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Where Does the Air Go?

By

Don Platts, Omicron
Dave Hanson, TJ|H2b Analytical Services

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Authors: Don Platts, Omicron
Dave Hanson, TJ|H2b Analytical Services

Abstract

Oil sampling to measure insulating liquid quality and perform dissolved-gas-analysis has been a cornerstone of the typical transformer maintenance program for several decades. In that timeframe, several monitoring products have been developed that also require a connection with the oil inside the tank. There are many oil sampling procedures available from ASTM, transformer manufacturers, service providers, and oil testing laboratories. The typical transformer owner assumes that if the sampling is done according to any of these procedures, or the monitors are installed per the manufacturers' instructions, that there is little or no risk involved.

Recent investigations have confirmed that these procedures may not always prevent air bubbles from entering the transformer tank when the samples are taken, or the monitor is commissioned. Further, for some specific cases, following those procedures will ensure that air bubbles will enter the transformer tank. Obviously, there is a serious risk of failure when air bubbles enter an energized transformer.

This paper and presentation will address the issues and define the conditions under which the ingress of air bubbles is certain to occur, even when the transformer is built according to IEEE standards, and the generally accepted procedures are followed.

Introduction

When author Don Platts worked for an electric utility, he purchased transformers that were delivered with a 'non-standard' drain valve. Rather than getting the typical globe valve, this was a ball valve. While the crew doing the assembly and oil fill liked this new valve, he raised a question about a potential problem that could be foreseen when taking oil samples from this valve. Specifically -- **Where does the air go?**

A review of industry standards, guides and instructions on sampling electrical insulating liquids reveals that the collective knowledge about this question has been reduced to a single caution. Do not sample from a tank under negative pressure. This caution has seemed adequate, since in their 80± years of collective experience in the industry, the authors are not specifically aware of a single flashover or failure of energized equipment due to sampling.

Nonetheless, the question remained and, when the authors and a transformer valve had a chance meeting at an industry event, the question was rekindled. The authors agreed to conduct a study to see what they might learn.

The obvious danger of having an air bubble move into the transformer is that this sampling is normally done with the transformer in-service. So the energized low voltage winding, leads, bushings, and perhaps a de-energized tap changer, or load tap changer leads will be in the vicinity of the path where this bubble will flow through the oil as it floats to the top of the oil volume.

Common sampling practices are illustrated in Figure 1

Common sampling practices

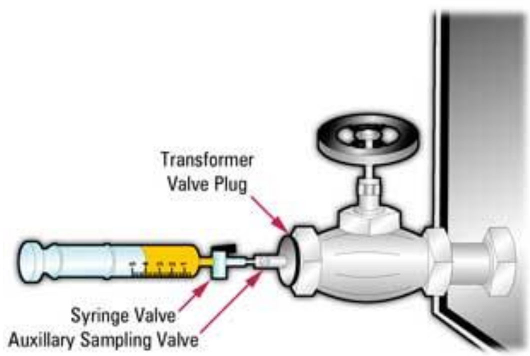


Figure 1 Common sampling practices

Review of Valve Types

Before we discuss the issues involved with sampling or installing a monitor probe, let's review the variety of valves that have been used as Transformer Drain Valves (as shown in Figure 2):

- Globe Valve
  - This valve provides a restricted flow path, resulting in turbulent flow. It can be used to regulate the flow rate of the liquid as multiple handle rotations are required to fully open or close it. This valve type was required by IEEE standards until the 1980's. In the field, it can be identified by the appearance of the valve body and by feeling the unusual, non-uniform, shape of the protrusions in the valve cavity. See Figure 3.

- Ball Valve
  - This valve can provide a 'full bore opening' through the valve to allow insertion of a probe. It has a 90°handle rotation to operate between fully open and fully closed. In the field, it can be identified by the appearance of the valve body and by feeling the smooth surface of the ball inside the valve cavity. See Figure 4.

- Gate Valve
    - This valve can provide a ‘full bore opening’ through the valve to allow insertion of a probe. It can be used to regulate low pressure flow of the liquid as multiple handle rotations are required to fully open or close it. In the field, it can be identified by the appearance of the valve body and by feeling the non-uniform, yet relatively flat, shape of the gate that serves as the blocking device inside the valve cavity. See Figure 5.

Figure 2 Photo of Globe, Ball, and Gate Valves. Note the differences in the construction of valve bodies.

