Hydrodynamic Analysis of Fuel Motion in a Binary Bubbling Fluidized Bed using Markov Chains Method

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Outline

Introduction

- A brief overview of the Theoretical Foundations and Description of The Problem

Methods

- A brief overview of methods used

Results

- The Results of the modeling and the discussion on them

Conclusion

- Summarized Results

Highlights

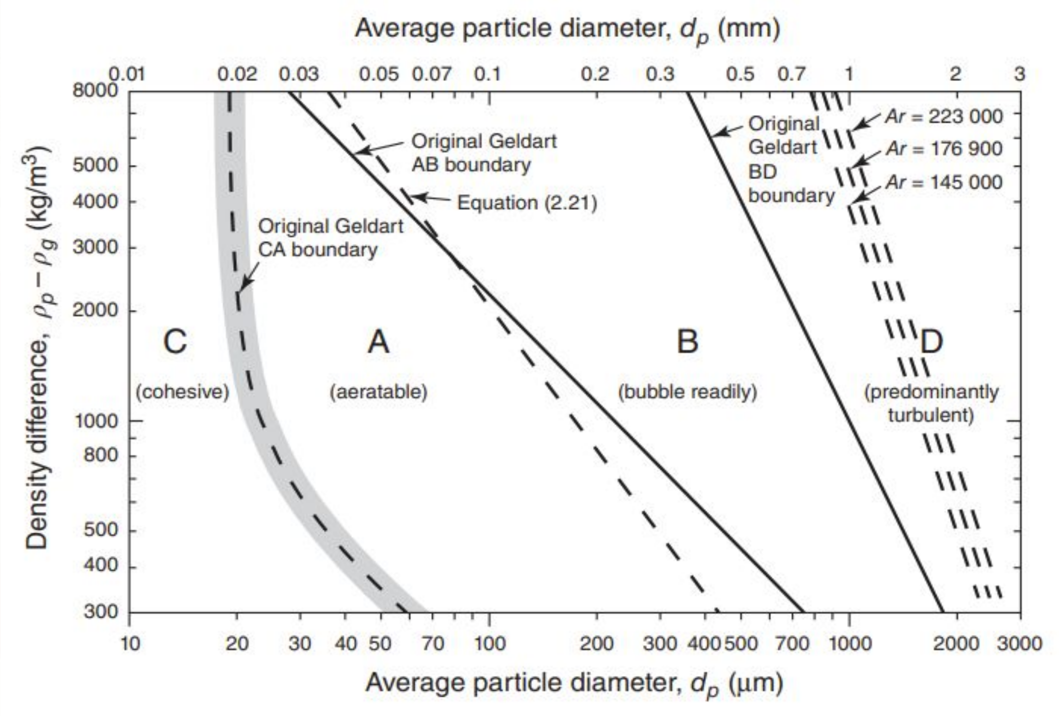
- This Research centers on the analysis of large solid particle behavior within binary fluidized systems
- Markov Chains Method as a statistical methodology was employed to capture this phenomena
- Parameters from the Markov Chain model were computed in a semi-experimental approach using both the literature and experiments
- 3 Particular Markov Chains were modeled and compared using statistical distance
- The Concept of Restricted and Unrestricted Movements was used and validated

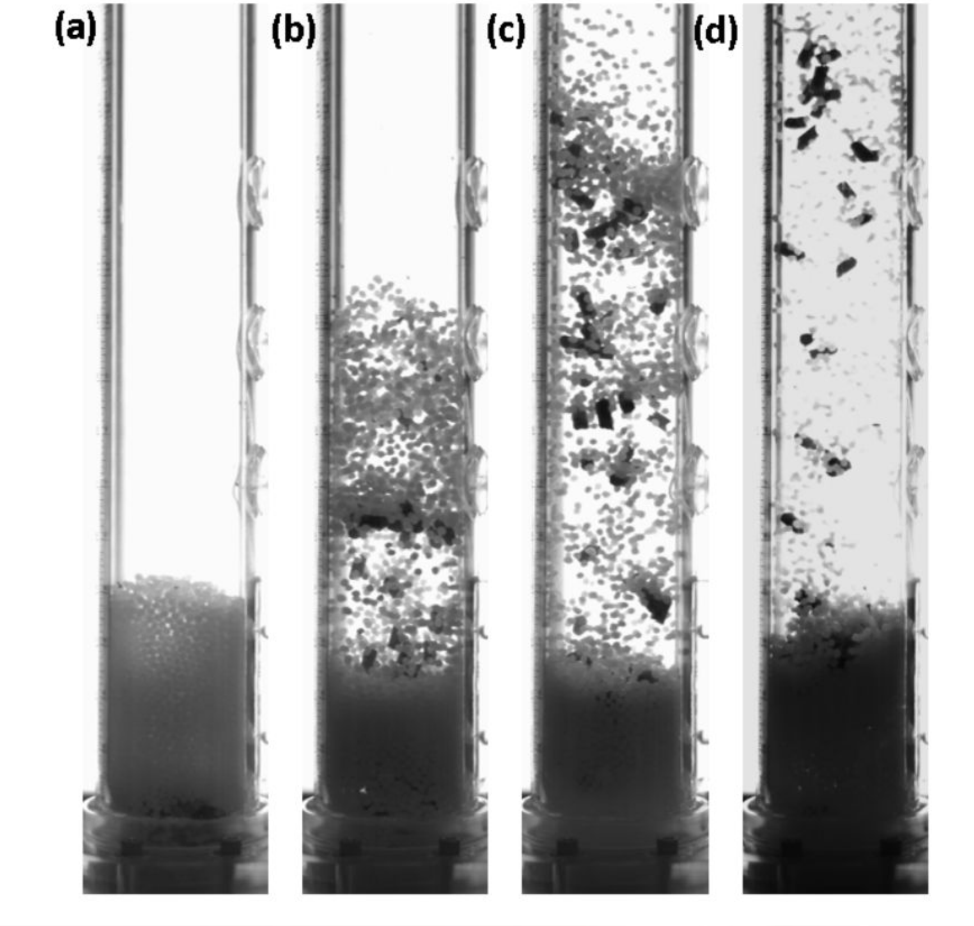
1. **Introduction**

- Fluidized Beds in Industry
- Using Fluidized Beds for Solid Fuel Conversion
- Binary Fluidized Beds and complexities added to the system

1. Introduction

- Binary Fluidization Systems For Biofuel particles
- Why Binary Fluidization





2. **Methods**

- Data at hand

Table 1
Properties of the bed materials.

Material	Particle size range (μm)	$d_{p,m}$ (μm)	ρ_P (kg/m^3)	ρ_b (kg/m^3)	Voidage (–) (fixed bed)	U_{mf} (m/s)	Geldart classification
Coarse sand	400–2000	770	2650	1350	0.49	0.44	B–D
Fine sand	50–700	220	2650	1406	0.47	0.05	B
FCC	30–300	80	1690	928	0.45	0.004	A

- Radioactive Particle Tracking (RPT)
- In each experiment, the location of the tracer is tracked every 10 ms for about 4 h until around one and half million points are finally acquired.
- The excess superficial gas velocities, i.e. ($U_e = U - U_{mf}$), chosen for the tests are U_e = 0.25 m/s and U_e = 0.50 m/s.

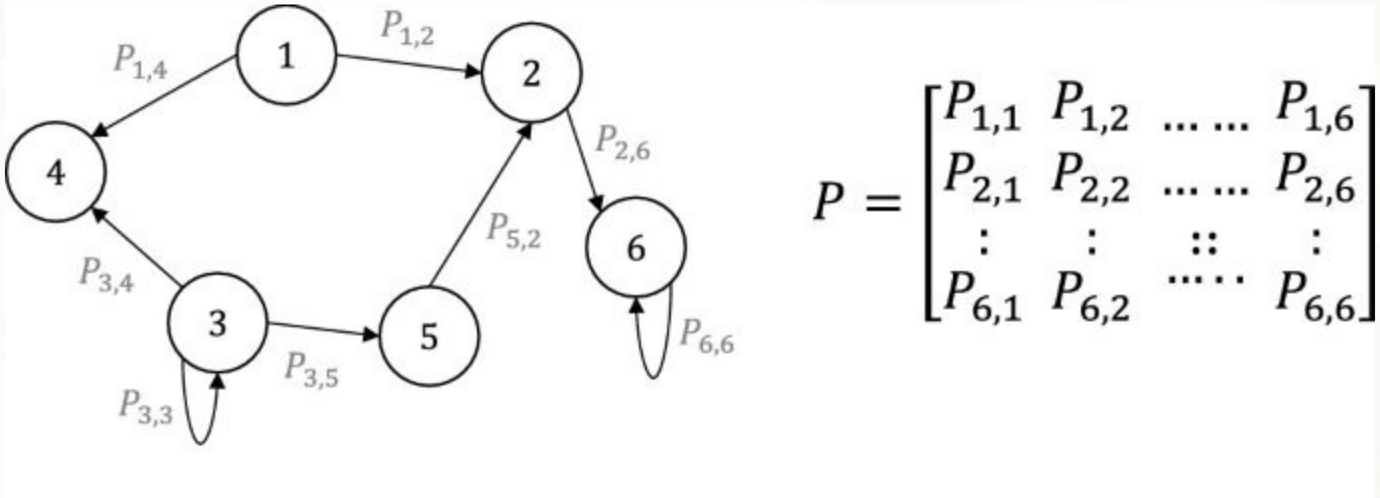
Table 2
Properties of the spherical objects.

Designation	Material	d_o (mm)	ρ_o (kg/m^3)
HDPE	HDPE	9.5	929
PTFE	PTFE	9.5	2166
Acetal-S	Acetal	4.8	1381
Acetal-M	Acetal	9.5	1368
Acetal-L	Acetal	19.0	1347

