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

Chao Yuan
Georgios Dimitrakis
Buddhika Hewakandamby
CONTENT

• 1. INTRODUCTION

• 2. LABORATORY SETUP

• 3. RESULTS AND DISCUSSION

• 4. CONCLUSION
OIL-WATER TWO-PHASE FLOW

(Katsutaka O)
MICROWAVE
What is resonant cavity?

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

(Liu, B., et al. 2017)
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 $\varepsilon$ 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?

\[ \text{TM}_{010} \]

(Mehdizadeh M., 2015)
How to quantify the attenuation?

S Parameter

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

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
Results and discussion

## TEST MATRIX

<table>
<thead>
<tr>
<th>Oil flow rate (L/min)</th>
<th>Water Volume Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>0, 10.51%, 12.11%, 14.03%, 15.87%, 18.06%, 19.55%</td>
</tr>
<tr>
<td>100</td>
<td>0, 7.85%, 9.60%, 12.82%, 13.91%, 15.39%, 17.30%, 20.07%</td>
</tr>
<tr>
<td>125</td>
<td>0, 5.99%, 8.41%, 10.18%, 12.49%, 14.01%, 17.28%, 19.16%</td>
</tr>
</tbody>
</table>
Results and discussion

$U_{oil} = 75 \text{ L/min}$
Results and discussion

$U_{oil} = 100 \text{ L/min}$
Results and discussion

\[ U_{\text{oil}} = 125 \text{ L/min} \]
Results and discussion

\[ \eta = \frac{f - f_0}{f_0} \]

Relationship between \( \eta \) and water-cut

Flowrates \rightarrow Relative shift of resonant frequency \rightarrow Water-cut
Results and discussion

\[ \text{TM}_{010} : \theta = -65.805\eta^2 + 7.8178\eta - 0.002 \]

\[ \text{TM}_{110} : \theta = -1127.6\eta^2 + 32.702\eta + 0.008 \]
Results and discussion

\[ TM_{010} : \theta = -65.805\eta^2 + 7.8178\eta - 0.002 \]

Relative error: -3.9% to 4.32%

\[ TM_{110} : \theta = -1127.6\eta^2 + 32.702\eta + 0.008 \]

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