Illustrations of a Globe Valve

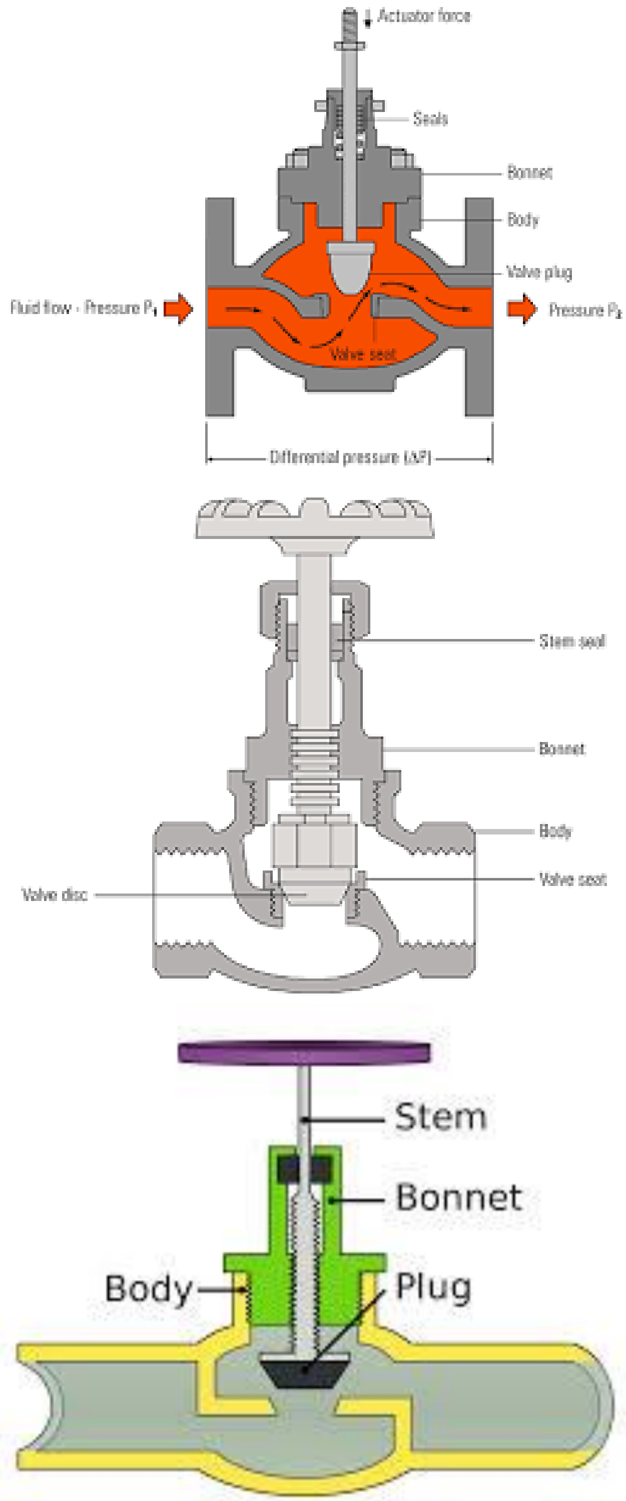


Figure 3 Globe Valves

Illustrations of a Ball Valve

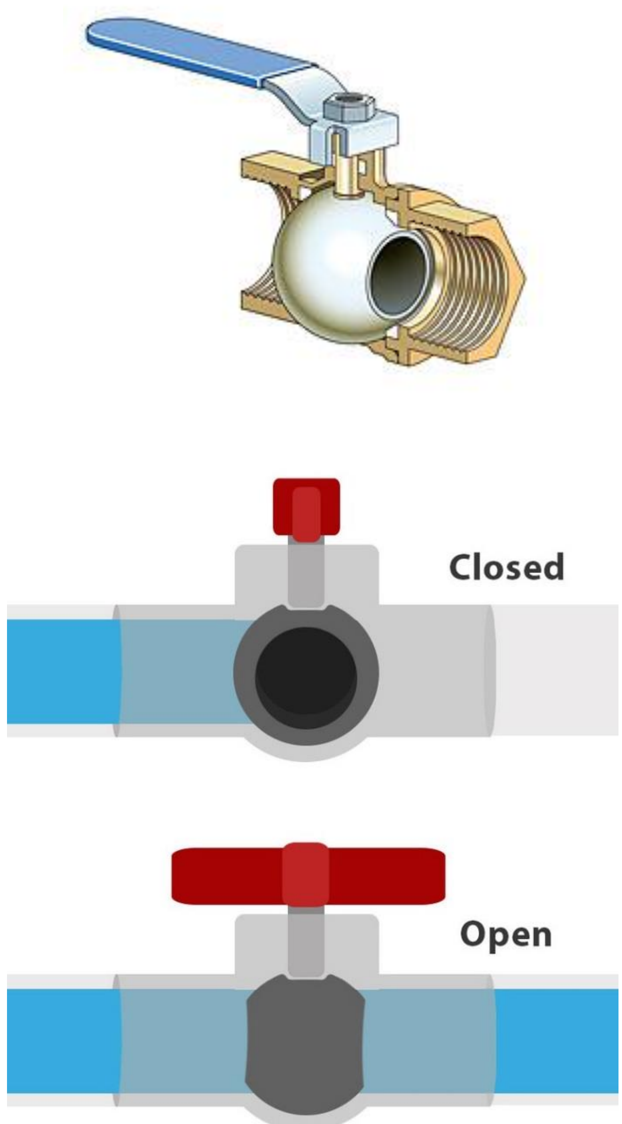


Figure 4 Ball Valves – a ball with a hole through it rotates around a vertical axis. Either allowing flow, or blocking flow.

