Flow Measurements for Gaseous Fuel Dispensers

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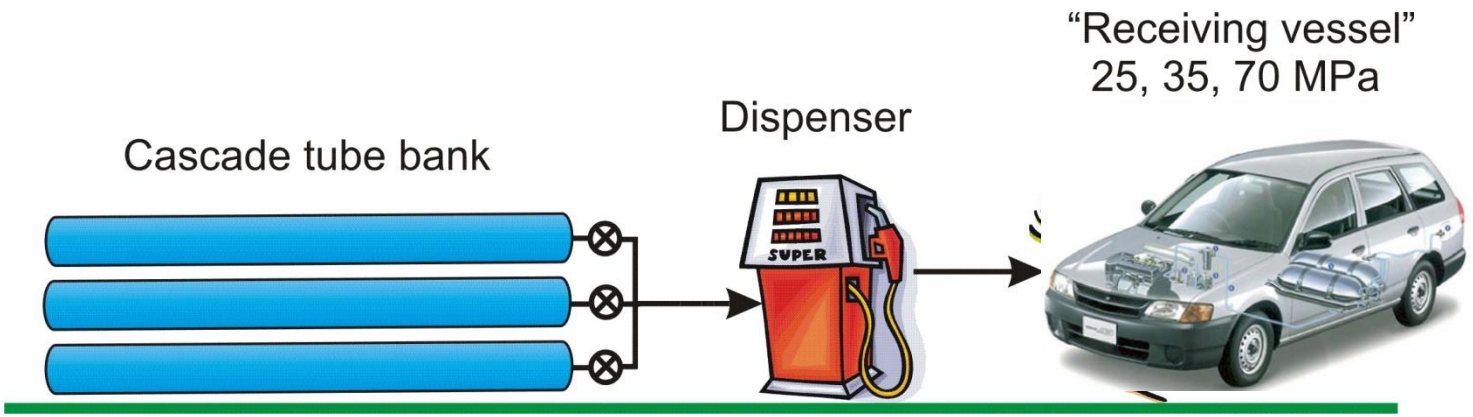
Motivation

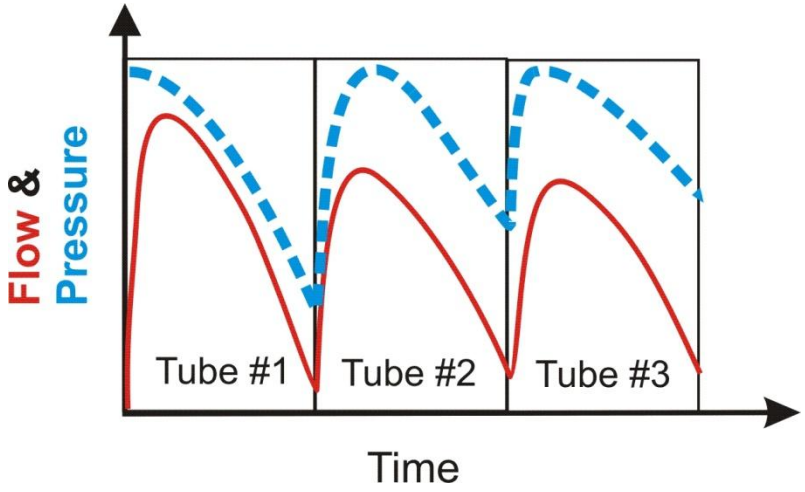
- Gaseous fuel dispensers (H_2 and natural gas) use coriolis flow meters to bill customers

- Reported errors > 10 % due to rapidly changing pressure, temperature, and flow transients
- Regulators expect < 1.5%

Gaseous Fuel Dispenser



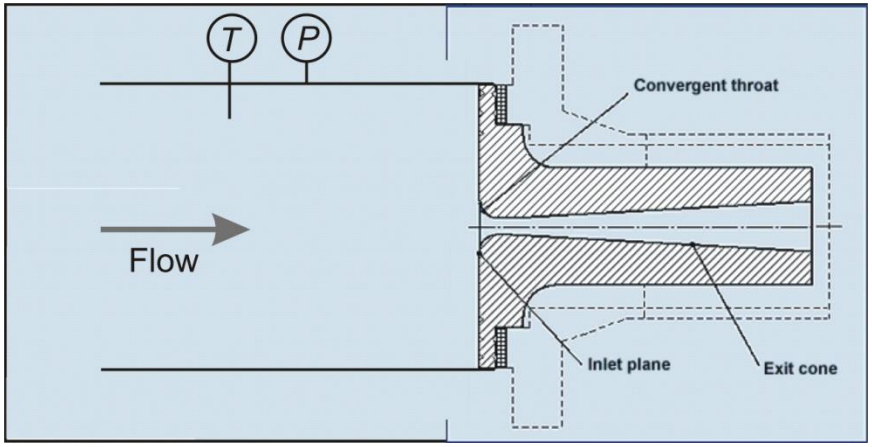
Conditions at the dispenser …

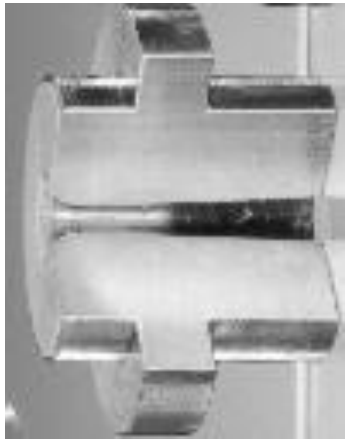


Technical Challenge

- Find a reference flow meter with fast time response
- Construct a calibration facility to provide transient flow conditions
- Evaluate candidate dispenser flow meters

Reference Flow Meter: Critical Flow Venturi (CFV)





$$\tau \approx \frac{\text{length scale}}{\text{speed of sound}} = \frac{0.001\,\text{m}}{350\ \text{m/s}} = 3\ \mu\text{s}$$

