



Model created in COMSOL Multiphysics 6.4

# Grain Packing

## *Introduction*

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Grain packing refers to the process of packaging grains of differing sizes into a container. Several factors, including the grain shape and size as well as contact forces, can influence the packing efficiency. Furthermore, as the grain size reduces to the scale of millimeters and lower, noncontact forces such as adhesion and van der Waals forces can also greatly influence the packing behavior. Therefore, the prediction of the packing efficiency for a given system of granular material is nontrivial.

This model uses the Granular Flow interface to model the packing behavior of spherical grains of five different diameters. The extent of the packing is characterized by the evaluation of the packing fraction. Three contact force models are used to demonstrate the importance of accurately modeling the contact forces in the packing simulations.

## *Model Definition*

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The geometry consists of a rectangular box of equal length and width of 0.2 mm and a height of 0.3 mm. A total of 5000 grains are released into the box and the grain diameters are drawn from a normal distribution with a mean of 10  $\mu\text{m}$  and a standard deviation of 2.5  $\mu\text{m}$ . Periodic boundary conditions are applied along the  $x$  and  $y$  directions to eliminate the wall effects. The grains are allowed to settle under the influence of gravity and the contact forces for a total of 8 ms. The overall kinetic energy of the grains is tracked to ensure that the resultant bed is stable.

The extent of the packing is characterized by the packing efficiency which is defined as the ratio of the total volume in the sample occupied by the grains divided by the total volume of the sample. The sample under consideration in this model is defined consistently with [Ref. 1](#) and is defined as all the grains located between 30% and 70% of the height of the overall packed bed.

Three contact force models are used to study their effect on the packing efficiency of the grains. The three contact force models are:

- Hertz–MD which is one of the most common force models used in discrete element method simulations
- Hertz–MD with adhesion which extends the Hertz–MD model with adhesive (noncontact) forces.
- Hertz–MD with adhesion and van der Waals forces which extends the previous force model and adds the (noncontact) van der Waals forces between grains that become important when the grain sizes approach the micron scale.

The model is solved using a single **Time Dependent** study step. After each study step, the solution is stored and the physics settings are modified before running the study step with a different contact force model

The grains are released into the domain using a **Release** feature and are allowed to settle under gravity and contact forces. The **Periodic Condition** feature is used in the  $x$  and  $y$  directions to eliminate wall effects in those directions.

The grain diameters are drawn from a normal distribution with a given mean and standard deviation. In the Granular Flow module, this is achieved by discretizing the continuous normal distribution into discrete bins. Five bins are chosen in this model to represent the discretized normal distribution. The probability calculations for each bin are evaluated as parameters in a **Parameters** feature.

The force computations in the Granular Flow interface rely on sophisticated search algorithms to speed up the simulation times. These algorithms can drastically reduce the number of grains or wall elements that each grain needs to check for contact by only checking the grains or wall elements that lie within a certain search radius of each grain. This search radius is by default equal to the grain radius itself. The search radius needs to be expanded when the contact force models include noncontact forces such as adhesive and van der Waals forces. This expansion of the search radius is controlled by the **Contact search expansion ratio** parameter present in the **Grain Properties** feature in the Granular Flow Interface. This value can be set to 1.0 for the first contact force model that does not contain any noncontact forces. For the other two contact force models, this value is set to 1.05 to expand the search radius by 5%.

## Results and Discussion

Figure 1 shows the packed grains using the Hertz-MD model. The grains are colored by their diameter. The grains have clearly formed a tightly packed bed.