2. **Methods**

- Markov Chains Method

$$S_{i+1} = P(S_i)S_i$$



(A) Graphical (B) Matrix

2. **Methods**

- Markov Chains Method – Single Phase

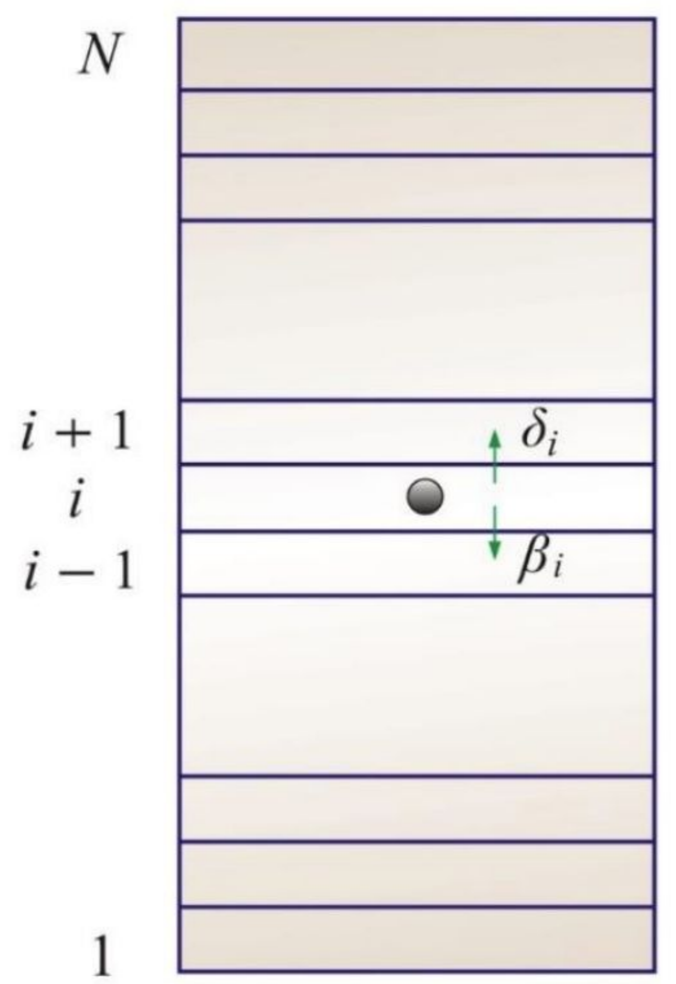
$$S = \{1,2,\cdots,N\}$$

$$p_{i.i} = \alpha_i = (1 - \beta_i - \delta_i)$$

$$p_{i.i-1} = \beta_i$$

$$p_{i.i+1} = \delta_i$$

$$p(n.j) = \sum_{i=1}^{N} p(n-1.i)p_{ij}$$



- Markov Chains Method – Lumped

2. **Methods**

- Markov Chains Method – Two Phase

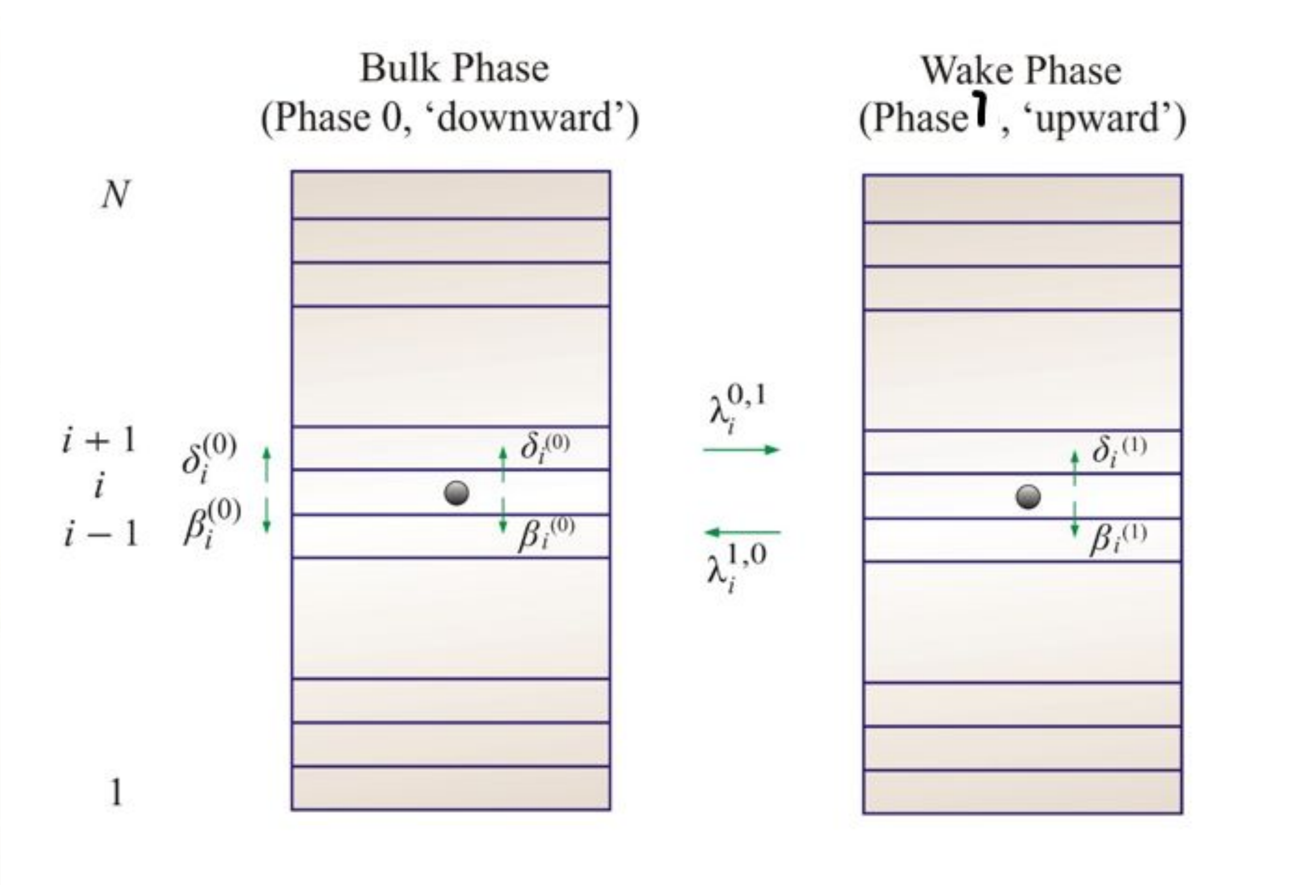
$$S = \{1,2,\cdots,N\} \times \{0,1\}$$

$$p_{(i.k)(i+1.k)} = \delta_i(1 - \lambda_i^{k.l}).$$

$$p_{(i.k)(i-1.k)} = \beta_i(1 - \lambda_i^{k.l}).$$

$$p_{(i.k)(i.k)} = \alpha_i\left(1 - \lambda_i^{k.l}\right) = (1 - \beta_i - \delta_i)(1 - \lambda_i^{k.l}).$$

$$p_{(i.k)(i.|k-1|)} = \lambda_i^{(k)}$$



2. **Methods**

- Markov Chains Method – Three Phase

$$S = \{1,2,\cdots,N\} \times \{0,1,2\}$$

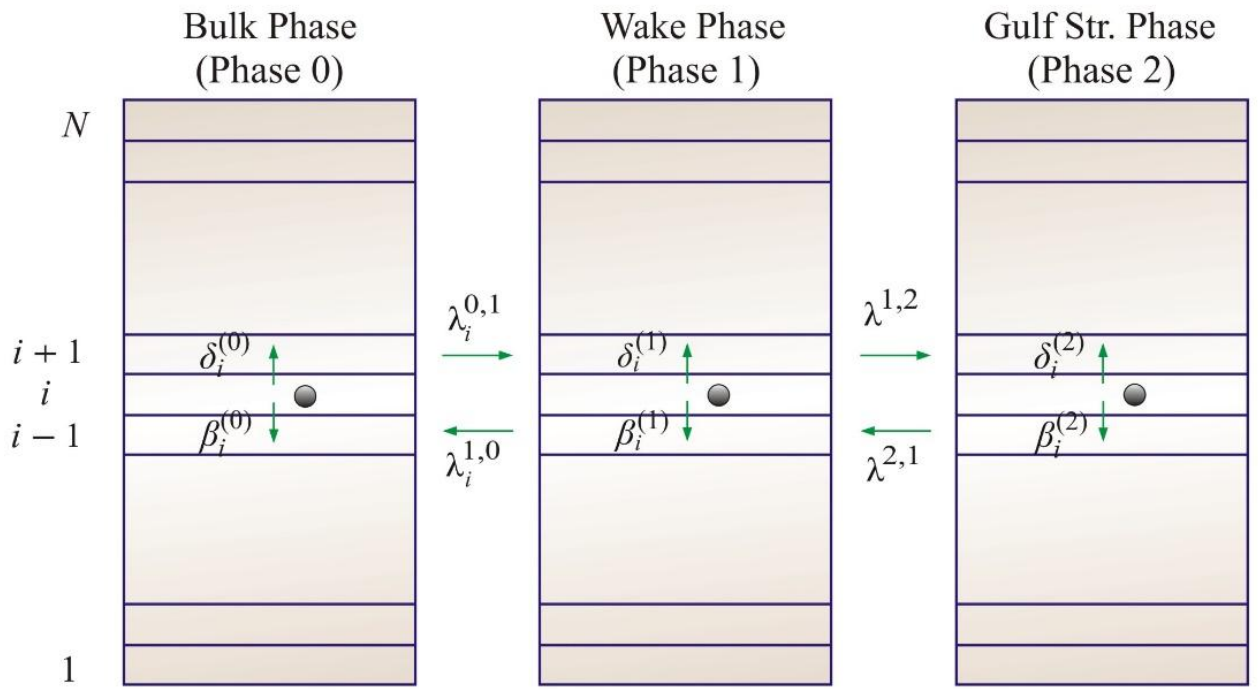
$$p_{(i.k)(i-1.k)} = \beta_i^{(k)}(1-\lambda_i^{k.l}-\lambda_i^{k.m}).$$

$$p_{(i.k)(i+1.k)} = \delta_i^{(k)}(1-\lambda_i^{k.l}-\lambda_i^{k.m}).$$

$$p_{(i.k)(i.l)} = \lambda_i^{k.l}.$$

$$p_{(i.k)(i.m)} = \lambda_i^{k.m}.$$

$$p_{(i.k)(i.k)} = \alpha_i^{(k)}(1-\lambda_i^{k.l}-\lambda_i^{k.m}) = (1-\beta_i^{(k)}-\delta_i^{(k)})(1-\lambda_i^{k.l}-\lambda_i^{k.m})$$



2. **Methods**

- Process of Modeling

2. **Methods**

- How to relate parameters to physical phenomena

$$v\frac{\Delta}{\varepsilon} = \tilde{v}\ \left[\frac{m}{s}\right].$$

$$\left(\Delta \times \beta_i^{(k)} - \Delta \times \delta_i^{(k)}\right)\frac{1}{\varepsilon} = (\beta_i^{(k)} - \delta_i^{(k)})\frac{\Delta}{\varepsilon}$$

$$v_i = \beta_i^{(k)} - \delta_i^{(k)}$$

$$\mathrm{D}\frac{\Delta^2}{\varepsilon} = \widetilde{D}\ \left[\frac{m^2}{s}\right].$$

$$\left(\Delta^2 \times \beta_i^{(k)} + \Delta^2 \times \delta_i^{(k)}\right)\frac{1}{\varepsilon} = (\beta_i^{(k)} + \delta_i^{(k)})\frac{\Delta^2}{\varepsilon}$$

$$2D_i = \beta_i^{(k)} + \delta_i^{(k)}$$

2. Methods

Computing Procedure for β

$$u_{s.down} = \frac{f_w \delta u_b}{(1-\delta - f_w \delta)}$$

Computing Procedure for δ

$$\rho_o V_o \frac{dU_o}{dt} = (\rho_f - \rho_o) g V_o + \frac{1}{2} C_D A_o \rho_f (U_f - U_o)^2$$

$$C_D = \frac{24}{\mathrm{Re_o}}\left(1 + \frac{Re_o^{2/3}}{6}\right) g(\varepsilon) \qquad Re < 1000$$

$$C_D = 0.44(\varepsilon) \qquad Re \geq 1000$$

$$Re_o = \frac{\rho_f |U_f - U_o| d_o}{\mu_f}$$

$$g(\varepsilon) = \varepsilon^{-\beta}$$

$$\beta = 3.7 - 0.65 exp^{\left[-\frac{(1.5 - \log Re_o)^2}{2}\right]}$$

$$\overline{U_o} = \frac{1}{\tau_r} \int_0^{\tau_r} U_o \, dt$$

$$u_b = 0.71\sqrt{g D_e}$$

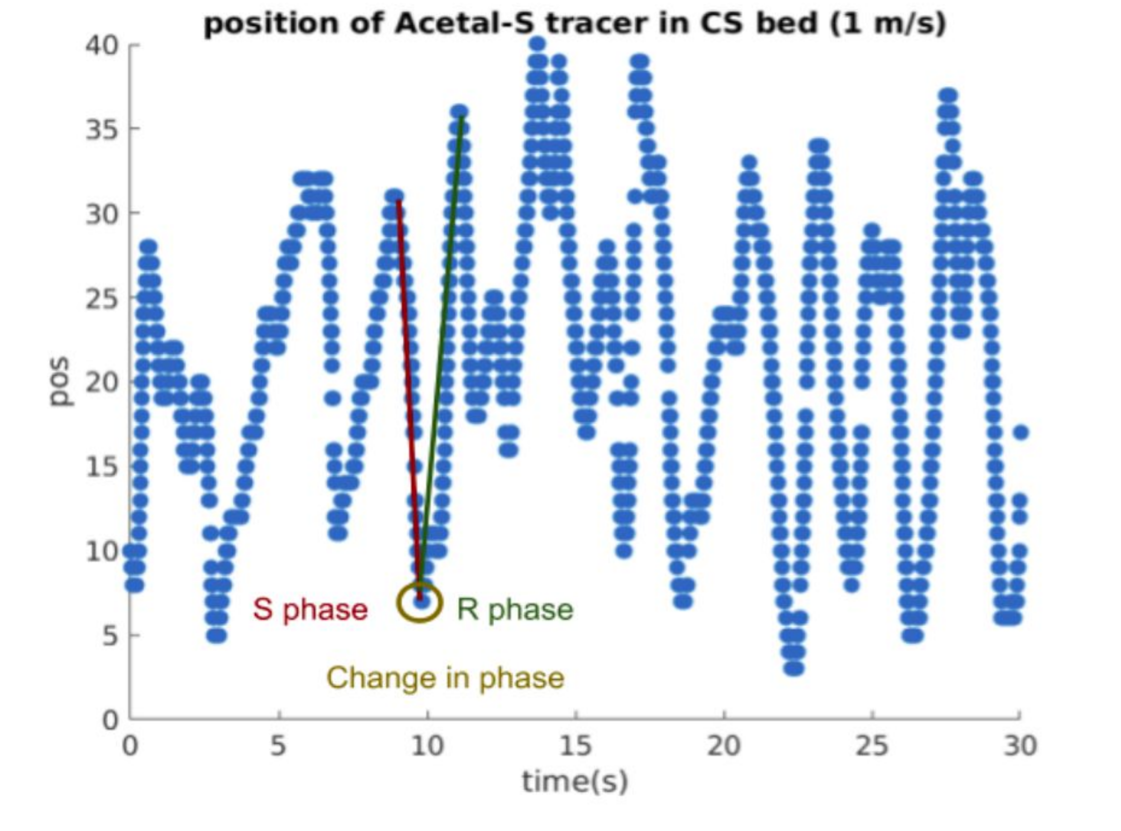
$$D_e = 0.54(u - u_{mf})^{0.4} \left(z + 4\sqrt{A_0}\right)^{0.8} g^{-0.2}$$

