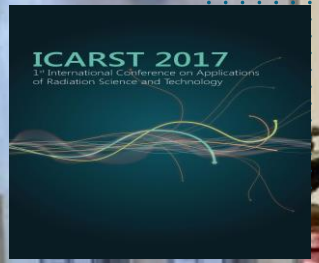
Bed Expansion in Upflow Moving Catalytic Packed/Expanded Bed Hydrotreating Reactor using Gamma-Ray Densitometry



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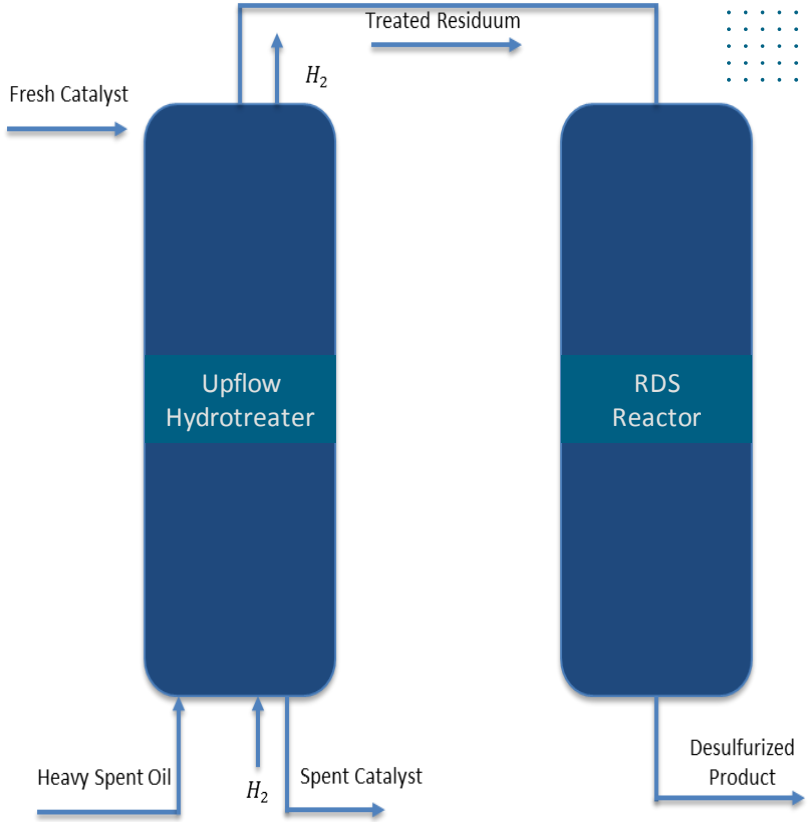
Multiphase Reactors Engineering and Applications Laboratory (mReal)

Uplfow Packed and Expanded Bed Hydrotreater

- Upflow Hydrotreater treats heavy crude oil (Scheuerman, Johnson et al. 1993)
- Guard Reactor to Residual Desuflurization (RDS) reactors
- This technology has a conical bottom to catalyst bed and is a combination of fixed bed and moving bed (Krantz, Earls et al. 2002)
- Spent catalyst replacement through conical bottom
- Upflow of gas and liquid over catalyst bed
- It can handles feed with varying degree of contaminants
- It can improve the life cycle of fixed bed RDS reactor



Problems In Industrial Reactor

- Coke deposition on one side of the reactor.
- Increased pressure drop either in the inlet distributor tray or in the outlet or both, and hence the total pressure drop over the reactor.
- Disturbance in the catalyst bed.
- Occasional difficulty in controlling the reactor temperature.
- Variations in product quality.
- Shortening catalyst cycle of fixed bed reactor.
- No clear pattern for these problems.
- Emergency shutdown.

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Motivation

- Efficient working of upflow hydrotreater with conical bottom has huge impact on hydroprocessing industry
- For proper working of this reactor; minimum random motion of and back mixing of catalyst is required and the catalyst bed expansion shall not be more than 10 percent by volume
- Bed expansion are never evaluated and quantified in OCR reactor

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Objectives

- Implement a noninvasive radioactive technique called Gamma-Ray Densitometry (GRD) along the axial length of the reactor for varying flow rate

- Demarcate packed and expanded bed region based on photon counts and flow regime trend

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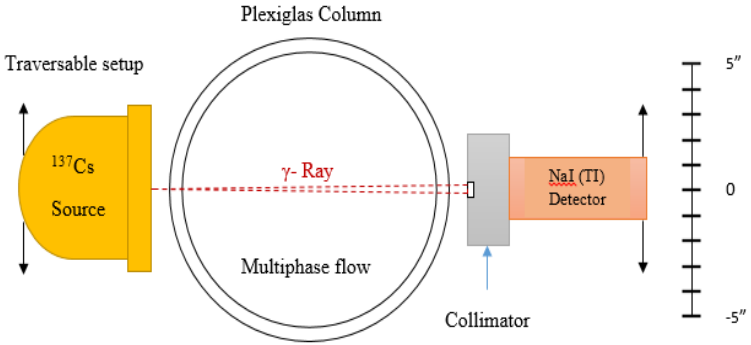
Gamma-Ray Densitometry (GRD)

