

Ebullated Bed: Setup and Analysis

CPFD Software

www.cdfd-software.com

Ebullated Bed Reactor

Model of an ebullated bed used to hydrocrack vacuum resid (VR) with hydrogen gas

3-phase VLS (vapor, liquid, solid) with liquid domain

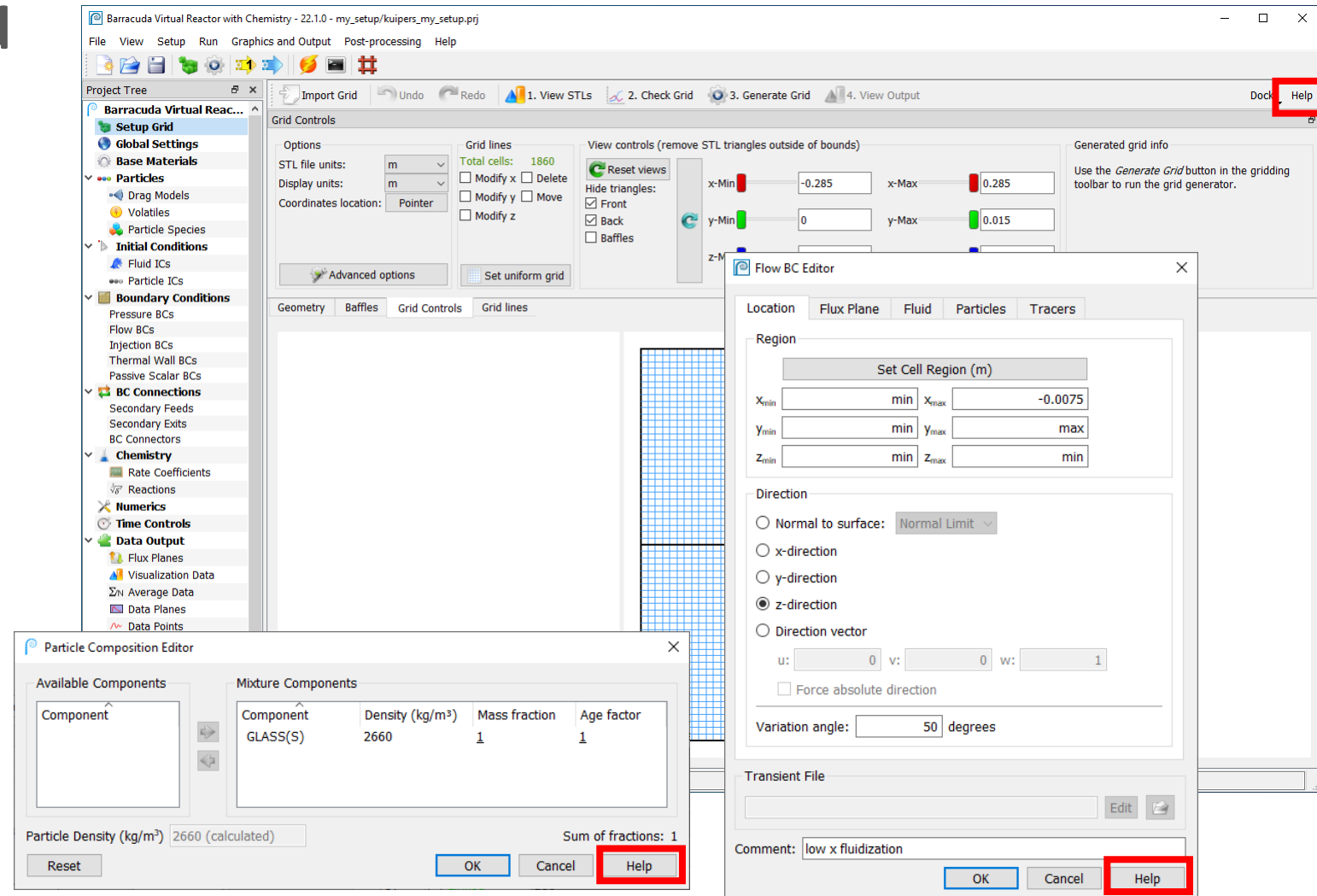
Isothermal and reacting system



How to Get More Information

All training materials have a limited amount of information about Barracuda and the GUI.

If you want to learn more, click on the Help button in the relevant dialog. This brings up the corresponding section of the User Manual.



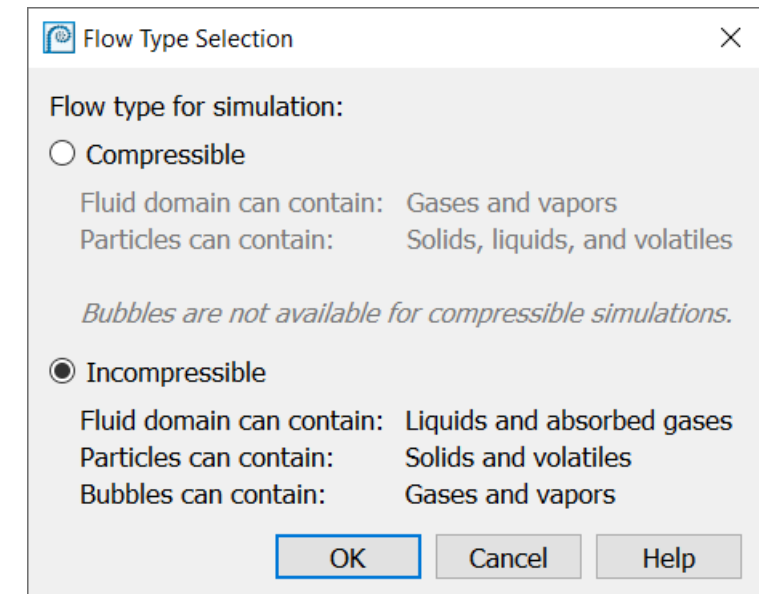
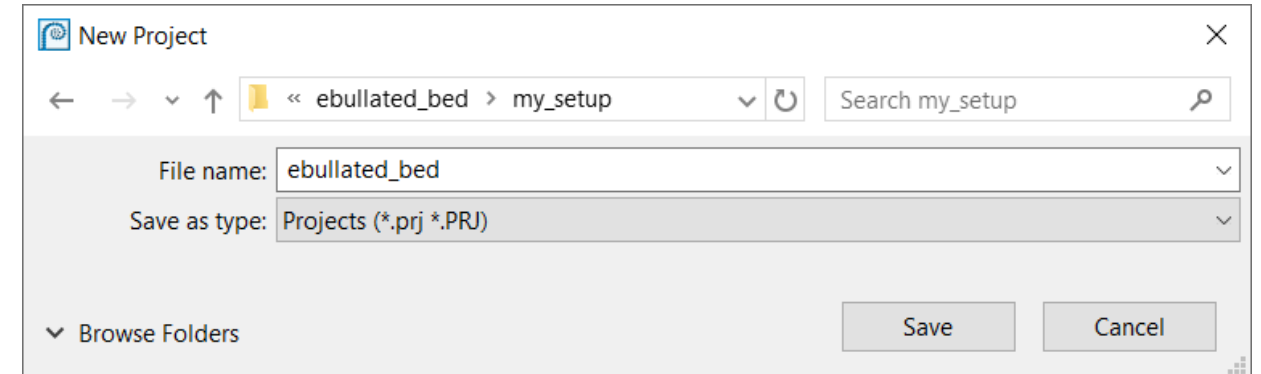
Project File

Make a new incompressible project file
in the supplemental training directory:

`\ebullated_bed\my_setup\`

With the project name:

`ebullated_bed.prj`



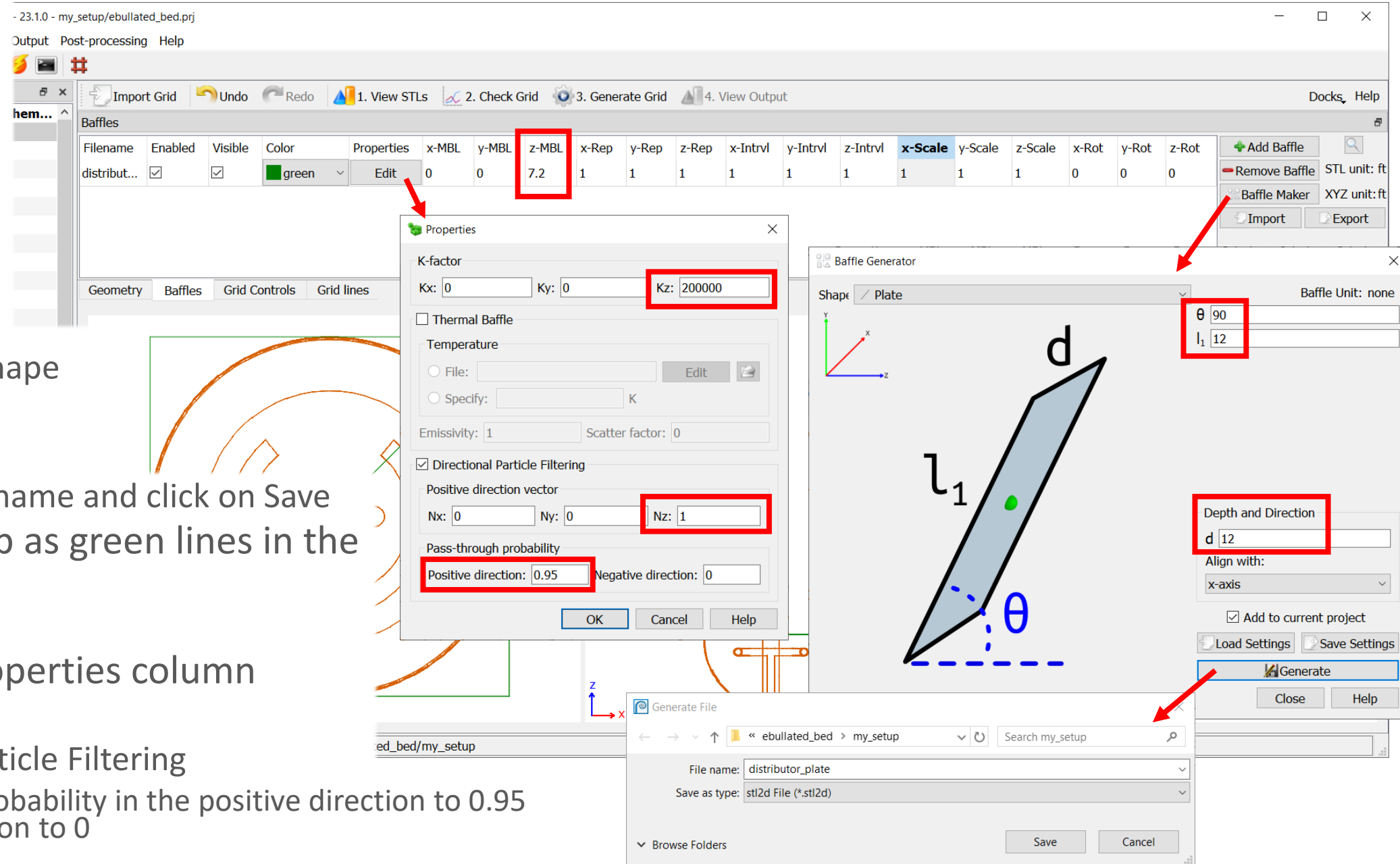
Setup Grid

Geometry tab:

- Add ebullated_bed.stl

Baffles tab:

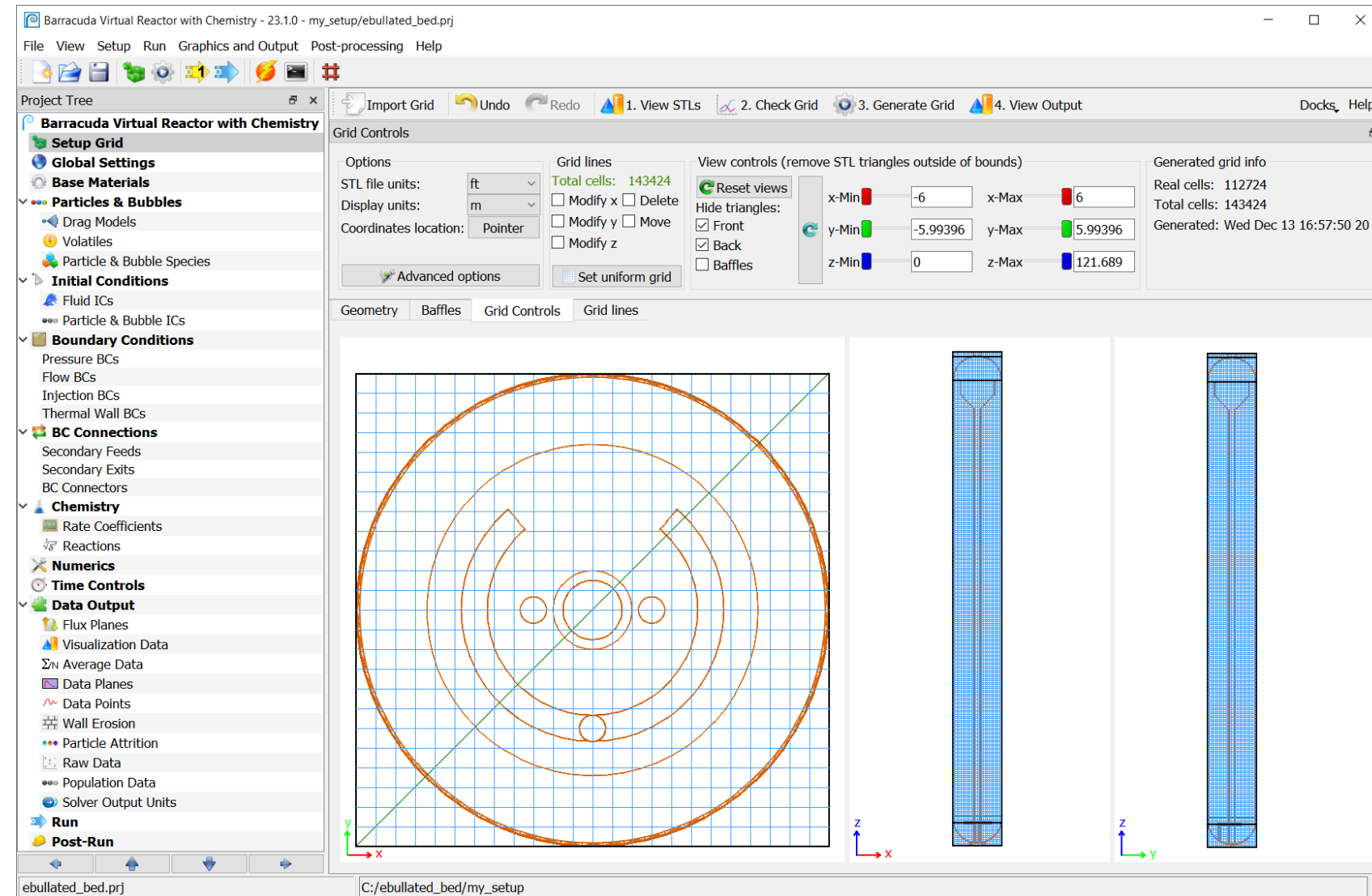
- Click on Baffle Maker
 - Select Plate for the Shape
 - Set l_1 and d to 12
 - Click Generate
 - Give the baffle a File name and click on Save
- The baffle will show up as green lines in the three grid panes
- Set the z-MBL to 7.2
- Click on Edit in the Properties column
 - $K_z = 200000$
 - Select Directional Particle Filtering
 - Set Pass-through probability in the positive direction to 0.95 and negative direction to 0
 - Click OK



Setup Grid

Grid Controls tab:

- Set STL file units to ft
- Select Merge and remove small cells in Advanced options
- Set uniform grid of 150,000 cells
- Modify z grid lines to capture the outlet pipe, recycle pan, and bubble ring
- Click on Generate Grid



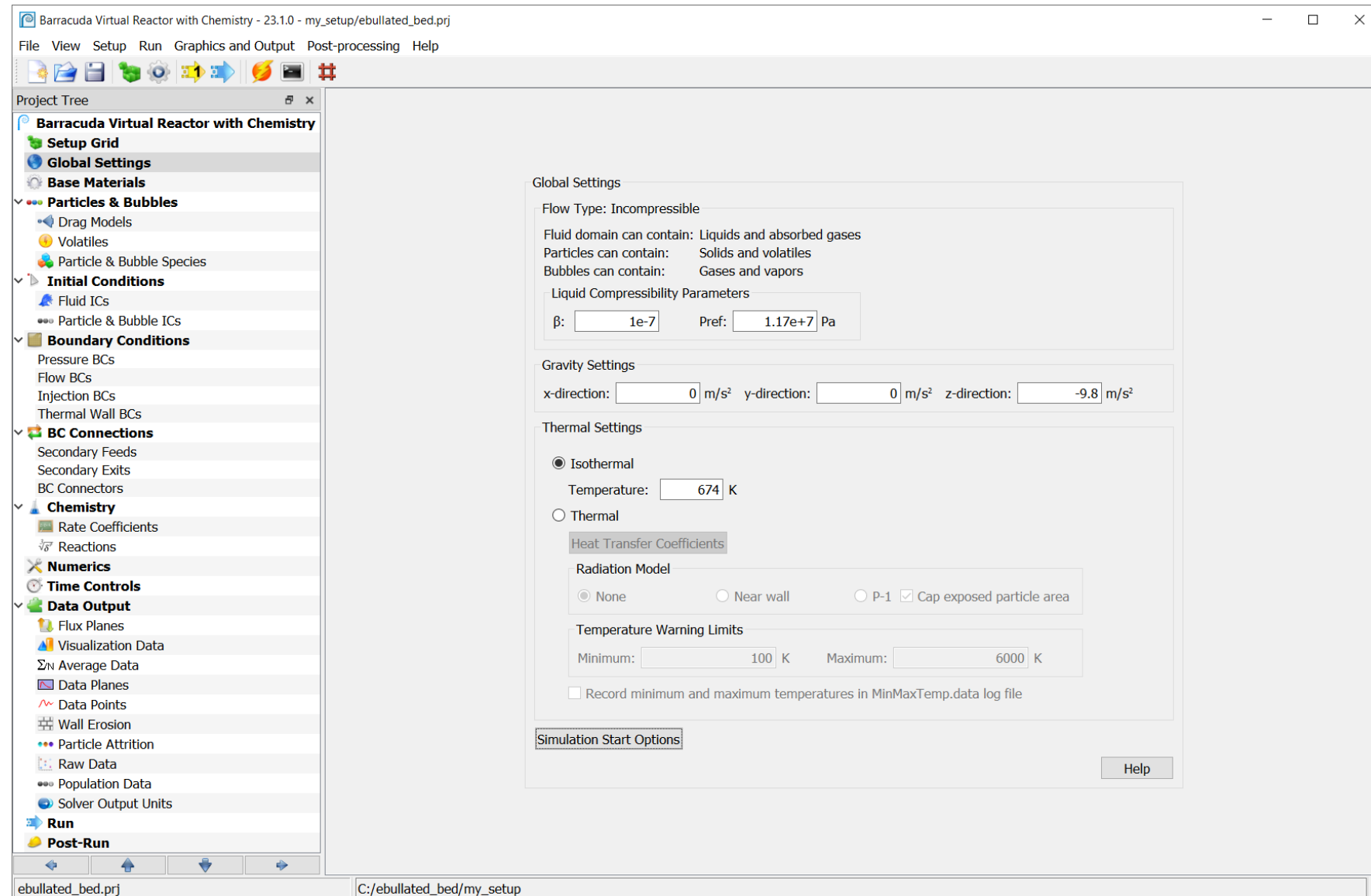
Global Settings

Liquid Compressibility Parameters:

- $\beta = 1e-7$
- $Pref = 1.17e+7$

Set Gravity in negative z-direction

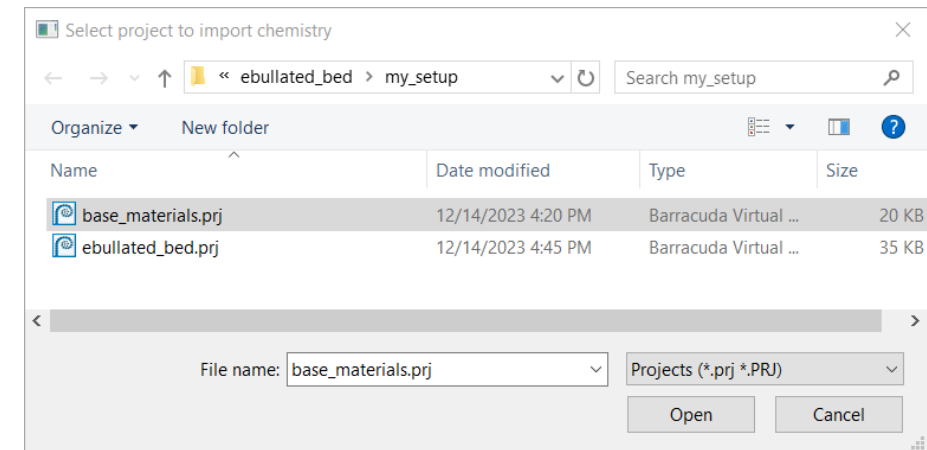
Select Isothermal and set the temperature to 674 K



Base Materials

The materials in this project have adjusted values for many physical properties. Import the base materials for this project:

- Click on File → Import from project
- Browse to select base_materials.prj and click Open
- Select Import Base Materials with Append option
- Click OK
- Verify that the materials match the list on the right



Project Material List

Material name	Phase(s)	Description
Catalyst	S	Catalyst
Diesel	L/V	Diesel
H2	G	H2 HYDROGEN. REF ELEMENT
Naphtha	G	C9H20 N-NONANE
Propane	G	Propane
VGO	L/V	Vacuum Gas Oil
VR	L/V	Vacuum Residue

Add Edit Copy Delete

Particles & Bubbles

Close pack volume fraction: 0.6

Normal-to-wall momentum retention: 0.5

Tangent-to-wall momentum retention: 0.5

Diffuse bounce: 4

Select Bubble Coalescence & Breakup

- Coalescence factor: 0.01
- Maximum bubble size: 0.1

Particles & Bubbles

Contact and Collision Models

Close pack volume fraction:

Maximum momentum redirection from collision:

☐ Blended acceleration model for the contact force

Stress Model Options

Wall Interactions

Normal-to-wall momentum retention:

Tangent-to-wall momentum retention:

Diffuse bounce:

Cloud Options

☒ Allow clouds to represent fractional particles/bubbles

Dense Fluid Forces

☒ Enable virtual mass force

☒ Enable lift force

☒ Bubble Coalescence & Breakup

Coalescence factor:

Maximum bubble size: m

Help

Particle Species

Create the Catalyst particle species:

- Click on Add Particle
- 100% Catalyst(S)
- 1660 micron diameter
- Use global value for close pack volume fraction
- Set sphericity to 0.713
- Use Nonspherical- Ganser drag model

Particle & Bubble Species Manager									
Species-ID	Species Type	Comment	Materials	Size	Sphericity	Emissivity	Drag model	Agglomeration	
001	Particle	Catalyst	Catalyst	1660 to 1660 micron-diameter	0.713	1	Nonspherical-Ganser	Off	
002	Bubble	Bubble	H2	400 to 1500 micron-diameter	-	-	Tomiyama-Roghair	Off	

Particle Composition Editor

Available Components		Mixture Components			
Component		Component	Density (kg/m ³)	Mass fraction	Age factor
		Catalyst(S)	1814	1	1

Particle Density (kg/m³) 1814 (calculated) Sum of fractions: 1

Reset OK Cancel Help

Particle Species Editor

Species-ID: 001

Comment: Catalyst

Materials: Applied Materials

Size Distribution

☐ File: Edit

Import Preset Distribution:

☒ Size Range:

Minimum: 1660 Maximum: 1660 micron-diameter

Close Pack Volume Fraction

☒ Use global value: 0.6 ☐ Specify value:

Surface and Shape

Sphericity: 0.713

Emissivity: 1.0

Scattering Factor: 0.0

☐ Agglomeration

Size Cut Point: 36 micron-diameter

Effective Size Filename: Edit

Drag Model

Model Name: Nonspherical-Ganser

Name	Link To Default	Value
------	-----------------	-------

☒ Multiplier (constant): 1

☐ Multiplier (predefined):

☐ Multiplier (from file):

OK Cancel Help

Bubble Species

Create the bubble species:

- Click on Add Bubble
- 100% H₂(G)
- 400-1500 micron diameter
- Specify a close pack volume fraction of 0.85
- Use Tomiyama-Roghair drag model

Particle & Bubble Species Manager

Species-ID	Species Type	Comment	Materials	Size	Sphericity	Emissivity	Drag model	Agglomeration
001	Particle	Catalyst	Catalyst	1660 to 1660 micron-diameter	0.713	1	Nonspherical-Ganser	Off
002	Bubble	Bubble	H2	400 to 1500 micron-diameter	-	-	Tomiyama-Roghair	Off

Mixture

Available Components

Component
Diesel(V)
Naphtha(G)
Propane(G)
VGO(V)
VR(V)

Mixture

Component	Fraction
H2(G)	1

Specify mixture by: Mass fraction Sum of fractions: 1

Reset OK Cancel Help

Bubble Species Editor

Species-ID: 002

Comment: Bubble

Materials: Applied Materials

Size Distribution

☐ File: Edit

☒ Size Range:

Minimum: 400 Maximum: 1500 micron-diameter

Close Pack Volume Fraction

☐ Use global value: 0.6 ☒ Specify value: 0.85

Surface and Shape

Sphericity: 1.0

Emissivity: 1.0

Scattering Factor: 0.0

☐ Agglomeration

Size Cut Point: 36 micron-diameter

Effective Size Filename: Edit

Drag Model

Model Name: Tomiyama-Roghair

Name	Link To Default	Value
------	-----------------	-------

☒ Multiplier (constant): 1

☐ Multiplier (predefined):

☐ Multiplier (from file):

OK Cancel Help

Fluid ICs

Fluid IC

- Pressure = $1.17\text{e}+7$ Pa
- Fluid species mass fractions
 - 0.4 VR(L)
 - 0.4 VGO(L)
 - 0.2 Diesel(L)

Fluid IC Editor

☒ Initial Conditions

Temperature: 300 K

Pressure: $1.17\text{e}+7$ Pa

Velocity: 0 0 0 m/s

Fluid species: Define Fluids

☐ Initial Conditions from File

IC file:

Region

Set Cell Region (m)

X_{min} min X_{max} max

Y_{min} min Y_{max} max

Z_{min} min Z_{max} max

Comment

OK Cancel Help

Mixture

Available Components

Component
H2(G)
Naphtha(G)
Propane(G)

Mixture

Component	Fraction
VR(L)	0.4
VGO(L)	0.4
Diesel(L)	0.2

Specify mixture by: Mass fraction

Sum of fractions: 1

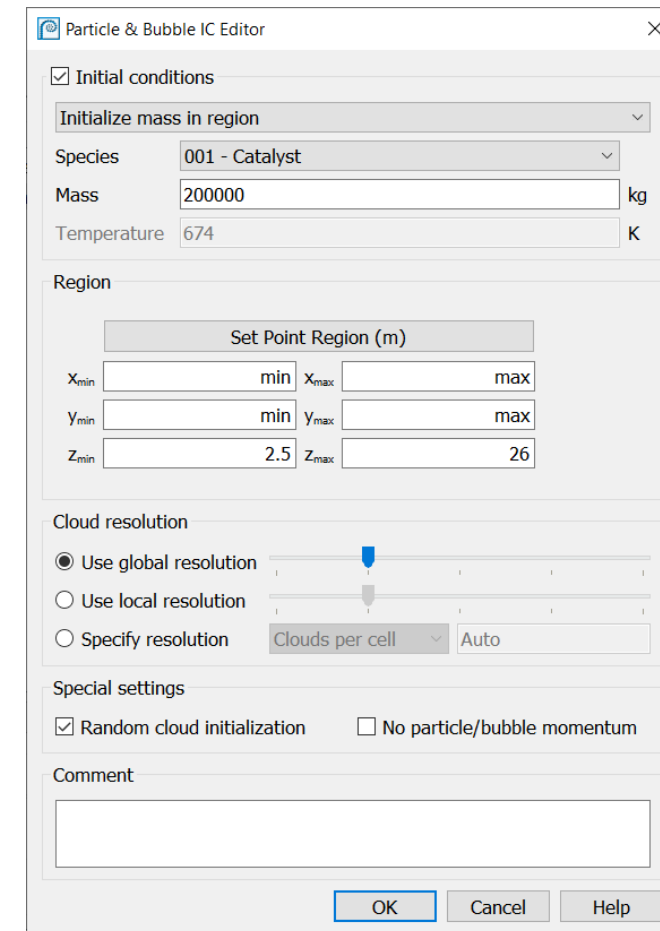
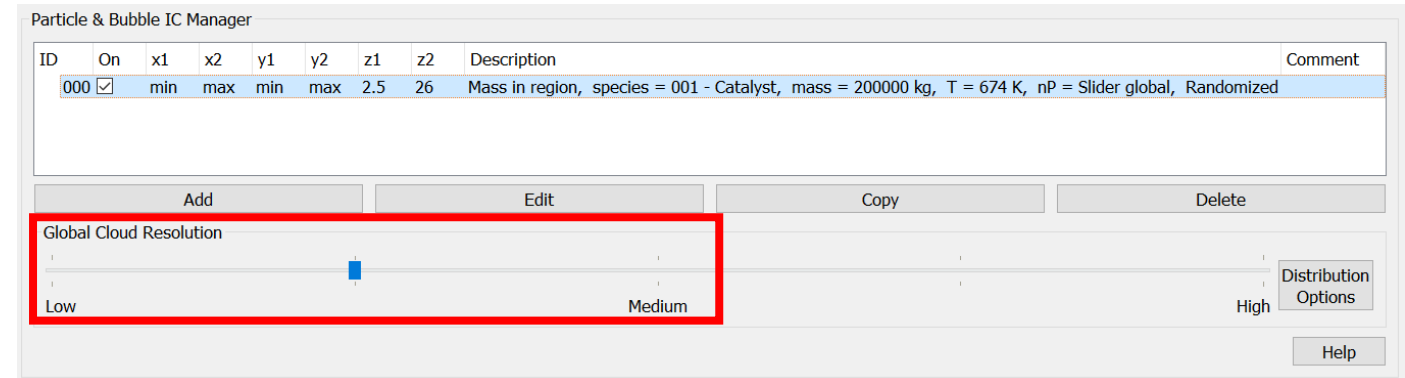
Reset OK Cancel Help

