Testing of a pulsed electro/magnetic field device on Marine gasoil and water

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Contents

Abstract

A pulsating Electro/magnetic field (EMF) apparatus produced by Lagur A/S is tested on Marine Gas Oil (MGO) and drinking water. The main goal is to investigate new techniques that can improve the combustion on maritime vessels engines and prevent scaling in water pipes. A Theoretical study have been carried out in support of this application.

The EMF treatment on MGO shows a reduction in viscosity and an accelerated degradation of diesel compared to the reference. The engine gas exhaust test are not conclusive due to lack of measurements.

The EMF treatment on drinking water shows an increase in charge on the particulate matter in the water, furthermore the droplet morphology is changed when applying EMF, indicating a change of lime scaling crystallization properties.

It is concluded that the Lagur A/S treatment has strong indication of effect on water, possibly leading to decrease of carbonate scaling. The EMF treatment on MGO is unlikely to have a significant effect on combustion economics, as a small change in viscosity does not necessarily lead to higher energy output. However, this effect could have a useful application for oil lubricants.

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Cover: Lagur system

Introduction

DTU Chemical Engineering have tested the effect of a commercial electromagnetic treatment system on Marine Gas Oil (MGO) and water. The LAGUR® water treatment system was originally based on a pulsed electro/magnetic field (EMF) treatment used to remove calcium scaling in drinking water systems.

In the spring of 2019, the LAGUR® system was fitted to the fuel tank line on a Mols-line ferry and there are indications of possible fuel savings. The system was originally installed in 2017 on the ships fresh water line to reduce lime scale coatings and bacterial germ growth with success. There is currently no clear explanation for the observed effects.

We have tried to replicate the observed effects from Mols-line by repeating the experiments on water and MGO, using 2 separate laboratory setup with the Lagur system, and measuring the exhaust fumes from one of the 4 MGO engine on the Samsø ferry. In addition to fuel savings, it is of interest also to investigate whether there should be less of pollutant.

Current literature [3-11] indicates that the underlying principles of the LAGUR® system pulsed electric field, could be able to break weak intra-molecular forces and charge particles in solution, thus lowering energy required to evaporate the fuel prior to combustion, and changing crystallization patterns of lime scale in water.

Potentially, the project may influence the optimization of a wide variety of processes in which surface interactions between liquids, particles and gas phase play a key role (such as fuel dispersion in a combustion chamber). The maritime industry is an obvious sector to investigate whether these pulsed EMF frequencies do have a measurable effect.

The project duration was 13 months starting from June 2020 to June 31. It was a joint project partly funded by the Danish Maritime foundation, Mols-Line and DTU Chemical Engineering department. [1]

Market potential of the Lagur EMF system

Current literature reports mixed results with some articles suggesting a 5% reduction in fuel consumption and reduction of hazardous NO emission due to better combustion profile [3, 6, and 9].

Any technology that can reduce energy waste is environmentally as well as economically important to consider, even if the chance of success is low. Since ship traffic constitutes 3% of global CO2 emission

If the Lagur system is proven to stop scaling in water systems, then a considerable benefit can be expected across multiple sectors. The benefits are less energy waste and better regulation of water heaters and heat exchangers, longer water pipe life, reduced water pressure in water pipes leading to less strain on water pipes in critical areas, and generally less cleaning needs of surfaces for end users.

The disadvantages are old water pipes could expose leaks as scaling is slowly removed from the water pipes, clogging problems could arise if scaling detaches suddenly from the water pipes, Unforeseen negative biological effects by changing the crystal structure of $CaCO_3$, Unforeseen negative biological effects by direct exposure to the Lagur system pulsed EMF.

The following commercial information is obtained from Lagur A/S:

- The Lagur system require no service (oldest systems are now running on 6th year with no service required so far – 10 year's warranty is offered)
- No chemicals used – huge environmental and CO_2-benefits from this (to give two examples: a. one open cooling tower in one building with a client has saved 6.000 cubic meter of water per year, 25.000 kwh, and 6,5 tonnes of chemicals (citric/sulfuric acid) and anti-fouling; a medium-sized hotel in Copenhagen saves roughly 1 tonnes of salt per 10 rooms yearly by shifting to a Lagur system)
- Leaves minerals and limescale in the water with benefits to public health
- Much cheaper total cost of ownership than current alternatives
- The total potential market for the current product portfolio in Denmark alone is conservatively estimated at: 4,5 million household units

Theory

The hypothesis for testing the Lagur EMF was to investigate if the MGO was better combusted in the Engine.

Prior to combustion, the MGO is pre- heated and injected in the engine, the MGO is evaporated separating the molecules and mixing them with air (in a large 1 MGO to 3 air ratio). This process is working against intra molecular forces (mainly Van der Waal´s), and is not exotherm but requires energy, the combustion itself is then the subsequent breaking of covalent bonds with oxygen, providing large amounts of energy and gas expansion.

It was believed that if the intra molecular forces between the large population of different molecules in MGO could be affected by EMF, then a better dispersion could be achieved, perhaps by increasing charge or aligning the molecules.

In the following, we shall therefor try to understand the effects that pulsed EMF have on hydrocarbons. This means that we have to investigate what modes are excitable by EMF in the suspension. Single covalent bonded molecules are excitable in the infrared region. However, collective modes at lower frequencies of several different molecules in the MGO are less understood but relevant for applied EMF.

The application of Electro/Magnetic field (EMF) radiation has previously been found to be important for de-aggregation and separation of MGO molecules. Several different effects has been found using a vast array of different devices ranging from simple stationary magnets to high magnetic field devices. When comparing the Lagur system to the available literature, it seems comparable to other devices tested and its pulsating EMF would be expected to have a reasonable influence on polar and a-polar liquids. [3-9]

The use of EMF is supposed to make combustion of the MGO more effective with respect to speed and yield. It is part of a greater study in splitting or de-aggregation of organic molecules where certain modes of inner degree of freedom in the molecules can be excited in the Giga Hz range and depending on the size of the molecules. However, also pulsed radiation of much lower frequencies has demonstrated strange effects of de-aggregation phenomena [2]. In general, aggregation and particularly fibrillation, is an important problem in chemistry and medicine.

Using a gas chromatography (see experimental section) it was concluded that MGO consists of at least 105 different compounds. There are many ways of separating such mix of molecules into classes of molecules of a certain size to a certain accuracy.
Many of these alkane molecules build up a complex spectrum of many particular frequencies.

In one of the next chapters we calculate the structure and spectrum of some individual molecule using quantum mechanics in order to see their absorption spectrum and how much that molecule are affected by external EM fields.

Application of EM radiation on a suspension of long hydrocarbon alkane molecules

A full treatment of electromagnetic irradiation on a suspension of oil molecules requires not only a treatment of single macro-molecules in the suspension but also the interaction between them in an electronic quantum setting. A quantum calculation is important if one wants to derive the spectrum for a given molecule in a suspension.

The molecules are treated as polar particles or chain-molecules in a field from an external source.A modulated or pulzating external field is described by E = Eo cos(omega t). The chain molecules are then treated as small dipoles.

Firstly, the analysis is made on a single molecule of the oil suspension and where the Energy function or the Lagrangian is constructed as the kinetic and potential energy of each macro molecule. This is approximated as a rod or a string having an orientation and described by the parametrization $(\hat{r}(\sigma),\varphi(\sigma))$ where $\hat{r}$ being the position vector and phi is the angular variable of a molecule that is axial-symmetric. σ is the length parameter.

Such an energy function basically describes the balance between the bending rigidity and torsion.
Here, the constant for bending rigidity is k_{Kappa} which is arising from the mean curvature $\kappa = 1(dr^2/d\sigma^2)1$ and α is the torsional constant for the torsion $\tau = (d\varphi/d\sigma)$. L and M are respecrively the length of the string and the mass.

A modulated or pulsating external field is described by either an electric field $E = Eo \cos(\omega t)$ or magnetic field $B = Bo \cos(\omega t)$. The chain molecules are then treated as small dipoles. We shall mostly concentrate on pulsating magnetic fields where ω is the cyclic resonance frequency with
$\omega = e/m B$. With addition of metallic ion such as Mg^{2+}.

We shall here be using a differential geometry picture of the structure and sxxdynamics of alkane molecules. Basically, this picture involving bending and torsion forces leads to a differential equation that dynamically describes the wave equation with length L, mass M and moment of inertia, I:

$$M/L\, k_{Kappa}\,(\partial^2 \hat{r}(\sigma)/\,\partial t^2) + I/L\,(\partial^2\varphi(\sigma)/\,\partial t^2) = c(\partial^2\hat{r}(\sigma)/\,\partial\sigma^2) + c_1(\partial^2\varphi(\sigma)/\,\partial\sigma^2)$$

The heuristic description of the winding state of a chain molecule can be extended to a well founded continuous measure using differential geometry and knot theory (L.H. Kauffman, Knots and Physics, World Sci. 1991 .

The topological conserved winding is given by the linking number of a closed curve.
A linking number of zero means that if one cuts the ribbon (with a scissor) along a central line, one will end up with two non-interwoven ribbons. If the linking number is ± 1 you will end up with two ribbons that are linked as links in a chain.\\

We now consider the chain molecule again as a rod or a string with an orientation and with the parametrisation given above.The eigenfrequency ν, for a rod molecule, can be estimated from the solution to the equation above in the energy calculations with the wave ansatz $\varphi = \varphi(\delta - vt)$ as:

$v = \sqrt{\alpha/I}$

The eigenfrequency, ν is then derived from the velocity v to be $\nu = 1/L \sqrt{(y/i)}$

where L is the length of the chain molecule which participates in one period of the wring mode, y(α) is the torsion constant per inverse unit length, and i is the moment of inertia of the backbone per unit length. The eigenfrequency for proteins can be estimated to be in the range $0.1 < \nu < 10$ GHz (Phys. Rev. E. 2000, Vol 61, 4310.) As can be seen, the frequency of the resonating wring modes in biological chain molecules turns out to be close of frequency level as those typical of radio- and microwave applications.

In our particular case here we chose C-18 as an example of the alkane molecule - octane.
It has the following parameters with: A length dimension of $L \approx 10$ Å and with moment of inertia i approximately 1 (amu Å^2) , 1 amu = 1.66 10^{-24}g, and torsion moment per length $y \approx$ 1500 kJ M and thus leading to a frequency of $\nu = 1/L \sqrt{(y/i)}$= 14 Ghz.

Calculating spectra from Quantum Mechanics.

We have, in order to find the effects of applying Electromagnetic, EM, radiation on MGO- , firstly studied the molecular structure of the involved alkane molecules on the atomic level which means that we have to perform a quantum mechanical calculation of the alkane molecular structure.
This is in order to find what modes that are important in the dynamics of the alkane molecules and therefore deriving the absorption spectra of the vibrational modes we will have to calculate the electronic wave function of each molecule in the oil. Such a calculation comprises all the electrons of the atomic structure of the alkane molecules. For that task we employ a quantum chemistry program from one of the popular computational packages used in theoretical chemistry problems.

First, the atomic structure of the desired molecules are constructed with the help of the quantum chemistry program on a computer and then the corresponding wave function is obtained from solving the many-body, electronic Schroedinger equation partly by e.g. a Hartree-Fock optimization in the form of a matrix equation system with Slater determinants. Once the electronic wave function is obtained under the chosen approximations, e.g. the Born Oppenheimer approximation, the vibrational spectra can be derived from the atomic polar and nonpolar tensors.

Such spectra are seen for various alkane molecules, e.g. C-12, C-18, C-24 and they show absorption peaks at around 3200 and 1800 cm-1both in the vibrational spectra of Raman scattering and Infra-red, IR, absorption. We found the following data for specifically chosen alkane molecules:

C-14 with energy E=-547.644337 AU (atom.u.), IR max peaks 3193, 3244 cm_{-1}, Raman 3185, 3193

C-18 with energy E=-703.784109 AU, (atom.u.), IR max peaks 3200, 3250 cm_{-1}, Raman 3200, 3150

C-24 with energy E=-937.992267, (atom.u.) AU, IR max peaks 1600, 3200 cm_{-1}, Raman 3200 cm_{-1}

In comparison to the real infrared spectra we see that the diesel oil is somewhat lower in the wavenumber but still in the infrared region of 4000-1000 cm-1 which is an indication that the molecules in the diesel-oil are larger than the C-18 alkane molecules and perhaps being more cross-linked. The numbers for C-24 shown above also indicate that the diesel oil spectra are corresponding to larger molecules. Generally, our analysis of collective modes in the alkane molecules apply when using external EM-fields.

