UNDERSTANDING WET GAS IN A SUPERCRITICAL CO_2 CYCLE

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What are we going to cover?

When can you get wet gas in a sCO_2 cycle?

What is a Wet Gas Compressor (WGC) and how is it useful for sCO_2 power cycles?

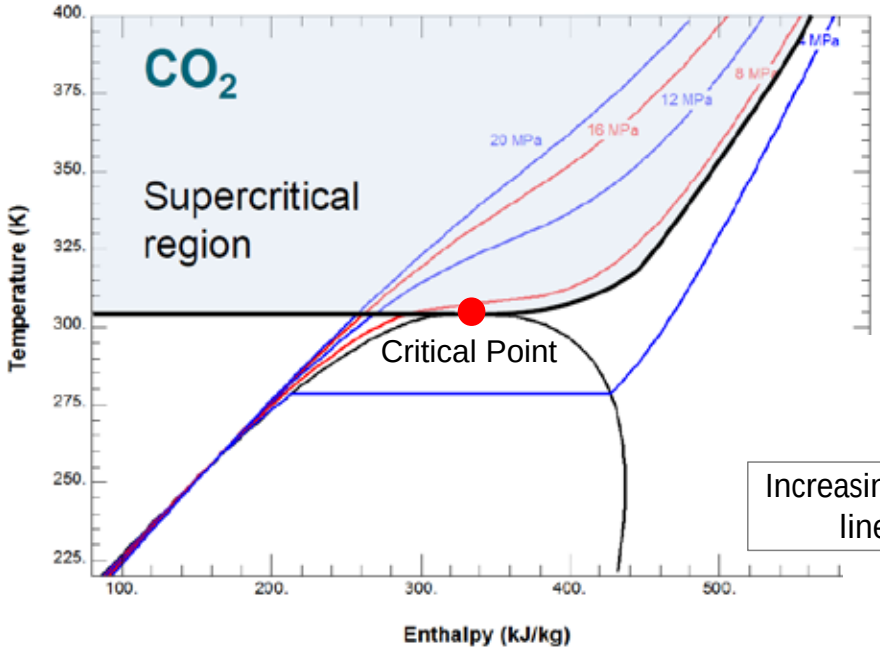
What are technology challenges for WGC?

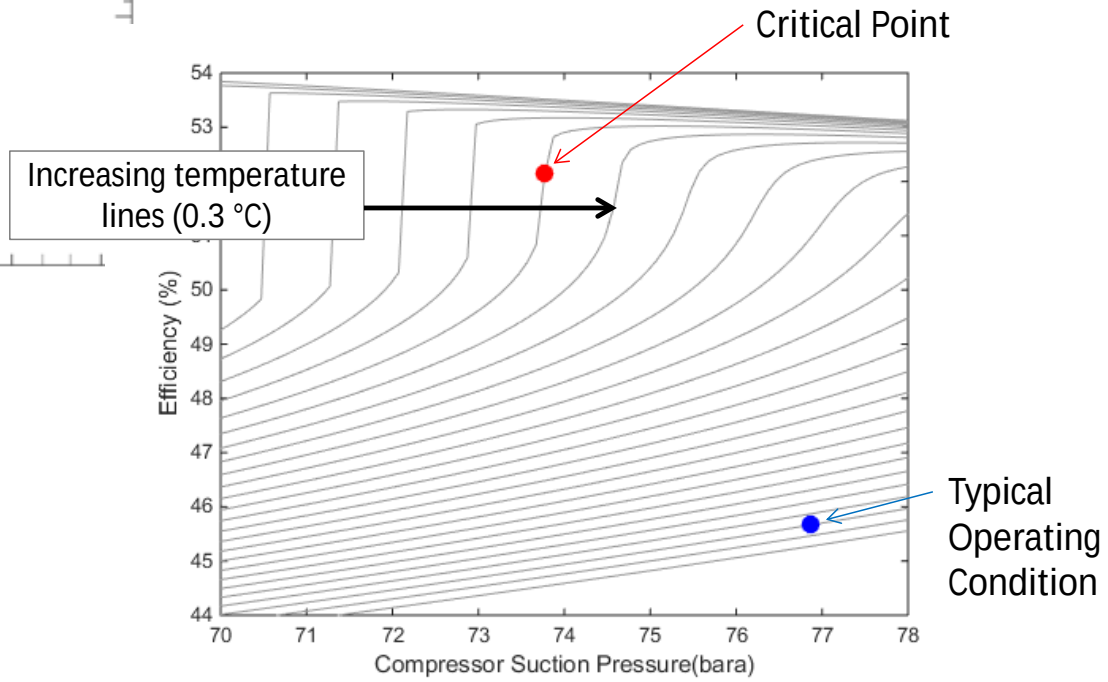
What's special about wet gas in CO_2?

Why does flow visualization matter for WGC?

What are the next steps to make sCO_2 WGC a reality?

