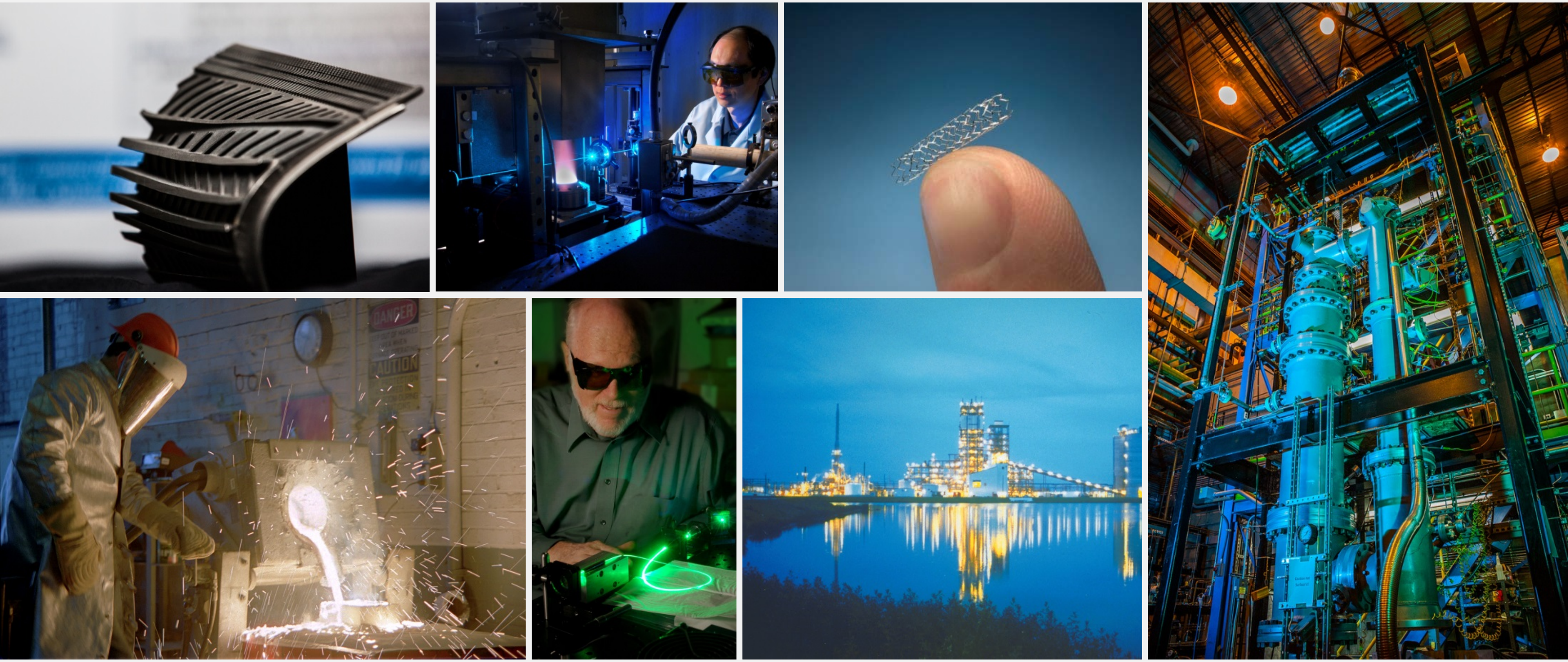
*Driving Innovation ♦ Delivering Results*



# Microwave Doppler Sensing of Sliding or Intermittent Particle Flows

B. T. Chorpening, M. Spencer,
J. Charley, R. C. Stehle, D. W. Greve

August 10, 2016

# Overview

- **Introduction – Chemical Looping**
- **NETL's Chemical Looping Reactor**
- **Microwave Doppler**
- **Measurement of L-valve flow**
- **Conclusions**

# Why Chemical Looping?

- **Options for *coal power* carbon dioxide capture/control:**
  - Solvent scrubbing
  - Advanced sorbents
  - Membranes
  - Oxy-fuel combustion: requires oxygen
- **Chemical Looping:**
  - No oxygen plant needed
  - Similar to familiar fluid bed technology
- **How can you "get there" quick (i.e., deploy, demonstrate)?**
  - Industrial applications- smaller size, easier NG fuel.
  - Possibly supply $CO_2$ to chemical/EOR needs?

**For an update on the status of these technologies:**

**2015 NETL $CO_2$ CAPTURE TECHNOLOGY MEETING**
Jun 23 – 26, 2015
Web-link listed below.

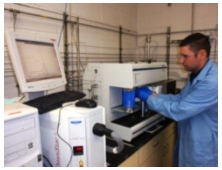
Coal

Natural gas

http://www.netl.doe.gov/events/conference-proceedings/2015/2015-co2-capture-technology-meeting

