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Development of the diagnostic tool dissolved gas analysis and marketing activities for condition assessment of power transformers

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Title (English)

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Title (Swedish)

Abstract

The possibility of using a mass spectrometer as detector for dissolved gas analysis was investigated and a website for the ABB Transformers Diagnostic Group was created. Oil samples of known gas concentrations were analyzed to select chromatographic configuration, method and ion masses for detection. The selectivity and the detection limits were evaluated. An encountered obstacle was the stability of the system.

Keywords

Dissolved gas analysis, transformers, ABB, marketing, gas chromatography

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Sammanfattning

En krafttransformator är en komplex anordning uppbyggd av många typer av material, exempel på två sådana är isoleroljan och pappersisolationen. Flera olika mätmetoder, fysikaliska såväl som kemiska, finns för att bilda sig en uppfattning om hur väl transformatorn fungerar. ABB Transformers Diagnostikgrupp säljer tjänster avsedda att säkerställa tillgängligheten hos transformatorer. Ett av de viktigaste verktygen för att avgöra transformatorns kondition är att analysera de gaser som är lösta i transformatoroljan. Denna analys utförs med headspace kopplat till gaskromatografi.

Syftet med detta examensarbete var att undersöka möjligheten att använda en mass-spektrometer som detektor istället för de två detektorer som vanligen används för analys av gaser lösta i olja. Då de tjänster som diagnostikgruppen erbjuder är tekniskt komplexa är marknadsföringen utmanande. Genomförande av en marknadsföringsförbättrande åtgärd för dessa tjänster var därför ett delsyfte.

Genom att analysera oljeprover med känd gaskoncentration kunde parameterar som val av kromatografisk konfiguration, val av metod, val av joner för detektion, selektivitet och detektionsgränser utvärderas. Resultaten visar att det är troligt att en mass-spektrometer kan användas i denna applikation men detta kunde ej verifieras då systemet ej var stabilt. En websida för Diagnostikgruppen skapades utifrån det behov som framkom vid intervjuer med nyckelpersoner och utifrån kartläggning av den befintliga marknadsföringen.

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1. Introduction

ABB Transformers in Ludvika, Sweden, is one of three subdivisions to ABB Power Products. Power products such as transformers, switchgears and circuit breakers are needed for transmission and distribution of energy. The business unit ABB Transformers manufactures a full range of transformers and reactors, as well as other electrical components crucial for power transmission. Besides production, there is also a service portfolio including everything required throughout the transformer life cycle.

Since a transformer is a large investment, it is important that it remains in good condition for as long as possible. If a unit is properly maintained, its time in service can be substantially prolonged. A failure in a transformer can have disastrous economic consequences for a heavy process industry. For example, interruptions in the production may cause serious economical losses. The magnitude of these losses may outnumber the cost of the transformer itself by far. Another big group of power transformer owners are the energy distributors. The transformers are often situated in critical locations within their power supply systems. These companies are dependent on their electrical equipment to be able to deliver power safely and without interruptions.

One of the power transformer services provided by ABB Transformers in Ludvika is transformer diagnostics. The Diagnostic Group, called MD, is the unit responsible for this service. The mission of the group is to give the customer a “good night sleep” concerning their transformers and reactors. This translates into ensuring the availability of the transformers in a cost efficient way. The group sells services aimed at assessing the condition of power transformers. This is done by performing chemical and physical analyses on a regular basis on the insulating transformer oil and paper. The analysis can reveal incipient faults and recommendations can then be made regarding the maintenance of the transformer. Consequently, condition assessments can expand the lifespan of the transformer, the risk of breakdowns will be minimized and the return on assets can be maximized. ABB Ludvika has been a transformer manufacturer for 100 years resulting in a vast experience of how transformers are designed and how they operate. The Diagnostic Group in Ludvika includes specialists with world-class competence in the field.

One very important analytical method is dissolved gas analysis, DGA. The presence and relative distribution of certain gases dissolved in the transformer oil are indicative of certain failure risks. DGA is a mature technique used by several laboratories around the world. It is also known as the most reliable single tool in diagnostics (Pettersson, 1995). The Diagnostics Group performs several thousands such analyses each year.

There are clear goals to increase the revenues from the unit. This can be achieved by raising prices and/or increasing volumes. The services sold by the group are often complex and thereby difficult for the customer to fully understand, why marketing is a challenge.

1.2. Aim of the project

The aim of this project was twofold. One part was to explore the possibility of using a mass spectrometer (MS) instead of the flame ionization and the thermal conductivity detectors used today for dissolved gas analysis. The second goal was to identify marketing areas in need for improvement and suggest solutions. One of the areas was then to be selected for immediate action.

2. Background

The following section presents the background of the project. This includes a brief presentation of the Diagnostic Group, the purpose of and procedure for dissolved gas analysis and possible advantages by using a mass spectrometer.

2.1. The Diagnostic Group

The Diagnostic Group was created in 1995, when the former chemical laboratory of ABB Transformers was reorganized. The broad services offered earlier were defined and a certain area of specialization was chosen. The new business plan was designed according to the results from an extensive customer value survey made by the people who later formed the group. Today the group consists of 11 people of which four have PhDs. The most common background is within physical or chemical engineering. A recruitment of an additional laboratory technician is planned.

The Diagnostic Group sells its services to owners of power transformers or related equipment. In addition to the external customers, the group also performs factory tests for the local transformer production. Some of the customers today are inherited from other units within ABB. This can be customers who bought transformers and have a strong relation to the company. There are three major groups of external customers: industry, power generators and power distributors. The customers have usually outsourced the maintenance and service of their power facility to an entrepreneur. In those cases it is the service provider and not the owner of the equipment that contacts the Diagnostic Group. The knowledge-level among the customers concerning the benefits of diagnostic services varies.

The market could be described as slowly awakening regarding the importance of the more advanced analyses. The Diagnostic Group is aiming at increasing the number of the advanced lifetime assessments (which also have the better margins). This is a niche where most competitors lack the competence to pose a threat, according to the Head of the unit. Today, many of the transformer fleets around the world are starting to reach a critical point where condition assessment is becoming urgent.

Sweden is the primary market. Customers served outside of Sweden are most often situated in neighboring countries where ABB does not have a local ABB-service unit, such as Finland or

Denmark. Furthermore, a number of customers outside the most immediate geographic area also exist. A typical feature for this category is a long-term relation with ABB in Ludvika.

There are three competitors in Sweden and one major global competitor. ABB has one of the largest market shares in Sweden, approximately 25% of the total market.

2.2. The transformer

Figure 1. Large power transformer. ABB Image data bank, with permission from Sven-Erik Jansson webmaster ABB Transfomers.

There is a great variety of transformers with different application areas and sizes. Small transformers can be found inside of electrical household equipment while large power transformers (Figure 1) can have sizes similar to entire houses. One small power transformer can provide electricity to about 3000 households (Carrander, 3 Oct. 07). Based on its design, a transformer can be used to either step up or down electric currents.

Energy is most often generated very far from the place where it is consumed; hence it needs to be efficiently transported. In order to avoid energy losses when transporting electrical energy over long distances, it is best to use a high voltage and a low current.

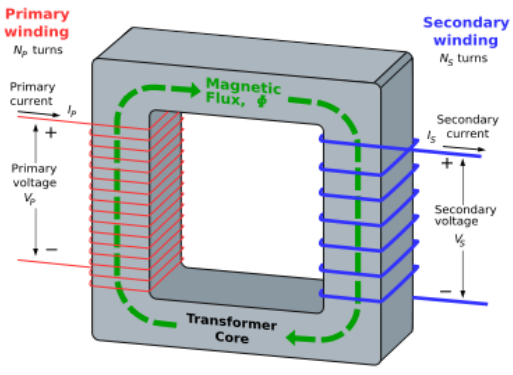

Figure 2. General transformer principle. Figure used with permission from wikipedia.org.

Whether it is a power transformer or any other kind of transformer, the design is based on the same principles. Very simplified, a core with magnetic features is wrapped with two pieces of conducting wire (Figure 2). A changing current is passing through one of the conductors, and as a result, a magnetic field is created through the core. The magnetic flux created in the core will pass through the area where the second conductor is wrapped. Due to electromagnetic induction, a voltage will be induced over the ends of the second conductor. The conductor inducing the electromagnetic field is the primary winding. The winding in which the new current is created is called the

secondary winding. The ability of the transformer to step up or down the voltage depends on the number of turns each wire is wrapped around the core.

Typical for larger power transformers are windings made of rectangular copper conductors (Figure 3). Each copper winding must be electrically insulated from all of the others, to make sure that the current travels through every turn. For this purpose, oil-impregnated paper is wrapped around the copper as insulation.

Figure 3. Rectangular copper wire wrapped with paper. With permission from Lena Melzer ABB Transformers Diagnostic Group.

When the transformer operates under high-temperature conditions, the paper insulation is in risk of degrading and becoming damaged. This is not a problem for small transformers which does not generate much heat, but high-power transformers (Figure 4) need some kind of thermal management. Heat needs to be transported away from the interior to avoid rapid ageing of the insulating materials. A solution to this problem is the usage of transformer oil. The entire transformer is put in a sealed tank filled with highly refined mineral oil. Tanks containing large power transformers require oil amounts of about 50-100 m^3 (Carrander, 3 Oct. 07). The oil is circulated in the tank, acting as a cooling medium and as a part of the dielectric insulation system. The oil must be able to withstand high temperatures and remain stable. If the oil does not meet the requirements, discharges of high energy in the transformer might cause a breakdown. Electric pumps can aid the circulation of the oil and fans and water-cooled heat exchangers are used to lower the temperature.

Figure 4. Paper insulated transformer without tank. Figure used with permission from Anna Nordh, security manager ABB Transformers.

2.3. Transformer oil

As previously described, the oil in the transformer has two functions: to act as a coolant and to insulate. Mineral oil (Figure 5) has been used for this purpose in over a century. Its physical and dielectric properties make it suitable for this purpose. For example, the viscosity is low even for low temperatures and the boiling interval starts at approximately 250°C. There are other fluids that can be used (e.g. silicon oils, certain esters), however, these are yet not as cost efficient as mineral oil. Other important factors are the compatibility of the fluid with the other materials in the transformer and the environmental impact.

Figure 5. Headspace vial with mineral oil. With permission from Lena Melzer ABB Transformers Diagnostic Group.

