Advanced Multi-Dimensional Capacitance Sensors Based Subsea Multiphase Mass Flow Meter to Measure and Monitor Offshore Enhanced Oil Recovery Systems

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Presentation Outline

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  - Salinity
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Technical Status

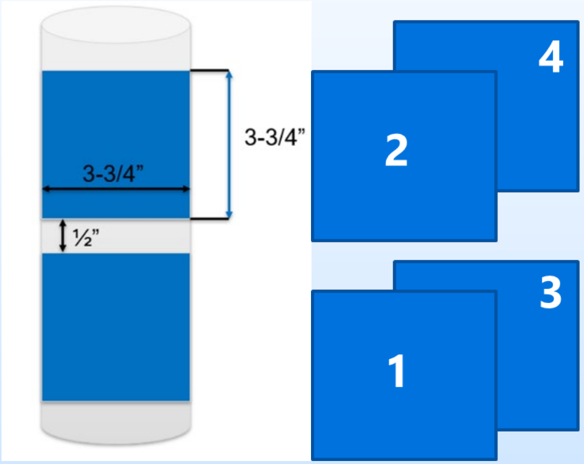
(Flow Loop)

- Designed a 3-Phase flow loop capable of up to 5000 bbl/day flow rate with Accuflow's assistance.
- Built the flow loop with Tech4Imaging's in house fabrication expertise
- Coriolis watercut flow meter
- Gas volume flow meter
- Sight glass
- Pressure and temperature transmitters
- Automated and programable control loop
- Pressure control valve

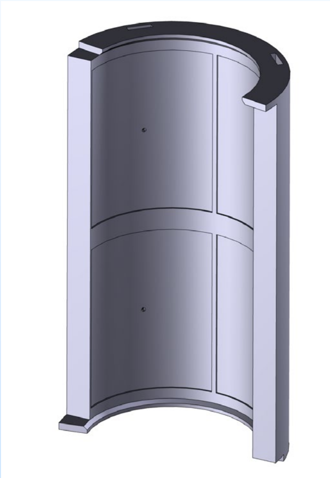
Technical Status

(Sensor Electrode Design)

- Through simulation and prototyping, the optimal electrode design for the ECVT sensor was narrowed to two main sensors.
- Both a 2x2 parallel plate design and a 2x4 cylindrical design were built and tested on the flow loop.
- 2x4 provided slightly better and more consistent results.
- 2x4 design also provided for easier manufacturing.



