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INCINERATION●COMBUSTION●HEAT TREATMENT●ENERGY CONVERSION

CFD MODELLING REPORT
PYROCORE 250kg PYROLYSIS UNIT

Prepared for:

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Doc No. 9401-0819

Issue 2

Revisions		
1	13/8/18	Issued to Client
2	19/8/18	Revisions for T3 determination error. Some plots revised, revised result file. V5 plots replace V4 plots where differences exist due to gas radiant temperature determination error in V4 run. Added V5 convergence plot. Added V5 result text file.

CONTENTS

EXECUTIVE SUMMARY

E1 AceFurnace Consulting Ltd was engaged by Pyrocore Ltd. to undertake computational fluid dynamics modelling to characterise the post-combustion flue gas residence time at 850°C in the gas oxidation secondary chamber of their 250 kg/h waste pyrolysis plant.

E2 This report describes the results obtained from complete volume modelling of the flue gas path with the following features:

1. A full volumetric model of the combustion chamber, muffle furnace with pyrolysis tube and part of the outlet flue duct.
2. Mixed is burned 3 gas combustion model (fuel gas, air and product gas)
3. Heat loss to the pyrolysis tube modelled as constant surface heat flux.
4. Heat loss to the walls modelled as heat flux per unit area at 0.8kW/m^2
5. Convective heat transfer using wall function with roughness.
6. IMMERSOL radiant heat transfer with emissivity of 0.8 for surfaces and gas absorption coefficient as calculated by Kaplan. Scattering coefficient is set to zero as there should be no particulate in the gases.

E3 Residence time was determined based on the coldest route through the model working volume as a minimum for each case, i.e. with the model programmed not to add residence time to gas passing through any regions below 850°C. The volume over which residence time can be accumulated covers the volume enclosing the gases, regions colder than the 850°C threshold do not participate in the accumulation of residence time. The plant applies all the combustion air at a single plane on the “Y” branch of the first secondary pass.

E4 Modelling has been done with the air rate at 200% of the stoichiometric ratio based on a gas analysis and 70% gas yield per kg of feed measured on a similar plant. (100% excess air) This is considered conservative as the working excess air rate under control will be between 60 and 75%.

E5 Modelling showed that with a threshold of 850°C, the criterion of 2 seconds residence time for design conditions was met. Overall predicted temperatures from the combustion model show that the volume average temperature will be around 1000°C.

E6 The spread of residence time across the outlet plane of the model shows only a small variation and at no point does the 2 second isosurface exit the model domain.

E7 A streamline time-of-flight check through the velocity field was consistent with the temperature dependent scalar method.

E8 The requirement for 2 seconds minimum residence under the conditions modelled is met.

1. Fuel and Combustion Calculations

1.1 The input conditions are defined by the combustion calculation based on a practical gas analysis from a similar plant and a heat and mass balance provided by the customer. These calculations define the stoichiometric ratio for the mixed is burned combustion model and also provides estimates for Cp and density. The calculations are included at Appendix A1.

2. CFD Software

2.1 The CFD model has been constructed using the PHOENICS CFD code from Concentration, Heat and Momentum Ltd of Wimbledon, UK

2.2 PHOENICS is a well-known and well validated code with the longest history and track record of any CFD code in use at the present time. It is used in industry and for academic research covering a wide range of applications. Further background details on the software can be found at www.cham.co.uk.

3. Working Assumptions

3.1 The working conditions supplied by the customer have been assumed correct and to describe the operation of the plant sufficiently accurately to act as inputs to the model boundaries.

3.2 AceFurnace Consulting made a spot check of the combustion calculations by input of the Pyrocore fuel parameters and overall combustion air rate to an independent calculation sheet and the results were found to be consistent and a reasonable match to the Pyrocore figures.

3.3 The Pyrocore HMB waste throughput rate was used in conjunction with practical gas analysis data from a non-Pyrocore plant operating under similar retort temperature conditions and waste input. This was considered to be better than a theoretically determined gas analysis when calculating the stoichiometric ratio and other gas properties. 100% excess air was used as the conservative “worst-case” for maximum massflow and lowest temperature in normal operation.

3.4 The model was run with the syngas inlet temperature 50°C lower than the Pyrocore assumption as it was considered that the gas would not exit at tube temperature.

