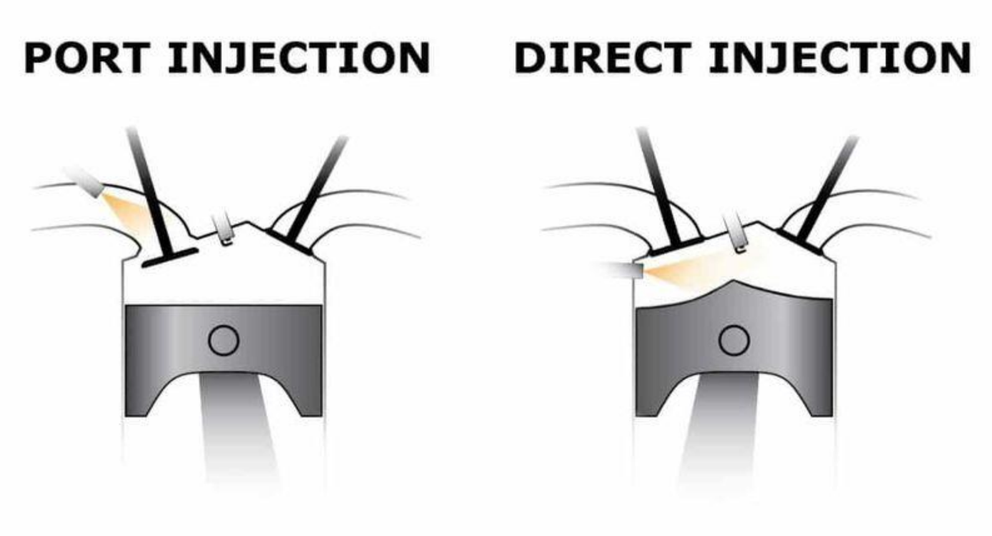
1. **Title – PFI Engine Simulation.**

2. **Objective –**

- **To import the CAD model of engine in converge Software and check for errors.**
- **To set up the case with proper grid size, material and boundary conditions.**
- **To solve the case using suitable solver and convert the result for Paraview software.**
- **To import output files in Paraview and generate required contours and plots.**

3. **Introduction –**

A heat engine is a device which transforms chemical energy of a fuel into thermal energy and uses it to produce work. Mainly, Heat engine is classified into two categories External combustion engine and internal combustion engine. when the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle, then engine is called external combustion engine and when the combustion of air and fuels take place inside the cylinder and are used as the direct motive force then engine is called as internal combustion engine.



Internal combustion engine can be classified further, according to the method of fuel input. Port Fuel Injected (PFI) engine, the fuel is sprayed into the intake ports to mix with incoming air. The fuel injectors in PFI configurations are typically mounted in the intake manifold and the air/fuel mixture is pulled into the cylinder head as the intake valve opens. Gasoline direct injection (GDI) engine, the fuel injectors are situated in the cylinder head and fuel is sprayed directly into the cylinder where the air / fuel mixing then occurs. In this study we are going to simulate fuel spray, combustion with a PFI engine.

4. **Theory -**

Simulating internal combustion (IC) engines is challenging due to the complexity of the geometry, spatially and temporally varying conditions, and complex combustion chemistry in the engine. Converge software is a powerful tool in CFD domain which comes with some special features to simulate IC engine. the biggest challenge in IC engine simulation is mesh refinement, because if we go deploy fine mesh on whole component, solver is going

to take years to solve. Converge comes with feature called adaptive mesh refinement, which refines mesh on the specific requirement like around the spark plug during combustion etc. Converge also provides combustion model, spray model and solver like SAGE which solves detailed chemistry, to capture every minute detail and so we can produce results which mimics actual IC engine.

Compression ratio – it is the ratio between the total volume of the combustion chamber which is left when the piston is at its bottom dead centre and the volume left inside the combustion chamber when the piston moves to its top dead centre. compression ratio determines the thermal efficiency of used thermodynamic cycle of the combustion engine. In general, it is desired to have a high compression ratio, because it allows an engine to reach higher thermal efficiency. Petrol is very volatile, the compression ratio for Petrol engine is typically lower. Thus, it varies from 10:1 to 14:1. Whereas for diesel engine it varies from 18:1 to 23:1.

`C.R.` = Total volume/ clearance volume

Combustion efficiency - Combustion efficiency is a measurement of how well the fuel being burned is being utilized in the combustion process. The lower the combustion efficiency, the less efficient the device is, making it expensive to run, wasteful of fuel, and harmful for the environment. Combustion efficiency depends on several parameters like amount of oxygen during combustion, amount of energy fuel can release, temperature of combustion chamber, turbulence etc.

Combustion equation – properties iso-octanes closely matches with gasoline so for this study we are considering it fuel. In combustion reaction fuel reactions with air and produces. Here we are considering theoretical air for combustion, this air contains oxygen and nitrogen, other gases are neglected. Combustion equation as follows –

` C_8H_18 +12.5(O_2+3.7N_2) ->8CO_2 +9H_2O +47N_2`

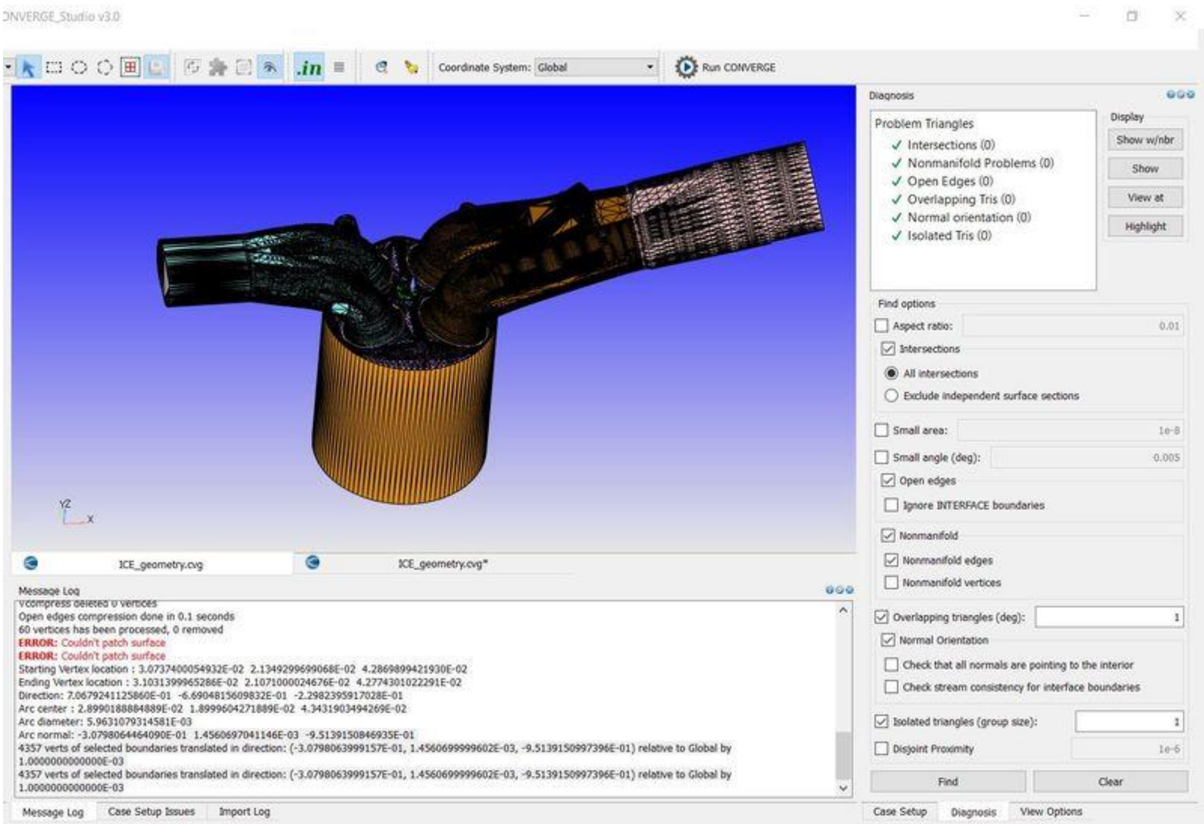
Mass fraction of products was calculated as shown as in following image -

Stoichiometric calculation				
Species	Moles	MW (g/mol)	Mass	Mass fraction
Co2	8	44.01	352.08	0.192304
H2o	9	18.01528	162.1375	0.088559
N2	47	28.0134	1316.63	0.719137
Total			1830.847	1

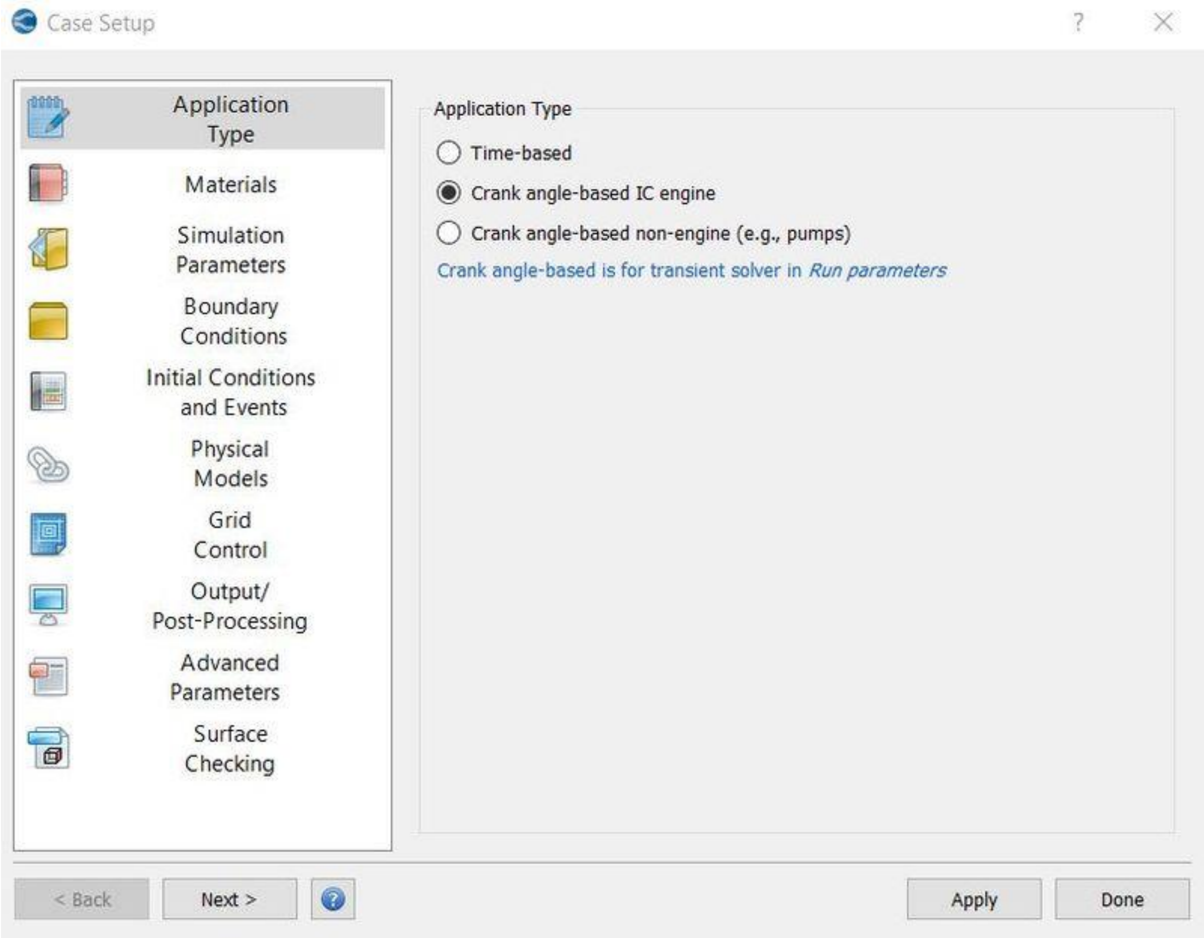
5. Procedure –

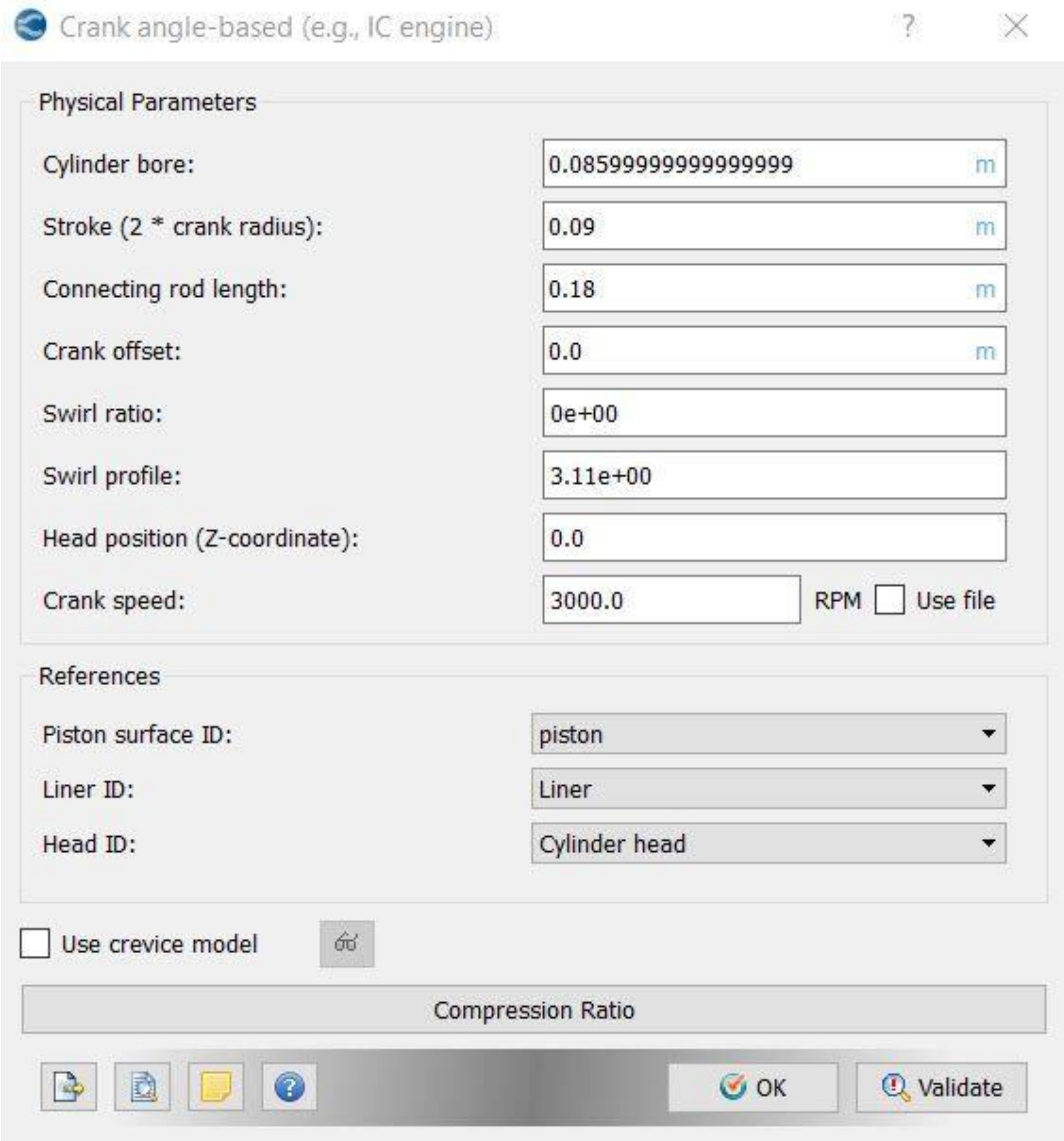
IC engine is always going be tricky due its complex nature. To generate desire result it is very important to choose right physical model with a perfect solver. In these of simulation it is advisable to grab right initial conditions, boundary conditions, physical model etc. because it will take a lot of time to solve. In this study we simulated IC PFI engine, for it the procedure was as followed -

1. First, we imported the model and ran diagnosis tool to find errors. We found no errors.

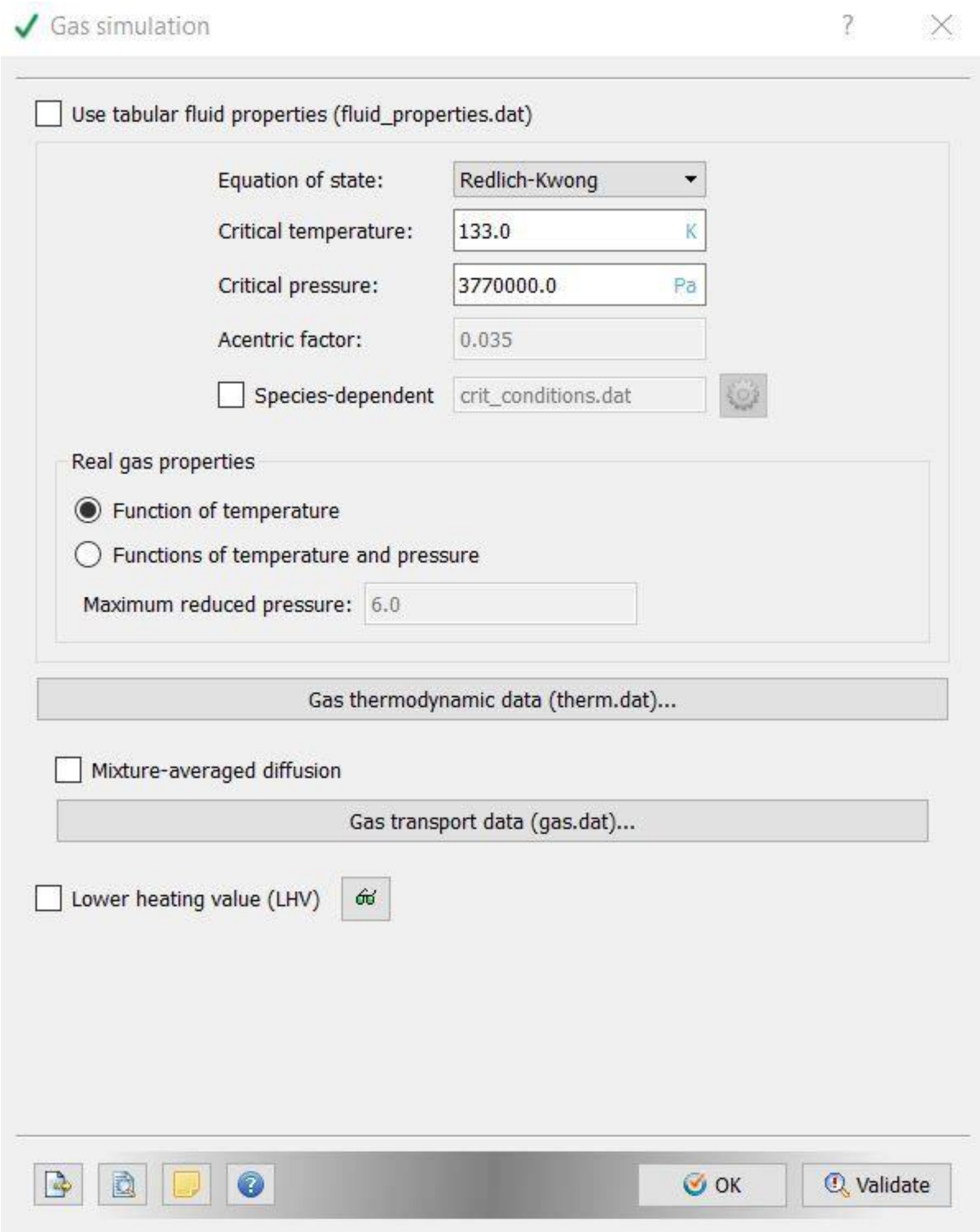


2. In the case setup we started with crank angles-based IC engine as application type. In crank angle-based menu some parameters were defined as shown in the following image.

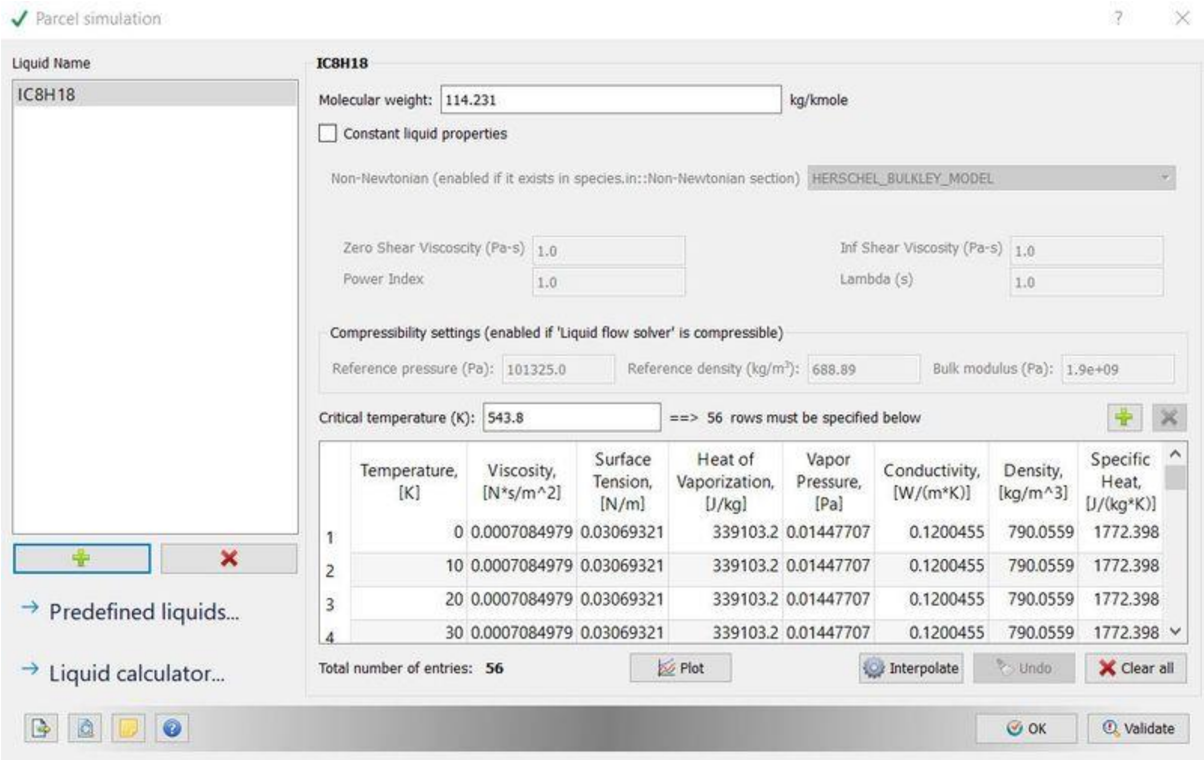




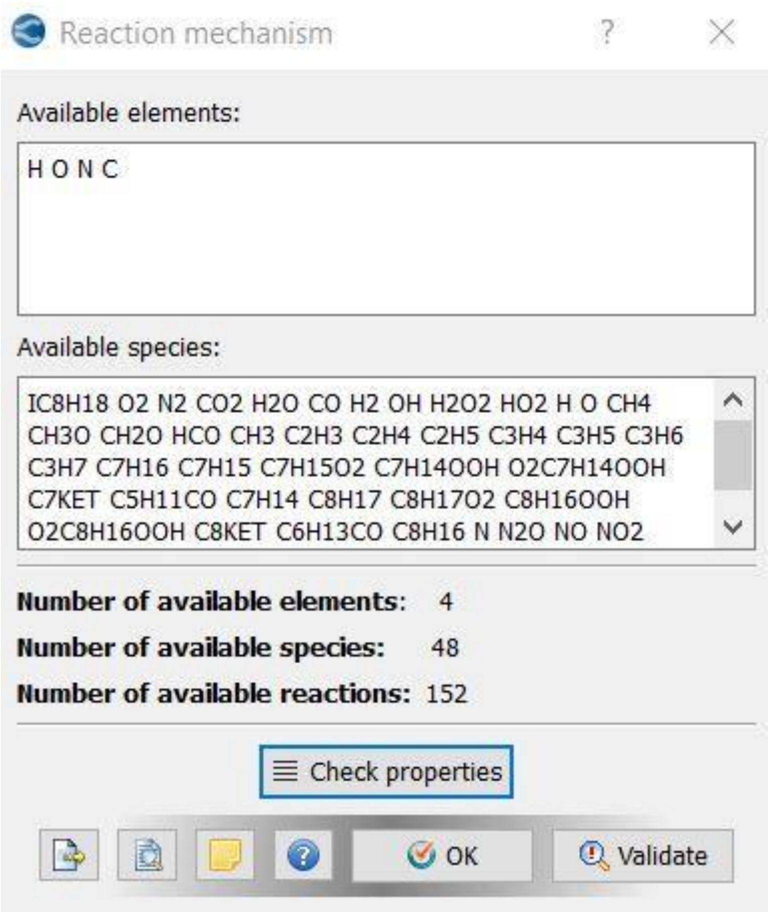
3. In gas simulation parameter therm.dat file was imported which contains gas thermodynamic data specifically related to IC engine.



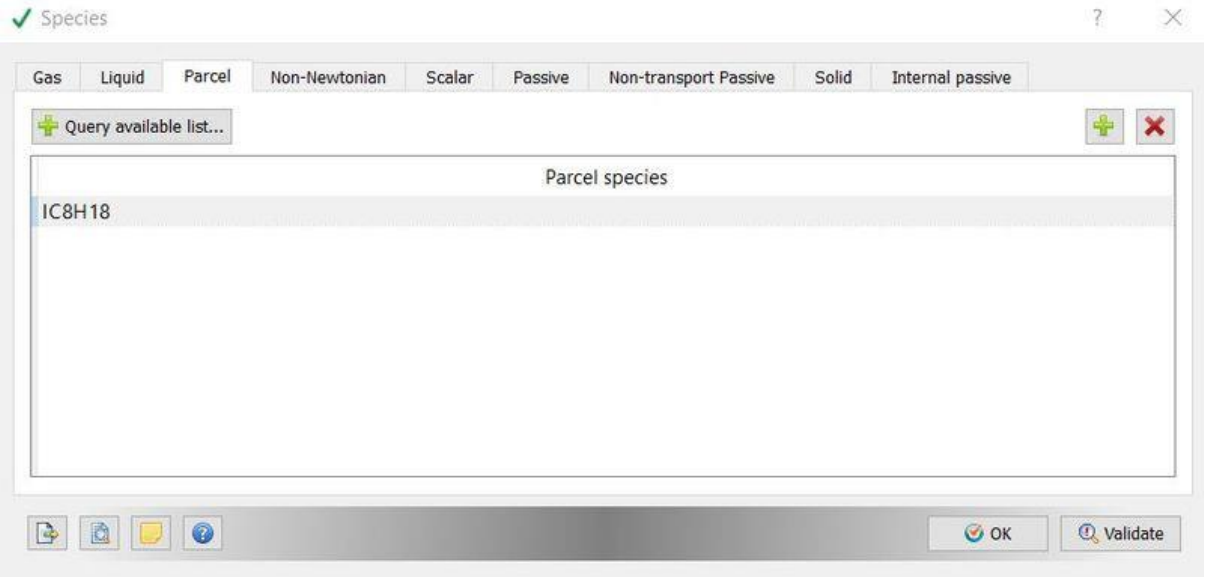
4. From the materials option parcel was enabled. In parcel simulation fuel IC8H18 was selected, which imported all the properties. Converge employs discrete Lagrangian parcels to simulate a special type of liquid in conjunction with spray modelling. In converge the Parcel simulation dialog box is for configuring properties of Lagrangian liquid parcels (such as for spray simulations).



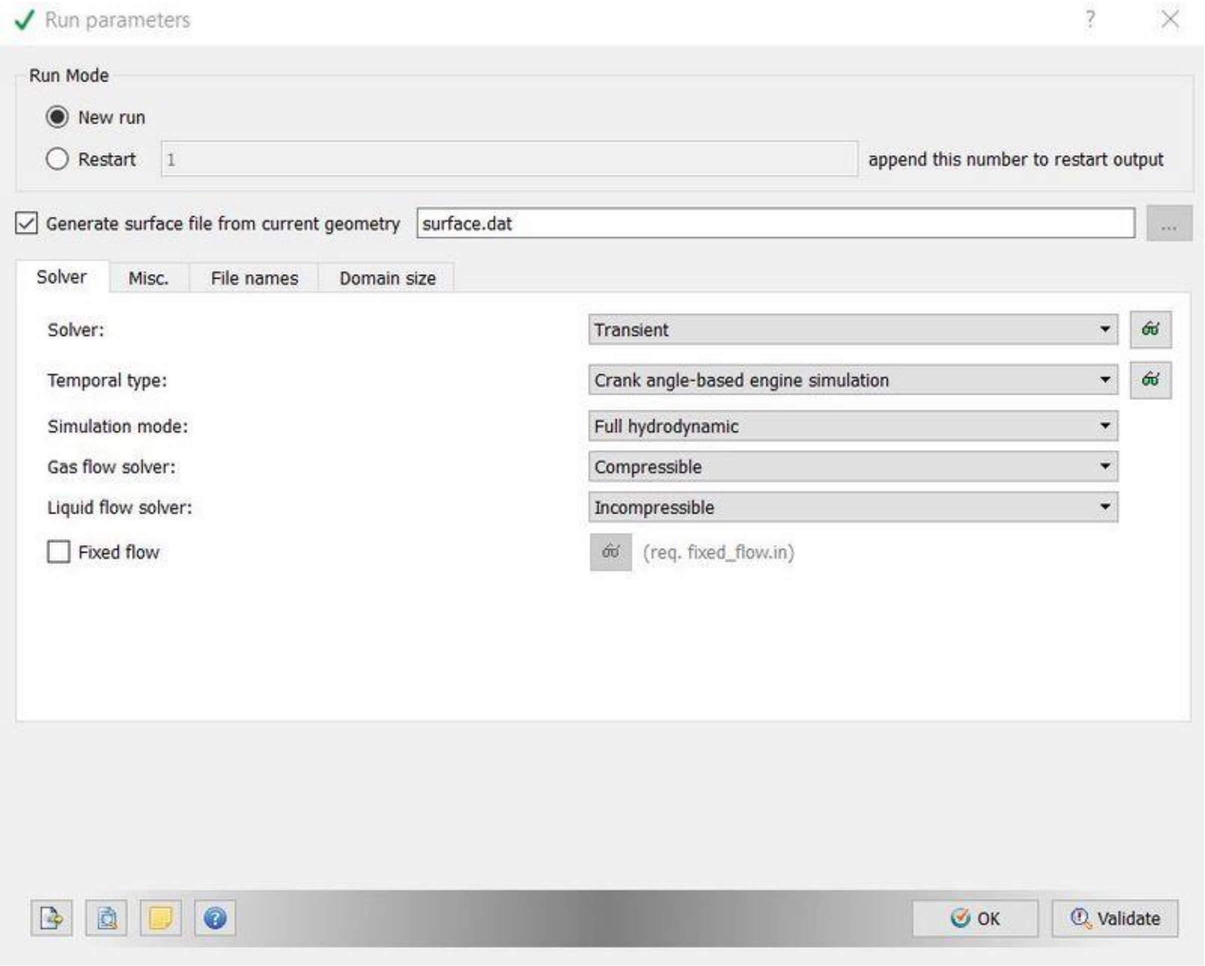
5. In reaction mechanism windows properties were checked to see the available species, which were imported by therm.dat file.



