# Measurement of Water Volume Fraction in Oil-water Upward Flow by Using Microwave Cylindrical Resonant Cavity


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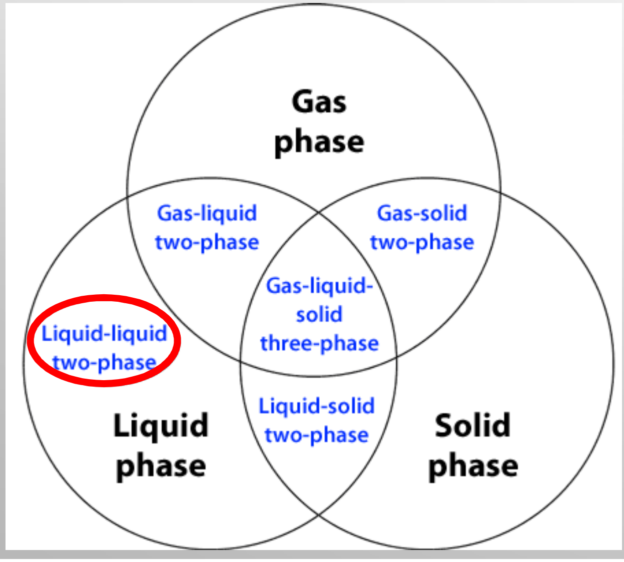
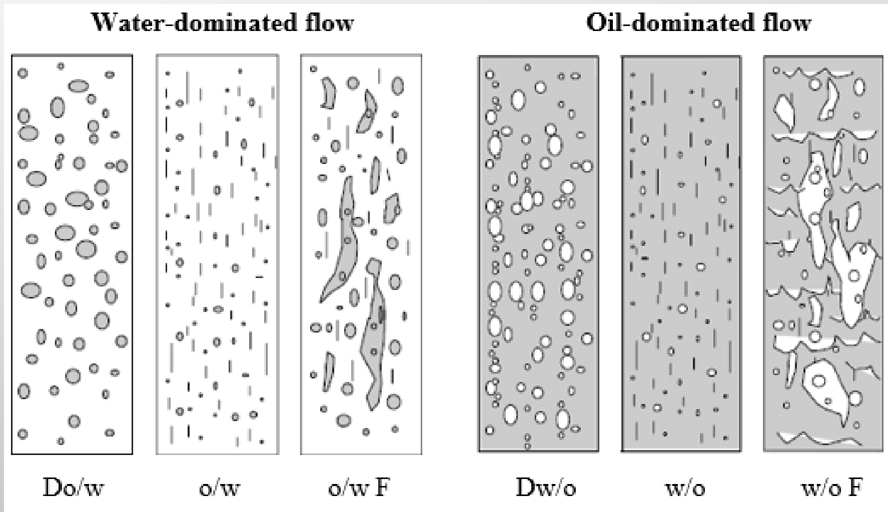
# CONTENT

# OIL-WATER TWO-PHASE FLOW




(Katsutaka O)




(Abduvayt P et al., 2004)

# MICROWAVE



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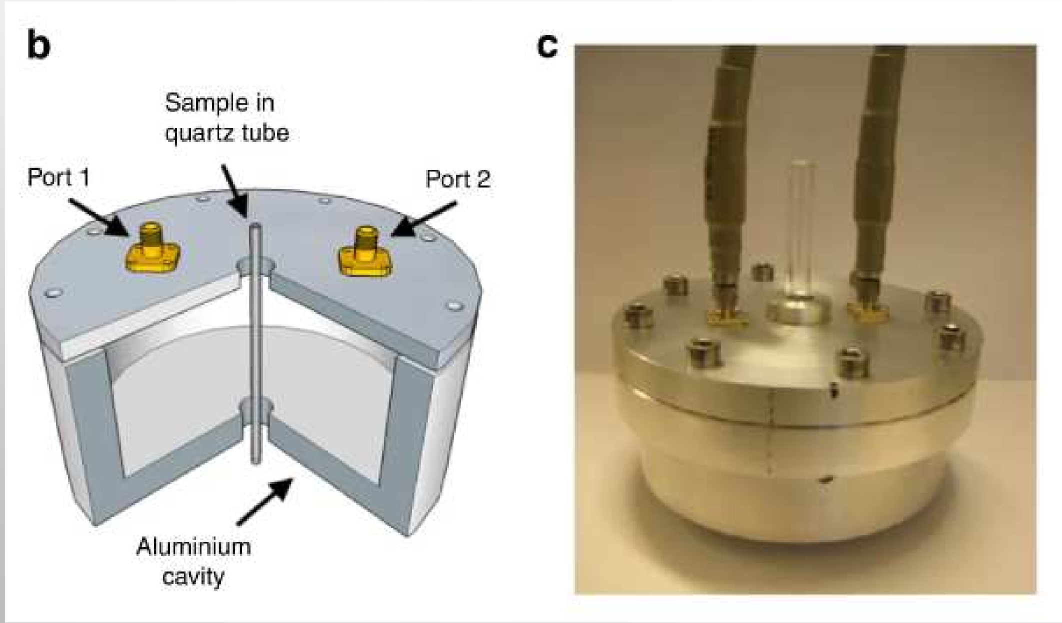
# What is resonant cavity?

A resonant cavity is a volume enclosed by metal walls that supports an electromagnetic oscillation.




