Heating & Cooling of Transformers

Day 22

ILOs – Day22

- Understand the heating and cooling processes in a transformer
- Design plain walled tank for a transformer to restrict temperature rise
- Realize how cooling tubes can enhance cooling of transformers
- List and explain the different cooling methods in transformers

Temperature rise of transformers

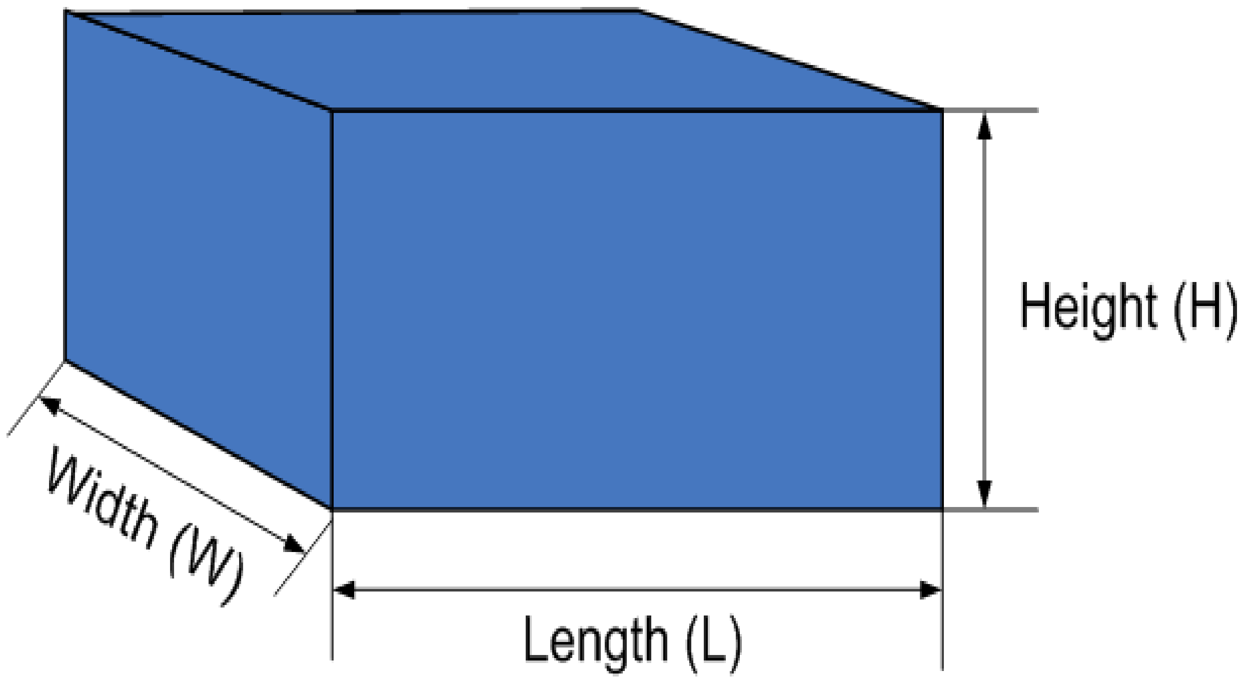
- Power losses occurring in a transformer core and winding are converted to thermal energy and cause heating of the corresponding transformer parts
- The heat is directed from its source to the outer surfaces so that it can be transferred to the cooling medium
- Temperature rise of transformer need to be limited within the maximum design limit otherwise life of the insulation will be severely affected
- Every 10^0 C rise in temperature beyond the designed limit reduces life expectancy of insulation by half
- It is thus important to not only design the transformer to operate with minimum losses, but also to design proper and effective cooling systems

Cooling of transformers

- Small transformers (< 50 VA) are natural air cooled, where coil and core are simply exposed to atmospheric air for cooling
- Distribution transformers (< 30 kVA) have plain walled tanks filled with oil that acts as coolant
- Bigger transformers need special cooling arrangements as ill be discussed in following slides

Transformer Tank

- Transformer tank is made generally from tin, or sometimes cast iron
- The tank encloses winding and core & is filled with oil



