



Model created in COMSOL Multiphysics 6.4

Grain Separation Using Vibrating Sieves

Introduction

Grain separation is an important process wherein a mixture of various species of grains are separated to isolate the grains based on their desired characteristics. It is used in numerous industries including agriculture, mining, food processing, and milling. A common and simple method of grain separation that utilizes gravity is to pass the grains through a sieve with holes so that the grains smaller than the holes can pass through, while the sieve filters out the larger grains. A series of sieves of different sizes can be strategically constructed to achieve multiple levels of separation based on grain size and shape. The separation speed can often be enhanced by vibrating the sieves, which has the effect of keeping the grains in constant motion, thus increasing the chances of a grain encountering a hole.

This example uses the Granular Flow interface to model the separation of a mixture containing grains of three sizes as they pass through two vibrating sieves with holes of different sizes. The separation efficiency of the machine is then quantified.

Model Definition

The geometry of the model consists of a rectangular box of dimensions 40 cm-by-100 cm-by-40 cm. The top surface has a rectangular inlet surface through which grains of diameters 10, 20, and 30 mm enter the box. Two sieves are located at heights of 10 cm and 20 cm from the bottom surface. The top sieve has a rectangular array of square-shaped holes of length 25 mm. The bottom sieve similarly has holes of length 12.5 mm. The entire box is then tilted so that it has an inclination angle of 5 degrees. This tilt helps the grains move away from the inlet surface through gravity, thus enhancing the chances of the grains encountering the holes, and also keeps the separated grains moving. The geometry is presented in [Figure 1](#) which shows the domain being divided into three compartments by the two sieves.

The grains are continuously released through the inlet for a period of 1.0 s at a frequency of 0.1 s. At each release time, a total of 500 grains are released such that the three types of grains have the same mass fractions. Both the sieves are vibrated with an amplitude of 5 mm and a frequency of 11 Hz. The vibrations are confined to the plane defined by the sieve. The mixture of grains pass through the two vibrating sieves which are designed such that the top sieve filters out the largest grains, while the bottom sieve filters out the medium-sized grains. The model is simulated for a total of 10 s.

Since, an ideal operation of the process filters out the three types of grains completely into the three compartments, we define a separation efficiency parameter to quantify the quality of the process. The separation efficiency is defined for each type of grain as the ratio of the

total mass of the grains (belonging to that grain type) in its ideal compartment divided by the total mass of that grain type in the domain.

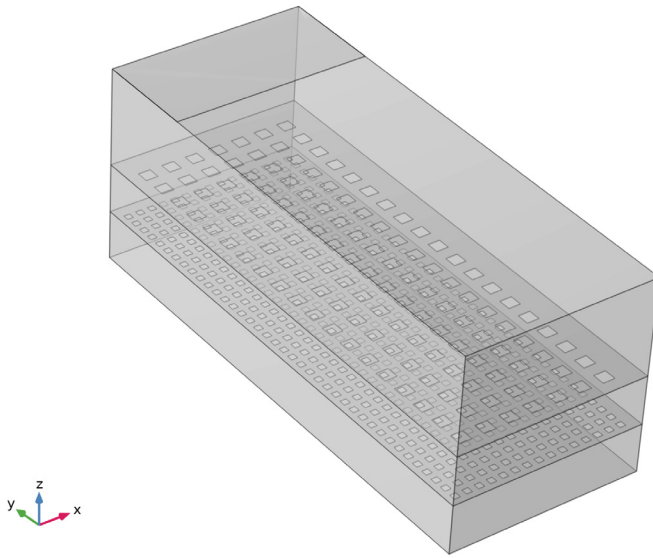


Figure 1: Model geometry.

Notes on the COMSOL Implementation

The model is solved using a single **Time Dependent** study step. The three types of grains are released into the domain using the **Inlet** feature. The vibration of the sieves is controlled by the **Wall Movement** settings in the **Wall** feature where a prescribed displacement is used to specify the rigid body motion of the sieves. This displacement is explicitly calculated by defining variables in the **Variables** node.

In order to evaluate the compartment that a grain belongs to at any given time, it is enough to measure the normal distance from the bottom stationary surface of the domain. When the entire domain is tilted as is the case in this model, this distance calculation can be simplified by defining a new orthogonal coordinate system whose *xy*-plane is oriented along the bottom surface. In this model, this is achieved by adding a **System from Geometry** node under the **Boundary System** node. The *z* coordinate in this new coordinate system can be used to identify the compartment a grain belongs to.

