Global Journal of Researches in Engineering
Mechanical and Mechanics Engineering
Volume 12 Issue 5 Version 1.0 Year 2012
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN:0975-5861

Comparative Analysis of Moisture Removing Processes from Transformer which are Used to Increase its Efficiency

By Prof. Ajay Bangar , Prof. Rajan Sharma, Prof. H.P.Tripathi & Anand Bhanpurkar

M.P.C.T. Gwalior, M.P. India.

Abstract - Thermal heating has been conventionally deployed for the moisture removal from transformers. Over the years the process has not remained efficient in terms of energy and effectiveness. Introduction of vacuum has improved the process largely but a lot needs to be done on the thermal engineering aspects of the moisture removal process. Transformer is required to withstand high voltages during the process of power transfer from primary to secondary. For this purpose it is required to have adequate insulation. In construction of transformer, the insulation system is the most important feature and hence requires maximum attention. Normally the insulating materials used are the oil, paper, and pressboard insulation. Cellulose containing insulation used in Oil filled Transformers, being hygroscopic material, contain 8 to 10% of moisture by weight at ambient temperature. But this moisture is injurious to the health of the transformers since it reduces the electric strength, resistivity and accelerates deterioration of solid insulation.

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GJRE-A Classification : FOR Code : 091305, 091399

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Strictly as per the compliance and regulations of:

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Keywords : Heating, Insulation, Drying, Vacuum, VPD, PI value.

I. Introduction

Energy intensive processes have always been an area of concern in the industry and to the society as a whole. Not only the use of energy is responsible for the increasing pollution level but is also detrimental to production of cost competitive products. Today globally the industry is looking for solutions to save the energy to maximum extent possible. In the transformer industry the process of heat extraction is done regularly as part of the production process. Various methods such as Autoclave drying, Vacuum oven drying, Air drying etc are deployed by the industries based on the technical know how, financial resources available or the processes established over a period of time. Though all these processes have been in practice for many years it cannot be confirmed that these are the most efficient or effective methods of moisture extraction. The criteria used to confirm the moisture extraction is the value of Polarisation Index. Many industries fail to understand or gauge the costs involved and their effect on the financial performance of the organisation. Therefore through this research a genuine attempt has been made to evaluate the newer method of moisture extraction i.e. Vapour Phase Drying against the conventional methods for the energy efficiency, cost effectiveness and also the achievement of the performance parameters of the process of Insulation drying. Fig 1 shows the effect of moisture content on the impulse voltage withstand strength of oil and paper. Fig 2 shows the influence of moisture on ageing time of paper.

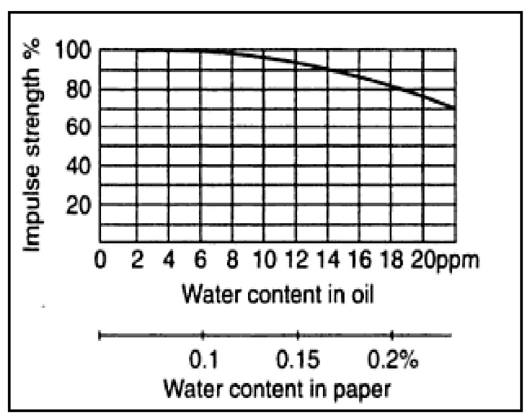

Fig 1

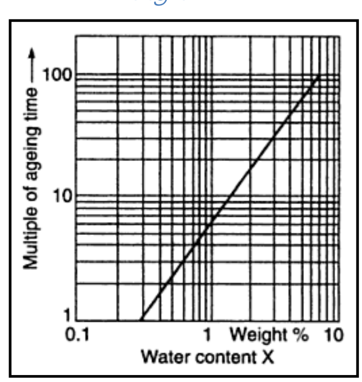

Fig 2

Author α : Prof, Mechanical Engineering Department, Maharana Pratap College of Technology, Gwalior, Madhya Pradesh India.
E-mail : abangar1000000@gmaill.com
Author σ : Prof, Mechanical Engineering Department, Maharana Pratap College of Technology, Gwalior, Madhya Pradesh India.
E-mail : rjnsharma@rediffmail.com
Authorρ : Prof, Mechanical Engineering Department, S.R.I.I.T. Banmore (Gwalior) Gwalior, Madhya Pradesh India.
E-mail : Hptripathi1967@gmail.com
Author ω : Student of M.E.(PIS), Mechanical Engineering, Maharana Pratap College of Technology, Gwalior, Madhya Pradesh India.
E-mail : anandb31@yahool.com

a) Basics of Insulation Drying

The insulation material which is cellulosic in nature is dried by creating low water vapour pressure around the insulation. The pressure inside the insulation is increased by heating and the pressure around is lowered by removing the water vapour. A 20°C temperature rise increases the internal pressure by more than 100%. Fig 3 shows the plotted values for pressure against humidity and temperature. It shows that the aim should be to achieve the highest processing temperature as per the ageing properties of the insulating material however the upper limit is to be kept about 110°C.