Transformer Tank

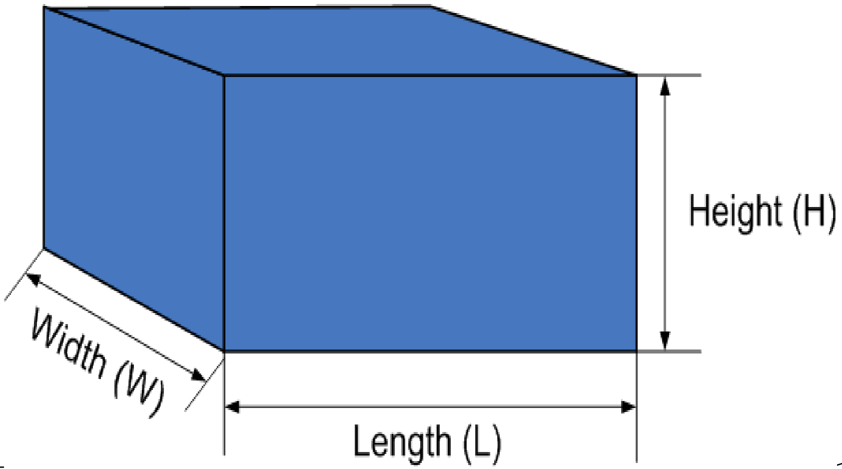
Out of the six surfaces of the metal tank, only four side surfaces can dissipate out the heat.

- Since bottom surface is placed on ground and
- top surface contains bushings, conservator, connection points, explosion vent etc.,
- these two surfaces are not efficient for dissipating away the heat.

Thus, heat dissipating surface area of tank is:

$$S_t = 2 \times H \times W + 2 \times H \times L$$

$$\Rightarrow S_t = 2H \times (W + L)$$



Transformer Tank

Plain wall transformer tank

Path of heat flow

Heat is generated inside the transformer due to various losses that include iron loss and copper loss.

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Heat generated in the core and winding is first **conducted** to oil

↓

Then oil carries the heat to the tank by **conduction and convection**.

↓

Finally the heat is dissipated to the outside atmosphere by **radiation** out of the tank surface.

↓

Atmospheric air also takes away heat from the tank surface by **convection** process.

Temperature Rise

- Heat dissipation **coefficient due to radiation** for plain tank surface to atmosphere is around 6.0 W/m^2-^{0}C.
- Heat dissipation **coefficient due to convection** from tank surface to atmosphere is around 6.5 W/m^2-^{0}C.

- Thus, total heat dissipated through the tank surface area is given by:

$$Q_T = (6.0 + 6.5) \times S_t \times \theta$$
$$\Rightarrow Q_T = 12.5 \times S_t \times \theta$$

- Where θ = Temperature **rise** over ambient
  = (Final temperature – ambient temperature)

Temperature Rise

According to **Newton's law of cooling**, at final steady state condition of temperature,

Heat dissipated = Heat generated

i.e. $$Q_T = 12.5 \times S_t \times \theta = P$$

Where ***P*** is the total power loss = Total copper loss + total core loss

$\therefore$ Steady state temperature **rise** $$\theta = \frac{P}{12.5 \times S_t}$$

Temperature Rise

$$\theta = \frac{P}{12.5 \times S_t}$$

If this final temperature rise of transformer as calculated is **more than the specified temperature rise value**, then the **entire design procedure need to be repeated** to restrict the temperature rise otherwise insulations will get damaged.

- Temperature rise can be restricted by either reducing the losses or
- by increasing the effective tank surface area for heat dissipation
- by adding radiator/cooling tubes or cooling fins outside the tank
- by fitting fans outside the tank to enhance heat dissipation