Cycle efficiency is critical to a sCO2 power cycle operation





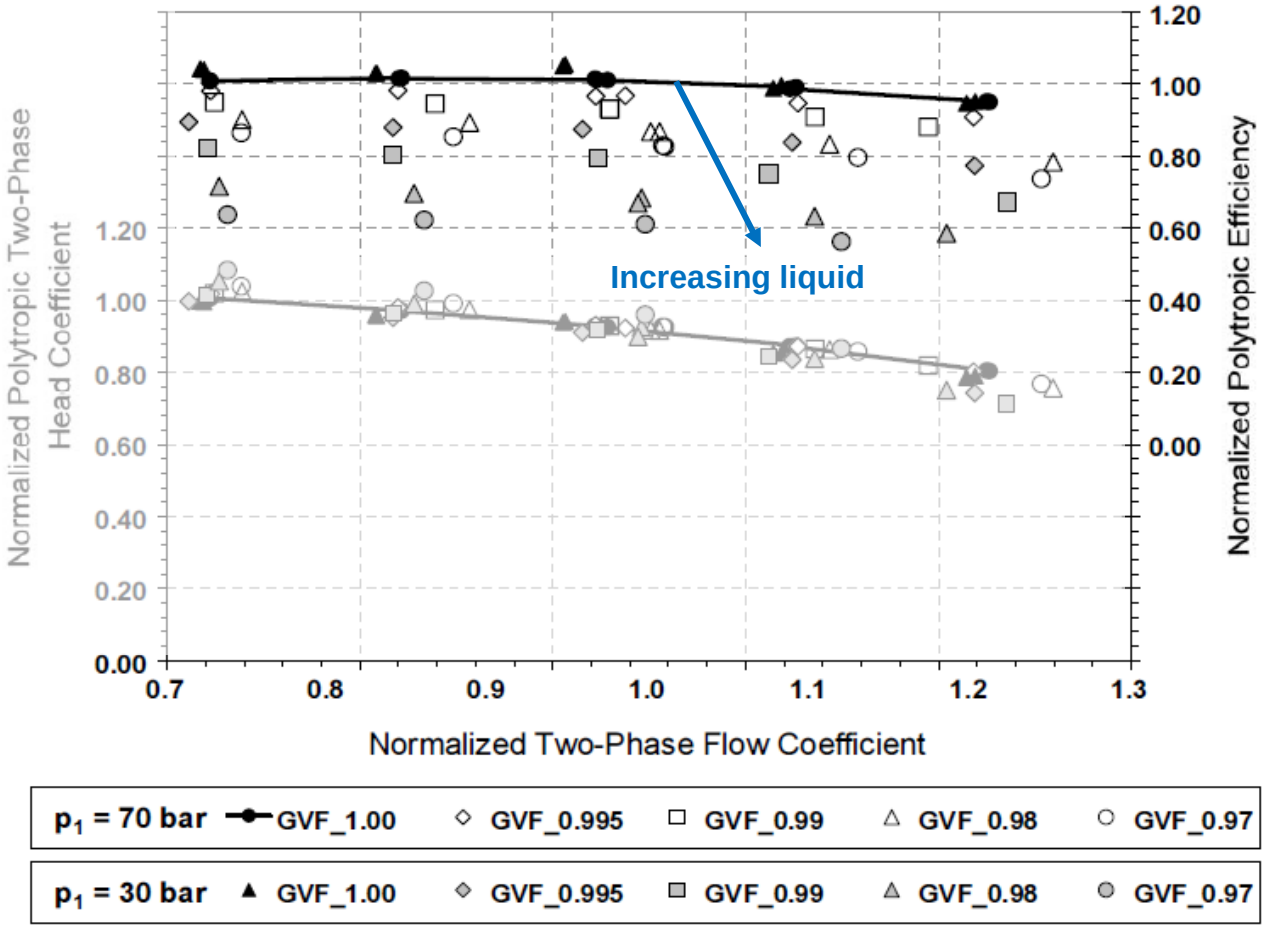
Operating at the critical point increases the risk of falling into the two-phase (gas/liquid) region

How to control/mitigate liquid

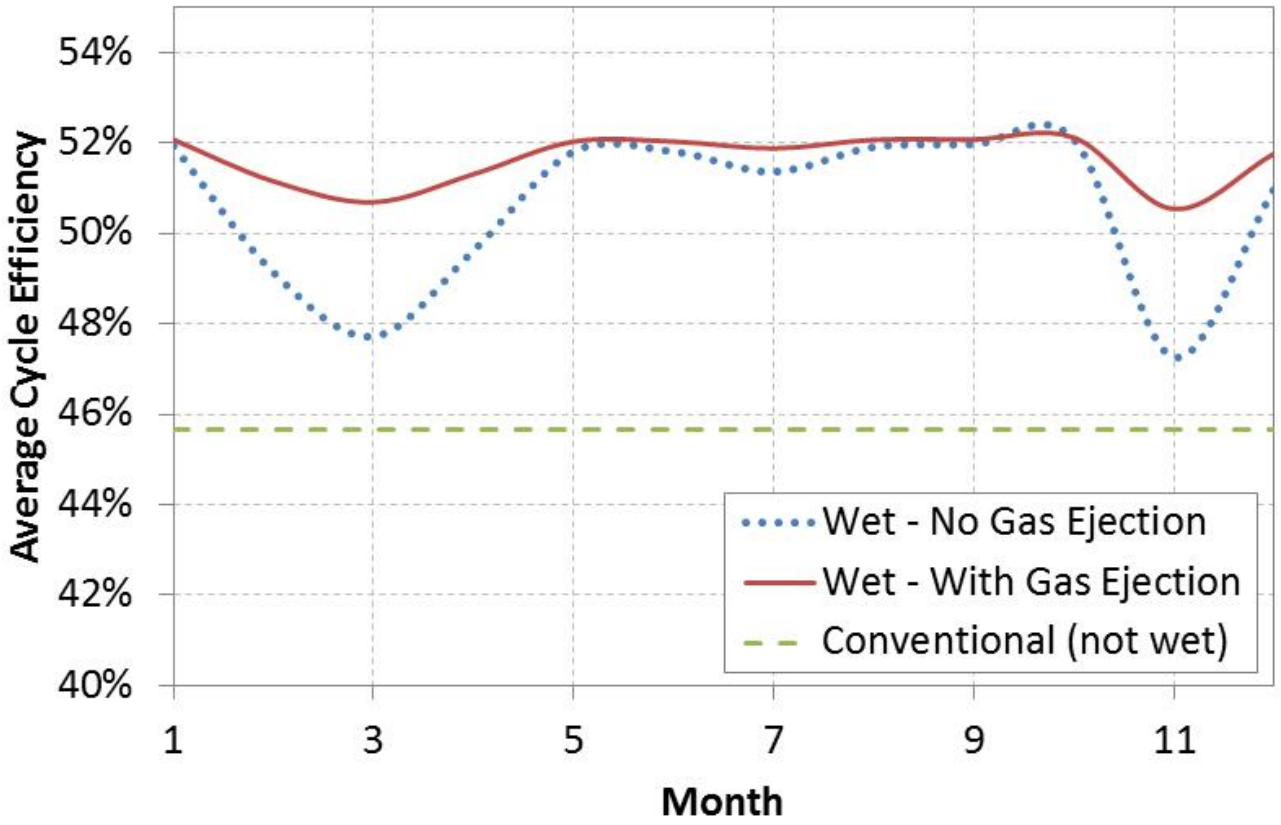
- Operating Away from Critical Point
- Upstream Separation
- Upstream Gas Temperature and Pressure Control

Wet Gas Compressor (WCG)

Can a wet gas compressor improve cycle efficiency?