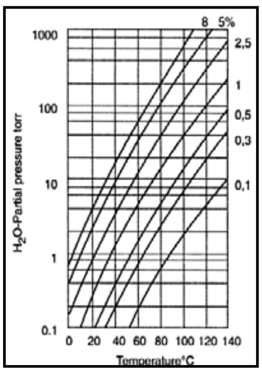

Fig 3

Two basic processes are adopted for drying of transformers.

(a) Vacuum Drying (Conventional)

(b) Vapour phase drying

b) Drying Time

The time of drying depends on the amount of moisture content to be left in the insulation and on the moisture contained in the insulating material such as laminated wood, press board, crepe paper etc. The drying time also increases considerably for higher operating voltage of the transformers. Fig 4 shows the Diffusion coefficient of low density oil-free press board at different drying temperatures with pressure level under atmospheric and over 0.1 to 1 Torr vacuum range.

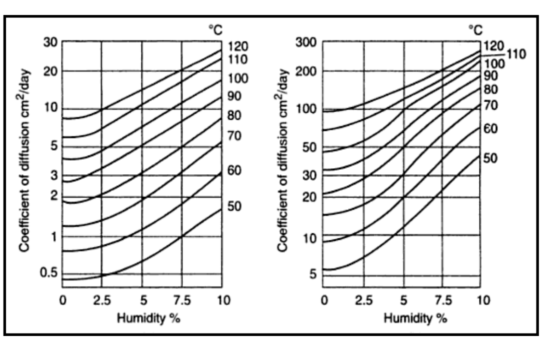

Fig 4

The moisture content in cellulosic insulation can be reduced to 2% from 8-10% by circualtion of dry air. But in case further reduction of moisture content is required it entails application of heating and vacuum to reduce the time required for drying. The longer the drying time, higher will be partial discharge inception voltage.

c) Vacuum Drying

In the method of vacuum drying the core coil assemble is initially heated to 100°C for about 24 hrs and then a high vacuum level is drawn in the vacuum oven. When higher vacuum level is achieved the heating time is reduced. Heating is done by the application of electric heaters and circulating the hot air in the oven chamber. The vacuum level is also related to the volatge class of the transfomer which determines the amount of residual moisture allowabel in the insulation. In general a vacuum level corresponding to an absolute pressure as low as 1.33 Pa or 0.01 torr can be obtained. To maintain the transformer active part temperature to the required value the pressure is increased to the atmospheric level by injecting hot dry air at intervals during the first few hours. During the vacuum cycle the water vapour is extracted and collected through a condenser in form of water and the qualntity of water collected is recorded at regular intervals. Many inductries use the method of alternated heating and vacuum cycle to effectively extract moisture. The vacuum drying cycle is consiedered compelte when a desired level of water colledtion is achieved for 2-3 consecutive hours.

d) Vapour Phase Drying

Vapour phase drying is the method which also applies vacuum but the method of heating is not thorugh air. In this method the carrier of heat is vapour of low viscosity solvent like kerosene with a sufficeintly high flash point instead of air. The vapour is heated in a chamber by the use of electric heaters and are passed over the core coil assembly kept inside for drying. The sovent vapours thus condense on the drying mass and are collected back in form of liquid solvent which is re-circualted in the system. For this purpose the Vapour phase drying systems have a evaporator and condense system in addition to the the vacuum chamber and vacuum pulling equipments such as vacuum pump, roots pump etc which are part of conventional vacuum system. Thus the system in total consists of solvent heat conveyer system consisting of storage, evaporation, condensation, filtration, solvent feedback and control arrangement.

This arangement is little more complex in nature as compare to the conventional vacuum system and has many more controls for the intermediate stages of the cycle. The cycle usually has intermediate pressure lowering cycle followed by the vacuum cycle. The intermediate lowering cycle allows the extraction of moisture and the vacuum cycle helps to heat up the mass and evaporate the moisture from inside the insulation materials.

The vapour phase drying system is very useful in removing oil from the core coil assemblies in case of repairs of rectification of transformers which is not possible in the conventional vacuum system. Fig 5 shows a typical Vapour Phase Drying System.