Design of cooling tubes

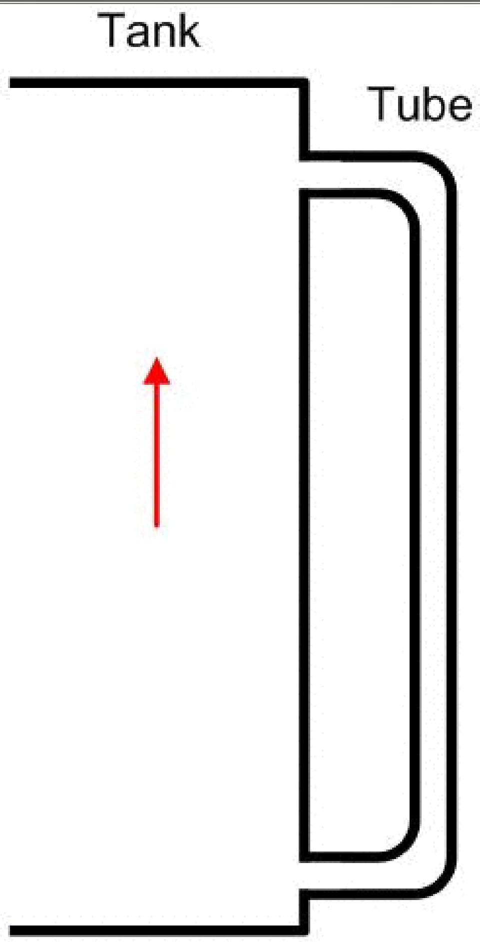
- Cooling tubes or radiator tubes are used to increase the effective surface area of the tank for heat dissipation.

- Thus, by using cooling tubes, temperature rise of transformer can be reduced.

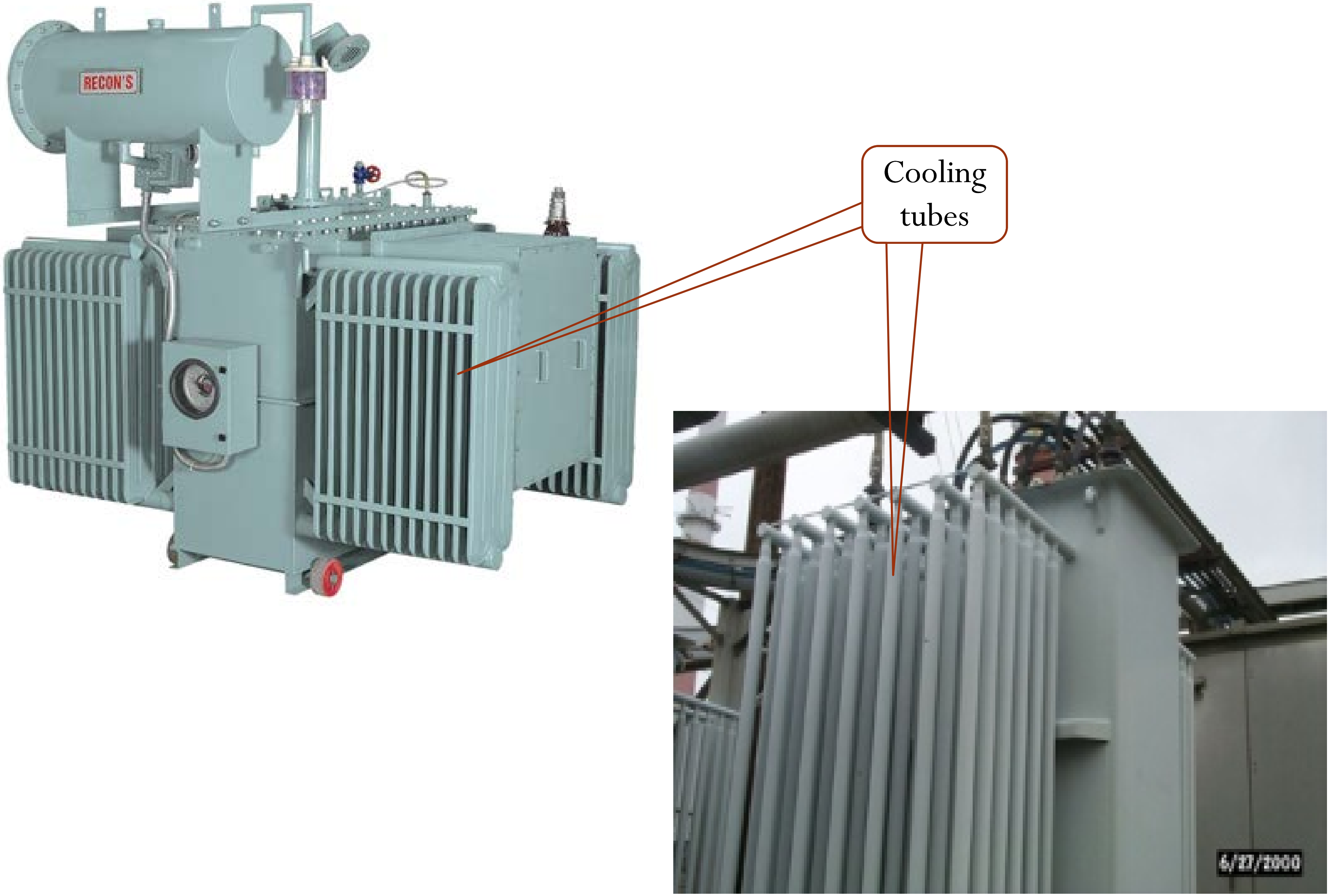
- Vertical cooling tubes connected outside the tank surface increase the cooling efficiency by helping the **convection of heat** through **natural circulation of oil** by **thermo-siphon effect.**