The mineral oil consists of (with some exceptions) different molecules of carbon and hydrogen. These molecules can be built from straight or branched alkanes (paraffinic/isoparaffinic structure), cycloalkanes (naphtenic structure) or aromates (aromatic structure). A typical mineral oil molecule might contain all of the mentioned structures.

The condition of the transformer is reflected in the transformer oil. An oil analysis can therefore present information about the status of the other materials inside. To tap a sample of oil is a convenient method to gain this kind of information. It is non-invasive and the amount of oil required is about one liter. For example, an analysis can provide information regarding paper degradation, hot spots and electrical faults. When conducting regular analyses, serious problems can be avoided. The analyses can give early warnings and proper action can be taken in time.

The results from the different tests performed are evaluated together. To create a complete picture of the situation, old test results as well as information about the design of the transformer and how it has been operating are also used.

2.4. Dissolved Gas Analysis

Simply put, DGA is a four-step process. The first step is sampling of oil from the transformer. This is followed by an extraction of the dissolved gases. The extracted gases are then separated, identified and quantified by gas chromatography (GC). Finally, the analysis is

interpreted according to an evaluation scheme. The IEC Publication 60599 specifies how the gas-in-oil analysis should be performed.

An analysis of the gases dissolved in the transformer oil provides a lot of information regarding the condition of the transformer. When the transformer ages, decomposition gases are generated from (mostly) the organic insulation. Gas formation is expected under normal circumstances, however, it can accelerate rapidly if the transformer is exposed to abnormal stresses. DGA has many application areas and can be used to supervise suspect transformers, to test hypotheses, to explain already occurred failures or disturbances and also to assign prioritizing scores to large populations of transformers (Pettersson, 1995).

DGA is considered as a mature technique and is used in several laboratories around the world (Pettersson, 1995). Gases resulting from the decomposition of the insulation are: hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), propane (C_3H_8), propene (C_3H_6) (oil deterioration) and carbon monoxide (CO) and carbon dioxide (CO_2) (paper deterioration). The concentration of nitrogen (N_2) and oxygen (O_2) are also of interest, even though these gases are not degradation products (oxygen is consumed during degradation). The amounts of oxygen and nitrogen can be an indicator of presence or absence of air in the transformer. Elevated amounts can point towards mistakes during the sampling procedure allowing entrance of air (and possibly also leakage of gas from the oil). The amount of each gas and its relative distribution is measured. It is also important to know the formation rate, why regular testing becomes necessary. The amounts and relative distribution of certain gases are characteristic for certain types of stresses and degradation. The severity of these disturbances can also be estimated with the information obtained.

2.5. Dissolved gas analysis procedure at the Diagnostic Group

When customers make an order for DGA, special syringes are sent for oil sampling. The filled syringes are then returned to the laboratory. The oil is transferred from the syringes to vials compatible with the instruments used for the analysis. The sample preparation is time consuming since it requires a large amount of manual work. It is very important that every step from the sampling of the oil to the preparation and analysis is kept airtight. After the preparation, the dissolved gases are extracted from the oil. The method used for this purpose is the headspace technique.

2.5.1. Extraction using a headspace sampler

A headspace is defined as the gas space above the surface of the liquid in a chromatography vial. Hence, a headspace analysis measures the gases present in this volume. This analysis can be used for volatile and semi-volatile liquid or gaseous samples. The analysis is automated and the principle is based on the established equilibrium between the liquid and the vapor phase (Figure 6). By speeding up the diffusion of gas from the liquid to the vapor phase, the equilibrium is hastened. For transformer oil, it is done through heat and agitation. After the heating and agitation, a needle penetrates the septa and pressurizes the vial. This is done to create a gauge pressure in the vial. After the pressurization the gas is transferred into the sample loop. It is the size of the sample loop that determines the sample volume. From the loop, the gas is transferred to the GC via the transfer line (Figure 7).

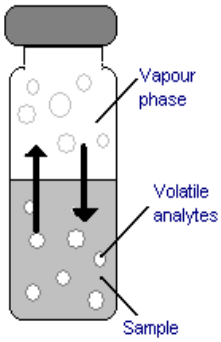

Figure 6. Equilibrium in a headspace vial.

Figure 7. Headspace sampler connected to a GC via the transfer line. Figure used with permission from Lena Melzer ABB Transformers Diagnostic Group.

2.5.2. Separation by gas chromatography

For separation of gases dissolved in transformer oil, gas-solid chromatography is used. In gas-solid chromatography, the gaseous analytes are adsorbed on a solid stationary phase. The nature of the gases determines the type of gas chromatography used. For example, N_2, O_2, H_2, CO_2 and CO can not be separated by gas-liquid chromatography (Skoog & Leary, 1992).

By using gas chromatography, the components of the sample can be separated, identified and quantified. The mobile phase transporting the sample is argon. From the transfer line, the sample enters the first chromatographic column. Two different columns are used. The reason for this is the different structures of the components in the gas mixture. The first column separates the hydrocarbons (CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_6 and C_3H_8) and the second one separates H_2, O_2, N_2, CO, and CO_2. The type of columns described by DGA standards and application notes for separation of the hydrocarbons vary, but a molecular sieve is most often used for the remaining gases. (Duvekot, sine anno; Brillante, Jalbert & Gilbert, 1995; ASTM

D 3612, 2007) The two columns are connected through rotating valves directing the flow. The entire setup with the columns, the valves and the detectors is rather complex.

2.5.3. Detectors

The GC is equipped with two detectors. A thermal conductivity detector (TCD) is used to quantify H_2, O_2 and N_2. This universal detector is non-destructive, why it can be used prior to the second one, the flame ionization detector (FID). The detector responds to changes in the thermal conductivity of the gas flowing around it. If the carrier gas is replaced or mixed with other types of molecules, the thermal conductivity will change. (Skoog & Leary, 1992)

As described by Skoog and Leary (1992), the flame ionization detector contains a burner which electrically ignites the effluent from the column mixed with hydrogen and compressed air. When organic compounds (containing carbon-hydrogen bonds) are pyrolyzed, they produce electrons and ions. The positively charged electrons and ions are attracted towards a negative electrode. When the ions and electrons hit the electrode, a current is induced. The FID is insensitive to non-combustible gases such as CO and CO_2, why they are converted to CH_4 by a Ni-reductor before passing the detector in DGA applications. The FID quantifies CH_4 (CO_2 and CO), C_2H_6, C_2H_2, C_2H_4, C_3H_8 and C_3H_6. The organic compounds could be detected by the TCD as well, but the FID has a higher sensitivity.

The usage of a TCD in series with a FID is standard procedure for dissolved gas analysis as described by the headspace sampling method of ASTM D3612 and in application notes (Duvekot, sine anno; Brillante, Jalbert & Gilbert, 1995; Betz & Keeler, 1999).

2.5.4. Evaluation of chromatograms

The detectors respond to substances exiting the column. The response signal is plotted against time, yielding a diagram with peaks (the chromatogram). To be able to quantify the unknown chemical components of customer samples, a series of four known standard samples are used. These standards are prepared to match the composition of the unknown samples as close as possible, but with varying known concentrations. The peak areas of the standard components (the gases aimed to detect) are plotted against their theoretical concentrations; hence a calibration curve is obtained for each expected substance. The peak areas of the unknown

samples are then compared to those of the standards and the concentration can be read of from the curve.

2.6. Mass spectrometry and advantages

Instead of the detectors mentioned above, a mass spectrometer can be used together with the GC. The different molecules in a sample would then be separated in the chromatographic column as usual, and then quantified and identified by the MS. When using a TCD and/or a FID, the identification of different compounds is based on their different retention times. The mass spectrometer on the other hand will add another dimension since it is selective and can identify compounds based on their characteristic mass spectrum or ion masses. Mass spectrometry is a powerful technique and is often used for elucidating chemical structures (Skoog & Leary, 1992). Consequently, unknown peaks in a gas chromatogram could be characterized and a more accurate evaluation of peak areas could be made in cases of co-elution. The sensitivity for mass spectrometers in general (typical detection limit 0.25-100pg) is also better than for FIDs and TCDs.

The compound exiting the chromatographic column is introduced in the ion source of the mass spectrometer. The ion source scatters the molecules into gaseous charged fragment ions. This is done through bombardment with, for example, electrons. Each kind of molecule will be scattered in a characteristic pattern (a mass spectrum). The charged fragments are then accelerated by an electric field towards a magnetic field. The magnetic force in the mass analyzer will deflect the ions based on their mass to charge ratio (m/z). Ions of different masses are thus separated. The detector registers the number of each ion mass that has been produced. The mass spectrometer operates under vacuum to avoid collisions between the ionized fragments produced in the ion source and air molecules.

The data is produced in the form of a mass chromatogram. Just as in the chromatograms resulting from the usual GC-set up, detected abundances are plotted against time. In addition, each point in time can be related to a mass spectrum. The mass spectrums are unique for each compound and functions as a fingerprint of the molecule.

The instrumental setup would be simplified if the two detectors used today could be replaced by the MS. As mentioned before, the setup with two columns, two detectors, a Ni-reductor and valves is very complex (Figure 8). The present system requires a high amount of maintenance. If one of the several components malfunctions, the entire system will be affected.

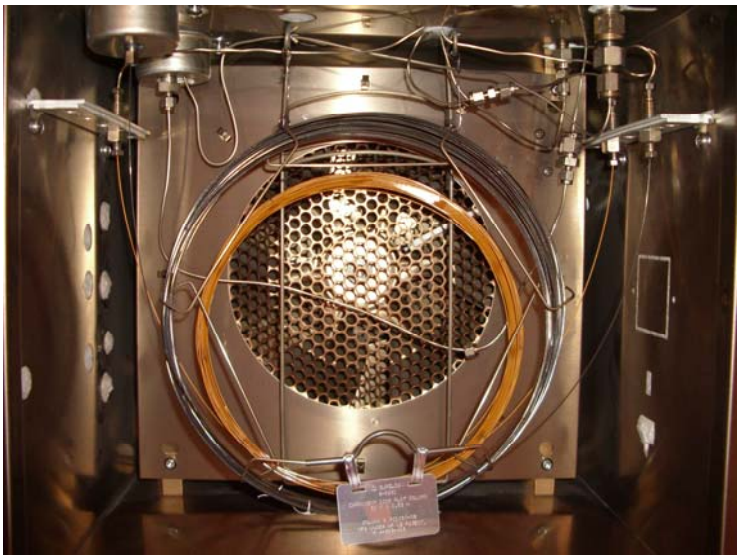

Figure 8. GC-oven interior for the regular DGA-set up. Picture used with permission from Lena Melzer ABB Transformers Diagnostic Group.