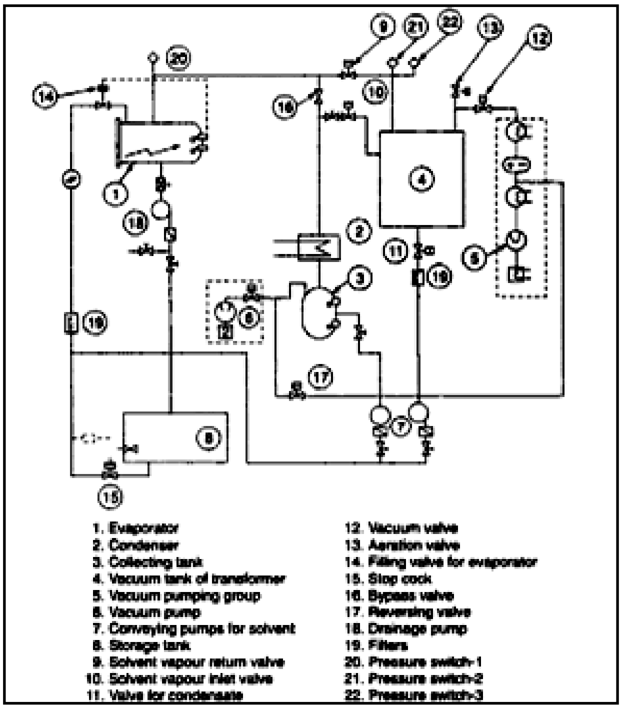

Fig 5

e) Properties of Solvent

The solvent used for vapour phase drying system should posses following properties for effective and efficient drying.

(a) Vapour pressure must be distinctly lower than that of water, so that a large pressure difference assists efficient water diffusion from the beginning of the heating phase.

(b) Evaporation heat should be very high.

(c) The solvent must not have any effect on the insulation properties and their expected life.

(d) The solvent must be reusable for un limited no of times however this not true practically as it is required to be topped up at regular intervals and to be changed after 3-5 years.

(e) Flash point should be above 55°C

Fig 6 shows the Vapour Pressure cuve of solvent and water

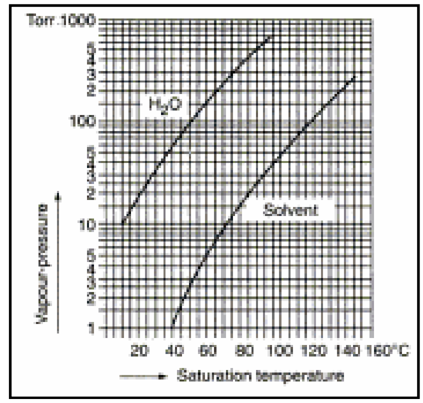

Fig 6

Table 1 below shows the physical properties of Solvent Vapour and Air.

Sl. No.	Physical properties	Hydrocarbon solvent	Air
1.	Specific density	0.785 g/cm^3 (liquid)	1.25 kg/m^3 (gaseous)
2.	Molecular weight	160	29
3.	Heat of Vaporization	306 × 10^3 W s/kg	–
4.	Specific heat	2.09 × 10^3 W s/kg°C (liquid)	1 × 10^3 Ws/kg°C (gaseous)
5.	Inlet temperature in vacuum vessel	130°C	110°C
6.	Outlet temperature from vacuum vessel at start of heating	90°C	90°C
7.	Vapour pressure at 130°C	140 torr	–
8.	Energy provided per mole	62.7 × 10^3 W s	581 × 10^3 W s
9.	Energy provided per mole	179 m^3 at 130°C	31.4 m^3 at 110°C
10.	Energy released per m^3	351 × 10^3 W s	18.4 × 10^3 W s

f) Drying Process

The drying process typically consists of following steps –

(a) Preparation

(b) Heating and drying

(c) Pressure reduction

(d) Fine vacuum

Fig 7 shows the sequence of operation of Vacuum Phase Drying in a vacuum vessel and the four typical stages of vapour phase of drying process

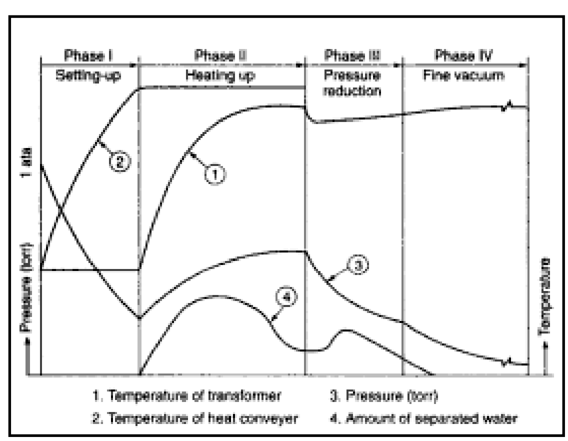

Fig 7

Global Journal of Researches in Engineering (A) Volume XII Issue V Version I Year 2012

g) Preparation

The complete evaporator and the condenser system is applied with full vacuum to the level of 5 torr before drawing the solvent in the evaporator and heating it to the level of 130°C. The vacuum chamber of the VPD is also applied with vacuum of 5 torr. The core coil assembly is kept with slope to assist draining of the solvent.

