This note is for theoretical topics only. Refer class sessions for numerical & application-level topics

Cooling in Transformers

- Cooling of Transformer is the process by which heat generated in the transformer is dissipated or treated to the safe value**. The major factor for the generation of heat in the transformer is the various losses like Core losses (hysteresis, eddy current, iron) and Copper loss**. Among all the various losses the major contributor of the heat generation is the **Copper loss or I^2R loss**.
- The core loss occurs in the core of transformer and copper loss occurs in the winding of the transformer. These losses appear in the form of thermal energy and increase the temperature of the transformer.
- If the temperature of the transformer continues to increase rapidly, it will result in the degradation of the insulation used in the transformer resulting in the damaging of the various parts and hence the failure of the transformer. Thus, proper removal or treatment of heat is necessary for the efficient working, longer life and higher efficiency of the transformer.

Methods of removing this heat can depend on the application, the size of the unit, and the amount of heat that needs to be dissipated. Basically, there are two types of transformers one is the **Dry type**, and another one is **Oil-immersed type**

Factors that determine the life expectancy of solid insulation,

1. Temperature,
2. Moisture
3. Oxidation

The temperature of solid insulation is the primary factor in transformer aging if moisture in the insulation is at a normal level (≤ 0.5 %)

For the cooling of transformers, the following cooling methods listed below are used

The various cooling arrangements of a transformer are

For Dry Type Transformer:

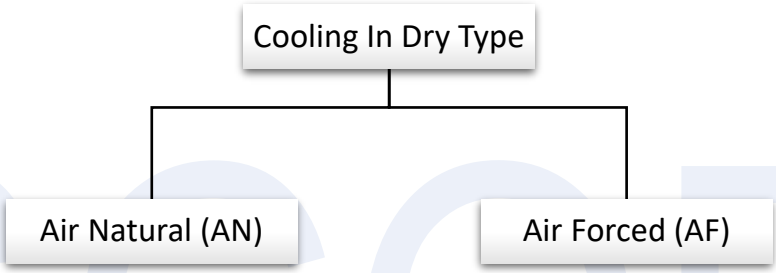
1. Natural Air Cooling (AN)
2. Forced Air Cooling (Air Blast)

This note is for theoretical topics only. Refer class sessions for numerical & application-level topics

For Oil Immersed Transformer:

1. Oil Natural Air Natural (ONAN)
2. Oil Natural Air Forced (ONAF)
3. Oil Forced Air Forced (OFAF)
4. Oil Natural Water Forced (ONWF)
5. Oil Forced Water Forced (OFWF)

Method of Cooling in Dry-type Transformers:



1. Natural Air Cooling (AN)

- By Air Natural method the generated heat in the transformer is cooled by the circulation of natural air. When the temperature of the transformer becomes higher as compared to the temperature of the surrounding air, by the process of **natural convection**, heated air is replaced by the cool air. This method is also known as a self-cooled method.
- In this method, **only natural circulation of air without using any fan, blower etc is used for cooling.**
- The surface area of the core and transformer winding is increased to dissipate the heat generated. Fins are made on the body of transformer similar to that in an engine to increase its surface exposure area.
- **This cooling is used for small transformer up-to voltage rating of 10 to 15 kV, and rating upto 3 MVA**

Fig (a): Natural air-cooling Transformer where fins are provided on the main tank of Transformer to increase its surface exposure

The advantages of this method of cooling are:

1. Freedom from dust
2. It is pollution-free
3. Low Side clearance
4. Capacity is high to support overloads

2. Air Forced (AF) or Air Blast

- We can say that it is the type of artificial cooling because the forced air is used for cooling purposes.
- With the help of fans and blowers, high velocity of air is forced on the core and the windings of the transformer.
- As the temperature inside the transformer goes beyond the standard safe level, an alarm is activated, and the fans and blowers are switched ON automatically.
- **This method is used for transformer rating from 3MVA to upto 15MVA**

