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Experimental Analysis of Vapour Phase Drying System

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Abstract

Electrical equipment such as power transformers with a paper-oil insulating system have varying moisture levels dependent on ambient and operating conditions. But this moisture is injurious to the health of the transformers since it reduces the electric strength, resistivity and accelerates deterioration of solid insulation. So it is always required to remove this moisture from the insulation to maintain its insulating properties. In industry lot of energy is spent on heating, vacuum and other means to remove the moisture which adds to cost of production apart from posing challenge to energy saving. Transformer is required to withstand high voltages during the process of power transfer from primary to secondary. For this reason 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. Conventional method used for removing such moisture content from transformer is Simple Vacuum Drying method. Over the period the process has not remained efficient in terms of energy and efficiency. Use of vacuum has improved the process largely but a lot needs to be done on the thermal engineering aspects of the moisture removal process. So advanced and more efficient method used for drying for transformer is Vapour Phase Drying Method. To understand advantages of Vapour Phase Drying System over Simple Vacuum Drying System, experimental setup for both systems is developed and trials are taken on both systems for drying of newspaper (100 grams) at different vacuum pressures and different durations. From results it observed that time required for drying in case of Vapour Phase Drying Method is very less. As compared to Vacuum Drying Method, increase in drying percentage by use of Vapour Phase Drying Method is around 70%.

Keywords: Moisture, Vacuum, Vapour, Drying, Insulation, Drying time,

1. Introduction

In the transformer industry the process of heat extraction is done regularly as part of the production process. Various methods used for drying of transformers are Hot oil spray drying, Vacuum oven drying, Air drying etc. 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. Effectives of drying can be studied on basis of drying time and percentage of drying in specific duration. Many industries fail to understand the costs involved in drying of transformers 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 [1].

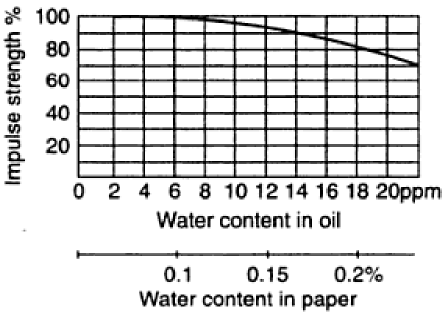

Fig.1 Effect of moisture content on the impulse voltage withstand strength of oil and paper [1]

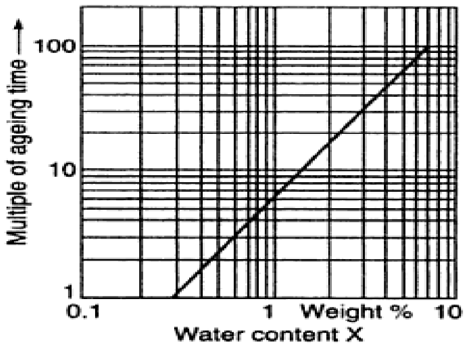

Fig.2 Influence of moisture on ageing time of paper [1]

The presence of moisture in a transformer deteriorates transformer insulation by decreasing both the electrical and mechanical strength. In general, the mechanical life of the insulation is reduced by half for each doubling in water content [1]; the rate of thermal deterioration of the paper is proportional to its water content [2]. Electrical discharges can occur in a high voltage region due to a disturbance of the moisture equilibrium causing a low partial discharge inception voltage and higher partial discharge intensity [3]. The migration of a small amount of moisture has been associated with flow electrification at paper/oil inter-faces and is presumed to be due to charge accumulation on highly insulating interfacial dry zones [4,5] . Water in mineral oil transformers also brings the risk of bubble formation when desorption of water from the cellulose increases the local concentration of gases in the oil [6]. The importance of moisture presence in paper and oil systems has been recognized since the 1920s. It is useful to know the moisture partitioning curves between oil and paper under equilibrium conditions.

