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Electrical Capacitance Volume Tomography (ECVT) is a 3D imaging technique for Multi-phase flow measurement.

ECVT is among few know non-invasive imaging tools that can be used for commercial applications (low cost, suitable for scale-up, fast, and safe)

Three-Phase flow systems are used in many energy processes.

Multi-Phase Flow Decomposition using ECVT is a new innovative advancement that responds to the instrumentation need of three-phase applications.
Complete ECVT System

Sensors

Data Acquisition

Reconstruction & Viewing

Solid Fraction

Bubble Iso-Surface & Tracking
Capacitance Sensors for Hot Unit
Sensor Design

24 channel Sensor

SECTION A-A

SECTION B-B

6 Plates Eq Spaced Each Row

Refactory Cement

ZONE | REV. | REVISIONS

A

B

0.79

2.10 Typ.

9.75

(0.79)
Inner Shell

Flanges must be aligned as shown prior to welding.

SECTION A-A
SCALE 1 : 4
Install sensor plate assy in shell
Use alignment jig to center assy
Install 24 bushing assemblies
Cast annulus with refractory cement.
After cure, remove alignment jig.

Shell and Flange Assy
Cast Plate Assy
24X Bushing Assy
Cast refractory cement flush to flange
Alignment Jig

SECTION D-D
SCALE 1 : 4
Three Phase Instrumentation Needs:
The Need

- Velocities of each phase in a three phase system
- Volume fractions and distribution of each phase
- Mass flow rate of each phase
- Catalyst volume estimation
- Reaction rate
- Solving the problem of more than three phases
Three Phase Imaging: Multiphase Flow Decomposition

Discrete

Well mixed
Multi-Phase Flow Decomposition

ECVT Imaging

Phase A

Phase B

Phase C
Maxwell–Wagner–Sillars (MWS) polarization

• MWS effect: mixture with one component having conductivity has different effective dielectric constant as function of frequency
• This phenomena happens only to mixtures, not single phases
• Effective dielectric constant is function of each phase electrical properties, volume fraction, and frequency.
• In ECVT, we can choose frequency, electrical properties of each phase are known, we can then solve for volume fraction distribution of each phase

\[ \varepsilon_{\text{effective}} = f\left( \left( \varepsilon'_1, \sigma_1, \varphi_1 \right), \left( \varepsilon'_2, \sigma_2, \varphi_2 \right) \cdots \left( \varepsilon'_n, \sigma_n, \varphi_n \right), \omega \right) \]

Where \( f \) is the formulation function, \( n \) is the number of phases in the multi-phase flow system, \( \omega \) is the angular frequency at which capacitance is being measured, and \( (\varepsilon'_n, \sigma_n, \varphi_n) \) are the complex permittivity, conductivity, and volume fraction of the \( n \)th phase, respectively.
Dielectric constant change as a function of frequency

Dielectric Constant of mixture

Properties
Volume fraction => Frequency

Frequency (f)

Dielectric Constant $\varepsilon_r$

$f_1$, $f_2$, $f_3$
Capacitance Measurement at Various Frequency

Digital Blocks and DDS are inside FPGA
Three Capacitance Measurements with Three reconstructed maps
Each voxel will have three equations with Volume fraction of each phase as the variable

$\varepsilon_{\text{effective}}$ for Each voxel
Solving Images to Phases

Image 1 at f1
Image 2 at f2
Image 3 at f3

Solve Three equations for each Voxel

Phase A
Phase B
Phase C
## Phase decomposition process

<table>
<thead>
<tr>
<th>Step</th>
<th>Process Description</th>
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<tbody>
<tr>
<td>1 Calibration</td>
<td>Determine frequency markers of mixture by sweep frequency calibration or by calculation from electrical properties of each phase in mixture</td>
</tr>
<tr>
<td>2 Measurement</td>
<td>Measure capacitance from ECT, ECVT, or AECVT sensors at all frequency markers determined in step 1</td>
</tr>
</tbody>
</table>
| 3 Reconstruction | Perform an image reconstruction of capacitance measurements at each frequency  
| | • A number of images equal to the number of frequency markers will be available in this step |
| 4 Phase decomposition | • For each Voxel in each image at a specific frequency, the effective dielectric constant is a function of electric properties of all phases and their volume fraction, assuming a well mixed cell  
| | • Each Voxel will a number of equations equal to the number of frequency markers. The only unknowns in those equations are the volume fraction of each phase.  
| | • The equations for each voxel are solved to determine the volume fraction of each phase in that voxel |
| 5 Phase viewing | • From step 4, each voxel will have the volume fractions of each phase.  
| | • For each phase, the volume fractions of all voxels are gathered to formulate an image of that phase alone  
| | • Multiple images will be generated, each showing only one phase |
Conclusion

• ECVT sensor for high temperature applications is under construction
• Multi-Phase Flow Decomposition is a new technology for imaging and decomposing three-phase systems:
  – Mixtures have different effective dielectric constants at different frequencies.
  – This phenomena, known as MWS effect, can be exploited to decompose a three-phase system into individual phases for imaging.
  – Capacitance is captured at different frequencies and images are reconstructed at each frequency.
  – The three images are then solved together for phase decomposition.