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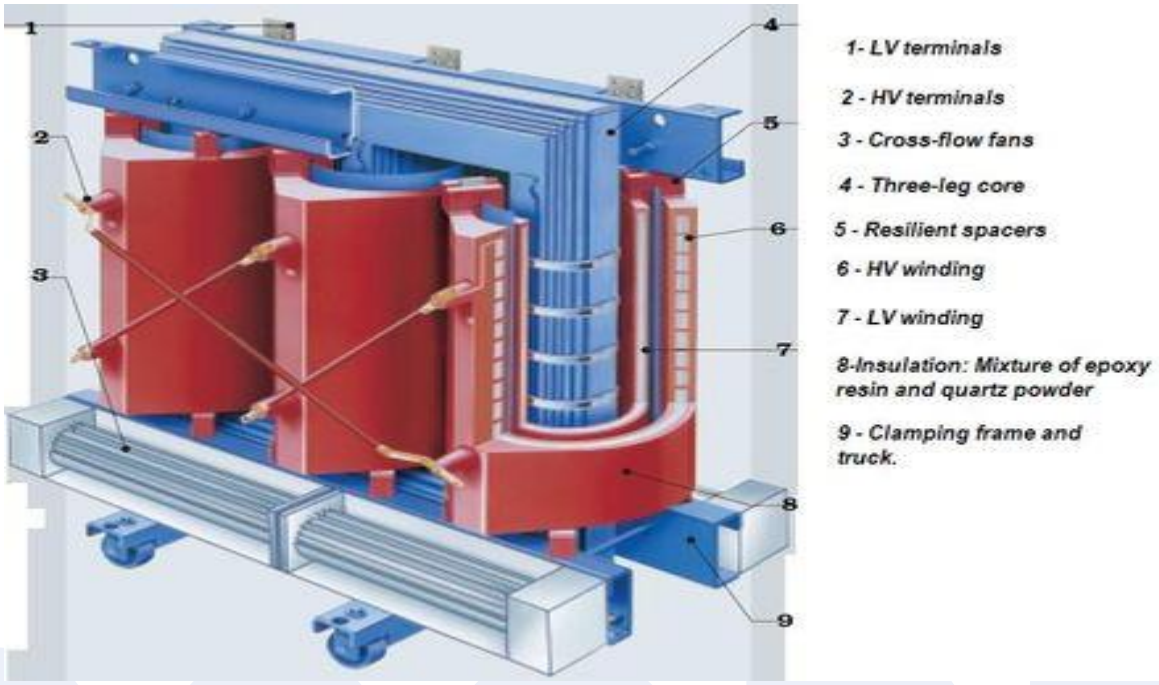

Fig (b): Dry Type Transformer with cross-Flow fans provided at the bottom of the structure

Use of this method of cooling is preferred for the transformer installed in the substation located in thickly populated areas, where oil is considered as fire hazard

Applications of Dry Type Transformers

1. They are used in different industries like gas, chemical, and oil
2. These are used in water protection areas which are environmentally sensitive
3. Forests
4. Used in substations of inner cities
5. Substations like indoor as well as underground
6. Renewable generation

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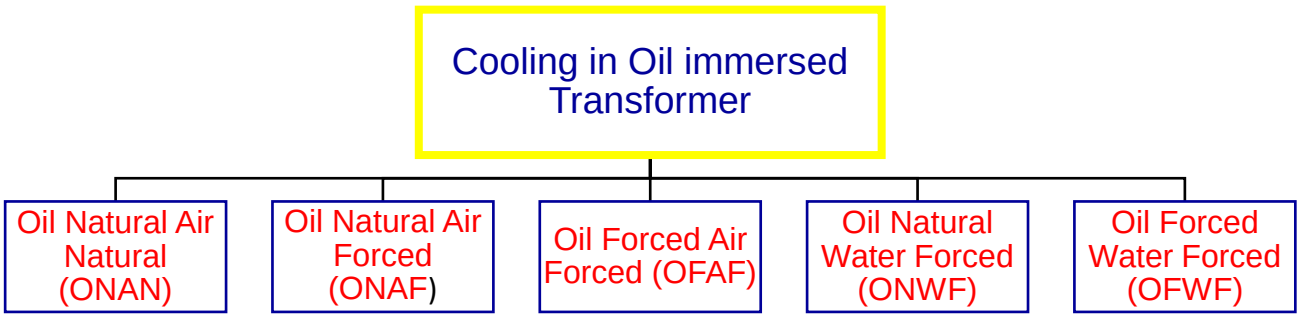
Method of Cooling in Oil-immersed type Transformer