Thermo-siphon effect

- In **thermo-siphon effect**,
- the hot oil inside the tank being lighter in weight, rises up
- enters the top end of cooling tubes,
- releases heat to the atmosphere through surface of the tubes,
- in the process the oil cools down,
- then heavy oil comes down through the tubes
- and re-enters the tank from the bottom.



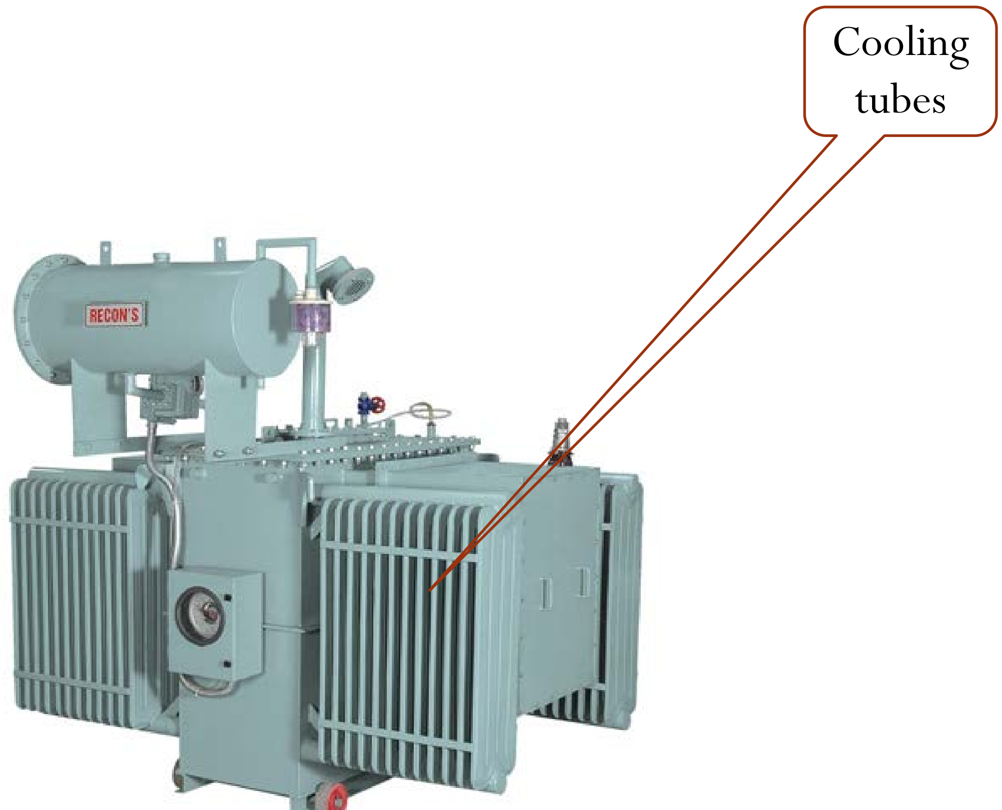
Cooling tubes



Cooling tubes

Design of cooling tubes

- Out of the four side surfaces of the tank, **two surfaces** are used for tap changers and indicators such as ammeters, voltmeters, temperature indicators etc.
- So, only two surfaces of the tank can effectively be used to place the cooling tubes.



