Real-Time 3-D Volume Imaging and Mass-Gauging of High Temperature Flows and Power System Components in a Fossil Fuel Reactor Using Electrical Capacitance Volume Tomography

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Meeting: Crosscutting Meeting 2018
Date: 04/10/2018
DOE award #: DE-SC0010228
Period of Performance: July 2017-July 2019
Subcontractors: The Ohio State University

Project Goals & Objectives

- The main technical objective of Phase II is to develop a functional Gas-Liquid ECVT demonstration system for real-time imaging and measurement of multiphase flows at high temperature.

Year 1 Milestones:

1. Finalize AECVT sensor design- end of 2nd quarter.
2. Fabricate sensor for gas-liquid applications at for high pressure/temperature applications- end of 3rd quarter.
3. Fabrication of testing chamber- end of 4th quarter.

Year 2 Milestones:

1. Development of reconstruction and feature extraction algorithms- end of 7th quarter.
2. Develop and demonstrate software and GUI- end of 8th quarter.
3. Demonstrate integrated system- end of 8th quarter.

TECH 4 IMAGING

Presentation Outline

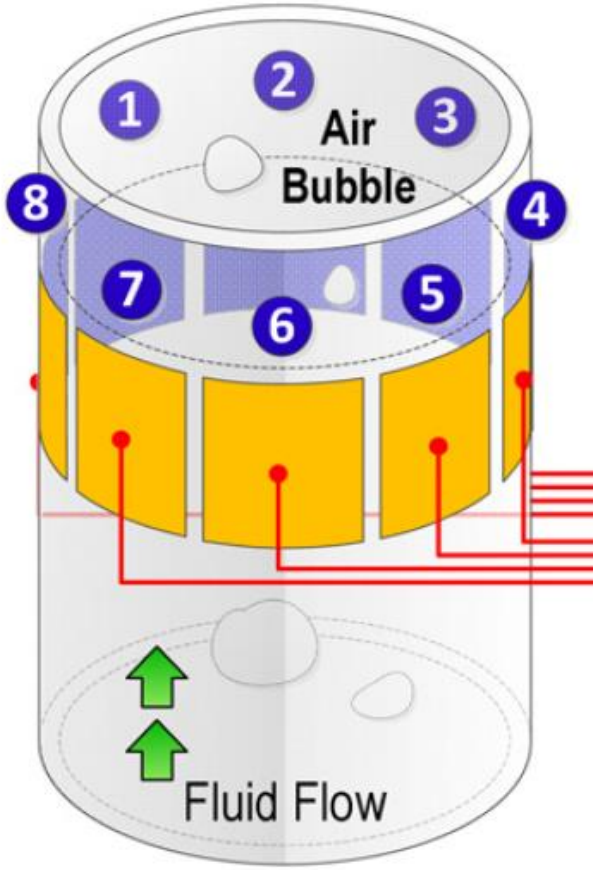
- Introduction to ECVT
- Electronic Design
- Sensor
- Software
- Testing
- Schedule

Electrical Capacitive Volume Tomography

- Electrical Capacitance Volume Tomography (ECVT) is a low cost noninvasive imaging technique to find the volumetric dielectric distribution from inter-electrode capacitance measurements.

- Electrodes respond differently to the change in permittivity distribution inside the sensing domain. These mutual capacitances are used to reconstruct the dielectric distribution in the sensing domain.

- ECVT is used in nondestructive testing, imaging of multiphase flows and for imaging of combustion flames and fluidized beds.



ECVT Sensor Model

The inter electrode capacitance is computed by

$$C = -\frac{1}{V}\iint_{\Gamma} \varepsilon(x,y)\nabla\phi(x,y)\cdot n dS\,.$$

The first order linear approximation $\Delta C = \frac{d\xi}{d\varepsilon}(\Delta\epsilon) + O((\Delta\epsilon)^{2})$

$$\mathbf{C_{M\times 1}} = \mathbf{S_{M\times N}G_{N\times 1,}}$$

Where $M = \frac{n(n-1)}{2}$ are the number of independent sensor measurements, N is the number of pixels in the sensing domain and the sensitivity matrix S is defined as

$$S_{ij}[n] = \frac{1}{V_i V_j}\int_{v[n]} \nabla\varphi_i \cdot \nabla\varphi_j dv$$