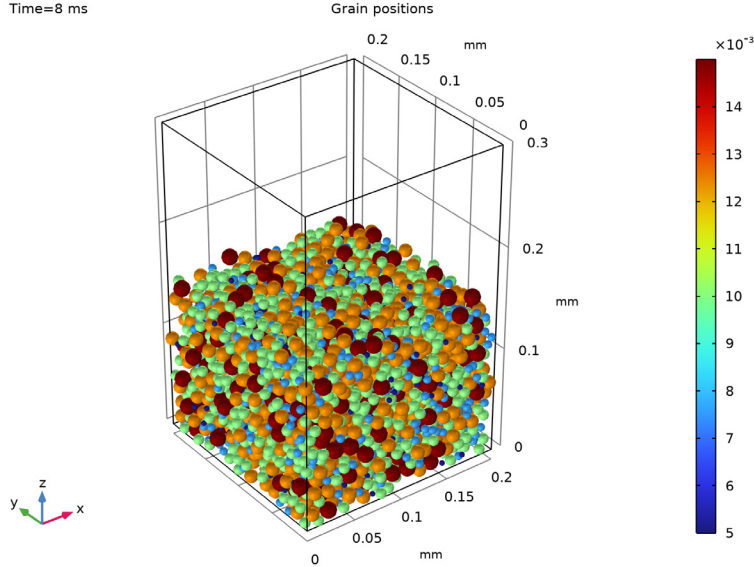
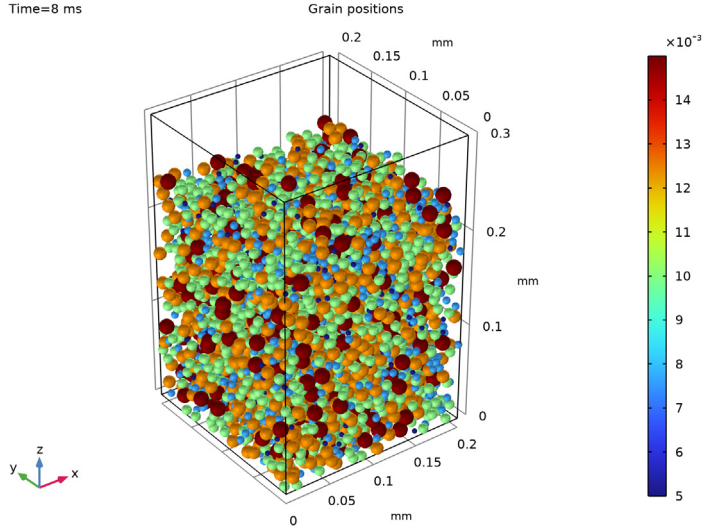


Figure 1: The packed grains using the Hertz-MD model.

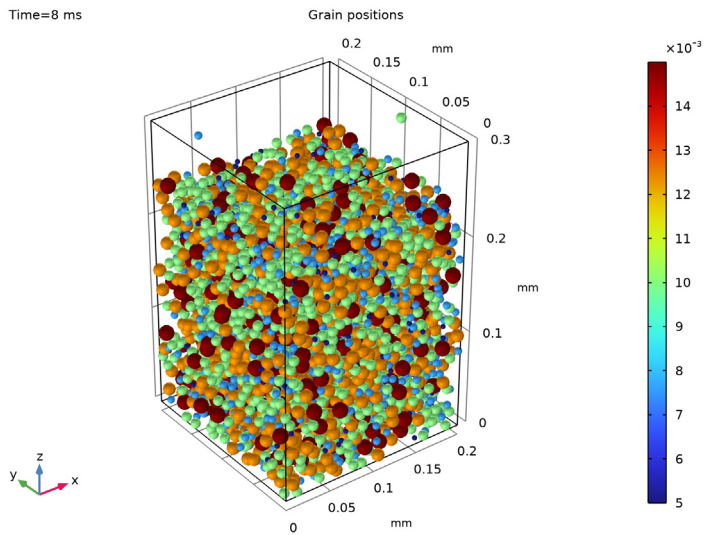
The packed grains resulting from the inclusion of the adhesive forces are shown in Figure 2. Figure 3 shows the packed bed resulting from the inclusion of the van der Waals forces. It is evident that the grain packing in these two cases is not as efficient as Figure 1. This is due to the nature of the adhesive forces which can cause grains to be weakly connected to each other even after a collision has taken place.

This decrease in packing efficiency is best visualized in Figure 4 where the packing fractions are plotted as a function of time for all three contact force models. The inclusion of the adhesive forces first reduces the packing fraction, and the inclusion of the van der Waals forces further decreases the packing efficiency.

Finally, Figure 5 shows the evolution of the overall kinetic energy of the grains as a function of time for each of the three contact force models. In all cases, the kinetic energy initially increases as a result of the acceleration due to gravity, and then starts reducing as the repeated collisions dissipate the kinetic energies. However the effect of the adhesive forces can be seen in the reduced dissipation rate of the overall kinetic energies.



