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SOLIDWORKS Flow Simulation

Results Calder Valley Skip Hire Ltd

Flow Simulation

Calder Valley Skip Hire

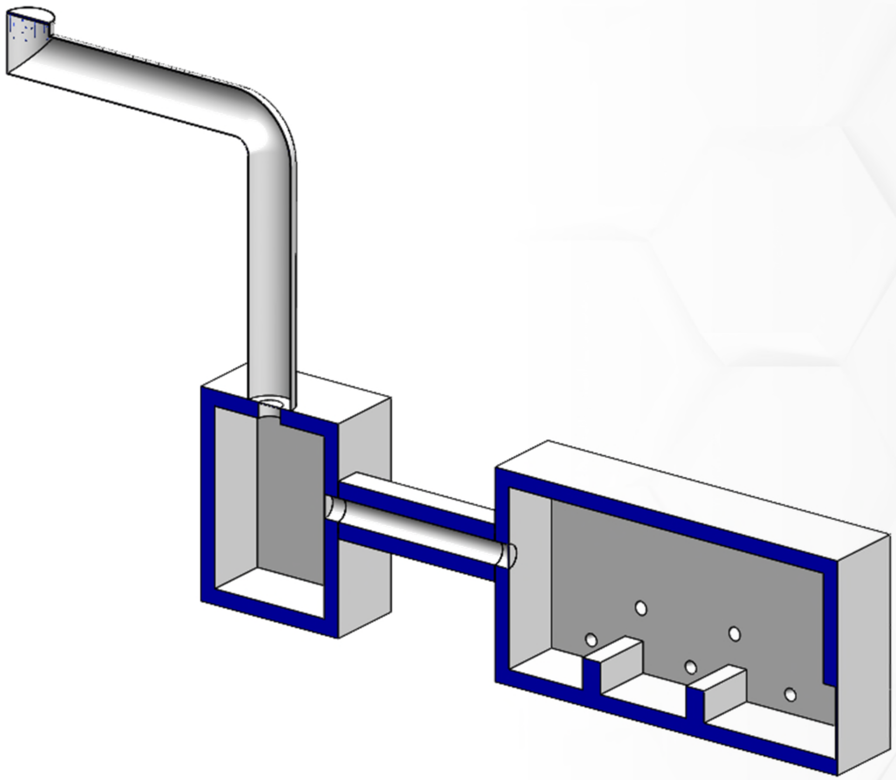
Calder Valley Skip Hire has requested computational fluid dynamics analysis of a small waste incineration plant (SWIP) which they have on their site at Sowerby Bridge. The SWIP has a primary combustion chamber for the combustion of wastes, in this case RDF, and a secondary chamber for the combustion of the resulting gasses. Under the Industrial Emissions Directive waste incineration plants must be designed, equipped, built, and operated in such a way that the gas resulting from the incineration of waste is raised in a controlled and homogeneous fashion, even under the most unfavorable conditions, to a temperature of at least 850°C for at least two seconds. Consequently, the purpose of these studies is to review temperatures, velocity, and primarily residence times within the secondary chamber based on the physical test data provided.

Model geometry

Calder Valley Skip Hire

Model geometry has been created from measurements that have been taken by hand and using a laser measure where possible these have then been related back to plan view drawings and checked where possible. Geometry simplification has then been completed to leave us with the closed fluid volume ready for simulation. Any dimensions which could not be measured due to lack of access have been estimated and have been highlighted and agreed with Calder Valley Skip Hire. Those estimates have been made from photos and available drawings and will, therefore, be within a few millimeters at most of the actual value. This would be expected to have only a trivial influence on the results.

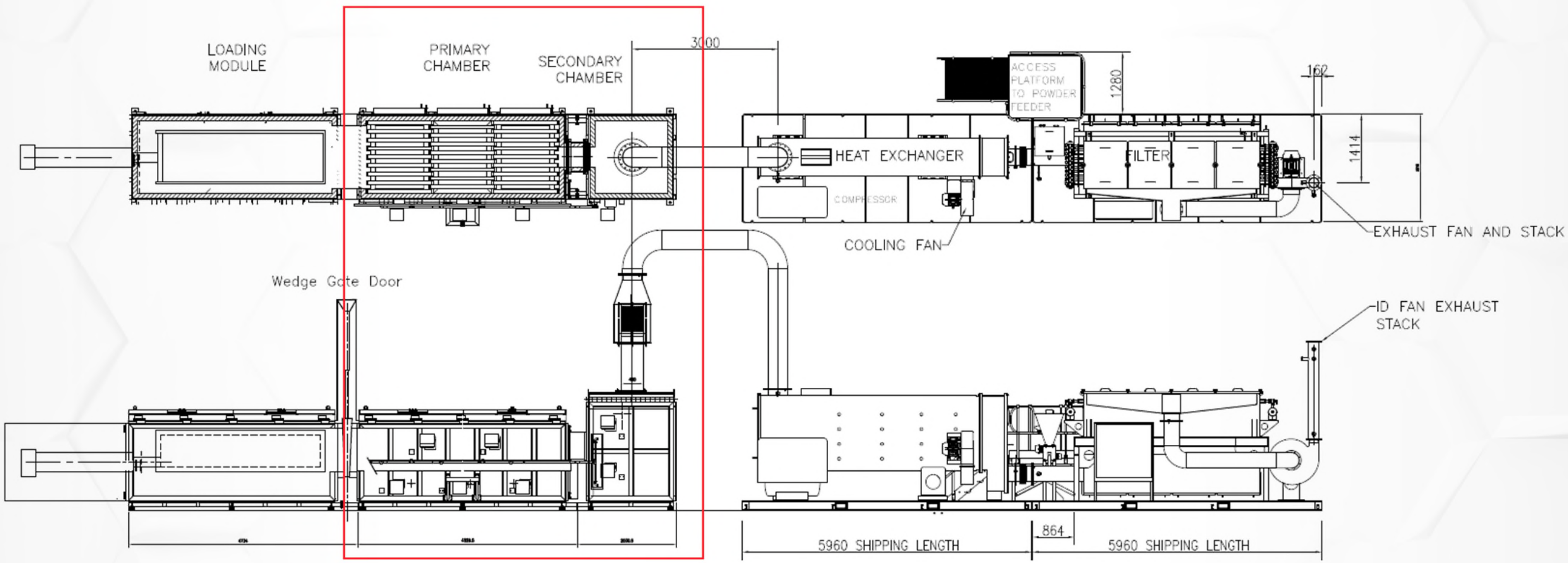
The image on the right shows a snapshot of this geometry in section. The total internal fluid volume is estimated from this at 17.5 cubic metres.



Flow Simulation

Calder Valley Skip Hire

Below is a representative plan view of the complete system. Highlighted in red is the area simulated in these studies which is adequate to assess residence times within the secondary chamber to a reasonable degree of accuracy.



Flow Simulation

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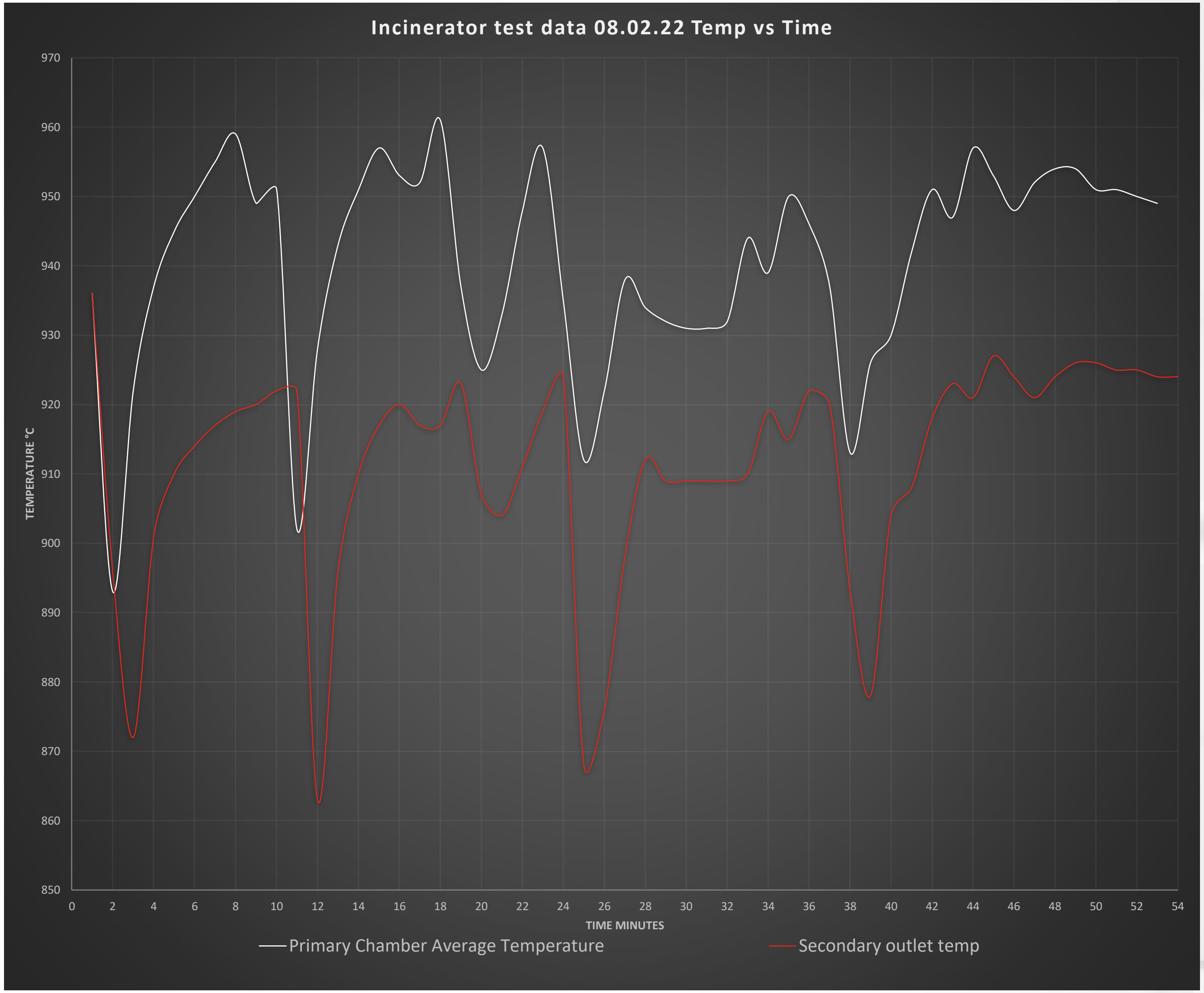
This is the physical R&D test data provided on **08.02.2022**. This temperature data has been used as temperature inputs and validation check points for these studies. This is to ensure close correlations with real world behaviour as this is vital to calculating the secondary combustion zone and, therefore, residence time. Some fluctuations can be seen here which are to be expected. However, it is significant to note that the temperatures are above the required 850°C and in the case of the secondary chamber the temperature recorded is at the outlet.