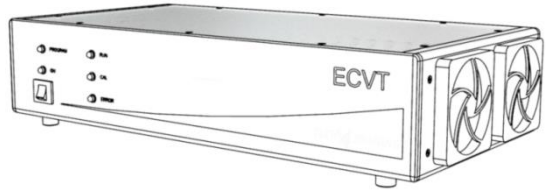
TECH 4 IMAGING

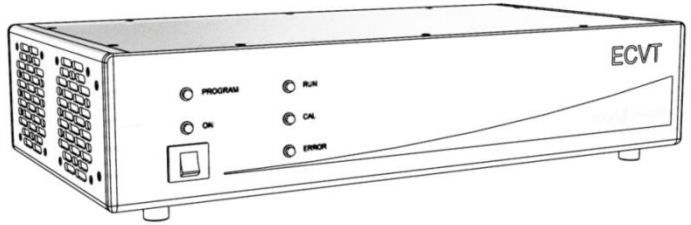
Overview

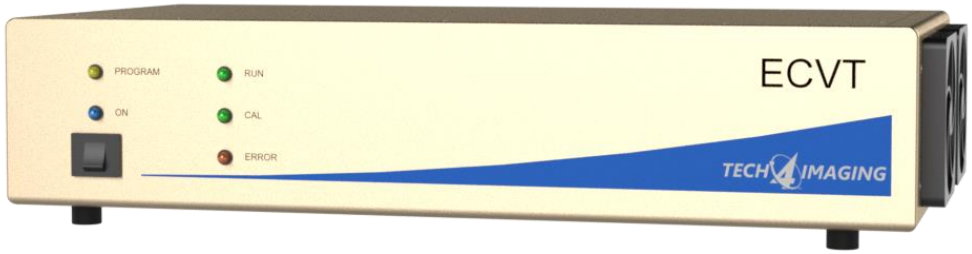
- Year of 2017 and 2018 to date
- Data Acquisition System (DAS)
- Firmware
- Sensor Design
- Software
- Algorithms

Data Acquisition System

1. Eliminated ghost images in conductive phases
2. Industrial grade enclosure
3. Reducing temperature drift

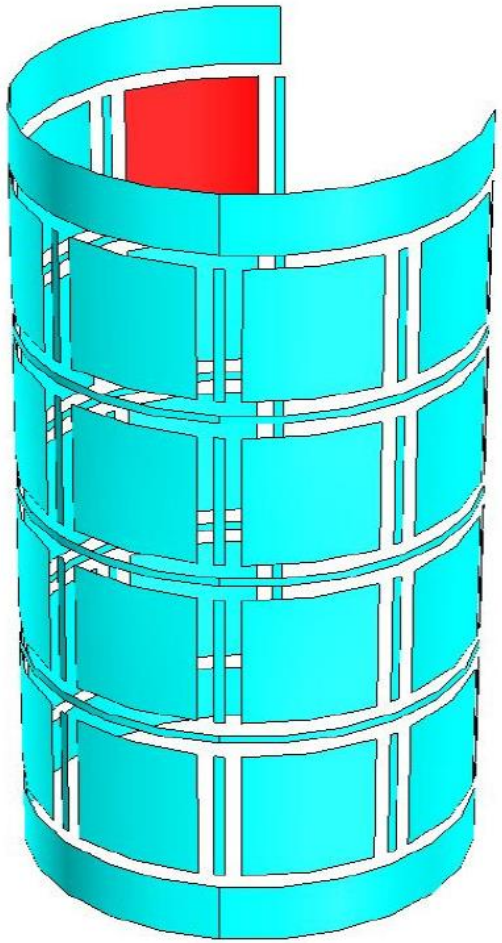






Channel Selection

- Activate only certain plate pairs during collection
- Increased acquisition speed due to less data