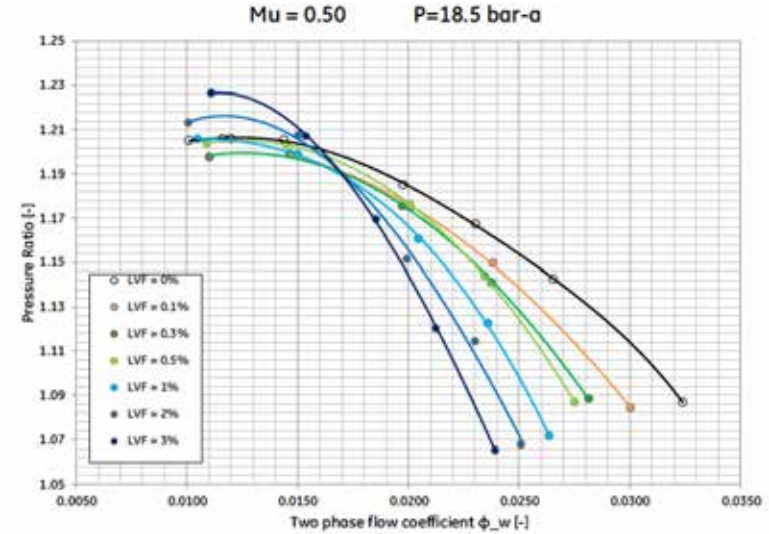


A WGC can improve cycle efficiency when compared to operating away from the CO_2 critical point

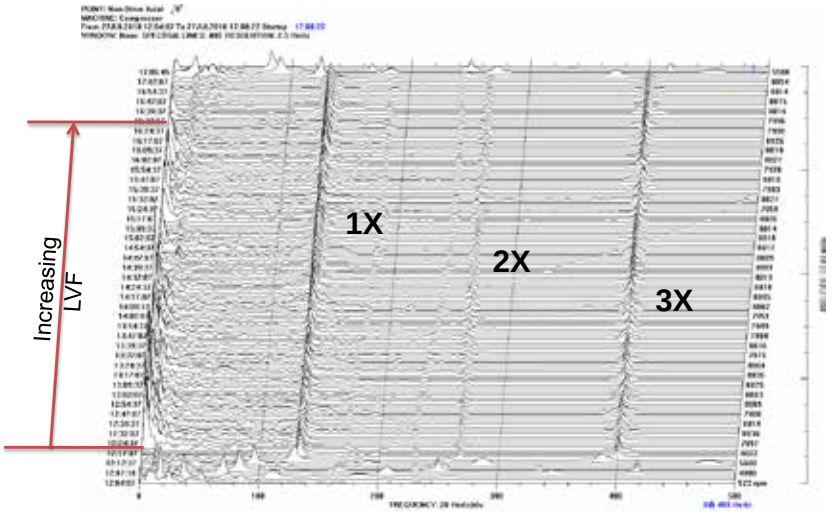


What challenges are there with WGC?

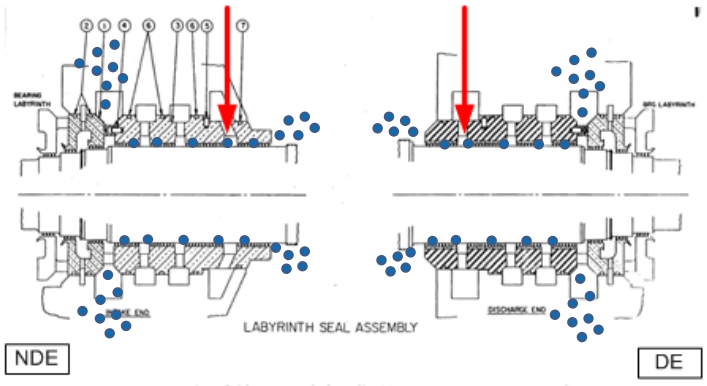
Aerodynamic



Mechanical



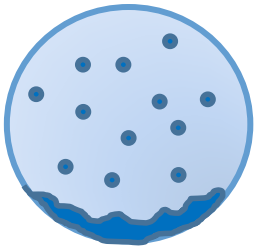
Shaft Sealing



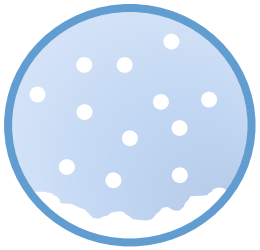
WHAT ARE UNIQUE CHALLENGES OF SCO_2 WGC?

