.e.

top oil enter into the transformer radiator through oil box. Another connection pipe is used as outlet i.e. cooled oil enter into the transformer after cooled oil leaving from the transformer radiator through oval pipes and oil box.

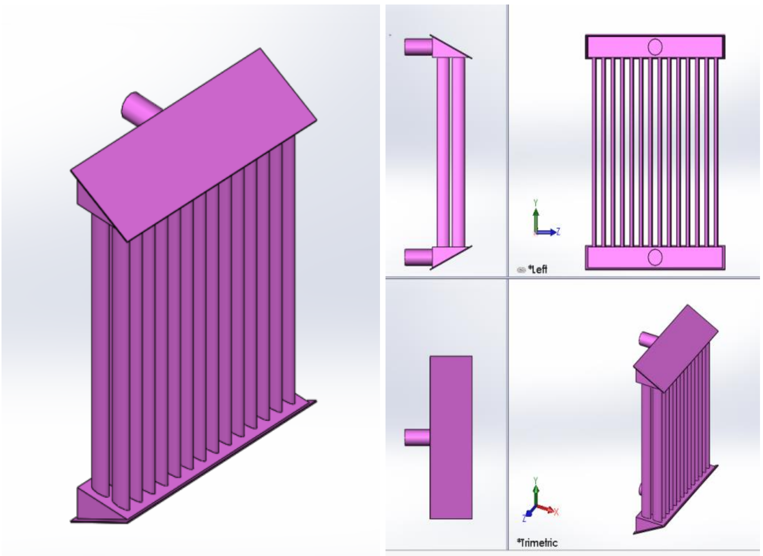

Figure 3.1 Conventional radiator geometry of 28 oval pipes

Figure 3.2 represents the one oval pipe space of conventional radiator i.e. distance between two oval pipes.

Figure 3.3 indicates the another oval pipe space of conventional radiator i.e. distance between two oval pipes.

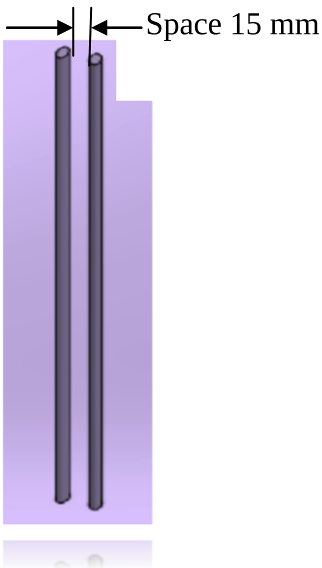

Figure 3.2 Oval pipe spacing 1

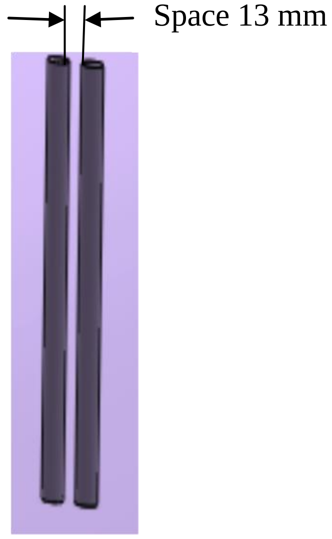

Figure 3.3 Oval pipe spacing 2

3.3 Modified radiator with and without fin arrangement

To reduce the cost of fabrication of conventional radiator, modified radiator is proposed with circular shape fin arrangement. Fins of circular shape are extracted after punching transformer tank and then used in modified radiator. As a result, no extra materials are required for fin arrangement. The main purpose is to reduce the number of oval pipes of conventional radiator which are used for cooling the transformer oil. If number of oval pipes can be reduced by using fins then materials cost and radiator fabrication processing time will be reduced. Moreover, welding and welding leakage testing time will be saved because arc welding of oval pipes with net plate is difficult and after leakages of welding testing, leakage build up is time consuming.

3.3.1 Model no. 01

Radiator geometry of 14 oval pipes without fin arrangement is shown in figure 3.4. In the radiator two row configuration of oval pipes are used because the purpose of oval pipes to increase heat transfer area but less occupied space. If single row configuration used for the radiator fabrication then it will occupy more space and also the radiator design will be changed. As a result, fabrication of the radiator will be difficult since fabrication of the radiator involved with cutting, fitting and welding process of raw materials. From one oval pipe to next oval pipe space one which has been changed with conventional radiator is 50 mm of oil box lengthwise and another space remain same is 13 mm of oil box widthwise. Oval pipe, oil box, and connection pipe size is as same as conventional radiator.

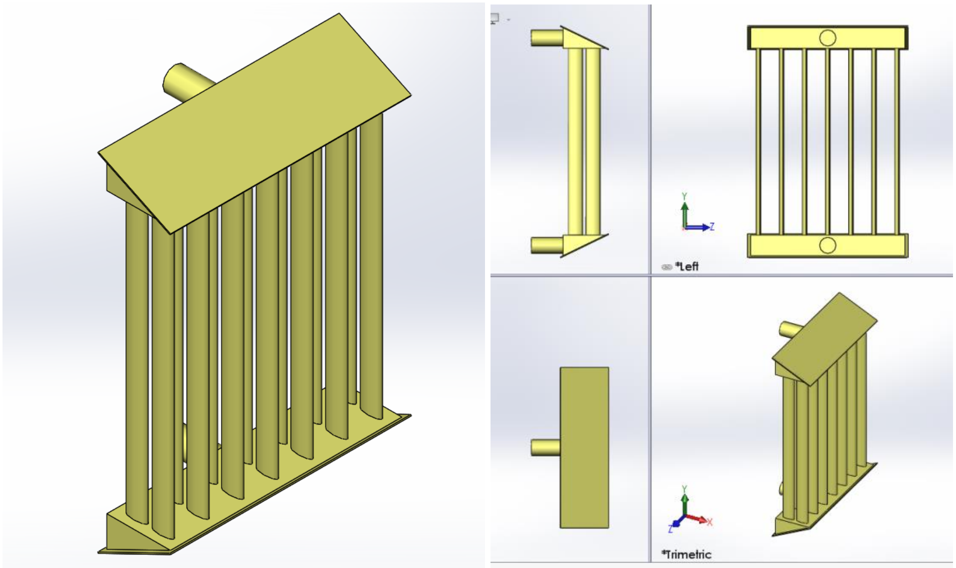

Figure 3.4 Radiator geometry of 14 oval pipes (Model no. 01)

3.3.2 Model no. 02

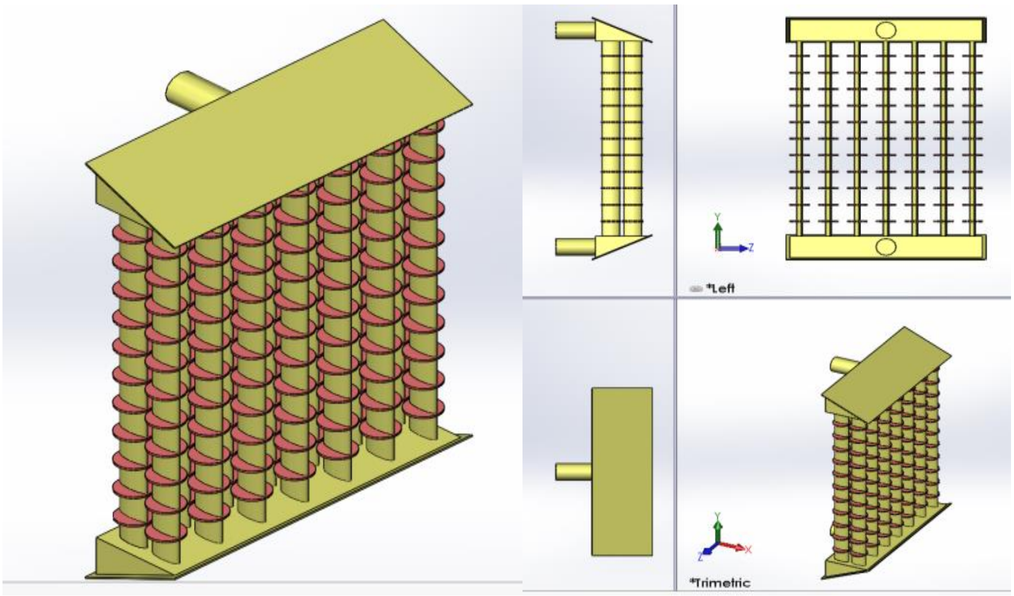

Figure 3.5 Radiator geometry of 14 oval pipes and fin arrangement (Model no. 02)

Radiator geometry of 14 oval pipes and 11 circular fin arrangement of each oval pipe is represented in figure 3.5. In each oval pipe distance from one fin to another fin is 50 mm longitudinally. The outer diameter of fin is 51 mm and thickness is 3.5 mm. Since maximum heat exchange with the outside world as panel-type radiator space was 45-50 mm [26] hence from one oval pipe to next oval pipe space one which has been changed with conventional radiator is 50 mm of oil box lengthwise and another space remain same is 13 mm of oil box widthwise. Oval pipe, oil box, and connection pipe size is kept same as conventional radiator.

3.3.3 Model no. 03

Figure 3.6 indicates the radiator geometry of 16 oval pipes and 11 circular fin arrangement with each oval pipe. In each oval pipe from one fin to another fin longitudinal distance kept same with model no. 02 which is 50 mm. The fin of same dimension is used for increasing heat transfer area of the radiator. Oval pipe space one which is kept same with model no. 02 is 50 mm of oil box lengthwise and another space is 13 mm of oil box widthwise. Oval pipe, oil box, and connection pipe size is kept same as model no. 02.

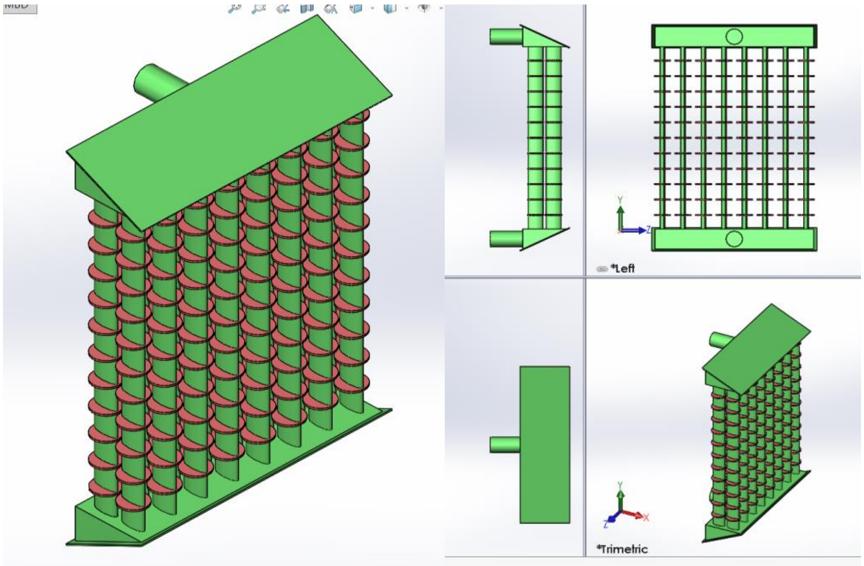

Figure 3.6 Radiator geometry of 16 oval pipes and fin arrangement

(Model no. 03)

3.3.4 Model no. 04

Figure 3.7 displays the radiator geometry of 18 oval pipes and each oval pipe contain 11 circular fin arrangement. In each oval pipe longitudinal distance from one fin to another fin is not changed in model no. 04. The outer diameter of fin and thickness remain same with model no. 03. From one oval pipe to next oval pipe space one is changed with conventional radiator which is 50 mm of oil box lengthwise and another space is not changed which is 13 mm of oil box widthwise. Oval pipe, oil box, and connection pipe size remain same as conventional radiator.

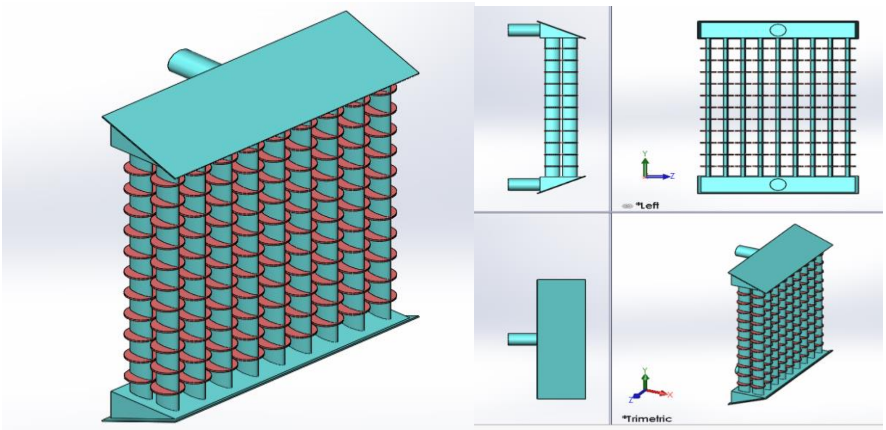

Figure 3.7 Radiator geometry of 18 oval pipes and fin arrangement (Model no. 04)

3.3.5 Model no. 05

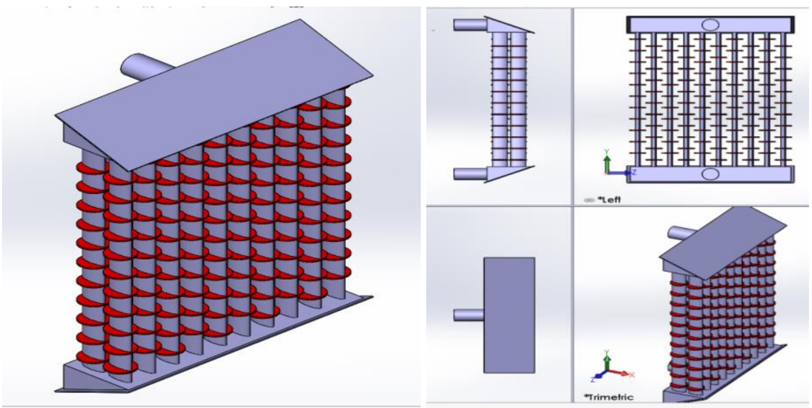

Figure 3.8 Radiator geometry of 20 oval pipes and fin Arrangement (Model no. 05)

Figure 3.8 represents the radiator geometry with 20 oval pipes and 11 circular fin arrangement of each oval pipe. In each oval pipe longitudinal distance from one fin to another fin is kept same as model no. 04. The fin sizes also remain identical with conventional radiator. From one oval pipe to next oval pipe space one which is not changed but kept same as model no. 04. Oval pipe, oil box, and connection pipe size is as same as conventional radiator.

3.4 Meshing

In CFD simulations Mesh (grid) module is the most crucial part. In order to determine the temperature of all body domains are split into small parts, which are called mesh elements. To calculate heat transfer equations ANSYS Fluent solver uses finite volume method. In order to start meshing operations boundary conditions should be defined. For meshing, inlet-velocity and outlet-pressure are inlet and outlet boundaries respectively.

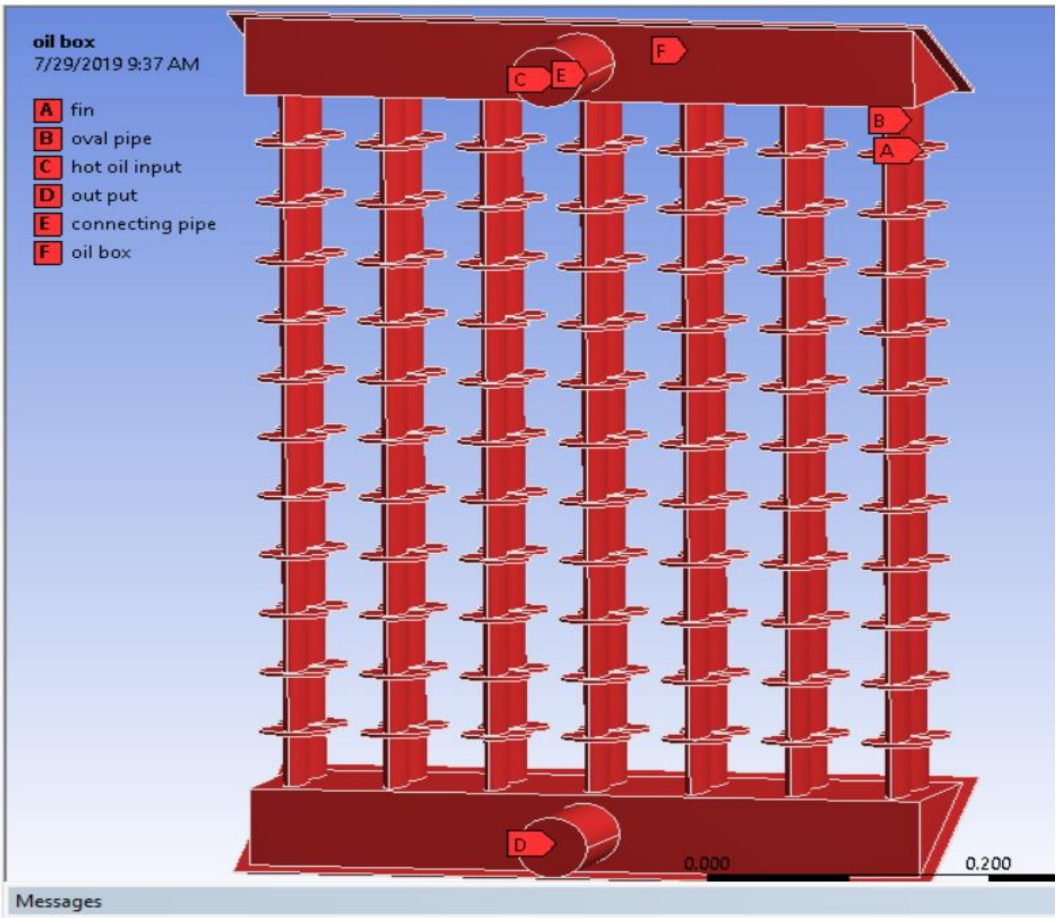

Figure 3.9 Domain view of the radiator

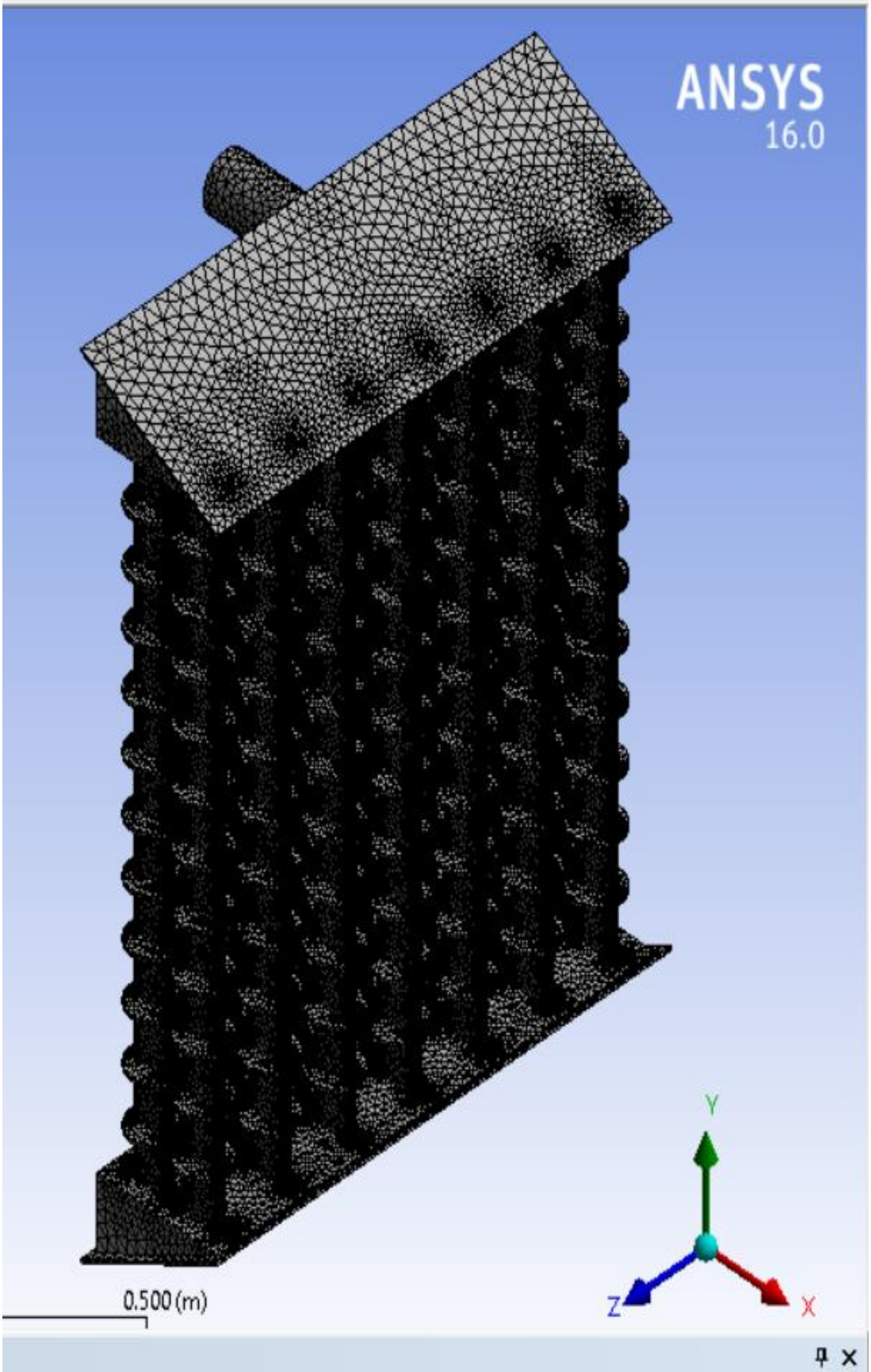

Figure 3.10 Mesh view of the Radiator

The name of different parts of radiator are selected which are called domain such as fin, oval pipe, hot oil input, output, connecting pipe, and oil box that is represented in figure 3.9. After selecting domains of the radiator Mesh is generated. Figure 3.10 represents the Mesh view of the Radiator. Tetrahedral Mesh is generated due to the complex geometry of fin [24]. The sizing of the Mesh is fine and smoothing is high.