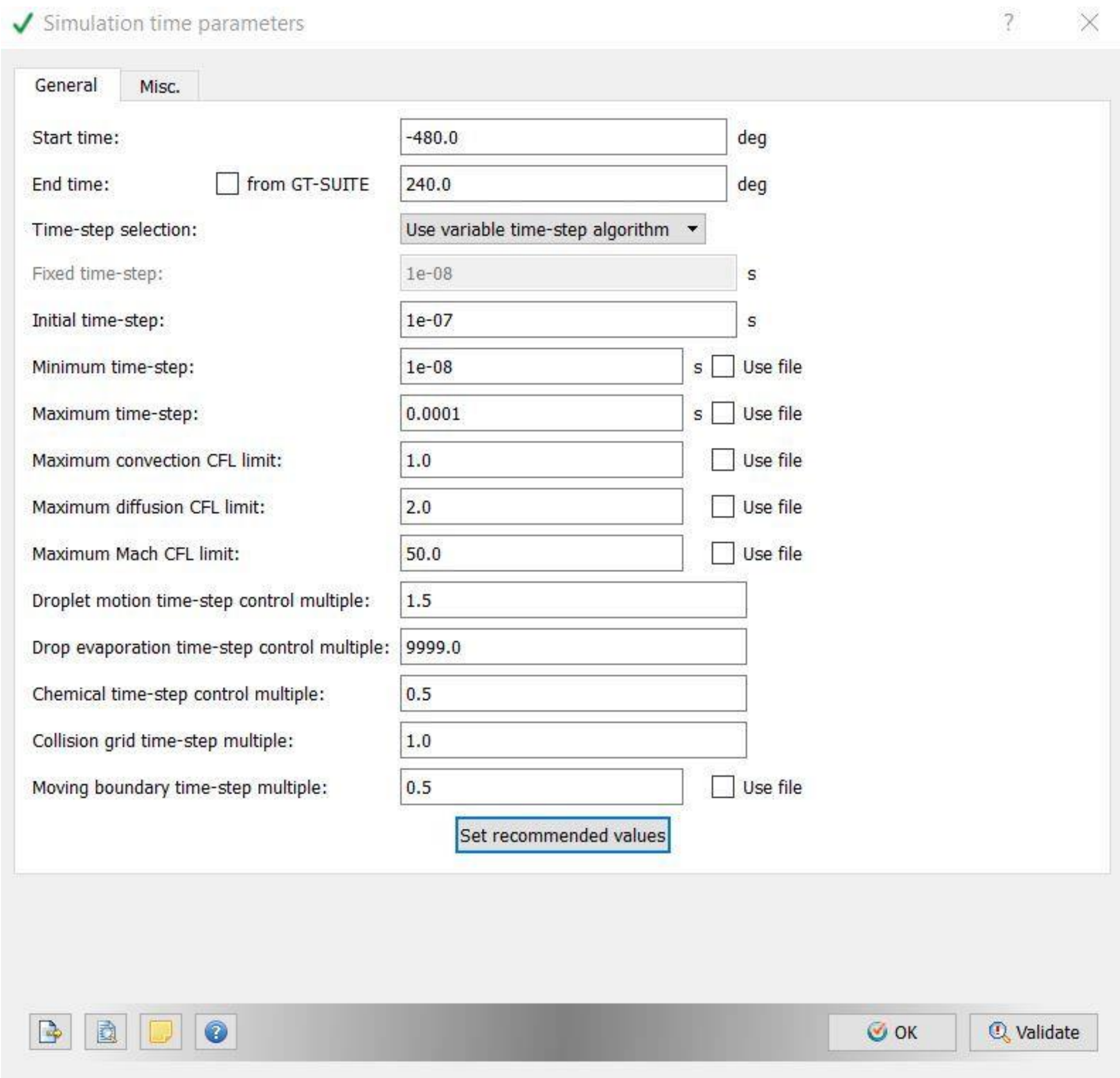
6. IC8H18 was defined in parcel option of species.



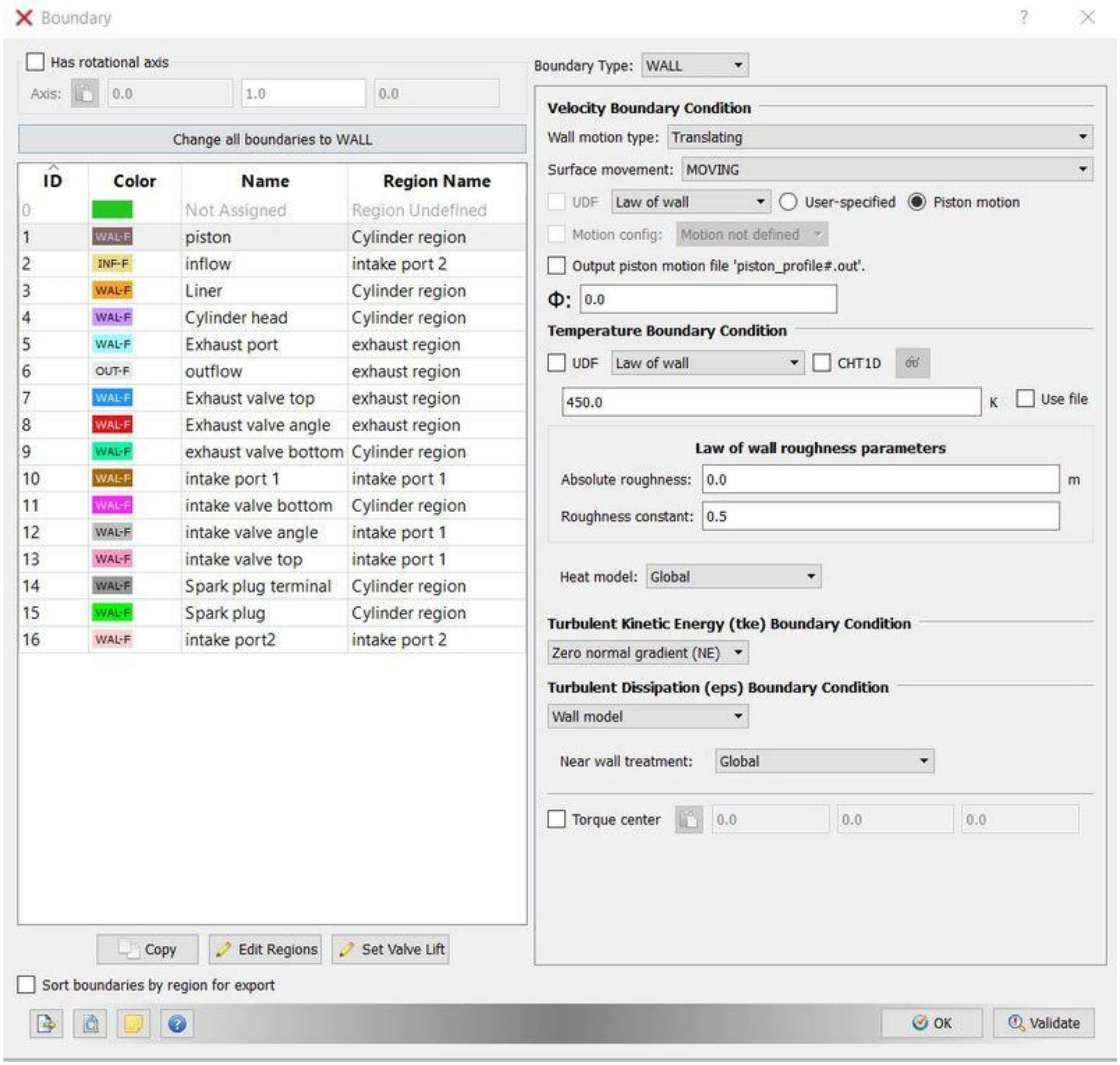
7. In run parameter transient was chosen as solver type with hydrodynamic simulation mode to simulate with the effect of liquid and gases. In temporal type crank angle-based engine simulation was chosen, because we wanted to run simulation on crank angles.

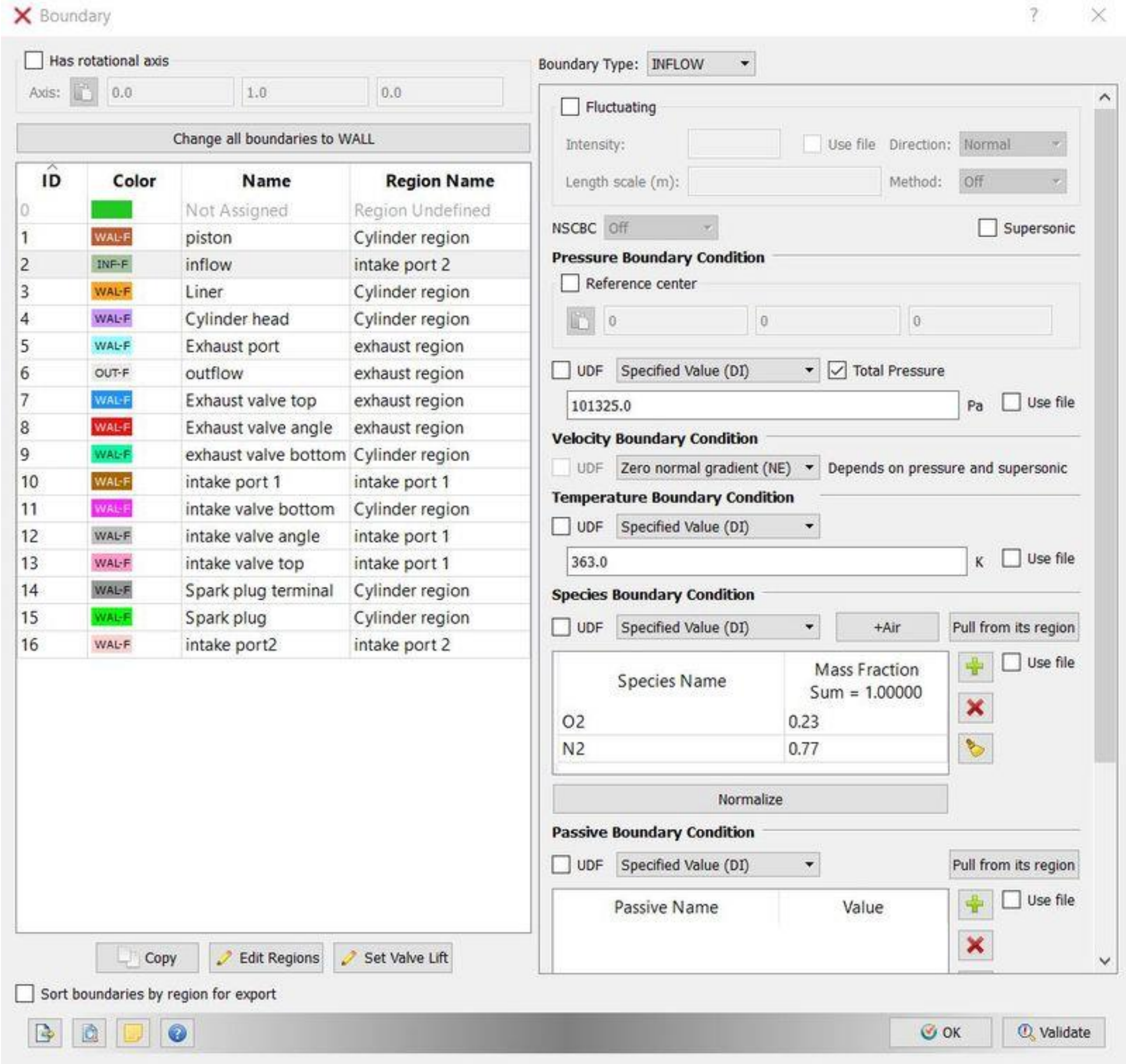


8. In simulation time parameter start and end time were specified in degrees, these were crank angles. Other parameters were defined as in the following image. Solver parameters were left as defaults.



9. There were 16 boundaries created in flagging process. Boundary conditions were given as the following images –


Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
2 INF-F inflow intake port 2
3 WAL-F Liner Cylinder region
4 WAL-F Cylinder head Cylinder region
5 WAL-F Exhaust port exhaust region
6 OUT-F outflow exhaust region
7 WAL-F Exhaust valve top exhaust region
8 WAL-F Exhaust valve angle exhaust region
9 WAL-F exhaust valve bottom Cylinder region
10 WAL-F intake port 1 intake port 1
11 WAL-F intake valve bottom Cylinder region
12 WAL-F intake valve angle intake port 1
13 WAL-F intake valve top intake port 1
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Translating
Surface movement: MOVING
UDF Law of wall User-specified Piston motion
Motion config: Motion not defined
Output piston motion file 'piston_profile#.out'.
Φ: 0.0
Temperature Boundary Condition
UDF Law of wall CHT1D
450.0 K Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: Global
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate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Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
2 INF-F inflow intake port 2
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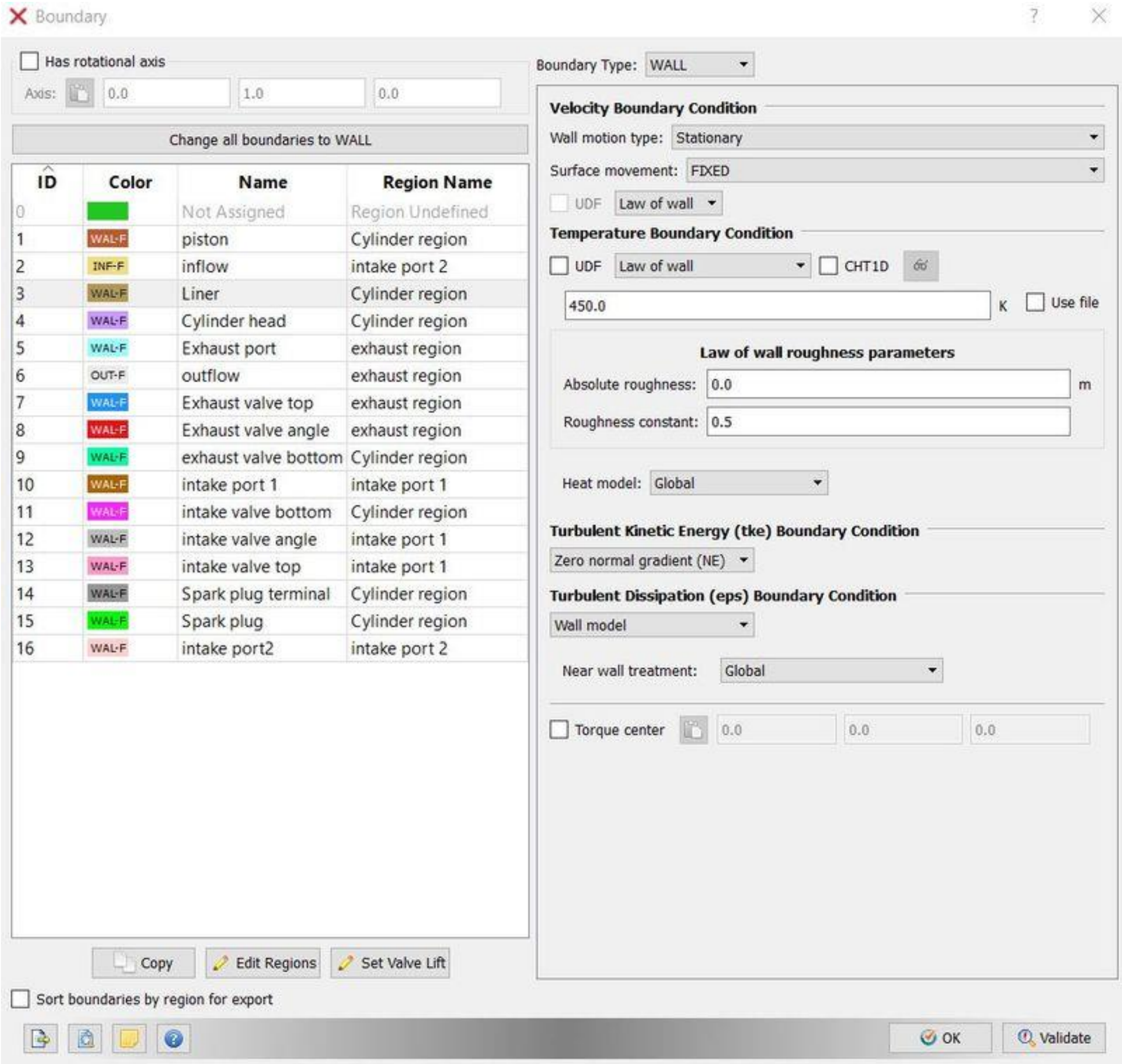
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: INFLOW
Fluctuating
Intensity:
Use file
Direction: Normal
Length scale (m):
Method: Off
NSCBC Off
Supersonic
Pressure Boundary Condition
Reference center
0 0 0
UDF Specified Value (DI)
Total Pressure
101325.0 Pa
Use file
Velocity Boundary Condition
UDF Zero normal gradient (NE)
Depends on pressure and supersonic
Temperature Boundary Condition
UDF Specified Value (DI)
363.0 K
Use file
Species Boundary Condition
UDF Specified Value (DI)
+Air
Pull from its region
Species Name
Mass Fraction Sum = 1.00000
O2 0.23
N2 0.77
Use file
Normalize
Passive Boundary Condition
UDF Specified Value (DI)
Pull from its region
Passive Name
Value
Use file
OK
Validate


Boundary
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Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
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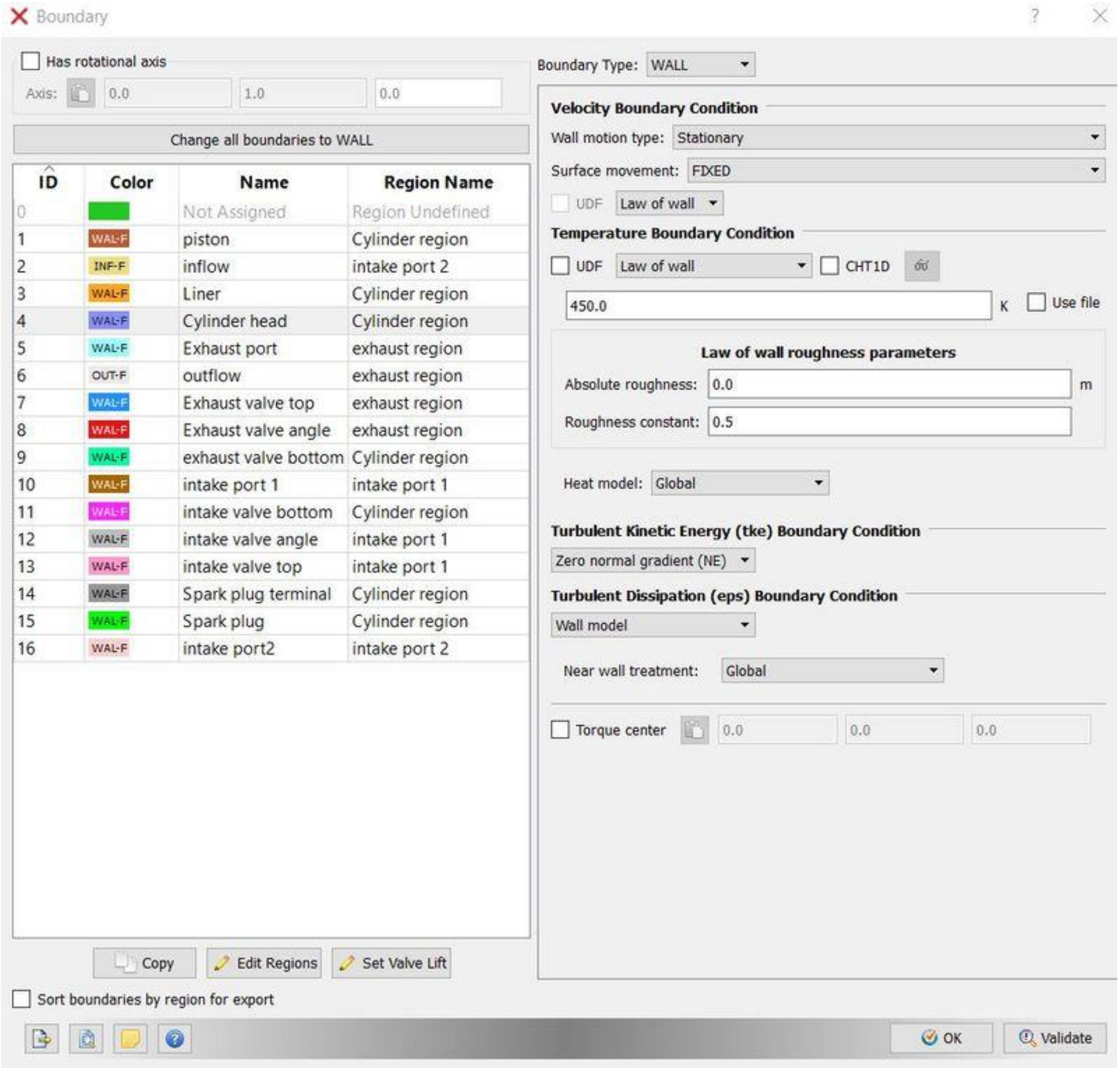
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Stationary
Surface movement: FIXED
UDF Law of wall
Temperature Boundary Condition
UDF Law of wall CHT1D
450.0 K Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: Global
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate


Boundary
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Heat model: Global
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Torque center 0.0 0.0 0.0
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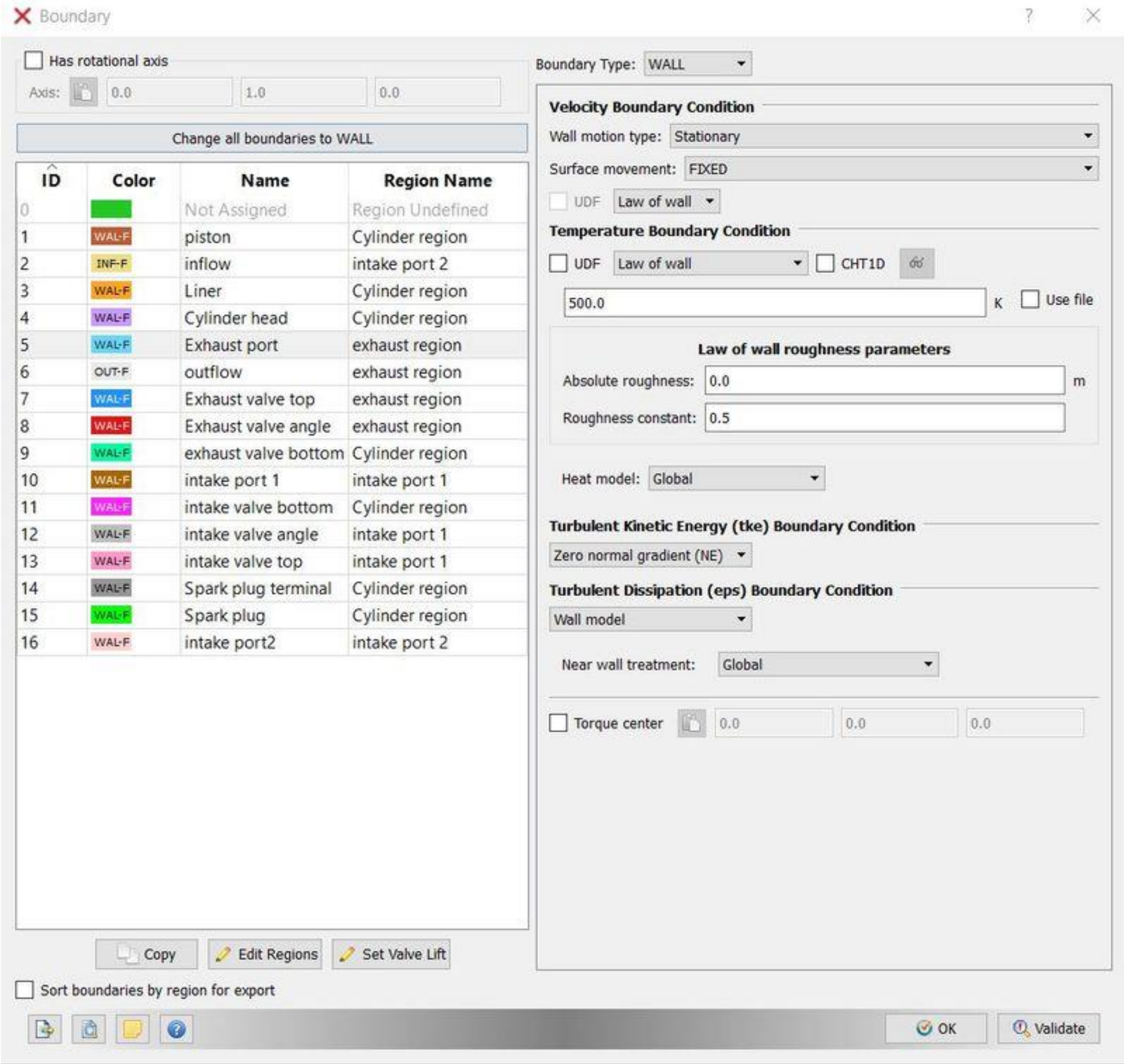
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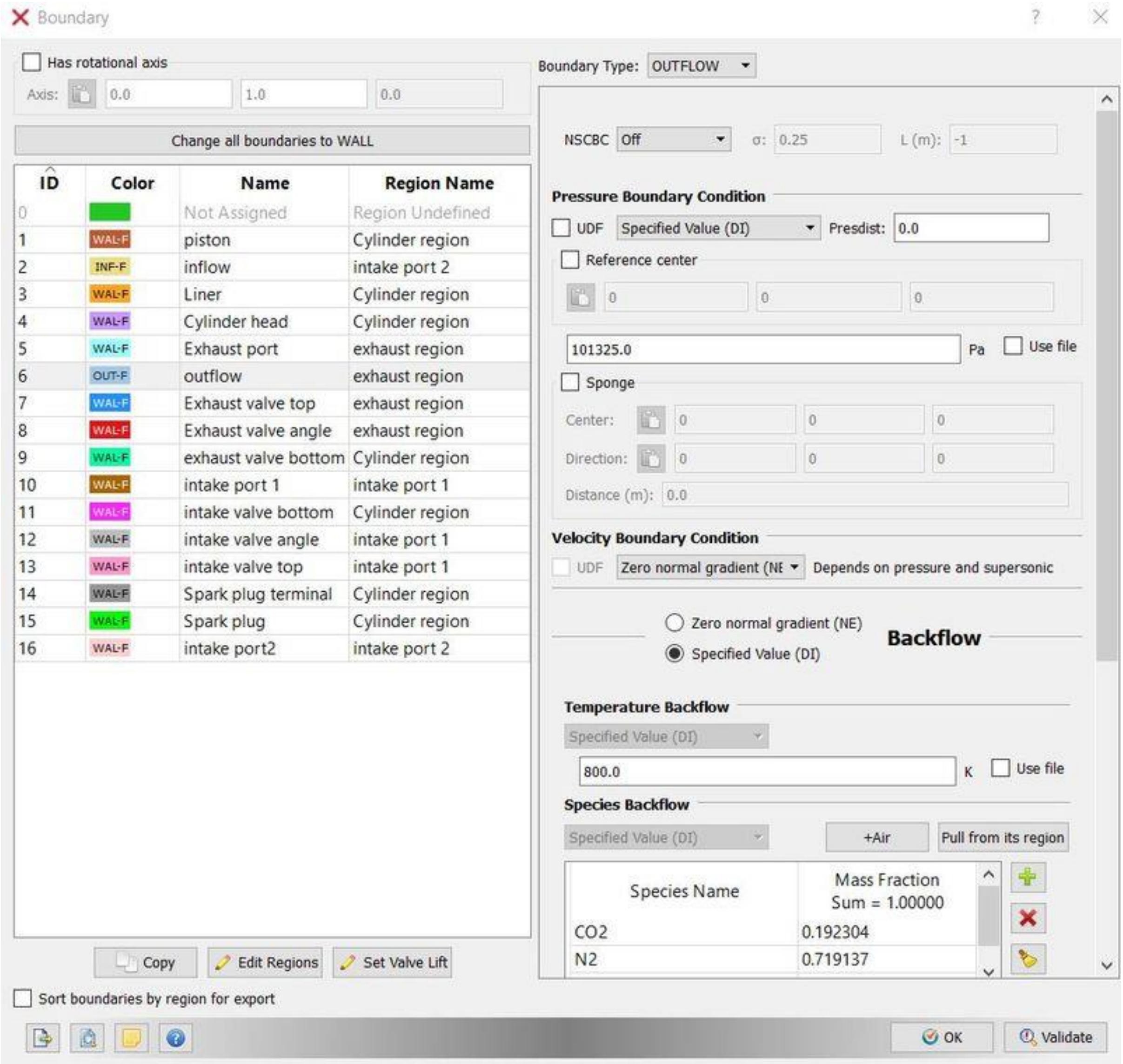
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Stationary
Surface movement: FIXED
UDF Law of wall
Temperature Boundary Condition
UDF Law of wall CHT1D
500.0 K Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: Global
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate


Boundary
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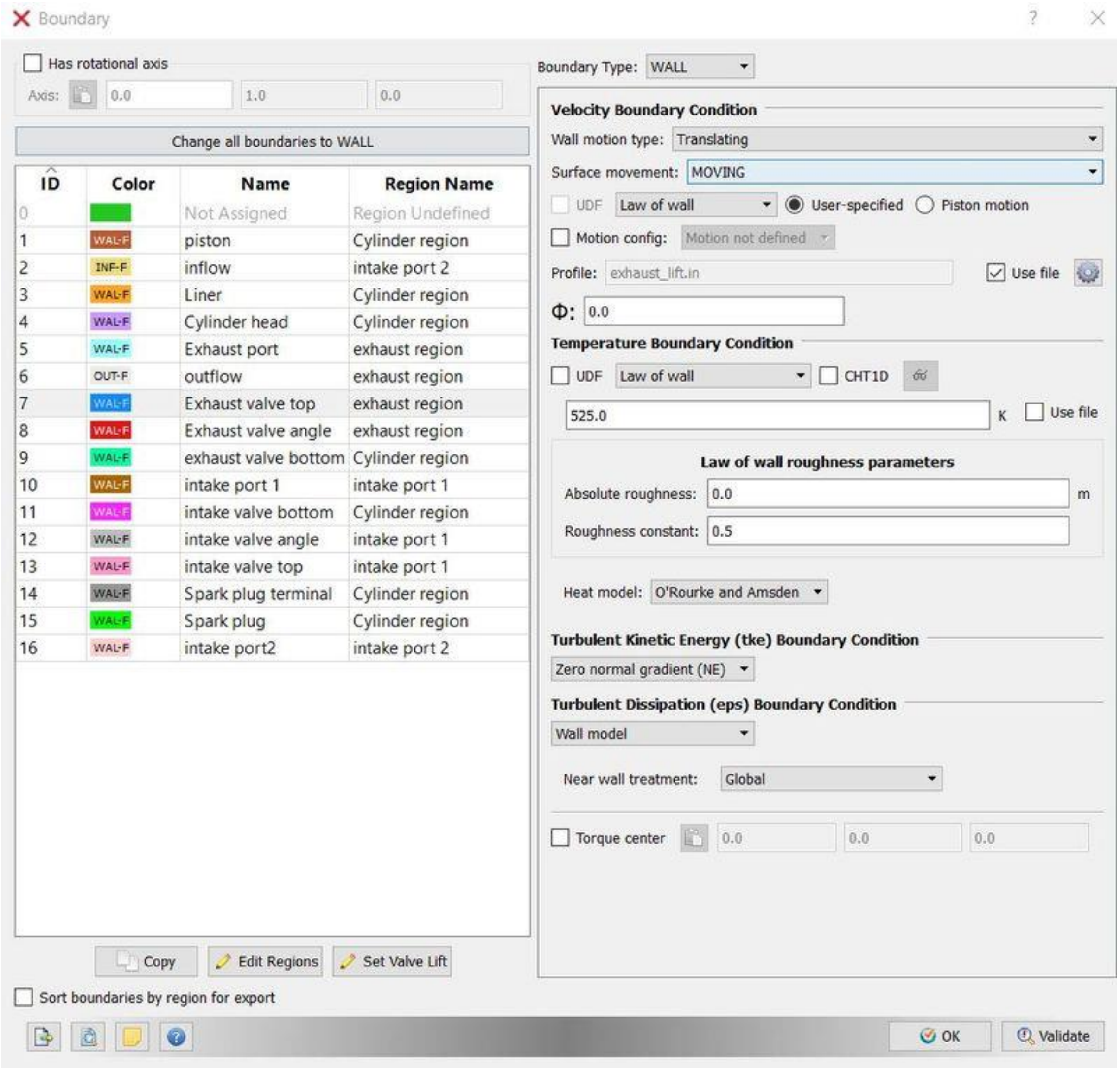
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: OUTFLOW
NSCBC Off σ: 0.25 L (m): -1
Pressure Boundary Condition
UDF Specified Value (DI) Presdist: 0.0
Reference center
0 0 0
101325.0 Pa Use file
Sponge
Center: 0 0 0
Direction: 0 0 0
Distance (m): 0.0
Velocity Boundary Condition
UDF Zero normal gradient (NE Depends on pressure and supersonic
Zero normal gradient (NE)
Specified Value (DI)
Backflow
Temperature Backflow
Specified Value (DI)
800.0 K Use file
Species Backflow
Specified Value (DI)
+Air
Pull from its region
Species Name
Mass Fraction
Sum = 1.00000
CO2 0.192304
N2 0.719137
OK
Validate


Boundary
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Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
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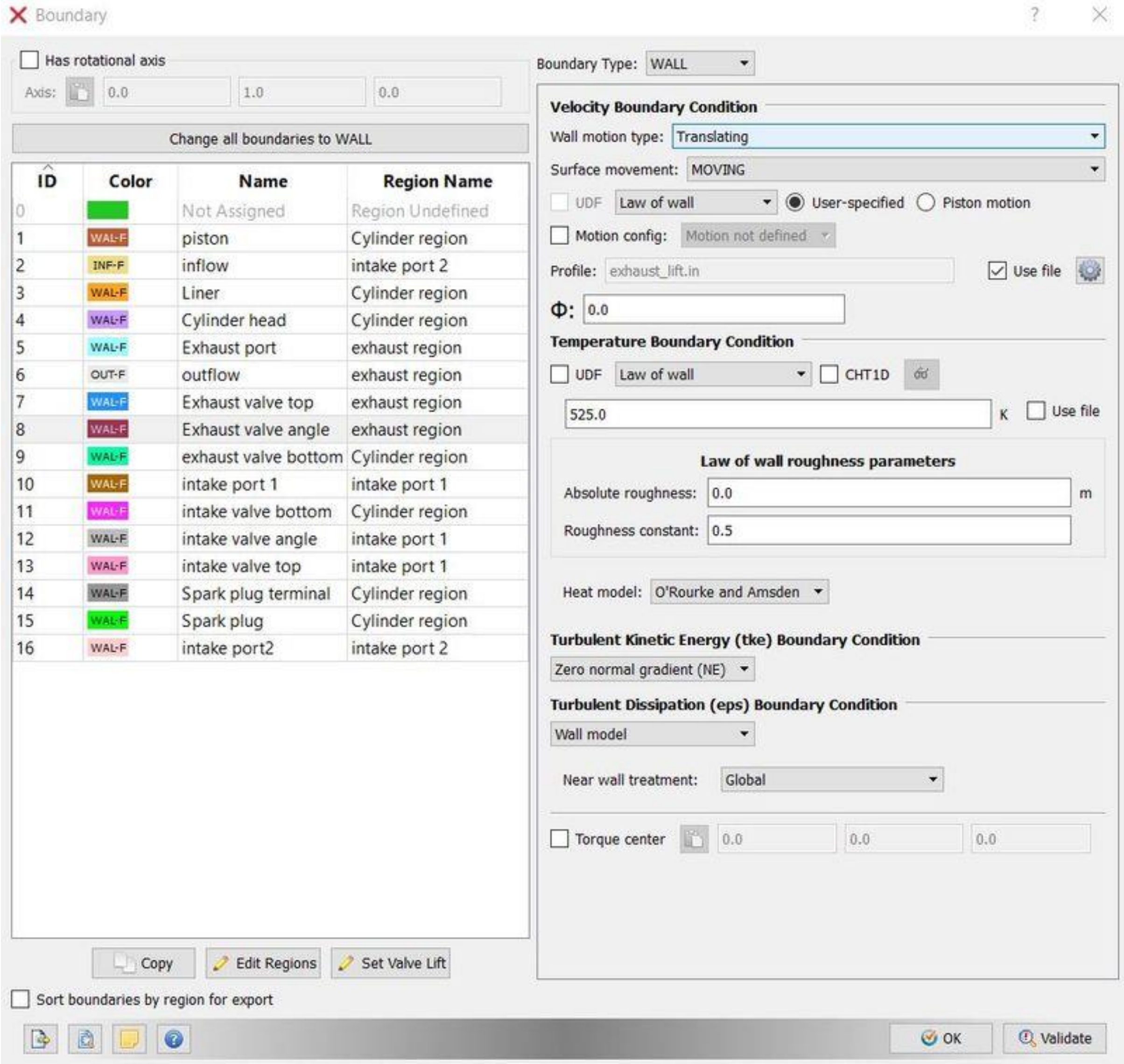
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Translating
Surface movement: MOVING
UDF Law of wall User-specified Piston motion
Motion config: Motion not defined
Profile: exhaust_lift.in
Use file
Φ: 0.0
Temperature Boundary Condition
UDF Law of wall CHT1D
525.0 K
Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: O'Rourke and Amsden
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate


Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
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Temperature Boundary Condition
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525.0 K Use file
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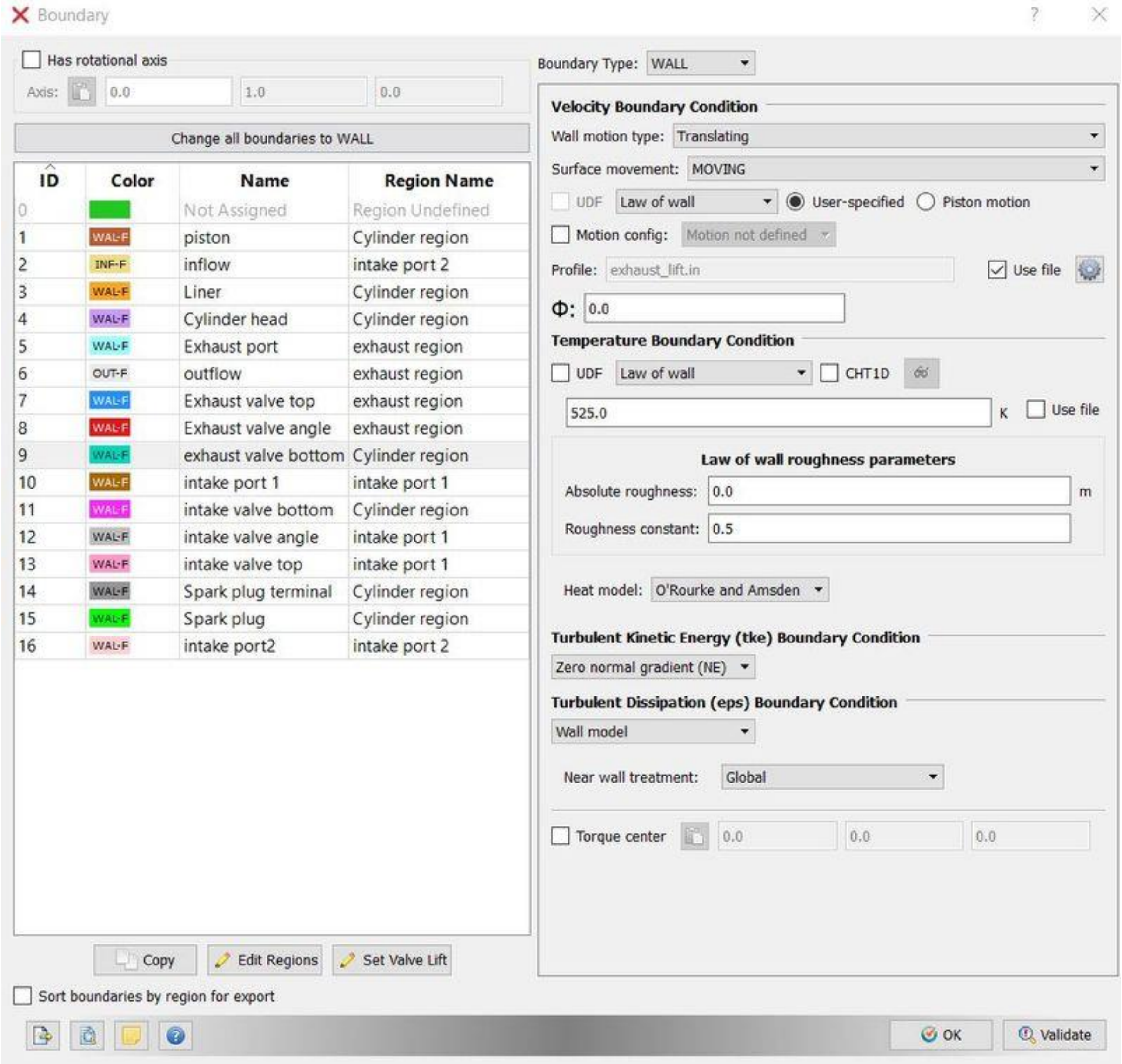
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate


Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
2 INF-F inflow intake port 2
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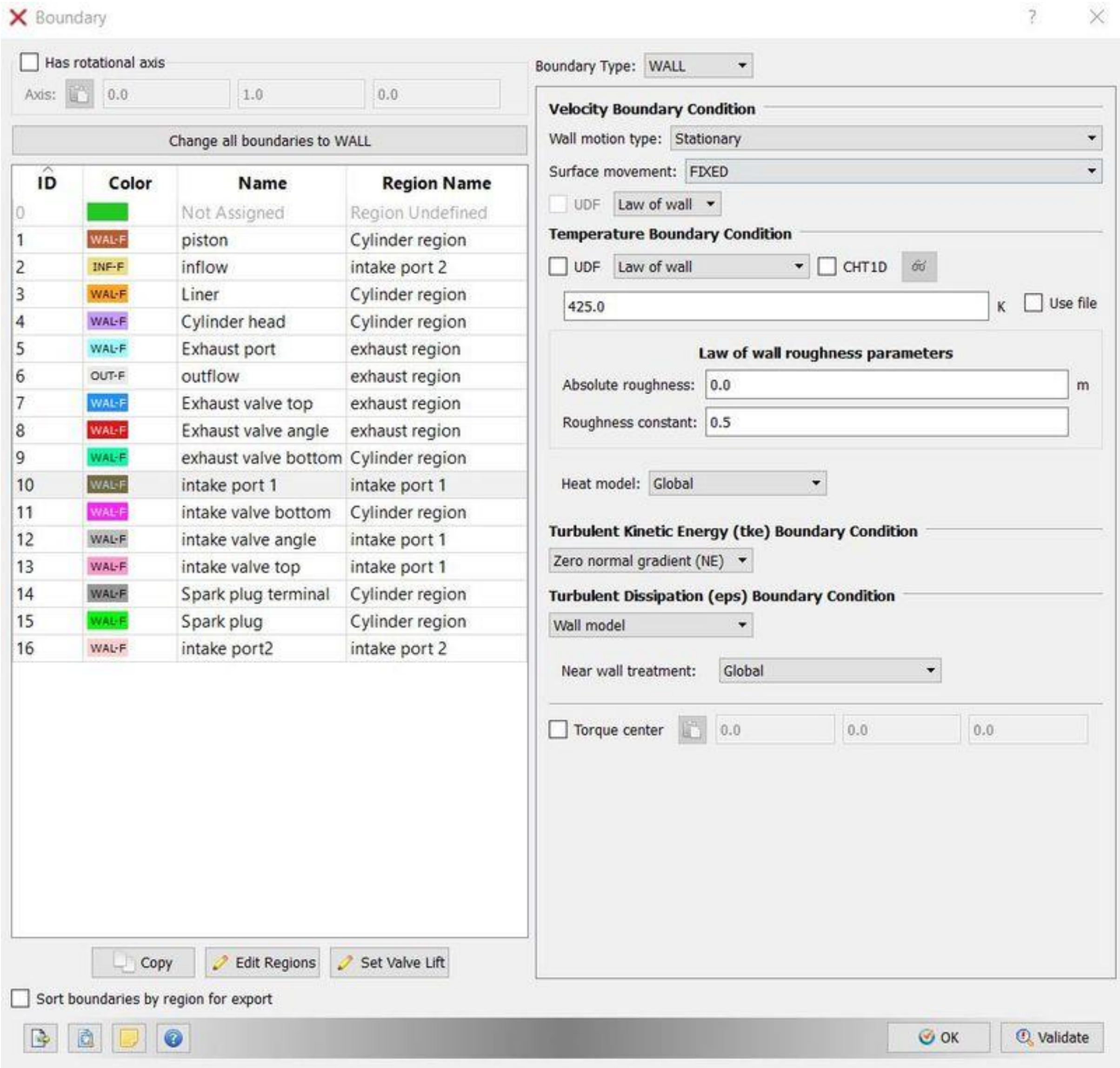
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Translating
Surface movement: MOVING
UDF Law of wall User-specified Piston motion
Motion config: Motion not defined
Profile: exhaust_lift.in Use file
Φ: 0.0
Temperature Boundary Condition
UDF Law of wall CHT1D
525.0 K Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: O'Rourke and Amsden
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate


Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
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14 WAL-F Spark plug terminal Cylinder region
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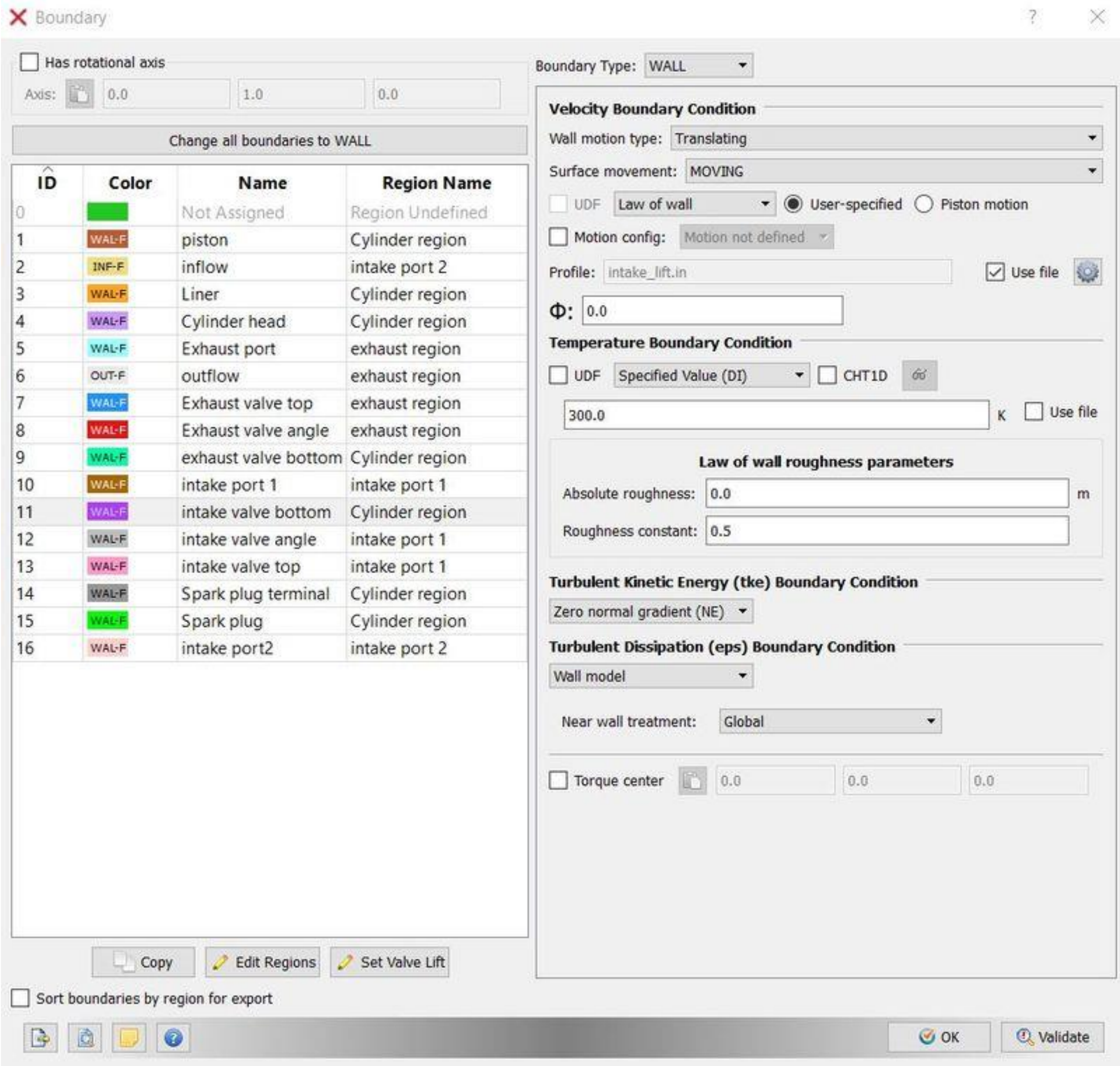
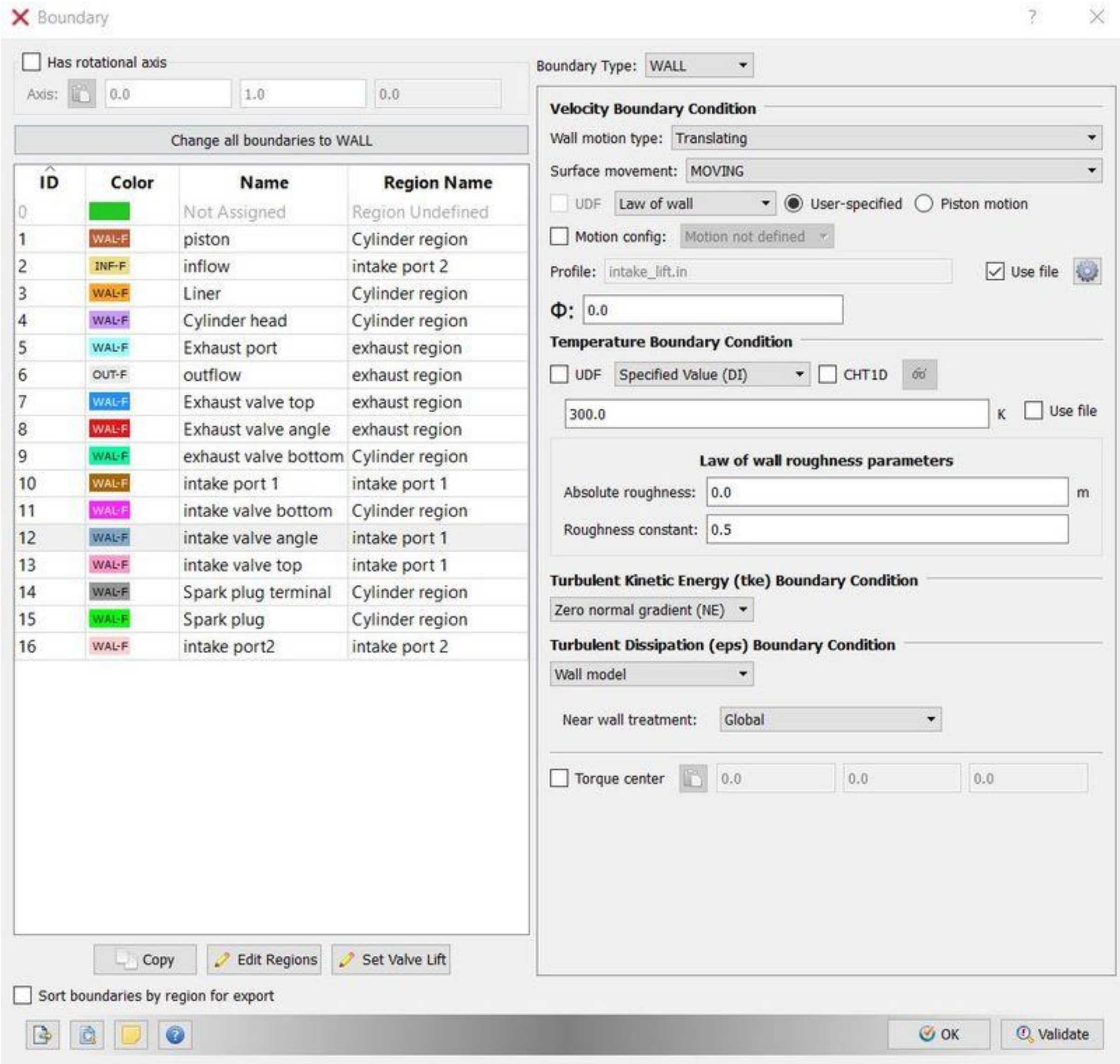
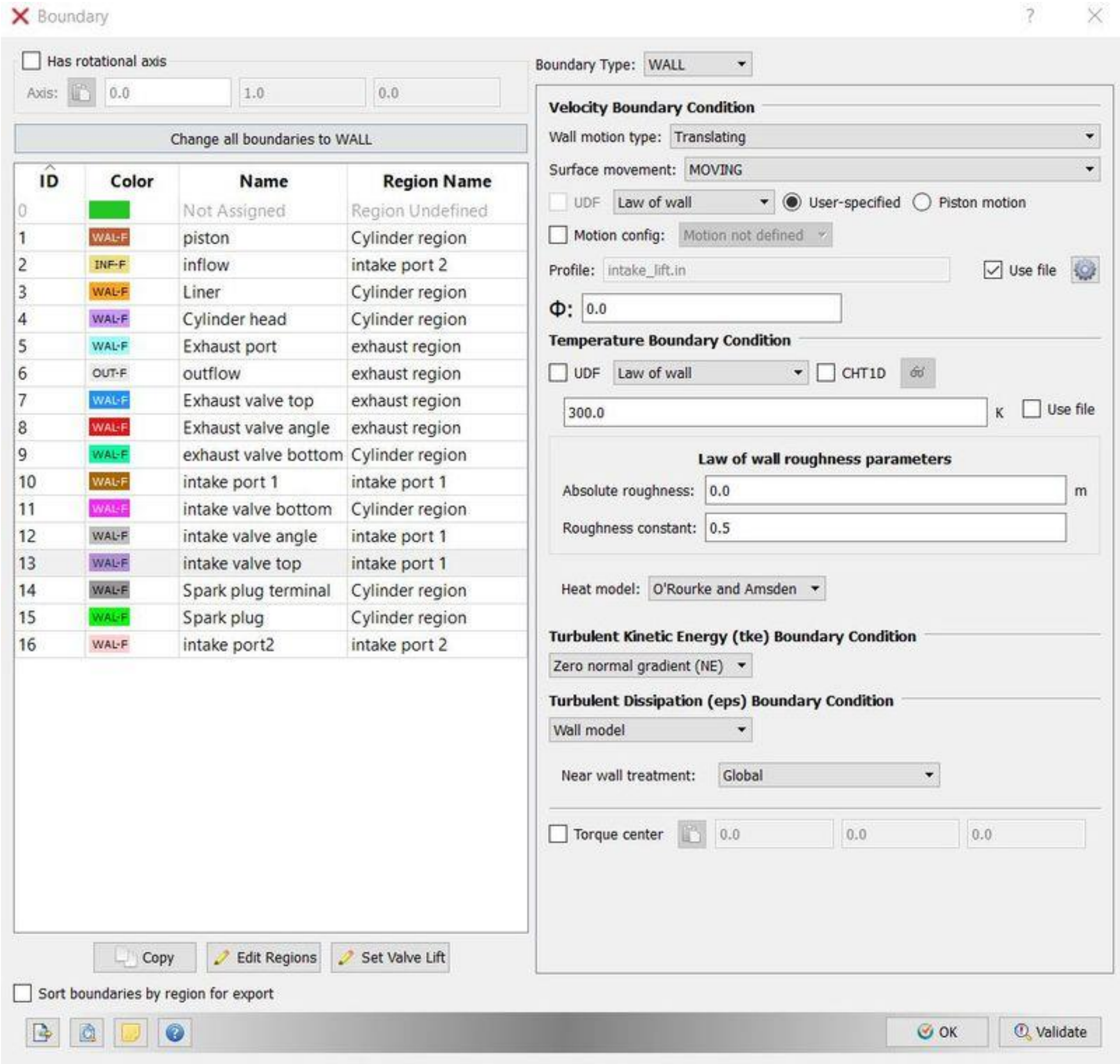
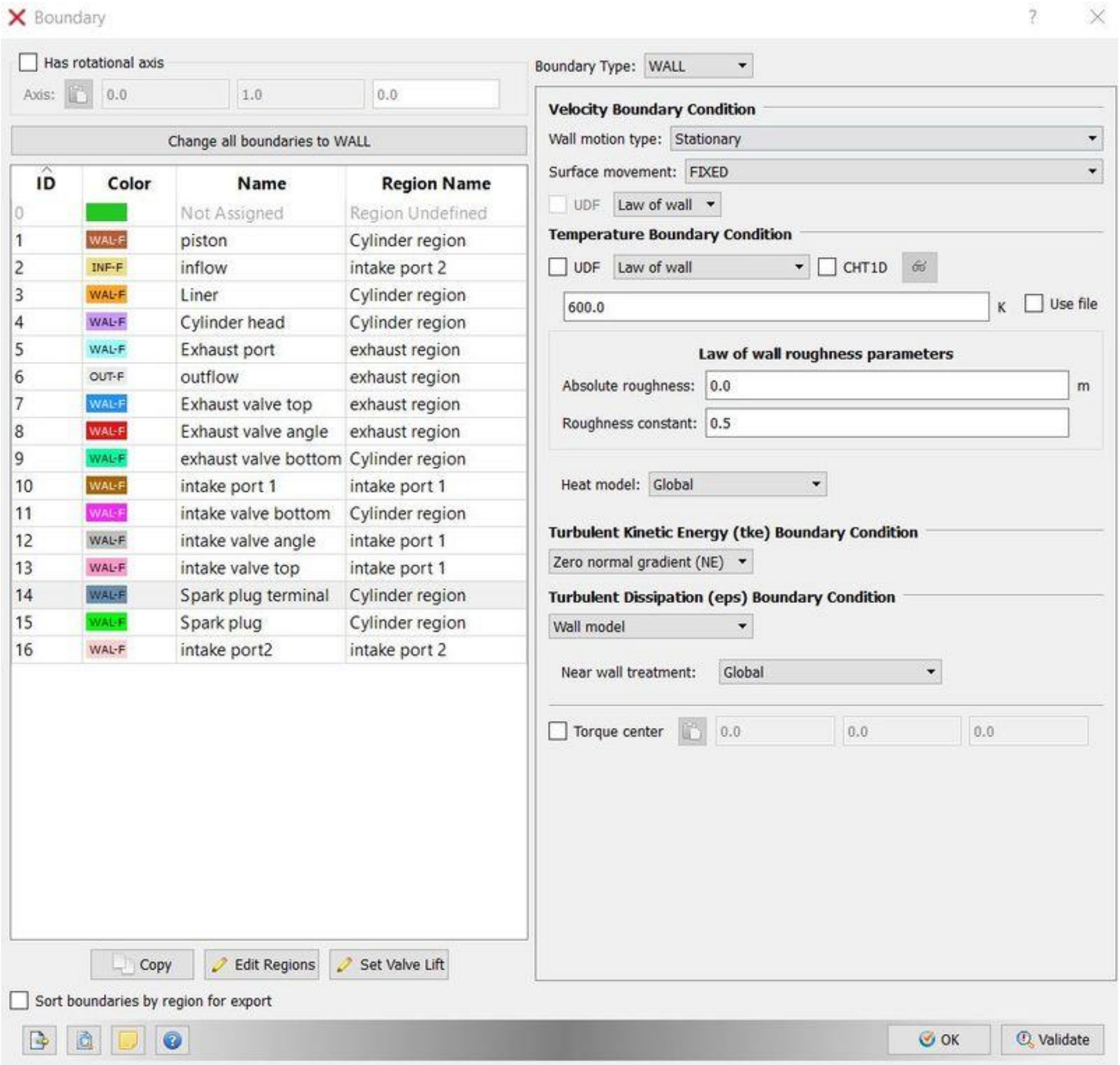
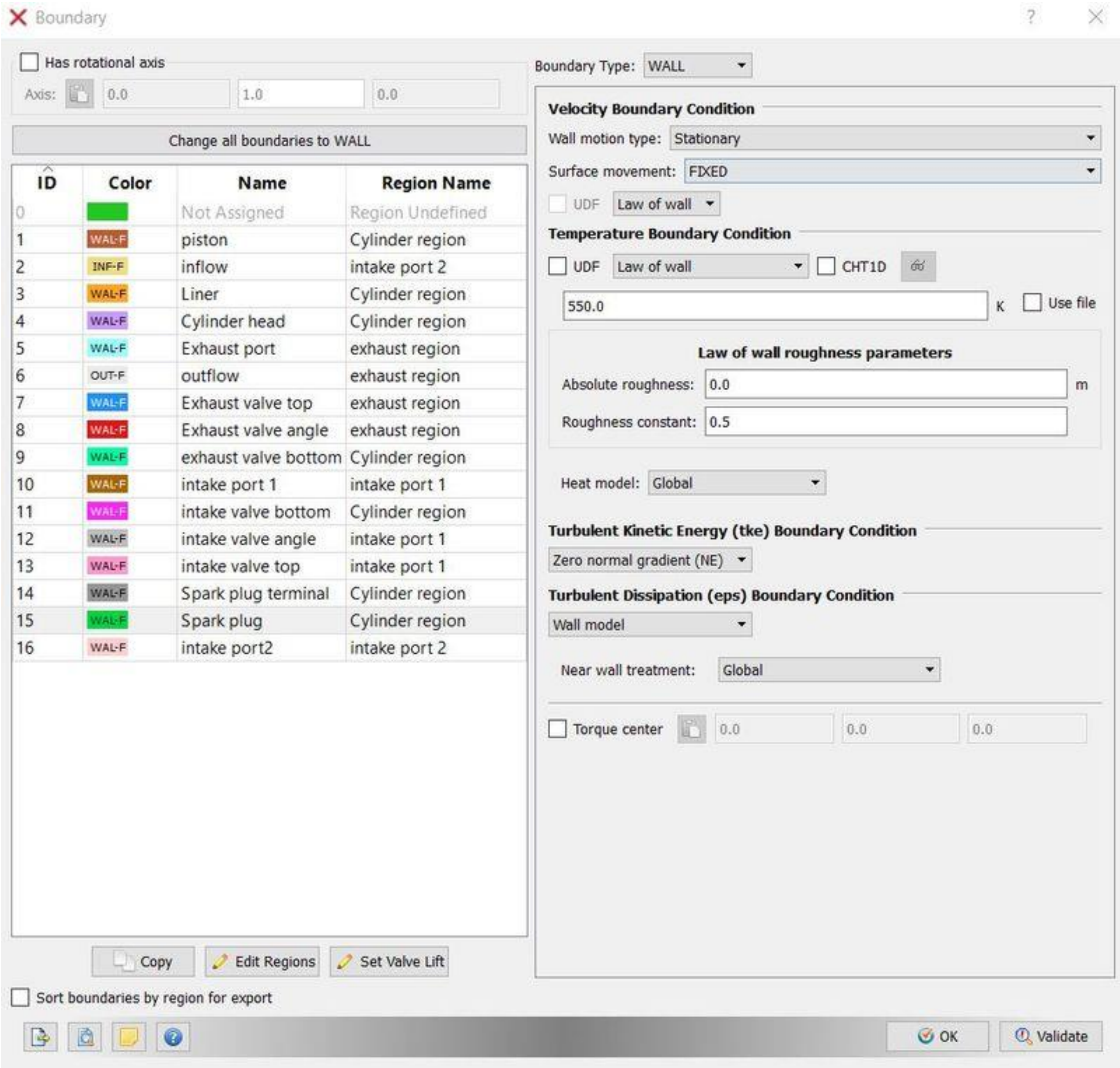
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Stationary
Surface movement: FIXED
UDF Law of wall
Temperature Boundary Condition
UDF Law of wall CHT1D
425.0 K Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: Global
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate

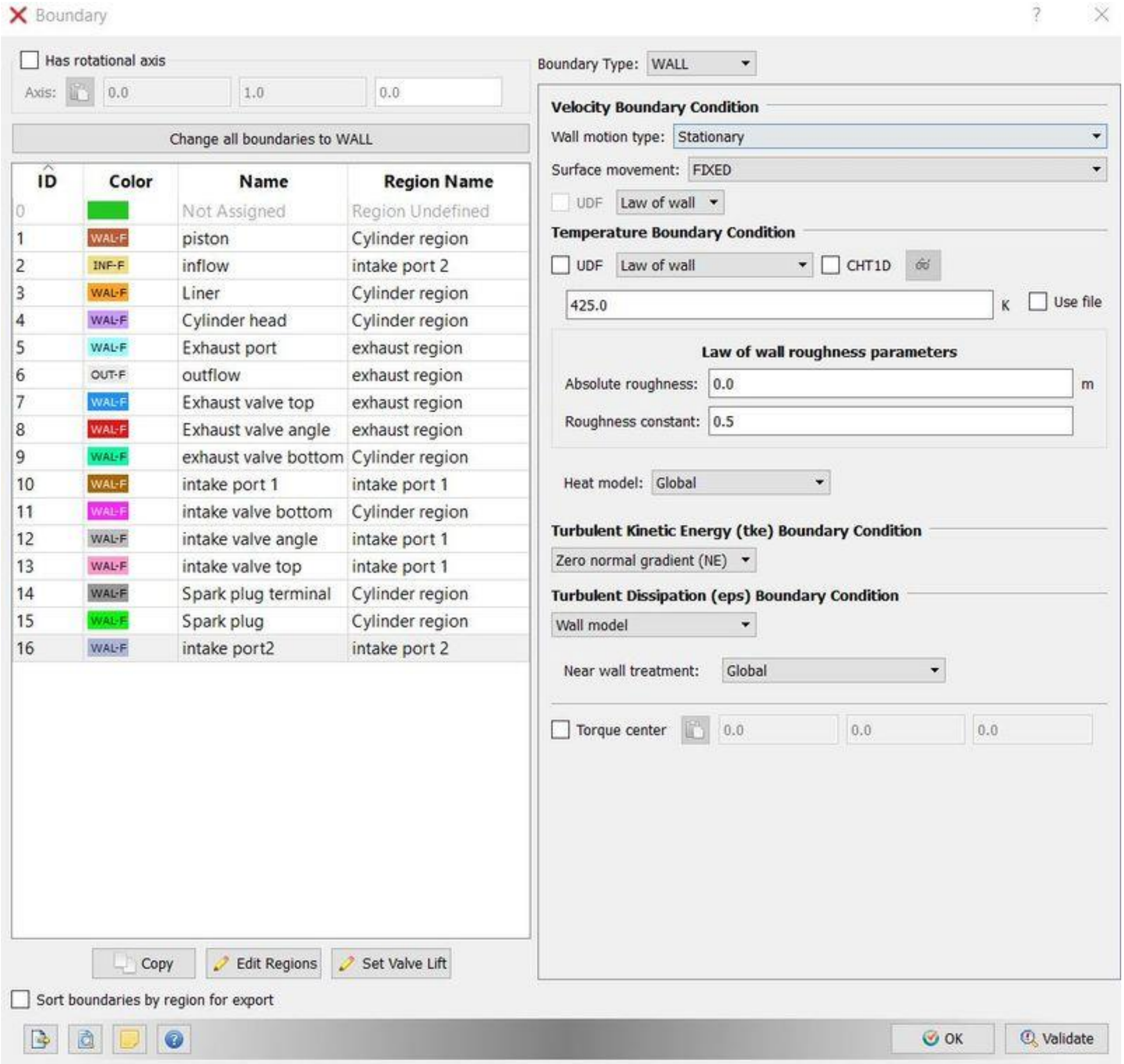

Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
2 INF-F inflow intake port 2
3 WAL-F Liner Cylinder region
4 WAL-F Cylinder head Cylinder region
5 WAL-F Exhaust port exhaust region
6 OUT-F outflow exhaust region
7 WAL-F Exhaust valve top exhaust region
8 WAL-F Exhaust valve angle exhaust region
9 WAL-F exhaust valve bottom Cylinder region
10 WAL-F intake port 1 intake port 1
11 WAL-F intake valve bottom Cylinder region
12 WAL-F intake valve angle intake port 1
13 WAL-F intake valve top intake port 1
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Translating
Surface movement: MOVING
UDF Law of wall User-specified Piston motion
Motion config: Motion not defined
Profile: intake_lift.in Use file
Φ: 0.0
Temperature Boundary Condition
UDF Specified Value (DI) CHT1D
300.0 K Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate


Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
2 INF-F inflow intake port 2
3 WAL-F Liner Cylinder region
4 WAL-F Cylinder head Cylinder region
5 WAL-F Exhaust port exhaust region
6 OUT-F outflow exhaust region
7 WAL-F Exhaust valve top exhaust region
8 WAL-F Exhaust valve angle exhaust region
9 WAL-F exhaust valve bottom Cylinder region
10 WAL-F intake port 1 intake port 1
11 WAL-F intake valve bottom Cylinder region
12 WAL-F intake valve angle intake port 1
13 WAL-F intake valve top intake port 1
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Translating
Surface movement: MOVING
UDF Law of wall User-specified Piston motion
Motion config: Motion not defined
Profile: intake_lift.in
Use file
Φ: 0.0
Temperature Boundary Condition
UDF Specified Value (DI) CHT1D
300.0 K
Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate

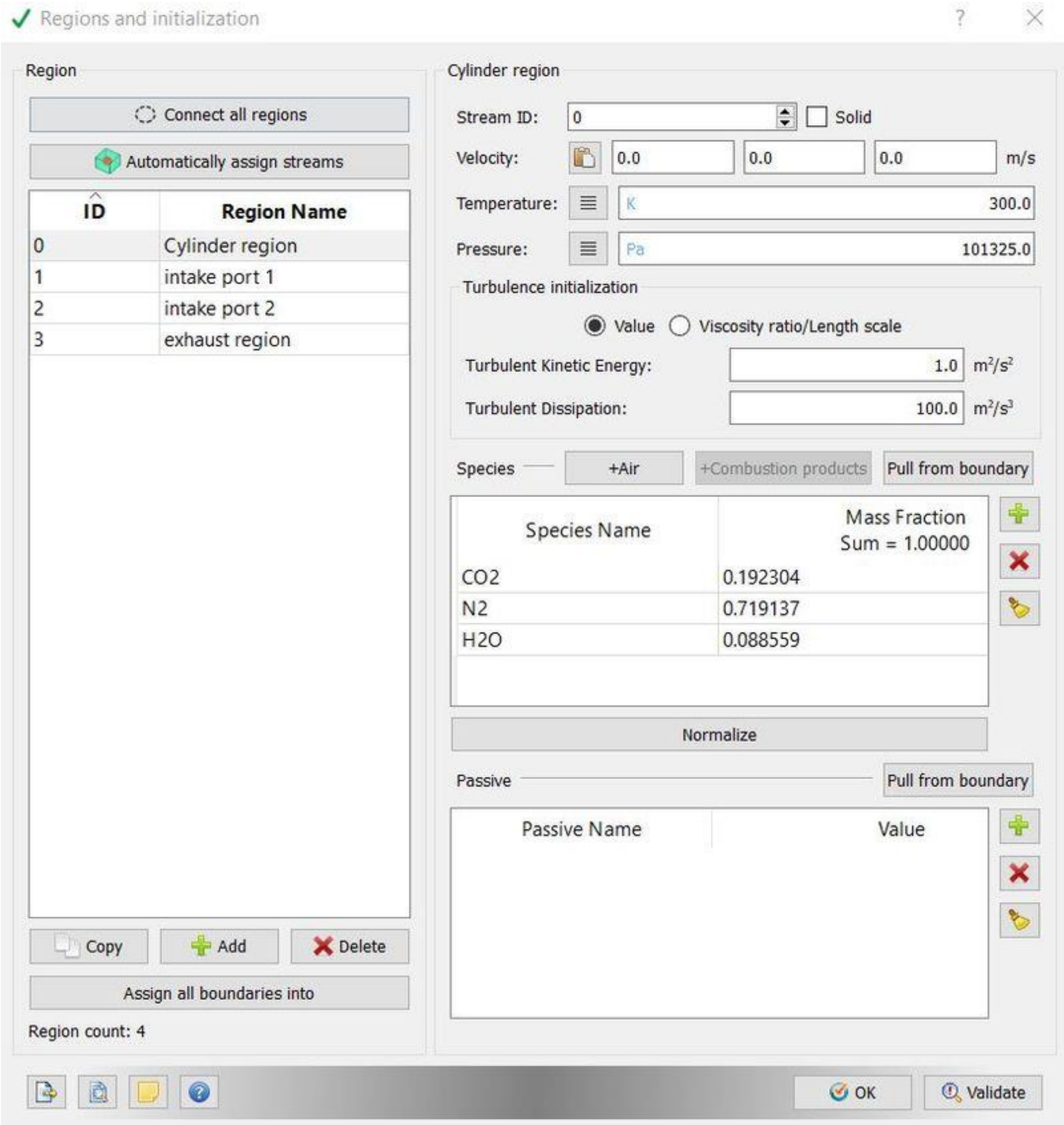

Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
2 INF-F inflow intake port 2
3 WAL-F Liner Cylinder region
4 WAL-F Cylinder head Cylinder region
5 WAL-F Exhaust port exhaust region
6 OUT-F outflow exhaust region
7 WAL-F Exhaust valve top exhaust region
8 WAL-F Exhaust valve angle exhaust region
9 WAL-F exhaust valve bottom Cylinder region
10 WAL-F intake port 1 intake port 1
11 WAL-F intake valve bottom Cylinder region
12 WAL-F intake valve angle intake port 1
13 WAL-F intake valve top intake port 1
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Translating
Surface movement: MOVING
UDF Law of wall User-specified Piston motion
Motion config: Motion not defined
Profile: intake_lift.in
Use file
Φ: 0.0
Temperature Boundary Condition
UDF Law of wall CHT1D
300.0 K
Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: O'Rourke and Amsden
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate

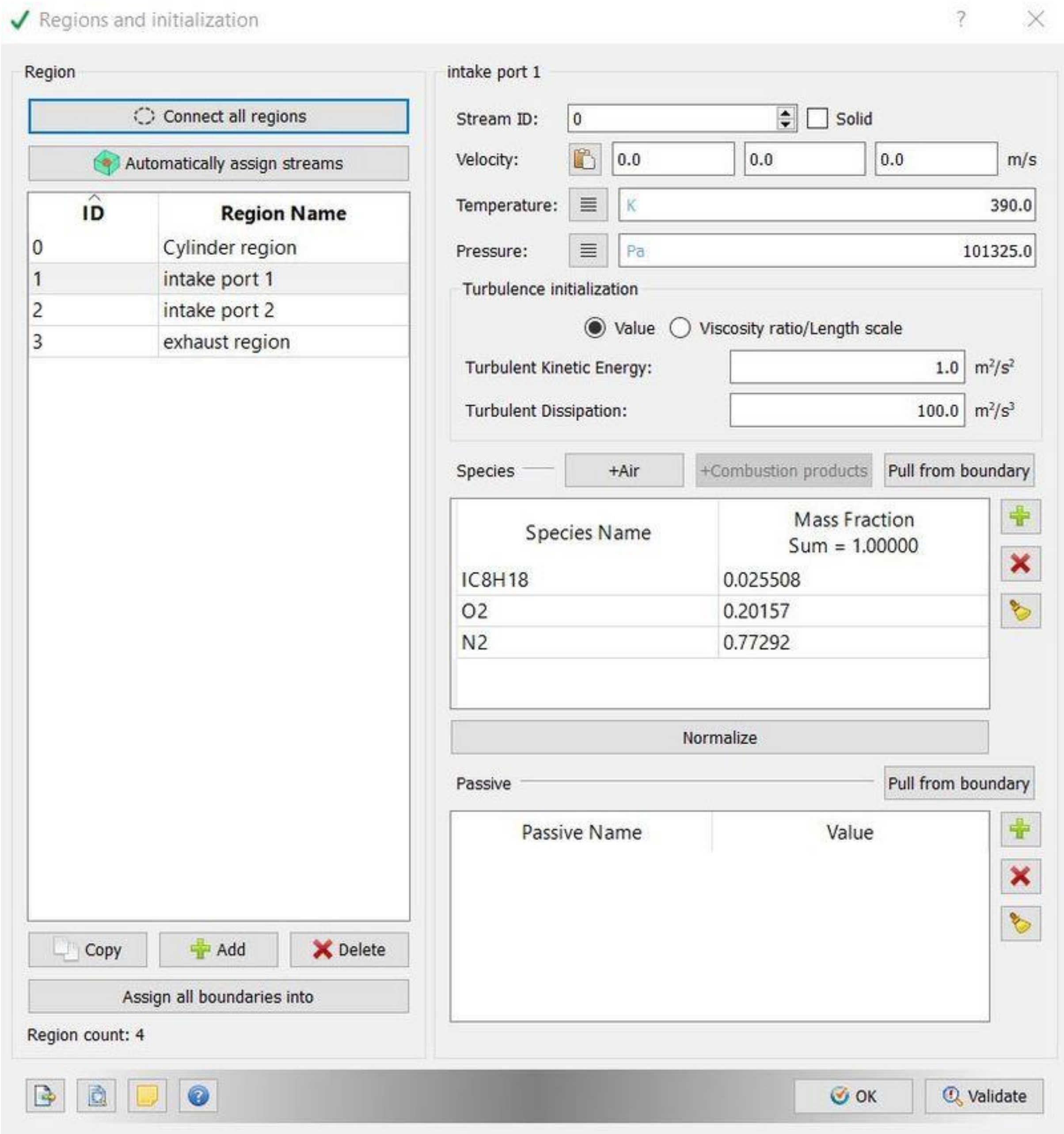

Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
2 INF-F inflow intake port 2
3 WAL-F Liner Cylinder region
4 WAL-F Cylinder head Cylinder region
5 WAL-F Exhaust port exhaust region
6 OUT-F outflow exhaust region
7 WAL-F Exhaust valve top exhaust region
8 WAL-F Exhaust valve angle exhaust region
9 WAL-F exhaust valve bottom Cylinder region
10 WAL-F intake port 1 intake port 1
11 WAL-F intake valve bottom Cylinder region
12 WAL-F intake valve angle intake port 1
13 WAL-F intake valve top intake port 1
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Stationary
Surface movement: FIXED
UDF Law of wall
Temperature Boundary Condition
UDF Law of wall CHT1D
600.0 K Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: Global
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate

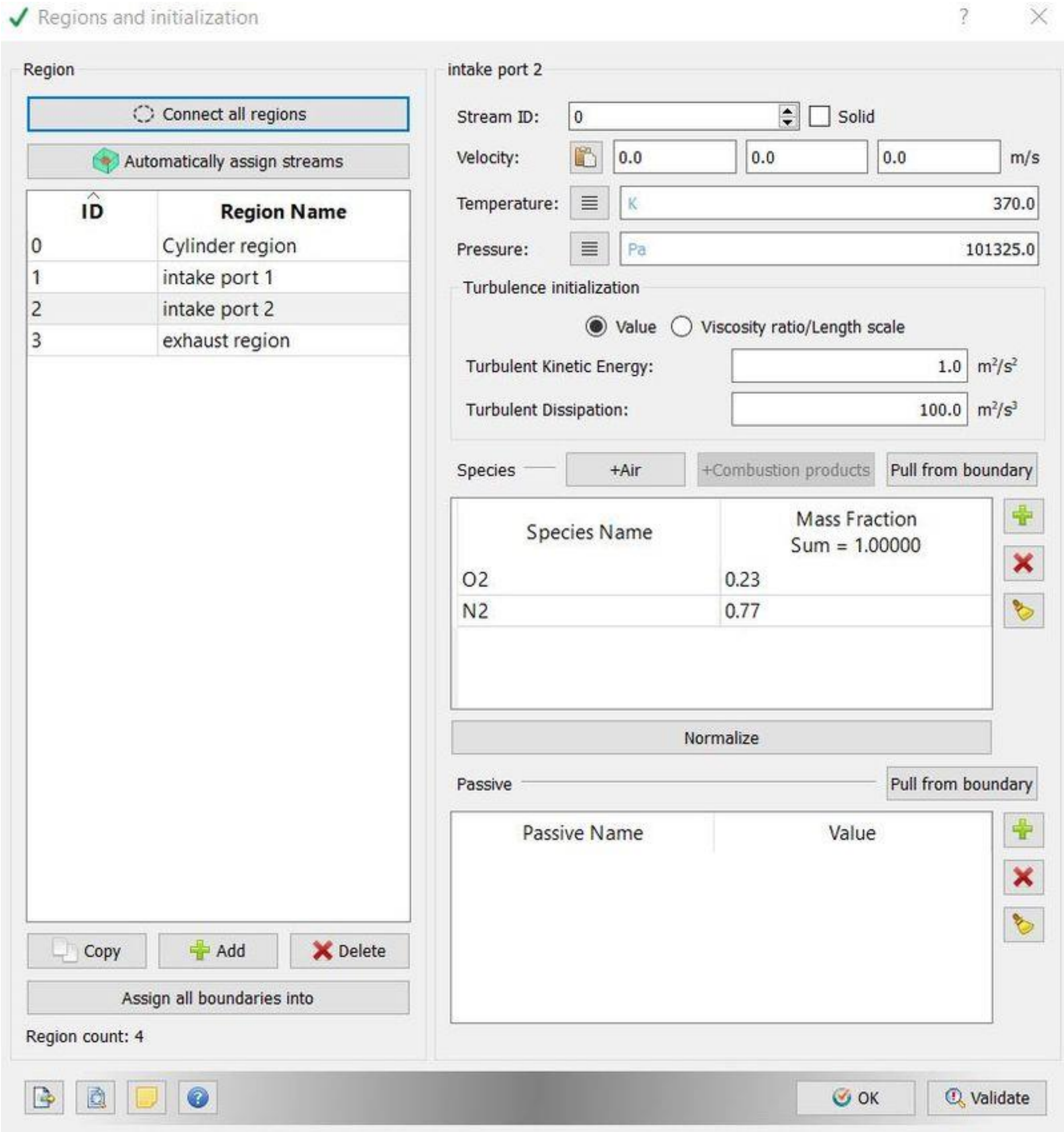

Boundary
Has rotational axis
Axis: 0.0 1.0 0.0
Change all boundaries to WALL
ID Color Name Region Name
0 Not Assigned Region Undefined
1 WAL-F piston Cylinder region
2 INF-F inflow intake port 2
3 WAL-F Liner Cylinder region
4 WAL-F Cylinder head Cylinder region
5 WAL-F Exhaust port exhaust region
6 OUT-F outflow exhaust region
7 WAL-F Exhaust valve top exhaust region
8 WAL-F Exhaust valve angle exhaust region
9 WAL-F exhaust valve bottom Cylinder region
10 WAL-F intake port 1 intake port 1
11 WAL-F intake valve bottom Cylinder region
12 WAL-F intake valve angle intake port 1
13 WAL-F intake valve top intake port 1
14 WAL-F Spark plug terminal Cylinder region
15 WAL-F Spark plug Cylinder region
16 WAL-F intake port2 intake port 2
Copy
Edit Regions
Set Valve Lift
Sort boundaries by region for export
Boundary Type: WALL
Velocity Boundary Condition
Wall motion type: Stationary
Surface movement: FIXED
UDF Law of wall
Temperature Boundary Condition
UDF Law of wall CHT1D
550.0 K Use file
Law of wall roughness parameters
Absolute roughness: 0.0 m
Roughness constant: 0.5
Heat model: Global
Turbulent Kinetic Energy (tke) Boundary Condition
Zero normal gradient (NE)
Turbulent Dissipation (eps) Boundary Condition
Wall model
Near wall treatment: Global
Torque center 0.0 0.0 0.0
OK
Validate

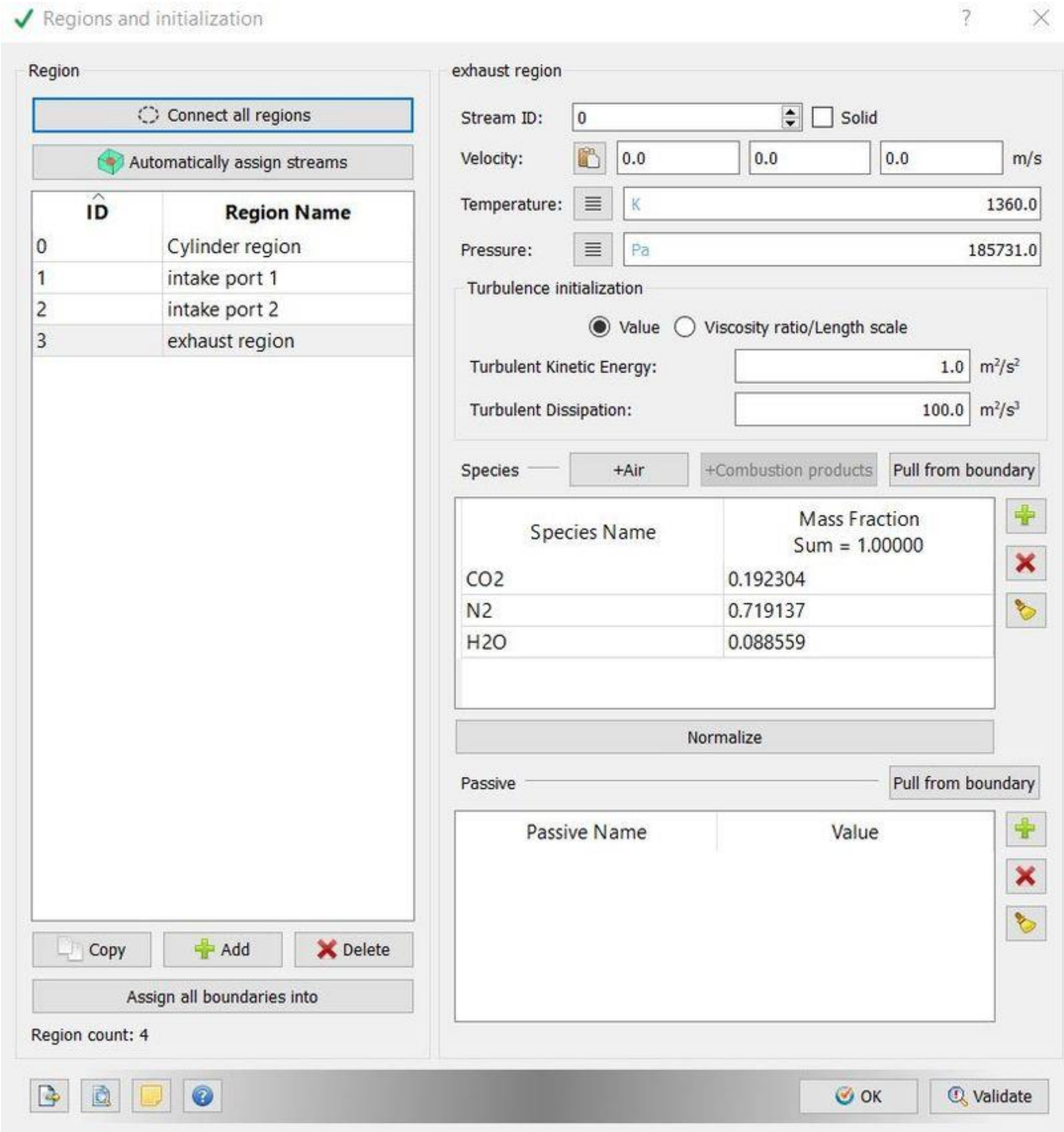


10. Four major regions were defined named cylinder region, intake port1, intake port2 and exhaust region. Region allows us to defined region-specific properties like exhaust and inlet region can not have same properties. Intake port 2 will have air only, in intake port1 fuel will injected so iso-octane mixes with air, mass fraction will be as shown in following image. In cylinder region and exhaust port there will be only O2, H2O and CO2 which are products of combustion reaction. Mass fraction of products was given as discussed in theory.