LVF and LMF

Liquid Volume Fraction & Liquid Mass Fraction

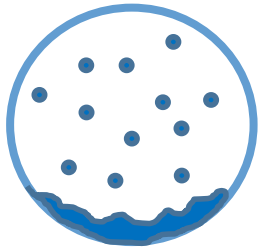


Two phase flow inside pipe



Gas

Volume – 1 ft^3
Density – 1 lbm/ft^3
Mass – 1 lbm



Liquid

Volume – 0.01 ft^3
Density – 100 lbm/ft^3
Mass – 1 lbm

$$LVF = 1\%$$

LVF = Liquid Volume Fraction

$$LMF = 50\%$$

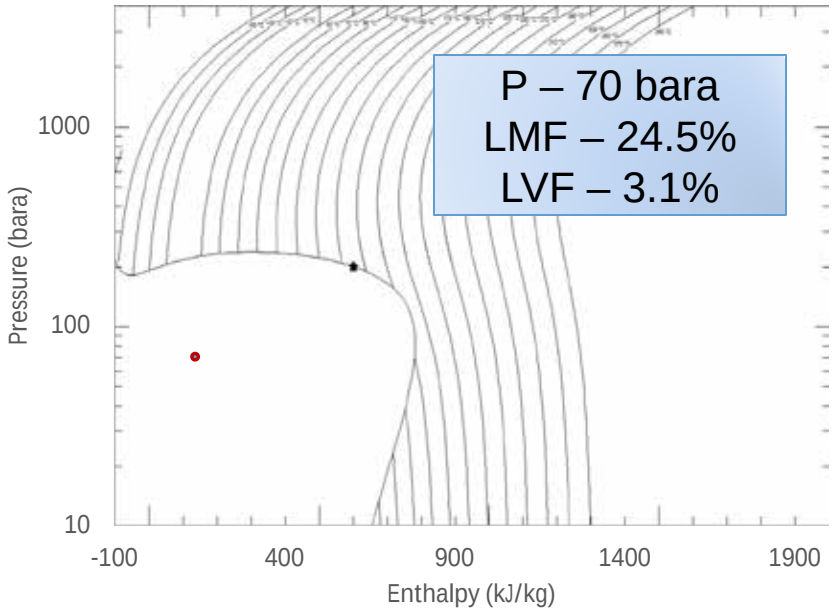
LMF = Liquid Mass Fraction

LVF and LMF

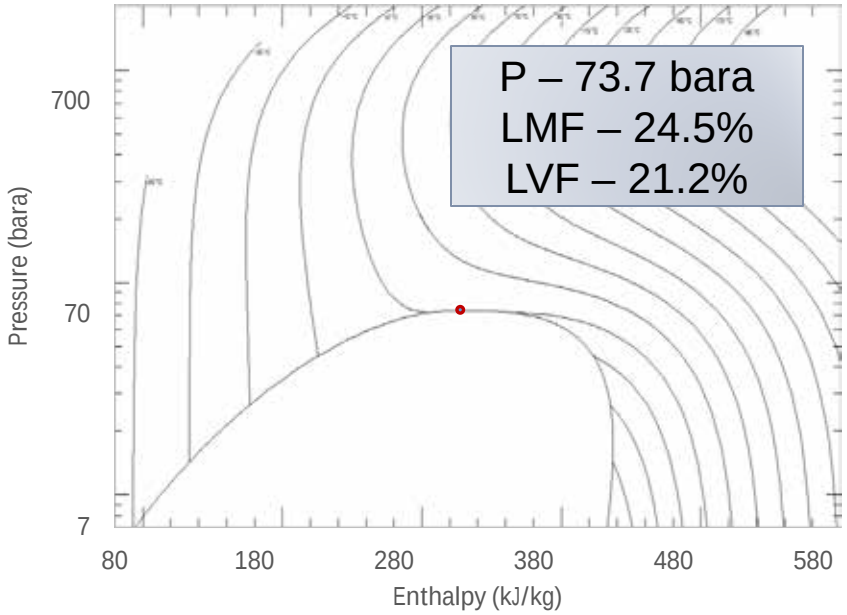
Liquid Volume Fraction & Liquid Mass Fraction