Discharge coefficient

Throat area

Critical flow function

Molecular mass

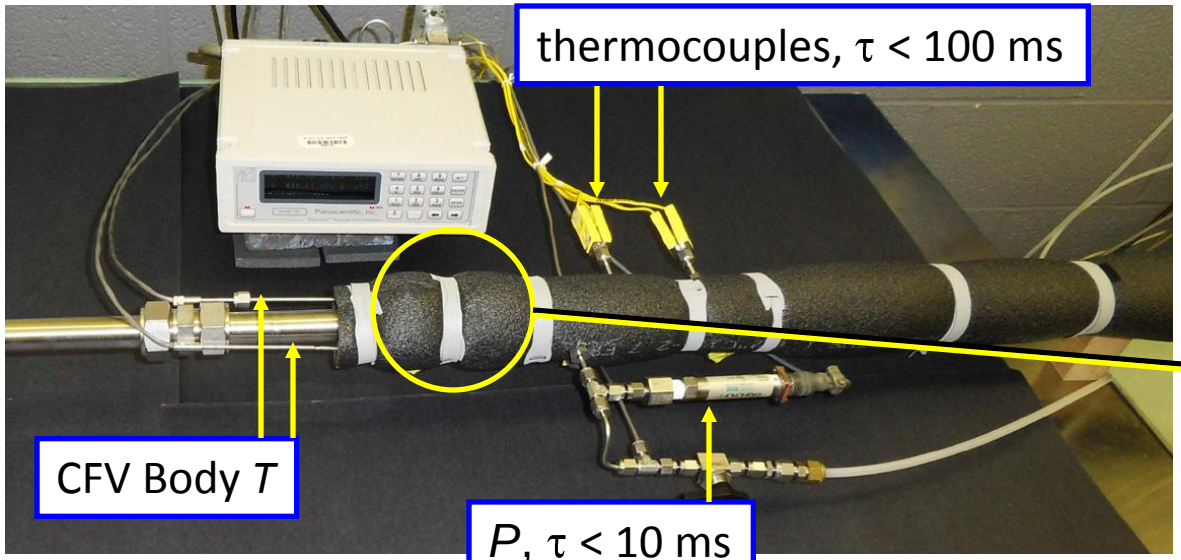
Mass flow

$$\dot{m}_{CFV} = \frac{C_d P_0 A C^* \sqrt{\mathcal{M}}}{\sqrt{R T_0}}$$

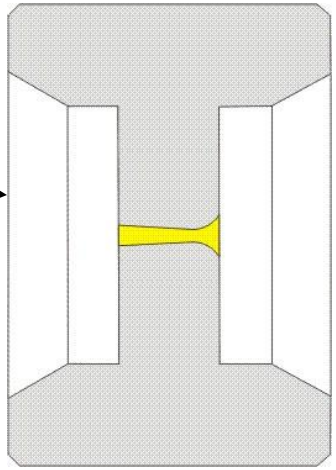
Universal Gas constant

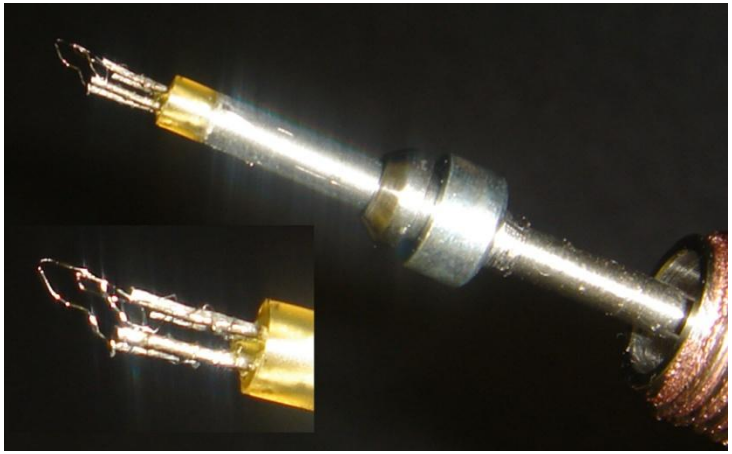
Pressure and temperature **< 100 ms possible**

Critical Flow Venturi Set-Up



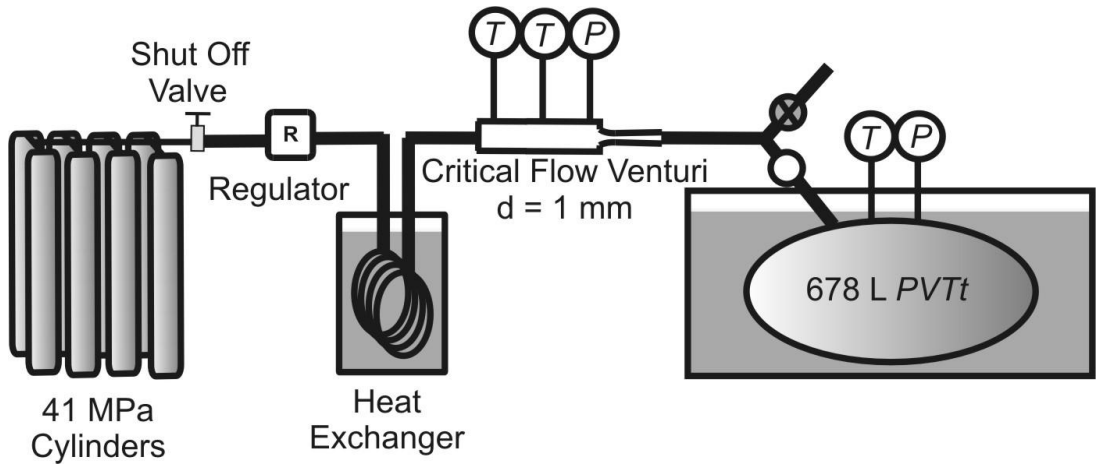
1 mm CFV in high pressure taper seal fitting