Illustrations of a Gate Valve

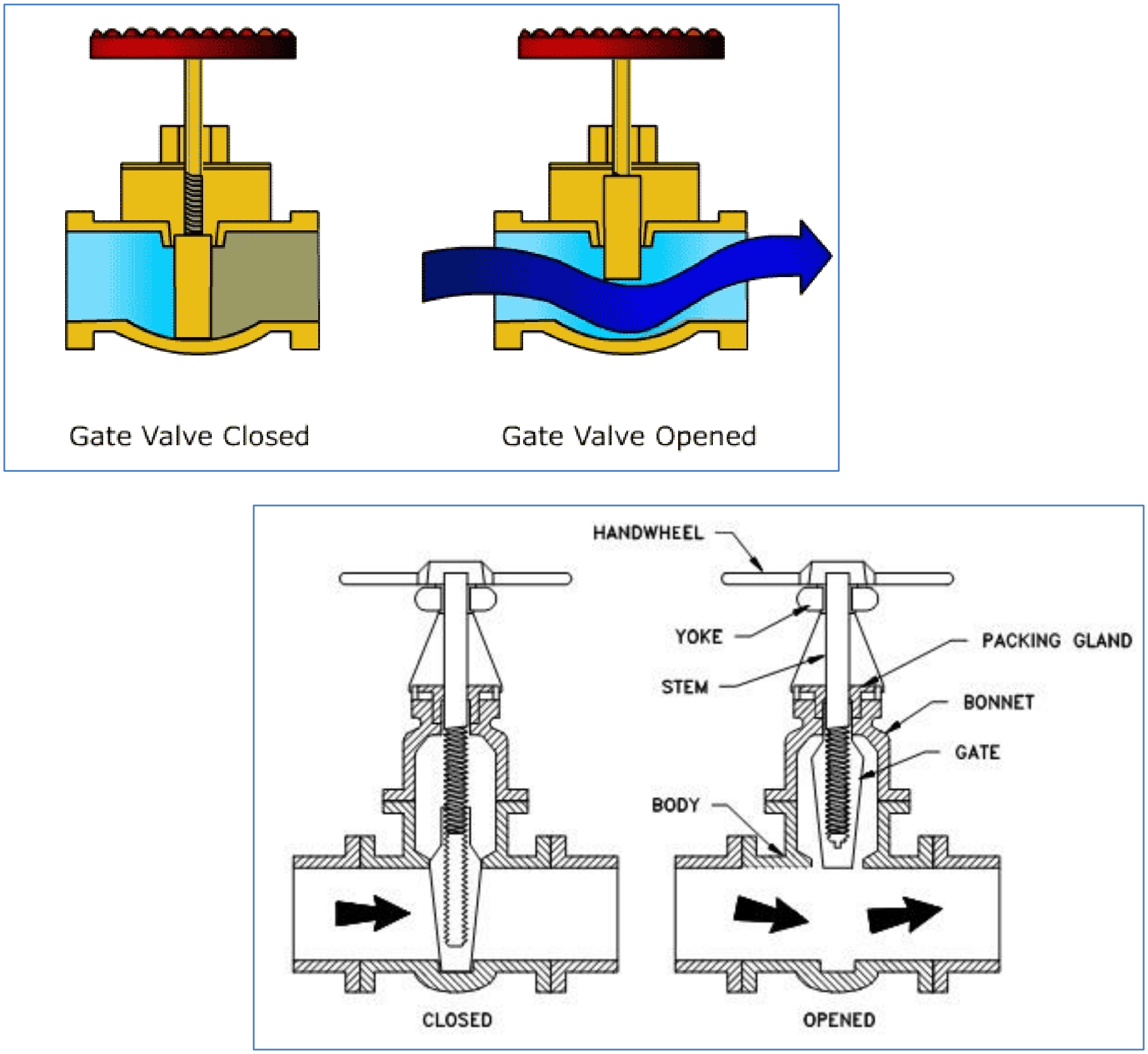


Figure 5 Gate Valves

Theory – Forces that lead to air ingress into the transformer:

It is recognized by the industry that sampling from a transformer with an internal pressure less than atmospheric pressure (also called negative gauge pressure) can lead to air ingress. The reason for this is simple. Remembering that pressure equals force per unit area, the force exerted by air at the air/liquid interface will be greater than the force exerted by the liquid. When that happens, air will enter.

In another scenario, consider what happens to air that is trapped in the valve body against the valve face when the valve is opened. For this discussion let's assume that the transformer is under positive gauge pressure. When the valve is opened a few things will happen:

1. With the pressure of the liquid being greater than the air, liquid will flow through the valve.
2. As the liquid begins to move past the valve face, the trapped air will compress.
3. Because of the difference in densities the liquid will move under the air.
4. With the liquid under the air, the air will experience buoyant forces.
5. Air that is no longer restrained by the valve face will enter the transformer.

From a review of Figures 6, 7 and 8 you can see that each valve type presents a different degree of opportunity for air ingress under this scenario. The ball valve loses all restraint at the valve face the moment it is opened. The gate valve loses restraint at the valve face by degree as the gate is raised. The globe valve uses buoyant forces provided by the liquid to maintain a level of restraint as the valve is fully opened.

In a third scenario, consider what happens to air in the valve body against the valve face that is not trapped. For this discussion let's assume the transformer is under positive gauge pressure. When the valve is opened a few things will happen:

1. With the pressure of the liquid being greater than the air, liquid will flow through the valve
2. As the liquid begins to move past the valve face, the air will not compress but rather will be moved by the liquid.
3. Because of the difference in densities the liquid will move under some of the air.
4. Where the liquid is under air, that air will experience buoyant forces.
5. Some of that air may become trapped in pockets.
6. The remaining air will be moved away from the valve. If any air becomes trapped against the valve face, it could become subject to the second scenario.