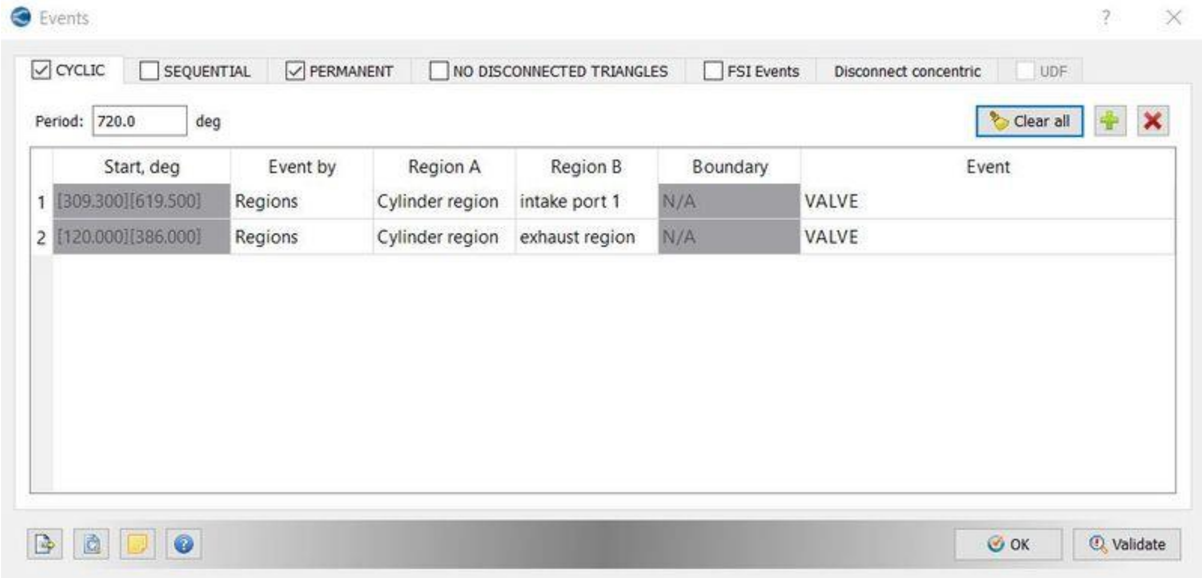

Regions and initialization
Region
Connect all regions
Automatically assign streams
ID
Region Name
0
Cylinder region
1
intake port 1
2
intake port 2
3
exhaust region
Copy
Add
Delete
Assign all boundaries into
Region count: 4
Cylinder region
Stream ID:
0
Solid
Velocity:
0.0
0.0
0.0
m/s
Temperature:
K
300.0
Pressure:
Pa
101325.0
Turbulence initialization
Value
Viscosity ratio/Length scale
Turbulent Kinetic Energy:
1.0
m²/s²
Turbulent Dissipation:
100.0
m²/s³
Species
+Air
+Combustion products
Pull from boundary
Species Name
Mass Fraction
Sum = 1.00000
CO2
0.192304
N2
0.719137
H2O
0.088559
Normalize
Passive
Pull from boundary
Passive Name
Value
OK
Validate

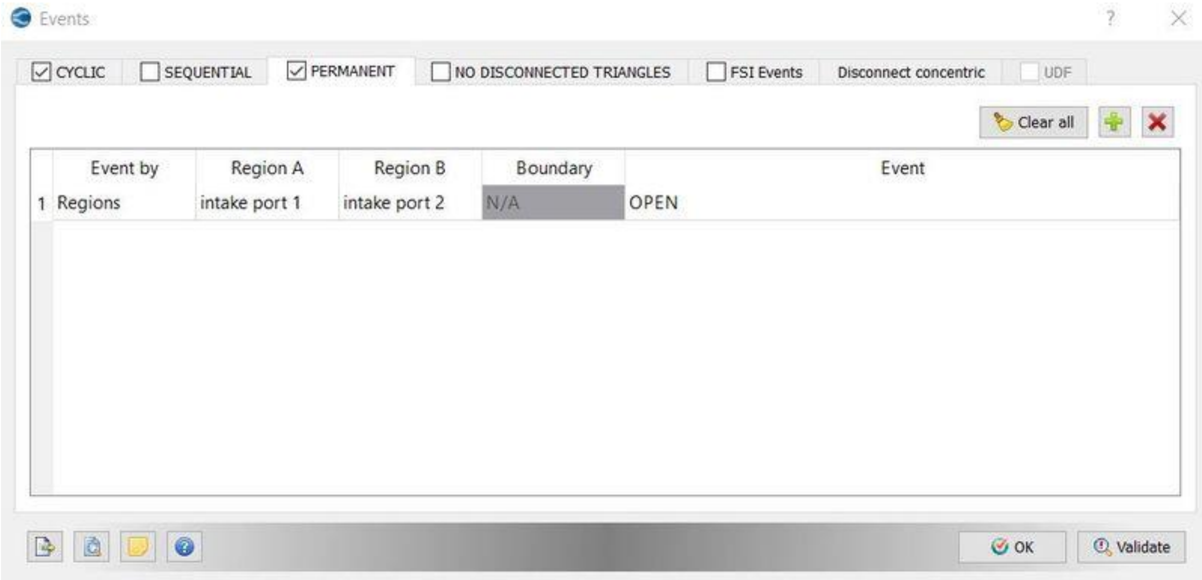

Regions and initialization
Region
Connect all regions
Automatically assign streams
ID
Region Name
0 Cylinder region
1 intake port 1
2 intake port 2
3 exhaust region
Copy
Add
Delete
Assign all boundaries into
Region count: 4
intake port 1
Stream ID: 0
Solid
Velocity: 0.0 0.0 0.0 m/s
Temperature: K 390.0
Pressure: Pa 101325.0
Turbulence initialization
Value
Viscosity ratio/Length scale
Turbulent Kinetic Energy: 1.0 m2/s2
Turbulent Dissipation: 100.0 m2/s3
Species
+Air
+Combustion products
Pull from boundary
Species Name
Mass Fraction
Sum = 1.00000
IC8H18 0.025508
O2 0.20157
N2 0.77292
Normalize
Passive
Pull from boundary
Passive Name
Value
OK
Validate


Regions and initialization
Region
Connect all regions
Automatically assign streams
ID
Region Name
0
Cylinder region
1
intake port 1
2
intake port 2
3
exhaust region
Copy
Add
Delete
Assign all boundaries into
Region count: 4
intake port 2
Stream ID:
0
Solid
Velocity:
0.0
0.0
0.0
m/s
Temperature:
K
370.0
Pressure:
Pa
101325.0
Turbulence initialization
Value
Viscosity ratio/Length scale
Turbulent Kinetic Energy:
1.0
m²/s²
Turbulent Dissipation:
100.0
m²/s³
Species
+Air
+Combustion products
Pull from boundary
Species Name
Mass Fraction
Sum = 1.00000
O2
0.23
N2
0.77
Normalize
Passive
Pull from boundary
Passive Name
Value
OK
Validate



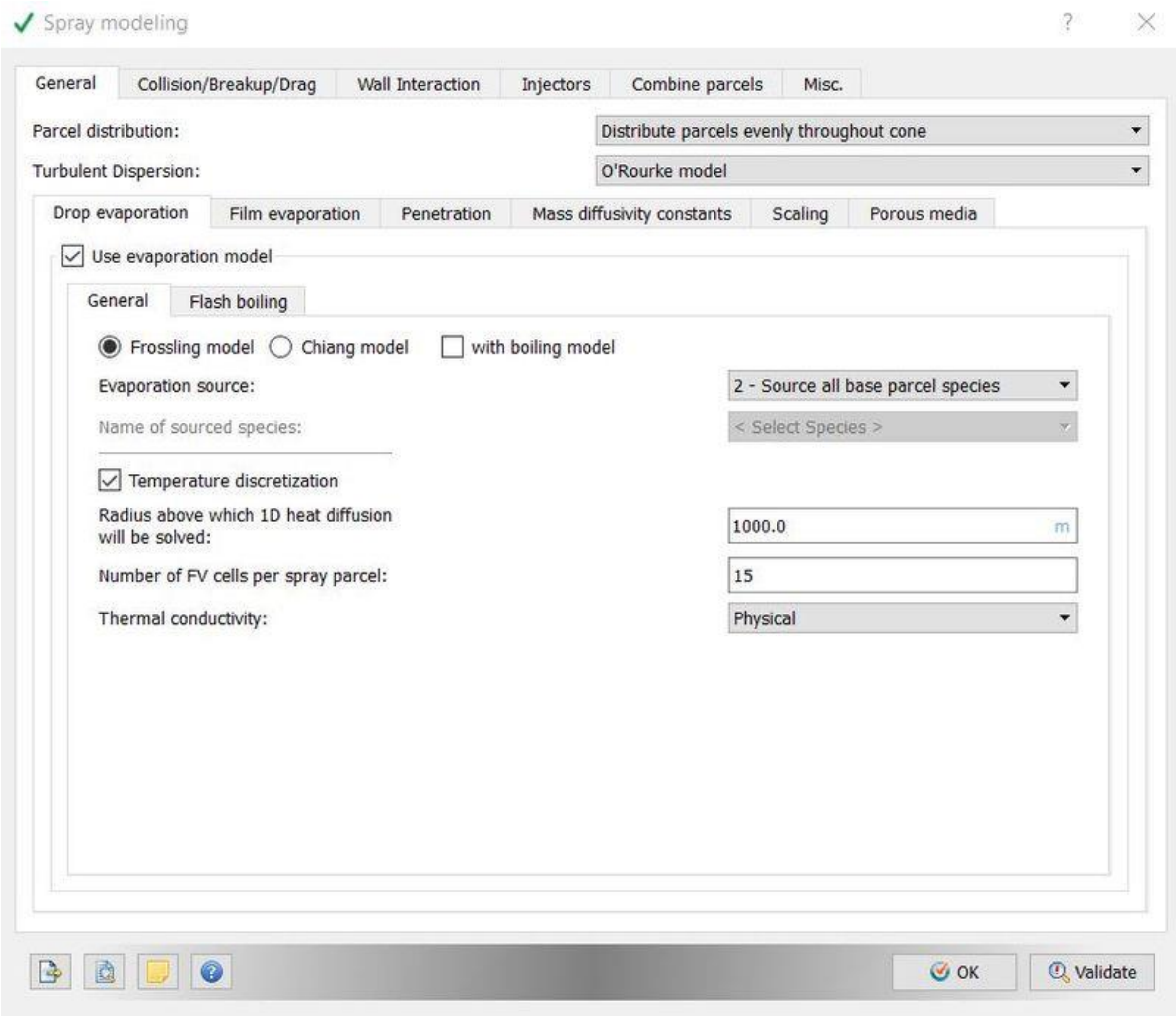
11. Event were enabled in initial conditions and we specified three events, two were cyclic which would replicate valve movement and one event was permanent which specified no barrier between intake port 1 and intake port 2. Between 309.3 and 619.5 degrees of crank angle there will no barriers between cylinder and intake port means valve will be open fuel will find its way towards cylinder, similarly between 120 and 386 exhaust valve will open and exhaust gases will be expelled by piston.



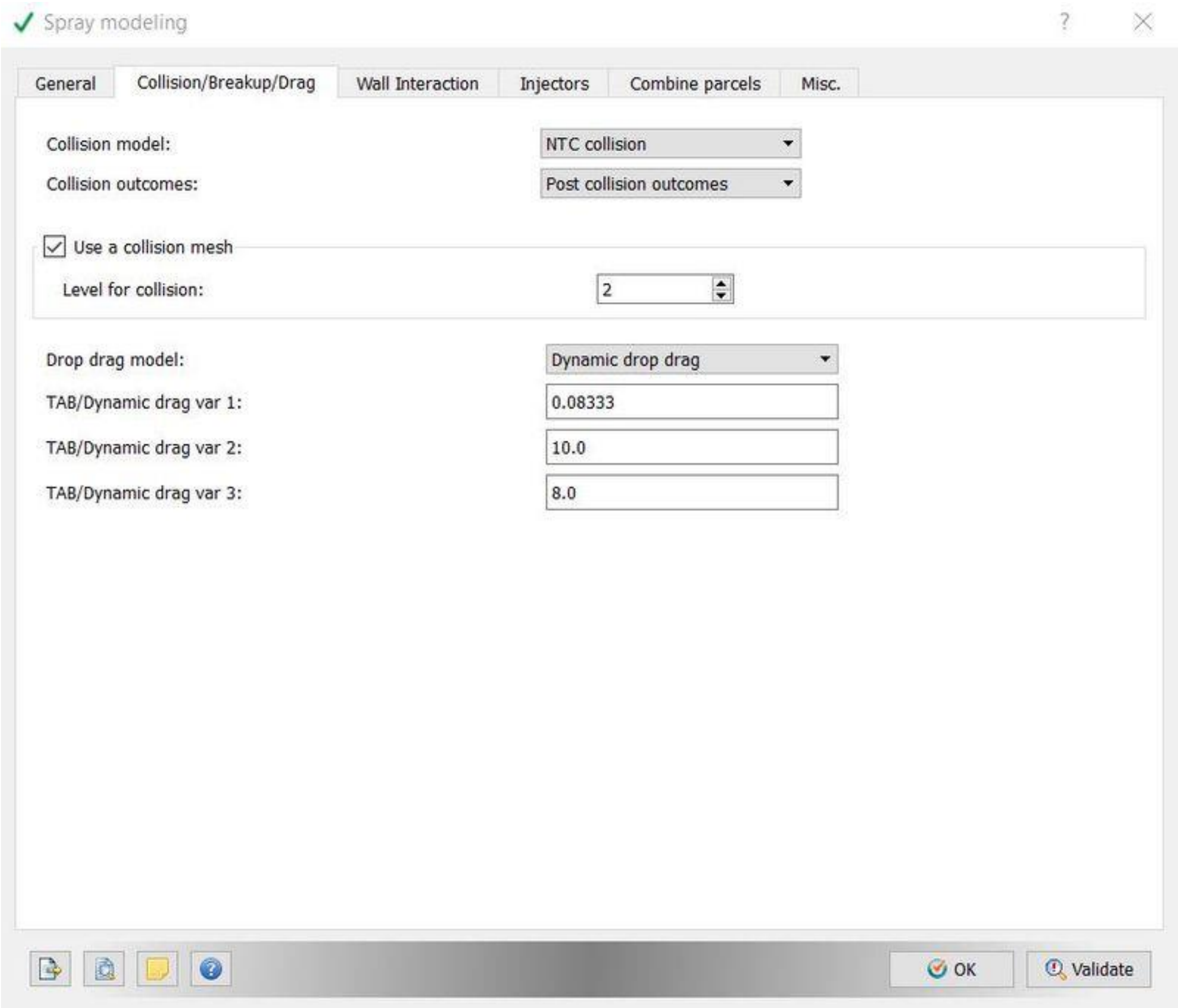


12. From physical model’s menu spray, combustion and source/sink model was enabled.

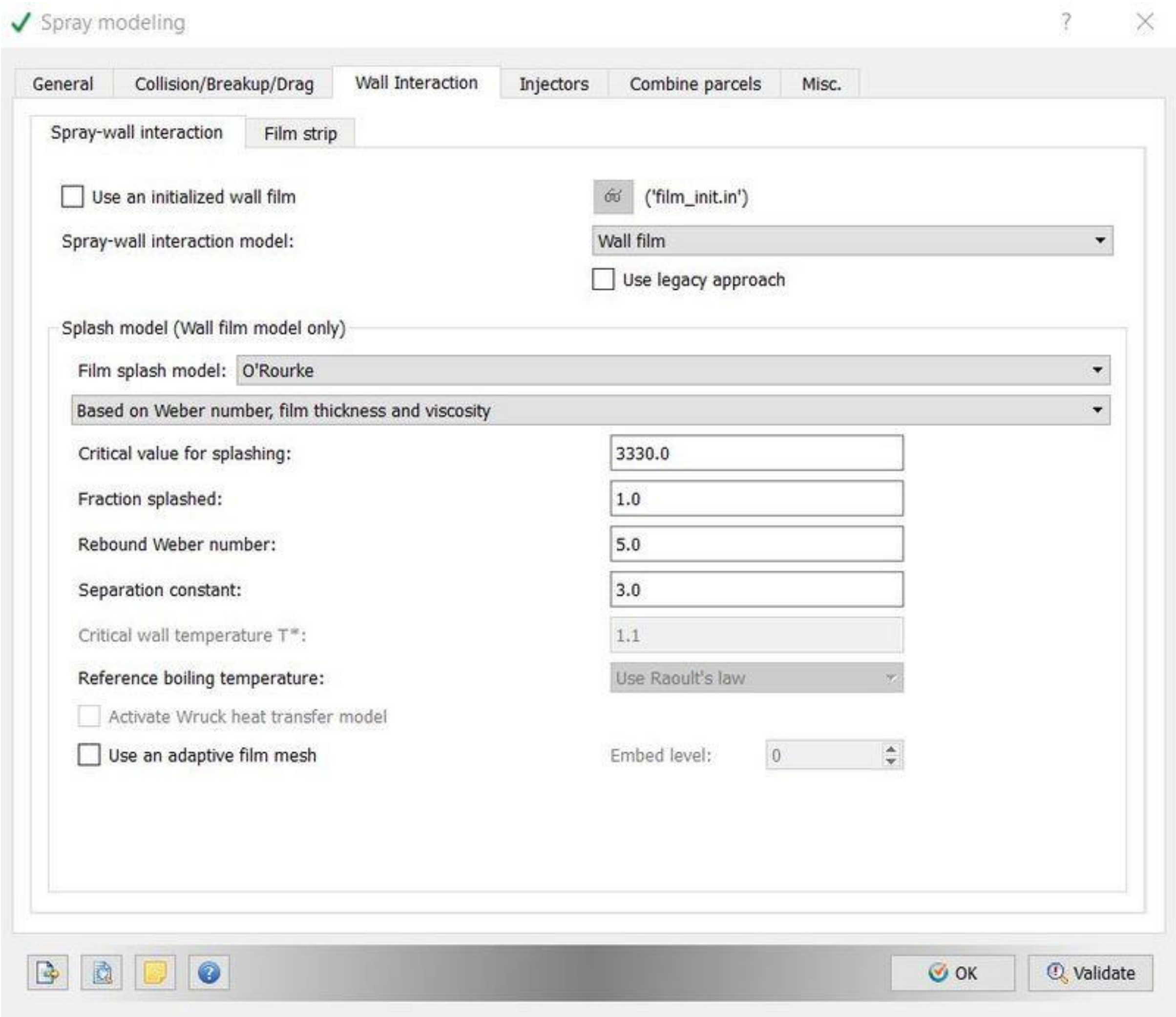
13. The Spray modelling dialog box is used to configure nozzles, injectors, boundary injections, injection rate-shapes, set various spray-related constants, and choose from several injection and drop models. We started with choosing drop evaporation option with frossling model, it determines how the radius of drop changes with time.



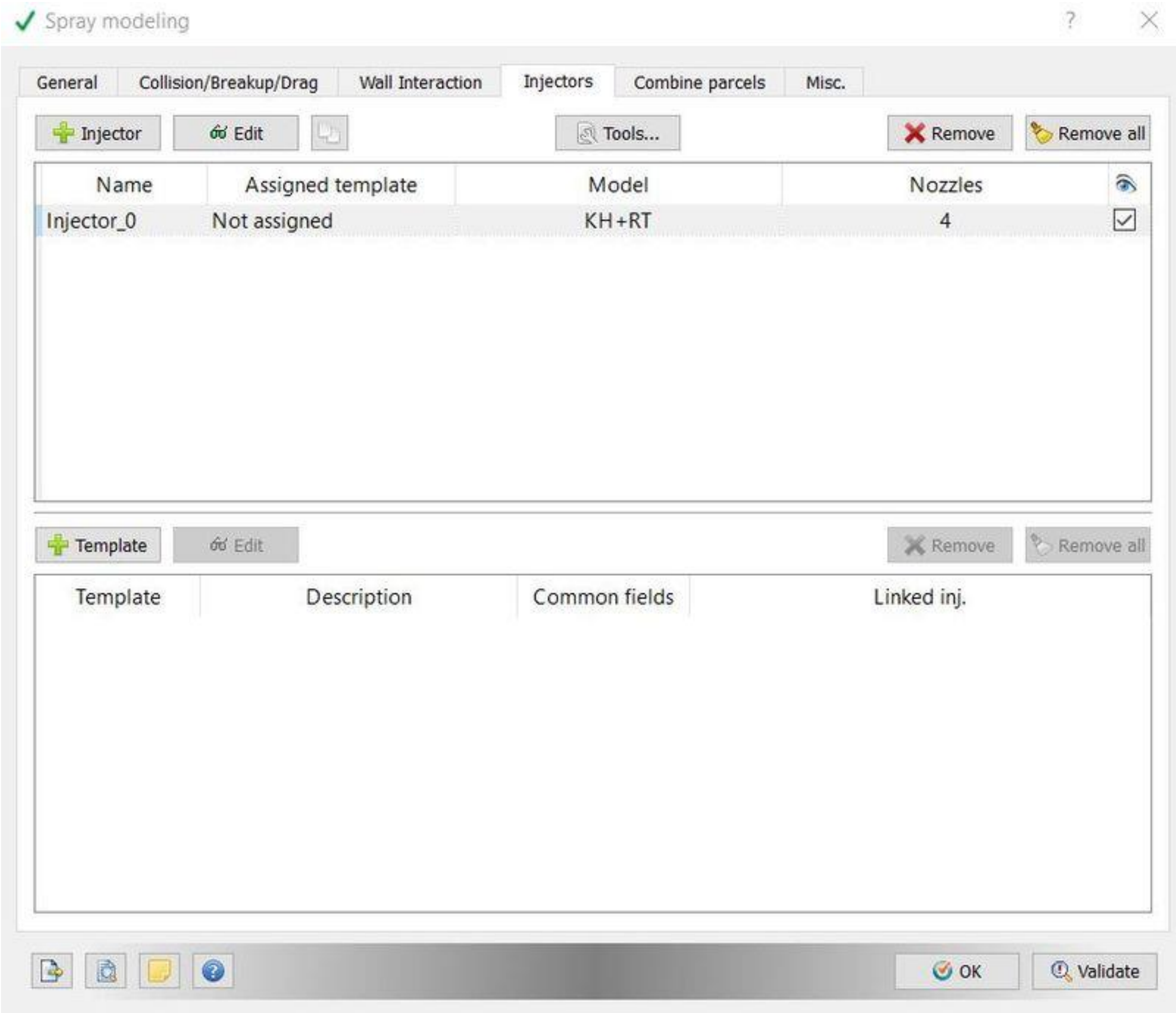
Converge contains the widely used O'Rourke and NTC collision models. These models are designed to estimate the number of droplet collisions and their outcomes in a relatively computationally efficient manner. We went with NTC model, since it is faster and more accurate than O'Rourke model.

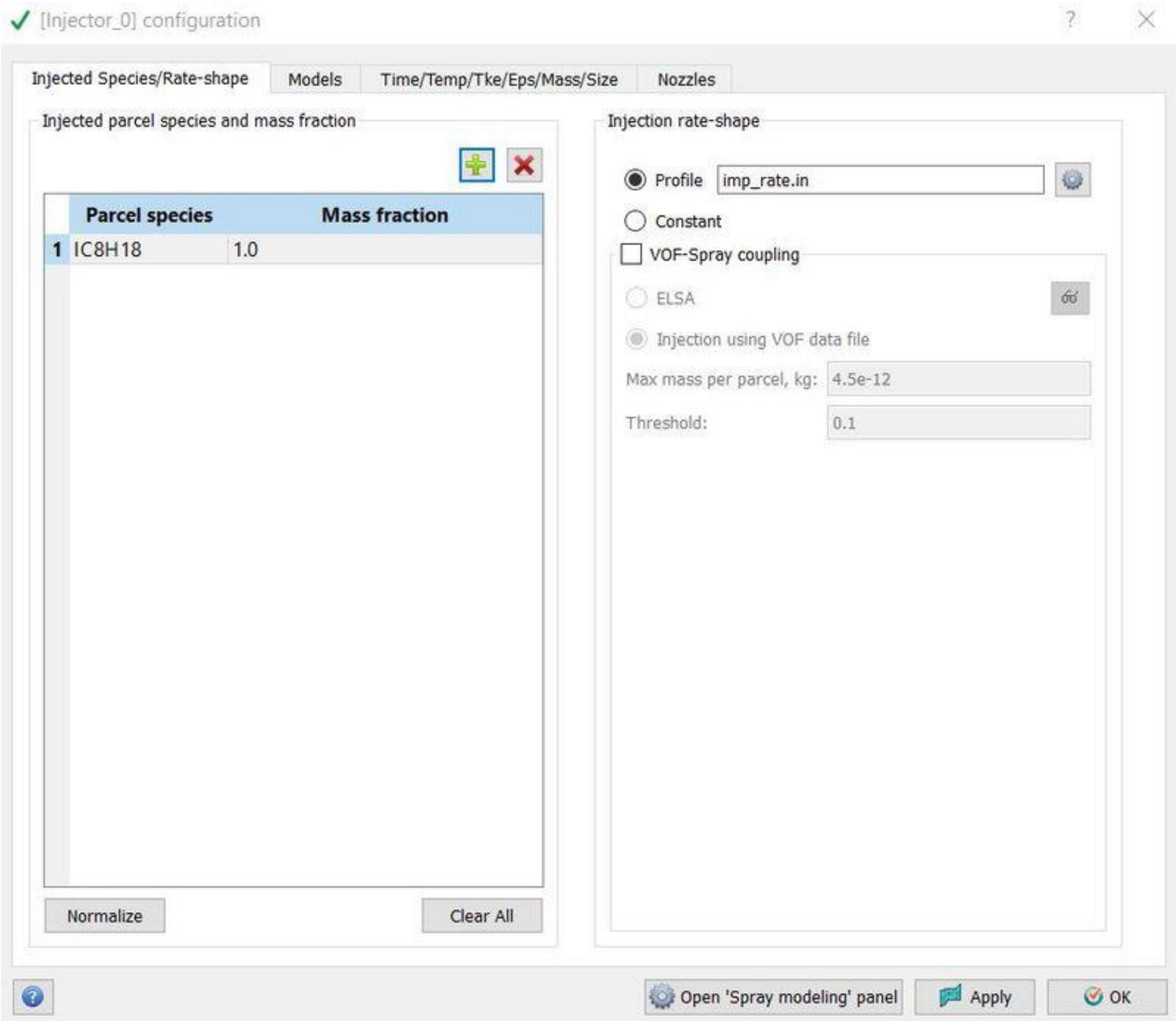


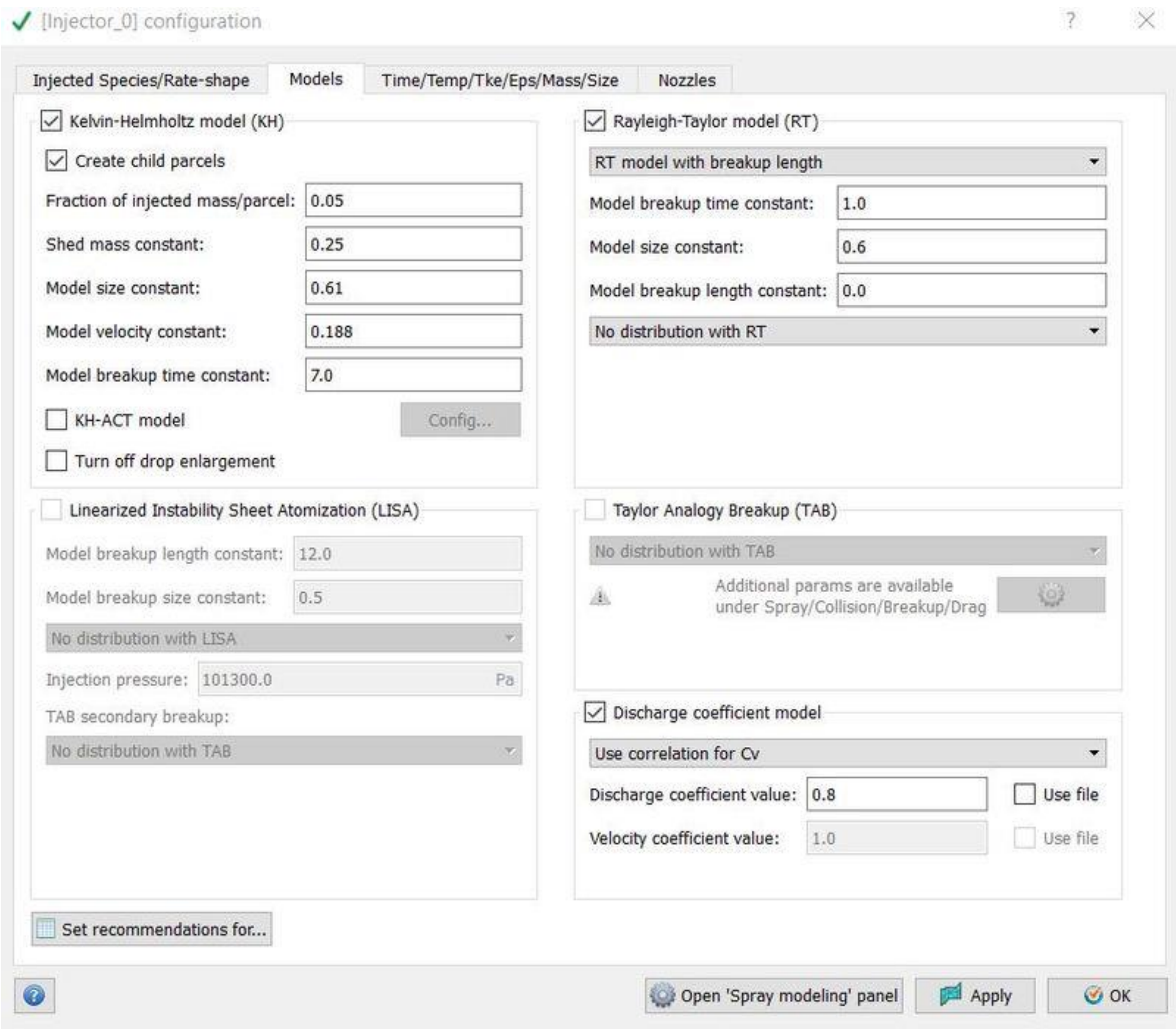
In wall interaction dialog box when define how liquid interacts with the walls and its parameter. wall film model is used for the modelling the interaction of liquid drops with solid surface and it comes with wall splashing option also. To determine the splash O'Rourke model is used and spray wall interaction wall film model was used.