# Integrated Experimental & Modeling Effort

TGA and Mass-Spec

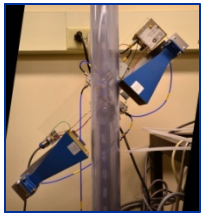


Lab-scale Fixed Bed Reactor

Integrated Cold Flow Unit

Chemical Looping Reactor

Single Fluidized Bed Reactor



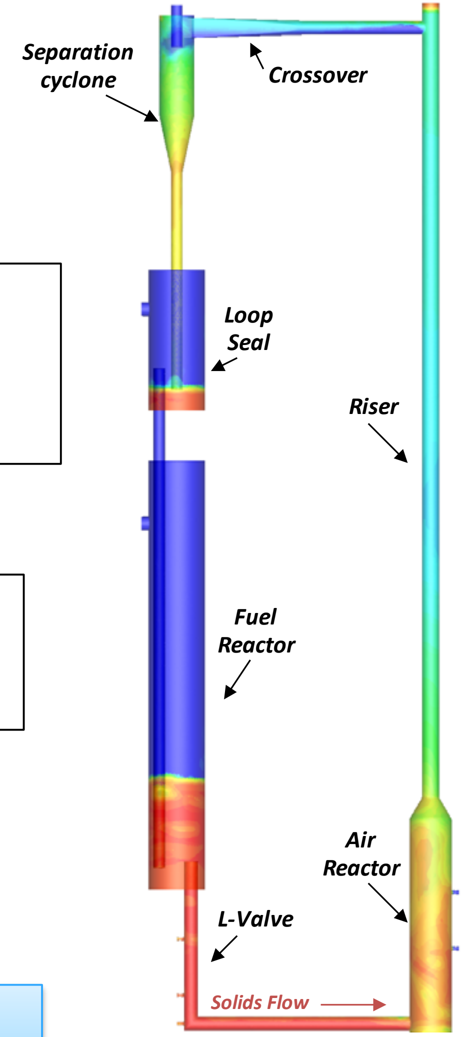
Microwave Sensor

**Carrier Development/Evaluation**
reaction model development via. parameter estimation

**Bed Reaction Rate**
Reaction model validation
Small scale validation of hydro, reaction and interactions

**Circulating Hydrodynamics V&V**
Solids Handling and Process Development

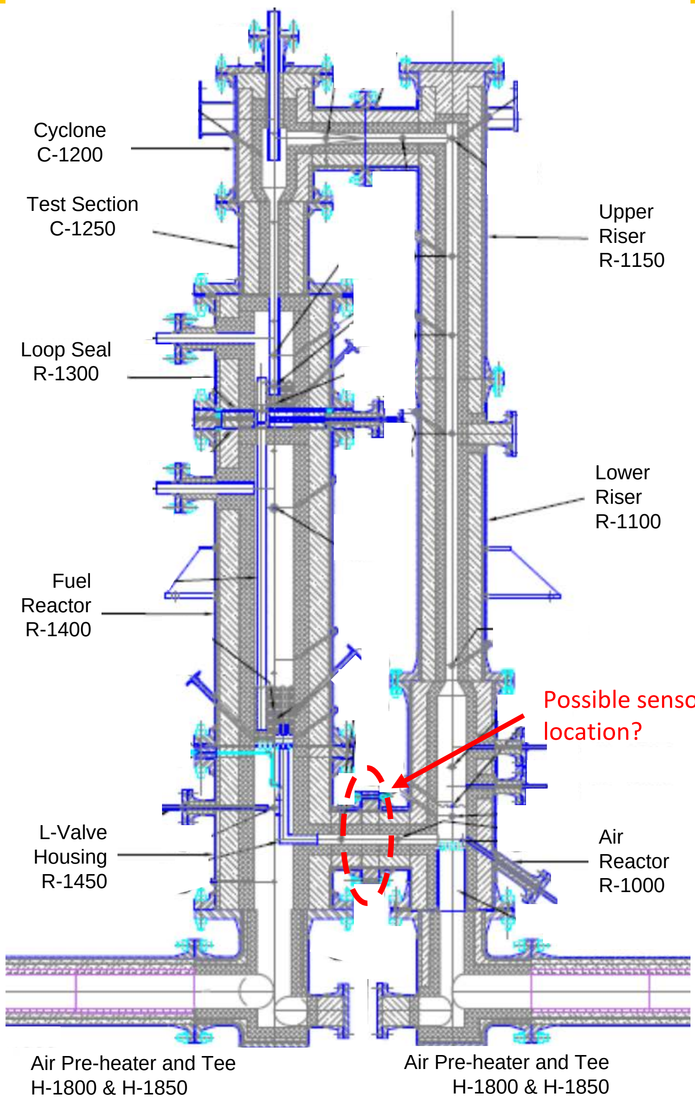
**Specialized Sensors and Instrumentation**




**3D multi-phase CFD modeling**

Sensor challenge: operation at 1000°C, ~63 g/s (500 pph) of material, pressurized

