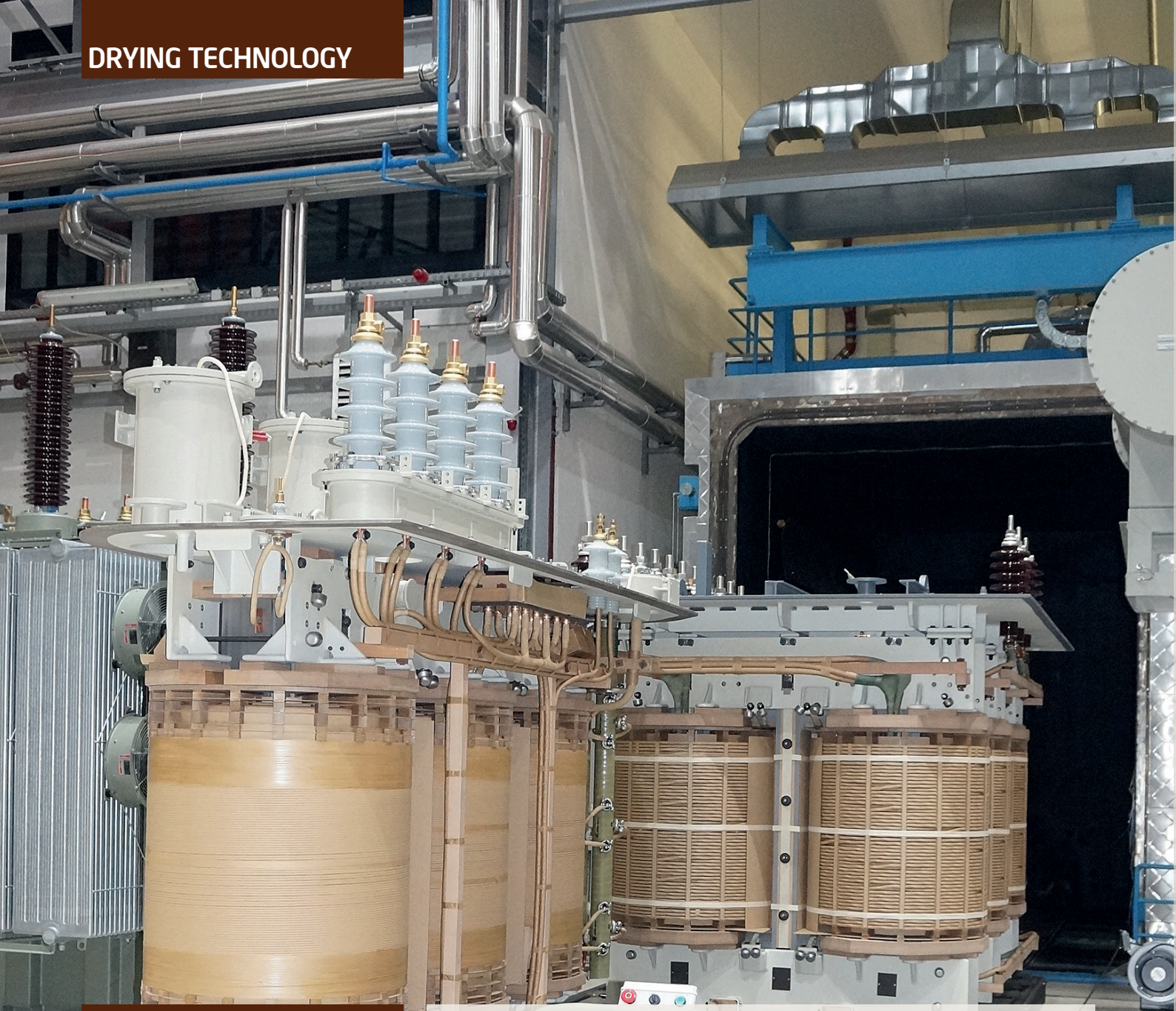

ABSTRACT

Vapor phase drying is the most effective method for drying transformer insulation in a manufacturing setting. The process does not lend itself well to transformer drying in the field for a variety of reasons, including the difficulty of removing residual kerosene which can cause a potential change in transformer oil flash point. Several techniques are available for transformer insulation drying in both the field and in manufacturing. Vapor phase drying as part of transformer manufacturing is discussed in this paper.