Particle & Bubble ICs

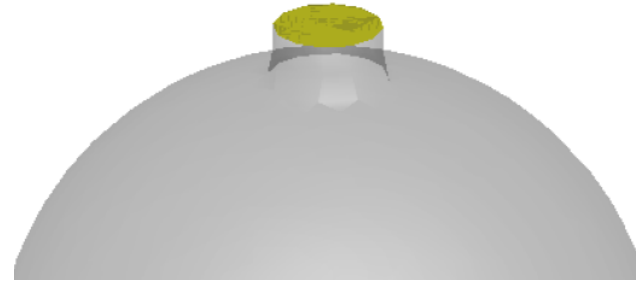
Set the Global Cloud Resolution between Low and Medium

Catalyst Particle IC

- Click on Add
- Initialize mass in region
- Species = 001 - Catalyst
- Mass = 200,000 kg
- Region
 - min, max for x-direction
 - min, max for y-direction
 - 2.5, 26 for z-direction
- Use global resolution



Pressure BCs



Add a pressure BC with information shown here for the outlet

Use 100% VR(L) for Applied Fluids

Pressure Boundary Conditions Editor

	Time (s)	Pressure (Pa)	Temperature (K)	Area Fraction	Particle Feed	K-Factor
1	0	1.17e7	674	1	On	0
2					On	

Add Row Delete Row Check Data Graph Update Simulation

File: Save Save As Close Help

Pressure BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Flow Conditions

☒ Transient file:

☐ Specify values:

Pressure BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Region

Select region (m)

X_{min} min X_{max} max

Y_{min} min Y_{max} max

Z_{min} max Z_{max} max

Direction

☐ x-direction
☐ y-direction
☒ z-direction

Pressure BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Behavior at Boundary

☐ No outflow
☒ Outflow with size filtering:
Minimum:
Maximum:
Units:

☐ Feed specified as volume fraction
☐ Feed specified as mass flux
☐ Feed specified as mass flow rate

Feed Settings

Comment:

Pressure BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Name:

Fluid species behavior:

☐ Bin by particle/bubble size bins

☒ Output raw particle/bubble data

☒ Output tracer data

Pressure BC Editor

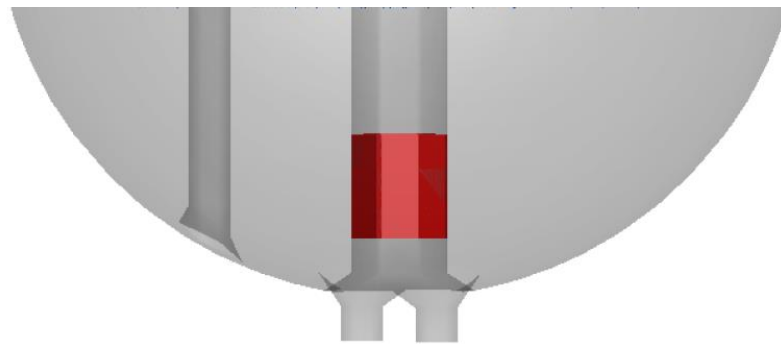
Location Flux Plane Fluid Particles/Bubbles Tracers

☒ Off
☐ Use BC Connector data
☐ Tracer feed
Species:
Resolution:

Comment:

Flow BCs

Add flow BC with information shown here for liquid recycle inlet under the baffle distributor



Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Region

Set Cell Region (m)

X_{min} -0.35 X_{max} 0.35

Y_{min} -0.35 Y_{max} 0.35

Z_{min} 0.5 Z_{max} 0.8

Direction

☒ Normal to surface: Normal Limit

☐ x-direction

☐ y-direction

☐ z-direction

☐ Direction vector

u: 0 v: 0 w:

☐ Force absolute direction

Variation angle: 15 degrees

Transient File

Comment:

OK Cancel

Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Name: FLUXBC_flow_recycle_inlet

Fluid species behavior:

Mass flow rate

☐ Bin by particle/bubble size 100 bins

☒ Output raw particle/bubble data

☒ Output tracer data

Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Flow Conditions

☐ Use transient file

☒ Use BC Connector data

☐ Specify values:

Velocity flow 0 m/s

Pressure: 0 Pa

Temperature: 674 K

Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

☐ Use transient file

☒ Use BC Connector data

☐ No outflow

☐ Outflow with size filtering:

Minimum: 0

Maximum: UNLIMITED

Units: micron-diameter

☐ Exit control: Edit

☐ Feed specified as volume fraction

☐ Feed specified as mass flux

☐ Feed specified as mass flow rate

Feed Settings

Edit Feed Feed Control

Transient File

Comment:

OK Cancel Help

Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

☐ Off

☒ Use BC Connector data

☐ Tracer feed

Species: 2000

Resolution:

☐ Use transient file

☒ Specify value: 100

Transient File

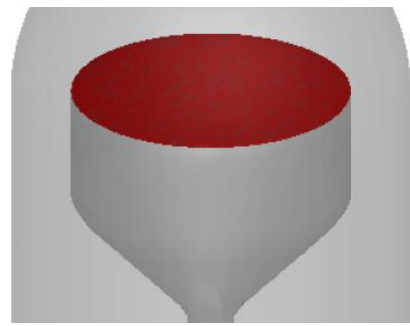
Comment:

OK Cancel Help

Flow BCs

Add flow BC with information shown here for recycle pan outlet

Use 100% VR(L) for Applied Fluids



Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Region

Set Cell Region (m)

X_{min} -1.3 X_{max} 1.3

Y_{min} -1.3 Y_{max} 1.3

Z_{min} 34.9 Z_{max} 35

Direction

☐ Normal to surface: Normal Limit

☐ x-direction

☐ y-direction

☒ z-direction

u:

☐ Force absolute

Variation angle:

Transient File

Comment:

Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Name: FLUXBC_flow_recycle_outlet

Fluid species behavior:

Mass flow rate

☐ Bin by particle/bubble size 100 bins

☒ Output raw particle/bubble data

☒ Output tracer data

Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

Flow Conditions

☒ Use transient file

☐ Use BC Connector data

☐ Specify values:

Velocity flow 0 m/s

Pressure: 0 Pa

Temperature: 674 K

Fluid Composition

Applied fluids: Define Fluids

Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

☐ Use transient file

☐ Use BC Connector data

☐ No outflow

☒ Outflow with size filtering:

Minimum: 0

Maximum: UNLIMITED

Units: micron-diameter

☐ Exit control: Edit

☐ Feed specified as volume fraction

☐ Feed specified as mass flux

☐ Feed specified as mass flow rate

Feed Settings

Edit Feed Feed Control

Transient File

outlet_flow_recycle.sff

Edit

Comment:

OK Cancel Help

Flow Boundary Conditions Editor

	Time (s)	Mass Flow Rate (kg/s)	Temperature (K)	Pressure (Pa)
1	0	-353	674	1.17e+7
2				

+ Add Row - Delete Row ✓ Check Data 📊 Graph ↻ Update Simulation

File: outlet_flow_recycle.sff Save Save As Close Help

Transient File

outlet_flow_recycle.sff

Edit

Comment:

OK Cancel Help

Flow BC Editor

Location Flux Plane Fluid Particles/Bubbles Tracers

☒ Off

☐ Use BC Connector data

☐ Tracer feed

Species: 2000

Resolution:

☐ Use transient file

☒ Specify value: 100

Transient File

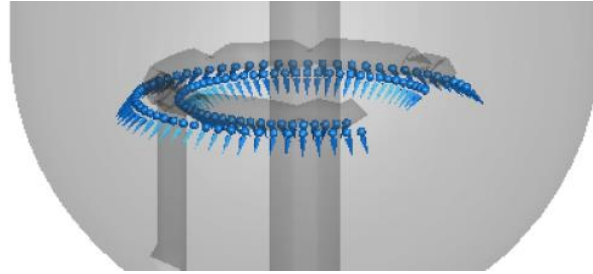
outlet_flow_recycle.sff

Edit

Comment:

OK Cancel Help

Injection BCs



Add H2 bubble injection BC

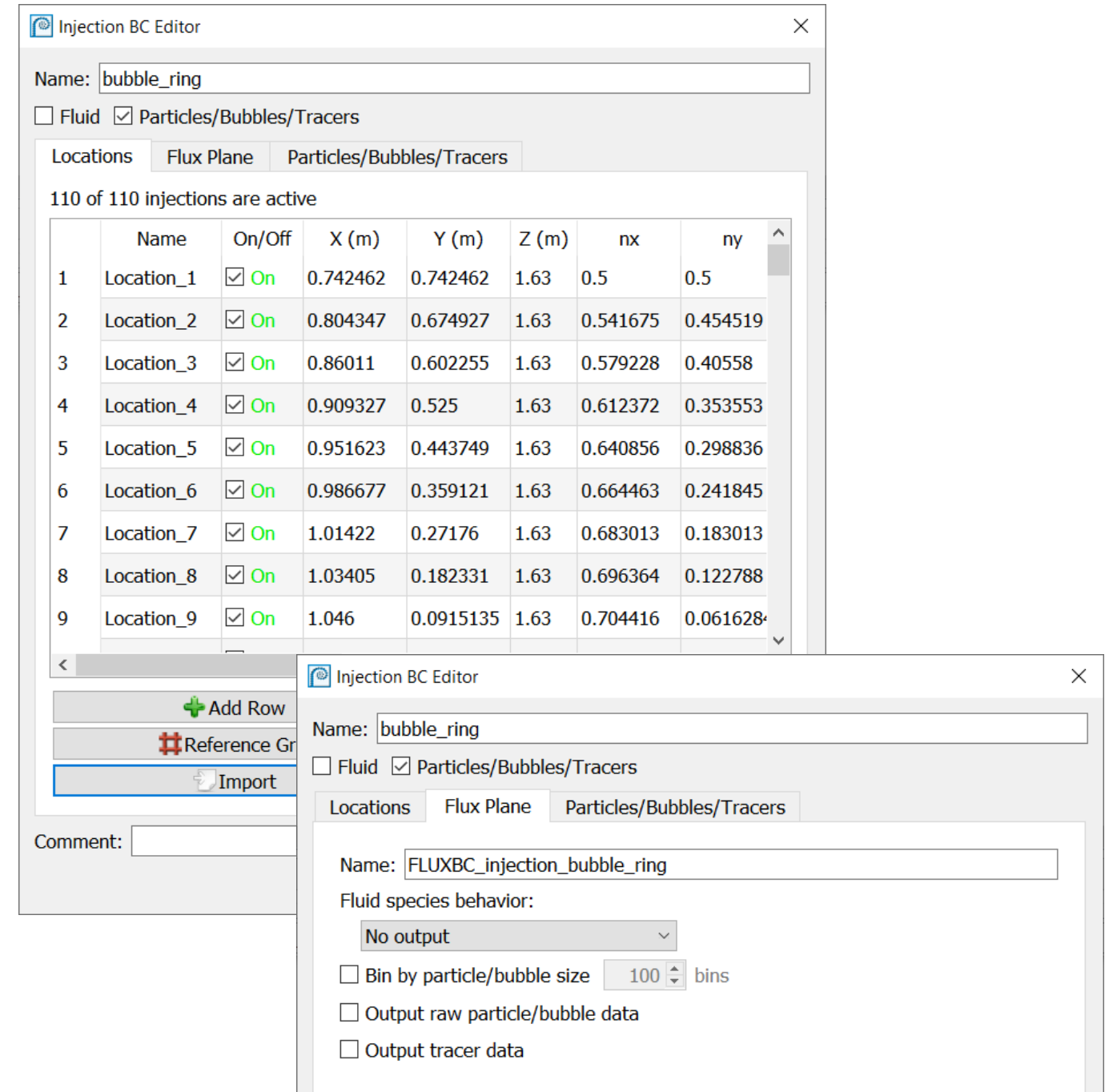
- Name = bubble_ring
- Select Particles/Bubbles/Tracers

Locations tab

- Import bubble_ring_locations.csv

Flux Plane tab

- Add a flux plane name



The screenshot displays the 'Injection BC Editor' window, which is used for configuring injection boundary conditions. The window is divided into several sections:

- Name:** bubble_ring
- Options:** ☐ Fluid, ☒ Particles/Bubbles/Tracers
- Locations tab:** This tab is active, showing a table of 110 injection locations. The first 9 locations are visible in the table below.

	Name	On/Off	X (m)	Y (m)	Z (m)	nx	ny
1	Location_1	<input checked="" type="checkbox"/> On	0.742462	0.742462	1.63	0.5	0.5
2	Location_2	<input checked="" type="checkbox"/> On	0.804347	0.674927	1.63	0.541675	0.454519
3	Location_3	<input checked="" type="checkbox"/> On	0.86011	0.602255	1.63	0.579228	0.40558
4	Location_4	<input checked="" type="checkbox"/> On	0.909327	0.525	1.63	0.612372	0.353553
5	Location_5	<input checked="" type="checkbox"/> On	0.951623	0.443749	1.63	0.640856	0.298836
6	Location_6	<input checked="" type="checkbox"/> On	0.986677	0.359121	1.63	0.664463	0.241845
7	Location_7	<input checked="" type="checkbox"/> On	1.01422	0.27176	1.63	0.683013	0.183013
8	Location_8	<input checked="" type="checkbox"/> On	1.03405	0.182331	1.63	0.696364	0.122788
9	Location_9	<input checked="" type="checkbox"/> On	1.046	0.0915135	1.63	0.704416	0.061628

Below the table, there are buttons for 'Add Row', 'Reference Gr', and 'Import'. A 'Comment:' field is also present.

The 'Flux Plane tab' is also visible, showing the following configuration:

- Name:** FLUXBC_injection_bubble_ring
- Fluid species behavior:** No output (selected from a dropdown menu)
- ☐ Bin by particle/bubble size (100 bins)
- ☐ Output raw particle/bubble data
- ☐ Output tracer data

Injection BCs

Particles/Bubble/Tracers tab

- Set up transient file as shown, turning on bubble flow after 10 seconds
- Select 002 - Bubble
- Set the Angle Expansion to 30°

Particle/Bubble Injection Boundary Conditions Editor

	Time (s)	On/Off	Temperature (K)	Velocity (m/s)	Mass Flow Rate (kg/s)	Number Density Manual
1	0	On	674	0	0	25
2	10	On	674	0	0	25
3	10.1	On	674	5	1.66	25
4		On				

Add Row Delete Row Check Data Graph Update Simulation

File: bubble_ring.sff Save Save As Close Help

Injection BC Editor

Name: bubble_ring

☐ Fluid ☒ Particles/Bubbles/Tracers

Locations Flux Plane Particles/Bubbles/Tracers

☐ Use BC Connector data

☒ Use transient file:
bubble_ring.sff

☐ Use specified values:
Velocity: 0 m/s
Mass flow: 0 kg/s
Temperature: 674 K
Number density: 125

Injection Type
Type: Particle/Bubble
Species: 002 - Bubble

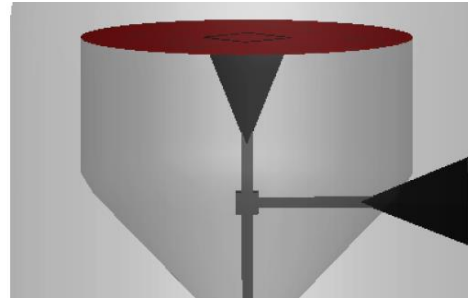
Angle Expansion
 θ_{e1} : 30° θ_{e2} : 30°

Angle Orientation
 α_{e1} : 0°

Comment:

OK Cancel Help

Secondary Feeds



Add secondary feed to use with BC Connector

- Select Fluid and Tracers

Flux Plane tab

- Add flux plane name
- Set up transient file as shown

Fluid tab

- 100% VR(L) for Applied Fluids

Tracers tab

- Verify species is set to 2000

The 'Secondary Feed Editor' dialog box is shown with the 'Flux Plane' tab selected. The 'Name' field is set to 'FLUXBC_vr_secondary_feed'. The 'Fluid species behavior' dropdown is set to 'No output'. The 'Bin by particle/bubble size' checkbox is checked, with a value of 100 bins. The 'Output raw particle/bubble data' and 'Output tracer data' checkboxes are unchecked. The 'Transient File' checkbox is checked, and the file path is 'vr_secondary_feed.sff'. The 'Comment' field is empty.The 'Secondary Feed Editor' dialog box is shown with the 'Fluid' tab selected. The 'Specify Values' section has 'Mass flow rate' set to 0 kg/s and 'Temperature' set to 674 K. The 'Fluid Composition' section has 'Applied fluids' set to 'Define Fluids'. The 'Transient File' checkbox is checked, and the file path is 'vr_secondary_feed.sff'. The 'Comment' field is empty.The 'Secondary Feed Editor' dialog box is shown with the 'Tracers' tab selected. The 'Specify Values' section has 'Resolution' set to 100 1/s and 'Species' set to 2000. The 'Transient File' checkbox is checked, and the file path is 'vr_secondary_feed.sff'. The 'Comment' field is empty.The 'Secondary Feed Flow File Editor' dialog box is shown. It contains a table with the following data:

	Time (s)	Fluid Mass Flow Rate (kg/s)	Fluid Temperature (K)	Tracer Resolution (1/s)
1	0	84.2	674	100
2				

Below the table are buttons for '+ Add Row', '- Delete Row', '✓ Check Data', 'Graph', and 'Update Simulation'. At the bottom, the 'File' field is set to 'vr_secondary_feed.sff', with buttons for 'Save', 'Save As', 'Close', and 'Help'.