3.5 A proportion of the cold air was applied at the preheater burner inlet to represent the constant cooling air when the burner is not running. This flow is subtracted from the overall combustion air flow.

4. Model Construction

4.1 The following features have been included in the model construction:

- Inputs as calculated mass-flows, temperatures and fluid properties from AFCL combustion calculations, literature resources and practical analysis of a similar plant in the case of gas composition. Syngas, combustion air and burner cooling air inlet planes represent the upstream boundary of the Qualifying Secondary Combustion Zone (QSCZ)
- “Mixed is burned” combustion of syngas generated in the retort tube with secondary air at an air rate of 200% of stoichiometric to produce a mixed flue gas flow. The combustion model is mixing-controlled with 3 gases; fuel gas,

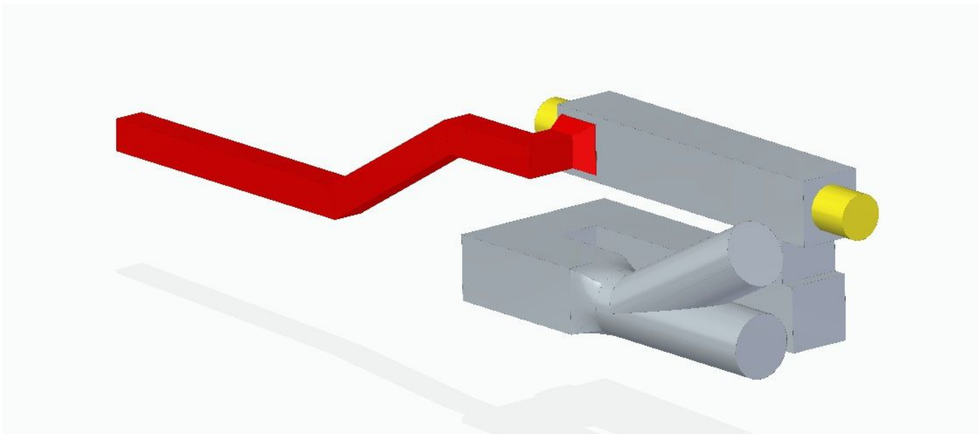
oxidant and product gas, each of which has separate properties of heat capacity and molecular weight.

- Output as a constant pressure boundary plane at the end of the flue duct, being the downstream boundary of the QSCZ.
- Calculations of velocity, pressure, temperature, turbulence, fuel concentration, oxidant concentration and product concentration, and residence time over the full width, full height and full depth of the QSCZ including oxidant injected as pre-heater burner cooling air on the horizontal limb of the “Y” section.
- Calculation of convective and radiant heat transfer to and from the gases and the walls of the QSCZ.
- Calculation of convective and radiant heat transfer to and from the gases, walls and retort tube and its effect on gas temperature surrounding the retort tube.
- Residence time simulation is controlled by a temperature threshold. Gases passing through parts of the volume that are too cold do not accumulate time.

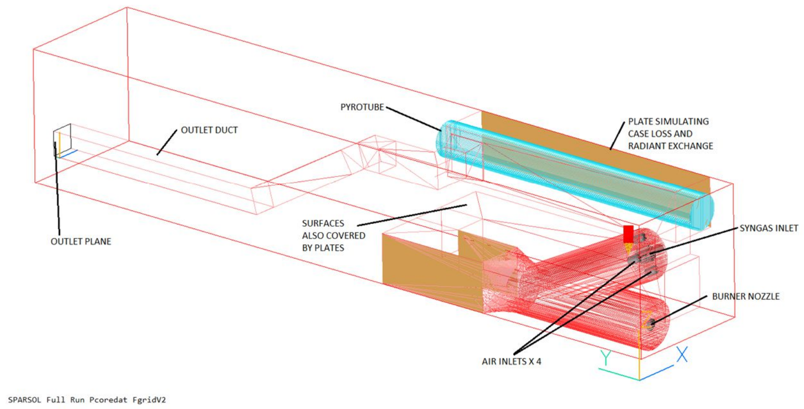
4.2 It is considered that the inclusion of the above model features is adequate to achieve a realistic representation of the physical processes controlling the behaviour of the gases within the combustor and subsequent flue gas path of the pyrolysis plant. The simulated flow is used within the model to calculate the residence time of the gases accounting for gas temperature, zones of high and low velocity, and heat losses to the walls of the furnace and retort tube.