Boundary conditions

Calder Valley Skip Hire

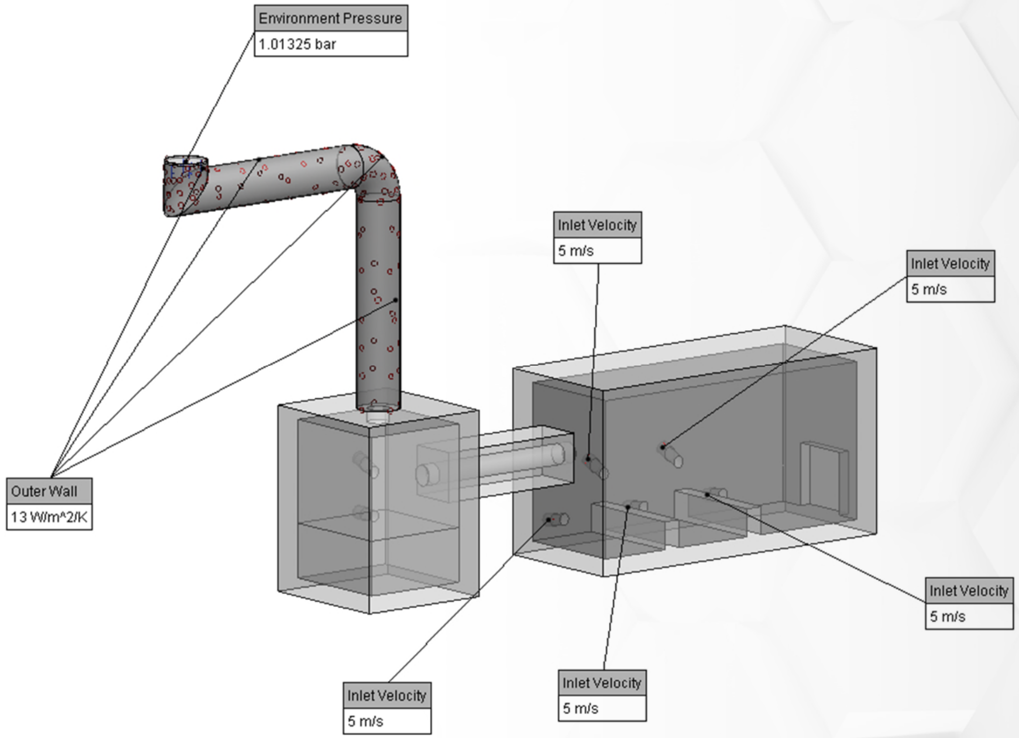
Boundary conditions have been assessed from information provided on the burners and physical test data. It is expected the velocity at each burner will be roughly 5m/s at a temperature of 920°C - 1100 degrees C°.

Velocity will be higher in the system when the burners are active, thus contributing to making this study an assessment under the most unfavorable conditions in terms of residence time. For the majority of the time during normal operations, the burners will not be required and the velocity will be lower.

The outlet in this study has been set as environmental pressure boundary condition, at atmospheric pressure, as exact measurements could not be obtained from the filtration unit within the flue due to limited access. In the absence of this data the next known point would be the emergency outlet which has been used in these studies.

However, it is worth noting this is not the usual outlet for this system. The emergency outlet would only ever be used in the case of a power cut or system fault. Under usual operating conditions these gasses will travel much further through a ceramic filtration system into a heat exchanger and subsequent filtration system. None of these have been simulated in this CFD project.

The emergency outlet has been simulated as this is assumed to be the absolute worst-case scenario in terms of reduced residence times. Based on physical data and previous studies this region forms the defined secondary combustion zone as it remains over the required 850°C and is after the last injection of combustible air. This study simulates an absolute worst case where the filter fails without blockage. Realistically, in normal operation it would be expected that the residence times would be higher due to the added back pressures from the filters and with none of the burners being active.

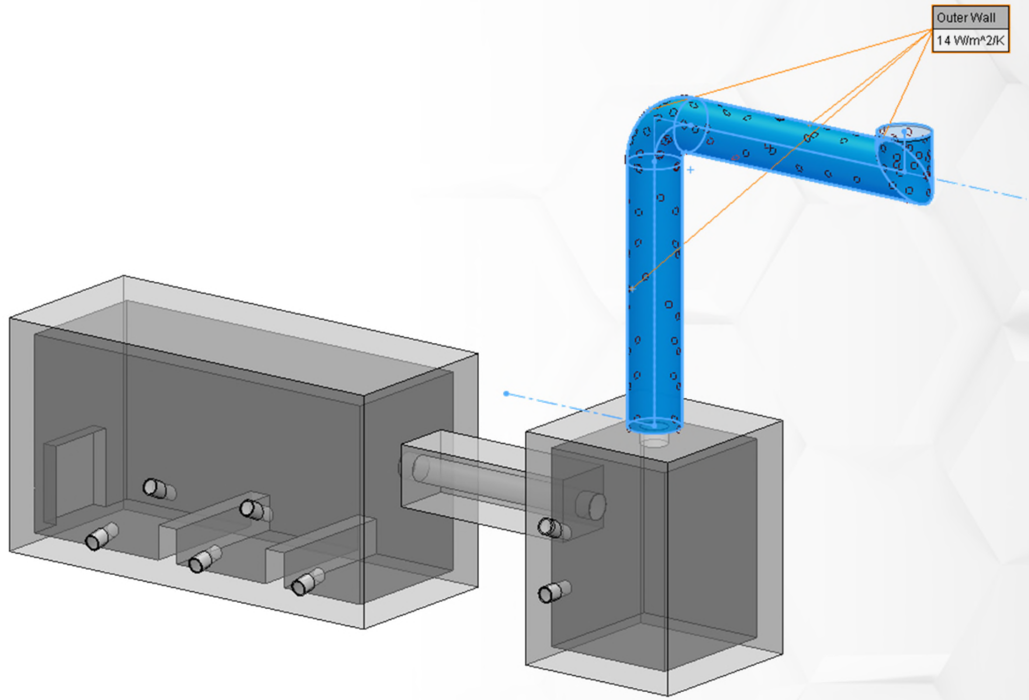


Boundary conditions

Calder Valley Skip Hire

Materials have been applied in the manufacture of the unit to prevent thermal losses as much as possible. To replicate this in the simulation materials have been applied to the parts within the study. These materials contain data on thermal conductivity, specific heat, and a specified heat transfer coefficient to an outside temperature of 20 degrees Celsius. The general material has been set as a dense cast concrete except for the flue as shown in blue which has been treated as steel.

Full data for these materials used can be found at the end of this report.



Boundary conditions

Calder Valley Skip Hire

For the first stage of this study, air has been used at each inlet at each burner at a set temperature. Assumptions are made with the air having a variable viscosity, specific heat, and thermal conductivity in respect to temperature, with the correct flow rates and temperatures derived from assumptions of Stoichiometric ratio regarding the waste and ratio of fuel. This is sufficient for simulating a two-chamber incinerator such as this one providing the incinerator isn't overloaded. This information serves as the basis of our study, and we have checked this against physical measurements taken on site. Using this as a basis, we have then simulated gasses or particulate traveling in this flow stream. At this point, we have measured the time different particulate takes to travel through various parts of the system. Nitrogen particles have then been used in this project as a tracer as this is expected to be one of the predominant gasses present during the burn of this type of RDF (Refuse Derived Fuel). Nitrogen has been selected not only because it is one of the predominant gasses present but also its atomic mass is one of the lightest anticipated to be present. Therefore, it Is expected to have a less favorable residence time as compared with other gasses which will be present.

Flow Simulation

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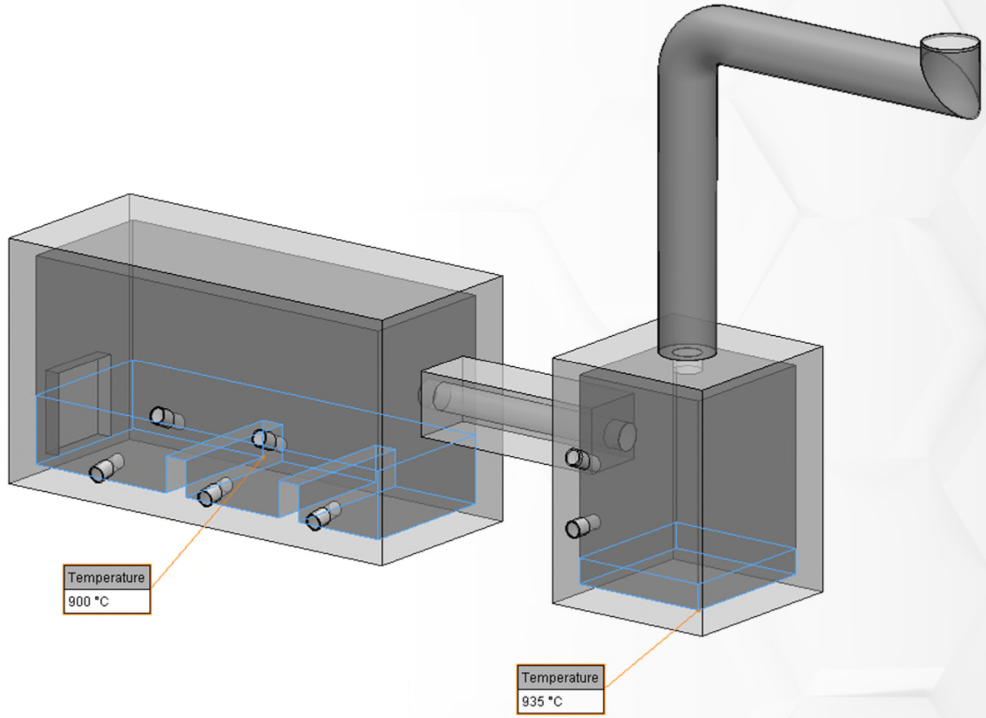
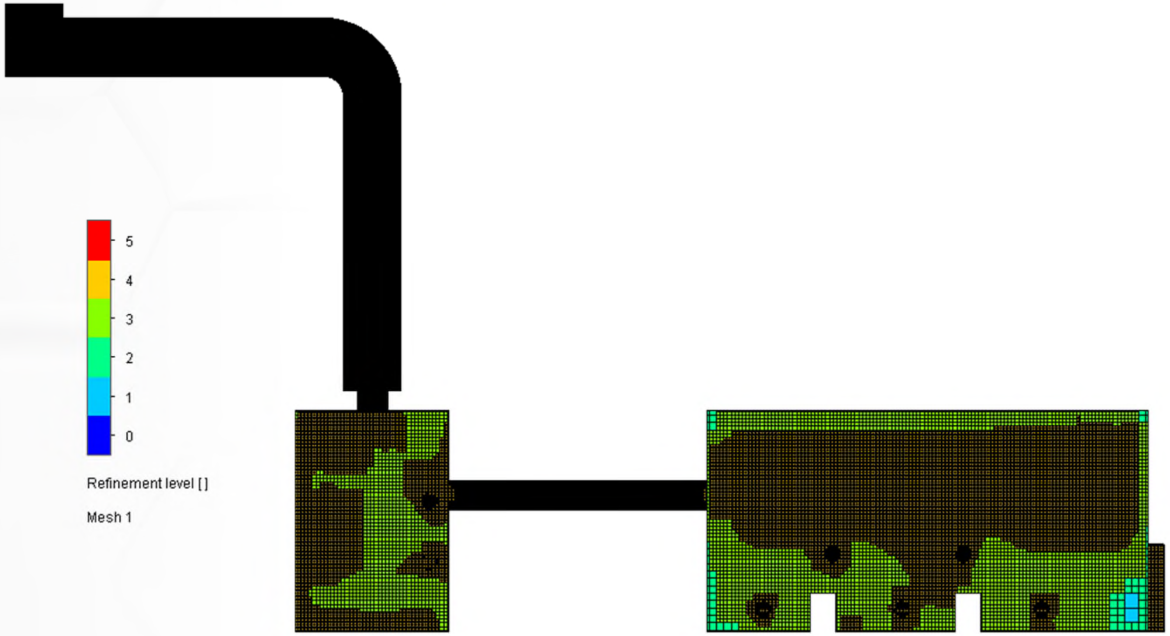
To try and better account for the combustion taking place inside the unit temperatures have been applied to each burner and also to each chamber to replicate temperatures measured from real-world testing. This has been carried out by modeling internal volumes and applying 900 °C to the first chamber and 935°C to the second chamber. These are consistent with the temperatures recorded in the R&D test. All other sections of the model excluding the burners have been assumed to generate zero thermal energy. The size of these volumes has been guided by the instruction manual which recommends that the unit runs at 1/3 of capacity for optimal burn and to avoid flashing.