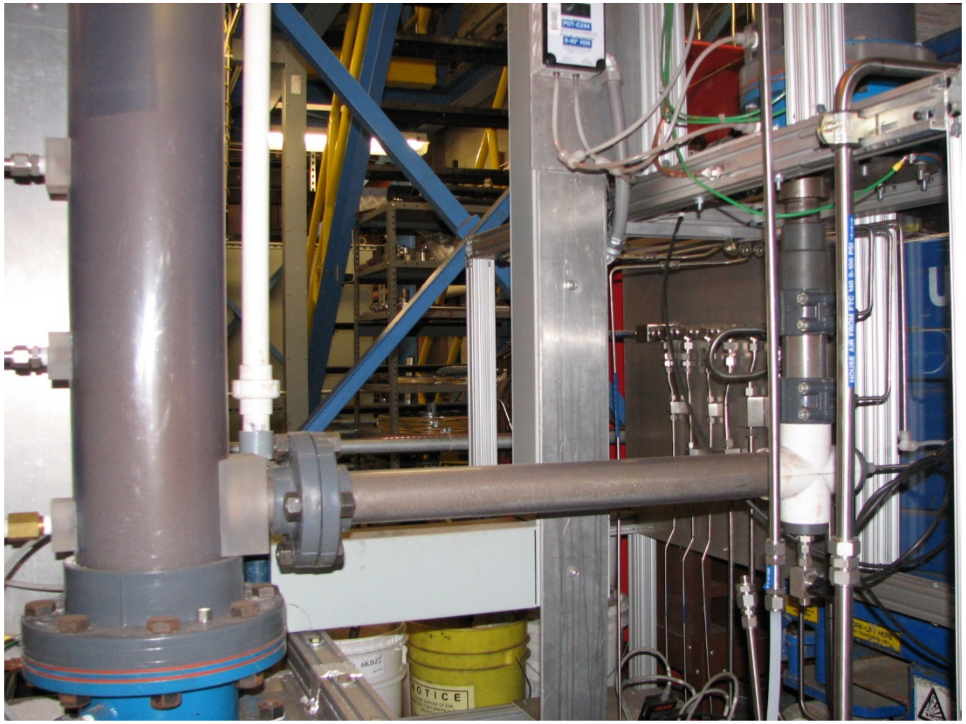
# NETL Chemical Looping Reactor

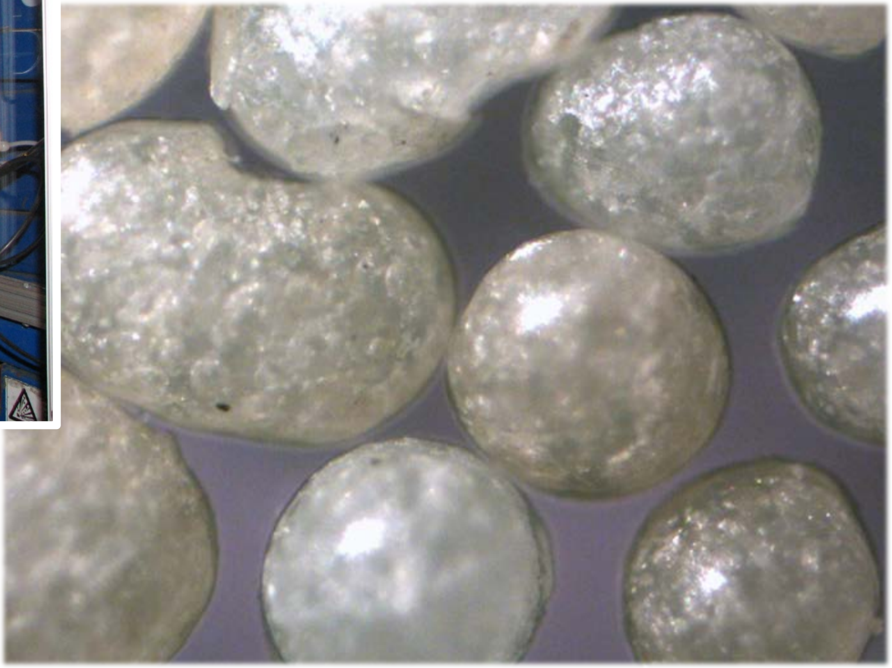



1000°C, max 12.5 atm (175 psig)

# Cold Flow CLR

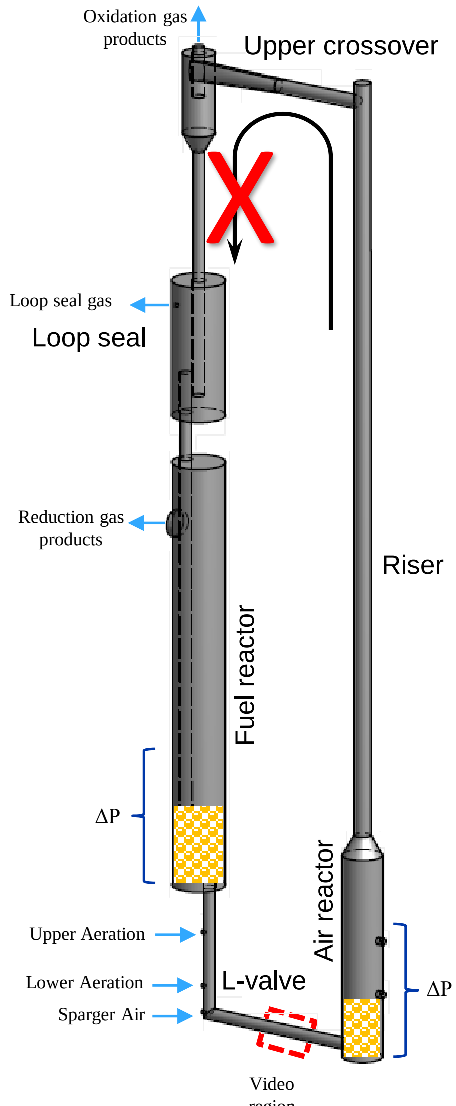
800 micrometer HDPE
Geldart B particles
Sauter Mean Particle Size: 871 µm
Particle density 0.86 g/cm$^3$
Minimum fluidization velocity: 17.4 cm/s
Refractive index ~ 1.5 @ 10 GHz