Commonly used carrier gases providing good chromatographic efficiencies and mobile phase flow rates for GC are helium or hydrogen, but these are not possible to use for the DGA routine tests with the FID/TCD. One of the gases quantified is hydrogen and helium is too similar to hydrogen concerning thermal conductivity, resulting in too poor sensitivity for hydrogen. The mass spectrometer on the other hand is sensitive enough to identify hydrogen separately and helium can be used as carrier gas.

To our knowledge, there are no previous reports on attempts made using a MS for DGA applications.

3. Method dissolved gas analysis

The first step was to test and choose a suitable chromatographic configuration. The GC was therefore injected manually with calibration gas containing all the gases of interest. Two different columns were evaluated, separately and coupled in series. The columns tested were the same as the ones used in the regular analysis.

When the chromatographic configuration was decided upon, an appropriate method (headspace and GC-settings) was chosen. The parameters studied were mobile phase flow rates and oven temperature programs. To do this, the headspace sampler was connected to the GC for extraction of gas from standard oil samples. Test runs were performed with a few vials in each run. In addition, ion fragments were chosen for each gas for the purpose of identification. The NIST mass spectral library facilitated the choice of which ions to use. The method described under "instruments and settings" was the chosen one. This method was then used for all of the following analyses.

In order to investigate the parameters described below (selectivity, repeatability, linearity, yield and accuracy) full headspace carousels with 44 samples were run.

In a later attempt a third column was evaluated, replacing the two previously used ones.

3.1. Sample preparation

A set of gas standards were prepared by introducing known amounts of calibration gas in degassed oil. The standard levels were chosen according to the calibration standards used for the regular DGA method. For each standard level (1-4), a large 250 ml air tight glass syringe was filled with oil. The appropriate amount of calibration gas was then injected into the large syringe through a septa. When the gas was dissolved, the content of the large syringe was distributed into smaller 20 ml glass syringes. Oil samples from customers are delivered in the same air tight 20 ml glass syringes as used for the standard preparation. The syringes are used for transferring accurate amounts of oil into 20 ml air free headspace vials used in the headspace instrument.

The empty headspace vials were capped with perforated aluminum caps fitted with butyl septa. The air was removed from the vials by purging with He. 8 ml of oil was then transferred to each vial from the smaller 20 ml glass syringes. The vials were weighed before and after the addition of oil.

3.2. Instruments and settings

The instruments used for all of the experiments performed were a HP 7694 Headspace Sampler (Hewlett Packard) and a 6890N Network GC System (Agilent Technologies). The headspace sampler had a total capacity of 44 vials per carousel. A 5975 inert Mass Selective Detector (Agilent technologies) was coupled to the GC, and the system was controlled by the Chemstation software (Agilent). Helium was used as carrier gas and the loop volume was 1 ml.

A constant flow of 2.5 ml/min was used in the GC-MS method. The initial oven temperature was set to 35°C and held for 10 min. The temperature was then increased by 10°C/min until 250°C was reached. This temperature was kept for 4.5 min.

The following headspace settings were used:

Oven: 70°C
Loop: 70°C
Transfer line: 70°C
Carrier gas pressure: 2.0 bar
Vial pressure: 0.4 bar
GC-cycle time: 46 min
Vial equilibration time: 30 min
Pressurization time: 0.5 min
Loop fill time: 0.15 min
Loop equilibration time: 0.05 min
Inject time: 0.3 min
Mixing speed: power 2 (high)

3.3. Chromatographic columns

As in the usual GC setup, two columns were used to separate the gases. The columns were connected in series. The first one was a Supelco Carboxen 1006 PLOT fused silica capillary column (30m x 0,32 mm) and the second one a Varian CP-Molsieve 5Å capillary column (2m x 0,32mm).

In addition, a Supelco Carboxen 1010 PLOT fused silica capillary column (30m x 0,32mm) was evaluated as a replacement for the two previously mentioned ones. This is a column designed for the specific purpose of gas analysis of transformer oil (Betz and Keeler, 1999).

3.4. Materials

20 ml flat bottomed headspace glass vials with aluminum crimp caps, fitted with 20 mm teflon/butyl septa (Agilent technologies) were used in all experiments. The oil used to prepare the oil standards was Nytro 10 XN (Nynäs Naphtenics). The composition of the calibration gas (confidence level 95%, blend tolerance 5% relative, AGA Gas AB) can be found in Table 1. The only difference between the gas used for preparation of gas standards for the GC-MS setup and the standards prepared for the usual GC routine analysis was the ground gas. Since helium is the carrier gas of choice in the GC-MS system, it was also used as ground gas as opposed to argon in the normal setup.

Gas	**Vol-%**
Hydrogen	6,02
Methane	1,00
Carbon monoxide	8,07
Carbon dioxide	60,2
Ethene	1,02
Ethane	0,99
Acetylene	1,00
Propene	7,79

Propane	7,93
Helium	Ground gas

Table 1. Composition of calibration gas

3.5. Selectivity

The selectivity was evaluated using selected ion masses (SIM) for the detection of the different gases. In order to determine which ion masses to use for identification of each compound, a full scan mode (1.6-100 Da) was used for the MS. Apart from the gases in the calibration standard, the amounts of oxygen and nitrogen are also of interest. The masses were chosen allowing co-eluting compounds to be separated. The selected ion masses were those presented in Table 2 (all masses are rounded off).

Gas	Corresponding m/z
hydrogen	2
oxygen	32
nitrogen	28
carbon monoxide	28
methane	16
carbon dioxide	44
ethylene	26
acetylene	26
ethane	26
propane	29
propene	41

Table 2. Gases of interest and corresponding m/z for detection

3.6. Detection limits

An often used method to determine the detection and quantification limits is to calculate the ratio of the height of the detected signal (S) and the height of the noise (N). The signal to noise ratio is commonly chosen as 3:1 for detection, and 10:1 for a quantification to be

accepted (ICH Harmonised Tripartite Guideline, 2005). When investigating the detection limits, no calculations were made. Instead, the height of the peaks relative the background noise was estimated according to the commonly used ratios.

3.7. Repeatability

To test the repeatability of the analyses, six separate vials prepared from the same concentration batch were run. All four concentration levels were tested (in total 24 samples). The approach was to evaluate the relative standard deviation (RSD) according to Formula 1 for each gas at each concentration level. (ICH Harmonised Tripartite Guideline, 2005; Nilsson, Stensiö & Lundgren, 2000).

$$\sigma = \sqrt{\left(\sum (X - \mu)^2\right) / N}$$

$$rel.strd.dev = (\sigma / \mu)100$$

σ = standard deviation

X = measured value

μ = mean value of data points

N= number of data points

Formula 1. Calculation of relative standard deviation

The acceptance criteria for the repeatability study were chosen to a 10% RSD. However, for the lower concentration levels, a somewhat larger RSD can be accepted due to the small peak areas.

3.8. Linearity

The linearity of the calibration curves for the respective gases was to be tested. One sample at each standard level was used. Blank samples were run to estimate the background noise and to see if there were peaks in the blanks co-eluting with the analyte peaks.

By plotting the peak areas from the chromatogram against the prepared theoretical concentrations for each standard level, data points are obtained. These points can then be tested for different types of regressions and the most accurate (giving the highest r^2-value) can be chosen. (ICH Harmonised Tripartite Guideline, 2005) A good linearity requires r^2-values >0.99 (Nilsson, Stensiö & Lundgren, 2000).

The resulting calibration curves can then be used to estimate the concentration of unknown samples using the obtained areas from the analysis. Separate standard curves are needed for each gas.

3.9. Yield

Duplicate samples from each standard level were used to test the yield. Just as for any unknown sample, the peak areas from the chromatograms were to be read of from the previously constructed standard curve. The duplicate samples run were from other batches than the samples used constructing the standard curve. The yield was to be calculated according to Formula 2 and the expected yield range was set to 90-110%.

$$\text{Yield} = (C_{experimental}/C_{theoretical})100$$

Formula 2. Yield

3.10. Accuracy

The accuracy was to be evaluated by comparing the results from 40 customer samples tested both by the GC-MS system and the normal GC setup.

4. Results dissolved gas analysis

The following section presents the results from the investigations made for the GC-MS system. This includes choice of chromatographic configuration and method, evaluations of selectivity and detection limits and the results from the full scale runs.

4.1. Chromatographic configuration

The (full length) carboxen 1006 column used prior to 2 m of the molecular sieve column was found to be the optimal configuration in terms of keeping the band broadening low and the resolution as high as possible.

The first three eluting compounds were (in order): hydrogen, oxygen and nitrogen. These gases are all separated by the molecular sieve column.

For longer pieces than 2 m of the molecular sieve, the band broadening (of the gases separated by the carboxen column) was unacceptable. A length of 1 m molecular sieve was found not to give a sufficient resolution of hydrogen and oxygen which elutes first. A, fragment have been found with the same retention time as oxygen with a mass of 2 Da in several of the analyses performed, why a baseline separation between the peaks of oxygen and hydrogen is required. However, the fragment can not be a product of the scattering of an oxygen molecule since oxygen only results in fragments of m/z 32 and 16.

Attempts made using only the carboxen 1006 column also resulted in co-elution of hydrogen and oxygen. The chromatograms from the experiments of placing the columns in reversed order (2 m molecular sieve + 30 m carboxen column) showed a significant increase in band broadening, excluding this column configuration as an option.

4.2. Choice of method

A suitable GC method was created by investigating the mobile phase flow rate and oven temperature program. The flow rate was varied between 1.5 - 6 ml/min. The best separation with respect to resolution of peaks and analysis time was achieved when using a flow rate of 2.5 ml/min.