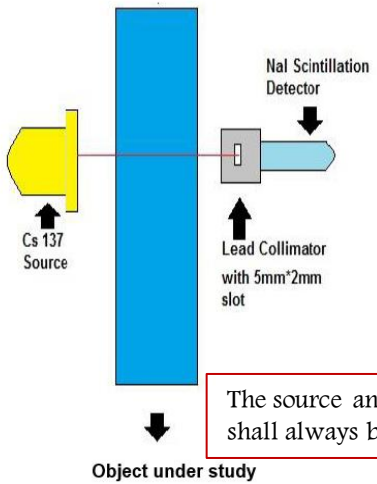
Components of GRD



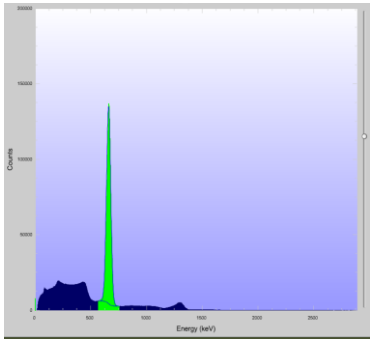
Sealed Source
(Cs-137 is sealed In source holder which Has small opening for Radiation)

Detectors
NaI scintillation detector mounted with lead collimator having a slit opening of 50mm (length) and 2mm(width)

Principle Behind GRD



The source and detector shall always be **aligned**.



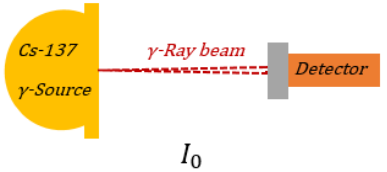
The counts generated at **energy peak-660Kev for Cs-137** (marked as green in the fig) is taken for analysis purpose.

- A focused beam of radiation is transmitted from the source, through the object under study, to the detector.
- As the density of the material under investigation changes , the amount of radiation receiving the detector changes.

Attenuation of γ – Ray

The reduction in the radiation intensity from I_0 to I can be expressed by The Beer – Lambert's law according to the following equation (Chen et al., 1998):

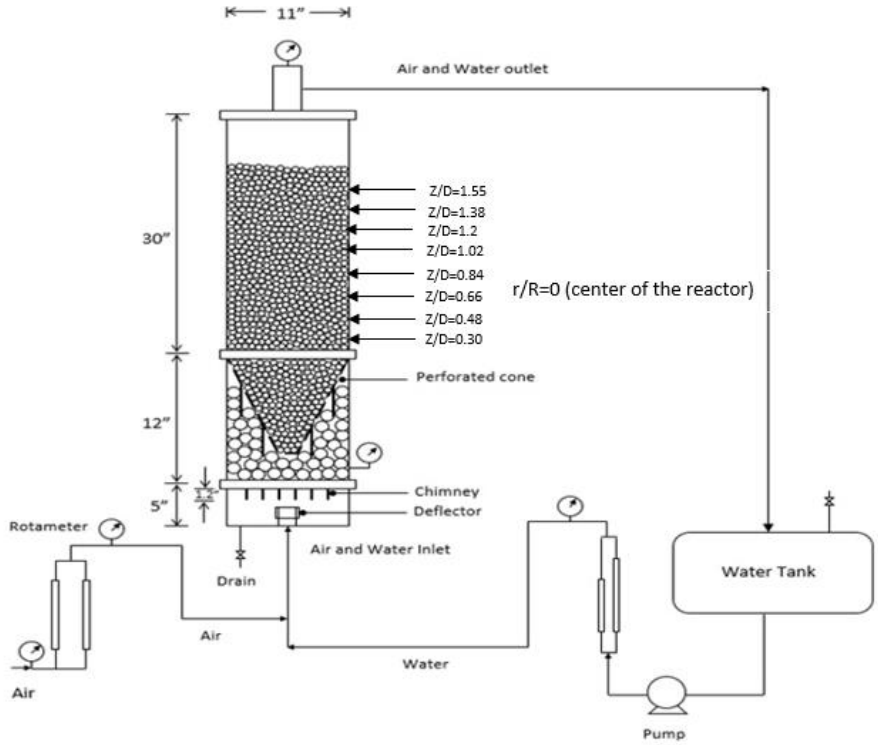
$$I = I_0 e^{-\mu\rho L}$$



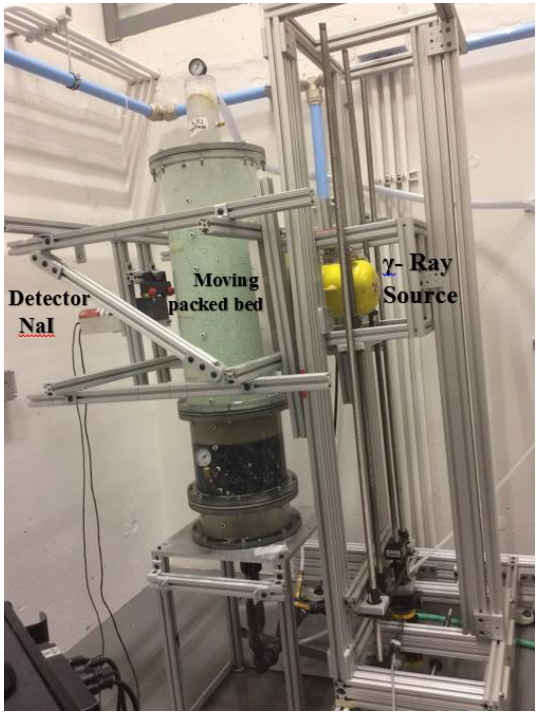
Atmosphere I_0 (Schlieper, 2000)

- I is the detected radiations (photons)
- ρ is the density of the subject under study
- μ is the mass absorption coefficient of the subject under study
- L is the total length for gamma ray beam path through the absorbing medium