3.5 Material properties

The properties of transformer oil such as density, specific heat, conductivity and viscosity are temperature dependent properties. With increasing temperature, density of the transformer oils decrease linearly. Thermal conductivity also decreases with increasing temperature. The naphthenic oil is chemically expressed by C_7H_{14}<*l*>. All properties of naphthenic oil and mild steel are taken at 364 K.

Table 3.1 Material properties of the transformer

Naphthenic oil		Mild steel	
Property	Property Value	Property	Property Value
Density	827.18 kg/m^3	Density	7850 kg/m^3
Specific heat	2476.2 J/kg-K	specific heat	490 J/kg-K
Thermal conductivity	0.1249 W/m-K	Thermal conductivity	46 W/m-K
Dynamic viscosity	0.05 kg/m-s		

3.6 Boundary conditions

In the experiment of conventional radiator, the maximum ambient temperature was 305 K and the maximum top oil temperature was 364 K. For simulation, ambient temperature is taken as 305 K and the input oil temperature is taken as 364 K. Heat transfer coefficient is assumed as 6 W/m^{2}K. Connecting pipe wall thickness is taken as 3 mm, oil box wall thickness is 2.5 mm, oval pipe wall thickness is 1.5 mm, and fin wall thickness is 1.75 mm.

3.7 Different parts of the radiator

Figure 3.11 and figure 3.12 display the connecting pipe and hot oil input respectively.

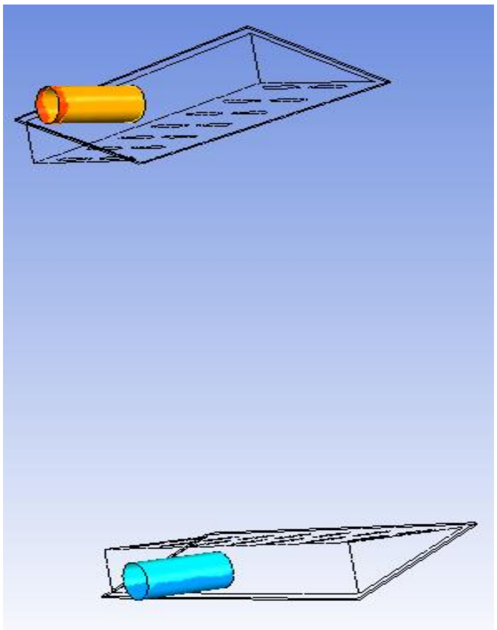

Figure 3.11 Connecting pipe

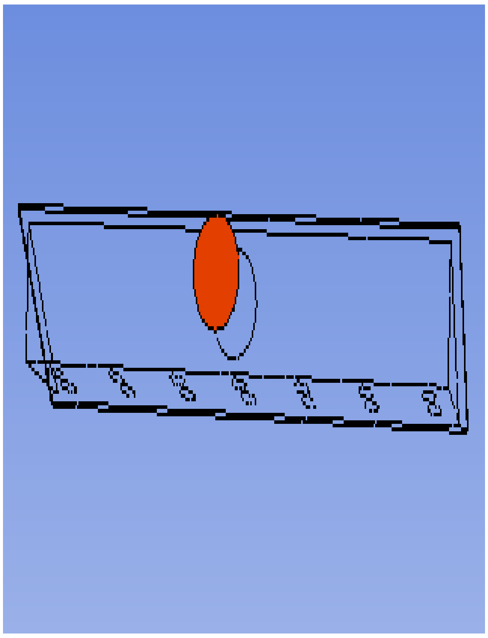

Figure 3.12 Hot oil input

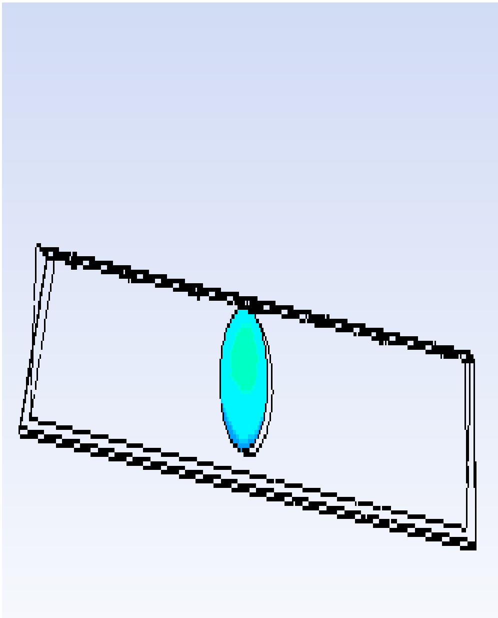

Figure 3.13 Output

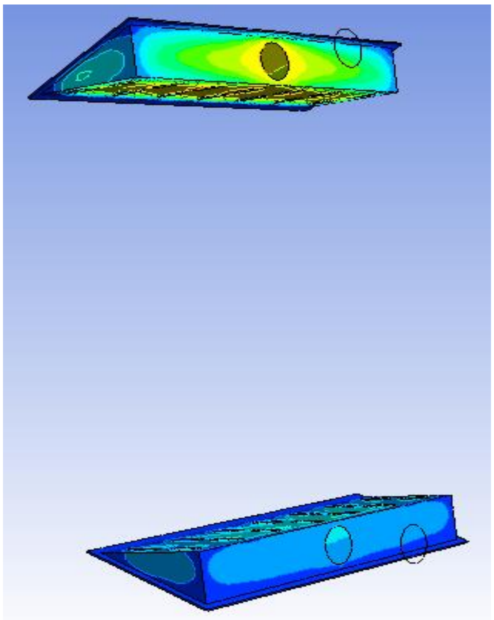

Figure 3.14 Oil box

Figure 3.13 and figure 3.14 represent the output and oil box respectively. Also, figure 3.15 and figure 3.16 indicate connecting pipe and hot oil input respectively.

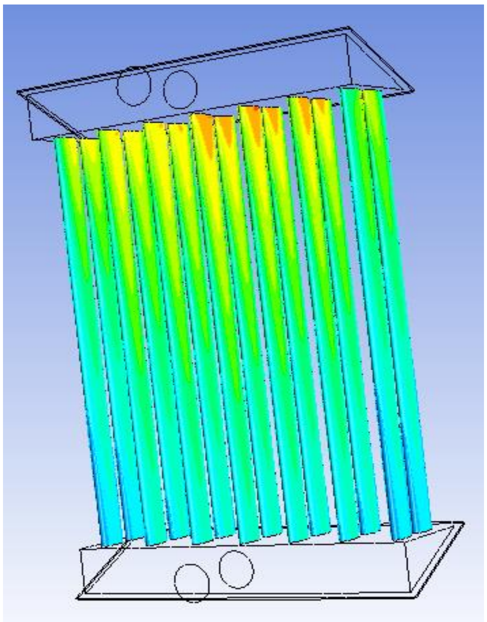

Figure 3.15 Oval pipe

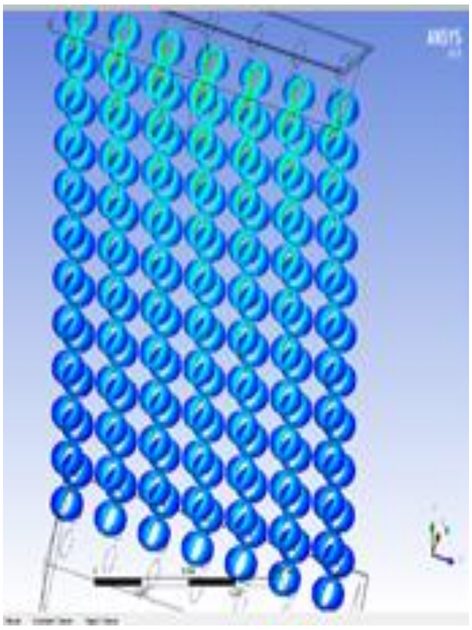

Figure 3.16 Fin

3.8 Temperature distribution

Due to total loss of active part the temperature of transformer oil increases. With increasing temperature the volume of the transformer oil increases due to decreasing density. Furthermore, dynamic viscosity of transformer oil decreases with increasing temperature. The following detailed temperature distributions at inlet zone, outlet zone, and along full radiator model are described one by one.

3.8.1 Temperature distribution of conventional radiator

Conventional radiator is consists of 28 oval pipes without fin arrangement. The temperature distribution at inlet zone of fully red of conventional radiator is displayed in figure 3.17. The red zone temperature is 364 K. The temperature distribution at outlet blue zone of conventional radiator is represented in figure 3.18. The blue zone temperature is obtained 313 K.

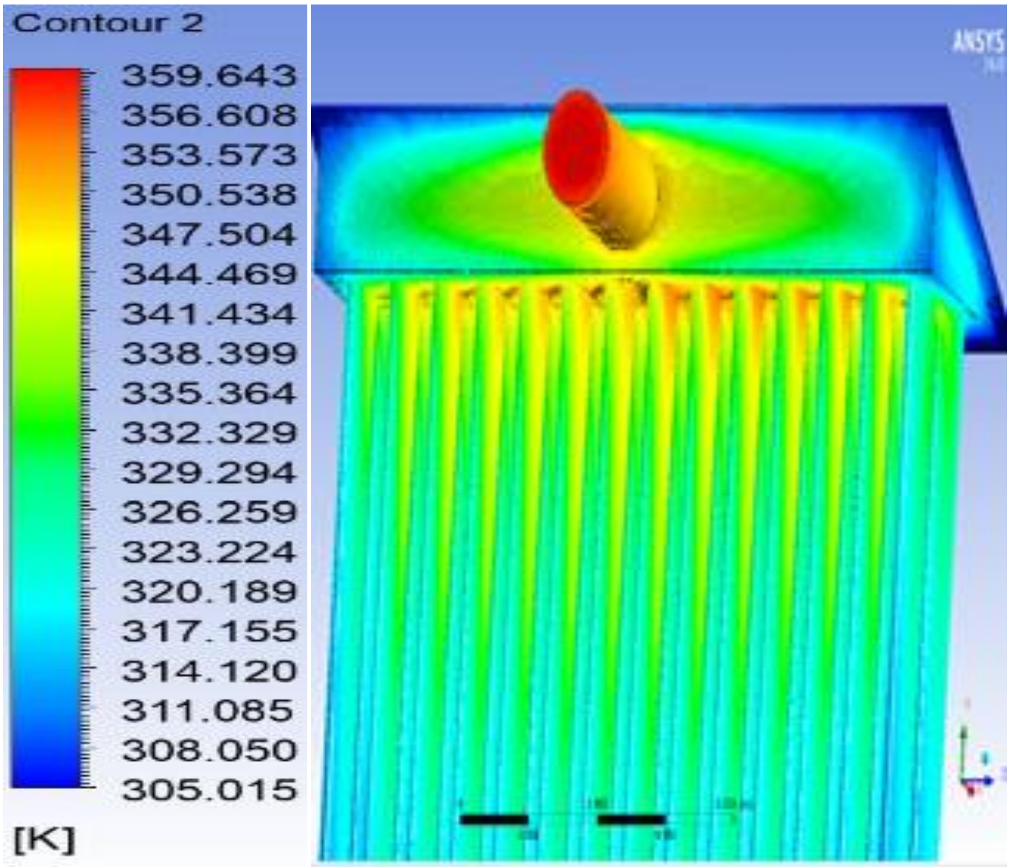

Figure 3.17 Temperature distribution at inlet zone of conventional radiator

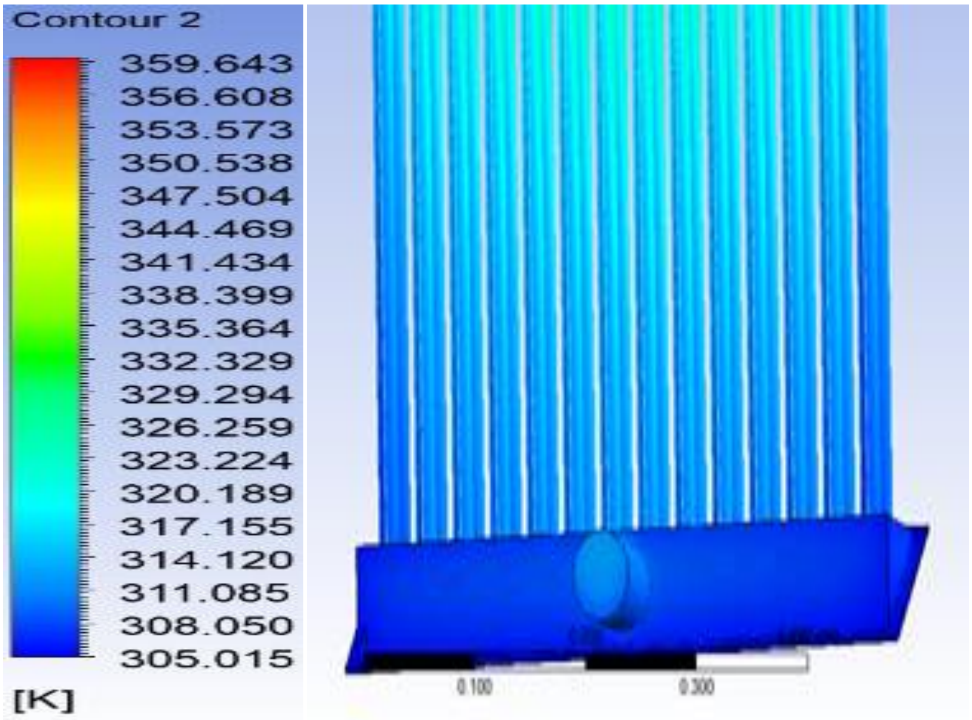

Figure 3.18 Temperature distribution at outlet zone of conventional radiator

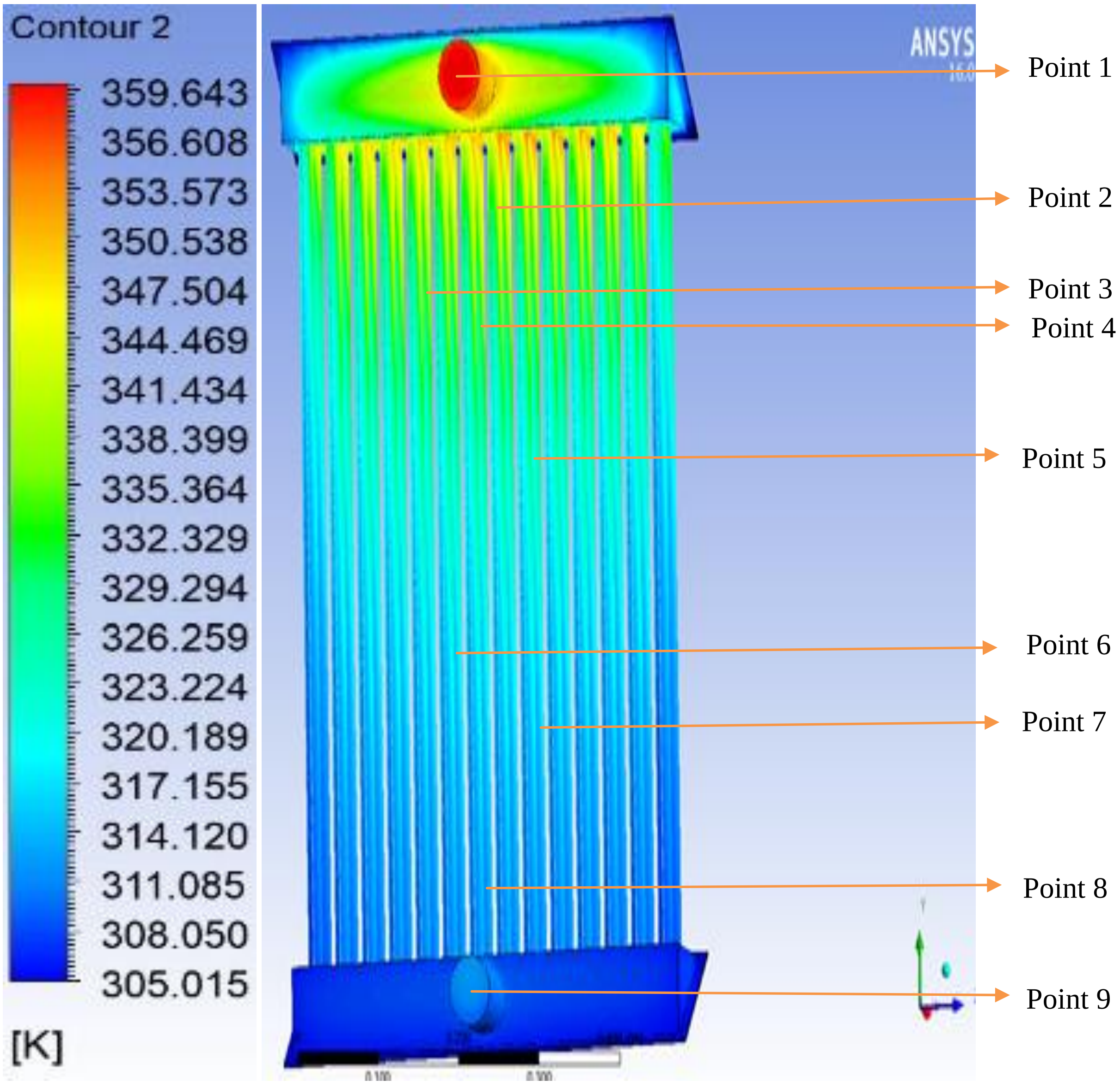

Figure 3.19 Temperature distribution along full radiator of conventional radiator

The temperature distribution along simulated full radiator model of conventional radiator is displayed in figure 3.19. Here the naphthenic oil temperature gradually decreases which tends to free stream temperature. Temperature at different location of full radiator of conventional radiator is represented in figure 3.20. It is seen that temperatures reduces from inlet to outlet of full radiator due to oil velocity since there is low viscosity in the transformer oil. Also, heat transfer occurs by conduction process and largely convection process.

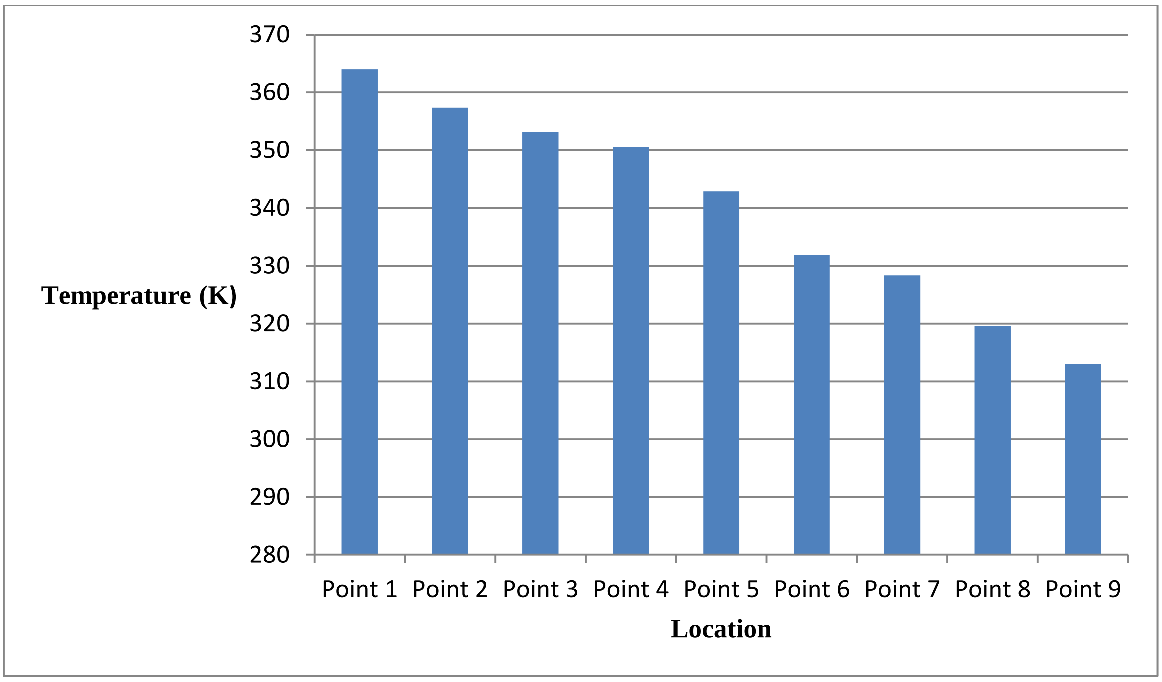

Figure 3.20 Temperature at different location of full radiator of conventional radiator

3.8.2 Temperature distribution of model no. 01

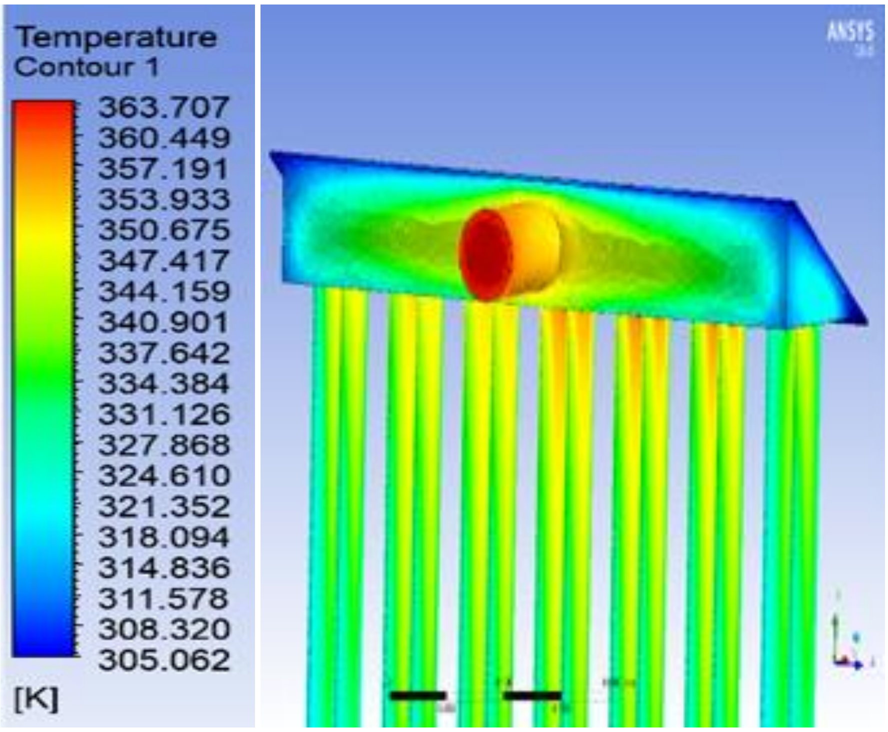

Figure 3.21 Temperature distribution at inlet zone of model no. 01

Model no. 01 is formed of 14 oval pipes without fin arrangement. The temperature distributions at inlet and outlet zones are shown in figure 3.21 and figure 3.22 respectively. Inlet temperature is 364 K and outlet temperature is gained 324 K. The temperature distribution along simulated full radiator is represented in figure 3.23. Temperature at different location of full radiator of model no. 01 is displayed in figure 3.24. It is seen that temperatures reduces from inlet to outlet of full radiator due to pressure drop of the transformer oil and temperature difference between oil and air. Also, heat transfer occurs by conduction process and largely convection process.