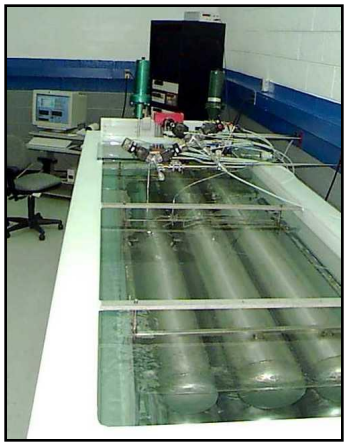




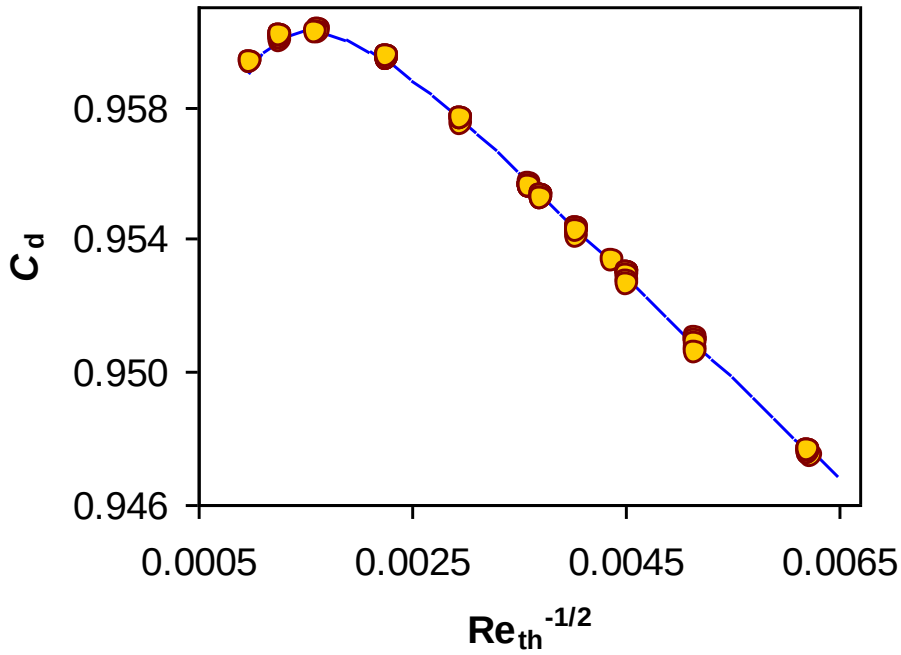
0.05 mm thermocouple pairs

Steady State CFV Calibrations

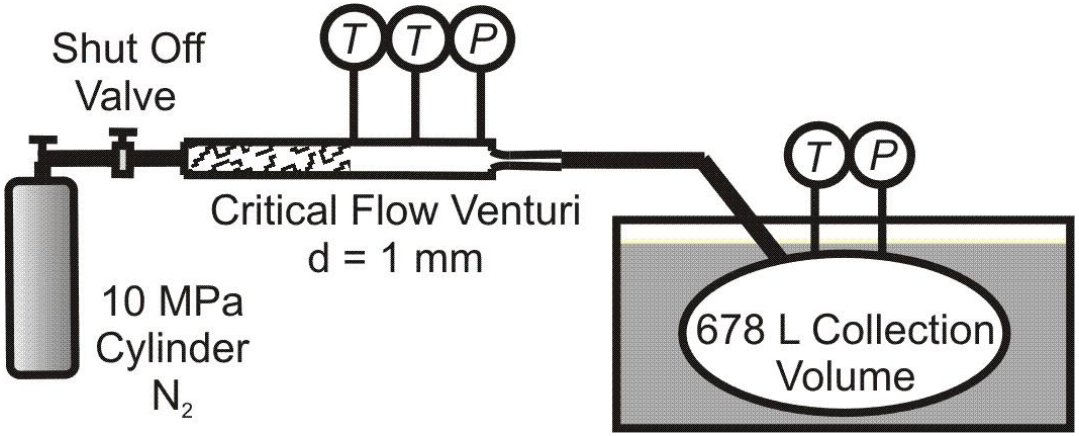


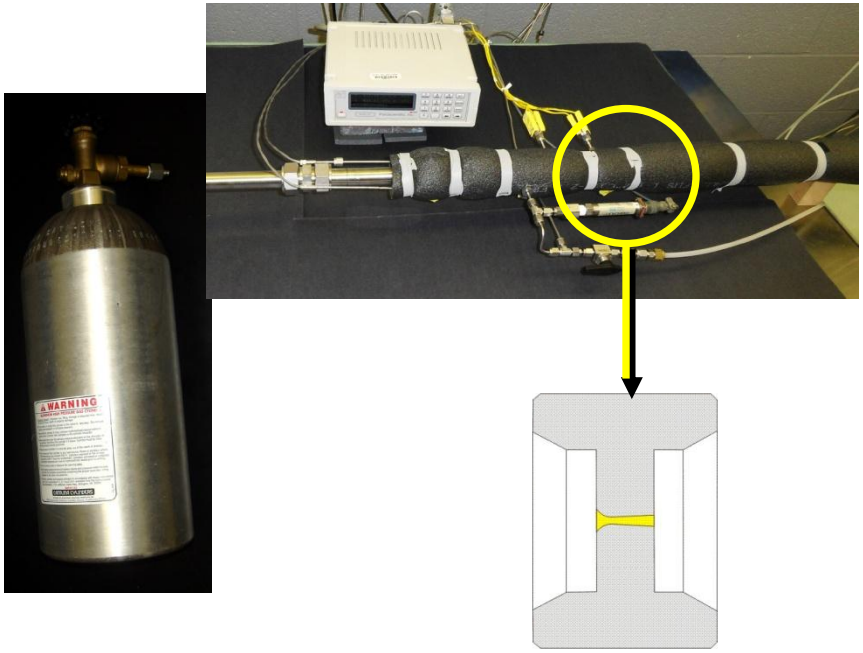


- P_0 = 30 MPa to 0.2 MPa
- Transition $Re \approx 4 \times 10^5$
- $U\,(C_d) = 0.07\ \%\ (k = 2)$