*Figure 2: The packed grains using the Hertz-MD with adhesion model.*



*Figure 3: The packed grains using the Hertz-MD with adhesion model with van der Waals forces enabled.*

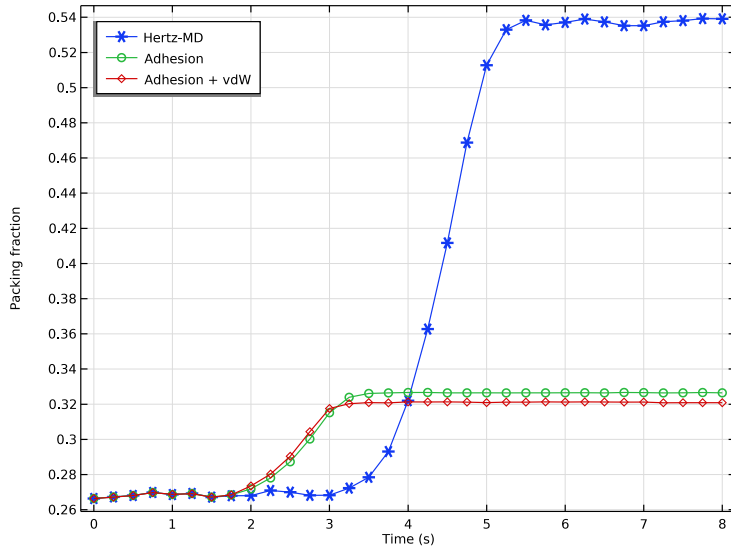


Figure 4: Packing fraction as a function of time.

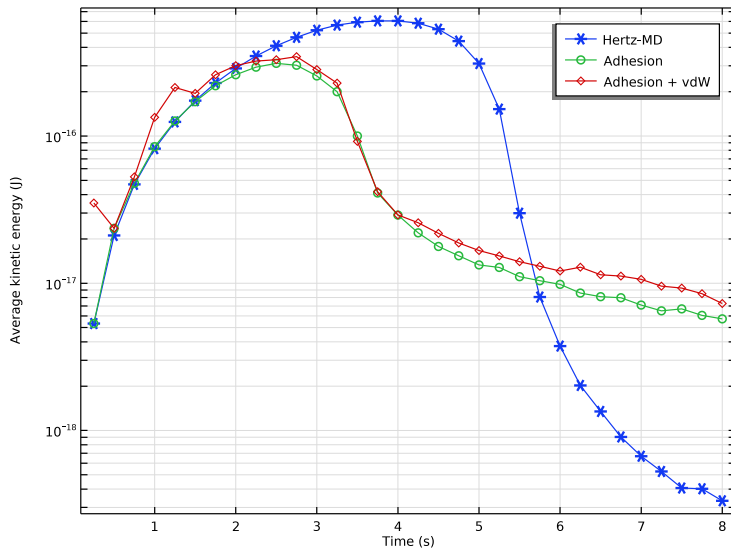


Figure 5: Average kinetic energy of the grains across the three force models.

## Reference

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I. E.J. Parteli, J. Schmidt, C. Blümel, K.E. Wirth, W. Peukert, and T. Pöschel, “Attractive particle interaction forces and packing density of fine glass powders,” *Sci. Rep.*, vol. 4, no. 6227, 2014; [doi.org/10.1038/srep06227](https://doi.org/10.1038/srep06227).

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**Application Library path:** Granular\_Flow\_Module/  
Flow\_and\_Material\_Characterization/grain\_packing


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## Modeling Instructions




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From the **Main Toolbar** menu, choose **New**.

### NEW


In the **New** window, click  **Model Wizard**.

### MODEL WIZARD


- 1 In the **Model Wizard** window, click  **3D**.
- 2 In the **Select Physics** tree, select **Fluid Flow** > **Granular Flow (gran)**.
- 3 Click **Add**.
- 4 Click  **Study**.
- 5 In the **Select Study** tree, select **General Studies** > **Time Dependent**.
- 6 Click  **Done**.

### GLOBAL DEFINITIONS

#### Model Parameters

- 1 In the **Model Builder** window, under **Global Definitions** click **Parameters I**.
- 2 In the **Settings** window for **Parameters**, type Model Parameters in the **Label** text field.
- 3 Locate the **Parameters** section. Click  **Load from File**.
- 4 Browse to the model's Application Libraries folder and double-click the file `grain_packing_parameters.txt`.

