TechCon® NORTH AMERICA 2017

Houston, Texas

Where Does the Air Go?

(Second Edition)

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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 actually 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.

Original paper published for TechCon 2016
Revised - December 2016

Introduction

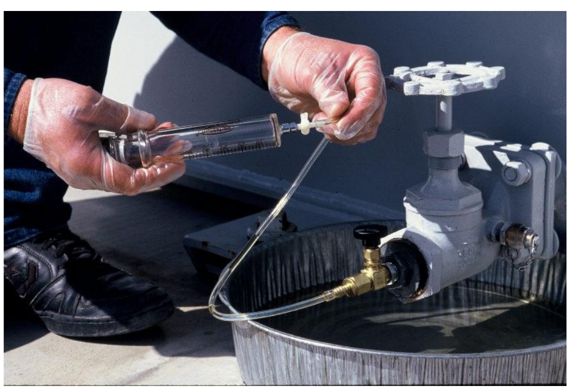
When author Don Platts worked for an electric utility, he purchased transformers that were delivered with a ‘non-standard’ drain valve. Rather than getting the typical globe valve, these units had ball valves. While the crew doing the assembly and oil fill liked this new valve, he raised a question about 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 aware of only a few events involving flashover or failure of energized equipment due to sampling, or air intrusion.

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 liquid.

Quick tests done by that utility, showed that there are conditions where air will enter the transformer, when the drain valve is opened to obtain a sample. This provided proof that the air intrusion is a serious issue. However, no further tests were performed under different scenarios, and there was no theoretical investigation.



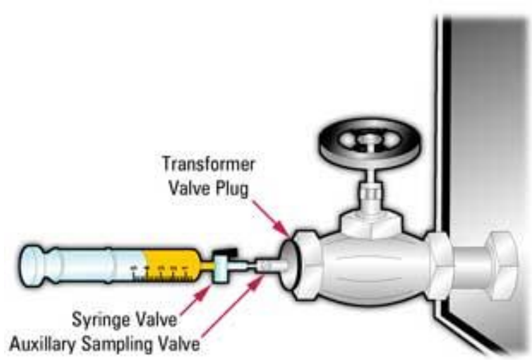


Figure 1 Common sampling practices

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 the external air at the air/liquid interface will be greater than the force exerted by the liquid. When that situation exists, and a valve is opened, air will move through the interface, and enter the transformer.

Consider what happens to air that is trapped inside the valve body - against the valve face, when the valve is opened. This is the case when a pipe plug, or closed sampling kit is connected to the open end of a valve. 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.

In another 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, if they exist.
6. The remaining air will be moved away from the valve.

Test of the Theory

TJH2b and OMICRON have both conducted tests using models of a transformer tank, with the three valve designs mounted on the models.

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

1. Will air enter the tank when the valve is opened - with the valve opening sealed by the original pipe plug?
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 2^{nd} valve located in the sampling connection? (see Figure 2)

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 examined for installing monitoring products prevent air intrusion?

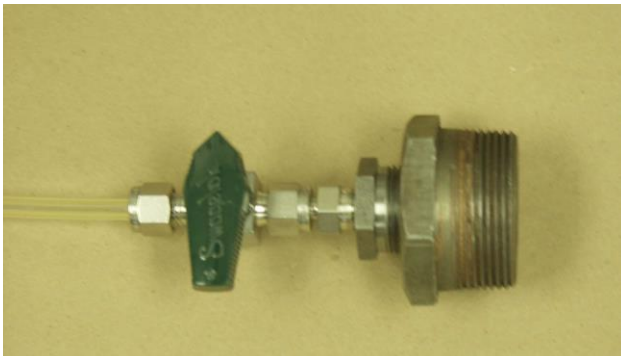


Figure 2: Sampling kit used by some utilities, with a pipe plug and reducer, and a small ball valve to control flow through the tubing

