Optical Fibre Probes - Fundamentals and Applications

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Outline

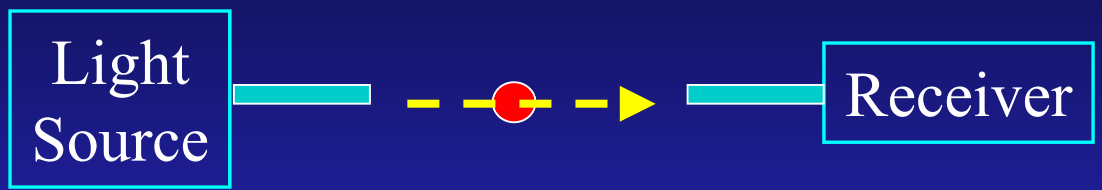
- Introduction
- Optical Voidage Probe
    - Calibration Methods
- Optical Velocity Probe
    - Calibration Methods
- Solids Flux Measurement
- Applications

Advantages

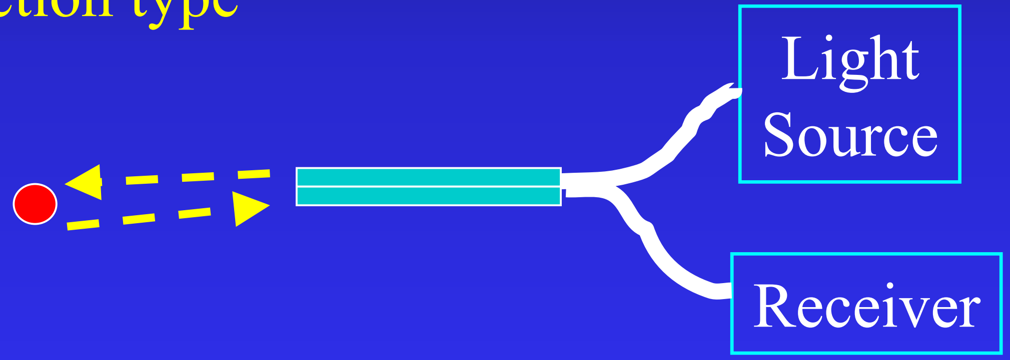
- High sensitivity
- Fast response
- Large dynamic range
- Small volume and light weight
- Fire- and shock-resistance
- Corrosion proof
- Freedom from disturbance by electric and magnetic fields
- Insulation against high voltage
- Suitable for remote transmission
- Multi-channel detection

Principles

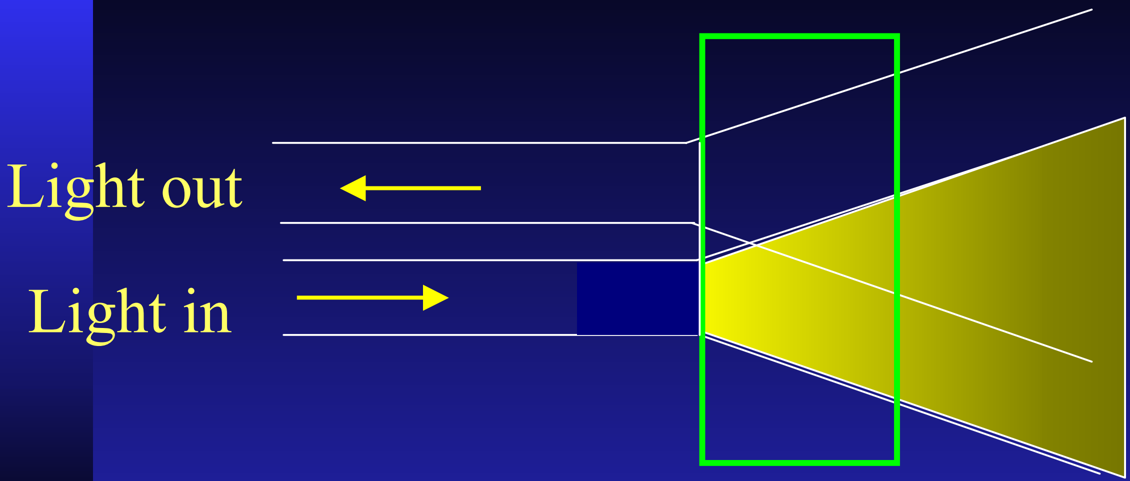
1) Transmission type

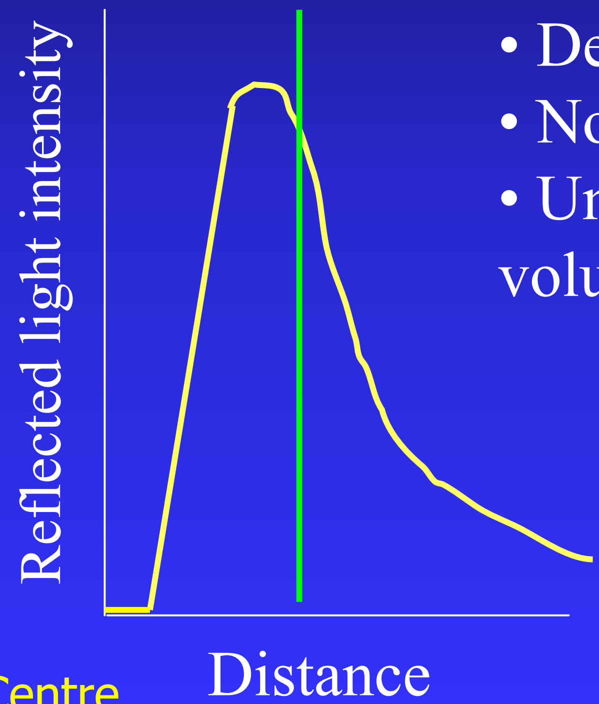


2) Reflection type



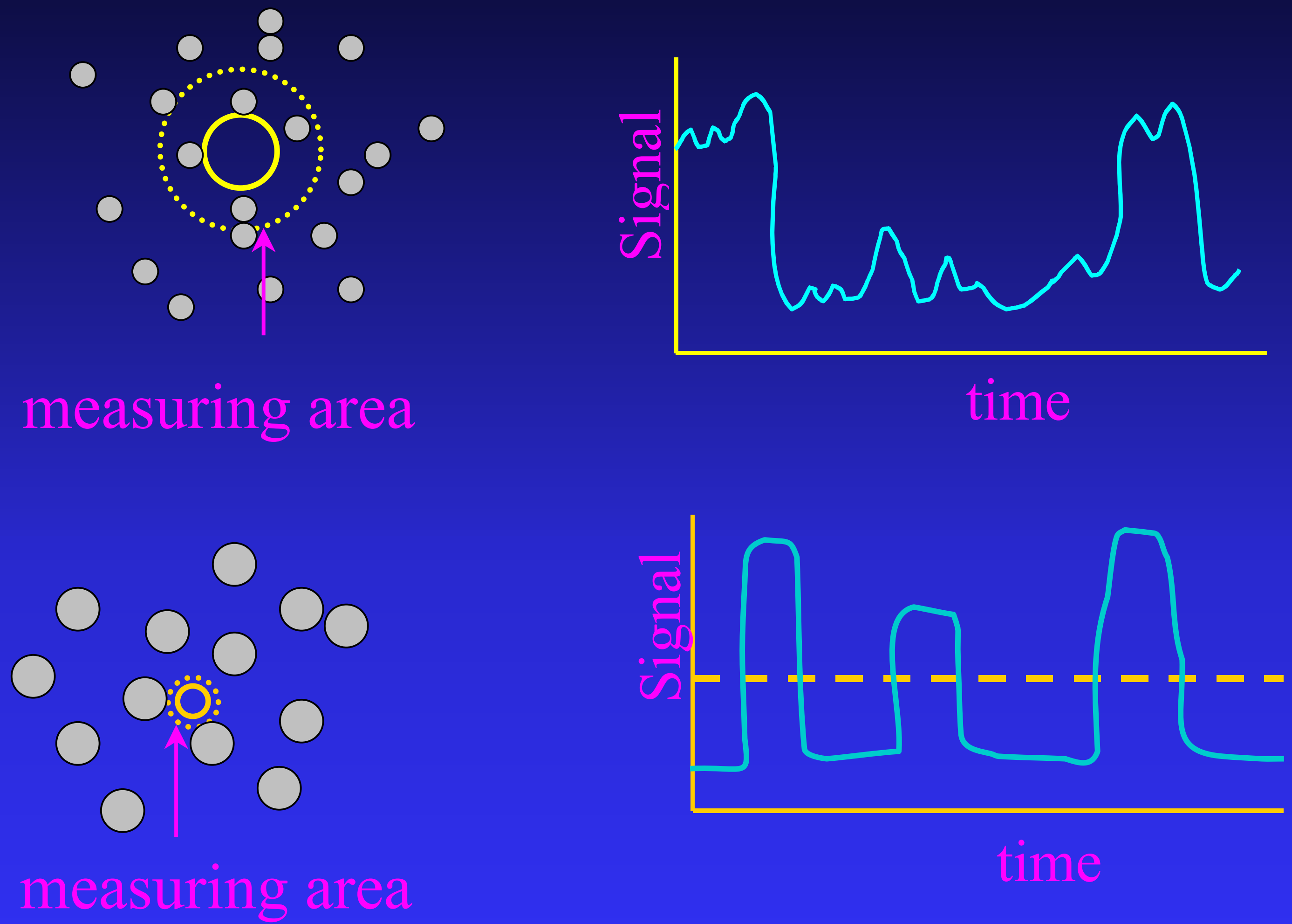
Measurement Volume





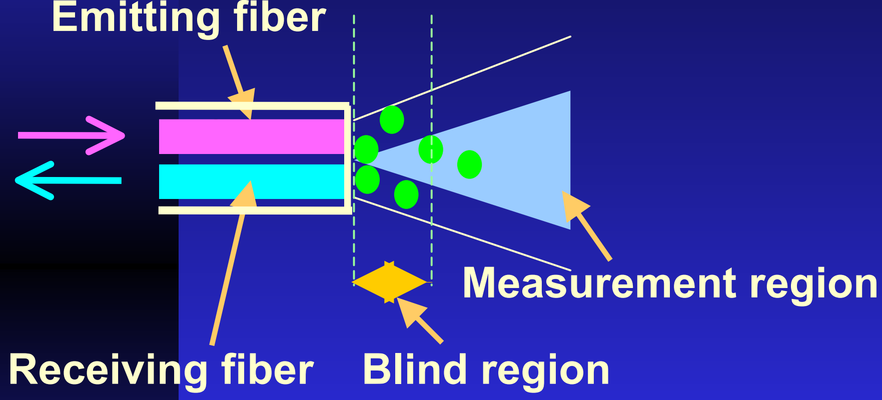
- Dead zone
- Non-linear response
- Undefined measuring volume

Particle-to-Probe Diameter Ratio

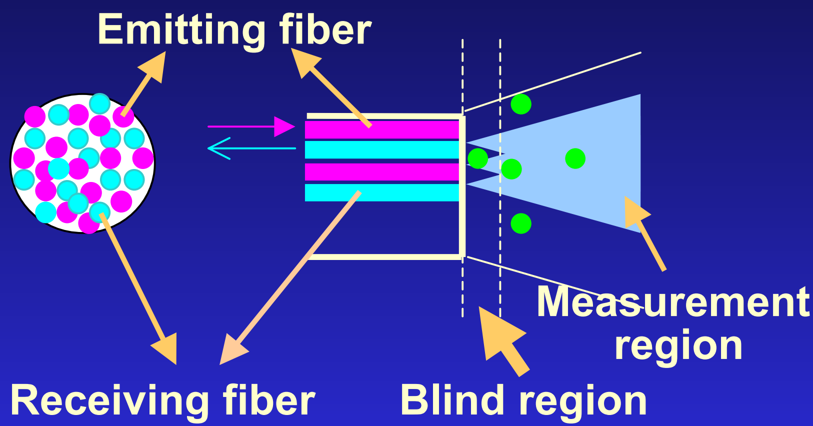


Configurations

GENERATION 1



GENERATION 2



Key Factors for Probe Design

- **Blind Region** (Wrong information)
- **Measurement Volume**

Advantages:

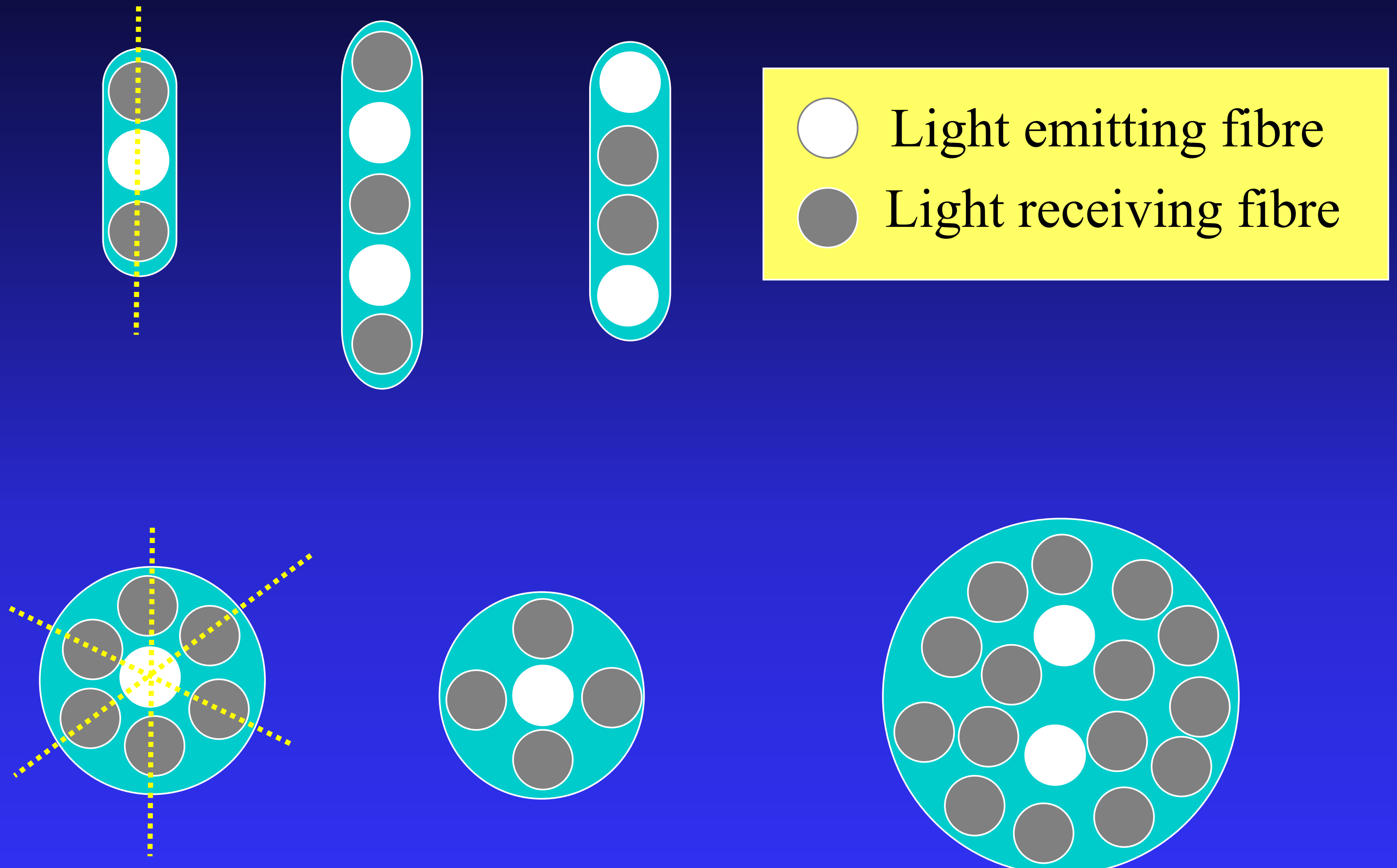
- Easy to design

Shortcomings:

- Blind region

  remedied by adding a glass window
- Infinite measurement volume
- Not good for dense flow, small particles

Particle Velocity Probes



Voidage Measurements

- Selection of suitable probe
- Effect of particle property
- Probe calibration
- Noise and/or error analysis
  - Background noise, static, …

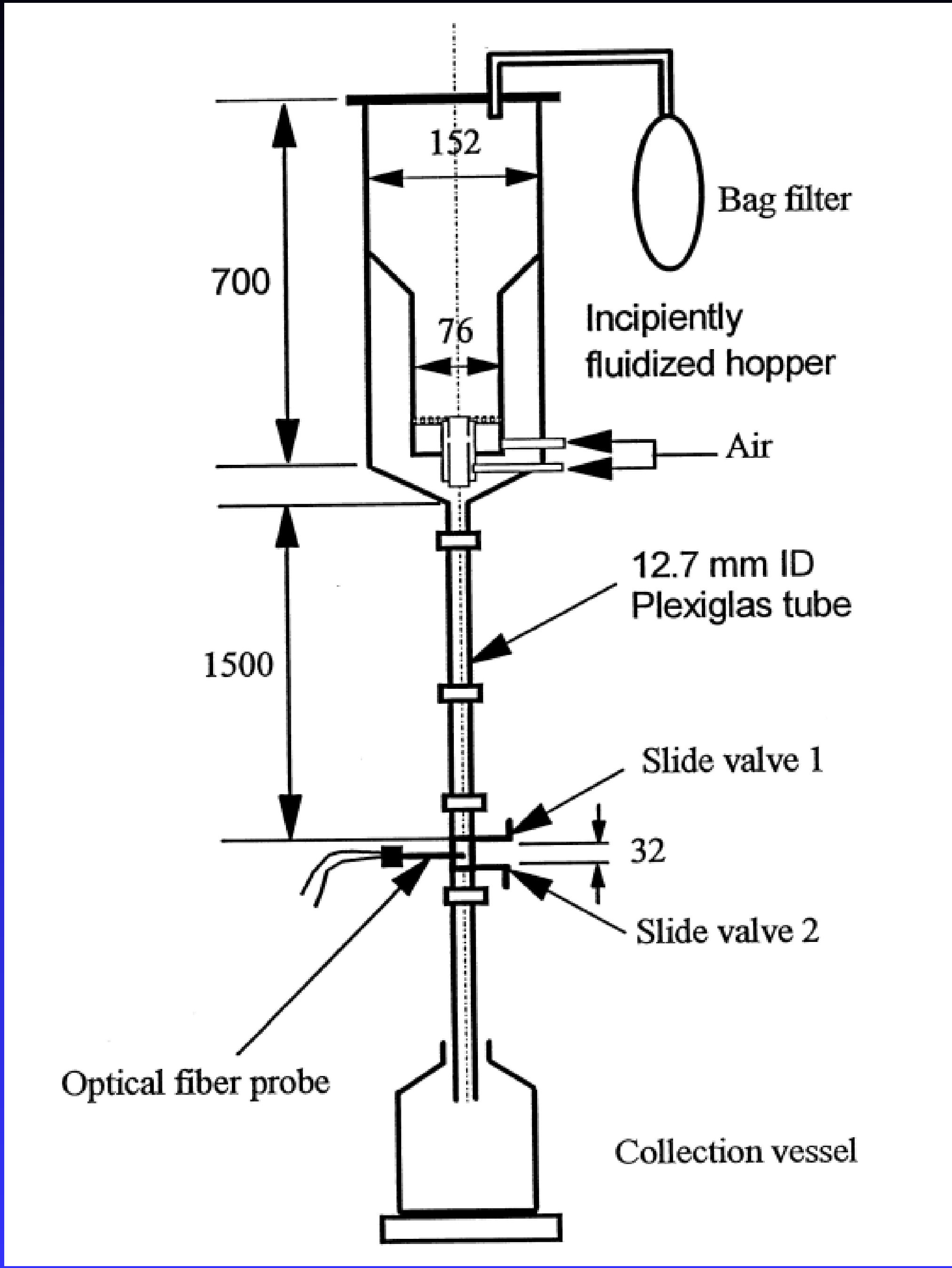
Probe Calibration

- Full calibration
  - Whole range of actual operation
- Partial calibration
  - Assume a function
  - Measure in empty column and packed bed
  - Check before each experimental run

Full Calibration methods

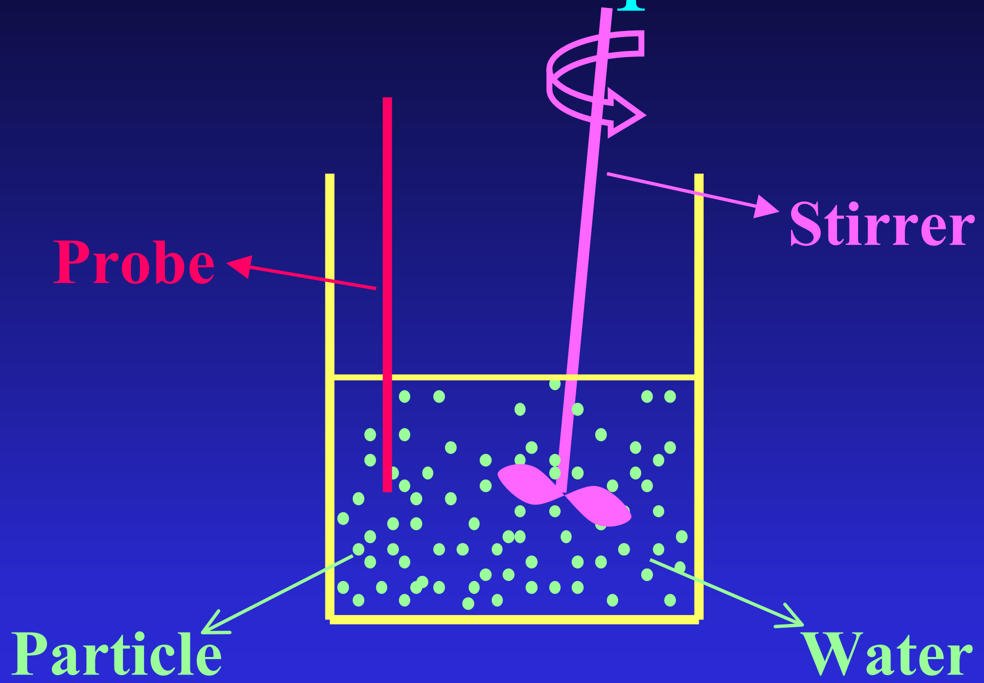
1. Dropping/trapping technique
2. Liquid-solids suspensions
3. FCC/Coke mixtures
4. FCC/polystyrene mixtures

Method 1: Dropping/ Trapping Technique



From Alan's Thesis

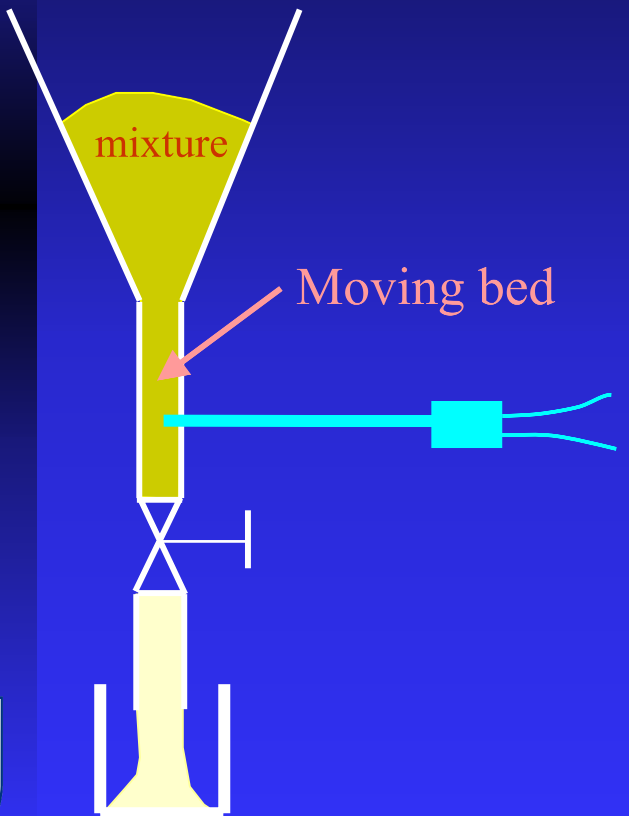
Method 2: Liquid-Solids Suspensions

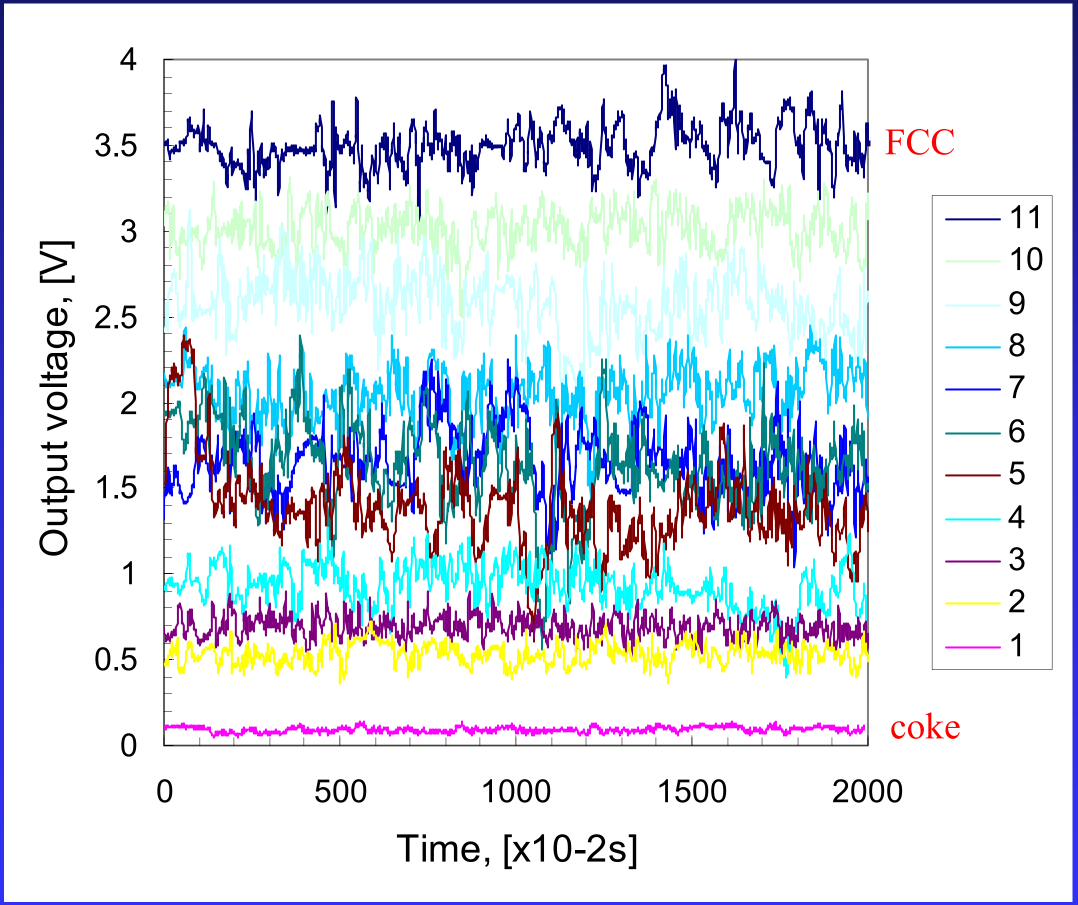


Disadvantages:

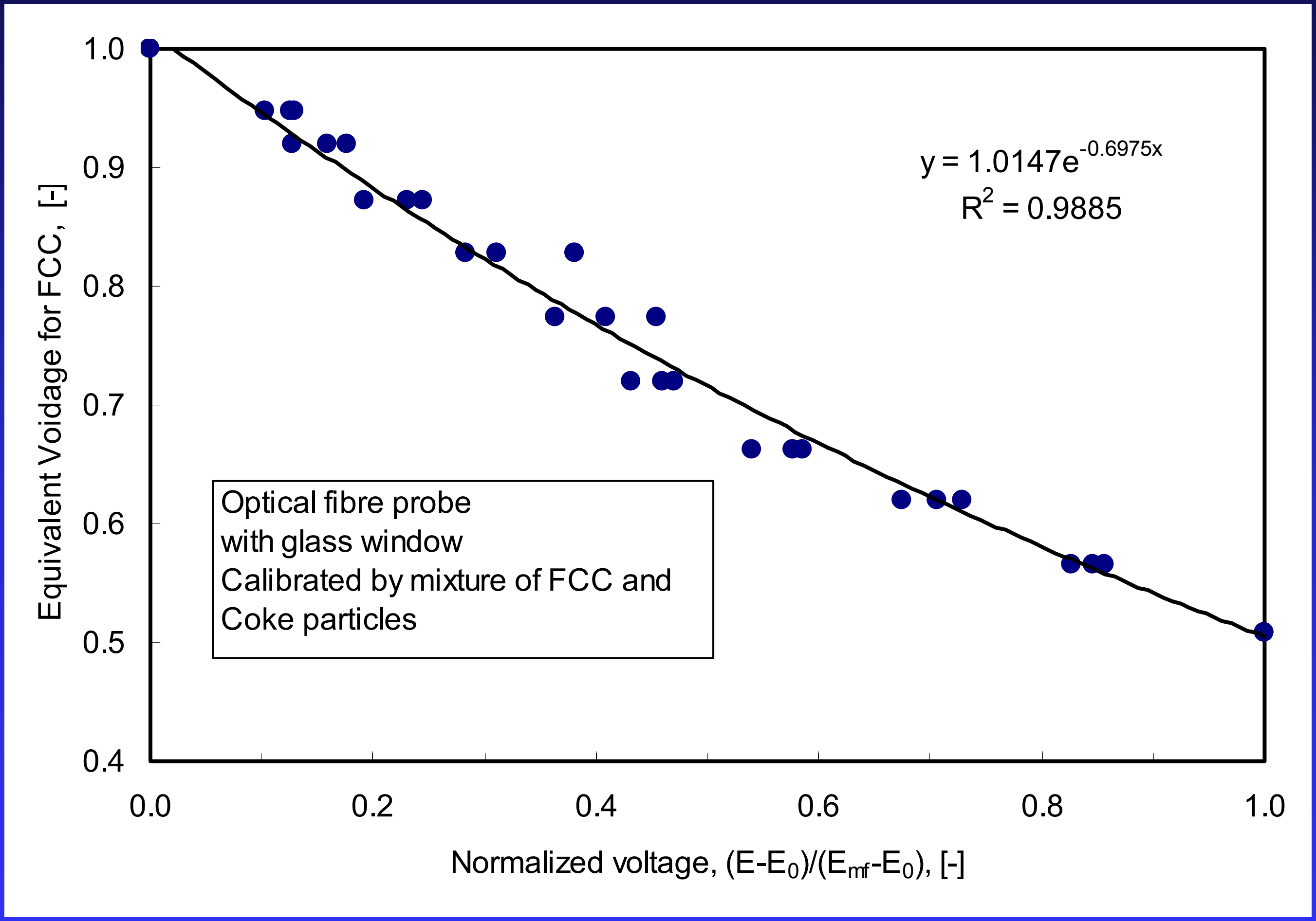
- Difficult to obtain uniform distribution
- Impossible to reach dense suspension

Method 3: FCC/coke Mixtures

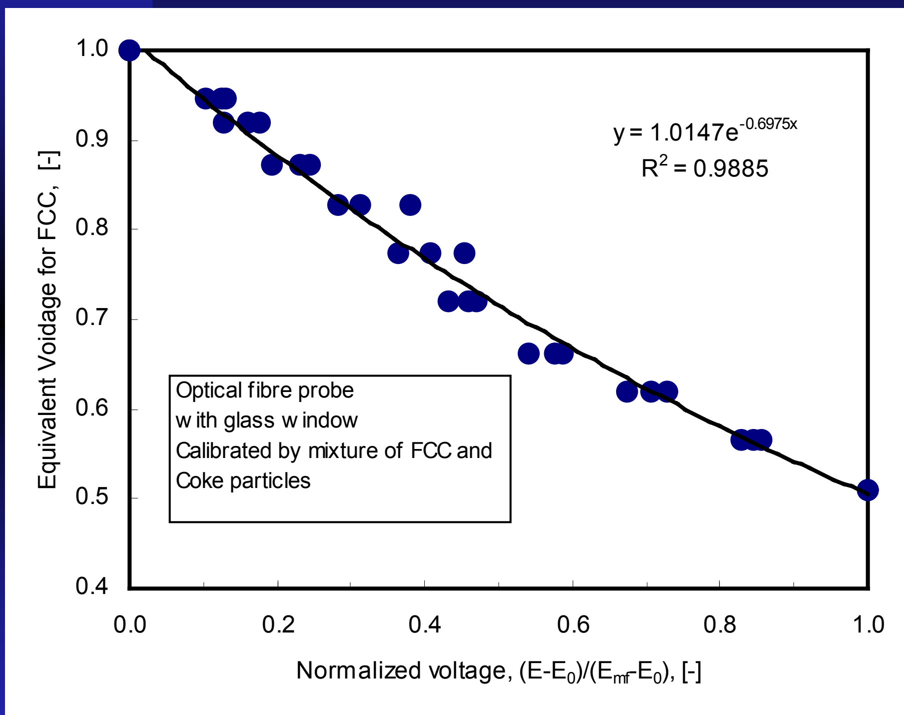




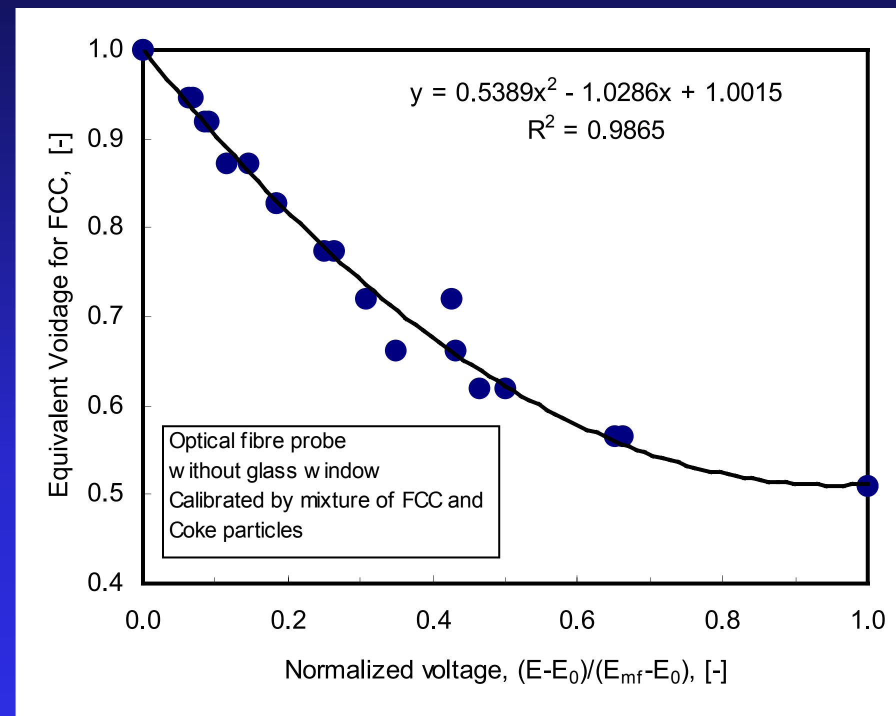
Calibration Curve: FCC/coke Mixtures



Necessity of Tip Window

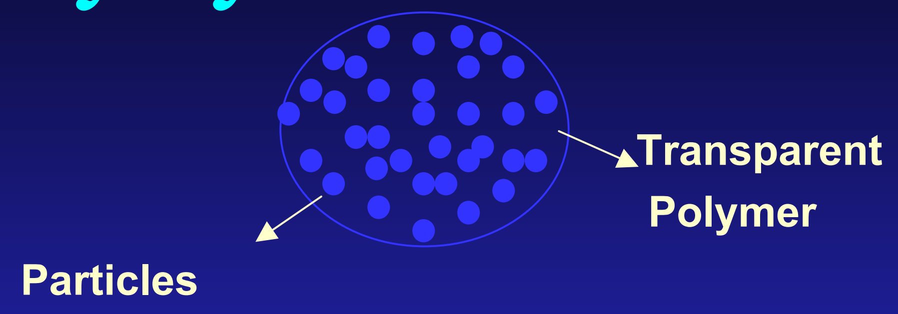


With Glass Window



Without Glass Window

Method 4: FCC/Polystyrene Mixtures

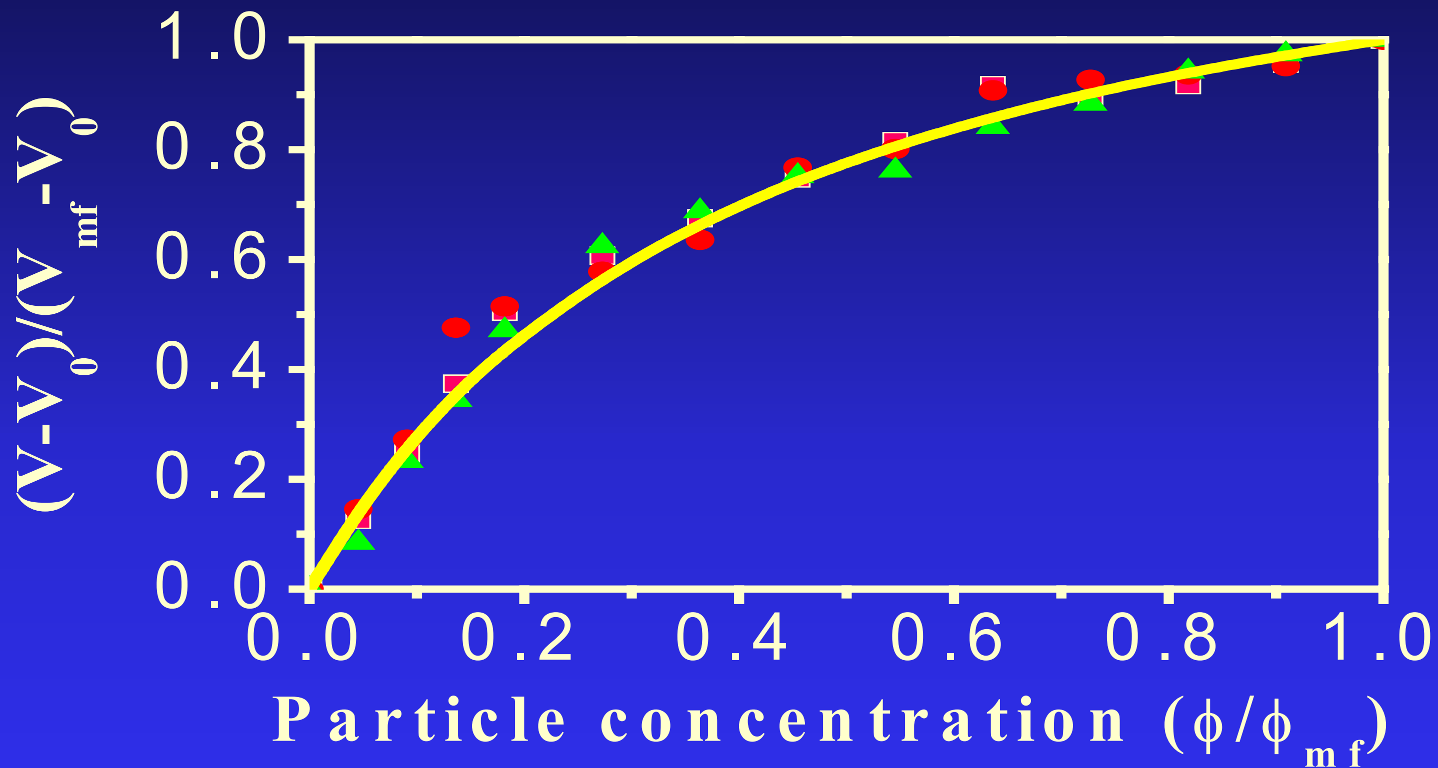


A series of 3-D uniform particles-transparent polymer mixture, covering various solid concentrations *from 0 to* ϕ_{mf}