Experimental Setup



Schematic diagram of lab scale uplow packed/expanded bed reactor



lab scale reactor

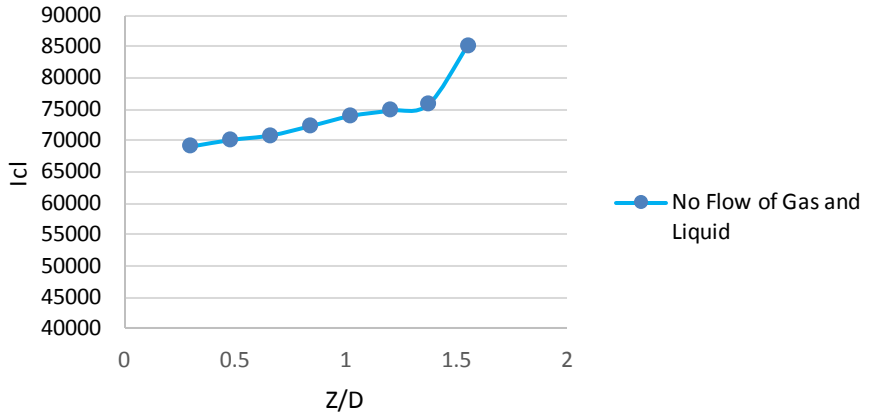
Experimental Condition

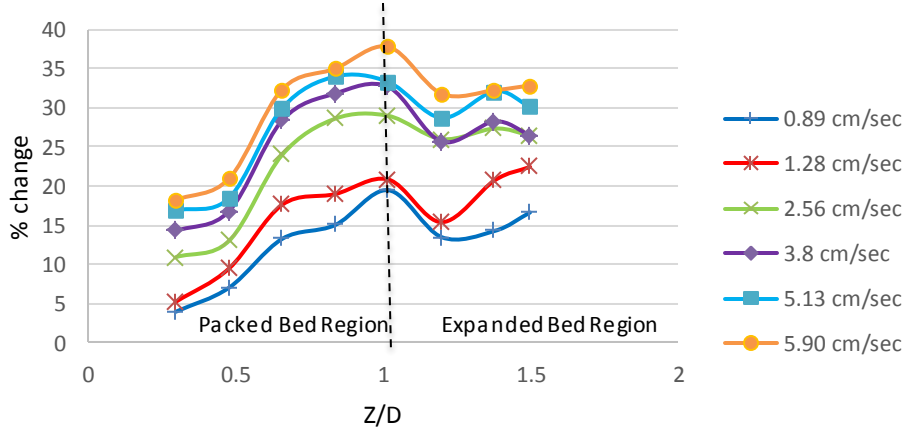
Liquid flow rate: 0.0175 cm/sec (Matching LHSV with industrial reactor)

Gas flow Rate: 0.89 cm/sec to 5.9 cm/sec

Bed Expansion– Based on Photon Count

Comparison with Packed Bed Count





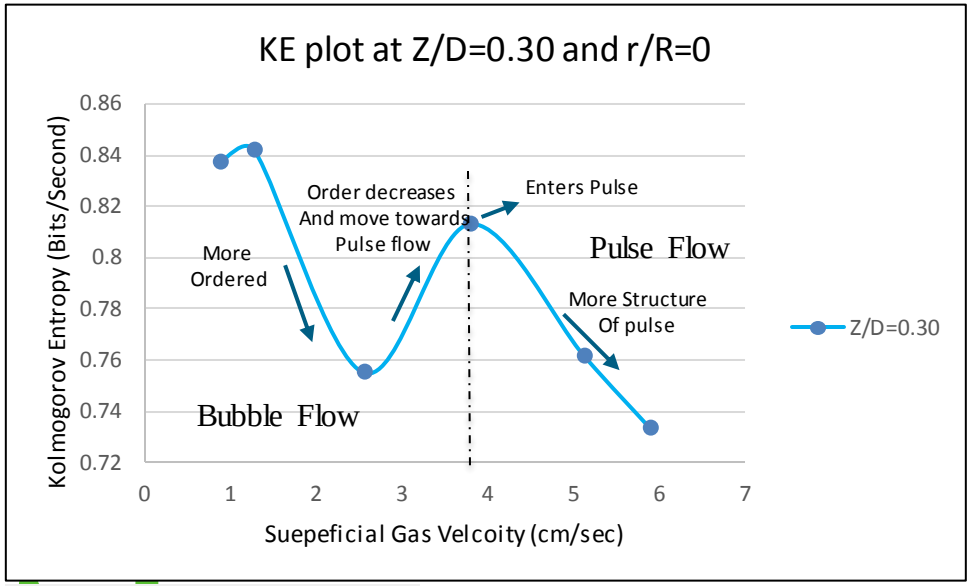
- I_{cl} is the photon count obtained for the case when catalyst bed is filled with liquid and no flow of gas and liquid
- This case represents the condition of packed bed as there is no movement of solids
- The photon counts are slightly increasing with height and is due to the increase in void space with height

- % change $=[(I - I_{cl})/ I_{cl}]$, whereas I is the photon count at flow rate, this represents the change in photon count with respect to packed bed
- The % change is increasing steadily till Z/D=1.2, and then it fluctuates
- Steady increase in the percentage change shows packed bed region and fluctuation represents expanded bed.
- After Z/D=1.2 the bed expands

Bed Expansion– Based on Flow Regime

Flow Regime in Packed Bed using Kolmogorov Entropy (KE)