The maximum allowed time step taken by the **Time-Dependent Solver** in Granular Flow is often limited by the collision time scales of the grain-grain and grain-wall interactions. The collision time scales are often strongly dependent on the material properties such as density

and Young's modulus with stiffer grains generally exhibiting smaller collision times, thus requiring even smaller time steps. In many instances however, the stiffness of the grains and walls have a very limited effect on the bulk behavior of granular materials, and the materials can thus be made artificially less stiff in order to speed up the simulations.

Results and Discussion

The grain positions at the end of the 10 s is shown in [Figure 2](#). The grains are colored based on their diameters. It can be seen that the top sieve completely filters out the largest (red) grains since they are too big to pass through its holes. Similarly, the bottom sieve has holes that are too small for the medium-sized (green) grains to pass through and therefore only the smallest grains are found in the bottom compartment. However, the separation is not ideal as some of the small grains can be seen in all the compartments, and some of the medium-sized grains can also be seen in the top compartment.

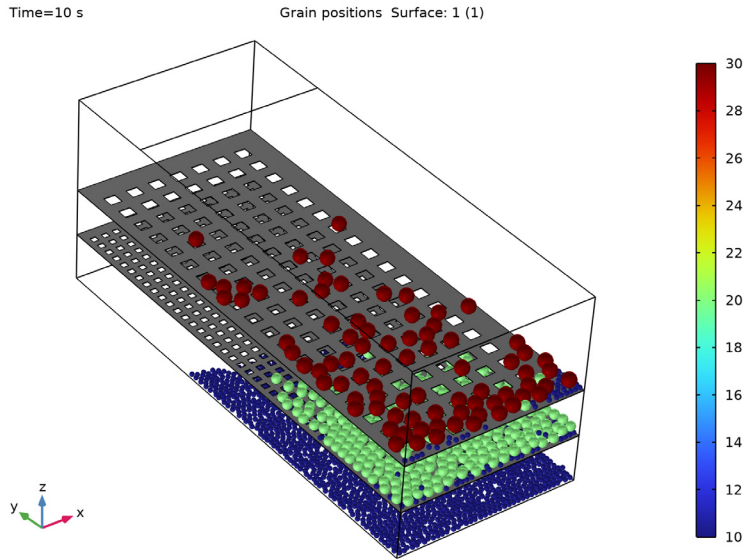


Figure 2: Grains of three different sizes being separated using vibrating sieves. The grains are colored by their diameters in mm.

[Figure 3](#) shows the overall number of the small grains in each compartment (bin) as a function of time. The number of small grains in the top bin rises sharply in the beginning as grains are released into the domain. However, as time progresses, this number slowly decreases as these grains filter down into the middle and bottom bins. The number of small grains in the bottom bin rises steadily until most of the grains have reached this bin, while the number in the middle bin rises slowly and then quickly falls as expected.

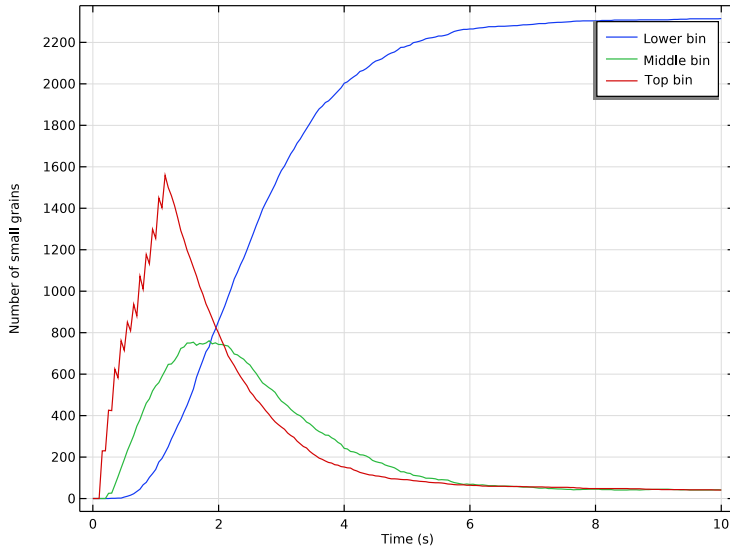


Figure 3: The distribution of the small grains across the three bins.

