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Measurement of penetration and cycle time of jets from an industrial fluid coking spray nozzle

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Francisco Sanchez, Cedric Briens, and Franco Berruti

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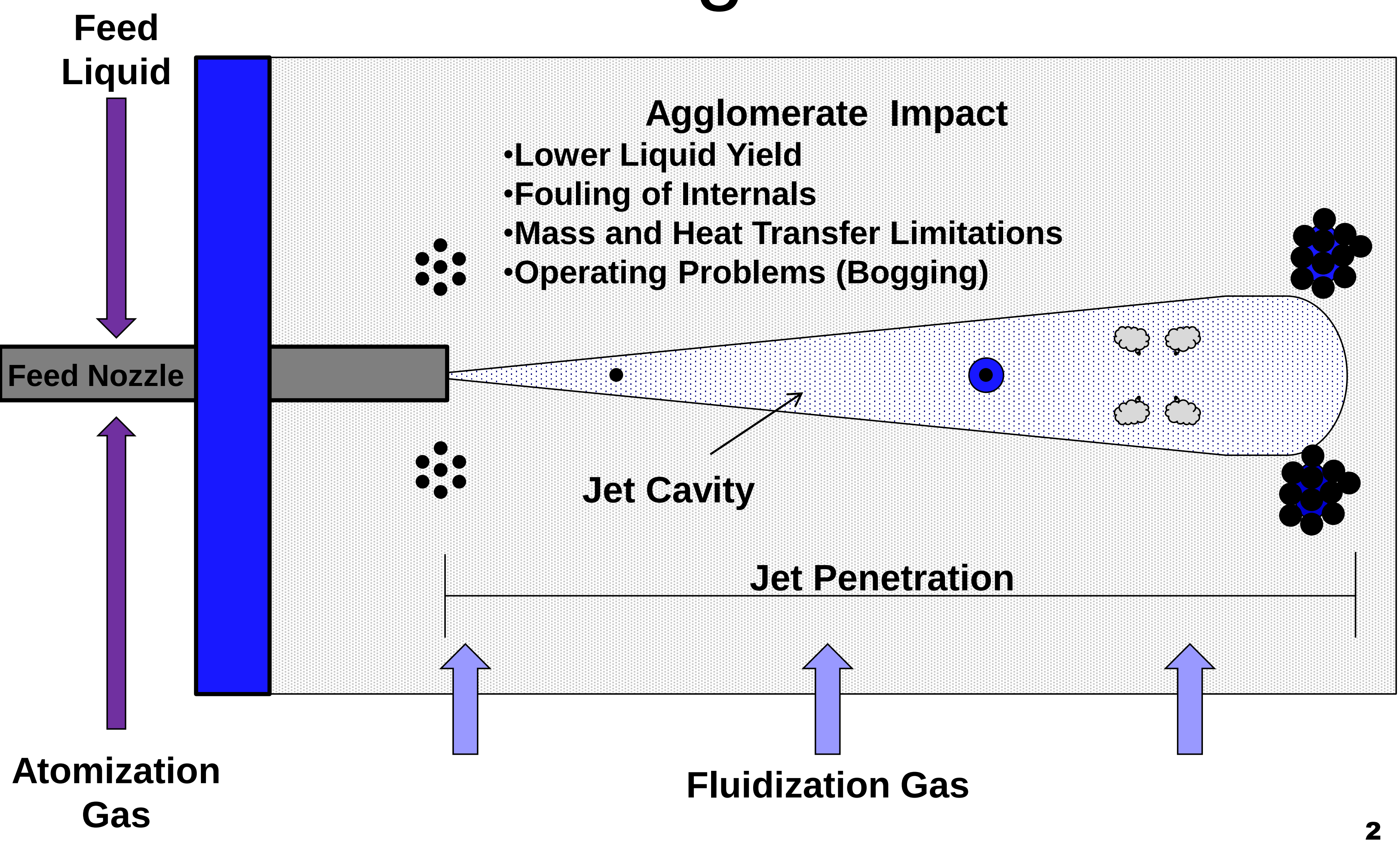
Western University · Canada

Institute for Chemicals and Fuels from Alternative Resources
The University of Western Ontario
icfar

