PRECISE DETERMINATION OF VOLUME PHASE FRACTION OF IN THREE PHASE MIXTURE USING ELECTROMAGNETIC RESONATING SENSOR

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ABSTRACT: *Phase fraction is one of the methods used in petroleum industry to meter and real time monitoring of oil production and extraction. The present study experiences and develops a new vertical resonant cavity made of Aluminum in vertical flow direction. It depends on measuring the reflected lector-magnetic field scattering parameters (S-parameters) for mixture statically and/ or dynamically in a new best microwave frequency range from 1-6 GHz. The volume fractions of water-oil-gas can be recognized depending on two horizontal shifts in frequency at main and about 5 GHz peaks at constant concentration of salinity and temperature range separately. Results show graduated shifts according to water volume fraction in mixture. The experimental results are confirmed that this non-intrusive and non-invasive sensor can be approved to get phase fraction accurately.*
KEYWORDS: Phase Fraction, Multiphase Oil-Water-Gas, Non-Invasive, Resonant Cavity Sensor.

INTRODUCTION

The flow measurement can be classified into three types, **Thorn R. et al**.
(1) Phase velocity measurement.
(2) Phase density measurement.
(3) Phase fraction measurement.
This study concentrate on the third type of measurement (real time and on line). The measurement should be done on oil wells production of mixed oil-water-gas multiphase without the neediness to a phase separation technique, **Hewitt G. F. et al.** The phase fraction can be identified as the percent ratio occupied by a phase within a multiphase mixture existed inside a specified geometry, **Crowe C. T**.

The present methods of measuring phase fraction are:
(1) Gamma Ray Attenuation.
(2) Electrical Impedance.
(3) Coriolis Mass Flow Meter.
(4) Nuclear Magnetic Resonance.
(5) Electromagnetic Wave Technique.

In the present work, the electromagnetic waves technique is chosen for multiphase oil-water-gas fraction measurement.

The literature survey for the current methods of measuring multiphase fraction from comparison regions are discussed as follows,

Z.Y. Wang et al. have analyzed the characteristics of multiphase oil-gas-water flowing through large cross-sectional-areas upward vertically using mini-conductance/ vertical electrode sensor. The study showed that the increase of oil to total liquid flow rate made the pattern of slug occurred at low gas flow-rates. The effect of increasing cross-sectional-area with reduced velocity will drop the phase inversion to be at higher flow ratios and vice versa. They investigate that any change in signal will present criteria for three phase characteristics. Also the study showed that a multiphase mixture has a high complexity and still much research work is required. The work could give a simple explanation of transition of a model in three phase flow. Whilst the theoretical analysis not adequate to solve such complexity.

Domenico Strazza et al. measured the two phase hold-up of inducting water bounded by oil at high viscosity. The developed probe examined to be used when inducting or conducting water. The conducting tests help to get accurate measures. The causes of the uncertainty of measures are investigated using a new model. This physical model help to design new electrodes for future work in multiphase mixtures which makes it developed by using multi-plates in concaved electrode.

Ajmal Shah et al. have studied the steam-water two phase flows numerically and experimentally. The liquid-gas volume fraction is measured experimentally using gamma ray densitometer technology. Validation of experimental work is done by using Fluent Eulerian method simulation suitable for multiphase mixtures. The simulated model contained researcher direct-contact- condensation model for improvement. A good agreement between the experimental and theoretical (simulation) results were shown. Main problem is complexity in the transport phenomena involved in steam jet pump.

Chao Tan et al. have measured the fraction percent of a two phase oil-water mixture flowing horizontally using a combination of cone meter and conductance on a ring sensor. The study focused to find a new method to identify the flow pattern and the phase fraction. Theoretically they estimated the flow rate depending on this combination technology. The study concentrated on a specified case of mixture in flow, but can be improved in future to include liquid-gas two phase estimation and also could be used for vertical direction flow. The researchers suggested a modification should be done on the sensor and its fusion process and on algorithm required.

Marco Joseda Silva and Uwe Hampel have examined a new method to visualize the three phase liquid-liquid-gas mixture using capacitance wire mesh sensor. It was the first invention in three phase visualization with this sensor type. The experimental results observed well the mixture of oil-water-gas at high resolution regardless of space or time. The images gave valuable information in quality for more investigation in future which needed deeper study with this type of sensor from the side of performance and limitations.

Yu.P. Filippov et al. have studied the effect of temperature in a model to explain salty water in oil two phase mixture. They used a combination of narrow device with

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radio frequency sensor. They introduce the effect of temperature in an old salty water-oil model done by researcher to get higher accuracy. The introduced temperature had shifted the resonant frequency

El Abd has made a comparison between two methods used to measure gas volume fraction of a two phase mixture. The tested methods in study were scattering using gamma ray with transmission, traditional Compton and Compton-Compton methods. The results showed a higher accuracy by Compton-Compton scattering method than the others. The designed device was simple and much safe from radiation that lead to lower the shielding. The device could be used for gamma ray demonstration. The method was suggested to be applied for other flow patterns in future.
Zhao An et al. have measured two phase hold-up of oil and water flowing horizontally. They used a sensor with concaved capacitor. They calculated the static response for different flow patterns and optimize the sensor. They conducted experiment to study the characteristics of the concave capacitance sensor. The sensor showed good performance for the dispersion of water in oil flow. The sensor has high sensitivity when the oil holdup is larger than 60%.The response of concaved capacitance sensor for six different oil–water flow of two phase horizontal model. Different patterns of flow were presented by using mini conductance array probes and the oil-holdup was obtained through the quick closing valve. The measured results indicated that, the optimized concave capacitance sensor has poor sensitivity for static and dynamic dispersion of water and oil in water but showed good performance for other flow patterns especially for dispersed static and dynamic water in oil with high oil holdup.