(Liu, B., et al. 2017)

# Microwave resonant cavity

## Some main resonant modes of cylindrical cavity

TM（transverse magnetic）& TE（transverse electronic）

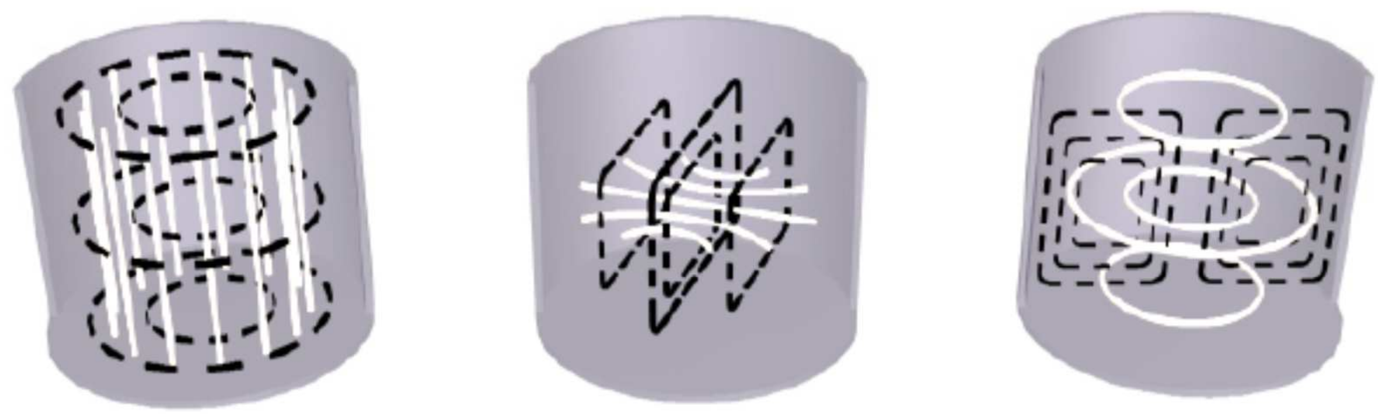



**Figure 2.** Main modes for a cylindrical cavity.

(Wylie, S R et al. 2006)

# Microwave resonant cavity

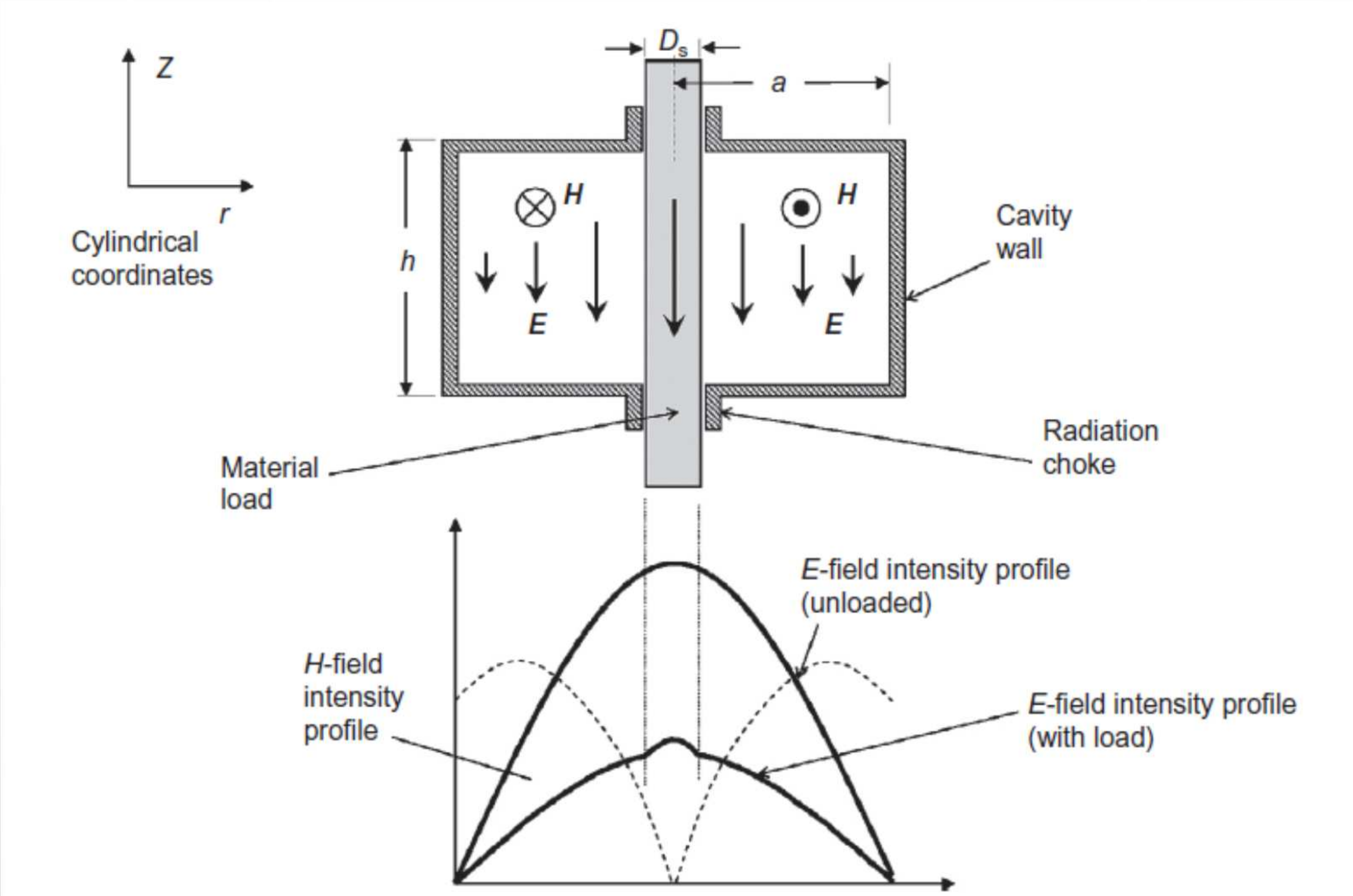
$$\text{TE mode}: f_{nml} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{p'_{nm}}{a}\right)^2 + \left(\frac{l\pi}{d}\right)^2}$$

