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Author: Rakeem Ahmed Hatinoor	**…………………………………………** **(Writer's signature)**

Faculty supervisor: Prof. Aly Hamouda
External supervisor: Ebbe G. Nyfors

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Abstract

Roxar watercut meter is based on Microwave resonance technology. This meter has high accuracy when there is a good mixture of oil and water. This technology uses the unique resonance frequency of a fluid to determine the watercut. The first meter was delivered in 1996. In this thesis the main focus is to investigate the effect gas has on the resonance frequency, and to verify software function created to indicate the GVF in mixture.

Nomenclature

Parameter	**Description**
α	Resonance cavity thermal expansion factor [1/K]
β	Water cut [%]
$\beta_{Correction}$	Water cut correction that is added to the calculated water cut [%]. The value may be input by user or calculated from inline calibration.
β_{KF}	Reference water cut from Karl Fischer analysis [%]
$\beta_{centrifuge}$	Reference water cut from centrifuge method [%]
$\beta_{reference}$	Reference % water when sample taken button was pressed or sample taken register set [%]
$\beta_{ST,Volume}$	The percent of water by volume at stock tank conditions [%]
$\beta_{ST,Weight}$	The percent of water by weight at stock tank conditions [%]
b_0	Offset of linear expression for water cut correction
b_1	Slope of linear expression for water cut correction
clf	Capacitive loss factor at resonance frequency
dcw	Dielectric constant of water at process temperature given conductivity $\sigma_{w,20C}$
$dcfw$	Dielectric constant of fresh water at process temperature
df	Dissipation factor of water
dlf	Dielectric loss factor at resonance frequency
ε_{mix}	Relative permittivity of mixture [F/m]
ε_{oil}	Relative permittivity of oil [?]
$\varepsilon_{oil,std}$	Relative permittivity of oil at standard conditions [?]
ε_{water}	Relative permittivity of water [?]
f_{vac15}	Vacuum resonance frequency at 15 °C [Hz]
f_{mix}	Mixture resonance frequency [Hz]
lf	Total loss factor

$P_{process}$	Process pressure [bara]
$P_{oil,org}$	Pressure at which the dry oil density is specified [bara]
Q_v	Total flow rate by volume [m^3/h]
ρ_{mix}	Mixture density [kg/m^3] ? [g/cm^3]
$\rho_{mix,TP}$	Mixture density of the sample used for calibration [g/cm^3]
$\rho_{oil,ST}$	Dry oil density at stock tank conditions [g/cm^3]
ρ_{oil}	Oil density at process conditions [g/cm^3]
$\rho_{oil,org}$	Dry oil density at $P_{oil,org}$ and $T_{oil,org}$ [kg/m^3] ? [g/cm^3]
$\rho_{oil,std}$	Oil density at standard conditions [g/cm^3]
ρ_{water}	Water density at process conditions [kg/m^3] ? [g/cm^3]
$\rho_{water,15C}$	Water density at temperature of 15 °C [kg/m^3] ? [g/cm^3]
$\rho_{water,TP}$	Water density at temperature T and pressure P [g/cm^3]
$T_{process}$	Process temperature [°C]
σ_{water}	Water conductivity at meter conditions [S/m]
$\sigma_{water,cal}$	Water conductivity at temperature $T_{water,cal}$ [S/m]
$\sigma_{water,20C}$	Water conductivity at temperature of 20 C [S/m]
SC	Sediment content [%]
SF_{oil}	Dry oil shrinkage factor
$\tau_{freshwater}$	Time constant of fresh water at process temperature
τ_{water}	Time constant of water at process temperature given conductivity $\sigma_{water,20C}$
$T_{centrifuge}$	Temperature at which $\beta_{centrifuge}$ is specified [°C]
$T_{mix,TP}$	Temperature at which $\rho_{mix,TP}$ is specified [°C]
$T_{oil,org}$	Temperature at which the dry oil density is specified [°C]
$T_{water,cal}$	Temperature at which the water conductivity is specified [°C]
W_{salt}	Weight percentage of salt [%]

List of Figures

1 Introduction

Measuring watercut is very important to the oil industry. Watercut is the fraction of the liquid phase that consists of water. Each cubic meter of water produced from a well only contributes negatively to the process equipment and to the environment. It is therefore crucial to have an optimized process to separate the water from the oil and have measurements to guarantee the quality. A watercut meter placed in the process gives valuable information and different technologies are used to measure watercut across a full range of applications.

In this thesis I have decided to investigate the Roxar watercut meter, which is based on microwave resonance frequency technology. The meter is made for measuring water in oil, so the liquid has to be oil continuously. In some occasions the watercut meter is subjected to a mixture of oil, water and gas. The purpose of this thesis is to:

1. Study what happens with Roxar watercut meter when gas is part of the mixture, and verify the non qualified gas software function in Roxar watercut meter.
2. If necessary and possible develop an improved gas detection function in the Roxar watercut meter.
3. Perform a flow loop test.
4. Investigate the result from the flow loop test and draw conclusion.

2 Theory

2.1 Different Watercut Measurement Technology

Different measurement technologies are used for measuring watercut. As previously mentioned, measuring watercut is very important to the oil industry. For example every cubic meter of water sold along with the oil could carry a price tag for the seller. Process optimization is therefore crucial, and a watercut meter placed in the process allows valuable information to be retrieved. This valuable information can be used to (Hennessy & Vikingstad):

- Improve separator performance
- Better chemical injection
- Help preventing scale, hydrate and corrosions
- And fiscal metering

There are a lot of different measurement technologies out in the marked for these purposes. Among the criteria for selecting which technology to use includes accuracy, sensing range and process characteristics ("Patents alert," 1997).

2.1.1 Capacitance WaterCut Measurement

Capacitance Technology has been used by the oil industry to measure watercut for almost 50 years. The technology exploits the significant difference in dielectric properties between oil (~ 2) and water (~75). ("Patents alert," 1997). The net capacitance of the 2-phase media is measured by transmitting a radio frequency voltage across the sensing elements. The net capacitance is directly related to the watercut. Good correlation can be reached provided that the dry oil capacitance as well as the water, capacitance is known. Capacitance goes up with increasing water cut and down with decreasing watercut.

The capacitive instruments have the key advantage of being a stable measurement technology. Simple design, insensitivity to water conductivity and ability to handle a majority of oil patch applications are other key features. It is a common misconception that capacitive instruments are limited to the lower segment of the non-linear capacitance vs.

watercut response curve. Recent developments have brought forward capacitance instruments able to measure up to inversion under unfavorable conditions and all the way to 100 % watercut under favorable water conditions.

Typical capacitance instruments utilize multipoint calibration curve to tie capacitance reading to tie water content. Some new developments have even made it possible to do away with strapping tables and rely solely on calculating the relationship, thereby being able to more accurately compensate for the dissimilar effects of temperature on the two media.

Capacitive instruments are among the lowest cost options relative to other measurement technologies, this while often performing very well in most common applications. Traditional disadvantage of capacitive instruments are their difficulty in handling changing process factors and their limitations in measurement range.

2.1.2 Spectroscopy WaterCut Measurement

Spectroscopic measurement is performed by emitting a infrared across a narrow slot.

The signal receptors thus measures, the absorption, reflection and scatter of the infrared beam and derives the watercut from the result(Basrawi, 1999).

Spectroscopic measurement has several advantages when used for watercut measurement. Firstly it has the ability to measure across the full range of watercut. Contrary to Capacitive devices the percentage error actually decreases as the watercut increases. The technology's accuracy at the high end of the watercut range separates it from other competitive technologies. The second large advantage, only available with this technology, is that it is unaffected by changes in density, salinity and entrained gas.

The main disadvantages of spectroscopy-based watercut products are that they lose resolution and accuracy at the lower cut ranges.. This limits their usefulness in mainstream low range applications. Spectroscopy-based measurements do not perform well for sites that have cut ranges of 0 – 5% water, for example LACT applications. Also, the fact that these devices are fitted with very narrow (few mm) slots where the infrared light is transmitted. It can always be questioned if these slots see a representative of the total flow, especially for thick oil applications. Additionally the measurement section becomes very prone to clogging by wax or debris. Wear and scratch will occur on the lenses if the oil contains sand or other abrasive particles, creating an endless loop of sensor eye replacements.

2.1.3 Density Watercut Measurement

Density is the only measurement method that uses a mechanical solution to measure watercut. A multitude of methods has been utilized such as differential pressure, densitometers and carioles meters. Good measurement can only be achieved by having a good knowledge of the dry oil density over the possible process temperature range. Density changes in the line will lead to major errors unless compensated for.

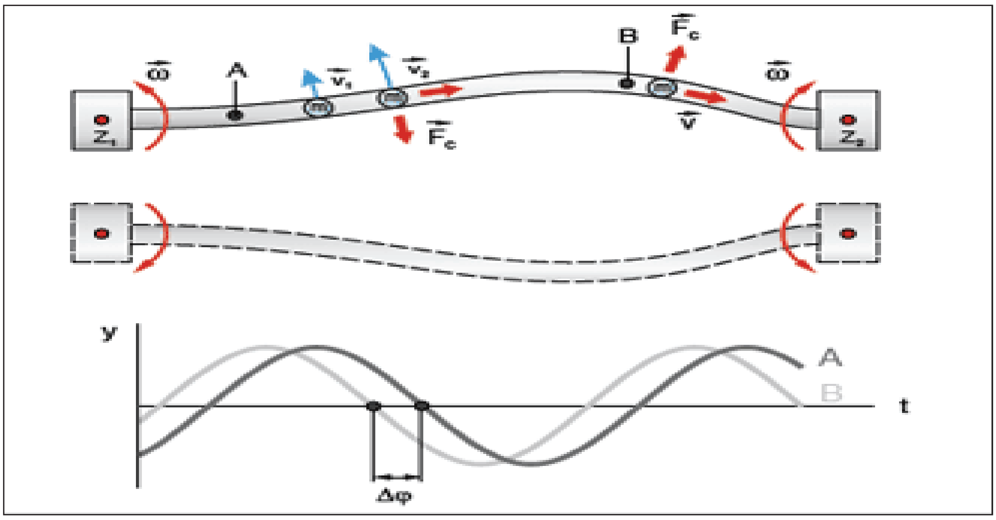


Figure 1 - Principle of Coriolis meter.

The advantages of this technology are its cost-effectiveness and its ability to provide additional information, such as possibly flow rate, temperature and density that can be used as input for process optimization like the “AutoGas” function on the Roxar watercut meter that will be tested during this thesis.

The disadvantage with using density measurement for watercut occurs when process variables start to change. Also, the use of density to measure watercut is typically confined to light oils due to the limited and sometimes non-existent difference in density between water and heavy oil. The method is of little use near to wells due to the uncertainty of actual API density of the oil coming out of the well. It can only be well used further downstream when parameters such as dry oil density is stable and well known.

2.1.4 Microwave Absorption Watercut Measurement

This technology is quite similar to Infrared absorption, but instead microwave absorption is used. The watercut is determined by the difference in the amount of energy sent compared to amount of received. Unlike infrared light that is used by Weatherford [Red eye Watercut Meter] Microwave are absorbed by water. This means that a higher watercut the more attenuated the signal will become(Hennessy & Vikingstad, 2007).

2.1.5 Microwave Resonance Watercut Measurement

Roxar watercut meter is based on Microwave (MW) resonance technology. This meter has high accuracy when there is a good mixture of oil and water. This technology uses the unique resonance frequency of a fluid to determine the watercut. The Roxar watercut meter uses patented microwave technology to measure the permittivity of fluid inside the Meter. This enables the meter to calculate the volume percent of water given the measured permittivity of the liquid (Oil and water). Meter needs several inputs in order to calculate the permittivity of water and oil, which are:

- Temperature
- Water (Conductivity or Density)
- Dry oil density

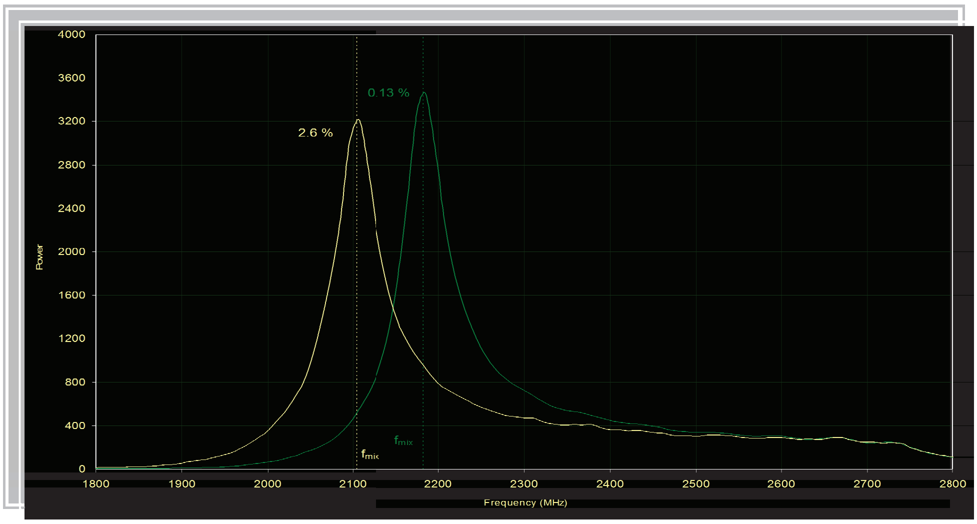


Figure 2 - MW resonance at different WC%, this picture is taken from Roxar manual

The two microwave antennas are mounted on the sensor were one transmits a range of microwave frequency (Transmitter) while the other measures the power (Receiver). Each sensor has a Microwave span design to fit the frequency of the spool piece is sent out of the transmitter, high and low frequency. The power from each frequency sent to the resonance cavity is measured on the receiver antenna and resonance frequency f_{mix} is determined. The f_{mix} is used to calculate the mix permittivity, which is used together with temperature to calculate watercut meter.

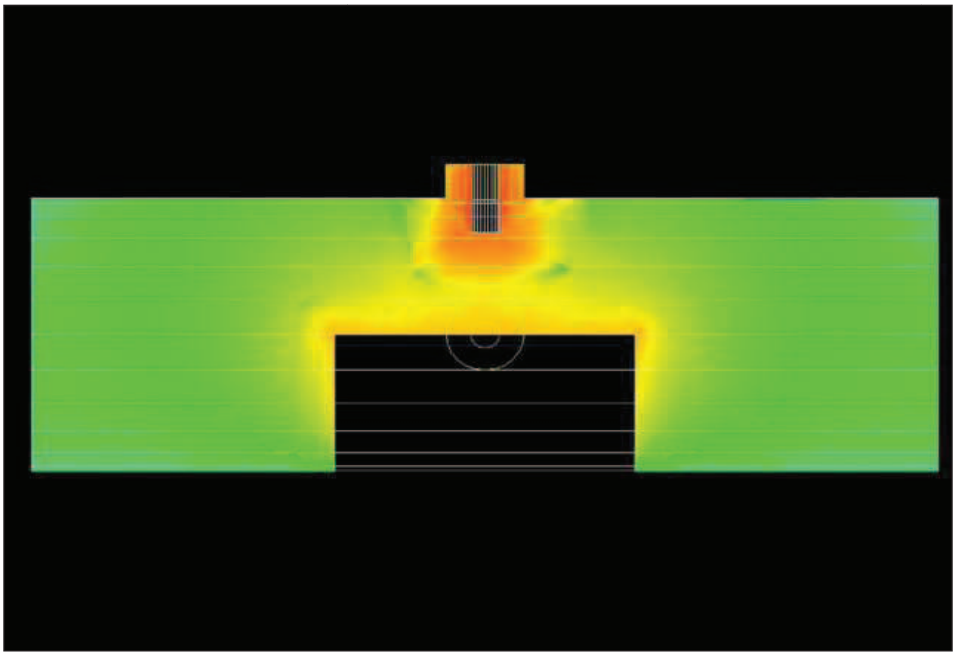


Figure 3 - MW Resonance frequency, this picture is taken from Roxar Watercut Manual.

The advantages of this technology is that it is temperature compensated, it can be Installed in line and in direct contact with the process fluid, it requires minimum maintenance and gives real time continuous water contents in the crude line by measuring dielectric.

Constants, it is designed for minimum pressure drop and is easily field calibrated for different process fluids. It comes in a high accuracy simple configuration only dry oil density; pressure and water conductivity or water density is required. The Meter can also be delivered with specified options for communication protocol, advanced calibrations and measurement functions, like the AutoZero, which is a software function that corrects the changing density of oil (Hennessy & Vikingstad, 2007).

The AutoZero function is an optional feature of the Roxar Watercut meter. It depends on flow density input rather than the calibration constant for oil density to calculate watercut. This allows the meter to measure accurately in change of oil density. It depends on data from life mix density meter and the microwave readings.

The disadvantage of this technology is that in order to achieve high accuracy some requirements on the flow must be met. The following requirements are:

- Flow velocity not lest then 1m/s
- Well mix flow.
- The water droplets should be no larger than 1/10th the diameter of the pipe.

As stated previously the Meter has many measurement functions that can justified its high cost. Meter comes in a large variety of sizes, ranging from 2 inches to 24 inches.

2.2 Flow Regimes

Flow regimes vary depending on operating conditions, fluid properties, flow rates and the orientation and geometry of the pipe through which the fluids flow. The transition between different flow regimes may be a gradual process. The following map in ***Figure 4*** shows a qualitative illustration of how flow regime transitions are dependent on superficial gas and liquid velocities in multiphase flow. ((Corneliussen, Mars 2.2005))

The flow regime in the Roxar watercut meter should be oil continuous, as droplet of water in oil. One of the Roxar watercut meter requirements is that flow should be mix flow and the water droplet should not be larger than 1/10th of the pipe diameter and with a flow rate not less than 1m/s. Roxar recommend that the meter should be installed vertically.
The most suitable flow regime for the Roxar watercut meter is annular flow as seen in (*Figure 6*. v).