Chao Tan et al. have measured oil-water two phase flow using conductance ring coupled cone CRCC meter. The CRCC meter used utilized the spatial characteristics of the coupled cone and conductance rings to achieve more reliable estimations on flow rate and phase fraction. The sizes of instruments were jointly optimized considering the overall pressure drop and sensitivity of electrical sensing field. The device was fabricated for static calibration and dynamic liquid-liquid (water and oil) mixture tests. The dynamic results of experiments showed that the proposed CRCC can deliver inferences on volume fraction of phase and individual flow rate with an associated average relative error below 5% after easy calibration. If a flow of two phase water and oil enters annular channel, phase occupation might have changed compared with in the full pipe cross-sectional-area. This may cause to change inversion point of phase, although the phase fraction remains the same, and further affected the measurement range of conductance rings. This was, however, a complicated issue which needed further investigation and understanding on the whole process. However, the proposed structure of CRCC provided a new way of integrating different measuring techniques for multiphase flow measurement such as it improve to include two phase of liquid and gas mixtures.

Current methods of monitoring cannot measure the mix as accurate as required due to limitation of technology. They are using intrusion and invasive techniques, which lead to a higher pressure drop and inaccurate readings because of corrosion and direct

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exposition to flow throughout the pipe. Moreover the reviewed techniques are limited to two phase liquid-liquid or liquid-gas phases. This study constrains on reflected S-Parameters interpretation when a phase-change fraction variation takes place with actually three phase liquid-liquid-gas mixture and exercising them on a sensitive frequency range to these changes, the detailed analysis of the spectrum has shown that frequencies higher than 6 GHz results in complex modes and can be ignored. Any frequency below 1 GHz has more noise than information and can be omitted as well. The spectrum between the frequency ranges of 1-6 GHz defines district peaks and used in further experimentation. Multiphase meters measurements based on the flow permittivity, and are affected by changes in the salinity of water phase and temperature of mixture. This is due to the strong relationship between the water permittivity and the conductivity, hence the salinity and temperature.

Microwave Spectroscopy

Microwave spectroscopy utilizes the transmission, reflection, absorption and scattering of Electromagnetic (EM) waves to study the materials and species. Any change in the rotational energy of the molecules is reflected through microwave frequencies in the range of 300 MHz to 300 GHz. They are related to the structure of the molecules in solids, liquids, gases and suspensions. Interaction of microwaves with materials is best perceived through the use of cavity sensors that can analysis the entire sample at once.

In order to measure the phase fractions in multiphase system the measurement were first taken over the full spectrum of 1-6 GHz. The detailed analysis of the spectrum has shown that frequencies higher than 6 GHz results in complex modes and can be ignored. Any frequency below 1 GHz has more noise than information and can be omitted as well. The spectrum between the frequency ranges of 1-6 GHz defines district peaks and used in further experimentation. This paper focuses on using microwave spectroscopy as a method to measure the phase fractions on three phase system of water, oil and gas in concentration of 0-35000 PPM (parts per million) or 5-60 ^{o}C of mixture temperature range. The measurements are taken at 10% increase in each of water and oil contents keeping the gas phase constant at 20%. The measurements are taken using non-invasive and non- intrusive resonant cavity based microwave sensor made of Aluminum as shown in figure (1).

Experimental set-up and Sample Preparation

The experimental set-up consisted of a cylinder cavity with an inside diameter of 8.9 cm, and height of 9.8 cm (see Figure 1). Sample tubes made of polypropylene were used to test the material inside the cavity. The cavity sensor was connected to Agilent network analyzer with a frequency range of 500 MHz to 20 GHz. The microwave energy was launched into the waveguide from port 1. Both the transmitted and reflected power was measured. However, the results from the reflected power were more promising and hence were used in further experimentation and discussed in this paper. The reflected power was captured and the data stored inside the analyzer for further analysis. Samples of saline water solution were prepared by adding Sodium Chloride (NaCl) to distilled water in a concentration of 0 to 35000 PPM with 5000

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PPM step change once and heated the samples from 5 ℃ to 60 ℃ temperature range with 5 ℃ other time to identify these changes. The samples were then tested as a single phase material as well as in three phase system of water, oil and gas (air) in different percentages i.e. 10-60% with 10% increase in its fraction between the samples. For each of the sample the percentage fraction of gas phase was fixed at 20% of the total sample whereas the percentage fraction of oil was decreased by 10% for each corresponding 10% increase in the water percentage as shown in table (1).