2. **Methods**

Computing λ from Experimental Data

- In 2-Phase Model
  - Ratio of changing path

- In 3-Phase Model
  - How to divide the phases



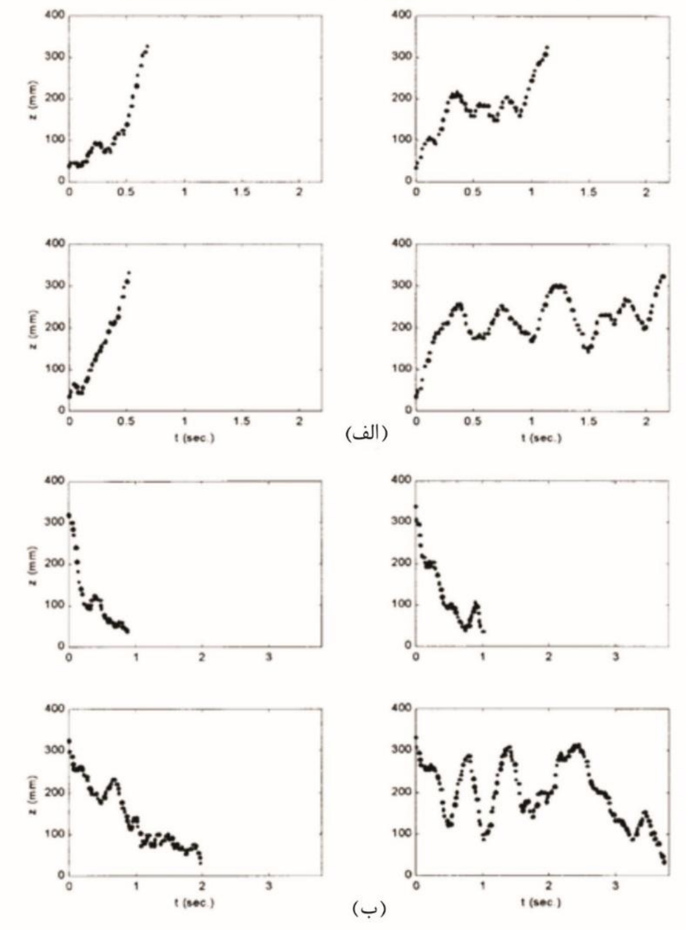
2. **Methods**

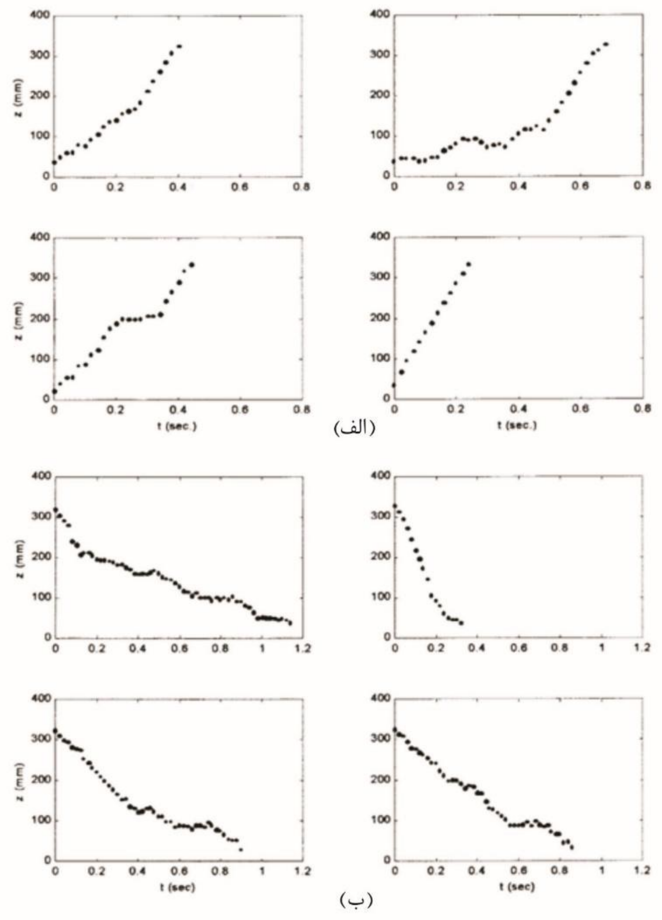
Restricted & Unrestricted Movements

- Definition
- Usage
- Variances of RTD for Dispersion & Convection Mechanisms

$$\sigma_t^2 = \left(\frac{2D_{sz}}{V_s^3}\right)L$$

$$\sigma_t^2 = \left(\frac{\sigma_\theta}{V_s}\right)^2 L^2$$





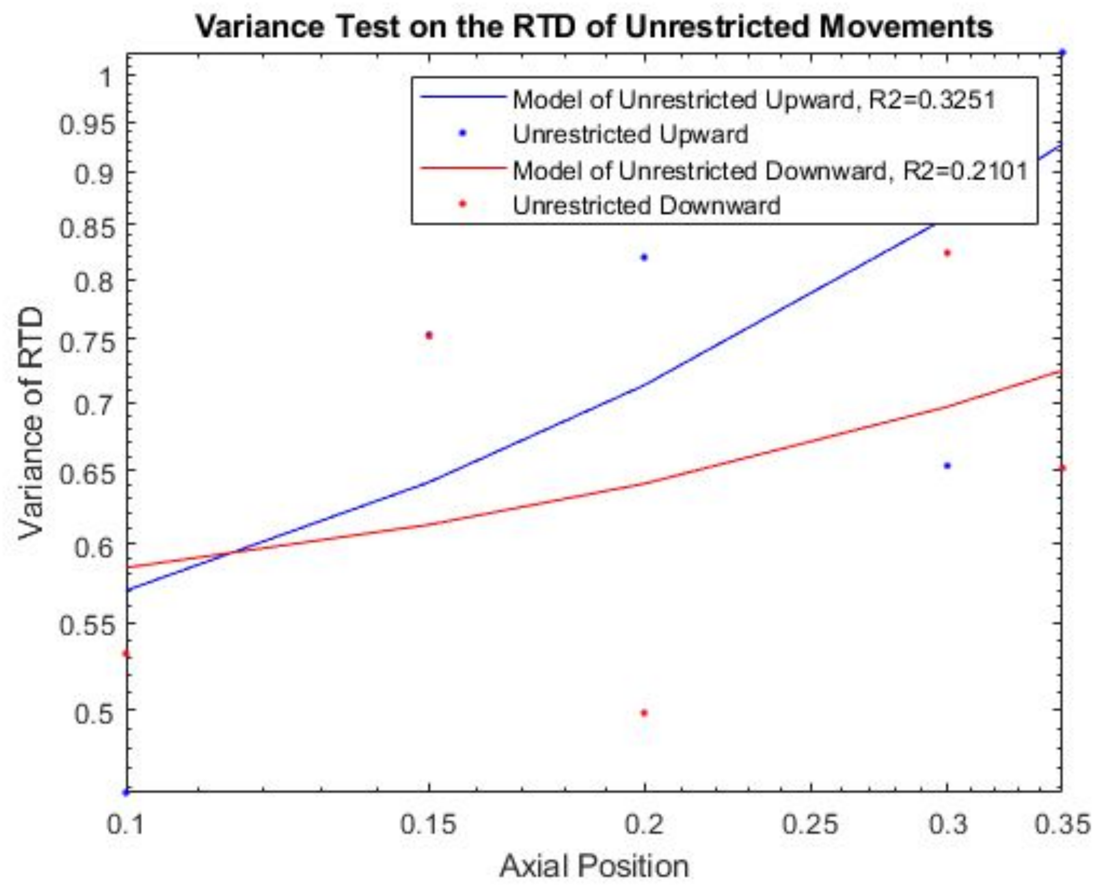
3. Results

Validity of Mechanisms using Restricted & Unrestricted Movements

- How to compute them
- What do they represent

$$\sigma_t^2 = (\frac{2D_{sz}}{V_s^3})L$$

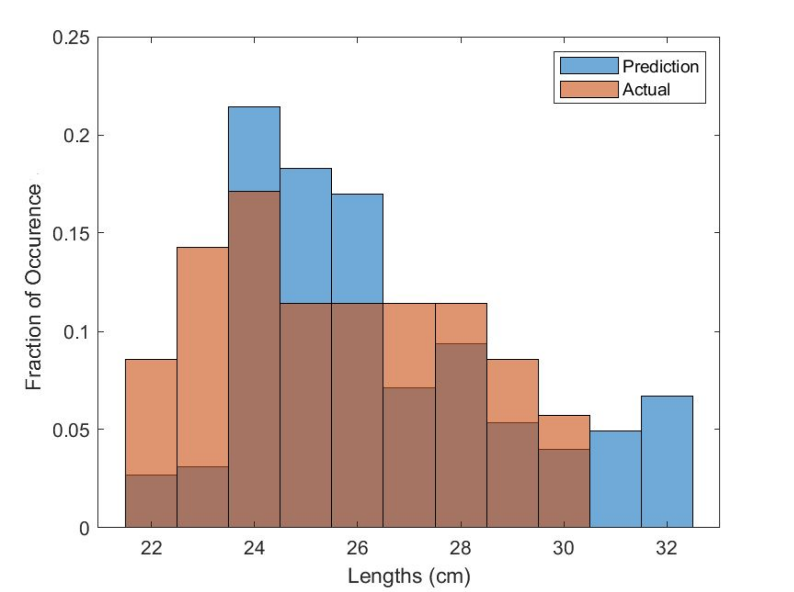
$$\sigma_t^2 = \left(\frac{\sigma_\theta}{V_s}\right)^2 L^2$$