BC Connectors

Add BC Connector

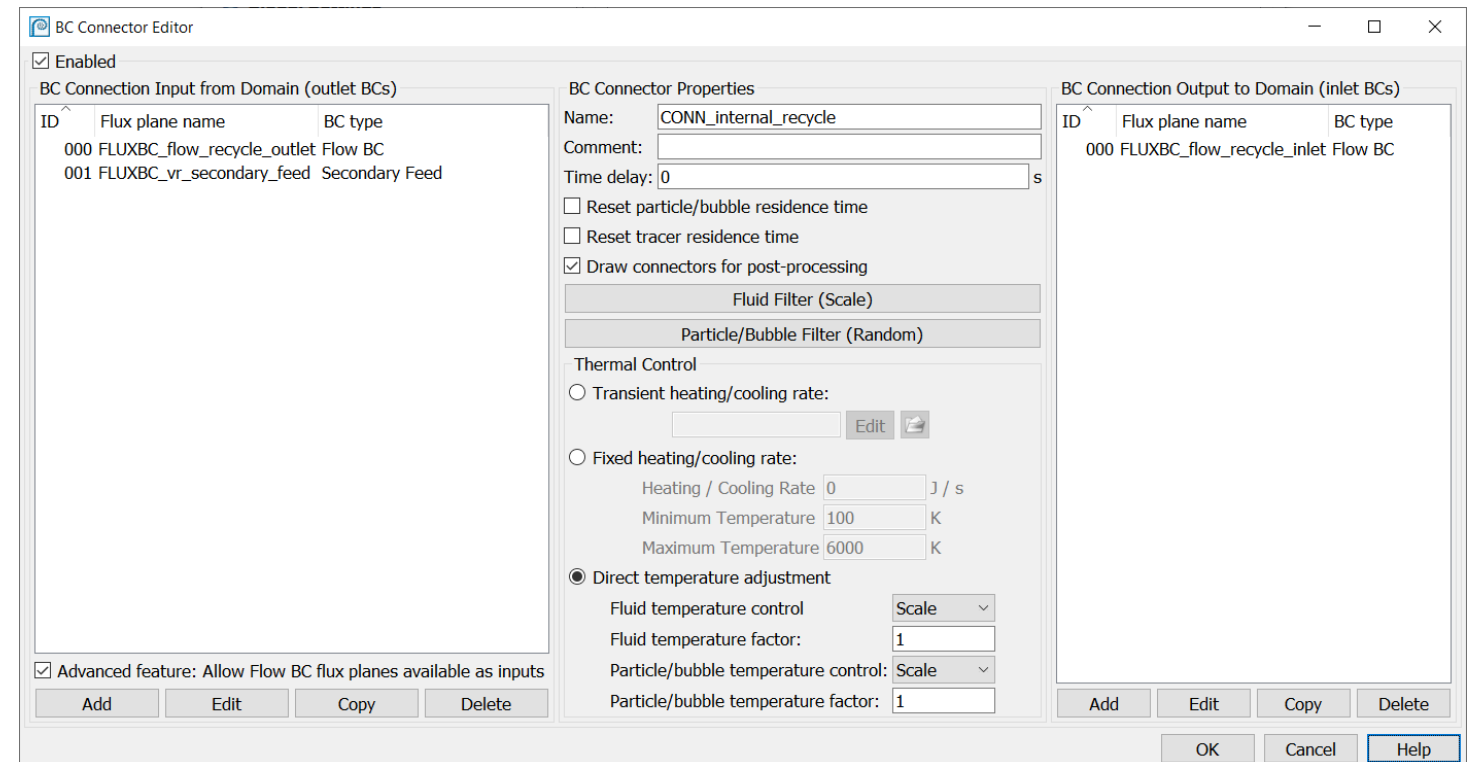
- Name = CONN_internal_recycle
- Select Draw connectors for post-processing

Input

- Select Advanced feature: Allow Flow BC flux planes available as inputs
- Add Flow BC
- Add Secondary Feed

Output

- Add Flow BC



The screenshot shows the 'BC Connector Editor' window. It is titled 'BC Connector Editor' and has a close button. The window is divided into several sections:

- Enabled:** A checkbox labeled 'Enabled' is checked.
- BC Connection Input from Domain (outlet BCs):** A table with columns 'ID', 'Flux plane name', and 'BC type'. It contains two rows:

ID	Flux plane name	BC type
000	FLUXBC_flow_recycle_outlet	Flow BC
001	FLUXBC_vr_secondary_feed	Secondary Feed
- BC Connector Properties:** A section with various settings:
 - Name: CONN_internal_recycle
 - Comment: (empty)
 - Time delay: 0 s
 - Reset particle/bubble residence time: (unchecked)
 - Reset tracer residence time: (unchecked)
 - Draw connectors for post-processing: (checked)
 - Fluid Filter (Scale): (button)
 - Particle/Bubble Filter (Random): (button)
 - Thermal Control:
 - Transient heating/cooling rate: (radio button, unchecked)
 - Fixed heating/cooling rate: (radio button, unchecked)
 - Heating / Cooling Rate: 0 J / s
 - Minimum Temperature: 100 K
 - Maximum Temperature: 6000 K
 - Direct temperature adjustment: (radio button, checked)
 - Fluid temperature control: Scale (dropdown)
 - Fluid temperature factor: 1 (input)
 - Particle/bubble temperature control: Scale (dropdown)
 - Particle/bubble temperature factor: 1 (input)
- BC Connection Output to Domain (inlet BCs):** A table with columns 'ID', 'Flux plane name', and 'BC type'. It contains one row:

ID	Flux plane name	BC type
000	FLUXBC_flow_recycle_inlet	Flow BC
- Advanced feature:** A checkbox labeled 'Advanced feature: Allow Flow BC flux planes available as inputs' is checked.
- Buttons:** At the bottom, there are buttons for 'Add', 'Edit', 'Copy', 'Delete', 'OK', 'Cancel', and 'Help'.



Reaction Chemistry

The kinetics have been adapted from [Stratiev et al \(2019\)](#). This model assumes that the vacuum residue reacts with the hydrogen gas bubbles to form Naphtha, Diesel, Vacuum Gas Oil (VGO), and Propane.

Take note of the following when defining your chemistry:

- Volume average will be used with these units
 - Reaction rate: $\text{mol/m}^3/\text{s}$
 - Fluid species: mol/m^3
- One rate coefficient and one reaction will be defined as shown on the next slide

Reaction Chemistry

Chemistry Coefficient Editor

Coefficient Properties

Name: **k0**

Type: Arrhenius Chem Rate

Coefficient is for reaction type: ☒ Volume-Average ☐ Discrete

Equation: $c_0 T^{c_1} p^{c_2} \rho_f^{c_3} \theta_f^{c_4} e^{-E/T+E0} \{type_s\}$

$k0 = 4e+09 \theta_f^{-1} e^{-22973/T} \theta_{Catalyst}^1$

Values

$c_0 =$

$c_1 =$ Temperature unit:

$c_2 =$ Pressure unit:

$c_3 =$ Density unit:

$c_4 =$

$c_5 =$

$E =$

$E0 =$

$type_s =$

Temperature Weighting

Fluid weighting factor:

Particle/bubble weighting factor:

Comment

OK

Chemistry Stoichiometric Equation Editor

Stoichiometric Equation Editor

Directions: Choose Equation Units for this Stoichiometric Chemistry.
Enter a stoichiometric reaction and rate equation in the blanks provided.
Use **Add Material** and **Add Coefficient** to insert either into the equation. Press the **Check** button to verify equation is valid.

Equation Units

Reaction rate units:

Fluid species units:

Enter a stoichiometric reaction:

Expected Power Law rate equation format: $c0 (k + k - ...) [material1]^power [material2]^power + c1 ...$
Example of valid Power Law rate equation format: $1.2 (1.5 * k0 - 3 * k1) [H2O]^{1.5}$
Example of invalid Power Law rate equation format: $(k0 * k1) [H2O]^{1.5}$ Coefficients cannot be multiplied.
Example of LH expected format: $(c0 k [] + c1 k [] + ...) / (1 + c2 k [] + c3 k [] + ...)^{power}$
Example of groups of rates: $(c0 k0 [O2] - c1 (0.5k1-k2))^{1.5} (c1(k3) [CO]^{0.5}[O2])^{-1}$

Enter a rate equation for the stoichiometric reaction in either Power Law or Langmuir-Hinshelwood form:

Particle & Bubble Dependence

Materials List

ID	Material name	Phase	Type	Exponent
00	Catalyst	S	volfrac	1

Material coefficient type:

Exponent on material:

Time Controls

Set Time step and End time

Set Restart intervals

Time Controls

This section allows configuration of the time step size to take during a period of time for the calculation. Only the first row is required. Subsequent rows can be entered to have different time steps for different time periods. For example, starting the calculation at a smaller time step is recommended, and then increasing the time step for rows 2-5 over simulation time.

Time step and duration settings

	Time step		End time	
1.	<input type="text" value="0.05"/>	s	<input type="text" value="500"/>	s
2.	<input type="text"/>	s	<input type="text"/>	s
3.	<input type="text"/>	s	<input type="text"/>	s
4.	<input type="text"/>	s	<input type="text"/>	s
5.	<input type="text"/>	s	<input type="text"/>	s

Advanced time step settings

Restart file intervals

Restart interval (IC_###) simulation seconds

Backtrack interval (IC_) realtime minutes


Help

Visualization Data Output



Set Output file interval and select options shown for Visualization Data Output

Visualization Data Output



Output file format
☒ Tecplot (*.plt files) ☐ GMV (Gmv.* files)

Output file interval
☒ Constant: s End time: 500s Number of output files: 501
☐ Time-varying: Edit 

Cell Data

Available Data		Selected Data
Fluid composition mass concentration		Bubble volume fraction
Fluid composition mole concentration		Bulk density
Fluid composition mole fraction		Cell indices
Fluid mass flux		Cell volume
Fluid temperature		Fluid composition mass fraction
P1 incident radiation flux		Fluid density
P1 radiation flux		Fluid velocity
P1 radiation flux from walls		Particle volume fraction
P1 radiation to fluids		Pressure
P1 radiation to particles		

Particle & Bubble Data

Available Data		Selected Data
Bubble mass		Bubble material
Bubble temperature		Bubble size
Bubble velocity		Bubble speed
Bubbles per cloud		Bubble volume fraction
Cell ID		Cloud ID
Chemical Reaction Rates		Particle size
Cloud mass		Particle speed
Drag		Particle volume fraction
Liquid fraction total		Residence time
Liquid mass total		Species