Design of cooling tubes

- Using large number of tubes however, will **reduce the spacing** between two successive tubes thus **restricting free flow of air** around the tubes, and in such a case **cooling efficiency goes down**.

- If it is found that even after adding cooling tubes, the temperature rise **still exceeds the specified limit**, then it is necessary to adopt some special **external methods of cooling**.

Transformer cooling methods

Methods of cooling in transformers

Based on the coolant used, the cooling methods can be classified as:

- Air cooling
- Oil and Air cooling
- Oil and Water cooling

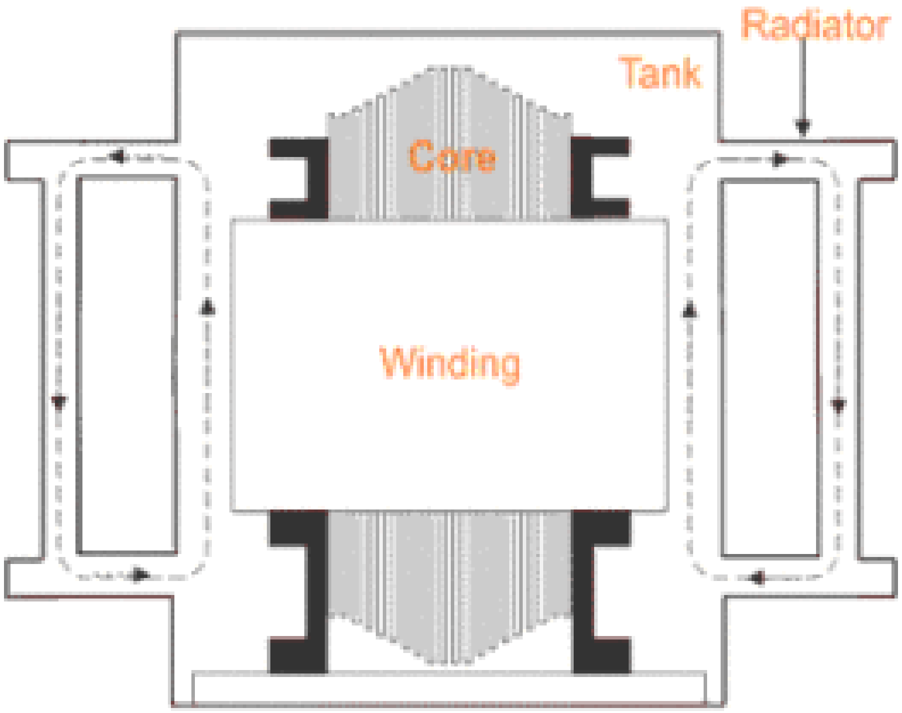
Methods of cooling of transformer

- AN – Air Natural
- AB or AF – Air Blast or Air Forced
- ONAN – Oil Natural Air Natural
- ONAF – Oil Natural Air Forced
- OFAF – Oil Forced Air Forced
- ONWF – Oil Natural Water Forced
- OFWF – Oil Forced Water Forced