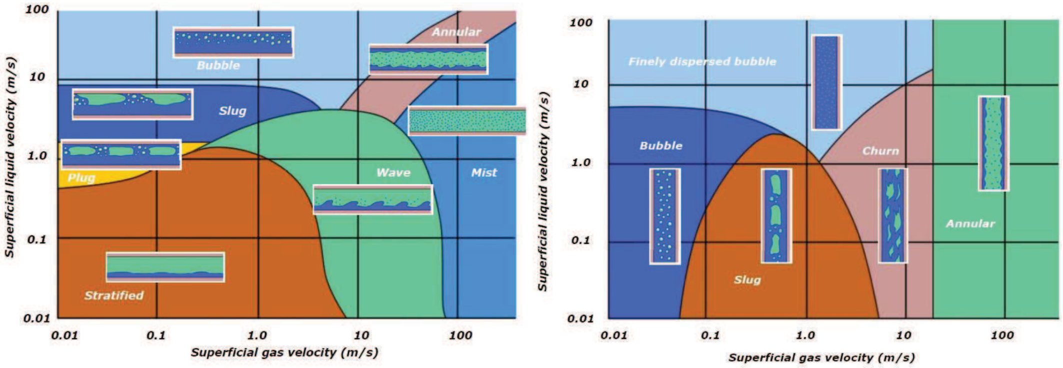


Figure 4 - Horizontal and vertical flow regimes. (Corneliussen, Mars 2.2005)

2.2.1 Flow Regimes Horizontal Pipes

In horizontal flows, the transitions are functions of factors such as pipe diameter, interfacial tension and density of the phases (Corneliussen, Mars 2.2005).
Laminar flow is not appropriate for Roxar watercut meter because the water and the oil flow separately. If the meter is installed horizontally a mixer should be installed in front of the meter in order to avoid a laminar flow.

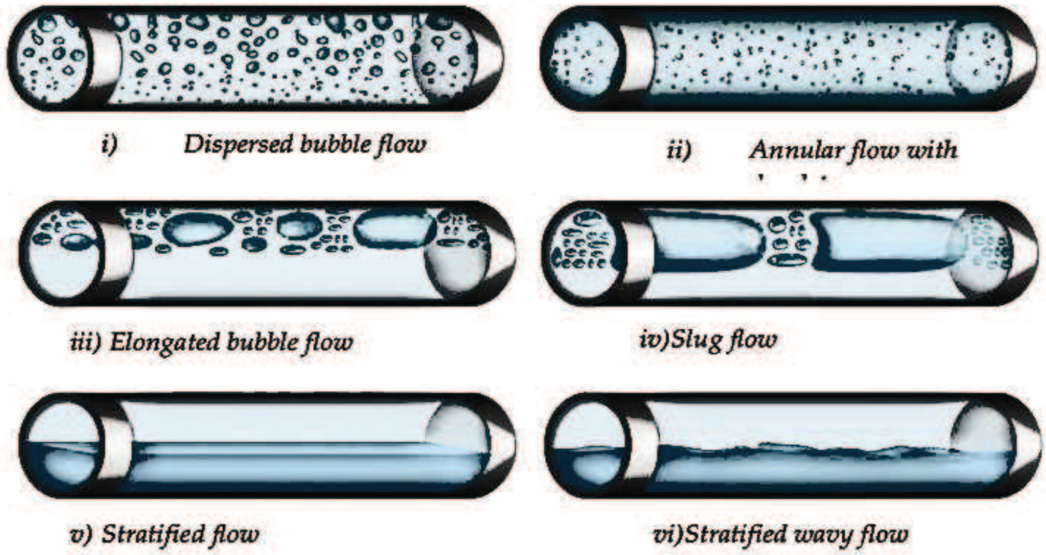


Figure 5 - Flow regimes in horizontal pipe. This picture is taken from (Bratland, 2010)

2.2.2 Flow regimes in vertical pipes

The flow regimes occurring in vertical are similar to those in horizontal pipes, but one difference being that the there is no lower side of the pipe which the densest fluid 'prefers'. One of the implications this has is that stratified flow is not possible in vertical pipes.

Most of the published measurements have been carried out on horizontal and vertical pipes, which is also what we have shown flow regimes for here. Pipelines generally follow the terrain and most often have other inclinations, so the complexity is often larger than illustrated here (Bratland, 2010).

Figure 6 - Gas-liquid flow regimes in vertical pipes. (Bratland, 2010)

2.3 Microwave sensors

The microwave sensors are not only used in the oil industry, they become more and more common in different areas of the industry. Many of the new measurement problems have been solved by various kinds of microwave sensors (E. Nyfors & Vainikanen, 1989)
The American Heritage Dictionary (The American Heritage Dictionary fourth edition, 2000) defines ”Microwave *n*, an electromagnetic wave whit a wavelength between that of infrared and short waves (one millimeter to one meter). The microwave sensors used in this thesis (Roxar Microwave sensors), the wavelength is always of the same order of the magnitude as the sensor. Microwave sensors are based on the interaction of microwaves with matter. This interaction may be in the form of reflection, scattering, refraction, emission, absorption, or change of speed and phase (E. Nyfors & Vainikanen, 1989).

Microwave sensors are used to measure a wide range of quantities like distance, movement, shape, and particle size, but the largest groups of applications are related to measurement of material properties.

Material measurements with microwaves are based on the fact that the contact between microwaves and the medium of propagation is completely determined by the relative permittivity and permeability of the medium:

$$\varepsilon_r \varepsilon'_r - j\varepsilon''_r$$
$$\mu_r = \mu'_r - j\mu''$$

For most practical materials that are subject of measurement with microwave sensors

$\mu_r = 1.$

In this thesis only the permittivity will therefore be considered to affect the interaction, unless otherwise stated. Different materials have different permittivity, and the permittivity of a mixture depends on the permittivity of the components, the composition (the relative abundance of the components), and the structure [von Hippel, 1954], [Becher, 1965], [Hasted, 1973]. (E. G. Nyfors, 2000)

By measuring the permittivity of the mixture, one therefore gets information about the composition. In a simple case of two components, the sum of which is 100 %, there is only one unknown if the structure, and the permittivity of the components are assumed to be known (e.g. oil drops in water or water drops in oil), making it possible to deduce the composition from one measurement of e.g. resonant frequency (E. G. Nyfors, 2000).
The mixture that contains more than two as the mixture that is studied in this thesis (e.g. oil water and gas) complicates the measurement and added more unknown into equations.

There are several advantages to microwave sensors. The sensors do not need mechanical contact with the object. Therefore, performing on-line measurements from a distance is possible, without interface to process. Additionally the microwave sensors see a very good contrast between water and most other materials, making them well suited for water content measurements. Microwave resonator sensors are inherently stable because the resonant frequency is related to physical dimensions. The sensors are insensitive to environment condition, such as water vapour and dust, and high temperatures. Microwave sensors are generally less sensitive to material build-up. Furthermore, microwaves penetrate all material except for metals. The measurement result therefore represents a volume of material, not only the surface. At low frequencies the dc conductivity often dominates the electrical properties of a material. The dc conductivity depends strongly on temperature and ion content. At microwave frequencies, the influence of the dc conductivity often disappears (E. G. Nyfors, 2000).

There are some disadvantages to the microwave sensors. The sensors are sensitive to more than one variable. Because of the relatively long wavelengths, the achievable spatial resolution is limited. The higher is the frequency, the more expensive are the electronic components. The microwave sensors have to be calibrated separately for different materials. Also, the sensors are often adapted to a specific application, which results in low universal applicability (E. G. Nyfors, 2000).

2.3.1 Cylindrical Fin Resonator Sensor (CFR)

The advantages of implementing the microwave sensor cylindrical fin resonator (CFR) include minimal obstruction to the flow and low manufacturing cost. The CFR sensor, with the fin extending from the wall to the center of the pipe, is a piece of sectorial waveguide with a sector angle of 2 π and open ends. The resonance modes are based on waveguide modes.

The resonant frequency in the CFR sensor of a resonance mode, based on a waveguide mode, is given by the following equation:

$$f_{r,vml} = \frac{c}{2}\left[\left(\frac{p}{\pi a}\right)^2 + \left(\frac{l}{L}\right)^2\right]^{1/2}$$

In the equation p represents p_{vm} or p'_{vm}. The lowest resonance mode is $TE_{1/2\ 10}$, which includes a resonant frequency that is independent of the length of the fin. However, as a result of the fringing field in the open ends, the resonant frequency is somewhat dependent of the length of the fin. Every mode with a relative resonant frequency $f_r > 1$ has a poor quality factor since the pipe provides no isolation. How well the resonance mode couples to the modes in the pipe determines the quality factor.

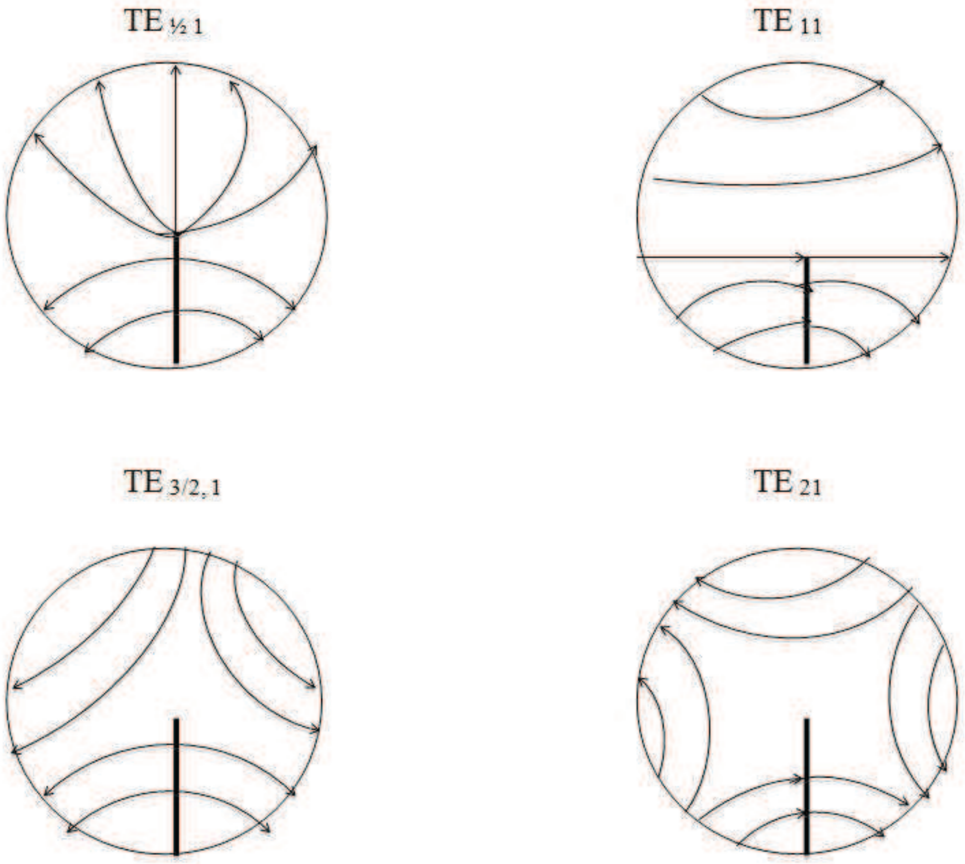


Figure 7 - The electric field configuration of the lowest modes in a sectorial waveguide with a sector angle of 2 π.

Figure 7 illustrates qualitatively the cross section of the electric field configuration of the modes $TE_{\frac{1}{2}\,10}$, TE_{11}, $TE_{3/2,1}$ and TE_{21}. The mode to be used for measuring purposes is $TE_{1/2\,10.}$ In order to avoid confusion of modes and influence of other modes on $TE_{1/2\,10}$, it is desirable to have largest distance as possible to the next mode, when the MUT is lossy and the peaks broad.

The used resonance mode, $TE_{1/2\,10}$, has an electric field with a strong radial component at the wall. Using coupling probes of the electric loops is more suitable because they are mechanically easier to implement and easier to stimulate for finding the optimal design.

2.4 Permittivity

In electromagnetism, *absolute permittivity* is the measure of the resistance that is encountered when forming an electric field in a medium. In other words, permittivity is a measure of how an electric field affects, and is affected by, a dielectric medium. The permittivity of a medium describes how much electric field (more correctly, flux) is 'generated' per unit charge in that medium. More electric flux exists in a medium with a high permittivity (per unit charge) because of polarization effects. Permittivity is directly related to electric susceptibility, which is a measure of how easily a dielectric polarizes in response to an electric field. Thus, permittivity relates to a material's ability to transmit (or "permit") an electric field (Hennessy & Vikingstad, 2007).

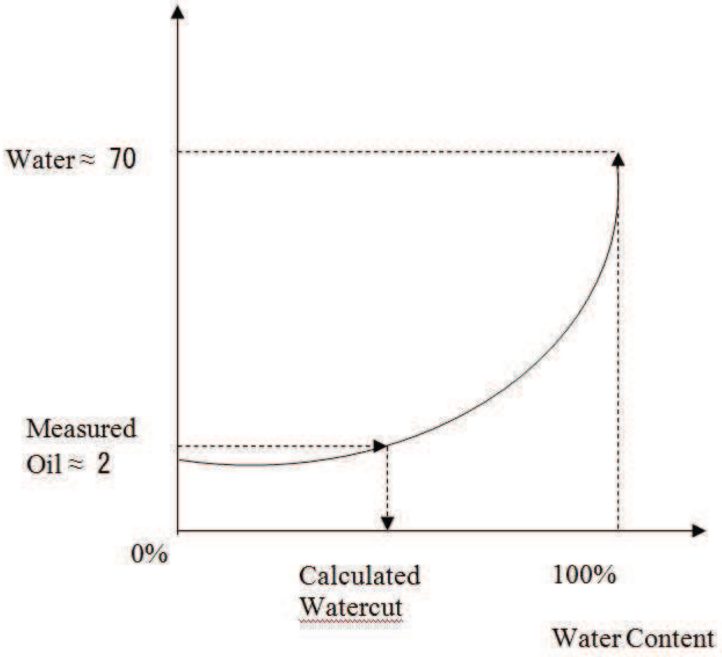


Figure 8 - Illustrates how the measured dielectric constant is used to determine the water content of a crude oil. Permittivity of oil is typically 2.2 – 2.4, while water > 70.

Permittivity of a mixture is directly related to the component of volume fractions and the respective component permittivity. In order for the meter to determine how much water is contained in a mixture, the dielectric constant of the oil and water has to be known in separate components. These values describe the end points of a mixing law, which describes the relationship between mixture permittivity and component volume fractions. The oil dielectric constant is the (0% water) endpoints 100% oil. The water dielectric constant is 100% endpoint (0% oil).

2.4.1 Resonance Frequency as Function of Permittivity

The permittivity of the mixture is calculated from the vacuum resonance frequency and the mixture resonance frequency:

$$\varepsilon_{mix} = \left(\frac{f_{vac}}{f_{mix}} \right)^2$$

Equation above is valid in most cases of dry or moderately moist dielectrics and for example an oil-continuous mixture of oil and water. It is not valid, especially at low frequencies, when the bulk ion conductivity is considerable, as for example in a water continuous mixture of oil and water, when the water contains salts. Because the resonance phenomenon disappears when the dielectric is very lossy.(E. G. Nyfors, 2000)

2.5 Algorithms used by Roxar Watercut meter.

In order for the watercut meter to perform its measurements and calculations, some inputs are required for performing the calculations.

2.5.1 Weight percentage of salt

Input:

Parameter	**Source**	**Description**
$\sigma_{water,20C}$	Calculation	Water conductivity at temperature of 20 °C [S/m]
$\rho_{water,15C}$	User input	Water density at 15 °C [g/cm^3]

Output:

Parameter	**Source**	**Description**
W_{salt}	Calculation	Weight percentage of salt [%]

If $\rho_{water,15C} > 0$ then:

$$W_{salt} = \frac{1000 \cdot \rho_{water,15C} - 999}{7.2}$$

else

$$W_{salt} = -0.017 + 0.63068 \cdot \sigma_{water,20C} + 0.0097457 \cdot \sigma_{water,20C}{}^{2} + 0.000314 \cdot \sigma_{water,20C}{}^{3}$$

If $W_{salt} < 0$, then $W_{salt} = 0$.

2.5.2 Water conductivity

To calculate the water conductivity, then the user has to provide the process water conductivity at a specific temperature.

2.5.2.1 Calculate the Std condition conductivity of water from user input conductivity

Input:

Parameter	**Source**	**Description**
$\sigma_{water,cal}$	User input	Water conductivity at temperature of $T_{water,cal}$ [S/m]
$T_{water,cal}$	User input	Temperature at which the water conductivity is specified [°C]

Output:

Parameter	**Source**	**Description**
$\sigma_{water,20C}$	Calculation	Water conductivity at temperature of 20 °C [S/m]

The conductivity of water at 20 °C is calculated iteratively. The initial value is set as:

$$\sigma_{water,20C} = \frac{\sigma_{water,cal}}{1 + 0.021 \cdot \left(T_{water,cal} - 20\right)}$$

The following steps are repeated until the difference between $\sigma_{water,20C}$ and $\sigma_{water,20C,previous}$ is less than 0.01:

$$\begin{aligned}
&\sigma_{water,20C,previous} = \sigma_{water,20C} \\
&k = 0.024471 - 0.0014185 \cdot \sqrt{\sigma_{water,20C}} \\
&\sigma_{water,20C} = \frac{\sigma_{water,cal}}{1 + k \cdot \left(T_{water,cal} - 20\right)}
\end{aligned}$$

2.5.2.2 Calculate the std condition conductivity of water from user input water density

Input:

Parameter	**Source**	**Description**
W_{salt}	Calculation	Weight percentage of salt [%]

Output:

Parameter	**Source**	**Description**
$\sigma_{water,20C}$	Calculation	Water conductivity at temperature of 20 °C [S/m]

Calculate $\sigma_{water,20C}$ from W_{salt}:

If $W_{salt} > 26$, then

$$\sigma_{water,20C} = 22.6,$$

else

$$\sigma_{water,20C} = 1.5813 \cdot W_{salt} - 0.04023 \cdot W_{salt}{}^{2} + 0.000664 \cdot W_{salt}{}^{3}$$

2.5.2.3 Calculate the standard condition water density from user input conductivity

If the water density has not been entered directly by the user, then the following calculations can be used to determine the water density.

Input:

Parameter	**Source**	**Description**
$\sigma_{water,20C}$	User input	Water conductivity at temperature of 20 °C [S/m]

Output:

Parameter	**Source**	**Description**
$\rho_{water,15C}$	Calculation	Water density at 15 °C [kg/L]

Calculate the weight percentage of salt in the water from the conductivity according to section 4.1. Calculate $\rho_{water,15C}$ from W_{salt}:

$$\rho_{water,15C} = 0.999 + 0.0072 \cdot W_{salt}$$

2.5.2.4 Cal the process condition water density from the Std condition water density

Input:

Parameter	**Source**	**Description**
$\rho_{water,15C}$	Calculation	Water density at 15 °C [g/cm^3]
$P_{process}$	Input	Process pressure [bara]
$T_{process}$	Input	Process temperature [°C]
W_{salt}	Calculation	Weight percentage of salt [%]

Output:

Parameter	**Source**	**Description**
ρ_{water}	Calculation	Water density at process conditions [g/cm^3]

$$a_1 = 1 - (0.00018562 + 0.000012882 \cdot W_{salt}) \cdot (T_{process} - 15)$$

$$a_2 = (0.0000041151 - 0.00000014464 \cdot W_{salt}) \cdot (T_{process} - 15)^2$$

$$a_3 = (0.0000000071926 - 0.00000000013085 \cdot W_{salt}) \cdot (T_{process} - 15)^3$$

$$a_4 = 1 + 0.000045 \cdot P_{process}$$

$$\rho_{water} = \rho_{water,15C} \cdot (a_1 - a_2 + a_3) \cdot a_4$$

2.5.3 Oil density

To calculate oil density, then the user has to provide dry oil density at standard condition.