Help

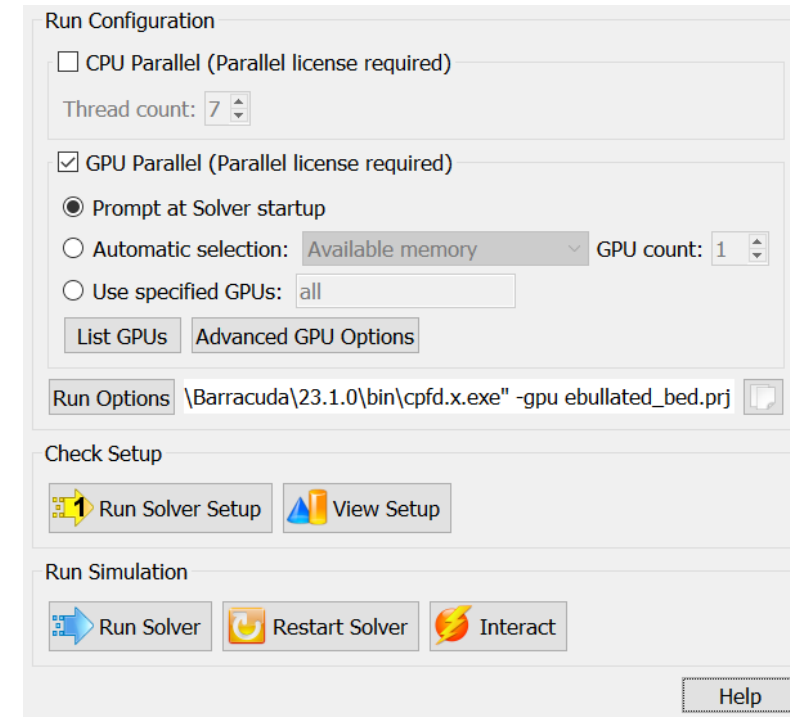
Run

If NVIDIA GPU card is available, select GPU Parallel

Run Solver Setup and View Setup

Once you have checked the setup, Run Solver to start the simulation

Due to the complexity of the chemistry, the following error may pop up when the solver starts up. It is safe to press 'c' to ignore this error.



```
"Barracuda Virtual Reactor - 23.1.0 - my_setup/ebullated_bed.prj" - "C:\Program Files\C...
#
# Barracuda release 23.1.0
# Solver version 23.1.0.x056
# Build date 2023-10-30 17:19:17 UTC
# Restart IC version 2310
#

===== ERROR =====
Your chemical rate equations have a summed error of -4.0278e-06 kg/s-m^3 with
minimum & maximum reaction rates being 4.0540e+00 & 1.4057e+02 kg/s-m^3 under
certain conditions. The error could be due to molecular weights not giving an
exact mass balance. See info.log for more detailed information.
If you think this error is acceptable, continue the calculation.
===== ERROR =====

Press 'c' to ignore and continue, 'q' to quit:
```



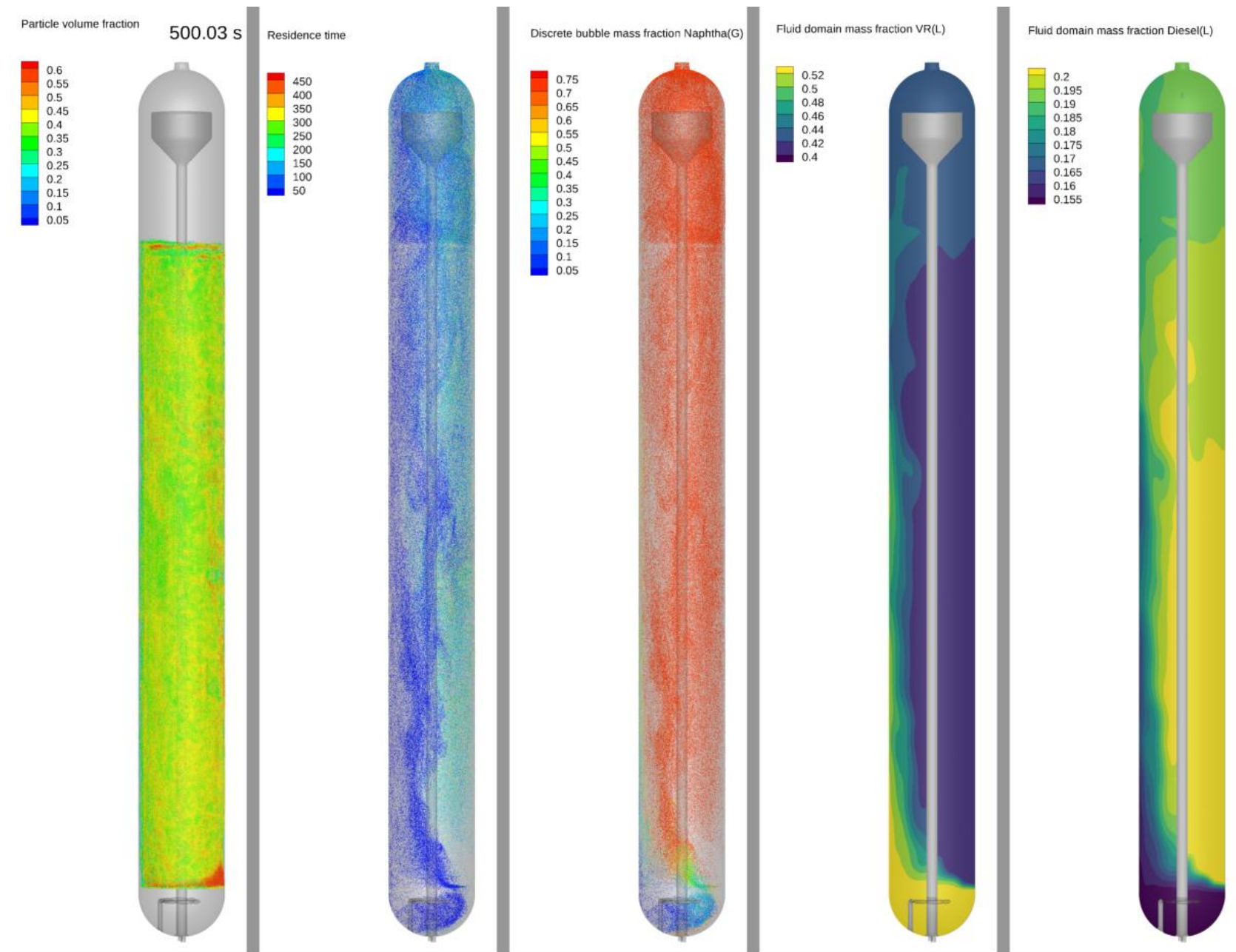
Post-Processing

Create a 5 frame view of the ebullated bed behavior as shown to the right

Specific hints for obtaining the desired views are on the following slides

Also see the following videos:

- [Frames](#)
- [Slices](#)
- [Contour legend](#)

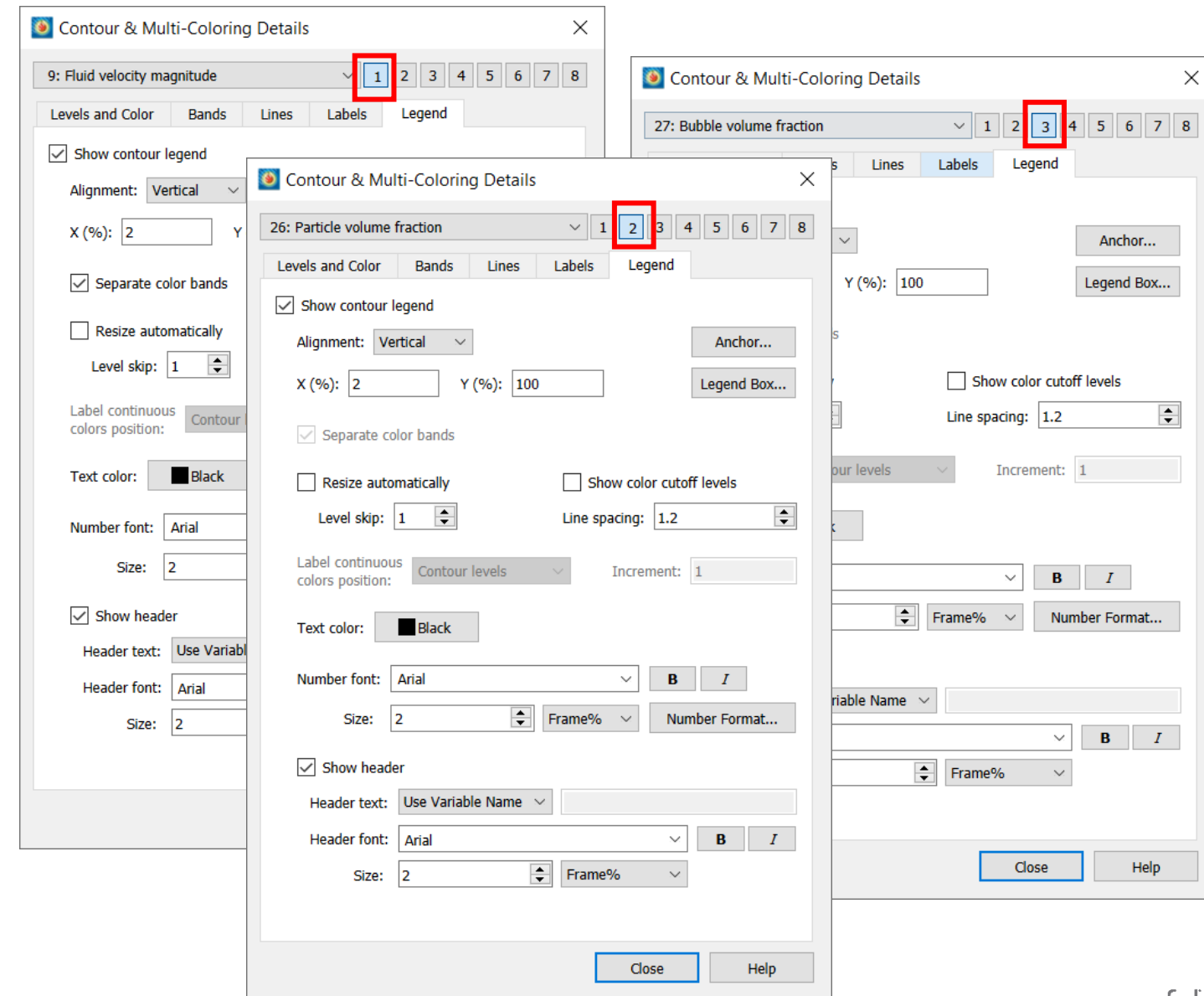


Using Contour Groups

When using fluid, particles, and bubbles in Barracuda, the contour groups in Tecplot become more important.