4.3 Model Physical Representation:

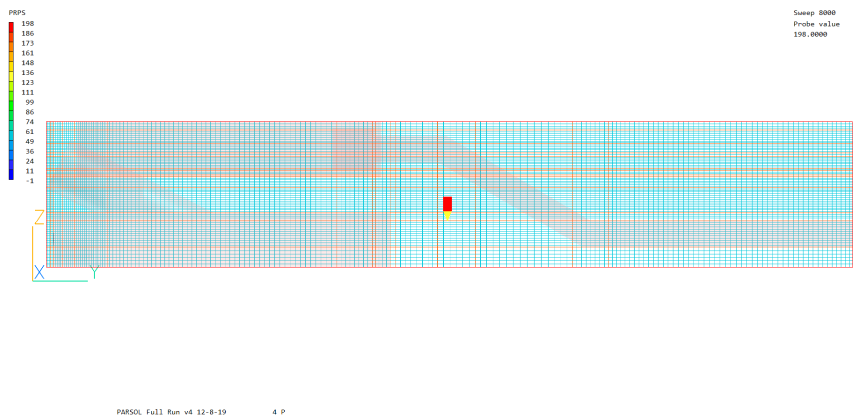
4.3.1 Working Volume



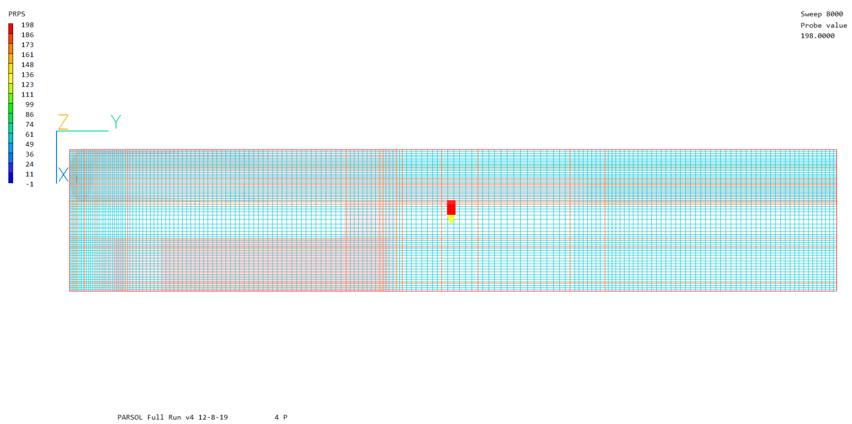
The grey solid represents the volume enclosed by the furnaces comprising the combustion section, residence section and muffle with pyrotube shown in yellow. The red section is the outlet duct portion included within the QSCZ.



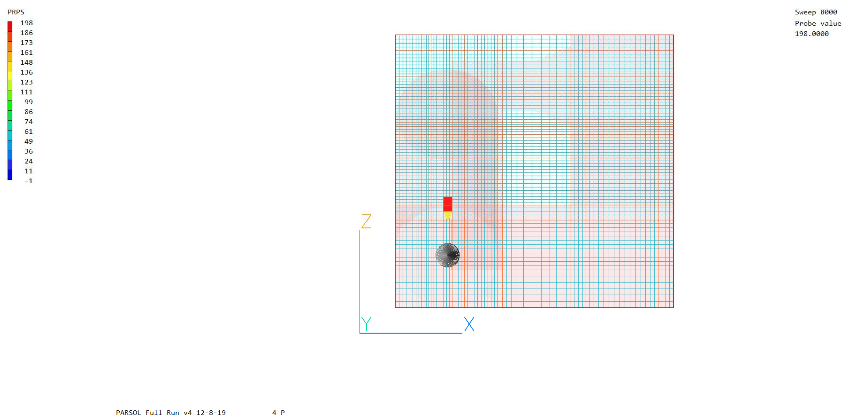
4.3.2 Showing the construction of the model within the PHOENICS VR editor.