The Lagur EMF system

The Lagur system consists of an EMF cylinder for in-line attachment to water pipes and an electronics box producing a set of alternating current signals to the coil in the EMF cylinder. The EMF cylinder is an INOX steel hollow cylinder with internal copper windings sealed in, the copper is not exposed to the water. Number of internal coil windings and thickness is proprietary information to the Lagur company. The coil exist in different internal diameter sizes, the one used in the experiment has a 1 inch I.D.

Figure 1 The lagur system. Left: the electronics box producing the pulsed EMF. Right.: The magnetic coil to be mounted in-line with the water pipes

The signal box is connected to 220 volt AC mains and produces a modulated signal in AC, consisting of at least two distinct signals, a fixed and a up-sweeping signal, apart from the EMF field, the signal can be heard acoustically when listening to the coil close up. The electronics box provides approx.. 40-60 watt of energy to the coil. There are no switches or regulators on the box and only operates in an on/off mode.

The internal electrical signal is measured to 10 volt peak to peak and 1 to 5 Ampere pulsed with varying with at 1 to 5 KHz

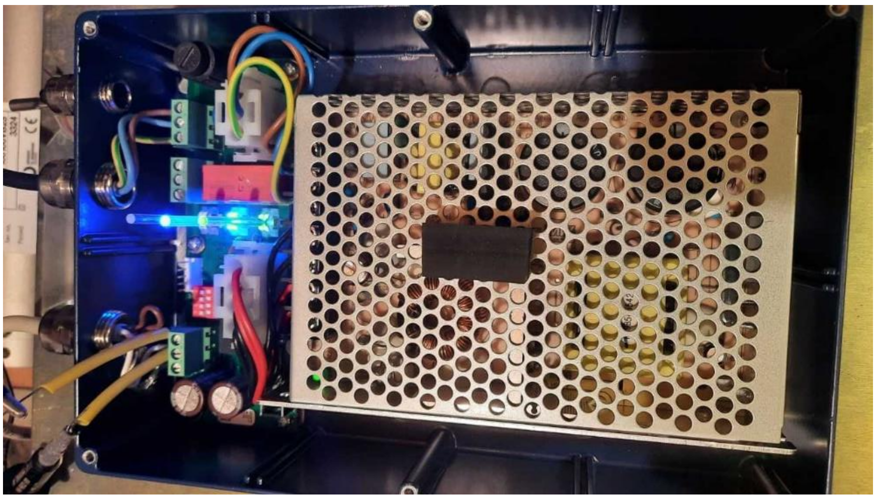

Fig. 2: The insides of the Lagur electronics box

Figure 3: Two distinct signal patterns measured directly from the internal electrical signal to the coil. Signal is 10 volt peak to peak and 1 to 5 Ampere pulsed with varying with at 1 to 5 KHz period.

The external magnetic field of the Lagur system was measured using several magnetometers. Since the signal was pulsating at approx..3-4 times pr second it was difficult to find a high sampling rate magnetometer that could catch the signal variation.
A simple smartphone app was initially used to measure the external field from the coil, although clearly indicating a high intensity field the signal was rather chaotic and not high quality enough to decifrate. Below is seen the plot from a smartphone magnetometer:

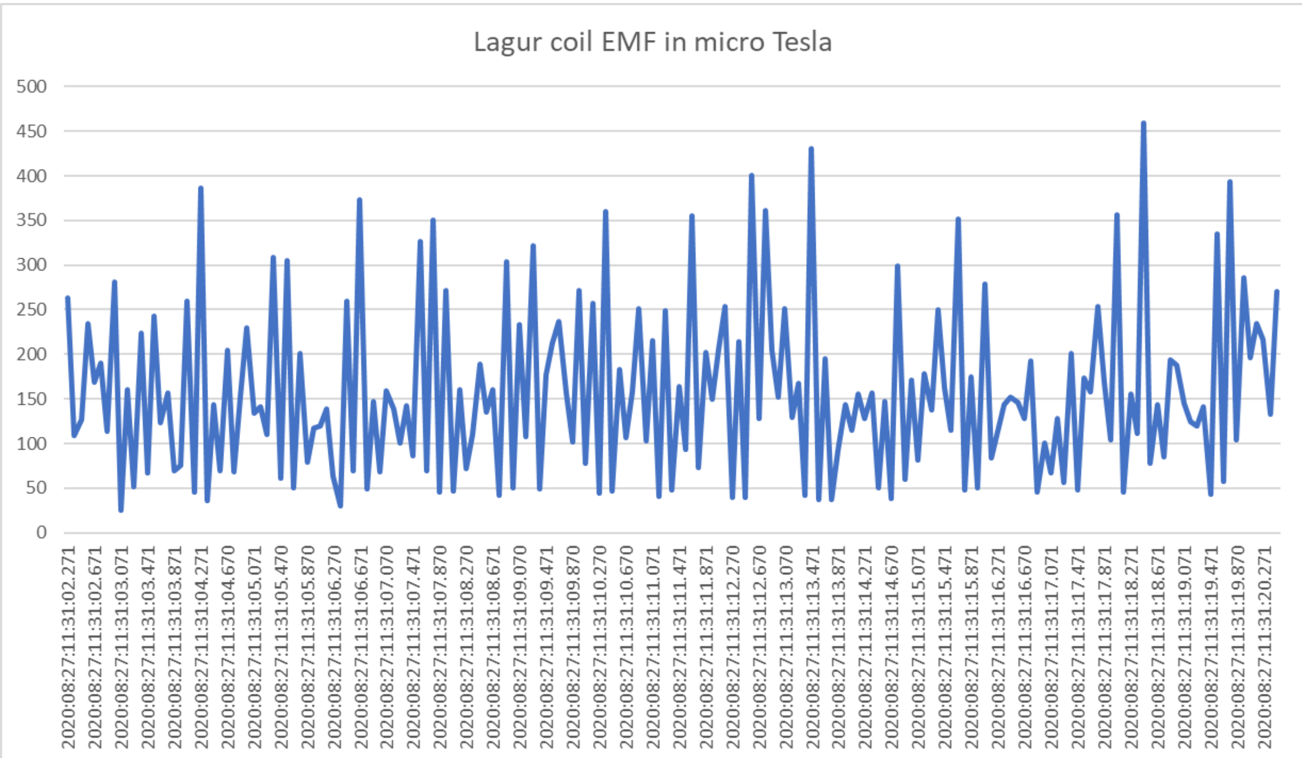

Figure 4: Lagur coil EMF strenght in micro tesla measured with a smartphone magnetometer.X axis is approx 3 data points pr. Second, a clear period is hard to detect.

DTU Space was kind to provide a high resolution magnetometer, showing a periodic 4-5 Hz signal with approx. 3000 micro tesla amplitude magnetic field strength directly from the center of the coil opening.

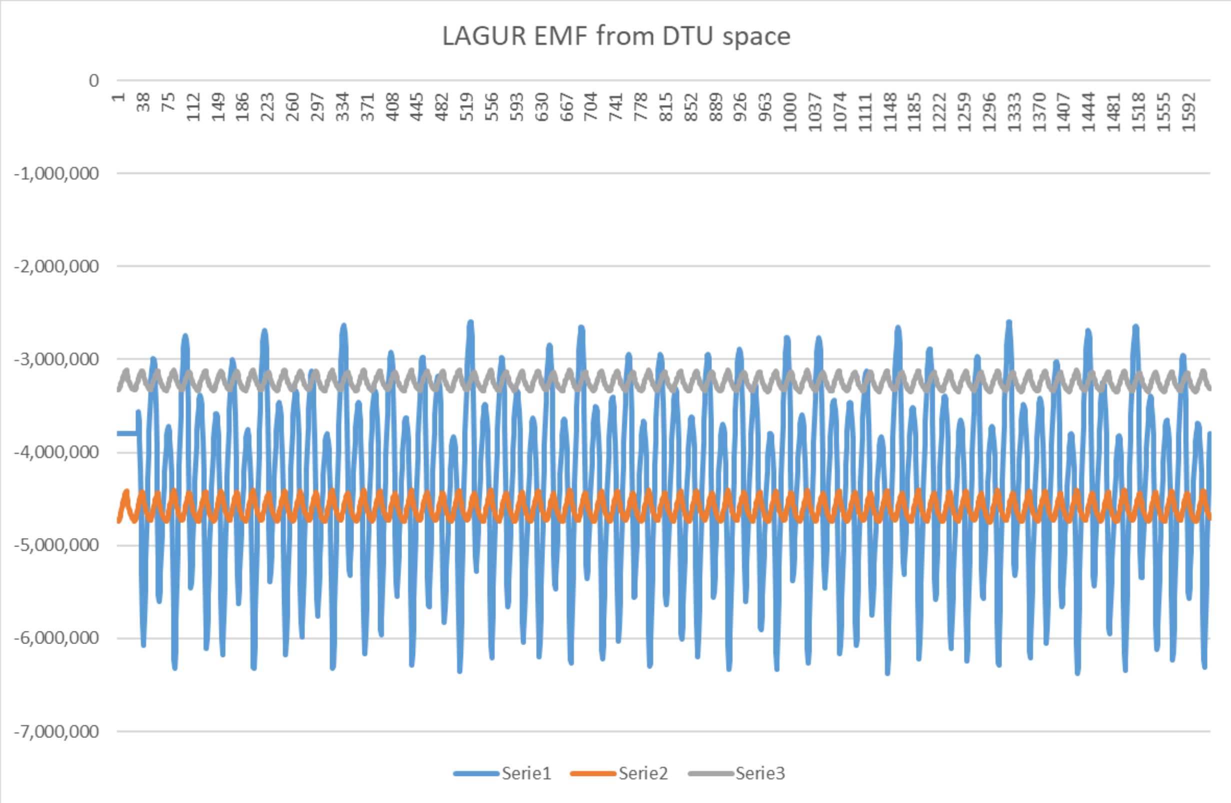

Figure 5:The magnetic periodic signal in x (blue) y (orange) and z (grey) . Y-axis in nano Tesla strength and X axis is 1/100 of seconds. Amplitude is approx. 3000 micro tesla, for comparison earths background radiation is 45 micro tesla

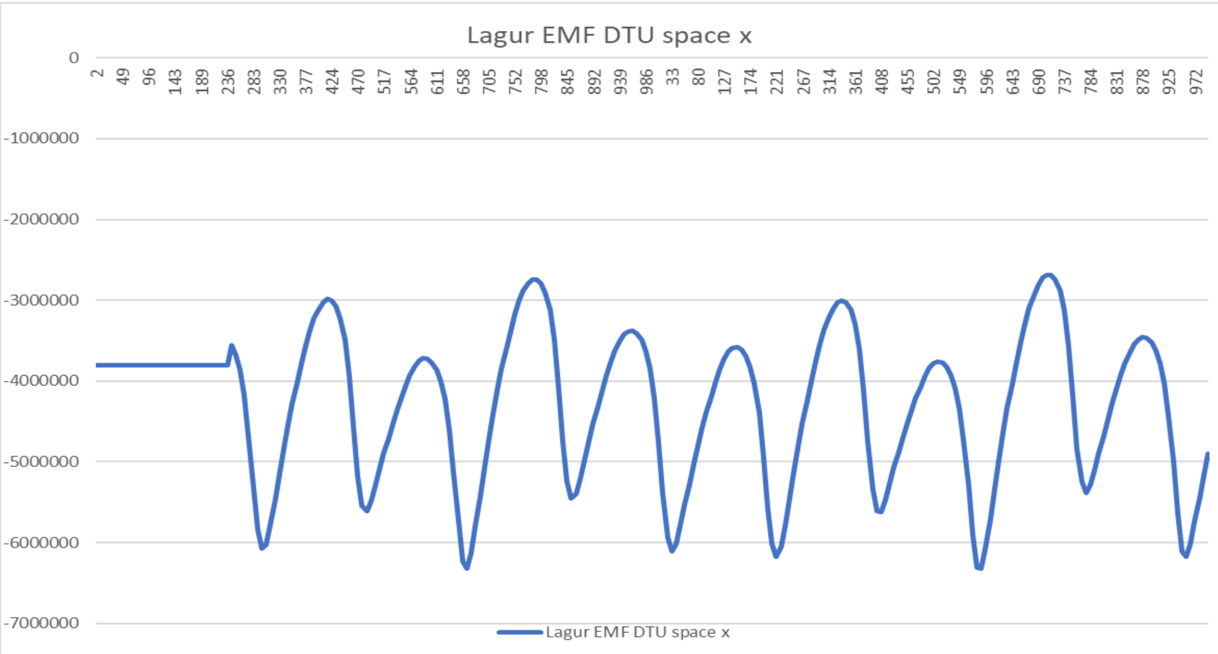

Figure 6: Zoom on two whole seconds in milli seconds interval (x-axis), giving 5 pulses pr.

second, y axis is nano Tesla, giving an amplitude of 3000 micro Tesla, this vary according to what magnetometer is used.