In order to find a suitable oven program, the initial temperature and time, the speed of the ramp and the maximum temperature was varied. To start with a temperature of 35°C in 10 minutes was found to be enough to separate the first five eluting compounds, which all elutes within 5 minutes. Earlier starts of the ramp resulted in bad resolution for the following four peak areas (carbon dioxide, ethane, ethylene and acetylene). An initial temperature of 30°C was tested but did not improve the resolution of the first two eluting peaks as compared to 35°C. A ramp speed of 10°C/min until the maximum temperature of 250°C (held at 4 min) was reached resulted in acceptable separation of all the remaining compounds and a reasonable analysis time (46min). 250°C was used since it is the maximum allowed temperature for the carboxen column and also for eluting all remaining compounds minimizing any ghost peaks for the next injection. For ramp speeds of 40°C/min, the propane and propene peak areas tended to co-elute.

The GC method including the optimal parameters as described above was headspace2SIM and this was found to be the best in terms of required analysis time and peak separation. The selected ion monitoring mode (SIM) was chosen to increase the sensitivity as compared to the full scan mode.

To a large extent the same headspace settings were used as in the original method. One parameter that had to be modified was the inject time. Since the columns used were thinner than those in the normal setup (0.32 vs. 0.53 mm), a lower flow had to be applied in order to achieve a satisfactorily chromatographic efficiency. Due to the lower flow, the injection time had to be slightly lengthened. In summary, the loop had to be purged for a longer time, otherwise, all of the expected gas was not injected into the GC-MS resulting in decreased sensitivity. However, too long injection times lead to brand broadening.

4.3. Selectivity

Hydrogen which elutes first, is not completely separated from the second co-eluting peak area of oxygen and nitrogen, but by using their corresponding ion masses of 2, 32 and 28 Da respectively, they can be quantified. The same mass can be used for quantification of carbon monoxide as for nitrogen. This is possible since nitrogen has a shorter retention time and will not interfere with the peak area of carbon monoxide. Methane can be quantified on its

molecular ion mass, 16 Da. Carbon monoxide which elutes just prior to methane also has a fragment of this mass, but this is not a problem due to baseline separation of the two peak areas. The separation of the first 5 compounds is illustrated in Figure 9 and the following 6 can be found in Figure 10.

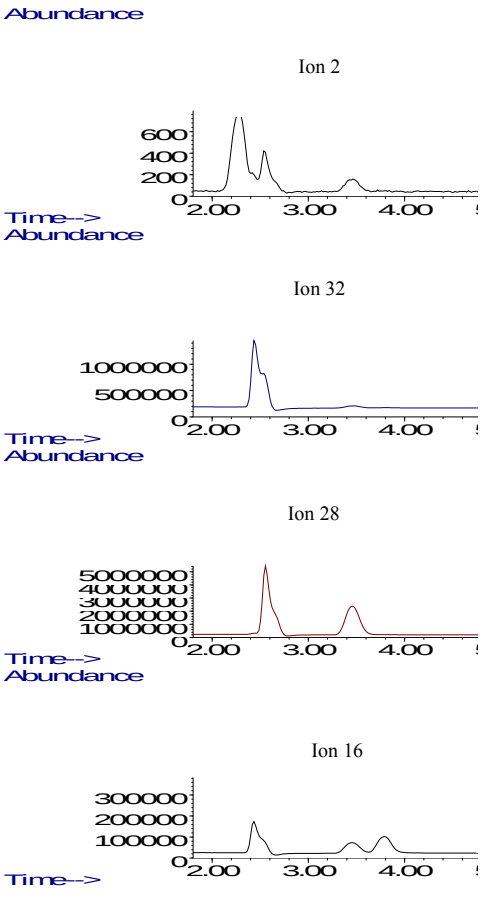

Figure 9. Elution of the first five compounds

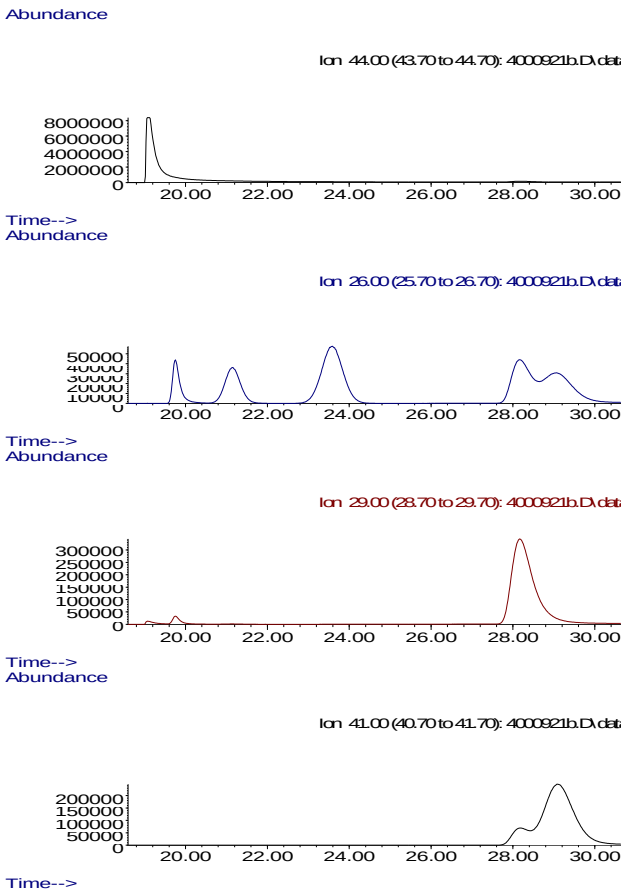

Figure 10. Elution of the six last compounds

Carbon dioxide can be quantified on its molecular ion, 44 Da. Ethane, ethylene and acetylene all elute short after carbon dioxide. The peak of carbon dioxide tends to smear and interfere with the three following ones. Since carbon dioxide contains an ion fragment of mass 28 Da, it is better to quantify the other compounds with similar retention times on other masses. The most prevalent ion fragment for ethane is 28, and the molecule ion of ethylene has the same weight. Fragments of weight 26 Da were chosen instead for both ethane and ethylene. The molecule ion of acetylene is 26 and this was the one used. There was a baseline separation between the peaks of ethane, ethylene and acetylene, hence they could be separated using the same masses.

The most prevalent ion fragment for propane is 29. This corresponds to the cleavage of one carbon with its three adjacent hydrogens from the rest of the molecule. Propene elutes right after propane and the two areas were not fully separated. Since propene does not contain any fragment with molecular weight 29 it can be used to quantify propane without any problems. The major molecule fragment of propene is 41 (which is the result of the loss of one radical H·). Also propane contains a fragment of this weight, but with a much lower abundance.

4.4. Detection limits

The observed peak heights for the different concentration levels with the present system were compared to the heights of the background noise. Table 3 summarizes the findings in terms of visibility, acceptable detection and quantification.

Gas (in order of elution)	Level 4	Level 3	Level 2	Level 1
Hydrogen	D, Q, V	D, Q, V	V	-
Oxygen	D, Q, V	D, Q, V	D, Q, V	D, Q, V
Nitrogen	D, Q, V	D, Q, V	D, Q, V	D, Q, V
Carbon monoxide	D, Q, V	D, Q, V	V	-
Methane	D, Q, V	D, V	V	-
Carbon dioxide	D, Q, V	D, Q, V	-	-
Ethane	D, Q, V	D, Q, V	D, Q, V	D, V
Ethylene	D, Q, V	D, Q, V	D, Q, V	D, Q, V
Acetylene	D, Q, V	D, Q, V	D, Q, V	D, V
Propane	D, Q, V	D, Q, V	D, Q, V	V
Propene	D, Q, V	D, Q, V	D, Q, V	D, V

Table 3. Summary of the investigation of detection and quantification limits for the different concentration levels. Q =may be quantified, D = detectable, V = visible

All gases are quantifiable (and detectable) for concentration level 4. Methane is detectable but can not be classified as quantifiable for concentration level 3 according to the criteria, however, the peak area is well defined and visible. The level 2 hydrogen peak was found to be clearly visible and defined but not detectable (Figure 11). No peaks of hydrogen, carbon monoxide or methane were visible on concentration level 1. Carbon dioxide was found to disappear at concentration level 2, despite the high amounts of the gas in the prepared standards. The peak areas of both carbon monoxide (Figure 12) and methane are well defined and clearly visible for concentration level 2, but the detection is unaccepted due to high background noise. One of the most critical gases is acetylene, which was found to be detectable on all tested concentration levels and quantifiable on all except the lowest one. Figure 13 presents the peak areas of ethane, ethylene and acetylene for concentration level 1. The peak area of propane was visible for concentration level 1 even though it did not meet the detection criteria.

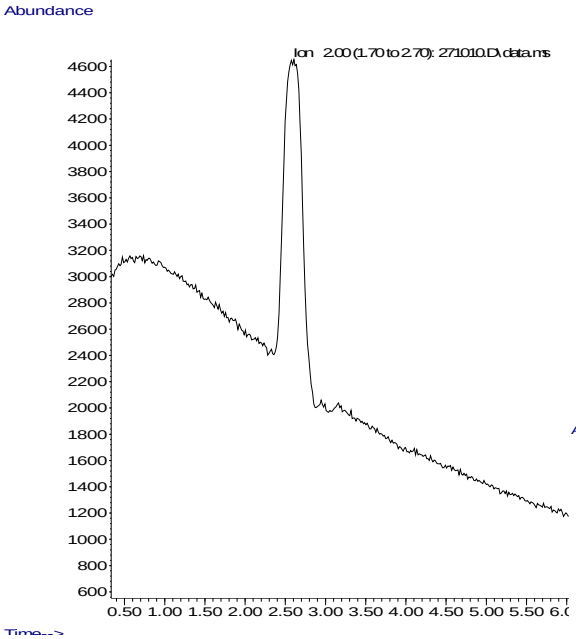

Figure 11. Peak area of hydrogen at concentration level 2.