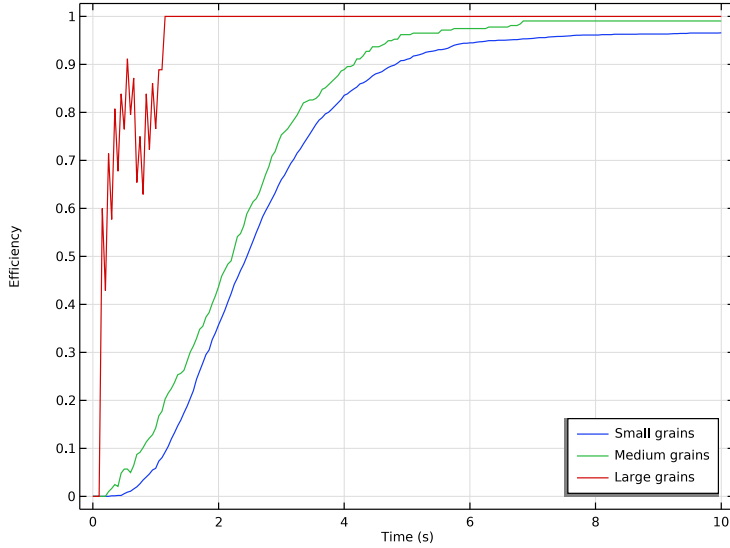


Figure 4: The separation efficiency of the sieves as a function of time.


Finally, the separation efficiency for all three grain types are shown as a function of time in [Figure 4](#). The efficiency curves for the small and medium grains increase steadily as a function of time and saturates at values between 0.95 and 1.0, while the efficiency curves for the large grains exhibit a noisy behavior up to 1.0 s. This is due to new grains being released at discrete time intervals. After 1 s however, the separation efficiency of the large grains quickly approaches 1.0 as they are completely filtered out by the top sieve.

Application Library path: Granular_Flow_Module/Mixing_and_Separation/
vibrating_sieves




Modeling Instructions

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

Parameters 1



- 1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.
- 2 In the **Settings** window for **Parameters**, locate the **Parameters** section.
- 3 Click  **Load from File**.
- 4 Browse to the model's Application Libraries folder and double-click the file `vibrating_sieves_parameters.txt`.

GEOMETRY I

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.



Work Plane 1 (wp1)

- 1 In the **Geometry** toolbar, click  **Work Plane**.
- 2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
- 3 In the **z-coordinate** text field, type Lz.
- 4 Click  **Build Selected**.

Work Plane 1 (wp1) > Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 1 (wp1) > Rectangle 1 (r1)

- 1 In the **Work Plane** toolbar, click  **Rectangle**.
- 2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type Lx.
- 4 In the **Height** text field, type inlet_width.
- 5 Locate the **Position** section. In the **yw** text field, type Ly - inlet_width.
- 6 Click  **Build Selected**.


Work Plane 2 (wp2)

- 1 In the **Model Builder** window, right-click **Geometry I** and choose **Work Plane**.
- 2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
- 3 In the **z-coordinate** text field, type Lz/4.

Work Plane 2 (wp2) > Plane Geometry



In the **Model Builder** window, click **Plane Geometry**.

Work Plane 2 (wp2) > Rectangle 1 (r1)



- 1 In the **Work Plane** toolbar, click  **Rectangle**.
- 2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type Lx.

4 In the **Height** text field, type L_y .





Work Plane 2 (wp2) > Square 1 (sq1)

- 1 In the **Work Plane** toolbar, click  **Square**.
- 2 In the **Settings** window for **Square**, locate the **Size** section.
- 3 In the **Side length** text field, type $hole_width$.
- 4 Locate the **Position** section. In the **xw** text field, type $hole_width$.
- 5 In the **yw** text field, type $hole_width$.
- 6 Click  **Build Selected**.

Work Plane 2 (wp2) > Array 1 (arr1)

- 1 In the **Work Plane** toolbar, click  **Transforms** and choose **Array**.
- 2 Select the object **sq1** only.
- 3 In the **Settings** window for **Array**, locate the **Size** section.
- 4 In the **xw size** text field, type $\text{floor}(0.99 * L_x / hole_width / 2)$.
- 5 In the **yw size** text field, type $\text{floor}(0.99 * L_y / hole_width / 2)$.
- 6 Locate the **Displacement** section. In the **xw** text field, type $2 * hole_width$.
- 7 In the **yw** text field, type $2 * hole_width$.
- 8 Click  **Build Selected**.

Work Plane 2 (wp2) > Difference 1 (dif1)

- 1 In the **Work Plane** toolbar, click  **Booleans and Partitions** and choose **Difference**.
- 2 Select the object **r1** only.
- 3 In the **Settings** window for **Difference**, locate the **Difference** section.
- 4 From the **Objects to subtract** list, choose **All objects**.
- 5 Click to select the  **Activate Selection** toggle button for **Objects to subtract**.
- 6 In the list box, select **r1**.
- 7 Click the  **Remove from Selection** button for **Objects to subtract**.
- 8 Click  **Build Selected**.