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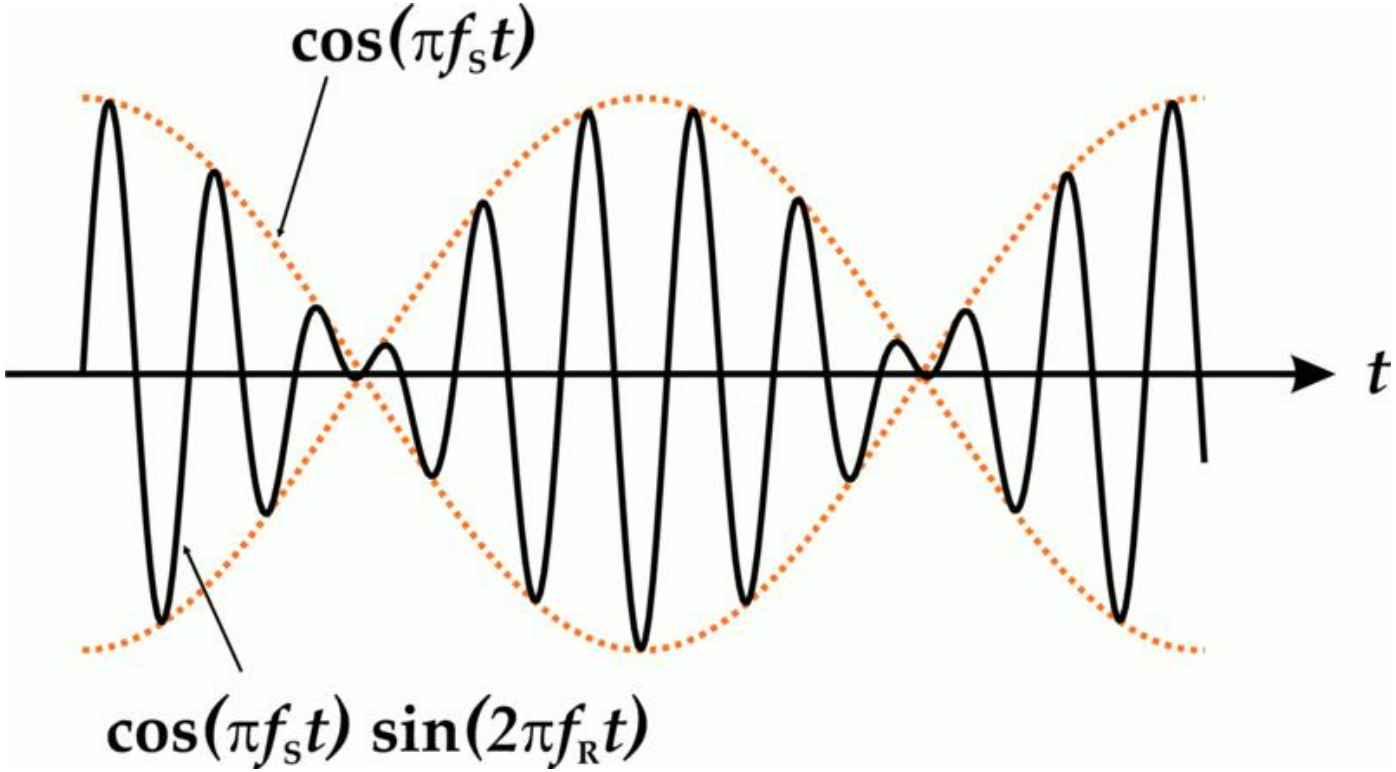
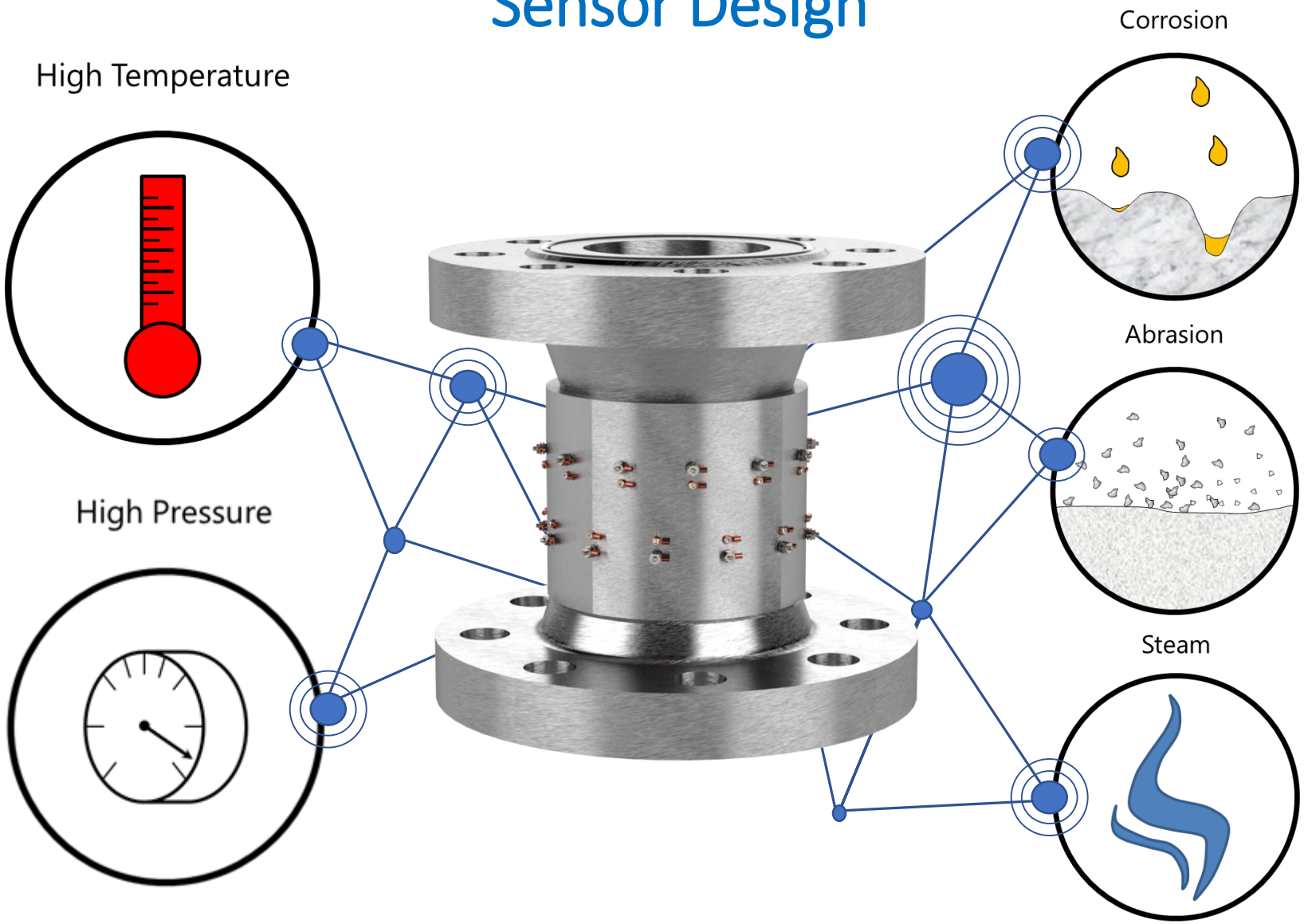
Dual Frequency

- MWS Effect
- 3 Phase
- DCPT Resolution



Sensor Design



Robust Electrodes

- Simple Conductive Plates
- Electrically Insulative Coating
- Smooth/Laminar Design
- Robust against
  - Heat
  - Pressure
  - Abrasion
  - Corrosion

