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DGA in a Box
A Utility's Perspective

By
Danny Bates
Alabama Power Company

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Abstract

Dissolved Gas Analysis (DGA) is considered one of the best methods for determining the internal condition of power transformers. The conventional method for obtaining this information requires that an oil sample be pulled into a glass syringe and transported to a lab for analysis using a gas chromatograph (GC). Quite often several hours and in some cases days elapse before the test results are obtained. A new method has been developed which allows DGA results to be obtained in the field eliminating the normal delay using the conventional method.

Comparison results of Gas Chromatography and Photo-Acoustic Spectroscopy are summarized using data obtained at two US utilities using both main tank and load tap changer (LTC) samples. Advantages of the ability to obtain results in the field are discussed.

Introduction

Alabama Power began using DGA in the late 1970's to determine if incipient faults were developing within power transformers. A limited number of samples were pulled on large units when problems were suspected. Due to limited experience with interpretation of results, small developing faults were often overlooked that eventually led to failure. Based on experience of others in the industry and published papers concerning the advantage of DGA a decision was made to implement a program in 1984 to use DGA on a scheduled interval and maintain historical results for comparison and trending on large critical units. In the past twenty years the program has been refined to include all power transformers and sample on an annual basis. In 1996 a program was implemented using DGA for load tap changers (LTC's). We have been successful with both programs in detecting faults before failure and extending maintenance intervals through the LTC analysis program.

In September 2003 Alabama Power began beta testing of the Kelman **Transport X** comparing our lab results to those of the Transport X. This paper provides our experiences and provides technical details and theory of operation.

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Portions of this paper are taken from a papers presented by Dr. Colin McIlroy at 2003 and 2004 diagnostics conferences (1) (2).

History

Alabama Power considers dissolved gas analysis to be the best non-intrusive tool we have to determine the internal condition of our transformer fleet. Over the years we have made a lot of progress in refining our initial program. Managers who were once skeptical of our recommendations to remove a GSU from service based on DGA now rely on us to routinely make these decisions. Quite often we have been able to repair critical units that if gone unattended would have eventually failed. Unfortunately, we don't catch all the problems and some units seem destined to fail in spite of our efforts. However, the ability to obtain a rush sample and have results within an hour would definitely give us an upper hand.

Currently our power transformer fleet consists of some 4,000 units ranging in size from small distribution type to large GSUs and large system autos. Our normal sampling interval is annual with the exception of GSUs which are sampled quarterly. In addition we sample 900 LTCs on an annual basis.

Our lab is located in the geographical center of the state and runs approximately 5,500 samples per year. Routine samples are pulled by our six regional maintenance centers and sent via courier in boxes of eight. Often there is as much as a two week delay from sampling to actually getting the results back. If a routine sample exceeds established flag-point values a confirmation sample is requested. Based on how critical the unit is or the level of gassing indicated we require a rush sample. This process can take as much as two days to get the results based on the location of the suspect unit. If necessary, the samples are delivered to the lab directly from the jobsite but from remote locations this still can take as much as six hours. Our operating procedures call for a DGA analysis sample before reenergizing a GSU that has tripped offline. Loss of revenue alone for an 800 megawatt unit is astronomical when you're waiting on lab results to determine if a unit can be placed back in service. Of course on-line DGA is the preferred method but until we have budget money to install such devices on critical units we still would prefer a faster method of obtaining DGA results.

A New Idea

Alabama Power is continually searching for new ideas and products that will enhance our maintenance process and increase reliability. Over the years we have experimented with several ideas and products of which some were successful and others were eventually scrapped. This

leads us to be cautious and often skeptical when approached by a manufacturer with a new technology.

When the first **Transport X** prototype was demonstrated to us in 2003 we were skeptical that DGA results could be obtained from such a small device using technology that we were not familiar with. And furthermore, to use it in the field under harsh conditions seemed impossible. We were familiar with our lab GC which required vacuum extraction and then running on a large machine in a very controlled environment. After some discussions we realized there might be potential in this device we agreed to be one of two US utilities to beta test the **Transport X**. We determined that duplicate samples taken from the same syringe ran on both our GC and the **Transport X** was the best method for beta tests. It was decided that the **Transport X** should be located at our lab and allow the chemist to compare the two. After lab test the unit would then be taken to the field to test its performance in real operating conditions.

Photo-Acoustic Spectroscopy for DGA

The **Transport X** uses Infra-red Photo-Acoustic Spectroscopy[1] (PAS) rather than conventional Gas Chromatography (GC) to measure the fault gases dissolved in an oil sample. The conceptual design of a practical PAS measurement module is shown in Figure 1. A simple hot wire source produces broadband radiation across the IR range that is focused into the measurement cell using a parabolic mirror. The chopper wheel rotates at a constant speed giving a stroboscopic effect to the light source. Before reaching the measurement cell the radiation is passed through one of a number of optical filters. These filters are designed to transmit the specific wavelengths chosen to excite one of the compounds under investigation.

The sample is introduced into the measurement cell and the acoustic signal level is recorded at the chopper frequency from the microphones as each optical filter is indexed into the light path. The series of readings produced then gives the concentration of the desired compounds in the sample.