Apart from the magnetic signature a clear high pich singing sound with a upsweep tone could be heard close up from the coil when in operation

When in operation It was noted that the coil got considerately warmer, reaching approx. 35C under flow conditions and up to 90 °Cin static conditions. This was clearly seen when using a thermal image camera. This was regarded as a fire hazard issue for stationary MGO exposure samples, but was otherwise not regarded as contributing to any substantial heating when coupled to a continuous flow pump.

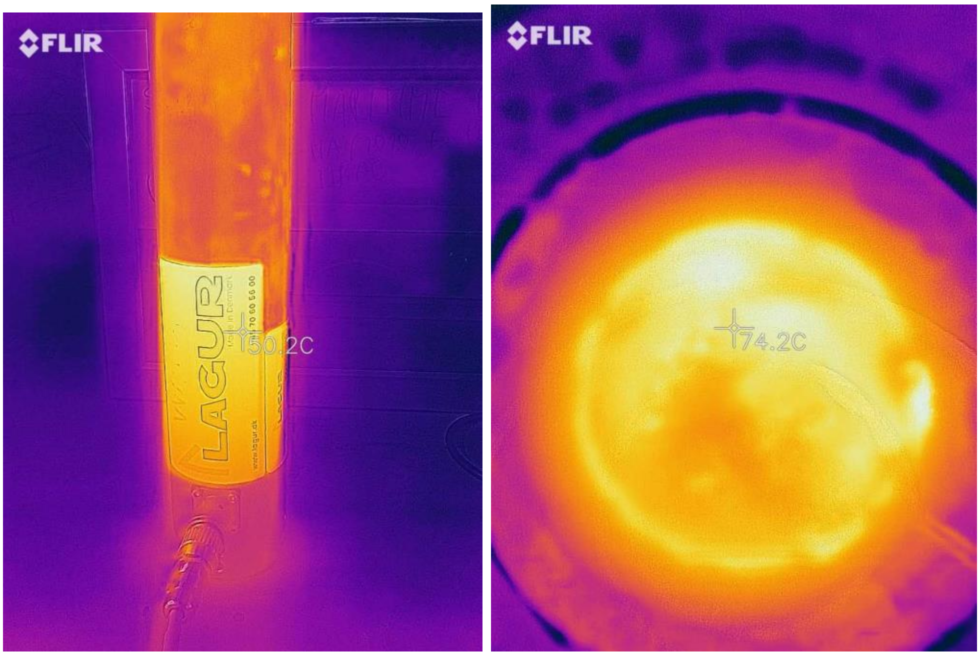

Figure 7.: Infra red images of the Lagur EMF coil after 2 hours run time. Left: whole coil , right: top of open coil showing heated water inside. The coil is loaded with water, reaching a temperature of 75C after 4 hours and up to 90 °Cfor longer durations of several days, showing a considerable heating effect from the coil when no flow is used through the coil.

Experimental

Experiments were divided into EMF effects on water and MGO. For this two separate Lagur systems for water and MGO with continuous flow were built. The primary goal was to investigate EMF effects on MGO and the secondary on water.

MGO Experiments

The effect of Lagur EMF treatment was tested on a 10 min exposure, 1 hour exposure and a long term 1 month exposure.
The tested parameters were: surafece tension, Viscosity, Density, MGO composition by gas chromatography, conductivity, particle charge, Infra red absorbance and visual /ultraviolet absorbance.
The MGO used was a Marine Gas Oil (MGO) donated from the Samsø ferry by the Mols line. The MGO is the standard MGO used in the Danish domestic ferry lines. The MGO quality is according to DMA standard, and provided by DCC Energy once every week from Kalundborg harbour. Fuel data are [9]:

- Contains 0,005% sulphur
- Density is 820-870 g/liter at 15C
- Viscosity is 1.9 to 3.7 cStokes
- Fuel energy is min. 42.7 M Joule/kg

Short term Lagur EMF exposure Sample

The short term effect should replicate the effects seen on the Samsø ferry. The MGO passes the Lagur system for a few seconds before being passed on to a pre-injection storage tank. From there it is heated and injected in the Caterpillar ship engine. The MGO is not stationary but kept in a continuos flow to avoid settling in the tank. When running at 80% engine load the pre- injection storage tank is emptied in approx. 5 min. This means a lag time of at least 5 min. is expected from where the MGO is Lagur EMF treated to its injected into the ship. Similary a min of 10 min and max of 30 min from treatment to measurement was kept when working on the Lagur treated MGO.
The 10 min and 60 min treatment was chosen as a reasonable exposure time, originally also a 60 sec exposure measurement was included but this was later skipped.
The 10 min and 60 min exposure was done directly by pouring the MGO in the lagur coil without flow and closed in both ends. The temperature of MGO reached approx. 50C after 60 min exposure in the enclosed EMF coil. This could affect readings but is unlikely.

Long term Lagur EMF exposure sample

When the Lagur system is mounted on water pipes, end user often report a change in lime scaling deposition after one month, indicating an accumulated effect only seen after long term exposure. Although realistically never used in any end user scenario, it was interesting to see if there were similar accumulating long term effects of exposing MGO to EMF effects.
The long term MGO system consists of a 10 liter closed polymer waste container connected to a MGO fuel pump (standard 12 volt car MGO pump) and the Lagur system (1 inch internal diameter tubing). The fuel pump was controlled by a 12 volt transformer. A set of reduction flange and tubing adapters were used. All elements were connected with transparent standard

plastic tubing for oils. The system was kept in a fume hood to remove eventual escaping organic vapours. The lagur system was turned on for an approx. total of 8 days in a one month period and always kept in a fire safe fumehood (only turned on during working hours due to fire hazard concerns). While pumping the coil temperature never went above 45℃ The setup can be seen in the below picture:

Figure 8.: the long term one month exposure setup

After a month it was clear the Lagur system was influencing a color change on the MGO , According to guidelines for MGO from MAN energy solutions this could indicate an oxidation/degradation event of the MGO caused by the exposure to the EMF from Lagur [7] Below is seen the color change after one month exposure to Lagur EMF.

Figure 9.: Long term 1 month exposure of MGO to Lagur system showing clear oxidation effects of the EMF treatment, reference MGO   remained un changed. Left picture: a 5 ml sample of ref MGO (green tube) and 1 month exposure (yellow tube), Right picture: the two cans with reference MGO (left large can) and 1 month exposed MGO (right small can).

Gas chromatrography

In order to have an overview of the compounds in MGO, 3 Rounds of Gas Chromatography (GC) were made.
The GC used was an Agilent 7890A GC fully automatic with a loading cartridge, c18 column and xxx carry gas.Temperature was started at 40 °C, then 20 °C/min to 350 °C for. Total run time was 19.5 min. Injection Volume was 0.05 µL.

All MGO samples indicate an average of 104 to 105 distinct compounds with different retention times, ranging from 4 carbon atoms to 28 carbon atom compounds, when compared to an internal standard. Below is seen an overview of the identified compounds.

Carbon length	Reference MGO % area	One month Lagur EMF % area
8	0.267	0.234
9	0.832	0.735
10	0.544	0.491
11	0.571	0.539
12	1.136	1.019
14	3.397	3.330
15	0.806	0.852
16	3.318	0.676
17	2.478	2.047
18	1.667	1.836
20	0.928	3.213
24	0.931	1.024

Table 1: Overview of % of each identified compound, according to retention time and an internal standard for C4 to C40 carbon atoms.

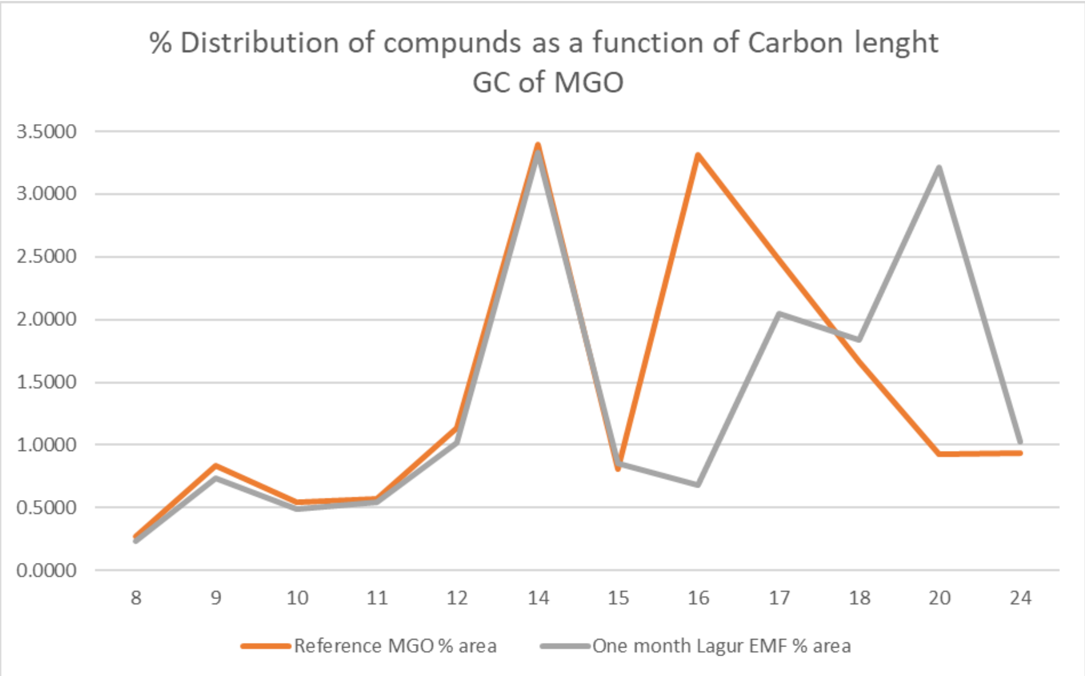

Figure 10: Graphic overview of % of each identified compound, according to retention time

and an internal standard for C4 to C40 carbon atoms

Generally, it is difficult to compare samples as the identification of 105 different compounds might not be accurate. But when comparing reference MGO to one month treated Lagur EMF, the one month Lagur treated sample has generally less C4 to C14 and more C16 to C28, furthermore an unidentified new compound (retention time 12.179 min and 0.3% area), with a corresponding to a length of approx.28 to 26 carbon atoms. The rest of the 105 different compounds were not identified as they did not correspond to a known internal standard retention time. See appendix for a sample of the total GC of MGO.

A fairly low difference was observed on the repeated measurements on the MGO samples. 6 samples of reference MGO was made and 3 samples of one month Lagur treated MGO. The short term treated Lagur was not analyzed as GC was not found sensitive enough for this, mostly due to difficulty in identification of each compound.

Many compounds qualify in number to a distinct carbon length but has vastly different retention time due to its difference in chemical structure geometry. This is because many of the 105 different compounds have aromatic rings and different positioning of the sidechains.

The useful information here is that there are at least 105 distinct compounds in MGO. A second conclusion is that there is a weak indication that a long exposure to EMF probably evaporates low carbon compounds and accumulates high carbon compounds above C16 in MGO.