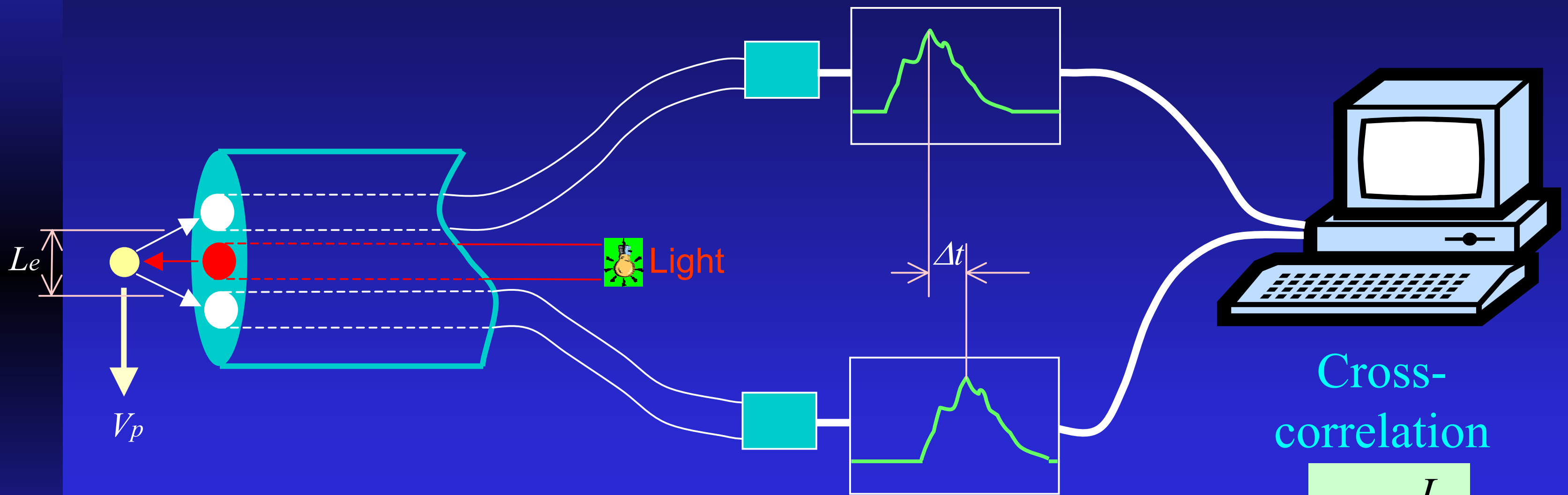
Advantages:

- **Uniform particle distribution (constant)**
- **Various particle fractions**

Calibration Curve: FCC/Polystyrene Mixtures



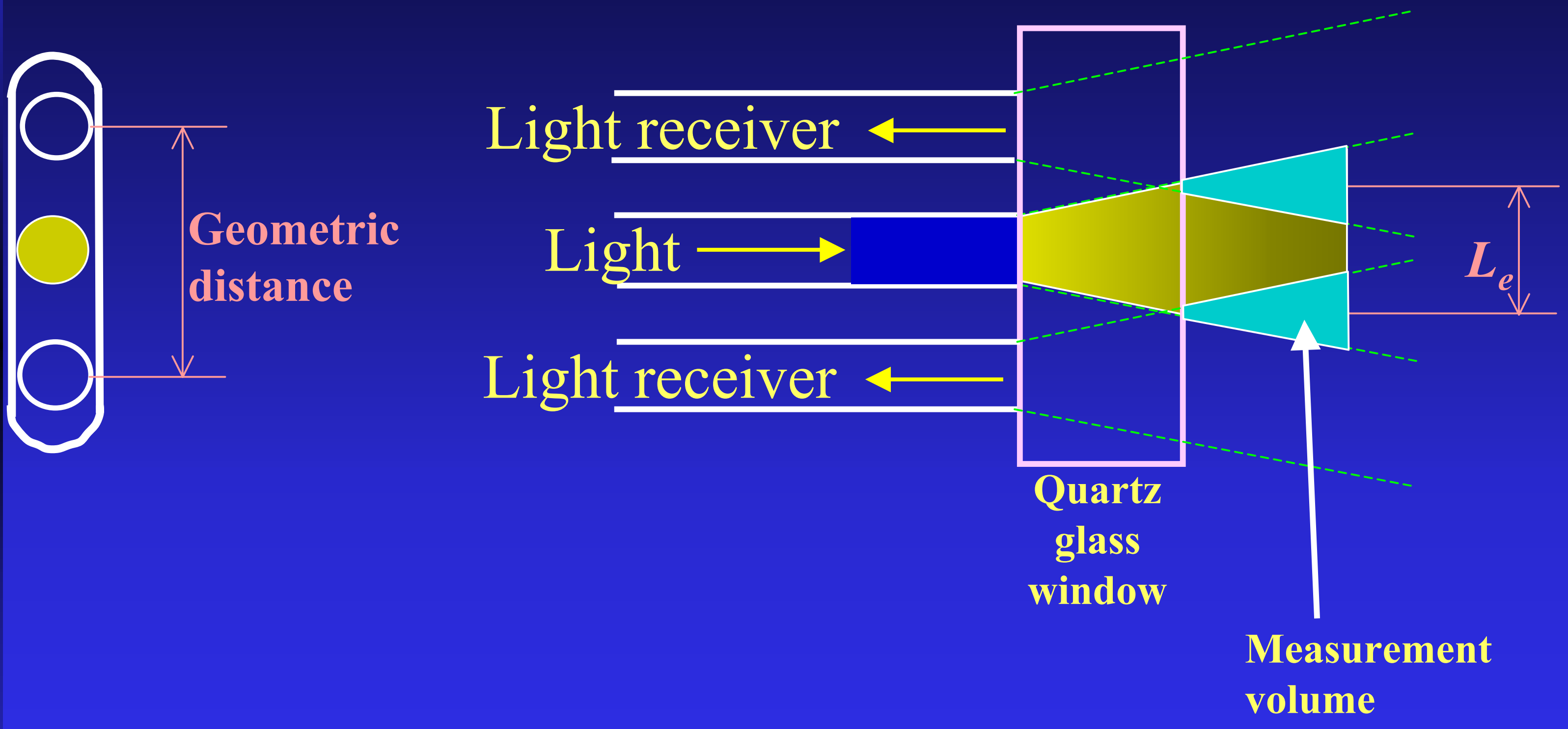
Particle Velocity Probe



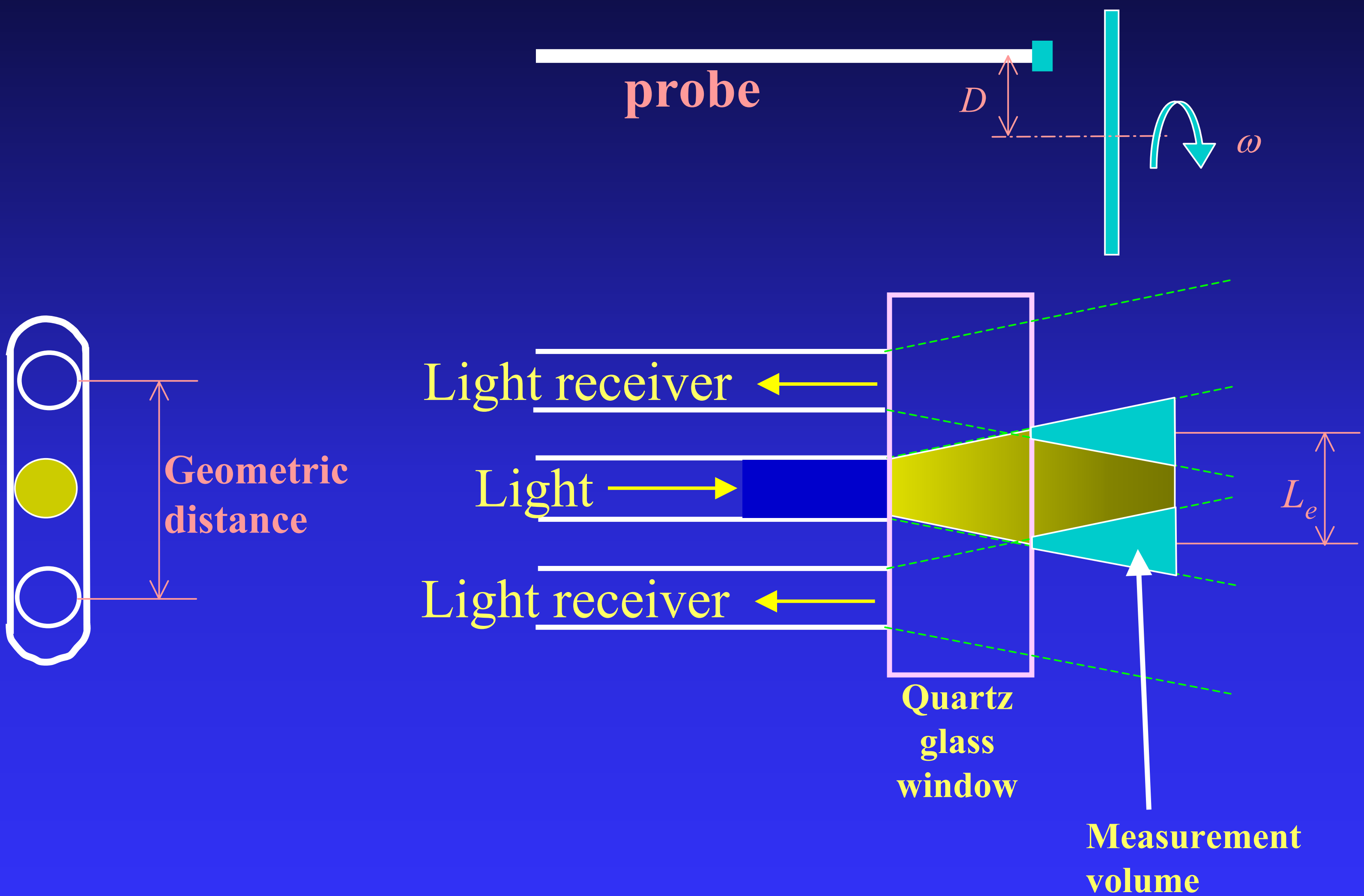
Cross-correlation

$$V_p = \frac{L_e}{\Delta t}$$

Effective Separation Distance



Calibration using Rotating Disk

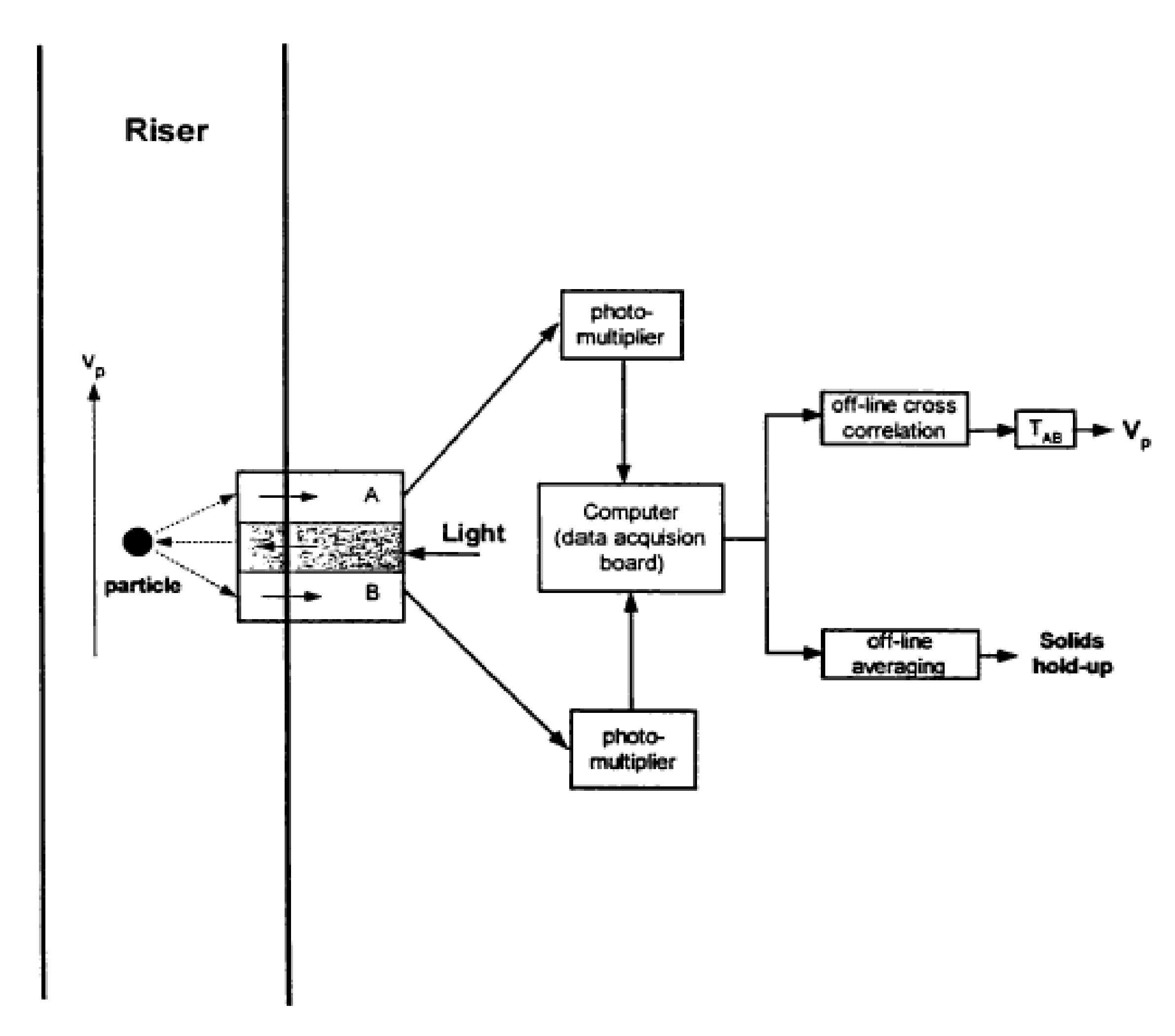


Solids Flux Measurements

- Simultaneous measurement of solids concentration and particle velocity

$$\overline{G_s} = \frac{1}{T}\int_0^T \rho_p \cdot V_p(t) \cdot (1-\varepsilon(t)) \cdot dt \neq \rho_p \cdot \overline{V_p} \cdot (1-\bar{\varepsilon})$$