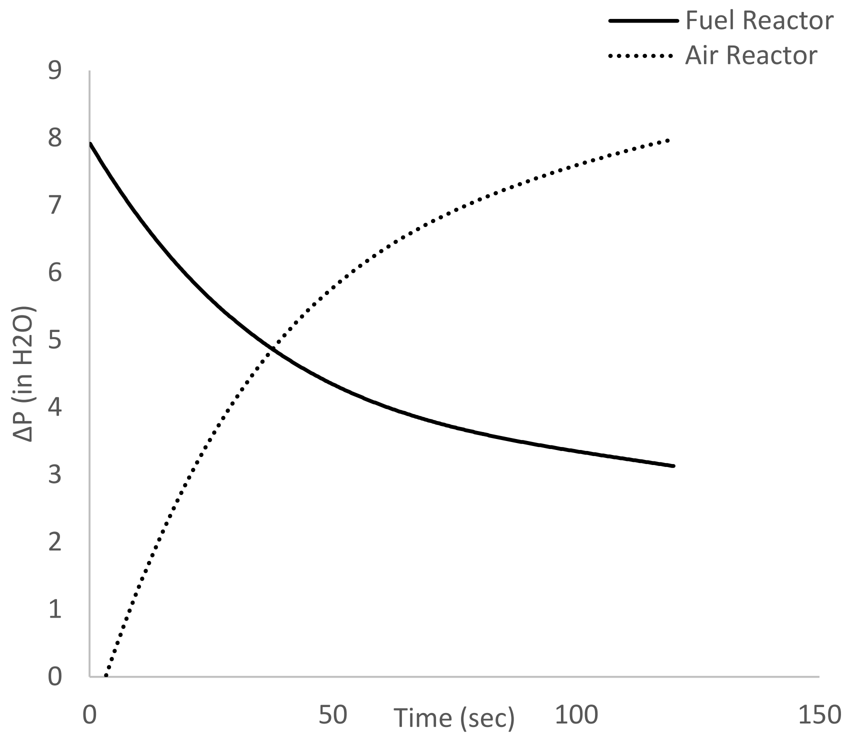


Same inside geometry as CLR
L-valve ID = 50 mm

# Flow from Pressure Drop across Reactors




Special case with no circulation through riser



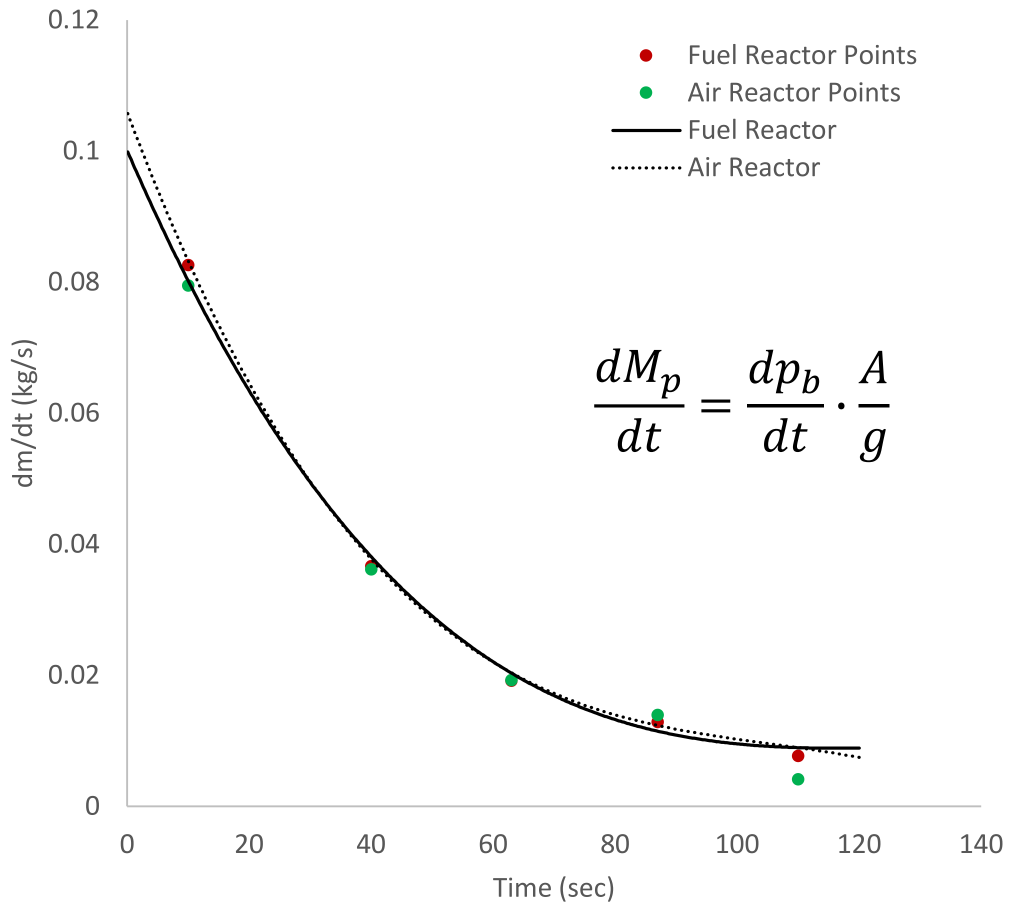

L-valve ID = 50 mm
Sparger air 40 SLPM
Lower aeration 10 SLPM, upper aeration 5 SLPM

# Flow derived from pressure drops

- **Fully fluidized bed, pressure drop balances weight of bed (see Fan and Zhu*)**
- **Assume voidage independent of height, neglect weight of gas**

$$\Delta p_b = \frac{M_p g}{A}$$

- **Flow declines during the test as FR empties**
- **Average points related to video segments**
- **Flow appears smooth in pressure data**

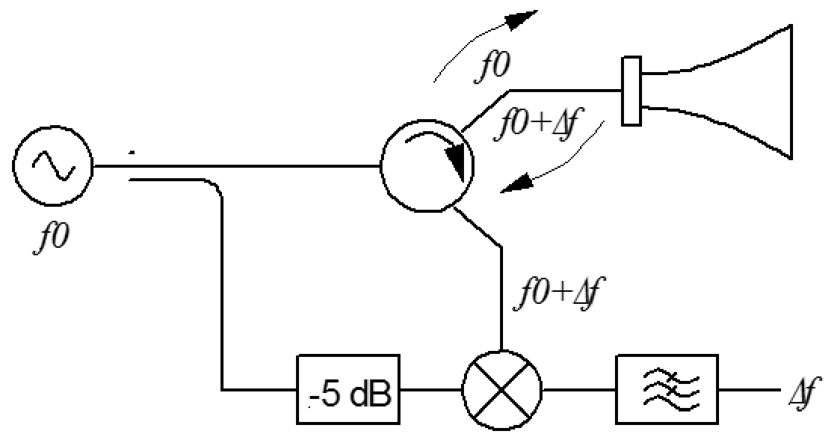


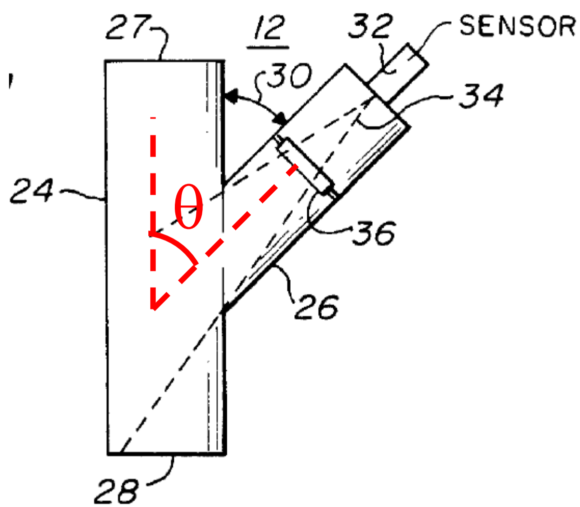

$$\frac{dM_p}{dt} = \frac{dp_b}{dt} \cdot \frac{A}{g}$$

*Fan, L.S., and Zhu, C. *Principles of Gas-Solid Flows*, Cambridge University Press, Cambridge, 1998 (pp. 378-379)