When the transformer is in equilibrium operation, this provides a quick way of examining the moisture content in paper to predict future failure by measuring the moisture in oil. Over the years, many scientists have reported such a set of curves, but there has not been a comprehensive review and comparison for different curve sets. The research spans several decades and is an important resource for electric utilities and insulation and testing equipment manufacturers.

As is well known, for a good insulation oil the dielectric power factor, the insulation resistance and the dielectric strength are utmost importance. These properties depend very sharply on the water content. ln figures 3 and 4 these characteristics for low viscosity and high viscosity insulation oil ore plotted against the water content respectively. The low viscosity oil K 8 is on insulation oil which is usually used for the impregnation of transformers, instrument transformer and high voltage cables. The high viscosity oil IDM 915 (Mineroloiwerke Fuchs) is on insulation oil for moss impregnated coble.

The graphs in Figures 3 and 4 show that the dielectric power factor is affected very considerably by emulsified water. As the moisture content becomes lower the power factor falls, until of 20 p,p.m. it reaches its minimum and remains constant, when only a small amount of water is still dissolved in the oil. The complete removal of the water dissolved in the oil brings therefore by itself no fundamental improvement of the dielectric power factor [11].

The dielectric strength behaves altogether differently. It is extraordinarily low in the emulsion region, which is only plotted here to a maximum of 200 p.p.m., and amounts to about 50 kV/cm for both considered oils. In the region of the solubility boundary the oil begins lo increase in strength.

After passing the solubility boundary then dielectric strength remains approximately constant up a residue moisture content of 20 p,p,m. On the other hand, at smaller residual moisture contents the dielectric strength again climbs by abt. 50%. From these curves it is proved that the dielectric strength is independent of how much water is emulsified in the oil. The dielectric strength will be determined by the dissolved water. lt is interesting to note that for a transformer oil (Figure 3) according to the VDE specification, a dielectric strength of at least 200 kV/cm will be required. ln order to reach with certainly this value, a transformer oil of this sort will have to be dried to residual moisture content of approximately 10 p.p.m.

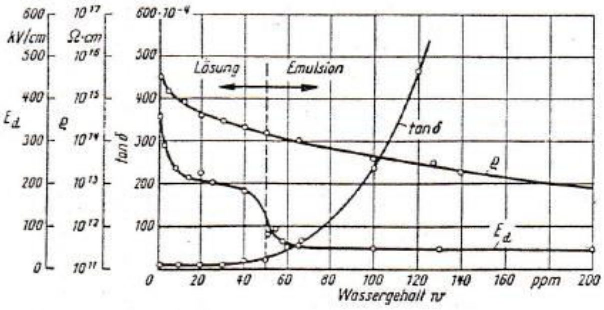

Fig.3 Relationship of dielectric power factor tan δ, specific insulation resistance ρ and dielectric strength E_d at low viscosity insulation oil (transformer oil) with water content at 23 °C [11]
1 p.p.m. = 10^{-6}parts of water in 1 port of oil
The ordinale scale for ρ is logarithmic
Lasung = solution; Emulsion: Emulsion;
Wassergehalt = Water Content

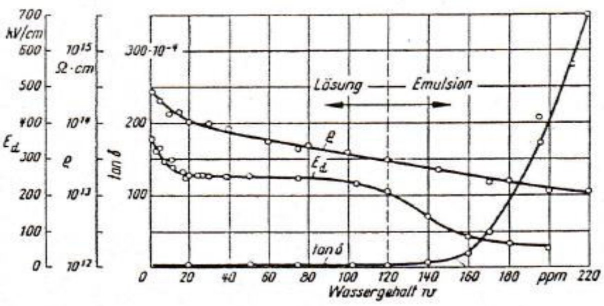

Fig.4 Relationship of dielectric power factor tan δ, specific insulation resistance ρ and dielectric strength E_d at high viscosity insulation oil (transformer oil) with water content at 23 °C [11]
Lasung = solution; Emulsion: Emulsion;
Wassergehalt = Water Content

2. Experimental Methodology

2.1 Vacuum Drying Method

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 voltage class of the transformer which determines the amount of residual moisture allowable in the insulation. In general vacuum level corresponding to an absolute pressure as low as 1.33 Pa 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 quantity of water collected is recorded at regular intervals.