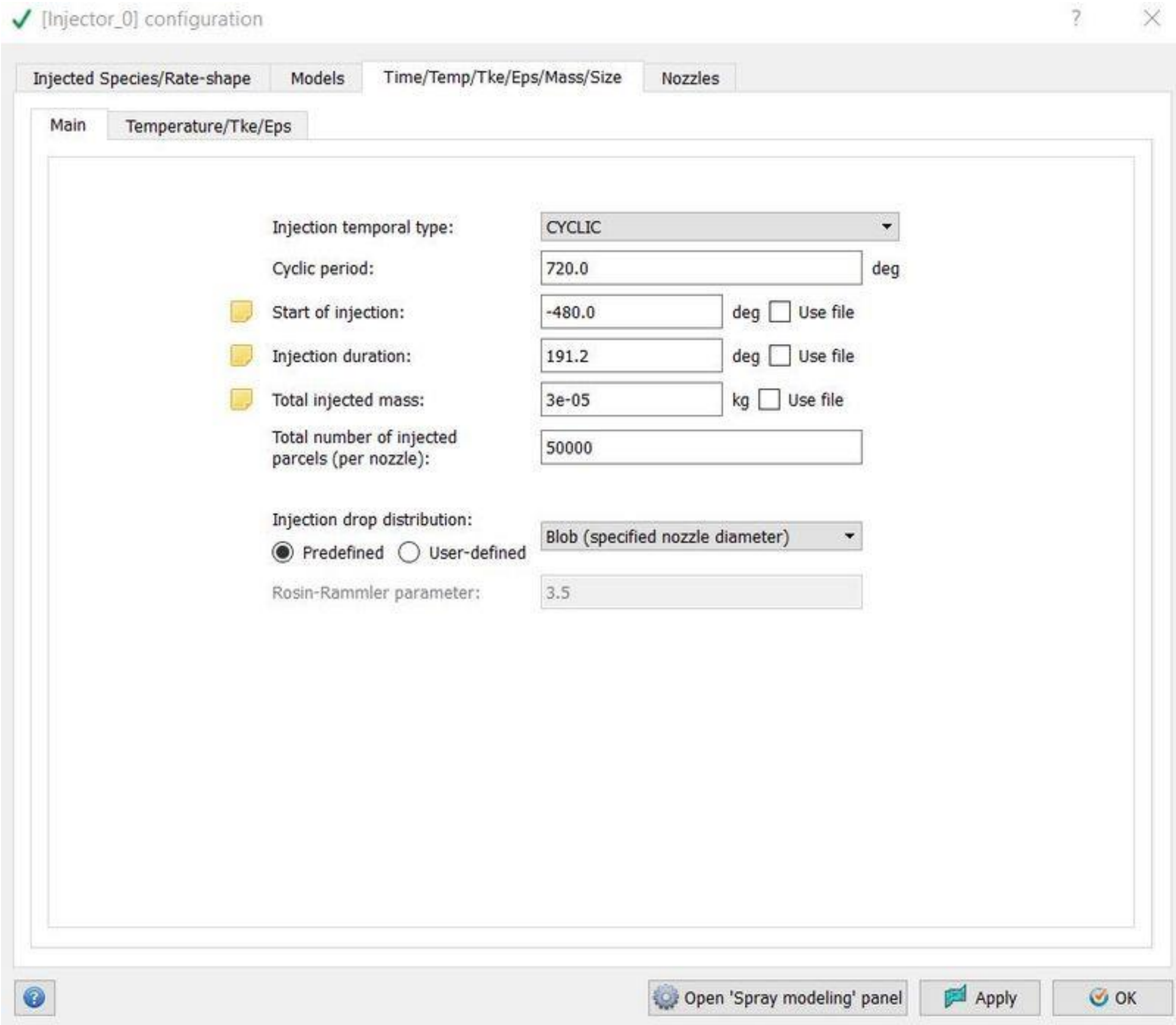


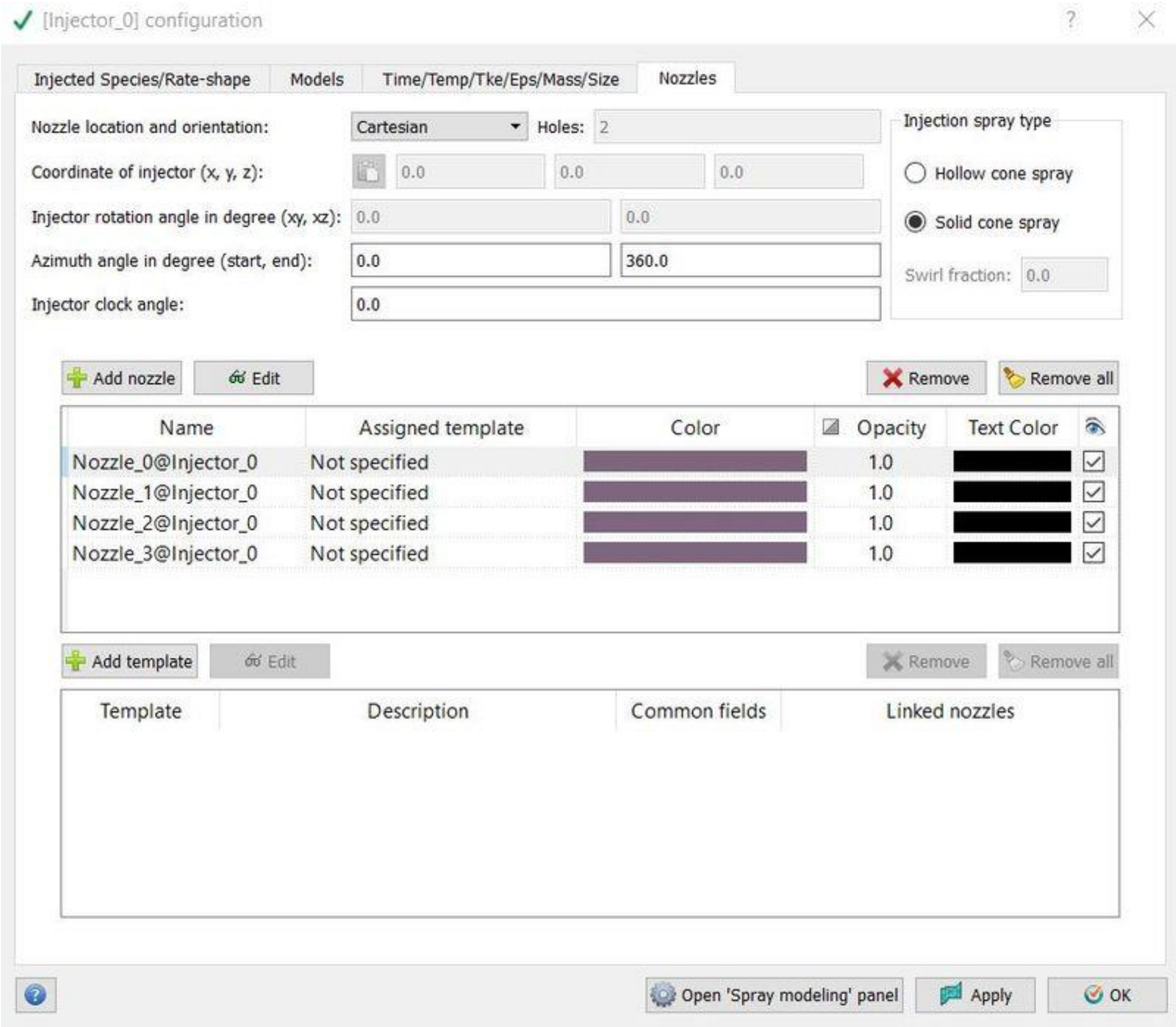
Converge offers two categories of liquid injection mechanisms: injectors and nozzles. An injector is a group of nozzles that have some of the same characteristics. Each injector can have any number of nozzles, each with its own hole size, cone angle, position, and orientation. We went with four nozzles with Kelvin-Helmholtz and Rayleigh-Taylor model. These models were responsible for prediction of liquid atomization and drop breakup. Time of injection, temperature, species and nozzle parameters were given as shown in following image.


Spray modeling
General
Collision/Breakup/Drag
Wall Interaction
Injectors
Combine parcels
Misc.
Injector
Edit
Tools...
Remove
Remove all
Name
Assigned template
Model
Nozzles
Injector_0
Not assigned
KH+RT
4
Template
Edit
Remove
Remove all
Template
Description
Common fields
Linked inj.
OK
Validate

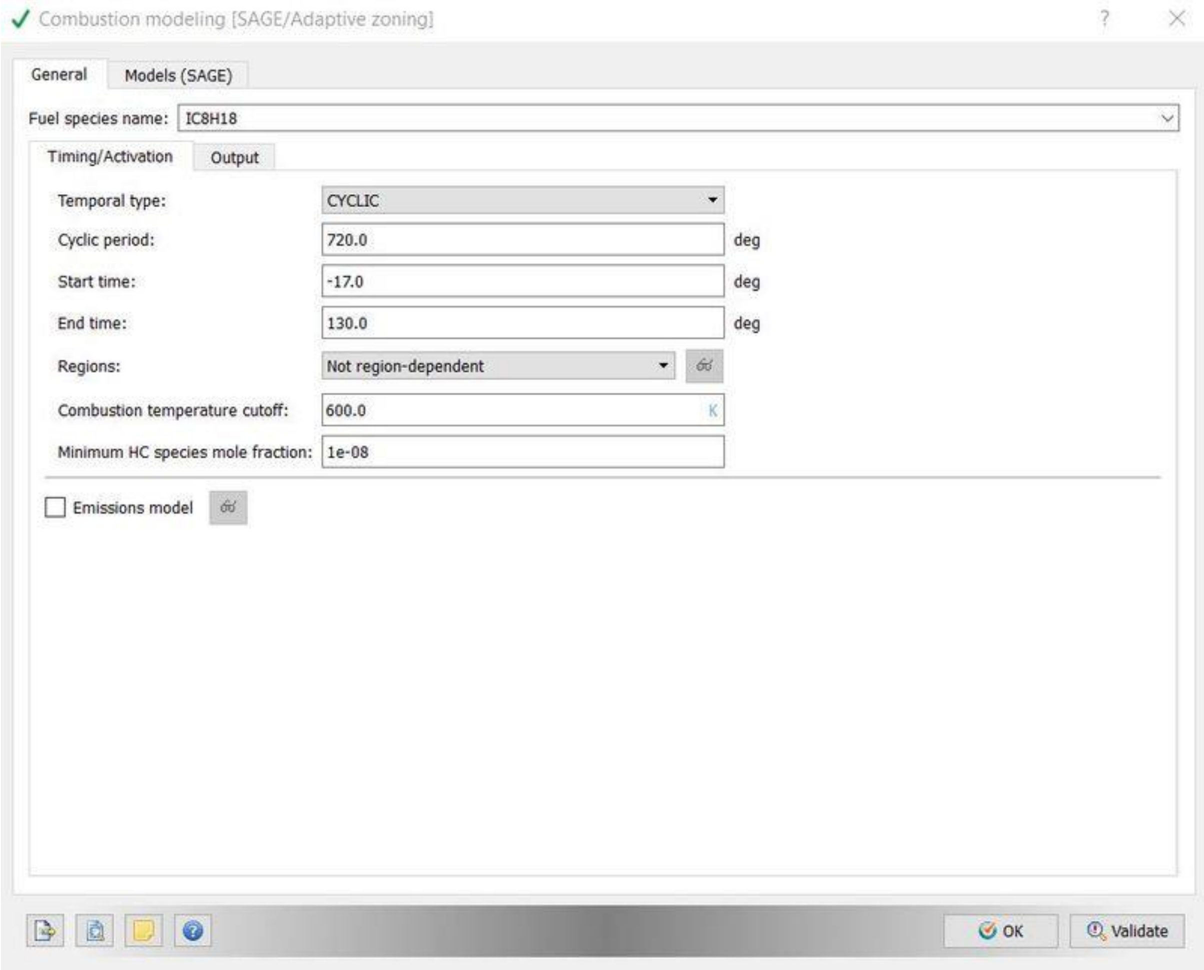

[Injector_0] configuration
Injected Species/Rate-shape
Models
Time/Temp/Tke/Eps/Mass/Size
Nozzles
Injected parcel species and mass fraction
Parcel species
Mass fraction
1 IC8H18 1.0
Normalize
Clear All
Injection rate-shape
Profile
imp_rate.in
Constant
VOF-Spray coupling
ELSA
Injection using VOF data file
Max mass per parcel, kg:
4.5e-12
Threshold:
0.1
Open 'Spray modeling' panel
Apply
OK

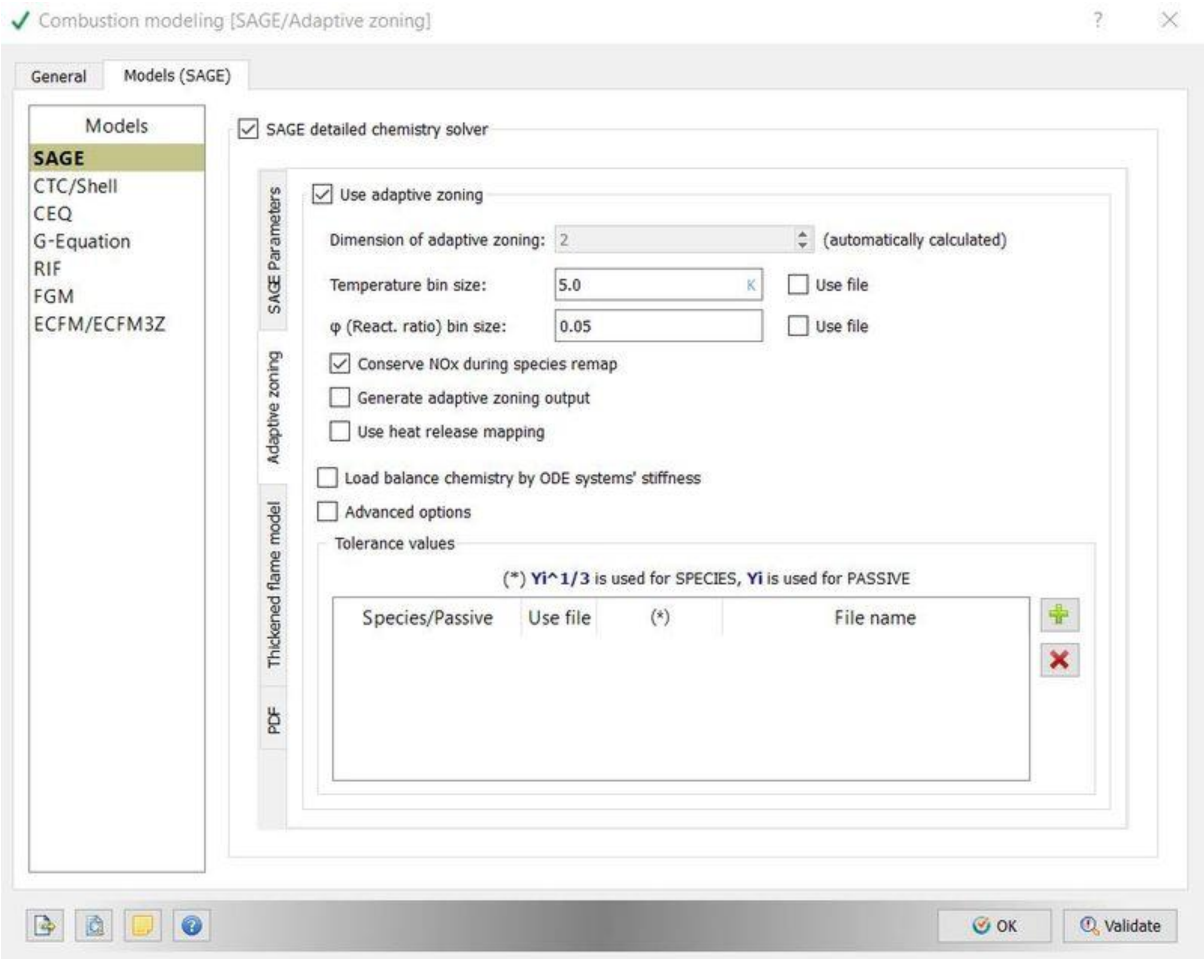

[Injector_0] configuration
Injected Species/Rate-shape
Models
Time/Temp/Tke/Eps/Mass/Size
Nozzles
Kelvin-Helmholtz model (KH)
Create child parcels
Fraction of injected mass/parcel:
0.05
Shed mass constant:
0.25
Model size constant:
0.61
Model velocity constant:
0.188
Model breakup time constant:
7.0
KH-ACT model
Config...
Turn off drop enlargement
Rayleigh-Taylor model (RT)
RT model with breakup length
Model breakup time constant:
1.0
Model size constant:
0.6
Model breakup length constant:
0.0
No distribution with RT
Linearized Instability Sheet Atomization (LISA)
Model breakup length constant:
12.0
Model breakup size constant:
0.5
No distribution with LISA
Injection pressure:
101300.0
Pa
TAB secondary breakup:
No distribution with TAB
Taylor Analogy Breakup (TAB)
No distribution with TAB
Additional params are available under Spray/Collision/Breakup/Drag
Discharge coefficient model
Use correlation for Cv
Discharge coefficient value:
0.8
Use file
Velocity coefficient value:
1.0
Use file
Set recommendations for...
Open 'Spray modeling' panel
Apply
OK


[Injector_0] configuration
Injected Species/Rate-shape
Models
Time/Temp/Tke/Eps/Mass/Size
Nozzles
Main
Temperature/Tke/Eps
Injection temporal type:
CYCLIC
Cyclic period:
720.0
deg
Start of injection:
-480.0
deg
Use file
Injection duration:
191.2
deg
Use file
Total injected mass:
3e-05
kg
Use file
Total number of injected parcels (per nozzle):
50000
Injection drop distribution:
Predefined
User-defined
Blob (specified nozzle diameter)
Rosin-Rammler parameter:
3.5
Open 'Spray modeling' panel
Apply
OK

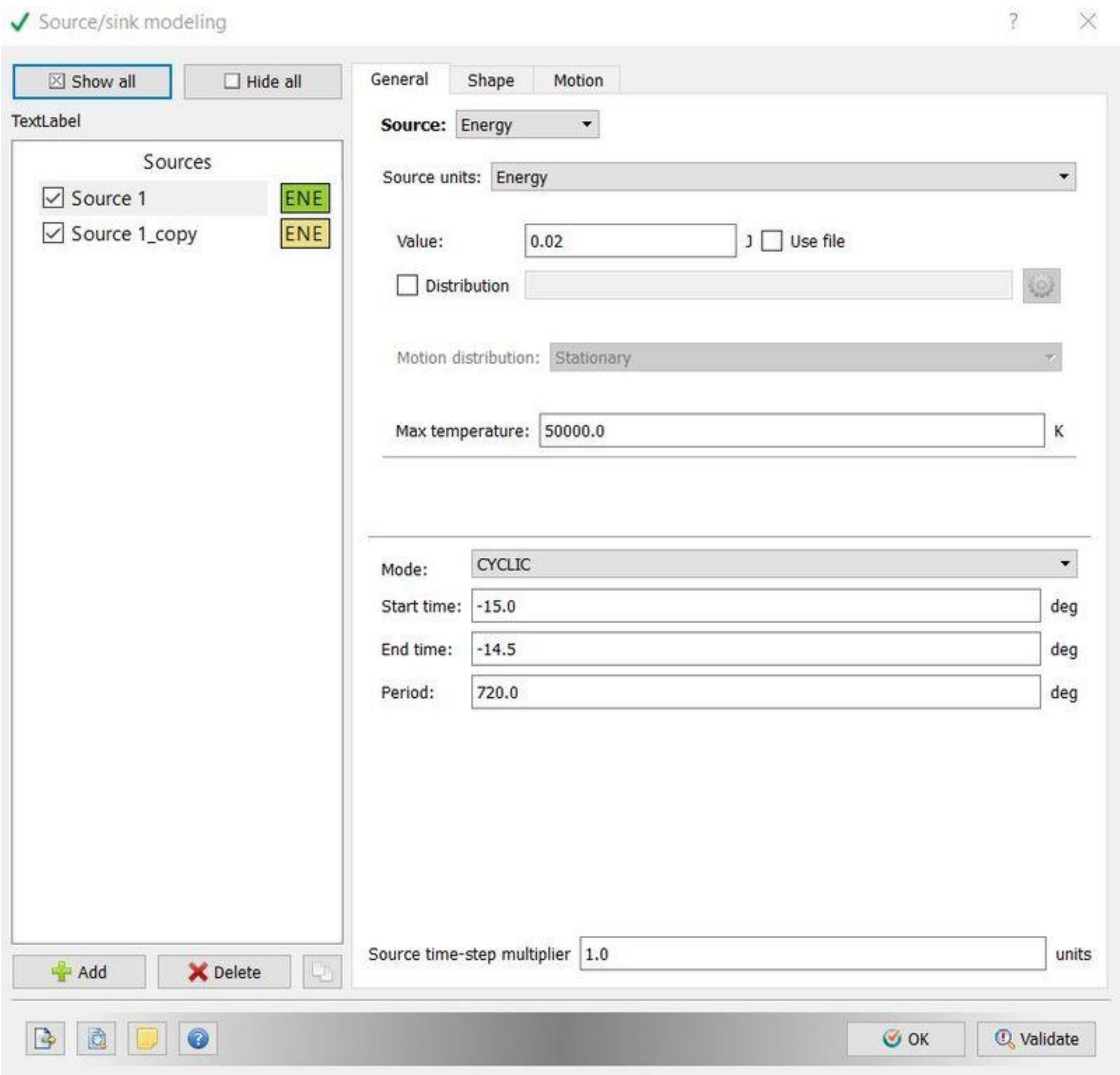


14. Combustion model in responsible for the chemical reactions and kinetics during combustion. We chose SAGE model, which solves for chemical reaction mechanism and its related parameters. In general setting, the time of combustion were defined in form of crank angles means combustion will take place between crank angle -17 to 130 degrees.

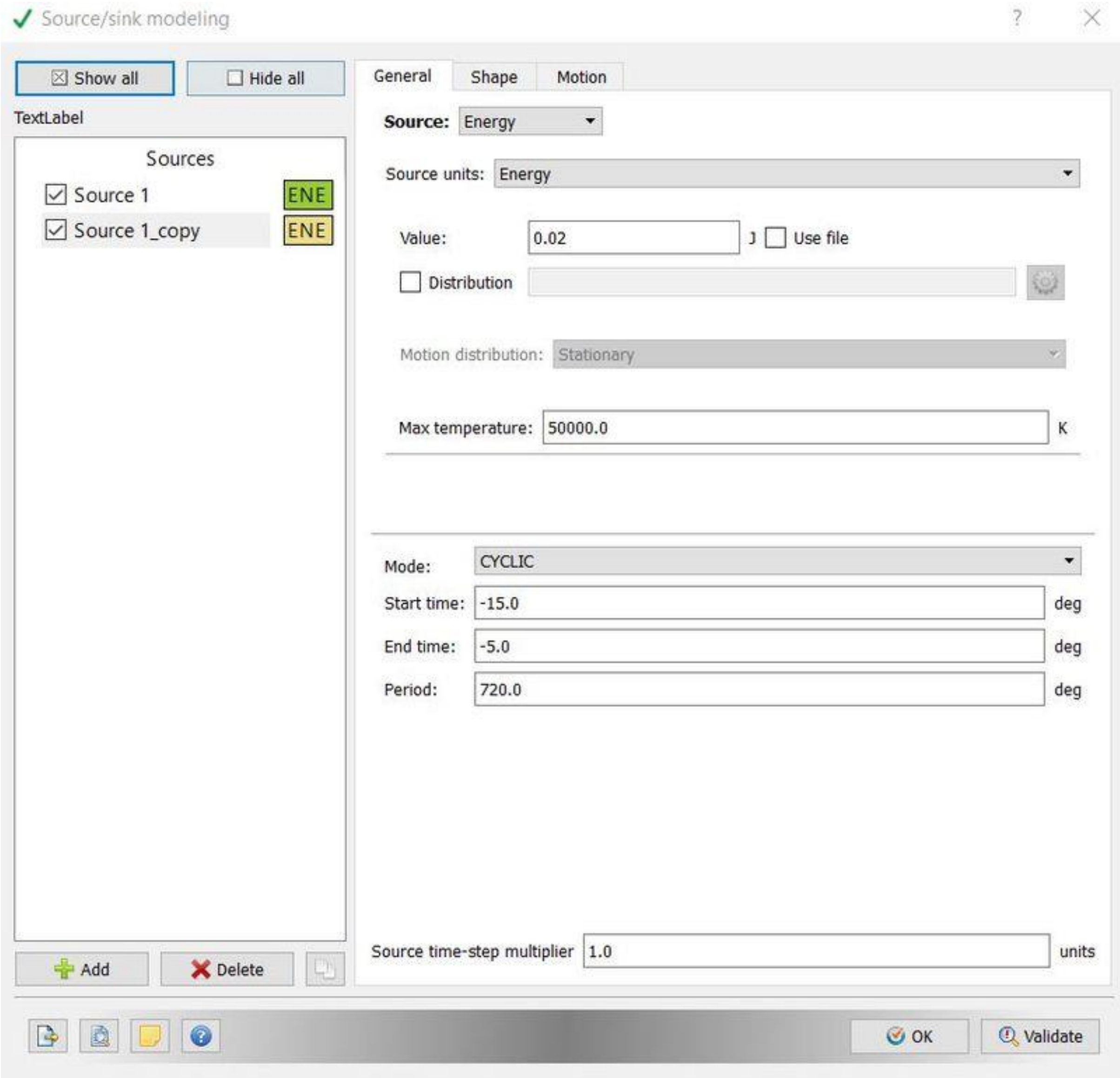

Combustion modeling [SAGE/Adaptive zoning]
General
Models (SAGE)
Fuel species name:
IC8H18
Timing/Activation
Output
Temporal type:
CYCLIC
Cyclic period:
720.0
deg
Start time:
-17.0
deg
End time:
130.0
deg
Regions:
Not region-dependent
Combustion temperature cutoff:
600.0
K
Minimum HC species mole fraction:
1e-08
Emissions model
OK
Validate



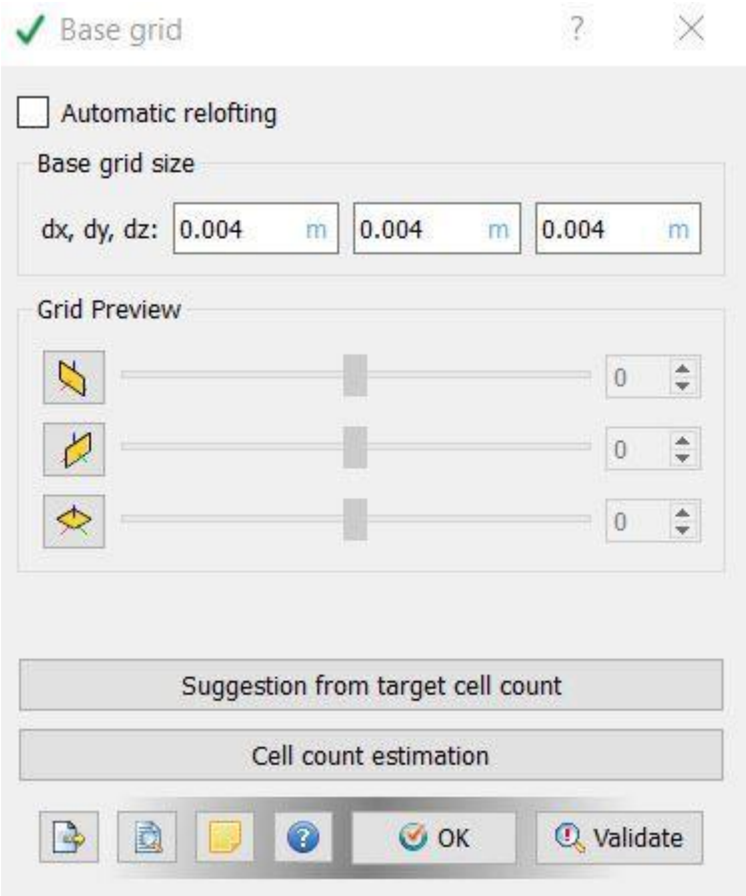
15. Source model was chosen to define an energy source basically we have spark plug for that. Spark timing in form of crank angles were given and sphere was chosen for shape means spark effect will propagate in spherical manner.