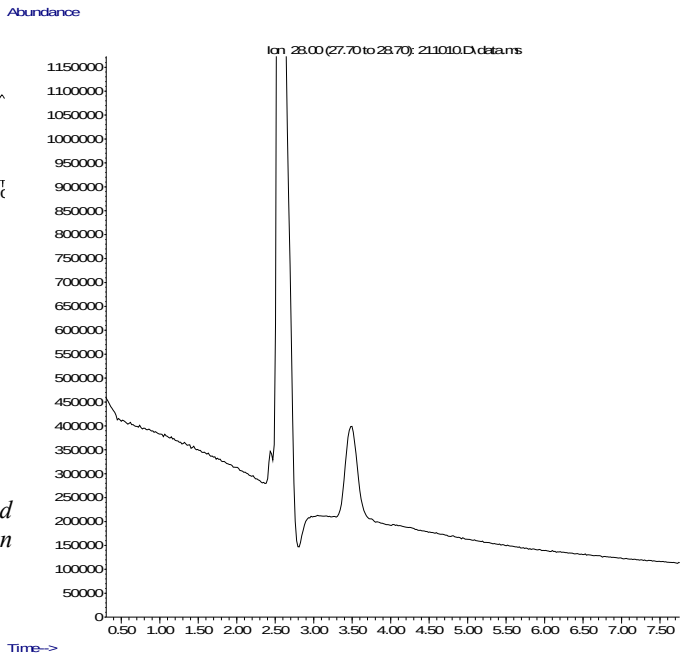

Figure12. Peak areas of nitrogen (RT=2,5min) and carbon monoxide (RT=3,5min) for concentration level 2. R T=retention time

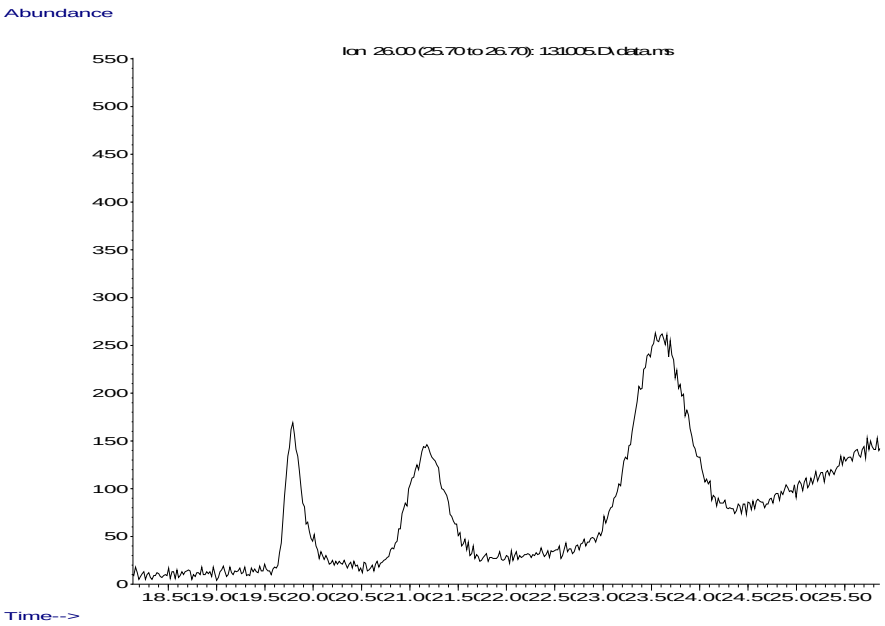

Figure 13. Peak areas of ethylene, ethane and acetylene for concentration level 1.

4.5. Linearity, repeatability and yield experiments

The first up-scaled run performed with a full carousel of 44 samples showed a remarkable decline in sensitivity. The amounts of gas detected (both peak areas and baseline) demonstrated a significant decrease for each sample run. The samples run at the later half of the series appeared to be almost empty with no visible peaks and an extremely low baseline. A number of vials (one for each concentration level and one negative control) from the same batches as those used in the first full carousel run had previously been tested using the regular DGA procedure. The purpose of the testing was to make sure they were correctly prepared; all vials tested were found to contain the expected amounts of gas. The purpose of the full carousel run was to investigate the repeatability, the linearity and the yield.

The following samples were analyzed (in order of testing):
4 test vials (to warm up the instrument)
6 vials of standard concentration 4 (investigating repeatability and linearity)
6 vials of standard concentration 3 (investigating repeatability and linearity)
6 vials of standard concentration 2 (investigating repeatability and linearity)
6 vials of standard concentration 1 (investigating repeatability and linearity)
3 negative controls without gas (investigating background noise)
2 vials of standard concentration 4, different batch than those above (investigating yield)
2 vials of standard concentration 3, different batch than those above (investigating yield)

2 vials of standard concentration 1, different batch than those above (investigating yield)

7 vials of other experimental purposes

Almost no parameters except the relative standard deviation (RSD) of the vials of concentration level 2 could be calculated from the run. During the analyses the system appears to have stabilized (Figure 14) when those vials were tested, since they did not show decreasing amounts of gas for each sample run. The RSD was calculated for all visible peak areas of level 2, except oxygen and nitrogen. Hydrogen, carbon monoxide and methane ranged between 4-8% in RSD, while the remaining gases varied between 17 and 34%. The detected amounts of gas for all concentrations levels (except level 2) perfectly matched the sequence order (Figure 15).

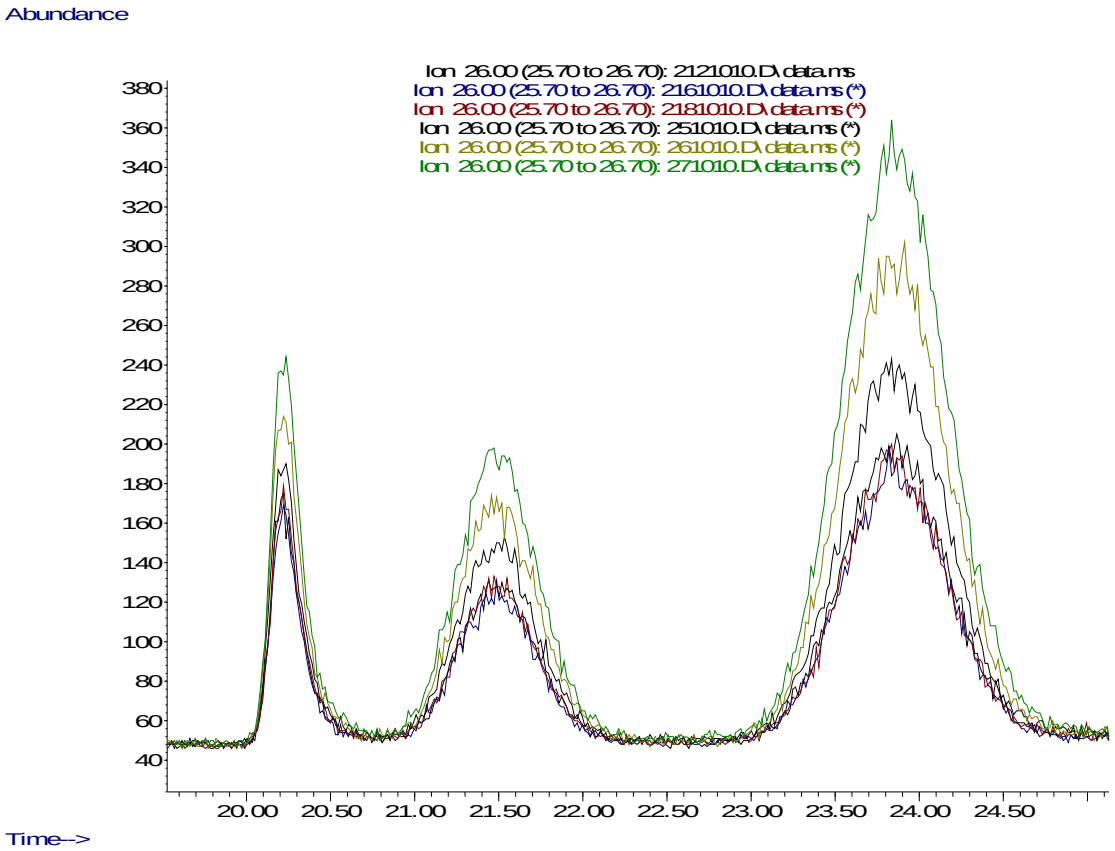

Figure 14. Detected amounts of gas did not follow the sequence order for standard level 2. Sequence order: 2181010, 2161010, 2121010, 251010, 261010 and 271010

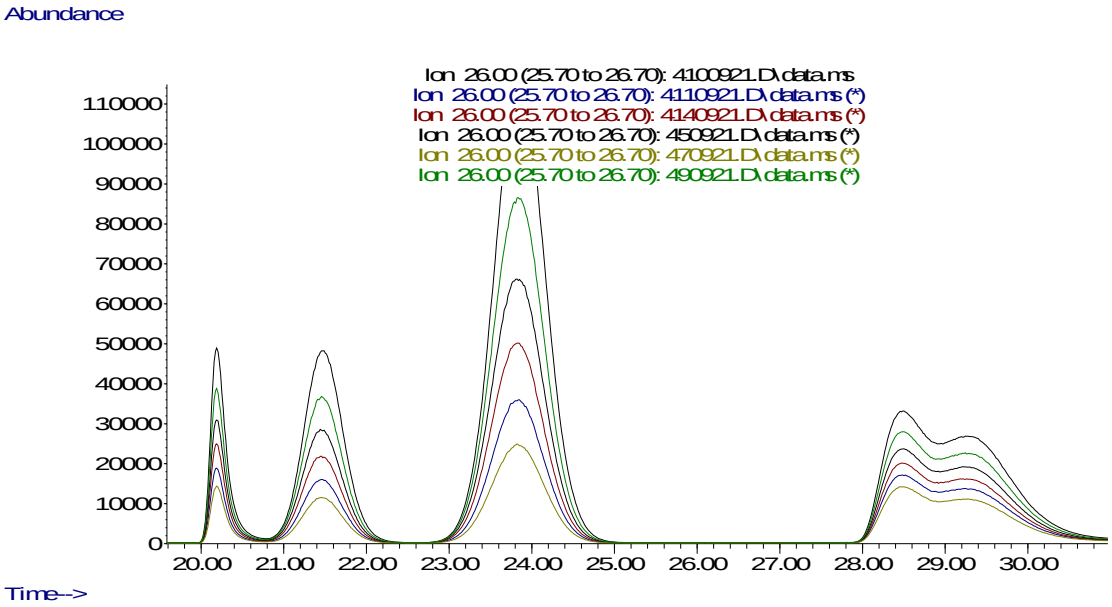

Figure 15: Detected amounts follow the sequence order precisely: 4100921, 490921, 450921, 4140921, 4110921 and 470921

Two more attempts were made with full carousels but without improvements. The sensitivity did not seem to recover between the runs. At the end of the second run, the baseline started to oscillate heavily. Due to the decreased sensitivity, the samples appearing empty and the oscillating base line, the ion source of the MS was demounted and cleansed. The columns were changed to another one used for a different routine analysis and so was the method. This analysis does not require headspace sampling, why the headspace connection to the GC was removed. The other analysis was performed without any of the previously experienced problems. A third attempt was then made with the columns, method and headspace sampler used for this project. The results from the run were the same as before with decreasing sensitivity. Unlike the results from the two earlier attempts made, the sensitivity was initially somewhat recovered but still lower than the initial samples of the first full carousel run.