Work Plane 3 (wp3)

- 1 In the **Model Builder** window, under **Component 1 (comp1) > Geometry 1** right-click **Work Plane 2 (wp2)** and choose **Duplicate**.
- 2 In the **Model Builder** window, click **Work Plane 3 (wp3)**.
- 3 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

4 In the **z-coordinate** text field, type $Lz/2$.

Work Plane 3 (wp3) > Square 1 (sq1)

1 In the **Model Builder** window, expand the **Component 1 (comp1) > Geometry 1 > Work Plane 3 (wp3) > Plane Geometry** node, then click **Square 1 (sq1)**.

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

3 In the **Side length** text field, type $hole_width*2$.

4 Locate the **Position** section. In the **xw** text field, type $hole_width*2$.

5 In the **yw** text field, type $hole_width*2$.

6 Click  **Build Selected**.

Work Plane 3 (wp3) > Array 1 (arr1)

1 In the **Model Builder** window, click **Array 1 (arr1)**.

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

3 In the **xw size** text field, type $\text{floor}(0.99*Lx/hole_width/4)$.

4 In the **yw size** text field, type $\text{floor}(0.99*Ly/hole_width/4)$.

5 Locate the **Displacement** section. In the **xw** text field, type $4*hole_width$.

6 In the **yw** text field, type $4*hole_width$.

7 Click  **Build Selected**.

Rotate 1 (rot1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Transforms > Rotate**.

2 In the **Settings** window for **Rotate**, locate the **Input** section.

3 From the **Input objects** list, choose **All objects**.

4 Locate the **Rotation** section. From the **Axis type** list, choose **x-axis**.

5 In the **Angle** text field, type θ .

6 Click  **Build Selected**.

Work Plane 4 (wp4)


1 In the **Geometry** toolbar, click  **Work Plane**.




2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane type** list, choose **Face parallel**.

4 On the object **rot1(1)**, select Boundary 1 only.

5 Click  **Build All Objects**.

6 Click the  **Show Grid** button in the **Graphics** toolbar.


- 7 Click the  **Transparency** button in the **Graphics** toolbar.
- 8 Click the  **Go to Default View** button in the **Graphics** toolbar. The geometry should look like [Figure 1](#).
- 9 In the **Definitions** toolbar, click  **Coordinate Systems** and choose **System from Geometry**.

DEFINITIONS

System from Geometry 2 (sys2)

- 1 In the **Settings** window for **System from Geometry**, locate the **System from Geometry** section.
- 2 From the **Work plane** list, choose **Work Plane 4 (wp4)**.




Variables 1

- 1 In the **Definitions** toolbar, click  **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
vib_dispx	$\text{vib_amp} * \sin(\text{vib_om} * t) * \cos(\text{vib_beta})$	m	Vibration displacement x
vib_dispy	$\text{vib_amp} * \sin(\text{vib_om} * t) * \sin(\text{vib_beta}) * \cos(\text{theta})$	m	Vibration displacement y
vib_dispz	$\text{vib_amp} * \sin(\text{vib_om} * t) * \sin(\text{vib_beta}) * \sin(\text{theta})$	m	Vibration displacement z
bin_idx	$\text{ceil}(-4 * \text{sys2.x3} / Lz)$		Bin index

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 ³	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*Eg	Pa	Basic
Poisson's ratio	nu	pois	l	Basic

GRANULAR FLOW (GRAN)

Small Grains

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**, type Small Grains in the **Label** text field.

3 Locate the **Granular Material Properties** section. From the **Granular material** list, choose **Grains (mat1)**.

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

Medium Grains

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

2 In the **Settings** window for **Grain Properties**, type Medium Grains in the **Label** text field.

3 Locate the **Granular Material Properties** section. From the **Granular material** list, choose **Grains (mat1)**.

4 Locate the **Size** section. In the d_g text field, type 2*dg.

Large Grains

- 1 Right-click **Medium Grains** and choose **Duplicate**.
- 2 In the **Settings** window for **Grain Properties**, type Large Grains in the **Label** text field.
- 3 Locate the **Size** section. In the d_g text field, type $3*d_g$.


Contact Between Grains I

- 1 In the **Model Builder** window, click **Contact Between Grains I**.
- 2 In the **Settings** window for **Contact Between Grains**, locate the **Contact Properties** section.
- 3 In the e_n text field, type e .
- 4 In the e_t text field, type e .
- 5 In the μ_s text field, type 0.5 .
- 6 In the μ_T text field, type 0.01 .
- 7 In the μ_{tw} text field, type 0.01 .