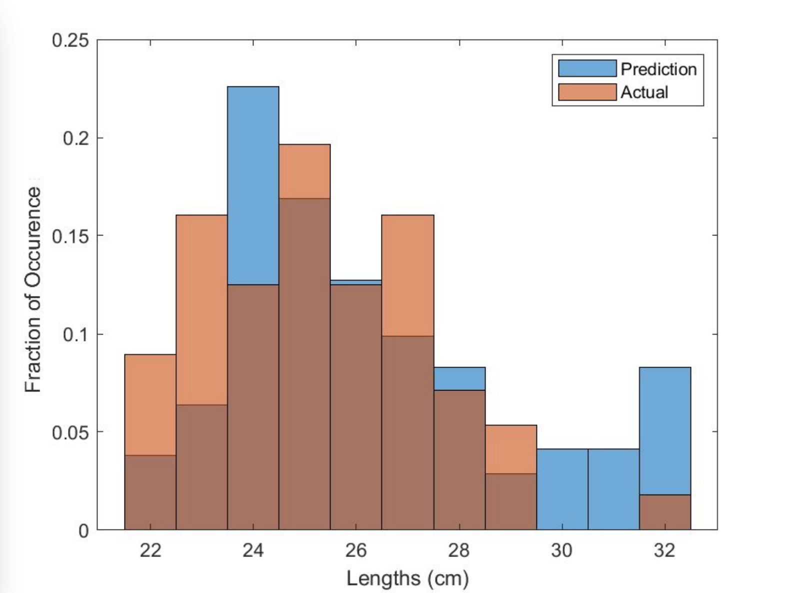
3. Results

Results for Acetal-S, $U_e = 0.25\ m/s$

Lumped Markov Chains Results



Histogram of Unrestricted Upward Movements



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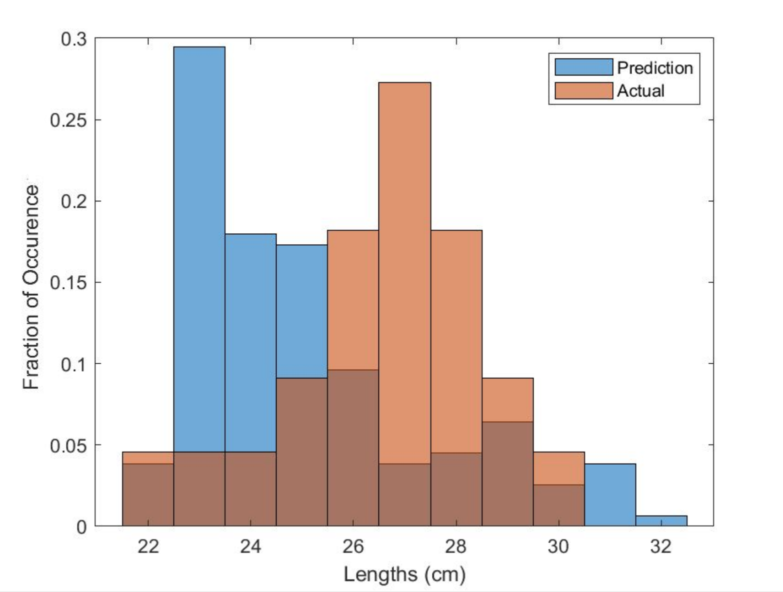
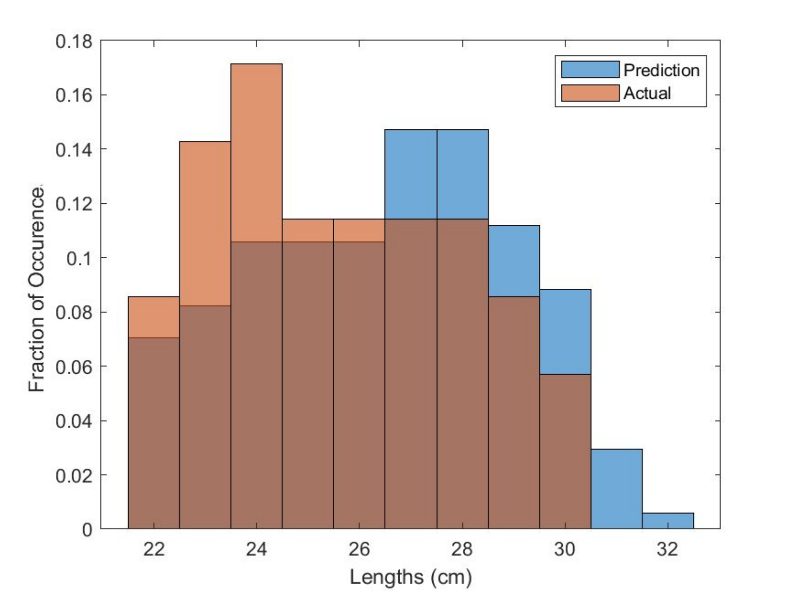


Histogram of Restricted Downward Movements

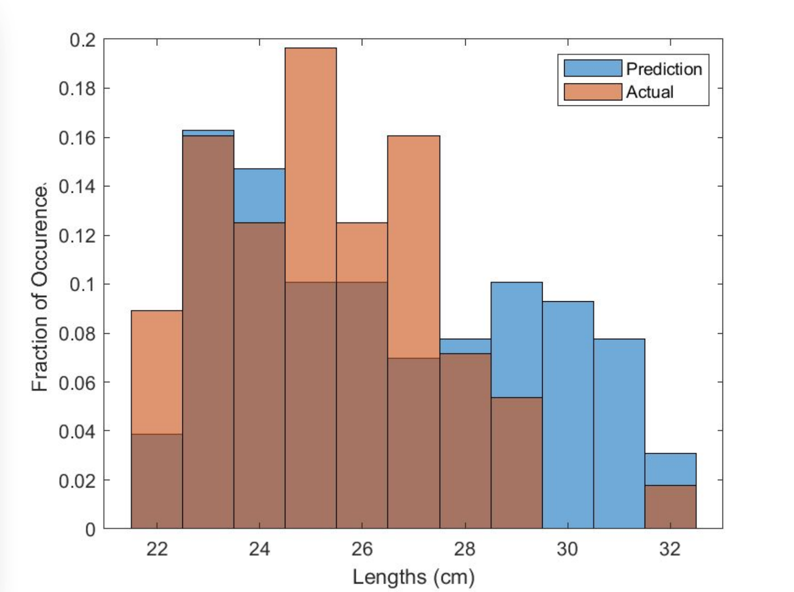
3. **Results**

Results for Acetal-S, $U_e = 0.25\ m/s$

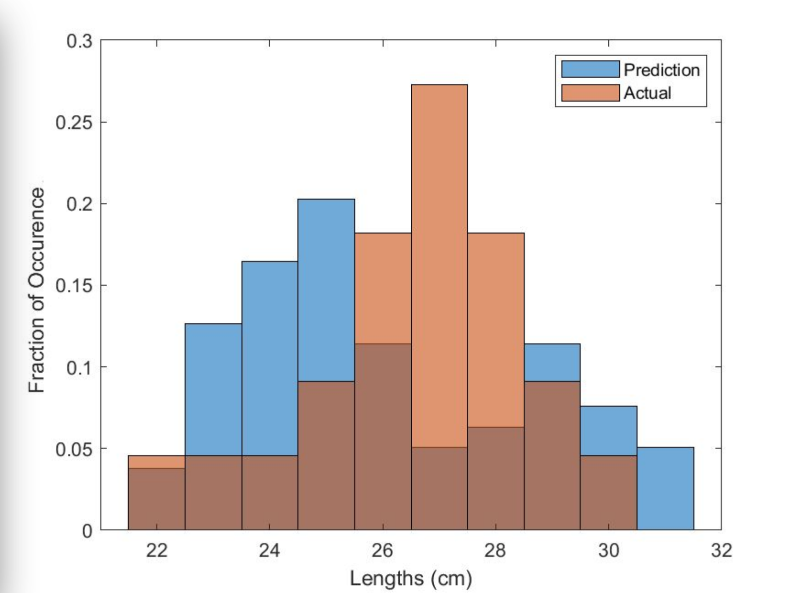
2-Phase Markov Chains Results



Histogram of Unrestricted Upward Movements



Histogram of Restricted Upward Movements

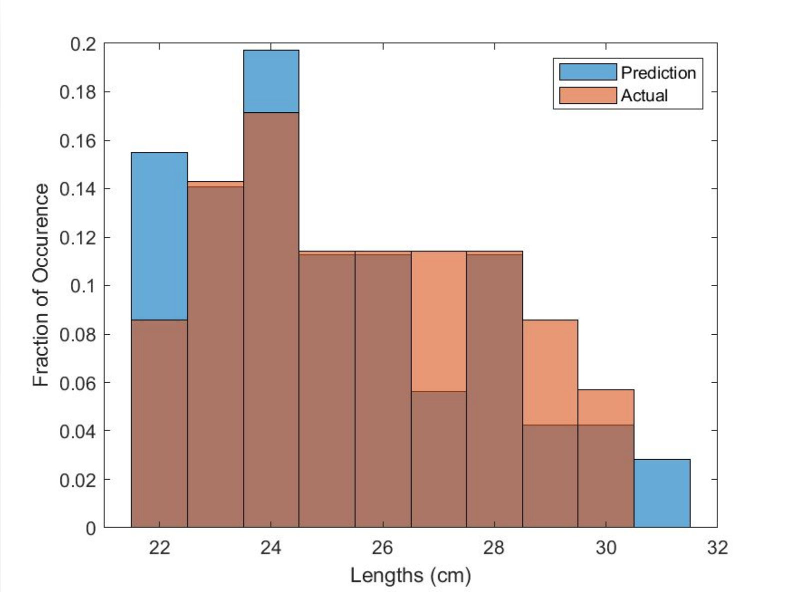


Histogram of Restricted Downward Movements

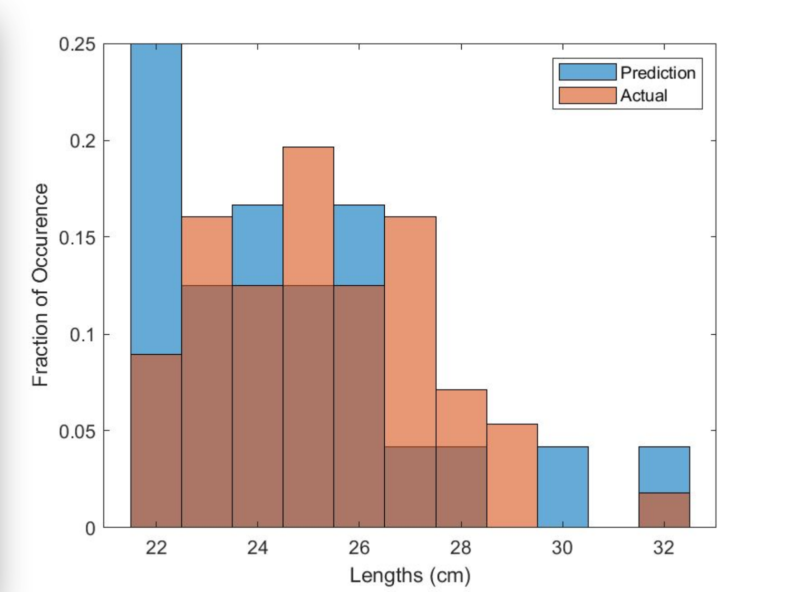
3. Results

Results for Acetal-S, $U_e = 0.25\ m/s$

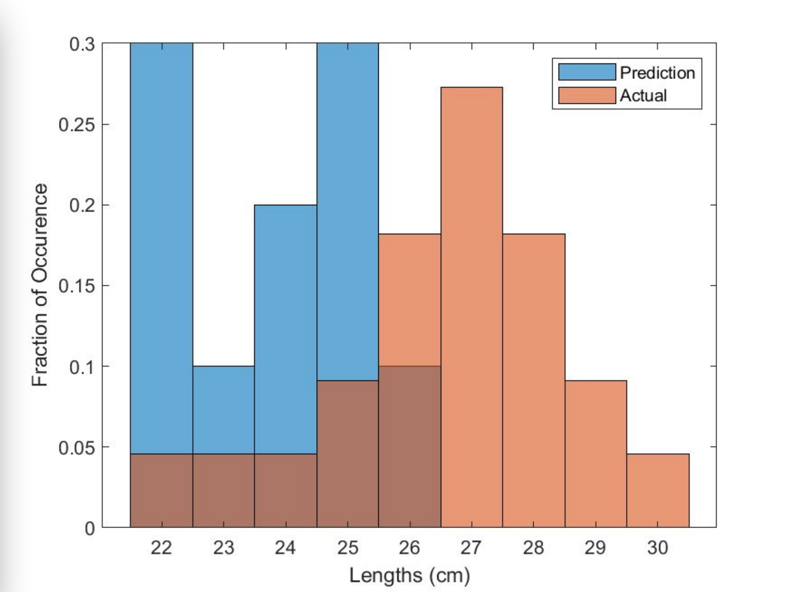
3-Phase Markov Chains Results



Histogram of Unrestricted Upward Movements



Histogram of Restricted Upward Movements



Histogram of Restricted Downward Movements

3. Results

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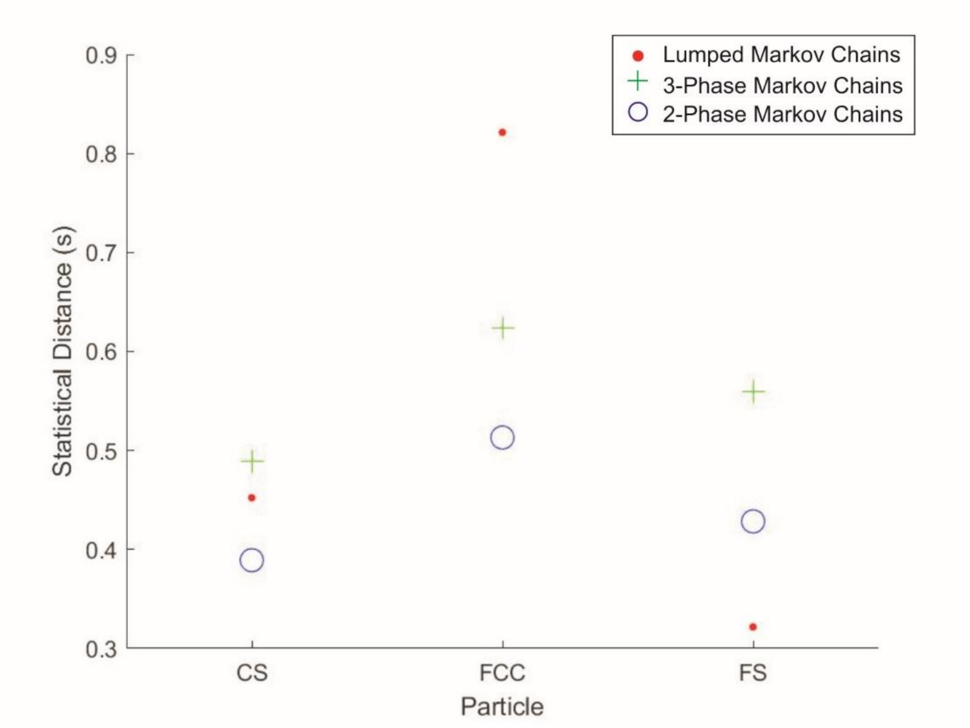
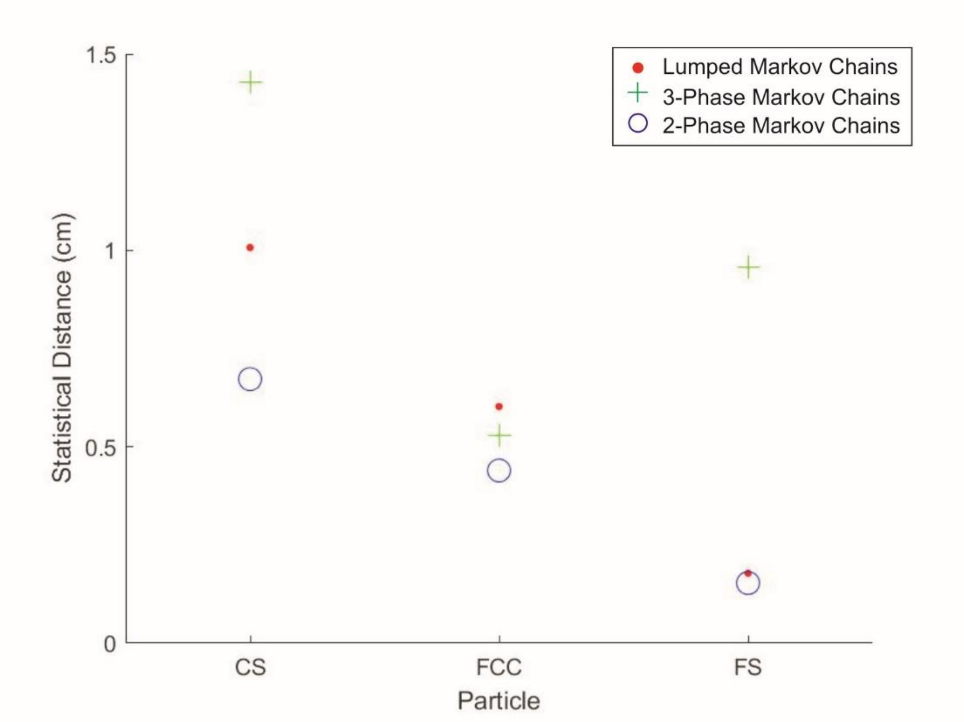
Comparing Results for Downward Restricted Movements