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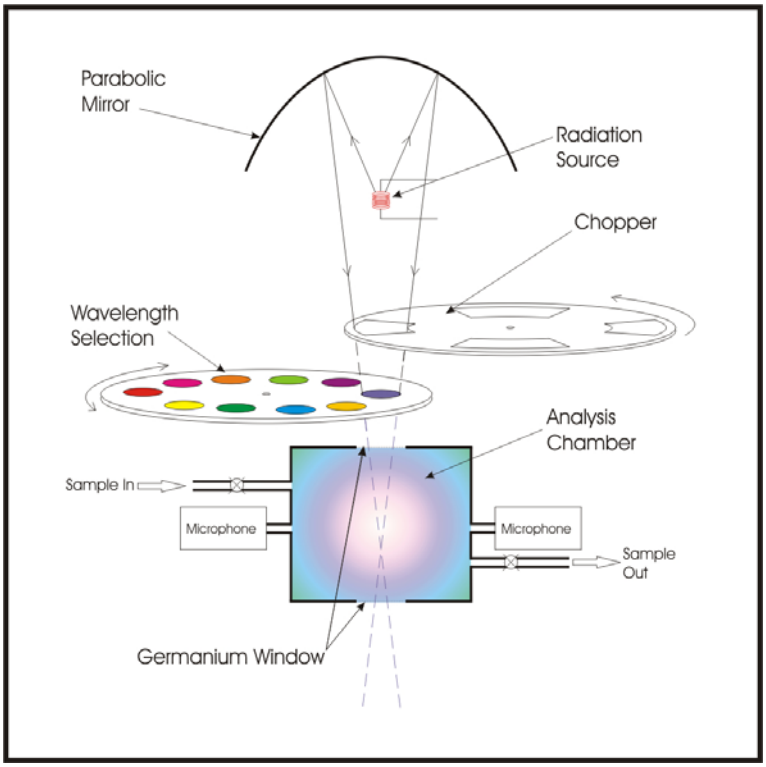

Figure 1. Photo-Acoustic Spectrometer Concept.

Photo-Acoustic Spectrometer Module

Kelman has developed the module shown in Figure 2 to provide the core of both the portable and fixed instrumentation for performing DGA on transformer oil.

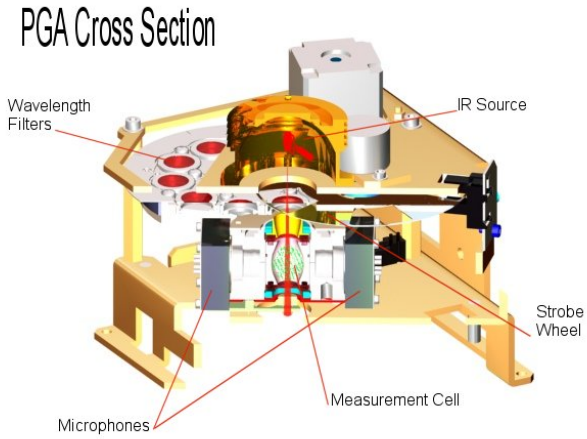

Figure 2. Photo-Acoustic Spectrometer Module.

The module measures approximately 160 x 150 x 140 mm (6.5 x 6 x 5.5 in), weighing less than 2 kg (5lb). It is entirely self-contained with all the electronic processing required to make the measurement and control the system. The **Transport X** uses this module coupled with a custom-designed system for the extraction of the gas from the sample to give a completely portable, self-contained analysis system. Figure 3 shows the system and illustrates the operation of the main elements in the design.

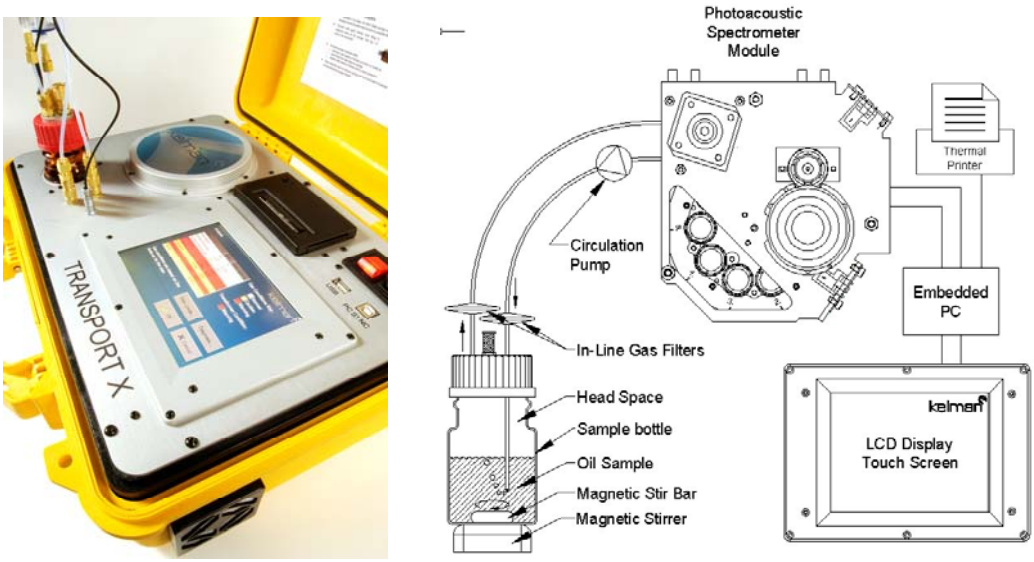

Figure 3. **Transport X** Portable DGA system, Principle of Operation.

The oil sample is drawn from the transformer in the conventional manner. It is then introduced into the measurement container directly from the sampling syringe. The oil is stirred while the air in the headspace is re-circulated though the sampling loop and oil to extract the dissolved gases. Once a stable equilibrium has been established the headspace gases are analyzed using the PAS spectrometer, and the results are presented on the integrated display.

Laboratory Investigations

We discussed our beta test ideas with our in-house chemist and he suggested that we take the comparison test to a higher level than we had originally planned. The methodology was to initially generate a large number of identical oil samples, each spiked with a known cocktail of the typical transformer fault gases. These samples were then analyzed using three different GC instruments and two **Transport X** units (prototype and pre-production units). The tests were performed over a period of 2 months in late 2003. The methodology is given in Appendix 1.

