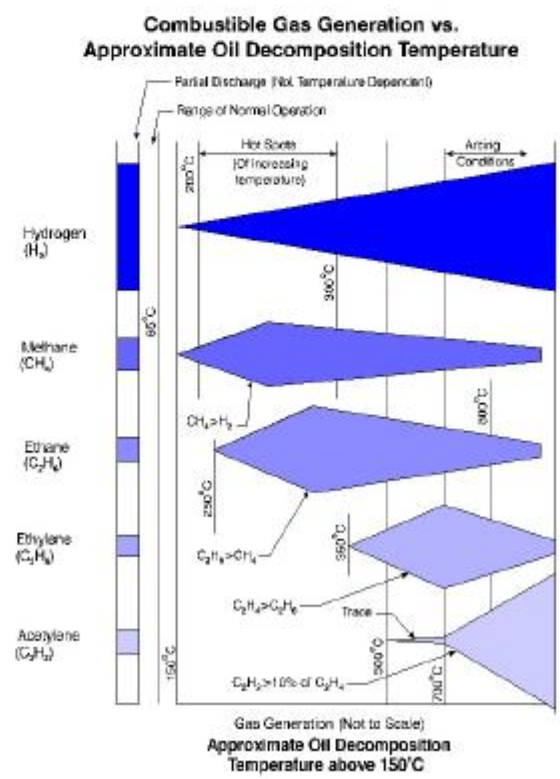
July 9, 2019

WHY OIL ANALYSIS IS IMPORTANT TO THE HEALTH OF YOUR LOAD TAP CHANGER

Maintaining your load tap changer fleet is crucial to continuous, safe operation of your transformers. Over time, contacts and other moving parts can start to show wear from repeated use or become damaged from intense heating inside the LTC. Many countermeasures exist for preventing LTC malfunction and critical failure, evolving over the years as the industry continues to study the effects of tap changer operation in oil.

Time-based maintenance, while oftentimes effective for routinely inspecting and maintaining all parts in good condition, can become expensive quickly, especially with large LTC fleets. Draining oil, opening the unit(s) and inspecting for wear or damage adds time and money that can be avoided with other, more sophisticated diagnostic tools.

Dissolved Gas Analysis, or DGA, analyzes the gasses captured within the oil, such as hydrogen, methane, ethane, ethylene and acetylene, to form a good diagnostic tool for the LTC. Prior to 1995, LTC DGA was considered of no value. Even today, dissolved gas and oil quality analysis are not widely used on a regular basis to assess and troubleshoot LTCs. Annual oil sampling for DGA coupled with online oil filtration systems can extend major maintenance intervals to 10+ years. As temperature inside the LTC increases, the amount of combustible gasses created via arcing and heating are dissolved into the oil, increasing over time. By studying the rise and fall of these gasses, detection of low, moderate and severe heating conditions are found without the cost of opening the unit for visual inspection. Severe heating conditions can lead to a critical fault and malfunction of the tap changer.



Combustible Gas Generation Versus Temperature.

The type of fault can be indicated by the dominant gas in the LTC, based on an increasing fault temperature that differs for each combustible gas. The ratios of each gas indicate the presence of heating, coking and arcing. While no industry accepted standards exist, we can analyze these gasses over time to form an idea of what is happening inside the tank.

One ratio to consider is ethylene over acetylene for arcing-in-oil type LTCs (both resistive and reactive) to predict when inspection of the load tap changer should occur. Because certain gasses appear more frequently as the fault temperature increases, we can detect low, moderate and severe heating conditions over time based on how much more ethylene is present compared to acetylene. These ratios are independent to the number of operations in the tap changer and also resistant to changes due to loss of gasses to the atmosphere. For vacuum-type LTCs, tracking the total combustible gas count over time can give some indication as to when the unit should be inspected.

$$\frac{\text{Ethylene}}{\text{Acetylene}}$$

Arcing Type LTC's (Resistive & Reactive)*	
<.5	Normal , continue annual sampling
.5< X<1	Warning, sample more frequently, trend
>1	Severe heating / coking probable, inspect,

* - Ethylene & Acetylene >50ppm

Total Combustible Gasses

Vacuum Type LTC's	
< 10 ppm	Normal , continue annual sampling
10< X<25 ppm	Warning, sample more frequently, trend
>25 ppm	Heating / coking probable, Inspect

Another ratio that can be considered is the Stenestam Ratio, which looks at the sum of methane, ethane and ethylene compared to acetylene.

Important to note that for each ratio calculation, a minimum count of gasses needs to exist before the ratio is effective. With small counts of gas, the ratio can vary wildly up and down the spectrum and have misleading results.