The ion source was again demounted. This time it was carefully investigated for any interfering particles. Small white particles were found and examined with microscope. The molecular sieve column used prior to the detector is known to sometimes release its packaging (Rosendahl, 11 Nov. 07; Magnusson 11 Nov. 07). This problem has been encountered in the regular DGA analysis. Similar particles as those found in the ion source of the MS could also be discharged from the end of the column. The instrument with the newly cleansed ion source was run again with the setup used for the other laboratory analysis. As earlier, no problems were apparent.

4.6. Carboxen 1010 column

The result with decreased sensitivity persisted for this column configuration as well, yet this column did not contain any molecular sieve particles.

For concentration level 3, baseline resolution was found for all of the compounds except the co-eluting oxygen and nitrogen (Figure 16). The separation of the last six compounds was very good (Figure 17). For the lower concentration levels tested, hydrogen was not visible but all other gases could be identified. The order of elution was changed compared to the order for the previous column configuration. For this column, ethane, ethylene and acetylene showed a reversed order of elution, as did propane and propene. The results regarding detection and quantification limits are summarized in Table 4.

Gas (in order of elution)	Level 3	Level 2	Level 1
Hydrogen	V	-	-
Oxygen	D, Q, V	D, V	D, Q, V
Nitrogen	D, Q, V	D, V	D, Q, V
Carbon monoxide	Ratio 2:1, V	V	V
Methane	D, V	V	V
Carbon dioxide	D, Q, V	D, Q, V	D, Q, V
Acetylene	D, Q, V	D, Q, V	D, Q, V
Ethylene	D, Q, V	D, Q, V	D, V
Ethane	D, Q, V	D, Q, V	V
Propene	D, Q, V	D, Q, V	D, V
Propane	D, Q, V	D, Q, V	V

Table 4. Summary of the investigation of detection and quantification limits for the different concentration levels. Q = may be quantified, D = detectable, V = visible

In neither of the two chromatograms from standard level 2, oxygen and nitrogen met the criteria for quantification, yet such amounts were found in chromatograms from standard level 1.

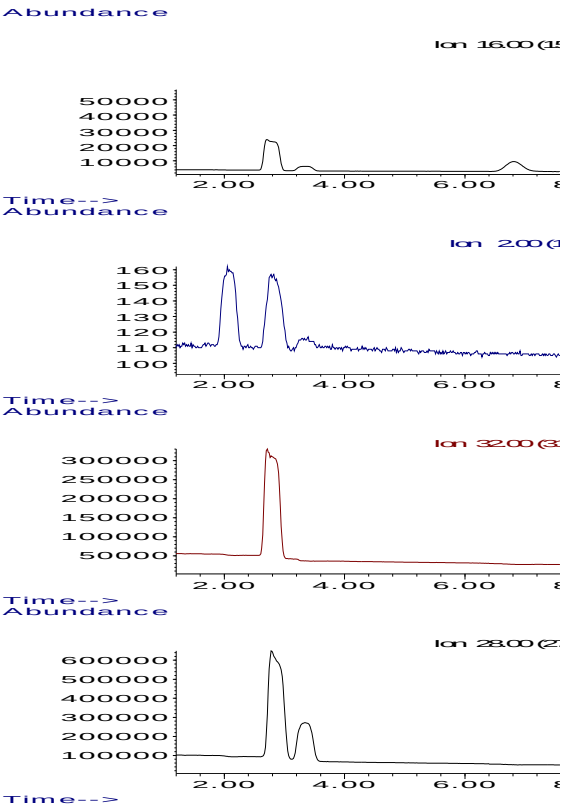

Figure 16. Separation of the first five compounds

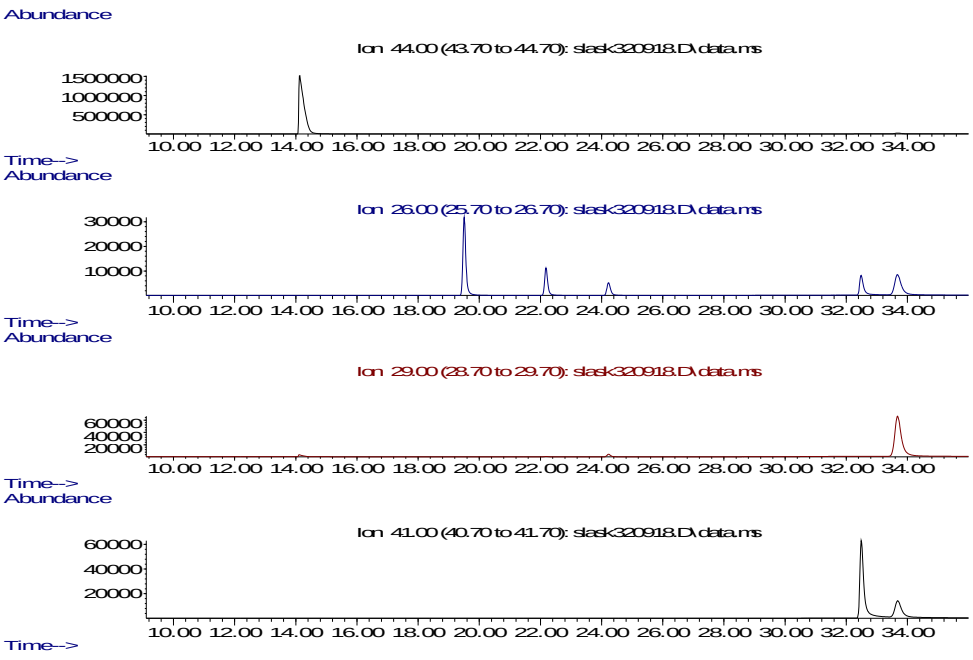

Figure 17. Baseline resolution for all of the last six compounds

5. Discussion dissolved gas analysis

The system of using two columns in series is not an ideal situation since the compounds separated by the carboxen 1006 column tends to be smeared by the molecular sieve. Since the carboxen 1010 column was found to separate all gases (except oxygen and nitrogen) further investigations using the column might be worthwhile. Evaluations could be made both for the GC-MS but also in the routine GC-set up. Apart from tests using only the carboxen 1010 column, it could also be connected in series with the molecular sieve. Beneficial adjustments in the method could be made for the carboxen 1010 column in view of the fact that the method was created while using a different chromatographic configuration. For example, an earlier onset of the ramp and a higher ramp speed might shorten the analysis time without affecting the resolution.

Due to the finding of a scattering fragment with the same retention time as oxygen and with a weight of 2 Da, hydrogen can not be quantified using only the carboxen column since the two compounds co-elute. Apart from this result, the carboxen column would have been an option.

To investigate detection and quantification limits based on the existing results might be somewhat misguiding since the circumstances for the analysis was far from ideal. Therefore the results are more of a hint towards what could be expected during better circumstances. Many of the visible peak areas are well defined and could be integrated with ease; however, they do not meet the criteria for detection (as shown for carbon monoxide at concentration level 2 in Figure 12). In most cases, this is due to high background noise. If the noise could be lowered, the detection might not be a problem for these gases.

It should also be noted that relatively few vials have been run for the two lower concentration levels since all initial attempts were made using stronger levels. The weaker concentrations were not prepared until the full carousel runs were to be initiated. Also, the sequences unfortunately always started with the highest concentrations moving on towards the lower at the end of the run. Since the sensitivity decreased for each vial, especially the results from the lower concentrations might not be reliable. If more attempts were to be made with a lower background noise, all gases may be detectable at all concentration levels.

A problem throughout the entire period when using the headspace connected to the GC was a leakage in the system. This problem is very often encountered for such applications. The problem was present for all column configurations tested. All exterior couplings from the headspace sampler to the GC were investigated with a leakage detector but without any results. When the instrument was tuned (a known amount of calibration gas is inserted into the MS and the detected amount of nitrogen is related to the amount calibration gas detected), the relative abundances of nitrogen varied between approximately 20-80%. For a correctly assembled system, without the headspace, the manufacturer of the GC can guarantee a maximum relative abundance of 10%. When the headspace transfer line was removed and the columns were switched for other analytic purposes, the relative abundance of nitrogen was approximately 3%. The high background noise might be (partly) an effect of the un-tight system. The filaments were controlled and had not been damaged by the air leakage, however, the sensitivity is always improved when the air level is minimized.

5.1. Linearity, repeatability and yield experiments

The most likely explanation why the problem with the decreased sensitivity was not discovered earlier could be the short series run initially. When evaluating the different chromatographic configurations and methods to use, test runs were made with approximately 1-4 vials. The problem might have been there, but since only a small number of chromatograms were available, the trend was not as easily discovered.

The finding of what was suspected to be column packaging material in the ion source pointed towards the molecular sieve being the reason for the decreased sensitivity. This theory could explain why the result was worsened the longer the sequences were run. To avoid this problem in the regular GC-setup, filters are used at the end of the columns. If this hypothesis was correct, the problem should have been avoided by using filters or by trying a different column. This was the reason why the carboxen 1010 column was tested. Unfortunately, the result with decreasing sensitivity persisted for this chromatographic configuration as well. The carboxen 1010 is similar to the previously used carboxen 1006, which is not known to release packaging material. A filter could be applied to evaluate the possibility of packaging material contaminating the ion source.

A plausible explanation to the decreasing sensitivity could be the leakage in the system. Since the problem was evident for both column configurations tested, it is likely not connected to the columns. The differences between this experimental set up and the regular analyses performed with the same GC are method, sample volume, columns and the usage of the headspace sampler and transfer line. The column assemblies were all performed by the same person and no leakages were indicated in the tunings of the regular laboratory set up. A good idea might be to investigate the 10 year old headspace sampler more closely. The sampling vault was changed approximately eight years ago and no recent maintenance has been performed.