Flow Simulation

Mesh

Total cells	2,174,809
Fluid cells	1,308,645
Solid cells	866,164
Fluid cells contacting solids	375,212

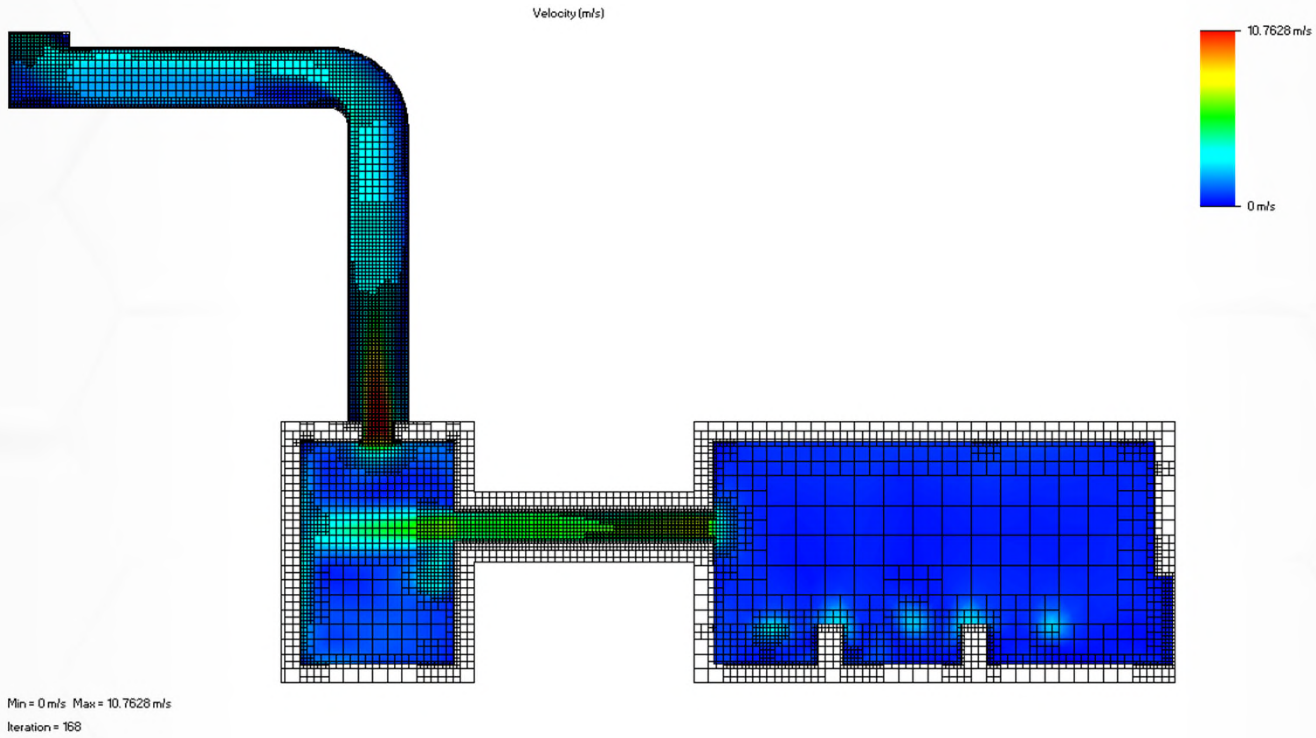


Before running the study, the mesh must be defined for both the fluid and solid volume. Here we can see the refinement level of the mesh used, with refinement added in narrow channels and high turbulence regions.

(There are no trimmed or irregular cells in this model.)

Flow Simulation

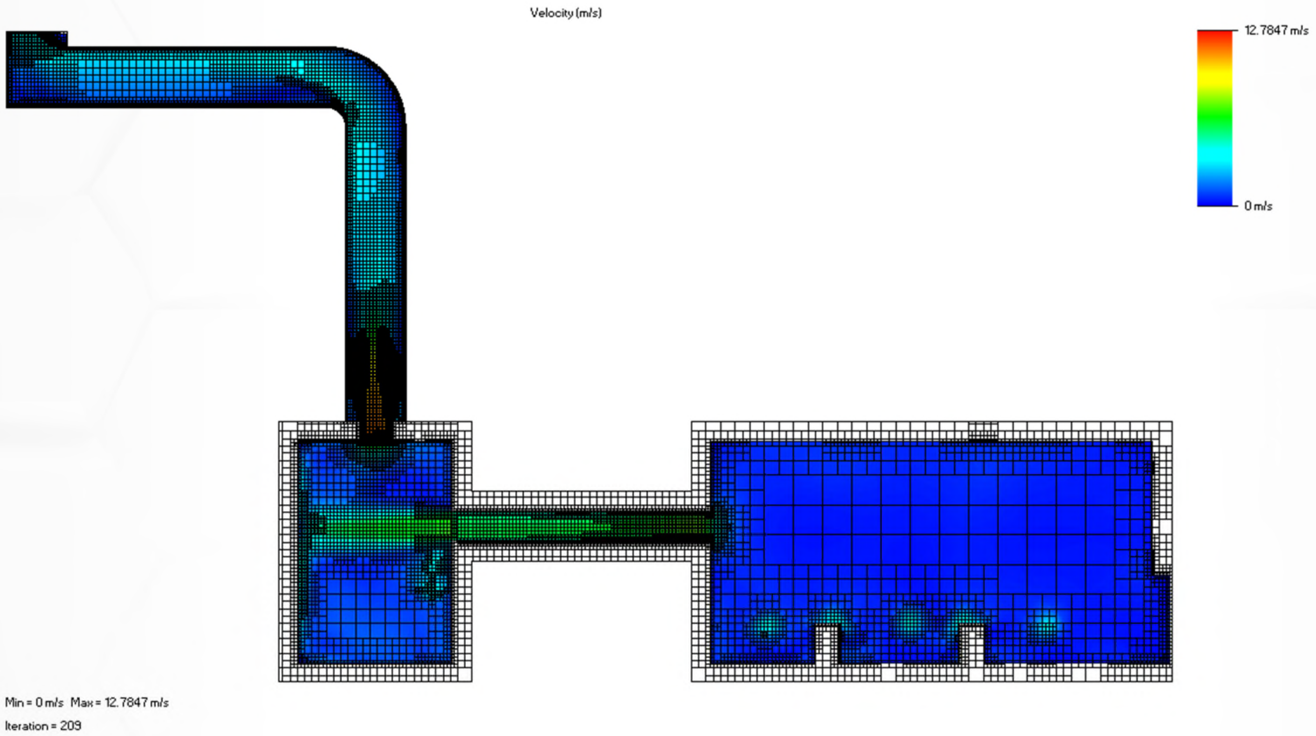
Mesh



Adaptive meshing has been used on this model so the mesh will automatically update and refine at 50 iteration intervals throughout the study. This is to help capture the airflow as accurately as possible and aid convergence.

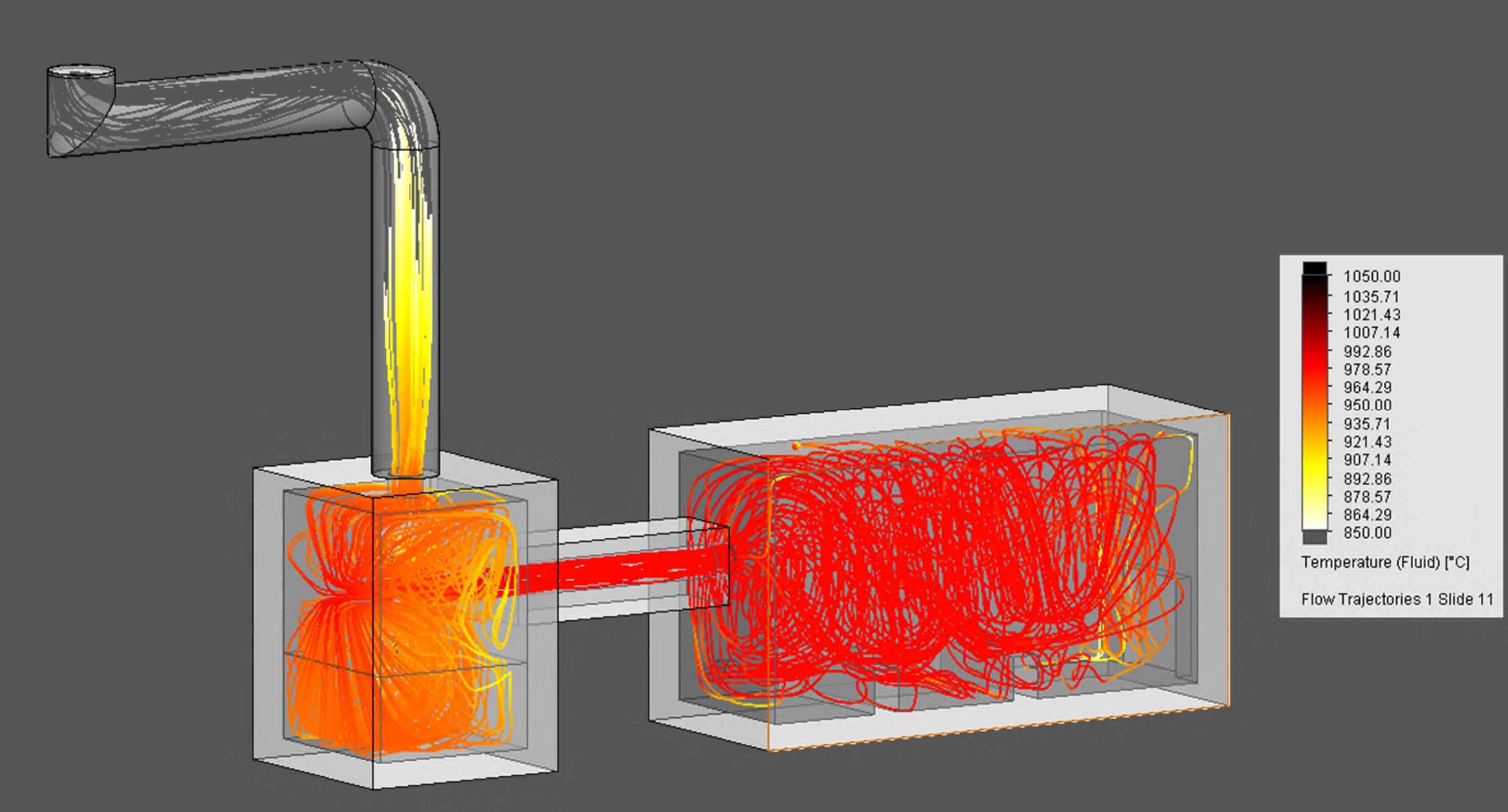
Flow Simulation

Mesh



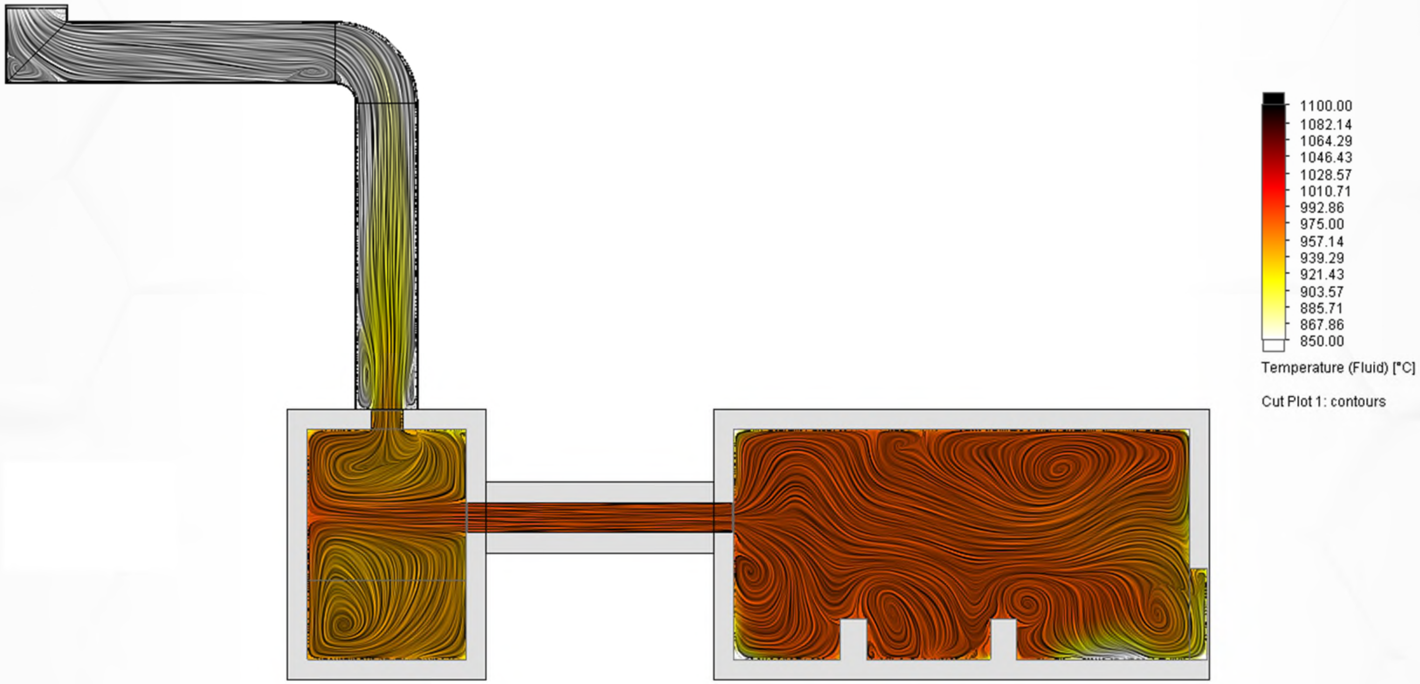
Snapshot 2 of updated mesh refinement.