KEYWORDS

Vapor phase, transformer drying, vacuum chamber, VPD

Vapor phase transformer drying – Part II

Vapor phase drying as part of transformer manufacturing process

Photo courtesy of Končar D&ST, Zagreb, Croatia

Typical vapor phase steps

Loading of coil(s): One or more coils are loaded into the vapor phase vacuum chamber (autoclave). Typically, a number of thermocouples are installed at various locations (depths & heights) in the coils to monitor and record the load temperature throughout the process.

If isostatic pressing is part of the system, press plates are set and hydraulics are connected.

Leak test and preheat: After the coil is inside the chamber with thermocouples connected, the chamber door is closed. Pressure is reduced by vacuum to a preset level and leak-up rate is checked to verify a tight door seal and vacuum integrity of the chamber. Preheating of the system in preparation for the next step begins.

Wet cycle: Vacuum pump(s) lower the pressure in the chamber to the appropriate starting level. Solvent is then introduced into the chamber, heated and circulated through a spray system. Hot solvent being sprayed onto the load at reduced pressure transfers heat. The temperature and pressure of the system provide an environment for rapid water evaporation. Sufficient heat is added by the spray system to both replace lost latent heat from water evaporation, and also to raise the load temperature for the 'dry cycle' step. As the hot solvent contacts the load and transfers heat, its temperature drops so that it runs down into the solvent pool for recirculation.

In some products, a higher end temperature is required to set epoxy impregnated components. Precise temperature control is required so as to heat rapidly while minimizing overshoot of the upper temperature limit of the insulation.

Water evaporating from the load leaves the chamber through the vacuum system and is condensed for collection ahead of the vacuum pumps. Relatively small amounts of solvent that carry over with the water are also condensed and collected.

Typically 90-95 % of the total water content is removed during the wet cycle

The length of the wet cycle is determined by the load (coil: insulation & winding) size. Typically 90-95 % of the total water content is removed during the wet cycle. It is not possible to remove all of the water content in this part of the cycle because dryness level is dependent on the vacuum level. In this step the vacuum level is controlled to optimize solvent use efficiency in the chamber.

The end of the solvent cycle is determined primarily by the temperature of the load and/or the amount of water collected from the load. The process is instrument driven, but often minimum times are set in the controls based on the load size/mass and coil type.

Dry cycle: The solvent is pumped out of the chamber while low vacuum is maintained. After the solvent drain is complete, vacuum is no longer limited and the vacuum system is allowed to lower the pressure further causing the remaining moisture to evaporate.

Because the load was raised to a specific temperature during the wet cycle, there is adequate residual heat in the coil materials for the remaining water to evaporate without significant temperature drop. Platecoils or other chamber wall heating methods may also be employed to provide radiant heat for this part of the process. Platecoils also serve to minimize heat loss through the insulated chamber walls during high vacuum. This consideration is especially important on vapor phases for shell form transformers, which have a relatively smaller heat sink than core form (higher insulation to metal parts ratio).

High vacuum continues until the balance of the water is extracted. It is also during this time that residual vapor phase solvent will evaporate under high vacuum and be removed with the final water for collection. This results in all solvent being removed from the system prior to addition of transformer oil during impregnation.

Impregnation: Dry, degasified transformer oil is pumped into the chamber to submerge the load under oil. Vacuum is maintained until the load is under oil, at which time dry air or nitrogen is used to break vacuum back to atmospheric pressure.

In the absence of air and water in the coil, oil fills all voids in the assembly in a process known as impregnation.

Oil drain and unload: Transformer oil is pumped rapidly from the chamber so that the coil can be unloaded. Sometimes it is advantageous to allow the coil to sit under oil until the production floor is ready to use the coil in the next step of assembly.