#### Normal Distribution I (ndI, ndI\_cum, ...)

- 1 In the **Home** toolbar, click  **Functions** and choose **Global** > **Normal Distribution**.
- 2 In the **Settings** window for **Normal Distribution**, locate the **Parameters** section.

- 3 In the **Mean** text field, type `dMean`.
- 4 In the **Standard deviation** text field, type `delta`.

#### *Diameter Distributions*

Next, discretize the normal distribution into five bins.

- 1 In the **Home** toolbar, click **Pi Parameters** and choose **Add > Parameters**.
- 2 In the **Settings** window for **Parameters**, type `Diameter Distributions` in the **Label** text field.
- 3 Locate the **Parameters** section. In the table, enter the following settings:

<b>Name</b>	<b>Expression</b>	<b>Value</b>	<b>Description</b>
d1	<code>dMean-2*delta</code>	5E-6 m	Diameter, bin 1
d2	<code>dMean-delta</code>	7.5E-6 m	Diameter, bin 2
d3	<code>dMean</code>	1E-5 m	Diameter, bin 3
d4	<code>dMean+delta</code>	1.25E-5 m	Diameter, bin 4
d5	<code>dMean+2*delta</code>	1.5E-5 m	Diameter, bin 5
p1	<code>0.5*(delta)*(nd1(delta/2+d1)+nd1(d1-delta/2))[1/m]</code>	0.073523	Population, bin 1
p2	<code>0.5*(delta)*(nd1(delta/2+d2)+nd1(d2-delta/2))[1/m]</code>	0.24079	Population, bin 2
p3	<code>0.5*(delta)*(nd1(delta/2+d3)+nd1(d3-delta/2))[1/m]</code>	0.35207	Population, bin 3
p4	<code>0.5*(delta)*(nd1(delta/2+d4)+nd1(d4-delta/2))[1/m]</code>	0.24079	Population, bin 4
p5	<code>0.5*(delta)*(nd1(delta/2+d5)+nd1(d5-delta/2))[1/m]</code>	0.073523	Population, bin 5

#### **DEFINITIONS**

##### *Variables 1*

- 1 In the **Home** toolbar, click **a= Variables** and choose **Local Variables**.
- 2 In the **Settings** window for **Variables**, locate the **Variables** section.



3 In the table, enter the following settings:

Name	Expression	Unit	Description
zmax	<code>gran.max(if(qz&lt;0.9*Lz, qz,0))</code>	m	Max height
include	<code>if(qz&gt;0.3*zmax&amp;&amp;qz&lt;0.7*zmax,1,0)</code>		Boolean for inclusion
count	<code>gran.sum(include)</code>		Number of grains included
vol_occ	<code>4*pi/3*gran.sum(include*gran.rg^3)</code>	m <sup>3</sup>	Occupied volume
vol_tot	<code>Lx*Ly*0.4*zmax</code>	m <sup>3</sup>	Total volume
pFrac	<code>vol_occ/vol_tot</code>		Packing fraction

## GEOMETRY I



- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.
- 2 In the **Settings** window for **Geometry**, locate the **Units** section.
- 3 From the **Length unit** list, choose **mm**.

### Block 1 (blk1)

- 1 In the **Geometry** toolbar, click  **Block**.
- 2 In the **Settings** window for **Block**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type `Lx`.
- 4 In the **Depth** text field, type `Ly`.
- 5 In the **Height** text field, type `Lz`.
- 6 Click  **Build All Objects**.

## MATERIALS

### Grains

- 1 In the **Materials** toolbar, click  **Blank Material**.
- 2 In the **Settings** window for **Material**, type `Grains` in the **Label** text field.
- 3 Click to expand the **Material Properties** section. In the **Material properties** tree, select **Basic Properties > Density**.
- 4 Click  **Add to Material**.
- 5 In the **Material properties** tree, select **Basic Properties > Poisson's Ratio**.