4.3.3 Showing the X plane Grid Mesh



4.3.4 Showing the Z plane Grid Mesh



4.3.5 Showing the Y Plane Grid Mesh

4.3.6 Total number of grid cells in the simulation domain is 970,632

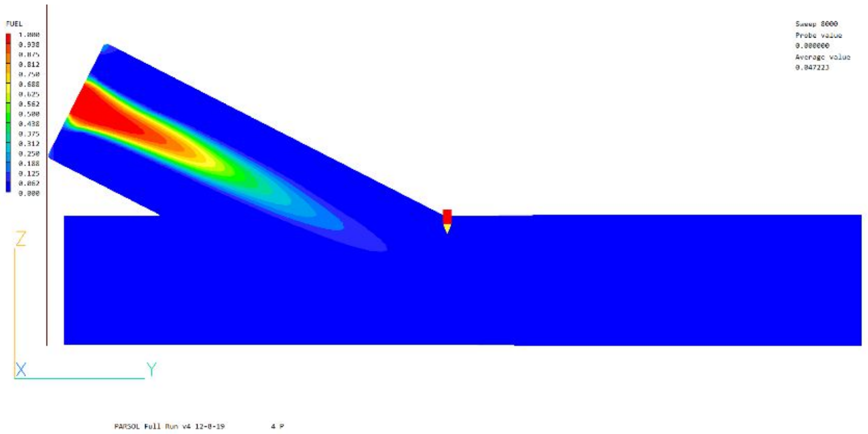
4.4 Input Values

4.4.1 Table of input values to the CFD model:

CFD Boundary Input Data						
Model Feature	*Flux*	*Type*	*Pos/Neg*	*Set Val*	*Units*	*Note*
SYNGAS INLET	mass	Fuel Gas	+	0.0563	kg/s	Via yield calculation
SYNGAS INLET	heat	NCV	+	11.8400	MJ/kg	Practical gas analysis calc NCV (NCV used as best way to handle product enthalpy and Cp)
SYNGAS INLET	mass	Stoich AFR	+	3.4810	None	Combustion calc using real gas
SYNGAS INLET	heat	Cp	+	1.2600	kJ/kg/K	Calc from gas analysis
SYNGAS INLET	mass	MW	+	25.0500	g/mol	Calc from gas analysis
SYNGAS INLET	mass	Density	+	0.3310	g/l @ T	Molar stp density with P*V/T
SYNGAS INLET	heat	Temperature	+	650.0000	°C	Pyrocore assumption - 50°C
AIR INLET 1-4	mass	Air	+	0.0909	kg/s	Stoich AFR from calc *2-burner cooling/4 inlets
AIR INLET 1-4	heat	Cp	+	1.1950	kJ/kg/K	Tables
AIR INLET 1-4	mass	MW	+	28.8400	g/mol	Calculated air mw
AIR INLET 1-4	heat	Temperature	+	25.0000	°C	Pyrocore HMB
BURNER AIR	mass	Air	+	0.0280	kg/s	Estimated from burner data
BURNER AIR	heat	Cp	+	1.1950	kJ/kg/K	As air inlets
BURNER AIR	mass	MW	+	28.8400	g/mol	As air inlets
BURNER AIR	heat	Temperature	+	25.0000	°C	Pyrocore HMB
WALL PLATES	heat	Wall loss	-	800.0000	W/m2	Generic furnace lining loss calc
WALL PLATES	heat	Emissivity	n/a	0.8000	None	Estimated typical for hot face refractory
PYRO-TUBE	heat fixed	Wall loss	-	170.0000	kW	Calc result in CFD 162
PYRO-TUBE	heat	Emissivity	n/a	0.8000	None	Estimated typical for oxidised Ni/Cr
PRODUCT GAS	mass	MW	+	28.3600	g/mol	Combustion calc
PRODUCT GAS	heat	Cp	+	1.3090	KJ/kg/K	Composite from dry air + moisture tables @ calculated moisture in product