Experimental Setup for Sampling Tests

A pressure chamber that could be filled with liquids and gases was built to test a variety of sampling conditions. See Figure 3. The chamber was made to allow different valve types to be mounted. Fittings on the top of the chamber allow the chamber to be pressurized or have the air 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. The authors chose to use water rather than an insulating liquid primarily for the convenience and safety of the experiments. Each of the hundreds of trials required that the test assembly be disconnected and all of the liquid drained out, before another trial could be started. Since water has a viscosity of 1 cSt and mineral (insulating) oil measures at 2.3 cSt @100C, 9.6 @ 40C and 19 @15C. Therefore, using water has no appreciable effect on the outcome of these experiments. [Note SAE 10 motor oil has a viscosity of 85 – 140 cSt, and honey is 10,000 cSt.]

Each study used a particular drain valve and a particular configuration of sampling equipment for collecting samples installed on the chamber. Twelve different chamber pressures of were used for the trials in each study, ranging from -100KPa, to 175KPa, in increments of 25KPa. As the drain valve was opened using each combination of a particular valve, configuration of sampling equipment and chamber pressure, the entire assembly was observed for bubble ingress. All bubbles were recorded regardless of size. See Figure 4.

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 (corresponding to the list of 6 test scenarios) 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 the results of all of the studies is found in Table 1.

Figure 3 Test Chamber –TJH2b

Figure 4 Result with bubble ingress

As the valve was opened during each of the test trials, the entire assembly was observed for bubble ingress

	The Effect of Restricted Connections to the Valve			The Effect of Unrestricted Connections to the Valve		
	Valve Type			Valve Type		
Tank Pressure	Ball Valve	Gate Valve	Globe Valve	Ball Valve	Gate Valve	Globe Valve
-100kPa	Bubble	Bubble	Bubble	Bubble	Bubble	Bubble
-75kPa	Bubble	Bubble	Bubble	Bubble	Bubble	Bubble
-50kPa	Bubble	Bubble	Bubble	Bubble	Bubble	Bubble
-25kPa	Bubble	Bubble	Bubble	Bubble	Bubble	Bubble
0kPa	Bubble	Bubble	No Bubble	No Bubble	No Bubble	No Bubble
25kPa	Bubble	Bubble	No Bubble	No Bubble	No Bubble	No Bubble
50kPa	Bubble	Bubble	No Bubble	No Bubble	No Bubble	No Bubble
75kPa	Bubble	Bubble	No Bubble	No Bubble	No Bubble	No Bubble
100kPa	Bubble	Bubble	No Bubble	No Bubble	No Bubble	No Bubble
125kPa	Bubble	Bubble	No Bubble	No Bubble	No Bubble	No Bubble
150kPa	Bubble	Bubble	No Bubble	No Bubble	No Bubble	No Bubble
175kPa	Bubble	Bubble	No Bubble	No Bubble	No Bubble	No Bubble

Table 1 The results are summarized for Restricted (on the left) situations where the air cannot escape such as a valve fitted with a pipe plug, or a closed valve in sample tubing. The results for Unrestricted situations where the air can escape such as a valve without a pipe plug, or without a closed valve in sample tubing are shown (on the right.

Evaluation of the Test Results

In the Theory section above, we discussed how air moves when there is a negative pressure inside the tank. Further, a theoretical explanation was provided to illustrate what happens to air that is trapped inside the valve body when the valve is opened. In the closed or "Restricted" case, air can move into the transformer. In the open or "Unrestricted" case, the air is free to move away from the transformer. These tests confirm the expected results based on the theoretical explanations.

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, based on the procedures found in ASTM D923-07. 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 Table 1 above, for cases with negative pressures, (-25 to -100kPa). There is no valve type that will allow safe opening of the drain valve without some air entering the transformer.

The conclusion from this is that we must make a strong recommendation. 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 there is really no need to perform the pressure check.

Sampling with a Closed Valve on the Sampling Fittings or Tubing

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

As shown in Table 1 above, the only valve type that will allow this operation without bubble ingress is the globe valve.