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Figure 7 is taken from a typical vapor phase cycle. The bright red line is the vacuum level. Most of the other lines are temperatures read from thermocouples placed in various locations in the insulation being dried. The wet cycle can be seen between hours zero and 105 where it remains relatively flat during the spraying of Isopar to add heat. The temperature lines show how this raises the temperature of the insulation rapidly so that under low pressure, water is removed continuously through this step.

After all thermocouples achieve a minimum value (in this case 110 °C), and extracted water measures the expected quantity, Isopar is removed from the vacuum chamber and vacuum is no longer limited. As the pressure drops, the relatively small amount of remaining water continues to evaporate. This process continues until endpoint milestones

Several vacuum chamber configurations are available depending on the factory layout and the coil types to be processed

(final pressure, air dewpoint, etc.) are achieved.

Vapor phase vacuum chambers

Several vacuum chamber configurations are available depending on the factory layout and the coil types to be processed.

With sufficient overhead lift capability, a top loading configuration such as the one in Figure 8 (shown with a hydraulically opened clamshell cover) could be used.

End loading configurations such as the one shown in Figure 9 are available with either vertical or horizontal opening doors. A trolley system is used to shuttle the load in and out of the chamber.

Trolleys might accommodate single coils or multiples. Isostatic presses, as shown in Figure 10, may be integrated into the trolley to maintain pressure on the coils which will undergo shrinkage as water is removed from the cellulose.

Dryness / endpoint

Several methods can be employed to predict completion of the drying process:

Vacuum level & coil temperature: Piper charts like the one in Figure 11 provide a good indication of the water content remaining in the coil based on its temperature and the final vacuum level achieved. Often there is a hold time that must expire after achieving the vacuum level target with coil temperature maintained above a minimum value to reach the desired dry point as indicated by the chart.

Vacuum dew point: Dew point instruments that provide continuous moisture content in the vacuum stream leaving the vapor phase chamber are a good indicator of the dryness of the system. Most dew point instruments come on scale early in the high vacuum dry cycle. The dew point

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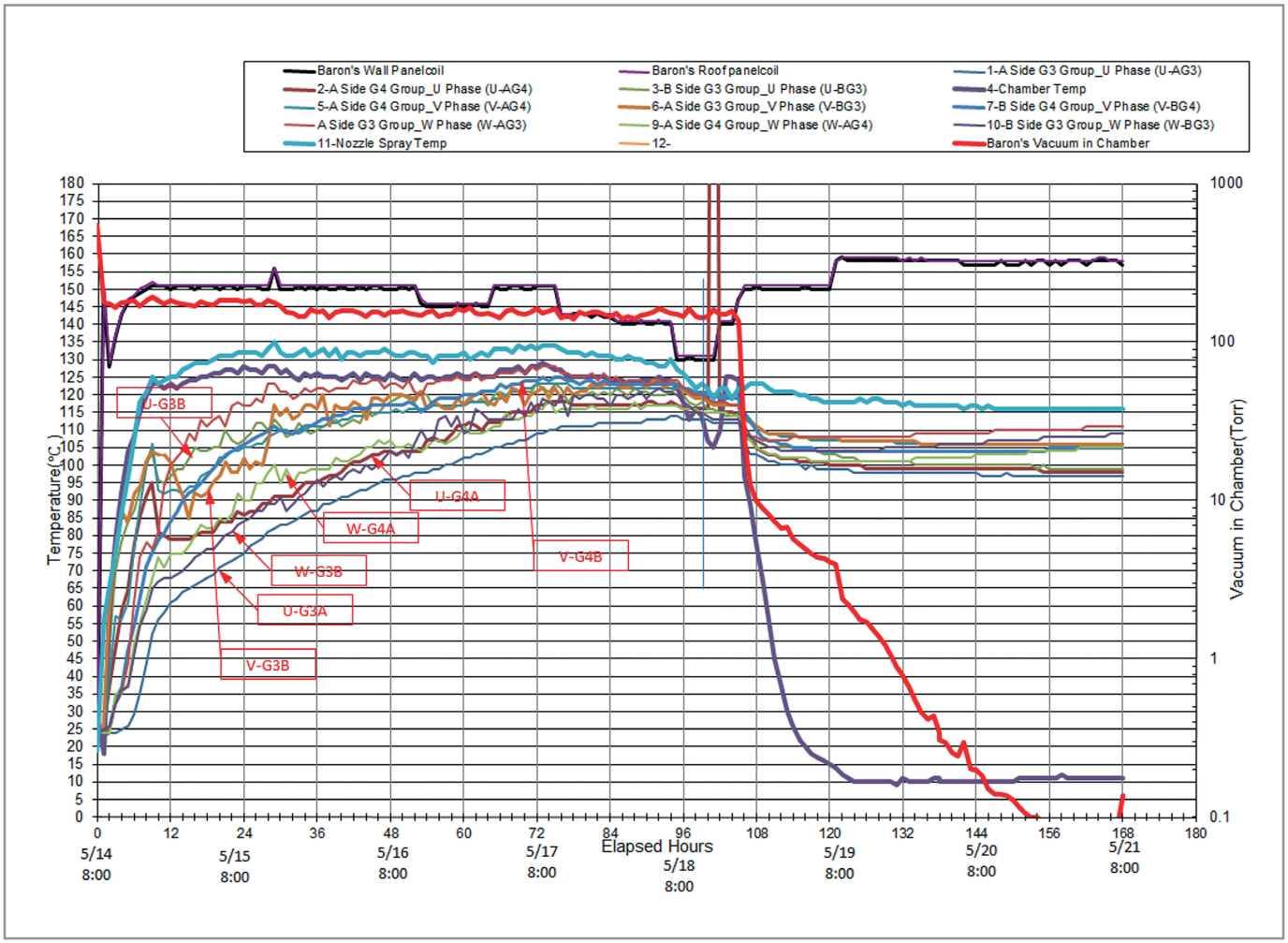