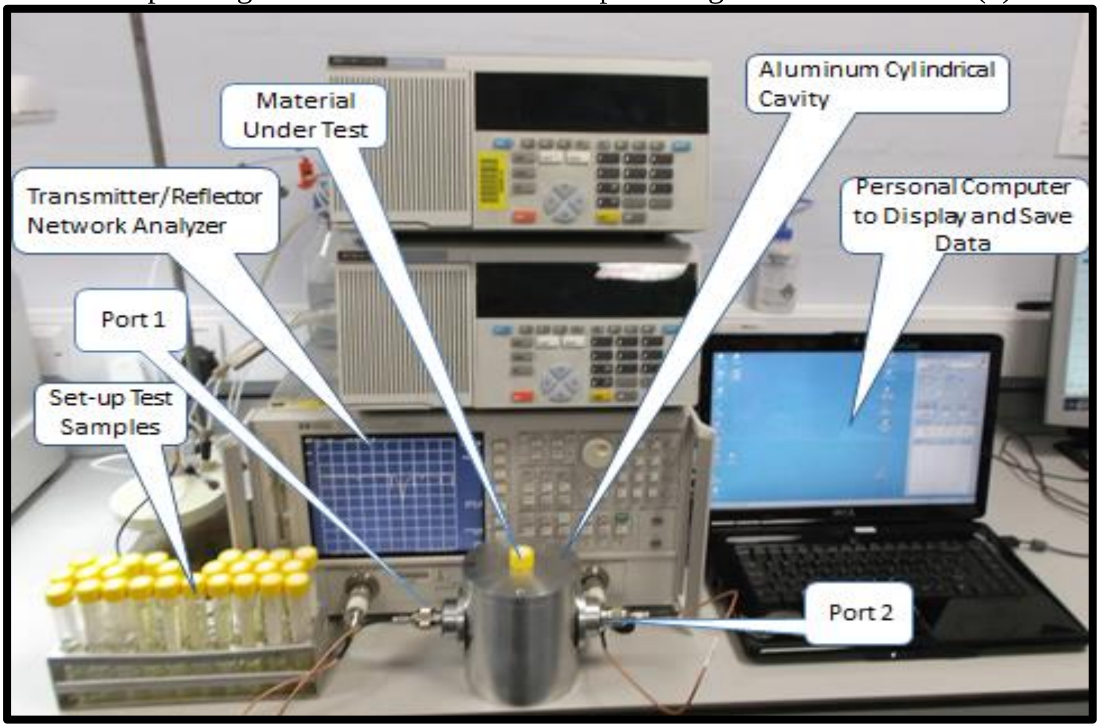

Figure 1: Experimental setup of microwave based measurement system using cylindrical cavity.

Figure 2: Ports 1 &2 with loop antenna at each one inside the cavity.

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Figure 3: Samples with water oil gas mixture preparation.

Table 1: List of samples prepared and tested in the microwave sensor

Volume Fraction of prepared samples				
Sample #	**Water%**	**Range of Variation**	**Oil%**	**Gas%**
1	**100**	**Salinity: 0-35,000 PPM or Temperature: 5-60 °C**	**0**	**0**
2	**10**		**70**	**20**
3	**20**		**60**	**20**
4	**30**		**50**	**20**
5	**40**		**40**	**20**
6	**50**		**30**	**20**
7	**60**		**20**	**20**

Simply after the completion of experimental setup arrangements especially the calibration procedure discussed in chapter four previously, the setup must be powered and test samples made ready. The tests began with a single water or oil or gas, respectively, to verify the difference of measured results between these single phases clearly.

RESULTS & DISCUSSION

Experimental results

These scattered (S_{11}) results represent a relation between the power in dB (watt) and frequency. These can be displayed directly on the VNA as a rectangular graph. The resonant frequencies can be seen as downward peaks. The peaks differed from each other depending on,

- Type of phase (single, double multi)
- Phase contents
- Salinity effect
- Temperature effect
- Pressure effect

When any one of the above factors are applied to tested sample a shift in the resonant frequencies will take place in two types,

(1) Horizontally in frequency.
(2) Vertically in power.

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The information available in literature was preferred on the horizontal one because of ability of frequency to be changed in a wide range. Never the less the vertical shift is used for results confirmation.

The multiphase results are executed at different salinity contents and different mixture temperature separately. The results experienced two types of horizontal peak shifts namely:-

(1) Main (4 GHz) peak shift in frequency.

(2) Around 5 GHz peak shift in frequency.

Normally all other peaks seen in figures are not resonant (peaks that change with any conditional change).

The experimental results show a clear relationship between the phase change in multiphase mixture and frequency shifting in the two peaks of the reflecting S-parameters S_{11}. These frequency shifting is directly proportional to any phase change of either volumetric contents of oil or water or gas (air).

Figures 4-a, 5-a, 6-a and 7-a show the location of main peak in the S_{11} measurements for pure water single phase and with one chosen multiphase of full range of measurements (40% water, 40% oil and fixed 20% gas) volumetric fractions to be present in this paper. The figures show a clear shifting in the frequency of these S_{11} results.

Figures 4-b, 5-b, 6-b and 7-b show the location of around 5 GHz frequency peak in the S_{11} measurements for pure water single phase and multiphase mixture with same volumetric factions mentioned above. Again a graduated shifting in frequency takes place in this peak with phase percent content change.