2.5.3.1 Calculate the standard condition oil density from user input density

Input:

Parameter	**Source**	**Description**
$\rho_{oil,org}$	Input	Dry oil density at $P_{oil,org}$ and $T_{oil,org}$ [g/cm^3]
$P_{oil,org}$	Input	Pressure at which the dry oil density is specified [bara]
$T_{oil,org}$	Input	Temperature at which the dry oil density is specified [°C]

Output:

Parameter	**Source**	**Description**
$\rho_{oil,std}$	Calculation	Oil density at standard conditions [g/cm^3]

$\rho_{oil,std}$ is found through an iterative process. The starting conditions are first set.

$$\rho_{oil,std} = \rho_{oil,org}$$

$$\rho_{oil,T1} = \rho_{oil,org} \cdot \left(1 - \frac{P_{oil,org}}{100000} \cdot \exp\left(1.38315 + 0.00343804 \cdot T_{oil,org} - (3.02909 + 0.0161654 \cdot T_{oil,org})\ln(\rho_{oil,std})\right)\right)$$

2.5.3.2 Calculate the process condition oil density from standard condition oil density

Input:

Parameter	**Source**	**Description**
$\rho_{oil,std}$	Calculation	Water density at standard conditions [g/cm^3]
$P_{process}$	Input	Process pressure [bara]
$T_{process}$	Input	Process temperature [°C]

Output:

Parameter	**Source**	**Description**
ρ_{oil}	Calculation	Oil density at process conditions [g/cm^3]

The density of oil is calculated as in the original WCM software code, where it is stated that it is “Calculated to API standard according to SG”:

$$a_1 = \frac{613.972 \cdot (T_{process} - 15)}{1000000 \cdot \rho_{oil,std}{}^2}$$

$$a_2 = \rho_{oil,std} \cdot \exp\left(-a_1 - 0.8 \cdot a_1{}^2\right)$$

$$a_3 = \exp\left(1.38315 + 0.00343804 \cdot T_{process} - \left(3.02909 + 0.0161654 \cdot T_{process}\right) \cdot \ln\left(\rho_{oil,std}\right)\right)$$

$$\rho_{oil} = \frac{a_2}{1 - 0.00001 \cdot P_{process} \cdot a_3}$$

2.5.4 Watercut calculation

The microwave resonance frequency is used to calculate of the permittivity of the fluid mixture inside the meter body. The permittivity of water and oil is calculated from models depending on user input conductivity of water, density of oil, and measured temperature and resonance frequency. An electromagnetic mixing formula (Bruggeman equation) is used to derive the watercut of the mixture.

The equations and algorithms used for finding the watercut from the microwave resonance peak and different input parameters are described in the following sections, and consist of the following main parts:

1. Calculate the mixture permittivity
2. Calculate the water permittivity
3. Calculate the oil permittivity
4. Calculate the water cut

2.5.4.1 Calculating the mixture permittivity

Input:

Parameter	**Source**	**Description**
$T_{process}$	Input	Process temperature [°C]
f_{mix}	Measurement	Resonance frequency of the mixture [Hz]
f_{vac15}	Input	Vacuum resonance frequency at 15 °C [Hz]
α	Input	Resonance cavity thermal expansion factor [1/K]

Output:

Parameter	Source	Description
ε_{mix}	Calculation	Permittivity of mixture [F/m]

To account for the thermal expansion effects, the vacuum frequency of the resonance cavity at the current temperature is calculated:

$$f_{vac} = \frac{f_{vac15}}{1 + \alpha \cdot \left(T_{process} - 15\right)}$$

The permittivity of the mixture is calculated from the vacuum resonance frequency and the mixture resonance frequency:

$$\varepsilon_{mix} = \left(\frac{f_{vac}}{f_{mix}}\right)^2$$

In this experiment the Bruggeman equation will be used in iteratively calculation where the permittivity of gas =1 will be added into the equation.

2.5.4.2 Calculating the water permittivity

Input:

Parameter	Source	Description
$T_{process}$	Input	Process temperature [°C]
f_{mix}	Measurement	Resonance frequency of the mixture [Hz]
$\sigma_{water,20C}$	Calculated	Water conductivity at 20 °C [S/m]
α	Input	Resonance cavity thermal expansion factor [1/K]

Output:

Parameter	**Source**	**Description**
ε_{water}	Calculation	Permittivity of water at meter conditions [F/m]
df	Calculation	Dissipation factor

The time constant of fresh water is computed as a function of temperature:

$$\tau_{freshwater} = \frac{1}{0.54655 + 0.0239 \cdot T_{process} + 0.0001446 \cdot T_{process}{}^{2}}$$

The time constant for the water in the meter is calculated based on the water conductivity $\sigma_{water,20C}$ input by the user:

$$\tau_{water} = \tau_{freshwater} \cdot \left(1 - 0.00915 \cdot \sigma_{w,20C} - 7.649 \cdot 10^{-5} \cdot \sigma_{w,20C}{}^{2}\right)$$

The dielectric constant of fresh water is a function of temperature:

$$dcfw = 87.74 \cdot e^{-0.00455 \cdot T_{process}}$$

The dielectric constant of the water in the meter is calculated base on the water conductivity $\sigma_{water,20C}$ input by the user:

$$dcw = dcfw \cdot \left(1 - 0.021942 \cdot \sigma_{water,20C} + 0.000603 \cdot \sigma^{2}_{water,20C} - 0.00003163 \cdot \sigma^{3}_{water,20C}\right)$$

The initial water permittivity estimate at the resonance frequency is then found as:

$$\varepsilon_{water,init} = 4.3 + \frac{dcw - 4.3}{1 + 2 \cdot \pi \cdot f_{mix} \cdot \tau_{water} \cdot 10^{-5}}$$

The permittivity is affected by capacitive and dielectric loss, which needs to be compensated for. The water conductivity at meter conditions is calculated using the temperature measurement:

$$\sigma_{water} = \sigma_{water,20C}\left(1+\left(0.024471-0.0014185\cdot\sqrt{\sigma_{water,20C}}\right)\cdot\left(T_{process}-20\right)\right)$$

The capacitive loss factor at the resonance frequency is calculated based using the water conductivity:

$$clf = \frac{\sigma_{water}}{2\cdot\pi\cdot f_{mix}\cdot 8.85\cdot 10^{-6}}$$

The dielectric loss factor at the resonance frequency is calculated using the dielectric constant and time constant of the water:

$$dlf = \frac{\left(dcw-4.3\right)\cdot 2\cdot\pi\cdot f_{mix}\cdot\tau_{water}\cdot 10^{-5}}{1+\left(2\cdot\pi\cdot f_{mix}\cdot\tau_{water}\cdot 10^{-5}\right)^{2}}$$

The total loss factor is then the sum of the capacitive and dielectric loss factors:

$$lf = clf + dlf$$

The dissipation factor of the water is found as:

$$df = \frac{lf}{\varepsilon_{water,init}}$$

The water permittivity when compensating for capacitive and dielectric loss is then found as:

$$\varepsilon_{water} = \frac{\varepsilon_{water,init}}{2}\cdot\left(\sqrt{1+df^{2}}+1\right)$$

2.5.4.3 Calculating the oil permittivity

Input:

Parameter	**Source**	**Description**
$T_{process}$	Input	Process temperature [°C]
f_{mix}	Measurement	Resonance frequency of the mixture [Hz]
ρ_{oil}	Input	Oil density at process conditions [kg/m^3]

Output:

Parameter	**Source**	**Description**
ε_{oil}	Calculation	Permittivity of oil at meter conditions [F/m]

The oil permittivity at the resonance frequency and process conditions is calculated:

$$A_1 = 0.582 - 0.00086 \cdot T_{process} + 0.0000008 \cdot T_{process}{}^2$$
$$A_2 = 0.00109 \cdot T_{process}$$
$$\varepsilon_{oil} = \left(\left(A_1 \cdot \rho_{oil} + A_2 \cdot \rho_{oil}^2\right) \cdot \left(1.076095 - 0.022188 \cdot \log_{10}\left(f_{mix}\right)\right) + 0.9875\right)^2$$

2.5.4.4 Calculating the water cut

Input:

Parameter	**Source**	**Description**
ε_{water}	Calculation	Permittivity of water at meter conditions [F/m]
ε_{oil}	Calculation	Permittivity of oil at meter conditions [F/m]
ε_{mix}	Calculation	Permittivity of the mixture flowing through the meter [F/m]
df	Calculation	Dissipation factor
$\beta_{correction}$	Input	Water cut correction factor [%]

Output:

Parameter	**Source**	**Description**
β	Calculation	Water cut [%]

The Bruggeman mixing formula is used to calculate the amount of water in the mixture. Oil is assumed to be the host fluid and water is the inclusive fluid. This gives the following expression:

$$\beta_{init} = 1 - \frac{\varepsilon_{mix} - \varepsilon_{water}}{\varepsilon_{oil} - \varepsilon_{water}} \sqrt[3]{\frac{\varepsilon_{oil}}{\varepsilon_{mix}}}$$

The initial water cut estimate needs to be compensated for dissipation:

$$df \geq 2.5 \Rightarrow \beta = \beta_{init} \cdot 102 \cdot \left(1 + 0.01 \cdot \left(\frac{29.48}{df^2} - \frac{24.24}{df} + 4.76 \right) \cdot \sin(\pi \cdot \beta_{init}) \right)$$

$$df < 2.5 \Rightarrow \beta = \beta_{init} \cdot 102 \cdot \left(1 + 0.01 \cdot \left(0.637 \cdot df^2 - 3.26 \cdot df + 4\right) \cdot \sin(\pi \cdot \beta_{init})\right)$$

Correct the water cut using $\beta_{correction}$:

$$\beta = \beta + \beta_{correction},$$

This is the final value that meter give s as out readings.

3 Experimental

The main objective in the experiment was to develop a software function in the Roxar watercut meter. The software function would enable the watercut meter to calculate the fraction of oil, gas and water.

3.1 Test Data and Evaluations

As described in the theory regarding the algorithms the meter is using, one can split the algorithms into three sections: measured-, input-, and calculated value. The measured value is the microwave resonance frequency of the liquid that passes through the meter body (f_{mix}). The calculated values are permittivity of the oil, water and the mix permittivity and watercut. While the input values are water conductivity, oil density and temperature.

The scenario studied in this thesis is the effect of gas on microwave resonance frequency. The Bruggeman mixing formula is used to calculate the amount of water in the mixture. The measured mixed resonance frequency (f_{mix}) and the calculated mixed permittivity will change when gas is part of the mixture. In the Bruggeman mixing formula, oil is to be the host fluid while water is the inclusive fluid. When gas is a part of the mixture the mix permittivity will decrease causing the meter to calculate incorrect watercut value. Normally when Roxar watercut is operating in conditions where you have a high ration of gas, the meter readings will be -1.5 % WC. In order to avoid this negative output value from the meter whenever free gas is present in the mixture, a software function called AutoGas will tested and develops. The algorithm used for the new software function AutoGas is iterative.

3.2 AutoGas function

AutoGas function1(Existing but not qualified software. Density model*)*, this software is implemented in the Roxar watercut meter, but has not been properly tested/qualified.

The AutoGas function2 (New software. Permittivity model with iteration loop*)* is not an optional feature of the Roxar watercut meter. It is developed for the purpose of solving the gas problem studied in this thesis and compared with AutoGas function1. However if the AutoGas function proves to be successful it will become an optional feature of the Roxar watercut meter. Similar to the AutoZero function, the AutoGas function relies on mix flow density input and mix permittivity rather than calibration of oil density in order to calculate fraction of gas, oil and water. This might allow the meter to remain accurate for any change in oil density due to gas influx. Using the data from both the density meter and the microwave antennas, the Roxar watercut meter will continuously measure the correct volume fraction of water, oil and gas present in the total mixture flowing through the meter body. This is not a multiphase meter but rather an advance watercut meter. The AutoGas function relies on a density meter with high accuracy when gas is part of the mixture, meaning that the Autogas function is only valid in low-pressure systems.

The Roxar watercut meter measures the resonance frequency of the mixture to determine the mixture permittivity by scanning the peaks in the resonance cavity. The equation for determining mixture permittivity is:

$$\varepsilon_{mix} = \left(\frac{f_{vac}}{f_{mix}} \right)^2$$

The complexity of developing the new software function was to add the permittivity of the gas into the equation. The flow that passes through the Roxar watercut meter is either water continuous or oil continues. High gas influx in the mixture is often detected when we have oil continuous flow with very low watercut. As previously mentioned using the Bruggeman equation in two-phase flow (oil and water), the oil is the host fluid and the water is the inclusive fluid. Adding gas, the Bruggeman equation will be used in the two following steps:

1. Water being the inclusive fluid
2. Gas being the inclusive fluid while liquid fluid, consisting of oil and water, being the host fluid.

The two steps enable the mix permittivity to be calculated in order to calculate watercut:

$$\beta_{init} = 1 - \frac{\varepsilon_{mix} - \varepsilon_{in}}{\varepsilon_{h} - \varepsilon_{in}} \sqrt[3]{\frac{\varepsilon_{h}}{\varepsilon_{mix}}}$$

Index (In) is the inclusive fluid while the index (h) indicates the host fluid.

3.2.1 AutoGas Algorithm

The algorithm used for the AutoGas function is iterative. In order for this function to work the meter depends on having life mix density meter input (Coriolis meter). The iteration process is based on the three following steps:

1. Assume the water fraction α_{water} and calculate the oil fraction α_{oil} from mix density, dry density and water density as input to the meter. External density meter measures the mix density:

$$\rho_{mix} = \rho_{oil} \cdot \alpha_{oil} + \rho_{water} \cdot \alpha_{water}$$

2. Based on mix density input, when the oil and water fraction is known the gas fraction can be calculated:

$$\alpha_{oil} + \alpha_{water} + \alpha_{gas} = 1$$

$$\alpha_{gas} = 1 - \alpha_{water} - \alpha_{oil}$$

3. Knowing the gas fraction a new mix permittivity has to be calculated from the Bruggeman mixing formula. The new calculated mix permittivity will act as liquid permittivity and as host fluid. Gas will be the inclusive fluid and its permittivity will be equal to 1.see the iterative loop block diagram in *Figure 10 - AutoGas function 2 (New software. Permittivity model with iteration loop.)*

If the difference between the calculated and measured permittivity is between ±0.0005, the iteration process has been covered. The AutoGas is density dependent software function.. In order to retrieve valuable information from the process the Roxar watercut meter needs to be combined with the Coriolis density meter.

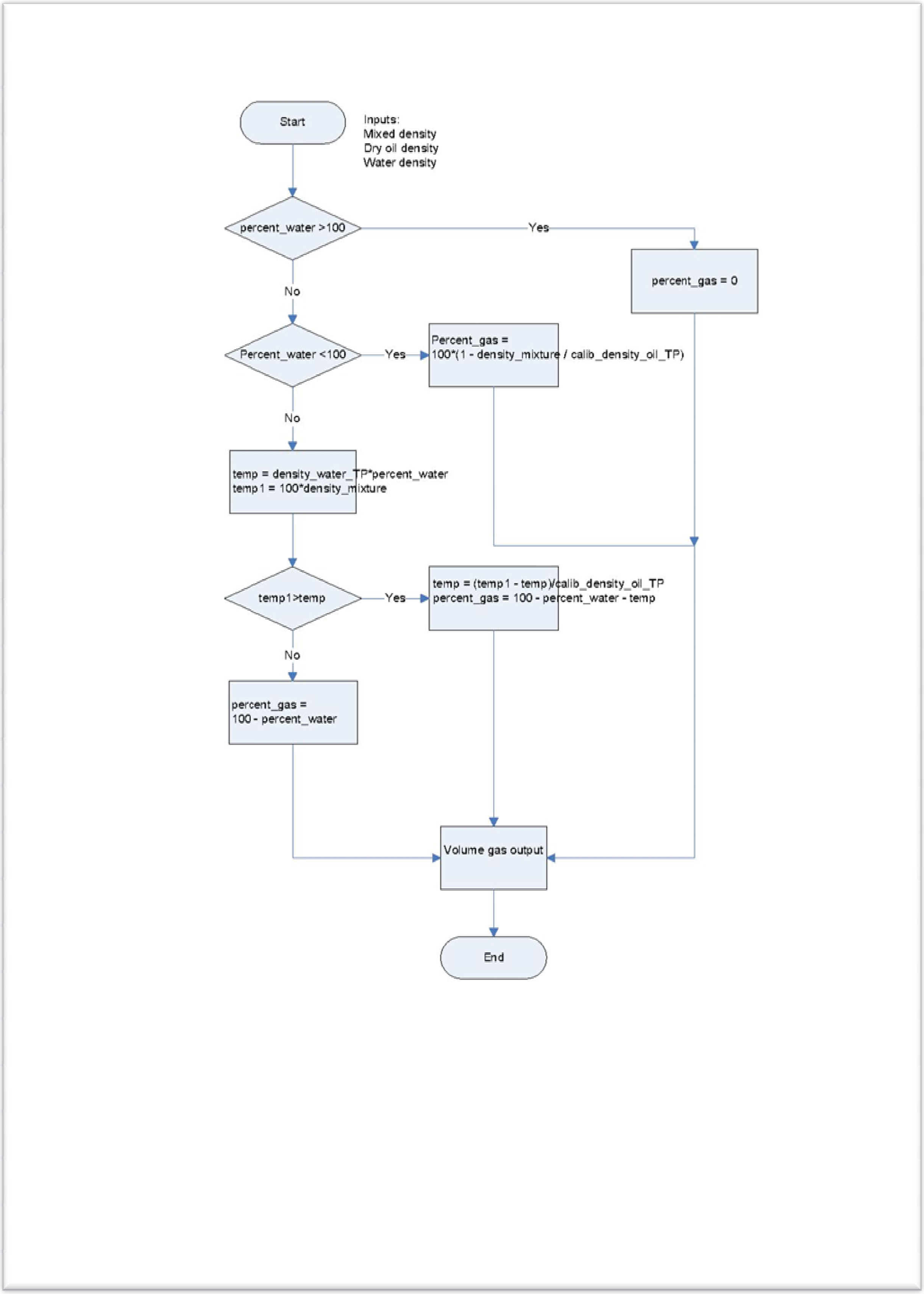


Figure 9 - AutoGas function 1(Existing but not qualified software. Density model)