Figure 7. Sample vapor phase data curves with insulation temperature and vacuum levels vs time

drops continuously as the coil dries with dropping pressure achieving dew point values of -30 °C or below.

Capture extracted water and measure: The water and solvent condensed from the vacuum stream during the **wet** (***low*** vacuum) cycle are easily condensed, collected and separated. Filter-separators will strip much of the water and further separation can be achieved by settling as the mixture cools. The water (if desired) can be measured. During the ***high*** vacuum **drying** phase, the pressure is too low to collect the water by condensing and it must be frozen from the vacuum stream using a cascade freeze trap. Collected ice is thawed and added to the measured water collected. If complete measurement of the extracted water during the entire cycle is desired, cascade cold traps can be utilized for this part of the cycle.

Solvent handling / recovery VDU (Vacuum Distillation Unit)

Though the solvent can easily be filtered and water removed, it will gradually accumulate transformer oil. Even after complete draining of the oil after impregnation there is a residual film of oil inside the chamber that will be dissolved into the solvent during the subsequent vapor phase cycle. Since the oil will dissolve into solution, it cannot be filtered out. On systems without an oil impregnation cycle, residual oils within the active parts will eventually cause the same issue.

However, as was presented in the vapor pressure chart in Figure 5 in Part I of this paper, the solvent and transformer oil (or other residual oils) can be separated by vacuum distillation in a small VDU (vacuum distillation unit – Figure 12) with the like-new solvent returned to the source tank.

This continuous maintenance of the solvent ensures that the boiling range re-

The water and solvent condensed from the vacuum stream during the wet cycle are easily condensed, collected and separated

Figure 8: Top loading clamshell chamber

Figure 9: End loading chamber with trolley

The continuous maintenance of the solvent ensures that the boiling range remains constant so that results are repeatable from one vapor phase cycle to the next

mains constant so that results are repeatable from one vapor phase cycle to the next.

Transformer oil purification equipment

Transformer oil purifiers of adequate capacity to rapidly fill the vapor phase chamber with highly purified oil are an important part of the overall system. Different approaches can be taken to suit each situation.

Small purifier with vacuum storage: If adequate vacuum storage is available, oil can be dehydrated to low moisture and degasified to low gas content (typically <10 ppm water and 0.25 % dissolved gas) and then stored under vacuum to maintain these levels. A high speed pump can then be used to transfer oil to the vapor phase when required so that the purifier does not have to be as large to meet the high flow rate demand of the vapor phase.