1. Oil Natural Air Natural (ONAN)

- This is the simplest transformer cooling system. The assembly of the core and windings are placed in the oil-immersed tank. As the core and the windings heat up the temperature of the oil in the transformer rises.
- In convectional circulation of oil, the hot oil flows to the upper portion of the transformer tank and the vacant place are occupied by cold oil. This hot oil which comes to upper side, will dissipate heat in the atmosphere by natural conduction, convection and radiation in air and will become cold. In this way the oil in the transformer tank continuously circulates when the transformer is loaded
- As the rate of dissipation of heat in air depends upon dissipating surface of the oil tank, it is essential to increase the effective surface area of the tank. So additional dissipating surface in the form of tubes or radiators are connected to the transformer tank. **This is known as radiator of transformer or radiator bank of transformer.**
- **This method of cooling is usually found in transformers of sizes under 5 MVA. The use of this cooling system above 5 MVA usually becomes expensive as a large surface area is needed for the cooling surface**

A simplest form on natural cooling or ONAN cooling arrangement of transformer is shown below:

Fig (c): Oil Natural Cooled Rectifier Transformer

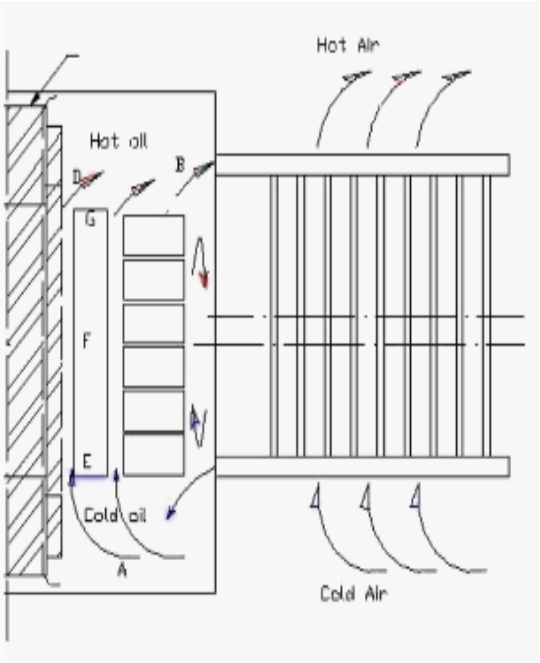
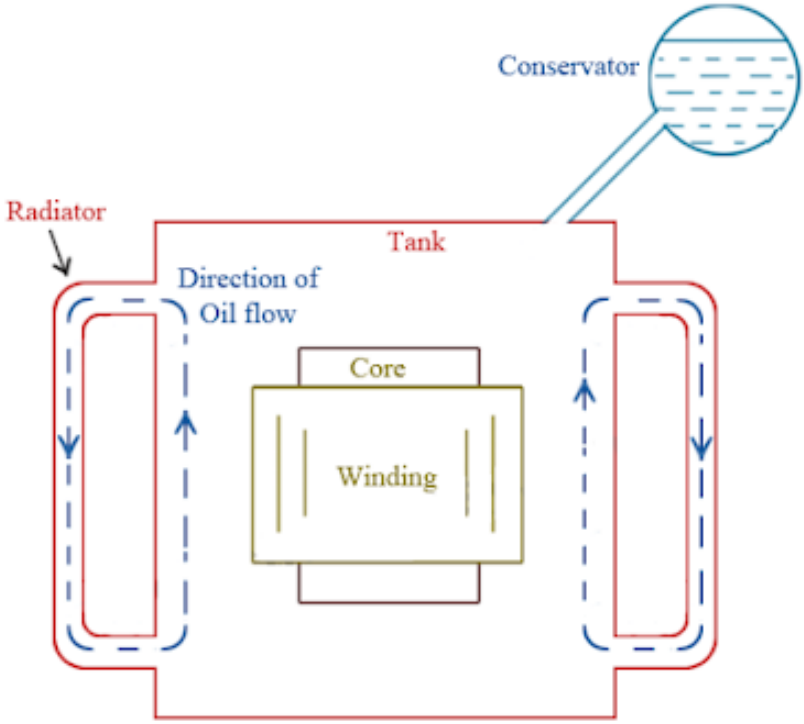