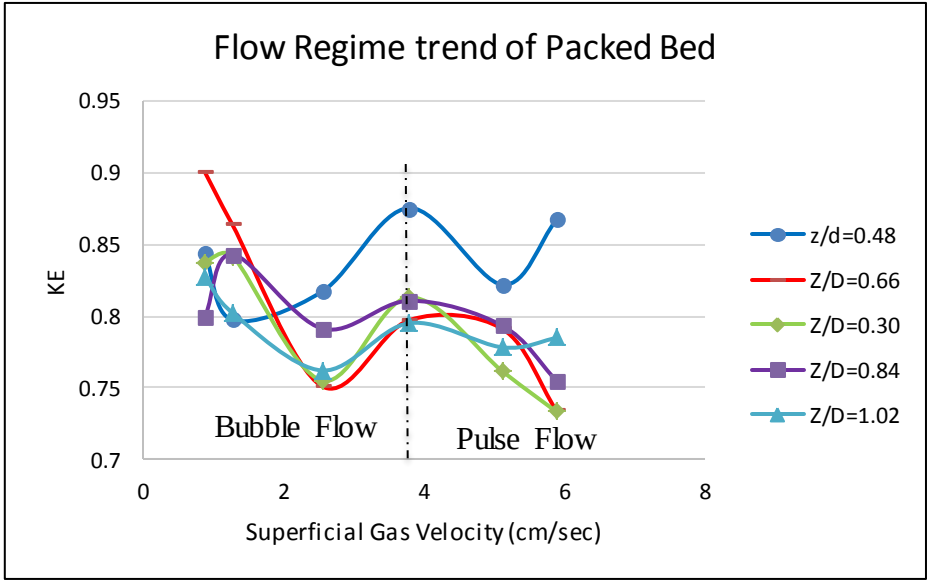
At Z/D = 0.3 and r/R = 0 (Bottom of the Bed)

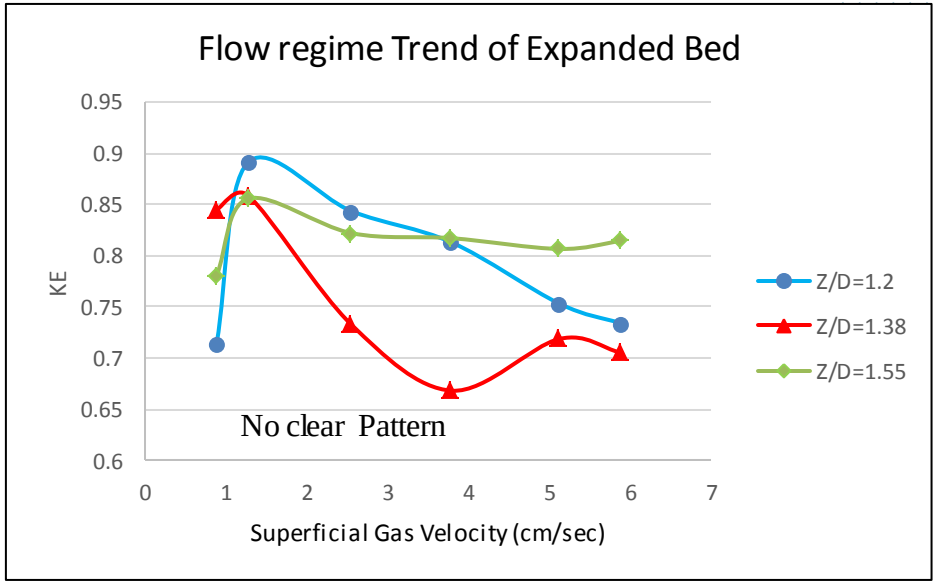


$$KE = -f_s ln\left[1 - \frac{1}{b_m}\right]$$

- The flow regime is obtained from the KE plot at the bottom of the bed which is essentially packed for varying flow rate
- The flow regime for packed bed are bubbly , pulse, and spray flow. This is observed for increasing gas flow rate for fixed liquid velocity
- At our flow case we didn't observe spray flow
- The local maximum in the KE curve has been employed as a criteria to identify the flow regime transition Nedeltchev, 2010).
- These maximum in the KE curve corresponding to the point of instability and the point of transition from one flow regime to another (Nedeltchev, 2010)
- The flow regime transition is seen at superficial gas velocity of 3.8 cm/sec

Bed Expansion- Based on Flow Regime





- KE values are plotted for varying flow rate of gas at fixed liquid velocity (0.0175 cm/sec)
- From Z/D=0.30 to Z/D=1.02 the flow regime trend shows similar pattern of packed
- The transitional velocity from bubbly to pulse flow for all the axial location in packed bed shows same at 3.8 cm/sec (gas)

- KE values are plotted for varying flow rate of gas at fixed liquid velocity (0.0175 cm/sec)
- From Z/D=1.2 to Z/D=1.55 the flow regime trend irregular trend and is mainly due to random motion of solids at this point
- This region depicts expanded bed part of the bed.
- Above Z/D=1.02 the bed is in expanded bed state

Remarks

- Gamma-Ray Densitometry is capable to demarcate the packed and expanded bed region in upflow packed/expanded bed reactor

- Bed demarcation is done based on the photon counts received at flow rate conditions, and then comparison with the packed bed case when the catalyst bed is filled with liquid and no flow rate.