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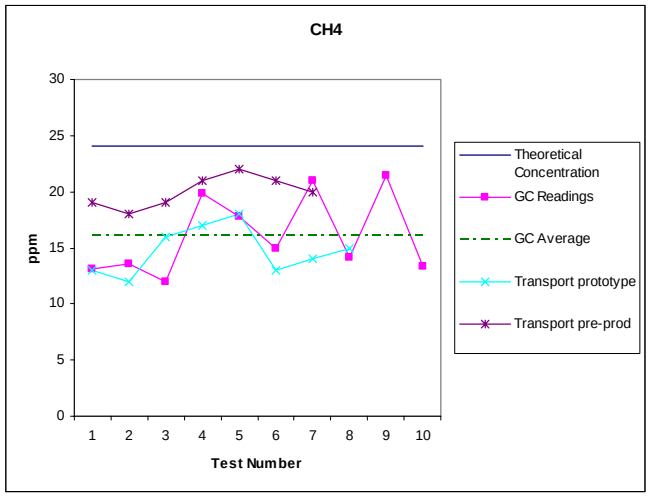
The results presented below show the comparison of all of the GC readings against those of the **Transport X**. Each gas is displayed separately for reasons of clarity however all gases were measured simultaneously on each occasion as for a normal oil sample. The aim of the experiment was to compare the GC and **Transport X** results in both amplitude and variability. Each graph gives the following information:

Trace 1 – Theoretical gas concentration based on the sample generation procedure.
Trace 2 – Individual GC readings in chronological order.
Trace 3 – The mean GC reading
Trace 4 – Individual **Transport X** readings (prototype unit 1)
Trace 5 – Individual **Transport X** readings (pre-production unit 2)

Two examples of **Transport X** are given to show the improvement between initial prototype unit and the pre-production device.

- Methane CH_4

In this case the **Transport X** readings for both units were within the spread of the GC results. It is interesting to note that the standard deviation of the **Transport X** unit 2 results is less than half that of the GC results.



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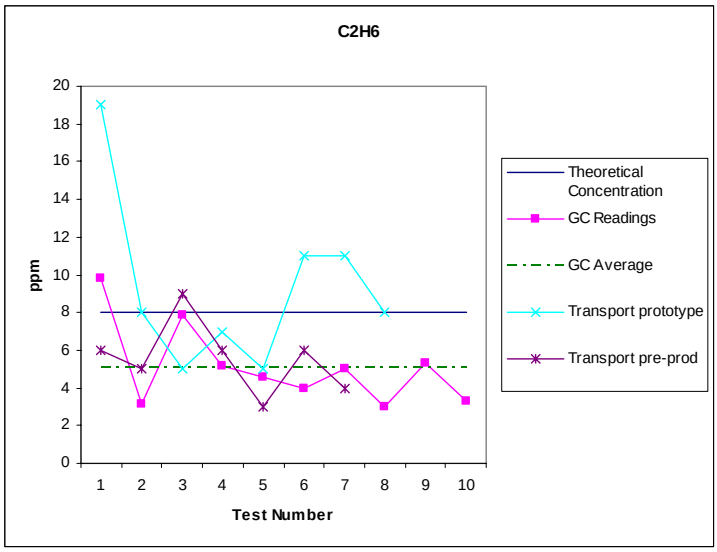
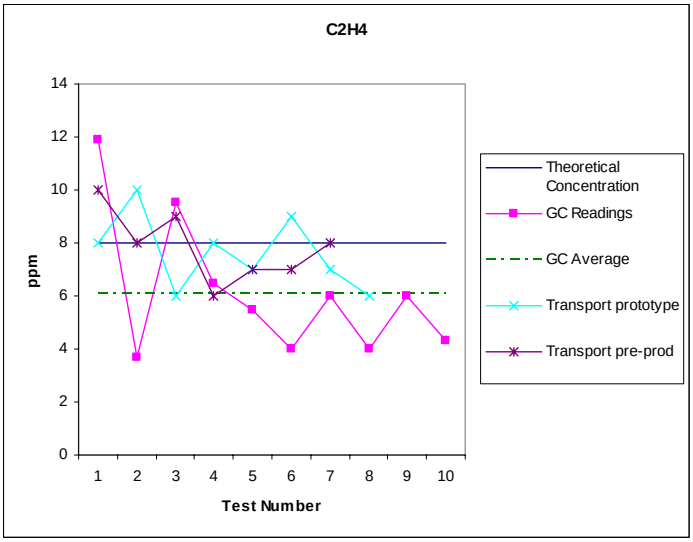
- Ethane C_2H_6

In this case all **Transport X** results for unit 2 are within the GC spread. The standard deviation of the **Transport X** unit 2 results are slightly better than the GC results.



- Ethylene C_2H_4

In this case all of the **Transport X** readings for both units were within the spread of the GC results. It is interesting to note that the standard deviation of the **Transport X** unit 2 results is less than half that of the GC results.