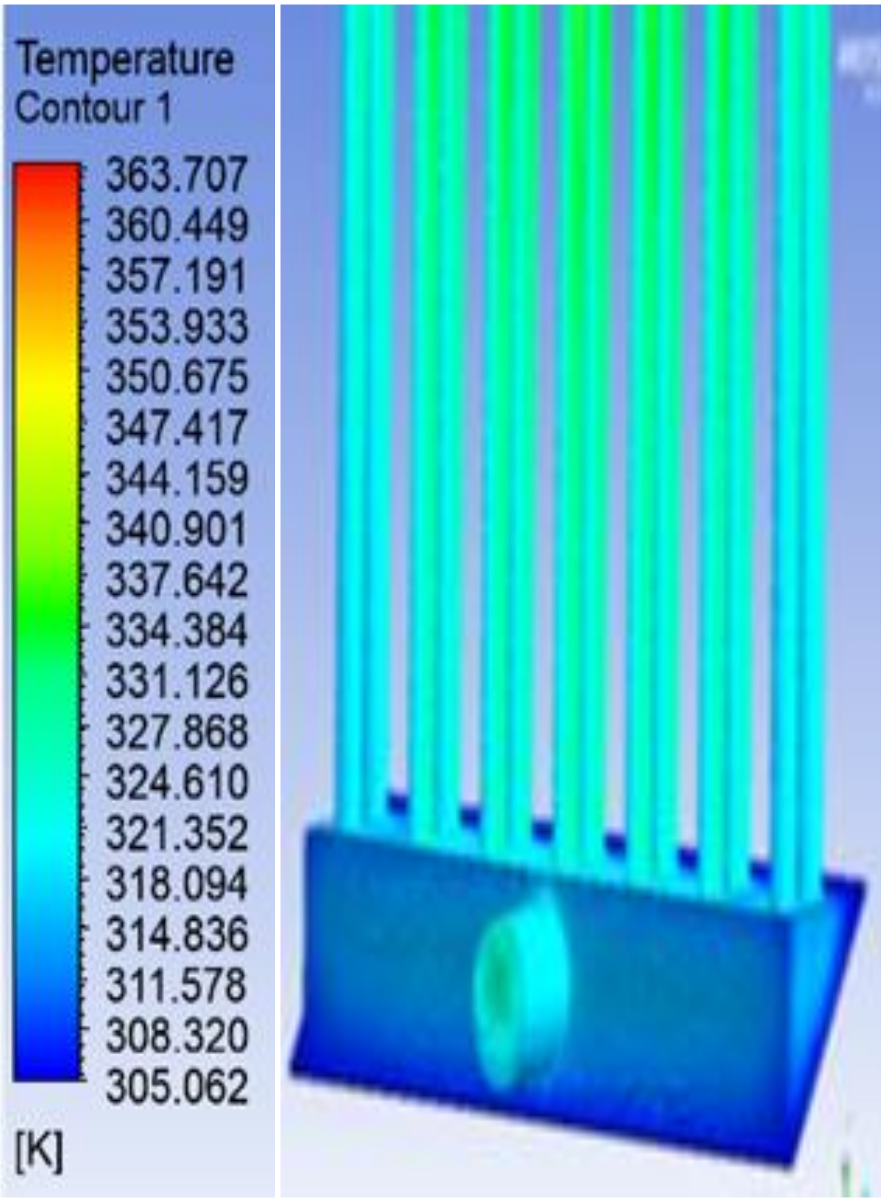

Figure 3.22 Temperature distribution at outlet zone of model no. 01

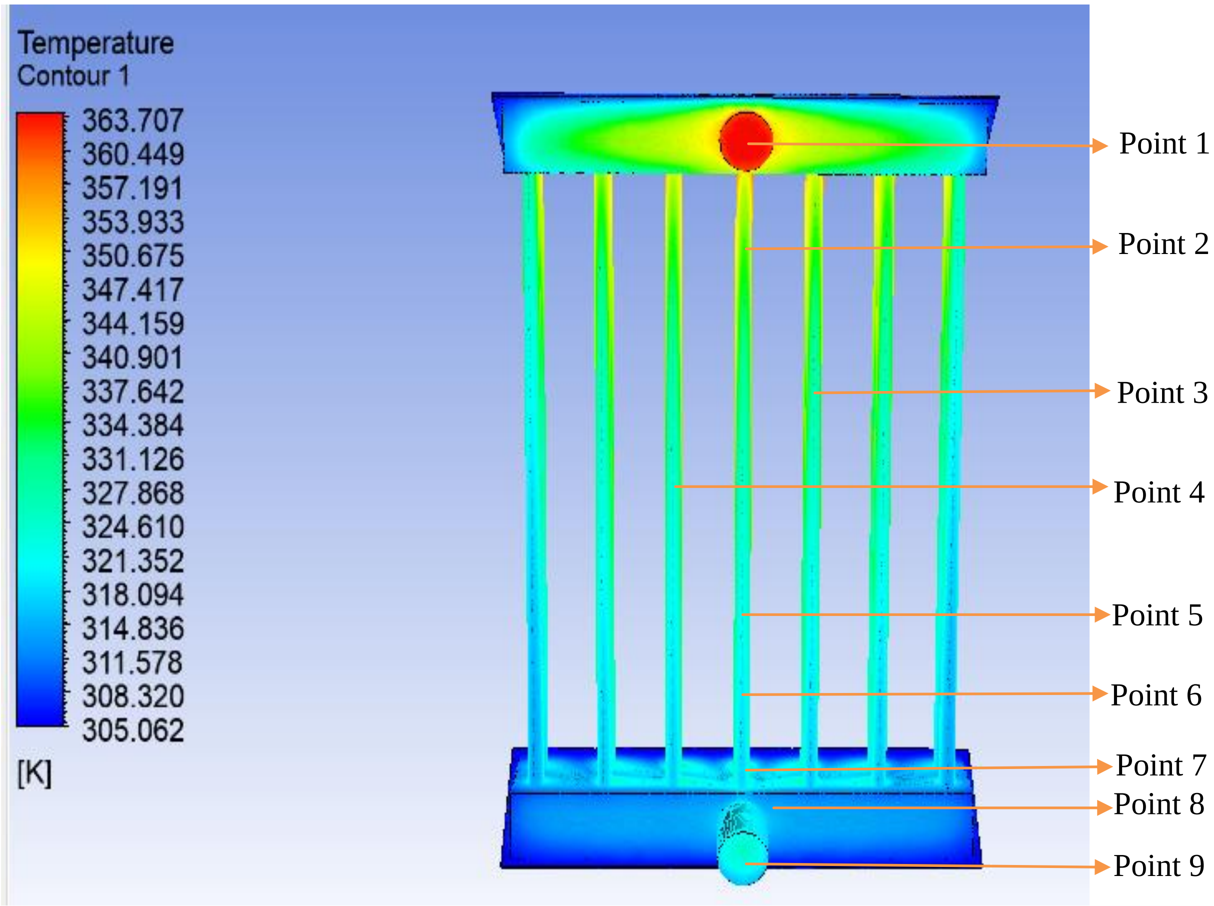

Figure 3.23 Temperature distribution along full radiator of model no. 01

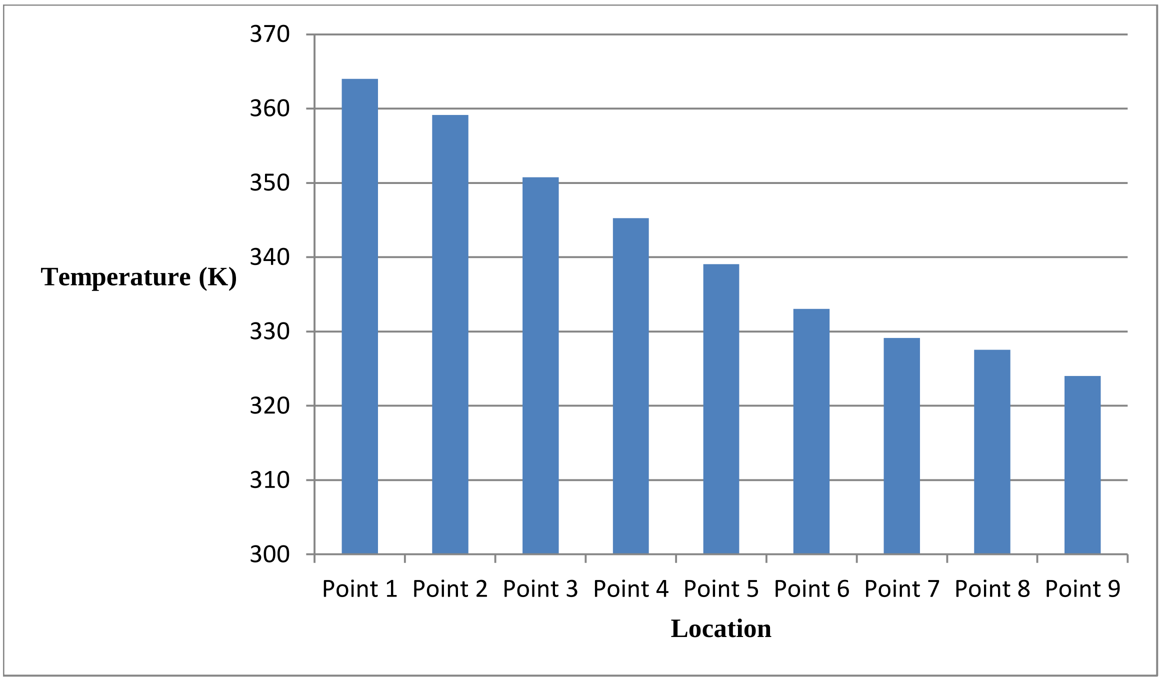

Figure 3.24 Temperature at different location of full radiator of model no. 01

3.8.3 Temperature distribution of model no. 02

Model no. 02 is made by 14 oval pipes with fin arrangement. The temperature distributions at inlet and outlet zones are shown in figure 3.25 and figure 3.26 respectively. Inlet temperature is 364 K and outlet temperature is 322 K. The temperature distribution along simulated full radiator model and the temperature distribution at fin arrangement are displayed in figure 3.27 and figure 3.29 respectively.

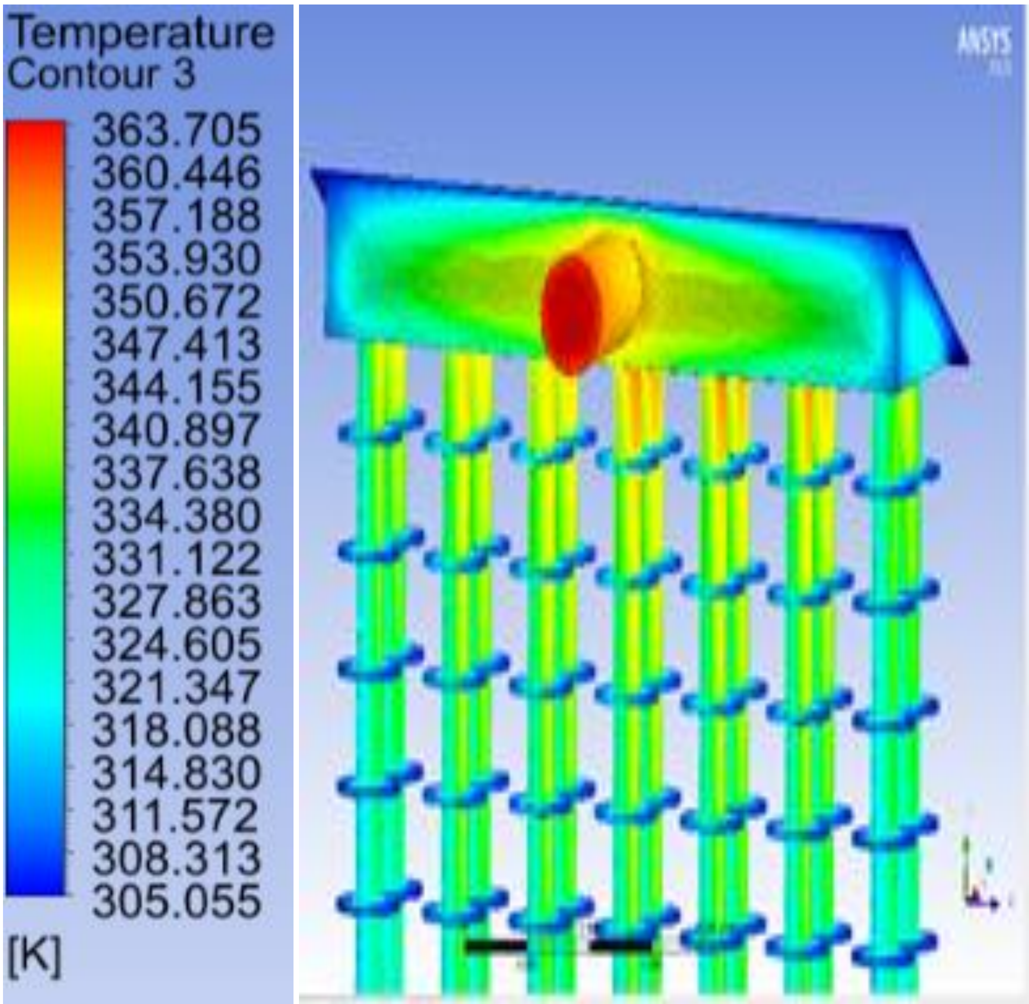

Figure 3.25 Temperature distribution at inlet zone of model no. 02

Temperatures at different location of full radiator of model no. 02 are represented in figure 3.28. It is seen that temperatures reduces from inlet to outlet of full radiator due to thermal conductivity, heat transfer coefficient and air velocity outside of the radiator.