PV-4A system

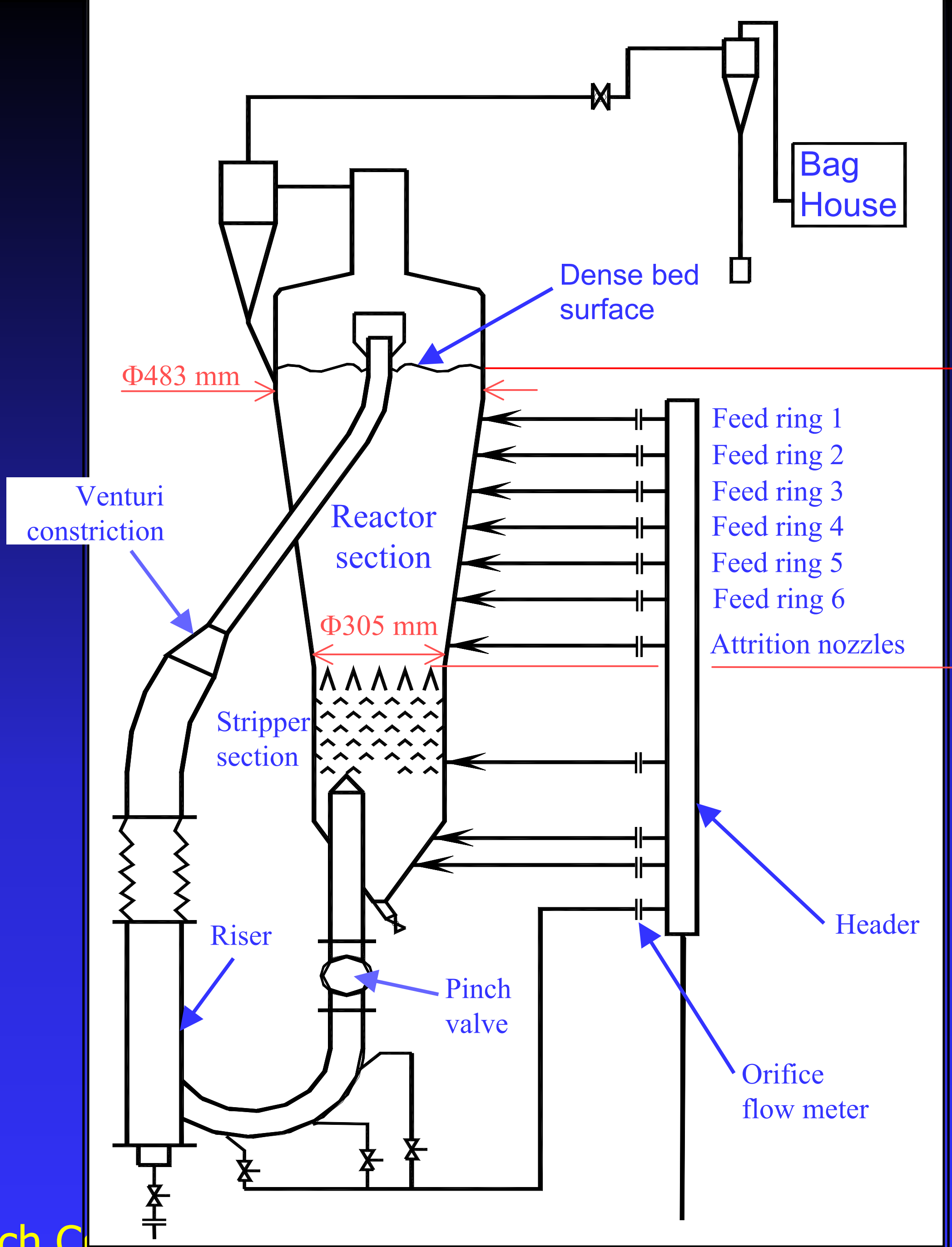


From Jinzhong Liu's Thesis

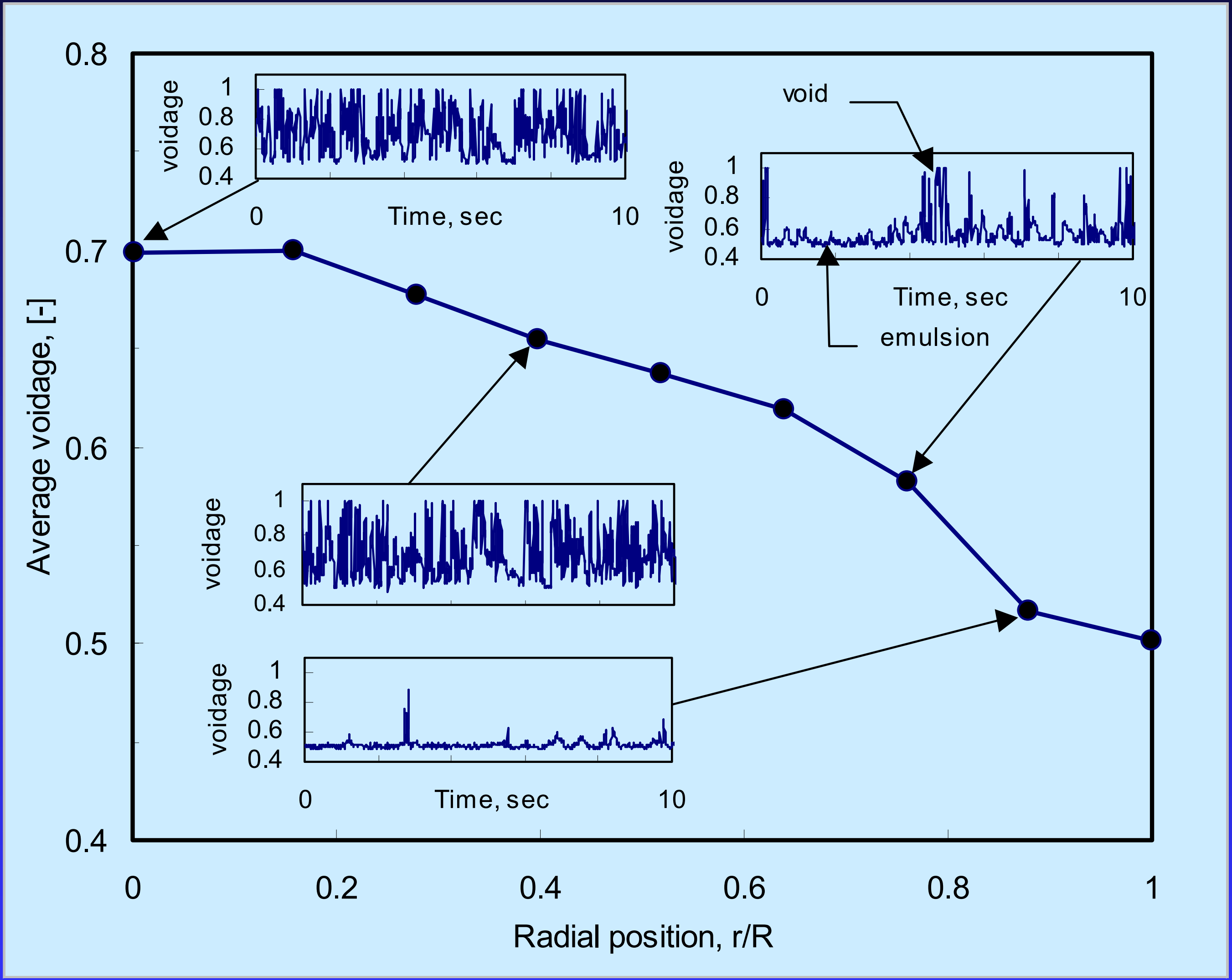
Applications

- Voidage and velocity measurements in risers
- Voidage and velocity measurements in a fluid coker cold model
- Voidage measurement in bubbling and turbulent fluidized beds
- Solids RTD in a riser
- Recent studies in spouted beds