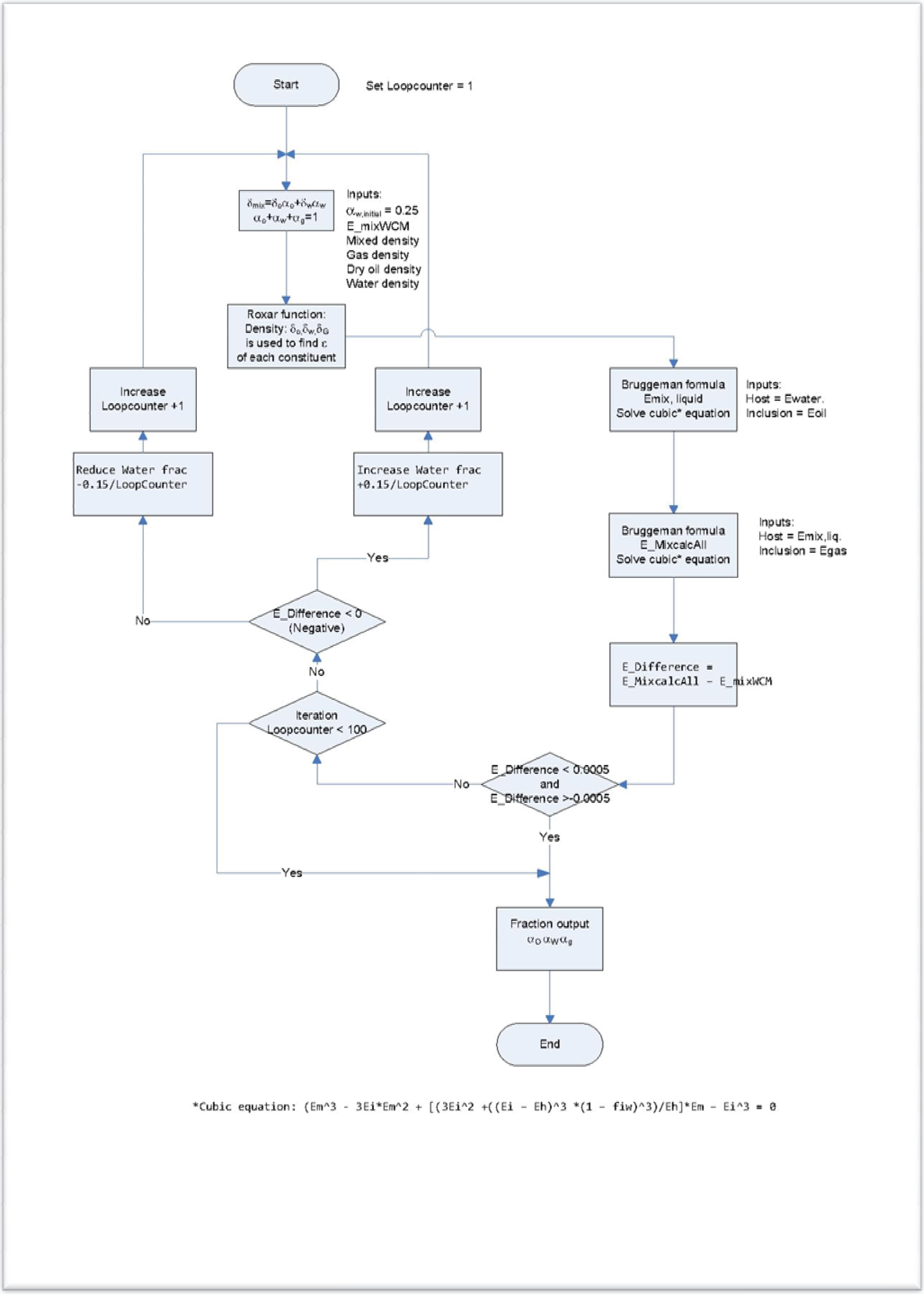


Figure 10 - AutoGas function 2 (New software. Permittivity model with iteration loop.)

3.3 Roxar Flow Test Facility

The Roxar flow loop test facility is build for the purpose of the clients who wants to either witness a flow test or verify that their Roxar Multiphase/ Wet Gas/ Watercut meter is operating according to its specifications in dynamic conditions. The flow parameters tested is:

- Liquid Volume rate (m^3/h)
- Gas volume rate (m^3/h)
- Watercut (%)

The flow laboratory offers great flexibility, large capacities, and quick variations of the flow rates. It enables testing at typical Wet Gas and Multiphase well conditions within the flow capacity allowed by the pumps and the compressors. The test rig is built to allow for examination of the effects of changing flow regimes on the meter's performance. The Roxar Flow Laboratory is located in Stavanger. However, all ongoing flow tests can be monitored at our premises in Roxar Bergen office.

The verification of the meter performance is based on a list of test points. A matrix of the test points is prepared as close as possible to the field process conditions with regard to the test rig capacity and operational limitations. The flow rates measured by the installed meter are compared with the test rig reference instrumentation downstream of the installed meter. The reference system is a single-phase measurement of oil, water-liquid-ratio and gas. The test fluids used in the Roxar Flow Laboratory are diesel, salt water ($MgSO4$ solution) and compressed air as (gas).

3.3.1 Description of the flow loop facility.

The Roxar test facility is a three-phase test rig with single-phase reference instrumentation. Single-phase reference measurement means that single phases of oil, water and gas are pumped and measured separately before being mixed and passed through the test section. The fluids are circulated in a closed-loop system. The mixing point is located in front of a manifold. Four horizontal pipe sections with diameters of 2", 3", 4" and 6" exit the manifold, allowing natural flow regimes to be developed for various meter sizes. This construction allows the testing of multiple meters of different sizes by the turning of valves. A blind-T is installed upstream of the Roxar Multiphase/ Wet Gas/ Watercut Meter. Downstream of the test section, the multiphase fluid flow is again separated into single phases.

3.3.2 Flow Loop Specifications.

The total length of the flow loop pipe is approximately 25-50 m with a pipe diameter of [2”, 3”, 4” and 6” inch]. The main part of the pipe material is a carbon steel and stainless steel.

The fluids specifications include diesel being used as oil with a density around [835-850 kg/m^3] and viscosity of [1.5-4.0 cSt/ 40 ^{0}C] with relative permittivity of [2.1-2.3]. The water density is approximately [1008-1025 kg/m^3], the water salinity can be adjusted while water conductivity is typically [3 S/m@ 20 ^{0}C]. When it comes to gas a compressed air is used as gas.

Chemical Composition of Air

Name	**Symbol**	**Percentage by volume**
Nitrogen	N2	78.084 %
Oxygen	O2	20.9476 %
Argon	Ar	0.934 %
Carbon Dioxide	CO2	0.0314 %
Neon	Ne	0.001818 %
Methane	CH4	0.0002 %
Helium	He	0.000524 %
Krypton	Kr	0.000114 %
Hydrogen	H2	0.00005 %
Xenon	Xe	0.0000087 %

Figure 11 - The chemical composition of air

3.3.3 Flow Loop Performance and Uncertainty Specifications

Reference Measurement	**Range**	**Nom. Diam.**	**Exp. Uncertainty 90% Conf. level**
Liquid flow rate **Micro Motion Coriolis**	**5-50 m^3/h** [water continuous] **5-60 m^3/h** [Oil continuous]	2” and 3”	2.0% rel.
Water Fraction **Roxar Full Cut Meter**	**0-100 %**	3”	2.0% abs.
Gas flow rate **Daniel liquid turbine meter**	**45-300 m^3/h**	3”	5.0% rel.
Gas volume fraction (GVF)	**0-100%**	-	2.0% rel.
Gas Supply Pressure	**<10 bar** [not regulated]	-	0.5% F(0.05bar g)
Oil/water Separator Temperature	**15-25 ^{0}C** [not regulated]	-	
Flow pressure transmitters	**0-10 bar g**	**-**	0.25% FS (0.00625 bar g)
Flow temperature transmitter	**0-50 ^{0}C**	**-**	0.5 ^{0}C

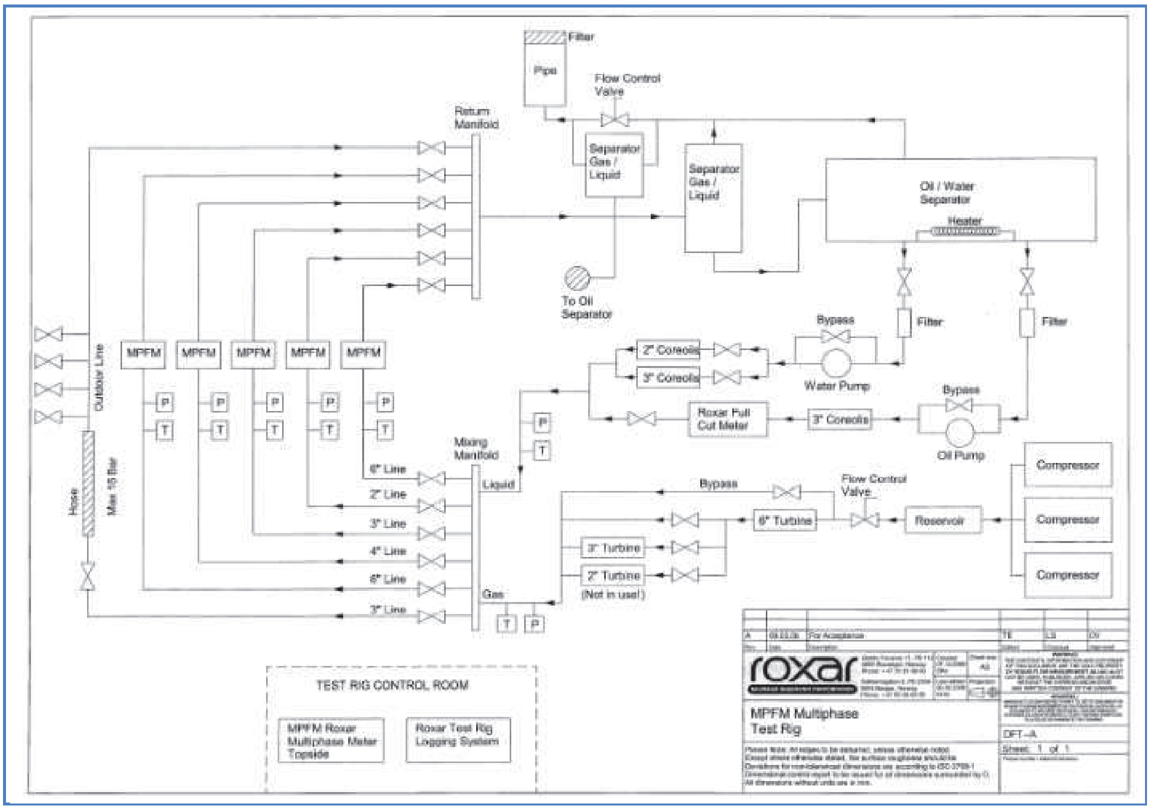


Figure 12 - Schematic of the Roxar Flow test loop.

3.4 Execution of the experiment

In order for the software to work a flow density input was required. The Roxar watercut is not suitable for the process with high GVF. Therefore finding out the limit of GVF that the meter could handle is part of the experiment in this thesis. The Roxar Flow loop facility described above was scheduled to be used during the test of the AutoGas function. A test matrix of 20-test point was prepared to test the AutoGas function. Unfortunately just before proceeding with the test, a major accident occurred in the Roxar flow loop facility. Most of the facility was under water and therefore the schedule test could not be run.

Obviously the flow loop test would have been the ultimate test to verify whether the AutoGas software function was working. The flow loop test would also be able to verify the maximum limit of GVF the meter could handle. The need for finding an alternative method was crucial. Two options were present and carefully evaluated:

1. Static sensor testing

Advantages of this alternative:

- Quick to setup test equipment.
- Fast and reliable results, due to stable sensor conditions.
- High repeatability.
- Low cost.

Disadvantages of this alternative:

- Will results be representative?

Requirements:

- Test jig/ equipment must be built.

2. Building a mini flow loop

Advantages of this alternative:

- Reliable and representative results.
- Good repeatability.

Disadvantages of this alternative:

- High cost and time consuming.
- Finding necessary equipment to build a loop that performs as expected.

Requirement:

- Acquire money and equipment.
- Build loop.

Based on the evaluations above it was decided to continue on with a static test. However, after the static test was conducted the second alternative of building a mini flow loop was executed. The decision of building a mini flow loop is explained in the results (chapter 6).

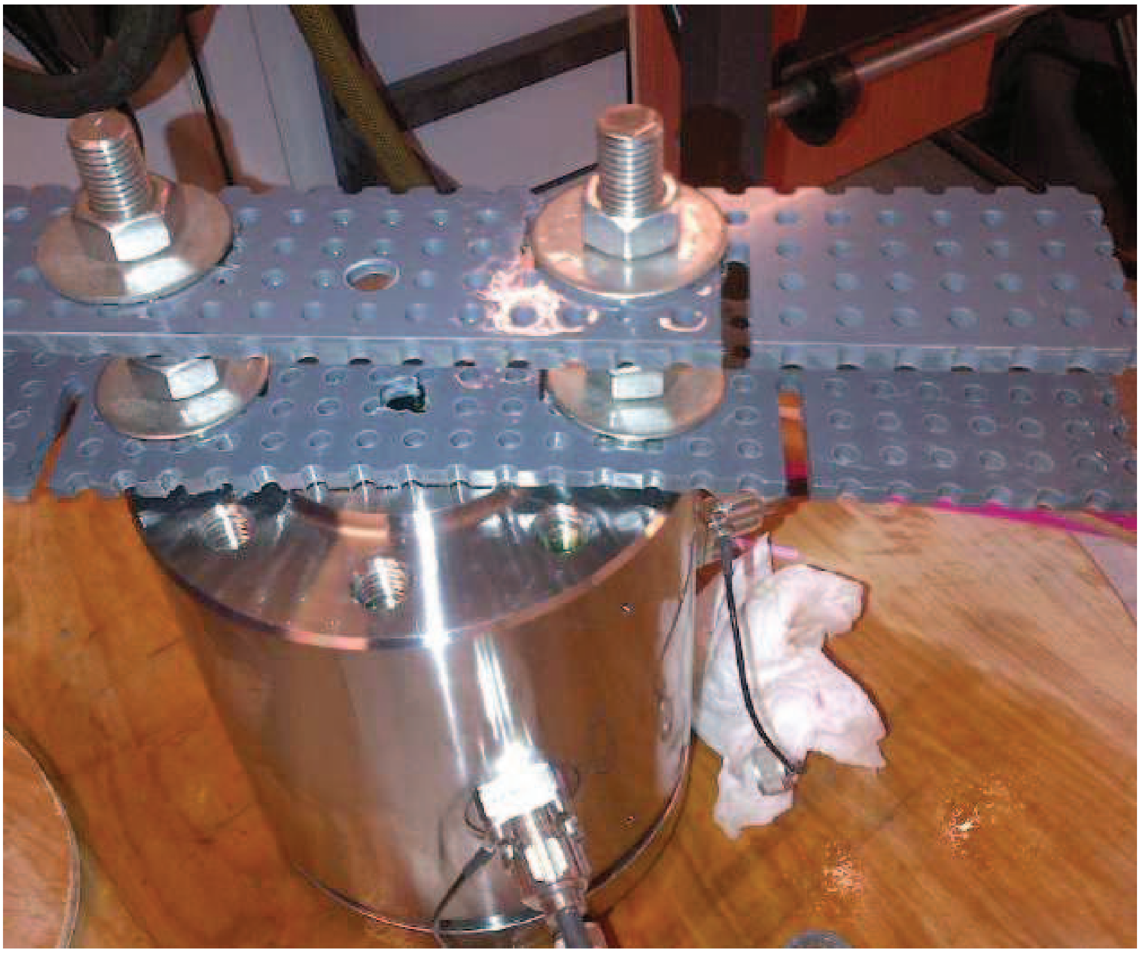


Figure 13 - Picture of the 2" CFR sensor and the test jig used during the Static test.

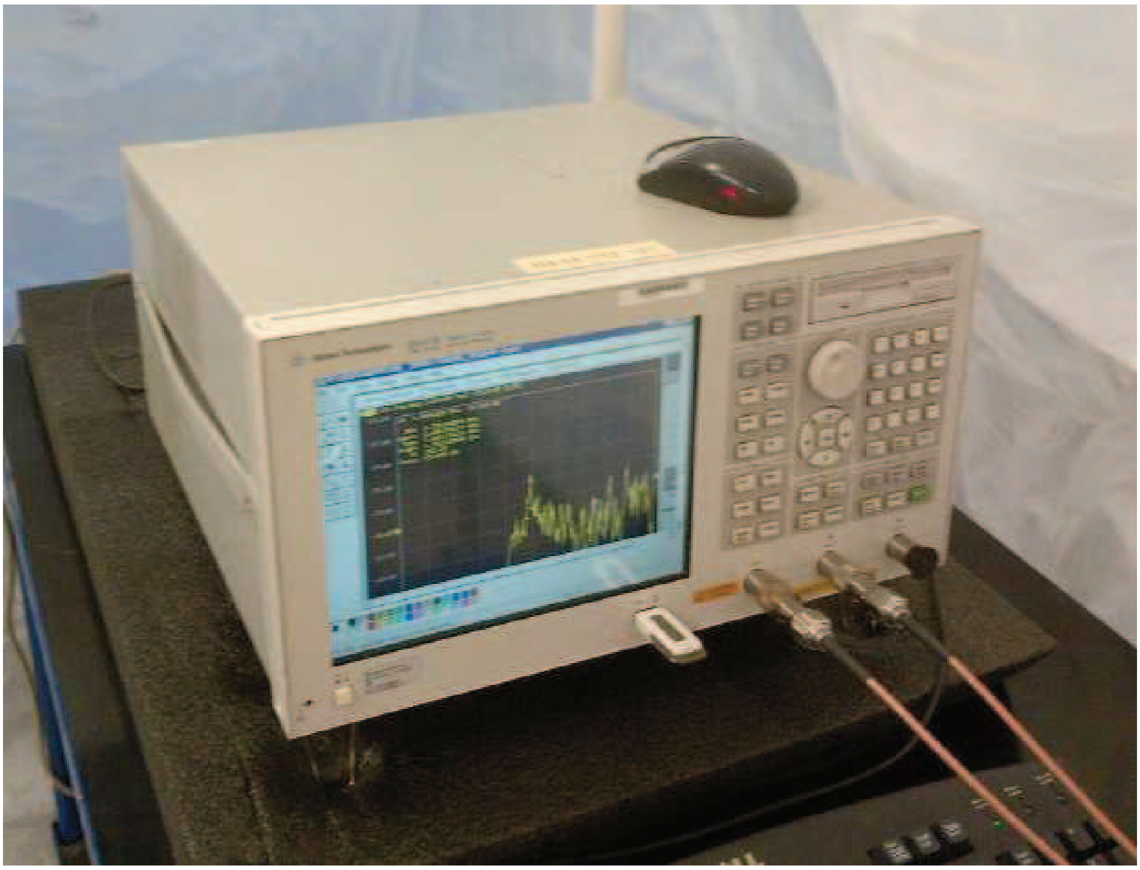


Figure 14 - The network analyzer used for recoding and measuring the resonance frequency.