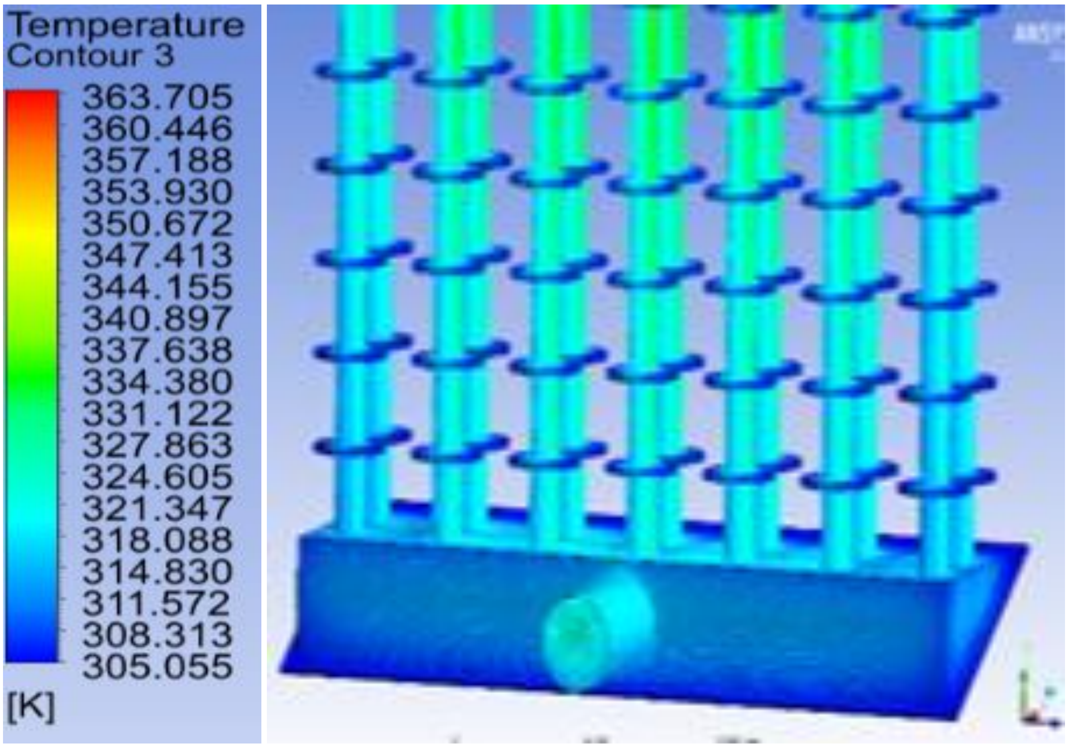

Figure 3.26 Temperature distribution at outlet zone of model no. 02

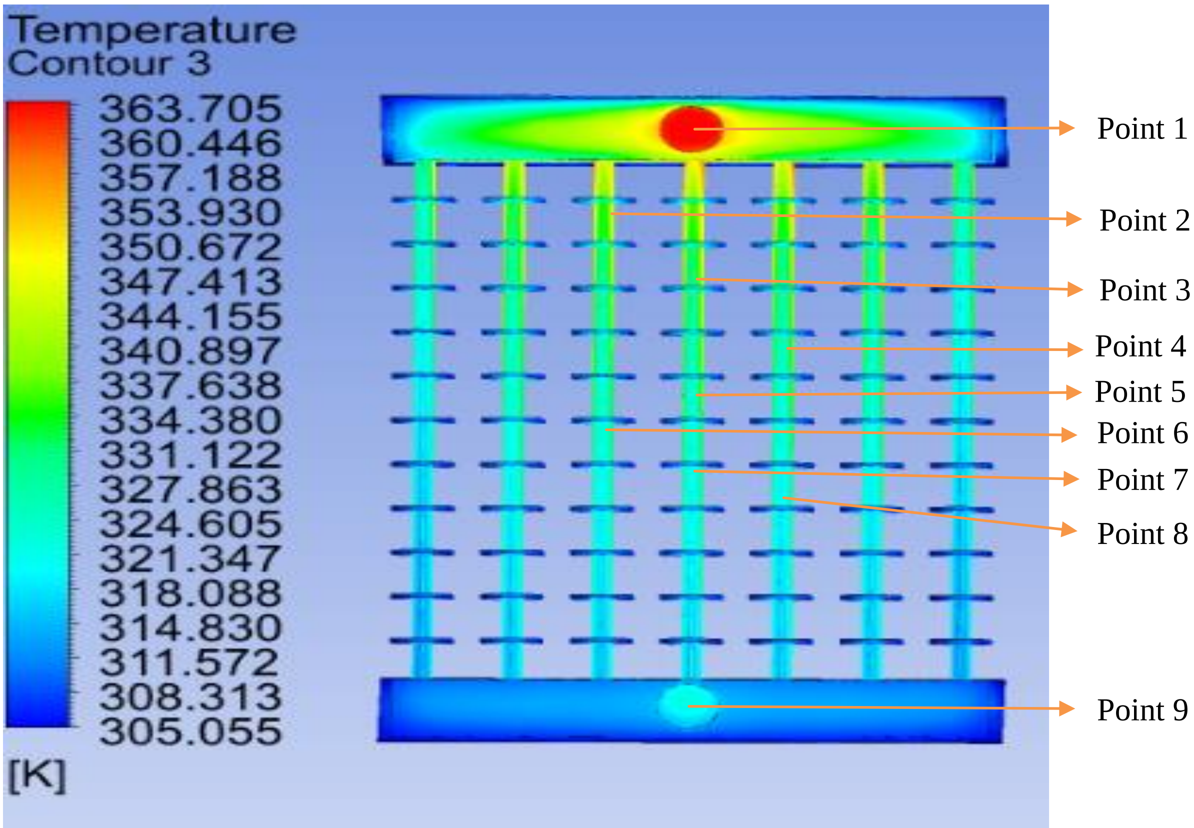

Figure 3.27 Temperature distribution along full radiator of model no. 02

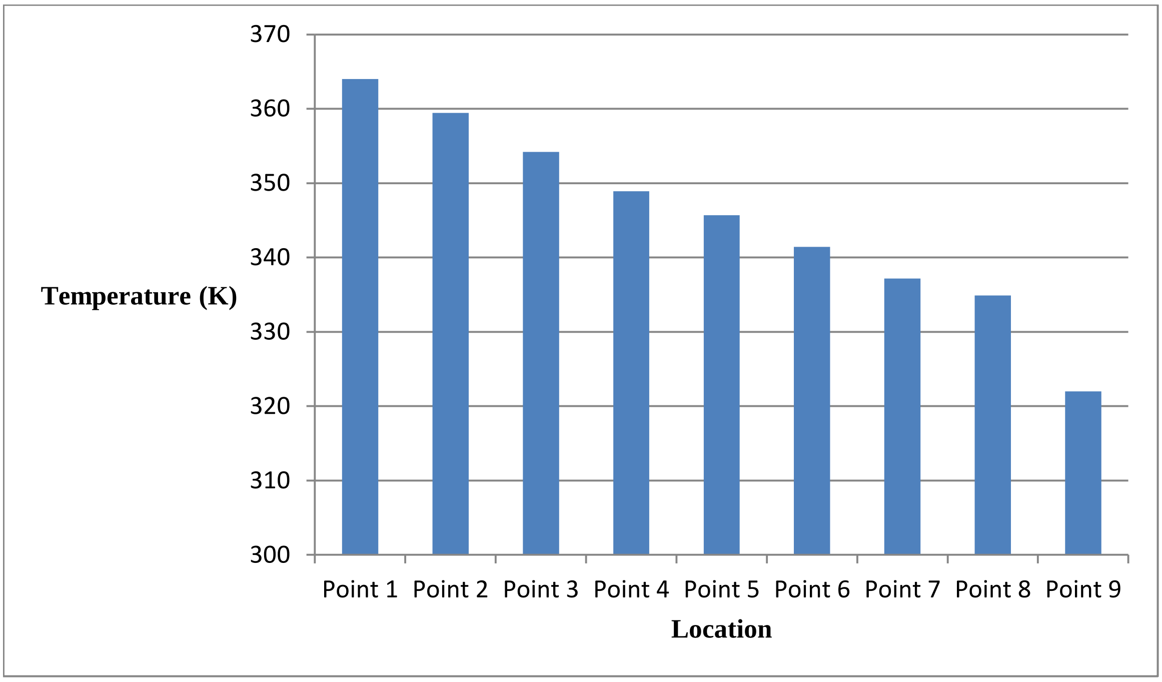

Figure 3.28 Temperature at different location of full radiator of model no. 02

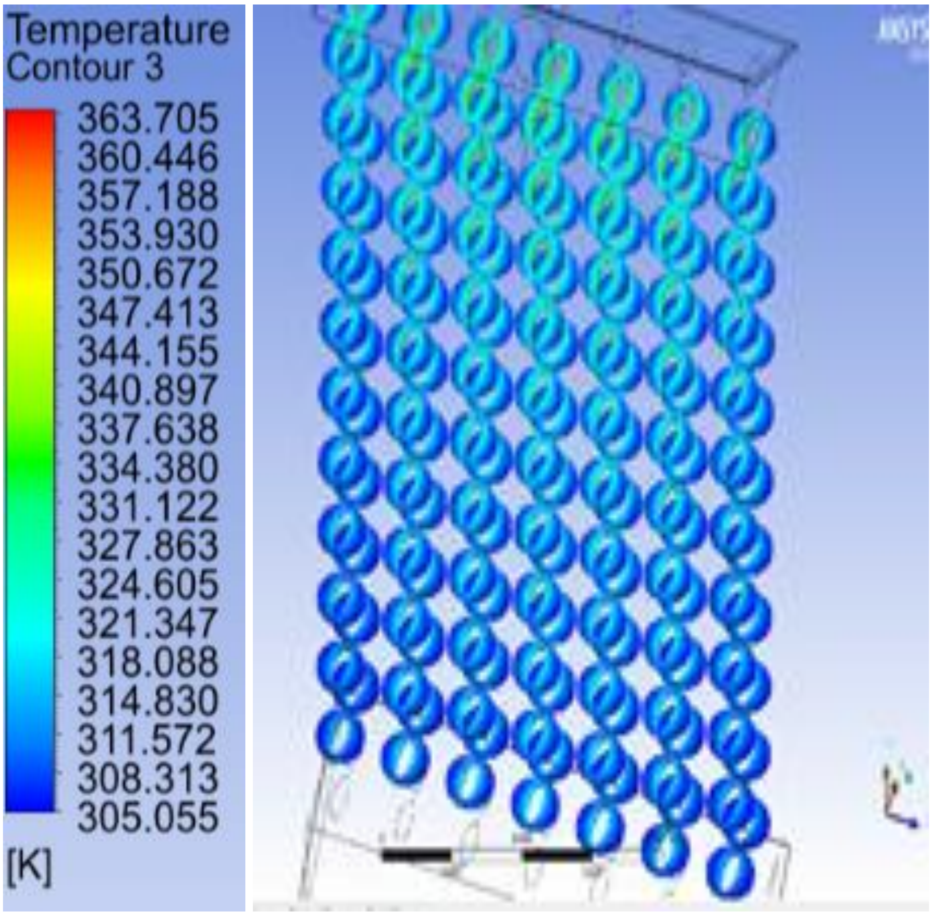

Figure 3.29 Temperature distribution at fin zone of model no. 02

3.8.4 Temperature distribution of model no. 03

Model no. 03 is consists of 16 oval pipes with fin arrangement. Figure 3.30 and figure 3.31 indicate the temperature distributions at inlet and outlet zones respectively. 364 K is the inlet temperature and 320 K is the outlet temperature. The temperature distribution along simulated full radiator model and the temperature distribution at fin arrangement are represented in figure 3.32 and figure 3.34. Figure 3.33 indicates the temperature at different location of full radiator of model no. 03. It is observed that due to oil velocity and low viscosity of the transformer oil temperatures reduce from inlet to outlet of full radiator. Also, conduction process and largely convection process are responsible for heat transfer.

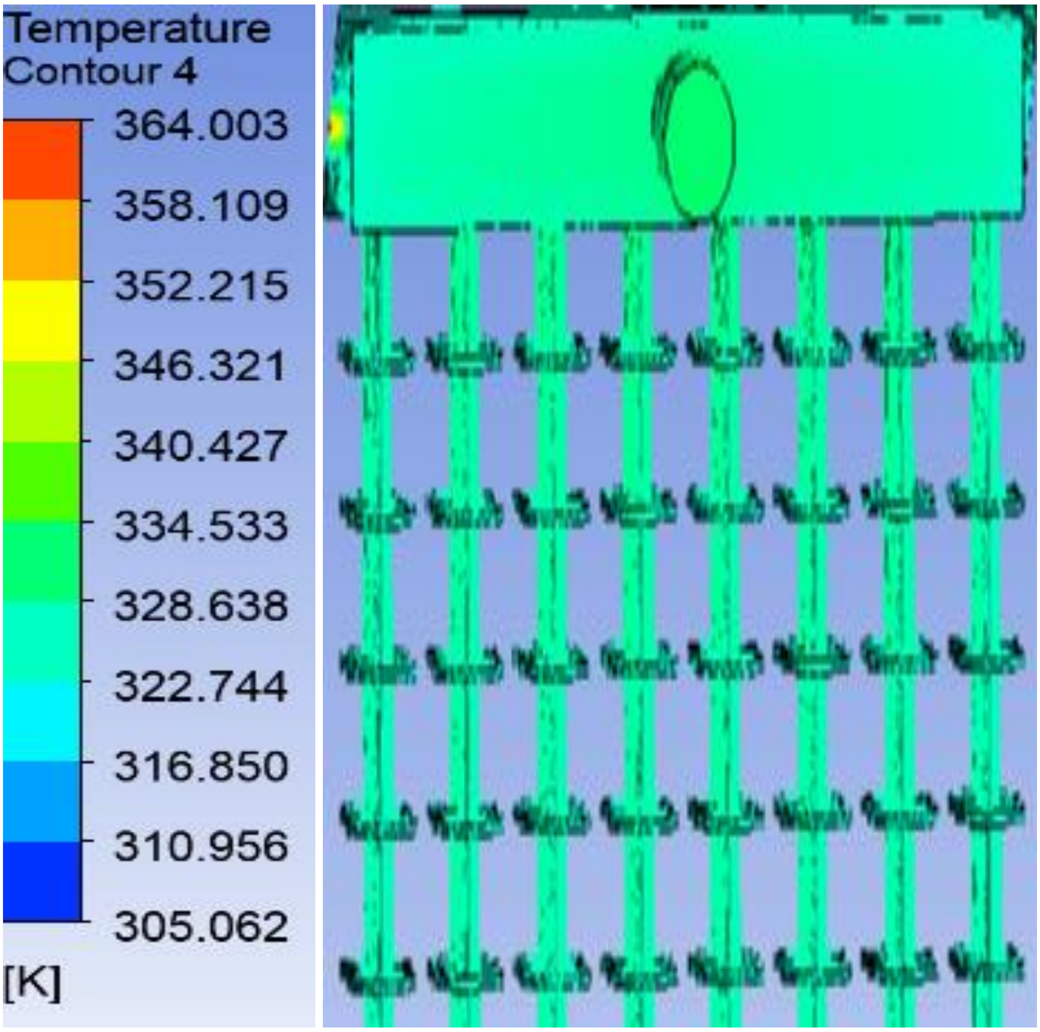

Figure 3.30 Temperature distribution at inlet zone of model no. 03

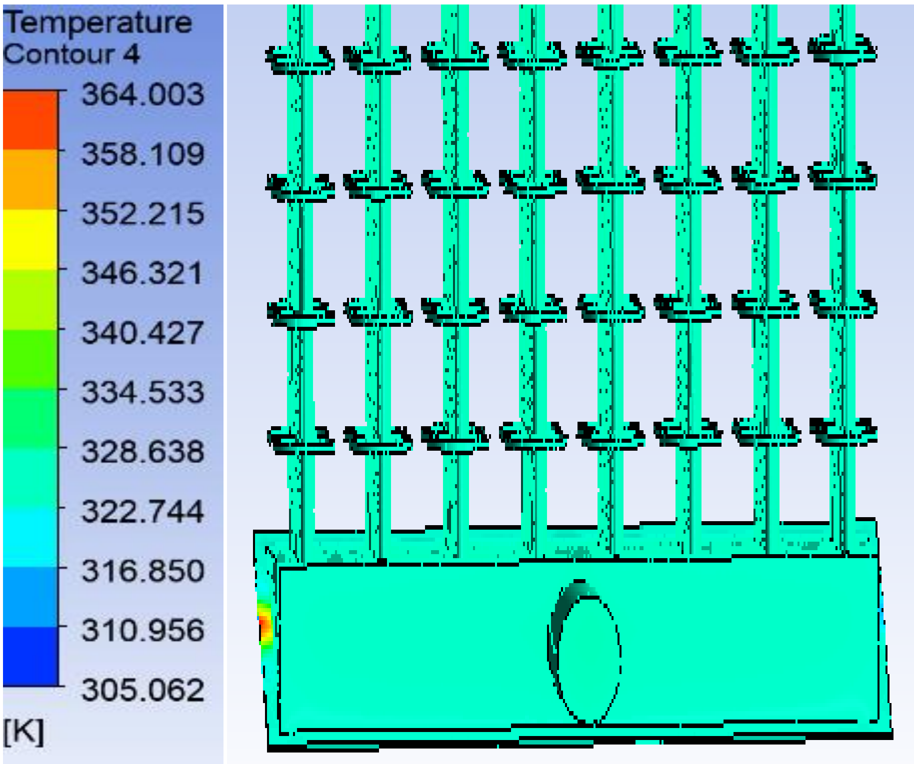

Figure 3.31 Temperature distribution at outlet zone of model no. 03

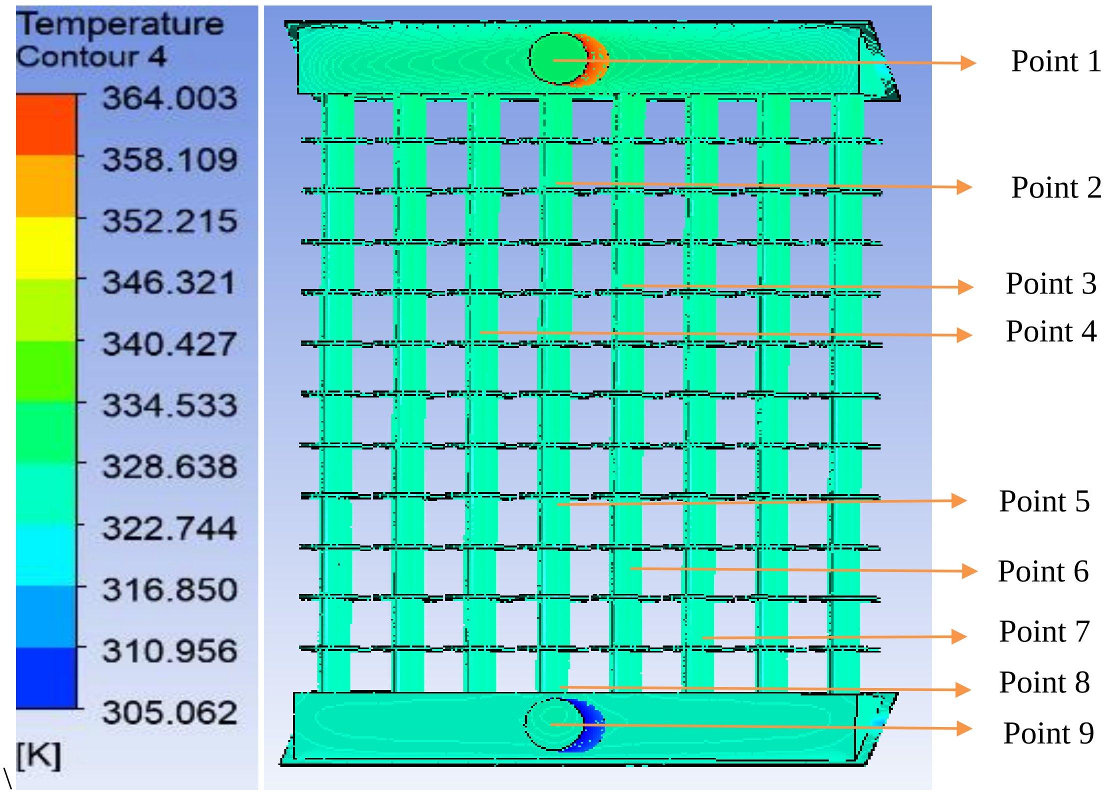

Figure 3.32 Temperature distribution along full radiator of model no. 03

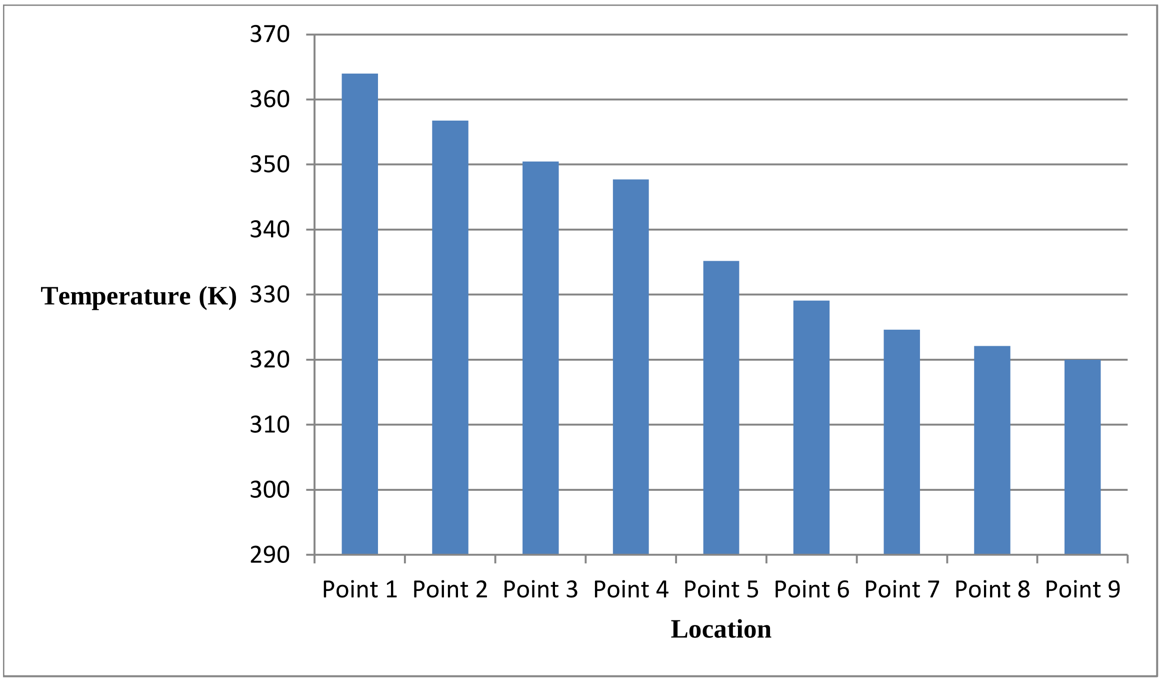

Figure 3.33 Temperature at different location of full radiator of model no. 03

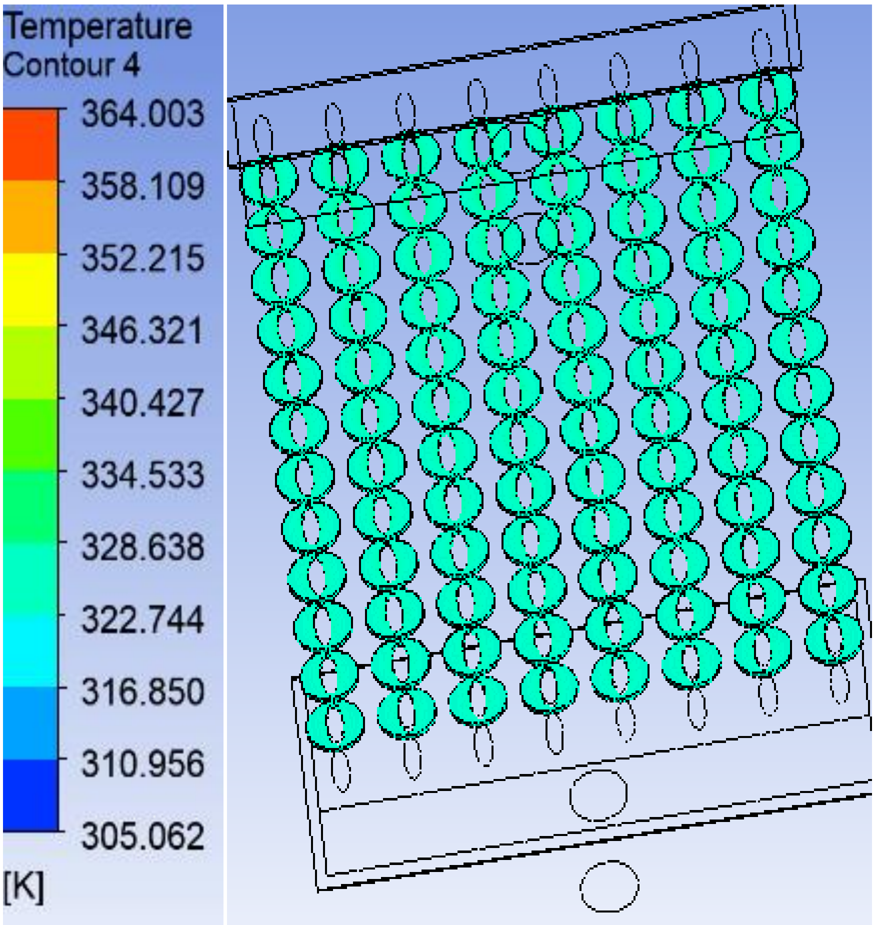

Figure 3.34 Temperature distribution at fin zone of model no. 03

3.8.5 Temperature distribution of model no. 04

Model no. 04 is fabricated by 18 oval pipes and fin arrangement. The temperature distribution of inlet zone of model no. 04 is displayed in figure 3.35. The red zone temperature is 364 K. The temperature distribution of outlet zone of model no. 03 is shown in figure 3.36. The blue zone temperature is 318 K.

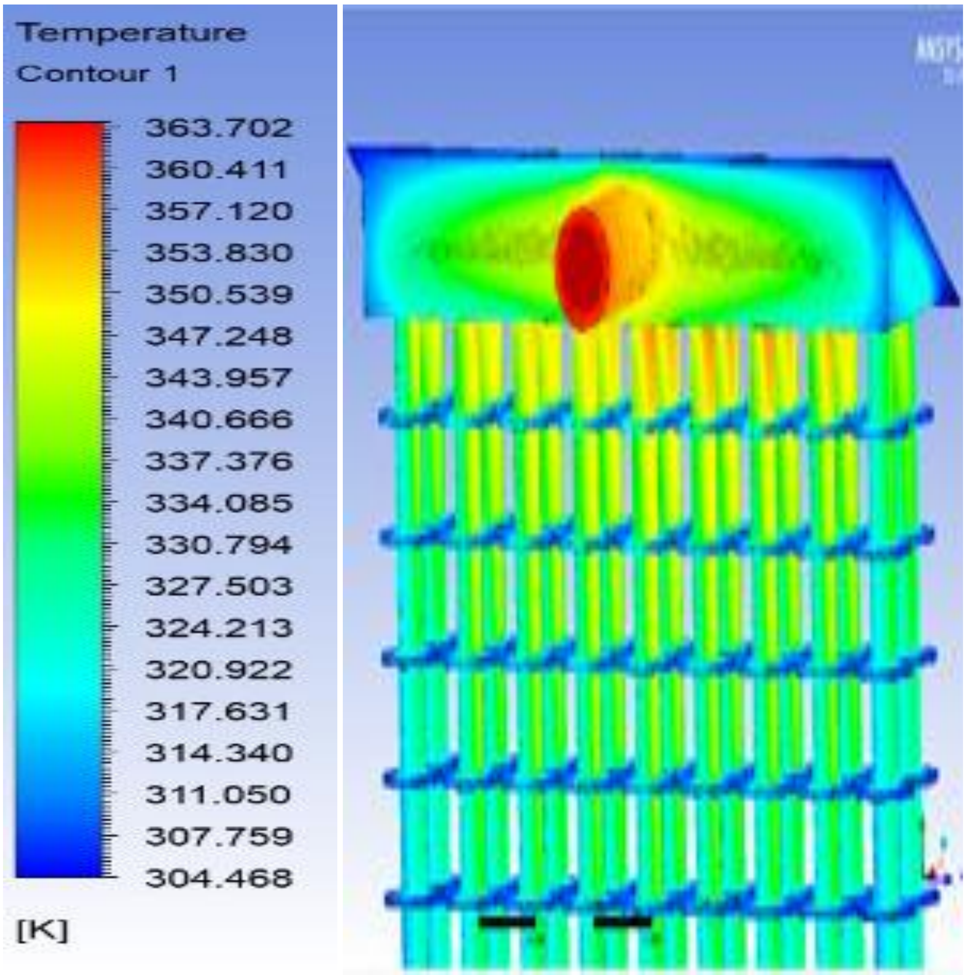

Figure 3.35 Temperature distribution at inlet zone of model no. 04

Figure 3.37 displays the temperature distribution along simulated full radiator of model no. 04. Here, the naphthenic oil temperature decreases gradually. The temperature distribution at fin arrangement is shown in figure 3.39. Here, few heat transfers occur. Figure 3.38 indicates the temperature at different location of full radiator of model no. 04. It is expressed that due to thermal conductivity, heat transfer coefficient and air velocity outside of the radiator temperatures reduce from inlet to outlet of full radiator.