Another explanation could be an adsorption of sample in the columns. The loop volume used in this experiment was larger than the regular loop. Besides the columns being narrower (0.32 mm vs. 0.53 mm), the total length was also shorter than the length of those normally used for DGA (32 m vs. 55 m). This theory would explain why the decreasing sensitivity persisted for the carboxen 1010 column and why the result was worsened the longer the sequences were run. This hypothesis could be investigated by trying a smaller sample loop.

Besides one major reason causing the decline in sensitivity, a number of minor contributing factors could be the explanation.

In order to evaluate the repeatability, linearity, yield and accuracy of the method, future investigations must start with the aim of obtaining a stable system including stable baseline and minimized air leakage over time.

6. Method marketing

In order to identify marketing areas in need for improvement, an investigation of the current situation was the first step. Previous marketing material and strategic analyses were studied. As a complement to the written information, interviews were conducted with key people.

The interview questions were constructed using the tools from Kotler's "Ten deadly marketing sins, signs and solutions" (2004) in order to ensure that the most important marketing areas were covered. Kotler is a well known authority within marketing, and the book has a hands on approach. The book presents 10 areas critical to market productivity and profitability. For each area, symptoms are described that are indicative to possible setbacks. Solutions to each problem are also offered.

The 10 deadly sins of marketing according to Kotler are:

1. The company is not sufficiently market focused and customer driven.
2. The company does not fully understand its target customers.
3. The company needs to better define and monitor its competitors.
4. The company has not properly managed its relationships with its stakeholders.
5. The company is not good at finding new opportunities.
6. The company's marketing plans and planning process are deficient.
7. The company's product and service policies need tightening.
8. The company's brand-building and communications skills are weak.
9. The company is not well organized to carry on effective and efficient marketing.
10. The company has not made maximum use of technology.

Some of the services offered by the Diagnostics Group are complex and often difficult for the customer to understand. What the customer actually purchases is knowledge, instead of products or simple services. The marketing challenges faced by this type of service provider are described in "Kunskapsföretagets marknadsföring" by Ahrnell and Nicou (1995). According to Ahrnell and Nicou, traditional marketing theory or concepts might not be applicable when selling knowledge intense services. Seven other means (presented below) on how this kind of company can compete are described. These seven competitive means have been used as a complement to the areas described by Kotler (2004) when evaluating the

market situation.

The seven means to compete for the knowledge intense company according to Ahrnell and Nicou are:

Customer selection: The customers and projects should be chosen strategically and the choice must be active.

Customer knowledge: The company needs to know its market and the individual customers very well to be able to bring the services into line with their needs.

Customer Value: The result from the service, the customer value, must be made tangible so the customer can understand the benefits.

Contacts: Abstract services are bought in trust. Recommendations from reliable sources become very important in this situation. The company should strive to cooperate and be recommended by key actors within the area.

Knowledge dissemination: Knowledge is the "product" offered and must be exposed. The company will gain trust and respect by spreading it.

Communication: The market communication should occur through personal dialogue rather than mass effort.

Culture of competence: Competence must be the foundation on which the company is built. However, continuous competence development is needed since it is perishable.

6.1. Interviews

The following persons were selected for interviews:

Lena Melzer	Head of the Diagnostics Group (MD)
Kjell Carrander	Principal Engineer (MD)
Lars Pettersson	Principal Engineer (MD)
Tord Wikars	Marketer (ME)
Magnus Ström	Vice president ABB Transformers (Marketing and Sales)
Peter Labecker	Head of the Transformer After Sales Market (ME)

Melzer, Carrander and Pettersson all belong to the Diagnostics Group and they have all been involved in the previous market planning activities. Wikars, who works with marketing and sales, belongs to another unit within ABB Transformers, ME. When promoting the services offered by ME, Wikars also mentions the services of MD since the two units are closely related. The close relationship between the two units made it interesting to interview Labecker (Head of ME). Ström is Head of Market (M), of which MD and ME are subunits.

Open ended questions were used and the type and number of questions varied for each person since they are knowledgeable within different areas. The interviewees were encouraged to make own suggestions for marketing improvements to be made and to highlight potential weak areas.

The results from the investigation of the current situation and the interviews were summarized and a number of suggestions for improvements were presented. The list was intended as a suggestion on what could be done and one area was chosen for immediate action (creation of a website for the Diagnostic Group). The choice was made in agreement with Melzer (Head of MD) and Önnerud (thesis instructor). Remaining areas will be left to the group for future

work concerning marketing improvements.

6.2. Construction of a website

In order to decide what to post on the webpage, other web pages and pages of the competitors were studied, suggestions made during the interviews were also taken into consideration. When discussing communication, Ahrnell and Nicou (1995) gives examples of information that should be provided the customer. The following examples were used as guidelines when creating the website: what it is like to be a customer of the Diagnostic Group, how the cooperation can be outlined, what the expectations will be on their part, the routines on how the results are reported, possible follow-ups and how the services are debited.

The text material was to a large extent reused and rewritten from previous documents, but some texts were created for this purpose alone. When needed, texts have been translated from Swedish to English and vice versa since versions of both languages were created. The ABB guidelines have been followed for the layout. Help was provided from the ABB Transformers webmaster Sven-Erik Jansson to post the material on the web.

7. Results marketing

The information presented below was gathered from the interviews and from the current marketing material.

7.1.1. Customer selection

The customers and projects are to a large extent chosen strategically to be in line with the plans for the future and to improve competence development. The Diagnostics Group has actively made the choice to cooperate with large actors within the industry such as E.ON, Svenska Kraftnät (SvK) and Oskarshamns Kraftgrupp (OKG). As explained by Melzer, the group is aiming at establishing itself as the partner of choice for the nuclear power generator market, why the cooperation with OKG is of high importance. Long term contracts have also been signed with ElektroSandberg, Banverket and ABB Service. Having clients with good images will reflect back and strengthen the image of the company. There is also a clear goal concerning the sort of projects to prioritize (more lifetime assessments).

7.1.2. Customer and competitor knowledge

The customer knowledge among the individuals of the group appears to be good; however, there is no conclusive place where the information is accessible. The database Wilab stores the results from the analyses made, but not much "soft" information about the customers are stored. Customer information is spread over different people, in different files and also in different business units. There is some information stored about the competitors and their services, but they are not systematically monitored.

A couple of years back, the customers were divided among the members of the group so each customer had their special contact person. There were benefits with this system, such as better service, but it also required a higher degree of autonomy from the employees. This system is not in use today, one reason is that several of the employees are rather new to the group.

7.1.3. Customer Value

When the unit and its services were restructured in 1995, results from an extensive customer value survey were used as guidelines. The service portfolio was designed based on the

customer needs and when those needs have changed over time, so has the services offered. When internal and external customers have experienced new problems, the Diagnostic Group has been working hard to find solutions. One such example is the area of testing for corrosive sulphur in oil. This is an area in which ABB has taken the lead and has been very influential in the development of new standard methods. These analyses are in demand by several customers today.

The clear focus on customer needs is combined with a high consciousness of the importance to communicate the *benefits* of the services. Presentation materials are designed to educate the customer and to increase awareness of *why* transformer diagnostics is needed. For example, this is done by showing how the customer can increase return on assets by conducting regular analyses. By showing this, the abstract services can be made tangible.

7.1.4. Contacts

Who are opinion leaders and key actors within the industry? The company could identify these individuals, pay them special attention and make sure to establish a good contact. It might be actual or potential customers, ABB colleagues, researchers, competitors or any other person with authority within the industry. These individuals can both influence potential customers and exchange ideas and thoughts with the group. By doing this, the group can enhance their understanding of the customer needs and values and also get a chance to demonstrate their competence. Information about where the industry is heading can aid the process of finding new opportunities. Since the competition is getting tougher it is important that the group remains visible.

Several such contacts might exist already, and in those cases, who has the contact and how is it managed? Valuable names and addresses should be documented (according to rules and regulations concerning documentation of personal information) to make sure that the information remains safe.

7.1.5. Knowledge dissemination

The dissemination of knowledge is facilitated through presence in several industry organizations (IEC for example). It is common for members of the group to be invited as speakers at conferences, since the competence of the group is well known within the industry.

Besides demonstrating and exchanging competence, important connections are also created on those occasions. Scientific articles and other written material are frequently published. By demonstrating and spreading know-how, the Diagnostic Group gain trust and respect among industry professionals.

7.1.6. Communication

The first step in the communication process according to Ahrnell and Nicou (1995) is to raise awareness and to create an interest. The authors also recommend basing the marketing on personal relations and networks, instead of making mass marketing efforts. The Diagnostic Group is involved in several activities aimed at raising customer awareness and to create interest: seminars, oil sampling courses, handing over brochures, experience exchanges within industry organizations and maintenance of personal contacts. All of these activities include personal interaction as recommended.

Customer visits has been a very efficient way to gain new customers in the past. Unfortunately, the group can not make these trips to the extent they would want to (due to lack of personnel and other reasons). Another ABB unit, ME, has a marketing resource (Wikars) making customer visits. The services offered by this unit are directed towards the same customers as MD has. When promoting the services of ME, the offerings from MD are also mentioned.

The Diagnostic Group both participates in educational events arranged by others and coordinates educational courses of their own. Examples are the VIP-seminars, the Ludvika Days and their own oil sampling courses. The VIP-seminars are arranged by the ABB Power Product business area, of which MD is a part. To participate as a lecturer at the Ludvika Days arranged by the Swedish ABB marketing and sales organization, news within the field is required. When this has been the case, the Diagnostic Group has participated. The VIP seminars and the sampling courses are targeting different groups. The seminars are directed towards the decision makers and the sampling courses towards the maintenance personnel of the customer organization. A VIP seminar is held every year, and the sampling courses up to two times a year.

The Diagnostic Group has a homepage available for ABB employees only on the ABB

intranet. No pictures or texts are posted on this page, but brochures and other written material can be downloaded. Few of the group's members visit the site. There is no homepage on the internet presenting the group or its' services. A web based tool called iTrafo is available for some customers. iTrafo is a database where the customers can log in and gain access to all information stored about their units.

There are a number of brochures presenting the services of the unit. For example, this material is used by Wikars (marketer of ME) when making customer visits. Some of the brochures are old, but major parts of the text is still of current interest. An update of the brochures is planned but no decisions have been made regarding when and by whom.

When the test results are reported to the customers, recommendations are always made regarding future testing. If the analysis indicates any abnormalities, the customers are contacted and reminded to send in new samples for follow-ups. When the units are found to be in god condition, no reminders are sent out (even though recommendations have been made).