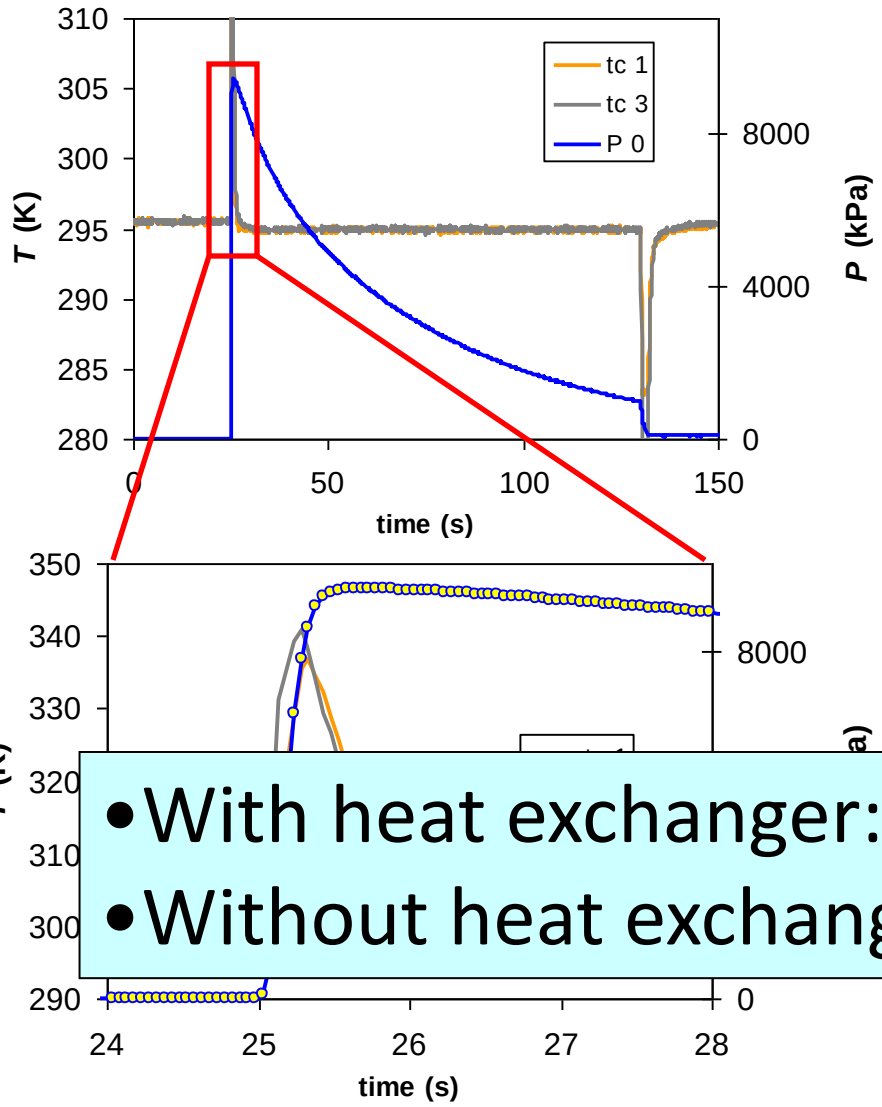


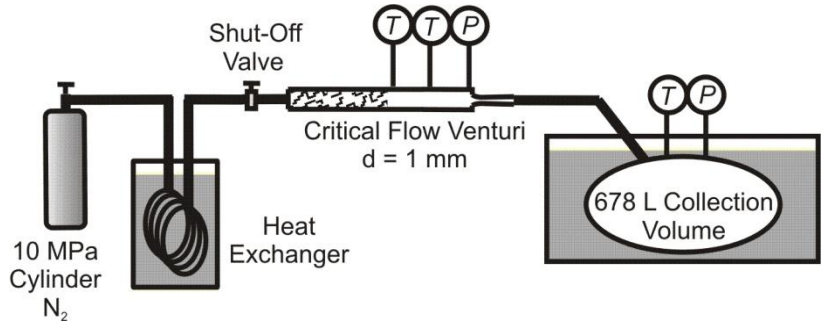
Blow-Down Test

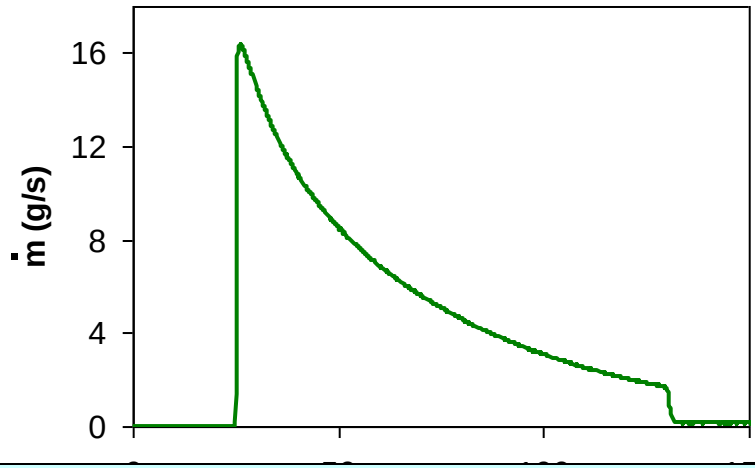




Steady State *T*, Transient *P*

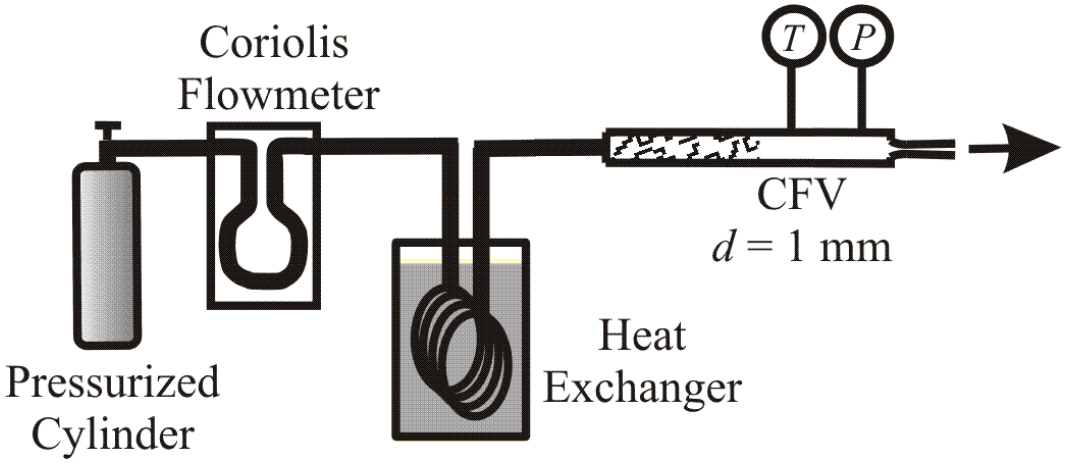


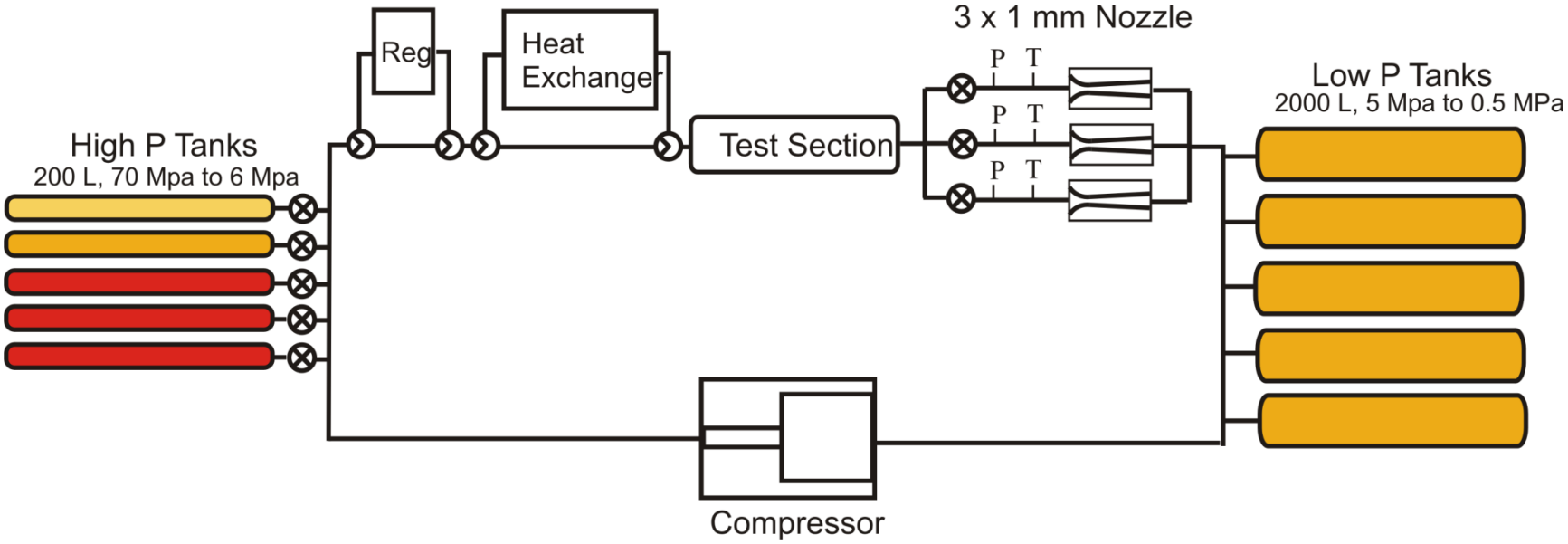




- With heat exchanger: 0.04 %
- Without heat exchanger: 0.38 % (*T* gradients)