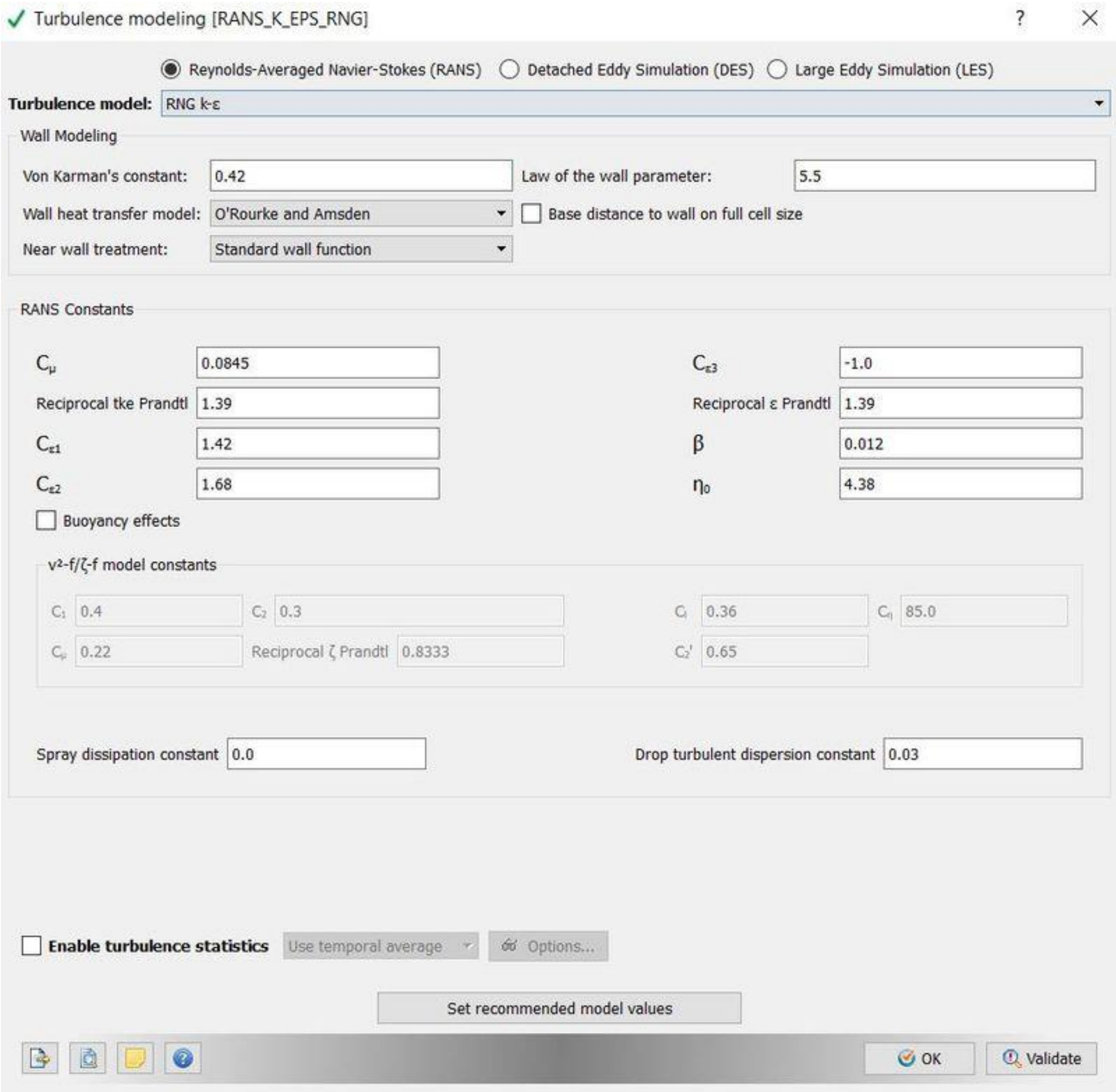


Source/sink modeling
Show all
Hide all
TextLabel
Sources
Source 1
ENE
Source 1_copy
ENE
Add
Delete
General
Shape
Motion
Source: Energy
Source units: Energy
Value: 0.02 J
Use file
Distribution
Motion distribution: Stationary
Max temperature: 50000.0 K
Mode: CYCLIC
Start time: -15.0 deg
End time: -14.5 deg
Period: 720.0 deg
Source time-step multiplier 1.0 units
OK
Validate

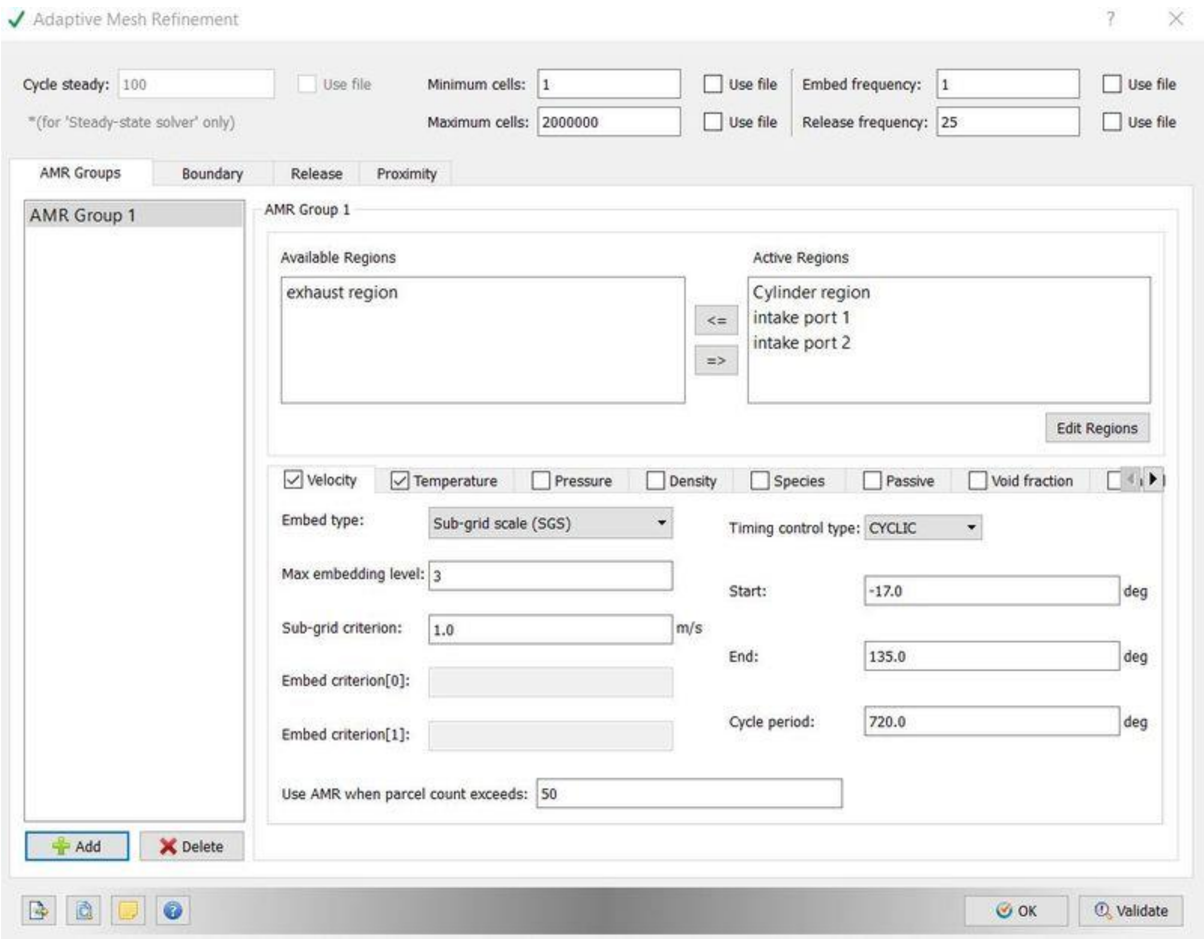


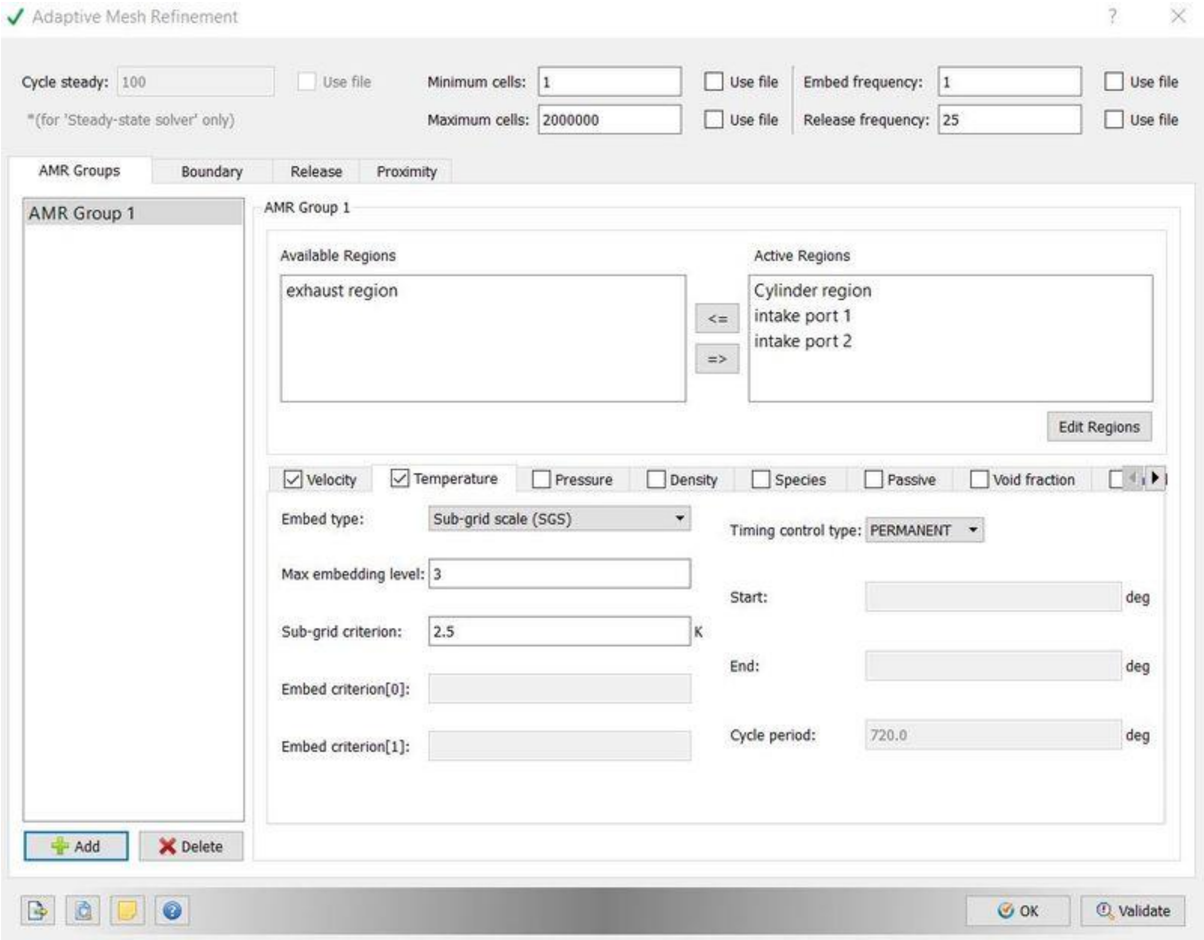
16. We chose k-epsilon turbulent model and base grid was chosen as 0.004m, since we would enable fixed embedding and AMR the global grid size won't be a big problem.


Base grid
Automatic relofting
Base grid size
dx, dy, dz:
0.004 m
0.004 m
0.004 m
Grid Preview
0
0
0
Suggestion from target cell count
Cell count estimation
OK
Validate

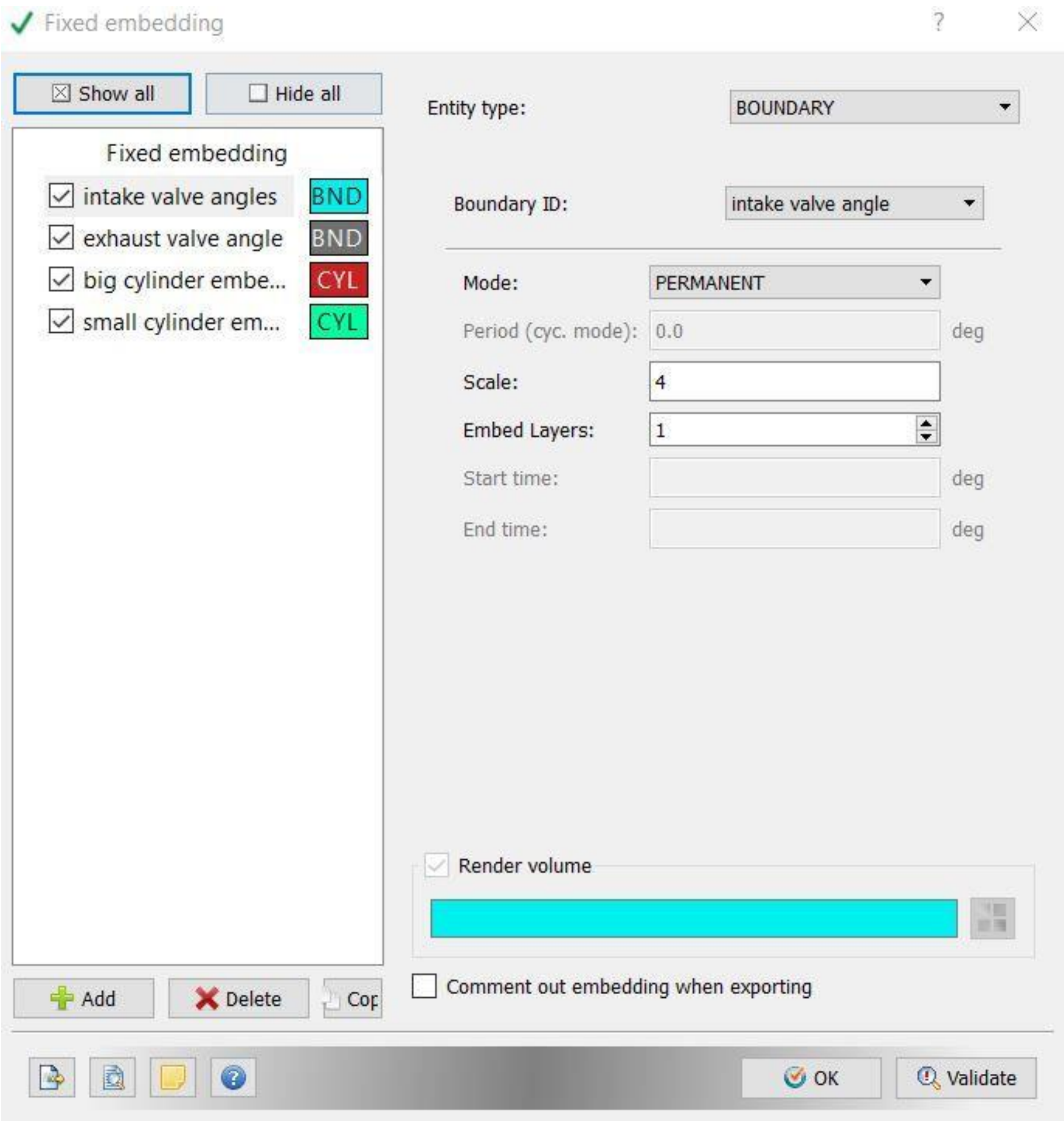


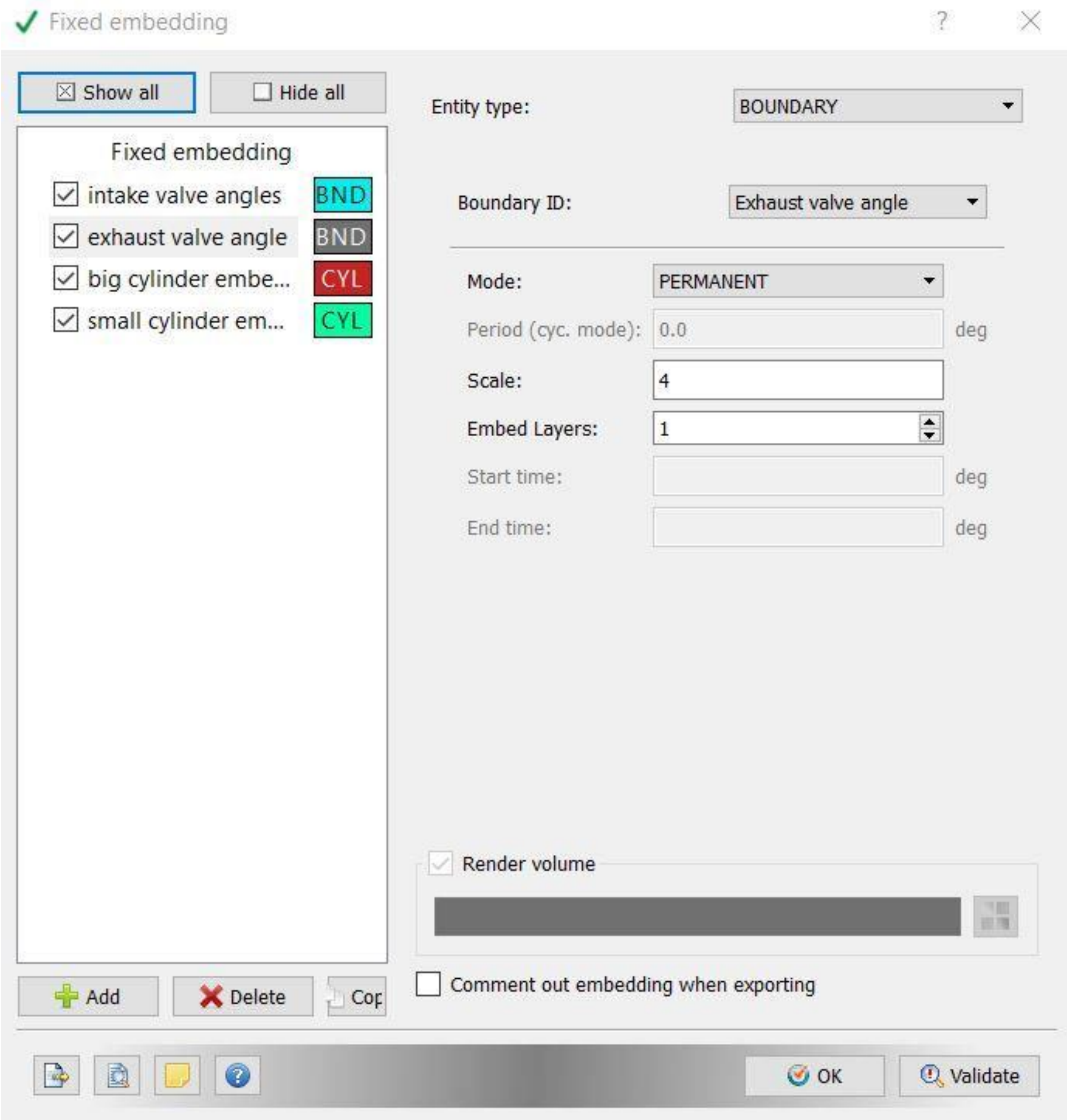
17. Adaptive mesh refinement option was enabled to get finer mesh. This option is very important because you can not deploy same sized mesh on whole model. Velocity and temperature were two criteria which chosen for AMR. In velocity criteria sub grid criteria was 1m/s means above it, cell will be become finer by a factor of 2^n, here n is embedded level, in our case it is 3 and mesh will get finer by 8 times between crank angle -17 and 135 degree. Similarly, when sub grid temperature goes beyond 2.5k mesh will get finer by a factor of 8.

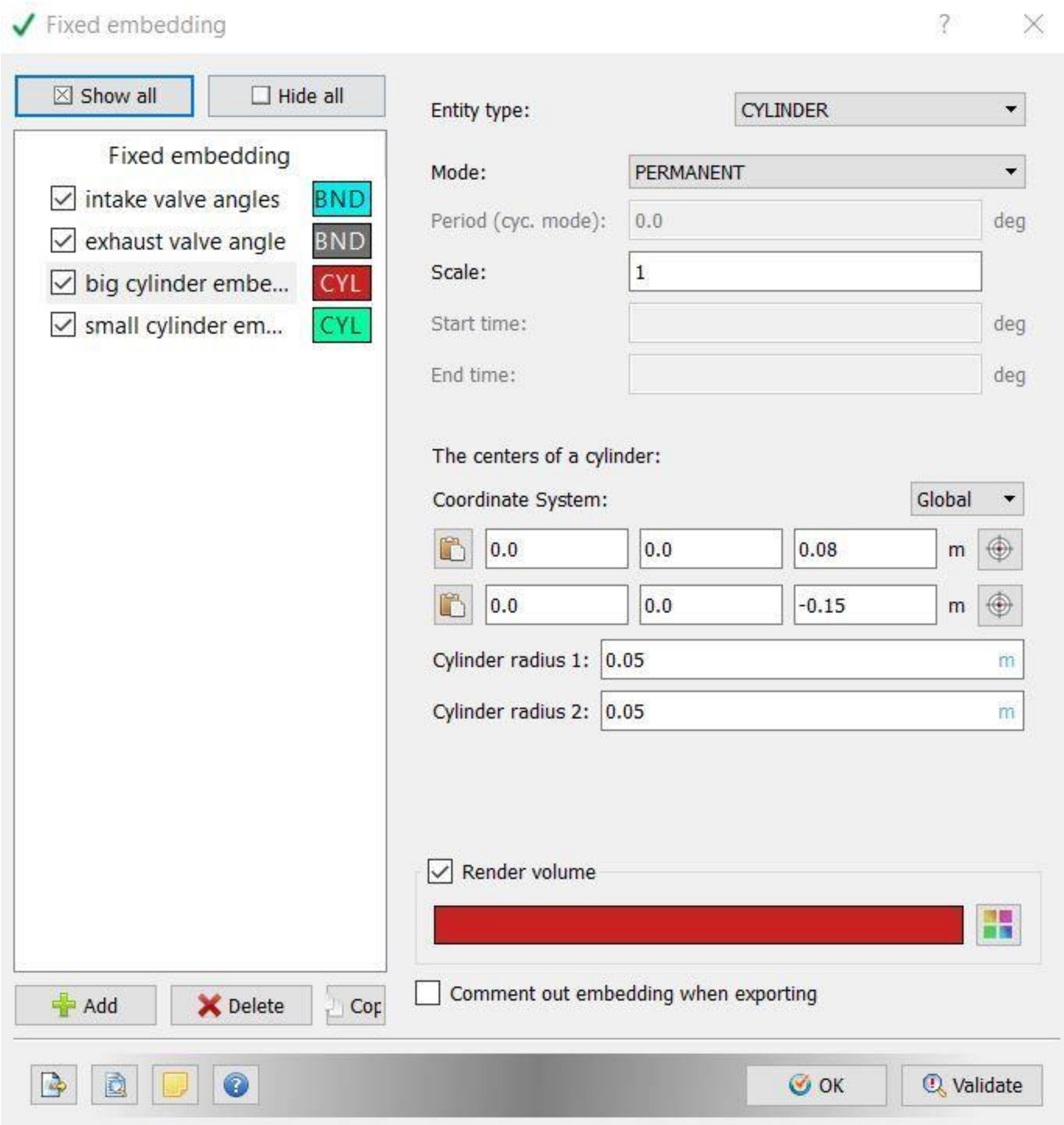

Adaptive Mesh Refinement
Cycle steady: 100
Use file
*(for 'Steady-state solver' only)
Minimum cells: 1
Use file
Maximum cells: 2000000
Use file
Embed frequency: 1
Use file
Release frequency: 25
Use file
AMR Groups
Boundary
Release
Proximity
AMR Group 1
AMR Group 1
Available Regions
exhaust region
<=
=>
Active Regions
Cylinder region
intake port 1
intake port 2
Edit Regions
Velocity
Temperature
Pressure
Density
Species
Passive
Void fraction
Embed type: Sub-grid scale (SGS)
Max embedding level: 3
Sub-grid criterion: 1.0 m/s
Embed criterion[0]:
Embed criterion[1]:
Timing control type: CYCLIC
Start: -17.0 deg
End: 135.0 deg
Cycle period: 720.0 deg
Use AMR when parcel count exceeds: 50
Add
Delete
OK
Validate

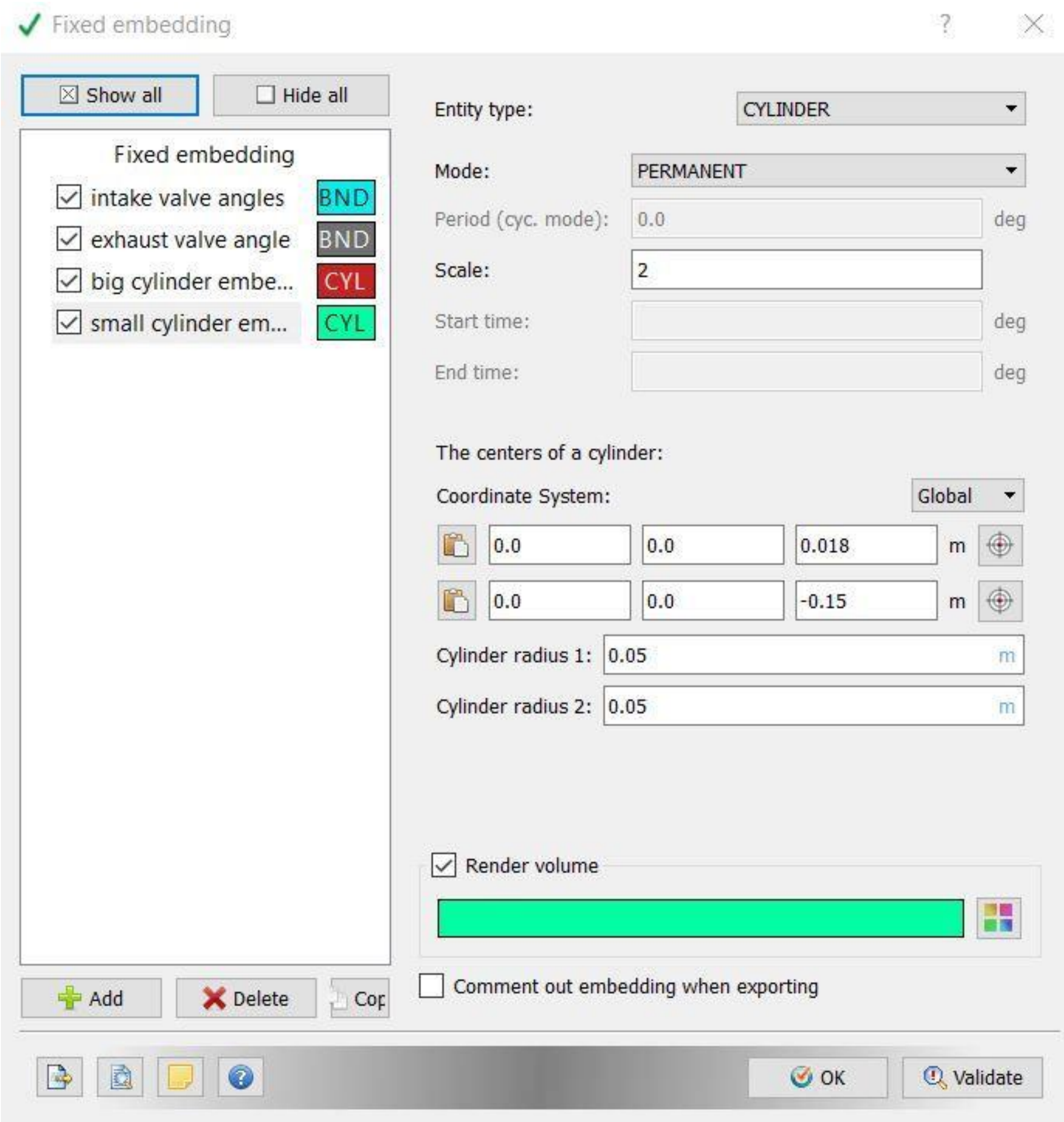


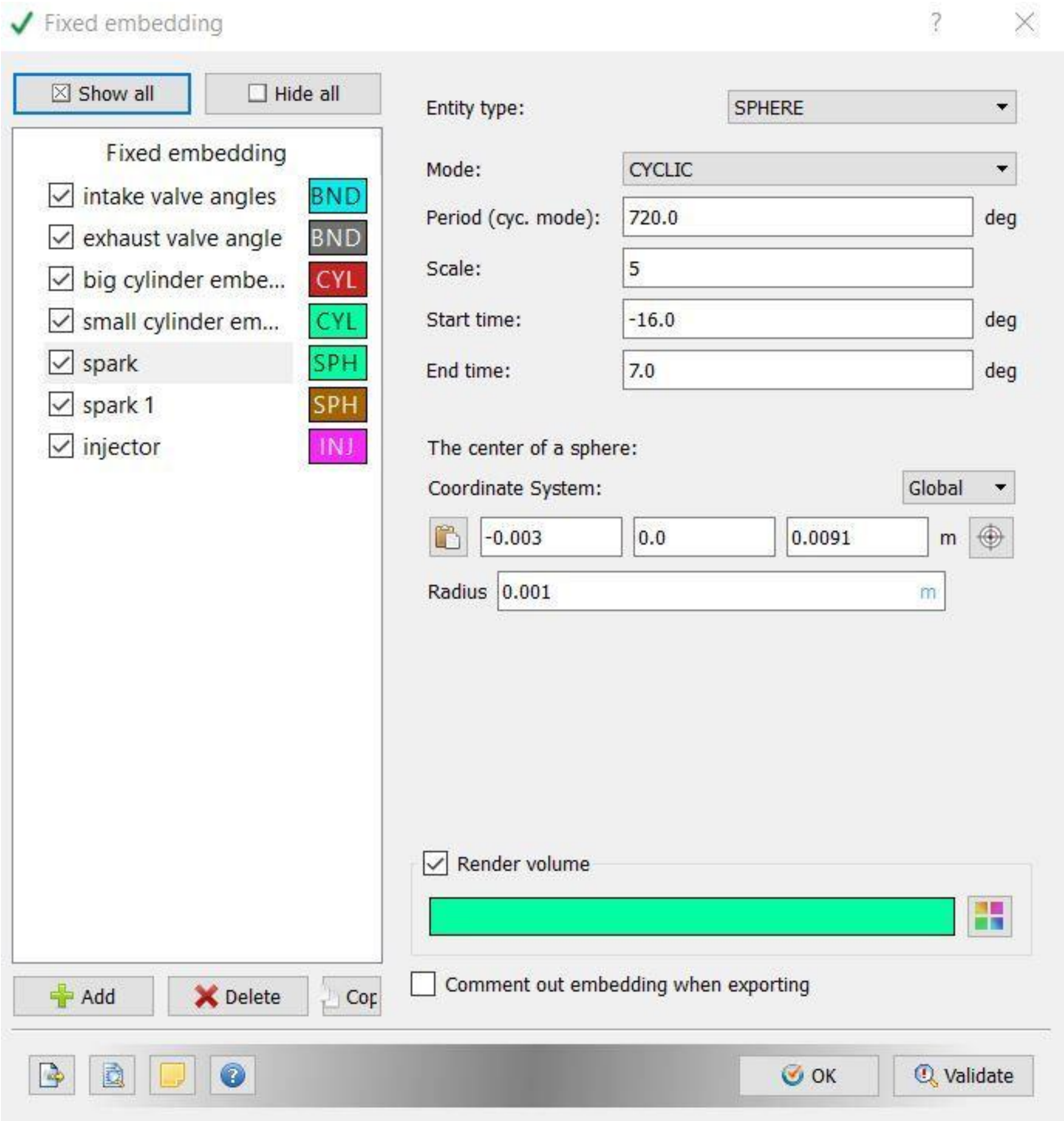
18. Fixed embedding option was enabled from grid control menu. Fixed embedding makes finer mesh of the basis of time or on the basis of crack angles. It is different from AMR because AMR option was dependent on the particular cell property. Fixed embedded was applied around spark plug, which had a form of sphere. For spark plug fixed embedding activated between crank angle -16 and 7degrees with a scale of 3 similar embedding was defined for spark plug distinguished in scale only. Converge provides special option for injector’s embedding. Other embedding can be seen by following images.