# Microwave Doppler

- Flow velocity determined from Doppler effect (frequency shift)
- Reflection magnitude related to density




particle velocity

$$\Delta f = 2f\frac{v}{c}\cos\theta$$

$$P_{reflected} = N\sigma_{total\ scattering}P(x)dx$$

number density

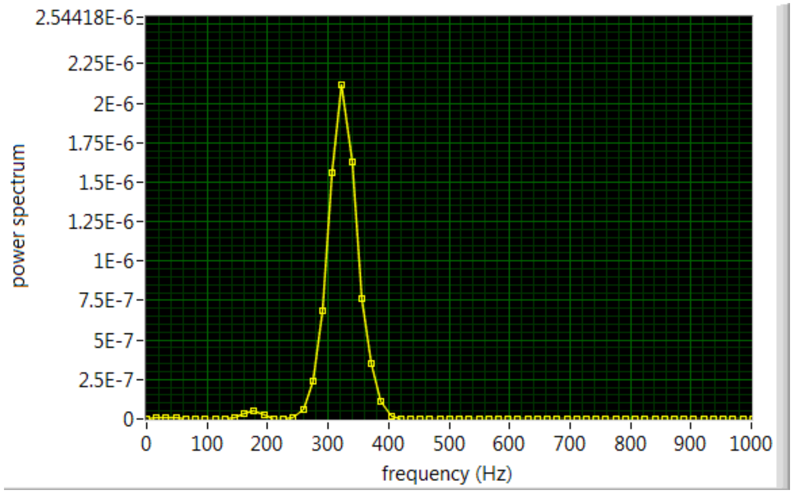
scattering cross-section

47 Hz per m/s @ 45°, 10 GHz

# Single particle vs. flow of many particles

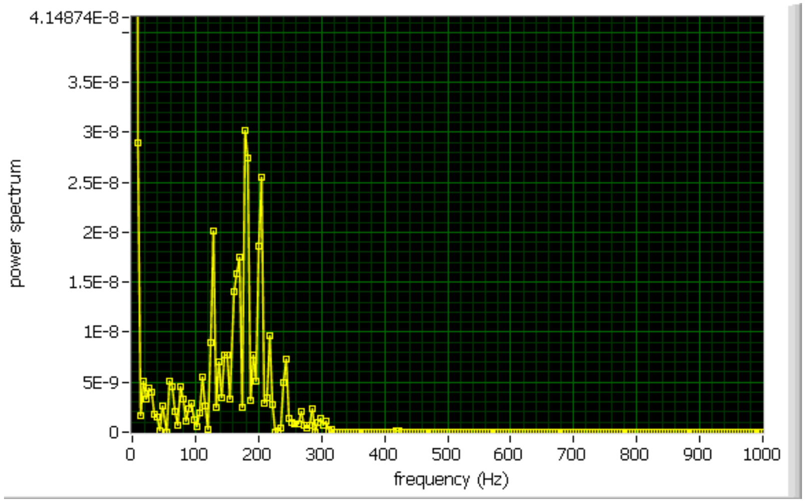
- Compute Fourier power spectrum of demodulated signal
- Get frequency shift of reflected signal

Single Particle




steel ball 0.157" diameter falling 1.8 m, horn angle 42 degrees; 10 GHz

Many Particles

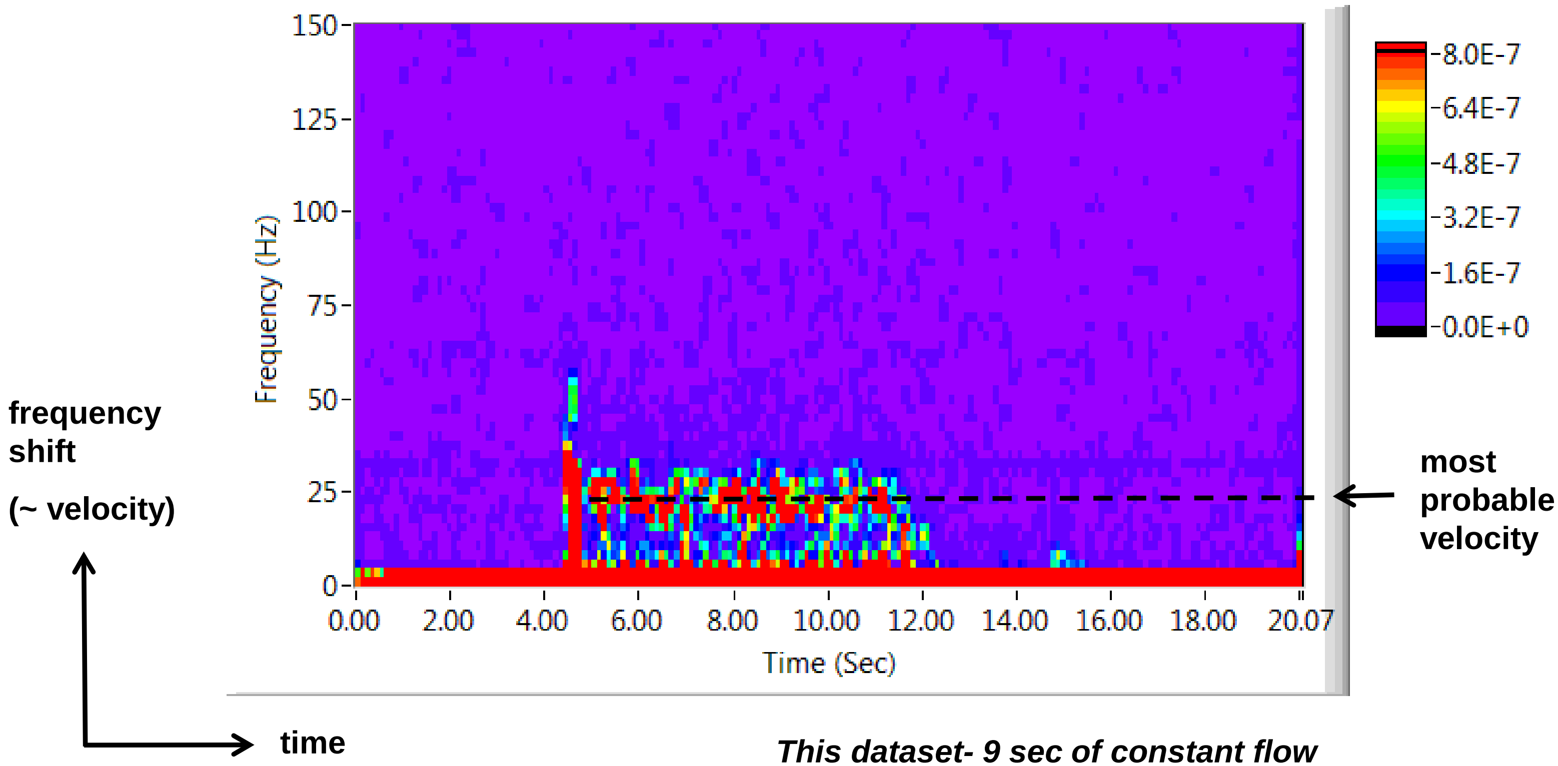



ilmenite falling 2.1 m, horn angle 52 degrees; 10 GHz

Many particles produce a frequency shift *distribution*

# Visualizing velocity for time-varying flow

1. **Perform a short-time Fourier transform**
2. **Make a time-frequency plot**




***This dataset- 9 sec of constant flow from table feeder***

# Video from L-valve

- **Data in the following slide is taken from dataset (condition4-15-52-59-f.avi)**