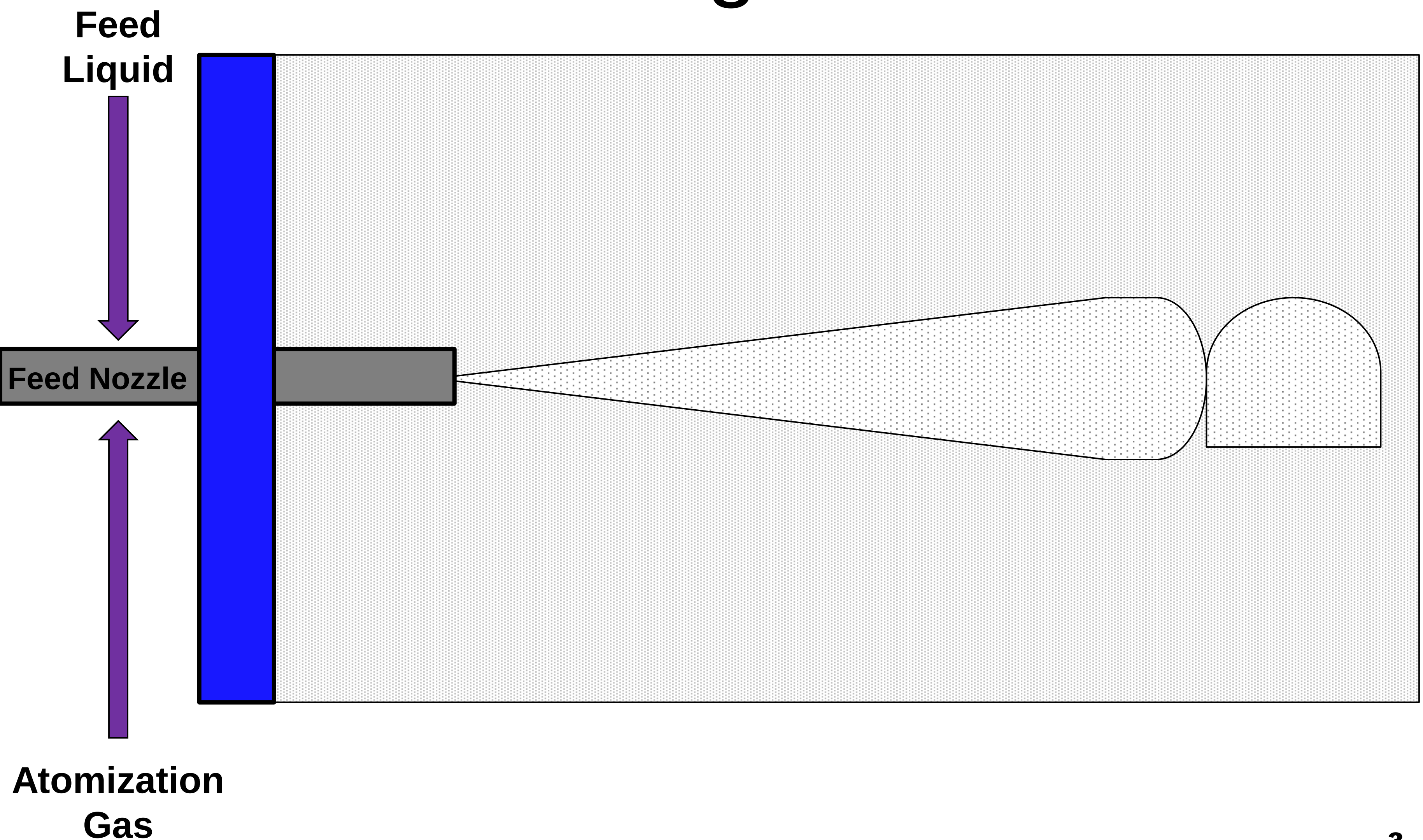
Western Engineering

Background



Feed Liquid
Agglomerate Impact
•Lower Liquid Yield
•Fouling of Internals
•Mass and Heat Transfer Limitations
•Operating Problems (Bogging)
Feed Nozzle
Jet Cavity
Jet Penetration
Atomization Gas
Fluidization Gas