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: Figure 5

Figure 5   Left to right are the Globe, Ball, and Gate Valves. Note the construction of valve bodies

- 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. In the field, it can be identified by the appearance of the valve body or by feeling the unusual, non-uniform, shape of the protrusions in the valve cavity. See Figures 5, 6.
- 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 handle, the appearance of the valve body, or by feeling the smooth surface of the ball inside the valve cavity. See Figures 5, 7.
- 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 Figures 5, 8.

Illustrations of a Globe Valve

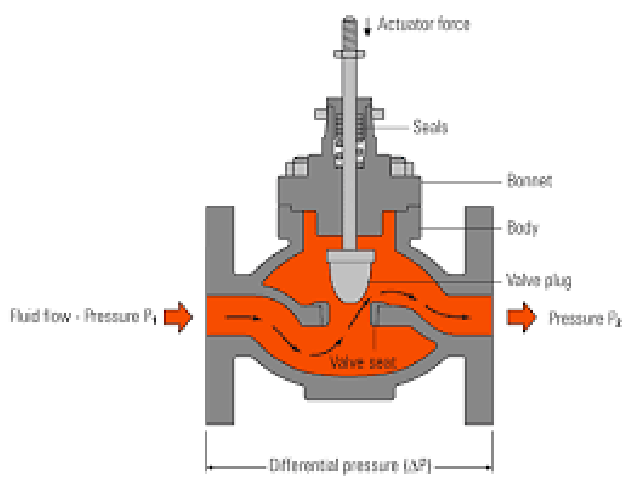


Figure 6 Globe Valve: The valve plug moves vertically to open, allowing liquid flow from input to output side, with vertical movement of the liquid through the valve seal. Source: spiraxsarco.com

Illustrations of a ball valve

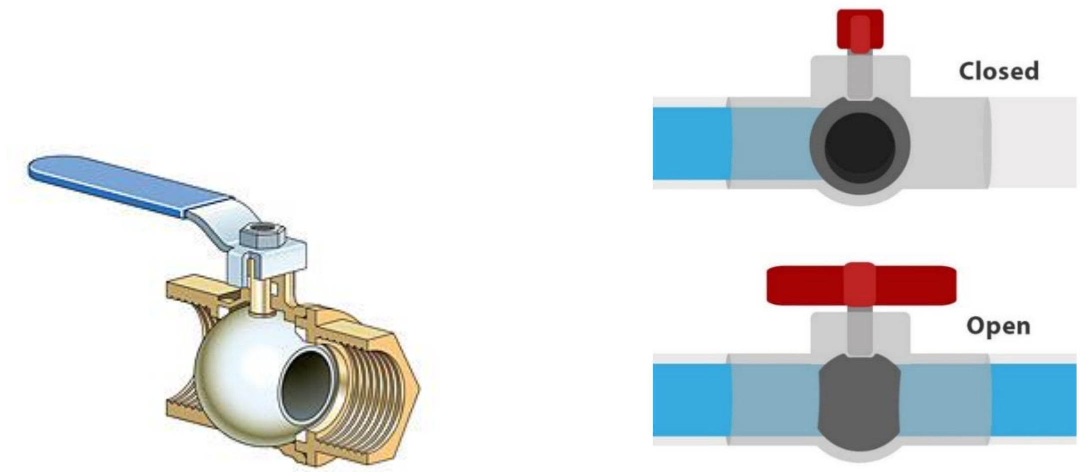


Figure 7 Ball Valves – A ball with a hole through it rotates around a vertical axis, either allowing flow, or blocking flow.