High flow rate purifier: Alternately, a larger flow rate purifier can be used to single pass the oil from storage and to process it as it transfers into the vapor phase.

Multi-stage purifier: For classes of transformers requiring lower water content (1-3 ppm) and lower gas content levels (<0.1 % total gas), multi-stage purifiers are available (Figure 13) to process oil at levels <100 microns (0.10 Torr).

Transformer oil purifiers of adequate capacity to rapidly fill the vapor phase chamber with highly purified oil are an important part of the overall system

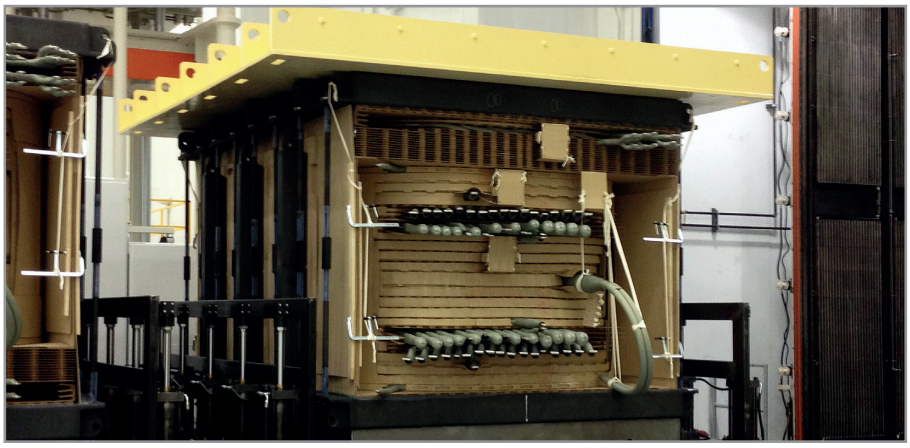

Figure 10: Isostatic press for shell form coil integrated into the trolley

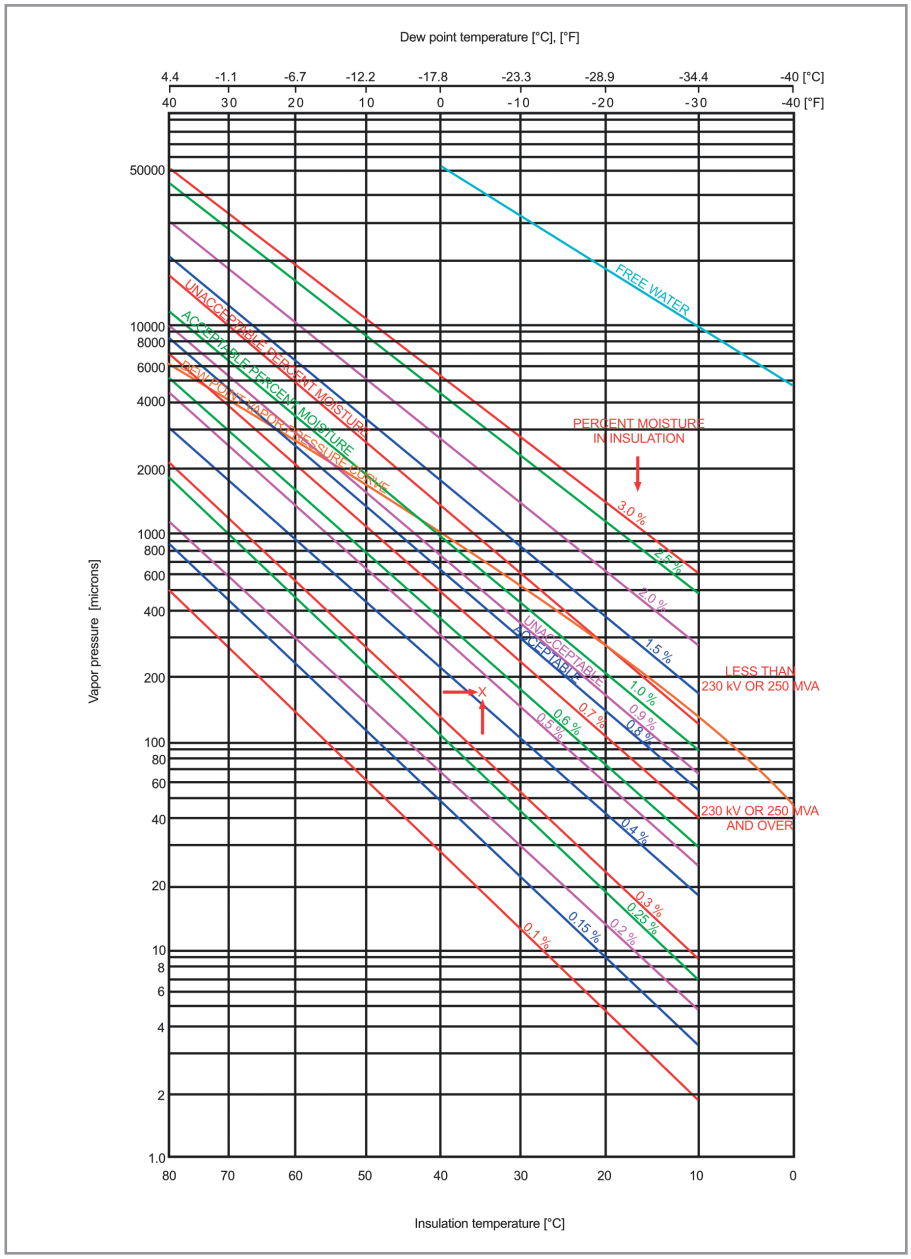

Figure 11. Piper chart (moisture equilibrium diagram)

By finding the intersection of the final pressure (vacuum) achieved during drying, and the insulation temperature at the final pressure, the colored line at the intersection provides a good estimate of the final percent of moisture (water) remaining in the insulation.