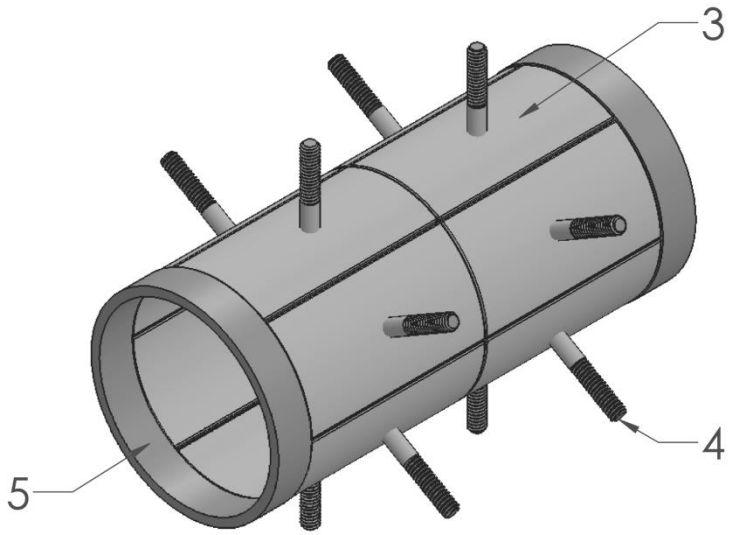


FIGURE **1b**

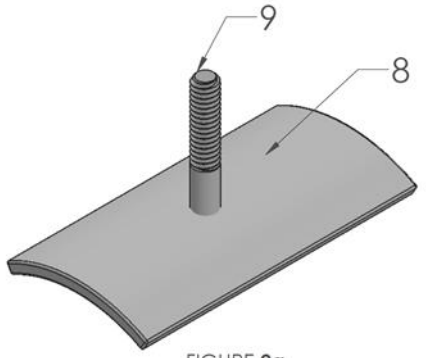


FIGURE **2a**

Minimal Maintenance

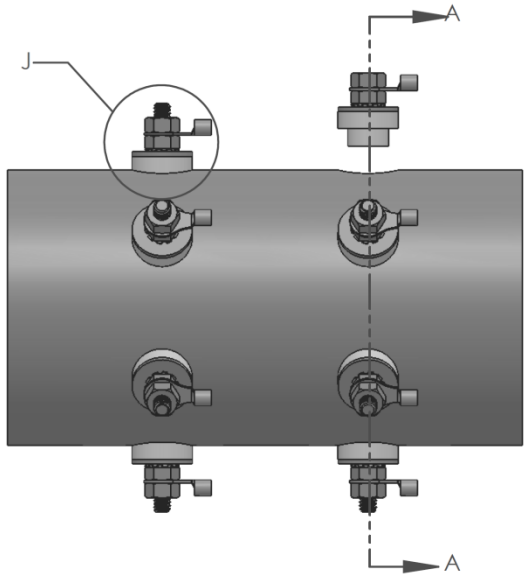
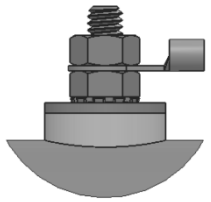
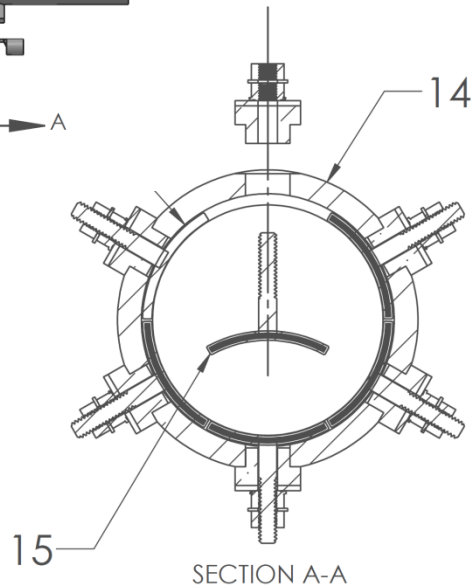


FIGURE **3a**



DETAIL J
FIGURE 3c



SECTION A-A
FIGURE **3b**

- Low Maintenance Parts
  - Non-mechanical
  - Field Removable
  - Field Replaceable
- Minimal Calibration Requirements
- Remote Diagnostics

Installation

- Inline
- Standard Flanges
- Matching ID
- Metal Outer Jacket
- Minimal Space Requirement

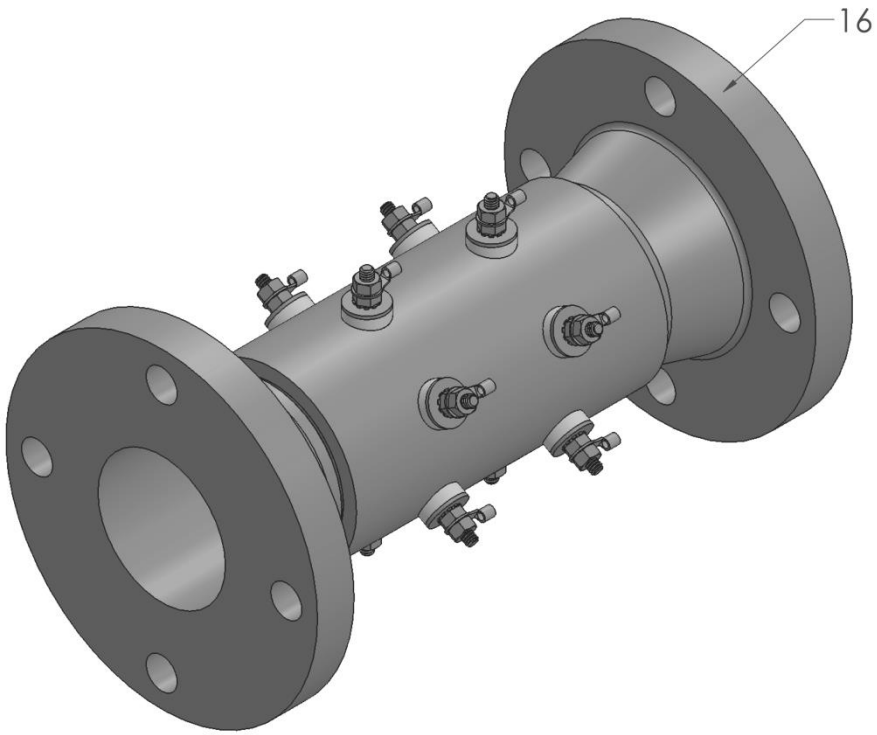


FIGURE 4a

TECH 4 IMAGING

Modularity

- Easily modified for various applications
- Exchange plastics, ceramics, and metals for electrode components.