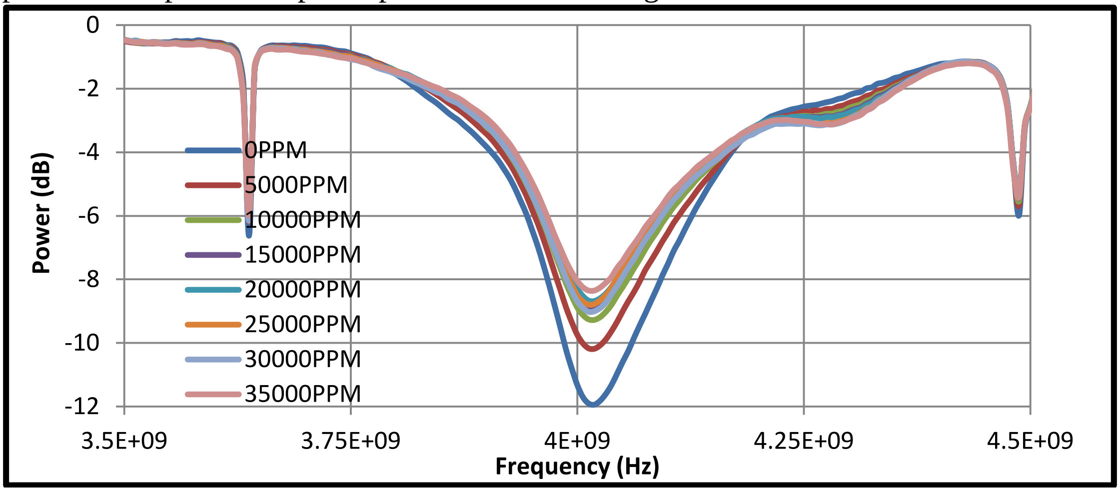

Figure 4-a: Experimental Reflected S-Parameter for different salinity of water-single phase at 3.5-4.5 GHz.

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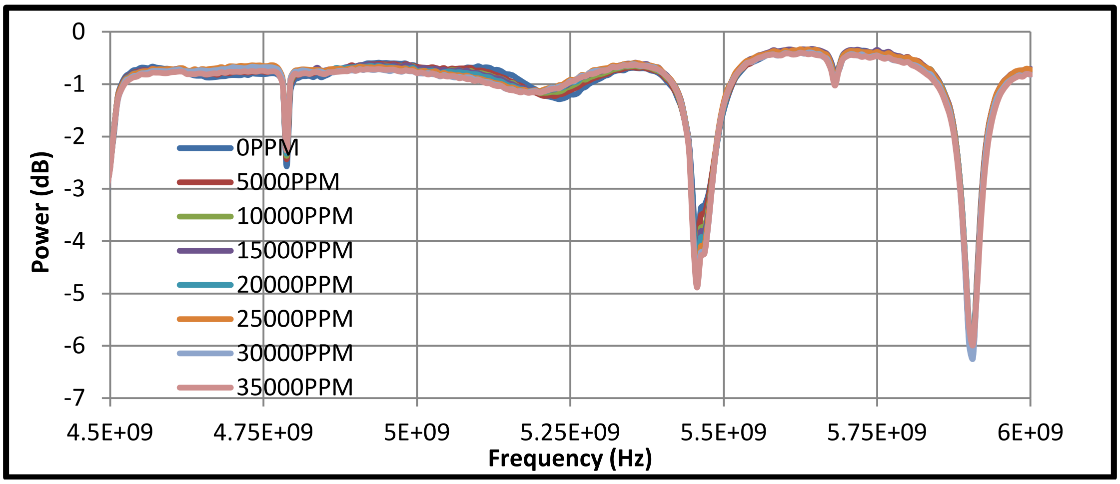

Figure 4-b: Experimental Reflected S-Parameter for different salinity of water-single phase at 4.5-6 GHz.

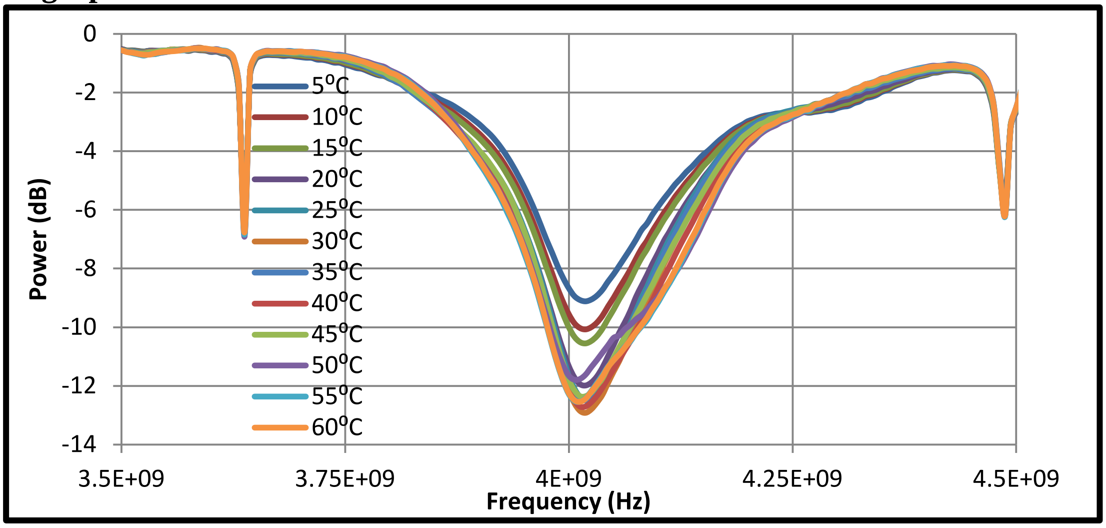

Figure 5-a: Experimental Reflected S-Parameter for different temperatures water-single phase at 3.5-4.5 GHz.