h) Heating and Drying

Heating is started after all the air has been taken out. The valves are kept open for the solvent vapours to enter the vacuum chamber and condense over the surface of the drying mass loaded. The condensation releases the heat and the loaded mass temperature increases thus causing evaporation of water. The mixture of water and solvent drains out for recirculation.

i) Pressure Reduction

During this stage the supply of solvent vapour is stopped and most of the solvent vapours present get absorbed by the insulation re-evaporate, condense out in the condenser and finally get returned to the evaporator. This phase continues till the pressure in the vessel reaches 15-20 Torr.

j) Fine Vacuum

This is the final stage of the cycle which immediately follows the pressure reduction stage. The vessel or the vacuum chamber is again reduced to pressure not exceeding .1 Torr. The water extraction is monitored and recorded at regular intervals. When the water extraction rate becomes constant to the desired level the cycle is stopped.

k) Comparative Study

As stated at the beginning the researchers conducted a systematic study of both the drying methods for their performance in terms of time required, Energy consumed and the results achieved for the transformer core coil assembly drying in form of the Polarisation Index (PI) value. The PI value is the ration of insulation resistance measured at 60 sec and 600 sec. For this the team of researchers worked to a decided plan and often continued in to the stretched hours to collect the required data. There were group meetings in between to discuss the progress, data and the corrections required to the further study. Few additional measuring arrangements were organised to collect the data and conclude the results and inferences.

Table 2 shows the data on the time required for completing the drying cycle for core coil assemblies of different rating transformers.

Table 3 shows the comparative data of energy consumption for the drying cycle of core coil assemblies of different rating transformers.

Table 4 shows the comparative data of Polarisation Index (PI) value achieved for the drying cycle of core coil assemblies of different rating transformers.

Rating	kV	Cycle Time in Hours (Avg)	
		Vacuum Drying	VPD
500 KVA	11	16	12
1000 KVA	11	16-18	12
2000 KVA	11	16-18	12-14
3000 KVA	33	30-36	24
5000 KVA	33	36	24
10000 KVA	33	36-42	24-30

Table 2

Rating	kV	Energy Consumption KWh (Avg)	
		Vacuum Drying	VPD
500 KVA	11	448	568
1000 KVA	11	476	550
2000 KVA	11	512	610
3000 KVA	33	893	776
5000 KVA	33	905	880
10000 KVA	33	1095	1080

Table 3

Rating	kV	Polarisation Index (PI)	
		Vacuum Drying	VPD
500 KVA	11	1.32 – 1.5	1.5 – 2.6
1000 KVA	11	1.3 -1.4	1.5 – 2.6
2000 KVA	11	1.3 -1.5	1.8 – 2.4
3000 KVA	33	1.2-1.4	1.4 – 2.5
5000 KVA	33	1.2-1.3	1.4 – 3.2
10000 KVA	33	1.2-1.5	1.4 – 3.0

Table 4

Advantages of Vapour Phase Drying

- The transformer manufacturing cycle time is reduced.
- Moisture extraction is ensured from the most difficult materials such as laminated wood and pressboards due to solvent heating.
- Lesser ageing of insulation due to reduced heating cycle time thereby less possibility of de-polymerisation.
- Oil soaked transformer core soil assemblies can be dried.
- Heating time is reduced by achieving rapid rate of heating.

II. Conclusion

After analysing the data of the Average Cycle time in Hours, Energy consumption in KWh and the value of Polarisation Index achieved it is seen that

- There is reduction of 29% in the cycle time required for drying of the core coil assemblies in the Vapour Phase Drying.
- There is increase in energy consumption for the smaller rating of the transformers but there is reduction of 6% in the cycle time required for drying of the core coil assemblies of larger rating in the Vapour Phase Drying. However the fact needs to be considered that the VPD used is of bigger size and energy is lost in preheating the empty space in case of smaller volume mass and hence may have a relation to the higher energy consumption.
- The average value of PI achieved is 1.4 in conventional Vacuum heating while in VPD it is improved greater than 2. Even though the acceptable value of PI $\geq$ 1.3 is achieved in both the systems the requirement of customers today is towards 1.5 to 2 PI. Therefore the VPD cycle is definitely better for the customer requirement and longer useful life of the transformers.

Therefore it is established with this study that the Vapour Phase Drying method is definitely advantageous over the conventional method in terms of time, Quality and material properties retention. It is more preferred for larger rating transformers but this research necessarily opens up the requirement of research and development of the VPDs of smaller sizes and ratings with economical investment requirement which can enable the manufacture of better products for our utilities, industries and elsewhere. The scope is big considering India's fast growth in the power sector.

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