6 Click  **Add to Material**.


7 In the **Material properties** tree, select **Basic Properties > Young's Modulus**.

8 Click  **Add to Material**.

9 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Density	rho	rhog	kg/m <sup>3</sup>	Basic
Poisson's ratio	nu	pois	l	Basic
Young's modulus	E	Eg	Pa	Basic

### Walls

1 In the **Materials** toolbar, click  **Blank Material**.

2 In the **Settings** window for **Material**, type Walls in the **Label** text field.

3 Locate the **Geometric Entity Selection** section. From the **Geometric entity level** list, choose **Boundary**.

4 From the **Selection** list, choose **All boundaries**.

5 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Young's modulus	E	2.5*Eg	Pa	Basic
Poisson's ratio	nu	pois	l	Basic

## GRANULAR FLOW (GRAN)

### Grain Properties 1

1 In the **Model Builder** window, under **Component 1 (comp1) > Granular Flow (gran)** click **Grain Properties 1**.

2 In the **Settings** window for **Grain Properties**, locate the **Granular Material Properties** section.

3 From the **Granular material** list, choose **Grains (mat1)**.

4 Locate the **Size** section. In the  $d_g$  text field, type d1.

### Grain Properties 2

1 In the **Physics** toolbar, click  **Global** and choose **Grain Properties**.

2 In the **Settings** window for **Grain Properties**, locate the **Granular Material Properties** section.

3 From the **Granular material** list, choose **Grains (mat1)**.

4 Locate the **Size** section. In the  $d_g$  text field, type d2.

#### *Grain Properties 3*

- 1 Right-click **Grain Properties 2** and choose **Duplicate**.
- 2 In the **Settings** window for **Grain Properties**, locate the **Size** section.
- 3 In the  $d_g$  text field, type d3.

#### *Grain Properties 4*

- 1 Right-click **Grain Properties 3** and choose **Duplicate**.
- 2 In the **Settings** window for **Grain Properties**, locate the **Size** section.
- 3 In the  $d_g$  text field, type d4.

#### *Grain Properties 5*

- 1 Right-click **Grain Properties 4** and choose **Duplicate**.
- 2 In the **Settings** window for **Grain Properties**, locate the **Size** section.
- 3 In the  $d_g$  text field, type d5.

#### *Contact Between Grains 1*

- 1 In the **Model Builder** window, click **Contact Between Grains 1**.
- 2 In the **Settings** window for **Contact Between Grains**, locate the **Contact Properties** section.
- 3 In the  $e_n$  text field, type en.
- 4 In the  $e_t$  text field, type et.
- 5 In the  $\mu_s$  text field, type mu\_s.
- 6 In the  $\mu_r$  text field, type mu\_r.
- 7 In the  $\mu_{tw}$  text field, type mu\_tw.

#### *Contact with Walls 1*

- 1 In the **Model Builder** window, click **Contact with Walls 1**.
- 2 In the **Settings** window for **Contact with Walls**, locate the **Contact Properties** section.
- 3 In the  $e_n$  text field, type en.
- 4 In the  $e_t$  text field, type et.
- 5 In the  $\mu_s$  text field, type mu\_s.
- 6 In the  $\mu_r$  text field, type mu\_r.
- 7 In the  $\mu_{tw}$  text field, type mu\_tw.

#### *Release 1*

- 1 In the **Physics** toolbar, click  **Domains** and choose **Release**.

- 2 Select Domain 1 only.
- 3 In the **Settings** window for **Release**, locate the **Released Grain Properties** section.
- 4 From the **Distribution of released grain properties** list, choose **Number fraction**.
- 5 In the  $N$  text field, type 5000.
- 6 In the table, enter the following settings:

Released grain properties	Number fraction of grains
Grain Properties 1	p1
Grain Properties 2	p2
Grain Properties 3	p3
Grain Properties 4	p4
Grain Properties 5	p5

#### *Periodic Condition 1*

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Periodic Condition**.
- 2 Select Boundaries 2 and 5 only.


#### *Periodic Condition 2*

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Periodic Condition**.
- 2 Select Boundaries 1 and 6 only.

### **STUDY 1: HERTZ-MD**

- 1 In the **Model Builder** window, click **Study 1**.
- 2 In the **Settings** window for **Study**, type Study 1: Hertz-MD in the **Label** text field.

#### *Step 1: Time Dependent*

- 1 In the **Model Builder** window, under **Study 1: Hertz-MD** click **Step 1: Time Dependent**.
- 2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.
- 3 From the **Time unit** list, choose **ms**.
- 4 In the **Output times** text field, type range(0,0.25,t\_fill).
- 5 In the **Study** toolbar, click  **Compute**.