$$\text{TM mode}: f_{nml} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{p_{nm}}{a}\right)^2 + \left(\frac{l\pi}{d}\right)^2}$$

Where *l*, *m* and *n* are the number of variations in the standing wave pattern in the cavity directions, $\mu$ and ε are the permeability and permittivity of the material, a and d is the internal radius and height of cylindrical resonant cavity, $p_{nm}$ is the $m^{th}$ root of the Bessel function of $n^{th}$ order, $p'_{nm}$ is the $m^{th}$ root of the derivative of Bessel function of $n^{th}$ order.

# How it works?

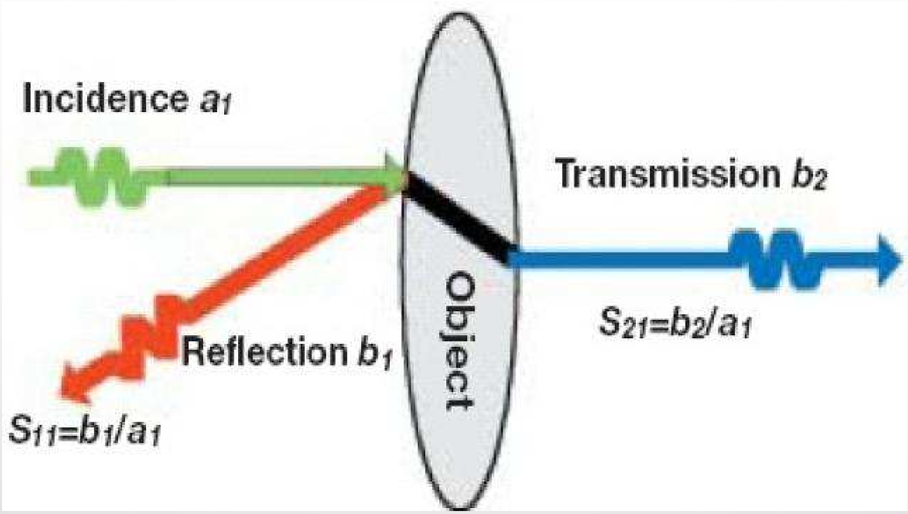
**$TM_{010}$**




(Mehdizadeh M., 2015)