1,000 microns = 1 Torr (millimeter of mercury) = 1.33 mbar

Conclusion

Vapor phase drying is the most efficient and effective method for the drying of transformer insulation in a manufacturing setting. It is advantageous over other methods in terms of time, repeatability and quality of end product.

Author

Greg Steeves is the General Manager and principle engineer of Baron USA, LLC, provider of transformer dry-out and dielectric fluid processing systems for OEM's, utilities and field service organizations worldwide. Greg joined Baron USA as Engineering Manager in 1987. He is currently responsible for managing the daily operations and overseeing the application, engineering design and manufacturing of oil purification equipment, vacuum chambers, vapor phase processing and transformer dry-out equipment. He earned his degree in Mechanical Engineering from Tennessee Technological University and is licensed in the state of Tennessee.

Figure 12. Vacuum Distillation Unit for solvent (VDU)

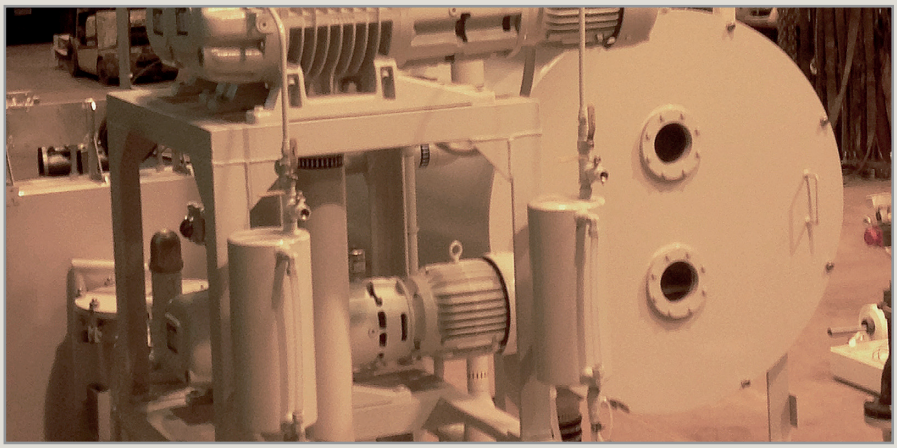

Figure 13. Multi-stage oil purifier