Fig (d): Oil flow diagram of ONAN



Oil Natural Air Natural (ONAN) - Cooling of Transformer

2. Oil Natural Air Forced (ONAF)

- In ONAF type, the forced air is used for the purpose of cooling the transformer. The cooling of oil will be faster if the area of the tank of the transformer is increased finally, which result in the increase in heat dissipation level.
- Forced air provides faster heat dissipation than natural air flow. **In this method, fans are mounted near the radiator and may be provided with an automatic starting arrangement**, which turns on when temperature increases beyond certain value.
- As the fans and blowers are installed, a high velocity of air is forcefully applied to the radiator and cooling towers which will help in cooling oil more quickly and efficiently.
- Normally for Power Transformers, Fans starts when the oil temperature reaches 80° C. Below this temperature of Oil, ONAN takes place but as soon as the oil temperature reaches 80° C FANs start and again cut off when a predetermined temperature of Oil reaches say 70° C
- **ONAF method is used for the cooling of the transformer of rating up to 60 MVA**

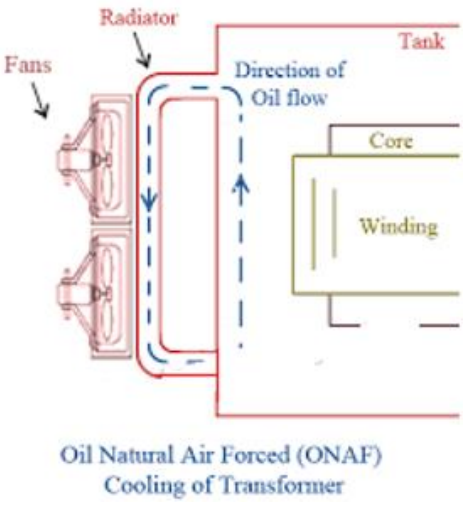


Fig (e): ONAF cooling of Transformer where fans are mounted below the radiators &

Fig (f): shows the Oil flow diagram of ONAF

3. Oil Forced Air Forced (OFAF)

- As the name itself says that both the oil and the air are applied by force for cooling of a transformer.
- The Heat Exchanger is installed through which hot oil is circulated with the help of a pump. The oil circulation is forced through the heat exchangers. Then compressed air is forced to flow on the heat exchanger with the help of fans.
- This method is similar to ONAN, as when there is low load on the transformer the cooling is done by a simple ONAN method. However, as soon as the load is increased, the generated heat will also be more and therefore the sensor gives an alarm that the dissipation of heat has exceeded the safe value and as a result, the fans and pumps are switched on automatically. Thus, the cooling takes place by OFAF method.
- **This cooling system is used in substations and power stations or where higher rating transformers are used, usually > 60MVA**