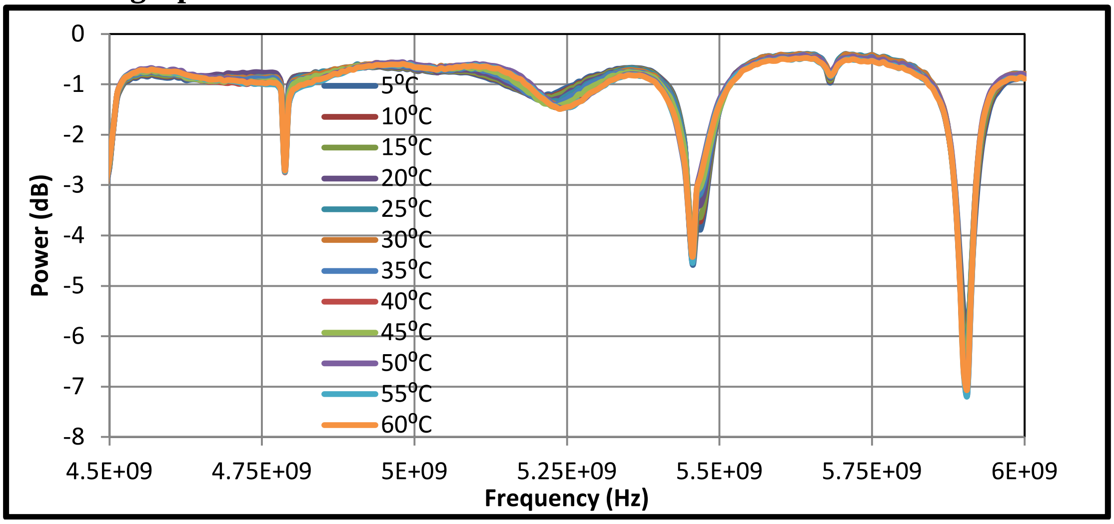

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Figure 5-b: Experimental Reflected S-Parameter for different temperatures water-single phase at 4.5-6 GHz.

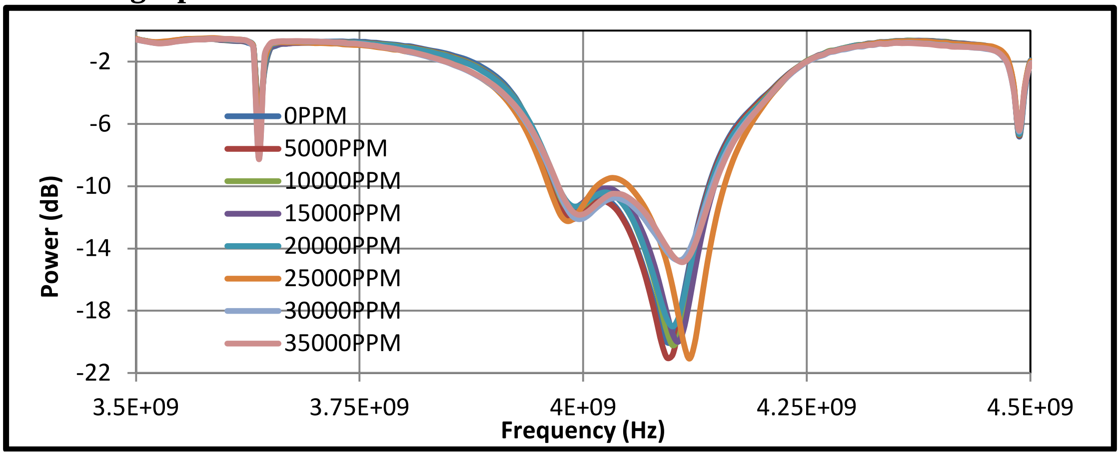

Figure 6-a: Experimental Reflected S-Parameter for different tested salinity and 40% water, 40% oil and 20% gas three phase at 3.5-4.5 GHz.