7.1.7. Culture of competence

When the Head of the Diagnostic Group was asked to name the one factor most critical for the success of the unit, she said knowledge. Competence is what the Diagnostic Group is all about. As mentioned by all interviewees, the differentiation strategy employed by the group is to provide superior performance in terms of quality and competence. A great advantage of being a transformer manufacturer is the unique knowledge about the detailed design of several of the customer's transformers. This advantage is of less importance for routine analyses, but crucial for the more advanced assessments. The Diagnostics group has also access to experts within related fields at the other ABB divisions. Also, projects are often selected for the opportunity of competence development. The personnel are working actively to broaden their areas of competence by varying their tasks. Research projects aimed at increasing the understanding and to find new better ways on how to do things are prioritized at the unit. Due to R&D efforts, the Diagnostic Group are working with and developing the latest methods.

7.1.8. Marketing plans and planning processes

Marketing plans have been made, but not recently. The designs of the plans vary, there is no

template on how they should be done and there is no routine regarding how often they need to be reworked. However, the attitude towards marketing planning activities is very positive.

Even though every employee is marketing the laboratory each time they interact with customers or other partners, there is no single person in the group except the Head that has marketing as an explicit part of his/her duties. No clear demands concerning marketing are imposed on the unit from higher up in the organization. The marketing activities made are initiatives from within the group. With this in mind it is easy to understand that the market planning (or at least the documentation of such) has been rather weak. This is not unique for the Diagnostic Group. A previously mentioned unit, ME, does not have any marketing plans outlined either. Both MD and ME are subunits of M, Market. None of these three departments have guidelines or policies for how often a marketing plan needs to be reworked or any template on how to do it.

7.1. Summary of marketing results

The following areas have been found to be well in accordance with the theories:

- Customer selection (active and based on strategy, competence development, profitability and image)
- Focus on customer needs and customer value (good at finding new opportunities)
- Knowledge dissemination (presence in industry organizations, publications, seminars etc.)
- Communication (arrangement of and participation in educational courses aimed at creating interest and raising awareness, communication through personal relations)
- Competence (continuous development through R&D, clear and consistent differentiation strategy)

The following areas have been identified where improvements can be made:

- Customer (and competitor) intelligence
  - No conclusive database for storage of "soft" customer information.
  - No systematic monitoring of competitors (services, prices, marketing activities etc)

- Contacts
  - No systematic mapping or documentation of opinion leaders and other key people within the industry.

- Communication
  - Few customer visits though proven effective in the past
  - Little coordination between MD and related units (though synergy effects could be possible)
  - No website on the internet
  - Update of brochures
  - No reminders to customers to send in new samples from units in good condition.

- Marketing plans and planning processes
  - Little support from above in the organization concerning marketing planning tools and routines.

All of the areas presented can not be improved within the scope of this thesis. This list is merely a suggestion on what could be done. One area (construction of a website) has been chosen for immediate action and remaining areas will be left for the future.

7.2. The website

The website is accessible through: www.abb.se, “Produkter & tjänster”, “Transformatorer” and “Diagnostik".

8. Discussion marketing

Since the Diagnostic Group is rather small, a full (or part) time marketing resource is not realistic or necessary. Instead, a possibility could be to spread the marketing activities among the members of the group. When divided into smaller tasks, the extra workload on the individuals could be kept manageable. Also, a number of the suggested areas only require attention a few times a year. Examples of different marketing responsibility areas/tasks that could be divided among the employees are: to monitor potential customers and identify new ones, to monitor competitor services and prices, creation of the marketing plan, website updates, brochure updates, diagnostic courses, customer visits, expansion/creation of a customer database, mapping of industry key people, reminders to customers to send in new samples etc. I believe the tasks can not be the responsibility of the group as a whole but needs to be allocated on individuals. Moreover, the head of the unit can not be expected to carry out all marketing activities alone. Another possibility to strengthen the marketing would be an increased cooperation between the different subunits of M (Market and Sales).

8.1.1. Customer and competitor knowledge

Increased cooperation between the different units concerning information exchange (MD/ME and ABB Service for example) would be beneficial. To avoid loss of important customer information due to e.g. retirements, the existing database could be extended. This would probably be more of a long term project since it is likely to require an extensive amount of work and time. Today, a number of employees have their own system where they keep this information. To have one place where all information is stored might increase the efficiency and facilitate the gathering of more. As soon as anything is done for a customer, a short notice could be made. The information should be searchable, open and available for the different units. Oftentimes, assignments made by one unit can create job opportunities for related units as well.

Even if the group is not mature enough to reintroduce the system with one assigned contact person for each customer, it is a possibility for the future. A drawback with this system was the concentration of information on individuals, but as mentioned above, routines on how to store such information would be beneficial in this case as well.

Since the competition is getting tougher, it might be a good idea to once in a while investigate competitor services offered, prices and possibly marketing activities. If any of the employees would gain any new such information, they should be encouraged to document it. Information about competitor prices can be valuable for the group when updating their own price list. For strategic purposes (e.g. service portfolio strategies) the services offered by the competitors may be interesting information.

8.1.2. Communication:

Considering the size of the group, I believe that the sort of marketing activities the group engages in today is a well balanced choice. What is left to wish for are for the customer visits to be performed more often. The major concern regarding customer visits is lack of time and traveling restrictions for some employees. When the laboratory is fully staffed with an additional technician as planned, more time could hopefully be available for other employees to take such trips. Since the group has limited resources on its own, but sells services that are related to those of other units, an increased cooperation between the units would be possible in some areas. Both the Heads of MD and ME are positive towards cooperation, but they have different ideas on how it could be outlined.

I believe the VIP seminars are targeting a very important group (the decision makers) and the Diagnostic Group should definitely be present as a lecturer during those occasions. Since the seminars are held once a year, customer visits targeting the same group could be a complement through out the year.

To prevent loss of customers for base analyses, reminders to send in samples for testing could be an idea. A possibility would be to include an alert in iTrafo when no samples have been sent in for testing within the recommended period of time.

Since the Diagnostics Group is a subunit of ABB Transformers, the brand awareness is high. ABB Transformers wants to be positioned as quality leaders and the same is true for the Diagnostic Group. It is very important to send out a clear and consistent message, and I believe the group is doing this. There is a great fit between how the Diagnostic Group market themselves and the ABB guidelines (ABB Hela bilden, 2007) on what to communicate. For example, the brand ABB should communicate technical leadership, pioneer spirit and local

presence. This description fits the Diagnostic Group as well. The ABB theme for market communication is to provide the customer with reliable distribution networks and access to electric power, increased industrial productivity and energy savings. As mentioned before, the mission of the Diagnostic Group is to "give the customer a good night sleep concerning their transformers and reactors". The mission is transferred into practice by assuring the availability of the transformer in a cost efficient way.

8.1.3. Marketing plans and planning processes

Since MD is a relatively small unit it is my opinion that they should be provided with guidelines for market planning from higher up in the organization (for example from ABB Transformers). The execution of the plans would then be the responsibility of the group. The guidelines should be simple and flexible but offer the subunits a starting point for their market planning activities.

It is important that the market plan is known to all members of the group and agreed upon. For a market plan to be effective, feedback and controls are needed to monitor the progress of the work. Important topics often covered by marketing plans are for example: the current market situation, opportunity and issue analysis, objectives and defined goals, marketing strategy, action programs, projected profit and loss statements and control (Kotler, 1999).

8.1.4. The website

A website is an inexpensive and easy way to present the Diagnostic Group and its services to the customers. Easy-to-understand descriptions of the complex services offered are provided. Current customers can use the site to find additional information and as a complement to the other communication channels. For potential customers, websites could facilitate the comparison of the different actors on the market. Apart from marketing directed towards customers, it can also be a good internal marketing tool. Employees at other (related) ABB units could access the site and learn more about the activities of MD. An easy-to-understand presentation of the group and the services may also be beneficial for recruiting purposes. Unfortunately, the ABB policy restricts the usage of simplified webpage addresses (urls) for the subunits. For the customers to find the page, I believe that the address should be basic and easy to remember. A suggestion was www.abb.se/transformers/diagnostics. Instead, the

customers must use the path www.abb.se, products and services, transformers and then transformer diagnostics.

The topic “New to diagnostics?” posted on the website was created according to the recommendations made by Ahrnell and Nicou (1995) about useful information to provide the customers (as discussed under method). A description of the employed researchers, their publications and presence in industry organizations is a good way for the group to further market their competence. According to Ahrnell and Nicou (1995), abstract services are bought in trust and often on recommendation. In line with their theory, references are provided on the website. Information about e-mail addresses and phone numbers to the different contact persons for each service could simplify for both customers and employees, increasing the chance to reach the right person immediately. Both for the convenience of the customers and for the group, information about prices are better to put on the web than in brochures, due to the easy updating.

A webpage offers many opportunities, except from posting information, it could also be used as an interactive media. Customers could e-mail questions and respond to material posted. Suggestions for the future are a dialogue box on the “contact us” page where questions can be written. A dialogue box could also be used as a fast way of ordering new sample vessels. Another suggestion is a category called “News”, information about upcoming events such as diagnostic courses or seminars could be posted here.

For the credibility of the website, it is important that it is updated regularly and that old information is removed. When new research publications have been made, they should be added to the existing list, just as with references. All that is required from the group in order to update, is to provide the IT-manager of ABB Transformers with a written word document.

9. Conclusions

A suitable method and two possible column configurations has been found. All gases of interest have been identified using these systems. As of now, the carboxen 1010 column is the most appealing alternative. A third configuration not yet evaluated might also be an option (the carboxen 1010 in series with the molecular sieve column). Future attempts with the carboxen 1010 column could be made both for the GC-MS and the regular GC-set up. The most important issue regarding future evaluations is to obtain a stable system including stable baseline and minimized air leakage over time. Considering the circumstances and the results obtained when investigating the detection limits, it is reasonable to believe that all gases could be detected on all tested concentration levels for a stable system.

The marketing activities of the Diagnostic Group are to a great extent in accordance with the theories of Ahrnell and Nicou (1995). The marketing awareness is high, but the resources are often scarce. An important area where improvements could be made is customer visits. Increased cooperation between MD and related units could create synergies and present a solution to the limited resources. A number of minor marketing improvements could be made by spreading such responsibility areas among the members of the group. The launch of the website is a good start and offers a platform for further improvements on the web.

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