Fig (g): OFAF cooling of transformer

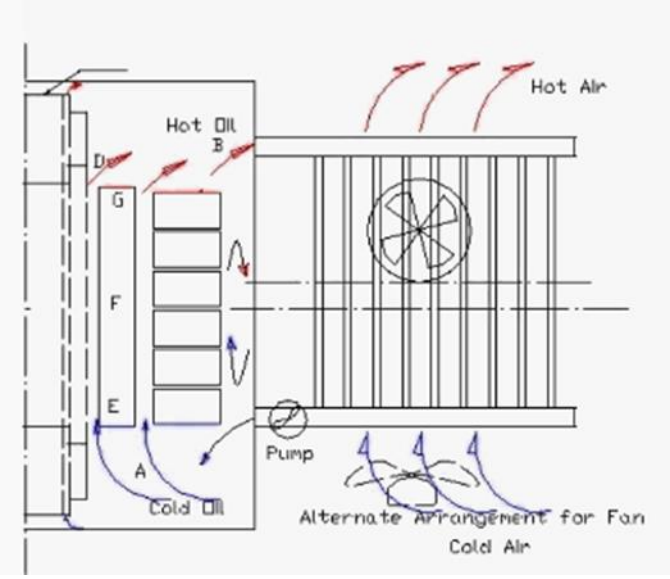
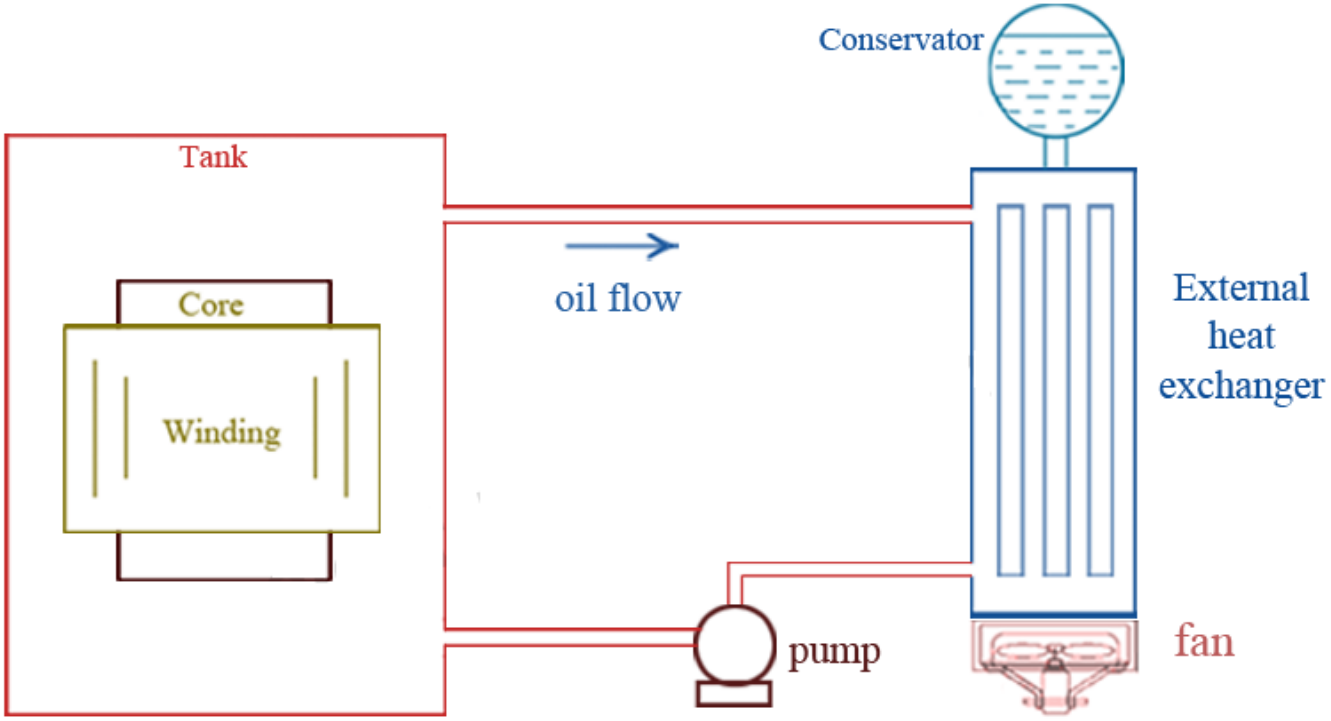