Viscosity and Density of MGO

The viscosity and density of MGO is measured in parallel on a Anton Paar Lovis 2000 DMA 4500 M microviscosimeter. Each group is an average of 3 separate samples repeated 10 in measurements, if the variation is too high the measurement is deemed ´"not valid".
All measurements were thermo stabilized at 20C by the microviscosimeter before measurements.
The density had very little variation (below 0.001 g/cm3) , but the dynamic viscosity had a 0.01 mPa·s repeated variation difference for the reference MGO. Any difference below 0.01 mPa·s should therefor not be regarded as significant.

Dynamic viscosity gives information on the force needed to make the fluid flow at a certain rate, while kinematic viscosity tells how fast the fluid is moving when a certain force is applied. Below is seen the values of 10 min, 60 min, one month Lagur and reference MGO.

	Density g/cm³	*Lovis Dyn. Viscosity mPa·s*	*Lovis Kin. Viscosity mm²/s*
reference MGO	0.8358	3.857	4.614
10 min lagur MGO	0.8358	3.802	4.549
60 min Lagur MGO	0.8359	3.804	4.551
one month Lagur MGO	0.8397	4.241	5.050

Fig.11: Density, Dynamic viscosity and Kinematic viscosity of MGO treated with Lagur EMF device.

The density is unchanged by the short term 10 min and 60 min Lagur EMF, however the one month treatment has a substantial higher density of 0.03 g/cm3, this could indicate high vapor preassure alkanes has evaporated through the lid of the container as it was not pressure sealed due to the tubings perforating the lid. If the Lagur EMF treatment aggravated this evaporation is hard to tell, perhaps the heating effect of the lagur coil was enough to increase evaporation of MGO fumes from the 5 liter can. The reference MGO can was also opened several times before measurement so some evaporation is also expected there, but otherwise it was kept closed.

Regarding the viscosity there is a significant drop in dynamic viscosity (0.05mPa/sec.) for 10 min and 60 min Lagur EMF treatment. Also the kinematic viscosity of MGO drops (0.05mm2/sec.) when treated for 10 min and 60 min with Lagur EMF. Since the heating effect of the Lagur coil is nullified by the equal temperature reading of the samples this can only be interpreted as a lasting effect of the Lagur EMF treatment.
The one month treated Lagur sample had a substantial increase in both dynamic and kinematic viscosity (0.4 mPa/sec. and 0.4 mm2/sec.), perhaps caused by evaporation of high vapour pressure alkanes.

Charge of particles and conductivity of MGO

Particle charge in liquid samples is measured the scattering of light by the particles using an electrode cell . While measuring the light scattering, the electrodes induce a magnetic charge on the particles in solution, this pushes the charged particles back and forth between the electrodes. Thus the light scattering will be affected by the sideways movement of the particles in the solution. Higher particle charge gives larger movement and higher scattering of light through the water sample. Smaller particles scatter light differently than larger particles, so information of particle size is also available from the measurement.
Below is seen the different charge profile of a particle in a polar solution and how particles scatter light.

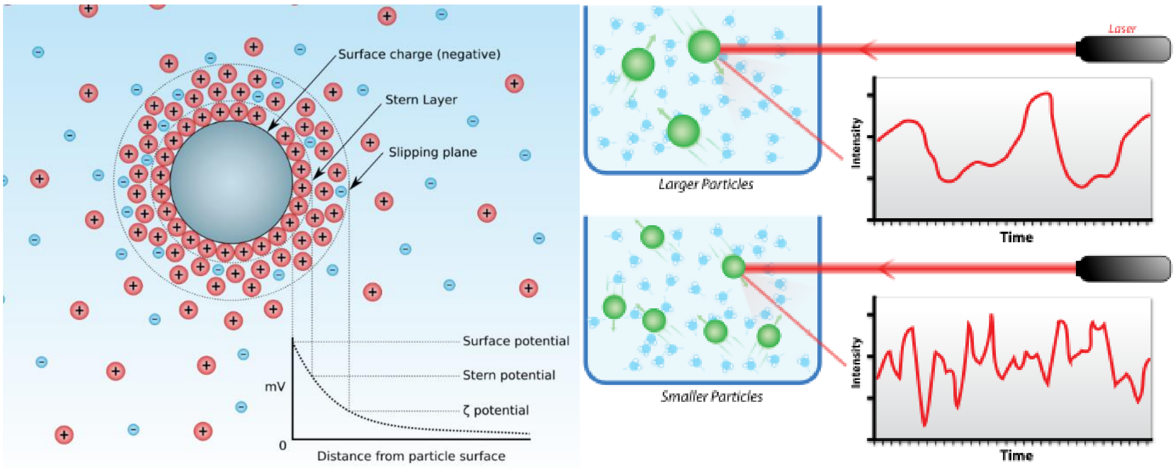

Figure 12: Left: Schematic drawing of zeta potential of a particle, Right: the size of the particle influences how light is scattered over time. Source: Martin Chaplin water website; [http://www1.lsbu.ac.uk/water/interfacial_water.html#b; Malverin Zetasizer µV](http://www1.lsbu.ac.uk/water/interfacial_water.html#b)

However, the measurement only makes sense if there are enough particles staying in solution to influence the dynamic light scattering. Very clear solutions, or solutions with precipitating particles, does not have enough impurities to influence light scattering and does not give a valid measurement.

All measurement were made using an Anton Paar Litesizer 500, at 23 °Cand a sample volume of 2 ml. Each sample is measured 100 times and replicated in duplicates.

MGO DLS		Zeta potential Volt	ZETA st. Dev. Volt	Conductivity mS/cm
Reference MGO 1		-0.0000630	0.0003874	0.0000150
Reference MGO 2		-0.0011101	0.0064365	0.0000152
10 min Lagur MGO 1		-0.0046598	0.0081644	0.0000148
10 min Lagur MGO 2		-0.0020219	0.0057917	0.0000152
60 min Lagur MGO 1		0.0017598	0.0094958	0.0000146
60 min Lagur MGO 2		0.0089556	0.0073980	0.0000148
one month LAGUR M		0.0007625	0.0061168	0.0000146

Table 2: Particle charge and conductivity of MGO, shown in sample duplicates

As seen from the above table the standard deviation is too large to deduct any information on charge difference in MGO, this is probably due to lack of charged particles in the solution. Furthermore all MGO samples have almost equal conductivity regardless of sample.

Fourier transformed infra-red spectroscopy (FT-IR) of MGO

The absorbance in the IR region represents the absorbance of light by the molecular bonds int the solution (first order harmonics). Any change in IR absorbance therefor indicates a fundamental change in the molecular structure of the sample, however small the change in absorbance might seem this therefore could reflect a substantial difference in the chemical composition, caused by de-composition or re-arrangement of the chemical molecular structure.

A standard Perkin Elmer FT-IR with a diamond crystal was used for the measurements. Each graph is repeated 3 times with identical results, for simplicity only one of each sample group is shown

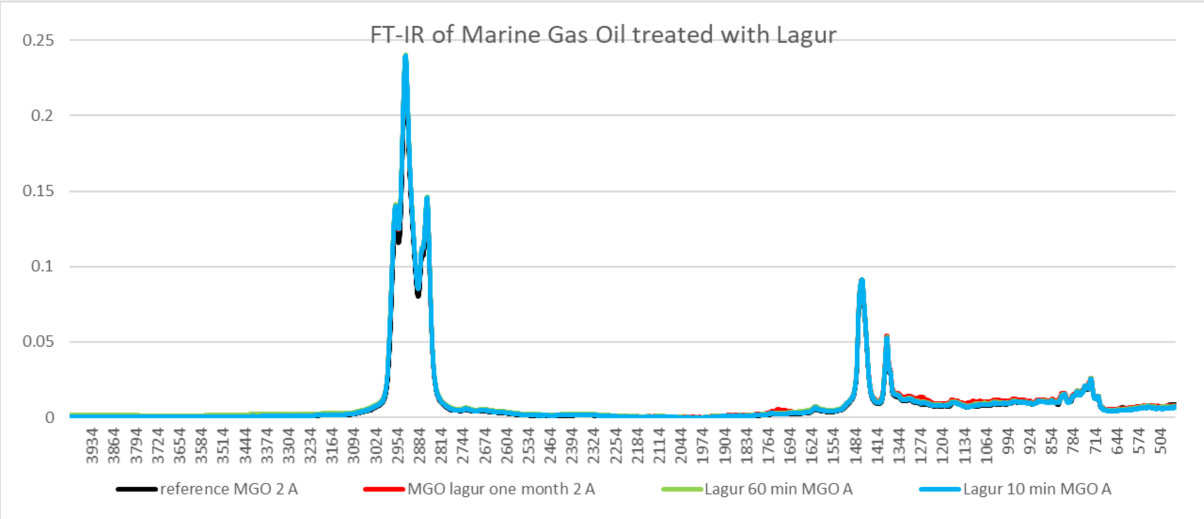

Figure 13: Total IR absorbance (y-aksis) as a function of cm-1 wave number (x-axis) of MGO with reference, one month, 60 min and 10 min Lagur EMF treatment.

Above is seen the total absorbance spectrum in the infrared region of untreated MGO, one month treatment of MGO, 60 min and 10 min Lagur EMF treatment.

No apparent mayor difference is to be seen, but when looking in the low 1100 to 1800 cm-1 region, the one month treatment has a few anomalies at 1730 cm-1 and 1300 to 1100 cm-1 region. below is seen a zoom cut out of this region

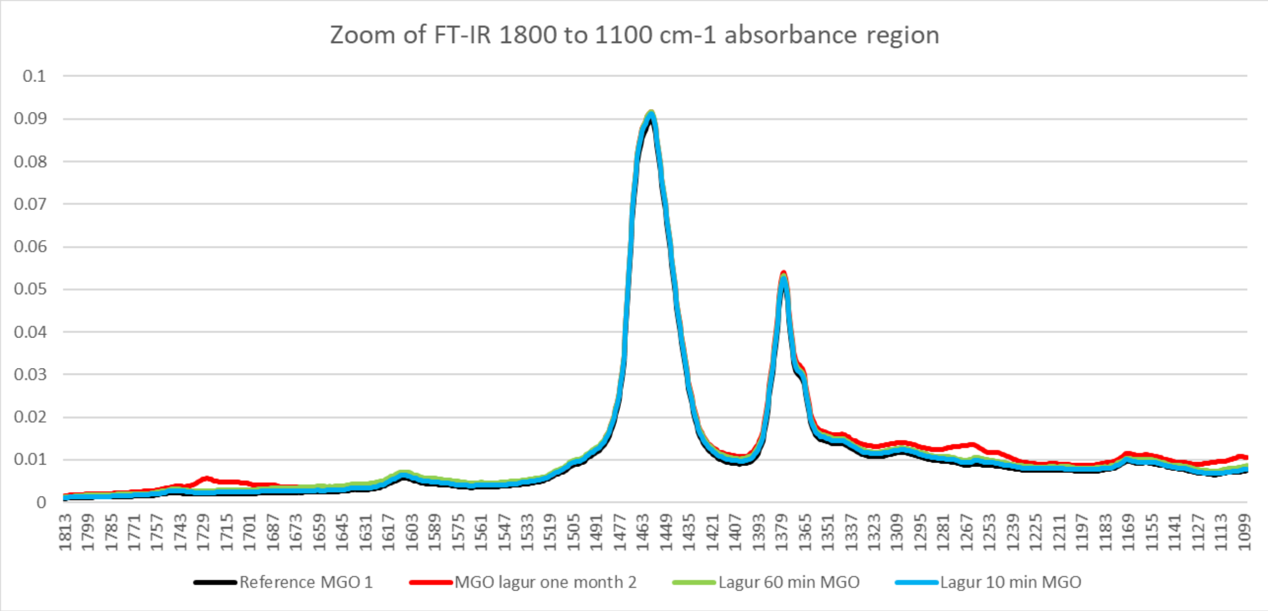

Figure 14: Zoom of 1800 to 1100 cm-1 region showing a few anomalous peaks of the one month Lagur treated MGO

This indicates a substantial difference between the reference and the long term treated MGO. This is to be expected as a visual difference is also to be seen. The peak at 1730 cm-1 could indicate the appearance of certain compounds not previously there in the long term treated MGO. The region from 1300 to 1100 cm-1 is probably just a degradation effect of different compounds.