4-15-52-59-f.-mo
vie

# Typical video from L valve

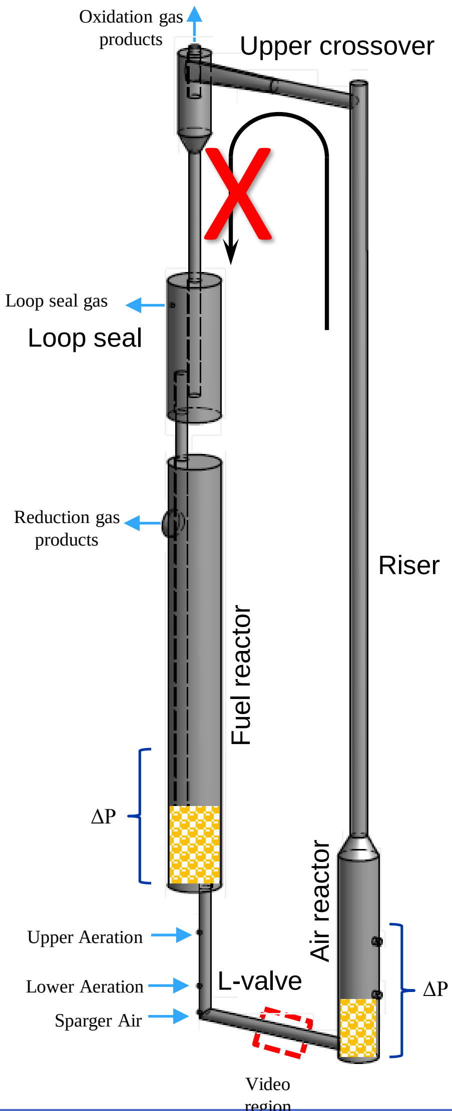
- V

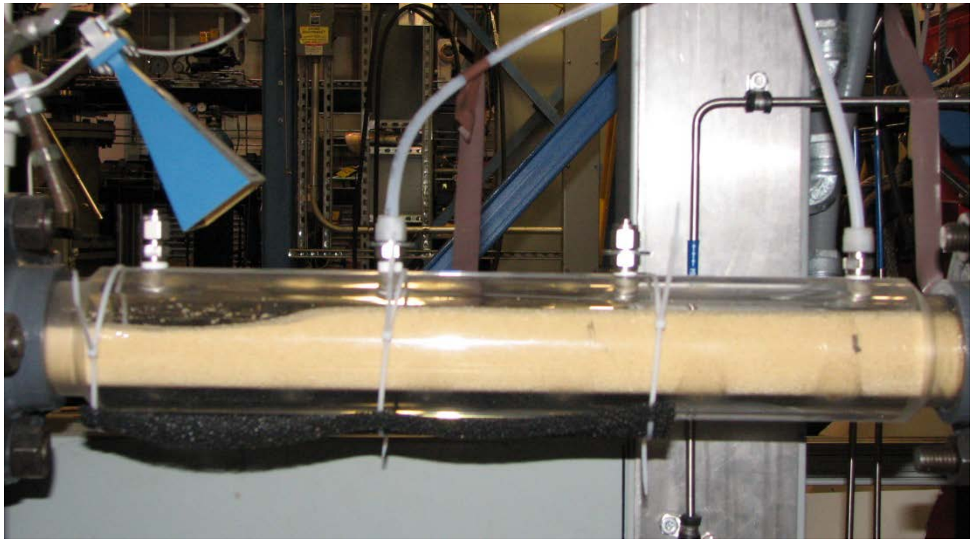
# Detected Doppler signal


Constant when particle mass is stationary

Oscillatory when particle mass is moving (Doppler shift)

# Time-sync'd microwave Doppler and video



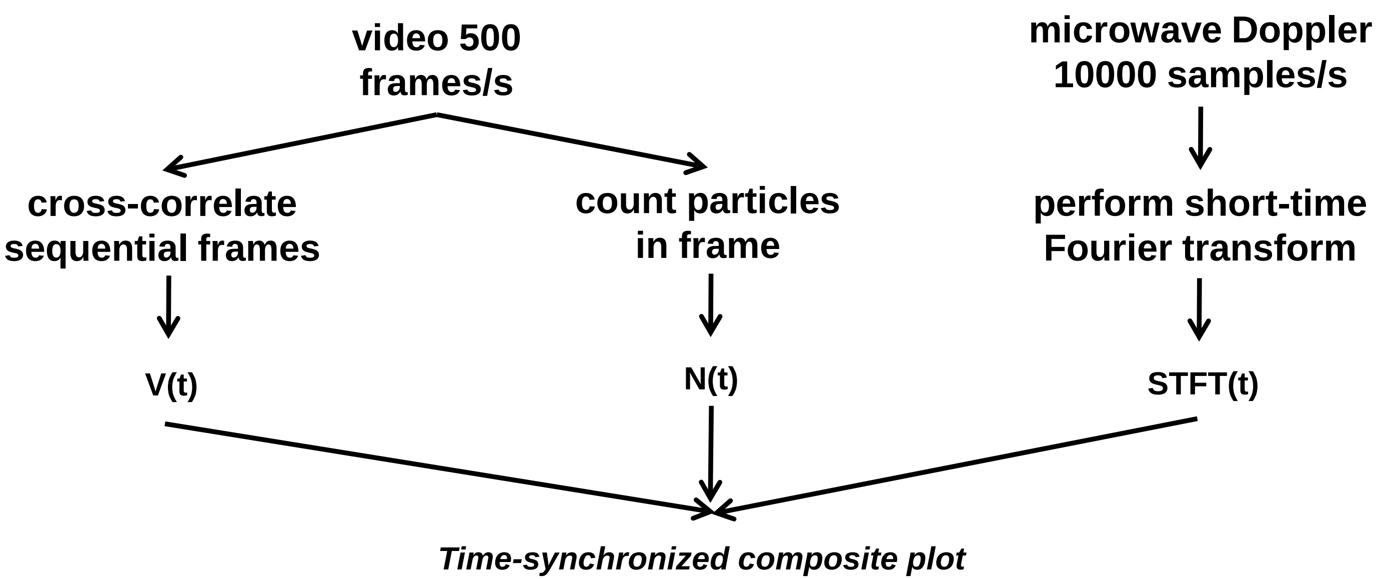



- **Several datasets collected during same test as flow through L-valve decreased**
- **Composite plots made of detected Doppler signal, particle number, velocity from video, and Doppler short time Fourier transform**