Illustrations of a Ball Valve Operation:

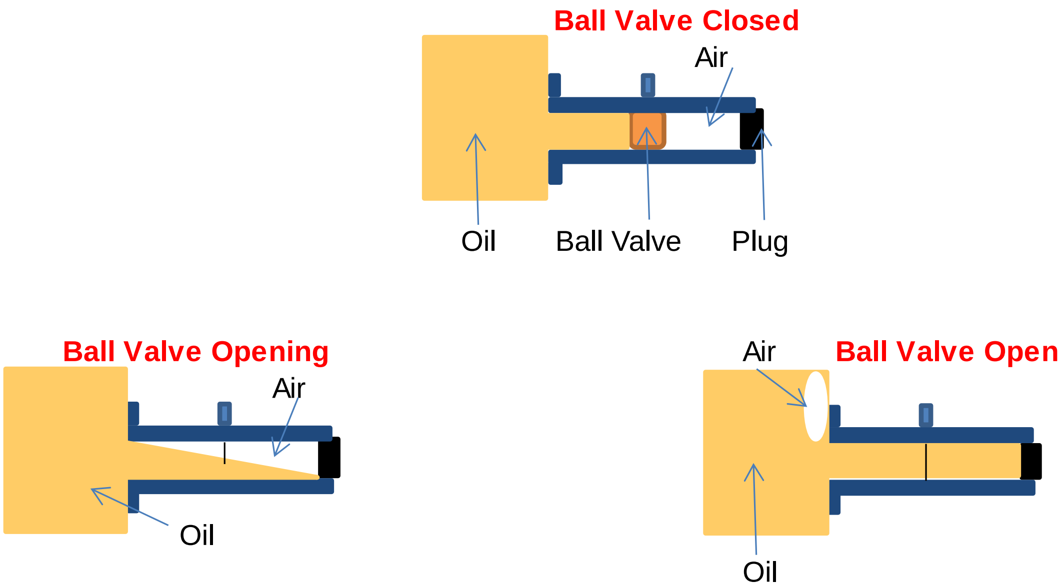
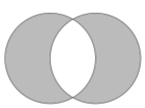


Figure 6: Danger of a Ball Valve when used as a transformer drain valve

A ball with a hole through it sits in the center of the valve body, and rotates on its vertical axis as the handle is moved. As the ball starts to rotate from its closed position, toward the open position, a small opening in the shape of a football, (or vesical pincis) appears. It is oriented vertically, so that it allows for the liquid to move under pressure, and to compress the air in the valve cavity, until the air in the space moves through the opening and back into the transformer.


The vesical pincis, or mandorla, shape is the white “football” shape in this diagram.

Illustrations of a Gate Valve Operation:

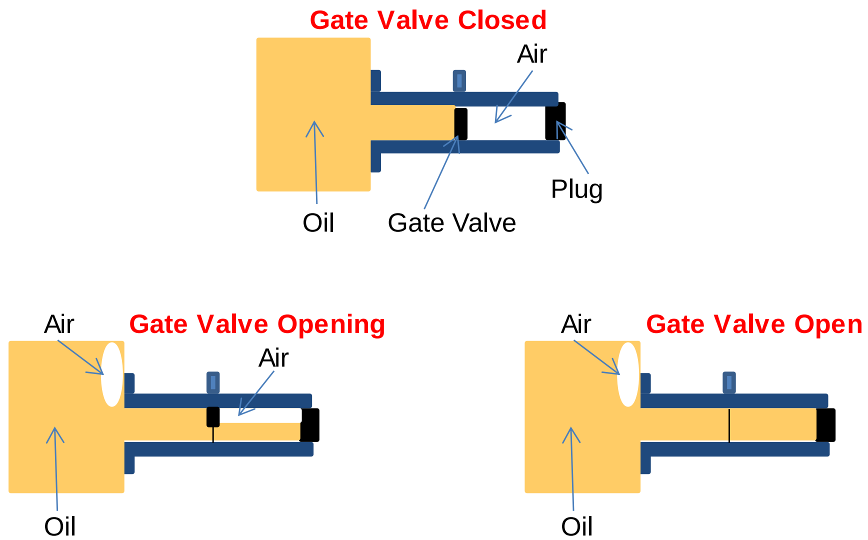


Figure 7: Danger of Gate Valve used as a transformer drain valve

A gate sits in the center of the valve body, and moves up and down on its vertical axis as the handle is rotated. As the gate lifts from its closed position, toward the open position, a small opening in the base of the valve cavity appears. It is oriented horizontally, so that it allows the liquid to move, under pressure, and to compress the air in the valve cavity. When the valve outlet is blocked or connected to a closed sampling system, the air in the space reaches a high enough pressure so that it moves through the opening and back into the transformer.

Illustrations of a Globe Valve Operation:

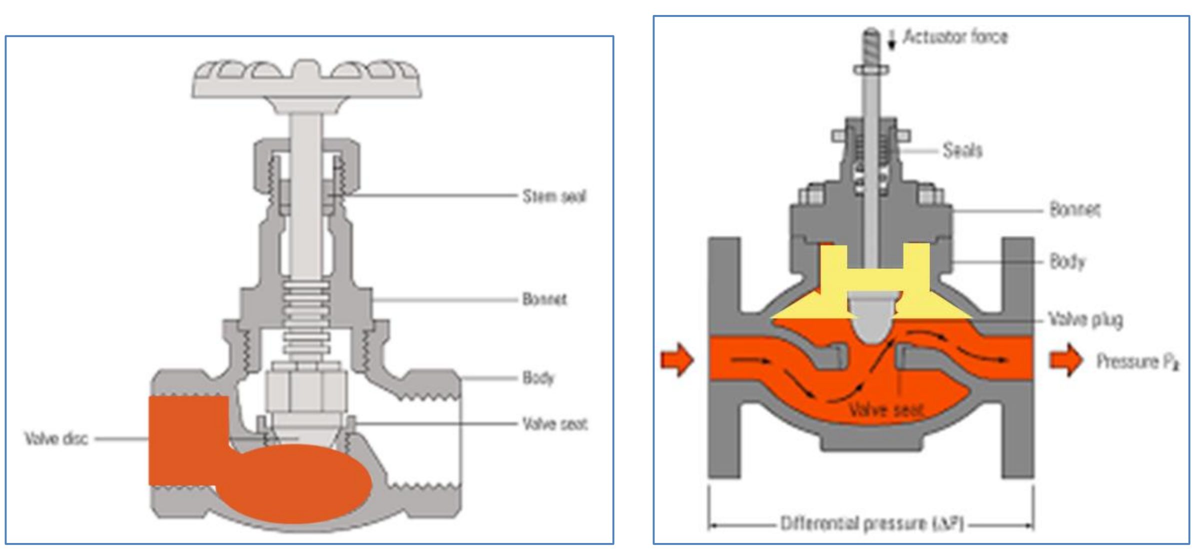


Figure 8: Minimal Danger with Globe Valve used as a transformer drain valve

The compressed air (yellow) floats above the liquid (orange) in the valve

A valve disk sits in a valve seat in the center of the valve body, and moves up and down on its vertical axis as the handle is rotated. As the valve disk lifts from its closed position, toward the open position, a small opening is created at the valve seat. It is oriented horizontally, so that it allows the liquid to move, under pressure, and to compress the air in the valve cavity. When the valve outlet is blocked or connected to a closed sampling system, the air is trapped in the valve cavity and cannot move down through the opening and back into the transformer. When the opening is unrestricted, some of the air will be forced out of the valve exit, with the flow of the liquid.

Test of the Theory

TJH2b and Omicron have both conducted tests using models of a transformer tank, with the various valves mounted on the models.

A series of test protocols were developed to address such questions as:

1. Will air enter the tank with the valve opening sealed by the original pipe plug - when the valve is opened?
2. Will air enter the tank when the valve opening is closed by a sampling plug and port, but there is no restriction in the tubing attached to the sampling plug?
3. Will air enter the tank when the valve opening is closed by a 2nd valve in the sampling connection? (see Figure 9)
4. Is it possible to safely test for positive pressure in the transformer tank using the documented procedures?
5. Does the pressure inside the tank effect the results?
   a. When there is a positive pressure in the tank

b. With a negative pressure in the tank at the valve?

6. Do the procedures we found for installing monitoring products prevent air intrusion?

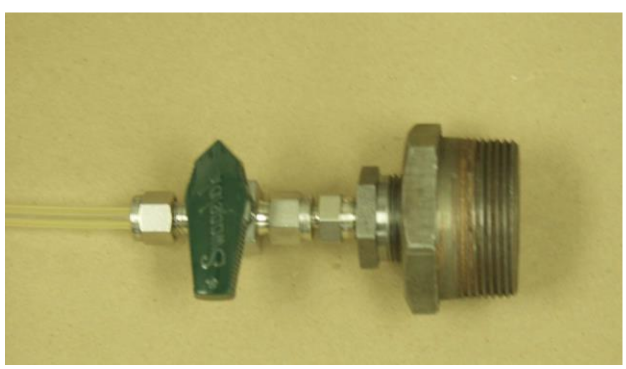


Figure 9: Sampling kit used by some utilities, with a pipe plug and reducer, small ball valve to control flow through the tubing, and fittings to connect to tubing

Sampling Experimental Setup

A pressure chamber that could be filled with liquids and gases was built to test a variety of sampling conditions. See Figure 10. The chamber was made to allow different valve types to be fitted to it. Fittings on the top of the chamber allow the chamber to be pressurized or evacuated. Pressure in the chamber can be monitored using fixed upper and lower pressure gauges. Water was chosen as the liquid for the studies described here and air was chosen as the gas.

Each study used a particular drain valve and a particular configuration of sampling equipment for collecting samples from the chamber. Chamber gauge pressures of -100KPa, -75KPa, -50KPA, 25KPa, 0KPa, 25KPa, 50KPa, 75KPa, 100KPa, 125KPa, 150KPa and 175KPa were used for the trials in each study. As a sample was collected using each combination of a particular drain valve, configuration of sampling equipment and chamber pressure, the entire assembly was observed for bubble ingress. See Figure 11. All bubbles were recorded regardless of size.

In the studies presented here, three types of drain valves were used, gate valves, globe valves and ball valves. The different configurations of sampling equipment can be broadly categorized into two groups: sampling equipment that completely closes the airspace external to the valve face (Restricted) and sampling equipment that does not close the airspace external to the valve face (Unrestricted). A summary of these studies is found in Tables 1 and 2.

Figure 10: Test Chamber –TJH2b
Figure 11: Result with bubble ingress

The Effect of Restricted Air Space at the Exterior Face of the Valve			
	Valve Type		
Tank Pressure (Gauge)	Ball Valve	Gate Valve	Globe Valve
-100kPa	Bubble	Bubble	Bubble
-75kPa	Bubble	Bubble	Bubble
-50kPa	Bubble	Bubble	Bubble
-25kPa	Bubble	Bubble	Bubble
0kPa	Bubble	Bubble	No Bubble
25kPa	Bubble	Bubble	No Bubble
50kPa	Bubble	Bubble	No Bubble
75kPa	Bubble	Bubble	No Bubble
100kPa	Bubble	Bubble	No Bubble
125kPa	Bubble	Bubble	No Bubble
150kPa	Bubble	Bubble	No Bubble
175kPa	Bubble	Bubble	No Bubble

Table 1 Results for situations where the air cannot escape such as a valve fitted with a pipe plug, or a closed valve in sample tubing.