2x2 Parallel Plate Configuration

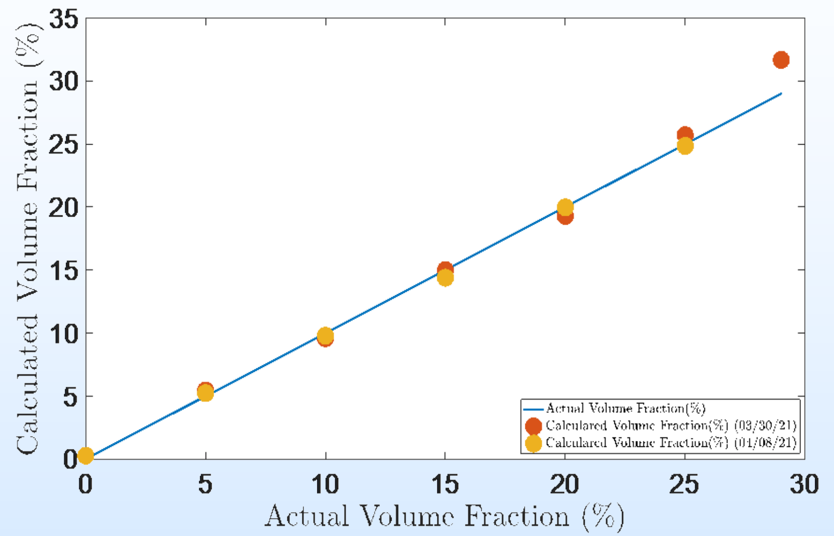


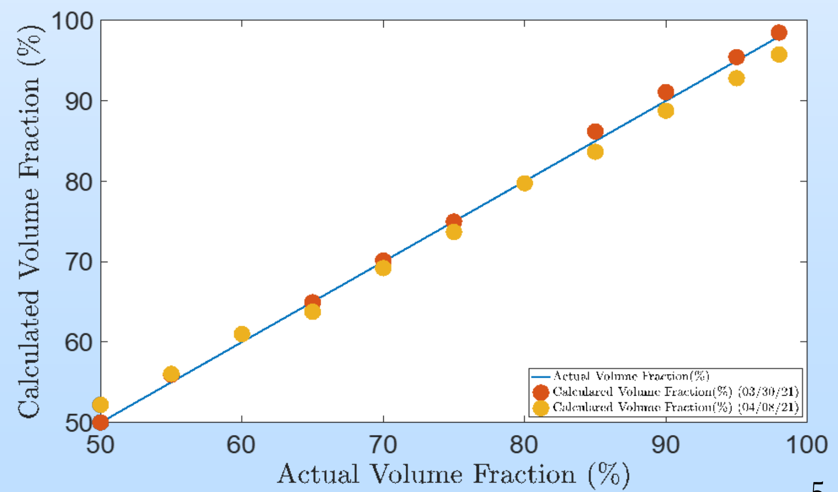
2x4 Cylindrical Plate Configuration (showing one half of a clam shell design)

Technical Status

(2-Phase Flow Algorithm)

- Results from the flow loop show 2-phase accuracy in both water-continuous and water-dispersed flows.
- Current state of the art capacitance-based solutions cannot provide measurements above 35% watercut.
- Graphs show ECVT measured water volume fraction on the y-axis and the Coriolis measurement on the x-axis.
- Two colors are taken 1 month apart, showing reproducibility over time.