Many industries use the method of alternated heating and vacuum cycle to effectively extract moisture. The vacuum drying cycle is considered complete when a desired level of watercollation is achieved for 2-3 consecutive hours [1].The schematic diagram of the experimental setup is shown in Fig.5.

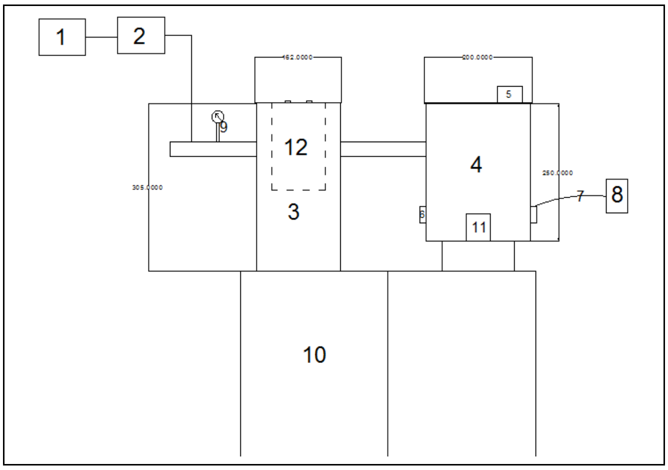

Fig.5 Layout of experimental setup

1. Motor
2. Vacuum Pump
3. Condenser
4. Vacuum Chamber
5. Lamp-Glass Arrangement
6. Heater
7. Thermocouple
8. Temperature Indicator
9. Pressure Gauge
10. Stand for experimental setup
11. Stand for keeping Sample
12. Cold Water Arrangement

Fig.6 shows the Developed experimental setup of Vacuum Drying System. Main units of experimental setup are vacuum chamber, condenser and vacuum pump.

Fig.6 Developed experimental setup of vacuum drying system

2.2 Vapour Phase Drying Method

Vapour phase drying is the method which also applies vacuum but the method of heating is not through air. In this method the carrier of heat is vapour of low viscosity solvent like kerosene with a sufficiently high flash point instead of air. For Vapour Phase Drying Method drying process takes in four stages which are Preparation, Heating-up, Pressure Lowering and Vacuum Treatment.

The vapour is heated in a chamber by the use of electric heaters and is passed over the core coil assembly kept inside for drying. The solvent vapours thus condense on the drying mass and are collected back in form of liquid solvent which is recirculated in the system. For this purpose the Vapour phase drying systems have a evaporator and condenser 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 arrangement 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 [1].

Fig.7 shows a typical Vapour Phase Drying System with Evaporator and Condenser arrangement. Fig.8a and Fig.8b shows the developed experimental setup of vapour phase drying system

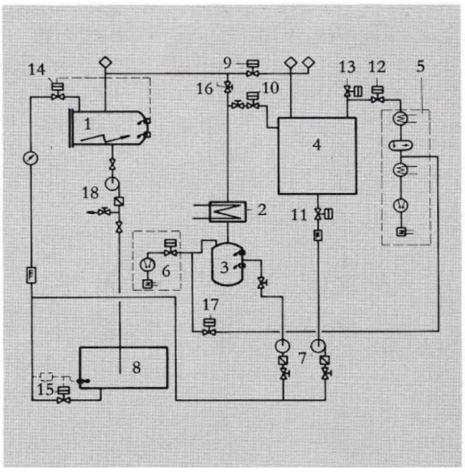

Fig.7 Typical vapour phase drying system [9]