Illustrations of a Gate Valve:

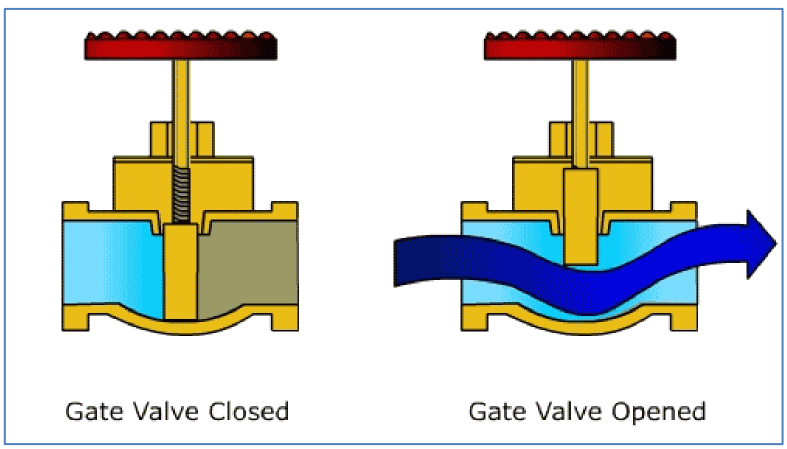


Figure 8 Gate Valves- A gate moves vertically to seal and block flow, or to open and allow liquid flow.

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 move 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 risk, based on the procedures that are provided to you.

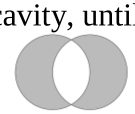
From a review of three different valves, shown in Figure 6, 7 and 8, you can see that each valve type presents a different degree of opportunity for air ingress under these scenarios. The ball valve loses all restraint at the valve face the moment it is partially opened. The gate valve loses restraint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

The globe valve was the type of drain valve required by IEEE standards up until the mid to late 1980's, when some customers started to ask for a "full bore opening" valve design 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 –when there is a positive pressure inside the tank.

As found in testing, and illustrated in the sketches below, the various valves behave differently, and will allow air intrusion under different conditions.

Illustrations of a Ball Valve Operation:

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 the liquid to move under pressure, through the bottom 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 overlap of 2 circles, the white "football" shape in this sketch.

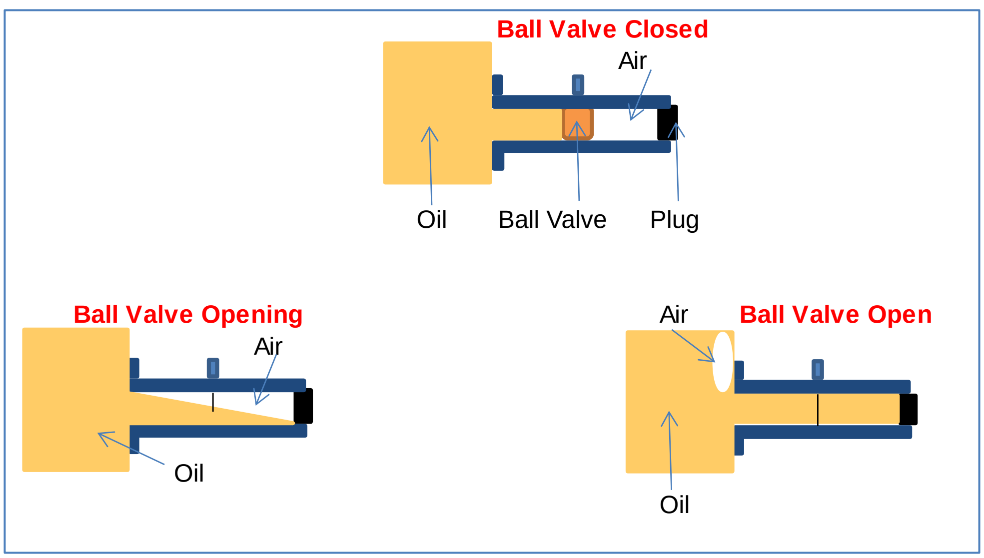


Figure 9: These sketches illustrate the danger of a gate valve when used as a transformer drain valve because when the valve outlet is blocked or connected to a closed sampling system, the trapped air moves back through the valve into the transformer.