Background



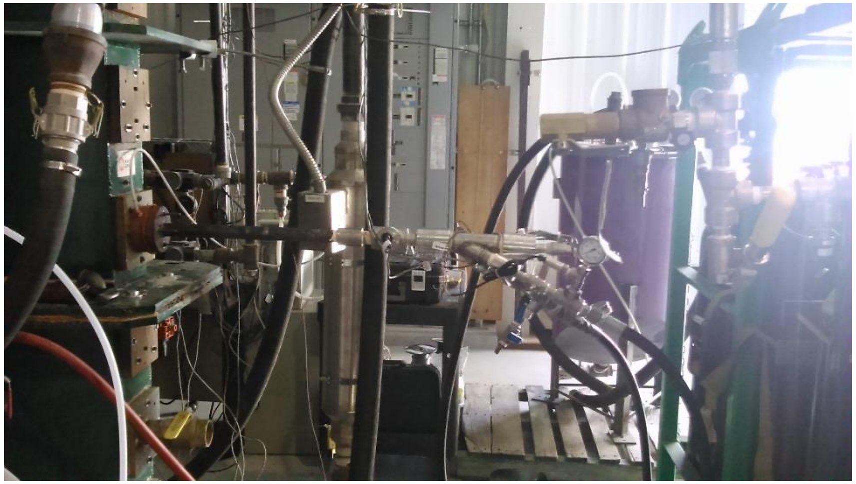
Background

- From Ben Li's work → bed hydrodynamics in region where agglomerates are released is important.
- In Fluid Cokers → large radial and vertical variations in bed hydrodynamics
- Changes in jet penetration can improve the liquid distribution in the fluidized bed:
  - Less agglomerate formation
  - More free moisture

Objectives

- Experimentally measure the Jet penetration of an industrial size spray nozzle.
- Compare it to values predicted from literature model.

Equipment – Pie Shape



Equipment – Industrial Size TEB Nozzles

- Fluidization bed conditions:
  - Injected Water: 18.28 liters.
  - Mass of fluidized sand: 7800 kg.

Conditions	Minimum	Maximum
Atomization Gas (N_2)	3.45 MPa	4.83 MPa
Blow Tank (H_2O)	1.75 MPa	2.07 MPa
Liquid Flow (H_2O)	178 LPM	236 LPM
GLR	1.6 %	3.0 %

Base et al. (1999), Patent Number: 6,003,789

Equipment – Industrial Size TEB Nozzles – Open Air Blast

Jet Penetration Measurement Challenges

- Video cameras: Probes destroyed by bubbles/jet

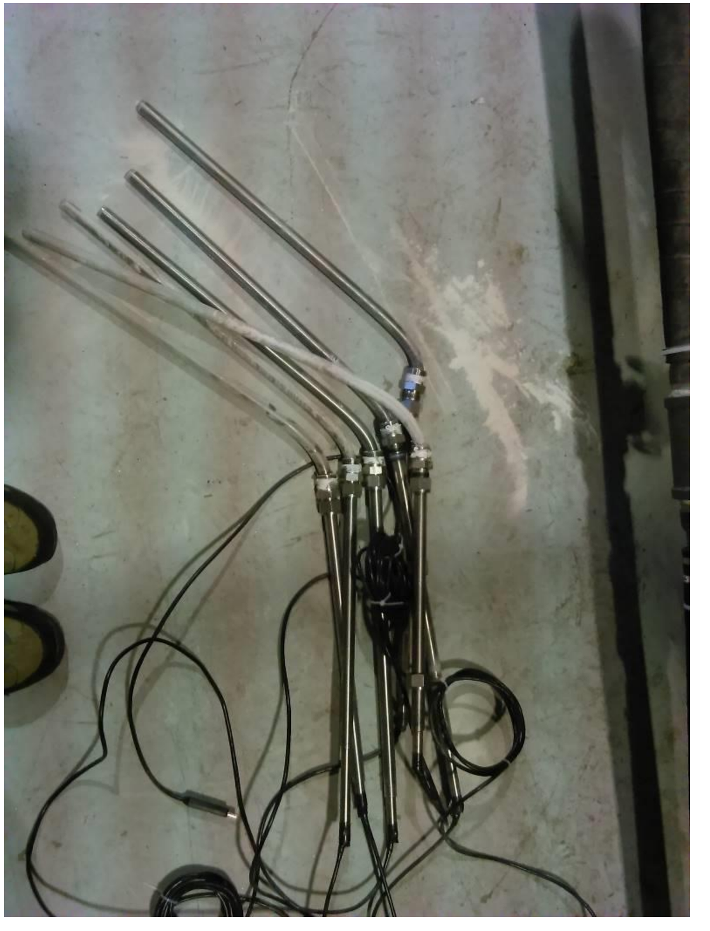
- Thermocouples: Bent by jet and response times are too slow.

