
## ABSTRACT

In the last column, the importance of sampling was emphasized, elaborating on the sampling frequencies, transformer size and the right timing. In this one, we will evaluate oil sampling for all transformer types as the most critical stage of DGA, the most dangerous for the transformer as well as for the staff. The sampling stage may revoke the statement that the DGA test as also other oil tests as non-invasive tests with online devices are not spared from risks to transformer operation, even more than offline. This column will present some of the unpleasant consequences of transformer sampling issue oil issues. Sampling transformer oil is also the most expensive stage of the whole DGA process.

Selecting the vessel for DGA and oil sampling cannot be an unconditional choice, and for this selection, many factors need to consider as transformer type, size, breathing mode, laboratory and tests device extraction and methods, sample team experience skills and capability, transport and delivery for sampling and even season and weather. When many factors are considered, the sampling will be more properly performed, representative, and the DGA diagnostics will be more comprehensive.



## KEYWORDS:

DGA, diagnostics, oil sampling

**The primary goal of sampling is to get a representative sample that may be easily and safely obtained, transported and analyzed**

# Transformer oil sampling - a dirty and dangerous mission

## Introduction

As in medicine, the sampling process importance and particularities are related to the sampling from transformers or other machines.

Fig. 1a shows an unfortunate consequence of a poor blood sampling. As for the medical case (Fig 1b), technicians sampling transformer oil need to be aware for their personal protection and also for equipment protection. For oil transformer sampling, personal protection is crucial not only for notorious PCB (polychlorinated biphenyl) but for all insulating liquids, like all minerals, and also for esters, where sampling technicians must carefully read the instructions and get organised before proceeding to the sampling process itself.

The primary goal of sampling is to get a representative sample that may be easily and safely obtained, transported and analyzed. Sampling processes need to be optimized for minimalizing their affect on samples and, at the same time to indicate correctly as many parameters of the sampled subject as possible of the sampled subject.

Isokinetic sampling is the extraction of a representative portion of the process stream without altering the physical and chemical properties of the sample. In isokinetic sampling, all phases (solid oxides and precipitates, liquid droplets, and vapour) of the sampled fluid enter the sampling nozzle with the same velocity vector (meaning the same velocity and direction of flow).

Sampling insulating oil from the bottom valve (Fig. 6) or Buchholz relay is not isokinetic sampling because the sampling direction is perpendicular to oil flow inside transformers and because of multi-phase expectancy that may appear at the bottom and top valves. This is a bigger challenge for online sampling, especially in online devices that use one port for oil entrance. In this case, the flow is restricted to a theoretical temperature gradient that may either exist or not. In case of two-port oil flowing DGA online device, other aspects should be considered, such as potential leaking, damage to thin tubing and above all, bubble formation due to a special flowing regime.

Another important issue that managers of sampling teams and transformer owners should be aware of is the necessity to adapt the sampling vessel size, shape, type, and materials that they are made of to both the transformer specifications and at the same time the laboratory and tests devices. Any extra handling of the oil will downgrade the quality of results for most oil tests, especially for DGA. DGA is a test that is most sensitive to air exposure, and it should be avoided at

**Oil sampling from transformers is intendedly done with the power on, so lethal accidents can easily happen if the personnel do not take electrical hazards into consideration**

any time, both during sampling, transportation and handling in laboratories. The diversity of gas from oil extraction imposes a careful consultation with the lab test provider before the sampling is planned. Also, for online devices, the type, location and design of the valve and the online device should match. Unfortunately, in many cases, the components of a transformer and DGA online device do not fit, to the detriment of DGA results.

## Personal safety of the sampling team, immediate and medium-term hazards

Transformer sampling is usually performed in a live transformer at a power station or substation, with a very high current and voltage. The environment contains high electromagnetic energy, such as magnetic flux density and static electricity. Unlike most maintenance teams that operate in a deenergized location, sampling oil from transformers is intendedly done with the power on. Lethal accidents can easily happen if the sampling personnel do not take electrical hazards into consideration. Electrical and magnetic fields may have a cumulative effect on the human body; therefore, the oil sampling team should be adequately protected.