Fig (h): Oil Flow diagram in OFAF



Oil Forced Air Forced (OFAF) - Cooling of Transformer

4. Oil Natural Water Forced (ONWF)

- This technology mainly practices in the American region.
- This method is quite efficient and cost-effective for large units but good maintenance is demanded when compared to the self-cooling method.
- This type of cooling is achieved by circulating water through spirally wound copper cooling coils assembled inside of a smooth tank. In order to prevent leakage of water into the oil, joint-less coils are used in water-cooled transformers.
- In Oil Natural Water Force cooling method, the transformer core and the windings are immersed in the oil tank. A radiator is installed outside the tank, as the temperature rises and the oil heats up and moves upward, the heat is dissipated by the natural process of convection and oil is passed through the radiator, but the water is pumped and passed through the heat exchanger for cooling of the oil.
- **This method of cooling is used for transformers for ratings above 500kVA.**

Fig (i): ONWF with water cooling pumps provided for Transformers

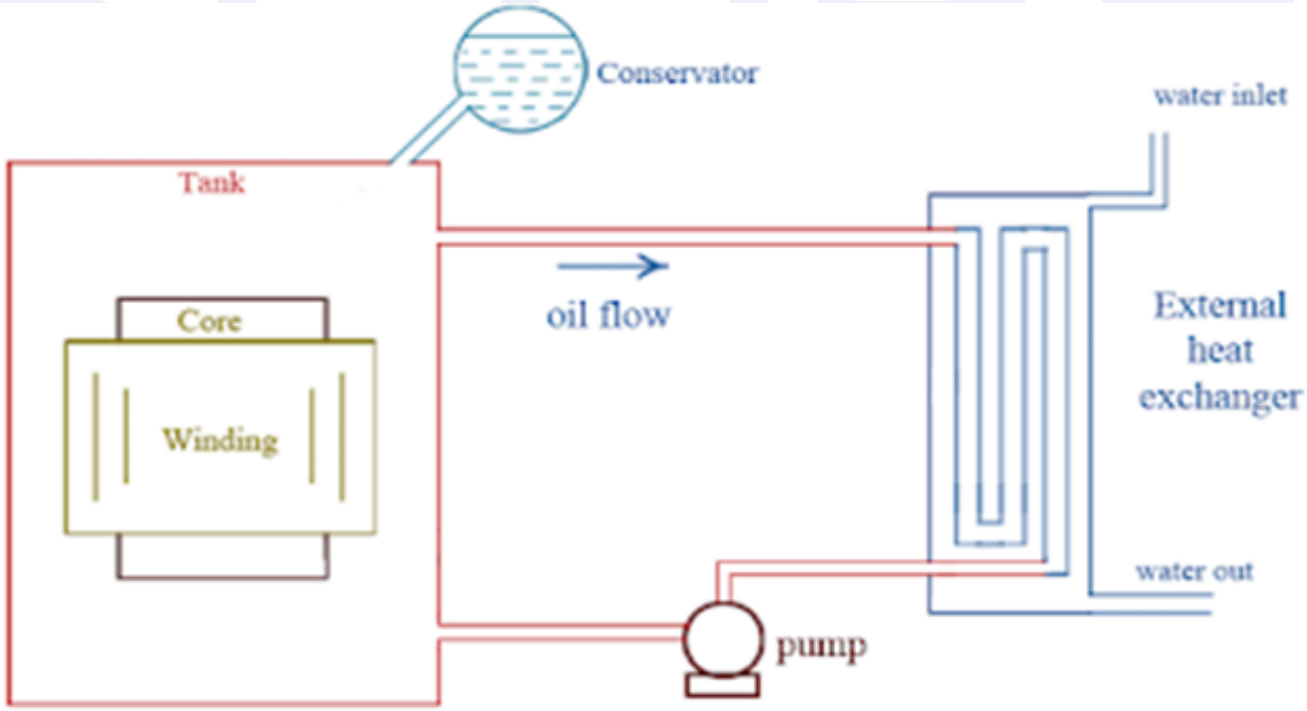
5. Oil Forced Water Forced (OFWF)

- As the name implies, in this method of cooling Oil is cooled using Water and oil is forced toward water. Here Water acts as the ultimate heat sink. A shell and tube type heat exchanger are used in which oil flows from the tube side and water from the shell side as shown in figure below.
- To have maximum cooling of Oil, oil is pumped from the Oil tank to the Heat Exchange and the direction of flow of oil in tube side is opposite to the direction of flow of water in the shell side. The heat exchanger is used to separate heat with the help of pressurized water.
- A heat exchanger is installed through which both oil and water are passed with the help of a pump. The level and pressure of the oil are always kept higher than that of water so that if any leakage occurs in the system the oil mixes with the water, but water does not get mixed up with the oil.