# How to quantify the attenuation?

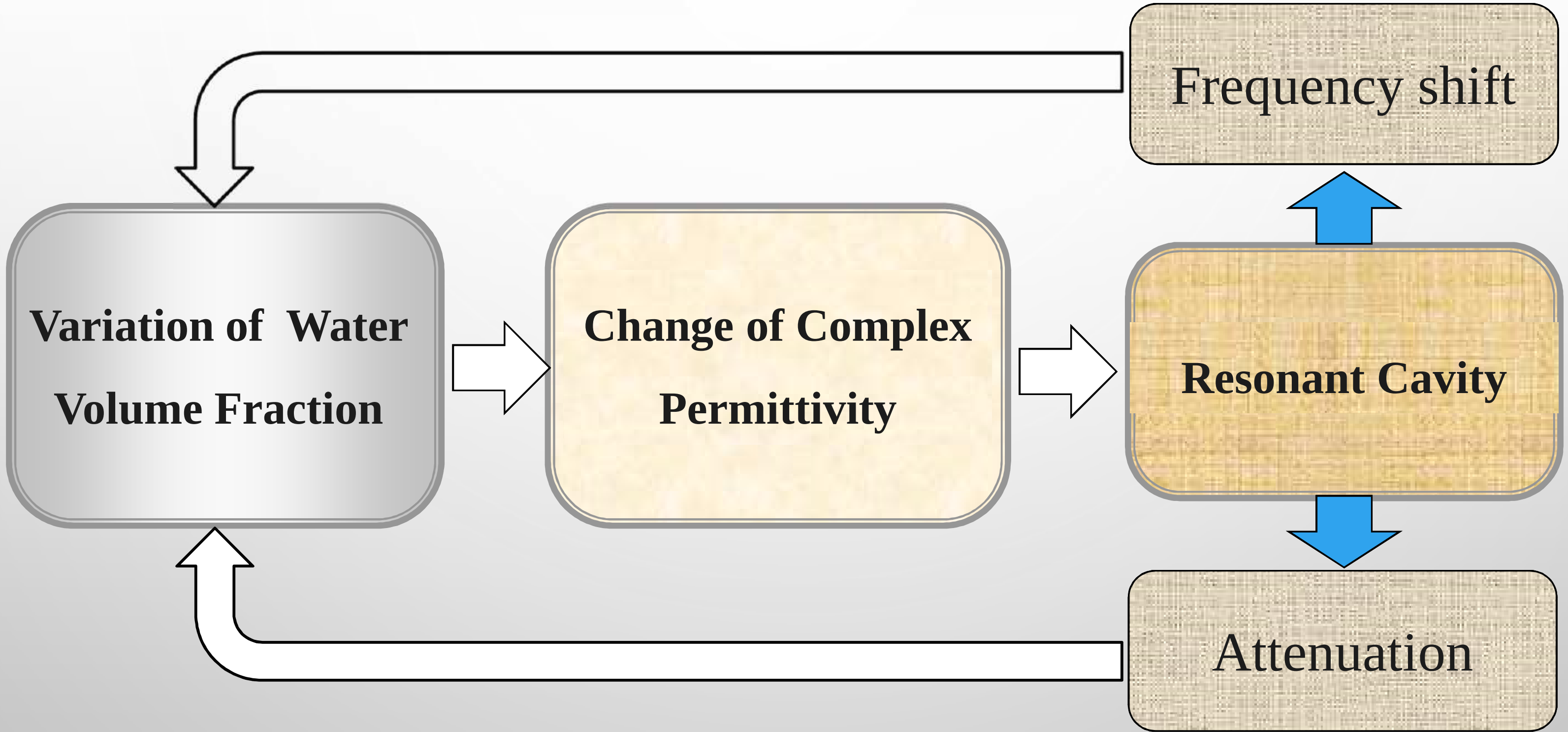
## S Parameter




$S_{21}=b_2/a_1$=Output power/ Input power

Insert Loss

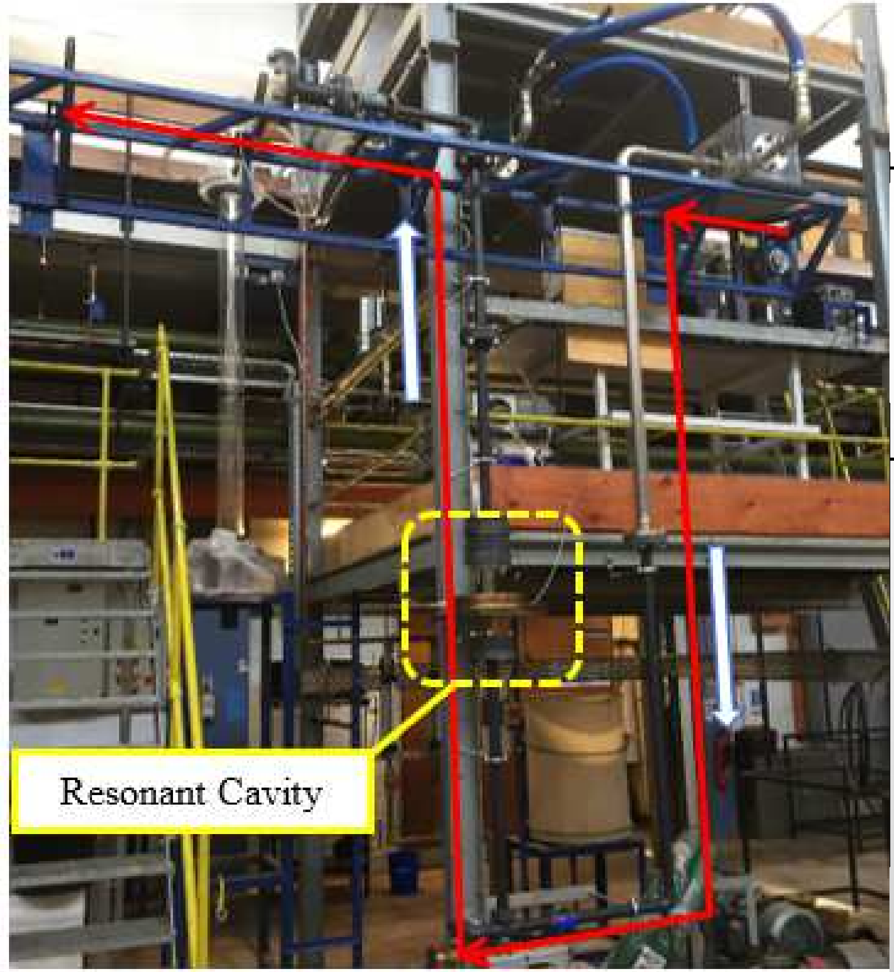
# Theoretical basis



# Microwave resonant cavity

Hewlett Packard 8753C network analyser utilising a 85047A S-parameter test set (300KHz-6GHz)