Figure 1. Sampling procedures in two cases in medicine: a) unsuccessful blood sampling, b) sampling for covid-19 test

In addition to the electrical hazards, sampling personnel are also exposed to many chemical hazards. Although new mineral insulating oils are not classified as hazardous products, most of the sampling is performed on used oils, which may contain carcinogenic species, specifically certain polynuclear aromatics (PNAs), sometimes called polycyclic aromatic hydrocarbons or PCAHs / PAHs. These are not present in fresh oils. Not all PNAs - even among those found in used oil - are carcinogenic. Among those which are, the potency varies considerably. The most well-known is probably benzo(a)pyrene, which is quite potent. (R. K. Hewstone, 1994). New oils contain different types of additives, declared or not, and several synthetic antioxidant additives are still in evaluation for toxicity.

**A very recent study regarding the toxicity of synthetic phenolic antioxidants (R. Liu and S. A. Mabury, 2020):**

*"Toxicity studies suggest some SPA's (synthetic phenolic antioxidants) may cause hepatic toxicity, have endocrine-disrupting effects, or even be carcinogenic. The toxicity effects of some transformation products are likely worse than those of the parent compound. For example, 2,6-di-tertbutyl-p-benzoquinone (BHT-Q) can cause DNA damage at low concentrations. Future studies should investigate the contamination and environmental behaviours of novel high molecular weight SPAs, toxicity effects of co-exposure to several SPAs, and toxicity effects in infants."*

All insulating oil manufactures, including those of non-minerals liquids such as natural esters, indicate in their SDS

**ENVIROTEMP™ FR3™ FLUID**

Monitoring procedures should be chosen according to the indications set by national authorities or recognized standards.

**Appropriate engineering controls:**

Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapor and mists below the applicable workplace exposure limits (Occupational Exposure Limits-OELs) indicated above. Emergency eye wash fountains and safety showers should be available in the immediate vicinity of use or handling.

**Personal protection equipment**

**Eye and face protection:**

Safety glasses, goggles, or face shield recommended to protect eyes from mists or splashing.

**Skin and body protection:**

Wear protective clothing as necessary to minimize prolonged skin contact. Selection of specific items will depend on task

**Respiratory protection:**

Respiratory protection should be worn when there is a potential to exceed the exposure limit requirements or guidelines. If there are no applicable exposure limit requirements or guidelines, wear respiratory protection when adverse effects, such as respiratory irritation or discomfort have been experienced, or where indicated by your risk assessment process. In misty atmospheres, use an approved particulate respirator.

**General hygienic measures:**

Handle in accordance with good industrial hygiene and safety practice. Avoid contact with skin, eyes and clothing. Wash hands before breaks and at the end of work. Wash contaminated clothing before reusing.

Figure 2. Safety data sheet (SDS), ENVIROTEMP™ FR3™ Fluid Bulk, Cargill

instructions that the liquids are to be handled only by observing adequate safety practices.

Similar indications may also be observed from SDS of Superfine:

**Although new mineral insulating oils are not classified as hazardous products, most of the sampling is performed on used oils, which may contain carcinogenic species**

**Exposure Limits**

No value assigned for this specific material, however the following exposure standards may apply:

| | OSHA PEL | | ACGIH TLV | |
|---|---|---|---|---|
| **Chemical Name** | **TWA** | **STEL** | **TWA** | **STEL** |
| Hydrotreated naphthenic mineral oil (as oil mist) | 5 mg/m$^3$ | n/a | 5 mg/m$^3$ | 10 mg/m$^3$ |
| 2,6-Di-tert-butyl-p-cresol | n/a | n/a | 2 mg/m$^3$ | n/a |

**Engineering Controls**

Adequate ventilation should be provided whenever the material is heated or mists are generated.

**Personal Protective Equipment**

**Eyes/Face**

- Safety glasses with side shields.
- Chemical goggles.
- Contact lenses may pose a special hazard; soft contact lenses may absorb and concentrate irritants. A written policy document, describing the wearing of lenses or restrictions on use, should be created for each workplace or task.

**Hands/Feet**

- Wear chemical protective gloves, e.g. PVC, Nitrile, Neoprene.
- Wear safety footwear or safety gumboots, e.g. Rubber.

Figure 3. Safety data sheet, superfine inhibited transformer oil, Hydrodec

**According to SDS, for all liquids, new mineral inhibited oils, and old mineral inhibited oils, even new natural esters, none of those should be released into waterways or into the environment**

This SDS also includes further warnings regarding mineral insulating oil that may be applicable to all mineral insulating oils:

**"Long-term (chronic) effects:**

Limited evidence suggests that repeated or long-term occupational exposure may produce cumulative health effects involving organs or biochemical systems.