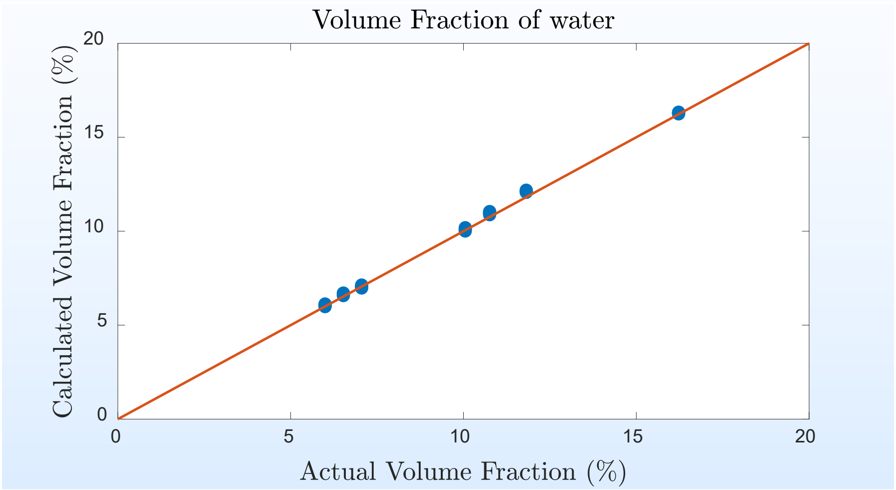


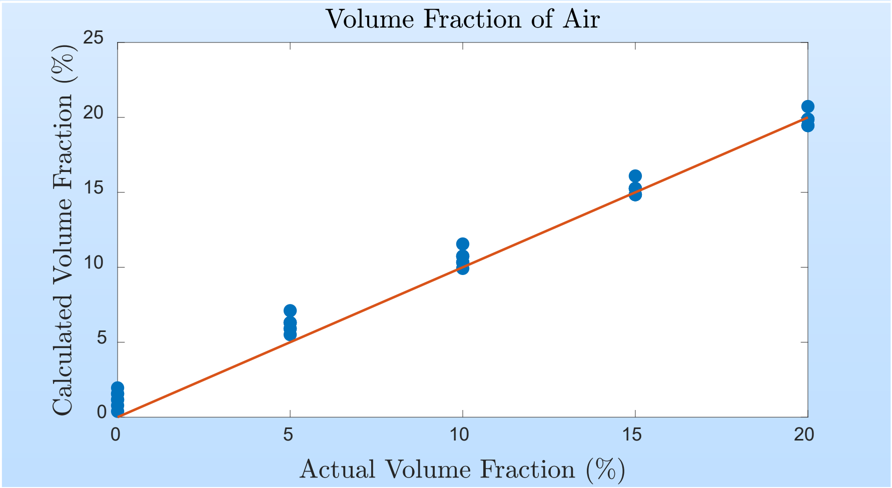


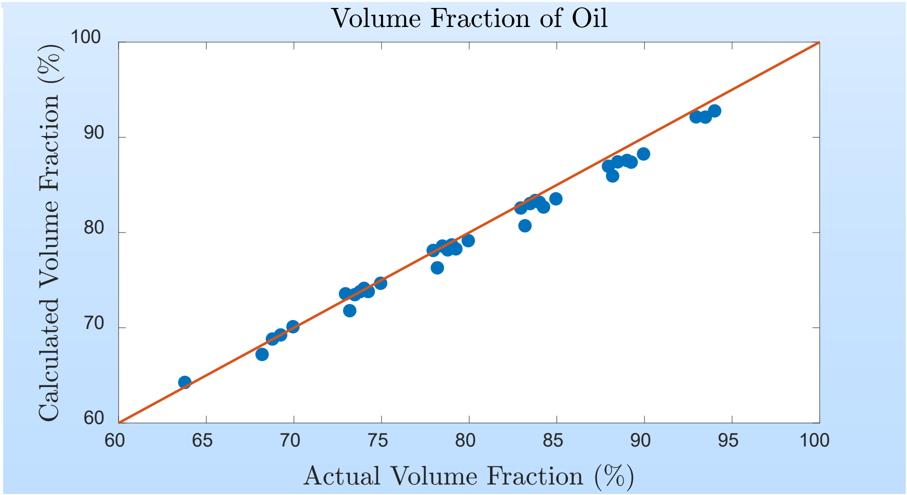
Technical Status

(3-Phase Flow Algorithm – Water Dispersed)

- Data shown from 3 full test replicates completed over the course of 1 month.
- Watercut from 0 to 100%
- Gas volume fraction from 0 to 20%
- Current state of the art measurement techniques such as Coriolis cannot determine the gas phase.



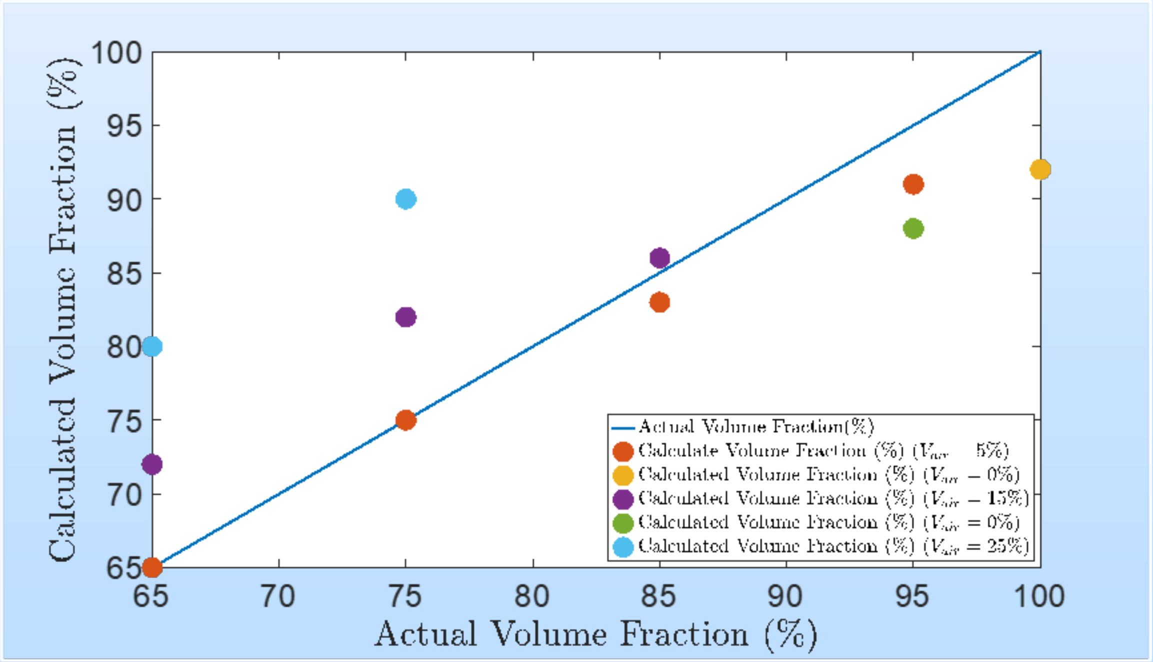




Technical Status

(3-Phase Flow Algorithm – Water Continuous)

- Water continuous data still requires further refinement to remove the effects of gas volume fraction on the measurement. The differences in signal level between variations in gas volume fraction versus water volume fraction are much smaller in water continuous and must be addressed in a different manner than in water dispersed scenarios.