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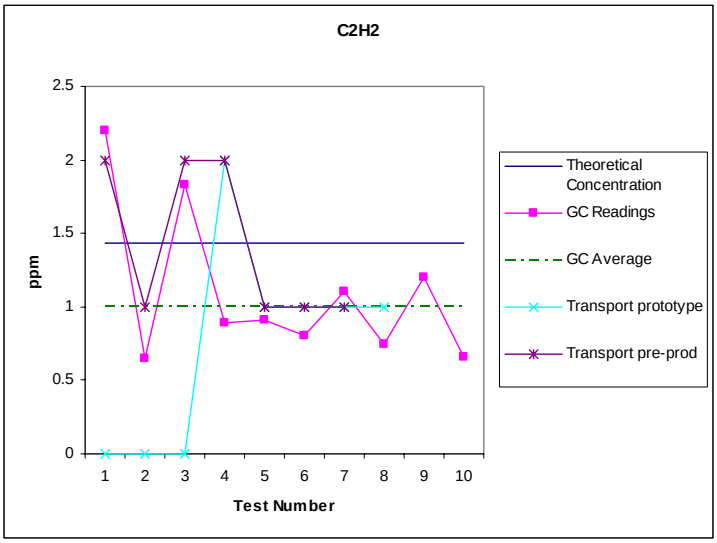
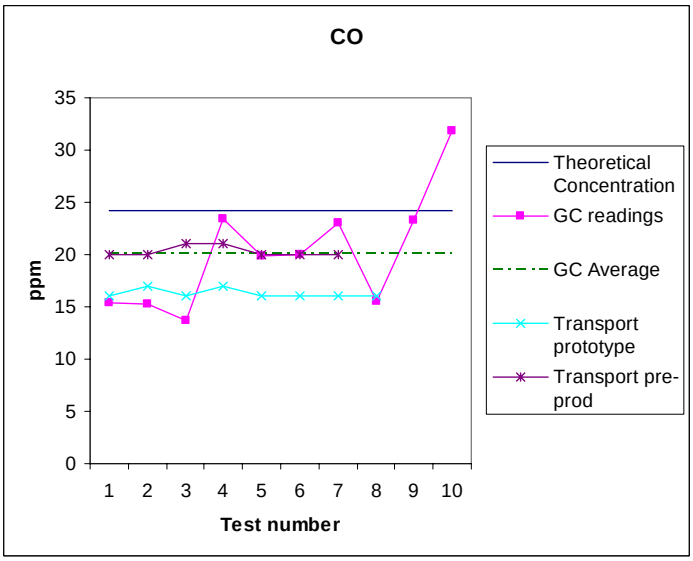
- Acetylene C_2H_2

In this case the test sample generated very low values for acetylene which make definitive judgements difficult, however all results from **Transport X** unit 2 are within the spread of the GC results.



- Carbon Monoxide CO

In this case all of the **Transport X** readings for both units were within the spread of the GC results. It is interesting to note that the standard deviation of all the **Transport X** results is less than one tenth that of the GC results.



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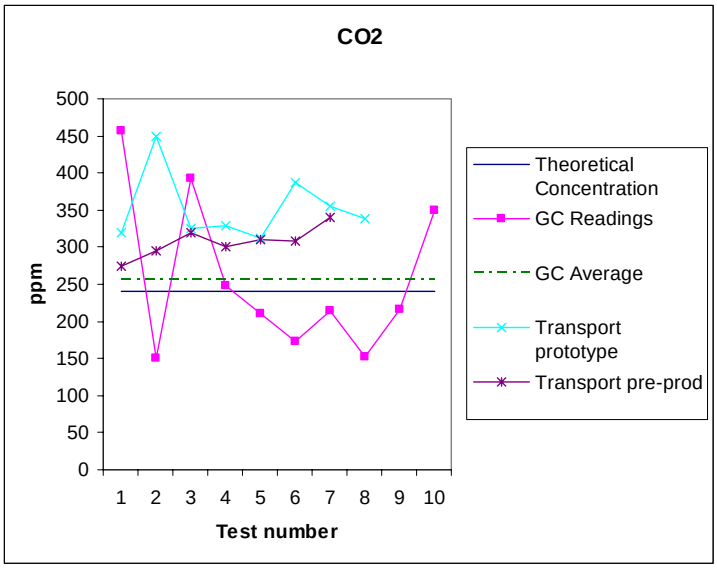
- Carbon Dioxide CO_2

In this case all of the **Transport X** readings for both units were within the spread of the GC results. It is interesting to note that the standard deviation of all the **Transport X** results is less than one fifth that of the GC results.



Analysis of Laboratory Investigations

Although the sample size is relatively small, the use of identical samples throughout the test means that there are some interesting conclusions that can be drawn from this study.

It is clear that in this study the results from the **Transport X** system exhibit less variability than the spread between the three GC instruments. The repeatability of the **Transport X** results were never worse than the GCs and in many cases it was significantly better, especially with CO and CO_2.

It is difficult to quantify the 'accuracy' of the measurements since few results from either method actually matched the theoretical concentrations and the test was only performed at a single level for each gas. However, in this sample the accuracy of the **Transport X** measurements appears at least equal to that of the GCs and in some cases it is better than the GC average.

In general it is fair to conclude that the **Transport X** and GC measurements are closely comparable and that the differences between the two techniques could easily be masked by other effects, such as sample preparation and handling.

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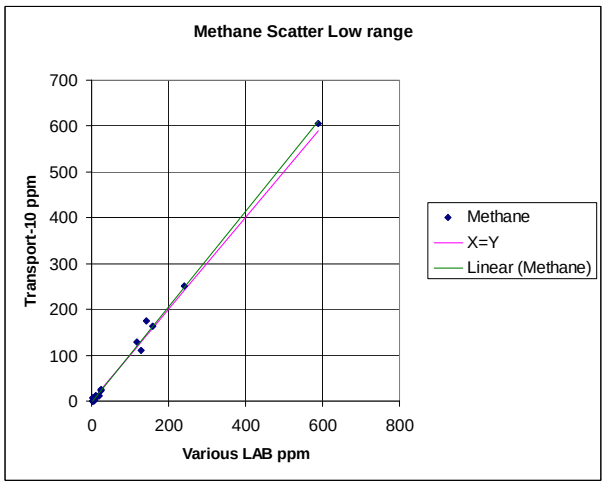
Field Results From Texas and Overseas