Figure 15 - Picture of the mini flow loop while circulating diesel and air.

Figure 16 - The used network analyzer connected to CFRS sensor used in measuring the resonance frequency.

Figure 17 - Picture of the mini flow loop before filled with diesel.

4 Result and Discussion

The results from the static test have been included in the thesis because the results were essential regarding building the mini flow loop.

4.1 Static Test

The purpose of the static test was to measure the resonance frequency when the CFR sensor is filled with a static mixture of fluid and gas. This was done by manually filling the sensor with diesel and then inserting straws filled with air, which had different straw diameter (different air volumes). The change in the resonance frequency caused by the straws with air would then be measured and recorded.

The sensor sensitivity is not uniform inside the measuring pipe area. It was therefore crucial for the straws to be in the same location in the sensor. A plastic plate with open holes was mounted on top of the sensor. Three different sizes of straws were then used during the static test. A serial of 18 test points were conducted in the static test. The results are presented according to the size of the three different straws.

4.1.1 Measured Resonance Frequency with straw 1

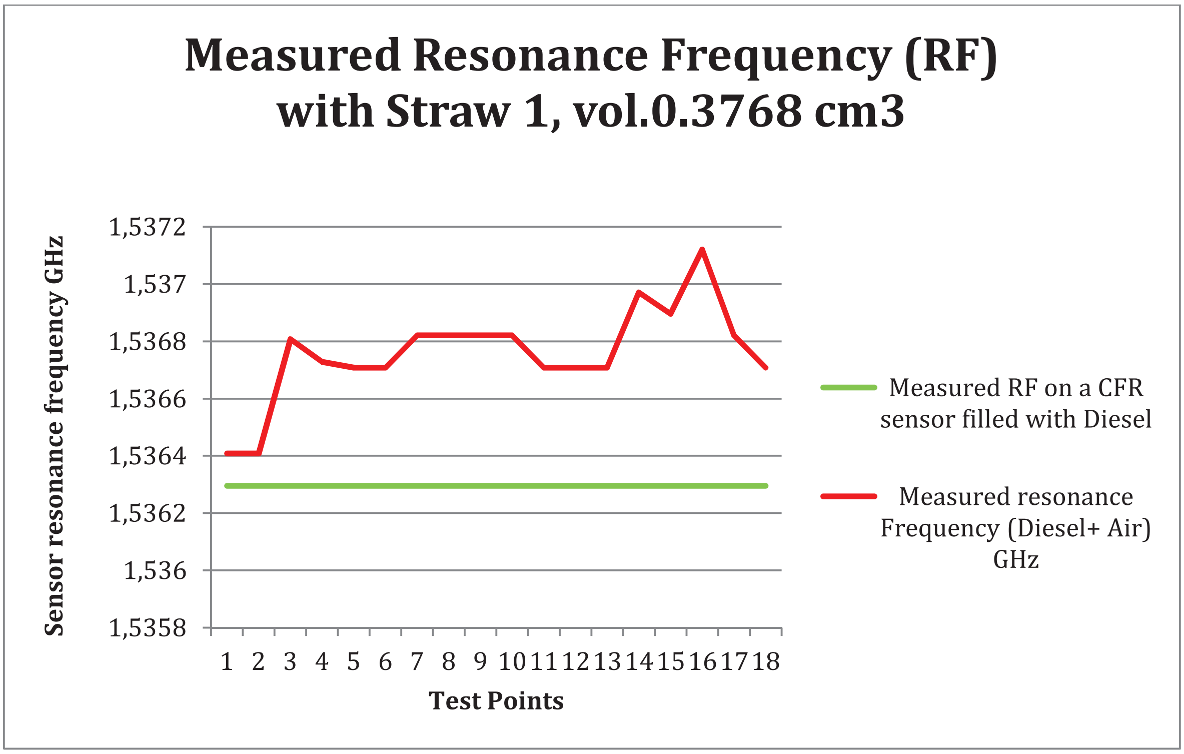


Figure 18 - Measured Resonance Frequency with Straw 1

Result/Discussion

In *Figure 18*, straw 1 represents volume of air equal to 0.3768 cm3. The test result indicates how difficult it is to measure the resonance frequency with the same amount of air volume inserted in the sensor. Test point 7-11 has the same resonance frequency equal to 1, 5367 GHz while the remaining test points deviates a lot.

4.1.2 Measured Resonance Frequency with Straw 2

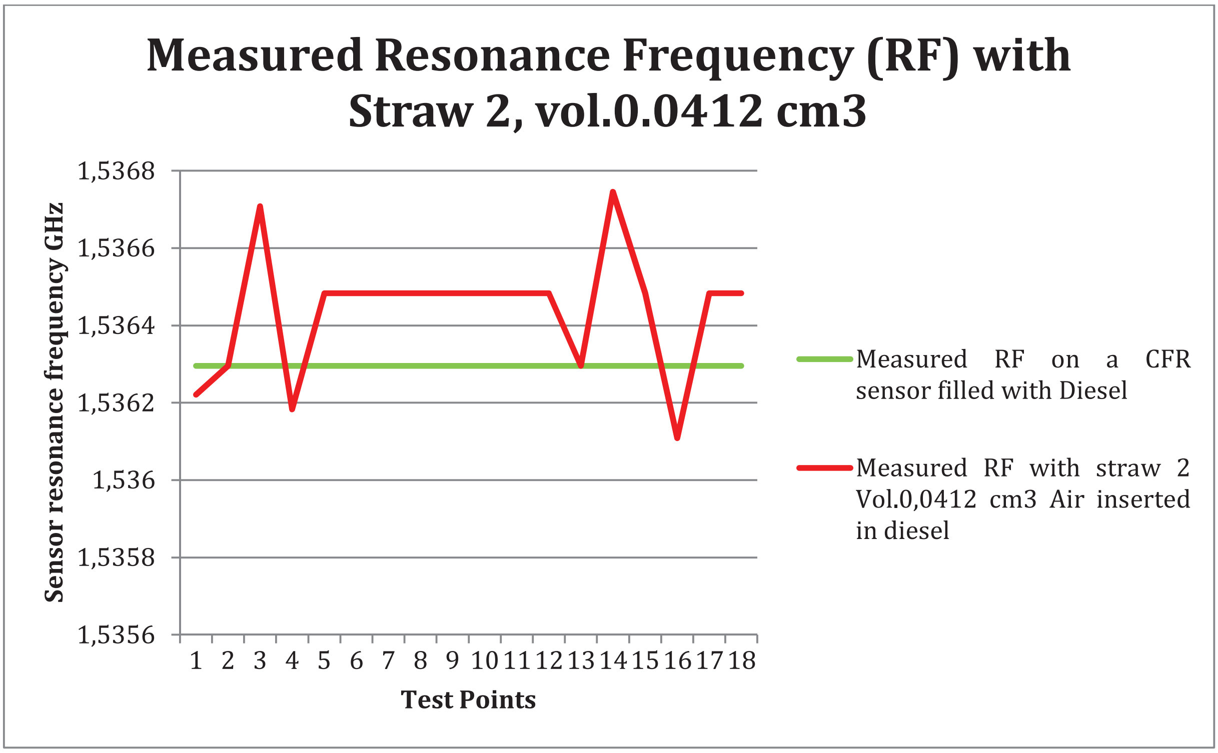


Figure 19 - Measured Resonance Frequency with Straw 2

Result /Discussion

Figure 19 shows the result of measured resonance frequency with straw 2 representing volume of air equal to 0.0412 cm^3. These test results also illustrates the difficulties of measuring the resonance frequency. Test point 14 shows the highest measured resonance frequency of 1.5368 GHz while test point 16 shows the lowest measured resonance frequency. The test points 4 - 11 has the same measured resonance frequency equal to 1,5364 GHz.

4.1.3 Measured Resonance Frequency with straw 3

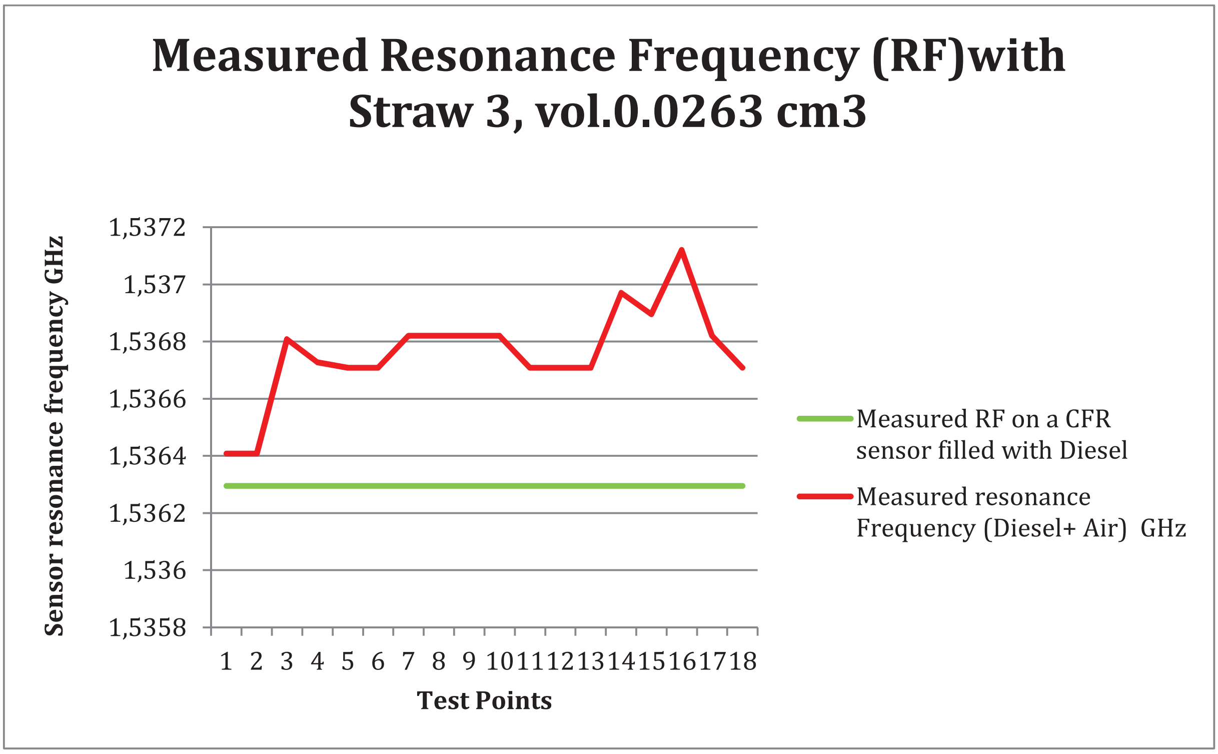


Figure 20 - Measured Resonance Frequency with Straw 3

Result/Discussion

In *Figure 20*, measured resonance frequency with straw 3 represents volume of air equal to 0.0263 cm^3. Measured resonance frequency varies throughout the 18 test points. However in test point 7 – 10 measured resonance frequency is constant and equal to 1.5368 GHz, while in test point 11– 13 measured resonance frequency is equal to 1.5367 GHz.

4.1.4 Final Analysis of the Static Test

Testing proved that the measured resonance frequency with the same straw gave different resonance frequencies. It was therefore very low repeatability and the result was not representative of the mixture. The volume of air in the straw is known, but even if the same volume or straw was inserted, it was not possible to get the same resonance frequency, because the CFR sensors do not have a uniform sensitivity inside pipe measuring area as seen in *Figure 18*, *Figure 19* and *Figure 20*. The result could not be trusted.

It was decided to move on and build a mini flow loop instead

4.2 Mini Flow Loop Test

The purpose of building the mini flow loop was to collect reliable result that could be tested on the software developed AutoGas. It was therefore important to get reliable reference values that could be tested. Building the mini loop was both costly and time-consuming.

The mini flow loop consist one diaphragm pump, 10-meter hose, 4 valves and one 2” CFR sensor which was the same sensor used in the static test as seen in *Figure 17*.

T-flanges were mounted just before the sensor so the flow that passes the sensor could be well mixed. A network analyzer RFM-772-027 was connected to the sensor to measure the resonance frequency.

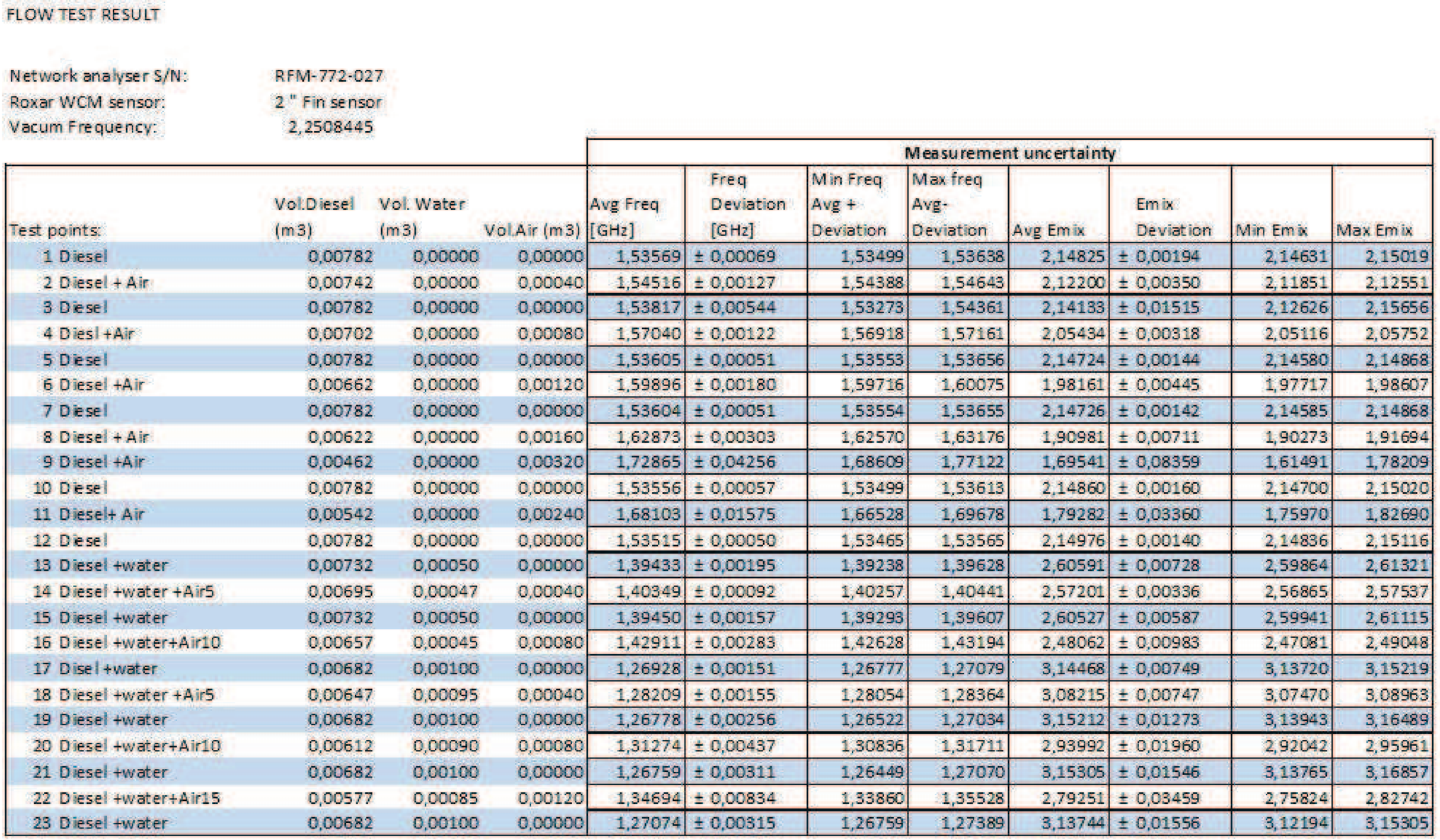
4.2.1 Test Matrix

After the flow loop was build it was filled with diesel and check for leakages, some of the hose connections was leaking and tightened. The loop was then filled 7.82 liter of diesel, which was maximum volume of the loop. A test point matrix consisting of 23-test point was constructed.