### **RESULTS**

#### *Grain Positions: Hertz-MD*

- 1 In the **Settings** window for **3D Plot Group**, type Grain Positions: Hertz-MD in the **Label** text field.


2 In the **Model Builder** window, expand the **Grain Positions: Hertz-MD** node.

#### *Color Expression 1*

1 In the **Model Builder** window, expand the **Results > Grain Positions: Hertz-MD > Grain Positions 1** node, then click **Color Expression 1**.

2 In the **Settings** window for **Color Expression**, locate the **Expression** section.

3 In the **Expression** text field, type `gran.dg`.

4 Click the  **Zoom Extents** button in the **Graphics** toolbar.

5 In the **Grain Positions: Hertz-MD** toolbar, click  **Plot**.

The plot of the packed grain positions for the Hertz-MD model should resemble [Figure 1](#).

### **GRANULAR FLOW (GRAN)**

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Granular Flow (gran)**.

2 In the **Settings** window for **Granular Flow**, locate the **Force** section.

3 From the **Contact force model** list, choose **Hertz-MD with adhesion**.

#### *Grain Properties 1*

1 In the **Model Builder** window, under **Component 1 (comp1) > Granular Flow (gran)** click **Grain Properties 1**.

2 In the **Settings** window for **Grain Properties**, locate the **Size** section.

3 In the  $\beta$  text field, type `1.05`.

4 Locate the **Adhesion Properties** section. In the  $\gamma$  text field, type `gamma`.

#### *Grain Properties 2*

1 In the **Model Builder** window, click **Grain Properties 2**.

2 In the **Settings** window for **Grain Properties**, locate the **Size** section.

3 In the  $\beta$  text field, type `1.05`.

4 Locate the **Adhesion Properties** section. In the  $\gamma$  text field, type `gamma`.

#### *Grain Properties 3*

1 In the **Model Builder** window, click **Grain Properties 3**.

2 In the **Settings** window for **Grain Properties**, locate the **Size** section.

3 In the  $\beta$  text field, type `1.05`.

4 Locate the **Adhesion Properties** section. In the  $\gamma$  text field, type `gamma`.

#### *Grain Properties 4*



1 In the **Model Builder** window, click **Grain Properties 4**.

- 2 In the **Settings** window for **Grain Properties**, locate the **Size** section.
- 3 In the  $\beta$  text field, type 1.05.
- 4 Locate the **Adhesion Properties** section. In the  $\gamma$  text field, type gamma.

#### *Grain Properties 5*

- 1 In the **Model Builder** window, click **Grain Properties 5**.
- 2 In the **Settings** window for **Grain Properties**, locate the **Size** section.
- 3 In the  $\beta$  text field, type 1.05.
- 4 Locate the **Adhesion Properties** section. In the  $\gamma$  text field, type gamma.


#### **ADD STUDY**

- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.
- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies > Time Dependent**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.

#### **STUDY 2: ADHESION**

In the **Settings** window for **Study**, type Study 2: Adhesion in the **Label** text field.

#### *Step 1: Time Dependent*


- 1 In the **Model Builder** window, under **Study 2: Adhesion** click **Step 1: Time Dependent**.
- 2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.
- 3 From the **Time unit** list, choose **ms**.
- 4 In the **Output times** text field, type `range(0,0.25,t_fill)`.
- 5 In the **Study** toolbar, click  **Compute**.

#### **RESULTS**

#### *Grain Positions: Adhesion*

- 1 In the **Settings** window for **3D Plot Group**, type Grain Positions: Adhesion in the **Label** text field.
- 2 In the **Model Builder** window, expand the **Grain Positions: Adhesion** node.

### *Color Expression 1*



- 1 In the **Model Builder** window, expand the **Results > Grain Positions: Adhesion > Grain Positions 1** node, then click **Color Expression 1**.
- 2 In the **Settings** window for **Color Expression**, locate the **Expression** section.
- 3 In the **Expression** text field, type `gran.dg`.
- 4 In the **Grain Positions: Adhesion** toolbar, click  **Plot**.

The plot of the packed grain positions for the Adhesion model should resemble [Figure 2](#).

### **GRANULAR FLOW (GRAN)**

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Granular Flow (gran)**.
- 2 In the **Settings** window for **Granular Flow**, locate the **Force** section.
- 3 Select the **Compute van der Waals force** checkbox.