- Bed demarcation is also done based on chaotic analysis (KE) of time series of GRD for flow regime identification. The packed area shows similar flow regime trend and with same transitional velocity. The expanded bed region shows irregular flow regime trend

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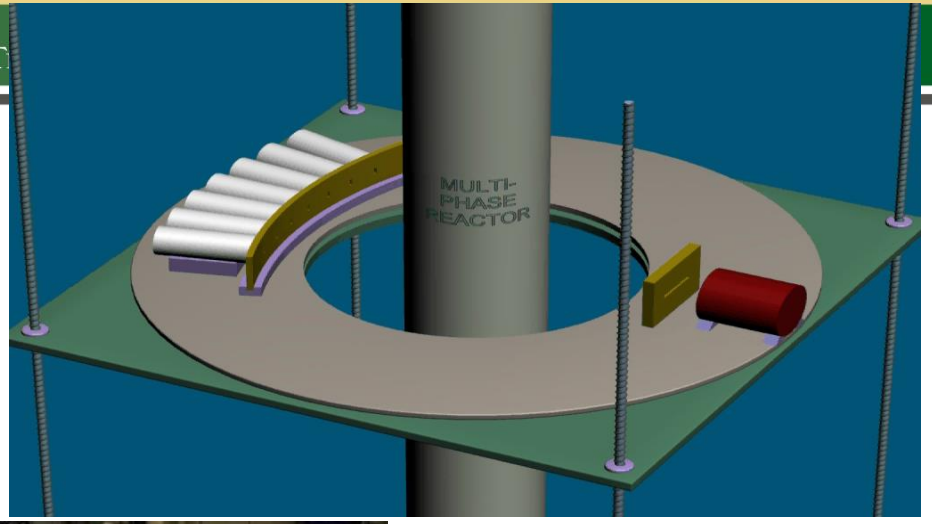
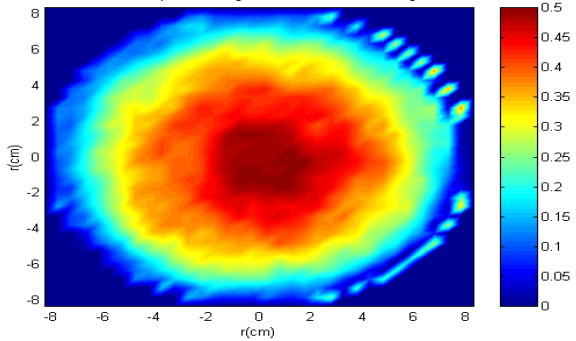
Computed Tomography (CT)

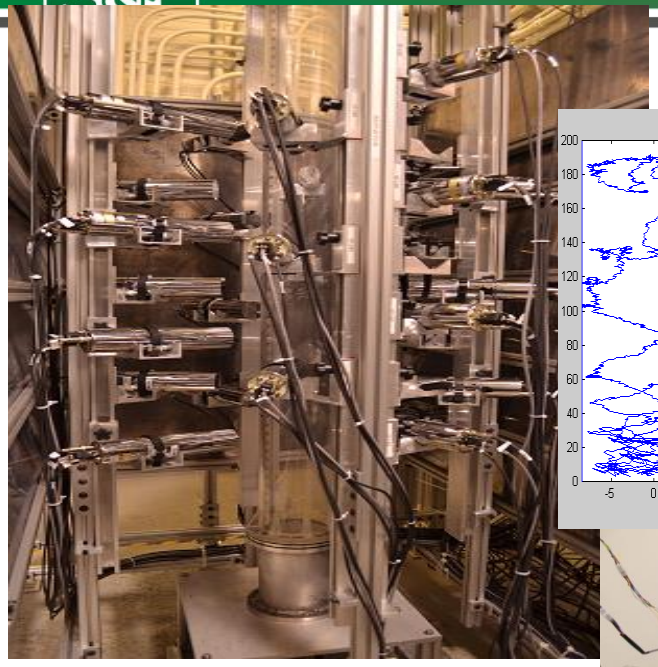
For Phase Distribution

M

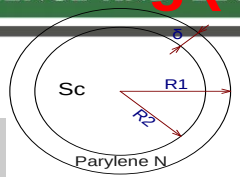


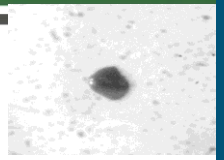


Radioactive Particle Tracking (RPT)

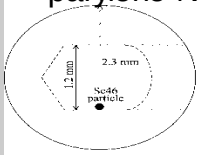


Picture of RPT

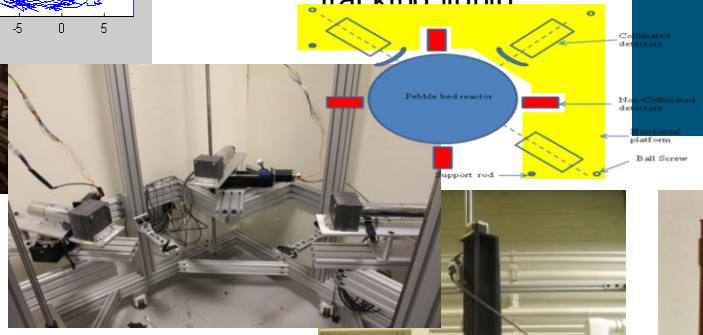




Sc^{46} particle coated with parylene-N, tracking solids



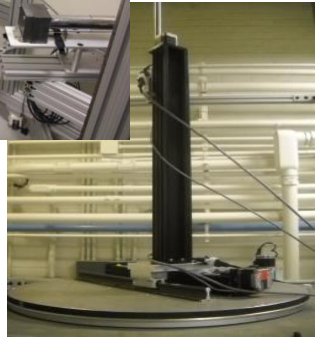
Sc^{46} particle in polypropylene ball, tracking liquid