# Liquid-liquid flow facility




Water drain

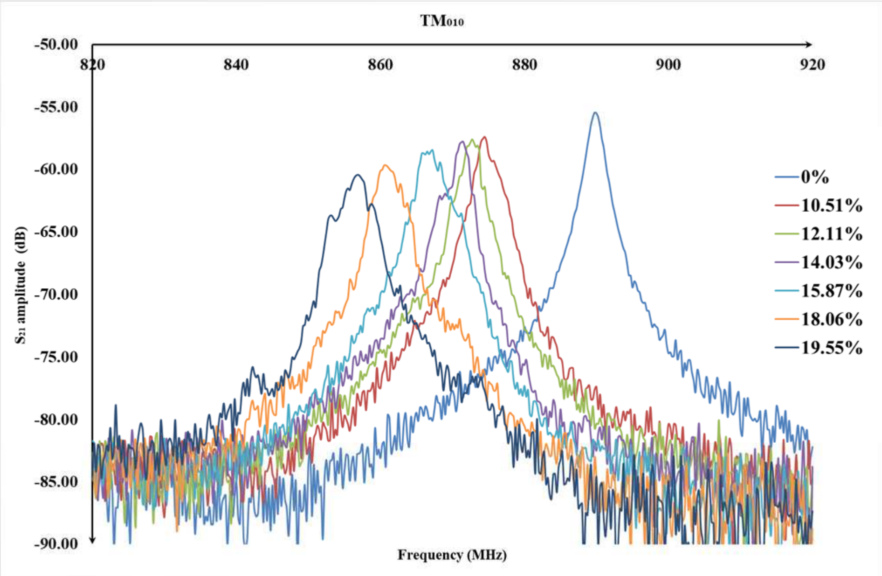
# Results and discussion

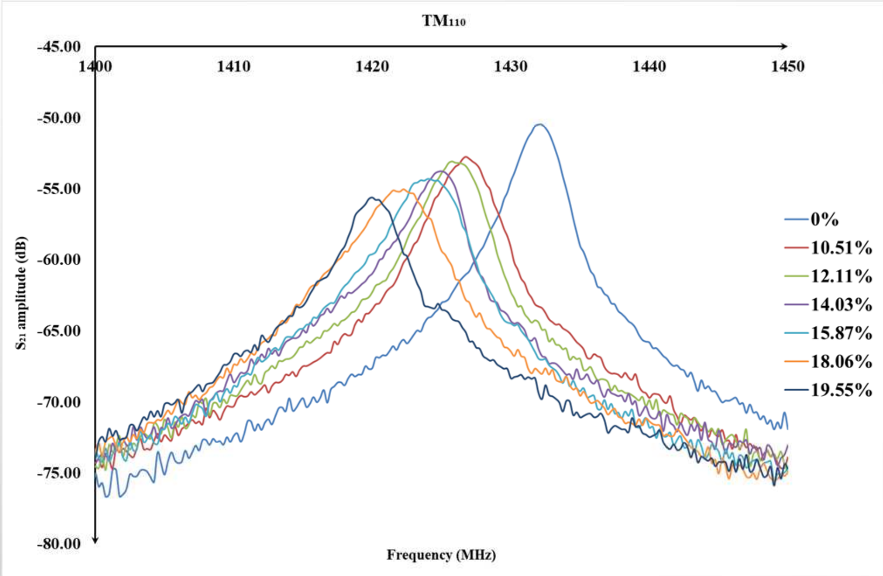
## TEST MATRIX

| Oil flow rate (L/min) | Water Volume Fraction |
|---|---|
| 75 | 0, 10.51%, 12.11%, 14.03%, 15.87%, 18.06%, 19.55% |
| 100 | 0, 7.85%, 9.60%, 12.82%, 13.91%, 15.39%, 17.30%, 20.07% |
| 125 | 0, 5.99%, 8.41%, 10.18%, 12.49%, 14.01%, 17.28%, 19.16% |