Illustrations of a Gate Valve Operation

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

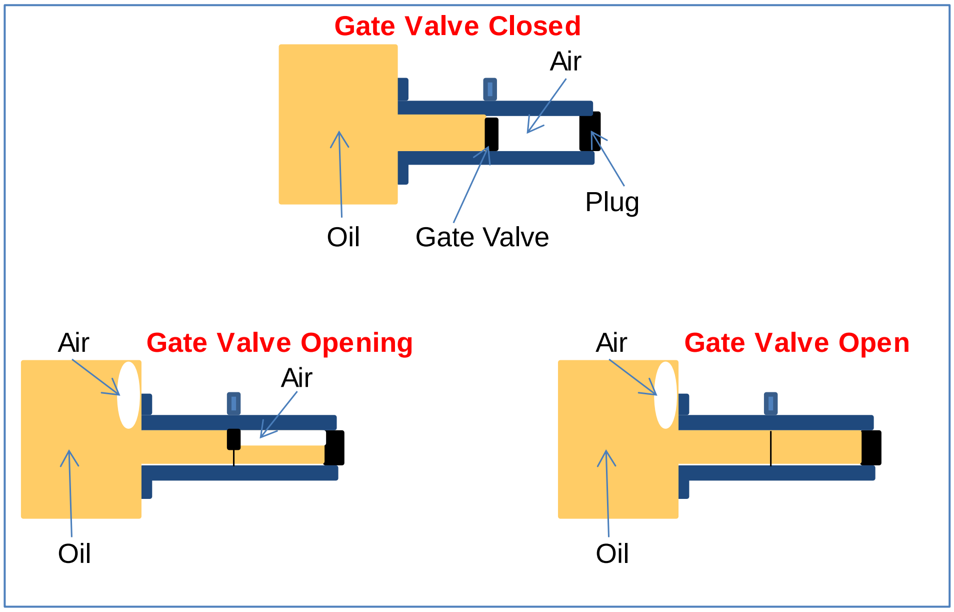


Figure 10: These sketches illustrate the danger of using a ball valve as a transformer drain valve because when the output is blocked, the pressurized air in the valve moves back through the opening into the transformer.

compress the air in the valve cavity. When the valve outlet is blocked or connected to a closed sampling system, the air in the cavity reaches a high enough pressure so that it moves through the opening and back into the transformer.

Illustrations of a Globe Valve Operation

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 horizontal opening is created at the valve seat. It allows the liquid to move vertically, under pressure, and to compress the air in the upper 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, most of the air will be forced out of the valve exit, with the flow of the liquid.

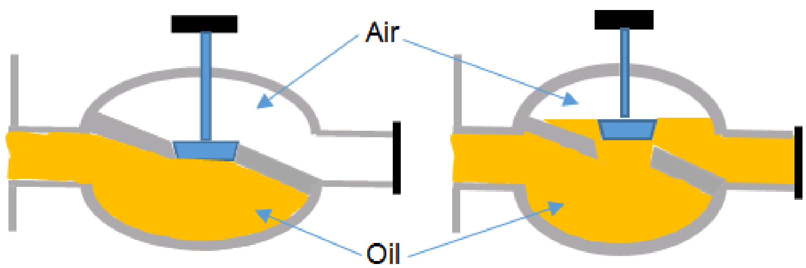


Figure 11: There is minimal danger with a globe valve used as transformer drain valve because the trapped air (white) floats above the liquid (yellow) and remains in the valve.

Oil Preservation System, and its 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 carefully address the topic of verification of the tank pressure. To do so, we need to understand the 3 different oil preservation systems widely used in the industry for power transformers.