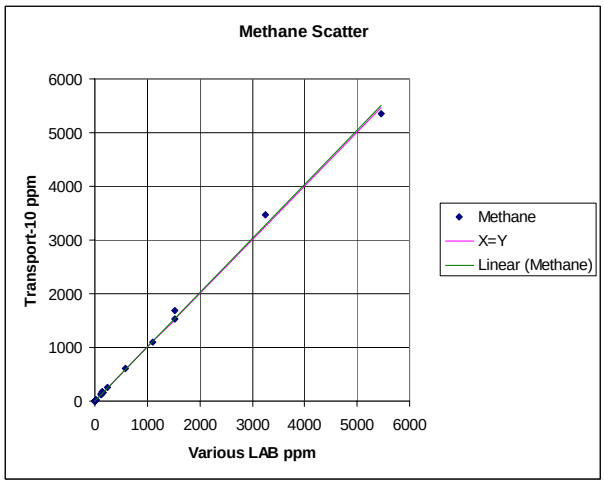
While we were performing our lab comparison test with spiked samples the other US beta site was taking a slightly different approach. Randy Cox of Oncor (now called TXU Electric Delivery) extended the study to include data from LTC's in various states of repair. These were then combined with test results from other sites to give the graphs below. The environmental conditions ranged from sub-arctic to desert and from temperate to sub-tropical.

In each case duplicate samples were taken, one being analyzed on-site with the **Transport X** and the other sent to the utility's normal lab (either in-house or contract). The results given here are a representative sample from the field trials. By definition they include the variability due to different oils, transformer designs, sampling techniques, sample handling and storage, different lab GCs and different **Transport X** units.

The results are presented as scatter diagrams for each gas in turn. In some cases two graphs are given to adequately cover the measurement range. In all cases the graph shows an ideal correlation (X=Y) and a best fit line to match the actual data.

- Methane CH_4





There is good correlation between the two methods over the full measurement range with excellent linearity.

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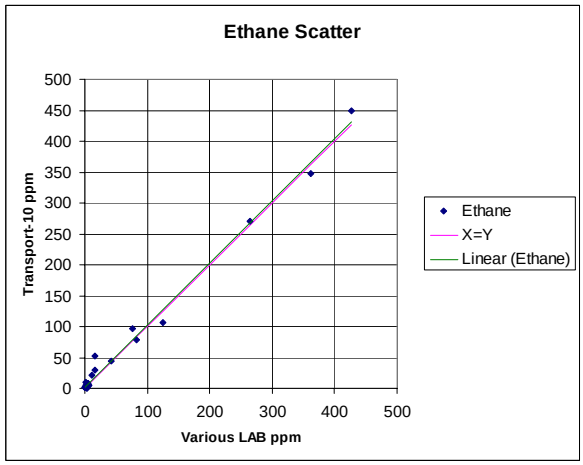
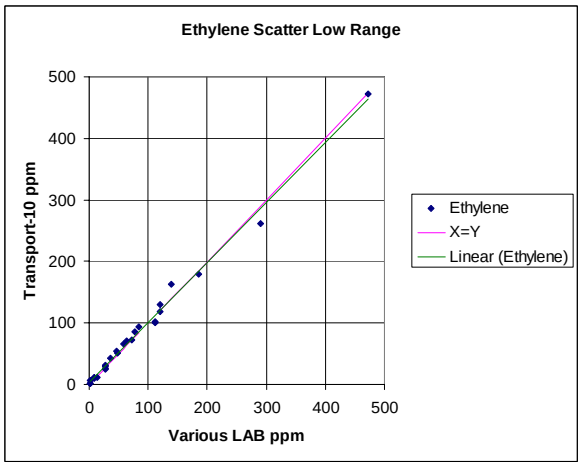
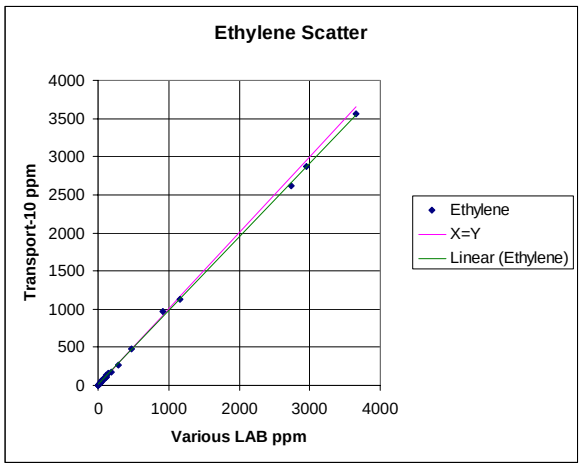
- Ethane C_2H_6

Once again there is good correlation between the two methods with ideal linearity.



- Ethylene C_2H_4





Once again there is good correlation between the two methods with ideal linearity.

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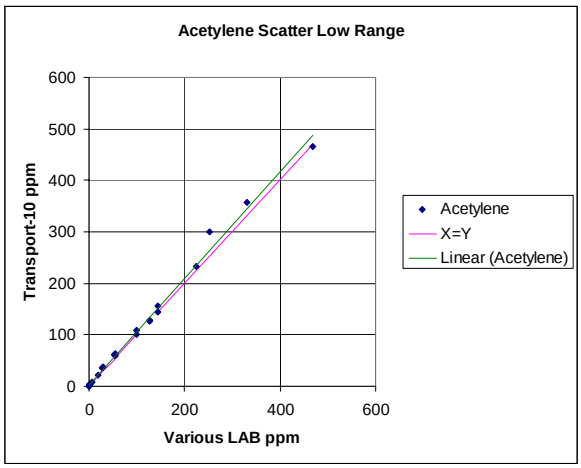
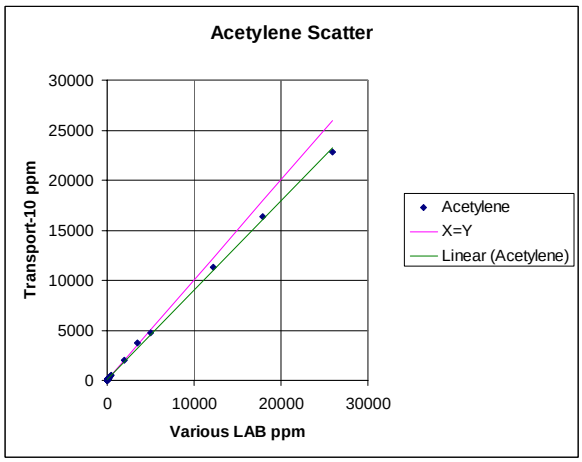
- Acetylene C_2H_2