- Triboprobes above jet:
  - Thick rods: resisted jet/bubbles
  - But: detected changes in moisture more than voidage

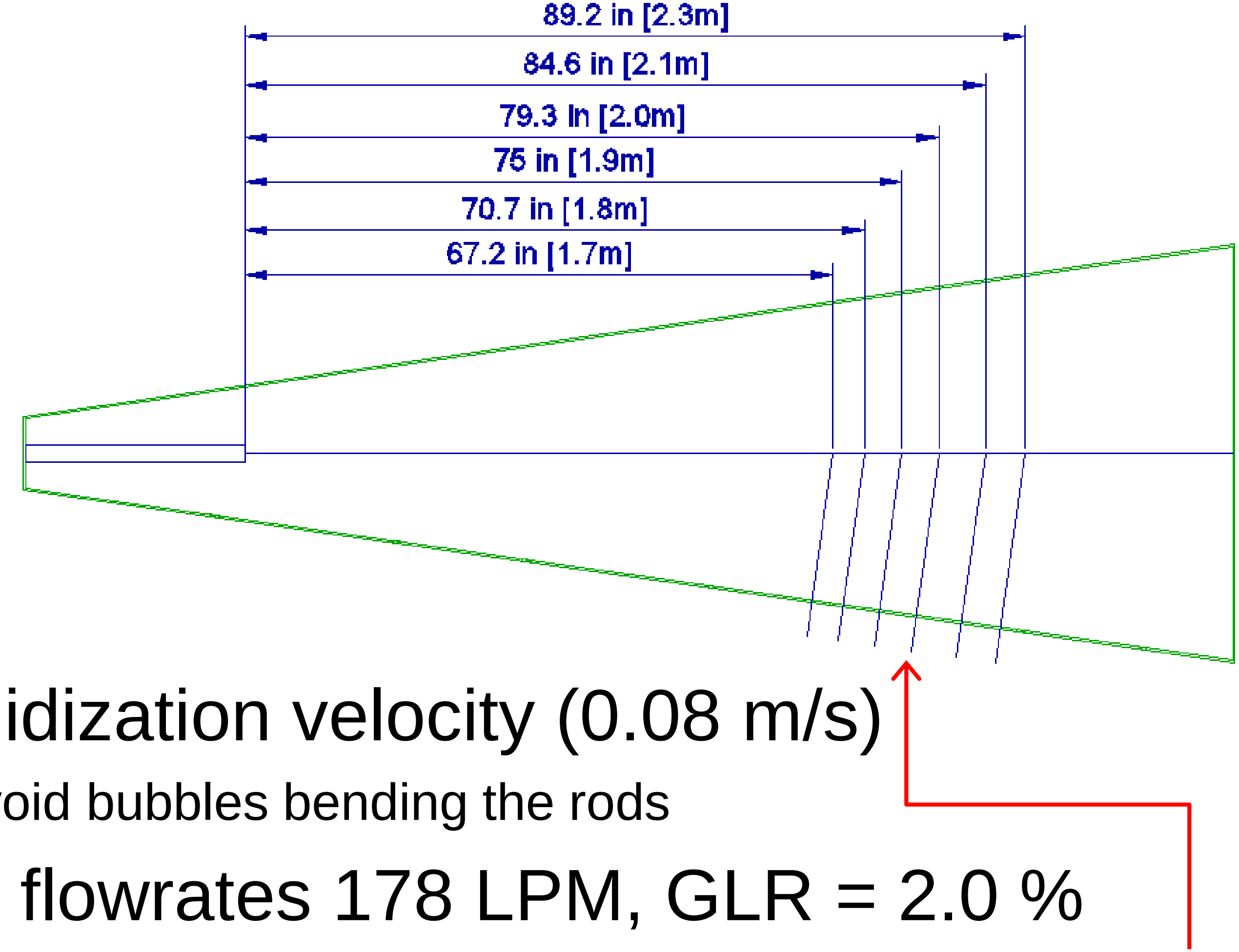
Jet Penetration Measurement Challenges

Issues:

- Probes bent by jet or bubbles (e.g. camera probes in photograph)
- Can we use this in our favor?
- 2 methods:
  1. Bendable tubes in jet path
  2. Vibration of thick, unbendable rods in jet path