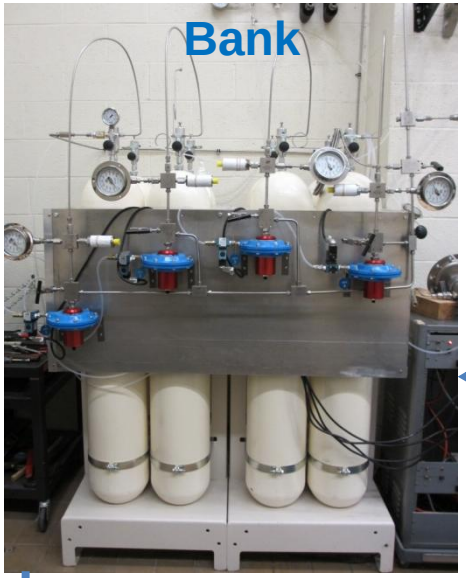
Transient Flow Facility

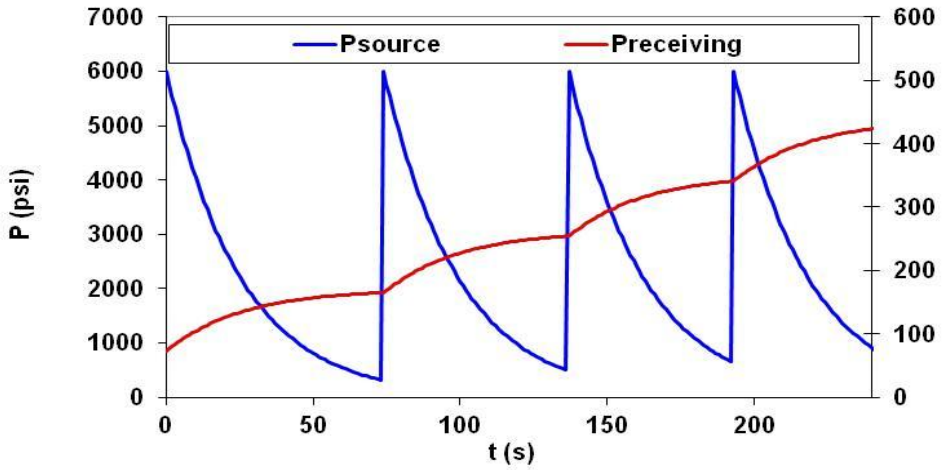


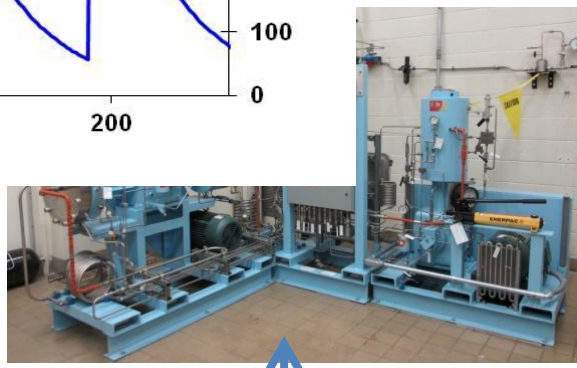


Transient Flow Facility

Source/Cascade Tube Bank



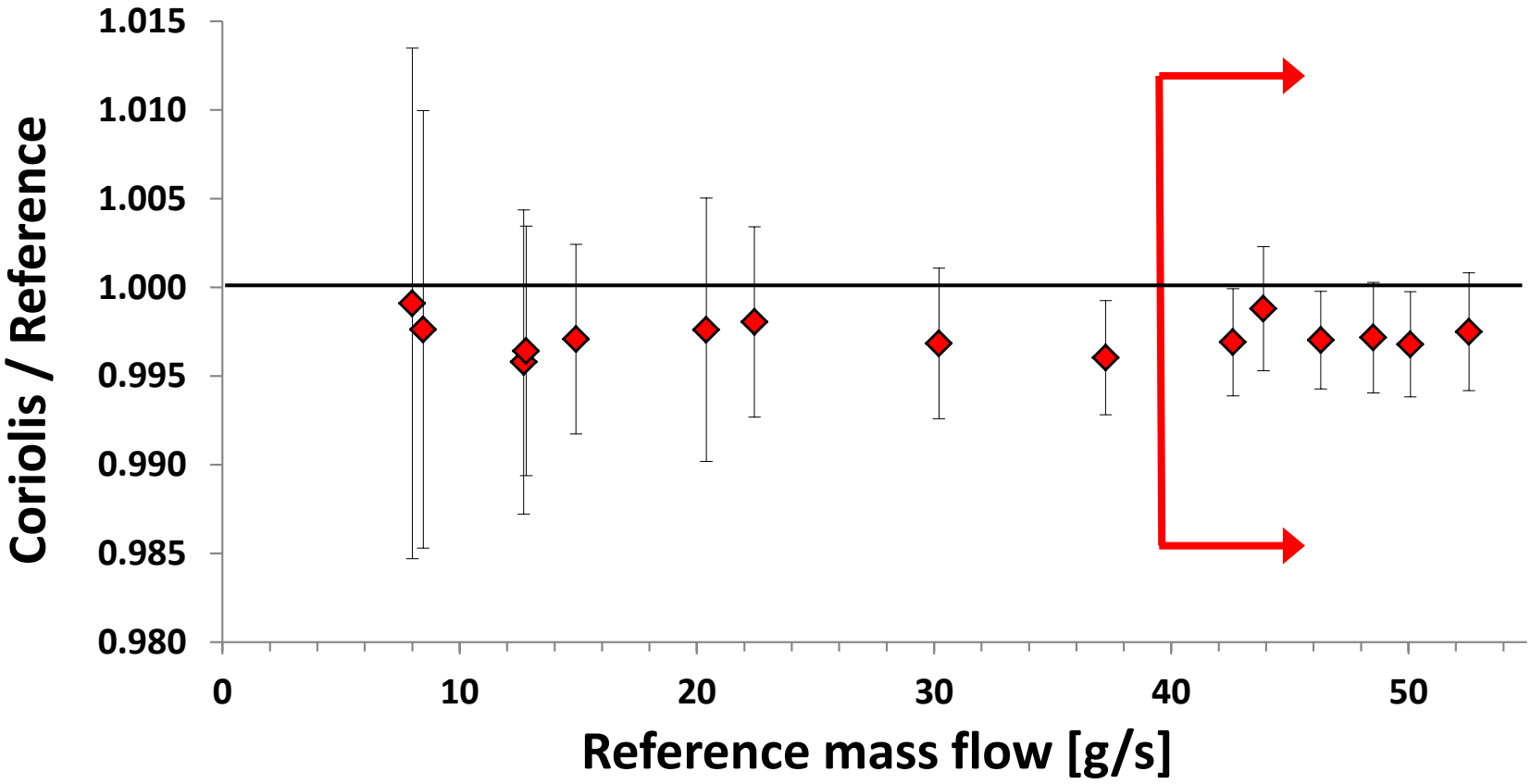




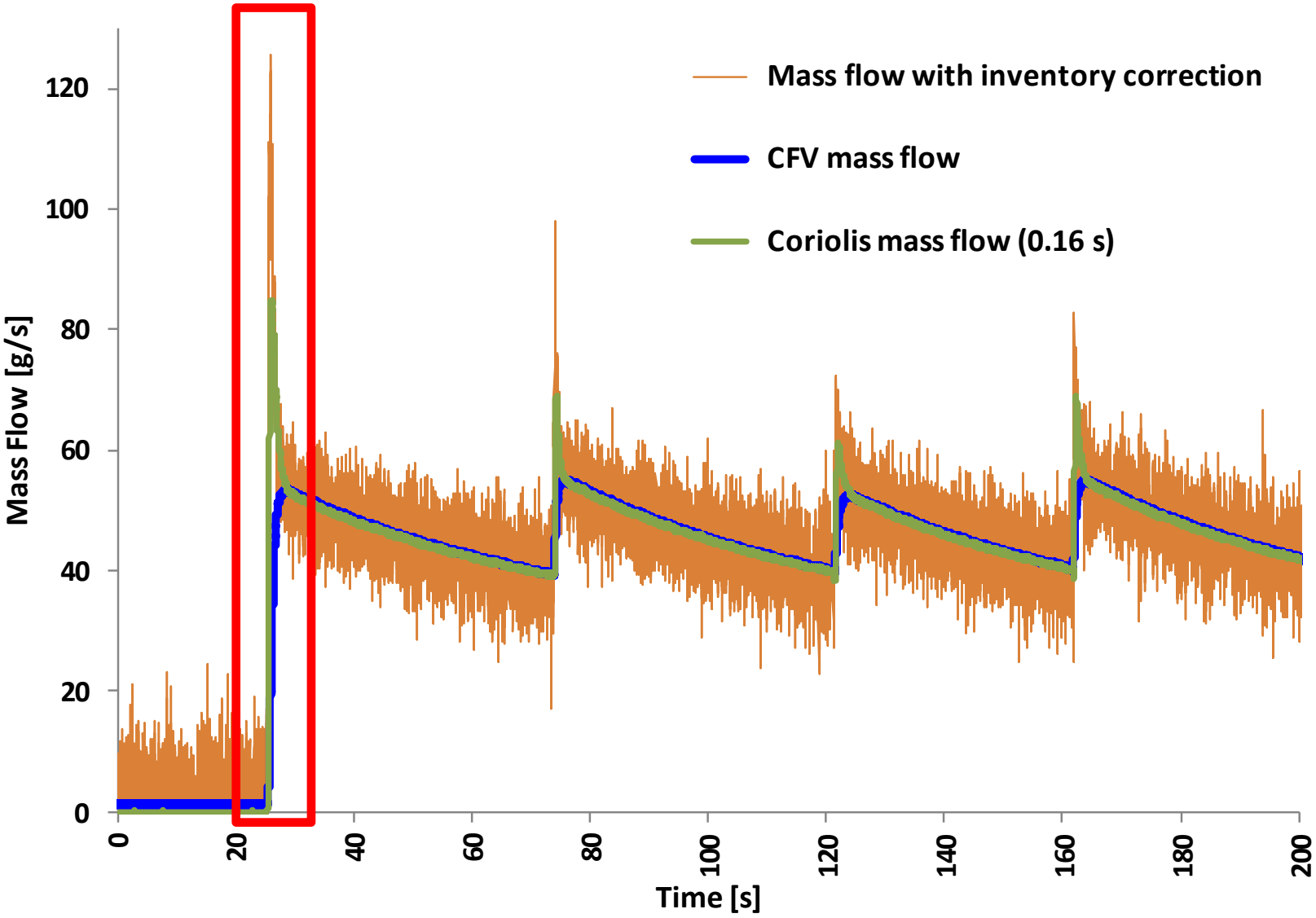