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 design, where the blanket of nitrogen is supplemented with a high pressure nitrogen supply cylinder. Through regulators, the system will maintain the pressure of the nitrogen in a close range of approximately 0-8 psi. These setting are adjustable, and will vary from one operator to another.
3. The third design 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 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. The typical range is -8 to +10 psi. To ensure safe sampling, you will need to rely on the pressure gauges. If there might be a chance of a negative pressure at the valve 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 nitrogen supply tank. So if the system is not in an alarm condition, there will be a 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 conservator design, if the valve to the conservator is open, and the transformer is performing normally, there will always be a static head pressure at the sampling valve. The amount of pressure can be calculated, and is dependent on 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.

Some transformer operators may decide to look at this problem of identifying the pressure at the valve and modify their procedures differently. Calculations show 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 examples in Table 2.

Calculation of Static Head Pressure				
Liquid Height Feet	psi gauge		N2 blanket gage	psi gauge at Valve
	Water	Mineral Oil		
1	0.43	0.40	0	0.40
5	2.16	1.99	0	1.99
10	4.33	3.98	0	3.98
10	4.33	3.98	-1.0	2.98
15	6.49	5.97	0	
15	6.49	5.97	-2.0	3.97

Table 2 Calculation of expected static head pressure at the drain valve, based on the height of the oil above the valve, and gas pressure.

Note: This table of calculated pressures is based on the following assumptions; mineral oil with a specific gravity of 0.92, and a water specific weight measured at 4°C. The actual pressure will vary with changes to the water or oil temperatures. Equations to perform these calculations are not provided, because the method used does not include the required temperature correction factors.

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 15 ft. of oil to provide the pressure, there should be a static head pressure of about 6 psi at the valve. Then, you could conclude that the actual pressure at the valve should be approximately 4 psi; a value that would certainly be safe for taking samples. Since there is a risk of the gauge being out of calibration, and the calculation of static head pressure being inaccurate for many operating temperatures, we do not recommend this practice. However, we acknowledge that it could be used.

Distribution Pad Mounted Transformers

Pad mounts are generally built with a sealed tank system. However, the gas space is filled with air, not nitrogen. There is generally no pressure/ vacuum gauge. There should be a pressure bleeder valve with a pull ring for manual operation. In most cases, the drain valve is located inside the doors of the compartment containing the electrical terminations. Many companies prohibit taking oil samples from an energized transformer because of the proximity to the exposed terminals inside this compartment.

Without a gauge to monitor pressure, and usually, a short tank height, it is difficult to determine if there is a positive pressure inside the tank. In most cases, the transformer will need to be de-energized before taking the sample. Therefore, the risk of air entering the tank and causing damage becomes extremely small. However, our recommendation would be that when sampling these units, the pressure bleeder be manually operated to equalize the pressure inside the tank. If a sample is taken with the unit energized, equalizing the pressure to ensure that there is no vacuum inside the tank must become a crucial step in the procedure.

An additional item to consider is the oil level in the unit before and after taking a sample. If the oil level is critically low, the sample should not be taken, until the oil level is brought back up to normal.

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 on an energized transformer by connecting it to the drain valve, then opening the drain valve, and then finally opening a port to bleed out the air in the system, is one that would be extremely 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.

Further, there could be a problem with the air bleed port. 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. So this case is not the Restricted, nor the Unrestricted case that were tested for this paper. It represents a third case of partial restriction. However, the results show that it will lead to air intrusion, similar to a Restricted case.

Only a few systems have been reviewed for this paper, we urge you to carefully investigate the procedures that are provided to you and the results and risks of the installation, *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 Concerns and Explanations

Drain Valve Location

Some manufacturers incorporate a design feature that will prevent air intrusion into the electrically stressed regions in some specific transformer designs, regardless of what valve is used. A failure due to air intrusion during sampling will not occur with this type design.

IEEE standards require that the drain valve must allow the oil to be pumped out of the transformer, down to a level of 1 inch above the floor. If the drain valve is mounted near the base of the transformer (as shown by the lower yellow globe valve in the photo- Figure 12), the oil can be pumped directly. However, some manufacturers will mount the drain valve higher on the tank, (similar to the height of the upper yellow gate valve in the photo).