Time of Movements



Length of Movements

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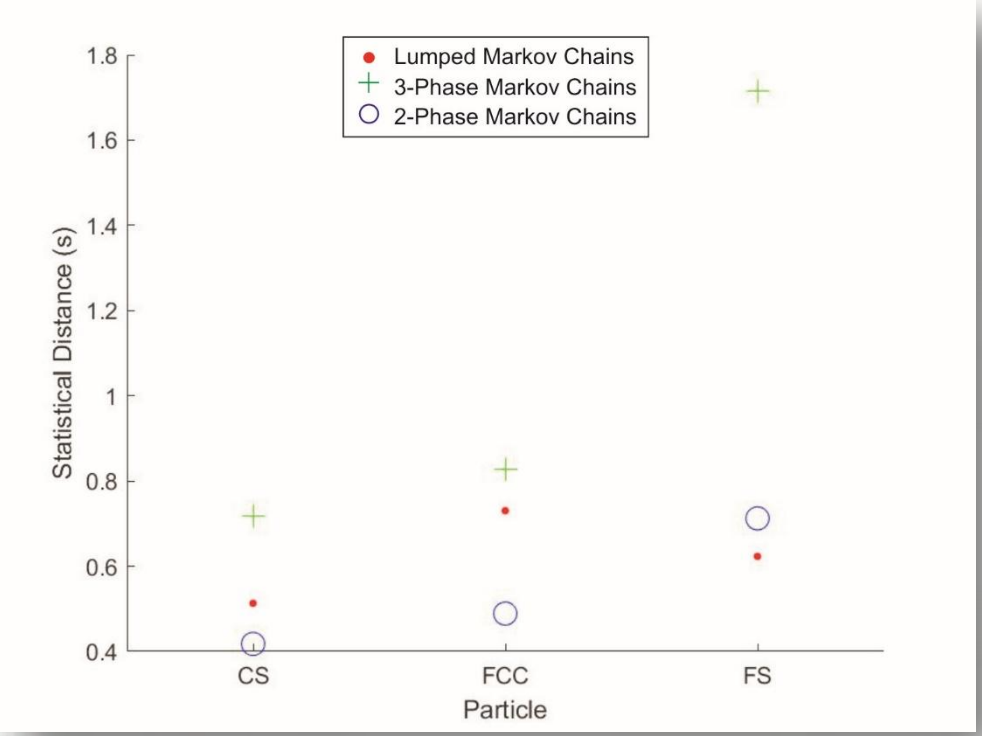
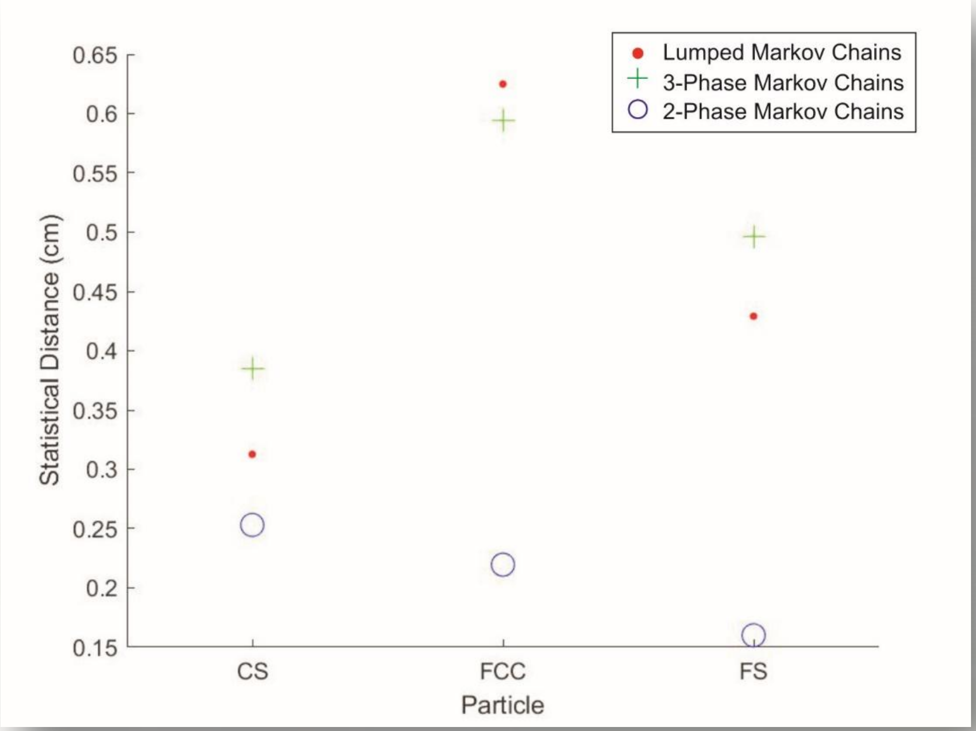


Time of Movements



Length of Movements

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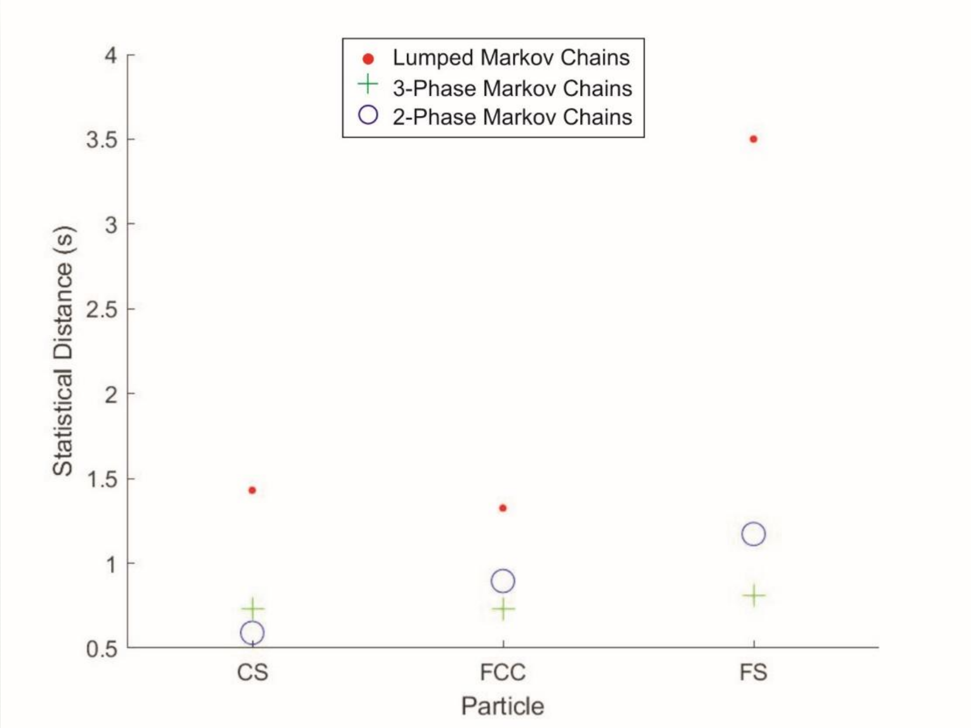
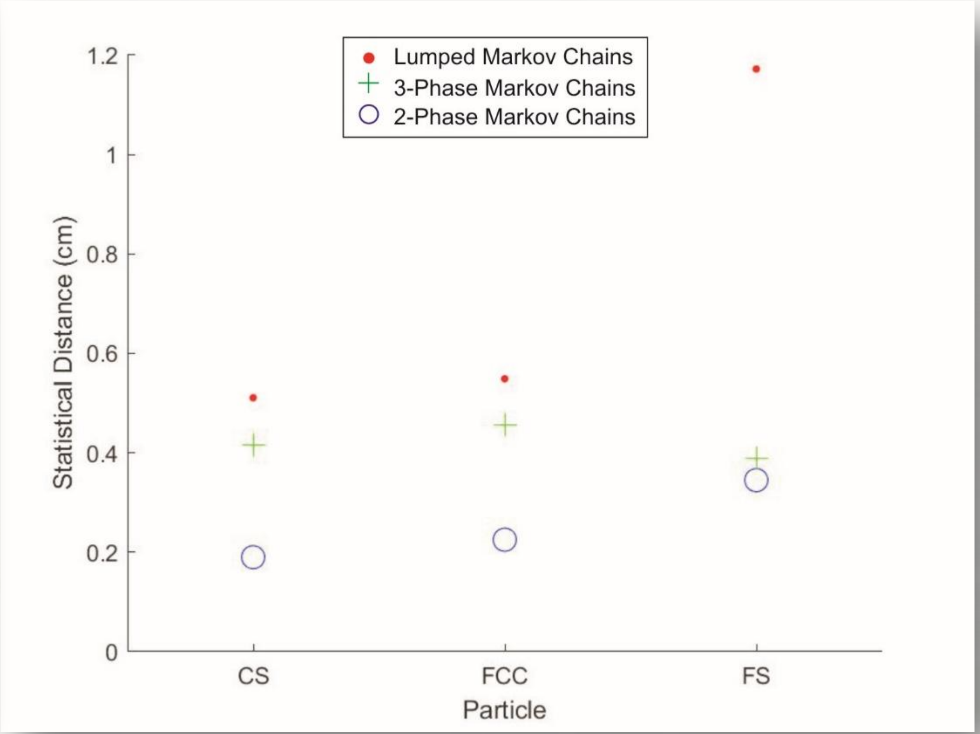
Results for Acetal-S, $U_e = 0.25\ m/s$