LVF — Gas and Liquid Density (P & T) Composition → **LMF**

Oil & Gas Application

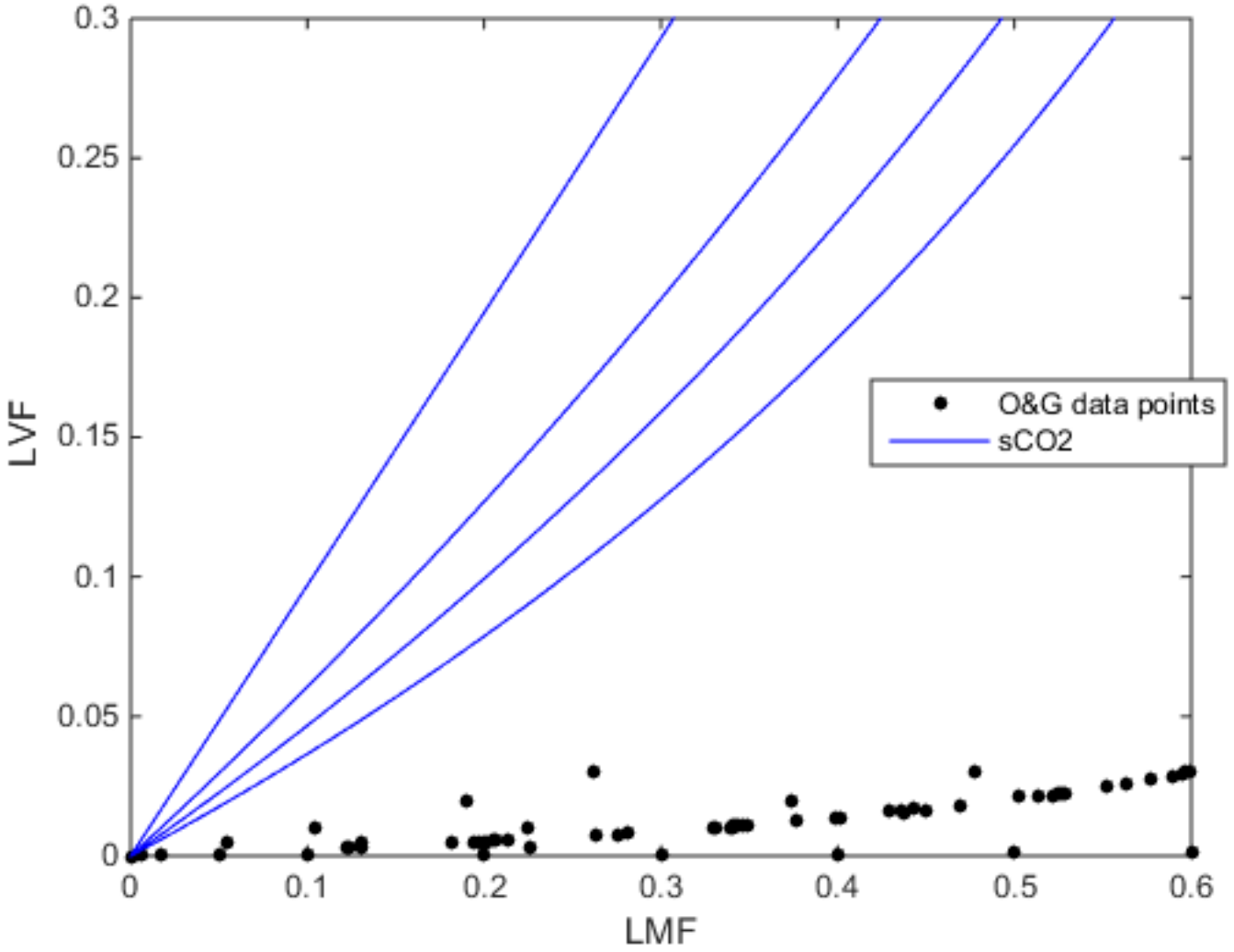


sCO_2 System

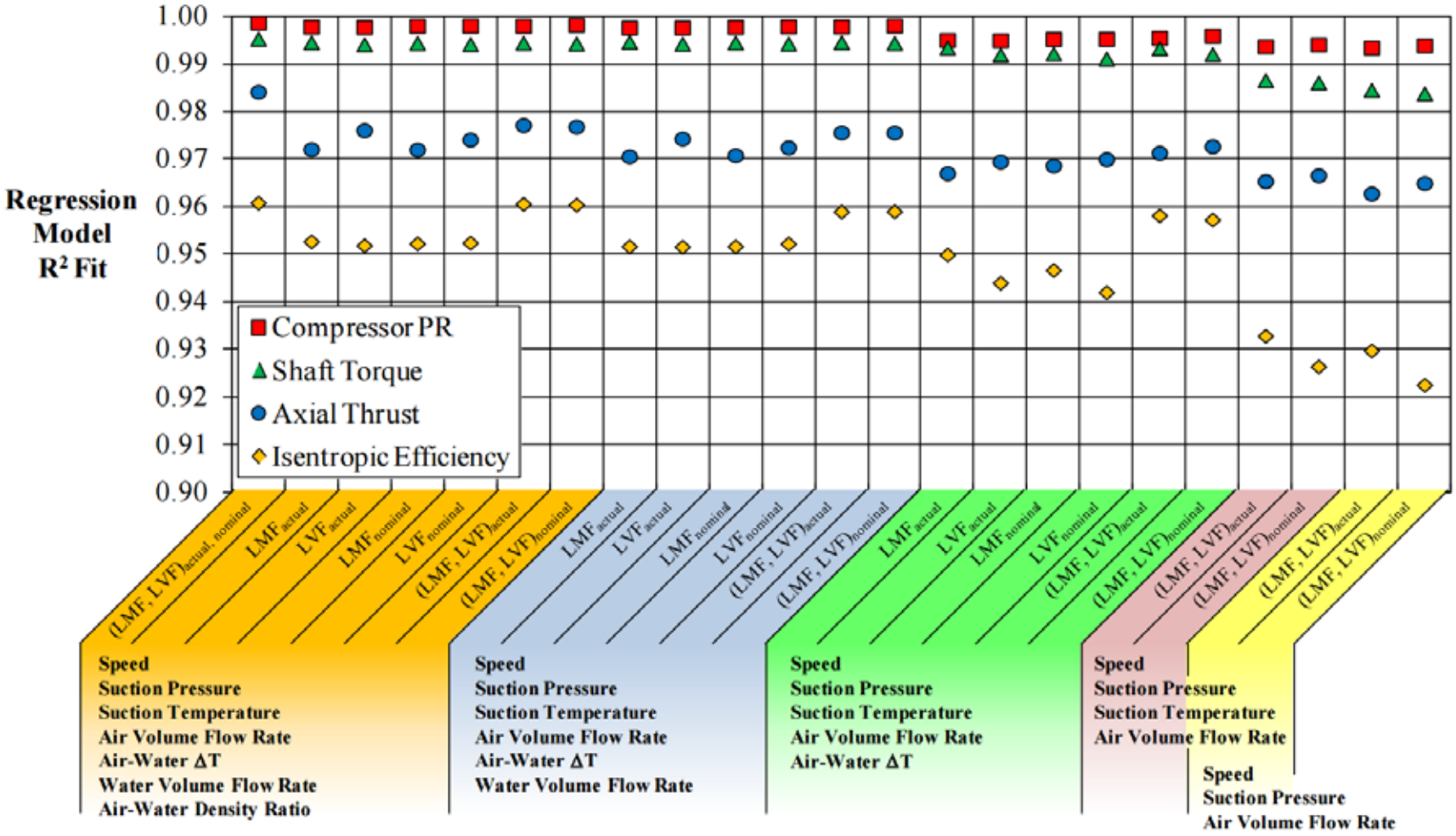


LVF and LMF

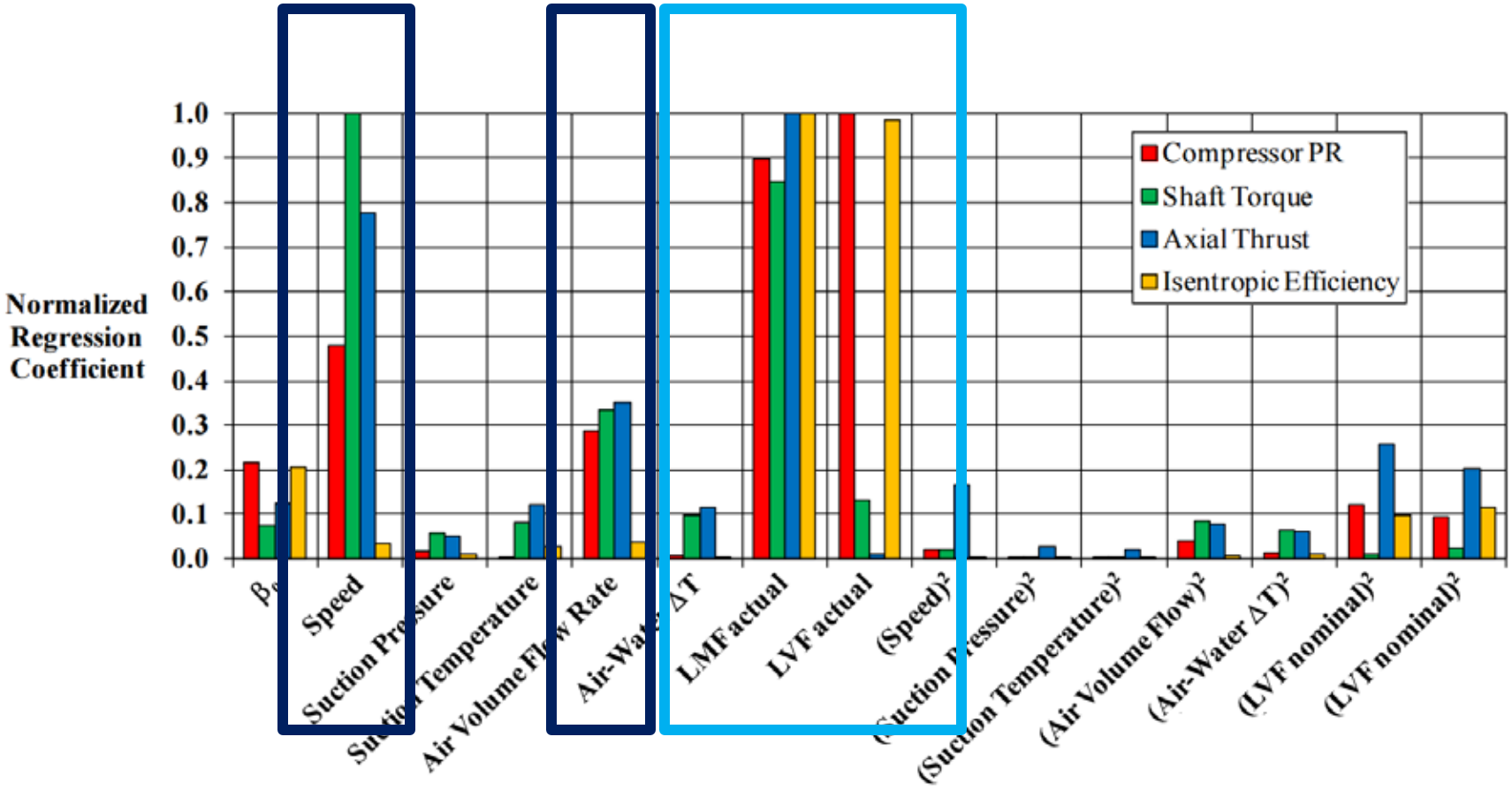
Liquid Volume Fraction & Liquid Mass Fraction



Does the LVF and LMF matter for WGC performance?