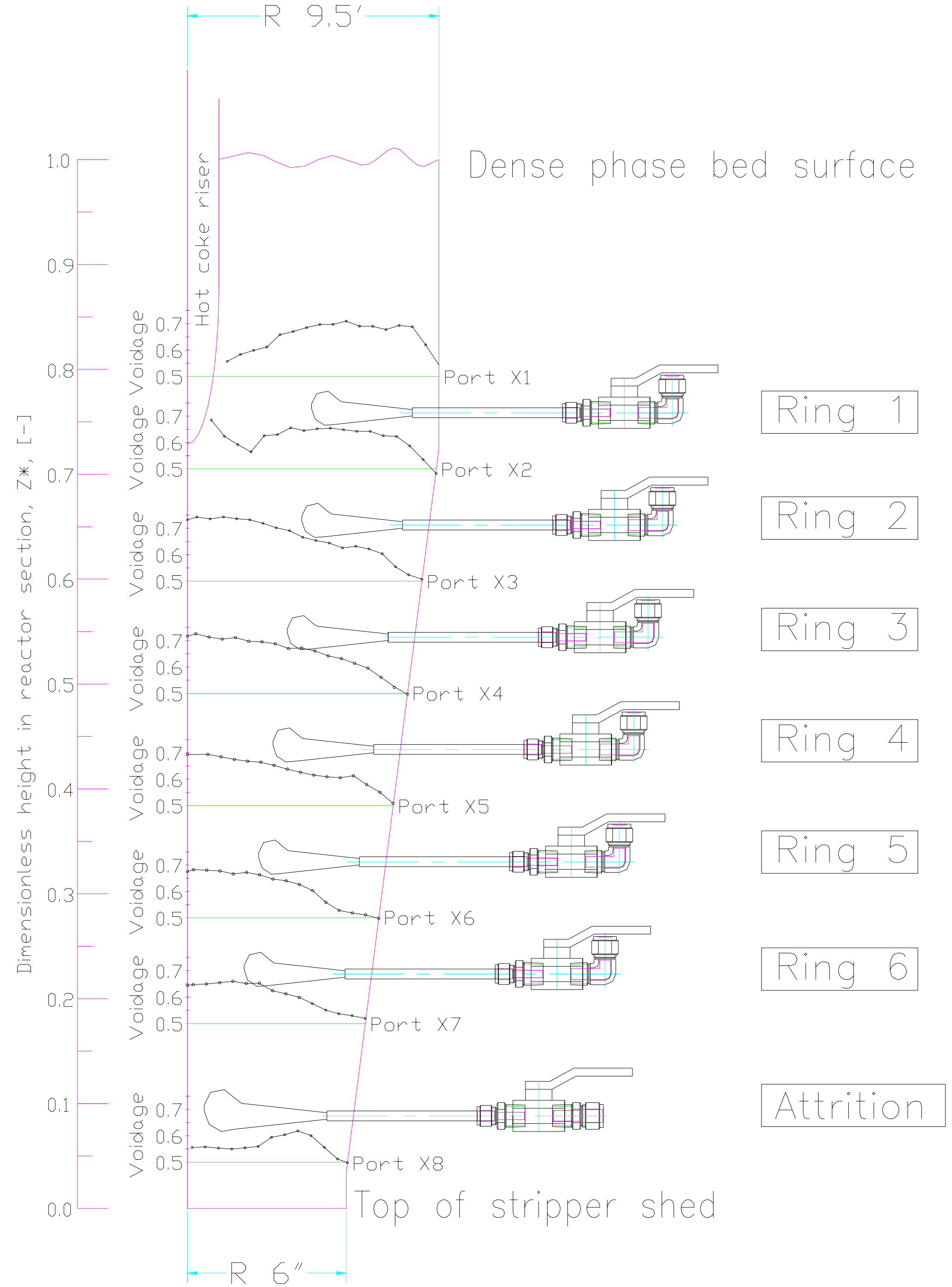
Fluid Coker Cold Model



Voidage Measurement in Fluid Coker Cold Model



Voidage Distribution in Reactor Section



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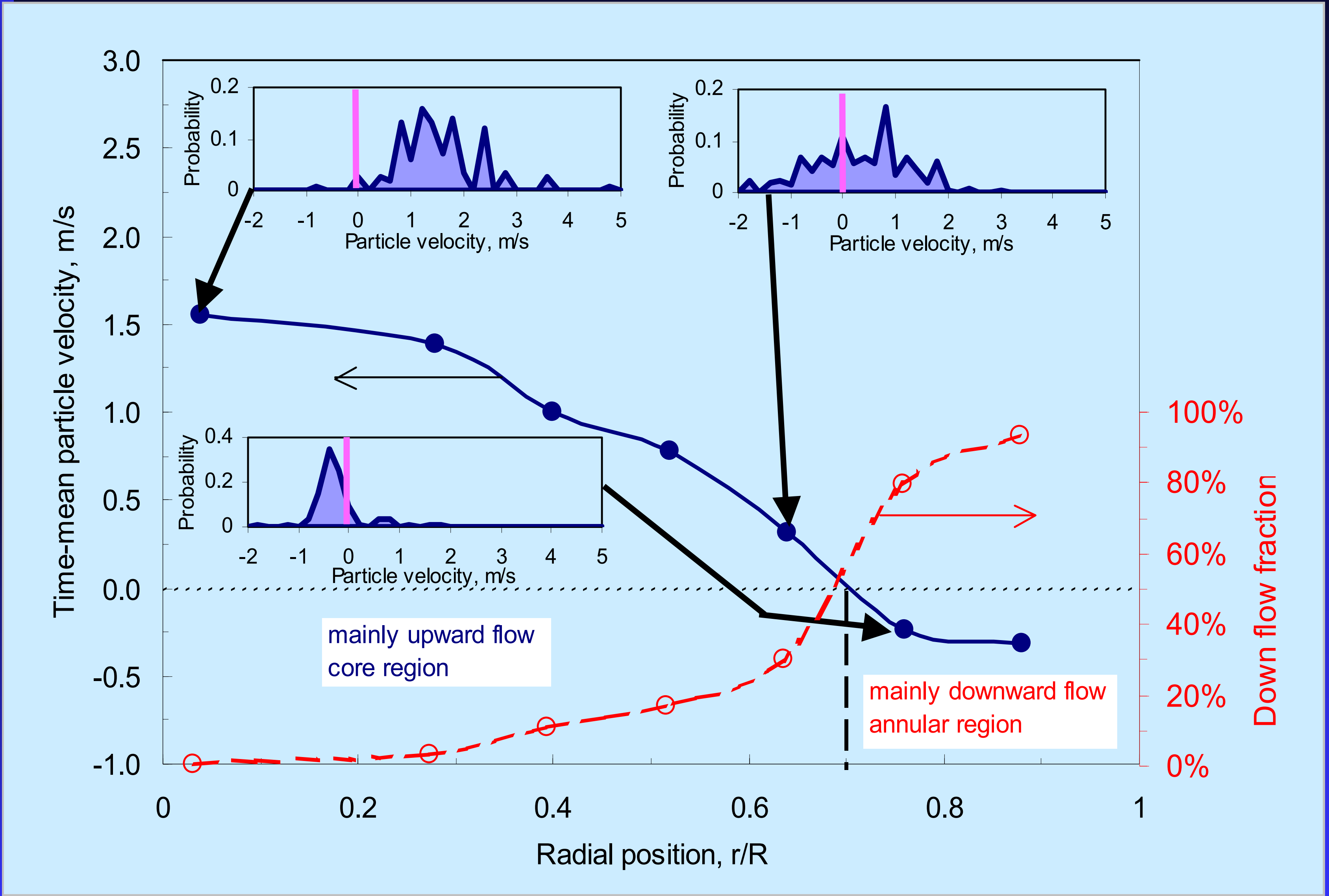
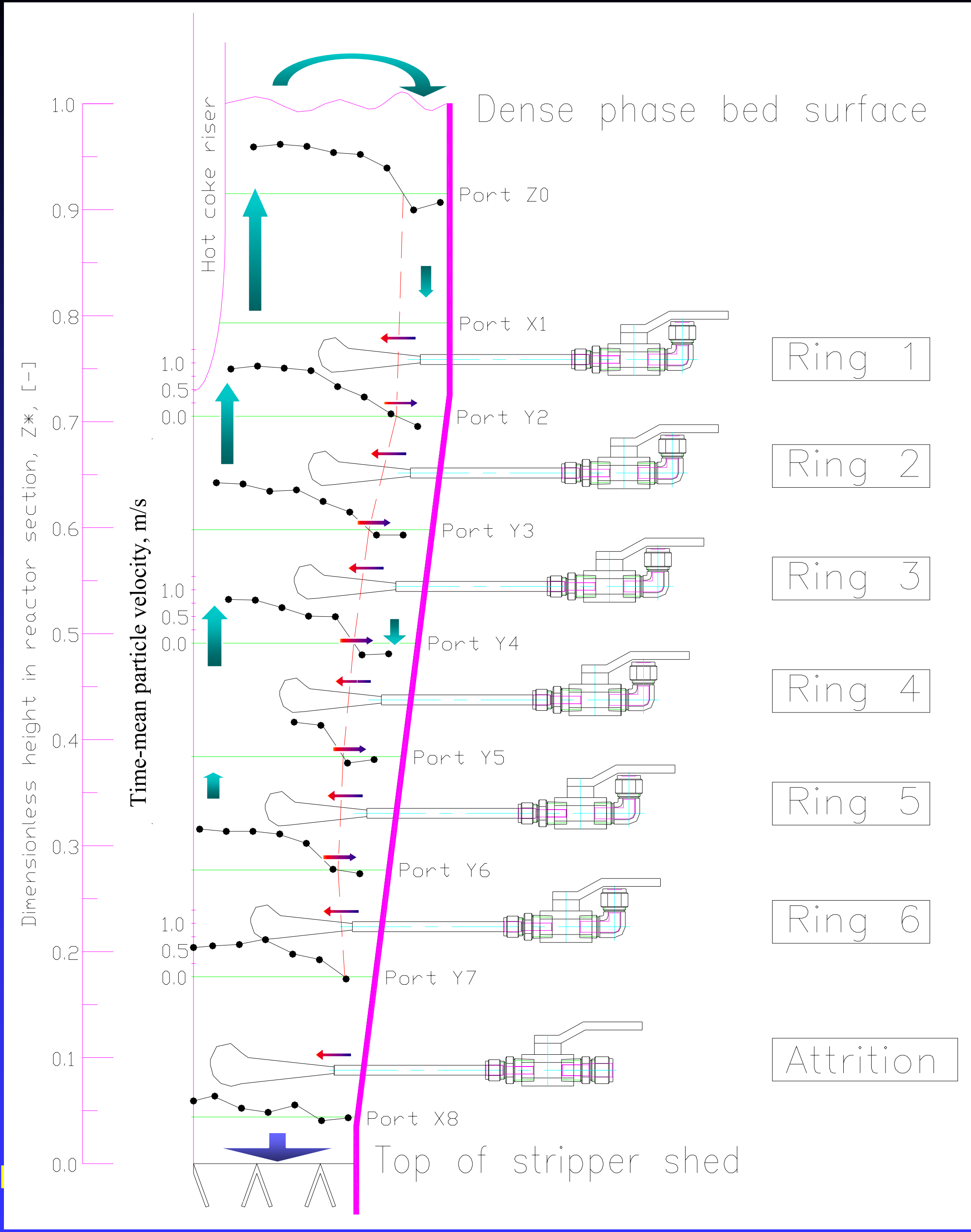
Time-Mean Particle Velocity



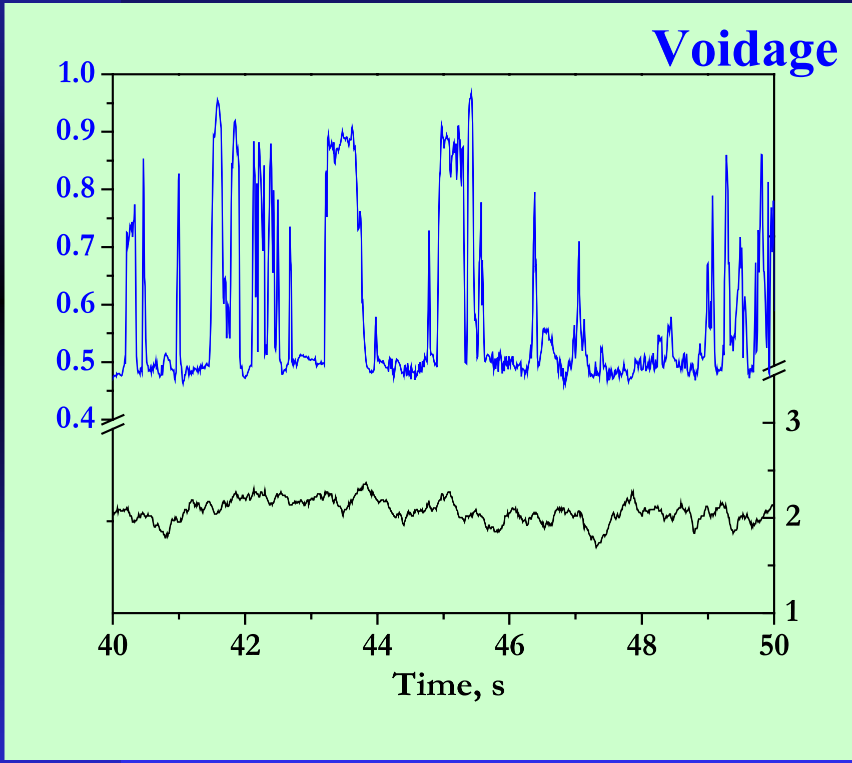
Core-Annulus Solids Flow Structure

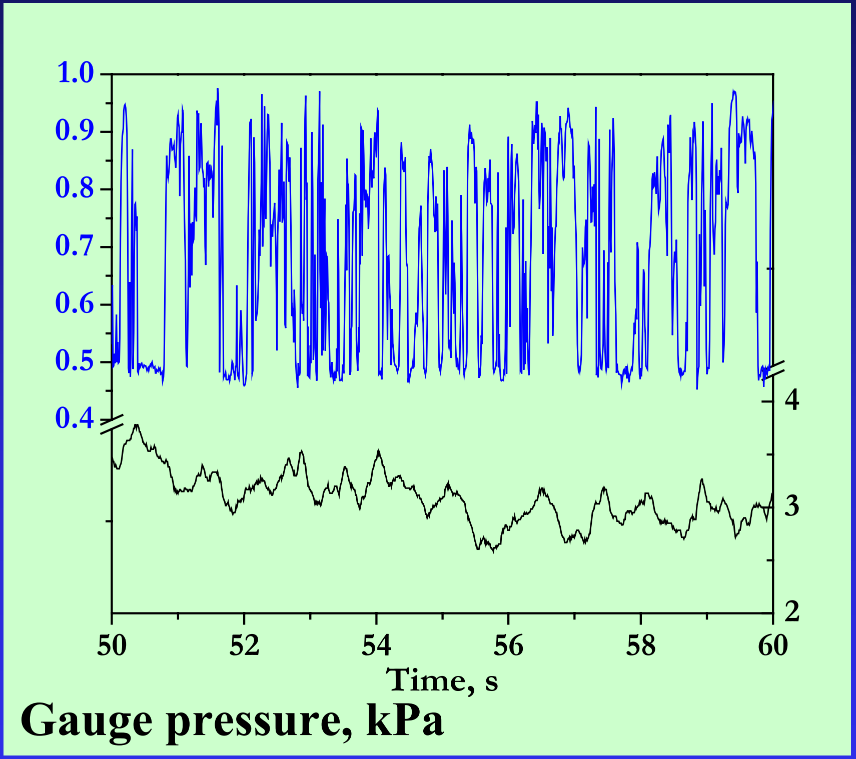


Application to Turbulent and Bubbling Fluidized Beds

Local Voidage Fluctuations

D=1.56 m, z=0.84 m, U_c=0.34 m/s, r/R=0.9





U=0.11 m/s

U=0.51 m/s

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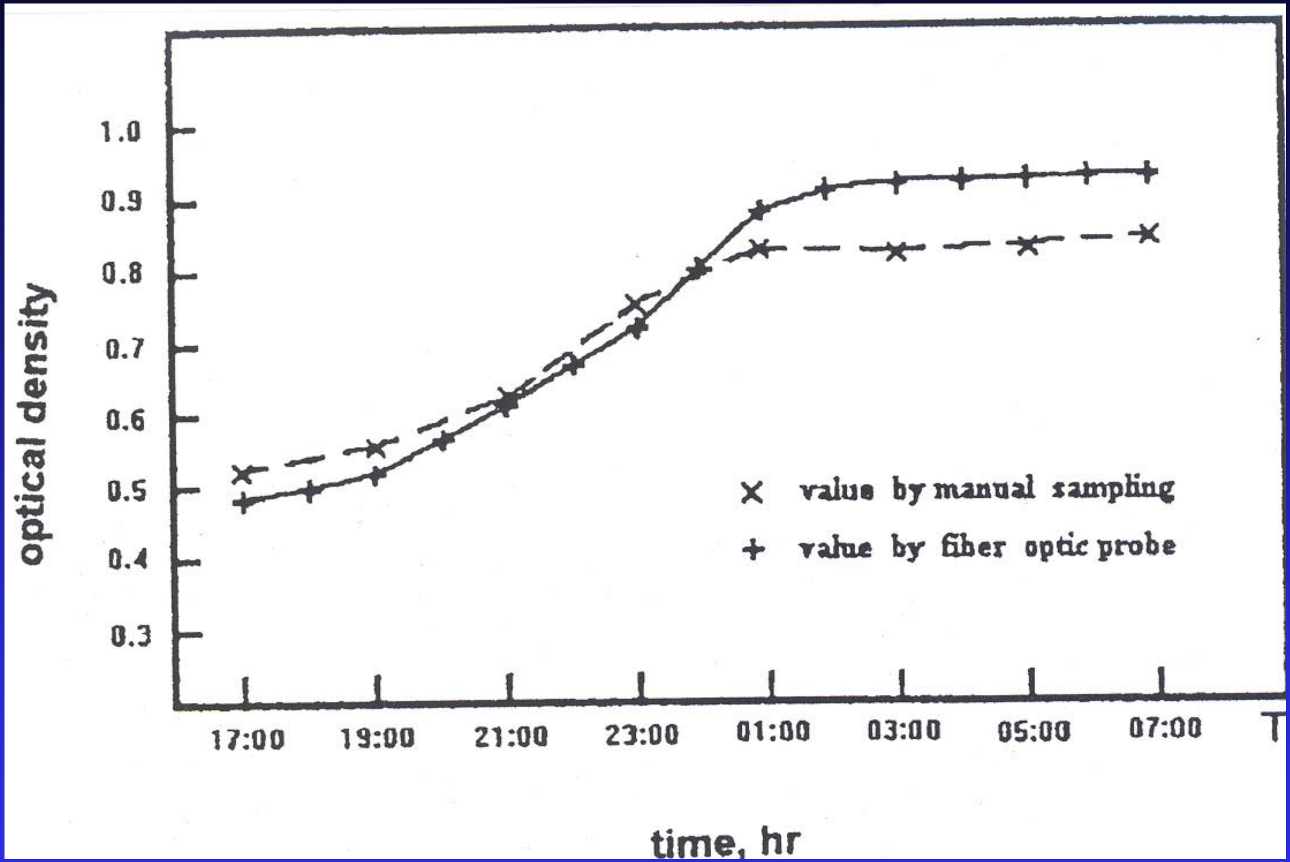
Cell Concentration in Fermentation