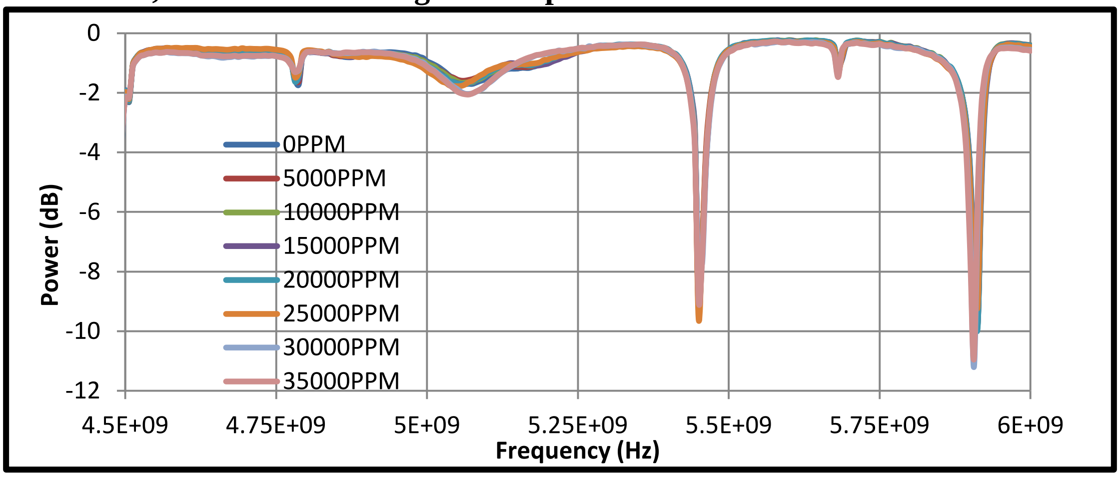

Figure 6-b: Experimental Reflected S-Parameter for different tested salinity and 40% water, 40% oil and 20% gas three phase at 4.5-6 GHz.

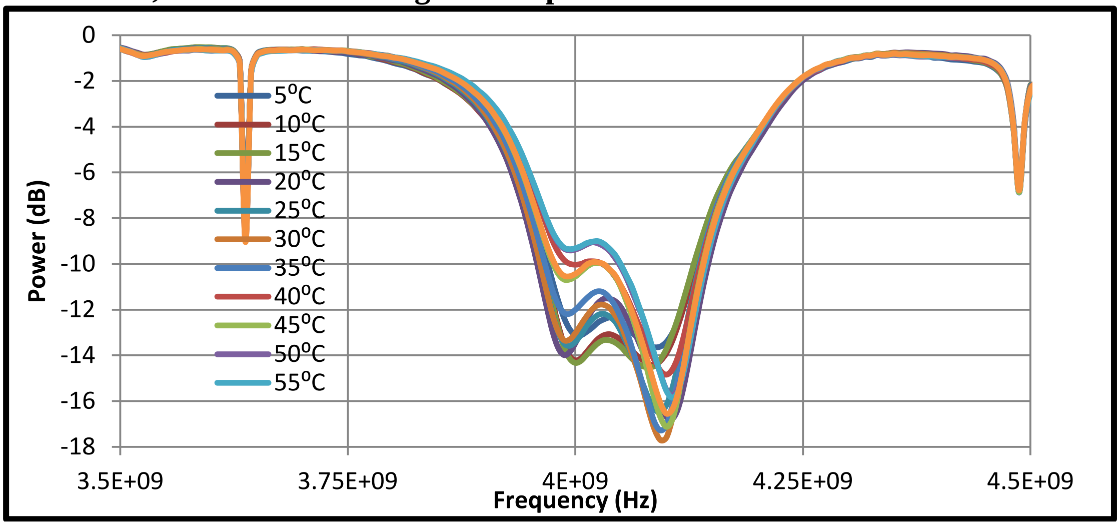

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Figure 7-a: Experimental Reflected S-Parameter for different tested temperatures and 40% water, 40% oil and 20% gas three phase at 3.5-4.5 GHz.

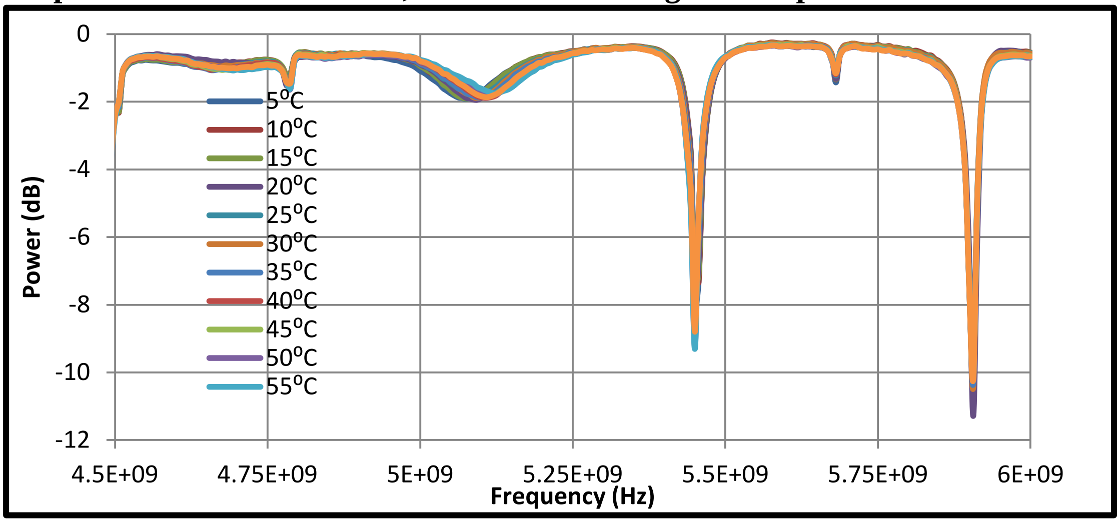

Figure 7-b: Experimental Reflected S-Parameter for different tested temperatures and 40% water, 40% oil and 20% gas three phase at 4.5-6 GHz.
The resume of these frequency shifting of each peak are shown in table 2 and 3.

Table 2: Frequency S_{11} Shifts with Salinity Variation at Different Water-Oil-Gas Fractions.