Test Bed

Receiving Vessel

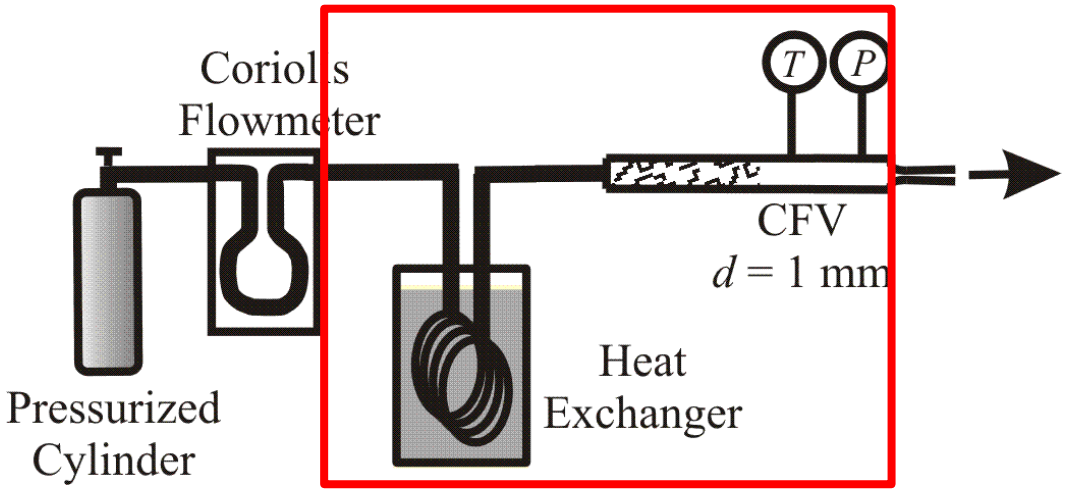
Steady State Coriolis Calibration



Simulated Cascade Fill



Inventory Volume Storage Effects



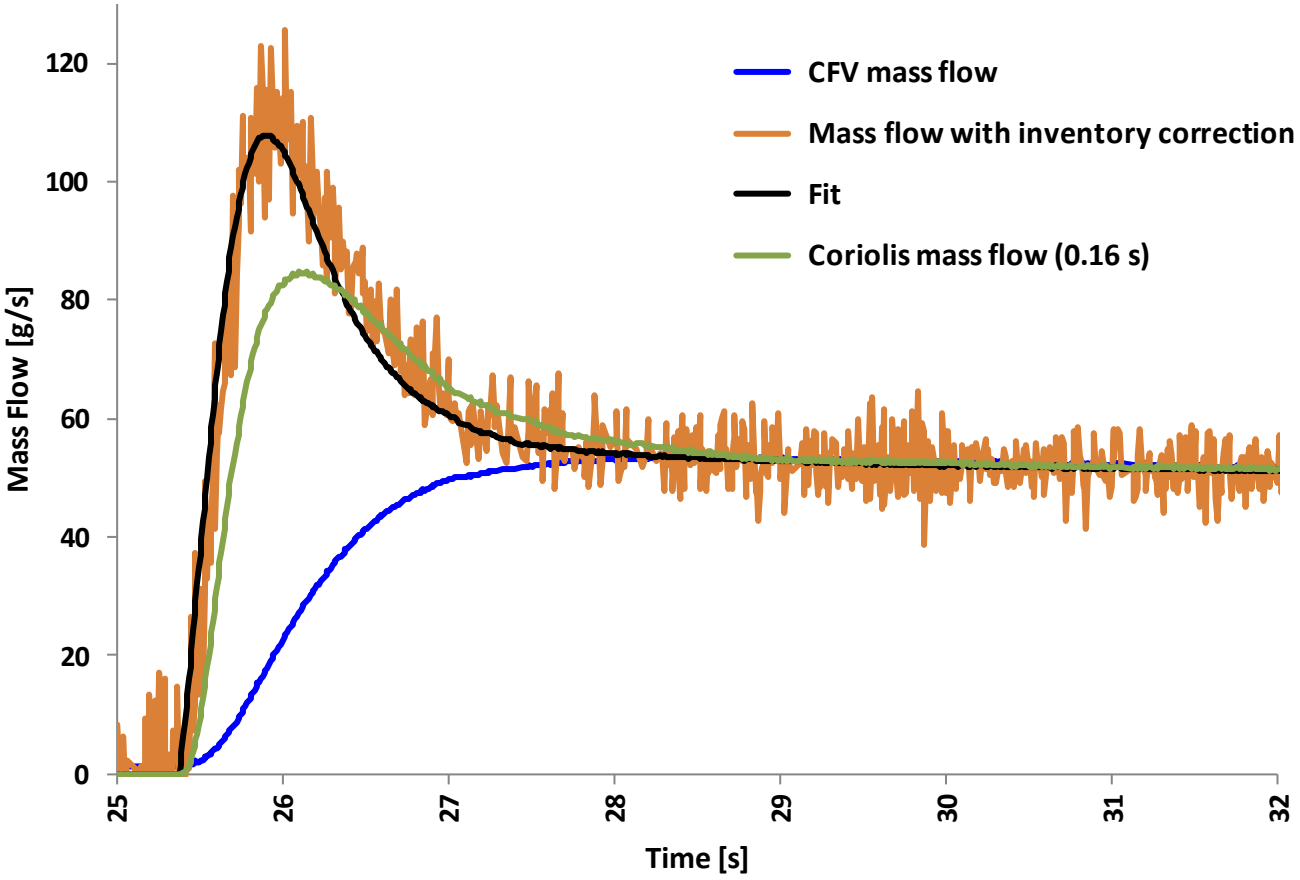
Inventory volume

Mass balance on control volume:

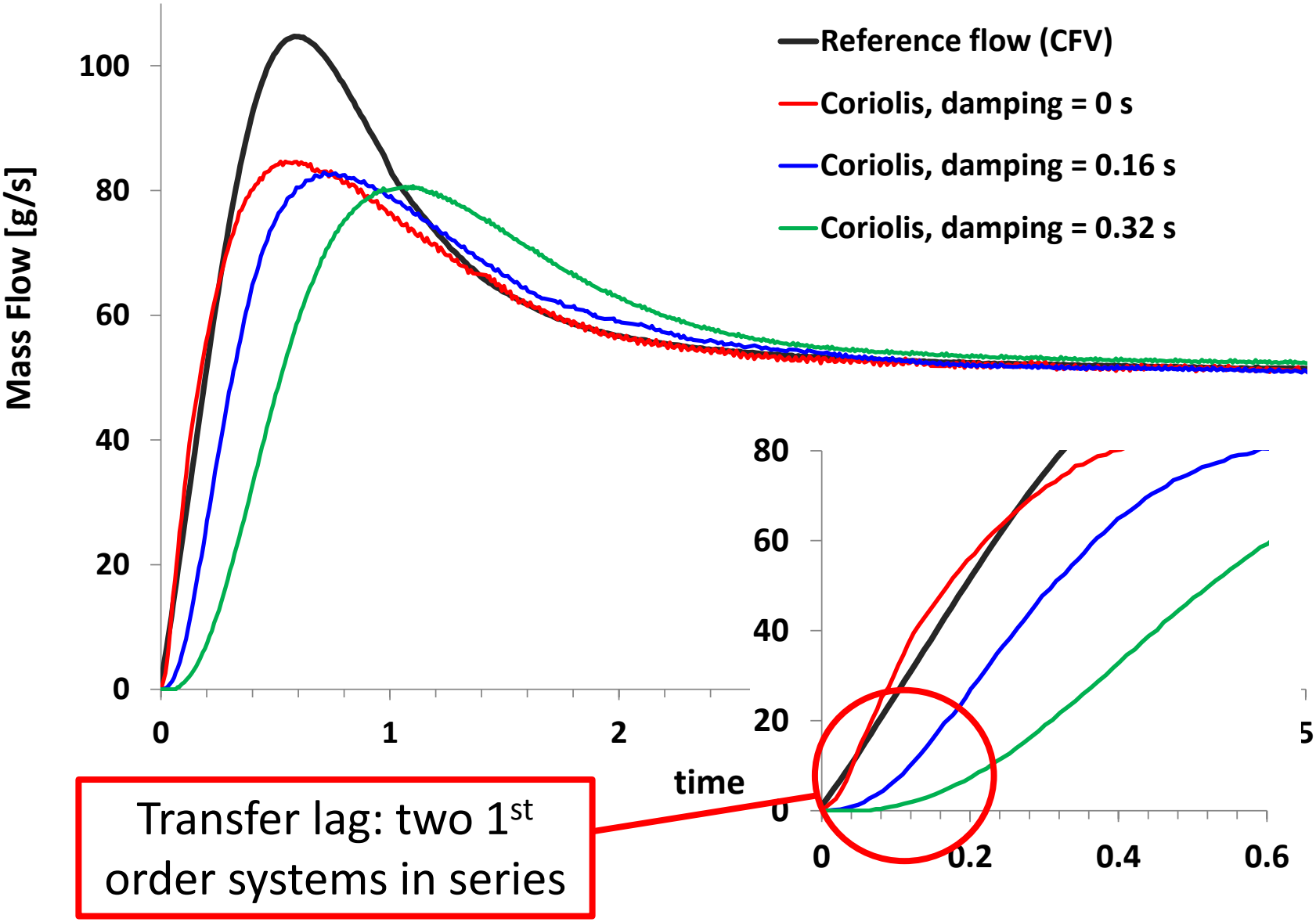
$$+ \; -$$

$$\frac{\sqrt{}}{\sqrt{}} + \; -$$

1st Transient

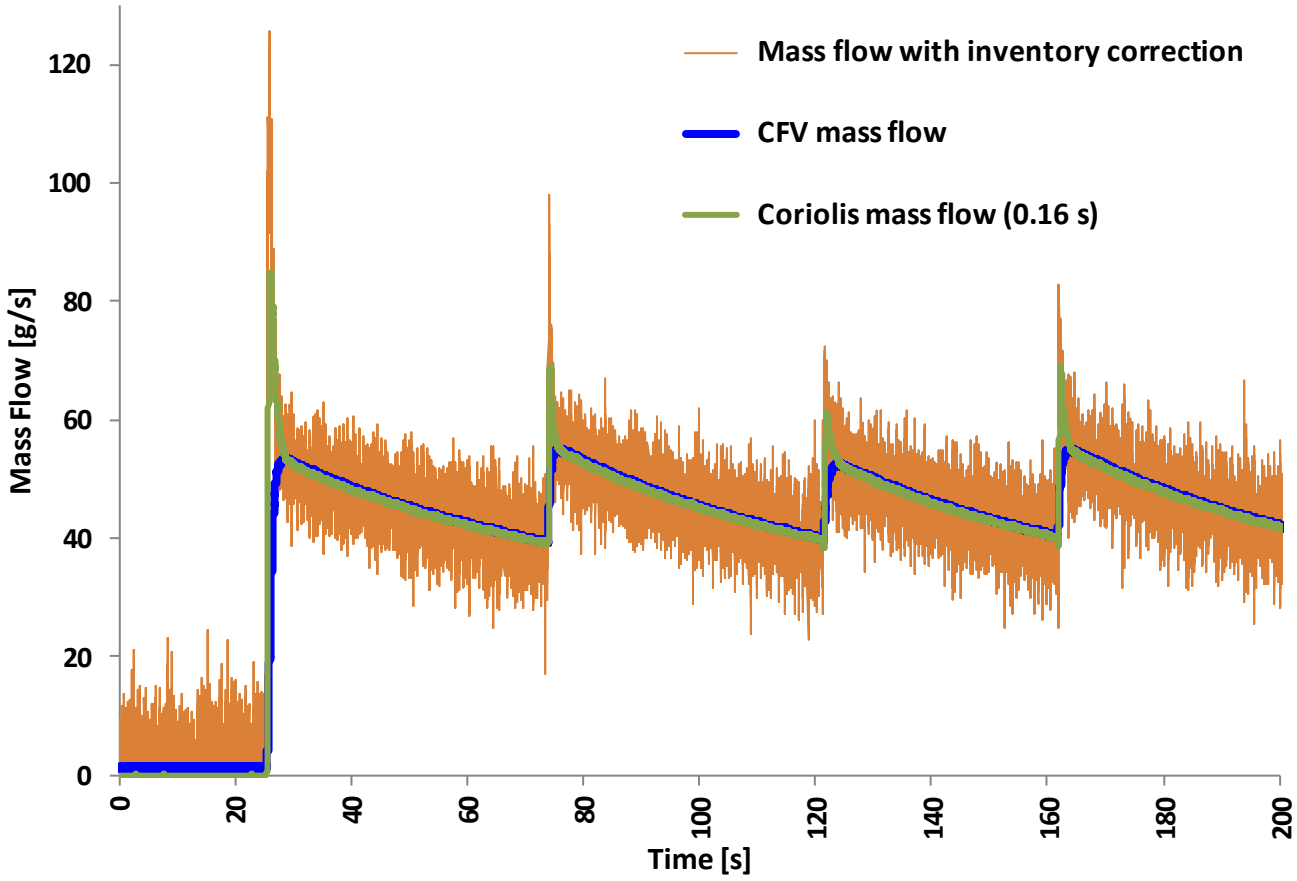


Various Coriolis Damping

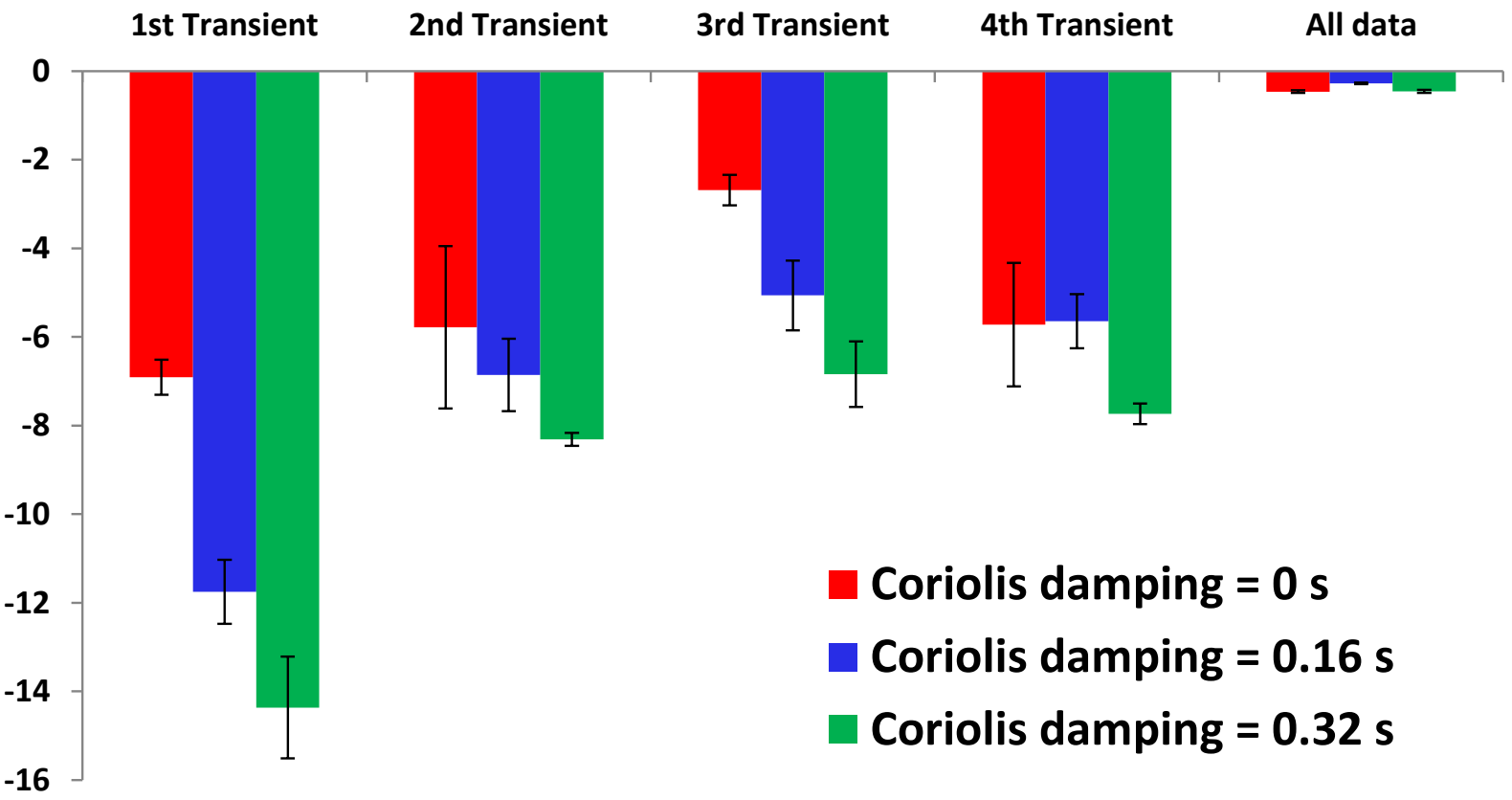


Transfer lag: two 1st order systems in series

Simulated Cascade Fill



% difference in totalized mass through the coriolis meter and reference CFV



Each transient: ~2 s, 100 g

All data: ~270 s, 12 kg

Uncertainty for Difference $\int \dot{m}\, dt - \Delta\rho V$

Uncertainty Component	Normalized Sensitivity Coefficient	Uncertainty (k = 1, %)
A) *PVTt* calibration		
1. *PVTt* standard	1	0.013
2. *P*	1	0.020
3. *T*	0.5	0.010
B) CFV mass flow		
4. $C_d A$ stability	1	0.025
5. *P*	1	0.050
6. *T*	0.5	0.010
7. *P* and *T* response time	1	0.010
8. *C**	1	< 0.001
9. *R*, $\mathcal{M}$	0.5	< 0.001
C) Integration		
10. Time	1	< 0.001
11. Numerical errors	1	0.005
12. Non-critical tails	1	0.005
D) $\Delta\rho V$		
13. $\Delta\rho$	1	0.007
14. *V*	1	0.010
Combined Unc. (*k* = 1)		**0.06**
Expanded Unc. (*k* = 2)		**0.13**

Future Capabilities?

- Sinusoidal flow changes at frequencies up to 20 Hz
- Available gases: N_2, He, ….
- Increase maximum flow and pressure from 30 MPa to 70 MPa