Figure 12 Photos of transformer valves and connected piping inside the transformer tank.

This elevated location provides more structural integrity in the tank, but it requires that a mechanical device must be installed inside the tank, (like the pipe elbow shown in the second photo Figure 12). Some manufacturers will use pipe, others will fabricate a 'box' attached to the side wall. It allows the oil to be pumped down to the required one inch level.

While this construction will eliminate the concern over air entering the tank, as described in this paper, there are other issues. A large quantify of oil (perhaps a gallon, or more) will be trapped inside the pipe or box. If you are going to get a good, representative sample of the bulk oil; you will need to drain away all of that oil, before you start to collect your sample.

If you are mounting a monitoring probe, you need to evaluate the effect of these mechanical devices. For DGA, the oil that is sampled will not be representative of the bulk oil. For other monitors, like a PD detection probe, the steel of the box or piping will block access to the desired signal.

Drain Value Orientation

If the valve face is not plumb (see sketch Figure 13), 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 in the 2nd sketch in Figure 13) 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.

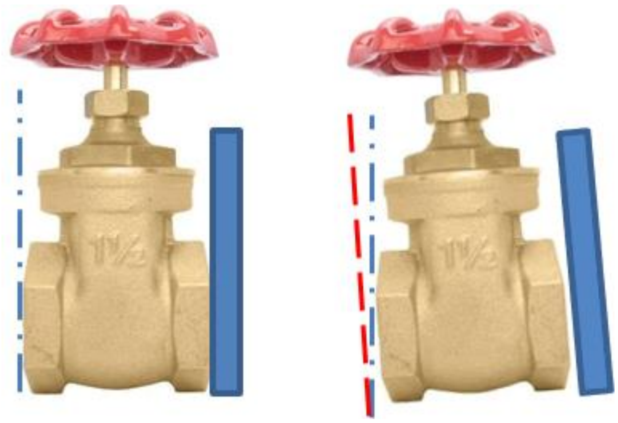


Figure 13 Blue line is vertical. Red line in second photo indicates actual angle of the valve opening face. It is not vertical, or plumb. The blue rectangle represents the tank wall on the right side of these valves.

Instrument Transformers

One of the cases of failure reported to the authors involved an instrument transformer, where a worker reportedly heard air go inside the unit as he was taking the sample. It failed immediately after re-energizing it.

These are generally built with a sealed tank system. There is generally no pressure/ vacuum gauge. There may be a pressure bleeder valve with a pull ring for manual operation. Many companies prohibit taking oil samples from an energized instrument transformer because of the proximity to the exposed terminals and the short electrical clearance.

Without a gauge to monitor pressure, and usually, a short tank height, it is difficult to determine if there is a positive pressure inside the tank. In most cases, the transformer will need to be de-energized before taking the sample.

Other Equipment Connected to the Drain Valve

There are a number of products sold as transformer accessories that require a pipe or hose connection to the valves of a transformer, such as filter systems, external coolers, external dry out systems, etc. One of the cases of failure reported to the authors involved an external cooler system connection to the transformer valves. Air in the hoses was not vented, and was allowed to enter the transformer. A quick analysis indicates that this was probably a scenario similar to our 'Restricted' case studies, where air in the hose entered the transformer when the drain valve was opened.

When connecting any of these external devices to the valves of an energized transformer, we urge you to carefully investigate the procedures that are provided by the manufacturer, and the results and risks of the installation, *before* attempting to install a monitoring system on an *energized* transformer.

Summary

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

Every one of the tests that have been done, demonstrate that air will flow into the transformer, as the valve is opened when the pressure inside the valve is less than the atmospheric pressure outside of the valve sealing mechanism. Any sampling procedure used 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 urged 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, when the valve is opened, 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.

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, when the valve is opened, 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.

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, when the valve is opened, 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.

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 the valves of an energized transformer. 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.