Table 3: Test Matrix Mini Flow Loop

Test matrix for mini loop			
Test points	Diesel fraction (%)	Water fraction (%)	Air fraction (%)
1	100,00	0,00	0,00
2	94,88	0,00	5,12
3	100,00	0,00	0,00
4	89,77	0,00	10,23
5	100,00	0,00	0,00
6	84,65	0,00	15,35
7	100,00	0,00	0,00
8	79,54	0,00	20,46
9	59,08	0,00	40,92
10	100,00	0,00	0,00
11	69,31	0,00	30,69
12	100,00	0,00	0,00
13	93,61	6,39	0,00
14	88,82	6,067	5,12
15	93,61	6,39	0,00
16	84,03	5,74	10,23
17	87,21	12,79	0,00
18	82,75	12,13	5,12
19	87,21	12,79	0,00
20	78,29	11,48	10,23
21	87,21	12,79	0,00
22	73,83	10,82	15,35
23	87,21	12,79	0,00

4.2.2 Results from flow test.



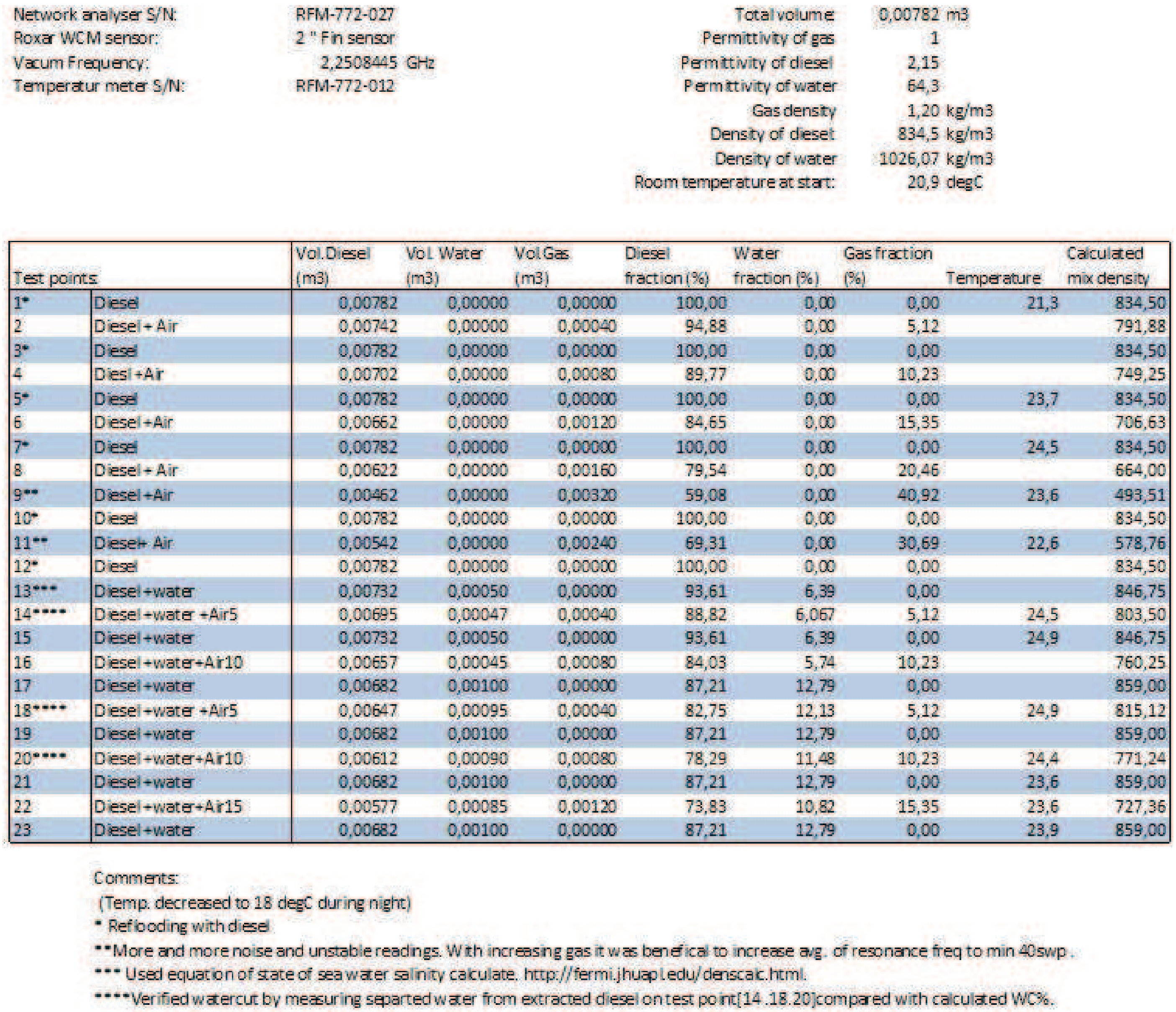
FLOW TEST RESULT

Network analyser S/N: RFM-772-027
Roxar WCM sensor: 2 " Fin sensor
Vacum Frequency: 2,2508445

				Measurement uncertainty							
Test points:	Vol.Diesel (m3)	Vol. Water (m3)	Vol.Air (m3)	Avg Freq [GHz]	Freq Deviation [GHz]	Min Freq Avg + Deviation	Max freq Avg- Deviation	Avg Emix	Emix Deviation	Min Emix	Max Emix
1 Diesel	0,00782	0,00000	0,00000	1,53569	± 0,00069	1,53499	1,53638	2,14825	± 0,00194	2,14631	2,15019
2 Diesel + Air	0,00742	0,00000	0,00040	1,54516	± 0,00127	1,54388	1,54643	2,12200	± 0,00350	2,11851	2,12551
3 Diesel	0,00782	0,00000	0,00000	1,53817	± 0,00544	1,53273	1,54361	2,14133	± 0,01515	2,12626	2,15656
4 Diesl +Air	0,00702	0,00000	0,00080	1,57040	± 0,00122	1,56918	1,57161	2,05434	± 0,00318	2,05116	2,05752
5 Diesel	0,00782	0,00000	0,00000	1,53605	± 0,00051	1,53553	1,53656	2,14724	± 0,00144	2,14580	2,14868
6 Diesel +Air	0,00662	0,00000	0,00120	1,59896	± 0,00180	1,59716	1,60075	1,98161	± 0,00445	1,97717	1,98607
7 Diesel	0,00782	0,00000	0,00000	1,53604	± 0,00051	1,53554	1,53655	2,14726	± 0,00142	2,14585	2,14868
8 Diesel + Air	0,00622	0,00000	0,00160	1,62873	± 0,00303	1,62570	1,63176	1,90981	± 0,00711	1,90273	1,91694
9 Diesel +Air	0,00462	0,00000	0,00320	1,72865	± 0,04256	1,68609	1,77122	1,69541	± 0,08359	1,61491	1,78209
10 Diesel	0,00782	0,00000	0,00000	1,53556	± 0,00057	1,53499	1,53613	2,14860	± 0,00160	2,14700	2,15020
11 Diesel+ Air	0,00542	0,00000	0,00240	1,68103	± 0,01575	1,66528	1,69678	1,79282	± 0,03360	1,75970	1,82690
12 Diesel	0,00782	0,00000	0,00000	1,53515	± 0,00050	1,53465	1,53565	2,14976	± 0,00140	2,14836	2,15116
13 Diesel +water	0,00732	0,00050	0,00000	1,39433	± 0,00195	1,39238	1,39628	2,60591	± 0,00728	2,59864	2,61321
14 Diesel +water +Air5	0,00695	0,00047	0,00040	1,40349	± 0,00092	1,40257	1,40441	2,57201	± 0,00336	2,56865	2,57537
15 Diesel +water	0,00732	0,00050	0,00000	1,39450	± 0,00157	1,39293	1,39607	2,60527	± 0,00587	2,59941	2,61115
16 Diesel +water+Air10	0,00657	0,00045	0,00080	1,42911	± 0,00283	1,42628	1,43194	2,48062	± 0,00983	2,47081	2,49048
17 Disel +water	0,00682	0,00100	0,00000	1,26928	± 0,00151	1,26777	1,27079	3,14468	± 0,00749	3,13720	3,15219
18 Diesel +water +Air5	0,00647	0,00095	0,00040	1,28209	± 0,00155	1,28054	1,28364	3,08215	± 0,00747	3,07470	3,08963
19 Diesel +water	0,00682	0,00100	0,00000	1,26778	± 0,00256	1,26522	1,27034	3,15212	± 0,01273	3,13943	3,16489
20 Diesel +water+Air10	0,00612	0,00090	0,00080	1,31274	± 0,00437	1,30836	1,31711	2,93992	± 0,01960	2,92042	2,95961
21 Diesel +water	0,00682	0,00100	0,00000	1,26759	± 0,00311	1,26449	1,27070	3,15305	± 0,01546	3,13765	3,16857
22 Diesel +water+Air15	0,00577	0,00085	0,00120	1,34694	± 0,00834	1,33860	1,35528	2,79251	± 0,03459	2,75824	2,82742
23 Diesel +water	0,00682	0,00100	0,00000	1,27074	± 0,00315	1,26759	1,27389	3,13744	± 0,01556	3,12194	3,15305

Figure 21 - The collected result from the flow loop test, with the uncertainty calculations.

Additional flow test data can be found in Appendix A.



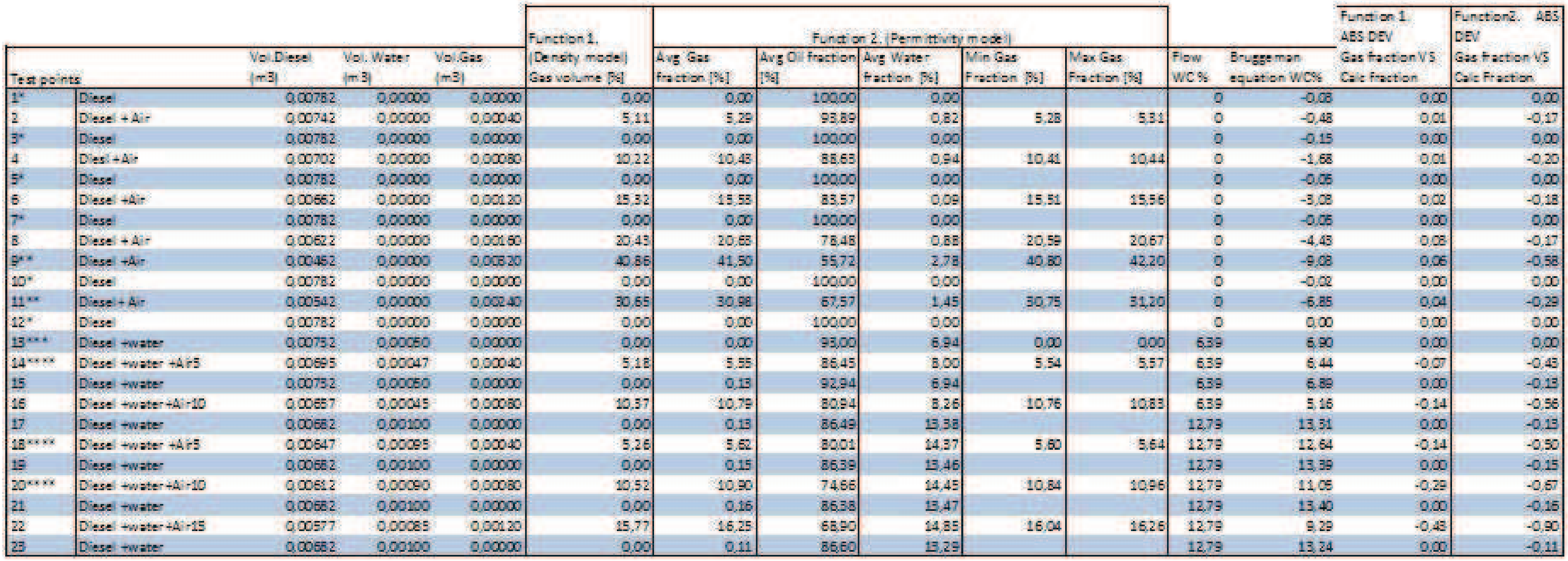
Network analyser S/N: RFM-772-027
Roxar WCM sensor: 2 " Fin sensor
Vacum Frequency: 2,2508445 GHz
Temperatur meter S/N: RFM-772-012

Total volume: 0,00782 m3
Permittivity of gas 1
Permittivity of diesel 2,15
Permittivity of water 64,3
Gas density 1,20 kg/m3
Density of diesel 834,5 kg/m3
Density of water 1026,07 kg/m3
Room temperature at start: 20,9 degC

Test points		Vol.Diesel (m3)	Vol. Water (m3)	Vol.Gas (m3)	Diesel fraction (%)	Water fraction (%)	Gas fraction (%)	Temperature	Calculated mix density
1*	Diesel	0,00782	0,00000	0,00000	100,00	0,00	0,00	21,3	834,50
2	Diesel + Air	0,00742	0,00000	0,00040	94,88	0,00	5,12		791,88
3*	Diesel	0,00782	0,00000	0,00000	100,00	0,00	0,00		834,50
4	Diesl +Air	0,00702	0,00000	0,00080	89,77	0,00	10,23		749,25
5*	Diesel	0,00782	0,00000	0,00000	100,00	0,00	0,00	23,7	834,50
6	Diesel +Air	0,00662	0,00000	0,00120	84,65	0,00	15,35		706,63
7*	Diesel	0,00782	0,00000	0,00000	100,00	0,00	0,00	24,5	834,50
8	Diesel + Air	0,00622	0,00000	0,00160	79,54	0,00	20,46		664,00
9**	Diesel +Air	0,00462	0,00000	0,00320	59,08	0,00	40,92	23,6	493,51
10*	Diesel	0,00782	0,00000	0,00000	100,00	0,00	0,00		834,50
11**	Diesel+ Air	0,00542	0,00000	0,00240	69,31	0,00	30,69	22,6	578,76
12*	Diesel	0,00782	0,00000	0,00000	100,00	0,00	0,00		834,50
13***	Diesel +water	0,00732	0,00050	0,00000	93,61	6,39	0,00		846,75
14****	Diesel +water +Air5	0,00695	0,00047	0,00040	88,82	6,067	5,12	24,5	803,50
15	Diesel +water	0,00732	0,00050	0,00000	93,61	6,39	0,00	24,9	846,75
16	Diesel +water+Air10	0,00657	0,00045	0,00080	84,03	5,74	10,23		760,25
17	Diesel +water	0,00682	0,00100	0,00000	87,21	12,79	0,00		859,00
18****	Diesel +water +Air5	0,00647	0,00095	0,00040	82,75	12,13	5,12	24,9	815,12
19	Diesel +water	0,00682	0,00100	0,00000	87,21	12,79	0,00		859,00
20****	Diesel +water+Air10	0,00612	0,00090	0,00080	78,29	11,48	10,23	24,4	771,24
21	Diesel +water	0,00682	0,00100	0,00000	87,21	12,79	0,00	23,6	859,00
22	Diesel +water+Air15	0,00577	0,00085	0,00120	73,83	10,82	15,35	23,6	727,36
23	Diesel +water	0,00682	0,00100	0,00000	87,21	12,79	0,00	23,9	859,00

Comments:
(Temp. decreased to 18 degC during night)
* Reflooding with diesel
**More and more noise and unstable readings. With increasing gas it was benefical to increase avg. of resonance freq to min 40swp.
*** Used equation of state of sea water salinity calculate. http://fermi.jhuapl.edu/denscalc.html.
****Verified watercut by measuring separted water from extracted diesel on test point[14.18.20]compared with calculated WC%.

Figure 22 - Calculated/ actual gas fraction and calculated / actual mix density.



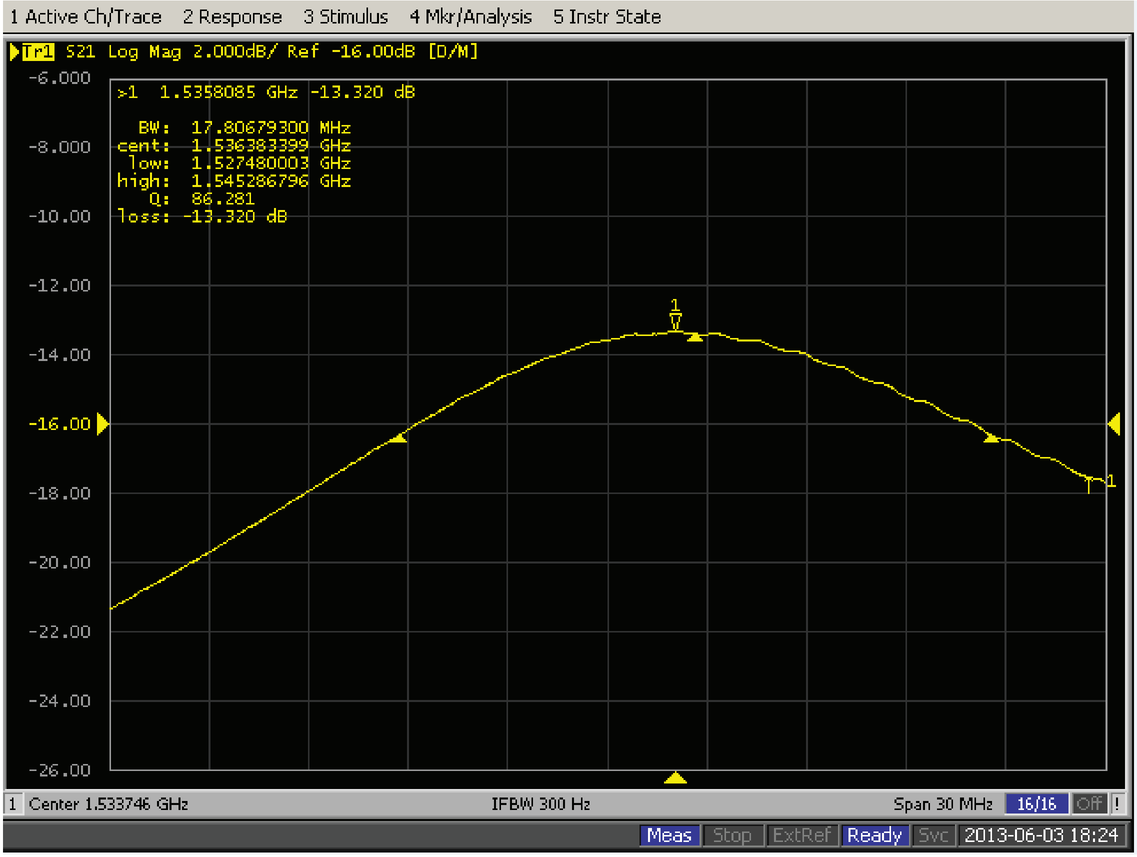
Test points		Vol.Diesel (m3)	Vol. Water (m3)	Vol.Gas (m3)	Function 1. (Density model)	Function 2. (Permittivity model)							Function 1. ABS DEV	Function2. ABS DEV
					Gas volume [%]	Avg Gas fraction [%]	Avg Oil fraction [%]	Avg Water fraction [%]	Min Gas Fraction [%]	Max Gas Fraction [%]	Flow WC %	Bruggeman equation WC%	Gas fraction VS Calc fraction	Gas fraction VS Calc Fraction
1*	Diesel	0,00782	0,00000	0,00000	0,00	0,00	100,00	0,00			0	-0,08	0,00	0,00
2	Diesel + Air	0,00742	0,00000	0,00040	5,11	5,29	93,89	0,82	5,28	5,31	0	-0,48	0,01	-0,17
3*	Diesel	0,00782	0,00000	0,00000	0,00	0,00	100,00	0,00			0	-0,15	0,00	0,00
4	Diesl + Air	0,00702	0,00000	0,00080	10,22	10,43	88,63	0,94	10,41	10,44	0	-1,68	0,01	-0,20
5*	Diesel	0,00782	0,00000	0,00000	0,00	0,00	100,00	0,00			0	-0,05	0,00	0,00
6	Diesel +Air	0,00662	0,00000	0,00120	15,32	15,53	83,57	0,09	15,51	15,56	0	-3,08	0,02	-0,18
7*	Diesel	0,00782	0,00000	0,00000	0,00	0,00	100,00	0,00			0	-0,05	0,00	0,00
8	Diesel + Air	0,00622	0,00000	0,00160	20,43	20,63	78,48	0,88	20,59	20,67	0	-4,43	0,03	-0,17
9**	Diesel +Air	0,00462	0,00000	0,00320	40,86	41,50	55,72	2,78	40,80	42,20	0	-9,08	0,06	-0,58
10*	Diesel	0,00782	0,00000	0,00000	0,00	0,00	100,00	0,00			0	-0,02	0,00	0,00
11**	Diesel + Air	0,00542	0,00000	0,00240	30,65	30,98	67,57	1,45	30,75	31,20	0	-6,85	0,04	-0,29
12*	Diesel	0,00782	0,00000	0,00000	0,00	0,00	100,00	0,00			0	0,00	0,00	0,00
13***	Diesel +water	0,00732	0,00050	0,00000	0,00	0,00	93,00	6,94	0,00	0,00	6,39	6,90	0,00	0,00
14****	Diesel +water +Air5	0,00695	0,00047	0,00040	5,18	5,55	86,45	8,00	5,54	5,57	6,39	6,44	-0,07	-0,43
15	Diesel +water	0,00732	0,00050	0,00000	0,00	0,13	92,94	6,94			6,39	6,89	0,00	-0,13
16	Diesel +water+Air-10	0,00657	0,00045	0,00080	10,37	10,79	80,94	8,26	10,76	10,83	6,39	5,16	-0,14	-0,56
17	Diesel +water	0,00682	0,00100	0,00000	0,00	0,13	86,49	13,38			12,79	13,31	0,00	-0,13
18****	Diesel +water +Air5	0,00647	0,00095	0,00040	5,26	5,62	80,01	14,37	5,60	5,64	12,79	12,64	-0,14	-0,50
19	Diesel +water	0,00682	0,00100	0,00000	0,00	0,15	86,39	13,46			12,79	13,39	0,00	-0,15
20****	Diesel +water+Air-10	0,00612	0,00090	0,00080	10,52	10,90	74,66	14,45	10,84	10,96	12,79	11,05	-0,29	-0,67
21	Diesel +water	0,00682	0,00100	0,00000	0,00	0,16	86,38	13,47			12,79	13,40	0,00	-0,16
22	Diesel +water+Air-15	0,00577	0,00085	0,00120	15,77	16,25	68,90	14,85	16,04	16,26	12,79	9,29	-0,48	-0,90
23	Diesel +water	0,00682	0,00100	0,00000	0,00	0,11	86,60	13,29			12,79	13,24	0,00	-0,11

Figure 23 - Results from software function 1 and 2, and calculated/actual gas fraction VS software function 1 and 2 gas fraction result.