Results 1


1050.00
1035.71
1021.43
1007.14
992.86
978.57
964.29
950.00
935.71
921.43
907.14
892.86
878.57
864.29
850.00
Temperature (Fluid) [°C]
Flow Trajectories 1 Slide 11

Flow Simulation

Results

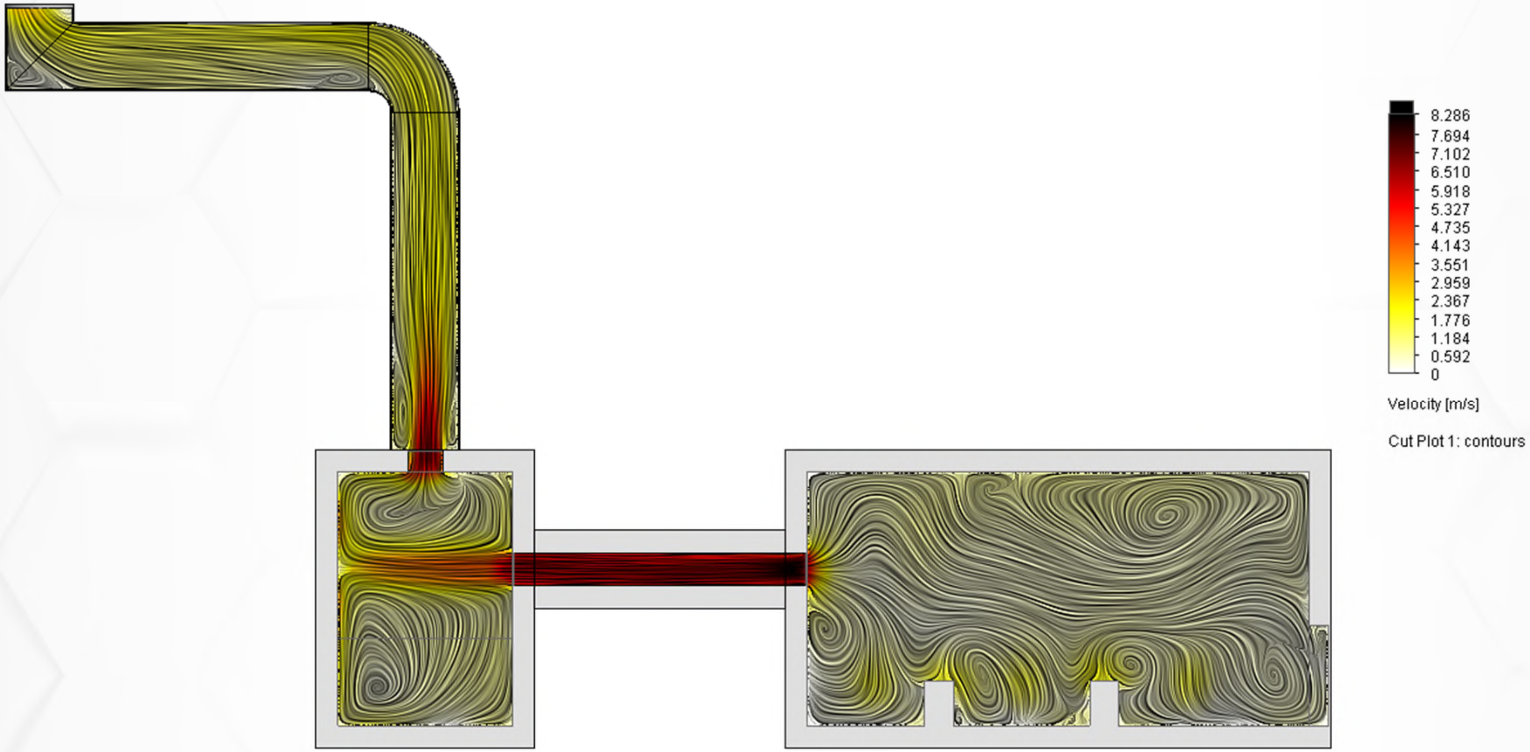


Temperature in section - plot maximum **976°C**

Here we can also see the gasses remain above the desired 850°C in the secondary chamber and significantly into the flue.

Flow Simulation

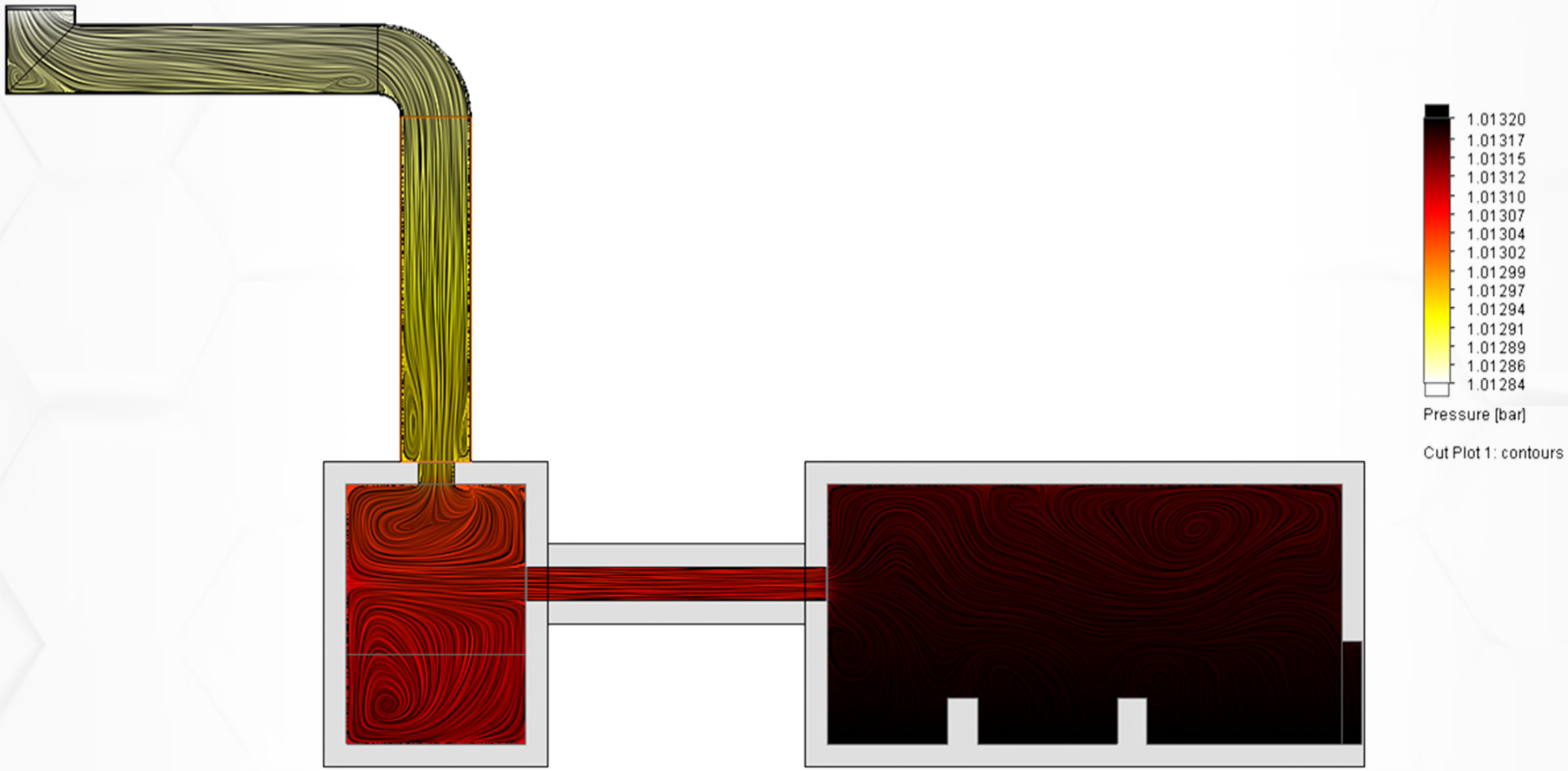
Results



This plot shows velocity in section halfway through the model with a maximum velocity at **8.28 m/s**

Flow Simulation

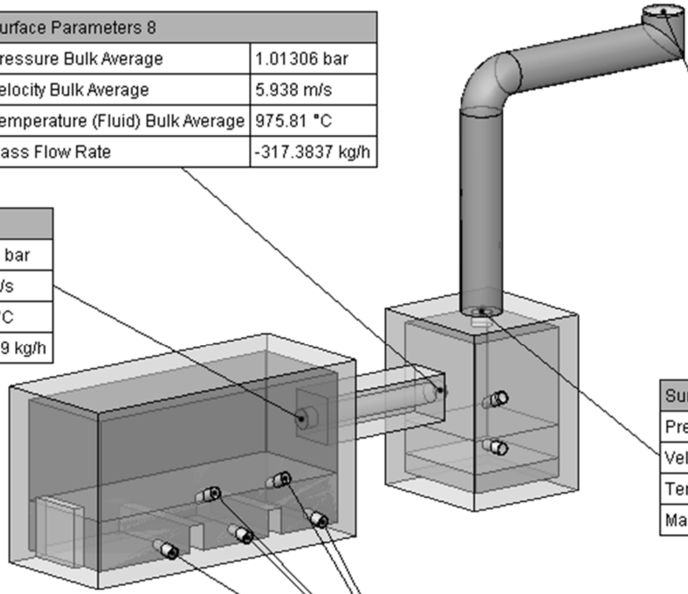
Results



Pressure in section Maximum 1.01320061 **bar**

Flow Simulation

Results



Surface Parameters 8	
Pressure Bulk Average	1.01306 bar
Velocity Bulk Average	5.938 m/s
Temperature (Fluid) Bulk Average	975.81 °C
Mass Flow Rate	-317.3837 kg/h

Surface Parameters 12	
Pressure Bulk Average	1.01311 bar
Velocity Bulk Average	6.689 m/s
Temperature (Fluid) Bulk Average	976.82 °C
Mass Flow Rate	323.9839 kg/h

Surface Parameters 6	
Pressure Bulk Average	1.01283 bar
Velocity Bulk Average	2.032 m/s
Temperature (Fluid) Bulk Average	460.52 °C
Mass Flow Rate	-340.5466 kg/h