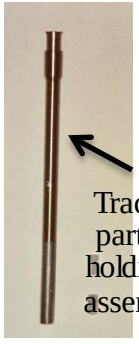


In Situ

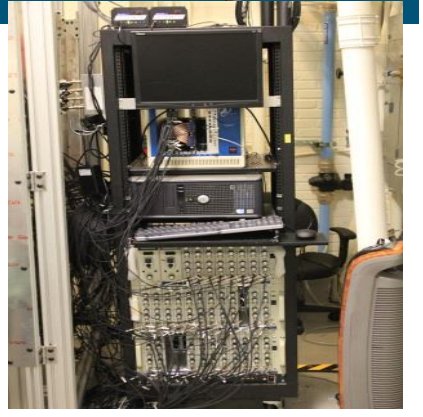
Manual

RPT Calibration

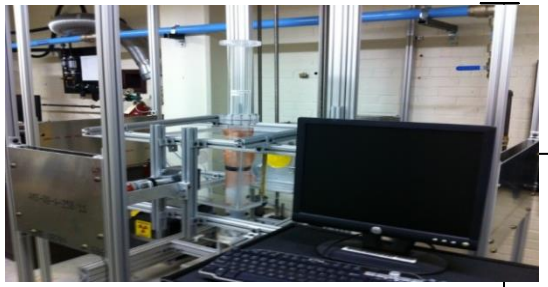


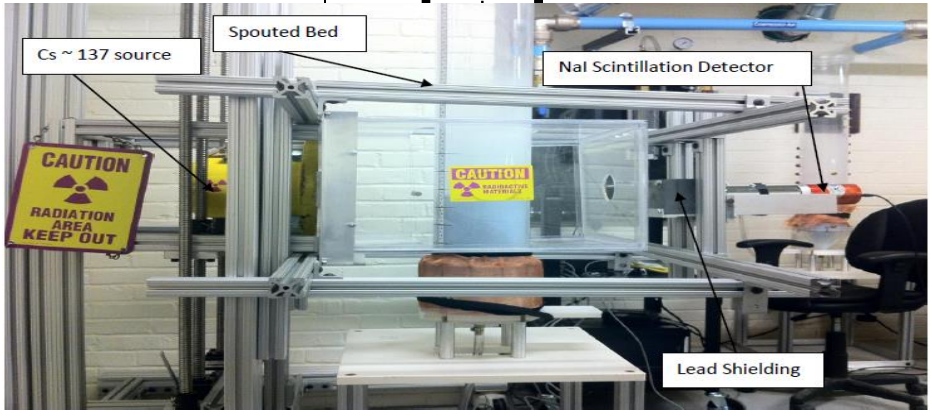


Tracer particle holding assembly



An On-line Technique Using NGD as Gamma Ray Densitometry (GRD)

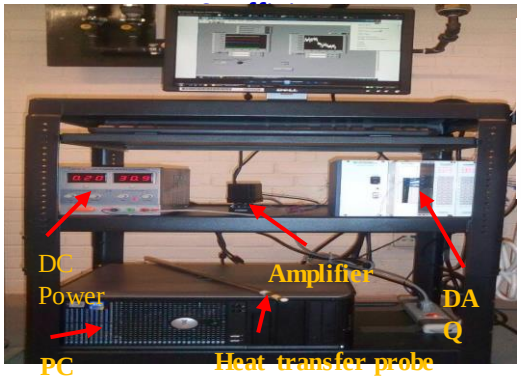


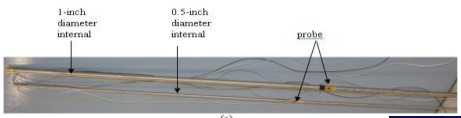


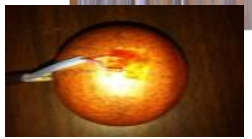
For Pinpointing Flow Pattern (Regime), Radial/Diameter Profile of Phases' Holdups Mal-distribution identification