4.2.3 Single-Phase Flow

There was no instrument measuring the flow fractions, it was therefore necessary to control the flow loop fractions manually. By knowing the total volume of the loop and the amount of drained fluid, it was possible to calculate the fractions. Each test points were run until stable conditions, but for a minimum of 5 minutes.

The first test point run was diesel and the resonance frequency was measured and recorded.



```
Tr1 S21 Log Mag 2.000dB/ Ref -16.00dB [D/M]
>1  1.5358085 GHz -13.320 dB

  BW:  17.80679300 MHz
cent:  1.536383399 GHz
 low:  1.527480003 GHz
high:  1.545286796 GHz
   Q:  86.281
loss: -13.320 dB
```

```
1  Center 1.533746 GHz          IFBW 300 Hz          Span 30 MHz  16/16
```

Figure 24 - The measured frequency response of the CFR sensor filled with diesel.

Result /Discussion

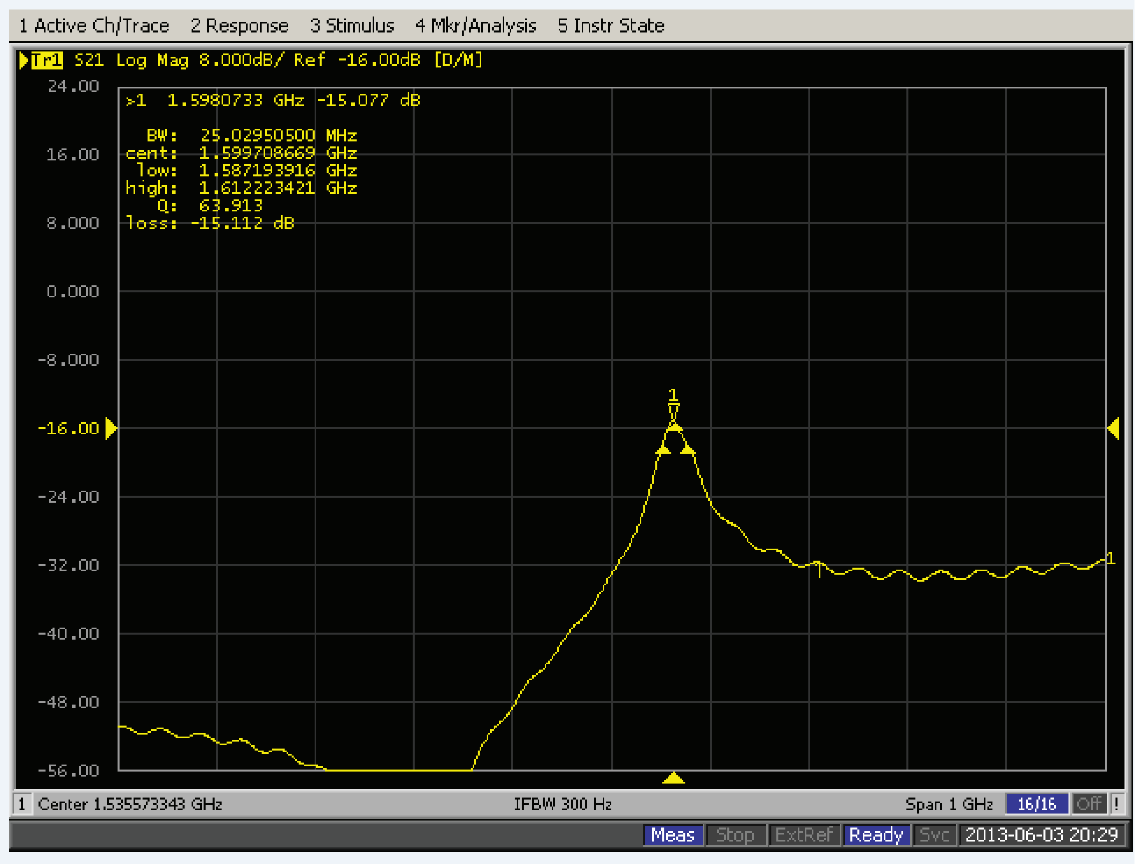
Every second test points from [1-12] as seen in the flow test result in *Figure 21*., are single phase diesel points. The measured resonance frequency on these points did not vary more [±0.540] MHz. This will according to AutoGas function 2, give a deviation of ±[0,2-0,4] abs% of the meter readings for water and oil, and ±[0.05] abs%.for gas

4.2.4 Two-Phase Flow

After each tests point with diesel and gas, the flow loop was then re-filled with the drained diesel, until the fluid sank to the initial start mark on the hose, which indicated a full flow loop and no leakage or loss of diesel. (7.82 liter of only diesel)

The single phase- test point with only diesel was then re-run., this was done in order to minimize uncertainty and improve performance. The first gas point run was two-phase flow (diesel and gas) with 5% GVF, in order to get 5% GVF in the system 0.4 liter of diesel was drained out of the loop. The system was closed and flow was then circulated until it was stable, but for a minimum of 5minutes. The resonance frequency was then measured.

This was repeated until all tests-points with diesel and gas was completed.



```
Tr1 S21 Log Mag 8.000dB/ Ref -16.00dB [D/M]
>1  1.5980733 GHz -15.077 dB

  BW:  25.02950500 MHz
cent:  1.599708669 GHz
 low:  1.587193916 GHz
high:  1.612223421 GHz
   Q:  63.913
loss: -15.112 dB
```

```
1 Center 1.535573343 GHz          IFBW 300 Hz          Span 1 GHz 16/16 Off !
2013-06-03 20:29
```

Figure 25 - The measured frequency response of the CFR sensor filled with diesel and 15% air.

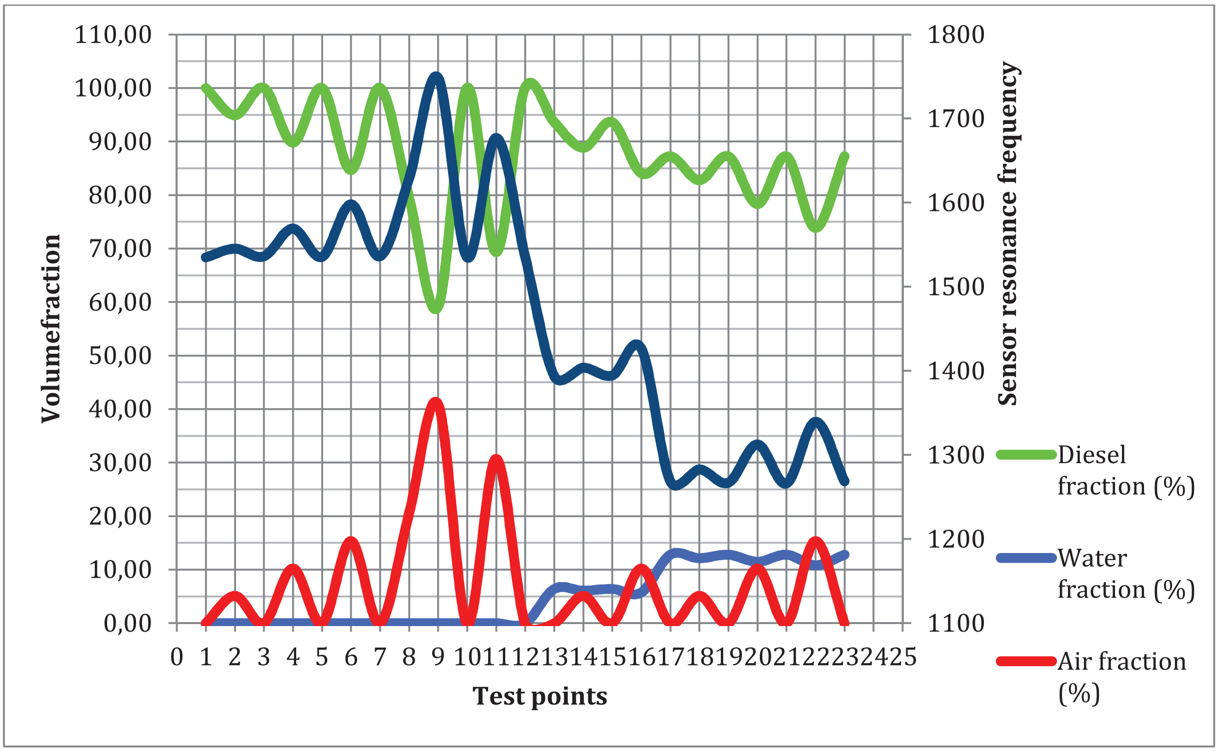


Figure 26 - The change of the resonance frequency due to change of volume fraction.

Result / Discussion

These test points were very interesting with regards to observing the effect of gas on the resonance frequency. As the volume of gas increased the resonance frequency increased this was as expected. The noise in these test points increased with increasing gas fraction and the deviation in these readings also increased. The averaging of the resonance frequency signal was increased in order to compensate for unstability and noise. As seen in flow test result *Figure 21* and *Figure 26*, at 40% GVF the measured resonance frequency varied [±4,256] MHz. This will according to AutoGas function 2, give a deviation of ± [2-4] abs% of the meter readings for water and oil, and ±[0.7] abs%. for gas

4.2.5 Three-Phase Flow

Before water was added to the system, 1 liter of water with temperature of 20 ^{0}C was dissolved with 36.7gram of salt in order to get a water conductivity of 5 S/m, identical to sea water conductivity. The method used for calculating salinity/ water density was equation of state.(Anati, 1999)

Now that salt is dissolved in water and the density of the water is known, a known volume of diesel was drained out and replaced with water. System was closed and the mixture of diesel and water was circulated in the flow loop. It was then circulated until it was stable before the resonance frequency was measured.

Finally test point consisting of three- phase mixture (diesel, water and gas) was run. Started with [6.4] % watercut [5, 10] % GVF. Increase loop mixture to 12.8 % watercut and [5, 10.15] %GVF. After stabilizing the mix of the fluid, a known volume was quickly drained and replaced by air, specifically test points [14 .18.20]. The watercut in the drained fluid was verified by measuring separated water from the extracted fluid and then compared with calculated watercut. The measured watercut had a difference of 0.01% compared with the calculated. The extracted fluid was then re-injected in flow loop, before continuing on next test point.

Result/ Discussion

The mini flow loop made it possible to record repeatable and reliable data. The result is used to verify the new Autogas function 1 and Autogas function 2.

Both AutoGas functions need certain input parameters to work, see chapter 4.

The difference/low deviation in the resonance frequency during the 3phase test point, indicate that the measurements conditions are stable and reliable. The frequency deviation is in the order of [0.1-0.8]MHz. At 10% GVF (Test point:16) the measured resonance frequency varied [±0,283] MHz. This will according to AutoGas function 2, give a deviation of ± [0.3-0.4]abs % of the meter readings for water and oil, and ±[0.08] abs%.for gas.

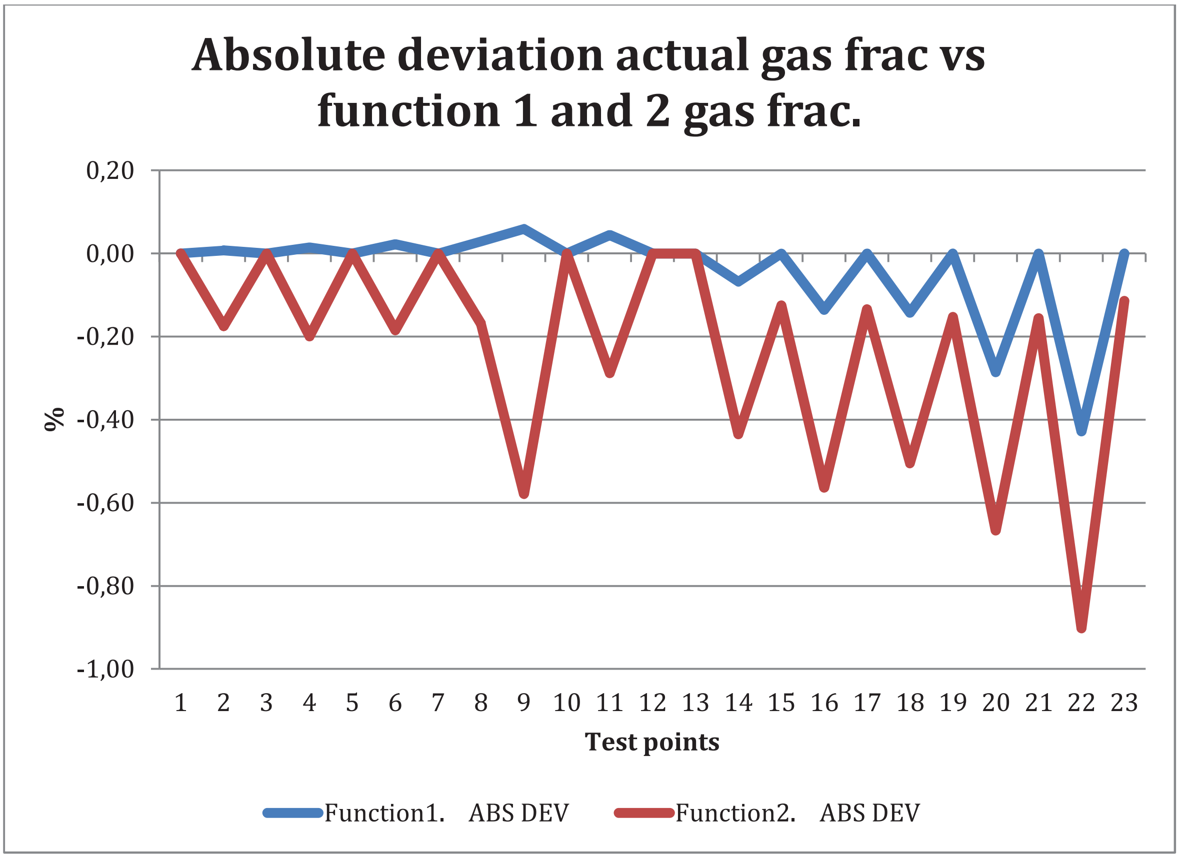


Figure 27 - Absolute deviation actual gas fraction vs. function 1 and 2 gas fractions

As seen in figure above, the test point [1-12] is diesel and gas, function 1 is very stable with low deviation .Function 2 gas points [2,4,6 and 8] have about same deviation ,its observed that a GVF higher than 20% gives increased absolute deviation. The three-phase test points gives increased deviation for both function 1 and 2.Test points whit only water and diesel have a stable deviation even when increasing watercut, but increasing watercut give increased deviation for the gas test points.

5 Conclusion

The purpose of this thesis was:

1. Study what happens with Roxar watercut meter when gas is part of the mixture, and verify the non qualified gas software function in Roxar watercut meter.
2. If necessary and possible develop an improved gas detection function in the Roxar watercut meter.
3. Perform a flow loop test.
4. Investigate the result from the flow loop test and draw conclusion

The result shows that Roxar watercut can measure gas accurately, but some limitations have been observed. Currently there is a limitation in the electronics and the range of the voltage controlled oscillators (VCO). Next generation microwave system, might not have this sweep limitations. In addition its observed that increasing gas fraction, will increase unstability in the meter resonance frequency, and thereby giving increased uncertainty, but this can most likely be improved by averaging or other algorithms. The Autogas function1 have through the results been verified and it performs fine. Autogas function 1 is a density based model, and increased uncertainty in the density from a live density meter will give increased deviations in calculated gas volume. It was observed that a ±5% density change gave about ±[4-5]%abs GVF change.

The AutoGas function2 is based on permittivity and density. The software was working satisfactory, but the result shows that the AutoGas function2 generally has a higher deviation than Autogas function1. The Autogas function2 have the ability to calculate the fraction of gas, water and oil, but it has more required input parameters, which all contribute to the total uncertainty.

The flow loop test planned in advance did not go as planned, due to an accident which occurred in the Roxar flow loop facility. Instead a mini flow was built in the Roxar production facility. All results were valuable, good and consistent as seen in *Figure 21*.