Comparing Results for Downward Unrestricted Movements



Time of Movements



Length of Movements

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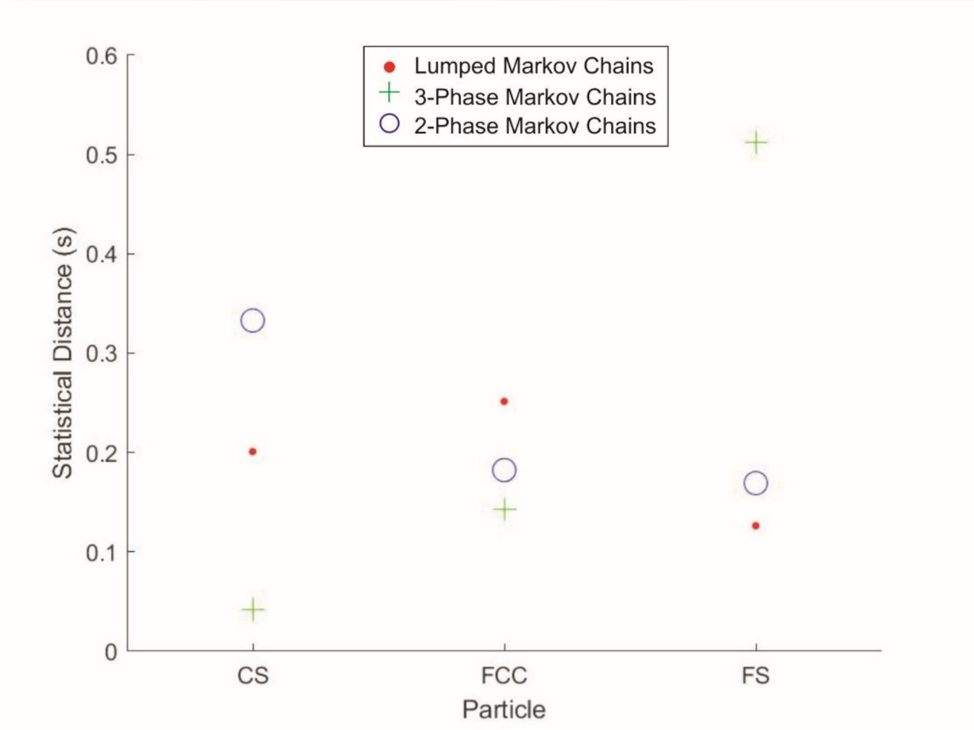
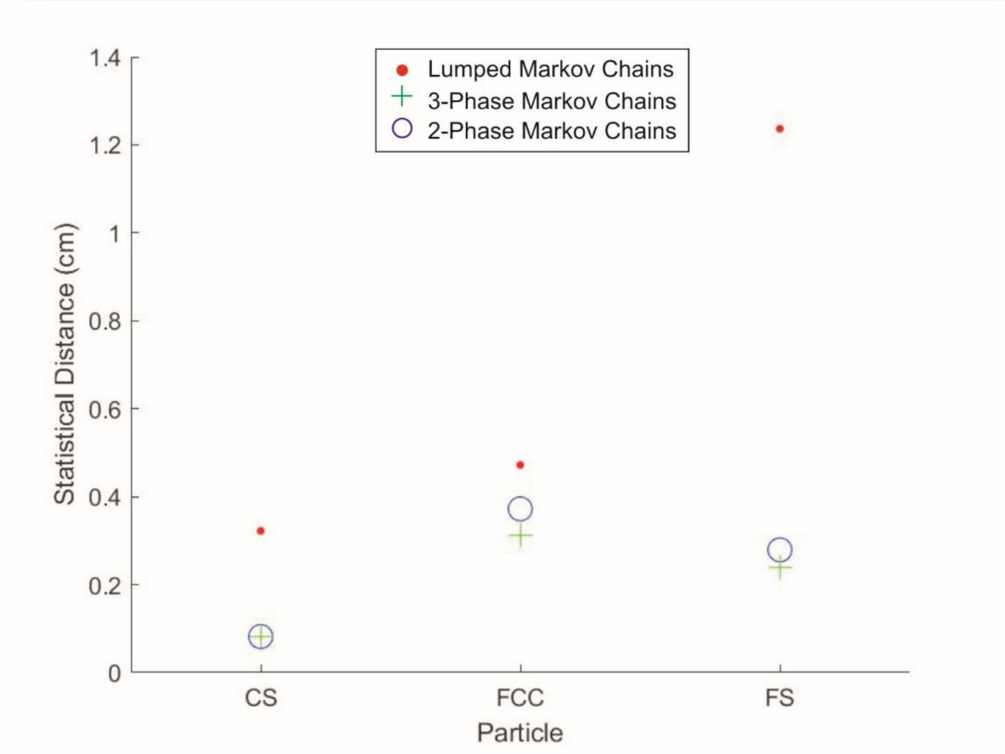
Comparing Results for Upward Unrestricted Movements



Time of Movements



Length of Movements

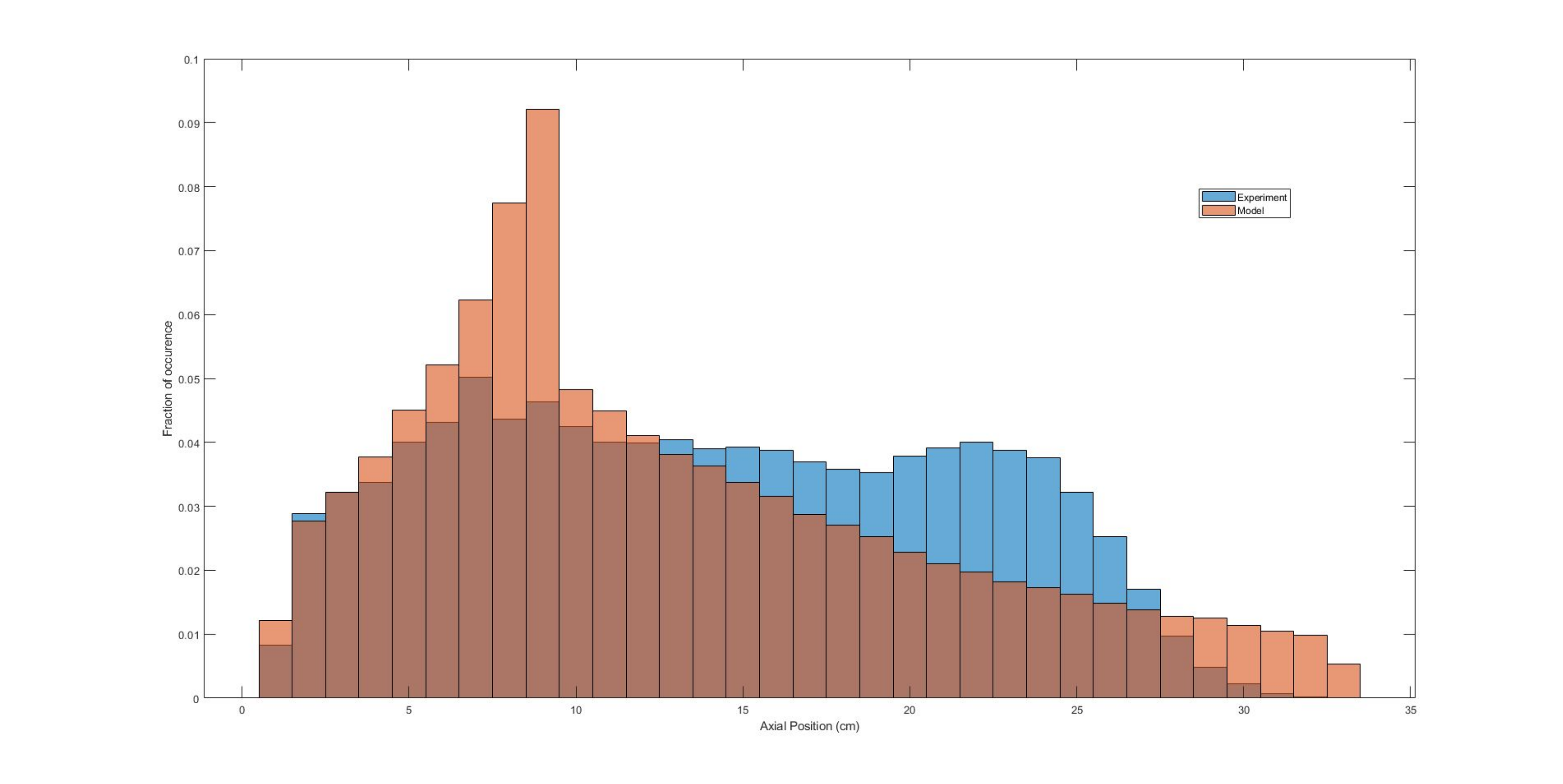
3. **Results**

Results for Acetal-S, $U_e = 0.25\ m/s$

Comparing Results for Axial Distribution of Particle occurence

Lumped Markov Chains

Coarse Sand Bed



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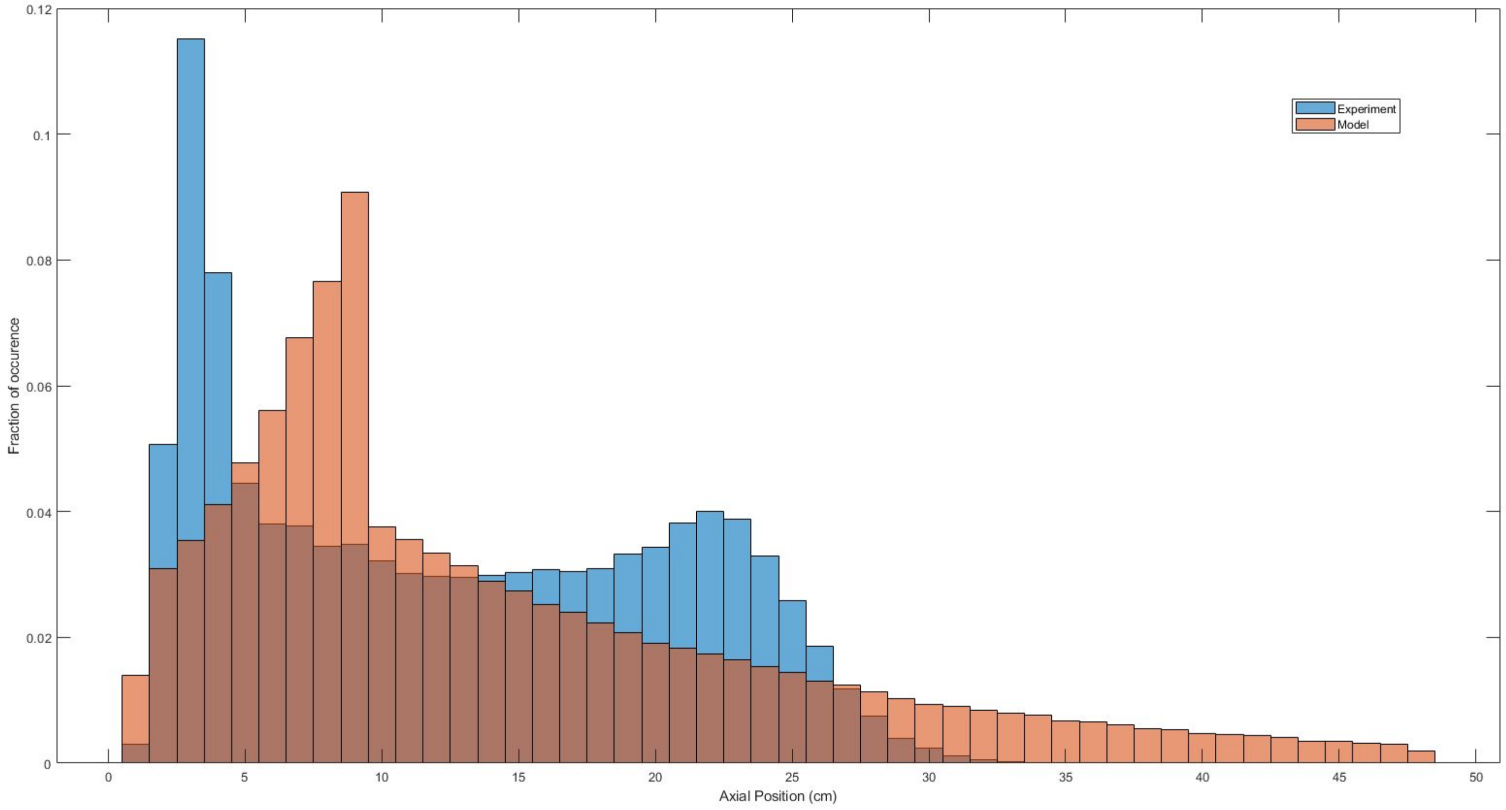