### **ADD STUDY**

- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.
- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies > Time Dependent**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.

### **STUDY 2: ADHESION + VDW**

In the **Settings** window for **Study**, type `Study 2: Adhesion + vdW` in the **Label** text field.

#### *Step 1: Time Dependent*


- 1 In the **Model Builder** window, under **Study 2: Adhesion + vdW** click **Step 1: Time Dependent**.
- 2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.
- 3 From the **Time unit** list, choose **ms**.
- 4 In the **Output times** text field, type `range(0,0.25,t_fill)`.
- 5 In the **Study** toolbar, click  **Compute**.

## RESULTS

### *Grain Positions: Adhesion + vdW*


- 1 In the **Settings** window for **3D Plot Group**, type Grain Positions: Adhesion + vdW in the **Label** text field.
- 2 In the **Model Builder** window, expand the **Grain Positions: Adhesion + vdW** node.

### *Color Expression 1*


- 1 In the **Model Builder** window, expand the **Results > Grain Positions: Adhesion + vdW > Grain Positions 1** node, then click **Color Expression 1**.
- 2 In the **Settings** window for **Color Expression**, locate the **Expression** section.
- 3 In the **Expression** text field, type `gran.dg`.
- 4 In the **Grain Positions: Adhesion + vdW** toolbar, click  **Plot**.

The plot of the packed grain positions for the + vdW model should resemble [Figure 3](#).

### *Packing Fraction*

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Packing Fraction in the **Label** text field.
- 3 Locate the **Data** section. From the **Dataset** list, choose **None**.
- 4 Click to expand the **Title** section. From the **Title type** list, choose **None**.
- 5 Locate the **Plot Settings** section.
- 6 Select the **x-axis label** checkbox. In the associated text field, type Time (s).
- 7 Select the **y-axis label** checkbox. In the associated text field, type Packing fraction.
- 8 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

### *Global 1*

- 1 In the **Packing Fraction** toolbar, click  **Global**.
- 2 In the **Settings** window for **Global**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Grain 1**.
- 4 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
pFrac	1	Hertz-MD

- 5 Click to expand the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Cycle**.

### Global 2

- 1 Right-click **Global 1** and choose **Duplicate**.
- 2 In the **Settings** window for **Global**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Grain 2**.
- 4 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
pFrac	1	Adhesion

### Global 3


- 1 Right-click **Global 2** and choose **Duplicate**.
- 2 In the **Settings** window for **Global**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Grain 3**.
- 4 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
pFrac	1	Adhesion + vdW


- 5 In the **Packing Fraction** toolbar, click  **Plot**.

The packing fraction as a function of time for the three force models should resemble [Figure 4](#).

### Average Kinetic Energy

- 1 In the **Home** toolbar, click  **Add Plot Group** and choose **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Average Kinetic Energy in the **Label** text field.
- 3 Locate the **Data** section. From the **Dataset** list, choose **None**.
- 4 Locate the **Title** section. From the **Title type** list, choose **None**.
- 5 Locate the **Plot Settings** section.
- 6 Select the **x-axis label** checkbox. In the associated text field, type Time (s).
- 7 Select the **y-axis label** checkbox. In the associated text field, type Average kinetic energy (J).
- 8 Locate the **Axis** section. Select the **y-axis log scale** checkbox.

### Global 1

- 1 In the **Average Kinetic Energy** toolbar, click  **Global**.
- 2 In the **Settings** window for **Global**, locate the **Data** section.

3 From the **Dataset** list, choose **Grain 1**.

4 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
gran.ave(gran.KEtot)	J	Hertz-MD

5 Locate the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Cycle**.

#### *Global 2*

1 Right-click **Global 1** and choose **Duplicate**.

2 In the **Settings** window for **Global**, locate the **Data** section.

3 From the **Dataset** list, choose **Grain 2**.

4 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
gran.ave(gran.KEtot)	J	Adhesion

#### *Global 3*

1 Right-click **Global 2** and choose **Duplicate**.

2 In the **Settings** window for **Global**, locate the **Data** section.

3 From the **Dataset** list, choose **Grain 3**.

4 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
gran.ave(gran.KEtot)	J	Adhesion + vdW

5 In the **Average Kinetic Energy** toolbar, click  **Plot**.

The average kinetic energy of the grains as a function of time for the three force models should resemble [Figure 5](#).