- Adjust based on
  - Temp
  - Press
  - Material in flow
  - Longevity
  - Cost

TECH IMAGING

Software

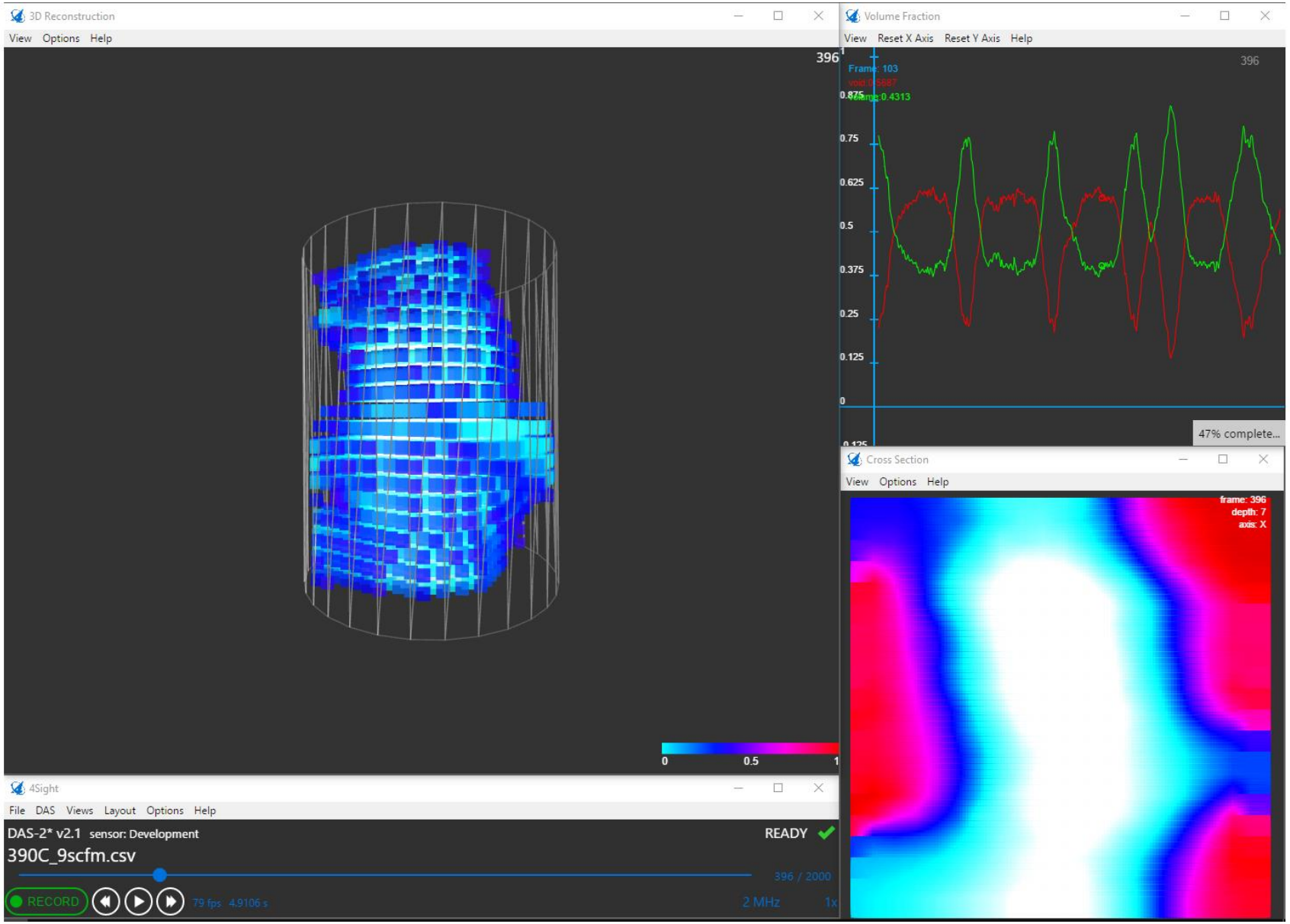
Firmware Integration
- Dual Frequency
- Channel Selection