M/F Samsø Engine experiments

The goal was to measure possible changes in viscosity, calorie value, gas emission and composition change of marine MGO, induced by the electromagnetic treatment of the LAGUR system. Ideally combustion test of LAGUR® ApS electrostatic effect should have been performed on a stationary marine engine, unfortunately this was not possible at the DTU Mechanic test facility in the project period (mainly due to Covid-19 restrictions). Instead the allocated funds for the stationary test engine run were used to acquire a TESTO 350 mobile marine gas analyzer and gas emission was measured on the samsø ferry.

M/F Samsø

The ferry was built in Greece in 2009 and sails between Ballen on Samsø and Kalundborg on Sjælland, Denmark. The ship is 91.4 m long and 16.2 meter wide.
The ferry has two identical machine room in each end , each with two Caterpillar 3512C HD main engines.
Each engine has a max power of 1250.000 Watts and operates between 600 and 1600 RPM. Normally the engine is operated on average at approx. 60% load with an average RPM of 1350. Fuel consumption is on average around 115 kg fuel pr hour.

Lagur system instalment on M/F Samsø

The Lagur system was installed 6 months before the project began, and can be turned on/off by a main switch. It is placed in line with the fuel before reaching a pre-mixing 20 liter fuel storage tank. Exposure time of the fuel is therefore quite short. Since consumption is 115 kg/hour it is estimated that the fuel is exposed to full power EMF in the 40 cm Lagur coil for only a few seconds before being passed on to the pre-mixing Fuel tank.
Unused fuel from the engine is returned to the pre-mixing 20 liter fuel storage tank. Thus the pre-mixing storage tank can be seen as a continuously topped up buffer tank.
Since average consumption is 115 kg/hour and MGO density is measured at 0.840 kg/liter , the 20 liter pre-mixing tank is emptied in approx. 12 min. Lag time from Lagur EMF exposure is therefore reasonably max. 12 min from EMF exposure. Below is seen the installed Lagur system in the machine room. It is noted that MGO that passes through the Lagur systems feeds MGO to both Caterpillar engines in the room.

Figure 15.: Lagur system installed on ship engine fuel line before reaching the pre-injection mixer tank. The system was installed 6 months before the project began.

Testo 350 Marine gas analyzer

The testo 350 MARITIME flue gas analyzer is certified for emission measurement on marine MGO engines (DNV GL and NK certificate according to MARPOL Annexe VI and NOx Technical Code 2008) and can be used to measure the gaseous flue gas concentrations of NO, NO2, SO2, CO, CO2-(IR) and O2. The system is fully automated with internal calibration. The Testo 350 Marine gas analyzer was therefore the natural choice for a transportable gas analysis system as it is the only one in Demark that has the sufficient ISO standard for marine use.
To investigate the EMF effect of Lagur it was interesting to see if a change in combustion was happening in the engine. For this the ratio of Nitrogen mono oxide(NO) to Nitrogen di-oxide (NO2) and the ratio of Carbon mono oxide (CO) to Carbon di oxide (CO2) could indicate a cleaner or less clean combustion caused by Lagur EMF.
Below is seen the Testo 350 maritime system and its gas probe inserted in the engines exhaust pipe.

Figure 16: Left: TESTO 350 gas anlyzer sensor box, Right: Gas Probe inserted in the center of the engine exhaust pipe.

Testo 350 Marine gas measurements

The Lagur exposed measurements were taken after the Lagur system had been turned on for 15 min. During measurements the Testo 350 operational guidelines were followed. The main difficulty was timing the measurements with a somewhat equal sailing profile of the ferry, i.e. sailing out of Kalundborg or approaching kalundborg. It was also attempted to take the gas samples while the engine was running at approx. 80% load. Coupled with a relatively short battery life of the Testo 350 analyzer of approx. 1 hour and a long re-charge time 8 hours for each operational hour, this proved to be quite a challenge. The measurements were made on 4 separate days and a total of 8 sailing trips. The gas samples were taken while the engine was running at approx. 80% load.

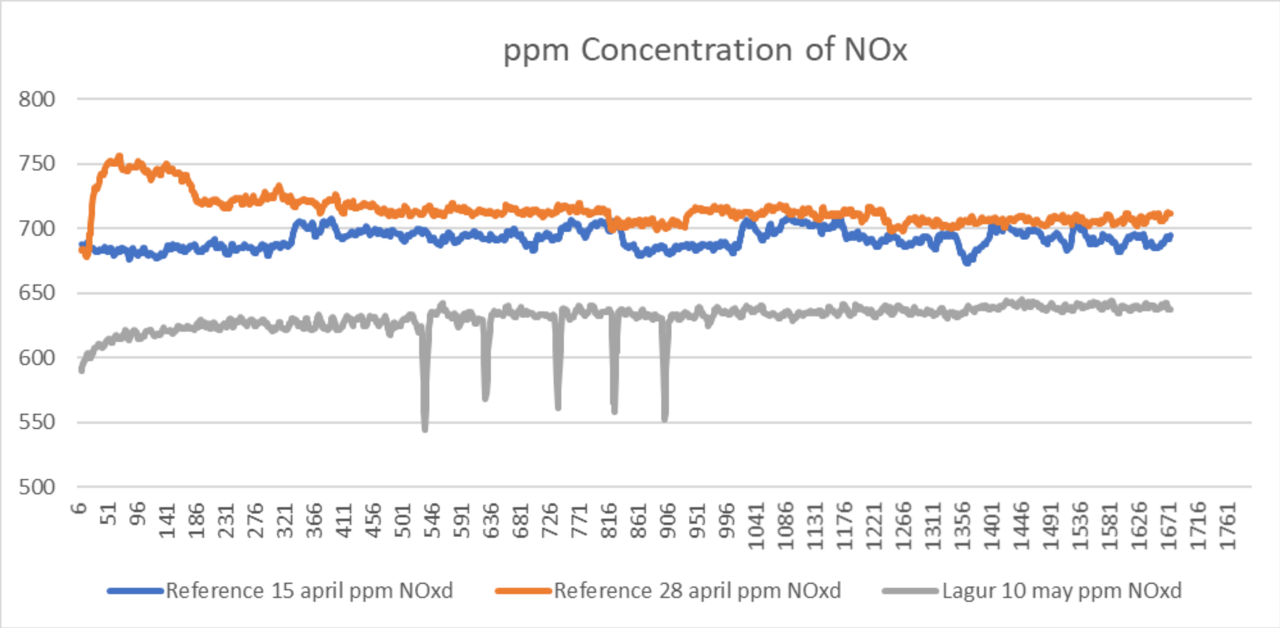

Figure 17: NOx concentration in exhaust gas. Y axsis in ppm NOx and x axis in seconds

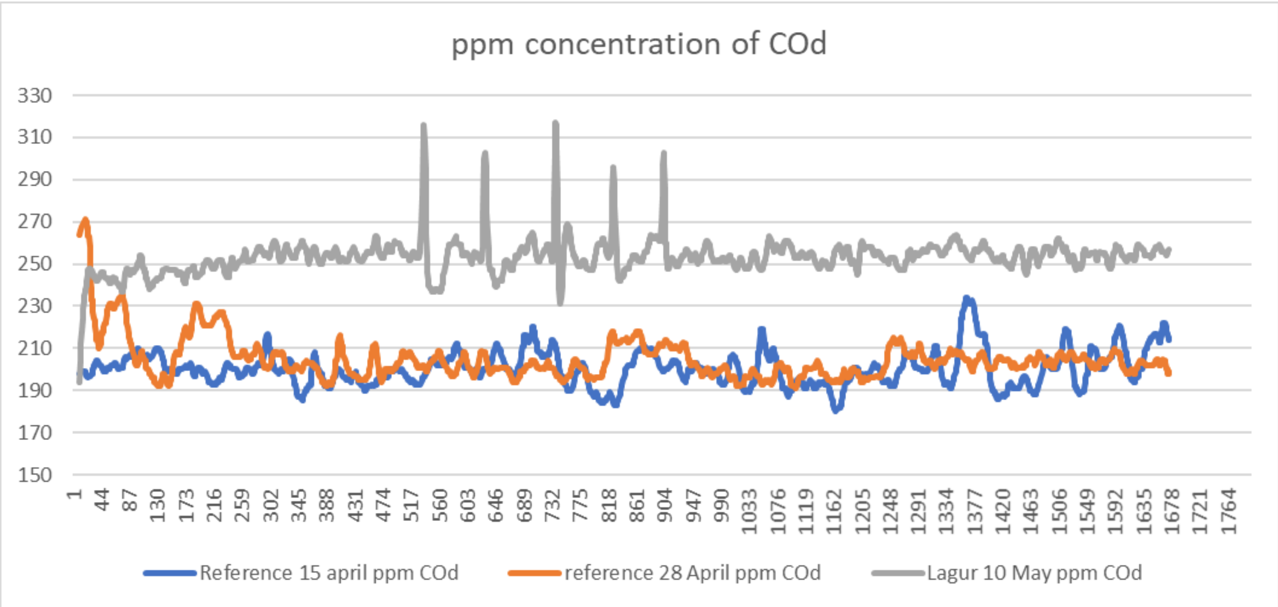

Figure 18: COd concentration in exhaust gas. Y axsis in ppm COd and x axis in seconds

Unfortunately too few measurements were done to conclude anything. However, the sensitivity of the Testo 350 was impressive. It is hoped that more measurements are made in the near future on the Samsø Ferry.

Water experiments

The secondary goal of the project was to see if there were measurable effects of the Lagur EMF treatment, specifically on scaling properties of the water. From previous projects on water quality testing it is concluded that ordinary test like pH, surface tension, IR/UV/visual light spectroscopy does not change significantly enough. This is not necessarily because a change is not taking place, but because measurements have a relatively large variation from sample to sample.
We choose to measure the charge of particles in suspension and conductivity, as this is directly related to electro/magnetic properties of the water. For this we used Polarized light microscopy and a microscope to visualize changes in drop morphology.

The water was tested for long term effect (using an aquarium) and short term 10 min and 1 hour treatment. The water samples were taken from DTU lyngby water, the chemical and physical characteristics are attached in appendix.

Lagur Test system for water

The long term water system consisted of a 120 liter Aquarium with a pool pump in line with the Lagur system (1 inch internal diameter tubing). A 1” to 12 mm reduction flange was used to connecting the tubing. All elements were connected with transparent standard plastic tubing. The system was regularly cleaned and kept running with the Lagur system on for at least 2 weeks during long term exposure.

Figure 19: The continuous flow system for testing of EMF on water

Dynamic light scattering and charge of particles in water

Particle charge in water samples is measured using an electrode cell . The electrodes induce a magnetic charge on the particles in solution, this pushes the charged particles towards the electrode, the light scattering will be affected by the movement of the particle. Higher particle charge gives larger scattering of light through the water sample. The measurement only makes sense if there are enough particles in solution to influence the dynamic light scattering.

All measurement were made using an Anton Paar Litesizer 500 at 23 °C and a sample volume of 2 ml. Each sample is measured 100 times and replicated in duplicates.

All water was tap drinking water from the lab at DTU [see appendix 1 for water quality]

The reference water was heated to 50°C for one hour as the Lagur system also heats at 50-60 °C when operational for one hour.

The duplicates showed almost no variation and with very low standard deviation, indicating a stable and valid measurement. Below is seen the total measured particle charge (zeta pot.) and conductivity.

WATER DLS			
	Zeta potential Volt	ZETA st. Dev. Volt	Conductivity mS/cm
Reference water	-0.0189031	0.0013018	1.3925351
10 min Lagur water	-0.0197304	0.0009707	1.4433035
60 min Lagur water	-0.0311319	0.0011826	1.4387479
one month LAGUR w	-0.0251665	0.0013113	1.1161300

Table 3: Zeta potential, standard deviation and conductivity of water samples

Both the particle charge and conductivity are affected by the Lagur EMF treatment.

The 10 min exposure has a very small non-significant increase in zeta potential (0.001 volt) and significantly higher conductivity (0.05 mS/cm).