1. Evaporator
2. Condenser
3. Collecting Tank
4. Vacuum Tank

5. Vacuum Plant
6. Leakage Air Pump
7. Conveying Pump
8. Storage-Lank
9. Solvent Vapour Inlet Valve
10. Solvent Vapour Return Valve
11. Valve For Condensate
12. Vacuum Valve
13. Aeration Valve
14. Filling Valve
15. Stoplock
16. Bypass Valve
17. Recovering Valve
18. Drainage Pump

Fig.8a Developed experimental setup of vapour phase drying system

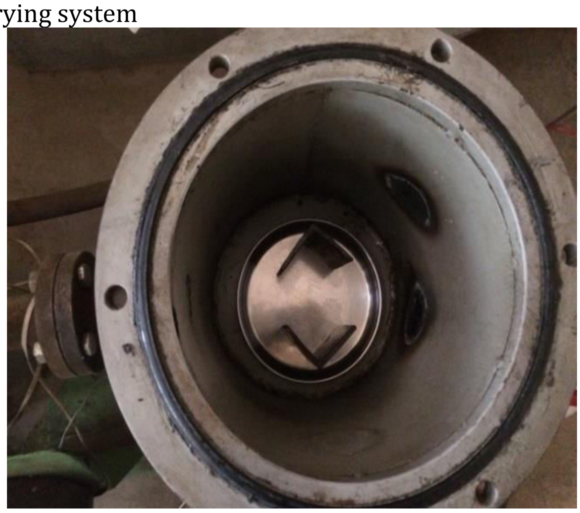

Fig.8b Developed experimental setup of vapour phase drying system (Kerosene kept in Vacuum chamber)

2.3 Experimental Procedure

Vacuum Drying Method and Vapour Phase Drying method are used for removing moisture content from insulation of transformer. But for existing setup it is not possible to take trials on transformers. So we have taken newspaper with moisture content as a sample for experimental trial. Method followed for conducting trials on Vacuum Drying System and Vapour Phase System is as following.

i. 100 grams of sample is weighted with weight scale and 30ml of water (30% of weight) is sprayed on sample
ii. Sample is weighted and its weight is identified as 130 grams
iii. Sample kept into Vacuum Chamber
iv. For Vapour Phase Drying system, Measured kerosene (50ml) is kept in vacuum chamber
v. Started vacuum pump
vi. Turned on heater after achieving desired pressure
vii. Switched off vacuum pump
viii. Weighted dry sample on weight scale

3. Results and Discussion

Main results which can show advantage of Vapour Phase Drying system(VPD) system over Vacuum Drying system are Moisture Extraction Rate and Drying Percentage.
Moisture extraction rate for particular time duration can be calculated as

$$Moisture\ Extraction\ Rate = W - D \qquad (1)$$

Where
W = Wet sample weight (grams)
D = Dry sample weight (grams)
Drying percentage can be calculated as

$$Drying\ Percentage = \frac{MW - MD}{MW} \times 100 \qquad (2)$$

Where, MD = Moisture content in Dry sample (ml)
MW = Moisture content in Wet sample (ml)

Percentage hike by use of VPD can be calculated as

$$Percentage\ hike\ by\ use\ VPD = \frac{A - B}{B} \times 100 \qquad (3)$$

Where,
A = Drying percentage for VPD
B = Drying percentage for Vacuum Drying

In current project work, trials are taken at three different pressure conditions (5 mbar, 7.5 mbar, 10 mbar) as well as for three different time durations (20 min, 40min, 60min) for both systems.
Results observed are given below:

3.1 For 5 mbar vacuum pressure

A) Moisture Extraction Rate

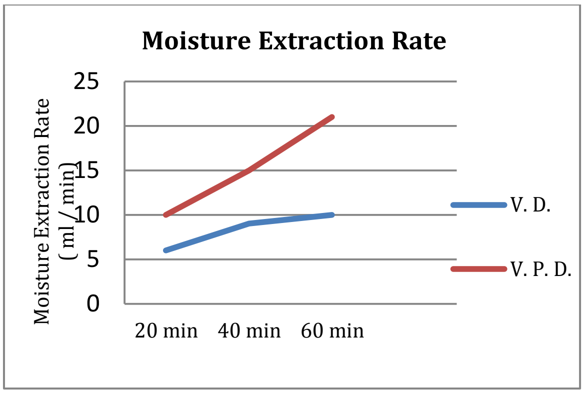

Fig.9 Graph of Moisture Extraction Rate against Time

Where,

V. D. = Vacuum Drying System

V. P. D. = Vapour Phase Drying System

Sample calculation for reading 1 (20 min)

From equations (1), For V.D.,

Moisture Extraction Rate = 130 – 124= 6 min/20 min

B) Drying Percentage

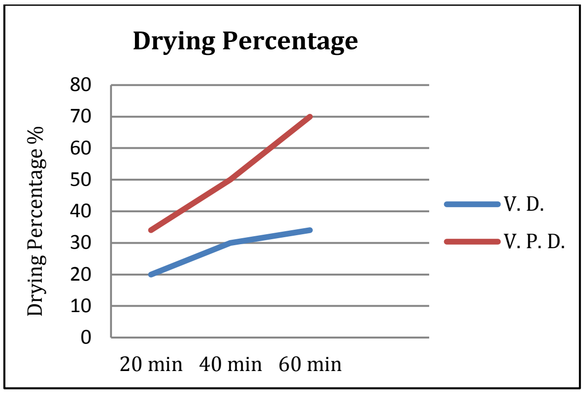

Fig.10 Graph of Drying Percentage against Time

Sample calculation for reading 1 (20 min)

From equations (2), For V.D.,

Drying Percentage $= \frac{30-24}{30} \times 100$ = 20 %

C) Percentage hike by use of VPD

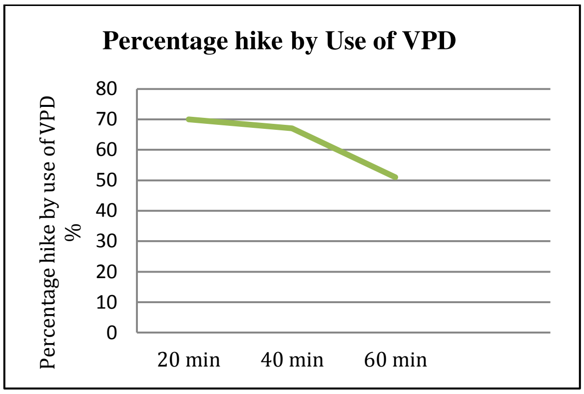

Fig.11 Graph of Percentage hike by use of VPD against Time

Sample calculation for reading 1 (20 min)