Distribution
- Licensing Structure
- Demo License

Imaging
- Image Reconstruction
- Velocimetry

Data
- Normalization
- Calibration

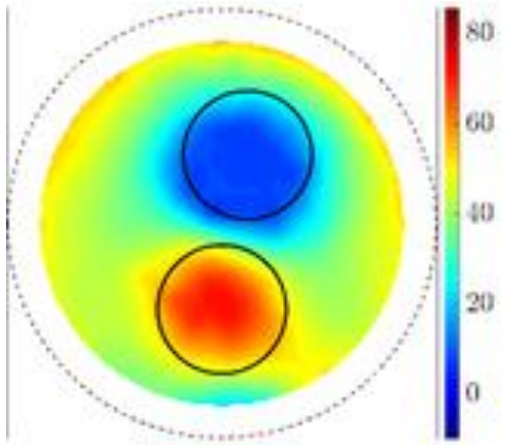
TECH 4 IMAGING



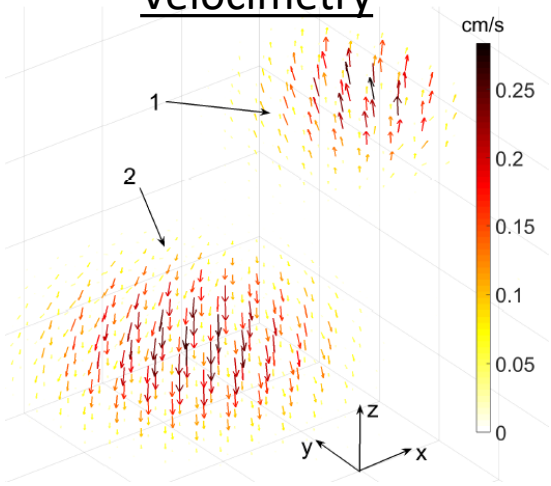
TECH 4 IMAGING

Algorithms

3 Phase



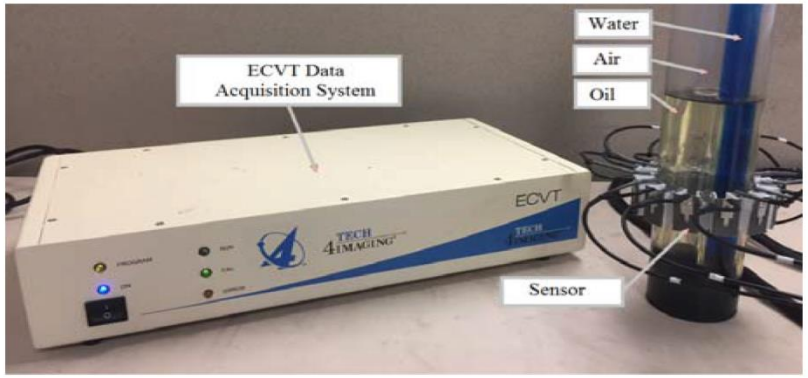
Velocimetry

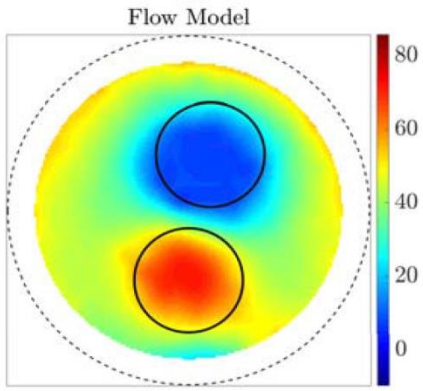


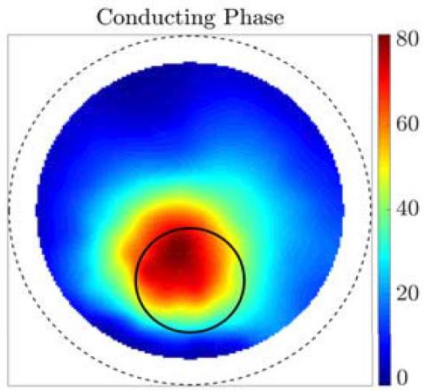
1. Three Phase Decomposition
2. Air-water systems
3. MWS DCPT
4. Velocimetry