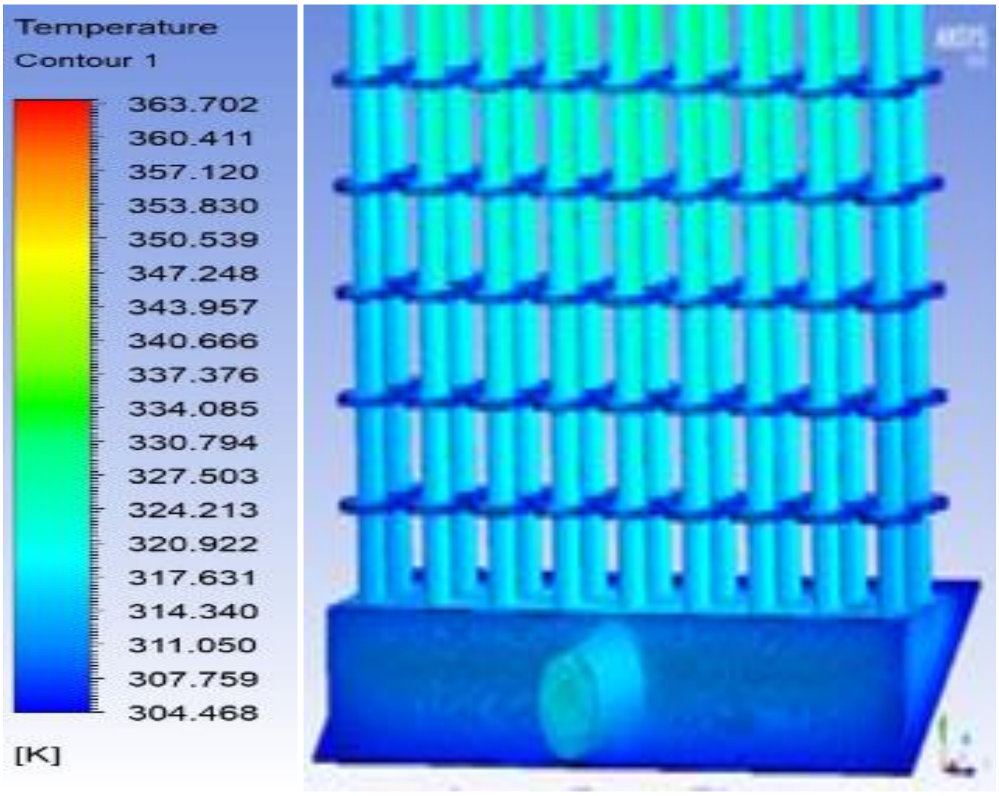

Figure 3.36 Temperature distribution at outlet zone of model no. 04

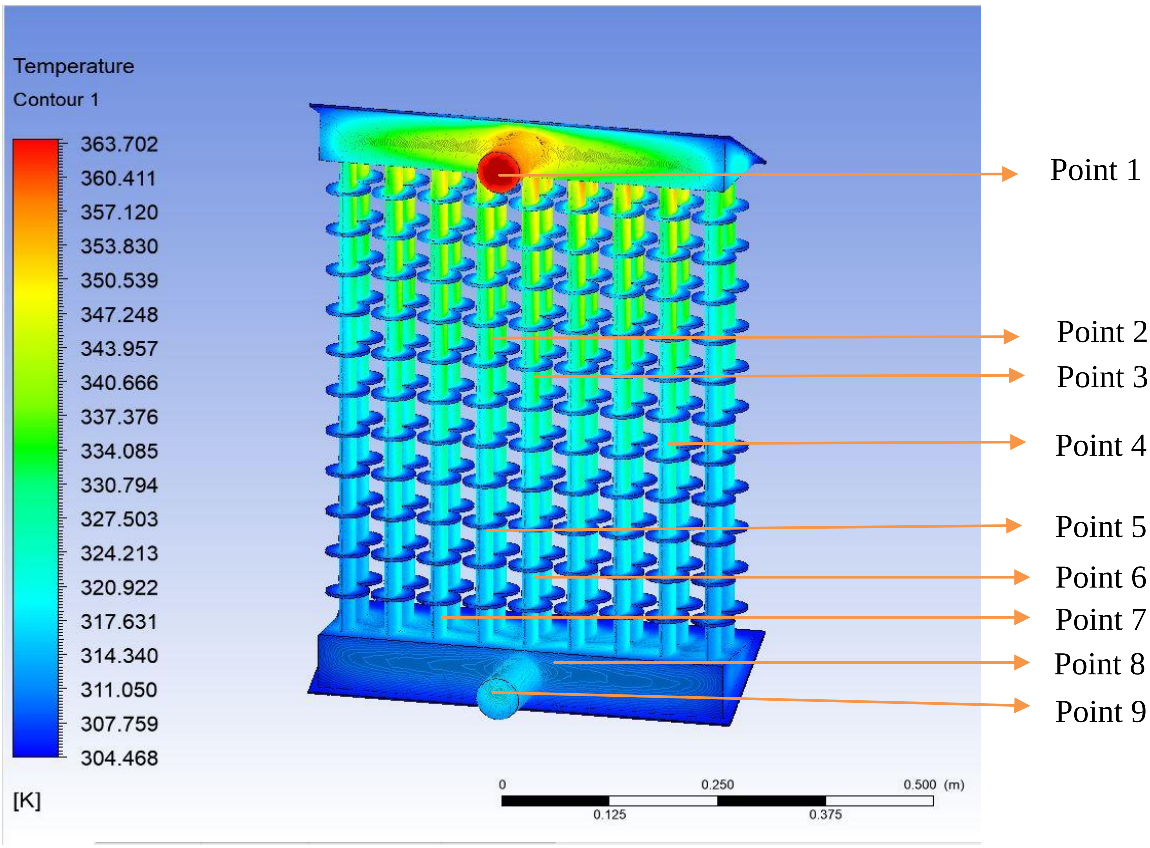

Figure 3.37 Temperature distribution along full radiator of model no. 04

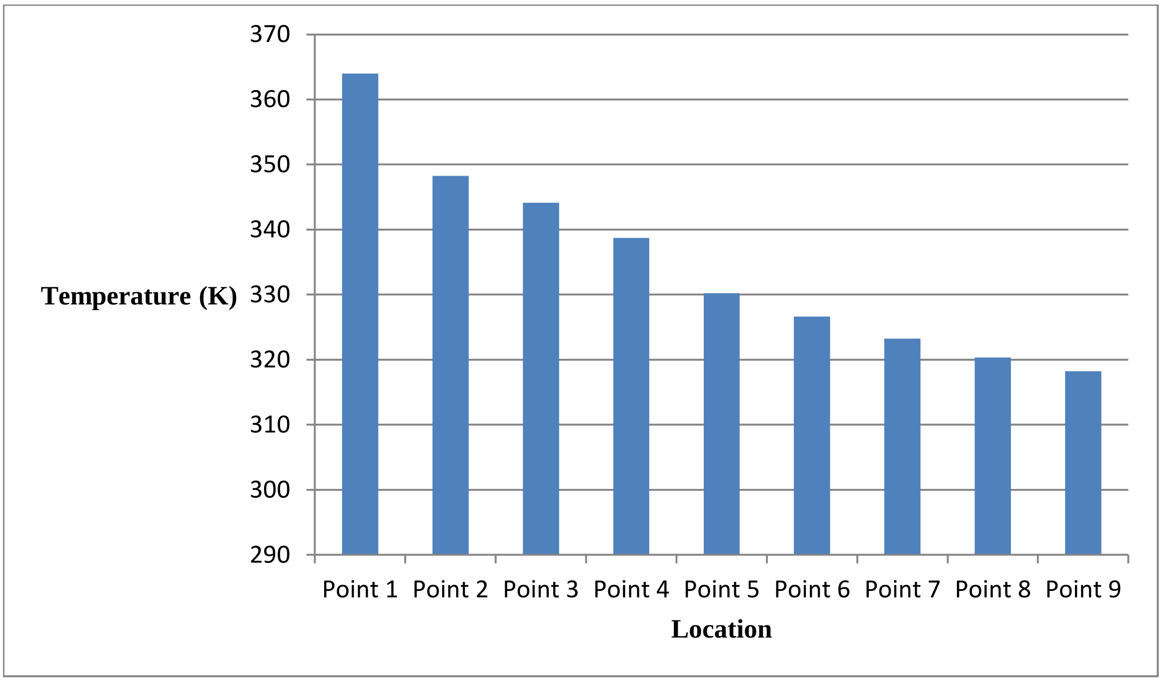

Figure 3.38 Temperature at different location of full radiator of model no. 04

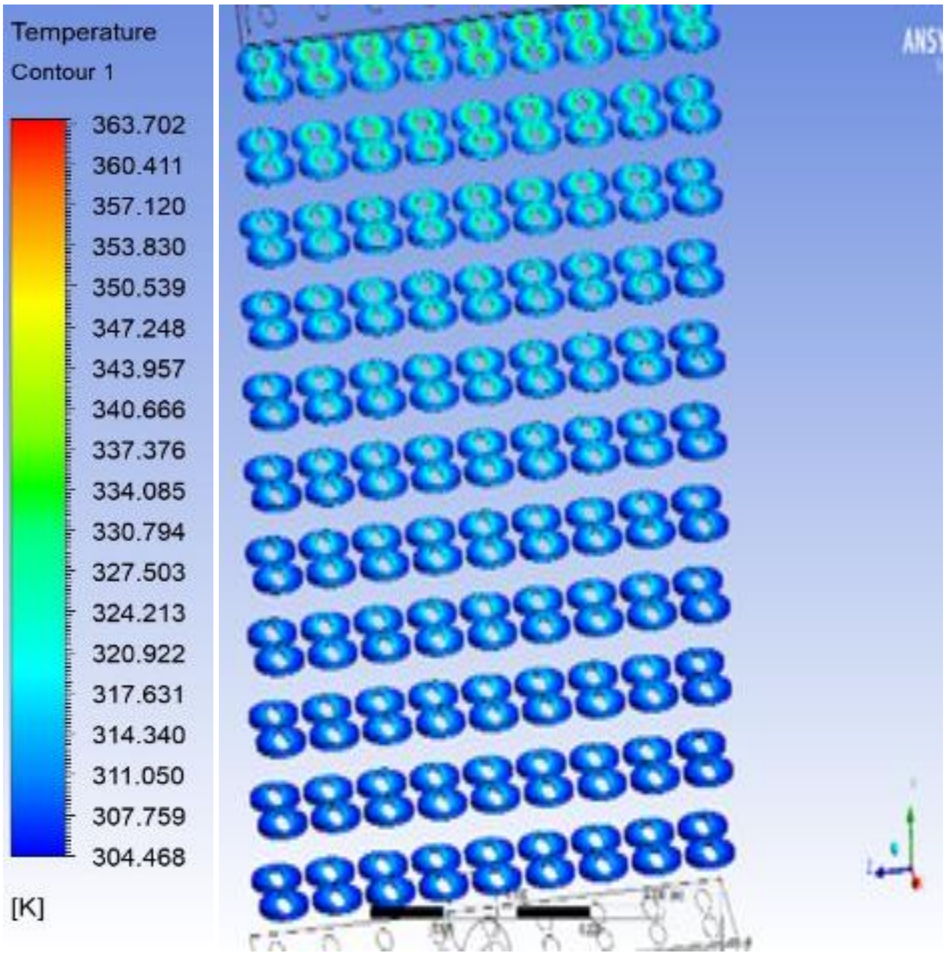

Figure 3.39 Temperature distribution at fin zone of model no. 04

3.8.6 Temperature distribution of model no. 05

Model no. 05 is consists of 20 oval pipes with fin arrangement. Figure 3.40 and figure 3.41 represents the temperature distributions at inlet and outlet zones respectively. 364 K and 316 K are the inlet temperature and the outlet temperature.

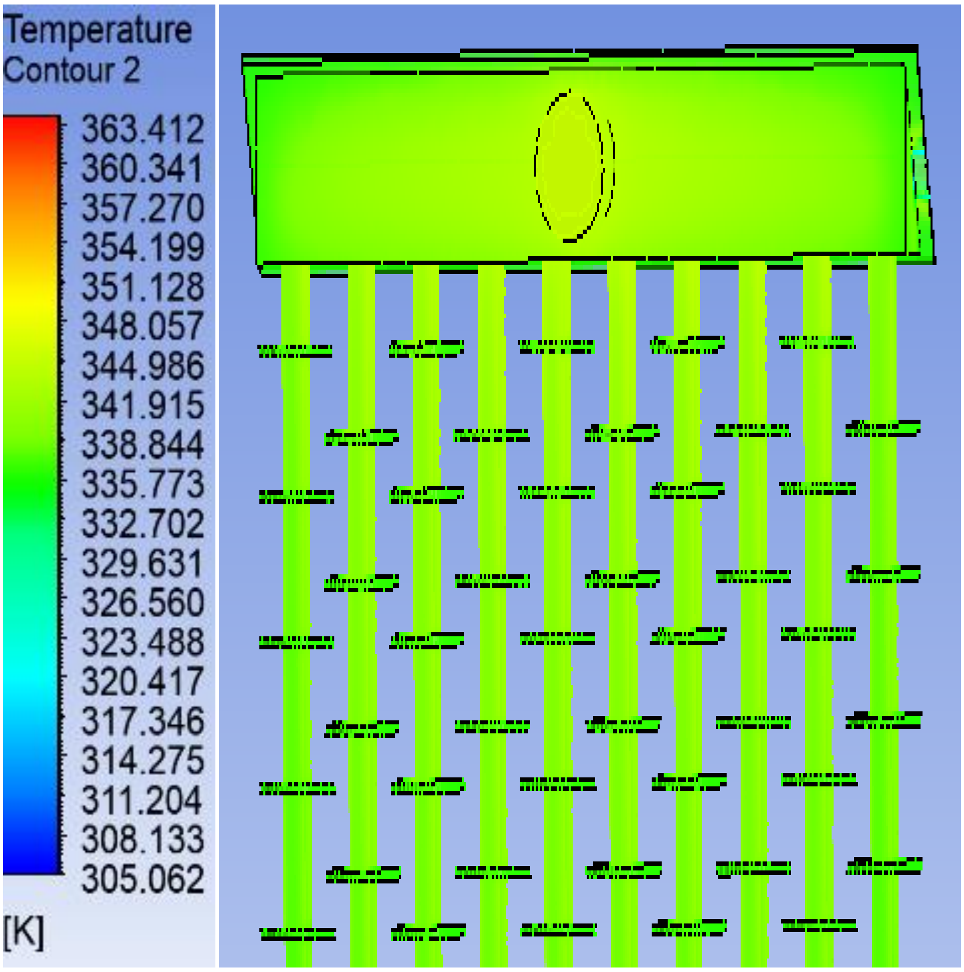

Figure 3.40 Temperature Distribution at inlet zone of model no. 05

The temperature distribution along simulated full radiator model and the temperature distribution at fin arrangement are represented in figure 3.42 and figure 3.44. Figure 3.43 indicates the temperature at different location of full radiator of model no. 05. It is observed that due to pressure drop of the transformer oil and temperature difference between oil and air temperatures reduce from inlet to outlet of full radiator. Also, conduction process and largely convection process are responsible for heat transfer.