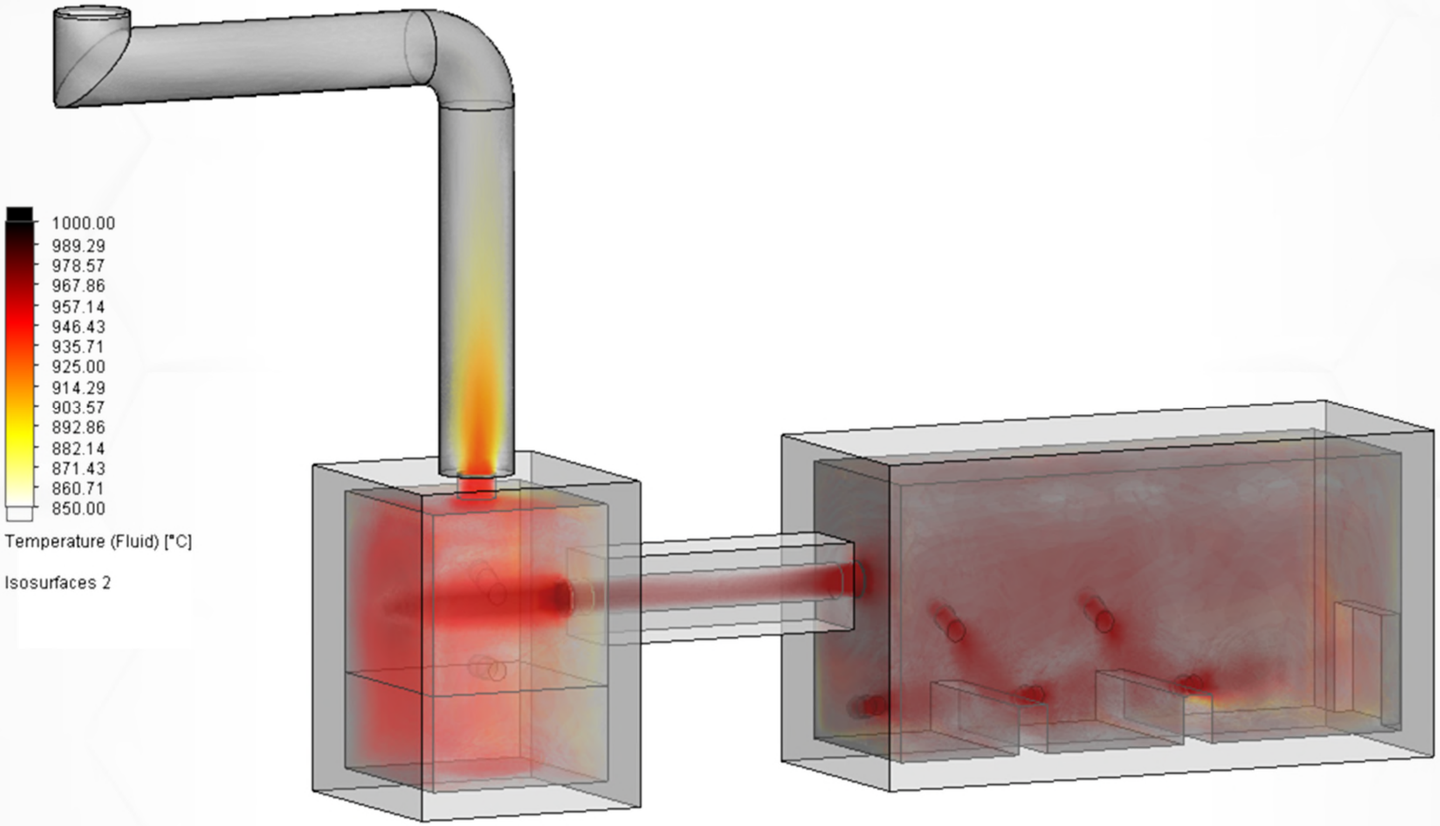
Surface Parameters 7	
Pressure Bulk Average	1.01295 bar
Velocity Bulk Average	5.811 m/s
Temperature (Fluid) Bulk Average	943.77 °C
Mass Flow Rate	-325.4929 kg/h

Surface Parameters 10	
Pressure Bulk Average	1.01318 bar
Velocity Bulk Average	5.260 m/s
Temperature (Fluid) Bulk Average	1136.52 °C
Mass Flow Rate	340.5470 kg/h

Surface parameters at key inlets and outlets.

Flow Simulation

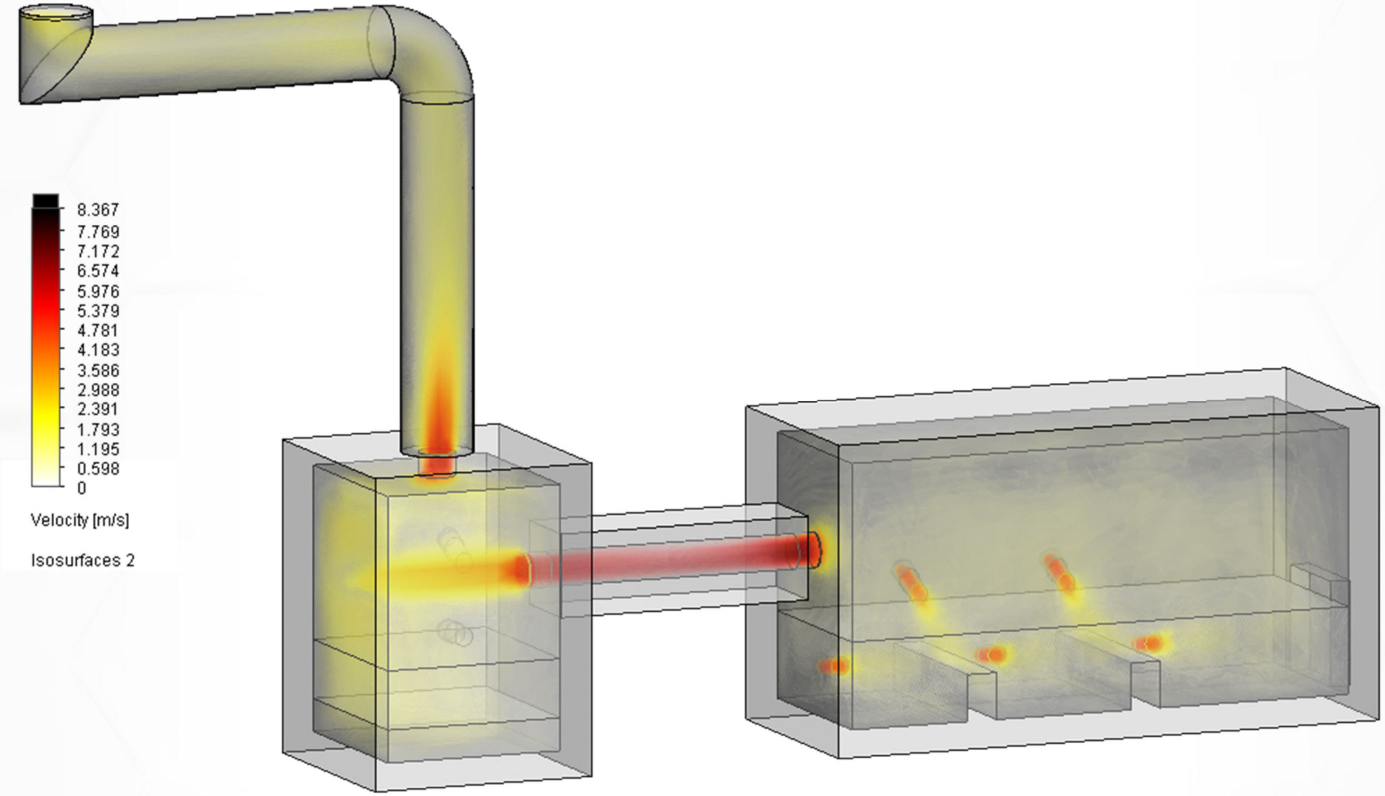
Results



This plot shows a Temperature ISO surface plot. This shows temperature distribution. Lower temperatures are primarily seen higher in the flue near the outlet as expected. This also shows good corelations with physical measurements. For example, the exit to the second chamber is expected to be 920°C.

Flow Simulation

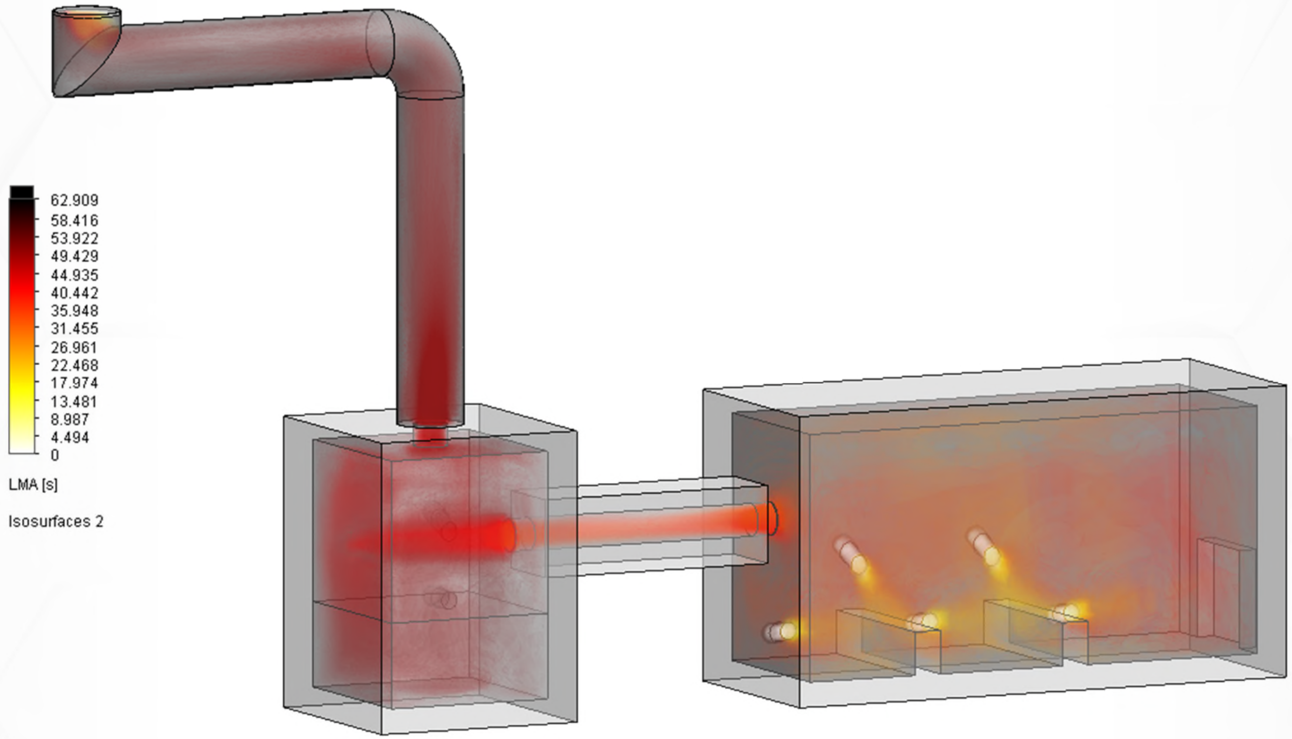
Results



This shows the Velocity Iso surface plot which shows areas of faster moving flow in darker regions.

Flow Simulation

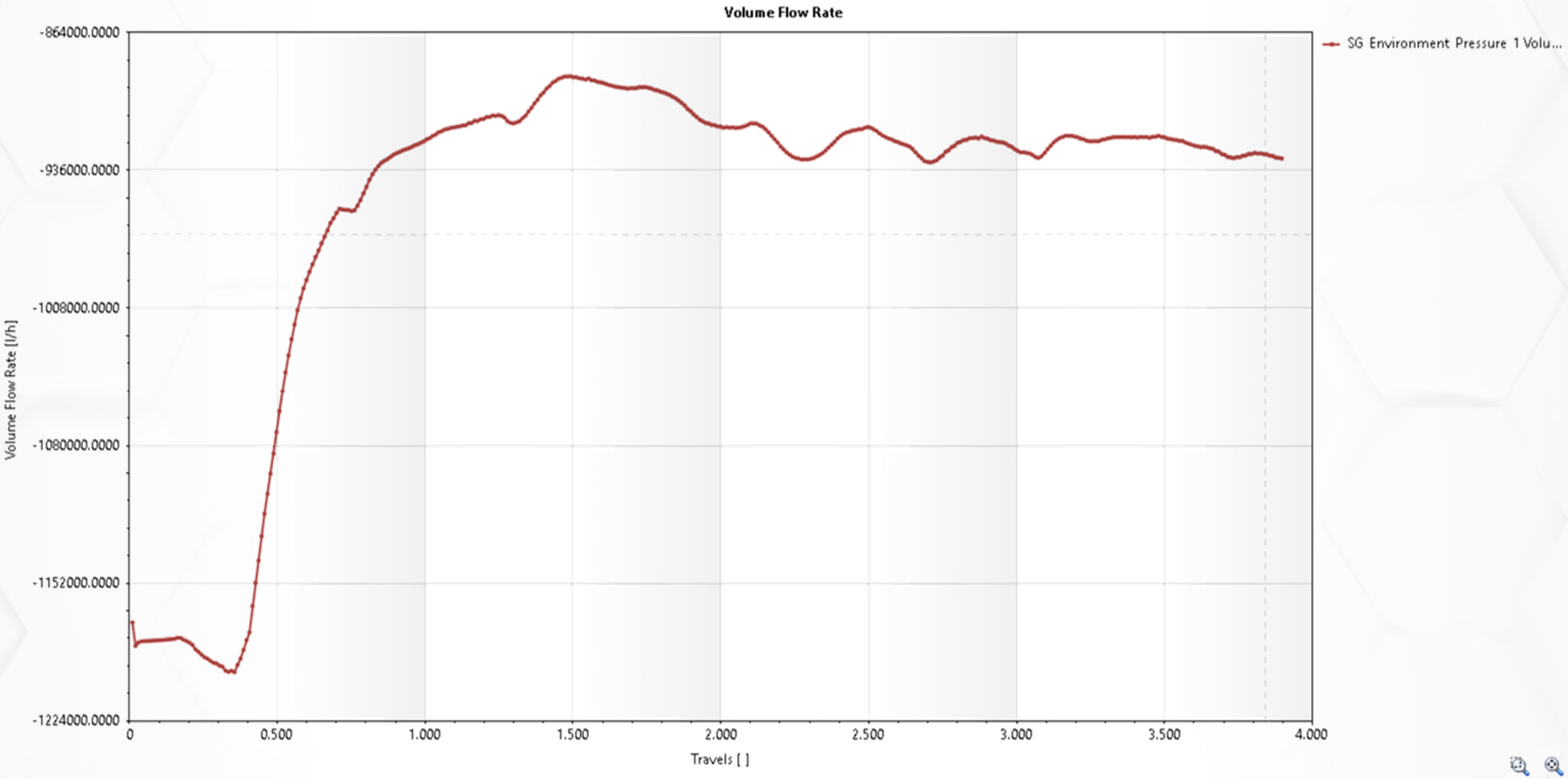
Results



This plot shows LMA local mean age of gasses within the unit in seconds. This is measured from each burner inlet from 0 seconds to the maximum as shown here at 62 seconds. These measurements serve to identify regions of recirculation and show typically how long the gas has been in a certain region. The plot shows that the majority of gasses at the flue have been in the system for ~40 seconds when measured from the burners.