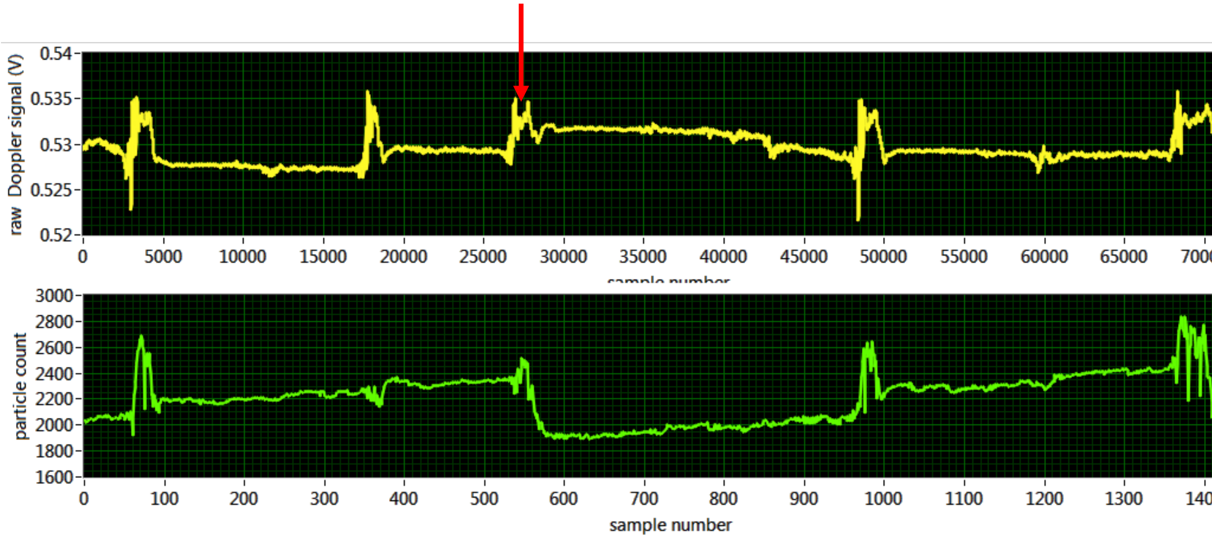
# Microwave Doppler for intermittent flow

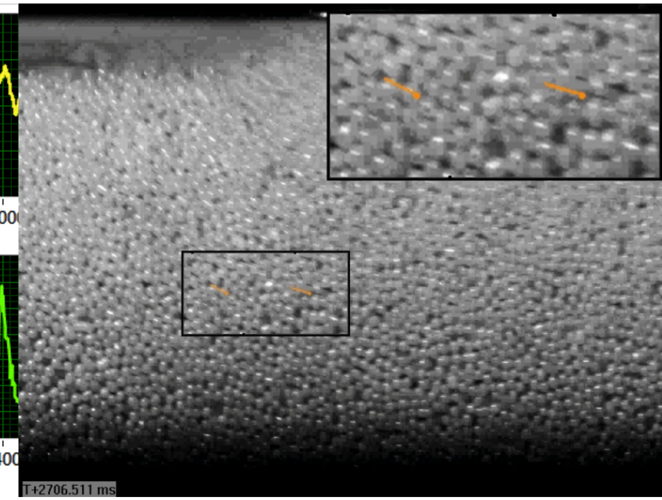
1. **Experiments performed in cold-flow system with transparent L valve**
2. **Create time-varying flow in L valve**
3. **Collect high-speed video (500 frames/sec)**
4. **Collect microwave Doppler data (24 GHz)**
5. **Compare**

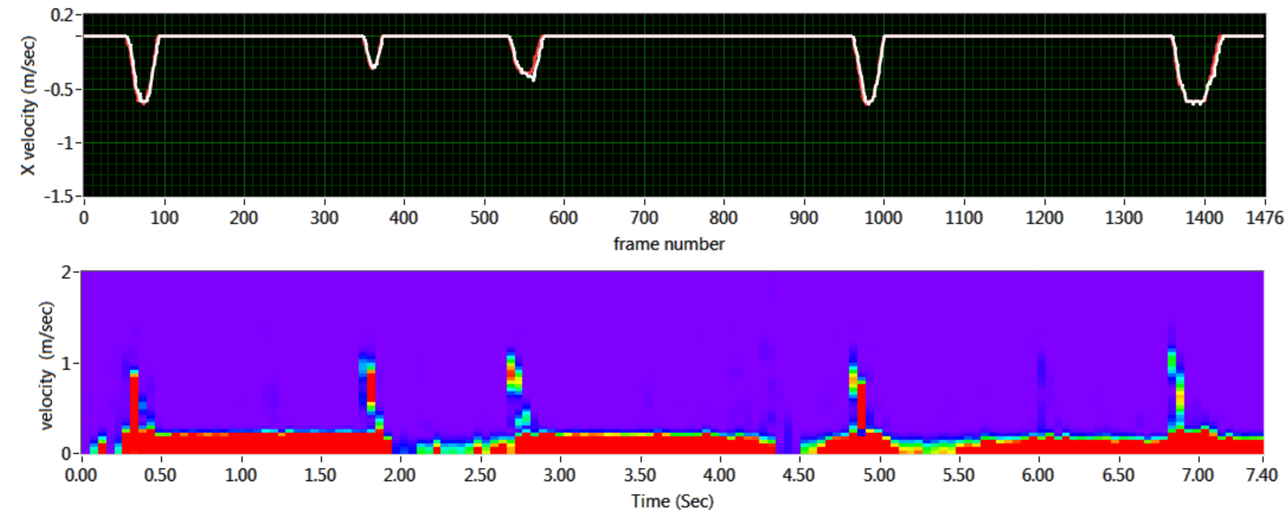
common trigger for synchronized data collection