Other Selected Sophisticated Techniques at Glance

Heat Transfer

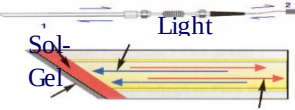




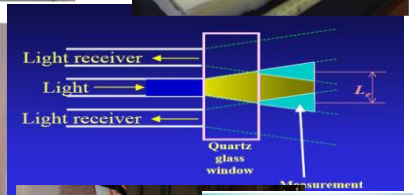


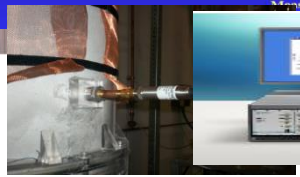
Pressure Transducers

Mass Transfer Probes

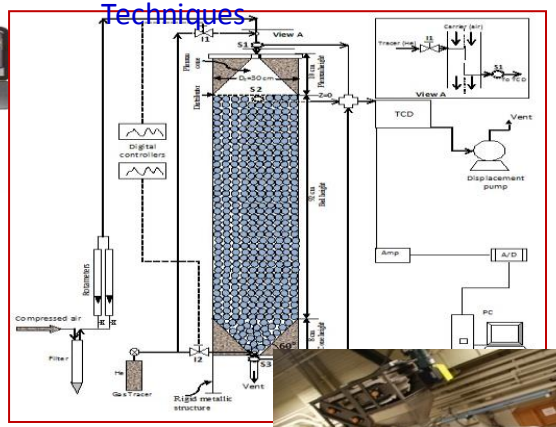


Gas-Solid optical probes

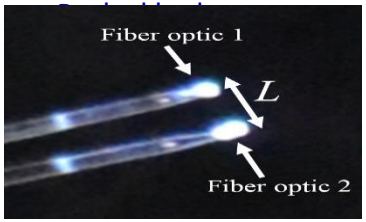


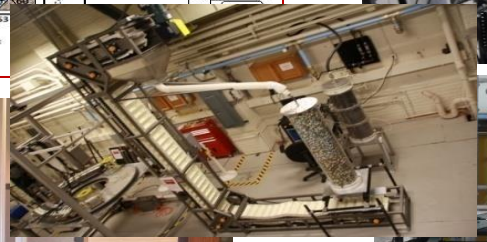


Gas/Liquid Dynamics – Tracer Techniques

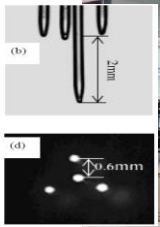


Optical Probes in

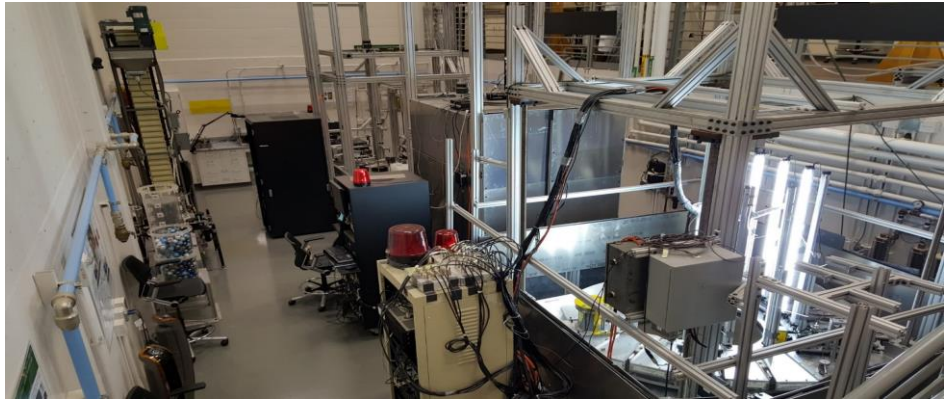


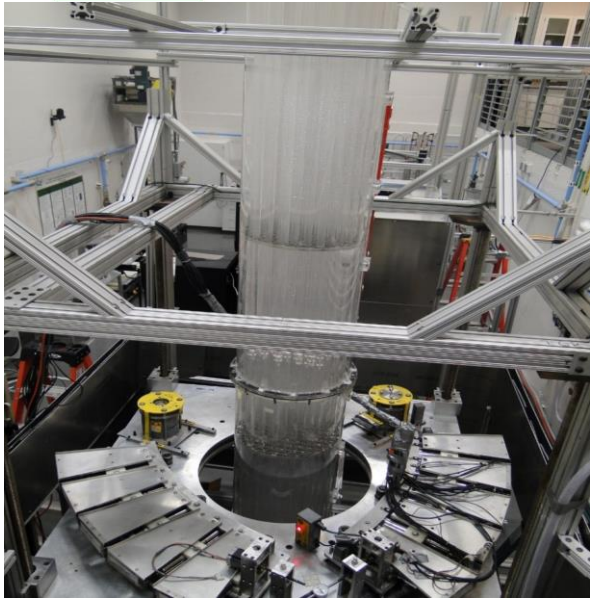


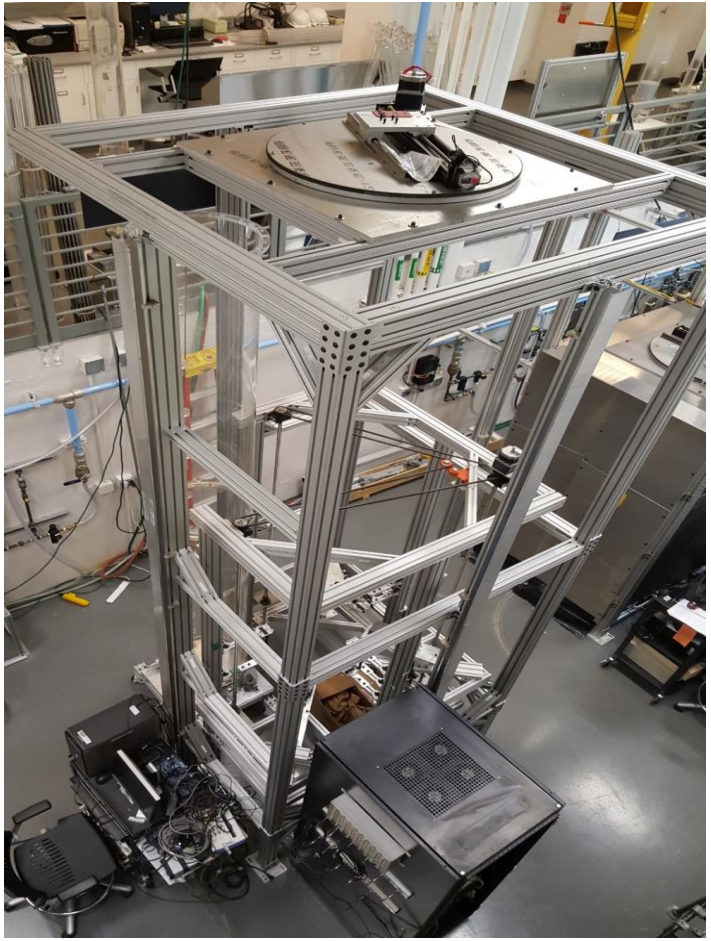
Rigs

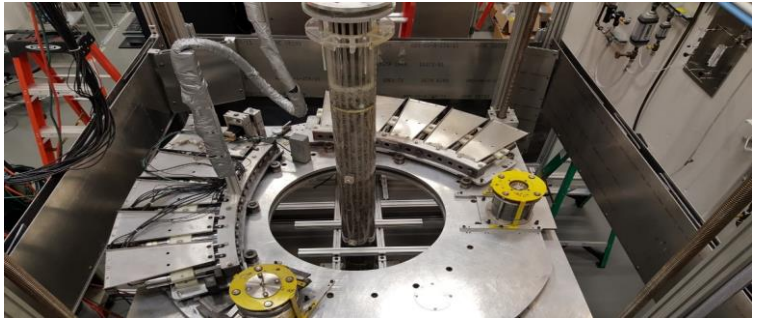


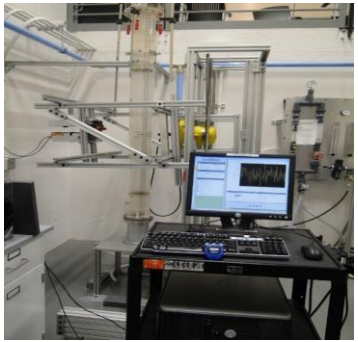
Radioisotope Laboratory for Advancing Industrial Multiphase Processes