The 60 min exposed Lagur EMF has a significantly higher particle charge (0.012 volt) and significantly higher conductivity (0.04 mS/cm).

The one month treated also has higher particle charge but significantly lower conductivity (-0.28 mS/cm). Perhaps due to particles and CaCO3 sedimentation in the one month period.

Since the reference water was heated to 50°C for 1 hour , de-gassing due to heating differences can be eliminated. It is therefor concluded that Lagur induces a change in conductivity and on particle charge. This is in accordance with theory regarding EMF effects on particles.

Drop drying effect of Lagur treated water

When water evaporates the ions and soluble compounds in the water drop precipitate forming crystallization rings as the water recede. This effect is dependable of crystallization patterns and a change in particle charge could be seen in this crystallization pattern. This is also known as the coffee ring effect. Thus a great deal of qualitative information could be extracted when looking at dry drops. Even though this method does not say anything about what is causing the change or how much it is changed, this method can be performed in the field by anyone with a USB microscope, some glass slides and a 10 µl pipette.

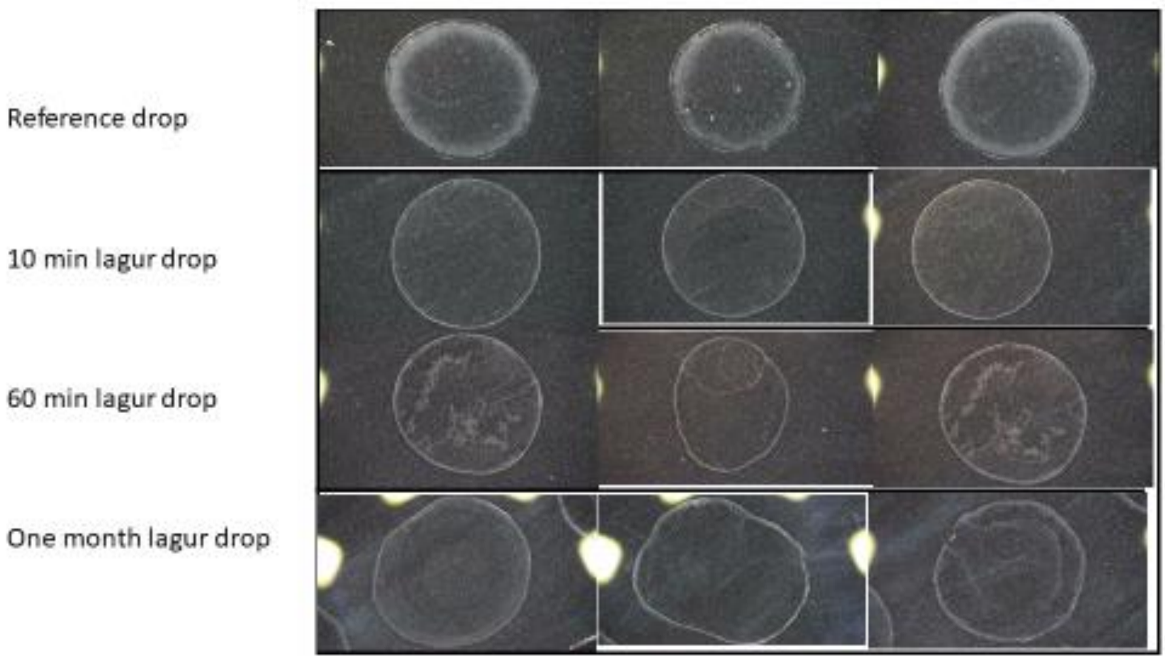

Figure 20: Morphology of dry water droplets from 10 µl water on a polished glass slide, indicating a change in crystallization behavior. Pictures are taken using a USB microscope with 100x magnification.

The morphology of the drops show a repeated effect from EMF during 3 separate rounds of experiments. Since there is a change in crystallization effect this (together with an increase in particle charge) could indicate a long term change in carbonate lime scaling processes.

The drying time of the drops also had some variations, attempts were made on timing the drying of the drop, but this showed no significant difference between treatments.

Conclusion

It is concluded that the Lagur EMF treatment affects:

1. Speeds up degradation processes of MGO.
2. Reduces the viscosity of MGO after a short-term treatment.
3. Increases particle charge in water samples.
4. Increases conductivity slightly in water.

Long term treatment of MGO with Lagur EMF

From the color change, GC data and FT-IR data it is quite clear that a long length treatment (approx. 8 days in a one month period) aggravates the aging of MGO. This could in part be explained by the heating induced by the Lagur EMF combined with a non pressure tight container. But this explanation is unlikely, since the reference container was equally opened several times and stored next to the container in similar conditions at all times.

It is believed that Lagur EMF induces an accelerated degradation process inherent in MGO. Although particle charge was not successfully detected in MGO, it is seen in Lagur EMF exposed water samples. This is expected since a pulsating EMF field induces a force on charged particles, thus probably accelerating chemical interactions between some of the 105 different compounds in MGO. This could explain the tendency to see more higher alkanes (above C16) in the Lagur treated MGO

Short term treatment of MGO with Lagur EMF

The viscosity measurements show a significant drop in dynamic viscosity (0.05mPa/sec.) for 10 min and 60 min Lagur EMF treatment.Equally the kinematic viscosity of MGO drops (0.05mm2/sec.) when treated for 10 min and 60 min with Lagur EMF.

A counter argument could be the heating effect of the Lagur coil while exposure reaches 30 °C after 10 min and approx. 50 °C after 60 min, when no flow is applied. But a lasting effect of a temporary heating process is unlikely, evaporation from the exposed sample was also kept to a minimum by closing the Lagur coil.
Since the viscosity is measured by equal temperature, this can only be interpreted as a lasting effect caused by the Lagur EMF treatment.

Testo 350 measurements

Due to lack of number of experiments the statistical foundation to determine if Lagur EMF treatment had a combustion efficacy effect can not be determined. However the detection method is quite sensitive to change of COx and NOx. More measurements will be taken in the near future.

Water particle charge change

The Lagur EMF treatment increases particle charge in water, and increases conductivity slightly. Probably due to the particle charge conductivity increase alone. The 10 min exposure has a and significantly higher conductivity (0.05 mS/cm). and the 60 min exposed Lagur EMF has a significantly higher particle charge (0.012 volt) and significantly higher conductivity (0.04 mS/cm). This indicates a proven effect of the Lagur EMF treatment on calcium scaling processes, whether this leads to significant reduced scaling cannot be concluded and should be addressed in a separate project.

Discussion and Further ideas

Here follows a series of ideas for further analysis of Lagur EMF effects on MGO and water

More testo 350 gas exhaust experiments

Due to time constraints not enough gas exhaust measurements were made. It is suggested to do a separate longer sample testing period with the Testo 350 as its sensitivity to change of COx and NOx and was impressive.

As stated in the theory section it was hypothesized that a change in dispersion efficiency should improve combustion. However, ship engines cylinders are already optimized for a specific compression and MGO combustion speed, so changing the rate of burn does not necessarily transfer to more power, unless the engine is not optimized.

On this note it was found that the Testo 350 also showed clear differences between engine 3 and 4, perhaps this could be used in general to determine and optimize combustion efficacy of each engine.

SEM of dry water samples

To obtain information about the crystallization process in detail, it is beneficial to use a scanning electron microscope

Near infrared spectroscopy of water samples

Water samples were tested using a standard infrared spectroscopy (FT-IR) but showed no significant change. The chemical engineering institute has newly acquired a Near infrared (NIR) instrument, that is able to measure visual to infrared absorbance of water solutions. The Infrared absorbance area is the region where the first order molecular motions of water arise. The near infrared area between visual and infrared light vibrations induce second order harmonics motions of water, this can be used to gain information about more subtle interactions of the water molecule and its contents. It is believed that since the particle charge is changed by the Lagur EMF , the second order harmonics of water could also be influenced.

Stationary engine and Calorimetry experiment

Before making a large scale stationary engine combustion test, it is advised to conduct small scale calorimetry test to aquire information about combustion profile of the 105 different compounds in MGO.

Gas Chromatography alternative use

Since the compounds are compared to an C4 to C40 carbon atoms alkane internal standard retention time , It could be argued that the 105 different retention times compounds is a good statistical information pool to gather information about more subtle charge and structural differences. The GC ability to align the retention times could indicate more subtle differences between the 105 compounds. This would require a large number of repeated experiments to avoid noise and sample to sample variation, probably 30 repeated sample measurements of each sample group.

Alternative placement of the Lagur system on M/F Samsø

It is estimated that the Lagur system on the Samsø ferry is exposing the MGO only for a few seconds (max 10 pulses EMF). To increase exposure time the Lagur system should be placed in line with the 20 liter MGO pre-mixer tank in direct contact with the engine, this ensures a longer treatment time as the pre-mixer tank is in constant flow, as unused MGO from the engine is returned to the tank.

Ion specific EMF irradiation

The current Lagur system has a fixed set of frequencies, that although sweeping in an up-frequency range is not tunable to different scenarios.

Ions and particles in solution are regarded as having a distinct eigen frequency, this eigen frequency depends on many factors such as hydration, charge, pH, temperature.

In a plasma field each ion has an ion cyclotron resonance [x] and can be attracted or repulsed by a EMF, this is a technique used in chemical vapor deposition in the semiconductor industry. It is still debated if ions in a water solution also has an equal resonance point due to water hydration damping the ion.

Nonetheless, it would be of general scientific interest if a tunable system could influence only certain ions or particles in solution. i.e. enhancing a chemical reaction between selected ions or to precipitate/aggregate particles in solution.

As a proof of concept a simple EMF system was assembled. The system consists of a signal generator, a 120 watt amplifier (HiFi Class D), a large copper coil (1 meter length, 30 cm internal diameter, 15 windings), and an oscilloscope to measure induced frequency. The testing of such a device is beyond the scope of this project but will be investigated further in the future. Below is seen the simple setup.

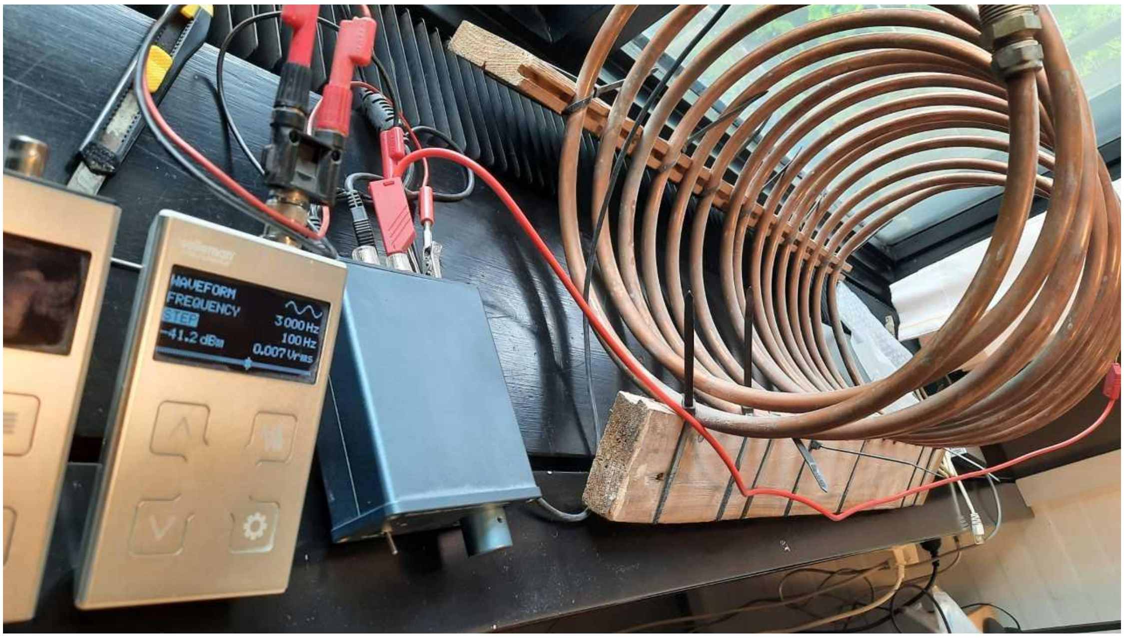

Figure 21.: A variable frequency EMF generator, consisting of a 120 watt amplifier, a pocket wave form generator, a large copper coil with 15 windings.