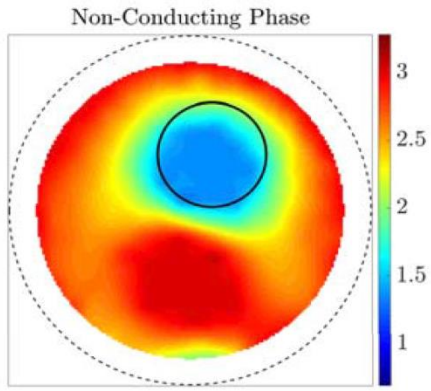
Three Phase Decomposition

- Air
- Oil
- Water



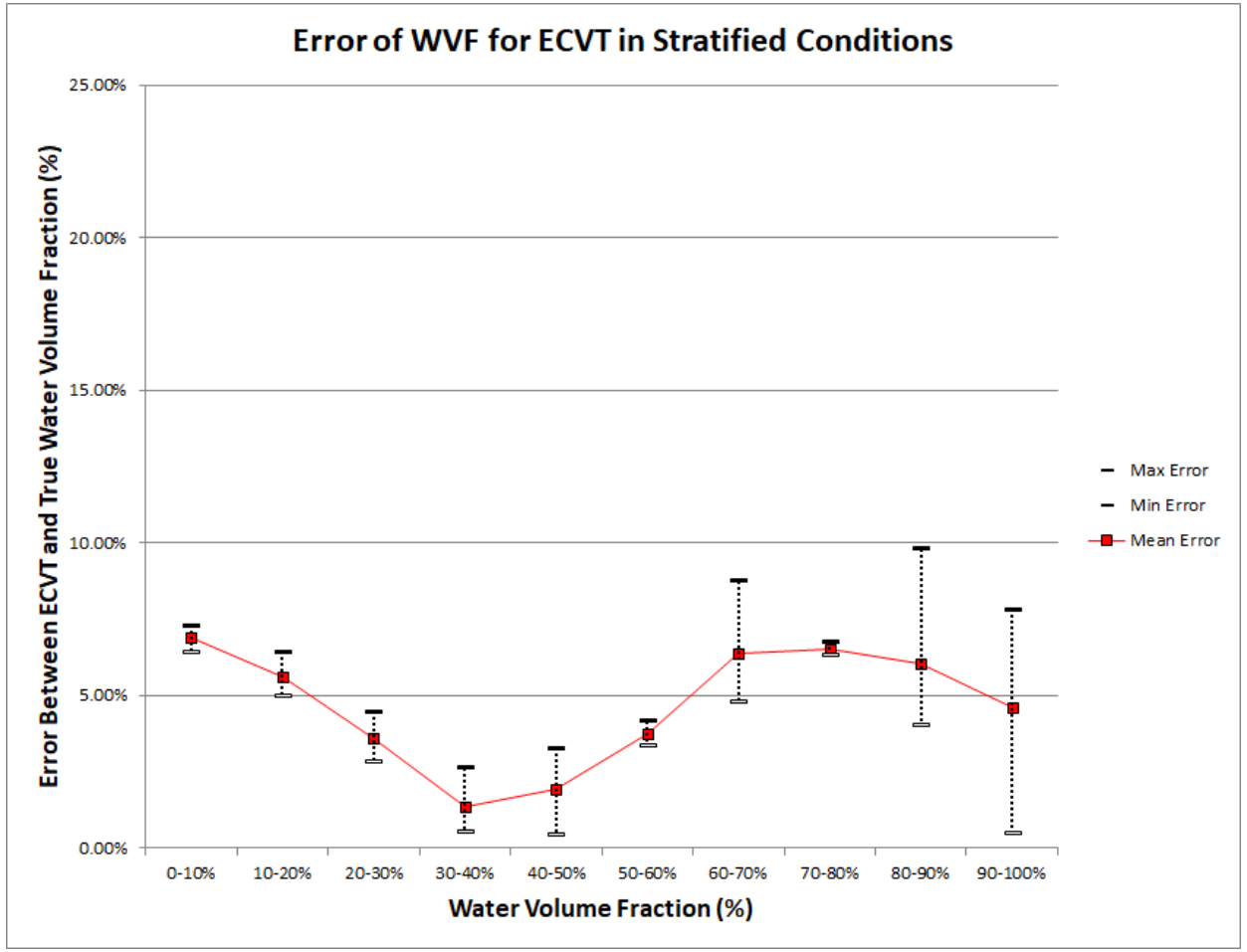






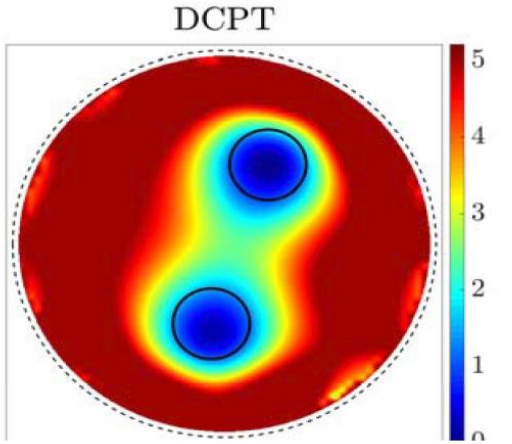
TECH 4 IMAGING

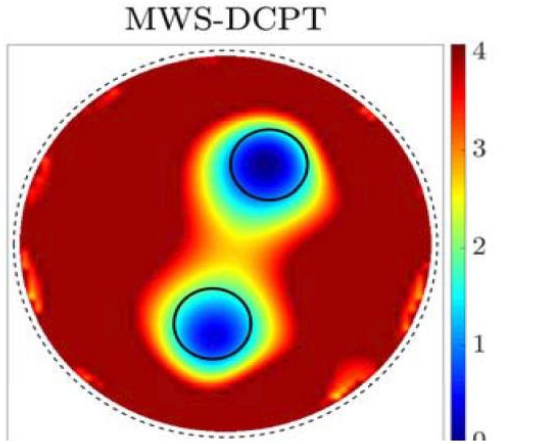
Volume Fraction for Air Water Systems

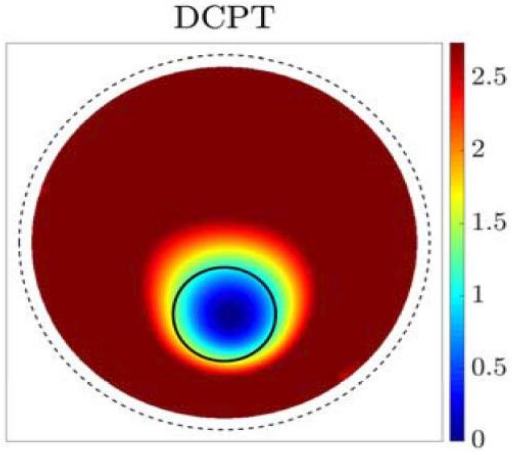


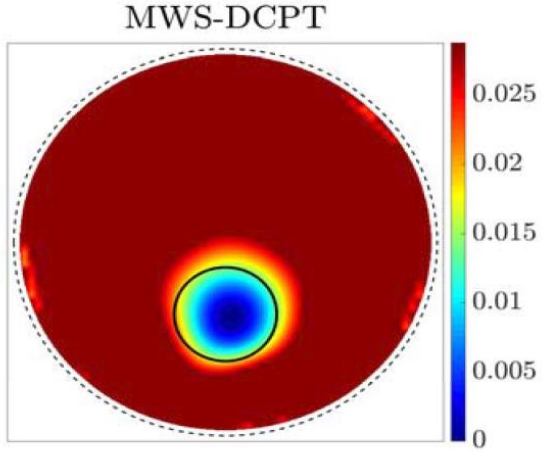
TECH 4 IMAGING

Increased Imaging Resolution for Air-Water Systems



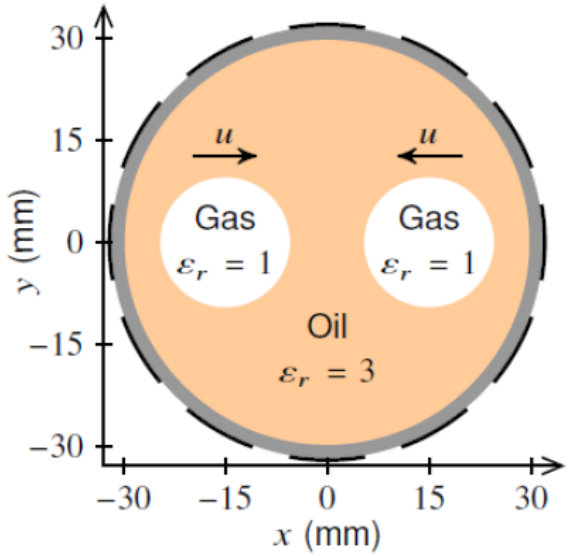




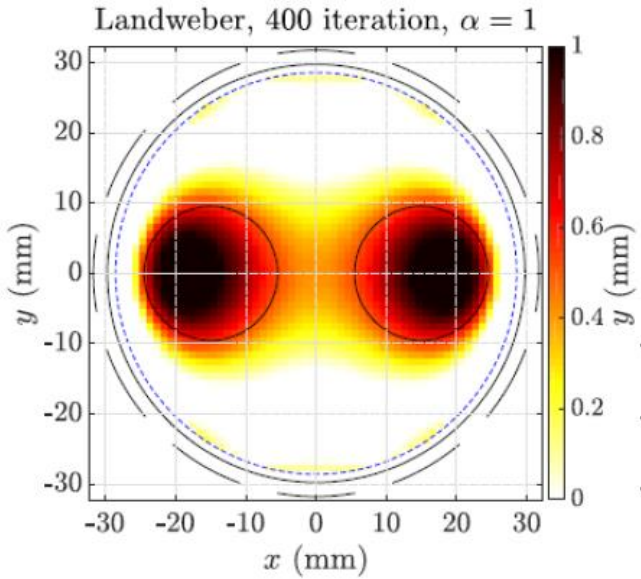


Velocimetry

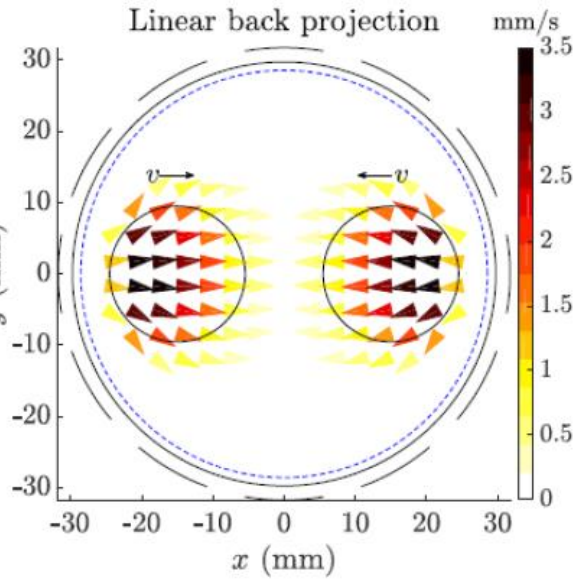
Model



Image



Velocimetry



Phase II B Schedule

Task 1: *Sensor Material Research & Investigation*
Task 2: *ECVT sensor mechanical design for high temperatures*
Task 3: *ECVT sensor fabrication*
Task 4: *Build test chamber*
Task 5: *Data Acquisition System (DAS) firmware and electronic design*
Task 6: *Testing*
Task 7: *Implement image reconstruction algorithm*
Task 8: *Develop feature extraction*
Task 9: *System integration and testing in real-time*
Task 10: *Software interface*
Task 11: *Finalize demonstration unit*

Tasks	Project period (Quarter)							
	1	2	3	4	5	6	7	8
Task 1	■							
Task 2	■	■						
Task 3			■					
Task 4	■	■	■	■				
Task 5			■	■	■			
Task 6				■	■	■	■	■
Task 7	■	■	■	■	■	■	■	
Task 8	■	■	■	■	■	■	■	
Task 9							■	■
Task 10						■	■	■
Task 11								■

TECH4IMAGING

Conclusion

- ECVT for harsh condition gas-liquid applications is under development.
- DAS will be able to operate in Dev 1 environment.
- Advanced feature extraction is under development:
  - Dual frequency
  - MWS-DCPT
  - New normalization
  - Velocimetry
- Software GUI is operational.

QUESTIONS ?

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