The Effect of Unrestricted Air Space at the Exterior Face of the Valve			
	Valve Type		
Tank Pressure (Gauge)	Ball Valve	Gate Valve	Globe Valve
-100kPa	Bubble	Bubble	Bubble
-75kPa	Bubble	Bubble	Bubble
-50kPa	Bubble	Bubble	Bubble
-25kPa	Bubble	Bubble	Bubble
0kPa	No Bubble	No Bubble	No Bubble
25kPa	No Bubble	No Bubble	No Bubble
50kPa	No Bubble	No Bubble	No Bubble
75kPa	No Bubble	No Bubble	No Bubble
100kPa	No Bubble	No Bubble	No Bubble
125kPa	No Bubble	No Bubble	No Bubble
150kPa	No Bubble	No Bubble	No Bubble
175kPa	No Bubble	No Bubble	No Bubble

Table 2 Results for situations where the air can escape such as a valve without a pipe plug, or without a closed valve in sample tubing

Evaluation of the Test Results:

Sampling with vacuum or negative gauge pressure in the transformer tank

There is no way to safely sample a transformer while it is under vacuum or negative gauge pressure. Be certain to confirm positive pressure before sampling

Testing for pressure with vacuum or negative gauge pressure in the transformer tank

Most sampling procedures include a test to determine if there is a positive pressure in the tank. Our test results demonstrate that they will be successful, if there is a positive pressure.

However, if there is a negative pressure in the tank at the valve, the test for pressure could be disastrous. Refer to the tables above, for cases with negative pressures, (-25 to -100kPa). There is no valve type that will allow safe opening of the drain valve without air entering the transformer.

The conclusion from this is that we must recommend that you do not perform a test for positive pressure, on an energized transformer, if there is any chance that the pressure is negative. If you know that there is no chance of a negative pressure, then again there is no need to perform the pressure check.

Sampling with a closed valve on the sampling fittings or tubing

The oil sampling procedure, or monitoring system installation procedure may include one or more steps where the result of those actions would be that air is forced into the transformer tank. If it includes any step to open a valve where there is a closed system (or just a pipe plug) attached to the external side of the valve, the procedure may need to be modified.

As shown in the tables above, the only valve type that will allow that operation without bubble ingress is the globe valve.

Concerns about Valve Type

If a transformer has a ball valve or gate valve as the drain valve, and it must be used for sampling, then we urge you to carefully review the procedures that you use, to ensure that you have a path for the air to escape whenever you open the valve, or when you touch a partially open valve. If this valve is used for a monitoring product, we urge you to carefully investigate the results of the installation and the procedures that are provided to you.

As noted before, the globe valve was the standard type of drain valve up until the 1980's, when some customers started to ask for a "full bore opening" design of valve to accommodate monitoring products. Many, but not all, manufacturers still use the globe valve as their standard drain valve. As a result, most transformers in-service today will not be effected by the issue of air ingress --with a positive pressure inside the tank.

Oil Preservation System, and the effect on the pressure in the tank

From the test results above, it is clear that there is no safe way to prevent air from entering a transformer if there is a negative pressure at the sampling location. Therefore, we need to address the topic of verification of the tank pressure very carefully. To do so, we need to realize that there are 3 different oil preservation systems widely used in the industry.

1. The sealed tank design has a layer of nitrogen above the transformer oil. It is compressible and allows space for the expansion and contraction of the oil.
2. There is a pressurized nitrogen system, where the blanket of nitrogen is supplemented with a high pressure nitrogen supply cylinder. Through regulators, it will maintain the pressure of the nitrogen in a close range of approximately (+/-) 3-8 psi. These setting are adjustable, and will vary from one operator to another.
3. The third is a conservator tank design. The conservator is mounted above the main tank and any bushing turrets, and serves as an expansion tank for the oil. The main tank is completely filled. Generally, there is a rubber bag or bladder in the conservator to separate the oil from the oxygen and moisture in the atmosphere.

In a conservator design, if the valve to the conservator is open, and the transformer is performing normally, there will always be a static head pressure in the liquid at the sampling valve. The amount of pressure can be calculated as shown in the Appendix. It is dependent of the height differential between the maximum oil level and the valve. If you suspect that the oil flow into, and out of, the conservator is not operating properly, and that there might be a chance of a negative pressure in the main tank, then we recommend that you do not attempt to take a sample.

In a pressurized nitrogen system, there are alarms for high and low pressure, and for low pressure in the supply tank of nitrogen. So if the system is not in an alarm condition, there will be a small pressure above the oil. To decide if it is safe to sample, you will need to rely on the pressure gauges. If you do not trust these gauges and regulators, or if there might be a chance of a negative pressure in the main tank, then we recommend that you do not attempt to take a sample.

In a sealed tank design, there will be a pressure/vacuum gauge, and a pressure/vacuum breather to regulate the pressure inside the tank under normal operating conditions. To ensure safe sampling, you will need to rely on the pressure gauges. If there might be a chance of a negative pressure in the main tank, then we recommend that you do not attempt to take a sample.

Calculation of expected static head pressure at the drain valve, based on the height of the oil above the valve.