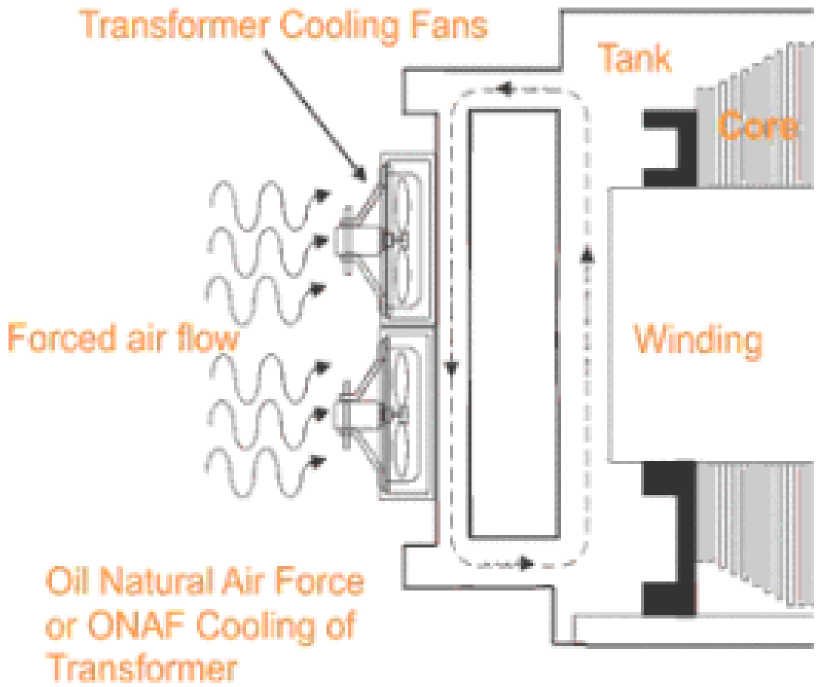
AN – Air Natural

Air Blast (AB) or Air Forced (AF)

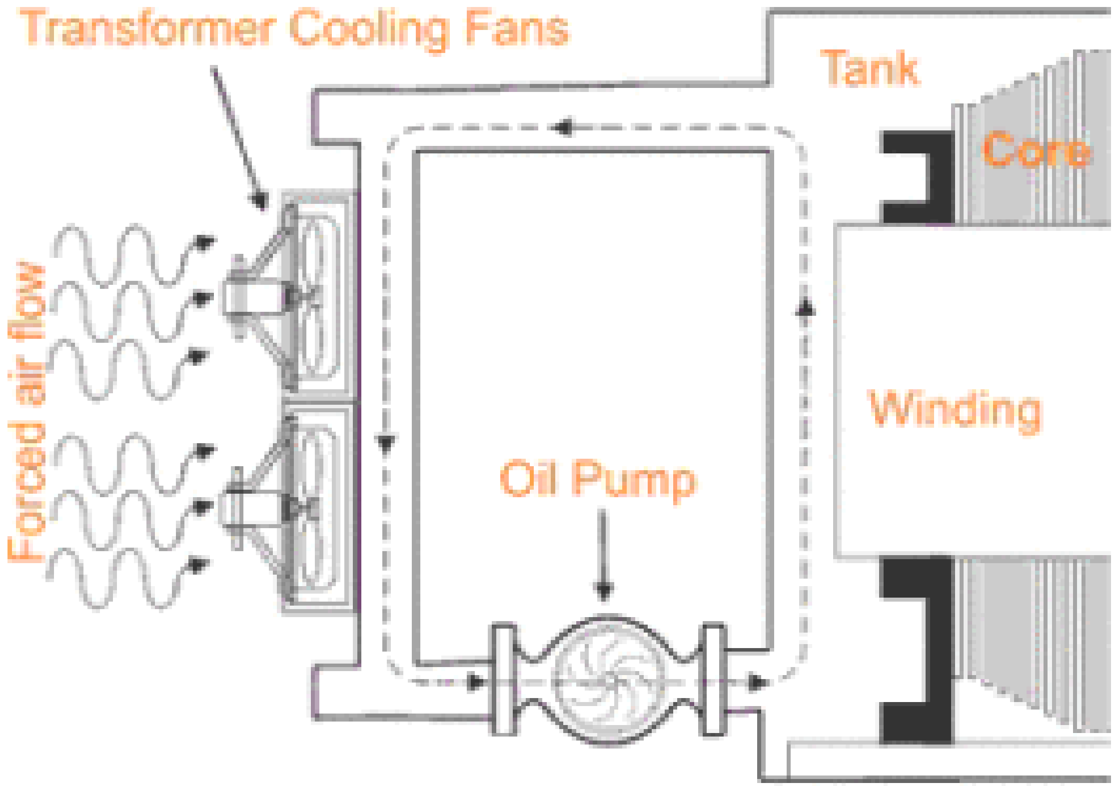
Oil Natural Air natural (ONAN)