Technical Status

(Salinity)

- A static test bench scale experiment was performed to see the effects of salinity on the algorithm.
- For water dispersed conditions, the results show good agreement regardless of the salinity.
- The algorithm is able to reproduce the volume fraction accurately within 3% absolute error as shown in the table. This confirms the analysis performed in the initial simulation.
- So far, the algorithm for water-continuous water volume fraction is more dependent on the salinity than the water-dispersed case, as hypothesized from the simulation.
- Further work is required to overcome this obstacle. Further work should also be completed on the water-dispersed case to prove reliability and how it works at higher salinity.
- We plan to add salinity as a variable to the flow loop by the end of the year.

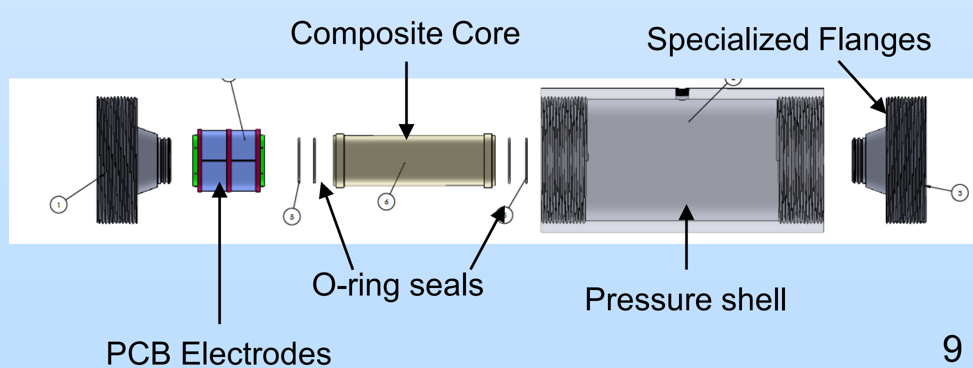
Case	35 ppt	50 ppt	87 ppt
5%	4.9	5.5	4.5
15%	18	15.6	15.4

Salinity and volume fraction measurements for water-dispersed

Technical Status

(Subsea Sensor Package)

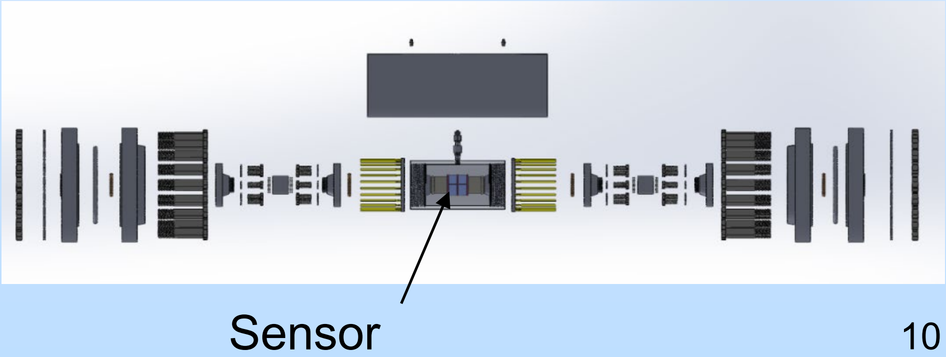
- Designed and built a subsea sensor package to withstand 2300 PSI internal pressure and 2300 PSI external pressure.
- Hydrostatically tested both internal and external pressure at separate times to prove that it can survive the differential.



Technical Status

(Subsea Environment Chamber)