Calculation of Static Head Pressure					Calculation of Static Head Pressure			
Liquid Height	psi gauge		N2 blanket		Liquid Height	psi gauge		N2 blanket
Feet	Water	Mineral Oil	gage		Feet	Water	Mineral Oil	gage
1	0.43	0.40			13	5.63	5.18	
2	0.87	0.80			14	6.06	5.58	
3	1.30	1.19			15	6.49	5.97	
4	1.73	1.59			16	6.93	6.37	
5	2.16	1.99			17	7.36	6.77	
6	2.60	2.39			18	7.79	7.17	
7	3.03	2.79			19	8.23	7.57	
8	3.46	3.19			20	8.66	7.97	
9	3.90	3.58			21	9.09	8.36	
10	4.33	3.98			22	9.52	8.76	
11	4.76	4.38			23	9.96	9.16	
12	5.19	4.78			24	10.39	9.56	
					25	10.82	9.96	

Table 3
Note: This table of calculated pressures is based on the assumptions of a mineral oil with a specific gravity of 0.92, and a water specific weight measured at 4°C. The pressure will vary with water/oil temperature.

Some transformer operators may decide to look at this problem and modify their procedures taking into account that a negative gas pressure measured above the oil does not always mean that there will be a negative pressure at the sampling valve. See Table 3. For example, if you read a -2 psi on the nitrogen gauge, and you believe it, you could look at the table above and find that for a large transformer with 18 ft. of oil to provide the pressure, there should be a static head pressure of 7.17 psi at the valve. Then, you could conclude that the actual pressure at the valve should be 5.17 psi; a value that would certainly be safe for taking samples. Since there is a risk of the gauge being out of calibration, and this table being inaccurate for many operating temperatures, we do not recommend this practice, but acknowledge that it could be used.

Installation of Monitoring System Components

The test results confirm that some monitoring product installation procedures can result in the introduction of air into a transformer. A procedure that tells you to install a monitor's probe by connecting it to the drain valve, then opening the drain valve, and then opening a port to bleed out the air in the system, is one that would be risky. The problems we have identified above will lead to air entering the transformer, before it can be bled out of the system. As a minimum, the bleed port should be opened – *Before* the drain valve is opened.

However, a bleed port that has a restriction, like a captured bleed screw, may not provide a sufficient open cross sectional area to allow the required volume of air to vent fast enough to prevent bubble ingress into a transformer. In those cases, trapped air can still be free to flow directly into the transformer tank, when the valve is opened. Tests done by Omicron have confirmed that this is possible, and could be a serious concern.

Only a few systems have been reviewed for this paper, we urge you to carefully investigate the results of the installation and the procedures that are provided to you, before attempting to install a monitoring system on an energized transformer.

Sampling Procedures

ASTM Sampling Procedures:

Relevant parts of the ASTM standard **ASTM D923-07 --Standard Practices for Sampling Electrical Insulating Liquids,** have been copied below

The test for positive pressure (ASTM D923-07, clause 7.2) must be modified, or eliminated, to prevent air from entering the transformer when there is a negative pressure at the valve. Our tests have demonstrated that when the drain valve is opened with a negative pressure inside the tank, air will always be drawn into the transformer. As a result, the condition that we want to avoid is actually caused by following this testing procedure.

> **ASTM D923-07 --Standard Practices for Sampling Electrical Insulating Liquids**
> 7.2 Check for positive pressure at a sampling outlet by placing a slug of insulating liquid in a piece of clear oil resistant plastic tubing and attaching it to the sampling port (also known as sampling cock) located on the side of the drain valve. With the valve closed, remove the drain valve pipe plug, making sure to catch any waste and debris, and then reinstall the pipe plug to equalize the pressure. While observing the slug of insulating liquid, open the sampling port and then slowly open the drain valve. If the slug moves towards the electrical apparatus, a negative pressure exists, and sampling is to be discontinued. If the slug moves away from the electrical apparatus, a positive pressure exists, and samples can be obtained safely. Close the drain valve and then close the drain valve port. Take extreme care in performing this procedure.

Implications for Oil Sampling Procedures and IEEE Standards

If someone attempts to take an oil sample from a ball valve or a gate valve, using standard techniques and equipment, an air bubble could very likely be introduced into the transformer. We recommend that all organizations that have published a sampling procedure take the time to study this paper, conduct their own experiments, and revise their sampling procedures, as necessary.

We recommend that the relevant IEEE (and IEC) Standards should dictate that drain valves, and any other valve specified by the user to be used as a sampling valve, must be a Globe valve.

Additional Concern:

If the valve face is not plumb (see sketch Figure 11), then the valve cavity will not have a level, horizontal top surface. This condition may be caused by several mechanisms. The valve may have been mounted that way during manufacture, it may have been bent and damaged during shipping and handling, or the transformer foundation may have settled, and the whole assembly is not level and plumb.

If the valve sealing mechanism is located at a slightly higher elevation than the valve opening, there will be a space that can trap a bubble, even when the rest of the valve cavity has been purged and filled with liquid. If the valve is opened fully, under this condition, this is another scenario where an air bubble can enter the transformer.

Our recommendation is that before taking a sample from a ball or gate valve, the valve opening be checked with a level to determine that it is essentially plumb. If the valve has a significant deviation from vertical, (as illustrated below) we do not recommend taking the sample. However, if it is tilted the other way, any bubble would be trapped at the open end of the valve, and then should not be a concern.

This is equally critical for the installation of monitoring device connections. If you find this type of condition, we recommend that you verify with the manufacturer that the installation can be done safely.

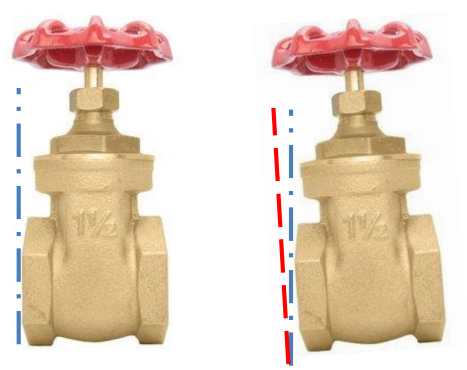


Figure 11 Blue line is vertical. Red line in second photo indicates actual angle of the valve opening face. It is not vertical, or plumb.