LVF and LMF both contribute significantly to the compressor performance in wet conditions



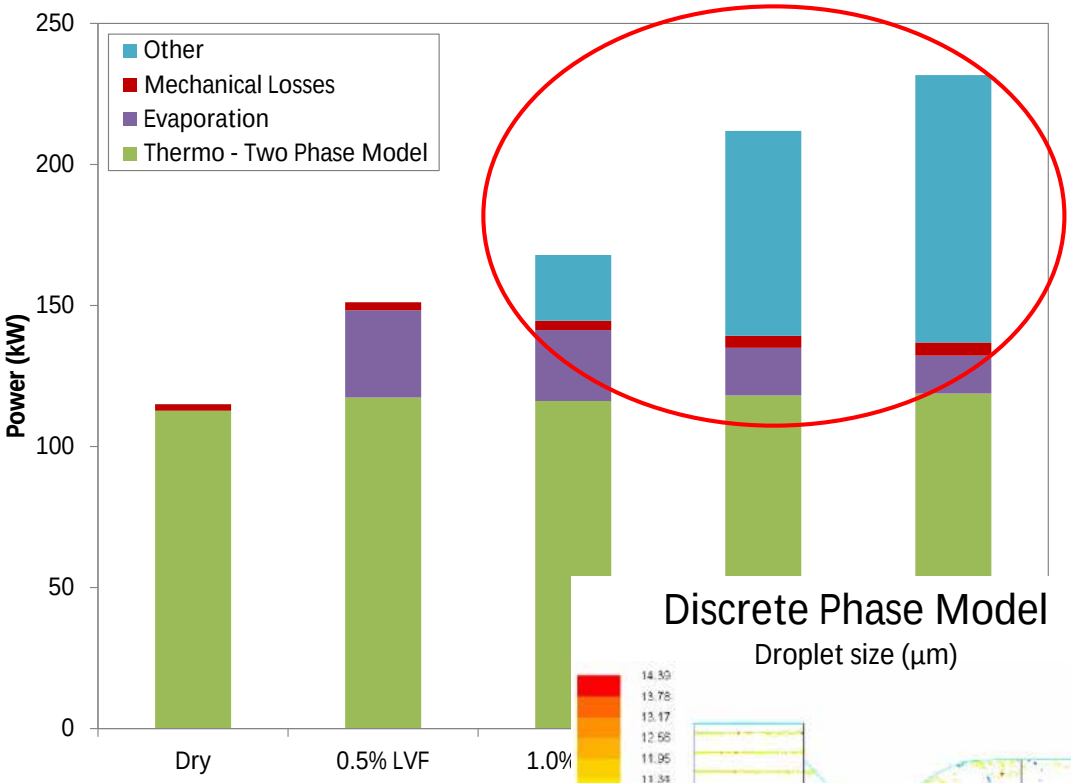
Conventional Dry Compressor

Wet Gas Compressor

What do we know at this point?

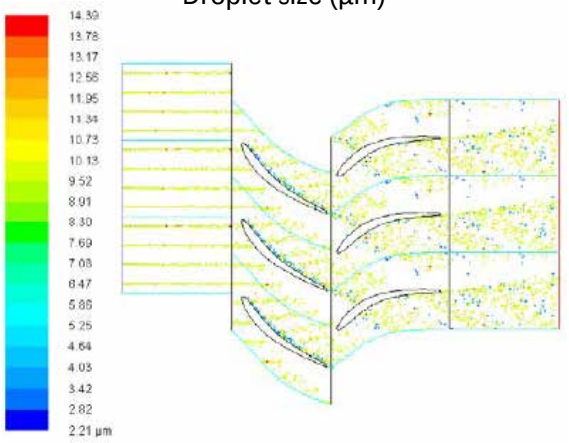
- WGC can lead to improvements in an sCO_2 cycle efficiency
- WGC is still a new technology (lots of challenges)
- The LVF and LMF for an sCO_2 cycle is significantly different than for oil and gas systems
- LVF and LMF are both important for understanding performance
- There is no data for wet gas with sCO_2

WGC performance cannot be currently predicted



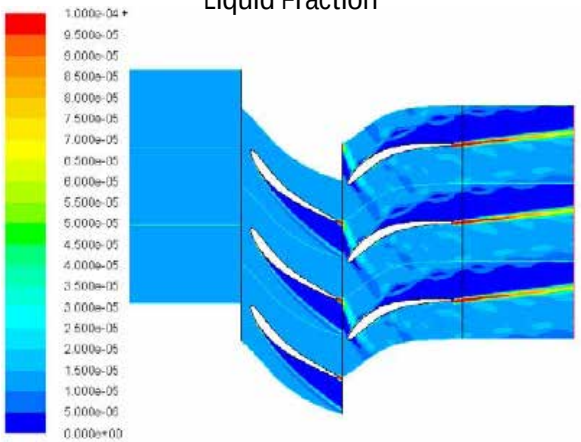
Discrete Phase Model

Droplet size (µm)