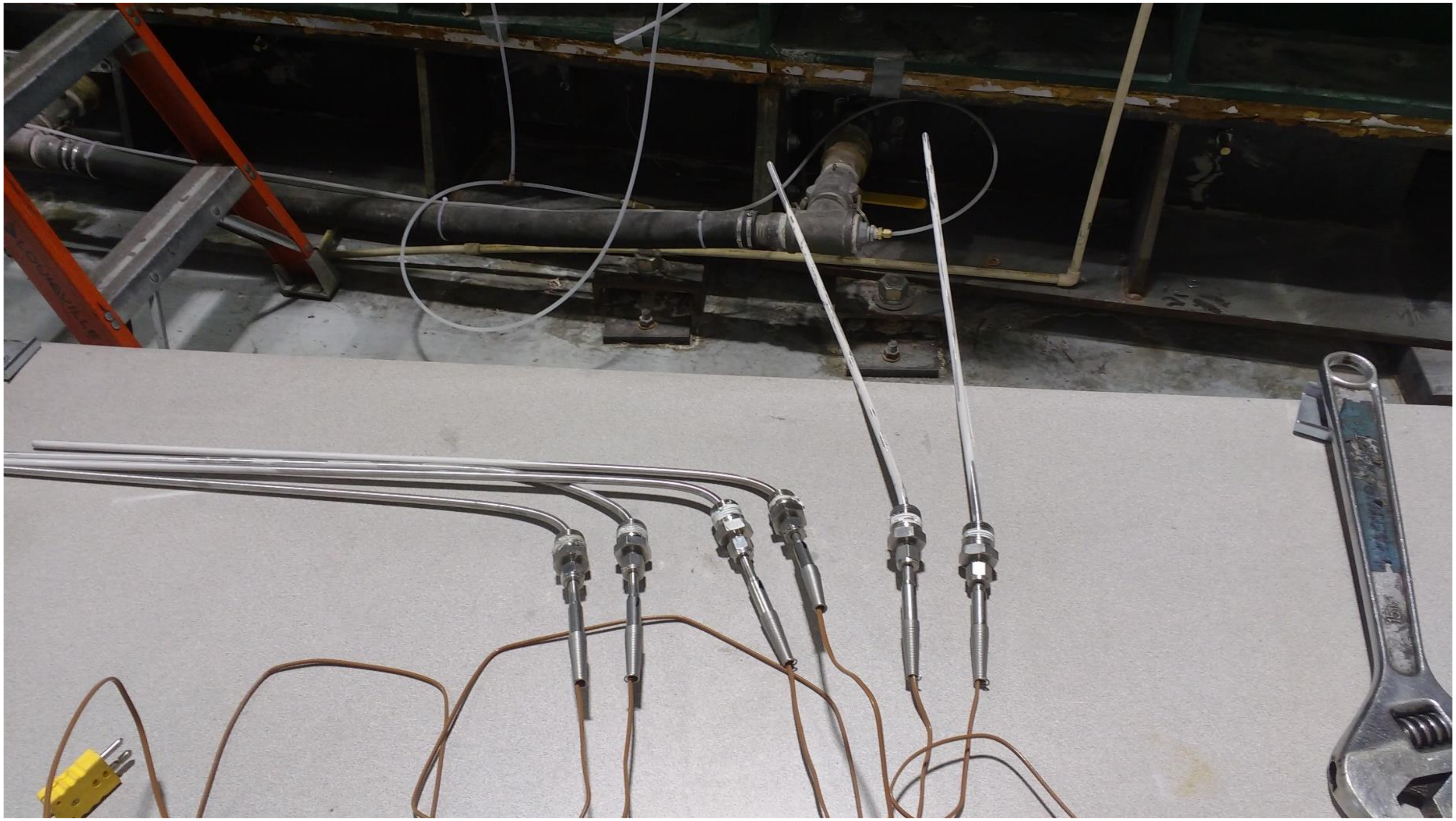
Jet Penetration
Bendable tubes deformation