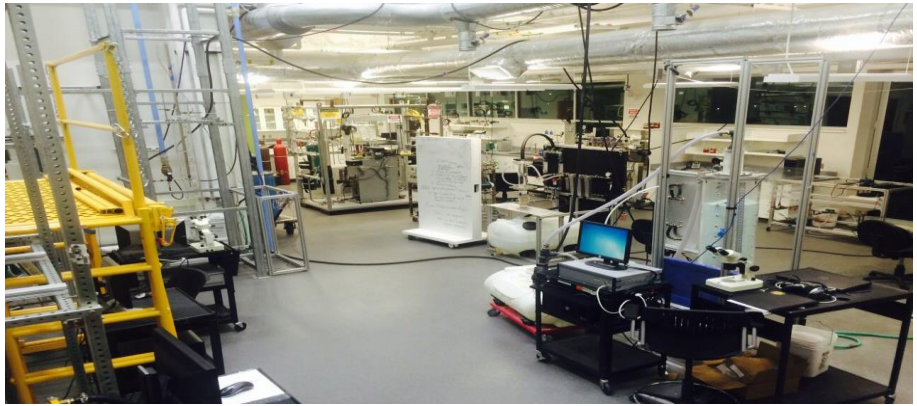


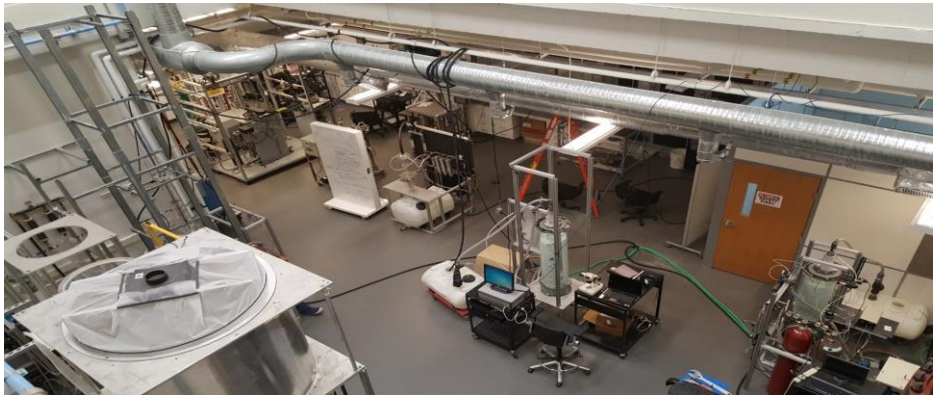




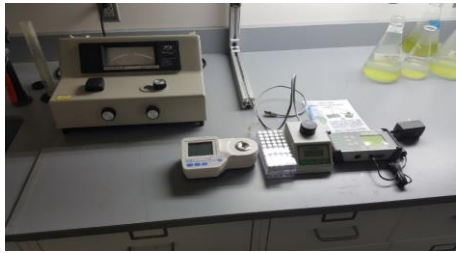
Dual Source Computed Tomography (DSCT) Technique

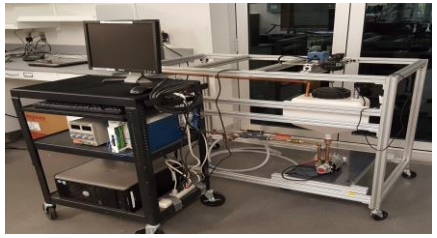
Non-Radioisotope Laboratory for Advancing Industrial Multiphase Processes





Microalgae Laboratory (Biological Lab)

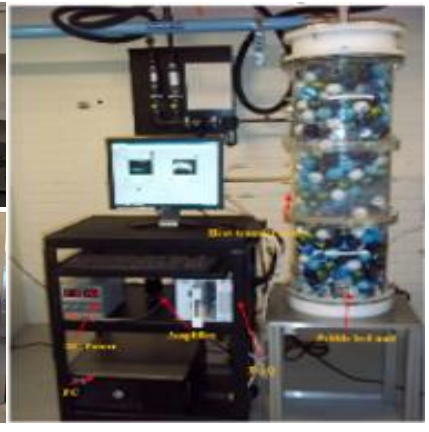


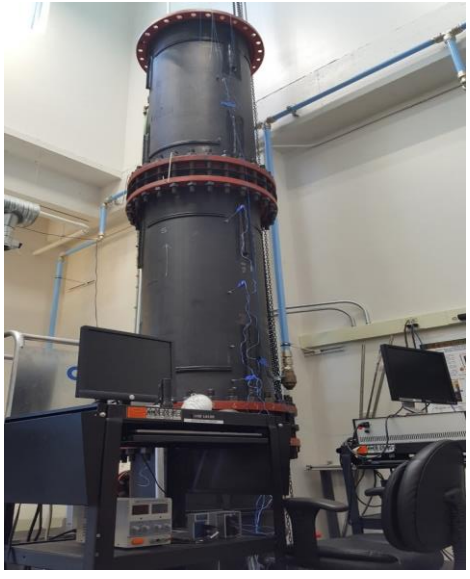











Acknowledgment

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