Lumped Markov Chains

FCC Catalyst Bed

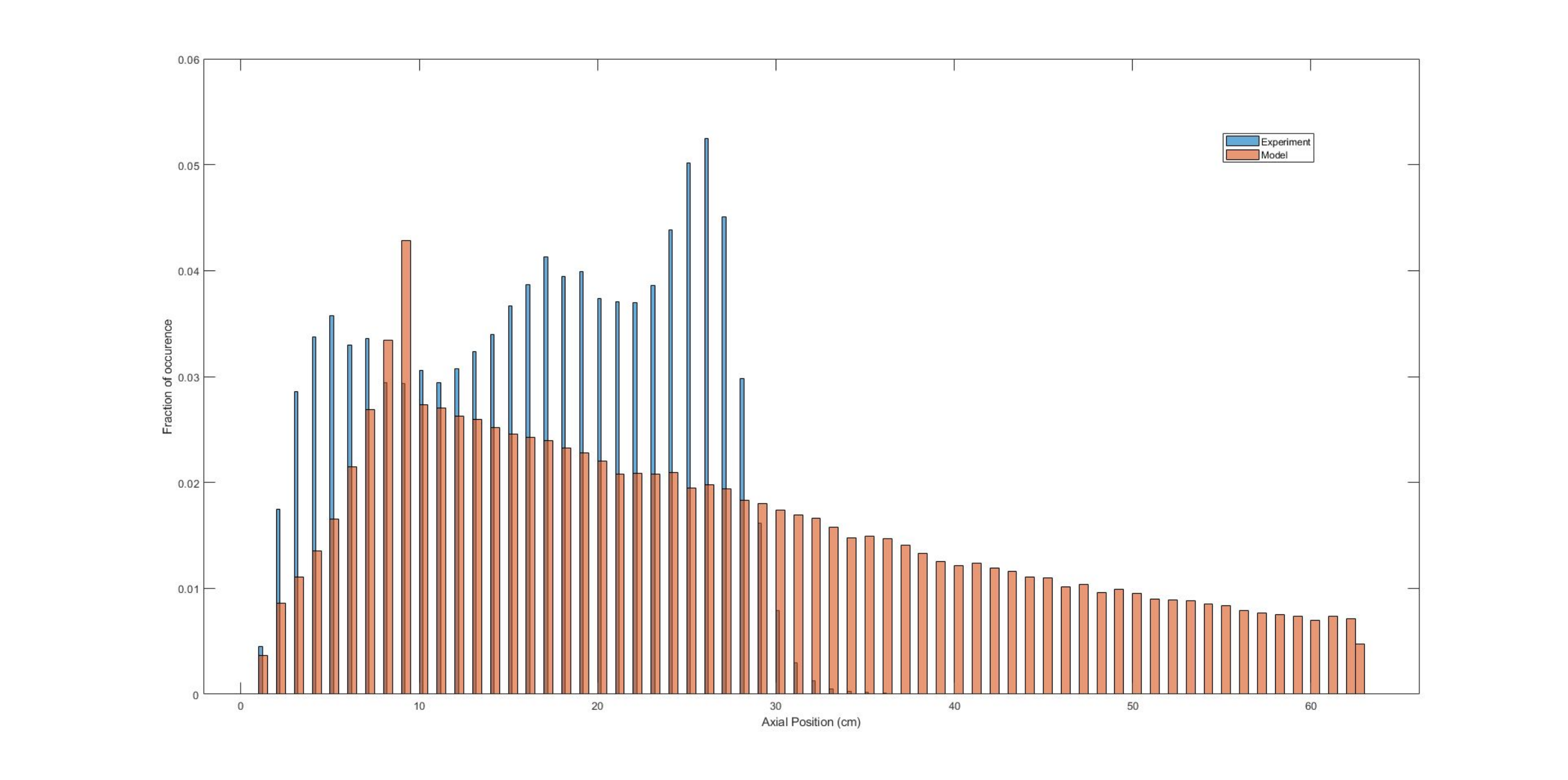
3. **Results**

Results for Acetal-S, $U_e = 0.25\ m/s$

Comparing Results for Axial Distribution of Particle occurence

Lumped Markov Chains

Fine Sand Bed



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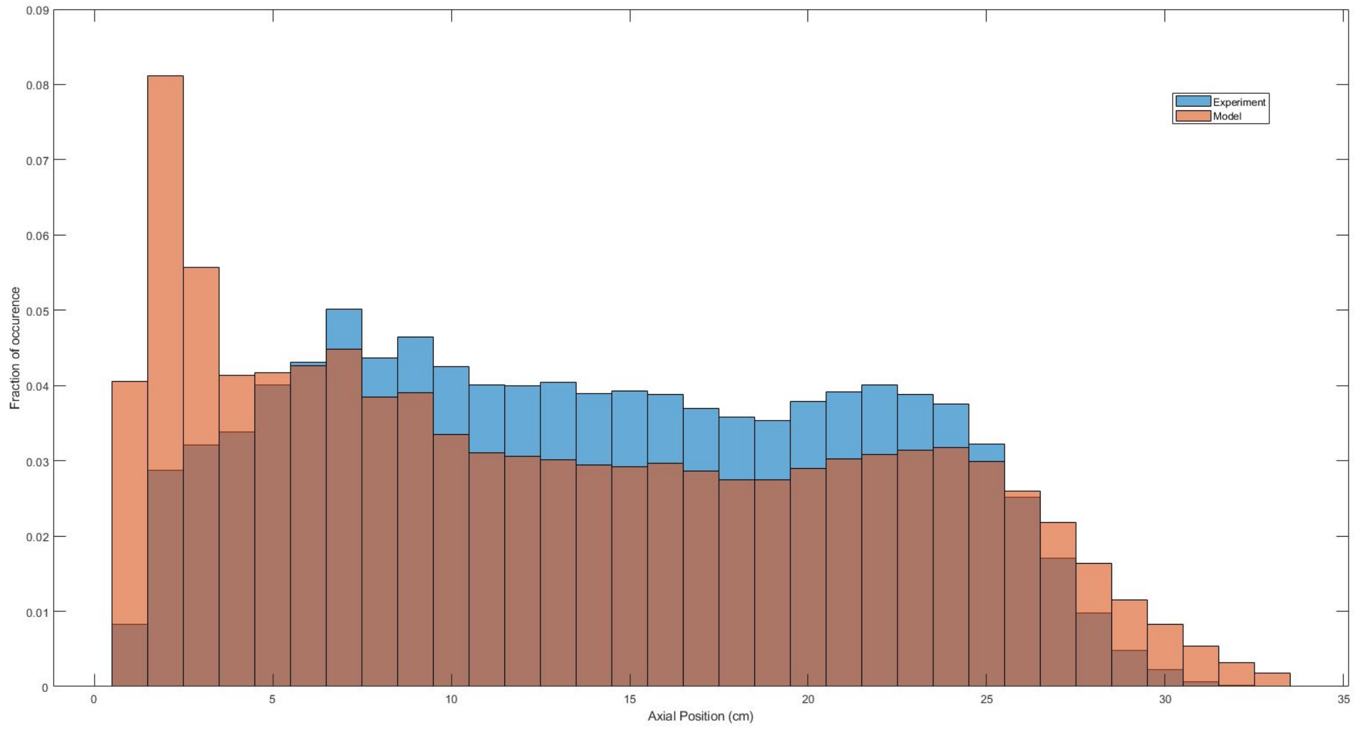

2-Phase Markov Chains

Coarse Sand Bed

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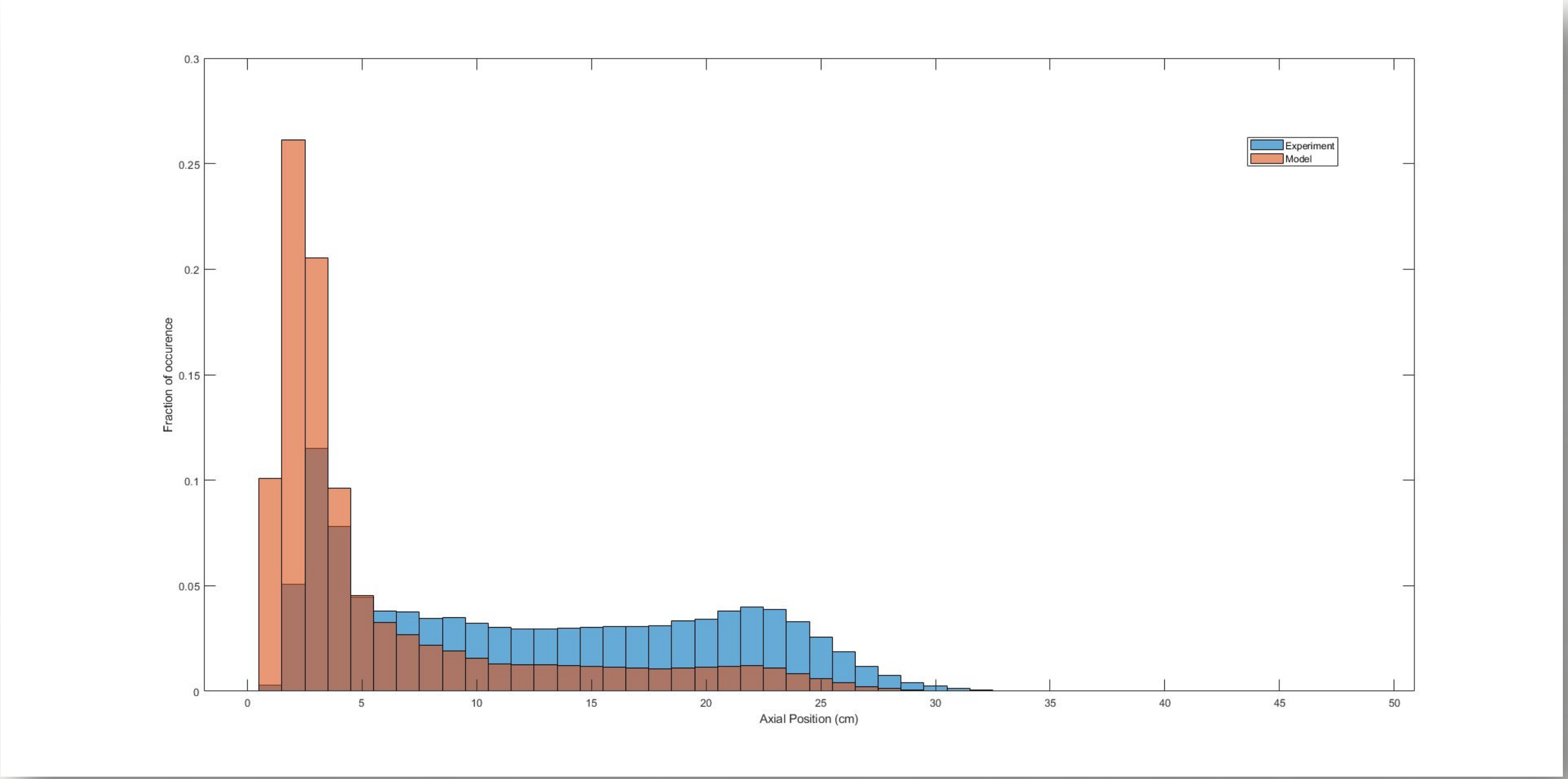

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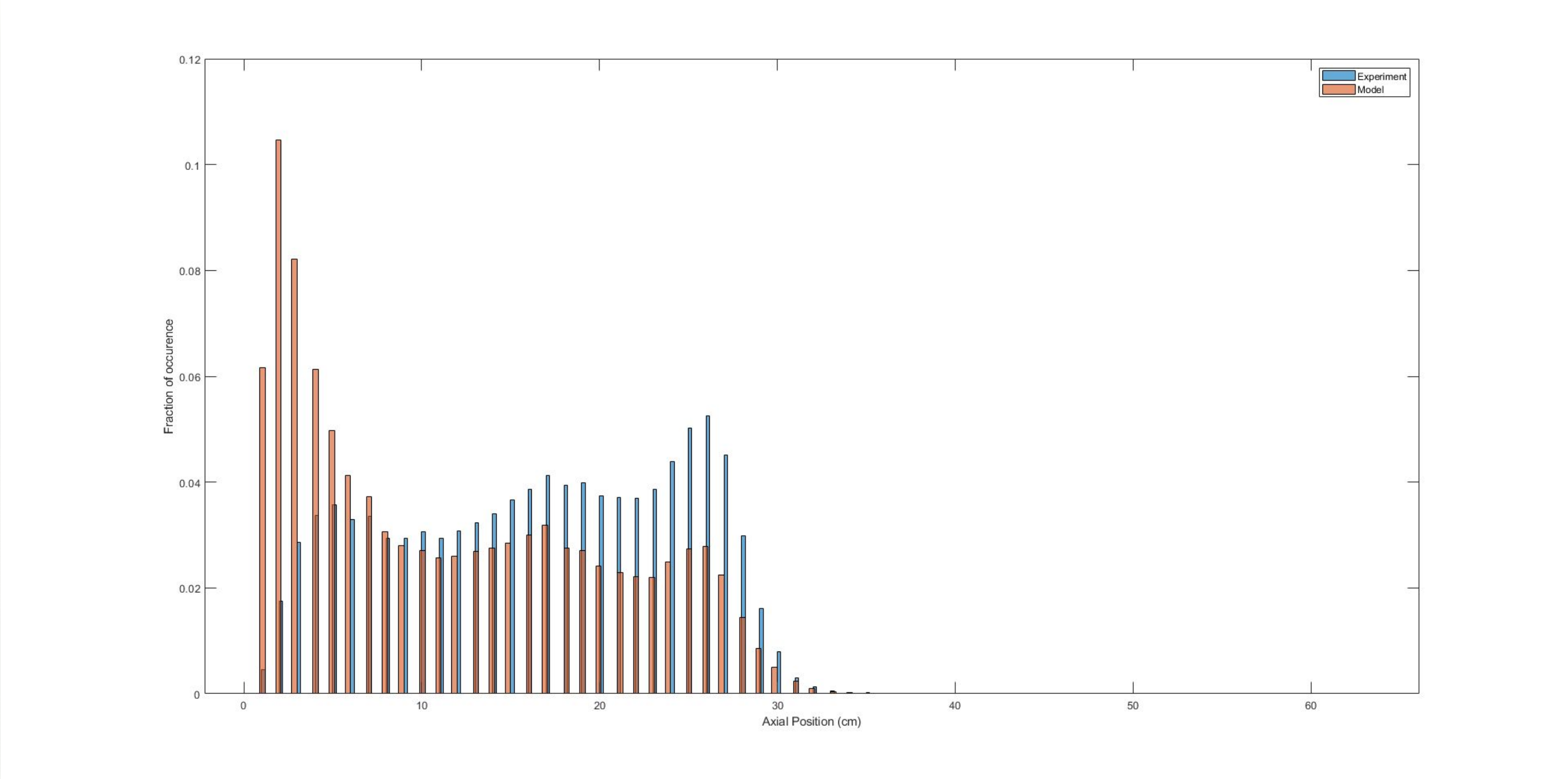