Volume Fraction			S_{11} Main Peak Frequency GHz		S_{11} Around 5 GHz Peak Frequency GHz	
Water%	Oil %	Gas %	0 PPM	35000 PPM	0 PPM	35000 PPM
10	70	20	3.95680	3.95353	4.88044	4.94457
20	60	20	3.96512	3.96070	4.94749	4.95272
30	50	20	3.97346	3.98045	5.01157	5.03935
40	40	20	3.98483	3.99540	5.07356	5.06457
50	30	20	3.99534	4.00233	5.10417	5.06713
60	20	20	4.00138	4.00923	5.11547	5.06813
100	0	0	4.01803	4.01461	5.23469	5.19242

Table 3: Frequency S_{11} Shifts with Temperature Variation at Different Water-Oil-Gas Fractions.

Volume Fraction			S_{11} Main Peak Frequency GHz		S_{11} Around 5 GHz Peak Frequency GHz	
Water%	Oil %	Gas %	5 °C	60 °C	5 °C	60 °C
10	70	20	3.95693	3.95545	4.950	4.950
20	60	20	3.96823	3.96584	4.955	4.953
30	50	20	3.98317	3.99837	5.058	5.063
40	40	20	4.00246	3.99016	5.071	5.108
50	30	20	4.01328	3.99526	5.079	5.125
60	20	20	4.01214	3.99757	5.085	5.129
100	0	0	4.018199	4.011973	5.20652	5.23913

Relation between water volume fraction in the multiphase oil-water-gas mixture with frequency measurements for two type of the peaks are shown in figures 8 and 9 at fixed salinity contents of 0 and 35000 PPM (parts per million). The same above relation are repeated in figures 10 and 11 but with fixed temperature of 5 and 60 °C.

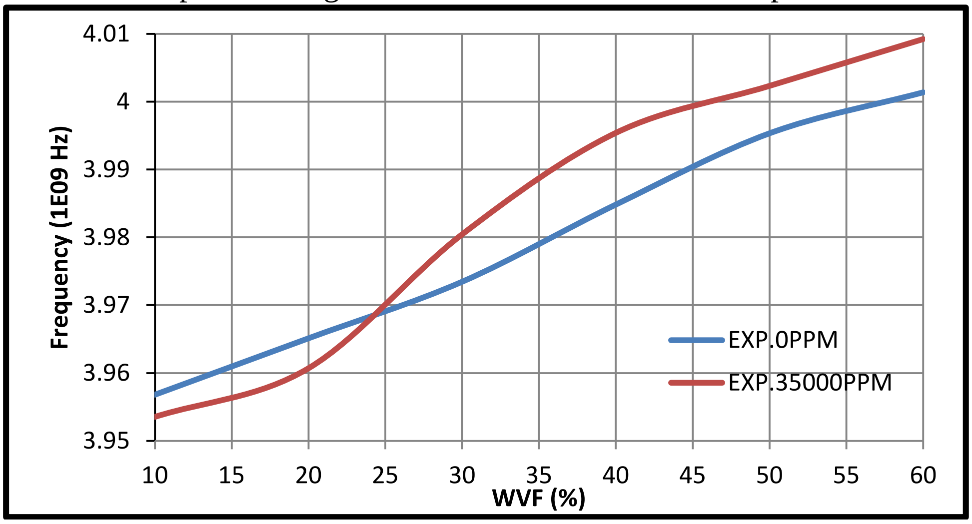

Figure 8: Frequency shift of experimental and reflected S-parameter (main peak) for (10-60%) water, (70-20%) oil and fixed 20% gas mixture at different salinity contents.

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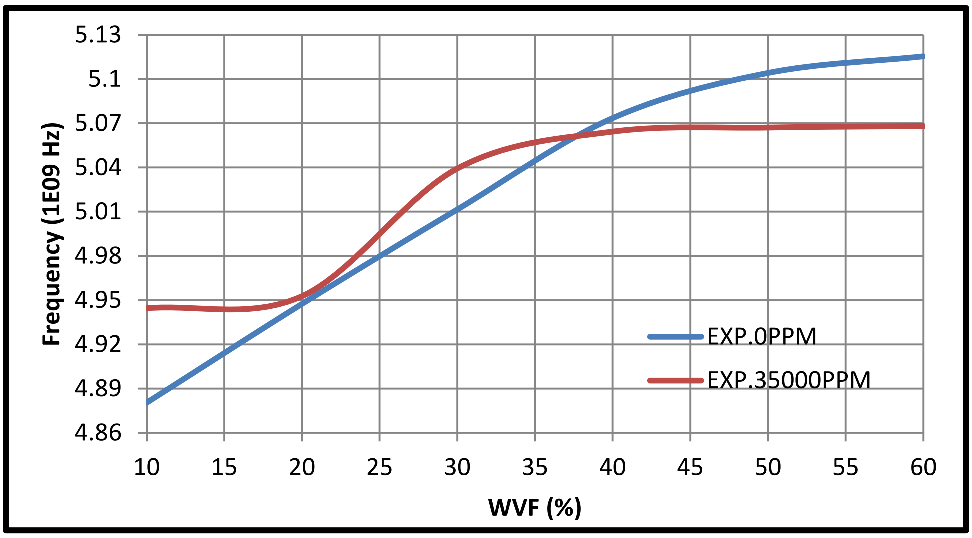

Figure 9: Frequency shift of experimental and reflected S-parameter (around 5 GHz Peak) for (10-60%) water, (70-20%) oil and fixed 20% gas mixture at different salinity contents.