This note is for theoretical topics only. Refer class sessions for numerical & application-level topics

- **This type of cooling system is commonly used in very large transformers with a 100 MVA rating or where banks of transformers are installed.** Mainly this type of cooling is done for the transformer installed at the hydropower plant

Fig (j): OFWF cooling of Transformer



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Dry Type Transformer	Oil Immersed Transformer
1. Dry type Transformer are the transformer which does not have any liquid like oil or silicone in it.	1. In such transformers, core and winding of transformers are immersed in the "transformer oil", hence its name.
2. Used for lower voltage rating and in areas which are having high moisture content.	2. Oil Immersed Transformer are used for higher voltage ratings
3. A dry transformer is a static device with a cooling medium of natural air.	3. Wet types often use oil or mineral oil, as well as fans, to cool. Other wet-type transformers can use silicone or hydrocarbons, which are a bit safer.
4. Efficiency is less compared to Oil Immersed	4. A liquid transformer is typically more efficient than a dry type.
5. Main applications in hotels, feeding basements or stilts of high-rise buildings, air ports, stadium, shopping malls, chemical, refinery plants and industries located in coastal regions	5. Liquid transformers are ideal for medium voltage and high-voltage applications and can be quieter than dry types.
6. Maintenance is a bit difficult compared to Wet Type	6. Easier to repair and re-cycle
7. Lower lifespan.	7. Longer lifespan

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The common alternatives for oil-immersed and air-cooled transformers:

ONAN (Oil immersed, Natural Circulation)	Self –Cooled by air- without oil pump or fan. Preferred for transformers less than 25kVA; but can be used upto 5 MVA
ONAF (Oil immersed, Natural circulation Forced Air Cooled)	Natural oil circulation-forced air cooling by fans. If fans are stopped transformer becomes ONAN type. Used for the cooling of the transformer of rating up to 60 MVA
OFAF (Oil immersed, Forced oil, Forced Air Cooled)	Oil circulation through coolers forced by pumps – air flow by fans. Used in substations and power stations or where higher rating transformers are used, usually > 60MVA.
OFWF (Oil –Immersed, Directed Forced oil, Forced Water)	Oil flow by pumps, directed right in to the windings – air flow by fans mainly for large power transformers, above 100 MVA.

This note is for theoretical topics only. Refer class sessions for numerical & application-level topics

Questions

1. Radiators in transformer are cooled by:
   a) By natural cooling
   b) by forced cooling using small fans
   c) by forced cooling using large fans
   d) by using external air
2. How much of heat dissipation is increased by air blast cooling compared to the natural cooling method in transformer?
   a) 50-70%
   b) 60-70%
   c) 50-60%
   d) 40-60%
3. What happens to the dissipation of energy losses in a transformer when the oil circulation rate is increased?
   a) increase of the oil circulation rate is not depending with energy losses
   b) increase of the oil circulation rate is directly proportional to the dissipation rate of energy losses
   c) increase of the oil circulation rate is directly proportional to the square of energy losses
   d) increase of the oil circulation rate is indirectly proportional to energy losses
4. What is the flow rate of the circulating oil in an air cooler with natural air cooling?
   a) 12.5 litre per minute per KW of losses
   b) 12 litre per minute per KW of losses
   c) 14 litre per minute per KW of losses
   d) 13 litre per minute per KW of losses
5. What type of cooling is preferred in transformers having a capacity of less than 5MVA?
   a) natural cooling
   b) forced cooling
   c) air blast cooling
   d) forced cooling and air blast cooling
6. What is the function of spacers?
   a) To insulate the coils from each other
   b) To provide free passage to the cooling oil
   c) To insulate coils and provide free passage
   d) Cannot be determined
7. In which type of immersed transformer, the oil is pumped through windings to extract heat:

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a) Oil immersed water-cooled transformer
b) Oil immersed forced air-cooled transformer
c) Oil immersed self-cooled transformer
d) Oil immersed forced oil-cooled transformer

8. The heat generated in the transformer is dissipated to the surroundings mainly by:
   a) conduction
   b) convection
   c) radiation
   d) All of the above
9. Oil used for transformer cooling should have low: **
   a) Dielectric strength
   b) Viscosity
   c) Flash point
   d) Melting point
10. OFWF type of cooling is employed for transformers of rating
    a) > 10 MVA
    b) < 10 MVA
    c) > 100 MVA
    d) Upto 3 MVA
11. Oil for transformer cooling should have high:
    a) flash point
    b) viscosity
    c) sludging tendencies
    d) Moisture content
12. ONAF type of cooling is suited for transformers of rating
    a) > 10 kVA
    b) < 10 MVA
    c) > 100 MVA
    d) Upto 60 MVA
13. The level of transformer oil is typically measured using a ___ **
    a) Magnetic Oil level Gauge (MOG)
    b) Venturimeter
    c) High Pressure Indicator
    d) None of these
14. Specific Resistance of Transformer Oil at **90** ℃ is desired to be in the range of **
    a) 1500×10^{12} ohm-cm
    b) 35×10^{6} ohm-cm
    c) 50×10^{9} ohm-cm
    d) 35×10^{12} ohm-cm

Transformer Cooling- Answer Key			
1	b	8	b
2	c	9	b
3	b	10	c
4	b	11	a
5	a	12	d
6	b	13	a
7	d	14	d

** #refer - **sessions 12.1-12.3**

NOTE: *This note is prepared on the topic cooling of Transformers for SSC JE / KPSC, KSEB Sub Engineer/ Diploma/ AE level exams, (Please refer to course outline shared in class)*
(Topics of Transformer oil, oil specifications and class of insulation are discussed in video sessions 12.1-12.3)

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The main functions of spacers in oil filled transformers. are to mechanically separate and support windings

Q. Spacers are provided between adjacent coils

A. to provide free passage to the cooling oil
B. to insulate the coils from each other
C. both (A) and (B)
D. none of the above

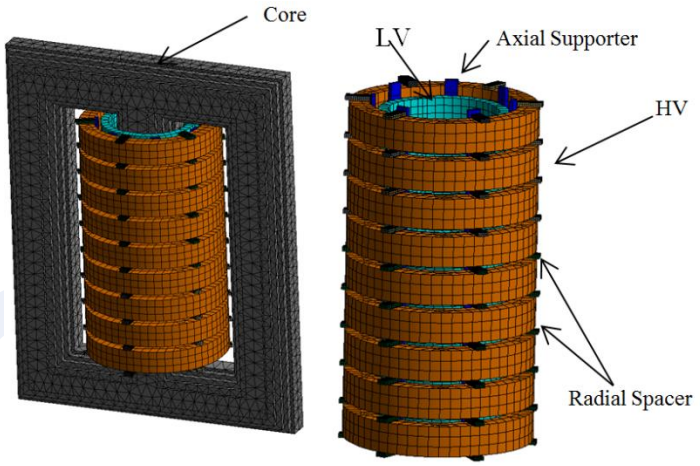

Fig: Oil Filled Transformer with spacers for separating and supporting Stacked Windings

#Note: Minimum standard specific resistance of transformer oil at 90 ℃ is 35 × 10^{12} ohm–cm and at 27 ℃ it is 1500 × 10^{12} ohm–cm

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Additional exam specific points are discussed in our class / Q&A Sessions. Please complete the same before final exams

(Additional MCQs will follow in Test-series & QCards)

*Points in **RED** should be noted*

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