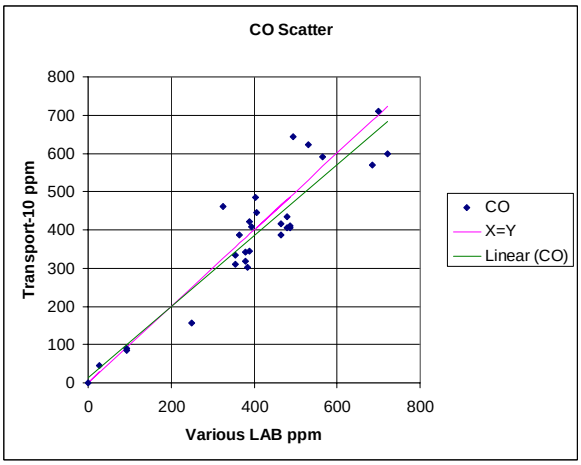




The correlation between the **Transport X** and GC results is excellent with ideal linearity in the measurement range. The linearity begins to break down at very high concentrations (20,000 – 30,000ppm) but this is 2–3 times greater than the quoted range of the **Transport X**. However these results were incorporated to show that the unit can be used in high acetylene concentrations, for example with LTC oils.

- Carbon Monoxide CO

In this case the mean linearity is good but the scatter is much greater than in the previous cases. On examination of the Lab results this may be explained by the greater variability (x10) observed in the Lab CO results compared with the **Transport X**.



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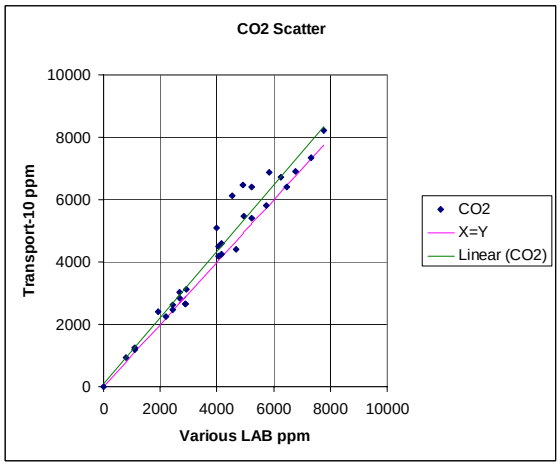
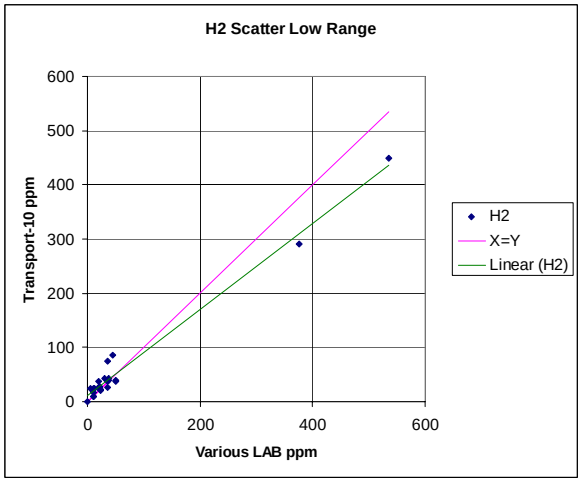
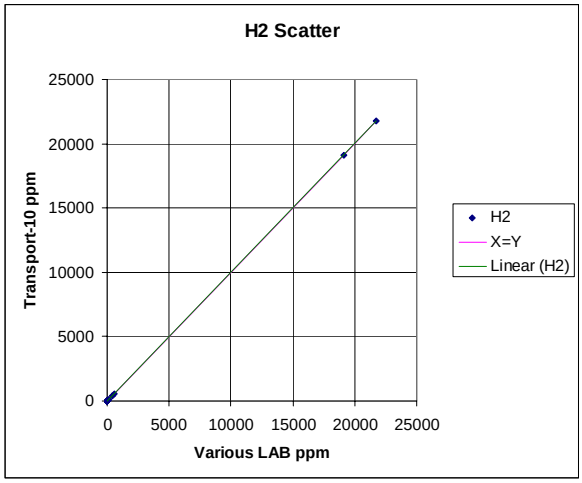
- Carbon Dioxide CO_2

Correlation between the two methods is good on average, but the scatter is not as tight as some of the other gases. Examination of the Lab results again may offer an explanation since the GC results demonstrate a greater variability (x5) compared to the **Transport X**.



- Hydrogen H_2





Over the full measurement range correlation and linearity appear to be excellent. The relative scarcity of results in the mid range make a definitive analysis difficult.

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Analysis of Field Results

It is clear that the Photo-acoustic measurements from the **Transport X** and the GC measurements from a range of labs show an excellent correlation, in spite of the fundamentally different approaches to both the gas extraction from the oil and the gas measurement technique. The correlation remains good over the entire measurement range of interest and the linearity is maintained at an ideal 1:1.

The scatter is remarkably low for Methane, Ethane, Ethylene, and Acetylene. The results for CO and CO_2 do not exhibit the same tight grouping, however the linearity remains excellent. These results are consistent with the lab findings in that the GC measurements showed a marked increase in variability over the **Transport X** for CO and CO_2. The linearity for H_2 is excellent; however more data points in the mid range concentrations are needed to accurately estimate the scatter between the two techniques.