Repeated or prolonged exposure to mixed hydrocarbons may produce narcosis with dizziness, weakness, irritability, concentration and / or memory loss, tremor in the fingers and tongue, vertigo, olfactory disorders, constriction of the visual field, paraesthesia of the extremities, weight loss, anaemia and degenerative changes in the liver and kidneys. Chronic exposure of petroleum workers to the lighter hydrocarbons has been associated with visual disturbances, damage to the central nervous system, peripheral neuropathies (including numbness and paraesthesia), psychological and neurophysiological deficits, bone marrow toxicities (including hypoplasia possibly due to benzene) as well as hepatic and renal involvement. Chronic dermal exposure to petroleum hydrocarbons may result in defatting, which produces localized dermatoses." [4]

On the one hand, sampling teams should be experienced and need to have a few years of training for sampling oils from transformers, but on the other, it may implicate a long exposure that may seriously affect their health.

According to SDS, for all liquids, new mineral inhibited oils, and old mineral inhibited oils, even new natural esters (SDS, FR3, paragraph 6.2), none of those should be released into waterways or into the environment. This means that transformer owners have the responsibility to double-check that sampling teams prevent and clean any accidental spills and to collect any waste liquids before and after the sampling. The sampling team's responsibility is to collect those materials and dispose of them according to the local regulations. During the DGA sampling, in contrast to sampling for other oil tests, avoiding a spill during a DGA sampling by syringes is not a simple mission even for the most experienced team. Furthermore, the clothes will very likely get contaminated during the sampling procedure.

## Hazards for transformer operation during sampling

In a majority of cases, oil sampling for DGA is performed on an energized transformer. This is probably the correct option because DGA is meaningful only if obtained from an energized and loaded transformer. Then gases may appear, and the oil circulation distributes the gases in the tank. Except during periods after oil treatments or after major alarms or failures, oil sampling for DGA from a de-energized transformer is useless.

Figure 4. Example of transformer damage due to low oil level

Oil sampling for DGA is not 100 % non-intrinsic test as it is presented in most of the guides and promoted by some organizations. As a rule of thumb, the oil volume is proportionally inverse to the impact of oil sampling from a transformer.

The lower the oil volume, the greater the influence of sampling. Of course, the sampling frequency also has a great influence.

## Less is more, less oil tests means more reliability and operational transformer life

In my carrier, I have observed much more transformers getting damaged by excessive and unnecessary oil sampling, as shown in Fig. 4, than transformers saved by a correct diagnosis originating from any oil sampling. Unfortunately, in many parts of the world, very commercially oriented maintenance companies have convinced unexperienced transformer users to perform such oil samplings for different oil tests, without consideration of the cumulative negative impact of repeated and frequent unnecessary sampling. In some cases, unnecessary oil treatment sessions have also been done. The main reason for such irreparable failures that may induce catastrophes to the transformers is excessive heating and the non-isolated area above the oil level. In one case, a very large food manufacturer has experienced a very costly bankruptcy only because the engineer responsible for maintenance was convinced that annual oil tests would save its vital transformers. Unfortunately, it has only caused the entire factory to suffer a major fire initiated by those relatively small but very important transformers.

## Negative pressure inside transformers

As all sampling standards state, it is crucial to avoid sampling during a negative pressure. For example, IEC60457:

*"Make sure that the oil in the energized electrical equipment is not under a negative pressure when taking an oil sample, since this could introduce air bubbles in the oil, induce electrical short-circuits in the equipment and put the sampling personnel at risk."*

The most common reason for this is nitrogen headspace above the oil that may, in special circumstances, become negative, meaning the transformer is both well-sealed, and nitrogen is missing. Those situations are very rare in our days because nitrogen blanketing is less popular, and the remaining ones are not new. Most of the nitrogen blanketing is also equipped with pressure gauges that allow the technicians to observe if nitrogen is missing.

**Sometimes, too many DGA sampling can cause damage to the transformer and eventually reduce the reliability and transformer life**

Nowadays, the negative pressure may occur without any warning signals, and it is much more prevalent in small, sealed transformers. In this type, especially during morning hours when sample teams prefer to operate due to workable temperatures, the oil inside the transformer is also affected by low temperatures and its volume contracts, which may cause a vacuum condition. Those are ideal conditions for penetration of bubbles at the first opening of valves. In an energized device, this may have fatal consequences for the equipment and sampling team. Even if the transformer is sampled de-energized, it is not recommended to try obtaining the oil by any pump or syringe.