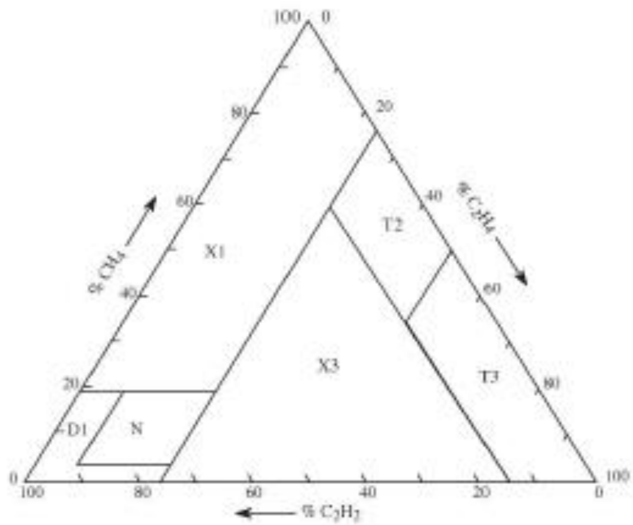
$$\frac{\underset{(CH4)}{\text{Methane}} + \underset{(C2H4)}{\text{Ethane}} + \underset{(C2H6)}{\text{Ethylene}}}{\text{Acetylene*}\ (C2H2)}$$

* Acetylene >500 ppm

Ratio	Diagnosis	Recommended Sampling Frequency
< .5	Normal	Sample Annually
.5 to 1	Possible Heating	Sample every 3-6 months
1 to 3	Possible Heating	Sample every 1-3 months
3 to 5	Possible Heating	Sample weekly to monthly
> 5	Overheating Probable	Remove From Service & Inspect

Stenestam Ratios

The Duval triangle is another great tool for trending heating and arcing gasses for LTCs. By plotting the gasses on the triangle, units moving from the “N” region (normal operation condition) to a fault condition can be detected. Coupled with infrared scans while in service, units headed towards failure can be reasonably confirmed.



Five zones of abnormal operation or faults are identified in the Triangle for LTCs of the oil type:
T3 = severe thermal fault with heavy coking of contacts (T > 700°C);
T2 = severe thermal fault with coking of contacts (300°C < T < 700°C);
X3 = fault T3 or T2 in progress, with light coking or increased electrical resistance of contacts;
D1 = abnormal discharges of low energy D1;
X1 = abnormal discharges of low energy D1, or thermal fault in progress;
N = Normal Operation

Note: Minimum gas levels should be >10ppm to apply this analysis method

While industry guides exist for analyzing DGA results, model-specific industry accepted limits are NOT available today. Generating such guidelines requires a significant number of LTCs and samples to form sound statistical results. Gas generation rates can vary due to model, design vintage, breathing type, frequency of operation and even maintenance practices across a fleet.

With all the discussion above, DGA is only half of the LTC condition assessment equation. Oil quality analysis is equally important for determining the health of your tap changer. Measuring key parameters such as inter-facial tension (IFT), acidity and water content, these tests provide an oil quality index and relative saturation that can be utilized as an additional indicator for chemical changes in the oil. Fluid quality index – (Acidity x 1000) / IFT – coupled with comparing the N2/O2 ratio in oil on free breathing units can detect the onset of sludge formation and contact filming before coking and contact damage occurs.

Warning Level	FQ Index	Meaning
Normal	1.0	New Oil , Good Condition
Alert	3.3 < FQ < 8	Consider Oil Reclamation
Warning	8 < FQ < 18	Oil Reclamation or Replacement Needed
Alarm	FQ > 18	Sludge Formation Assured

As moisture and oxygen in the oil increase, the heat from loading acts as an accelerant to oil oxidation and sludge formation. This contact sludge, or film, adds resistance to the contact which, in turn, increases heating even further. As this resistance rises, the rate of heating and sludge increases as well, leading to "thermal runaway" and formation of coke.

Oil chemistry affects can be mitigated. Monitor oil quality and DGA annually and trend results. Determine oil quality index – (Acidity x 1000) / IFT – and replace oil when quality index is greater than 18 during maintenance. Use online oil filtration on arcing-in-oil reactive and resistive-type LTCs. On units flagged by oil analysis, use infrared in conjunction with oil testing data to verify temperature differences between the LTC and main tank.