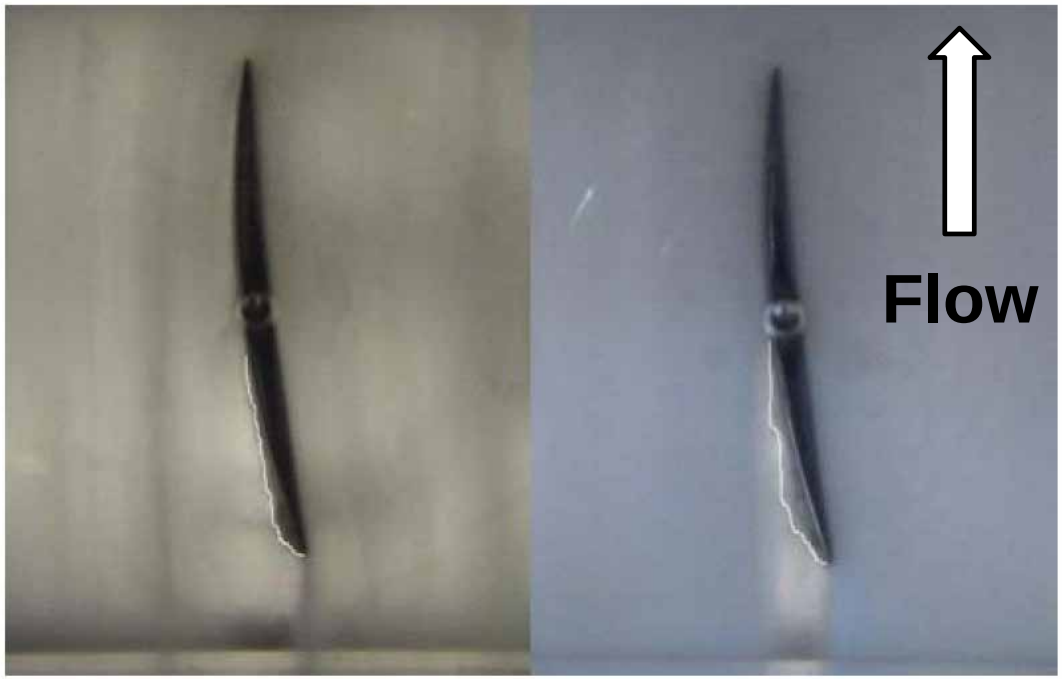


Multiphase Model

Liquid Fraction



Liquid on the aerodynamic surfaces significantly influences WGC performance

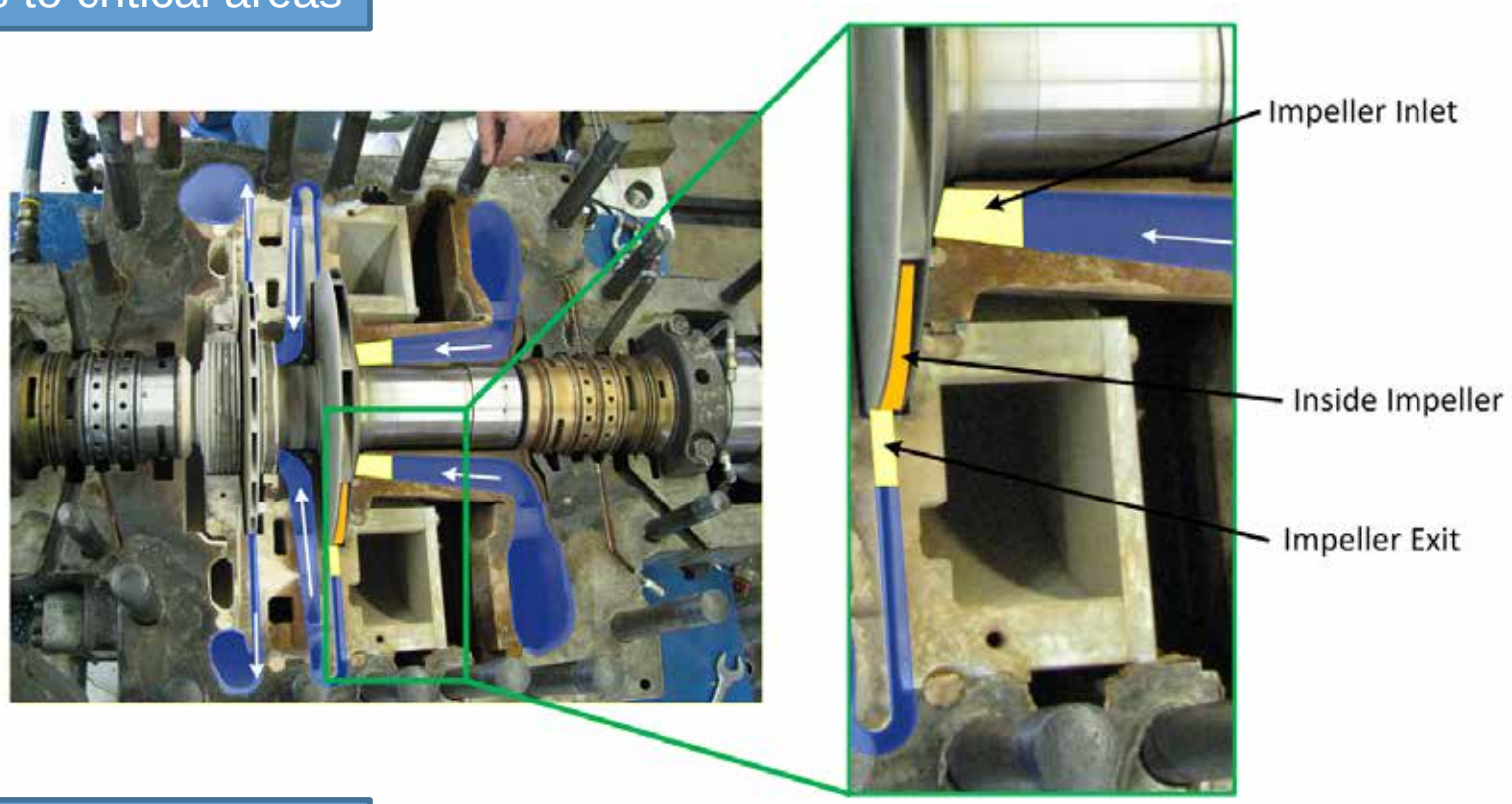


LVF 1.0% **LVF 3.0%**

Flow visualization is required to fully understand wet gas flow and its impact on performance

What are the biggest challenges with flow visualization in a compressor?

Access to critical areas



Providing sufficient light

Fogging/wetting of windows

What techniques can be used for two-phase flow visualization?

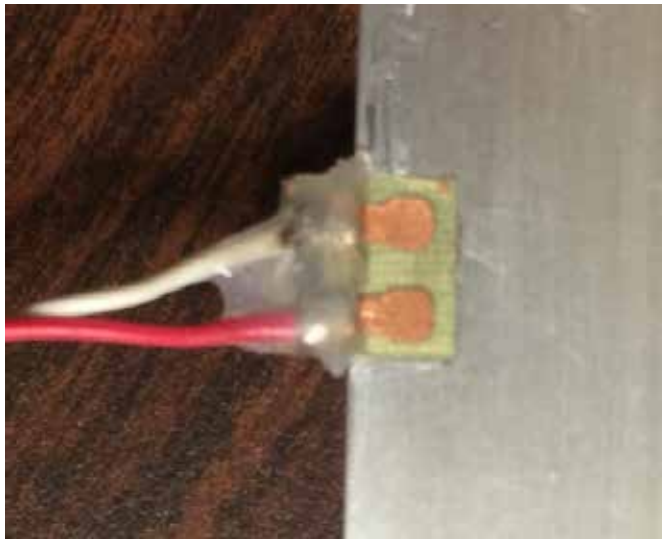
- Surface flow visualization
- Particle tracer methods
- Optical reflective index methods
- Light scattering methods
- Photographic methods