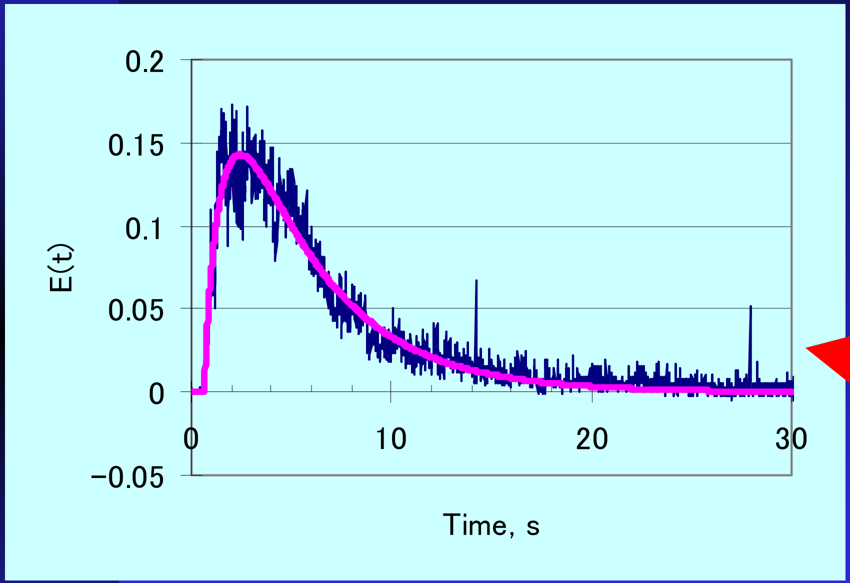


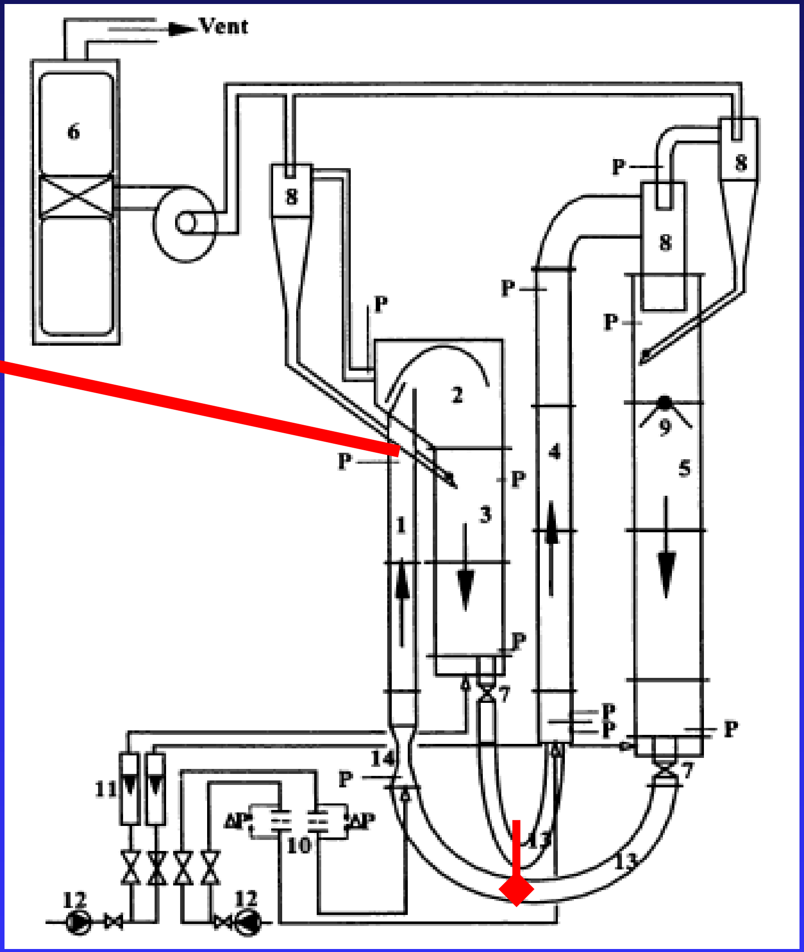
Qin and Liu (1982): Cell concentration measurement using transmission-type optical fibre probe for glutamic acid fermentation.

Solid RTD Measurement using Phosphorescent Particle Tracer

- Tracer particles:
  - Mixture of phosphorescent and FCC
- Activating light:
  - UV light
- Detection:
  - Optical fibre probe

Measurement Result in a Riser





Practical Operation of Probes

- Voidage Probe
- Velocity Probe
- Phosphorescent Particle Detection

Contacts

- Optical Fibre Probe Application
  - Dr. Naoko Ellis; nellis@chml.ubc.ca
  - Dr. Xuqi Song; xsong@chml.ubc.ca
- Optical Fibre Probe Design and Fabrication
  - Dr. Heping Cui

    hcui@membranereactor.com

Application and Its Potentials

* **Systems**

Gas-solid, gas-liquid, liquid-solid, gas-liquid-solid

Dense and dilute

* **Parameters**

Bubble (bubble fraction, velocity & size distribution)
Emulsion (voidage, phase fraction, motion direction)

Cluster (voidage, fraction, velocity & size distribution)
Particles (velocity, fraction)
Broth (phase fraction, voidage)

Remarked Points

* **Design**

  Blind spot
  Measurement volume
  Intrusion
  Electricstatic free and attrition free
  Size and its suitability to systems

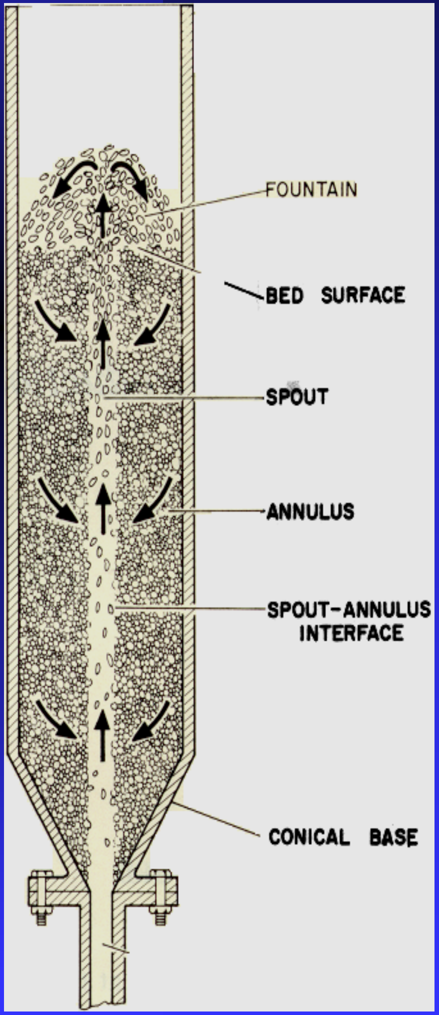
* **Application**

  Light properties of fluid and particles
  Probe selection and calibration
  Sampling accuracy (limit, data size, frequency)

* **Signal Analysis**

  Possible zero shift
  Effective method to identify correct data
  Especially for velocity measurement

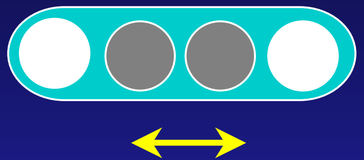
Case Study:
Optical Velocity Probe Calibration and Application in Spouted Fluidized Bed



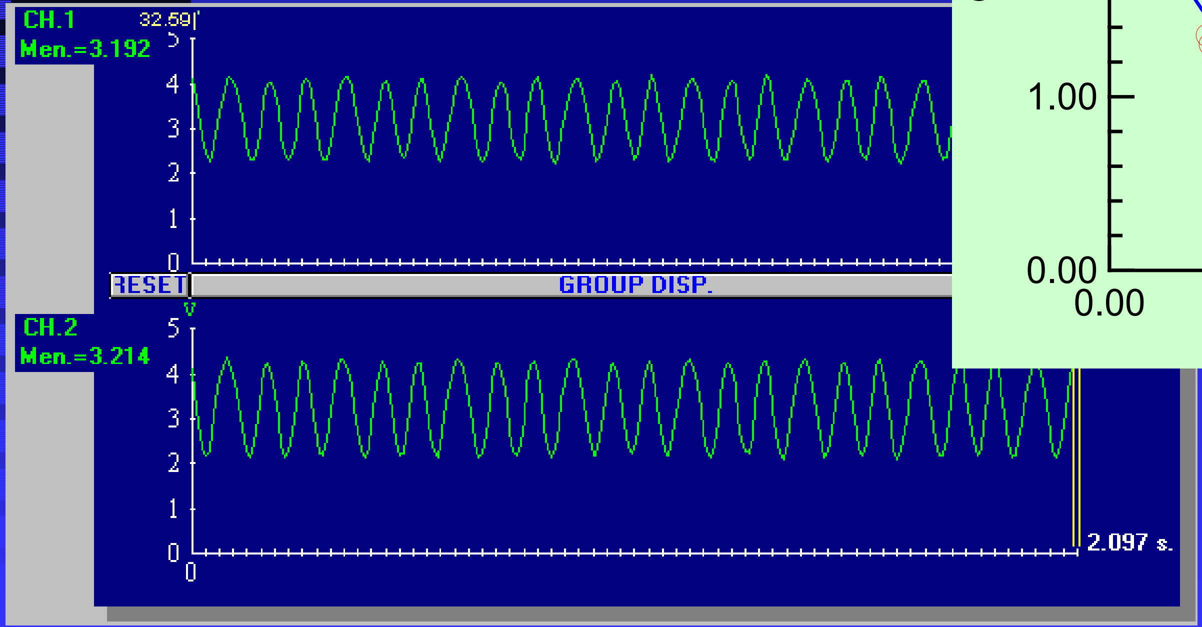
Investigation by Zhiguo Wang

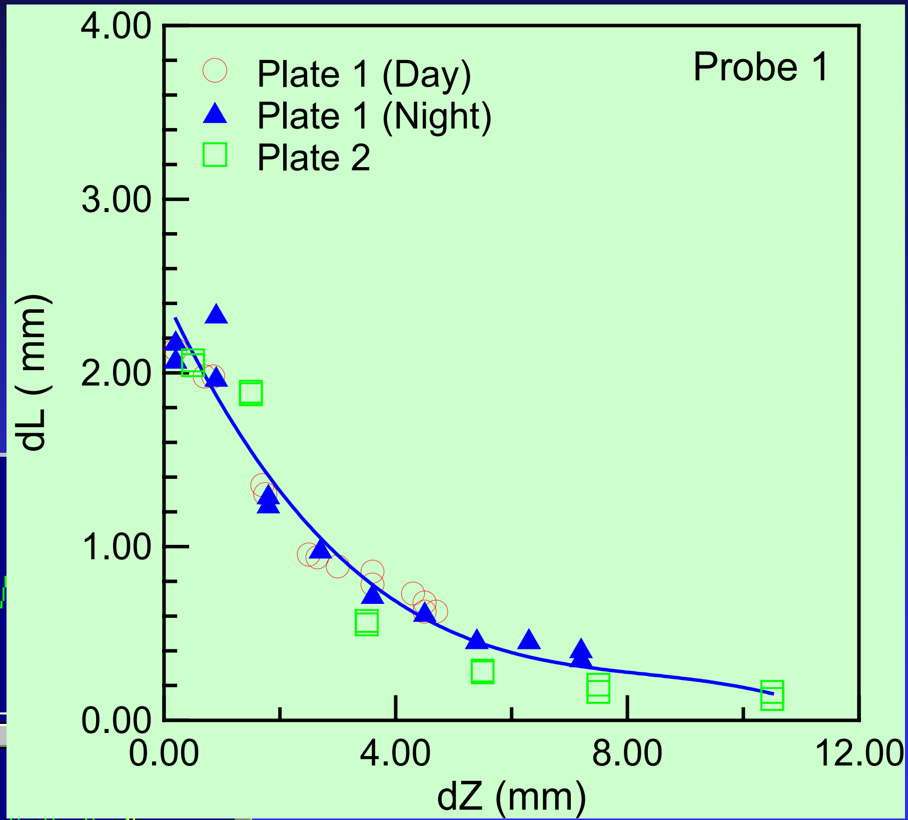
System:
1.16 mm diameter glass beads
Optical velocity probe
Fibre diameter: 15 µm in 2.5mm bundles