From equations (3),

Percentage hike by use of VPD $= \frac{34-20}{20} \times 100$

= 70 %

3.2 For 7.5 mbar vacuum pressure

A) Moisture Extraction Rate

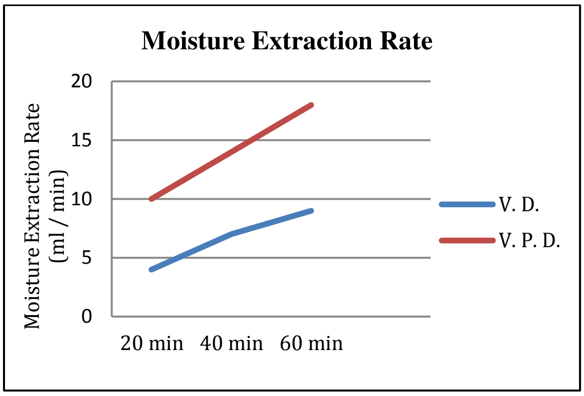

Fig.12 Graph of Moisture Extraction Rate against Time

B) Drying Percentage

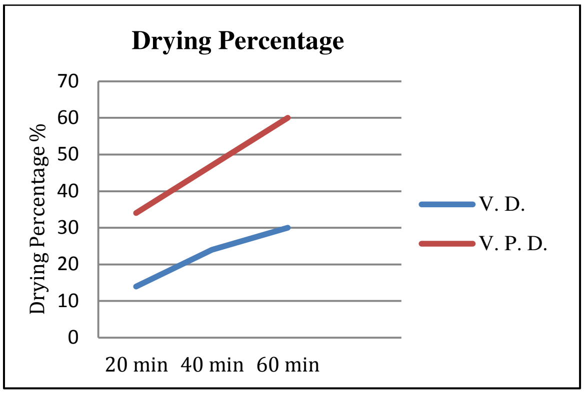

Fig.13 Graph of Drying Percentage against Time

C) Percentage hike by use of VPD

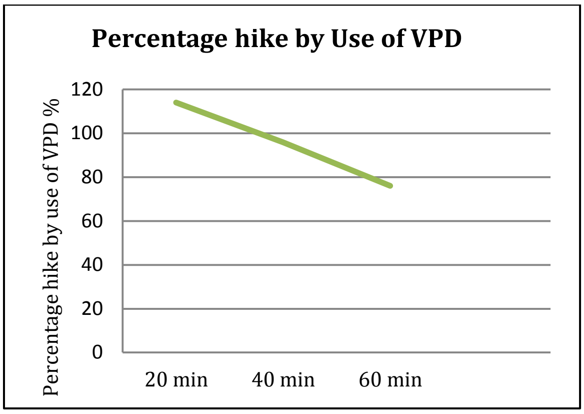

Fig.14 Graph of Percentage hike by use of VPD against Time

3.3 For 10 mbar vacuum pressure

A) Moisture Extraction Rate

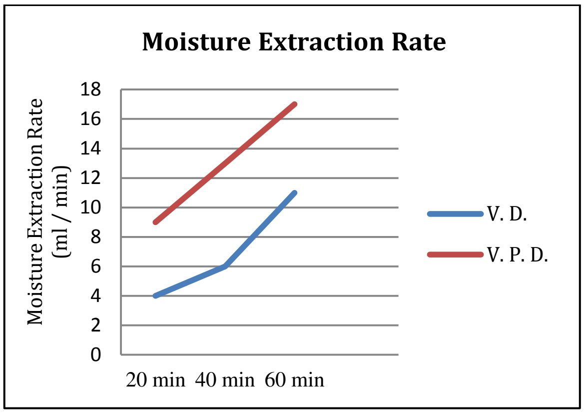

Fig.15 Graph of Moisture Extraction Rate against Time

B) Drying Percentage

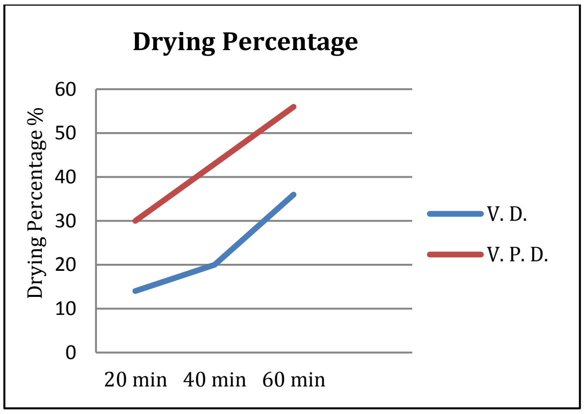

Fig.16 Graph of Drying Percentage against Time

C) Percentage hike by use of VPD

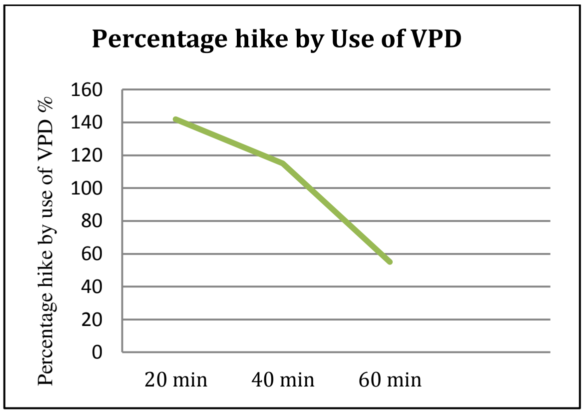

Fig.17 Graph of Percentage hike by use of VPDagainst Time

From figure 9, 12 and 15 it is observed that moisture extraction rate in case of Vapour Phase Drying System is always higher than that of Vacuum Drying System. Main reason behind this increase in moisture extraction rate is change in heating medium. In Vapour Phase DryingSystem heating is not through air. In this method the carrier of heat is vapour of low viscosity solvent like kerosene with a sufficiently high flash point instead of air. While selecting solvent for Vapour Phase Drying System following properties should beconsidered so that effective drying of sample can be achieved.

i. 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.
ii. Evaporation heat should be very high.
iii. The solvent must not have any effect on the insulation properties and their expected life.
iv. 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.
v. Flash point should be above 55°C

Some characteristic of Vapour Phase Drying system are given below. Because of such special features VapourPhase Drying System is always advantageous than Conventional Vacuum Drying System.