For large power transformers with a membrane the negative pressure inside

**During morning hours when sample teams prefer to operate due to workable temperatures, the oil inside the transformer is also affected by low temperatures and its volume contracts, causing a vacuum condition**

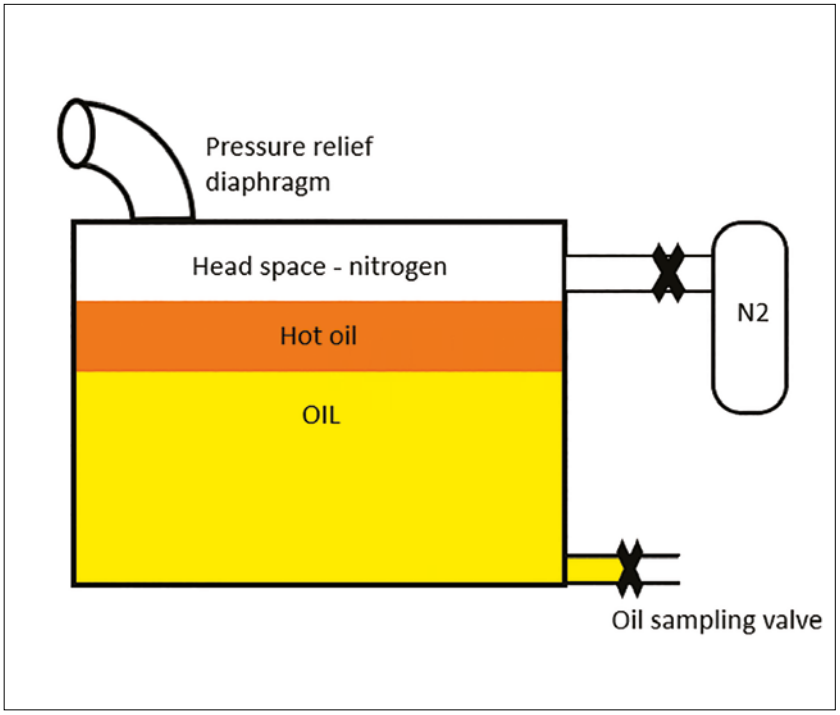


Figure 5. Blanket transformer with nitrogen and headspace (FIST 3.30 Transformer Maintenance)

**The recommendation is to sample oil and gases from the Buchholz relay only in emergencies because even if it has already been performed many times, there is always a risk of an unpleasant industrial accident**

transformers may appear as well due to several reasons, as described in Fig. 6 and explained below.

Those are the most vulnerable location that may induce failures during sampling:

1. Valves 1 and 2 should be open during transformer operation. Those valves are normally closed during vacuum treatments and dehydration of the active part. If the valves are accidentally left closed after a maintenance session, and the oil cannot freely flow from and to the conservator, vacuum and negative pressure may form in the main tank. Sampling teams should always observe the position of those valves. See Fig. 7.
2. Broken membrane. If the membrane in the conservator is damaged, it loses its floating capability and plugs the entrance hole of the oil into the main tank, and then there is again the same situation as with valves 1 and 2.
3. Valves 4 and 5 should be opened and closed in the correct order to avoid any bubble that may be trapped between valves 4 and 5 to enter the main tanks. This is a crucial point since many sampling teams still tend to randomly manipulate those valves, which is incorrect.
4. Buchholz valve 6: Many utilities prohibit sampling oils from this valve during normal operation. Although it is correct, many have used this valve as a top oil valve in the absence of any other top oil valve. The main reason of banning this valve as a usual sampling valve at normal operation is the potential of introducing any bubbles trapped in the tube of the relay and tripping the transformer, or even worse, reaching the active part and causing a short circuit. Nevertheless, even if there are no trapped bubbles, any extra oil flow through the relay may trigger the corresponding flow relay switch. The recommendation is to sample oil and gases from the Buchholz relay only in emergencies because even if it has already been performed many times, there is always a risk of an unpleasant industrial accident (Fig. 7).