Analysis Conclusion

The results of controlled lab experiments and practical field trials clearly demonstrate that the Photo-Acoustic Spectroscopy and modified headspace gas extraction used in the **Transport X** is directly comparable to the conventional techniques of GC used in a wide variety of labs. In many cases the variability of the **Transport X** results is significantly better than that displayed by some of the GC results. Indeed it is remarkable that the differences between the two techniques are so small, especially given the wide spread of equipment, technicians, and laboratories.

In general it can be concluded the two techniques will give directly comparable DGA results over a wide range of typical transformer and LTC oils and that any differences between the two may be attributed to normal experimental errors.

Field Application

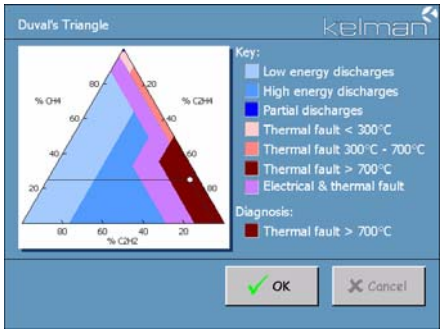
After we completed the beta testing two commercial products were purchased and we began using the **Transport X** in the field. The units are used when a confirmation or rush sample is required. One of the units was assigned to the maintenance area that is most remote from our lab. Our plans eventually call for having a **Transport X** located in each of the six maintenance areas. Also, the generation group has expressed interest in using the **Transport X** for sampling of auxiliary transformers located inside the plants. We don't intend to replace our current program using our in-house lab but rather to compliment it with the **Transport X**.

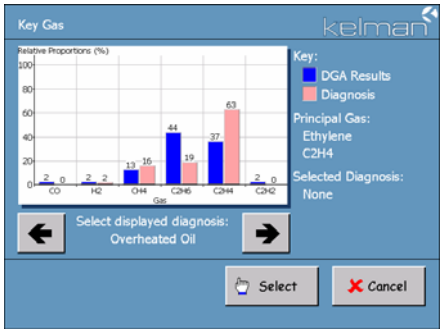
We have found that the **Transport X** is easy to operate and requires little expertise other than the ability to pull a good sample. The actual gas values are easily obtainable and approximately twenty minutes is required to run the test. We haven't experienced any real problems other than the time required to run the sample when oil temperature is excessively high. Kelman is currently working to solve the temperature problem. While the field results don't always match

our GC results exactly we are satisfied that decisions can be made concerning whether or not to place a unit back in service or if further investigation is necessary. However, very recently our in-house laboratory has changed from vacuum extraction of the gas sample to the headspace method (ASTM 3612 C) and it has been observed that latest results match up extremely closely with the **Transport X**. A recent example of the value of this device occurred when we changed high side taps on a unit that had low levels of arcing gasses with 5ppm acetylene. Two days after placing the unit back in service a sample was taken and ran on the **Transport X**. Results indicated that severe arcing was going on inside the unit (788 ppm acetylene) so preparations were made to switch the unit out immediately. After the unit was taken out of service we took another sample to determine rate of rise. This sample contained 992 ppm acetylene and results were confirmed with a sample sent to our in-house lab. Internal inspection revealed a disk to disk failure in the HV tap winding. If left in service this unit was subject to a possible violent failure. This case alone was enough to justify our efforts during the beta tests of the **Transport X**.

Recent Developments

Recent developments to the **Transport X** allow communication with a PC in order to download records, upload information and export into third party programs. The **Transport X** now also includes embedded software to assist in the diagnosis of DGA results. These algorithms include Rogers' Ratios, Duval's Triangle and IEEE Key Gas methods, as well as user settable gas thresholds for 'Caution' and 'Warning' levels. These developments allow users who are not familiar with interpretation of DGA results to run analysis programs, define threshold values, trend results and generate reports.





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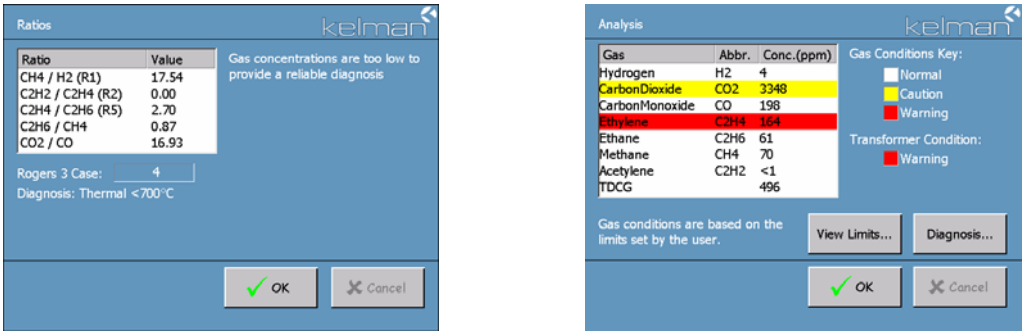

Figure 4: **Transport X** DGA diagnosis software

We have also just started our evaluation of the **Transfix** system from Kelman. This uses the same measurement technology to give permanent on-line DGA at hourly intervals. The test site chosen was as a new LTC installation that basically had zero level gas content. This particular LTC is a resistive type which creates low levels of gas each time it steps. This somewhat simulates a developing fault in a power transformer. Initial results are encouraging and I expect to be able to report on the system progress in future presentations.