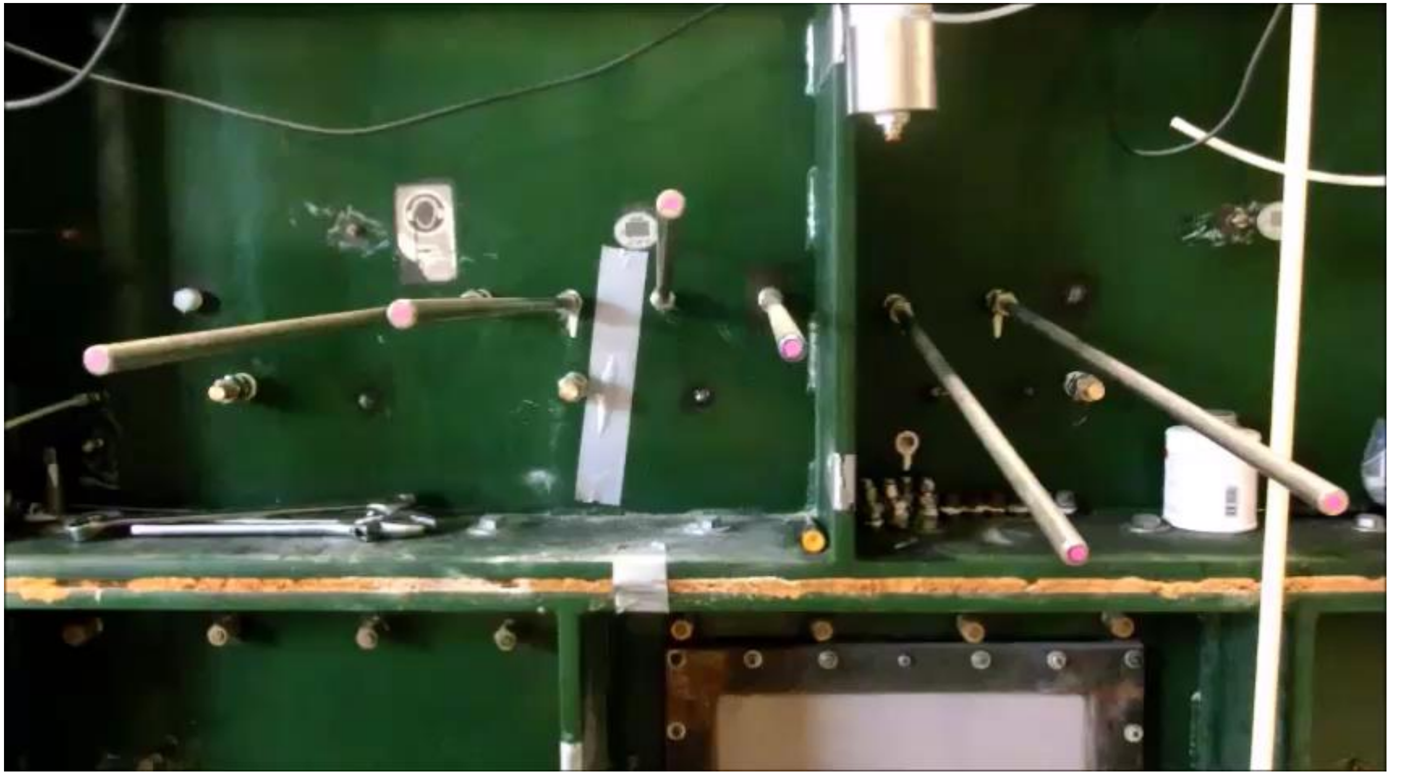
- Bed fluidization velocity (0.08 m/s)
  - Avoid bubbles bending the rods
- Nozzle flowrates 178 LPM, GLR = 2.0 %
- Predicted by Ariyapadi's correlation = 1.99 m