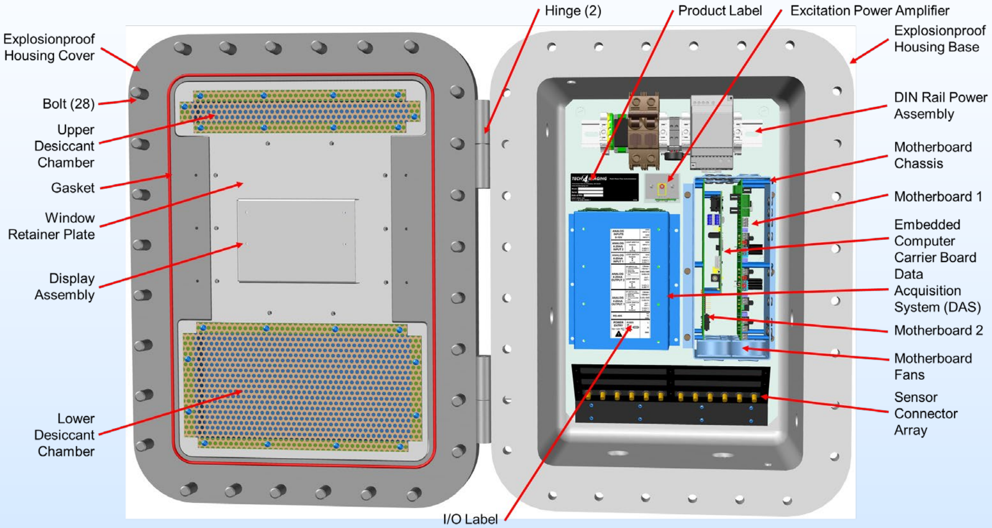
- Designed and built a subsea environment chamber to simulate outer pressure of 5000 feet below sea level on ECVT sensor.
- Designed to integrate on three phase flow loop.
- Successfully tested the sensor design with hydrostatic pressure on the outside of the vessel equal to 5000 feet below sea level (~2300 PSI).

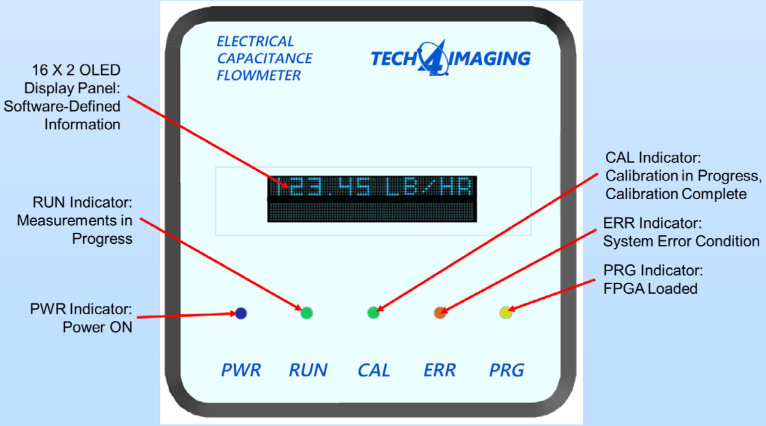


Technical Status

(C1D1 Electronics Package)

- Designed and partially built/assembled C1D1 area compliant data acquisition system for deploying to field testing.
- Discussed general certification with multiple certification agencies for EMC, hazardous locations, and basic safety.
- To be completed by end of year.





Accomplishments to Date

- Designed and built 3-Phase flow loop for validating ECVT mass flow rate data against Coriolis two-phase and gas single-phase flow meters.
- Collected data on a range of flow regimes including 0-100% watercut and 0-25% GVF.
- Validated a method for measuring 3-Phase oil continuous mixtures at up to 5000 bbl/day flow rate.
- Validated a method for measuring oil in 3-Phase water-continuous mixtures at up to 5000 bbl/day flow rate.
- Developed a method for measuring 3-Phase oil continuous mixtures regardless of water salinity (yet to be validated on the flow loop).

Accomplishments to Date

- Optimized sensor electrode design based on simulation and flow loop experimentation to provide most accurate results.
- Designed and built subsea environment chamber to simulate subsea water pressures on the flow meter housing down to 5000 feet below sea level.
- Designed, built, and tested an ECVT sensor that can withstand the subsea pressures down to 5000 feet below sea level, as well as an internal pressure of up to 2300 PSI.
- Developed an electronics enclosure for use in C1D1 rated environments to enable on-shore field testing next year.

Accomplishments to Date

– Demonstrated an early version of the flow meter in action on the flow loop to a well know phase separator/flow meter supplier for the oil and gas industry. They were very excited about the progress and have offered opportunities for us to deploy our flow meter for field testing next year.

Lessons Learned

- Initial flow loop pressure was going to be much higher. Discovered that the required pumps for target pressure were cost prohibitive and we reduced the target pressure. Our commercial partner agreed that proving the results at this new target pressure was adequate to prove it would work in a higher-pressure environment as long as it was hydrostatically tested to the higher pressure for safety.
- Reaching the precision required to fit the subsea environment chamber together required multiple iterations on some components with the fabricator which pushed back the schedule in Q1 Y2, though we eventually got it to fit together and hold pressure with the sensor inside.
- Upon going for certification of the equipment for C1D1 to prove safe operation in field testing in Y3, we discovered that it was very costly and we would have to go through it again if field testing produced any required changes before the product could be put on the market. To overcome this, our commercial partner identified field testing partners that would perform their own design review to certify the equipment for testing on their field wells. Then we would go for general certification after field testing.