- Fluid is contour group 1
- Particles are group 2
- Bubbles are group 3

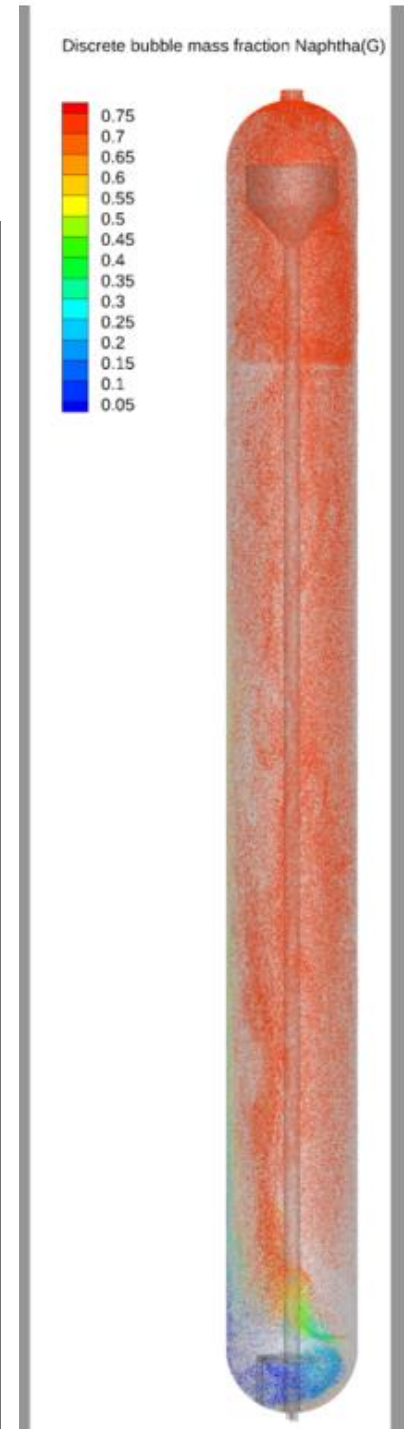
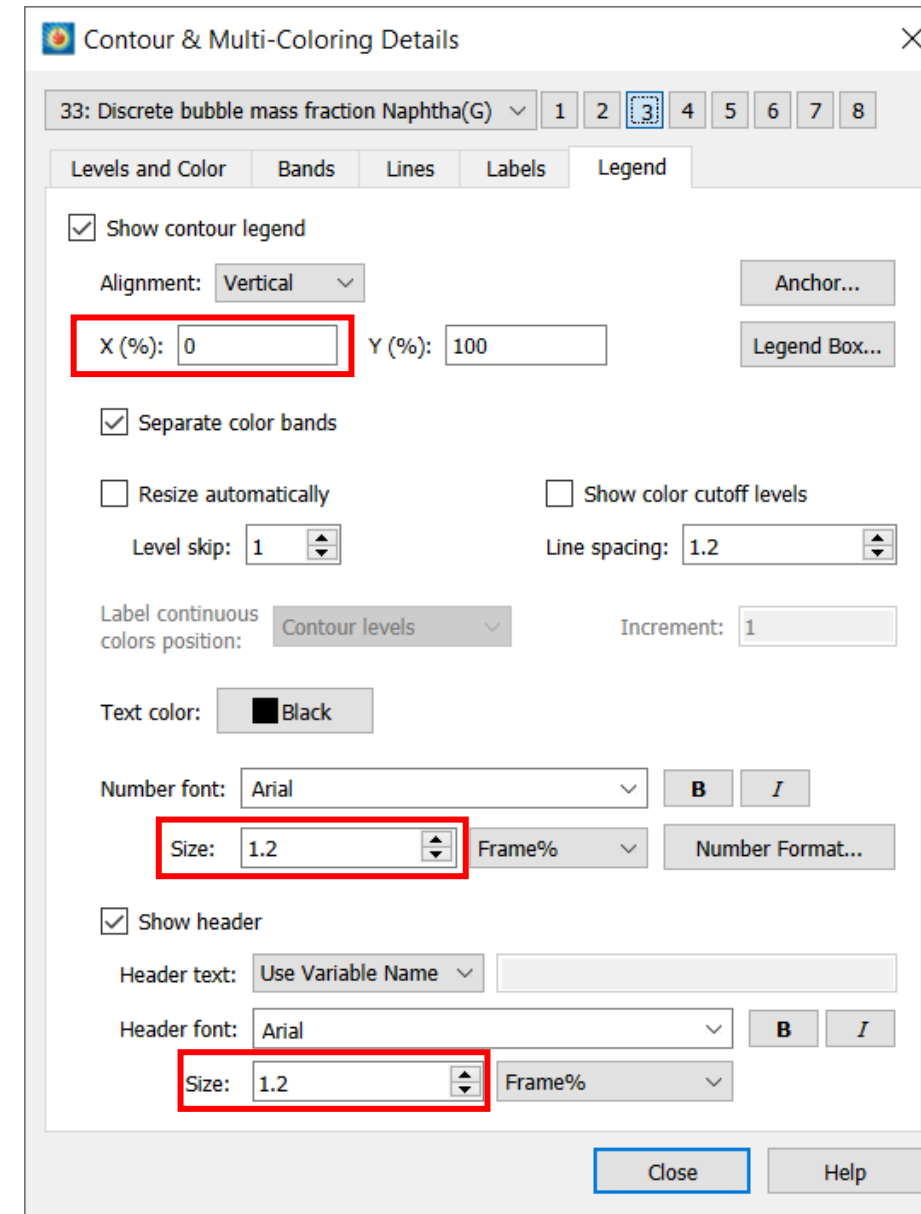
For views with multiple frames, ensure that the group is correct when adjusting the frame contour legend



Adjusting Legend Text Sizes

When using multiple frames in a view, the text size may need to be adjusted. To do this:

- Legend tab of Contour editor
- Set X(%) to 0
- Adjust size of “Number font” and “Header font” until the legend label fits the size of your frame



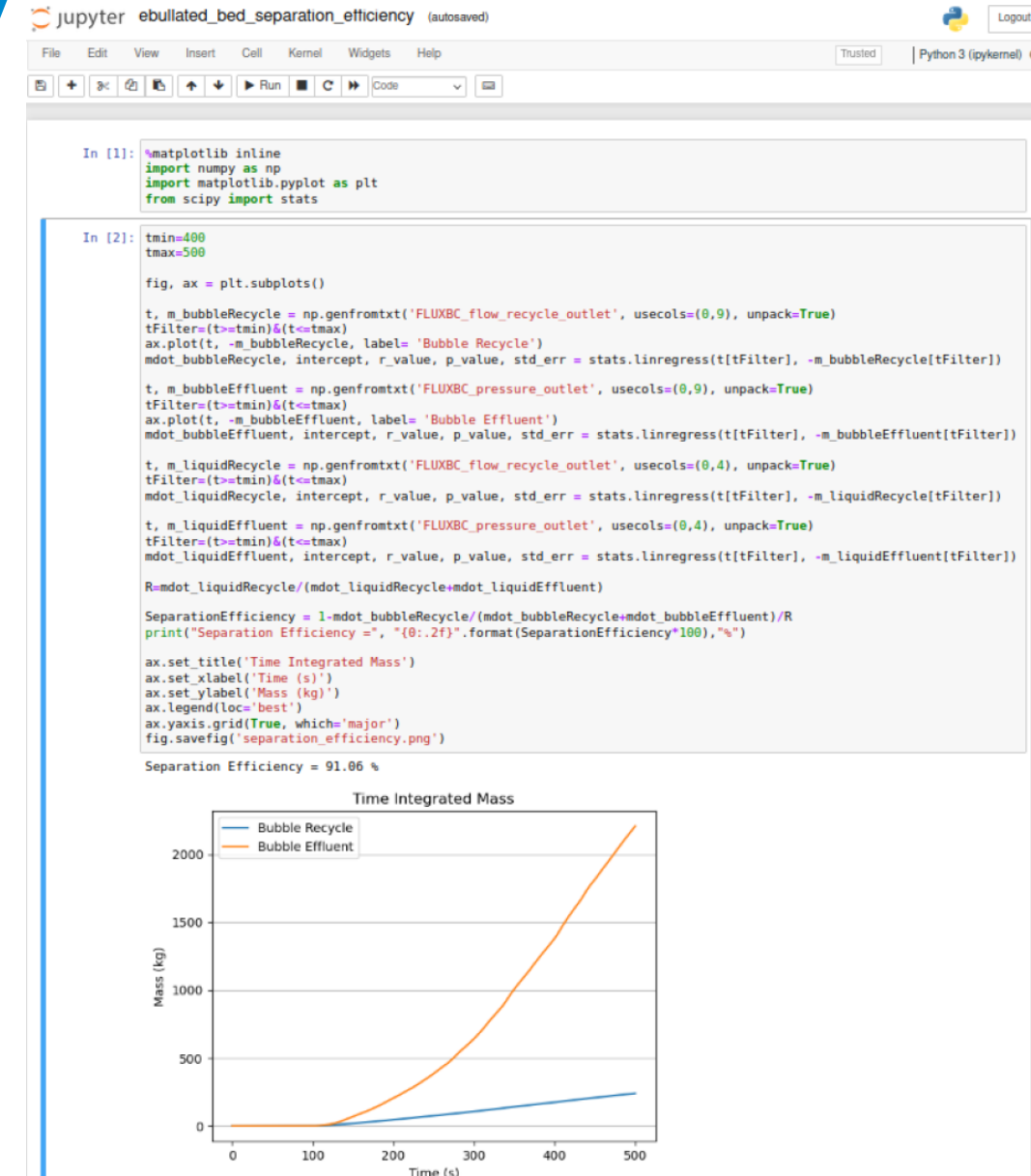
Post-Processing: Separation Efficiency

The separation efficiency of the reactor can be calculated using the included Jupyter notebook:

`ebullated_bed_separation_efficiency.ipynb`

Helpful support site posts:

- [Using Jupyter Notebook](#)
- [Installing Anaconda Python](#)



Post-Processing: Calculating Fluid Residence Time

Tracers were introduced in the secondary feed of VR(L). This support post shows how to create a histogram of fluid residence time using tracers.

<https://cpfd-software.com/using-tracers-in-a-barracuda-virtual-reactor-model/>