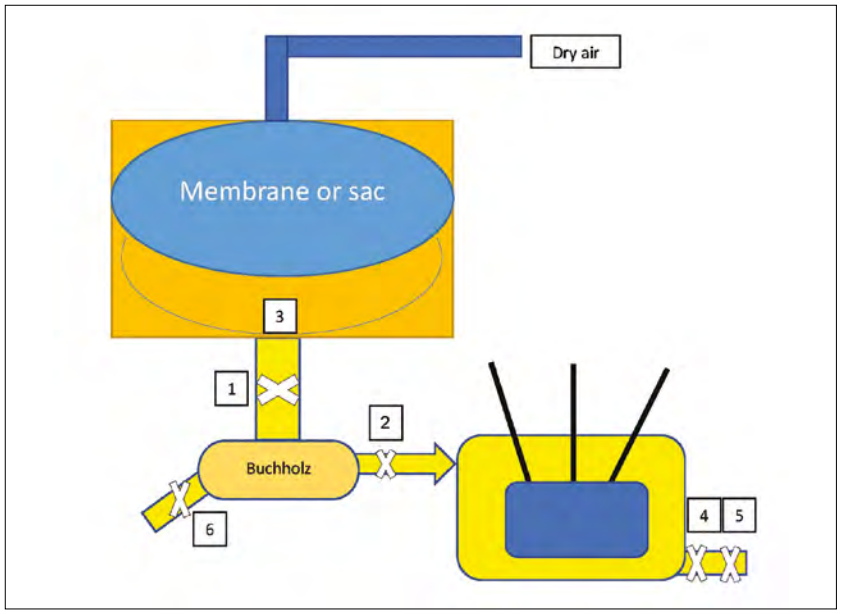


Figure 6. Schematic location of problematic spots for negative pressure formation in common non-free-breathing transformers with a sac in the conservator.


Figure 7. Buchholz relay with two valves. At normal operation, always open.

Fig. 8 shows a typical sample port with two valves. In such a situation, the order of opening and closing down the valves are:

1. Opening: first the outer valve and then the inner valve.
2. Closing: first the inner valve and then the outer valve.

This sequence will prevent any potential bubbles from coming out of the main tanks and reduce the risk to the sampling team and transformer.

Figure 8. Examples of 2 valves assembly of sampling valves.

This sampling location is, of course, an error because of a potential bubble that may enter the transformer from the area between the valve and front opening. Also, this space may contain unflushed oil with a very different composition and gases than the main bulk inside the tank. By opening the side valve only, both the oil sample and the transformer itself may be periclitated.

## Synchronize the size, shape, and materials for sampling vessels

According to IEC60475, DGA may be collected in one of the five categories of vessels. Of course, each class of those vessels may greatly vary. For example, syringes may be matched by number, ground-in plungers may have better sealing. Also, bottles may be clear or opaque brown. The bottle transparency makes it easy to observe contamination such as particles or free water but promotes the production of gases inside the bottles due to sun or light exposure after sampling. Metal bottles may be made of aluminium or other metals that may react with a specific insulating liquid. For ampoules, the variety is also quite large in size, shape, valve location and more. From a practical aspect, sampling in the different vessels may deliver particularly different gas compositions after sampling and transport. Among so many factors affecting DGA results, the shape, material, etc., of the DGA sampling vessel also affect those values.

**Among so many factors affecting DGA results, the shape and material, as well as other parameters of the DGA sampling vessel, may also affect the results**

Figure 9. One valve to ports, which is the correct one for oil sampling?

Table 1. Table 2 of IEC60475 - Sample containers for oil tests (Y = Yes)

| Sample container | Syringe | Flexible bottle | Bottle | Flexible bottle | Ampoule | Ampoule | Oil volume |
|---|---|---|---|---|---|---|---|
| Material | Glass | Metal | Glass | Plastic | Glass | Metal | ml |
| Oil test | | | | | | | |
| Dissolved gases | Y | Y | Y | | Y | Y | 25–100 |

**Syringes also have a few disadvantages as there is a high risk of breaking them during handling and transportation, so they need to be used only by a very skilled and experienced team both in the field and in a laboratory**

Table 1 represents Table 2 of the IEC standard describing the compatibility of the vessel and storage for the dissolved gasses. Besides this table, users also need to consider two important factors for selecting the correct vessel shape and material for DGA tests.

First are the testing laboratory requirements according to the specifications of their own measurement system. For example, for head space, it is much easier and more direct to transfer the oil directly from the sampling syringe to the vials. Other vessels such as bottles or ampules will need an additional transfer that may induce more interference due to additional air exposure of the oil.

Figure 11. Direct transfer of the oil to the vial for being tested according to headspace DGA

But syringes also have a few disadvantages as there is a high risk of breaking them during handling and transportation. Also, syringes need to be used only by a very skilled and experienced team both in the field and in a laboratory. Bottles can be filled more easily, and they are more robust for handling and transportation.

Syringes are also sensitive to manufacturing quality, but even the best manufactures cannot avoid leakages from the piston and / or the tip. As shown in Fig. 13, normal sampling teams and transformer users cannot afford to coat the piston with additional sealing materials, as is one in the case of commercial gas in oil sampling. The fact is that this spot on the syringe body is susceptible to undesired leakage in all the syringes. Another sensitive spot is the syringe tip and the three-way valve.