Oil Natural Air Forced (ONAF)

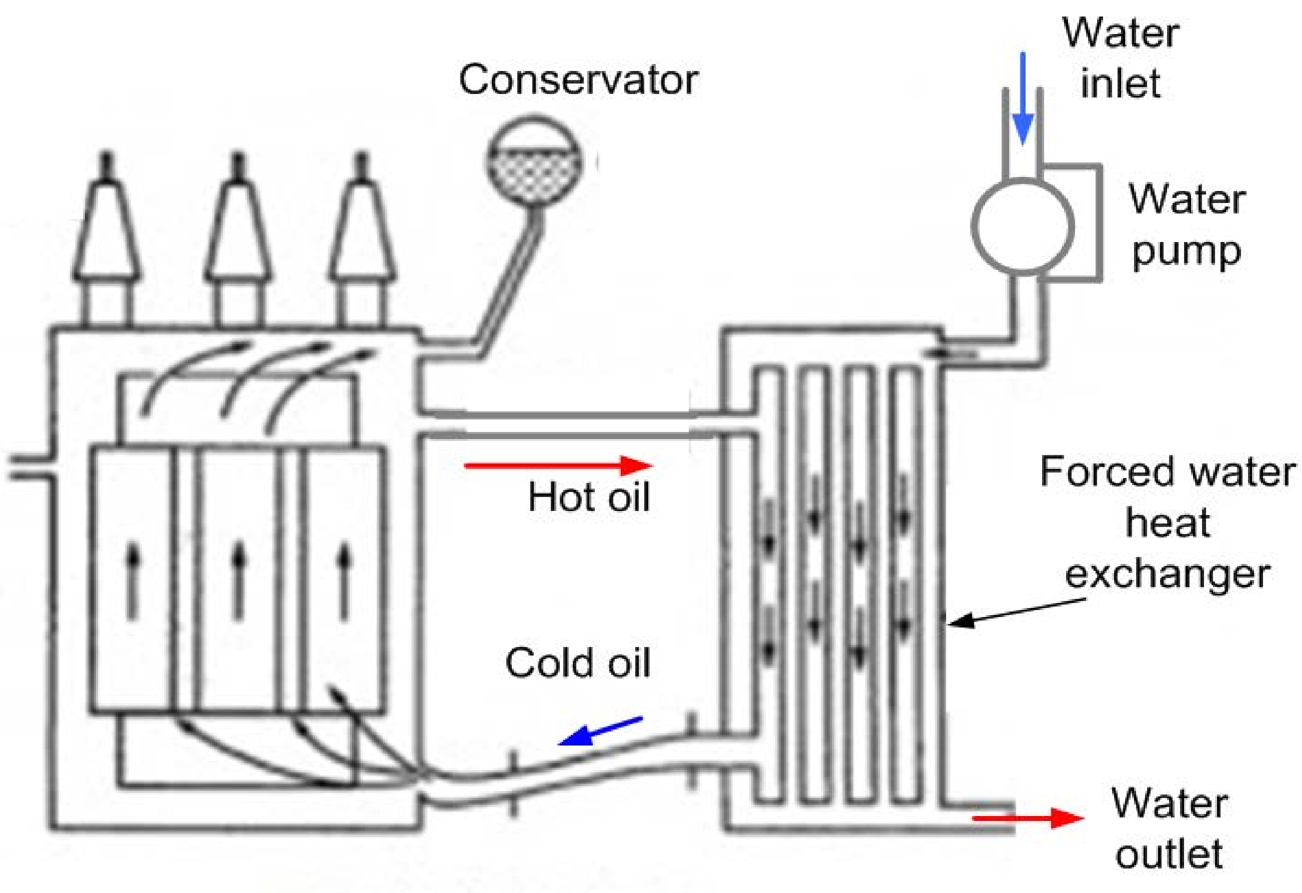


Oil Forced Air Forced (OFAF)



Oil Forced Air Forced or OFAF Cooling of Transformer

Oil Natural Water Forced (ONWF)



Oil Forced Water Forced (OFWF)