2-Phase Markov Chains

Fine Sand Bed

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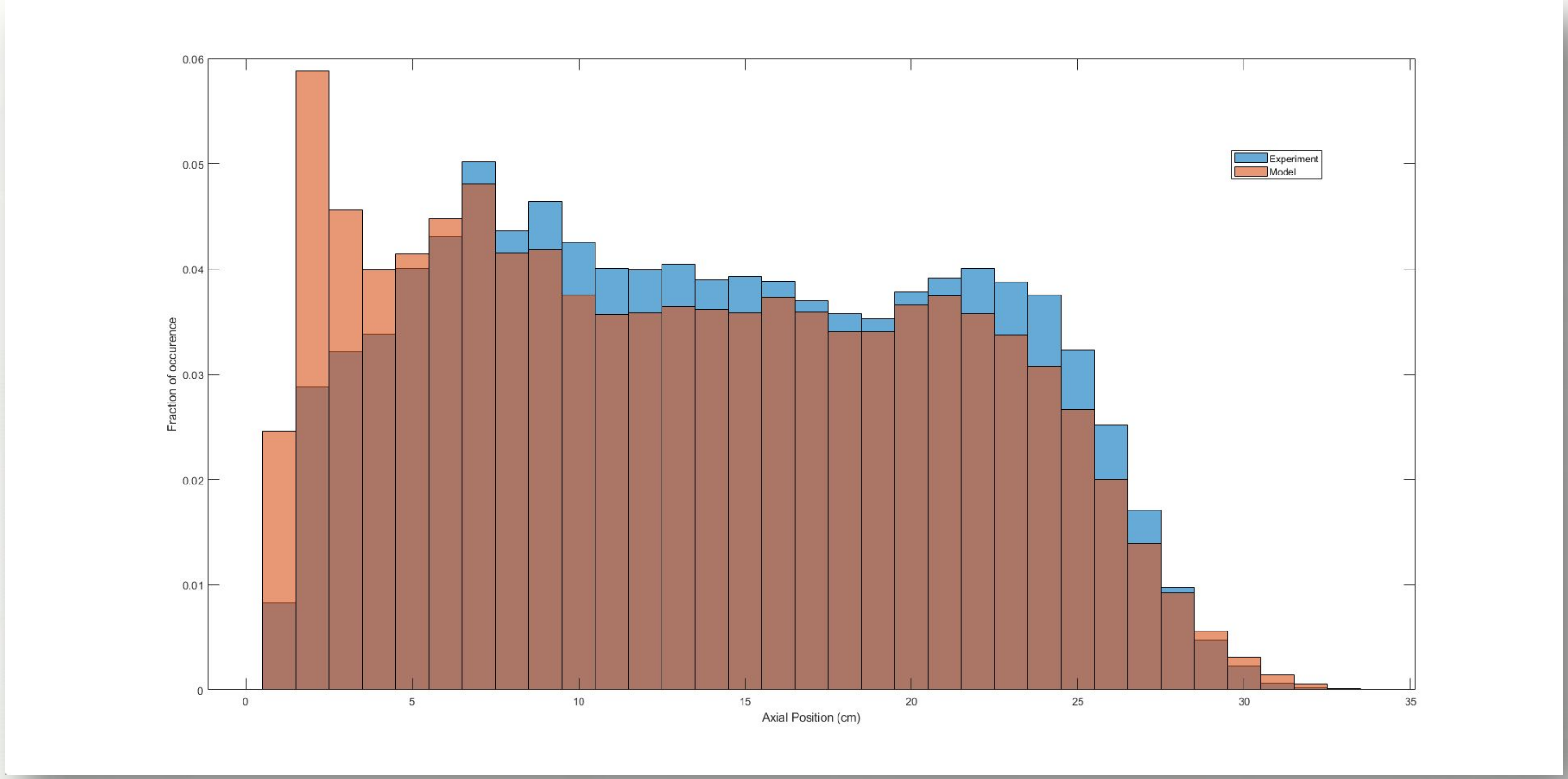
3-Phase Markov Chains

Coarse Sand Bed



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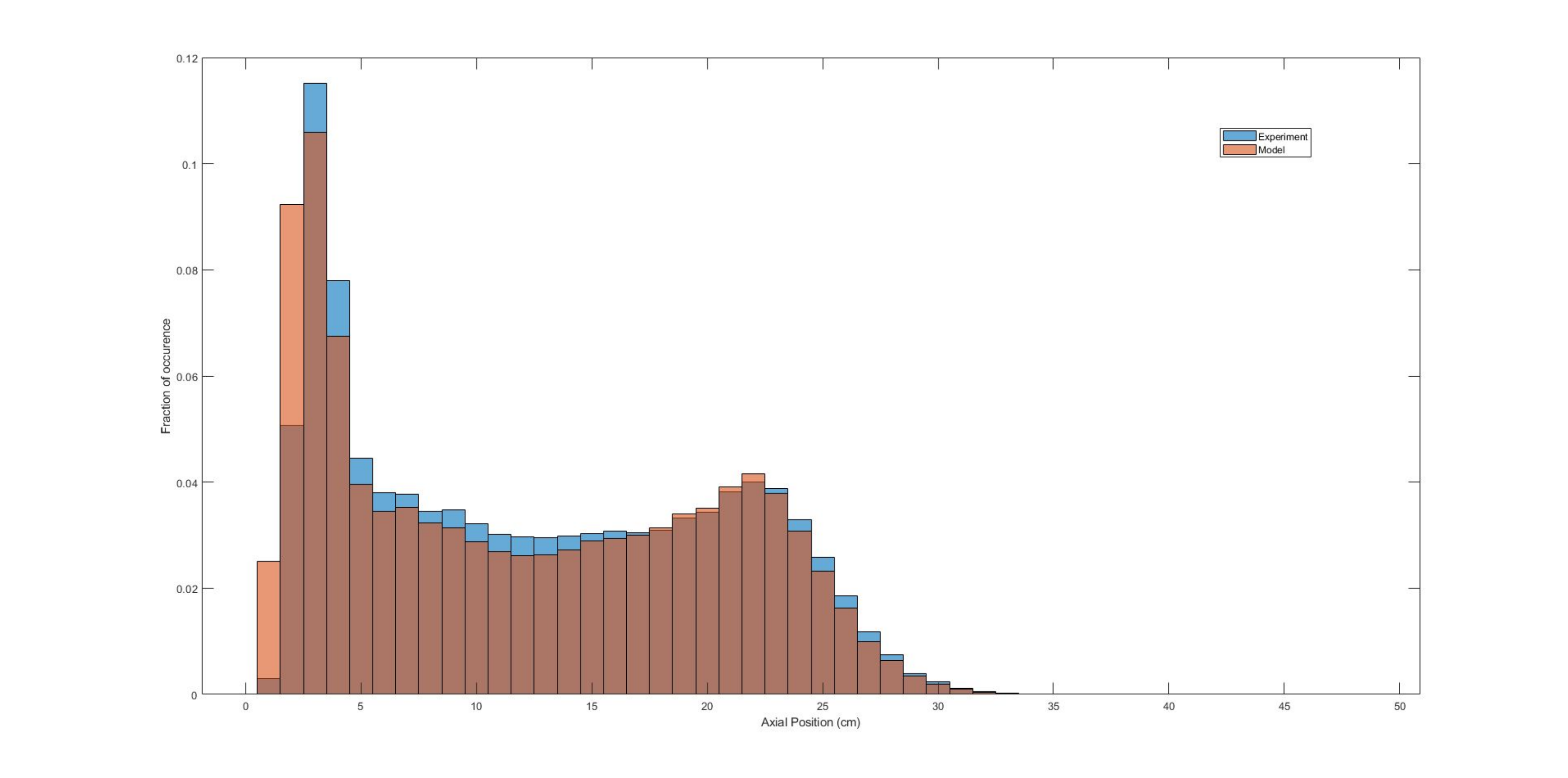

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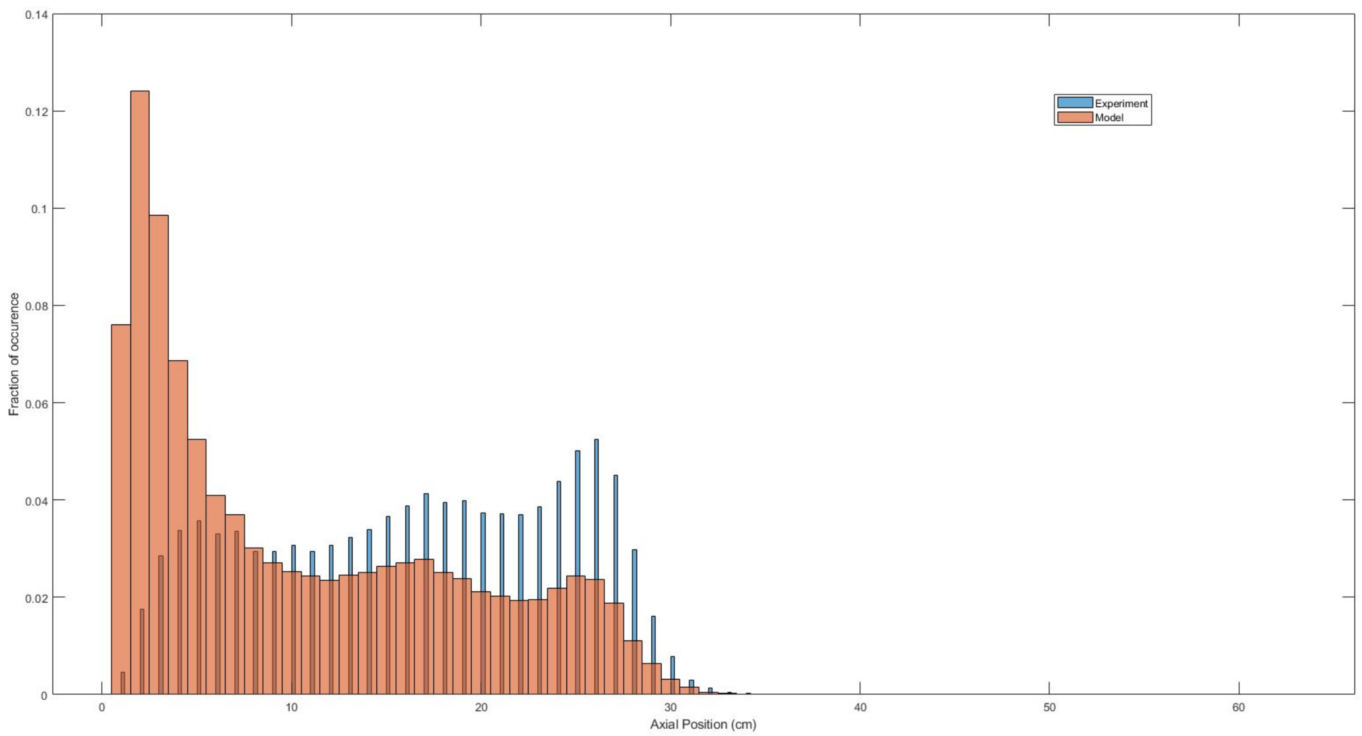

3-Phase Markov Chains

Fine Sand Bed

4. **Conclusion**

- This Research centers on the analysis of large solid particle behavior within binary fluidized systems
- Markov Chains Method as a statistical methodology was employed to capture this phenomena
- Parameters from the Markov Chain model were computed in a semi-experimental approach using both the literature and experiments
- 3 Particular Markov Chains were modeled and compared using statistical distance
- The Concept of Restricted and Unrestricted Movements was used and validated

Thanks for your attention

Any Questions ?