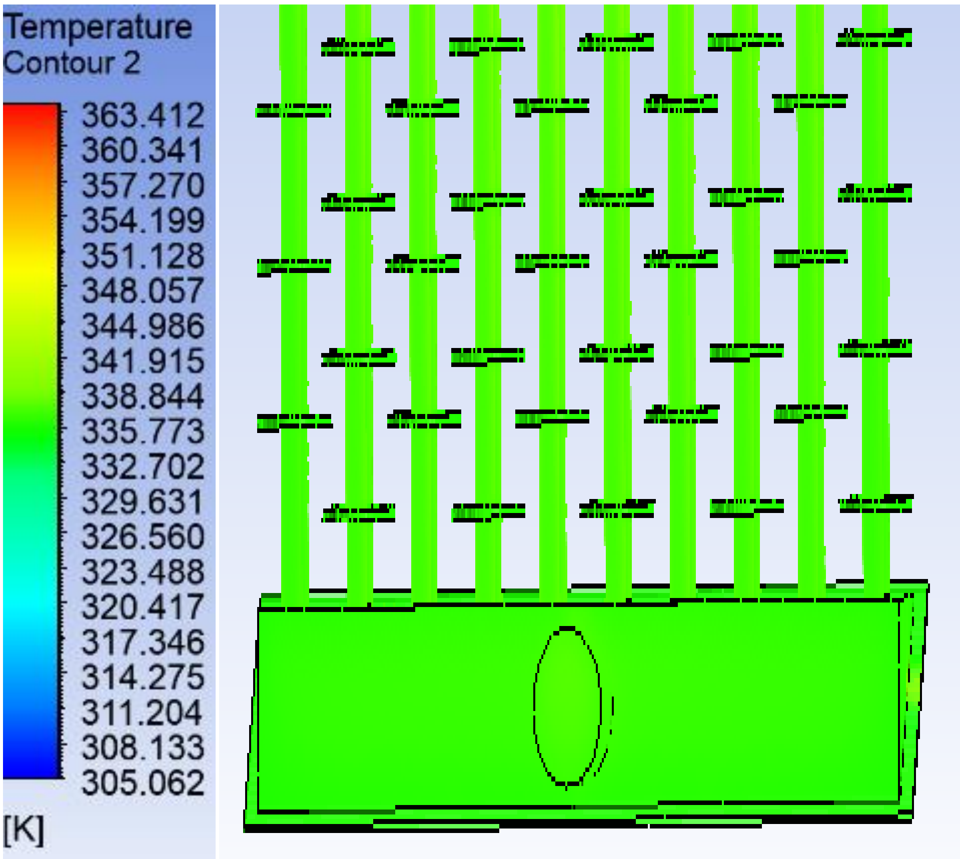

Figure 3.41 Temperature distribution at outlet zone of model no. 05

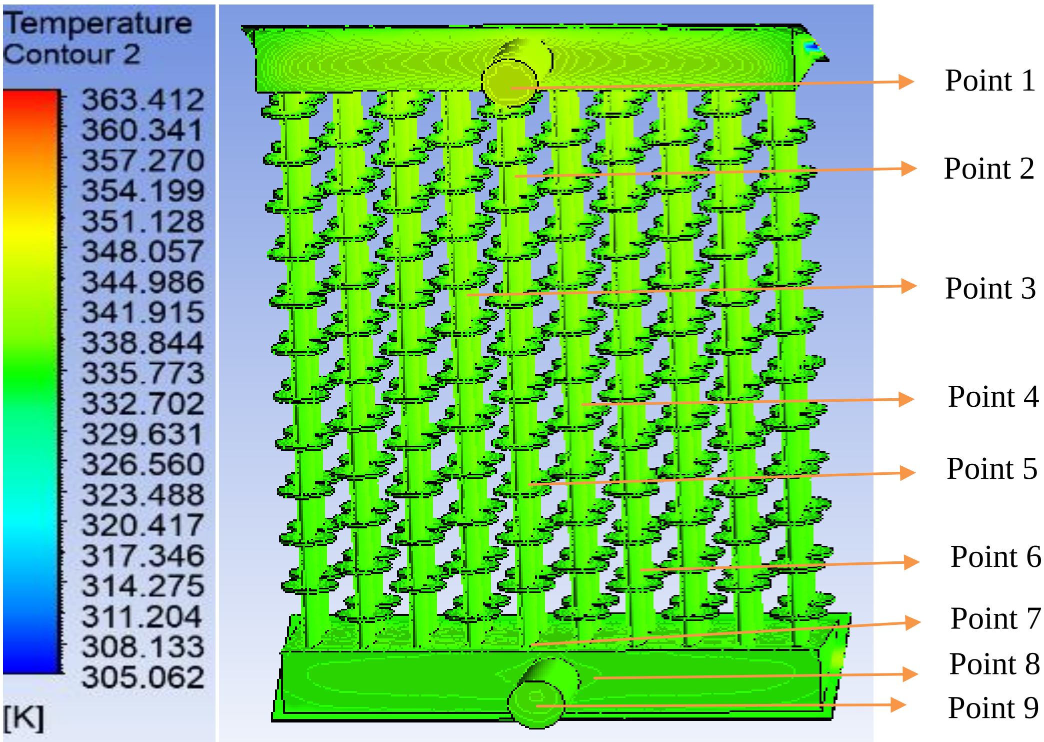

Figure 3.42 Temperature distribution along full radiator of model no. 05

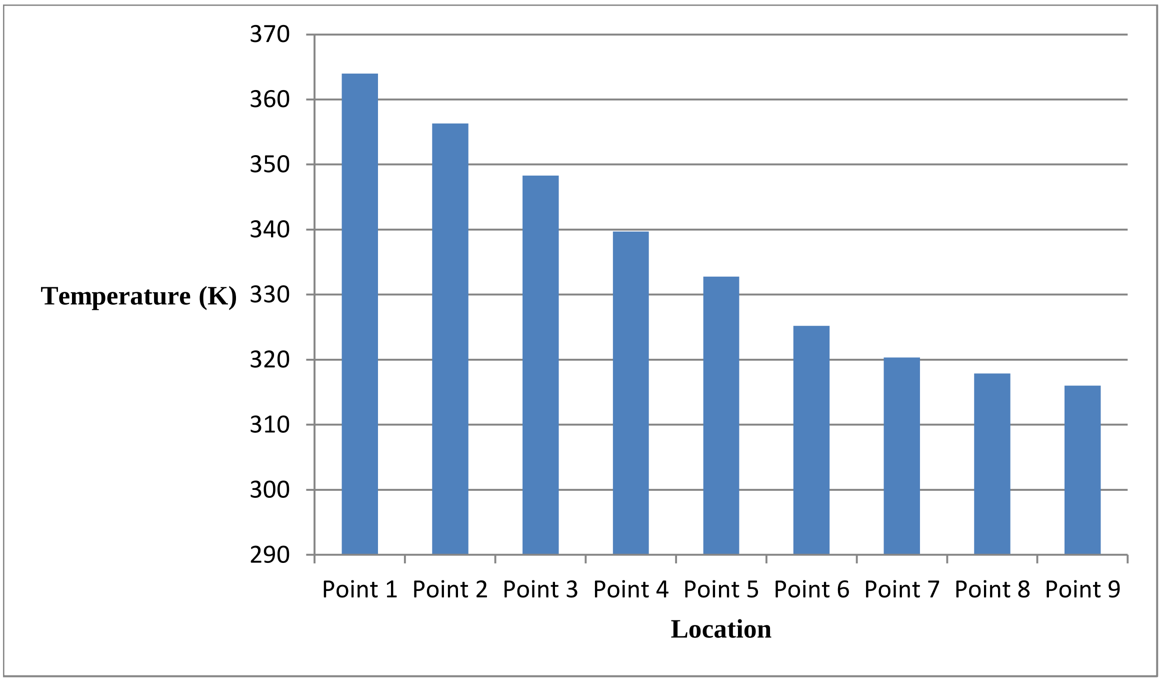

Figure 3.43 Temperature at different location of full radiator of model no. 05

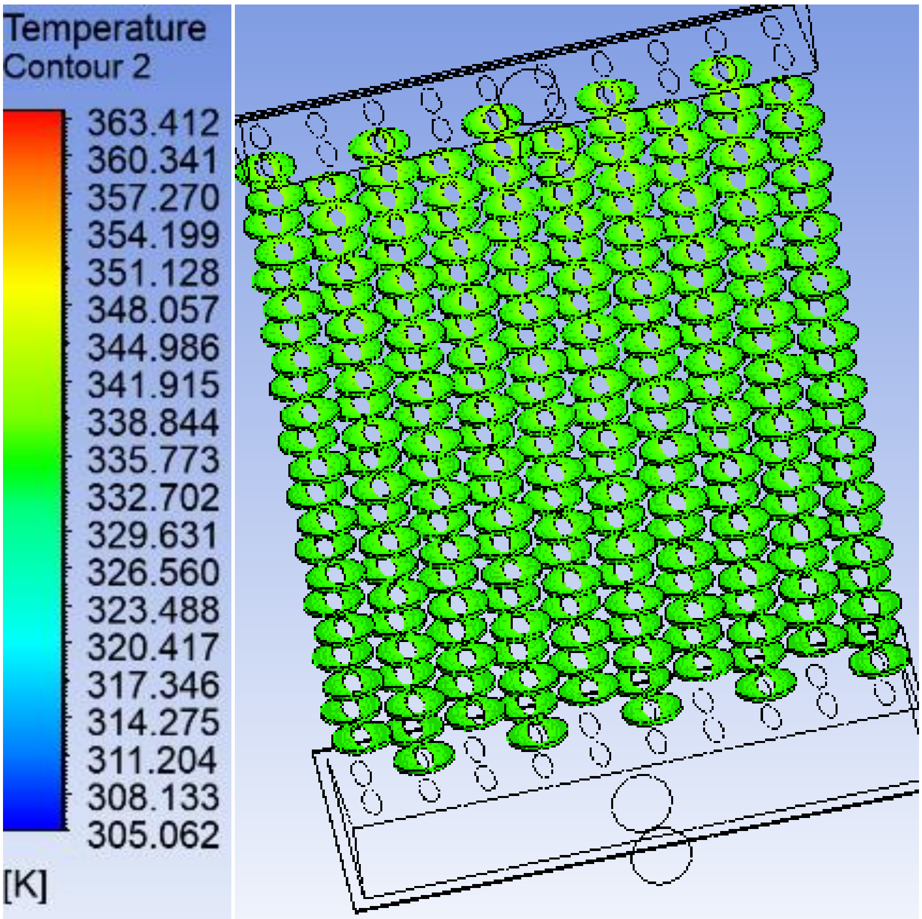

Figure 3.44 Temperature distribution at fin zone of model no. 05

3.9 Conclusion

From simulation, oil temperature at different points of radiator geometry of different types of model can be determined. It can be seen that the outlet oil temperature is comparatively lower than top oil temperature (inlet) with fin arrangement. Thus, it can be said that effective thermal management can be achieved using fin arrangement with reduced number of oval pipes. For verification and validation of simulation as well as to compare the results of the transformer radiator with and without fin arrangement the thermal performance of transformer radiator with and without fin arrangement will be analyzed through experiment in chapter 4.

Chapter 4

Experiment

4.1 Introduction

In ONAN (Oil Natural Air Natural) cooling system the volume of the transformer oil increases in the transformer due to heat from active part. Then the hot transformer oil move upward and enter the transformer radiator where the transformer oil cooled through natural convection more than conduction. After being heated by the hot transformer oil in the radiator, the hot natural air around the radiator move upward and cold natural air occupy the place thus it occurs continuously during the transformer's operation. The thermal performance of transformer radiator with and without fin arrangement is analyzed through experiment in this chapter. Experimental set up of 200 kVA, 11 kV transformer radiator such as conventional radiator i.e. 28 oval pipes without fin arrangement, model no. 01 i.e. 14 oval pipes without fin arrangement, and model no. 02 i.e. 14 oval pipes with fin arrangement are discussed. Heat run test of 200 kVA, 11 kV transformers of conventional radiator, model no. 01 i.e. 14 oval pipes without fin arrangement, and model no. 02 i.e. 14 oval pipes with fin arrangement are also presented.

4.2 Experimental setup of conventional radiator

The radiator of conventional radiator i.e. 28 oval pipes without fin arrangement is attached with tank by flange and rubber gasket joint so that radiator can be changed easily as per requirement. One thermometer is attached with top cover for measuring top oil temperature. Another thermometer is attached with connecting pipe of tank for measuring outlet oil temperature. Figure 4.1 represents the experimental setup of 200 kVA, 11 kV transformer and the conventional radiator of 28 oval pipes with no fin arrangement under heat run test.

Figure 4.1 200 kVA, 11 kV transformer of conventional radiator under heat run test

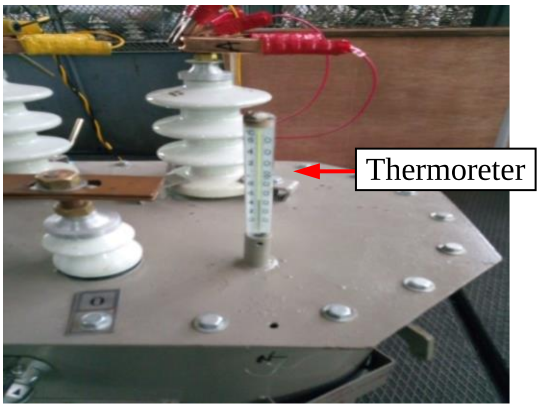

Figure 4.2 Thermometer arrangement

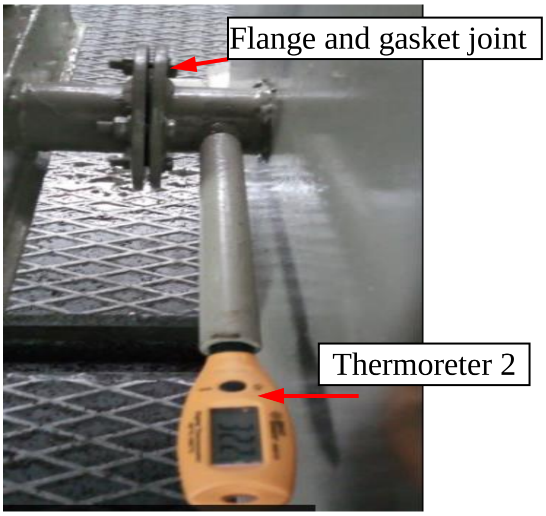

Figure 4.3 Radiator connection with Tank

Figure 4.2 displays the thermometer arrangement for measuring top oil temperature. Radiator connection with Tank by flange and gasket joint and thermometer for measuring outlet oil temperature is represented in figure 4.3.

4.3 Experimental setup of model no. 01

By flange and rubber gasket joint the radiator of model no. 01 i.e. 14 oval pipes without fin arrangement is connected with tank so that radiator can be assembled easily as per design. In order to determine top oil temperature one thermometer is engaged with top cover. For obtaining outlet oil temperature another thermometer is attached with connecting pipe of tank. Figure 4.4 indicates the experimental set up of 14 oval pipes radiator without fin arrangement of the 200 kVA, 11 kV transformer under heat run test.

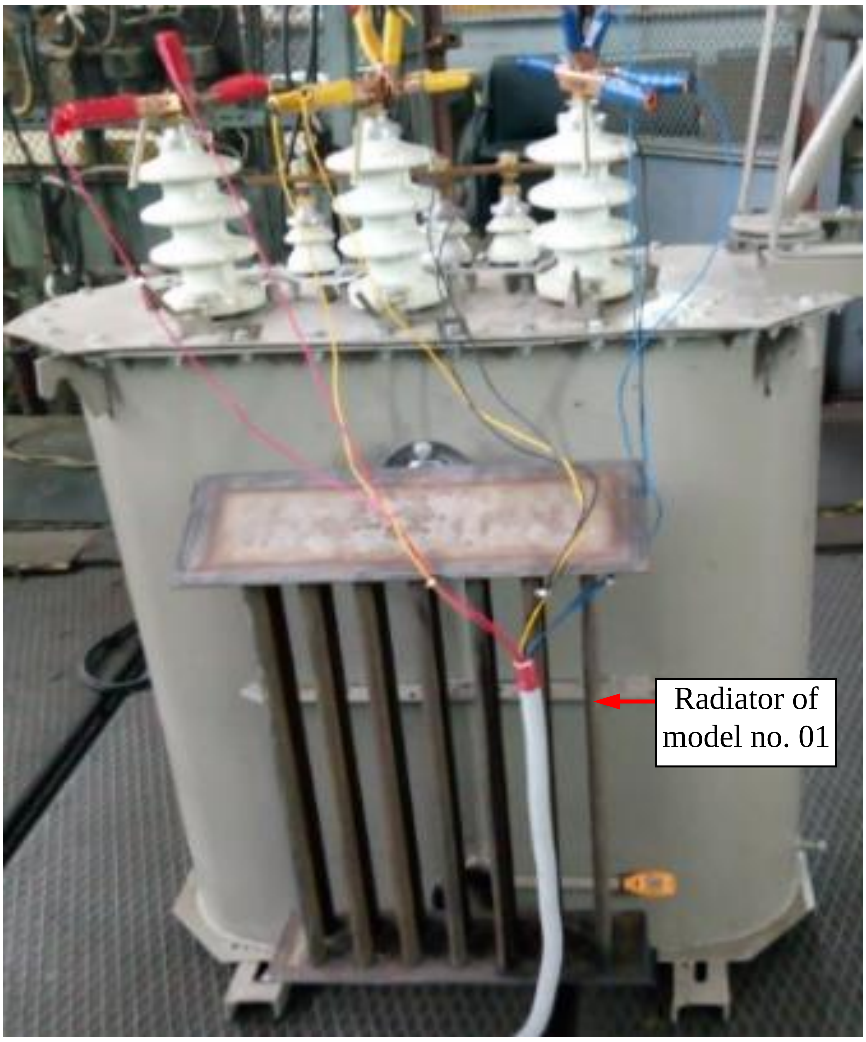

Figure 4.4 200 kVA, 11 kV transformer of model no. 01 under heat run test

4.4 Experimental setup of model no. 02

Through flange and rubber gasket joint the radiator of 14 oval pipes with fin arrangement of model no. 02 is assembled with tank. One thermometer for determining top oil temperature is attached with top cover. To measure outlet oil temperature another thermometer is engaged with connecting pipe of tank. Figure 4.5 displays the experimental setup of modified radiator of 14 oval pipes with fin arrangement of the 200 kVA, 11 kV transformer under heat run test.

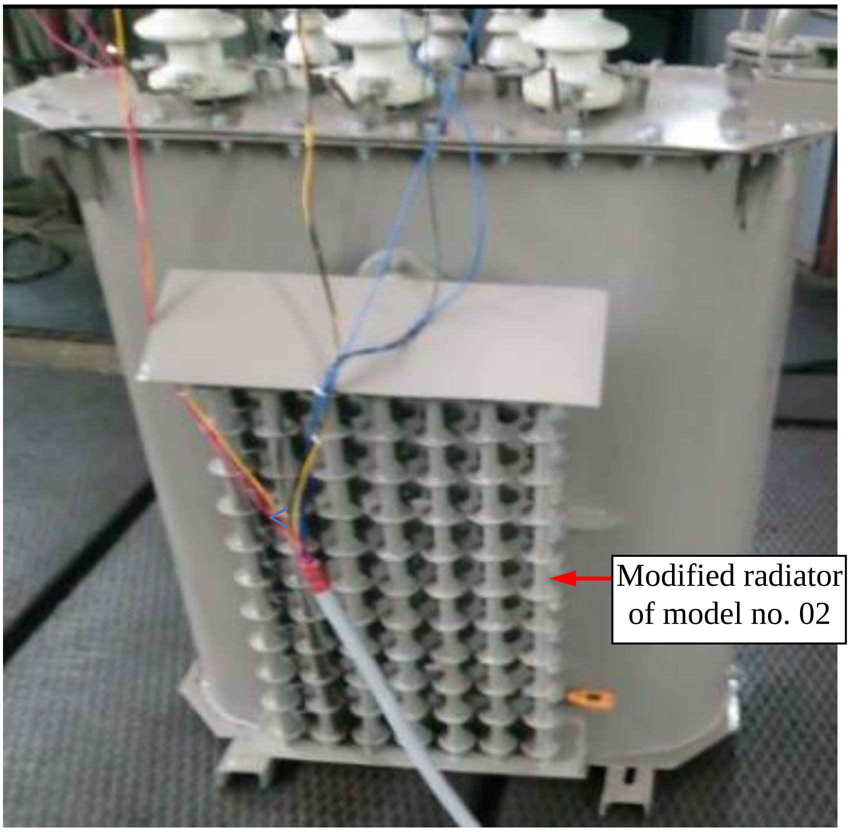

Figure 4.5 200 kVA, 11 kV transformer of model no. 02 under heat run test

4.5 Conclusion

From experiment, inlet oil temperature and outlet oil temperature of three types of radiator can be measured through two thermometers. It can be seen that the outlet oil temperature is lower as compared to top oil temperature (inlet) and thus thermal performance of three types of radiator can be analyzed. In order to compare the thermal performance of the transformer radiator with and without fin arrangement, the result will be discussed in chapter 5.

Chapter 5

Results and Discussion

5.1 Introduction

The simulation results i.e. the ambient temperature, the top oil temperature (inlet), and outlet oil temperature of different types of radiator are presented in this chapter. Furthermore, the experimental results of three types of radiator such as conventional radiator i.e. 28 oval pipes without fin arrangement, model no. 01 i.e. 14 oval pipes without fin arrangement, and model no. 02 i.e. 14 oval pipes with fin arrangement are presented. Besides these, comparison of the results of the transformer radiator with and without fin arrangement is discussed. Cost analysis of the radiator with fin arrangement which is the bottleneck of this research is also done in this chapter.

5.2 Simulation results

The ambient temperature, the inlet oil temperature, and the outlet oil temperature of different types of radiator are shown in table 5.2.

Table 5.2 The ambient temperature, the top oil temperature (inlet), and the outlet oil temperature of different types of radiator

Types of radiator	**Ambient temp. T (K)**	**Top oil temp. (K) (inlet))**	**Outlet temp. (K)**	**ΔT (K) between inlet and outlet**	**ΔT (K) between inlet and ambient**
Conventional Radiator (28 oval pipes without fin)	305	364	313	**51**	**59**
Model no. 01 (14 oval pipes without fin)	305	364	324	**40**	**59**
Model no. 02 (14 oval pipes with fin)	305	364	322	**42**	**59**
Model no. 03 (16 oval pipes with fin)	305	364	320	**44**	**59**
Model no. 04 (18 oval pipes with fin)	305	364	318	**46**	**59**
Model no. 05 (20 oval pipes with fin)	305	364	316	**48**	**59**

The simulation results had been published in the thesis paper, theoretical investigation of heat transfer enhancement of transformer radiator modified with fin arrangement done by Rashid [32]. From simulation result it is seen that thermal performance enhancement occurs due to fin arrangement. The temperature difference between top oil temperature (inlet) and ambient is 59 as per considered value. As much as the value will be low, the thermal performance will be high that is desired. The desired value can be observed through experimental results.

5.2.1 Temperature difference between inlet and outlet of different types of radiator (simulation)

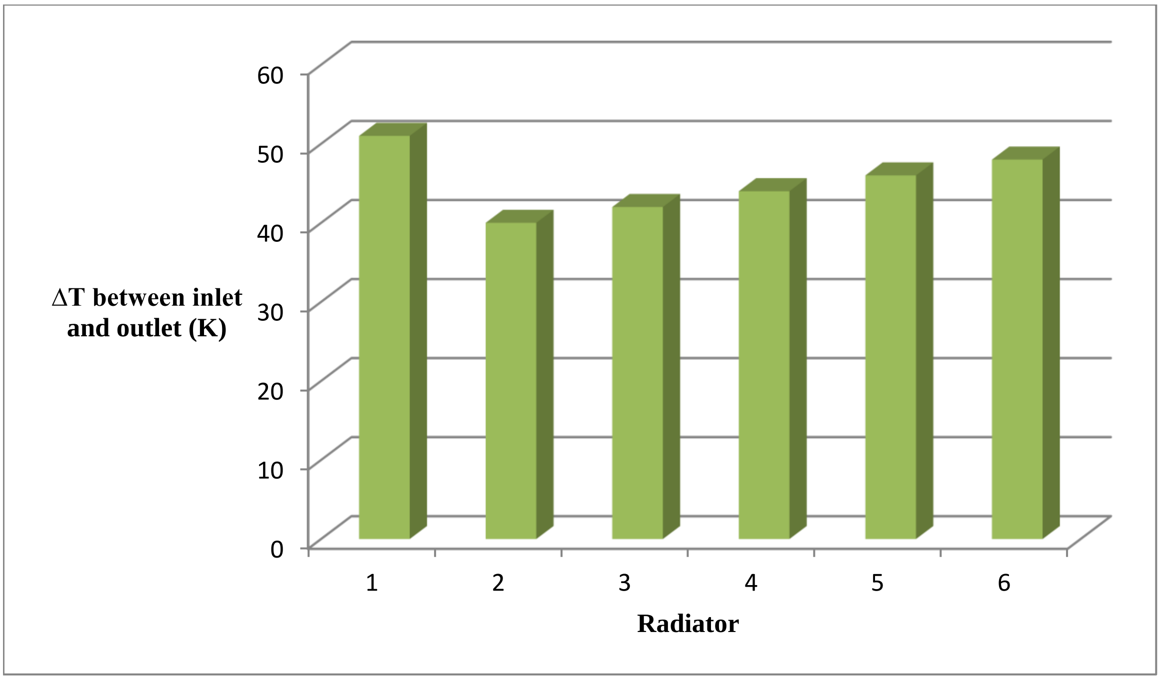

Figure 5.1 Temperature difference between inlet and outlet of different types of radiator (simulation)

Figure 5.1 displays the temperature difference between inlet and outlet of different types of radiator. The temperature difference between inlet and outlet of conventional radiator is more because there are 28 numbers of oval pipes i.e. heat transfer area is more. Then the temperature difference between inlet and outlet of model no. 01 is less than conventional radiator since there are only 14 numbers of oval pipes i.e. less heat transfer area. But with increasing heat transfer area i.e. oval pipes with fin arrangement, the temperature difference between inlet and outlet is increasing.

5.3 Experimental results

The experimental results of three types of radiator such as conventional radiator i.e. 28 oval pipes without fin arrangement, model no. 01 i.e. 14 oval pipes without fin arrangement, and model no. 02 i.e. 14 oval pipes with fin arrangement are described below.