Lessons Learned

- The cost and time required to add and remove salt to the flow loop system is much higher than anticipated and we have to be more diligent with what testing is to be performed at each salinity level before we raise it to the next level. Once saturated, the entire system will have to be flushed, properly disposed, and replaced to return to non-saline flow.
- When the flow loop has been run for a certain period, it must rest to allow complete separation of the phases. This resting time has made testing periods much longer than anticipated.

Project Summary

- Key Findings.
  - Proved that a 3-phase flow loop can be economically built and used to effectively test the 3-phase flow meter prior to field testing.
  - Proved that the flow meter system can be packaged for subsea deployment.
  - Proved that the flow meter is accurate for 3-phase water-dispersed flow and 2-phase flow for all watercuts.
  - Developed a strategy for measuring with varying levels of salinity in 2-phase and 3-phase water dispersed flows.
- Next Steps.
  - Refine algorithm for 3-phase water dispersed flow
  - Introduce salinity for 3-phase water continuous flow on the flow loop
  - Integrate subsea chamber and full field test unit to flow loop
  - Develop field testing plans
  - Obtain certification for field testing safety

Appendix

- Benefit to the Program
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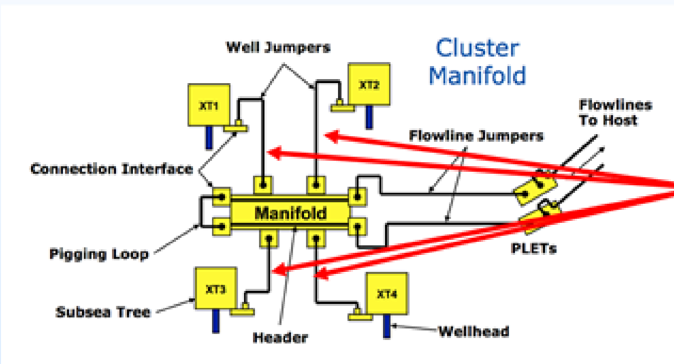
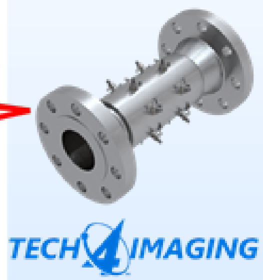
Benefit to the Program

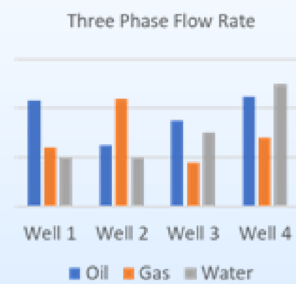
Subsea Manifold



Multi-Dimensional ECVT MPFM



Mass Flow Rate and Analytics



Benefits to EOR

- Information in Establishing New EOR
- Water Breakthrough Monitoring
- Subsea Separator Monitoring
- Custody Transfer
- Large Cost Savings compared to other MPFMs

The goal of this project is to combine the recent advances in ECVT into a single deployable commercial 3-phase flow meter capable of reporting the volumetric or mass flow rates of water, oil, and gas in real-time that will be an integrable part in reducing cost, increasing efficiency, and improving safety in Enhanced Oil Recovery (EOR) systems in subsea oil fields.

Project Overview

Goals and Objectives

The major objective of this project is to provide a means for EOR developers to measure and monitor multiphase flows in situ on subsea platforms to reduce cost, increase efficiency, and provide early detection and mitigation when changes in the well occur such as water breakthrough. With the success of this project, an operational certified TRL 7 MPFM will be operating on a live onshore field well next to a phase separator that is verifying the accuracy over a range of operating conditions. This MPFM will also be tested in a relevant subsea environmental chamber to prove the mechanical integrity of the equipment in such an environment. Additionally, a data sheet will be developed for the MPFM that is representative of field operating conditions and that offer a competitive advantage over existing MPFMs on the market for subsea applications.

This device is critical for lowering the cost and technical barrier to moving EOR operations to the sea floor by providing real time remote monitoring of subsea flow systems at critically distributed points rather than one central location. Such information as provided by this device would increase sustainability, lower environmental impact of EOR operations, and significantly reduce costs by replacing traditional methods of obtaining similar measurements.