As stated both AutoGas functions are working, and recommendation is to implement both Autogas function1 and 2 in the Roxar watercut meter, and perform dynamical test in real field applications. The results showed that both AutoGas functions will be affected by variations in the density input. Therefore a certain uncertainty/deviations of the live density meter, will add to the uncertainty of the output from the functions. Both functions are behaving similarly, when seeing only a density change.

Further studies:

- It will be interesting to see the effect, if hydrocarbons gases (C1-C6) were used instead of non-hydrocarbon gases (CO2, N2).
- Final Analysis of the Mini Flow Loop
- Perform test with meter electronics vs network analyzer.
- Integrate flow meter, density meter and temperature meter in the test loop.

6 References

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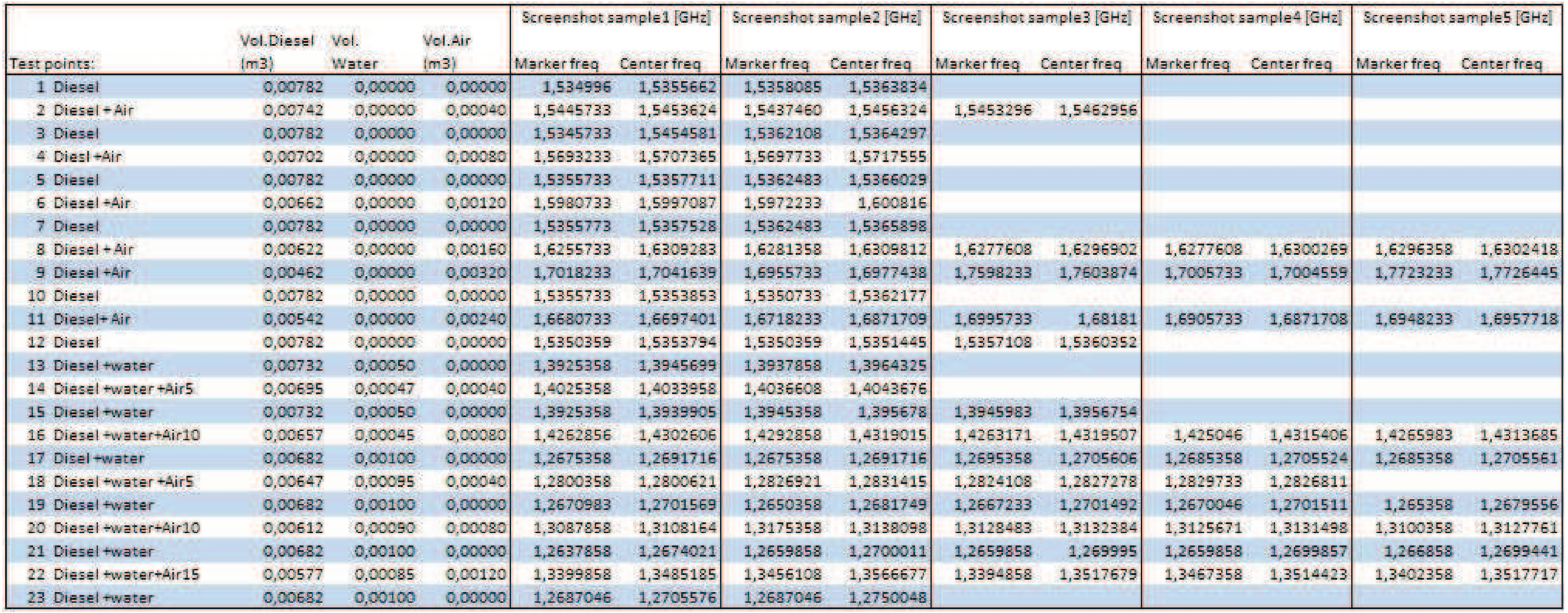
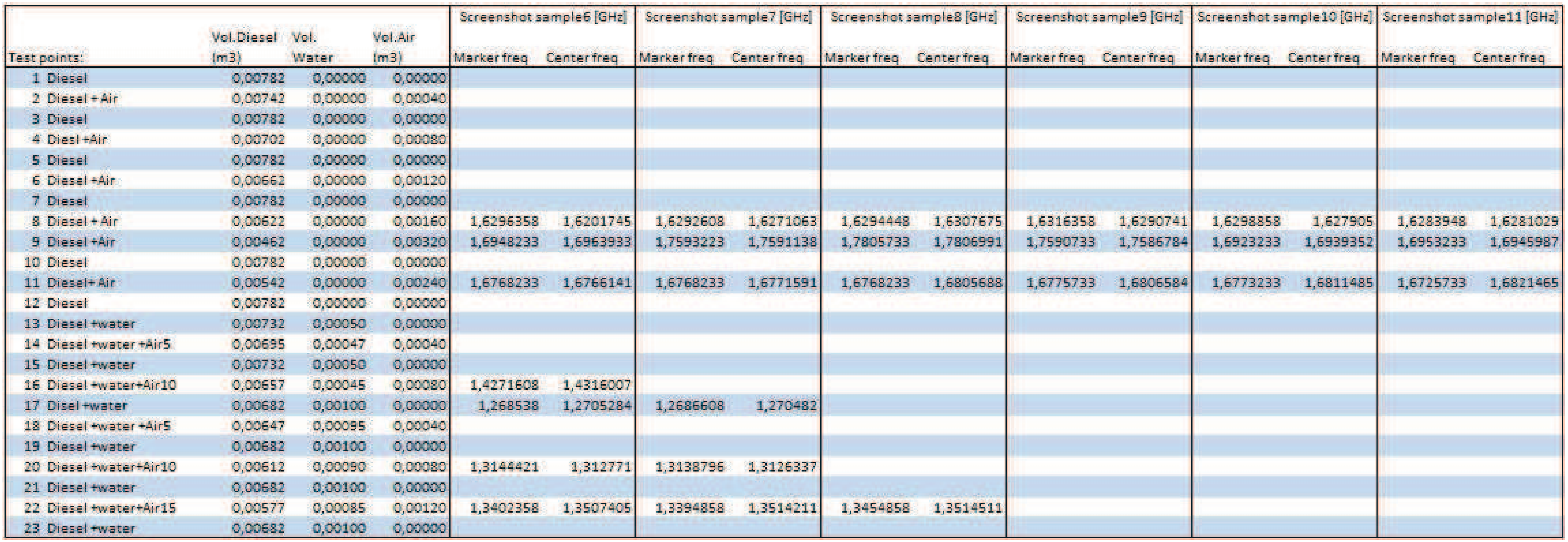
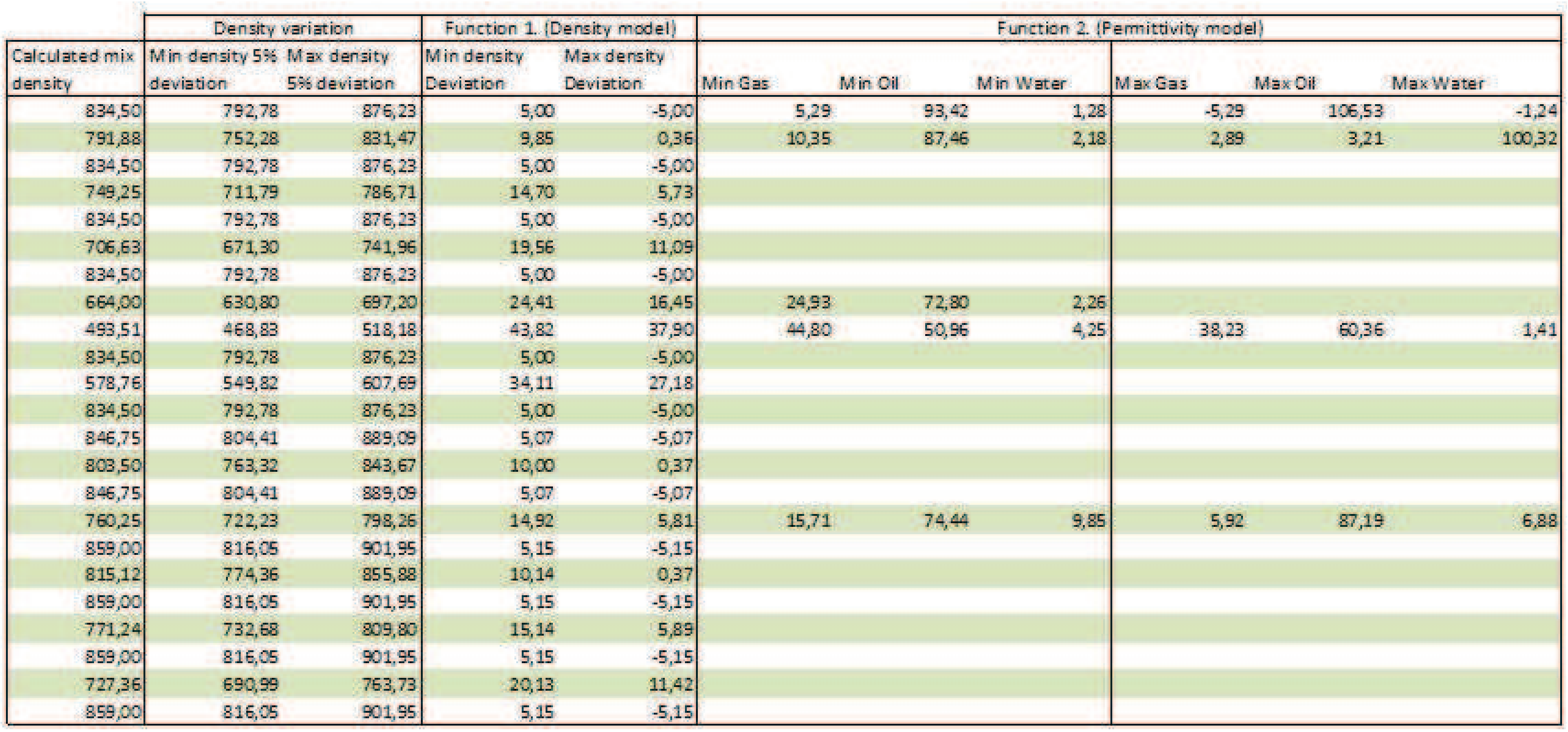
7 APPENDIX A



Test points:	Vol.Diesel (m3)	Vol. Water	Vol.Air (m3)	Screenshot sample1 [GHz]		Screenshot sample2 [GHz]		Screenshot sample3 [GHz]		Screenshot sample4 [GHz]		Screenshot sample5 [GHz]	
				Marker freq	Center freq	Marker freq	Center freq	Marker freq	Center freq	Marker freq	Center freq	Marker freq	Center freq
1 Diesel	0,00782	0,00000	0,00000	1,534996	1,5355662	1,5358085	1,5363834						
2 Diesel + Air	0,00742	0,00000	0,00040	1,5445733	1,5453624	1,5437460	1,5456324	1,5453296	1,5462956				
3 Diesel	0,00782	0,00000	0,00000	1,5345733	1,5454581	1,5362108	1,5364297						
4 Diesl +Air	0,00702	0,00000	0,00080	1,5693233	1,5707365	1,5697733	1,5717555						
5 Diesel	0,00782	0,00000	0,00000	1,5355733	1,5357711	1,5362483	1,5366029						
6 Diesel +Air	0,00662	0,00000	0,00120	1,5980733	1,5997087	1,5972233	1,600816						
7 Diesel	0,00782	0,00000	0,00000	1,5355773	1,5357528	1,5362483	1,5365898						
8 Diesel + Air	0,00622	0,00000	0,00160	1,6255733	1,6309283	1,6281358	1,6309812	1,6277608	1,6296902	1,6277608	1,6300269	1,6296358	1,6302418
9 Diesel +Air	0,00462	0,00000	0,00320	1,7018233	1,7041639	1,6955733	1,6977438	1,7598233	1,7603874	1,7005733	1,7004559	1,7723233	1,7726445
10 Diesel	0,00782	0,00000	0,00000	1,5355733	1,5353853	1,5350733	1,5362177						
11 Diesel+ Air	0,00542	0,00000	0,00240	1,6680733	1,6697401	1,6718233	1,6871709	1,6995733	1,68181	1,6905733	1,6871708	1,6948233	1,6957718
12 Diesel	0,00782	0,00000	0,00000	1,5350359	1,5353794	1,5350359	1,5351445	1,5357108	1,5360352				
13 Diesel +water	0,00732	0,00050	0,00000	1,3925358	1,3945699	1,3937858	1,3964325						
14 Diesel +water +Air5	0,00695	0,00047	0,00040	1,4025358	1,4033958	1,4036608	1,4043676						
15 Diesel +water	0,00732	0,00050	0,00000	1,3925358	1,3939905	1,3945358	1,395678	1,3945983	1,3956754				
16 Diesel +water+Air10	0,00657	0,00045	0,00080	1,4262856	1,4302606	1,4292858	1,4319015	1,4263171	1,4319507	1,425046	1,4315406	1,4265983	1,4313685
17 Disel +water	0,00682	0,00100	0,00000	1,2675358	1,2691716	1,2675358	1,2691716	1,2695358	1,2705606	1,2685358	1,2705524	1,2685358	1,2705561
18 Diesel +water +Air5	0,00647	0,00095	0,00040	1,2800358	1,2800621	1,2826921	1,2831415	1,2824108	1,2827278	1,2829733	1,2826811		
19 Diesel +water	0,00682	0,00100	0,00000	1,2670983	1,2701569	1,2650358	1,2681749	1,2667233	1,2701492	1,2670046	1,2701511	1,265358	1,2679556
20 Diesel +water+Air10	0,00612	0,00090	0,00080	1,3087858	1,3108164	1,3175358	1,3138098	1,3128483	1,3132384	1,3125671	1,3131498	1,3100358	1,3127761
21 Diesel +water	0,00682	0,00100	0,00000	1,2637858	1,2674021	1,2659858	1,2700011	1,2659858	1,269995	1,2659858	1,2699857	1,266858	1,2699441
22 Diesel +water+Air15	0,00577	0,00085	0,00120	1,3399858	1,3485185	1,3456108	1,3566677	1,3394858	1,3517679	1,3467358	1,3514423	1,3402358	1,3517717
23 Diesel +water	0,00682	0,00100	0,00000	1,2687046	1,2705576	1,2687046	1,2750048						



Test points:	Vol.Diesel (m3)	Vol. Water	Vol.Air (m3)	Screenshot sample6 [GHz]		Screenshot sample7 [GHz]		Screenshot sample8 [GHz]		Screenshot sample9 [GHz]		Screenshot sample10 [GHz]		Screenshot sample11 [GHz]	
				Marker freq	Center freq	Marker freq	Center freq	Marker freq	Center freq	Marker freq	Center freq	Marker freq	Center freq	Marker freq	Center freq
1 Diesel	0,00782	0,00000	0,00000												
2 Diesel + Air	0,00742	0,00000	0,00040												
3 Diesel	0,00782	0,00000	0,00000												
4 Diesl +Air	0,00702	0,00000	0,00080												
5 Diesel	0,00782	0,00000	0,00000												
6 Diesel +Air	0,00662	0,00000	0,00120												
7 Diesel	0,00782	0,00000	0,00000												
8 Diesel + Air	0,00622	0,00000	0,00160	1,6296358	1,6201745	1,6292608	1,6271063	1,6294448	1,6307675	1,6316358	1,6290741	1,6298858	1,627905	1,6283948	1,6281029
9 Diesel +Air	0,00462	0,00000	0,00320	1,6948233	1,6963933	1,7593223	1,7591138	1,7805733	1,7806991	1,7590733	1,7586784	1,6923233	1,6939352	1,6953233	1,6945987
10 Diesel	0,00782	0,00000	0,00000												
11 Diesel+ Air	0,00542	0,00000	0,00240	1,6768233	1,6766141	1,6768233	1,6771591	1,6768233	1,6805688	1,6775733	1,6806584	1,6773233	1,6811485	1,6725733	1,6821465
12 Diesel	0,00782	0,00000	0,00000												
13 Diesel +water	0,00732	0,00050	0,00000												
14 Diesel +water +Air5	0,00695	0,00047	0,00040												
15 Diesel +water	0,00732	0,00050	0,00000												
16 Diesel +water+Air10	0,00657	0,00045	0,00080	1,4271608	1,4316007										
17 Disel +water	0,00682	0,00100	0,00000	1,268538	1,2705284	1,2686608	1,270482								
18 Diesel +water +Air5	0,00647	0,00095	0,00040												
19 Diesel +water	0,00682	0,00100	0,00000												
20 Diesel +water+Air10	0,00612	0,00090	0,00080	1,3144421	1,312771	1,3138796	1,3126337								
21 Diesel +water	0,00682	0,00100	0,00000												
22 Diesel +water+Air15	0,00577	0,00085	0,00120	1,3402358	1,3507405	1,3394858	1,3514211	1,3454858	1,3514511						
23 Diesel +water	0,00682	0,00100	0,00000												



	Density variation		Function 1. (Density model)		Function 2. (Permittivity model)					
Calculated mix density	Min density 5% deviation	Max density 5% deviation	Min density Deviation	Max density Deviation	Min Gas	Min Oil	Min Water	Max Gas	Max Oil	Max Water
834,50	792,78	876,23	5,00	-5,00	5,29	93,42	1,28	-5,29	106,53	-1,24
791,88	752,28	831,47	9,85	0,36	10,35	87,46	2,18	2,89	3,21	100,32
834,50	792,78	876,23	5,00	-5,00						
749,25	711,79	786,71	14,70	5,73						
834,50	792,78	876,23	5,00	-5,00						
706,63	671,30	741,96	19,56	11,09						
834,50	792,78	876,23	5,00	-5,00						
664,00	630,80	697,20	24,41	16,45	24,93	72,80	2,26			
493,51	468,83	518,18	43,82	37,90	44,80	50,96	4,25	38,23	60,36	1,41
834,50	792,78	876,23	5,00	-5,00						
578,76	549,82	607,69	34,11	27,18						
834,50	792,78	876,23	5,00	-5,00						
846,75	804,41	889,09	5,07	-5,07						
803,50	763,32	843,67	10,00	0,37						
846,75	804,41	889,09	5,07	-5,07						
760,25	722,23	798,26	14,92	5,81	15,71	74,44	9,85	5,92	87,19	6,88
859,00	816,05	901,95	5,15	-5,15						
815,12	774,36	855,88	10,14	0,37						
859,00	816,05	901,95	5,15	-5,15						
771,24	732,68	809,80	15,14	5,89						
859,00	816,05	901,95	5,15	-5,15						
727,36	690,99	763,73	20,13	11,42						
859,00	816,05	901,95	5,15	-5,15						