Jet Penetration

Bendable tubes deformation

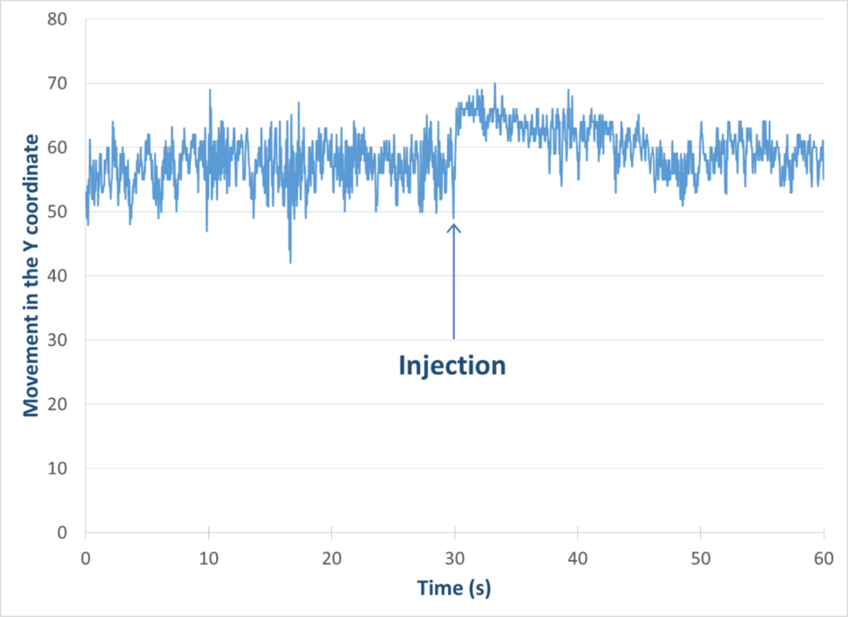


Jet Penetration
Vibrating Rods

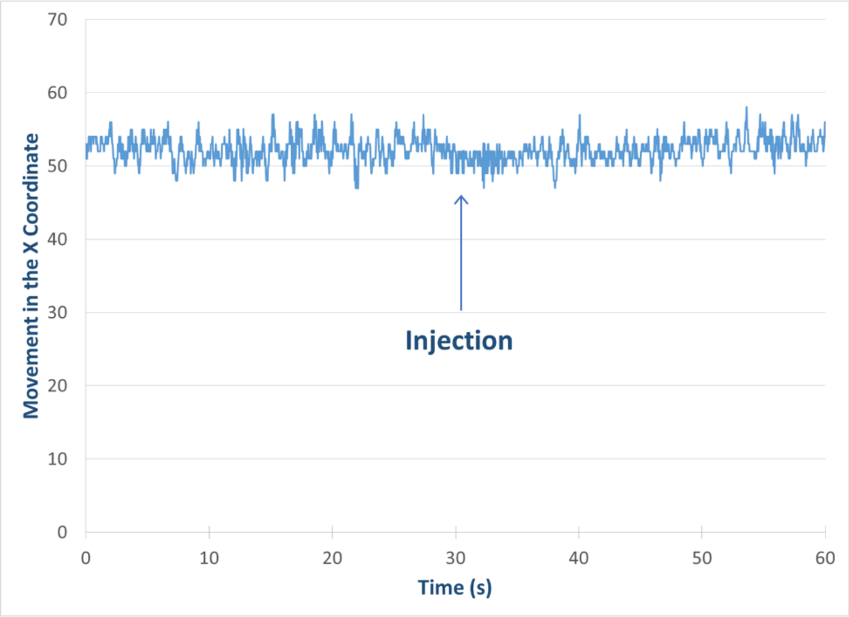


Vibrating Rods
Movement in X and Y Coordinates From Video Analysis

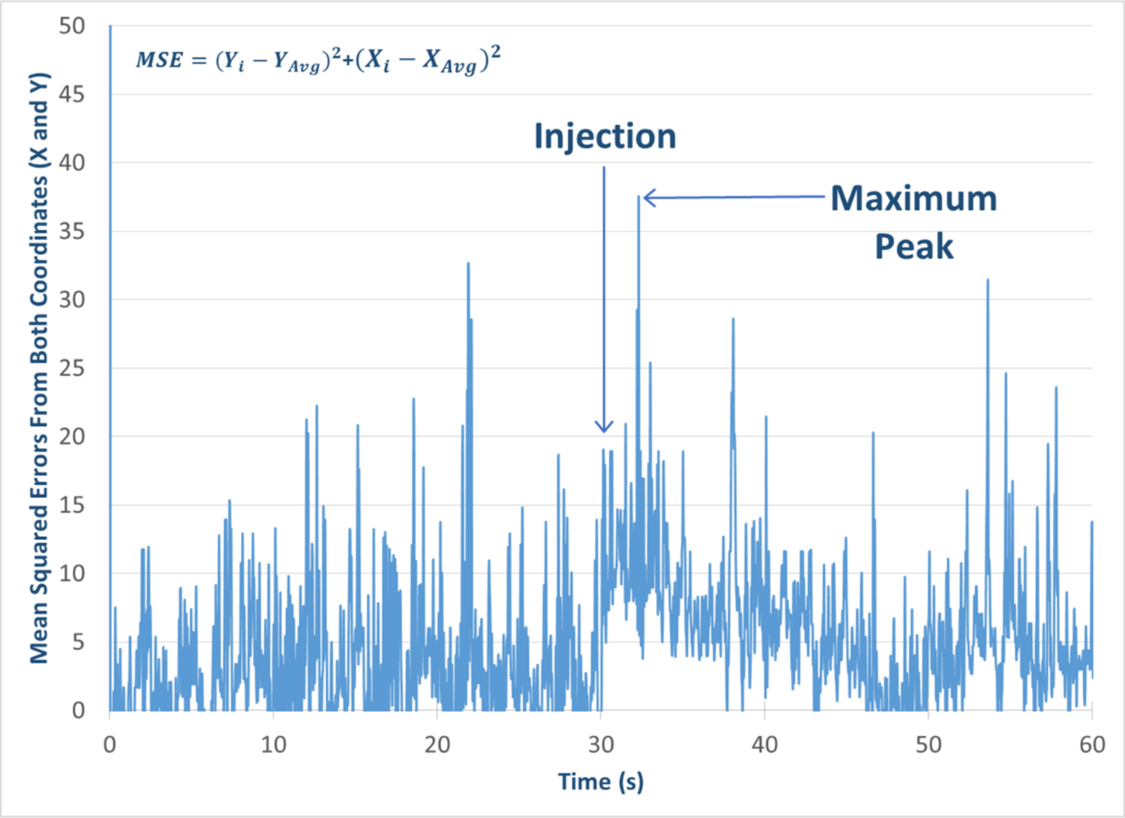
Y Coordinate



X Coordinate



Vibrating Rods
Mean Sum of Errors



Vibrating Rods Results

Description	Run #1	Run #2	Run #3	Run #4	Run #5
LPM	187.08	176.25	197.18	236.17	236.13
GLR	1.8%	3.0%	1.9%	1.6%	1.6%
Atomization Gas (g/s)	63.04	88.95	63.04	62.95	63.11
Jet Penetration from Ariyapadi Correlation (m)	2.03	2.03	2.07	2.21	2.21
Jet Penetration from Rod Vibration Technique (m)	1.98	2.02	2.03	2.02	2.02
Error (m)	**0.05**	**0.01**	**0.04**	**0.19**	**0.19**

Conclusion

- At low liquid flowrates, measured jet penetrations agree with predictions from Ariyapadi's correlation.
- At higher liquid flowrates, measured jet penetrations are 10% lower than predictions from Ariyapadi's correlation.

Acknowledgements

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Securing Canada's Energy Future

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Thank You!

Jet Penetration – Ariyapadi's Correlation

$$L_{Jet} = \frac{5.52}{g^{0.27}} \frac{1}{\left(\rho_p - \rho_g\right)^{0.27}} \left(\frac{G_L^2 (1 + GLR(S))}{\rho_L \left(1 - \epsilon'\right)}\right)^{0.27} d^{0.73} C_g$$

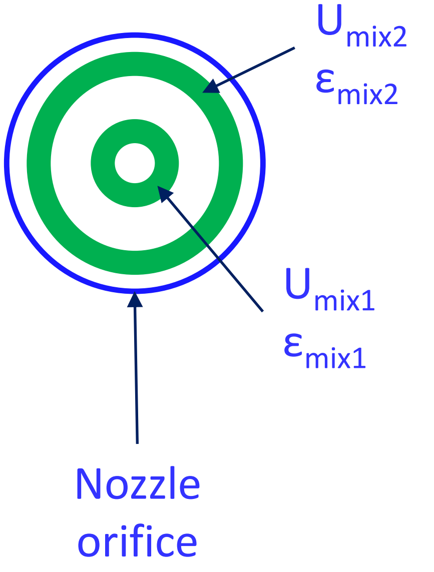
- g = Gravity (m/s^2)
- ρ_p = Density of the particles (kg/m^3)
- ρ_g = Density of the gas (kg/m^3)