Access to the inside of the impeller is one of the most difficult challenges in flow visualization

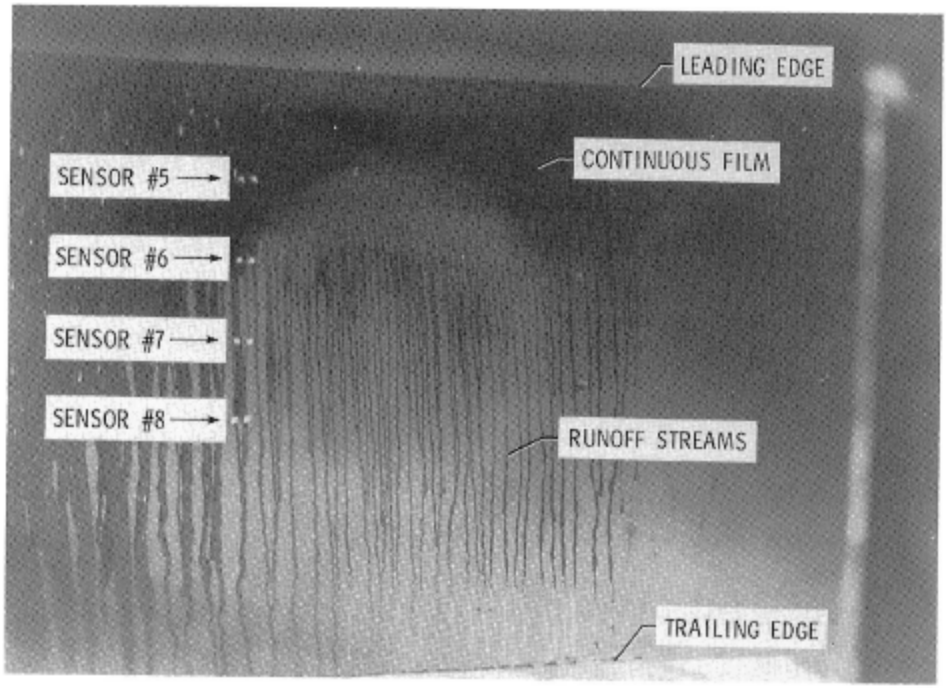
Shrouded

Unshrouded

Non-optical methods are considered for understanding liquid film thickness on surfaces



Electrical Resistance Probe

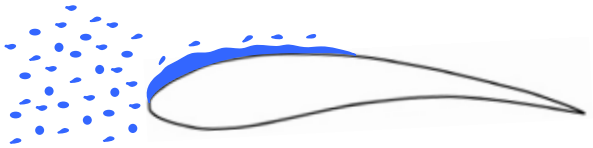


What work has been done for WGC flow visualization?

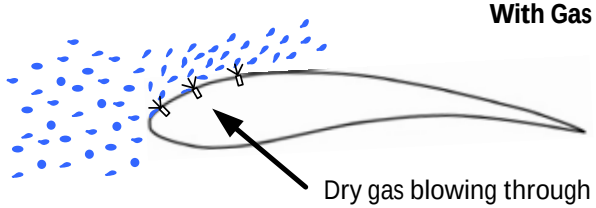
Southwest Research Institute

Flow

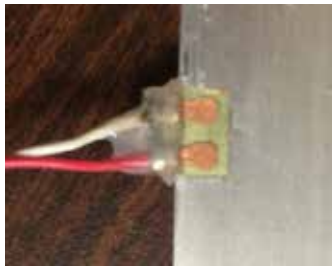
Without Gas Ejection



With Gas Ejection



Testing conducted at SwRI



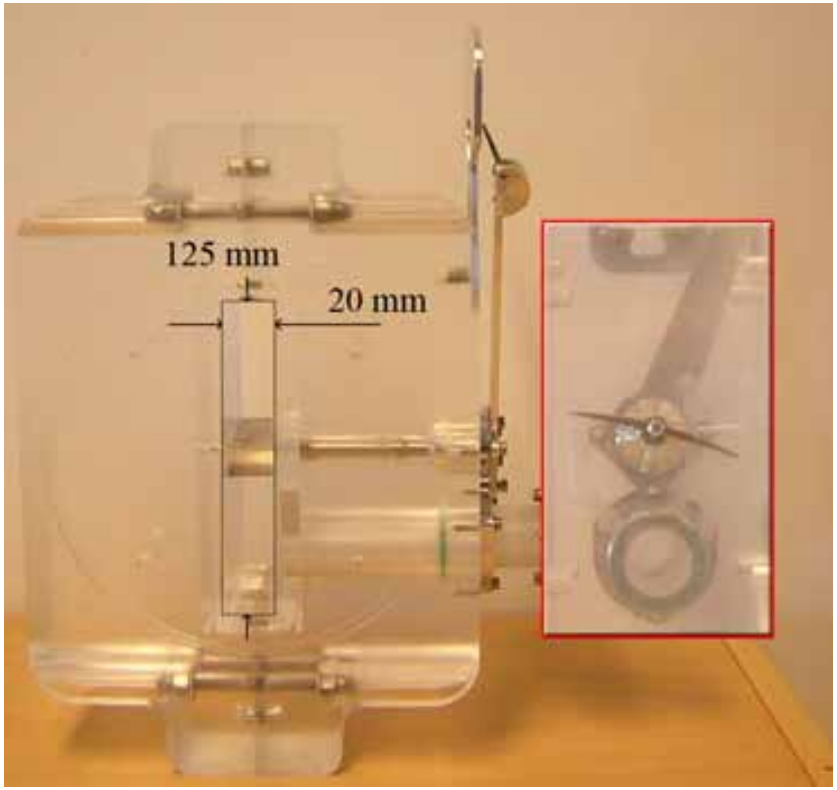
Uncoated

4.5 SCFM Air
0.65 GPM Water
2% LVF

Coated

What work has been done for WGC flow visualization?

Norwegian University of Science and Technology



Now, what do we know?

- WGC performance cannot be predicted
- Liquid attachment to aerodynamic surfaces is significant
- Flow visualization is needed to understand wet gas flow in a compressor
- Flow visualization is difficult due to
  - Access to critical areas
  - Lighting requirements
  - Two-phase flow effects
- Non-optical methods must be considered
- Some work has been done in flow visualization for wet gas

What is needed to make sCO_2 WGC a reality?

Test Data!	Flow visualization near the critical point
Flow Simulations	Design compressor Predict performance
Test Data	Compressor performance

Questions?

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