Ampoules are less popular in our days and are a remnant of the last century procedures. Some users and laboratories are still comfortable using them out of a habit. They were matched very well with vacuum mercury extraction systems, but those systems are very rare on our days, and syringes are also good for such extractions. Metal ampules are popular in the gas sampling application industry, like environment or natural gas.

Besides matching with the laboratory, the DGA vessel needs to fit with the transformer size and type. For nitrogen blanketing units, bottles are a better choice than syringes or ampules, and for small, sealed transformers, a limited oil volume taken with a syringe is a better choice than bottles. For free-breathing transformers, it is less important to make an effort of sampling with a syringe, and a bottle will be

quite suitable. For new non-free breathing transformers, it is worth obtaining a good sample with quality and expensive syringes for the sake of accurate DGA results. Syringes are at least ten times more expensive than any bottle type, and most of the users reuse and transport them clean and then fill them again. On the contrary, bottles permit only single use and provide a great advantage for transport, cleaning, and of course, the cost. However, syringes are still, in most cases, the best vessel for obtaining an accurate DGA result if all precautions are taken.

Table 2 contains a compilation of recommendations for selecting the best vessel according to the transformer and laboratory specifications.

Additional caution is also necessary in the case of a three-way plastic valve on the top of syringes. Some new insulating oil liquids are not compatible with some medical three-way plastic valves, and they may imperil the DGA sample. The same consideration is needed for bottle caps.

Figure 12. A special box for preserving sensitive syringes during transportation

**Syringes are still, in most cases, the best vessel for obtaining an accurate DGA result if all precautions are taken**

## Conclusion:

1. DGA is not a non-intrinsic test as probably considered. DGA sampling may affect transformer operation up to a catastrophic failure.
2. Negative pressure inside the main tank may be very dangerous and may exist in all transformer types, not only in the nitrogen blanket type.
3. DGA sampling and testing should be performed only if there is a real need and benefit, and periodical tests should be minimized and synchronized with transformer specifications. For small, sealed transformers,

Table 2. Optimization and recommendation for selecting DGA vessels according to the transformer and laboratory specifications

| Sample container | Syringe | Flexible bottle | Bottle | Ampoule | Ampoule | Oil volume ml |
|---|---|---|---|---|---|---|
| **Material** | glass | metal | glass | glass | metal | |
| **Sealed transformer** | +++ | - | - | + | - | 30 |
| **With membrane in conservator** | +++ | ++ | + | ++ | - | 30–200 |
| **New transformer** | +++ | - | - | - | - | 30–200 |
| **Free-breathing transformer** | + | ++ | + | + | + | 30–100 |
| **Over pressurized transformer** | - | +++ | +++ | ++ | ++ | 30–100 |
| **Head space DGA** | +++ | - | - | - | - | 30 |
| **Partial vacuum extraction** | +++ | - | - | ++ | ++ | |
| **Multi-stroke vacuum extraction** | +++ | +++ (non-mercury) | +++ (non-mercury | - | - | 100–200 |
| **Portable device** | +++ (for MS special one) | - | - | - | - | 50 or 110 (MS) or 100 (ES) |


Figure 13. A leaking syringe (left) versus one sealed with special grease (True North by Morgan Schaffer)

**Some new insulating oil liquids are not compatible with some medical three-way plastic valves, and they may imperil the DGA sample**

oil sampling may cause more damage than it will prevent.

4. DGA sampling is not isokinetic sampling, meaning that sampled oil may contain different dissolved contaminants than bulk oil. This may be more relevant for DGA online devices with a single sampling port.
5. DGA sampling team should be adequately protected against all electrical and chemical hazards. Used insulating liquids may contain harmful species for humans and the environment.
6. DGA sampling vessels should be selected very carefully, in accordance with transformer and test devices specifications. Material compatibility of sampling vessels and equipment to the insulating liquids should be tested before a sampling session.
7. Sampling for DGA online devices should periodically undergo leak test verification and be equipped with special accessories to avoid bubble formation.
8. For a two-valve sampling port, opening and closing should be performed in a specific sequence for avoiding any bubble entering the main tank. Front large valves should always be preferred for a DGA sampling procedure.

***Disclaimer: The information presented here is for educational purposes only. Sampling teams and transformer owners need to consult relevant manufactures and service providers in each specific case.***

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