Case Study: Waukesha® UZD® - Resistive-type LTC with arcing selector switch

For an example of how both DGA results and oil quality data can be utilized as tools for LTC assessment, let's take a look at the data from this UZD:

Dissolved Gas Data										
Date	H2	O2	N2	CH4	CO	CO2	C2H4	C2H6	C2H2	Total Gas
10/4/2000	10	19970	58941	22	57	1021	73	14	644	80752
5/18/2001	127	15456	68728	34	112	1267	125	15	1248	87112
10/23/2001	112	22281	53502	46	74	2329	169	16	1211	79742
5/30/2003	194	11739	84928	34	177	1779	118	9	1005	99981
12/2/2004	22	12670	59689	13	40	1410	72	5	606	74527
12/28/2005	120	17352	58569	31	31	1364	110	8	1018	78603
8/11/2006	112	10330	73573	30	235	2559	99	7	866	87811
9/26/2006	113	12173	60057	25	111	1933	86	5	789	75294
4/8/2008	63	9627	57063	16	78	1138	74	6	538	68603
8/7/2009	119	546	72205	49	400	3403	106	16	631	77477
8/27/2009	182	21821	98559	28	184	2890	90	6	752	124292
9/23/2011	196	16476	85089	39	173	3556	102	6	1089	106728
4/20/2012	65	21592	66962	18	39	1506	73	5	741	91003
4/24/2012	64	22791	77153	19	61	1672	74	5	722	102471
3/28/2013	67	30726	57807	18	43	1797	74	30	663	91245

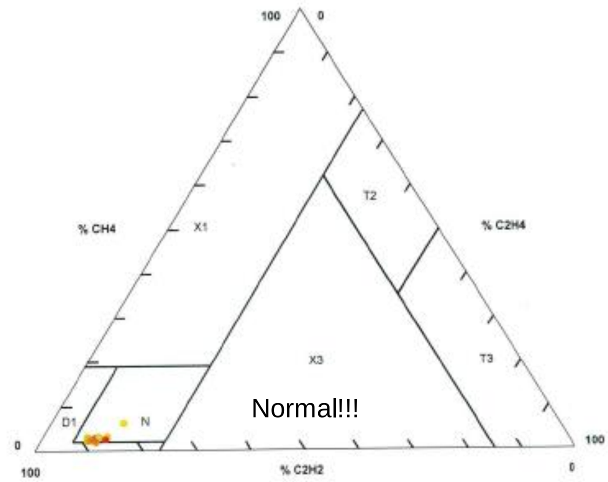
Oil Qualtiy Data							
Date	Diel 1816	Moisture (ppm)	il Saturati	Acid	IFT	pf25	Color
8/7/2009		62					
8/27/2009	25.0	40		0.520	17.0		3
9/23/2011		41					
4/20/2012		18					
4/24/2012		30					
3/28/2013	40.0	30		0.220	10.0	0.136	3

Suspect breather repaired around August 2009

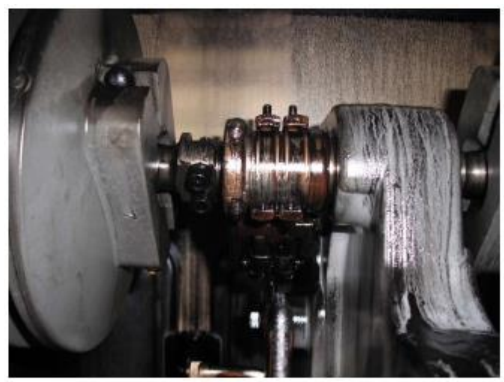
FQ Index = 22 N2 / O2 = 1.88 (132)
Ethylene / Acetylene = .11

The ethylene over acetylene ratio of 0.11 is “normal” according to the accepted guidelines, but the fluid quality index of 22 triggered an inspection of the tap changer (should be below 18 under normal operation). If DGA results alone were used, this unit likely would not have been flagged for inspection, as it appears to be in the normal operation range when plotted on the Duval Triangle.

Upon opening the unit, one can clearly see that this was a good catch, as film was beginning to form on many components of the LTC. Thermal runaway/coking may have unexpectedly occurred before the next maintenance cycle.



Sludge On Inside of Door



Film on Reversing Switch Contact

Film on Selector Switch Contacts

Early stages of coking on Reversing Sw Springs

Using traditional DGA alongside oil quality data, SPX Transformer Solutions has formulated a patented algorithm to analyze your fleet data and create a prioritized listing of units most in need of maintenance before significant damage occurs. With a large population of load tap changers and enough statistical data points, SPX Transformer Solutions can provide a FREE fleet consultation, giving a detailed, targeted approach to maintenance greatly exceeding industry standard DGA analysis guidelines.

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Drew Stillwell joined SPX Transformer Solutions in March 2018 as a technical support specialist for the Components Group in Dallas, Texas. Beginning his career in the engineered valve industry, he worked as an application engineer and sales analyst before transitioning to his current role at SPX Transformer Solutions. Drew holds a Bachelor of Science Degree in Mechanical Engineering from University of Massachusetts.

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