# Results and discussion

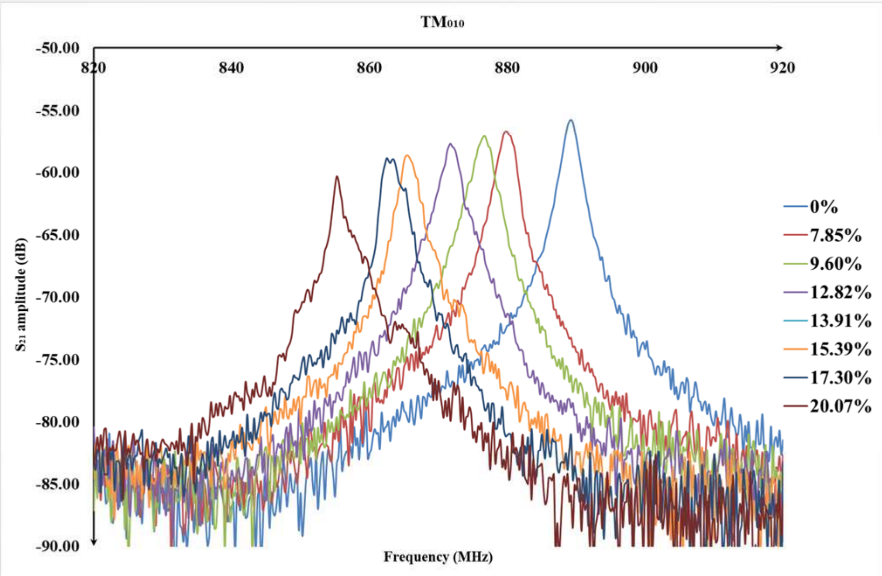
## $U_{oil}$=75 L/min

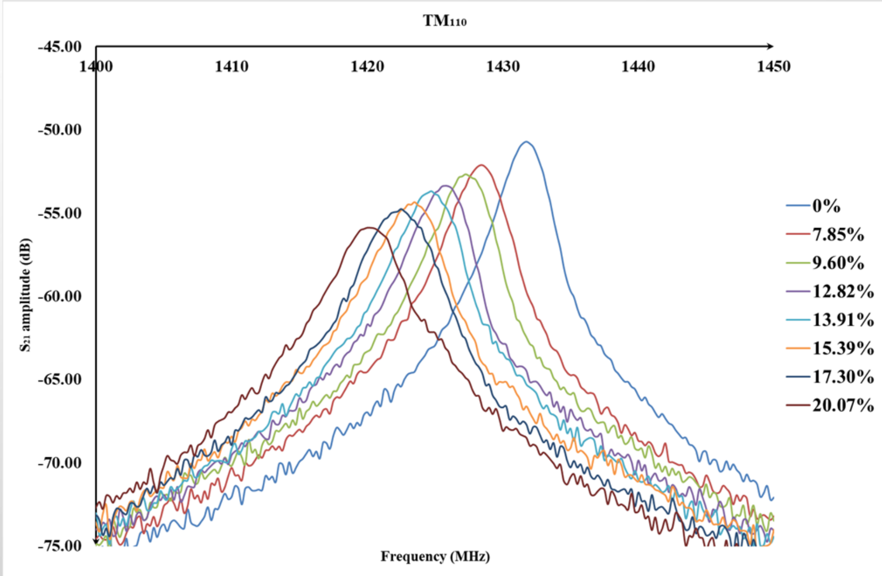


# Results and discussion

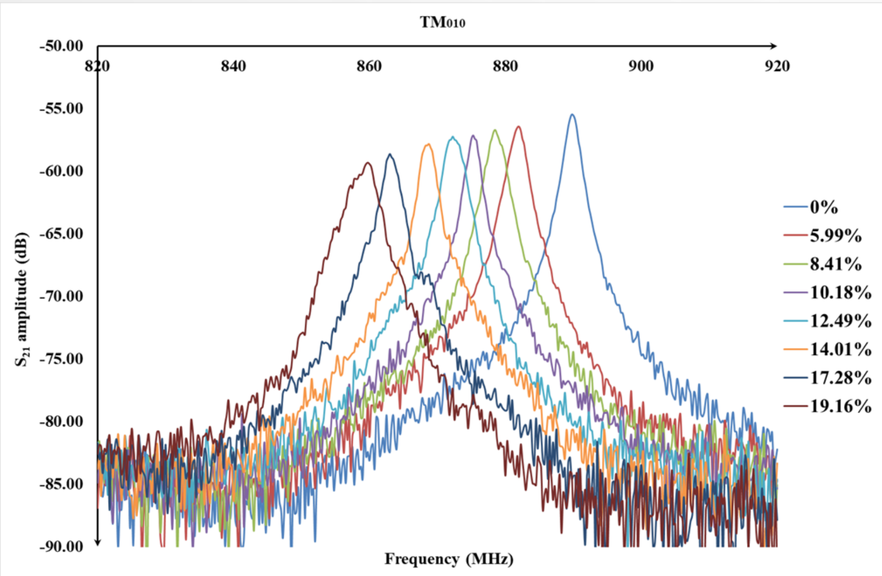
## $U_{oil}$=100 L/min

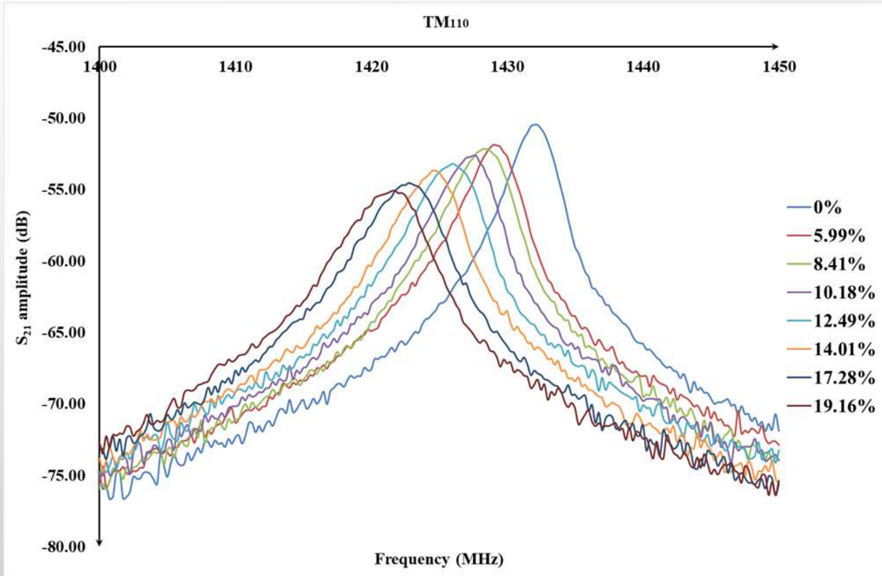


# Results and discussion

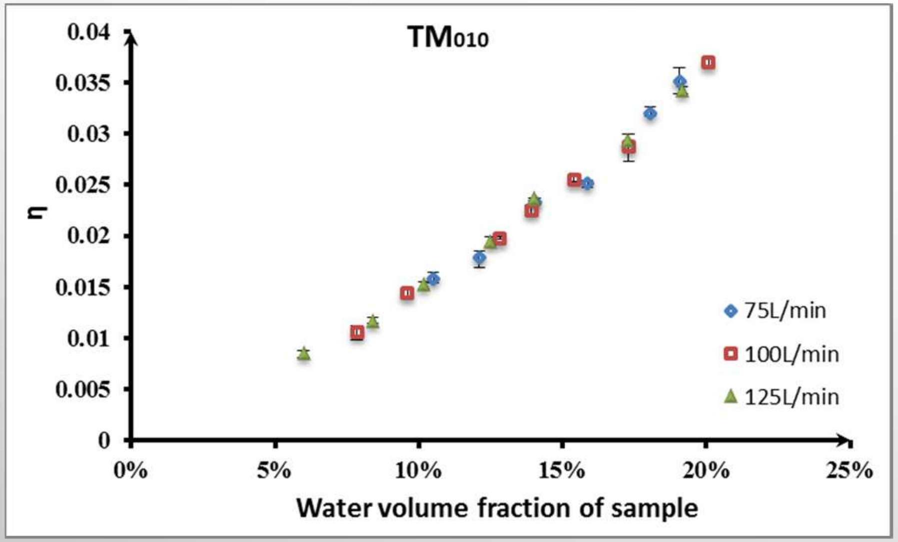
## $U_{oil}$=125 L/min

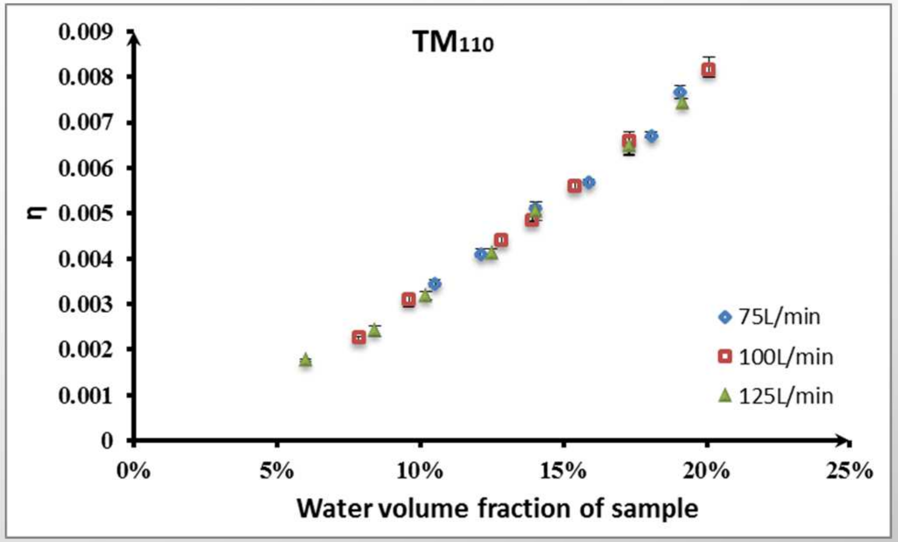


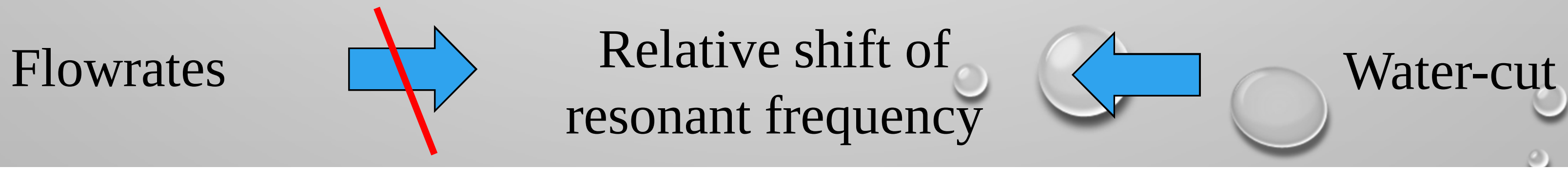
# Results and discussion

$$\eta = \frac{f - f_0}{f_0}$$