Ideally a fed-back mechanism could be constructed, where a direct measurement on the ions in solution could be coupled to a frequency generator stepper using an Arduino or Rasperry Pie controller. The controller would alter the EMF frequency until a signal is obtained from the ions in solution. Here an ion selective electrode could be used, alternatively the charge of particles/ions could be monitored using Dynamic light scattering, or using a spectroscopic method like Near infrared spectroscopy.

Pilot Micro-wave irradiation experiments on alkane- molecules.

In the EM radiation experiments we take as our starting point our calculated frequencies. They show many absorption-peaks where some represent collective modes at around 1800 cm-1 and which correspond to a frequency of around: 9-10 GHz. This is then a possible frequency value for adjusting or choosing the range of our investigation with a Voltage generator apparatus. A first pilot experiment could be of employing microwaves from a magnetron with a fixed frequency of 2.24 GHz and then observe the effect coming out of that irradiation by employing spectroscopy measurements.

Before applying the Electromagnetic field the experiments have been about measuring physical properties such as viscosity, density and conductivity of the MGO under investigation. Firstly, the experimental efforts have been about getting an overall FTIR Absorption spectrum of the MGO. This is shown in figure 1 that exhibits a wealth of spectral peaks for all the chemical components of ordinary commercial MGO.

In order to analyze fuel consumption we have made experiments employing 3 types of apparatus being the FTIR, the viscosiometry machineand the dynamics light scattering machine. In the following tables the results of these experiments are presented. Basically the results show that applying electromagnetic fields to MGO- s will decrease the level of viscosity. The same applies to the density.

We have previously made experiments on defibrillation of organic chain molecules, especially with respect to proteins. These aggregate at elevated temperature and concentration. When applying electromagnetic, EM,-radiation the samples were demonstrated to be defibrillated in spite of an increased temperature caused by the irradiation. Especially in the microwave region around 1 GHz, the effect of EM-radiation in defibrillation of protein sample was observed, [2]

The frequency of the applied electromagnetic radiation depends of course on the size and the quantum (electronic) structure of the particularly molecules and the collective modes. As we found out in the theoretical section above the eigen-frequency for the collective twist-modes (wringons) on alkane molecules of particularly C-18 molecules is around 10 GHz. For proteins it is around 5 GHz.

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A personal thanks to Daniel Løgstrup Nielsen from MAN Energy solutions for countless discussions around fundamental understanding of ship diesel engines.

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Appendix

1.GEUS Water analysis of DTU Lyngby water

Here are data about water sample quality copied from the danish GEUS database the 28. feb. 2015 Lyngby Vandværk:

Magnesium, Mg	Mg/l	18	Hydrogencarbonate, HCO3-	Mg/l	325
Calcium, Ca++	Mg/l	107	Chlorid, Cl-	Mg/l	93
Natrium, Na+	Mg/l	43	Sulfat, SO4--	Mg/l	45
NVOC	Mg/l	2,5	Dry residue	Mg/l	527
O2 - dissolved	Mg/l	8,7	Conductivity	mS/m	88
pH		7,8	Lime scale hardness	OdH	19

Total Lime scale hardness 19 OdH is a collective of temporary hardness= 14 OdH (alkalinity hardness) and lasting hardness = 5 OdH
In the dry residue is CaCO3 47,5 % of the 527 mg/l. residue

CO2/CaCO3 equilibrium

temperature	OC	15	20	25
CO2	Mg/l	8,5	8,5	8,5
CO2,eq (ligevægtkonc)	Mg/l	33	40	48
pH (målt)		7,8	7,8	7,8
pHS (ligevægts-pH)		7,21	7,13	7,05
Precipitation level of CaCO3	Mg/l	32	38	44

Here follows data of Milli-q water:

Millipore Milli-Q® Integral ultrapure water (Type 1)
Resistivity at 25 °C1 18.2 MΩ•cm
TOC2 ≤ 5 ppb
Particulates (size > 0.22 µm)3 < 1 particulate/mL
Bacteria3,4 < 0.01 CFU/mL
Pyrogens (endotoxins)4 < 0.001 EU/mL
RNases4 < 1 pg/mL
DNases4 < 5 pg/mL
Flow Rate Up to 2 L/min

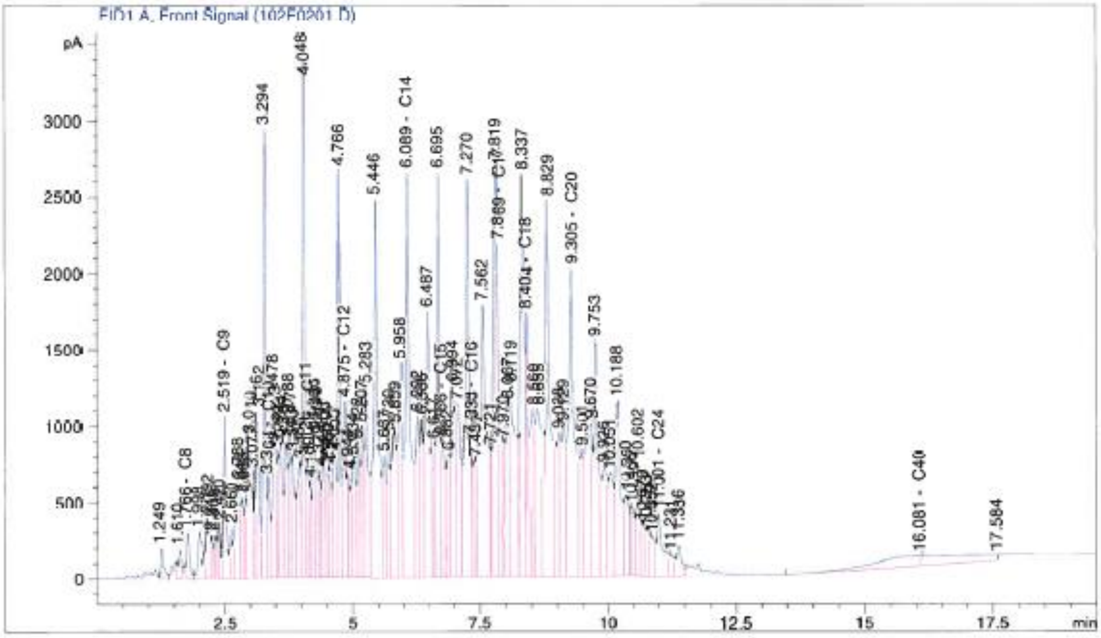
2. Gas Chromatography raw data

Reference MGO sample

Data File C:\CHEM32\1\DATA\AUGUST 2020\MB DIESEL 12082020 2020-08-12 10-26-30\102F0201.D
Sample Name: D2untreated

===

Acq. Operator : Michael B. Seq. Line : 2
Acq. Instrument : Instrument 1 Location : Vial 102
Injection Date : 8/12/2020 11:33:13 AM Inj : 1
Inj Volume : 0.05 µl
Sequence File : C:\Chem32\1\DATA\August 2020\MB DIESEL 12082020 2020-08-12 10-26-30\MB DIESEL 12082020.S
Method : C:\CHEM32\1\DATA\AUGUST 2020\MB DIESEL 12082020 2020-08-12 10-26-30\D2887_19062019.M (Sequence Method)
Last changed : 6/21/2019 7:46:40 AM by Vu
Method Info : Inject 0.05 uL using 0.5uL Syringe



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Area Percent Report

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Sorted By : Signal
Calib. Data Modified : 11/21/2013 9:04:56 AM
Multiplier: : 1.0000
Dilution: : 1.0000
Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Area %	Name
1	0.398		0.0000	0.00000	0.00000	
2	0.437		0.0000	0.00000	0.00000	C5
3	0.581		0.0000	0.00000	0.00000	
4	0.635		0.0000	0.00000	0.00000	
5	0.689		0.0000	0.00000	0.00000	C6
6	1.078		0.0000	0.00000	0.00000	
7	1.144		0.0000	0.00000	0.00000	C7

Instrument 1 8/12/2020 11:52:50 AM Michael B. Page 1 of 3

Sample Name: D2untreated

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Area %	Name
68	7.437	VV	0.0367	2219.46558	0.46238	?
69	7.562	VV	0.1236	1.70572e4	3.55353	?
70	7.721	VV	0.0223	1322.58765	0.27553	?
71	7.819	VV	0.0588	1.13005e4	2.35424	?
72	7.869	VV	0.0581	8999.83691	1.87494	C17
73	7.970	VV	0.0287	1891.58057	0.39407	?
74	8.067	VV	0.0710	6076.81836	1.26598	
75	8.119	VV	0.1157	1.11094e4	2.31442	?
76	8.337	VV	0.0607	1.14530e4	2.38600	
77	8.404	VV	0.0660	8137.99658	1.69539	C18
78	8.560	VV	0.0880	7449.86621	1.55203	?
79	8.655	VV	0.0963	8514.45215	1.77382	
80	8.829	VV	0.0977	1.79004e4	3.72919	?
81	9.038	VV	0.0710	5431.51611	1.13155	?
82	9.129	VV	0.0943	7456.55225	1.55343	
83	9.305	VV	0.1034	1.58362e4	3.29915	C20
84	9.501	VV	0.0754	4527.39746	0.94319	?
85	9.670	VV	0.1030	8183.36572	1.70484	?
86	9.753	VV	0.0853	9711.87500	2.02328	?
87	9.926	VV	0.0879	5210.56738	1.08552	?
88	10.051	VV	0.0880	4775.84570	0.99495	?
89	10.188	VV	0.0865	7474.13574	1.55709	
90	10.360	VV	0.0779	3377.46240	0.70363	?
91	10.466	VV	0.0656	2282.30225	0.47547	?
92	10.602	VV	0.0756	3930.22803	0.81879	?
93	10.679	VV	0.0521	1418.82263	0.29558	?
94	10.753	VV	0.0682	1687.41040	0.35154	?
95	10.852	VV	0.0691	1411.74304	0.29411	?
96	11.001	VV	0.1117	3508.66284	0.73096	C24
97	11.231	VV	0.0709	755.11969	0.15731	?
98	11.386	VV	0.0900	1339.98779	0.27916	?
99	12.525		0.0000	0.00000	0.00000	C28
100	13.799		0.0000	0.00000	0.00000	C32
101	14.383		0.0000	0.00000	0.00000	
102	14.933		0.0000	0.00000	0.00000	C36
103	16.081	VV	0.7872	4258.61523	0.88720	C40
104	17.584	VV	1.3653	4537.86914	0.94538	?