Contact with Walls I

- 1 In the **Model Builder** window, click **Contact with Walls I**.
- 2 In the **Settings** window for **Contact with Walls**, locate the **Contact Properties** section.
- 3 In the e_n text field, type e .
- 4 In the e_t text field, type e .
- 5 In the μ_s text field, type 0.5 .
- 6 In the μ_T text field, type 0.01 .
- 7 In the μ_{tw} text field, type 0.01 .


Inlet I

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Inlet**.
- 2 Select Boundary 11 only.
- 3 In the **Settings** window for **Inlet**, locate the **Release Times** section.
- 4 In the **Release times** text field, type $\text{range}(0, 0.1, 1)$.
- 5 Locate the **Released Grain Properties** section. From the **Distribution of released grain properties** list, choose **Mass fraction**.
- 6 In the N text field, type 500 .

7 In the table, enter the following settings:

Released grain properties	Mass fraction of grains
Small Grains	1
Medium Grains	1
Large Grains	1


Vibrating Sieves

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 In the **Settings** window for **Wall**, type **Vibrating Sieves** in the **Label** text field.
- 3 Select **Boundaries 6** and **9** only.
- 4 Locate the **Wall Movement** section. From the **Wall motion** list, choose **Translation**.
- 5 Specify the dx vector as

vib_dispx	X
vib_dispy	Y
vib_dispz	Z

STUDY I

Step 1: Time Dependent

- 1 In the **Model Builder** window, under **Study I** click **Step 1: Time Dependent**.
- 2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.
- 3 In the **Output times** text field, type **range(0,0.05,10)**.
- 4 In the **Study** toolbar, click  **Compute**.




RESULTS

Grain Positions (gran)



In the **Model Builder** window, expand the **Grain Positions (gran)** node.

Color Expression 1


- 1 In the **Model Builder** window, expand the **Results > Grain Positions (gran) > 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 From the **Unit** list, choose **mm**.

- 5 Click the  **Go to Default View** button in the **Graphics** toolbar.
- 6 Click the  **Transparency** button in the **Graphics** toolbar.
- 7 In the **Grain Positions (gran)** toolbar, click  **Plot**. The grain positions at the end of the study should resemble [Figure 2](#).


Animation 1

- 1 In the **Grain Positions (gran)** toolbar, click  **Animation** and choose **Player**.
- 2 In the **Settings** window for **Animation**, locate the **Frames** section.
- 3 From the **Frame selection** list, choose **All**.
- 4 Click the  **Play** button in the **Graphics** toolbar.


Distribution of small grains

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Distribution of small grains in the **Label** text field.
- 3 Locate the **Data** section. From the **Dataset** list, choose **Grain 1**.
- 4 Locate the **Plot Settings** section.
- 5 Select the **x-axis label** checkbox. In the associated text field, type Time (s).
- 6 Select the **y-axis label** checkbox. In the associated text field, type Number of small grains.


Global 1

- 1 In the **Distribution of small grains** toolbar, click  **Global**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
<code>gran.sum(if(gran.sidx==1&&bin_idx==1,1,0))</code>	1	Lower bin
<code>gran.sum(if(gran.sidx==1&&bin_idx==2,1,0))</code>	1	Middle bin
<code>gran.sum(if(gran.sidx==1&&bin_idx==3,1,0))</code>	1	Top bin


- 4 In the **Distribution of small grains** toolbar, click  **Plot**. The distribution of the small grains across the three bins as a function of time should resemble [Figure 3](#).

Separation Efficiency

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Separation Efficiency in the **Label** text field.

- 3 Locate the **Data** section. From the **Dataset** list, choose **Grain 1**.
- 4 Locate the **Plot Settings** section.
- 5 Select the **x-axis label** checkbox. In the associated text field, type Time (s).
- 6 Select the **y-axis label** checkbox. In the associated text field, type Efficiency.
- 7 Locate the **Legend** section. From the **Position** list, choose **Lower right**.

Global 1

- 1 In the **Separation Efficiency** toolbar, click  **Global**.
- 2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
<code>gran.sum(if(gran.sidx==1&&bin_idx==1, gran.mg,0))/gran.sum(if(gran.sidx==1, gran.mg,0))</code>	1	Small grains
<code>gran.sum(if(gran.sidx==2&&bin_idx==2, gran.mg,0))/gran.sum(if(gran.sidx==2, gran.mg,0))</code>	1	Medium grains
<code>gran.sum(if(gran.sidx==3&&bin_idx==3, gran.mg,0))/gran.sum(if(gran.sidx==3, gran.mg,0))</code>	1	Large grains

- 4 In the **Separation Efficiency** toolbar, click  **Plot**. The separation efficiency as a function of time should resemble [Figure 4](#).