Annex A

Drain and Filter Valve Requirements found in IEEE standards

IEEE Std C57.12.00™-2010
IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers
No mention of drain valves in any clause.

C57.12.10
IEEE Standard Requirements for Liquid-Immersed Power Transformers
5.1.8 Drain and filter valves
A combination drain and lower filter valve shall be located on the side of the tank in Segment 1. This valve shall provide for drainage of the liquid to within 25 mm (1 in) of the bottom of the tank.
The drain valve shall have a built-in 0.375 in sampling device, which shall be located in the side of the valve between the main valve seat and the pipe plug.
The sampling device shall be supplied with a 5/16-in×32-threads-per-inch (5/16-32 in) male thread for the user's connection and shall be equipped with a cap.
The size of the drain valve shall be 2 in National Pipe Thread (NPT) and shall have tapered pipe threads (in accordance with ASME B1.20.1) with a pipe plug in the open end.
The upper filter valve shall be provided and located below the 25 °C liquid level in Segment 1. The size of the upper filter valve shall be 2 in NPT, and the upper filter valve shall have 51 mm (2 in) NPT (in accordance with ASME B1.20.1) with a pipe plug in the open end.

IEEE C57.12.26 Three-Phase Distribution Transformers for Use With Separable Insulated High-Voltage Connectors (34 500 Grd Y/19 920 V and Below; 2500 kVA and Smaller)
7.6 Tanks
7.6.1
A one inch upper plug (or cap) for filling and pressure testing shall be provided. A one inch NPT drain valve with a built-in sampling device shall be provided. Both the filling plug or cap and the drain valve shall be located within the low voltage termination compartment.

IEEE Std C57.12.34™-2009
IEEE Standard for Requirements for Pad-Mounted, Compartmental-Type, Self-Cooled, Three- Phase Distribution Transformers, 5 MVA and Smaller; High Voltage, 34.5 kV Nominal System Voltage and Below; Low Voltage, 15 kV Nominal System Voltage and Below

8.10.2 Pressure testing and oil access
A 1 in NPT upper plug (or cap) for filling and pressure testing shall be provided in the low-voltage compartment. A 1 in NPT drain plug (or cap) for transformers rated 75 kVA to 500 kVA and a 1 in NPT drain valve with built-in sampling device for transformers rated 750 kVA to 5000 kVA shall be provided in the low-voltage compartment. Suitable means for indicating the correct liquid level at 25 °C shall be provided.

IEEE Std C57.12.36™-2007 IEEE Standard Requirements for Liquid-Immersed Distribution Substation Transformers
5.1.8 Drain valves, filter valves, and connections
A combination drain and lower filter valve shall be located on the side of the tank in segment 1. This valve shall provide for drainage of the liquid to within 25.4 mm (1 in) of the bottom of the tank.

The drain valve shall have a built-in 3/8 in sampling device, which shall be located in the side of the valve between the main valve seat and the pipe plug.
The sampling device shall be supplied with a 5/16 in, 32 threads/in, male thread for the user's connection and shall be equipped with a cap.
The size of the drain valve shall be 1 in NPT, for transformers through 2500 kVA and 2 in NPT for the larger kilovolt-ampere ratings, and the drain valve shall have tapered pipe threads with a pipe plug in the open end.

Biographies

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

Don's career has been focused in the electric utility industry, with PPL Electric Utilities, as an independent consultant, and then with SPX Transformer Solutions. During more than 40 years in engineering, he has work experience in multiple functional areas related to transformer applications.

Don is an IEEE Life Member, and has been an active participant in the IEEE PES Transformers Committee since 1988. Presently he serves as the Past Chair of the Committee for 2016 and 2017.

He has authored and presented technical papers, and training modules related to utility transformer applications at industry conferences and seminars sponsored by several organizations.

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 has mainly focused on transformers, tap-changers, bushings, and gas- and oil-filled circuit breakers.