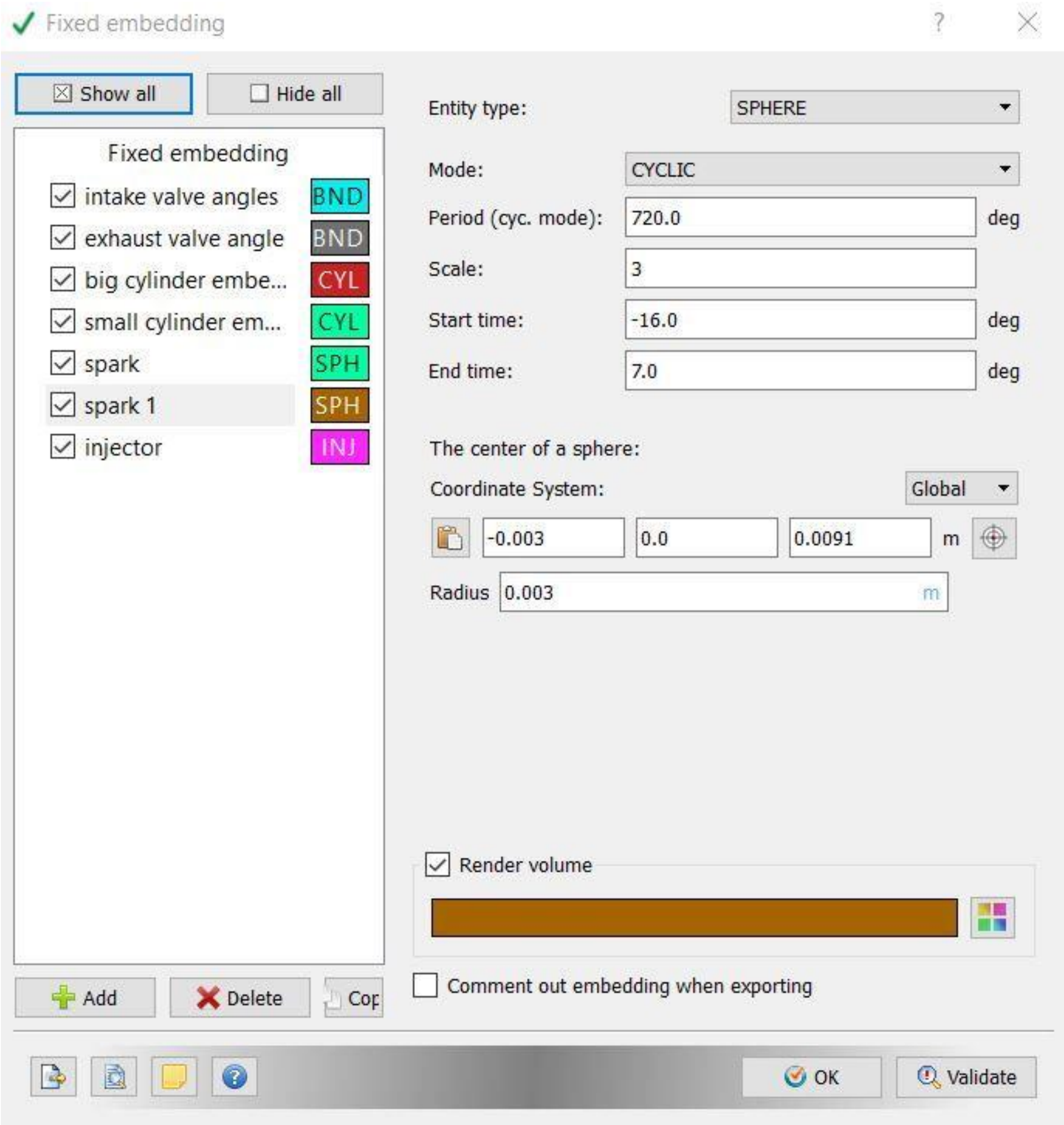

Fixed embedding
Show all
Hide all
Fixed embedding
intake valve angles
BND
exhaust valve angle
BND
big cylinder embe...
CYL
small cylinder em...
CYL
Add
Delete
Entity type:
BOUNDARY
Boundary ID:
intake valve angle
Mode:
PERMANENT
Period (cyc. mode):
0.0
deg
Scale:
4
Embed Layers:
1
Start time:
deg
End time:
deg
Render volume
Comment out embedding when exporting
OK
Validate

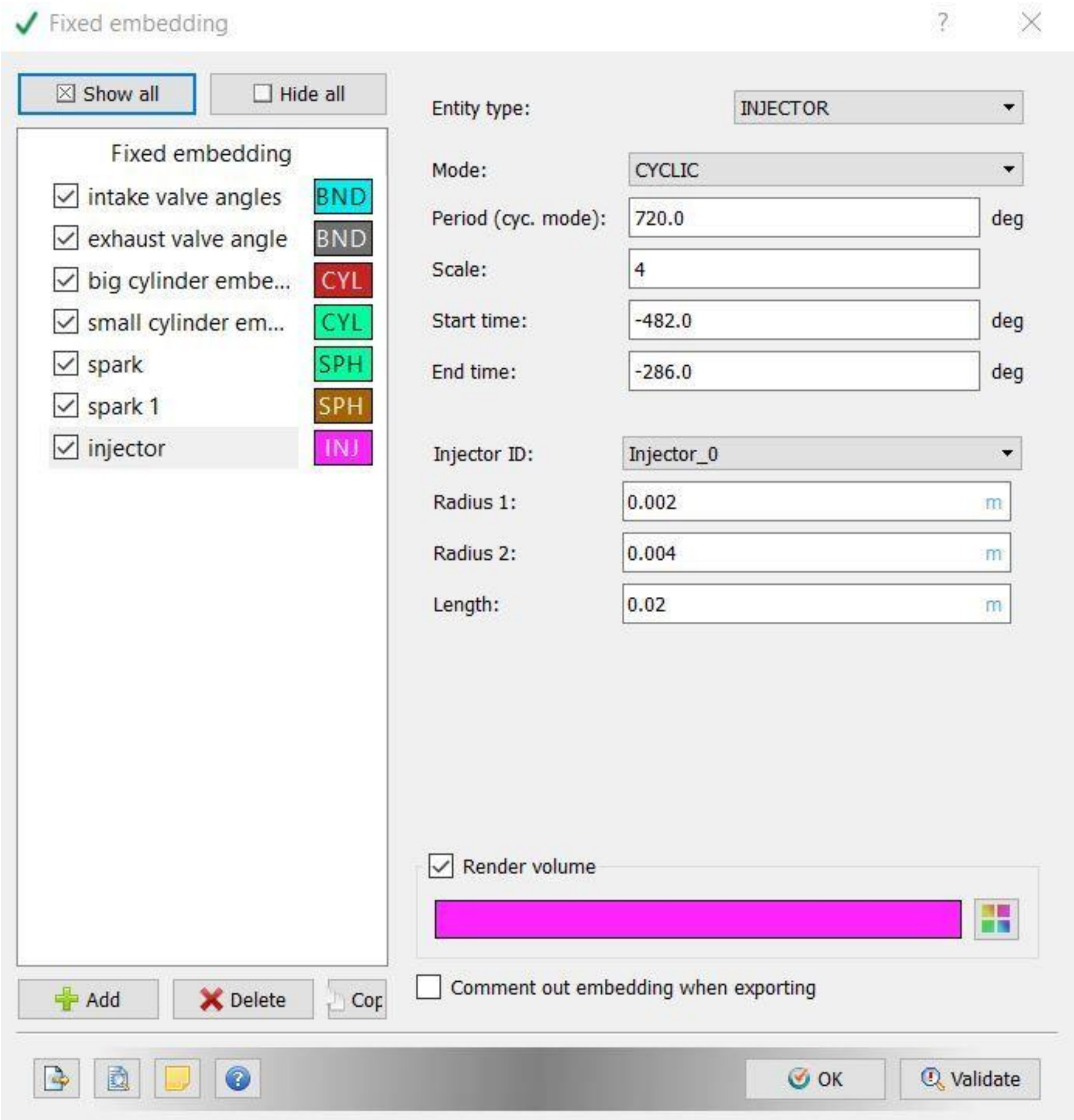

Fixed embedding
Show all
Hide all
Fixed embedding
intake valve angles
BND
exhaust valve angle
BND
big cylinder embe...
CYL
small cylinder em...
CYL
Entity type:
BOUNDARY
Boundary ID:
Exhaust valve angle
Mode:
PERMANENT
Period (cyc. mode):
0.0
deg
Scale:
4
Embed Layers:
1
Start time:
deg
End time:
deg
Render volume
Comment out embedding when exporting
Add
Delete
Cop
OK
Validate


Fixed embedding
Show all
Hide all
Fixed embedding
intake valve angles
BND
exhaust valve angle
BND
big cylinder embe...
CYL
small cylinder em...
CYL
Add
Delete
Cop
Entity type:
CYLINDER
Mode:
PERMANENT
Period (cyc. mode):
0.0
deg
Scale:
1
Start time:
deg
End time:
deg
The centers of a cylinder:
Coordinate System:
Global
0.0
0.0
0.08
m
0.0
0.0
-0.15
m
Cylinder radius 1:
0.05
m
Cylinder radius 2:
0.05
m
Render volume
Comment out embedding when exporting
OK
Validate

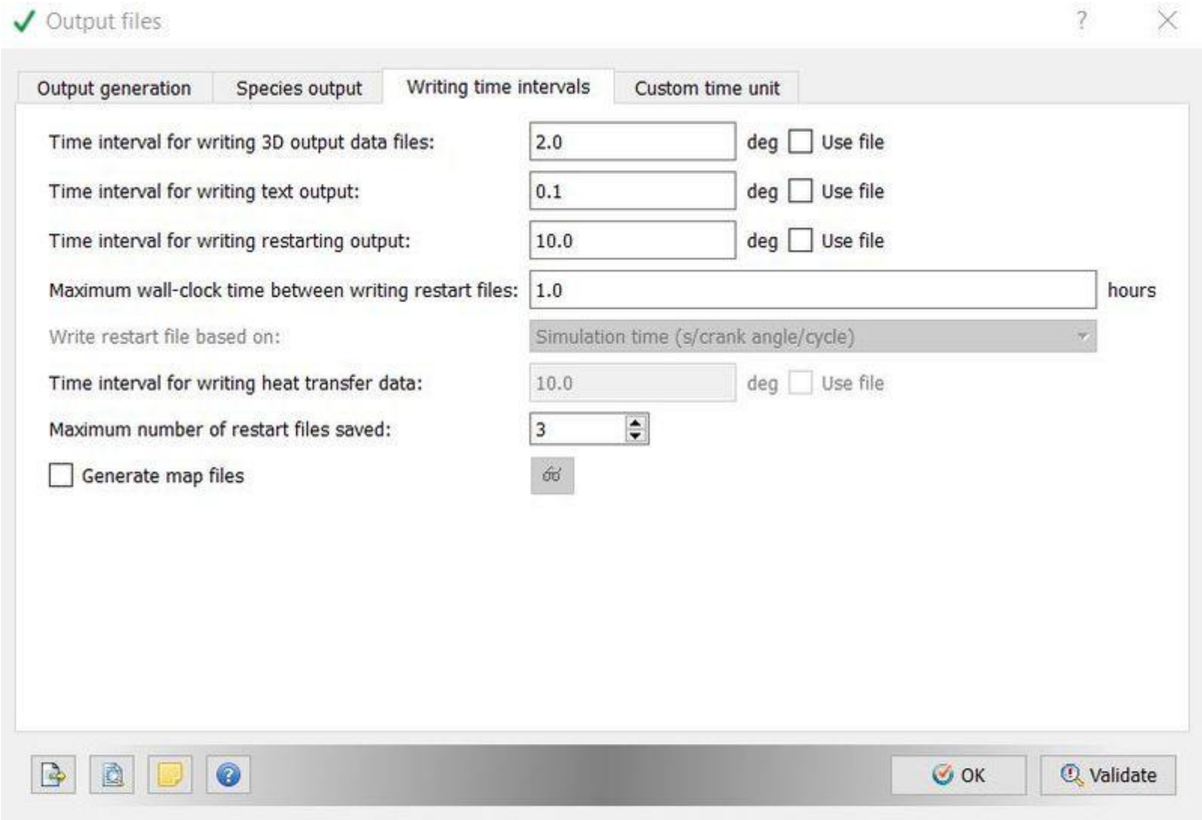

Fixed embedding
Show all
Hide all
Fixed embedding
intake valve angles
BND
exhaust valve angle
BND
big cylinder embe...
CYL
small cylinder em...
CYL
Add
Delete
Cop
Entity type:
CYLINDER
Mode:
PERMANENT
Period (cyc. mode):
0.0
deg
Scale:
2
Start time:
deg
End time:
deg
The centers of a cylinder:
Coordinate System:
Global
0.0
0.0
0.018
m
0.0
0.0
-0.15
m
Cylinder radius 1:
0.05
m
Cylinder radius 2:
0.05
m
Render volume
Comment out embedding when exporting
OK
Validate


Fixed embedding
Show all
Hide all
Fixed embedding
intake valve angles
BND
exhaust valve angle
BND
big cylinder embe...
CYL
small cylinder em...
CYL
spark
SPH
spark 1
SPH
injector
INJ
Add
Delete
Entity type:
SPHERE
Mode:
CYCLIC
Period (cyc. mode):
720.0
deg
Scale:
5
Start time:
-16.0
deg
End time:
7.0
deg
The center of a sphere:
Coordinate System:
Global
-0.003
0.0
0.0091
m
Radius
0.001
m
Render volume
Comment out embedding when exporting
OK
Validate


Fixed embedding
Show all
Hide all
Fixed embedding
intake valve angles
BND
exhaust valve angle
BND
big cylinder embe...
CYL
small cylinder em...
CYL
spark
SPH
spark 1
SPH
injector
INJ
Add
Delete
Cop
Entity type:
SPHERE
Mode:
CYCLIC
Period (cyc. mode):
720.0
deg
Scale:
3
Start time:
-16.0
deg
End time:
7.0
deg
The center of a sphere:
Coordinate System:
Global
-0.003
0.0
0.0091
m
Radius
0.003
m
Render volume
Comment out embedding when exporting
OK
Validate

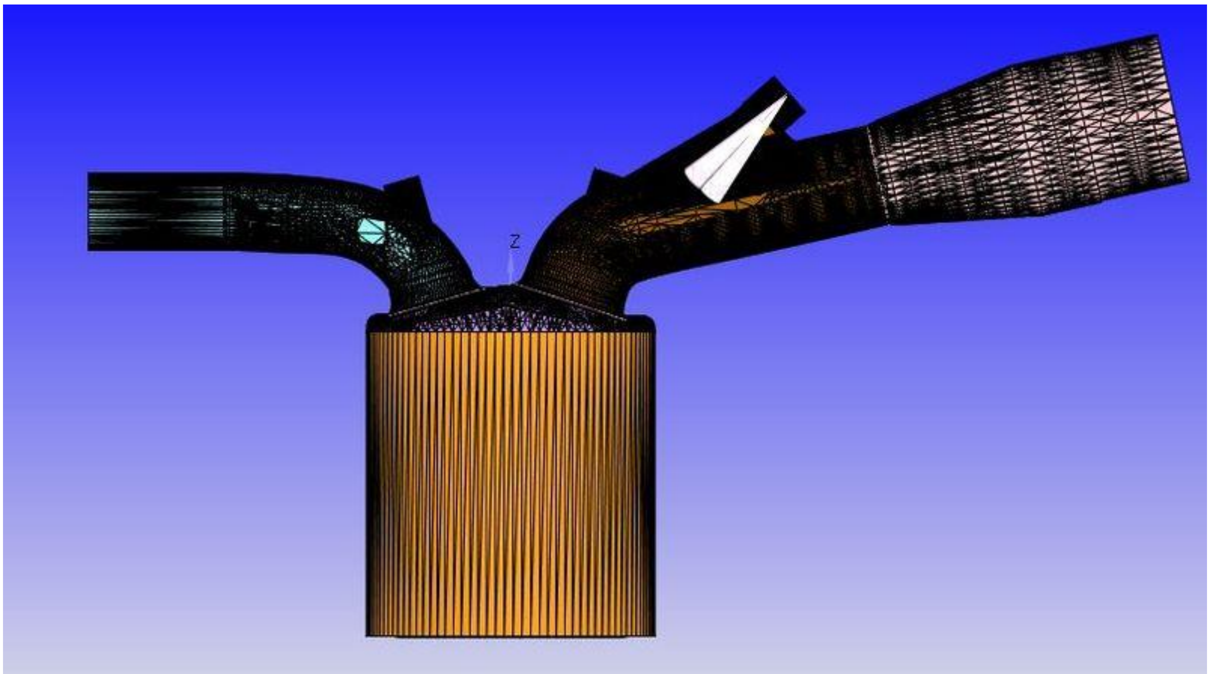


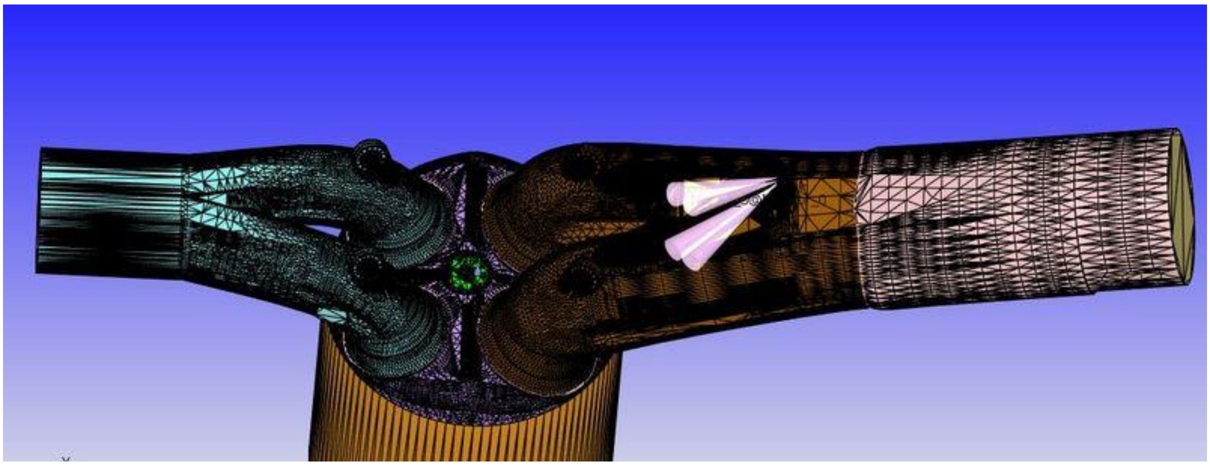
19. Time interval for writing 3D output data files was set to 2second for writing text output it was 0.1 second, other parameters of output files was left as default.



6. Results –

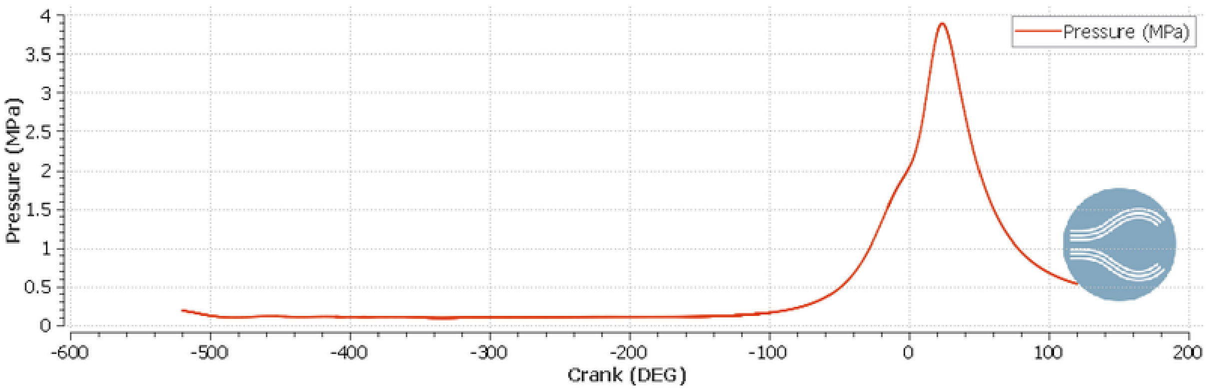
CAD Model -



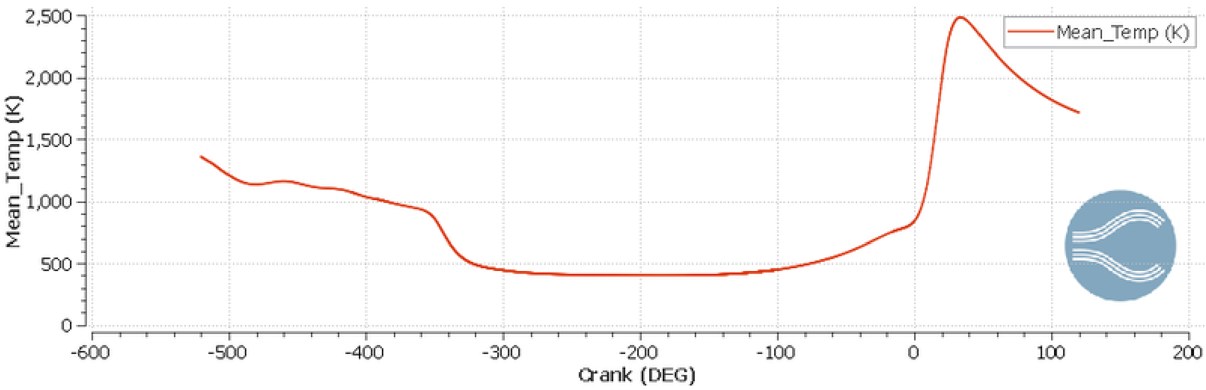


We simulated PFI engine and generated some useful results. Animation for flame propagation and for spray formation has also created. in Animation valve and piston movement can be seen easily so we assure ourself that velocity profile we imported in boundary conditions. Similarly, if we look at the pressure plot of combustion chamber, we can see there is a peak of pressure values, again it is validating theory that during combustion cylinder will bear peak pressure.

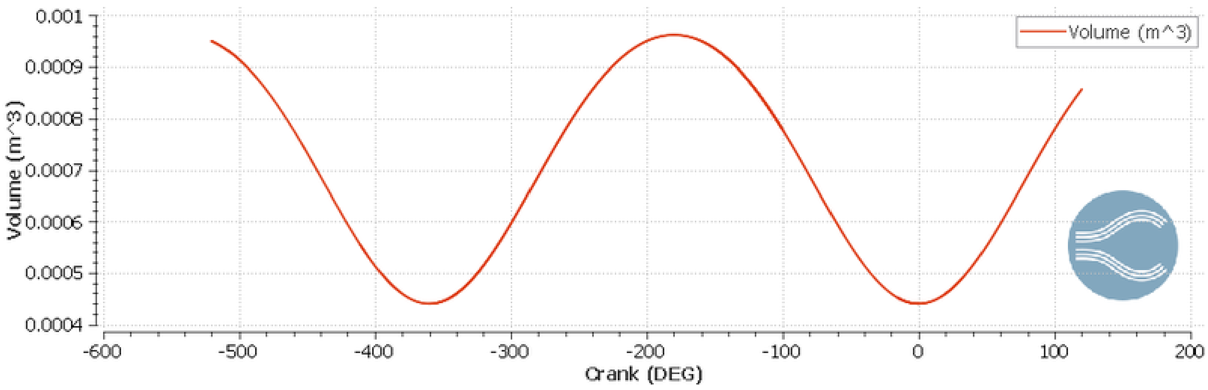
Pressure plot(Cylinder region) -



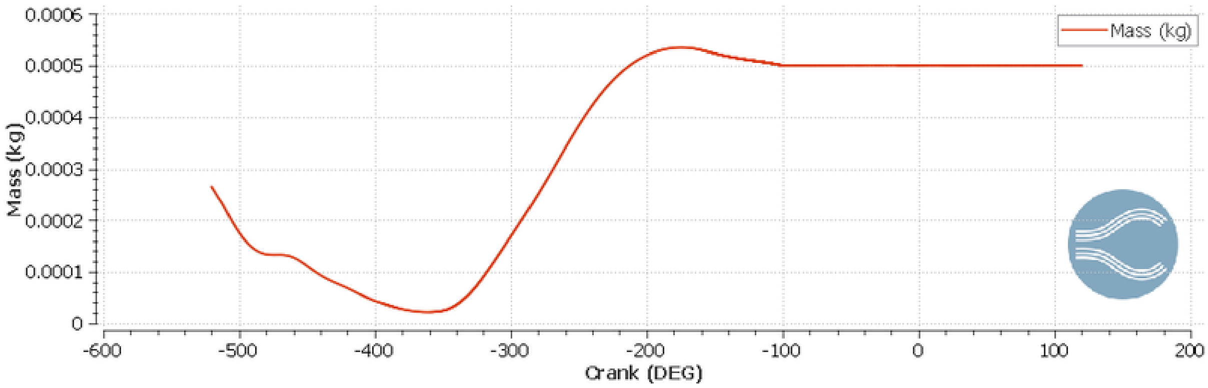
Mean Temperature plot(Cylinder region) -



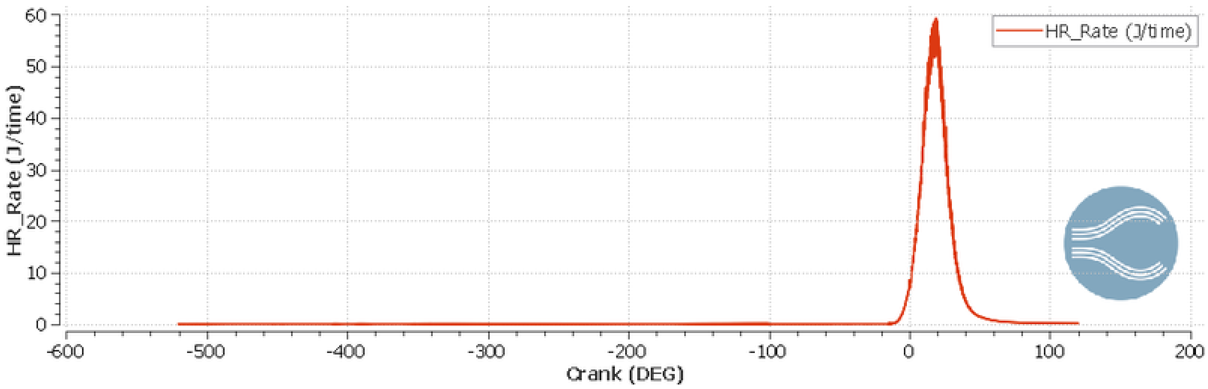
Volume plot -



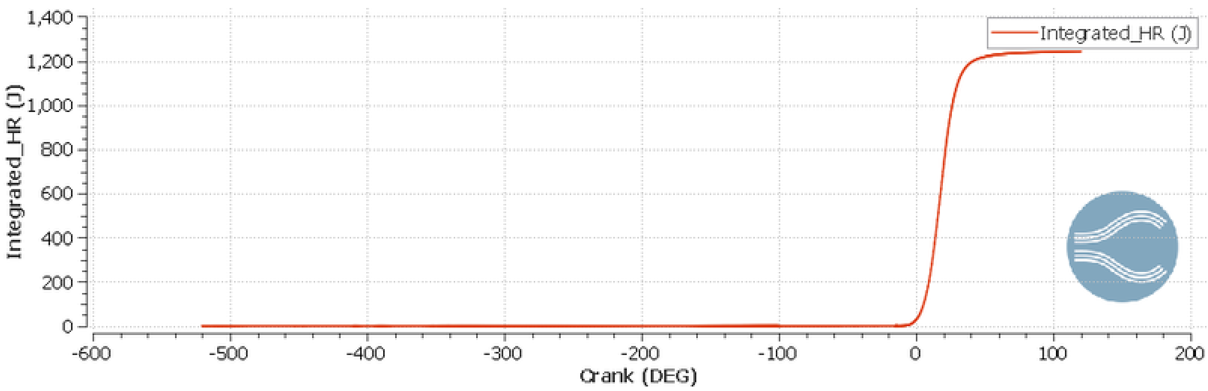
Mass flow rate -



Heat Released -



Integrated Heat Released -



Some performance parameters are calculated as follows.

1. Compression ratio –

Volume measure from graph –

Maximum volume – 5.724e-4

Minimum volume – 5.7036e-5

Compression ratio(C_r) = Maximum volume/ Minimum volume

C.R. = `(5.724*10^-4)/(5.7036*10^-5` = 10.036

2. Combustion efficiency –

Lower calorific value of fuel (LCV) = 44 MJ/K

Fuel injected = 3e-5Kg

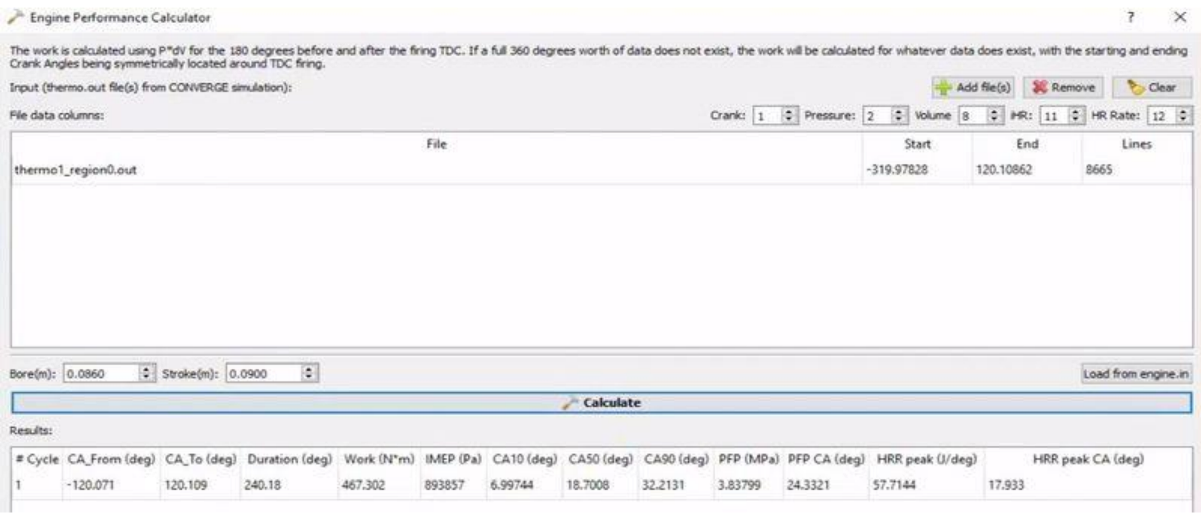
Potential energy of fuel = fuel injected*LCV = `3*10^-5*44*10^-6` = 13.2J

Total heat released (Taken from integrated heat released graph) = 1241.11 J

Combustion efficiency = Total heat released / potential energy of fuel

Combustion efficiency = `1241.11/13.2` = 94.03%

3. Power and torque –



Here -

CA10, CA50 and CA90 are indicating crack angle at 10%, 50% and 90% combustion of mixture, respectively.

From engine performance calculator we got –

Total duration of combustion (In terms of crank angle) = 240.199degree

Gross work = 468.646 N-m

Engine speed = 3000RPM = 50 RPS

Revolution in degrees = 360*50 = 18000degree/second

Combustion time = duration of combustion/ total revolution in one cycle
= `240.199/18000` = 0.0133s

Power = gross work/combustion time = 468.646/0.0133 = 35.236KW

Torque = `(Power*60)/(2*pi*N`

T = `(60*35.236*10^3)/(2*pi*3000)`

T = `112.160N-m`

4. The need of wall heat transfer model

It is known that heat transfer in engines affects engine efficiency and emission. An increase of heat transfer to the combustion chamber walls is lower the in-cylinder pressure and the average gas temperature and this reduces the work per cycle transferred to the piston. Thus, the magnitude of engine heat transfer is strongly dependent on engine efficiency. Since the engine heat transfer is important, the accurate predicted engine heat transfer results are needed. For it, wall heat transfer model is used. We chose O'Rouke and Amsden wall heat transfer model. If some one wants wall temperature without using wall heat transfer model, he have to solve additional equations and it is a time consuming process, so, to use wall heat transfer model is always beneficial.