5.3.1 Experimental result of conventional radiator

Table 5.3 Heat run test of conventional radiator

Time	Temperature, T (K)			ΔT (K) **between inlet and outlet**	ΔT (K) **between inlet and ambient**
	Ambient	Top oil (inlet)	Outlet		
08:30 AM	302	302	302	**0**	**0**
09:00 AM	303	309	305.6	**3.4**	**6**
09:30 AM	303	317	307.1	**9.9**	**14**
10:00 AM	305	325	310.2	**14.8**	**20**
11:00 AM	303	333	314.3	**18.7**	**30**
12:00 PM	302	339	318.2	**20.8**	**37**
12:30 PM	302	341	321.1	**19.9**	**39**
01:00 PM	302	343	323	**20**	**41**
02:00 PM	301	347	324.8	**22.2**	**46**
03:00 PM	301	349	325.1	**23.9**	**48**
04:00 PM	301	351	326.2	**24.8**	**50**
05:00 PM	301	351	326.8	**22.2**	**50**
06:00 PM	301	353	327.2	**25.8**	**52**
07:00 PM	301	353	327.8	**25.2**	**52**
08:00 PM	301	353	328.2	**24.8**	**52**

Heat run test is shown in table 5.3. From table 5.3, it is observed that, three temperature differences between top oil temperature (inlet) and ambient temperature are taken after one hour interval and it is not more than 60 as per standard. Therefore, heat run test of conventional radiator is satisfactory.

5.3.2 Temperature vs. time curve of conventional radiator

Temperature vs. time curve is shown in figure 5.2. Here, time is taken in X-axis and temperature (K) is taken in Y- axis. Ambient temperature, top oil temperature (inlet) and outlet temperature are plotted in Y- axis. Different markers indicate ambient temperature, inlet temperature and outlet temperature. The top oil (inlet) temperature is increasing with time due to lower viscosity of transformer oil since there is low resistance in the transformer oil and it can flow easily. The top oil (inlet) temperature becomes stable at temperature 353 K and three data are same for three consecutive hours. In the conventional radiator the temperature reduces from inlet oil temperature to outlet oil temperature due to effect of thermal conductivity and heat transfer co-efficient since heat transfer occurs by conduction process and largely convection process. The ambient temperature changes due to change of weather condition.

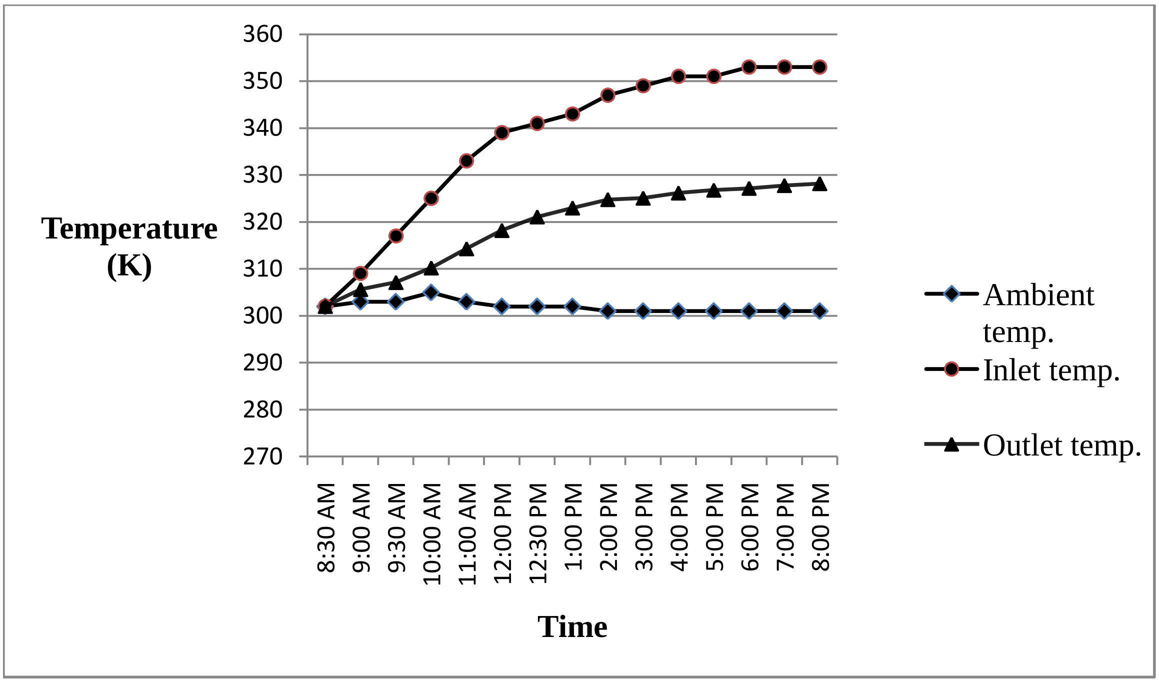

Figure 5.2 Temperature vs. time curve of conventional radiator

5.3.3 Temperature difference between inlet and outlet vs. time curve of conventional radiator

Temperature difference between inlet and outlet vs. time curve of conventional radiator is represented in figure 5.3. Temperature difference between inlet and outlet with time is not linear since outlet oil temperature reduces due to effect of air velocity, difference between oil and air, oil velocity and oil distribution.

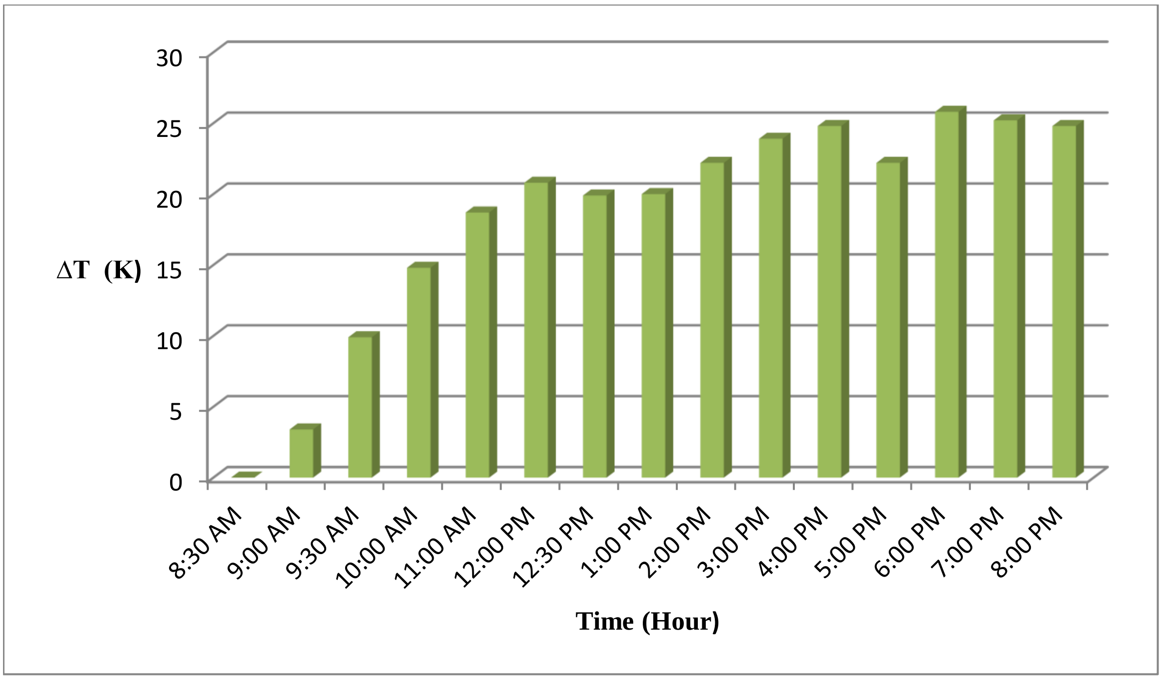

Figure 5.3 Temperature difference between inlet and outlet vs. time curve of conventional radiator

5.3.4 Temperature difference between inlet and ambient vs. time curve of conventional radiator

Figure 5.4 indicates temperature difference between inlet and ambient vs. time curve of conventional radiator. Temperature difference between inlet and ambient is increasing with time due to inlet temperature increases with time for higher Nusselt number and Reynolds number.

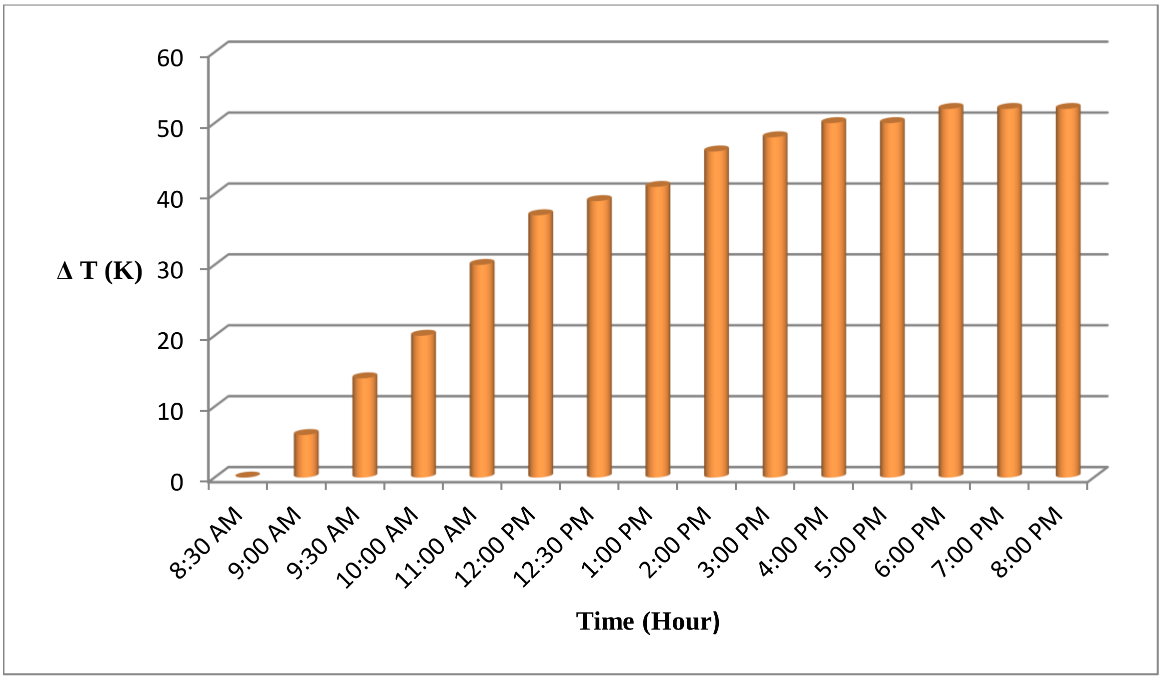

Figure 5.4 Temperature difference between inlet and ambient vs. time curve of conventional radiator

5.3.5 Experimental result of model no. 01

Heat run test is shown in table 5.4. From table 5.4, it is observed that, three temperature differences between top oil temperature (inlet) and ambient temperature are taken after one hour interval and it is not more than 60 as per standard. Therefore, heat run test of model no. 01 is satisfactory.

Table 5.4 Heat run test of model no. 01

Time	Temperature, T (K)			ΔT (K) **between inlet and outlet**	ΔT (K) **between inlet and ambient**
	Ambient	Top oil (inlet)	Outlet		
08:00 AM	300	300	297.9	**2.1**	**0**
08:30 AM	300	307	298.3	**8.7**	**7**
09:00 AM	300	316	301.3	**14.7**	**16**
09:30 AM	300	323	304.9	**18.1**	**23**
10:00 AM	300	327	308	**19**	**27**
11:00 AM	302	337	313.6	**23.4**	**35**
12:00 PM	303	343	318.5	**24.5**	**40**
01:00 PM	304	347	322.3	**24.7**	**43**
02:00 PM	304	353	326.2	**26.8**	**49**

03:00 PM	305	355	327.6	**27.4**	**50**
04:00 PM	305	358	329	**29**	**53**
05:00 PM	303	361	331.1	**29.9**	**58**
06:00 PM	303	361	331.7	**29.3**	**58**
07:00 PM	303	361	331.8	**29.2**	**58**

5.3.6 Temperature vs. time curve of model no. 01

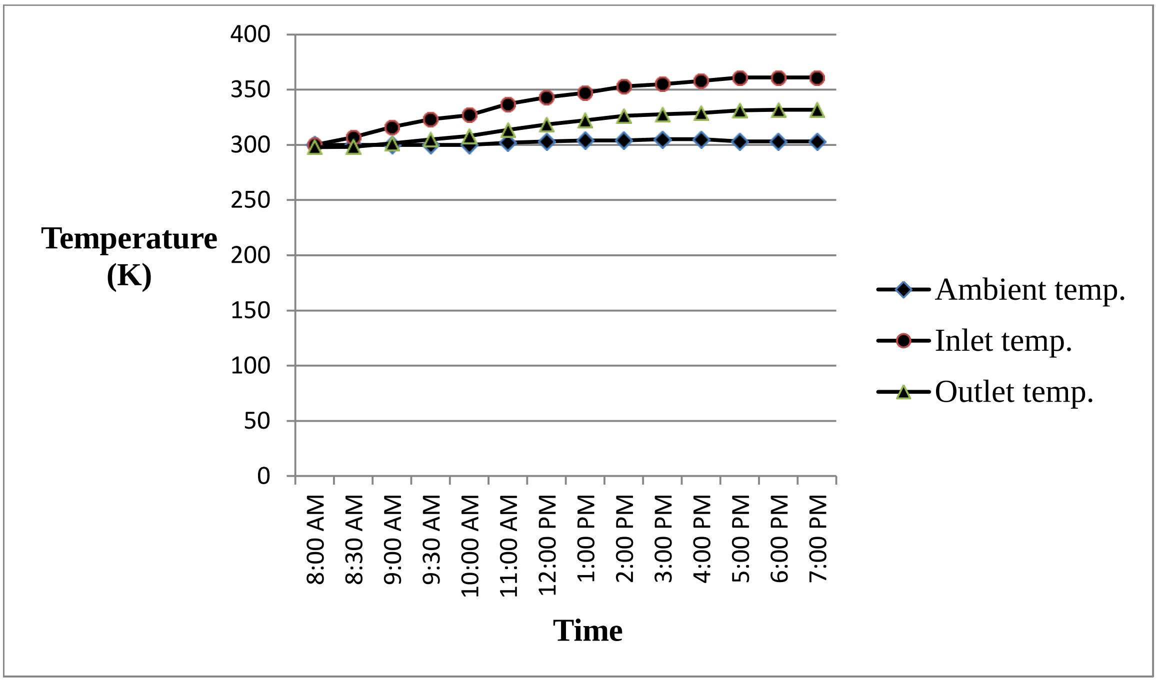

Figure 5.5 Temperature vs. time curve of model no. 01

Temperature vs. time curve is shown in figure 5.5. Here, time is taken in X-axis and temperature (K) is taken in Y- axis. Ambient temperature, top oil temperature (inlet) and outlet temperature are plotted in Y- axis. Different markers indicate ambient temperature, inlet temperature and outlet temperature. The top oil (inlet) temperature is increasing with time due to lower Prandtl number and density of transformer oil. Then the transformer oil moves upward due to buoyancy forces or thermo syphon effect. The top oil (inlet) temperature becomes stable at temperature 353 K and three data are same for three consecutive hours. In the radiator of model no. 01 the temperature reduces from inlet oil temperature to outlet oil temperature due to effect of lower viscosity and air velocity. The ambient temperature changes due to change of weather condition.

5.3.7 Temperature difference between inlet and outlet vs. time curve of model no. 01

Temperature difference between inlet and outlet vs. time curve of conventional radiator is represented in figure 5.6. Since air velocity, oil velocity and oil distribution are responsible for reducing outlet oil temperature hence the temperature difference between inlet and outlet with time is not linear.

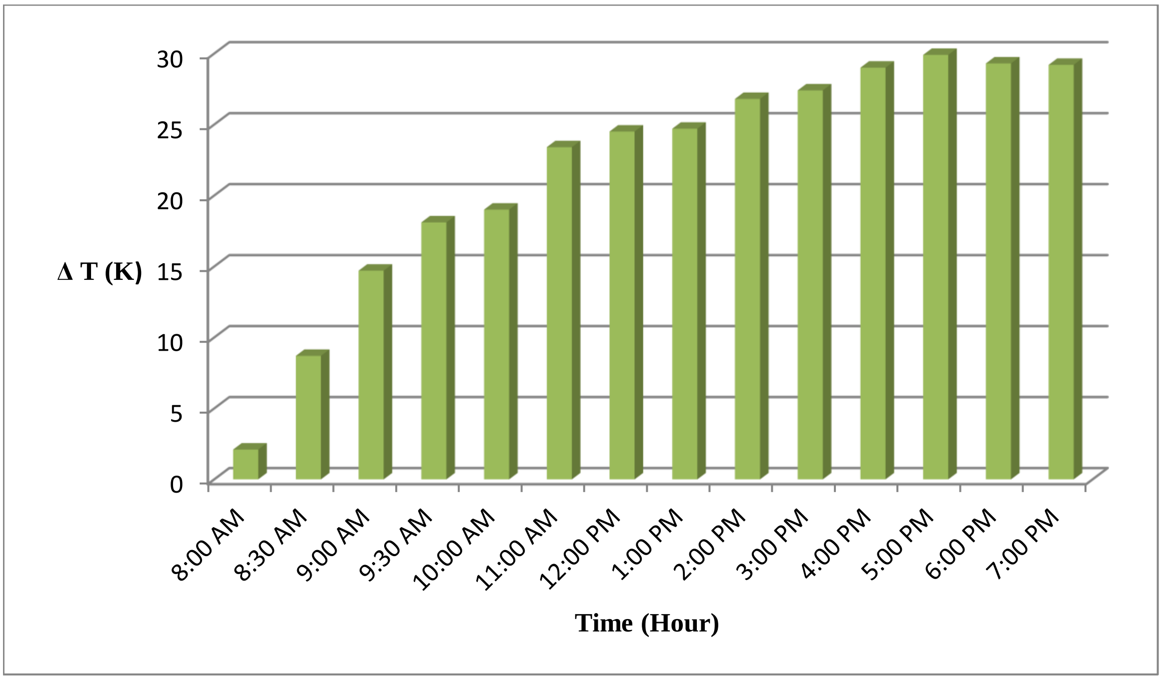

Figure 5.6 Temperature difference between inlet and outlet vs. time curve of model no. 01

5.3.8 Temperature difference between inlet and ambient vs. time curve of model no. 01

Figure 5.7 indicates temperature difference between inlet and ambient vs. time curve of conventional radiator. Since for higher Nusselt number and Reynolds number inlet temperature increases with time hence temperature difference between inlet and ambient is increasing with time.

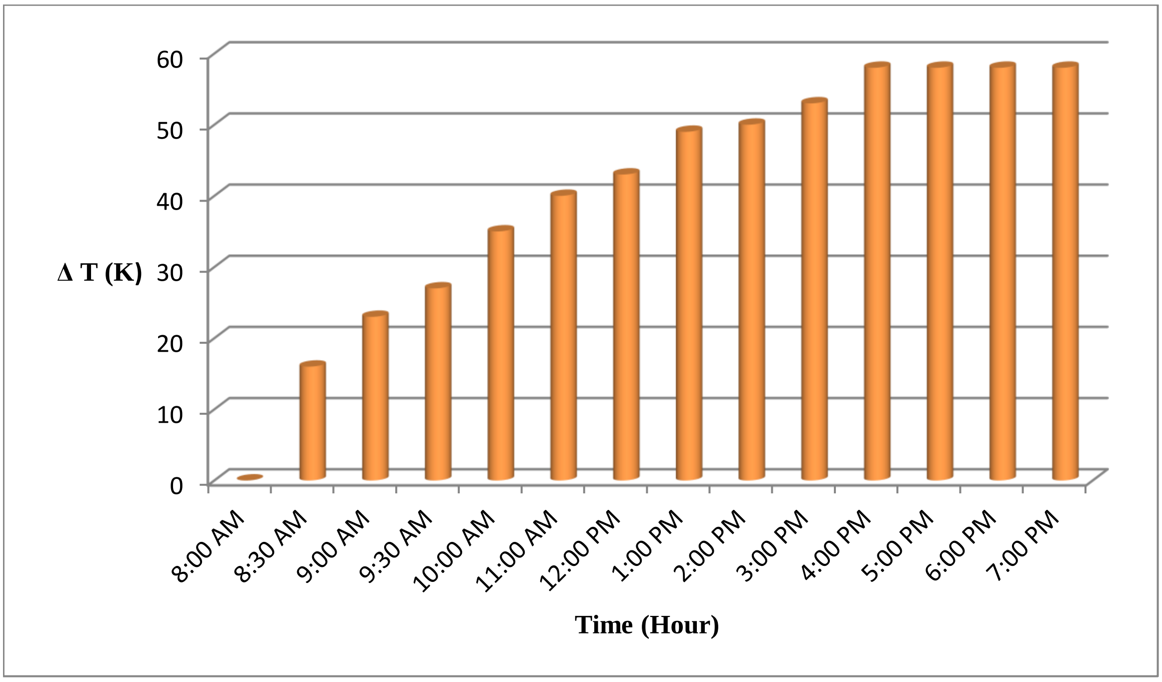

Figure 5.7 Temperature difference between inlet and ambient vs. time curve of model no. 01

5.3.9 Experimental result of model no. 02

Heat run test is shown in table 5.5. From table 5.5, it is observed that, three temperature differences between top oil temperature (inlet) and ambient temperature are taken after one hour interval and it is not more than 60 as per standard. Therefore, heat run test of model no. 02 is satisfactory.