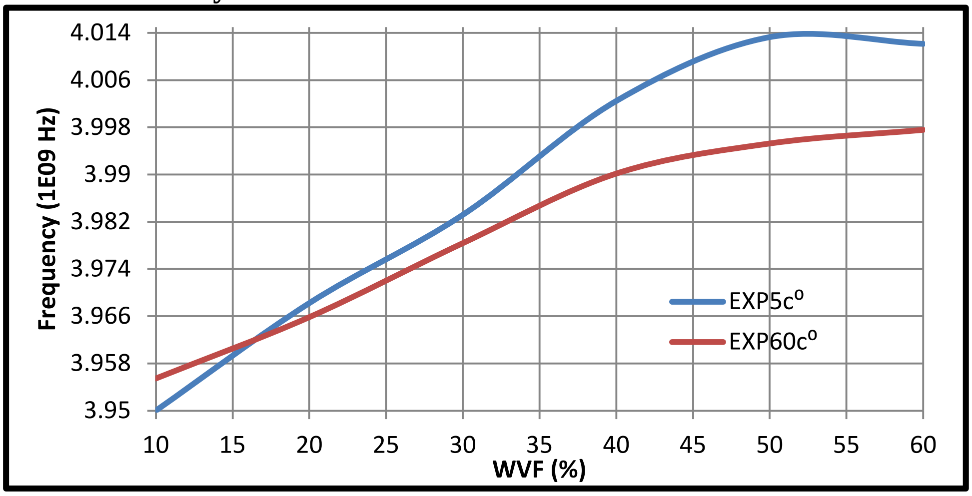

Figure 10: Frequency shift of experimental and reflected S-parameter (main peak) for (10-60%) water, (70-20%) oil and fixed 20% gas mixture at different temperature range.

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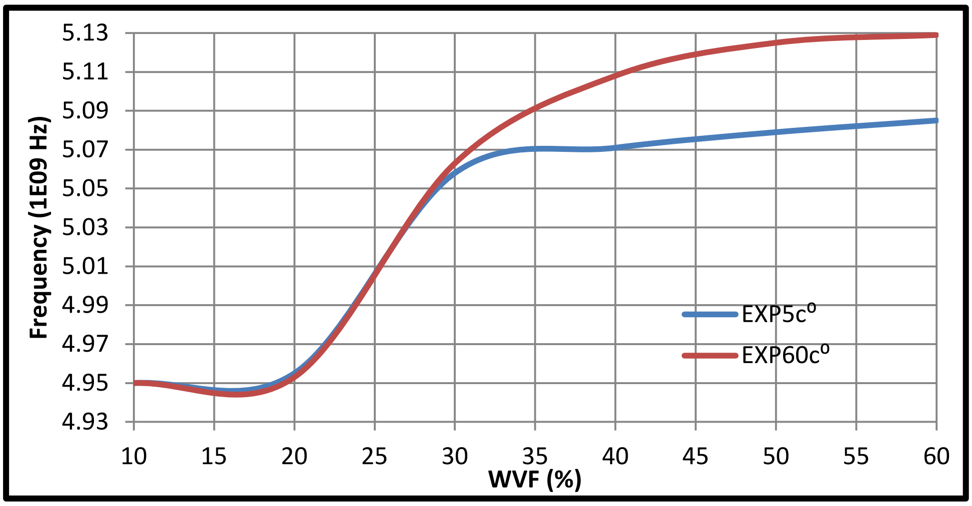

Figure 11: Frequency shift of experimental and reflected S-parameter (around 5 GHz Peak) for (10-60%) water, (70-20%) oil and fixed 20% gas mixture at different temperature range.

Empirical Formulation Results

The behavior of S_{11} results is estimated empirically from experimental data to have a complete picture of S_{11} parameter change as phase fraction or salinity content or temperature difference. Empirical equation which represents the S_{11} relation at different phase fraction is:

$$f = a \cdot (WVF)^{b} \qquad \dots (1)$$

Where **f** is frequency and **WVF** is water volume fraction in mixture. Values of a, b constants are shown in table 4.

Table 4: Empirical Constants.

Type	S_{11} Main Peak		S_{11} Around 5 GHz	
	Values of a	Values of b	Values of a	Values of b
0 PPM Salinity	3.9748	0.0020	4.5654	0.028
35000 PPM Salinity	3.7543	0.0201	4.7499	0.0164
5 °C Temperature	3.8606	0.0095	4.7412	0.01
60 °C Temperature	3.8952	0.0064	4.6673	0.0234

CONCLUSIONS

The conclusions can be summarized as follows,

(a) For the three phase water-oil-gas stepped by 10 percent change in water and oil, fixed 20 percent gas experimental analysis, the effect of phase content change at constant saline concentration causes,

(1) Graduated frequency increase of S_{11} with increased WVF (Water volume fraction) in the main peak.

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(2) Graduated frequency increase of S_{11} with increased WVF in the around 5 GHz frequency peak.

(b) The study introduce the S_{11} real time monitoring guide between 3.5-6 GHz frequency as a standardized method to specify the water-oil-gas phase content from the comparison with the studied two peaks and profiles.

(c) The measuring method used in the study has a low power consumption within 0 dB (1.0 milliWatt), which is applicable for safety requirements.

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