Flow Simulation

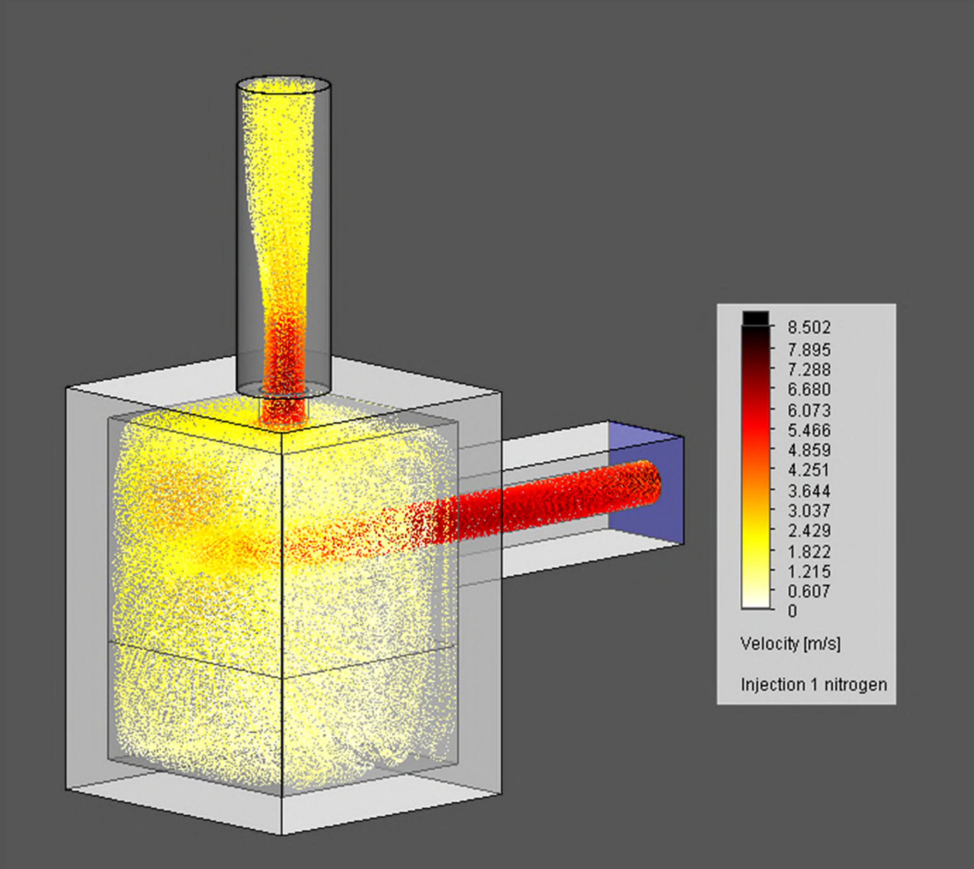
Results



Snapshot of one of numerous convergence goals used. The above tracks convergence of the volume flow rate at the outlet.

Full convergence data and simulation data can be provided upon request. [SLDPRT & FLD format]

Result 2 - Nitrogen study



Second Chamber to outlet using study 1 as reference.
Residence time measured to the outlet shown above.

Flow Simulation

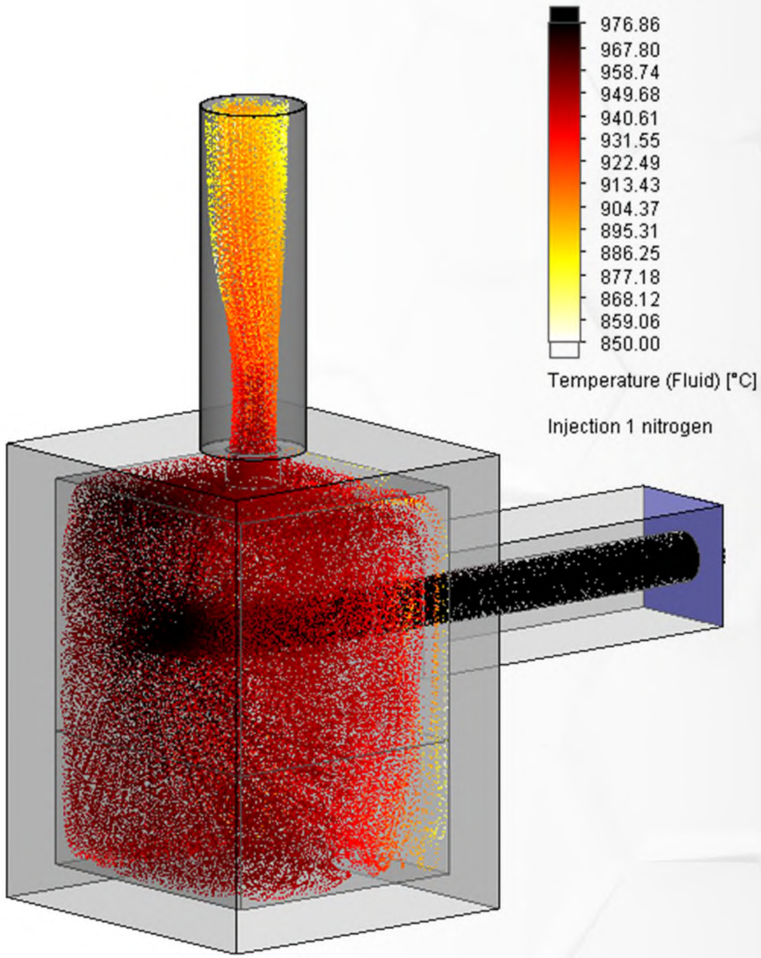
Nitrogen study

In this study, nitrogen has been inserted in the secondary chamber inlet into the existing flow stream which is similar to a tracer in real-world testing. From this, we can then calculate residence time and visually review the trajectory of each particle. The residence time is measured to the end of the combustion zone which is defined as the location where the temperature drops below 850°C. To account for this and take this measurement the length of the flue has been reduced as shown on the right to allow us to measure residence time to this point.

A sample of 250 points has been taken to provide the average min and max data. Full data can be provided upon request.

Particle size used: 2.57E-07

Please see Reference for density data

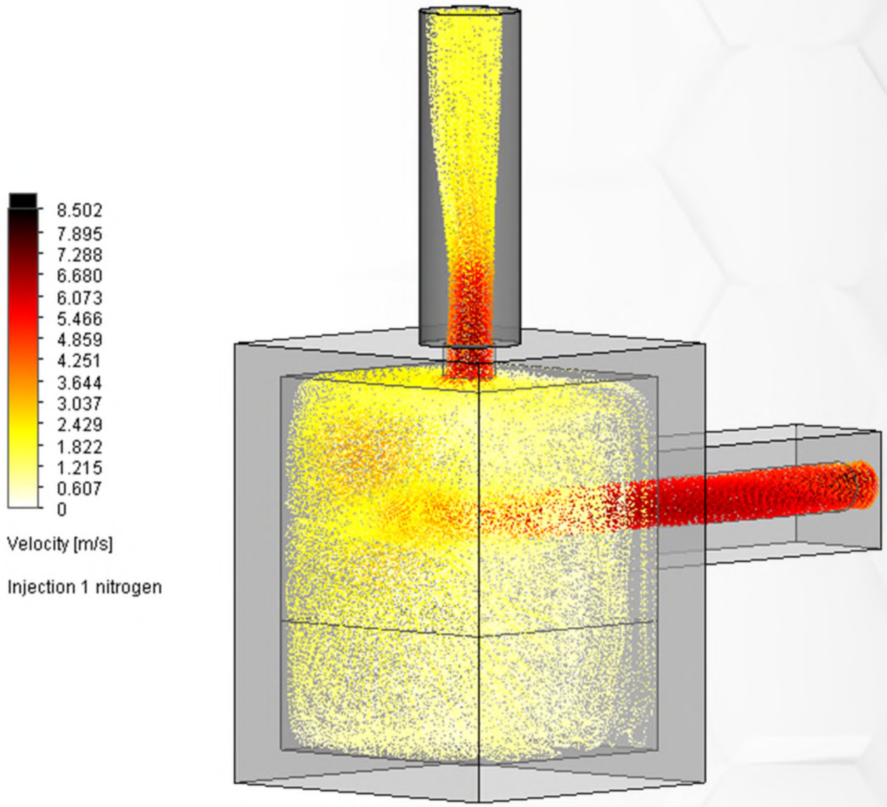


Flow Simulation

Nitrogen study

On the right there is shown the velocity profile for the nitrogen particles which are being tracked to measure residence time. Below the residence times for the nitrogen to travel from the secondary chamber inlet to the outlet are recorded.

Residence time Measurement	Time in Seconds
Average	13.9
Median	11.9
Min	2.18
Max	61.3



Flow Simulation

Conclusions

The results previously shown in section 1 are used to help to identify the start and end of the combustion zone. This is then used in section 2 to measure residence time in line with published DEFRA guidance. According to this guidance, the residence time measurement starts where the temperature exceeds the required 850°C after the last injection of combustible air. and ends where the temperature drops below 850°C .

When measuring residence time from these locations we can state with a reasonable degree of confidence that the residence time of at least 2 seconds at a minimum of 850°C will be achieved. In normal operating conditions the residence time will be expected to be longer as the conditions simulated in this study are highly unfavorable in terms of velocity and, therefore, residence time.

It is also worth mentioning that 'heavier' gasses will be present and if they were used for the tracer the residence time would be expected to increase further as these gasses would linger and recirculate in the system for longer. The use of nitrogen alone in the assessment of residence time represents a worst-case assessment as the gasses resulting from combustion will include ‘heavier’ gasses as well as nitrogen. Further, as stated above, the simulation in this study has not included the ceramic filtration unit within the flue. The effect of the ceramic filtration unit will be to add back pressure and extra volume which we expect to increase residence time further.