i. The entire process takes place in a practically oxygen free atmosphere. As a result,drying can be effected at higher temperature than conventional method.
ii. Heat is transmittedby a hydrocarbonvapour.Full use is being made of its heat of condensation.
iii. Heat is released to entire free surface of the material to be dried, especially to thecoldestpoint, where condensation is most active. The result is a largerheat-transfer surface than in conventional processes. Use of the condensation effect also ensuresheat transfer to internal surfaces of the material to be dried.As the net result of these variousfeatures shorter heating times are achieved with smaller temperature differences.
iv. Use of a heat carrierwith a lower vapourpressure than water ensures continuous water-extraction from initial heating to completionof the drying under high vacuum.

3.4 Result showing Moisture Extraction Rate against all Vacuum Pressures for V. P. D.

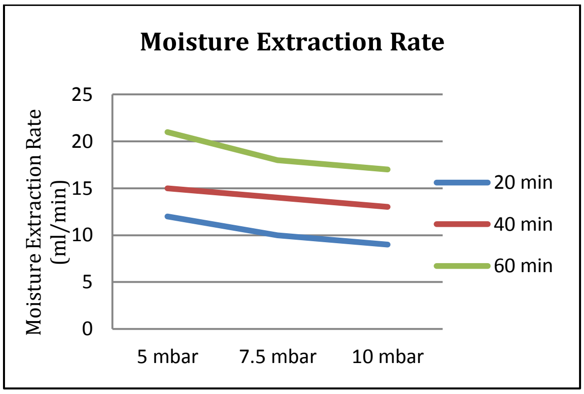

Fig.18 Graph of Moisture Extraction Rate against all Vacuum Pressures for V. P. D.

From all above results it is observed that moisture extraction rate decreases as vacuum pressure increases for Vapour Phase Drying System as well as for Vacuum Drying System.

4. Conclusions

After analysing the data of Moisture extraction rate in ml / min and drying percentage, it is seen that

i. There is 70 % increase in drying percentage of sample by use ofVapour Phase Drying System.
ii. There is reduction of 67% in the cycle time required for drying of sample in the Vapour Phase Drying.
iii. Moisture extraction rate increase as vacuum pressure decreases for all time durations in case of Vapour Phase Drying method.

Therefore it is established with this experimental analysis that the Vapour Phase Drying method is definitely advantageous over the conventional method in terms of Time required for drying, Moisture extraction rate and Drying percentage.

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