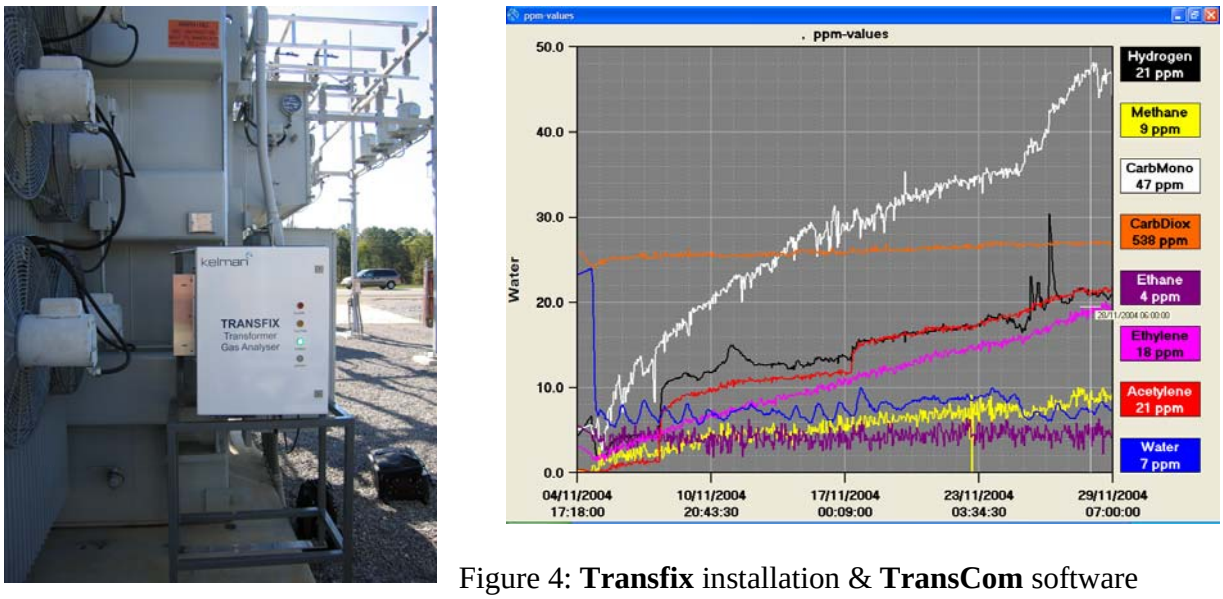

Figure 4: **Transfix** installation & **TransCom** software

Conclusion

If we only had one tool in our toolbox to determine the condition of our transformer fleet then Alabama Power would choose DGA as that tool. We have made much progress since our program was first implemented twenty years ago. As stated earlier we can't catch all imminent failures using DGA but our success rate exceeds the failure rate. We feel that with the addition of the Transport X we now have the ability to make critical decisions concerning problem units quicker than before therefore improving our reliability.

References

1. McIlroy, Colin**.** "*Photo-Acoustic Spectroscopy, A New Technique for Dissolved Gas Analysis in Oil*". EPRI Substation Equipment Diagnostics Conference, New Orleans, LA, USA. February 23–26, 2003

2. McIlroy, Colin**.** "*A Comparison of Photo-Acoustic Spectrometer and Gas Chromatograph Techniques for Dissolved Gas Analysis of Transformer Oil*". EPRI Substation Equipment Diagnostics Conference, New Orleans, LA, USA. February 15-18, 2004

Biography

Danny Bates is Equipment Test Team Leader at Alabama Power Company. He has held this position since 1985. The Equipment Test Group provides maintenance and testing support to the maintenance regions and generating plants. Other responsibilities include researching and implementing on-line monitoring and on-line test devices.

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Appendix 1

Gas-in-Oil Standard. A standard gas mix in the following concentrations was obtained from Airgas.

Hydrogen	608 ppm
Oxygen	9856 ppm
CH4	603 ppm
CO	606 ppm
CO2	6006 ppm
C2H4	200 ppm
C2H6	200 ppm
C2H2	36 ppm

The balance is Nitrogen.

To obtain the test oil, 2.0 ml of this mix was completely dissolved in 50 ml of new mineral oil which had been vacuum (10-4 torr) degassed for 4 hours.

GC analysis consists of extracting the gas out of 25 ml of oil via Doble-style vacuum degasser. This is a one-piece glass item of about 200 ml capacity plus 4 ml graduated in tenths for reading volumes extracted. It has three high-vacuum valves, two of which are three-way and a septum for a needle (gas-tight syringe). The one-way valve is the stopcock for the mercury used as a liquid piston and is attached by Tygon tubing to a 500 ml reservoir.
The GC is set up with two automated Valco valves, 8 and 10-port, each with a 1/4 ml sample loop. The gas is sampled from the Doble extractor with a gas-tight syringe and injected into the GC to fill the loops. Gas extracted must be ~1ml in order to completely fill both loops. The run is started and the first valve injects its loop for separation on a 1/8 in., 4 ft. stainless column packed with mol sieve 13X. There are five gases separated by this column: hydrogen, oxygen, nitrogen, methane and carbon monoxide. The first three of these are detected with a Thermal Conductivity (hotwire) Detector. Argon must be used as carrier to obtain positive deflection for all three of the detected gases. The TCD effluent is routed through a methanizer (nickel catalyst) and then to the Flame Ionization Detector. Methane can be observed eluting after the nitrogen peak if signal output is then switched to view the FID. Carbon monoxide is first hydrogenated in the methanizer then burned in the FID (as methane) for detection of the fifth peak. During the first few minutes of the run, the second loop is injected and is directed to a 1/8 in., 6 ft. stainless steel column containing a porous polymer (e.g., Hayesep A) for the separation of the final four peaks: carbon dioxide, ethylene, ethane and acetylene. The effluent of this column is vented through a restrictor until after CO has entered the detector train. Of course, the timing of the valve switching is very critical at every step. As with CO, the CO2 is changed to methane in the methanizer before FID detection. The last peak, acetylene is eluted around 5 minutes and afterwards the valves are switched to backflush the mol sieve column to the detector for another five minutes.