- ρ_L = Density of the liquid (kg/m^3)
- GL = Superficial liquid mas velocity ($kg/m^2 \cdot s$)
- GLR = Gas to liquid mass ratio
- S = Mean slip velocity ratio
- ε' = Mean void fraction at slip conditions
- d = Nozzle tip diameter (m)
- C_g = Nozzle geometry parameter

Ariyapadi's model with empirical factor C_g for a scale-down nozzle. (2004)

Jet Penetration – Ariyapadi's Correlation

- Although locally, there is no slip between the gas and liquid phases, there is an apparent slip factor S in the nozzle throat because:
  - There is a radial velocity profile
  - There is a radial distribution of the gas holdup

$$S = \frac{\int_0^1 U_{mix}(\eta)\epsilon(\eta)d\eta}{\int_0^1 U_{mix}(\eta)[1-\epsilon(\eta)]\eta d\eta}\frac{1-\epsilon'}{\epsilon'}$$



Jet Penetration – Ariyapadi's Correlation

$$S = \frac{\int_0^1 U_{mix}(\eta)\epsilon(\eta)d\eta}{\int_0^1 U_{mix}(\eta)[1-\epsilon(\eta)]\eta d\eta}\frac{1-\epsilon'}{\epsilon'}$$

- U_{mix} and ε' refers to the local gas-liquid mixture at sonic velocity and the local void fraction.
- η=Radial coordinate.
- 1st step: Assume a mean voidage ε'.
- 2nd step: Calculate a radial coordinate $\eta = \frac{1.015}{1.015-\epsilon'}$
- 3rd step: Calculate $U_{mix}(\eta) = \sqrt{\frac{\gamma RT}{m_w}}\left(\frac{\rho_g}{\epsilon(\eta)(\rho_g\epsilon(\eta)+\rho_l\epsilon(\eta))}\right)^{0.5}$
- 4th step: Obtain the mean slip velocity
- 5th step: Obtain a new mean voidage $\varepsilon = \frac{1}{\left(\frac{\rho_g}{\rho_l}(GLR)S+1\right)}$