Totals : 4.80007e5

2 Warnings or Errors :

Warning : Calibration warnings (see calibration table listing)
Warning : Calibrated compound(s) not found

==

*** End of Report ***

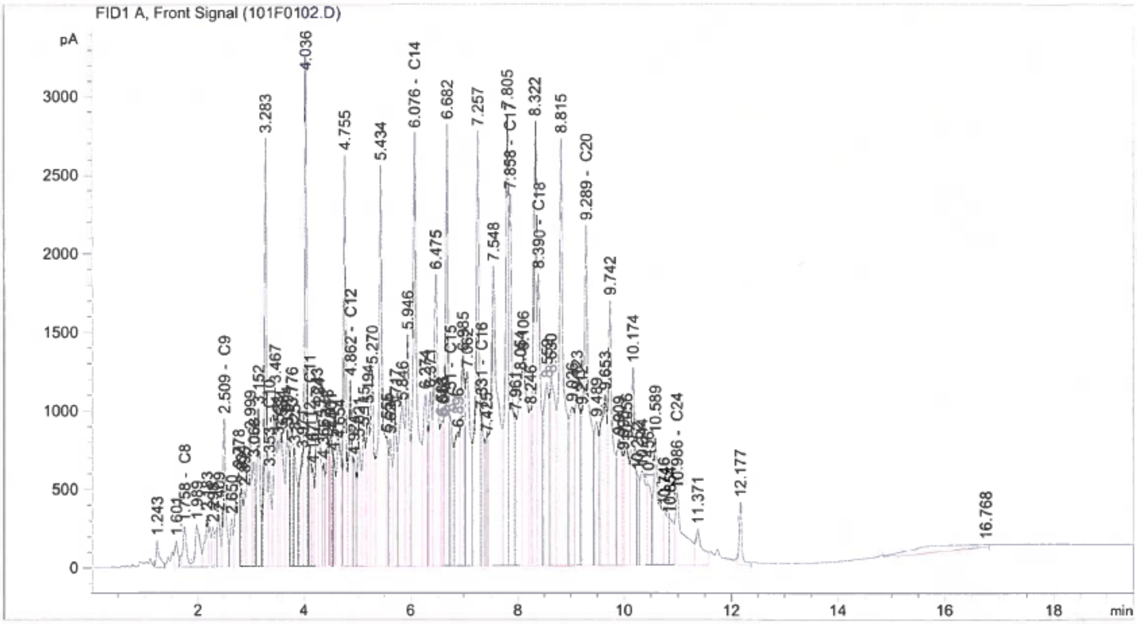
Instrument 1 8/12/2020 11:52:50 AM Michael B. Page 3 of 3

One month treted Lagur EMF MGO

```
Data File C:\CHEM32\1\DATA\APRIL 2021\MB DIESEL 210421 2021-04-22 14-24-06\101F0102.D
Sample Name: lagur treated

=====================================================================
Acq. Operator   : Michael B.                    Seq. Line :   1
Acq. Instrument : Instrument 1                   Location : Vial 101
Injection Date  : 4/22/2021 2:58:28 PM                Inj :   2
                                              Inj Volume : 0.05 µl
Sequence File   : C:\Chem32\1\DATA\April 2021\MB DIESEL 210421 2021-04-22 14-24-06\MB DIESEL
                  210421.S
Method          : C:\CHEM32\1\DATA\APRIL 2021\MB DIESEL 210421 2021-04-22 14-24-06\D2887_
                  19062019.M (Sequence Method)
Last changed    : 6/21/2019 7:46:40 AM by Vu
Method Info     : Inject 0.05 uL using 0.5uL Syringe
```

lagur




```
=====================================================================
                        Area Percent Report
=====================================================================

Sorted By              :      Signal
Calib. Data Modified   :      11/21/2013 9:04:56 AM
Multiplier:                   :      1.0000
Dilution:                     :      1.0000
Use Multiplier & Dilution Factor with ISTDs


Signal 1: FID1 A, Front Signal
```

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Area %	Name
1	0.398		0.0000	0.00000	0.00000	
2	0.437		0.0000	0.00000	0.00000	C5
3	0.581		0.0000	0.00000	0.00000	
4	0.635		0.0000	0.00000	0.00000	
5	0.689		0.0000	0.00000	0.00000	C6
6	1.078		0.0000	0.00000	0.00000	
7	1.144		0.0000	0.00000	0.00000	C7
8	1.243	VV	0.0594	718.92188	0.14521	
9	1.483		0.0000	0.00000	0.00000	
10	1.601	VV	0.0596	711.46222	0.14370	

Data File C:\CHEM32\1\DATA\APRIL 2021\MB DIESEL 210421 2021-04-22 14-24-06\101F0102.D
Sample Name: lagur treated

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Area %	Name
76	8.246	VV	0.0412	3008.95874	0.60776	
77	8.322	VV	0.0592	1.14550e4	2.31373	?
78	8.390	VV	0.0681	9091.73047	1.83639	C18
79	8.552	VV	0.0839	7965.50684	1.60891	?
80	8.630	VV	0.0930	8720.27832	1.76136	
81	8.815	VV	0.0943	1.89690e4	3.83145	?
82	9.026	VV	0.0767	6224.24805	1.25720	?
83	9.123	VV	0.0867	7718.52197	1.55902	?
84	9.212	VV	0.0239	1772.43005	0.35800	
85	9.289	VV	0.0966	1.59079e4	3.21315	C20
86	9.489	VV	0.0730	5184.78174	1.04725	?
87	9.653	VV	0.1062	8850.80176	1.78772	?
88	9.742	VV	0.0871	1.05767e4	2.13632	?
89	9.909	VV	0.0830	5271.22754	1.06471	?
90	9.995	VV	0.0230	1143.07898	0.23088	?
91	10.056	VV	0.0783	4499.07422	0.90874	?
92	10.174	VV	0.0747	6657.61279	1.34473	?
93	10.252	VV	0.0408	1812.94055	0.36619	
94	10.344	VV	0.0917	4340.66064	0.87675	?
95	10.456	VV	0.0725	2795.56519	0.56466	?
96	10.589	VV	0.1031	6105.65967	1.23325	?
97	10.746	VV	0.0721	2006.90747	0.40536	?
98	10.854	VV	0.0873	1550.93713	0.31327	?
99	10.986	VV	0.1411	5067.93359	1.02364	C24
100	11.371	VV	0.1111	1915.15967	0.38683	?
101	12.177	VV	0.0568	1496.63110	0.30230	?
102	12.525		0.0000	0.00000	0.00000	C28
103	13.799		0.0000	0.00000	0.00000	C32
104	14.383		0.0000	0.00000	0.00000	
105	14.933		0.0000	0.00000	0.00000	C36
106	16.010		0.0000	0.00000	0.00000	C40
107	16.768	VV	2.7220	3196.75562	0.64569	?

Totals : 4.95088e5

2 Warnings or Errors :

Warning : Calibration warnings (see calibration table listing)
Warning : Calibrated compound(s) not found

===

*** End of Report ***

3. Zeta potential raw data MGO

Standard report

Created by: labuser
Created at: 02-06-2021 15:50:47

Anton Paar

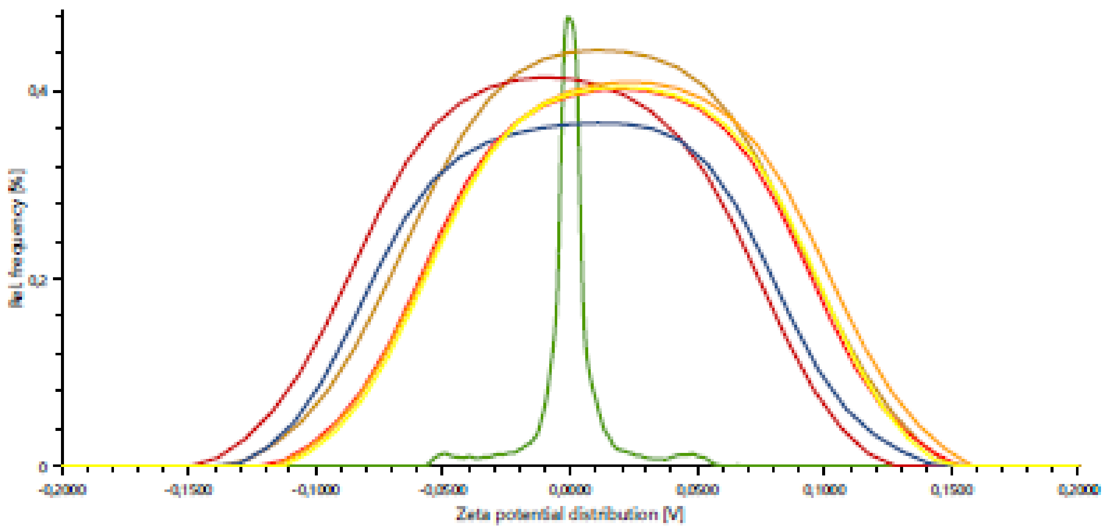
Statistics

Name	Mean zeta potential	Distribution peak	Conductivity	Electrophoretic Mobility
Mean value	0,0005 V	0,0103 V	0,000 mS/cm	0,0009 µm*cm/Vs
Standard deviation	0,0043 V	0,0121 V	0,000 mS/cm	0,0117 µm*cm/Vs
Rel. standard deviation	823,66 %	117,33 %	1,67 %	1253,02 %

Measurements

Name	Temperature [° C]	Processed runs	Mean zeta potential [V]	Distribution peak [V]	Conductivity [mS/cm]	Electrophoretic Mobility [µm*cm/Vs]
diesel mgo ref 1	23,0	100	-0,0001	-0,0005	0,000	-0,0035
mgo diesel ref 2	23,0	100	-0,0011	0,0106	0,000	-0,0030
10 min lagur mgo zeta 1	23,0	100	-0,0047	-0,0107	0,000	-0,0127
lagur 10 min mgo zeta 2	23,0	100	-0,0020	0,0109	0,000	-0,0055
one hour lagur mgo zeta 1	23,0	100	0,0018	0,0204	0,000	0,0048
one hour lagur mgo zeta 2	23,0	100	0,0090	0,0211	0,000	0,0244
1 month lagur mgo	23,0	100	0,0008	0,0205	0,000	0,0021

Zeta potential distribution



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4. Zeta potential raw data water

Standard report

Created by: labuser
Created at: 02-06-2021 15:38:45

Anton Paar

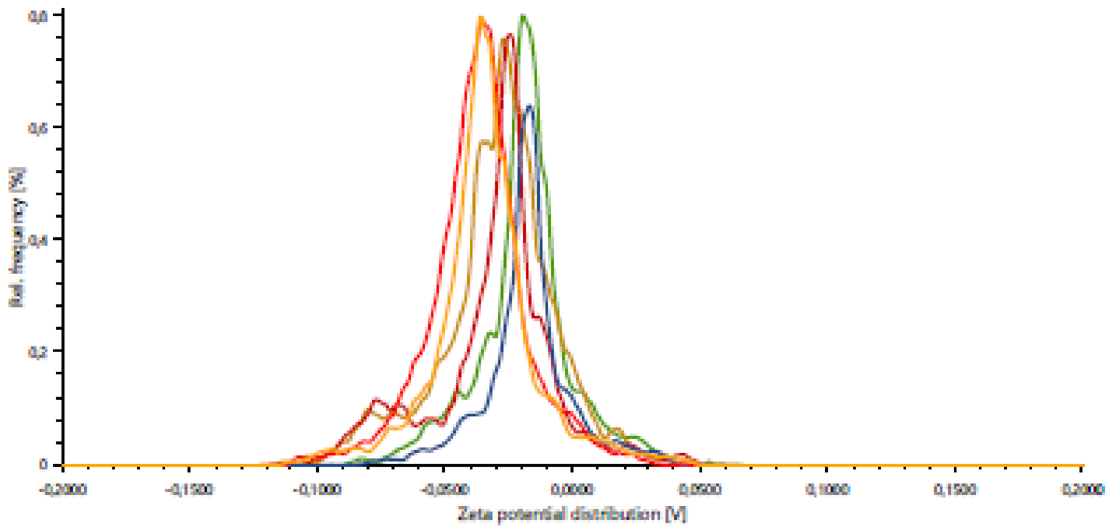
Statistics

Name	Mean zeta potential	Distribution peak	Conductivity	Electrophoretic Mobility
Mean value	-0,0251 V	-0,0264 V	1,319 mS/cm	-1,3804 µm*cm/Vs
Standard deviation	0,0054 V	0,0079 V	0,169 mS/cm	0,2964 µm*cm/Vs
Rel. standard deviation	21,47 %	29,95 %	12,82 %	21,47 %

Measurements

Name	Temperature [°C]	Processed runs	Mean zeta potential [V]	Distribution peak [V]	Conductivity [mS/cm]	Electrophoretic Mobility [µm*cm/Vs]
reference tap water	23,0	100	-0,0189	-0,0192	1,393	-1,0410
Aquarium one month lagur water	23,0	100	-0,0252	-0,0268	1,116	-1,3860
one day lagur water	23,0	100	-0,0240	-0,0249	1,088	-1,3234
10 min lagur tap water	23,0	100	-0,0197	-0,0167	1,443	-1,0866
60 min lagur tap water	23,0	100	-0,0311	-0,0352	1,439	-1,7145
60 min lagur tap water 2	23,0	100	-0,0314	-0,0357	1,435	-1,7308

Zeta potential distribution



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5. Calculated absorbance of alkanes

Below is seen an example of vibrational spectrum calculated using the Spartan Molecular dynamics program, the shown example is a linear C24 molecule.