Project Overview

Goals and Objectives

Phase I / Budget Period I

1.) The Recipient will Run tests on three phase flow loop to verify previous lab bench scale tests on three phase decomposition keeping oil, gas, and water quality constant while varying the volume fractions and flow rates

2.) Build high pressure flow loop at a Recipient facility

3.) Run tests on Recipient flow loop to verify testing results at high pressures

4.) Run tests on commercial loop to verify in house testing results for water cut measurement in a three phase system

5.) Test effects of salinity, solids, and oil quality in basic lab tests

Project Overview

Goals and Objectives

Phase II / Budget Period II

6.) Run tests at commercial flow loop to verify in house full three phase algorithm keeping oil, gas, and water quality constant while varying the volume fractions and flow rates

7.) Test on Recipient high pressure flow loop for effects of salinity, solids, and oil quality in a pressurized flow and adapt algorithm to measure and/or compensate for these variables

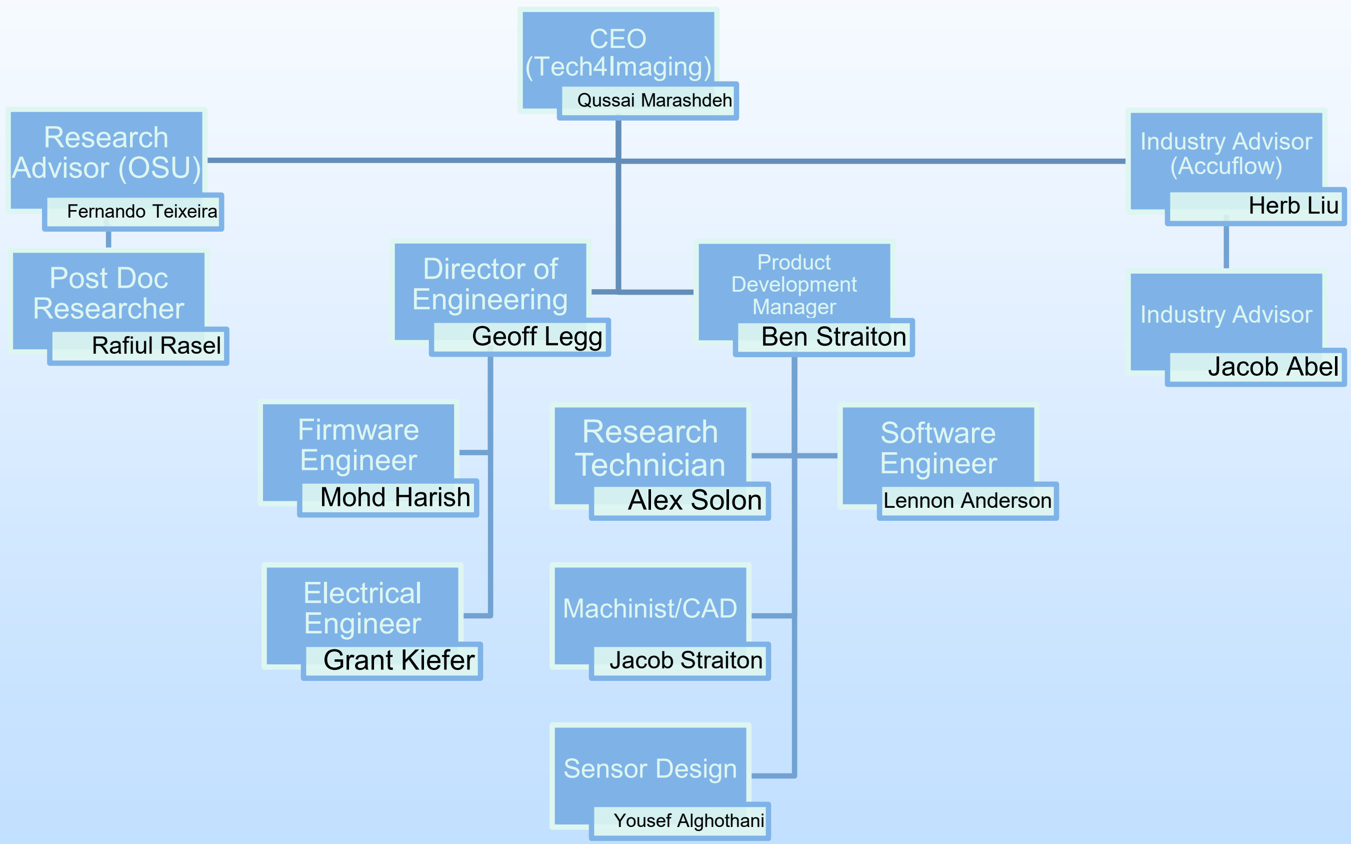
8.) Achieve appropriate certification of the system for field deployment