Calibration without Glass Window using a Rotating Disk



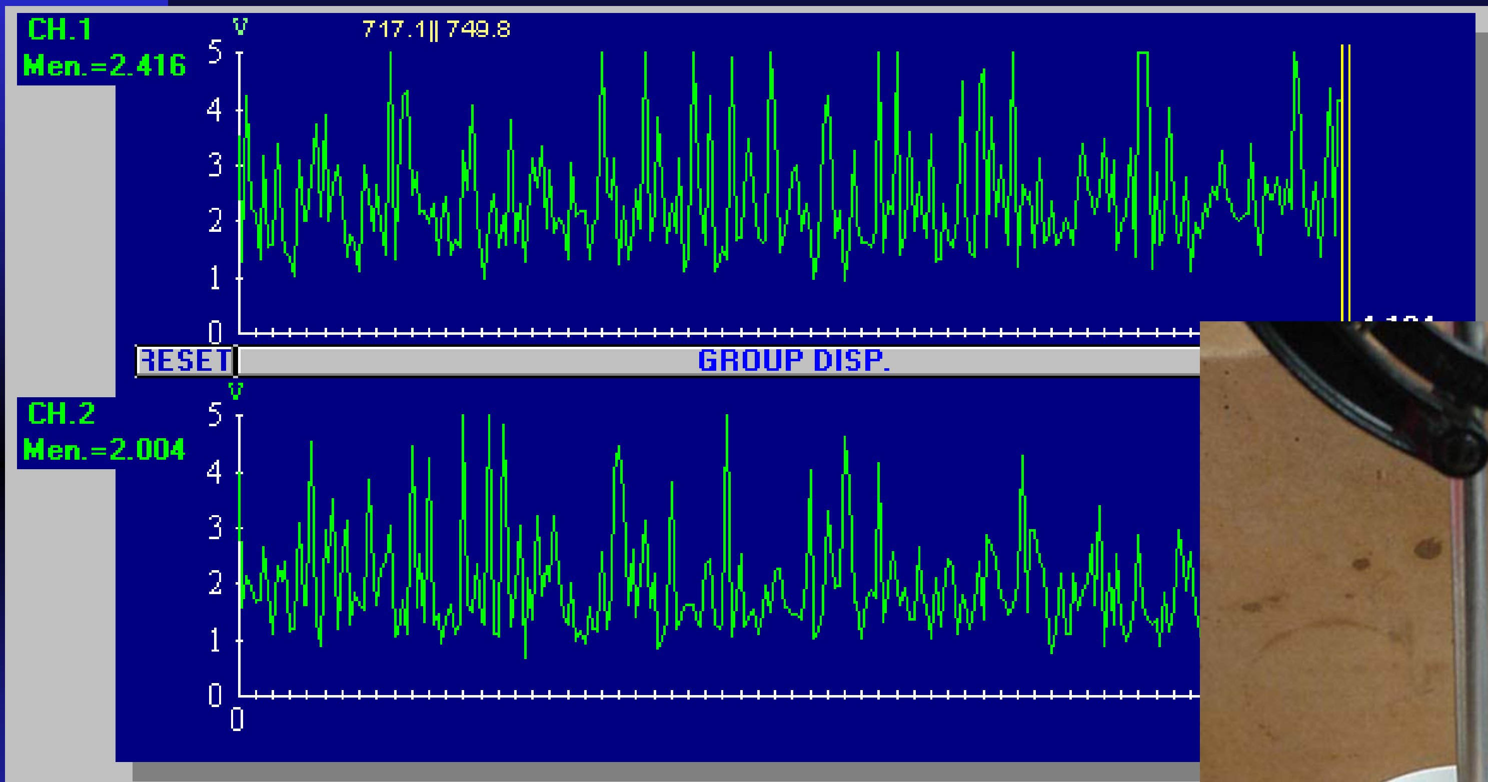
Effective distance
dL



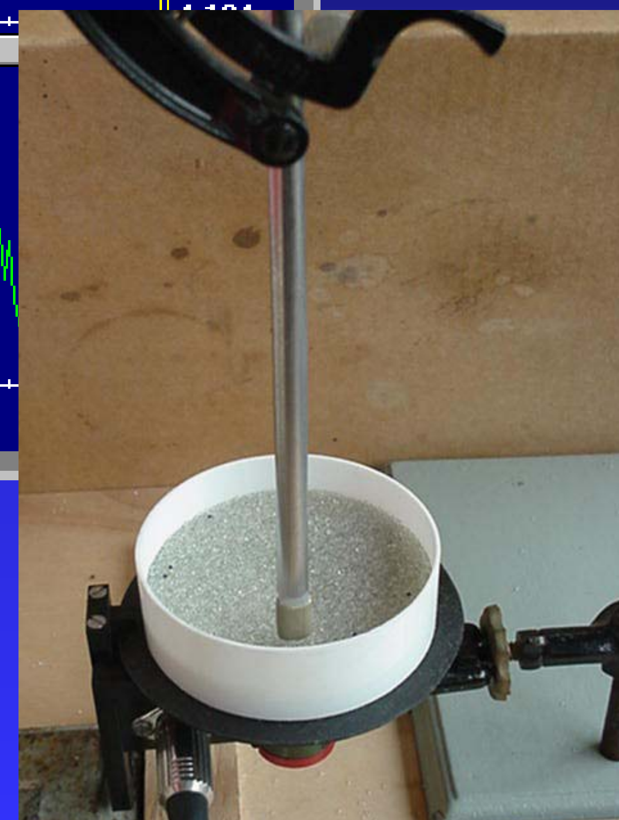


dZ: distance between probe tip and disk

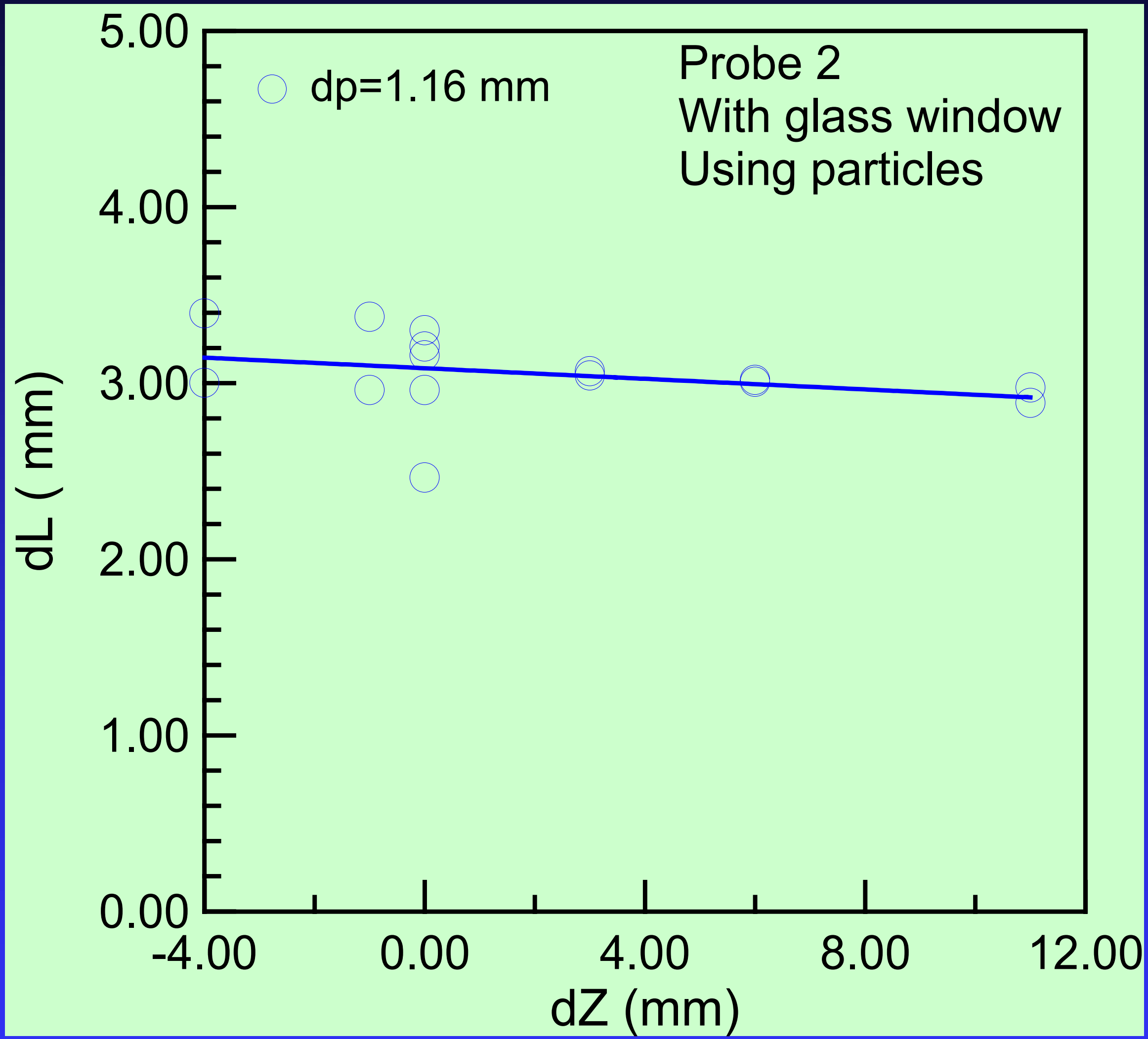
Calibration using Rotating Plate



延迟时间(ms)	8.448	平均速度(m/s)	.308
相关系数	.33	信号平均值(V)	2.416/2.004



Calibration with Glass Window



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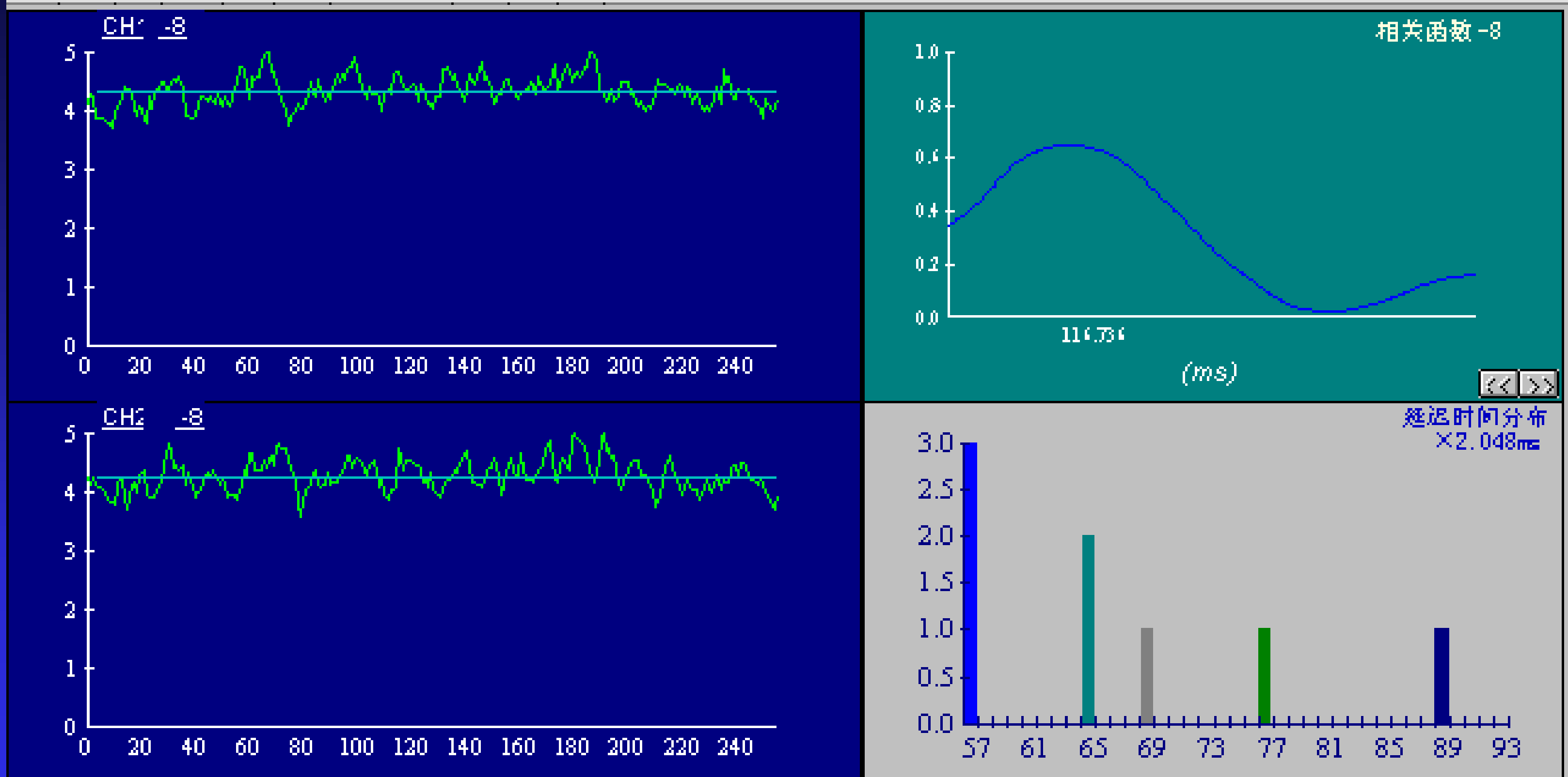
Spouted Bed Annulus



延迟时间 (ms)	133.12	平均速度 (m/s)	.023
相关系数	.64	信号平均值 (V)	4.445/4.401

	No.	延迟	速度m/s	COR	平均值	分组时段	V
★	3	89	.017	.72	4.59/4.54	16.7-- 25.1 s.	
★	4	57	.027	.63	4.42/4.40	25.1-- 33.5 s.	
	5	69	.022	.63	4.40/4.36	33.5-- 41.9 s.	
	6	65	.023	.63	4.37/4.34	41.9-- 50.3 s.	
	7	57	.027	.64	4.34/4.28	50.3-- 58.7 s.	
	8	57	.027	.65	4.33/4.28	58.7-- 67.1 s.	