Table 5.5 Heat run test of model no. 02

Time	Temperature, T (K)			∆**T** (K) **between inlet and outlet**	∆**T** (K) **between inlet and ambient**
	Ambient	Top oil (inlet)	Outlet		
08:00 AM	294	294	294	**0**	**0**
08:30 AM	294	302	296	**6**	**8**
09:00 AM	295	312	298.1	**13.9**	**17**
09:30 AM	296	318	301.5	**16.5**	**22**
10:00 AM	297	323	304.8	**18.2**	**26**
11:00 AM	299	333	310.6	**22.4**	**34**
12:00 PM	300	340	315.4	**24.6**	**40**
01:00 PM	301	346	319.3	**26.7**	**45**
02:00 PM	302	350	322.7	**27.3**	**48**
03:00 PM	302	353	325.2	**27.8**	**51**

04:00 PM	302	356	326.2	**29.8**	**54**
05:00 PM	302	358	328.2	**29.8**	**56**
06:00 PM	302	358	329.6	**28.4**	**56**
07:00 PM	302	358	328.9	**29.1**	**56**

5.3.10 Temperature vs. time curve of model no. 02

Temperature vs. time curve is shown in figure 5.8. Here, time is taken in X- axis and temperature (K) is taken in Y- axis. Ambient temperature, top oil temperature (inlet) and outlet temperature are plotted in Y- axis. Different markers indicate ambient temperature, inlet temperature and outlet temperature. The top oil (inlet) temperature is increasing with time due to effect of heat transfer coefficient of transformer oil since there heat transfer occurs by convection process in the transformer oil. The top oil (inlet) temperature becomes stable at temperature 353 K and three data are same for three consecutive hours. In the radiator of model no. 02 the temperature reduces from inlet oil temperature to outlet oil temperature due to pressure drop and oil velocity. The ambient temperature changes due to change of weather condition.

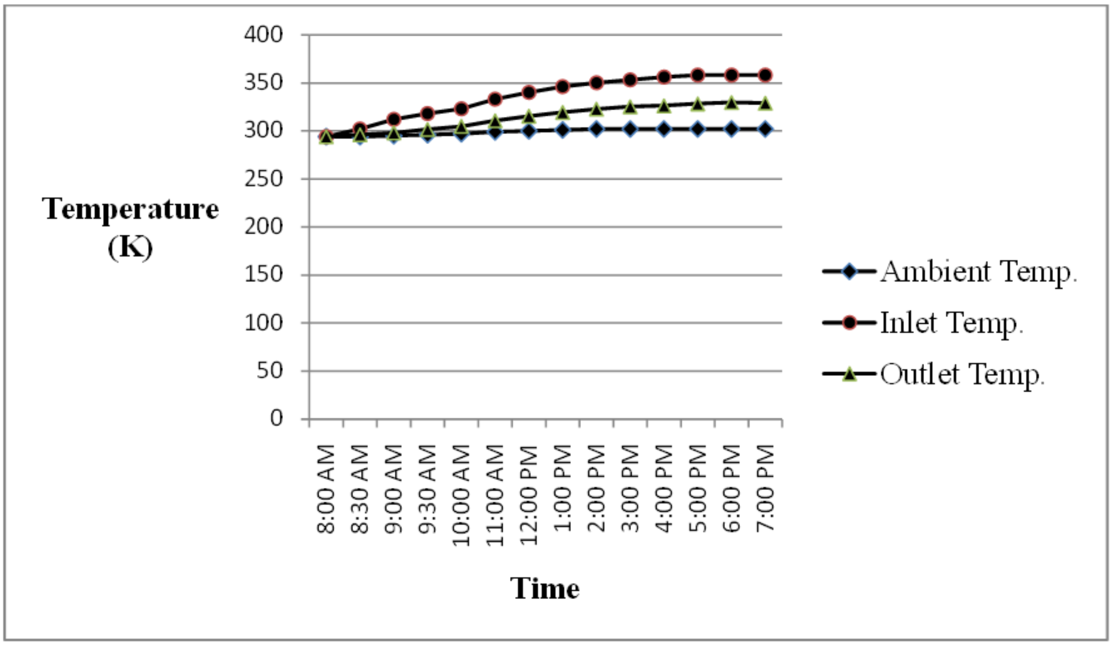

Figure 5.8 Temperature vs. time curve of model no. 02

5.3.11 Temperature difference between inlet and outlet vs. time curve of model no. 02

Temperature difference between inlet and outlet vs. time curve of conventional radiator is represented in figure 5.9. Since effect of thermal conductivity, air velocity, oil velocity and oil distribution the outlet oil temperature reduces hence the temperature difference between inlet and outlet with time is not linear.

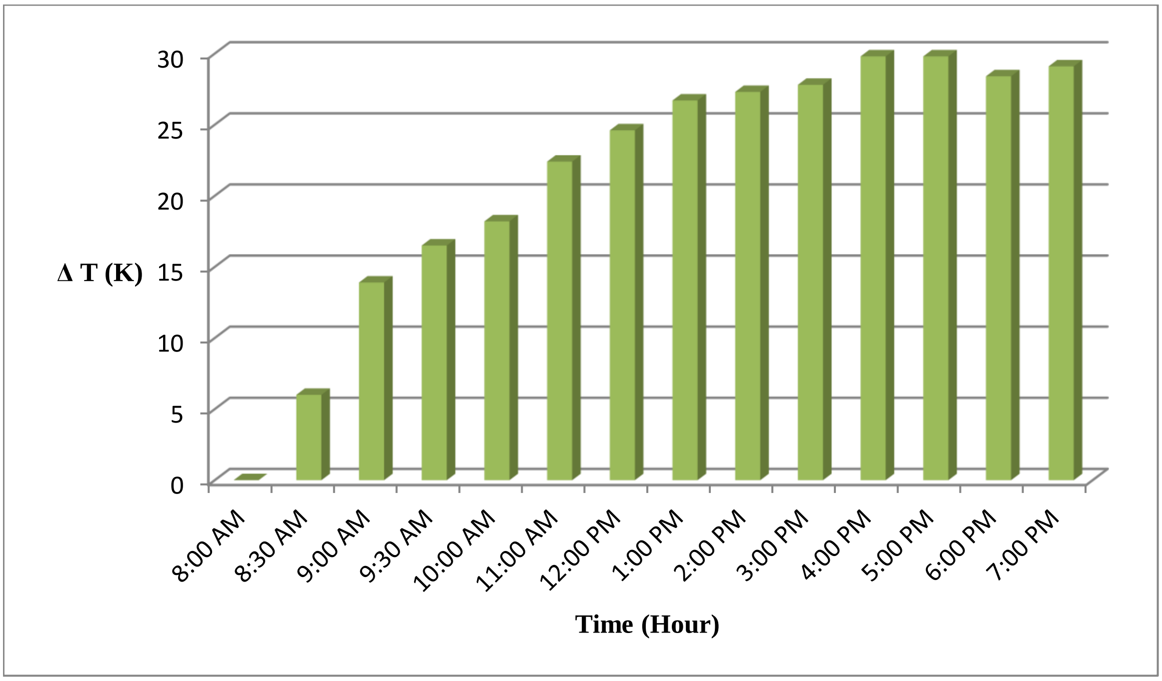

Figure 5.9 Temperature difference between inlet and outlet vs. time curve of model no. 02

5.3.12 Temperature difference between inlet and ambient vs. time curve of model no. 02

Figure 5.10 indicates temperature difference between inlet and ambient vs. time curve of conventional radiator. Due to inlet temperature increases with time for higher Nusselt number and Reynolds number, the temperature difference between inlet and ambient is increasing with time.

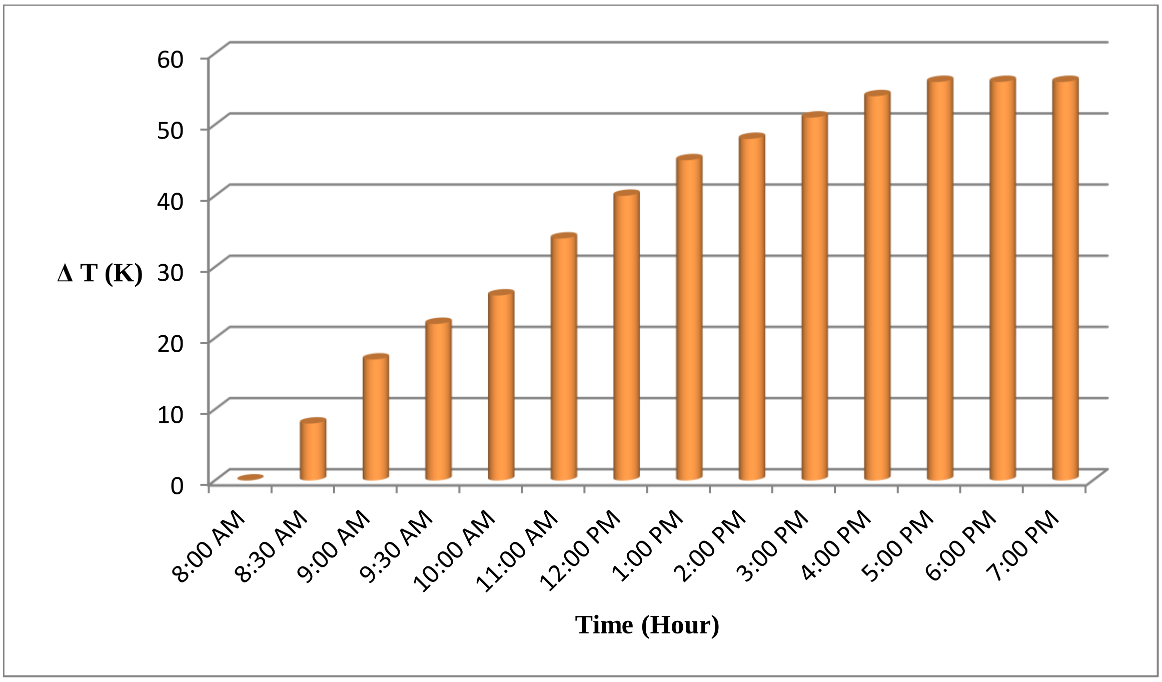

Figure 5.10 Temperature difference between inlet and ambient vs. time curve of model no. 02

5.4 Comparison of the results of the transformer radiator with and without fin arrangement

Table 5.6 Simulation and Experimental results

Types of radiator	Simulation result				Experimental result			
	Temperature (K)				Temperature (K)			
	Ambient	Top oil (inlet)	Outlet	Difference between inlet and ambient	Ambient	Top oil (inlet)	Outlet	Difference between inlet and ambient
Conventional	305	364	313	**59**	301	353	327.7	**52**
Model no. 01	305	364	324	**59**	303	361	331.5	**58**
Model no. 02	305	364	322	**59**	302	358	328.9	**56**

- From simulation result of conventional radiator, the top oil (inlet) temperature is considered as 364 K and the outlet temperature is 313 K. The temperature difference is 51 K.

- From experimental result of conventional radiator, the stable (saturated) top oil (inlet) temperature is 353 K and the corresponding outlet temperature is 327.7 K (average). The temperature difference is 25.3 K.
- From simulation result of model no.01, the top oil (inlet) temperature is considered as 364 K and the outlet temperature is 324 K. The temperature difference is 40 K.
- From experimental result of model no. 01, the stable (saturated) top oil (inlet) temperature is 361 K and the corresponding outlet temperature is 331.5 K (average). The temperature difference is 29.5 K.
- From simulation result of model no. 02, the top oil (inlet) temperature is considered as 364 K and the outlet temperature is 322 K. The temperature difference is 42 K.
- From experimental result of model no. 02, the stable (saturated) top oil (inlet) temperature is 358 K and the corresponding outlet temperature is 328.9 K (average). The temperature difference is 29.1 K.
- From experimental result of conventional radiator, the stable (saturated) top oil (inlet) temperature is 353 K and the corresponding ambient temperature is 301 K. The temperature difference is 52 K.
- From experimental result of model no. 01, the stable (saturated) top oil (inlet) temperature is 361 K and the corresponding ambient temperature is 303 K. The temperature difference is 58 K.
- From experimental result of model no. 02, the stable (saturated) top oil (inlet) temperature is 358 K and the corresponding ambient temperature is 302 K. The temperature difference is 56 K.
- Therefore, it is observed that, by reducing half oval pipes in model no. 02, the top oil (inlet) temperature and the ambient temperature difference is only 4 K whereas it is higher (6 K) for model no. 01 with no fin arrangement with compared to the conventional radiator.

5.5 Cost analysis

Cost analysis is essential in order to compare the cost of conventional radiator i.e. 28 oval pipes without fin arrangement and modified radiator i.e. 14 oval pipes with fin arrangement. In order to proper insulation of active part, the transformer oil such as mineral oil is used in the transformer. While the temperature of the transformer oil increases then it is required to cool the transformer oil at definite limit by using external radiator. In General Electric Manufacturing Company Limited, conventional radiator is used for cooling purpose of the 200 kVA, 11 kV transformers. The thermal performance of conventional radiator is ok. But to reduce the cost of the conventional radiator, the radiator is modified by reducing the number of oval pipes and by introducing fin arrangement. From simulation and experimental result it is seen that the thermal performance of the transformer radiator with fin arrangement is effective. As a result, to have lower cost and enhanced thermal performance of the transformer radiator, the transformer radiator with fin arrangement can be chosen for cooling the transformer. Total material cost of conventional radiator is 4448/- taka, total man-hour cost is 3640/- taka, and total cost is 8088/- taka. Total material cost of modified radiator i.e. 14 oval pipes with fin arrangement is 2996/- taka, total man-hour cost is 3402/- taka, and total cost is 6398/-taka. Therefore, modified radiator cost is lower than conventional radiator cost. Also, in modified radiator transformer oil required less as compared to conventional radiator since volume of conventional radiator is more. Figure 5.11 displays the conventional radiator of 28 oval pipes without fin arrangement. Figure 5.12 displays the modified radiator of 14 oval pipes and fin arrangement.

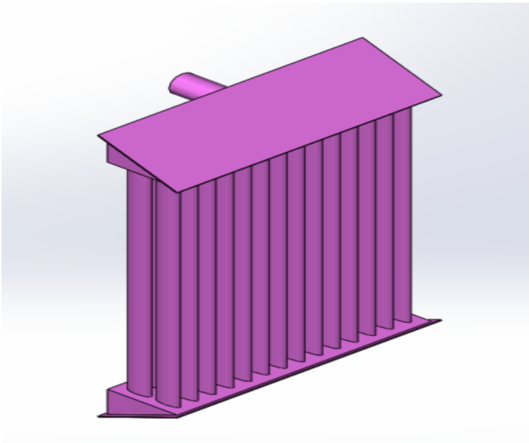

Figure 5.11 Conventional radiator of 28 oval pipes without fin arrangement

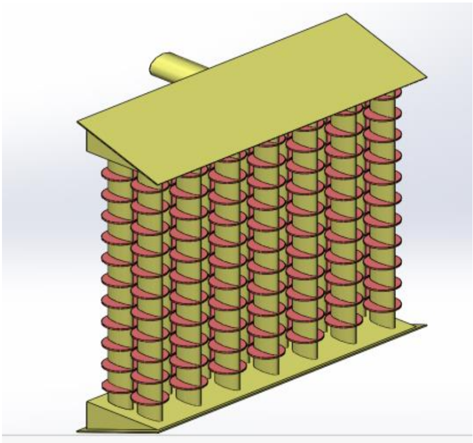

Figure 5.12 Modified radiator of 14 oval pipes and fin arrangement (Model no. 02)

5.6 Conclusion

From simulation and experimental result, the thermal performance of radiator geometry of different types of model is discussed and comparison of the results of the transformer radiator with and without fin arrangement is done. Through heat transfer coefficient thermal performance of the transformer radiator with and without fin arrangement is compared. Furthermore, it can be seen that modified radiator cost is less as compared to conventional radiator cost. As a result, it can be expected that, modified radiator with fin arrangement can be implemented instead of conventional radiator i.e. 28 oval pipes without fin arrangement for reducing the cost of the transformer with enhancement of thermal performance. Conclusion and references will be provided in chapter 6.

Chapter 6

Conclusion

The thermal performance of the transformer conventional radiator as well as modified radiator with and without fin arrangement through simulation and experiment of 200 kVA, 11 kV three phase distribution transformer is represented in this paper. From simulation result it is observed that the thermal performance i.e. the temperature difference between the top oil (inlet) and the outlet increases with increasing of fin arrangement. From experimental result it is also observed that the thermal performance i.e. the temperature difference between the top oil (inlet) and the ambient decreases with increasing of fin arrangement. The cost of the conventional radiator and the modified radiator with fin arrangement is analyzed. CFD (Computational Fluid Dynamics) simulation of a distribution transformer is limited to significant number of elements because supercomputers are needed to perform finite volume method based simulation programs. Since modified radiator with fin arrangement is designed for thermal performance enhancement and cost effective, it is observed that it is effective. Because difference between the top oil (inlet) temperature and the ambient temperature of modified radiator with fin arrangement is acceptable as per standard and only 4 K more as compared to conventional radiator. Theoretically it is shown that thermal performance of model no. 01 (14 oval pipes without fin arrangement) is more since heat transfer coefficient is more. Therefore, modified radiator with fin arrangement can be implemented instead of conventional radiator of 28 oval pipes without fin arrangement for cost effective with enhanced thermal performance.

6.1 Further recommendations

- Experiment can be performed by others modified radiator with fin arrangement in order to obtain desired value i.e. the temperature difference between the top oil (inlet) and the ambient tends to the conventional radiator.

- By changing fin number at each oval pipe experiment can be performed through modified radiator.
- Through changing space of oval pipes experiment can be performed with modified radiator.

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Appendix A

A.1 Calculation of heat transfer coefficient

A.1.1 Heat transfer coefficient for conventional radiator

The heat transfer, $Q = m\, C_p \Delta T$

Where, m = Mass of napthenic oil, kg

C_p = Specific heat of napthenic oil, J/kg-K

ΔT = Temperature difference between top oil (inlet) and outlet, K

Density of napthenic oil, $\rho = m/V$

Where, V = Volume of conventional radiator, m^3

So, $m = \rho\, V$ = 827.18 × 0.013 = 10.75 kg

Let, time required to flow 10.75 kg is 13 minutes

So, mass flow rate = 10.75/780 = 0.013 kg/s

In simulation the heat transfer, Q = 0.013 × 2476.2 × 51 = 1641.72 W

Again, the heat transfer, $Q = h\, A\, \Delta T$

Where, h = Heat transfer coefficient, W/m^2K

A = Heat transfer area of conventional radiator, m^2

ΔT = Temperature difference between top oil (inlet) and ambient, K

So, h for **conventional radiator** = 1641.72/ 2.099 × 59 = **13.2 W/m^2K (Simulation)**

In experiment the heat transfer, Q = 0.013× 2476.2 × 25.3 = 814.422 W

Again, the heat transfer, $Q = h\, A\, \Delta T$

So, h for **conventional radiator** = 814.422 / 2.099 × 52 =**7.5 W/m^2K (Experiment)**

A.1.2 Heat transfer coefficient for model no.01 (14 oval pipes without fin arrangement)

The heat transfer, $Q = m\, C_p \Delta T$

Where, m = Mass of napthenic oil, kg

C_p = Specific heat of napthenic oil, J/kg-K

ΔT = Temperature difference between top oil (inlet) and outlet, K

Density of napthenic oil, $\rho = m/V$

Where, V = Volume of model no.01 radiator, m^3

So, $m = \rho\ V$ = 827.18 × 0.007 = 5.79 kg

Let, time required to flow 5.79 kg is 7 minutes

So, mass flow rate = 5.79 /420 = 0.014 kg/s

In simulation the heat transfer, Q = 0.014 × 2476.2 × 40 = 1386.67 W

Again, the heat transfer, $Q = h\ A\ \Delta T$

Where, h = Heat transfer coefficient, W/m^2K

A = Heat transfer area of model no.01 radiator, m^2

ΔT = Temperature difference between top oil (inlet) and ambient, K

So, h for **model no.01 radiator** = 1386.67 /1.26 × 59 = **18.7 W/m²K (Simulation)**

In experiment the heat transfer, Q = 0.014× 2476.2 × 29.5 = 1022.67 W

Again, the heat transfer, $Q = h\ A\ \Delta T$

So, h for **model no.01 radiator** = 1022.67 /1.26 × 58 = **13.9 W/m²K (Experiment)**

A.1.3 Heat transfer coefficient for model no.02 (14 oval pipes with fin arrangement)

The heat transfer, $Q = m\ C_p \Delta T$

Where, m = Mass of napthenic oil, kg

C_p = Specific heat of napthenic oil, J/kg-K

ΔT = Temperature difference between top oil (inlet) and outlet, K

Density of napthenic oil, $\rho = m/V$

Where, V = Volume of model no.02 radiator, m^3

So, $m = \rho\ V$ = 827.18 × 0.007 = 5.79 kg

Let, time required to flow 5.79 kg is 7 minutes

So, mass flow rate = 5.79 /420 = 0.014 kg/s

In simulation the heat transfer, Q = 0.014 × 2476.2 × 42 = 1456.01 W

Again, the heat transfer, $Q = h\,A\,\Delta T$

Where, h = Heat transfer coefficient, W/m^{2}K

A = Heat transfer area of model no.02 radiator, m^2

ΔT = Temperature difference between top oil (inlet) and ambient, K

So, h for **model no.02 radiator** = 1456.01 /1.88 × 59 = **13.1 W/m^{2}K (Simulation)**

In experiment the heat transfer, Q = 0.014× 2476.2 × 29.1 = 1008.8 W

Again, the heat transfer, $Q = h\,A\,\Delta T$

So, h for **model no.02 radiator** = 1008.8 /1.88 × 56 = **9.6 W/m^{2}K (Experiment)**

Therefore, it is seen that heat transfer coefficient for conventional radiator is lower as compared to model no. 01 radiator and model no. 02 radiator. Also, heat transfer coefficient for model no. 01 radiator is more as compared to model no. 02 radiator. So, from theoretical calculation, it can be expressed that thermal performance of model no. 01 radiator is more as compared to model no. 02 radiator and conventional radiator.