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Thank you

Alex.Hall@solidsolutions.co.uk

Reference

Gasses used

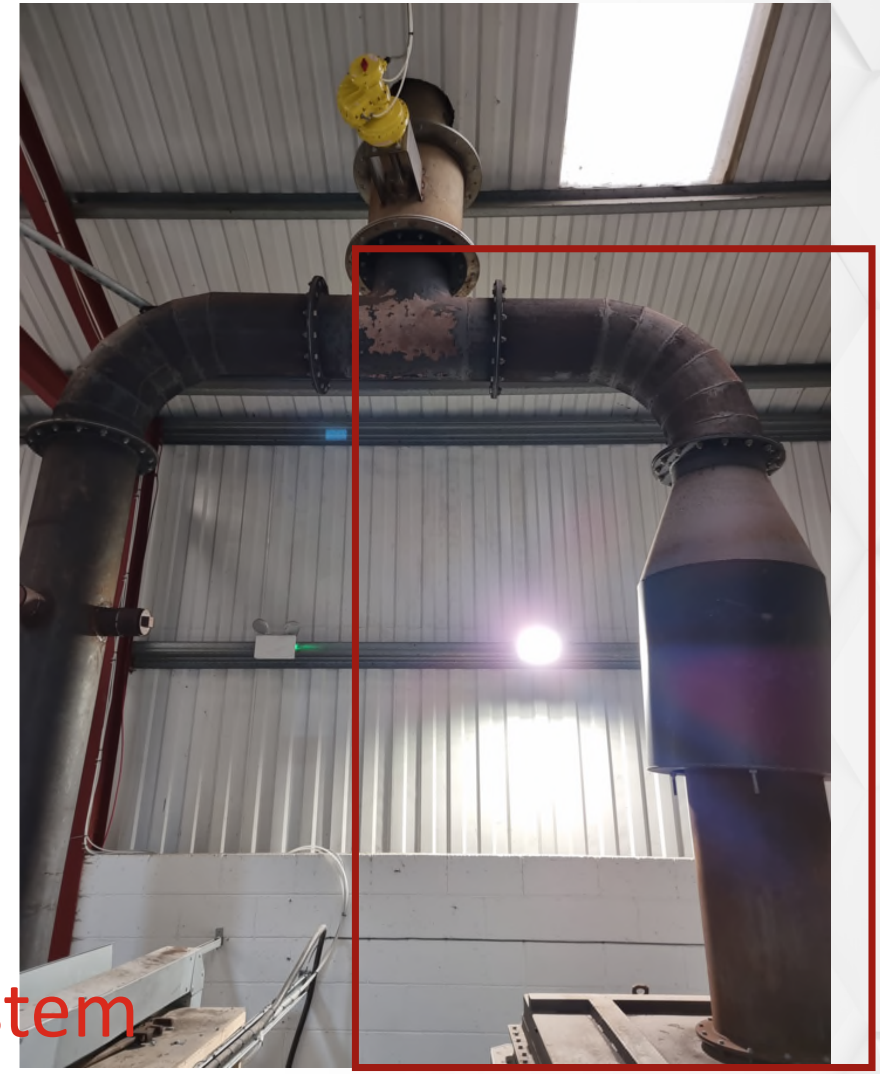
A snapshot from Inside the first chamber.

Reference

Gasses used

Emergency outlet and inlet to heat exchanger

The flue system includes the ceramic filtration unit previously referred to.



Flue system

Reference

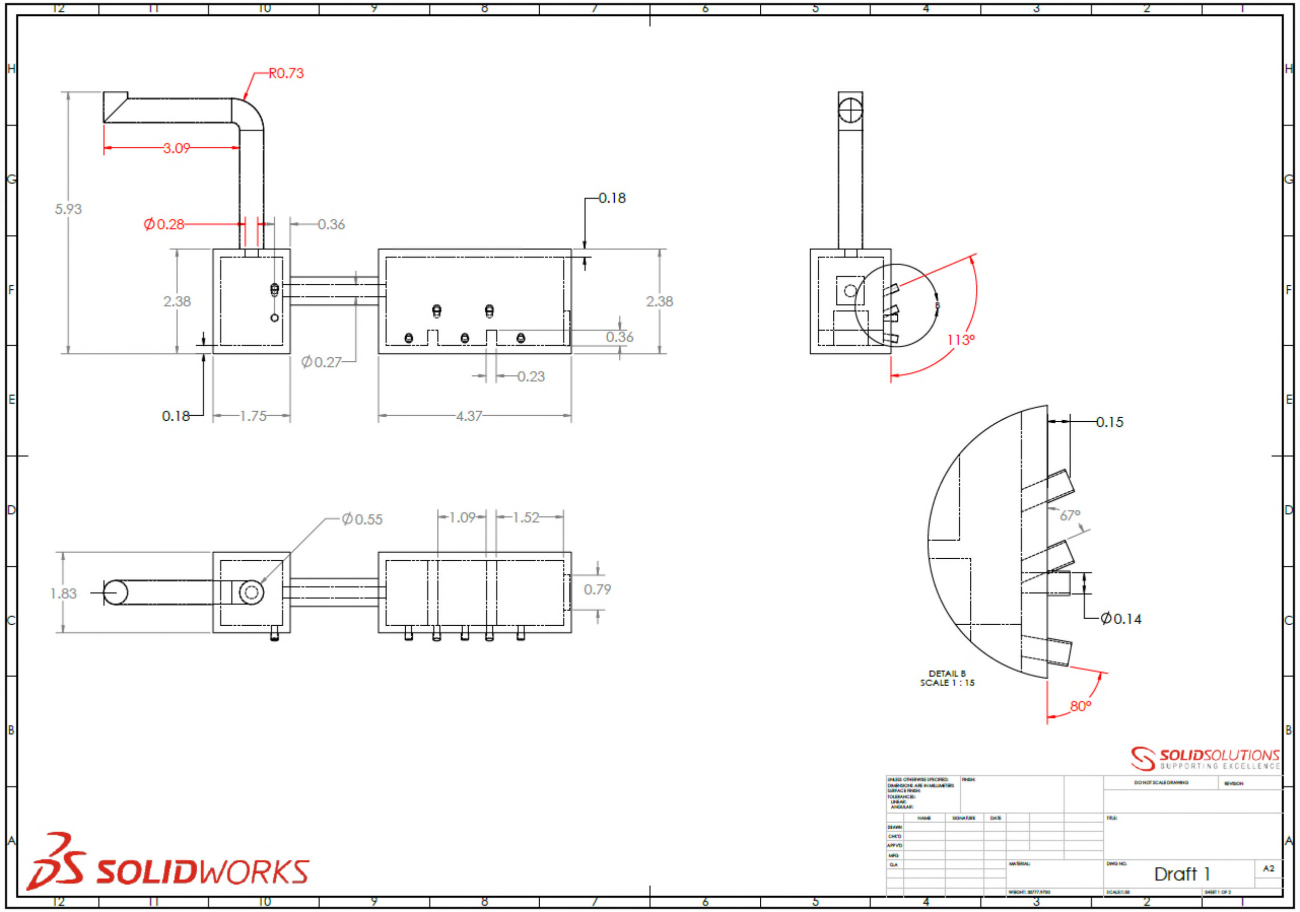
Gasses used

Reference images from 2nd chamber

Video can be provided if required.

Reference

Drawing provided – Red indicates approximations



The approximations are believed to make negligeable difference to the final result.

Reference

Gasses used

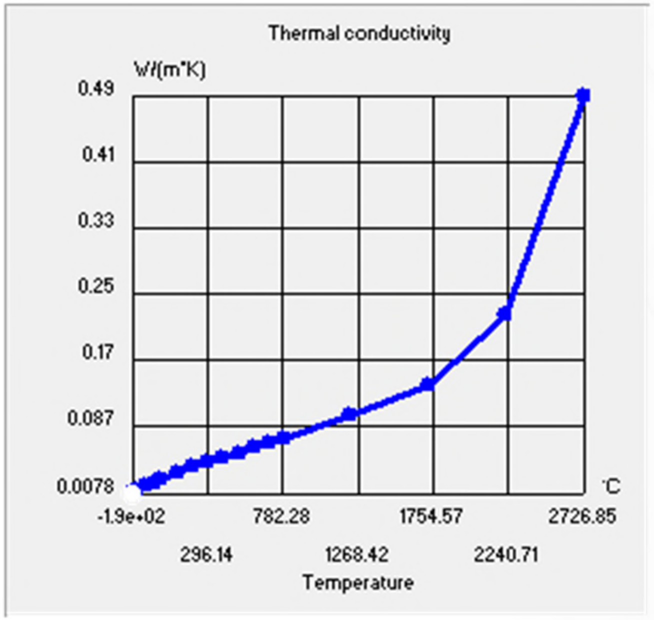
Gas data used: Air - 0.02896 Kg/Mol

Air

Property:

Thermal conductivity

Temperature	Thermal conductivity
-190 °C	0.007792292 W/(m*K)
-180 °C	0.008699455 W/(m*K)
-170 °C	0.009594987 W/(m*K)
-160 °C	0.010502149 W/(m*K)
-150 °C	0.011420942 W/(m*K)
-100 °C	0.015863712 W/(m*K)
-50 °C	0.020166918 W/(m*K)
0 °C	0.0243073 W/(m*K)
100 °C	0.031866987 W/(m*K)
200 °C	0.038728856 W/(m*K)
300 °C	0.044776605 W/(m*K)
400 °C	0.050475446 W/(m*K)
500 °C	0.056174287 W/(m*K)
600 °C	0.061524219 W/(m*K)
700 °C	0.066641545 W/(m*K)



Reference

Gasses used

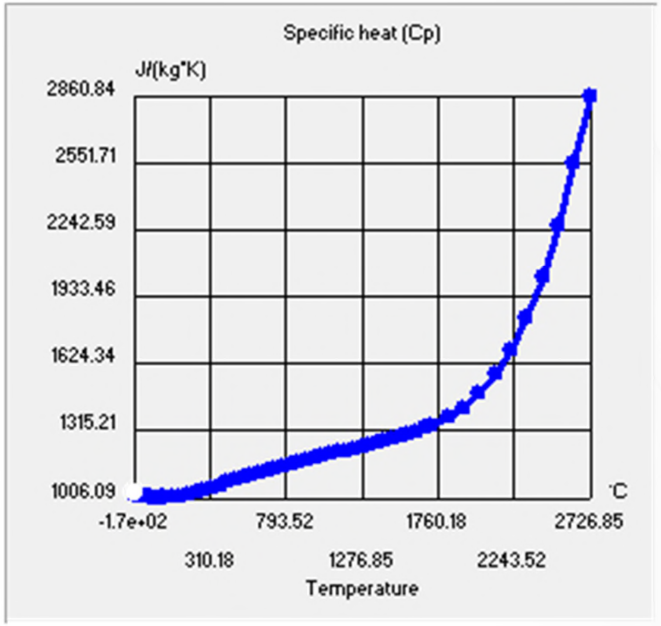
Gas data used: Air - 0.02896 Kg/Mol

Air

Property:

Specific heat (Cp)

Temperature	Specific heat (Cp)
-173.15 °C	1029.11499 J/(kg*K)
-163.15 °C	1022.41612 J/(kg*K)
-153.15 °C	1018.22932 J/(kg*K)
-143.15 °C	1014.87988 J/(kg*K)
-133.15 °C	1012.78648 J/(kg*K)
-123.15 °C	1011.11176 J/(kg*K)
-113.15 °C	1009.85572 J/(kg*K)
-103.15 °C	1009.01836 J/(kg*K)
-93.15 °C	1008.181 J/(kg*K)
-83.15 °C	1007.34364 J/(kg*K)
-73.15 °C	1006.50628 J/(kg*K)
-63.15 °C	1006.50628 J/(kg*K)
-53.15 °C	1006.50628 J/(kg*K)
-43.15 °C	1006.08761 J/(kg*K)
-33.15 °C	1006.08761 J/(kg*K)



Reference

Gasses used

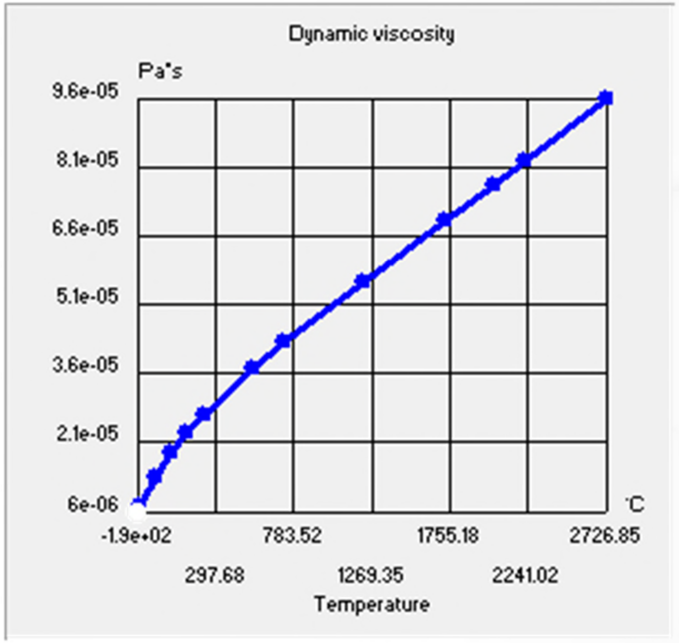
Gas data used: Air - 0.02896 Kg/Mol

Air

Property:

Dynamic viscosity

Temperature	Dynamic viscosity
-188.15 °C	6.04e-06 Pa*s
-173.15 °C	7.11e-06 Pa*s
-73.15 °C	1.33e-05 Pa*s
26.85 °C	1.85e-05 Pa*s
126.85 °C	2.3e-05 Pa*s
226.85 °C	2.7e-05 Pa*s
526.85 °C	3.7e-05 Pa*s
726.85 °C	4.24e-05 Pa*s
1226.85 °C	5.57e-05 Pa*s
1726.85 °C	6.89e-05 Pa*s
2026.85 °C	7.66e-05 Pa*s
2226.85 °C	8.18e-05 Pa*s
2726.85 °C	9.55e-05 Pa*s



Reference

Particles used

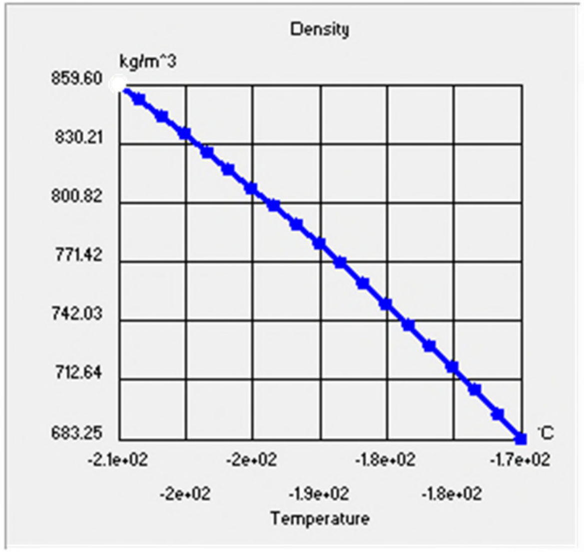
Data used:

Nitrogen

Property:

Density

Temperature	Density
-208.15 °C	859.6 kg/m^3
-206.15 °C	851.25 kg/m^3
-204.15 °C	842.79 kg/m^3
-202.15 °C	834.21 kg/m^3
-200.15 °C	825.51 kg/m^3
-198.15 °C	816.67 kg/m^3
-196.15 °C	807.69 kg/m^3
-194.15 °C	798.56 kg/m^3
-192.15 °C	789.27 kg/m^3
-190.15 °C	779.8 kg/m^3
-188.15 °C	770.13 kg/m^3
-186.15 °C	760.26 kg/m^3
-184.15 °C	750.16 kg/m^3
-182.15 °C	739.82 kg/m^3
-180.15 °C	729.19 kg/m^3



Reference

Particles used

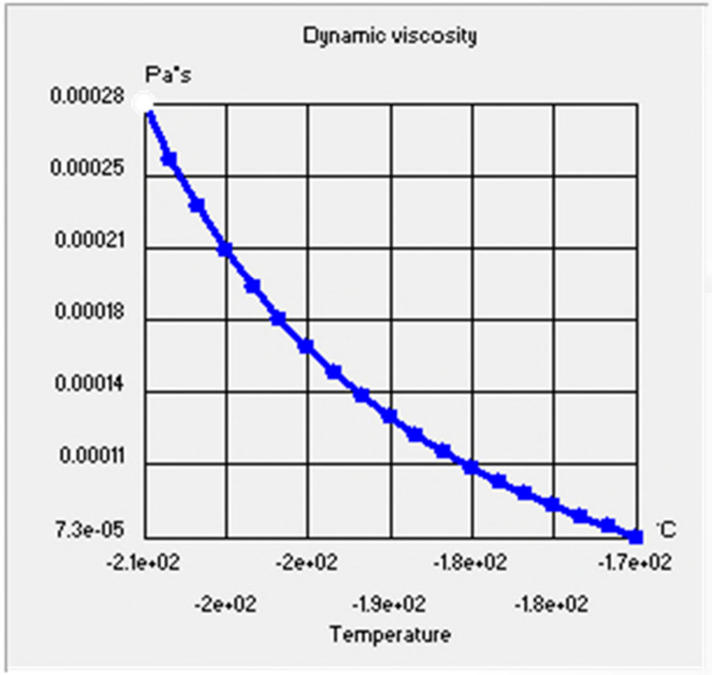
Nitrogen

Data used:

Property:

Dynamic viscosity

Temperature	Dynamic viscosity
-208.15 °C	0.00028011 Pa*s
-206.15 °C	0.00025349 Pa*s
-204.15 °C	0.00023033 Pa*s
-202.15 °C	0.00021011 Pa*s
-200.15 °C	0.00019237 Pa*s
-198.15 °C	0.00017675 Pa*s
-196.15 °C	0.00016294 Pa*s
-194.15 °C	0.00015067 Pa*s
-192.15 °C	0.00013973 Pa*s
-190.15 °C	0.00012993 Pa*s
-188.15 °C	0.00012111 Pa*s
-186.15 °C	0.00011314 Pa*s
-184.15 °C	0.0001059 Pa*s
-182.15 °C	9.9298e-05 Pa*s
-180.15 °C	9.324e-05 Pa*s



Reference

Particles used

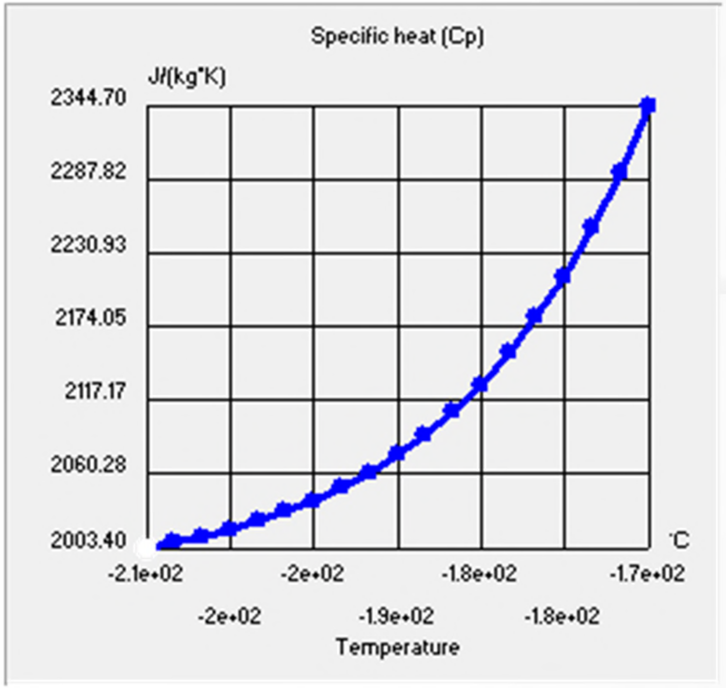
Nitrogen

Data used:

Property:

Specific heat (Cp)

Temperature	Specific heat (Cp)
-208.15 °C	2003.4 J/(kg*K)
-206.15 °C	2007.3 J/(kg*K)
-204.15 °C	2011.9 J/(kg*K)
-202.15 °C	2017.3 J/(kg*K)
-200.15 °C	2023.7 J/(kg*K)
-198.15 °C	2031.1 J/(kg*K)
-196.15 °C	2039.8 J/(kg*K)
-194.15 °C	2049.9 J/(kg*K)
-192.15 °C	2061.6 J/(kg*K)
-190.15 °C	2075.1 J/(kg*K)
-188.15 °C	2090.6 J/(kg*K)
-186.15 °C	2108.6 J/(kg*K)
-184.15 °C	2129.2 J/(kg*K)
-182.15 °C	2153.1 J/(kg*K)
-180.15 °C	2180.7 J/(kg*K)



Reference

Particles used

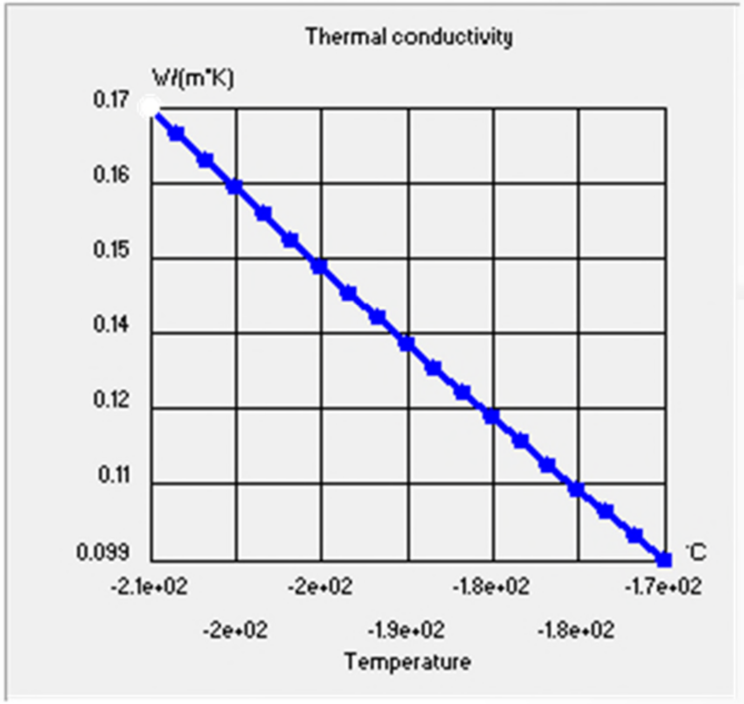
Nitrogen

Data used:

Property:

Thermal conductivity

Temperature	Thermal conductivity
-208.15 °C	0.17315 W/(m*K)
-206.15 °C	0.16858 W/(m*K)
-204.15 °C	0.16408 W/(m*K)
-202.15 °C	0.15962 W/(m*K)
-200.15 °C	0.15522 W/(m*K)
-198.15 °C	0.15087 W/(m*K)
-196.15 °C	0.14657 W/(m*K)
-194.15 °C	0.14231 W/(m*K)
-192.15 °C	0.13815 W/(m*K)
-190.15 °C	0.13402 W/(m*K)
-188.15 °C	0.12993 W/(m*K)
-186.15 °C	0.12588 W/(m*K)
-184.15 °C	0.12188 W/(m*K)
-182.15 °C	0.11791 W/(m*K)
-180.15 °C	0.11398 W/(m*K)



Reference

Solids used

Data used:

Property	Value
Name	Steel Stainless 302
Comments	Cr18/Ni8
Density	7900 kg/m^3
Specific heat	500 J/(kg*K)
Conductivity type	Isotropic
Thermal conductivity	16.29999 W/(m*K)
Electrical conductivity	Conductor
Resistivity	7.2e-07 Ohm*m
Radiation properties	☐
Melting temperature	☑
Temperature	1400 °C

Property	Value
Name	Cast concrete (dense)
Comments	
Density	2100 kg/m^3
Specific heat	1000 J/(kg*K)
Conductivity type	Isotropic
Thermal conductivity	0.8 W/(m*K)
Electrical conductivity	Dielectric
Radiation properties	☐
Melting temperature	☑
Temperature	1550 °C

Reference

LMA Local mean age result quantity is described by SOLIDWORKS development team as:

Where: x_i is the *i*-th coordinate, *r* is the density, u_i is the *i*-th velocity component, *m* is the dynamic viscosity coefficient, m_t is the turbulent eddy viscosity coefficient, *s* and s_t are the laminar and turbulent Schmidt numbers. The equation is solved under the $t = 0$ boundary condition on the inlet opening.

LACI (local air change index) is equal to i.e., reciprocal to the Dimensionless LMA - is the second eigenvalue of the symmetry square of velocity gradient

Particle studies do not capture particle to particle interaction but this is not considered to be significant in these studies.

Smooth wall conditions have been used in these studies. In the particle studies an ideal reflection wall condition has been used which means that absorption and accretion have been ignored. Again, if real world conditions had been taken into account it is anticipated that they would serve only to increase residence times above those simulated in this study.

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End of Report

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