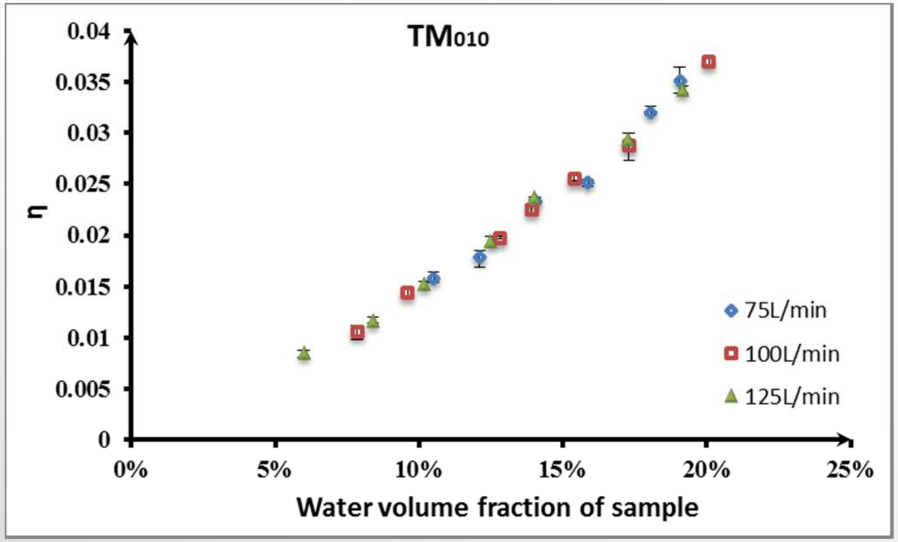


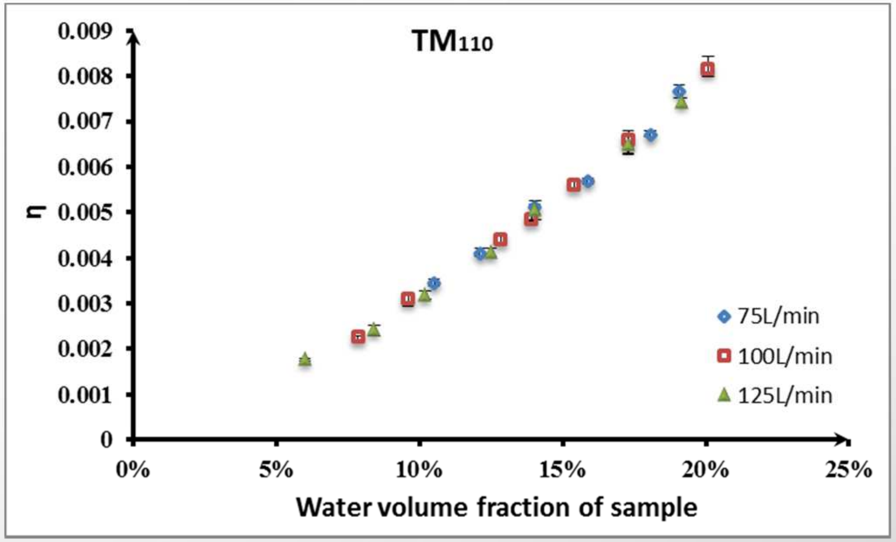




Relationship between η and water-cut



# Results and discussion

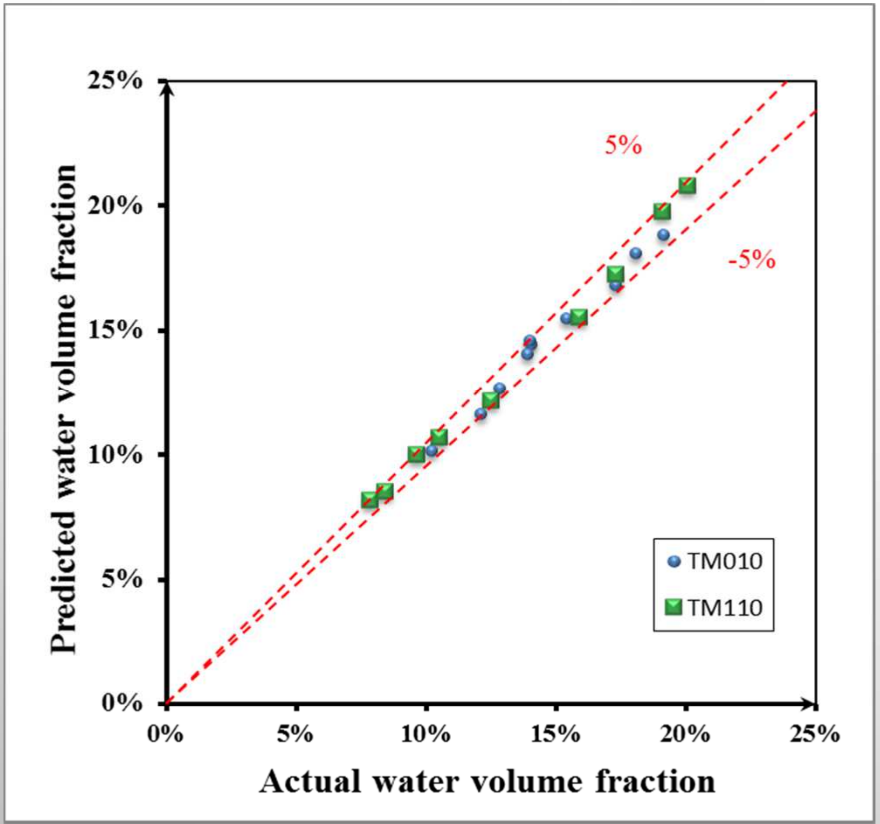



$$\mathrm{TM}_{010}: \theta = -65.805\eta^2 + 7.8178\eta - 0.002$$

$$\mathrm{TM}_{110}: \theta = -1127.6\eta^2 + 32.702\eta + 0.008$$

# Results and discussion




$$\mathrm{TM}_{010}: \theta = -65.805\eta^2 + 7.8178\eta - 0.002$$

Relative error: -3.9% to 4.32%

$$\mathrm{TM}_{110}: \theta = -1127.6\eta^2 + 32.702\eta + 0.008$$

Relative error: -2.58% to 4.44%

# Conclusion

- Resonant frequency was sensitive to the variation of water cut with very good repeatability.
- Measurement of water content in the continuous flow was feasible and robust and was not affected by the changing flow rates.
- The relative error between the measured and the predicted water volume fraction in oil ranged from -3.9% to 4.32% and -2.58% to 4.44% for $TM_{010}$ and $TM_{110}$ mode respectively.

Thank you for listening

Obrigado por ouvir

谢谢聆听