Summary

There are many oil sampling procedures available from ASTM, transformer manufacturers, service providers, and oil testing laboratories. The typical transformer owner assumes that if the sampling is done according to any of these procedures, and when a monitoring device is installed per the manufacturers' instructions, that there is little or no risk involved.

The tests performed in these studies have documented cases where it is certain that air will enter the transformer, during the procedures described. Further, there are several other cases where it is very likely that air will enter the transformer during the sampling procedure, or the installation of a monitor. Even with a valid sampling procedure, a very simple error of opening the wrong valve first could lead to introducing a large air bubble into the oil where it could affect the dielectric strength of the oil and solid insulation materials, leading to a potential transformer failure.

Negative pressure inside the main tank

All of the tests that have been done, demonstrated that air will flow into the transformer, when the valve is opened, if the pressure inside the valve is less than the atmospheric pressure outside of the valve sealing mechanism. Any sampling procedure is nearly certain to result in air entering the transformer.

This is also true of the steps described as the method to determine whether there is a positive pressure in the tank. That test procedure is quite risky, in that it will result in air entering the tank, if the internal pressure is less than the atmospheric pressure outside.
The purpose of the test is to try to determine if there is a risk that air can enter the tank during sampling. Since, all of the test results in this investigation demonstrate that this procedure will result in air entering, our recommendation is that this test SHOULD NOT be performed.

The results demonstrate that the industry must be required to develop a new test procedure.

Positive pressure inside the main tank, but restricted or closed system of sampling equipment, or a monitor mounted on the valve.

If the drain valve on the transformer is a ball valve or gate valve, and there is no OPEN vent in the sampling equipment, then the air in the volume of the valve housing would be trapped, and it would be free to flow directly into the transformer tank, when the valve is opened. Similarly, if there is no OPEN vent in the monitoring equipment mounted on the valve, the result will be the same.

If the valve used were a globe valve, in most cases, all of the available air will be trapped in the chamber of the valve, and it would not be free to flow into the transformer tank, when the valve is opened.

Positive pressure inside the main tank, but un-restricted or OPEN vented system of sampling equipment, or a monitor mounted on the valve.

If the drain valve on the transformer is a ball valve or gate valve, and there IS an OPEN vent in the sampling equipment, then the air in the volume of the valve housing would not be trapped inside, and it would be free to escape through the vent, rather than moving into the transformer tank, when the valve is opened. Similarly, if there IS an OPEN vent in the monitoring equipment mounted on the valve, the result will be the same. However, a bleed port that has a restriction, like a captured bleed screw, may not provide a sufficient open cross sectional area to allow the required volume of air to vent. In those cases, trapped air can still be free to flow directly into the transformer tank, when the valve is opened.

If the valve used were a globe valve, in most cases, all of the available air will be trapped in the chamber of the valve, and it would not be free to flow into the transformer tank, when the valve is opened.

Conclusion

The authors urge all transformer owners, operators, and service contractors to review their existing procedures, and to become very cautious when performing oil sampling, or installing monitoring devices on transformer valves. Anyone doing this type of work should be able to identify the type of valve that he/she is working with, be aware of the methods for determining the pressure inside the main tank, be aware of the conditions that can lead to air entering a transformer, and take all precautions to ensure that the work can be done as safely as possible.

The sequence of connecting the sampling equipment and opening of valves is crucial.
Sampling should not be attempted if there is a negative gauge pressure inside the tank.
For many workers, this will require new training, using a modified training program, and revised sampling procedures.

Biographies

Donald W Platts joined Omicron Electronics Corp. USA in October 2014 where he now provides technical support and training related to transformer applications and testing for customers and staff.

Donald's career has been in the electric utility industry, with PPL Electric Utilities, SPX Transformer Solutions (formerly known as Waukesha Electric Systems) - an equipment supplier to the industry, and as an independent consultant. During more than 40 years in engineering, he has work experience in multiple functional areas related to transformer applications, from product specification and design studies, to purchase contracts (with approved supplier evaluations, factory inspections, and witness testing programs), to maintenance programs, and failure analysis of distribution and power transformers. In these senior level roles he worked closely with management, engineering groups, field crews, and manufacturers. He also participated in, or led, external engineering committees and working groups at PJM, EEI, NERC, and IEEE. Don has also provided technical support for a power transformer manufacturer Sales and Marketing group, working directly with customers; providing recommendations for application issues and correctly specifying equipment to meet the customer's needs.

Don has been an active participant in the IEEE PES Transformers Committee since 1988. Presently he serves as the Chair of the Committee for 2014 and 2015. He is also a member of the IEEE PES Technical Council.

He has authored and presented technical papers, and training modules related to utility transformer applications at industry conferences and seminars sponsored by several organizations (IEEE, Omicron, Weidmann, TJH2b, Doble, PPL Electric Utilities, SPX Transformer Solutions, and PJM Interconnection).

Don received his BS in Electrical Engineering from Lafayette College and is a licensed Professional Engineer in Pennsylvania.

Dave Hanson is the President and CEO of TJ/H2b Analytical Services, Inc. He has been active in the field of insulating materials testing since 1978. He has been involved with the development of test methods and diagnostic criteria for high-voltage electric equipment. His involvement extends to transformers, tap-changers, bushings, and gas- and oil-filled circuit breakers.