9.) Install flow meter on an onshore field well next to a three-phase separator to verify final accuracy in field conditions

10.) Test the mechanical and electrical integrity of the system in an environment which simulates subsea operation

11.) Build comprehensive data sheet reporting the test results over varying volume fractions, velocities, flow rates, salinities, solids content, and oil quality for marketing and commercialization purposes

Organization Chart



Gantt Chart

		Task	Year 1				Year 2				Year 3			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Milestone	Phase I													
	1.0	Project Management and Planning	■	■	■	■	■	■	■					
	1.1	Data Management Plan	■											
	1.2	Technology Maturation Plan	■											
	2.0	Develop test matrices and tests	■											
	2.1	Design low pressure three phase flow test for task 4.0	■											
	2.2	Determine specifications for subsea operation	■											
	2.3	Design high pressure three phase flow test for Task 7.0 based on specifications of Task 2.2	■											
	2.4	Design subsea environment test based on specifications of Task 2.2	■											
	2.5	Design third party tests for Task 10.0 based on test designed in Task 2.3	■											
*	3.0	Sensor design and build for low pressure three phase flow test	■	■										
	4.0	Low pressure three phase flow loop testing		■	■									
*	5.0	Design and build high pressure flow loop at Tech4Imaging facility	■	■										
*	5.1	Design and build subsea environment chamber	■	■										
*	6.0	Design and build sensor for high pressure flow loop and subsea operation												
	7.0	Run high pressure tests on Tech4Imaging's flow loop to replicate results of the low pressure flow loop tests			■	■								
+	7.1	Run static subsea environment chamber test			■	■								
	8.0	Algorithm development for three phase mass and volumetric flow rates	■	■	■	■								
	9.0	Data acquisition system electronics design, fabrication, and testing	■	■	■	■								
+	10.0	High-pressure third-party testing verification of water cut readings				■								
	11.0	Lab tests for variability in salinity, oil quality, solids content, and hydrocarbon scaling	■	■	■	■								
*	Minor Milestone													
+	Major Milestone													

Gantt Chart

			Year 1				Year 2				Year 3			
		Task	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Milestone	Phase II													
	12.0	Develop and refine test matrices and tests for Phase II												
	12.1	Design low pressure three phase flow test incorporating salinity, oil quality, and solids content variables												
	12.2	Design high pressure three phase flow tests incorporating subsea environment												
*	13.0	Test variables such as salinity, oil quality, and solids content on Tech4Imaging flow loop												
	13.1	Algorithm development for investigated variables												
	14.0	Integrate complete system												
	14.1	Incorporate subsea chamber into high pressure flow loop												
*	14.2	Test integrated flow measurement system on subsea flow loop												
+	15.0	Certify data acquisition system for Class 1 Division 1 operating environment												
*	16.0	Develop test plan for final field test and obtain required paper work/certifications												
		Go/No Go Point												
		National Environmental Policy Act (NEPA) approval of the Phase II site and field activities (Task 16.1)												
		Submittal of all deliverables for the work completed up to Subtask 16.0												
		Submittal of a Go/No-Go Report that includes, at a minimum, the following												
		1) Providing details showing that the developed data acquisition system has passed the certification according to Task 16.0 before moving forward.												
		2) a complete field test plan developed per but not limited to Task 16.0;												
		3) a technical briefing on the final design, field test plan activities and a discussion on whether or not the final design would lead to any technical and/or cost changes												
+	16.1	Test final system implementation on an active field well alongside a three-phase separator for validation												
+	17.0	Develop data sheet based on all testing and verification done during Phase I and Phase II												
	18.0	The Recipient will submit data to NETL-EDX												
*	Minor Milestone													
+	Major Milestone													

Bibliography

- Journal, multiple authors:
  - Rasel, R., Straiton, B., Marashdeh, Q., Teixeira, F., 2020, Toward Water Volume Fraction Calculation in Multiphase Flows Using Electrical Capacitance Tomography Sensors, IEEE Sensors Journal, v. 21, p. 7702 - 7712, available at: ieeexplore.ieee.org.
  - Working on two other publications currently.