# Intermittent Flow monitoring



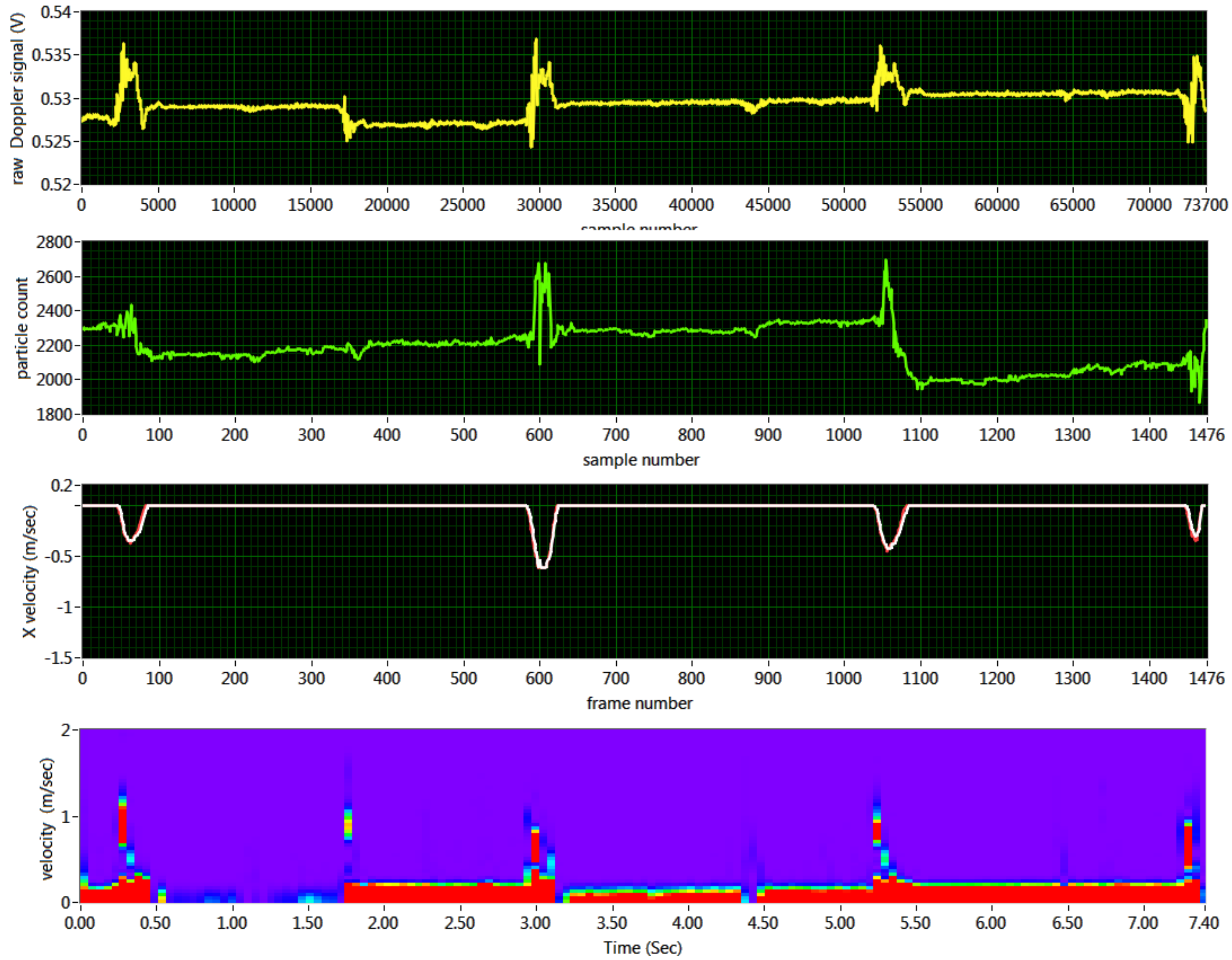




video

Doppler shift velocity

# Declining flow rate – still intermittent



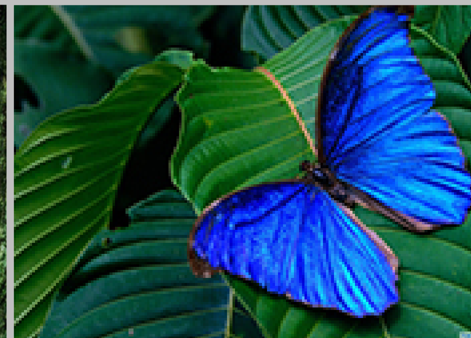
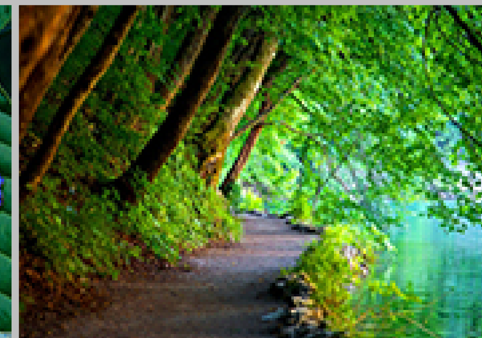
# Conclusions

- **Microwave Doppler shown to be sensitive to intermittent dense flow, verified with video**
- **Intermittent behavior not observed in pressure data**
- **Potential exists to aid in chemical looping operation**
- **Future work**
  - Refine approach
  - Modify CLR to allow application
  - Examine effect of different particles

This project was funded by the Department of Energy, National Energy Technology Laboratory, an agency of the United States Government. Mr. Charley was funded through a support contract with AECOM, Inc. Dr. Greve was supported in part by through the ORISE Faculty Research Program. Michael Spencer and Richard Stehle were supported through ORISE. 

# It’s All About a Clean, Affordable Energy Future



NETL

*For More Information, Contact NETL*

**the ENERGY lab**

*Delivering Yesterday and Preparing for Tomorrow*