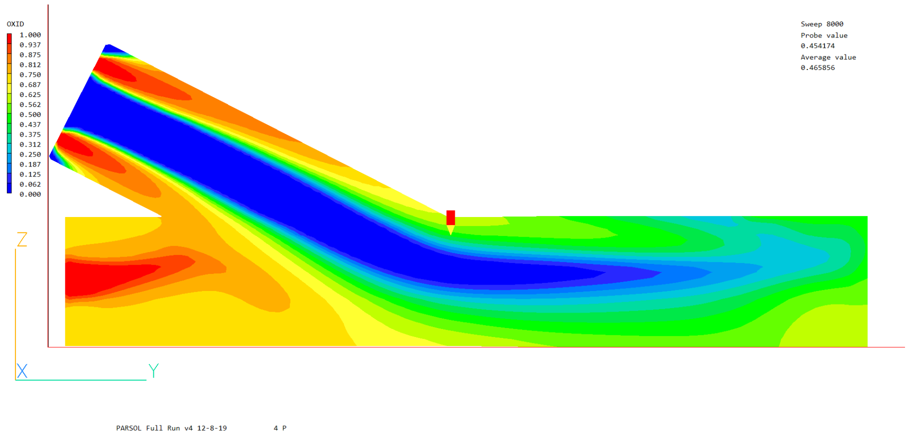
5. Results for Normal Running Case

5.1 Combustion Model

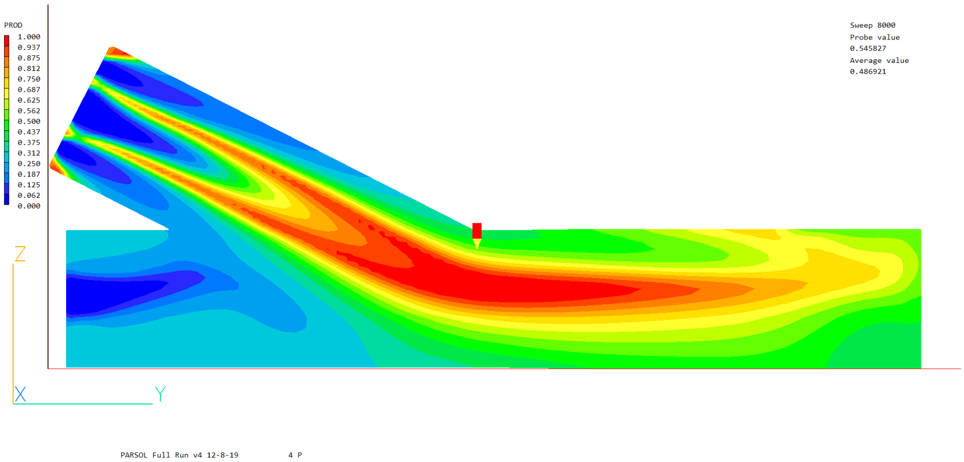


5.1.1 Showing the fuel concentration profile at the mid-X plane of the combustion section. The combustion section is the first leg of the "U" shaped secondary chamber with the "Y" piece. The syngas from the retort enters on the axial centre of the upper limb and the preheater burner is on the axial centre of the lower limb.

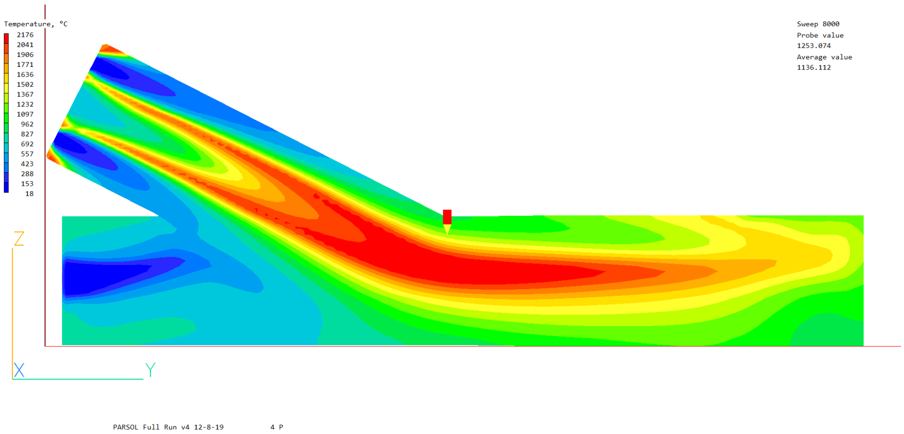
The air inlets (x4) surround the syngas inlet and the flow is parallel with no swirl. Because of this arrangement, the mixing of fuel and oxidant is relatively slow resulting in a long flame.



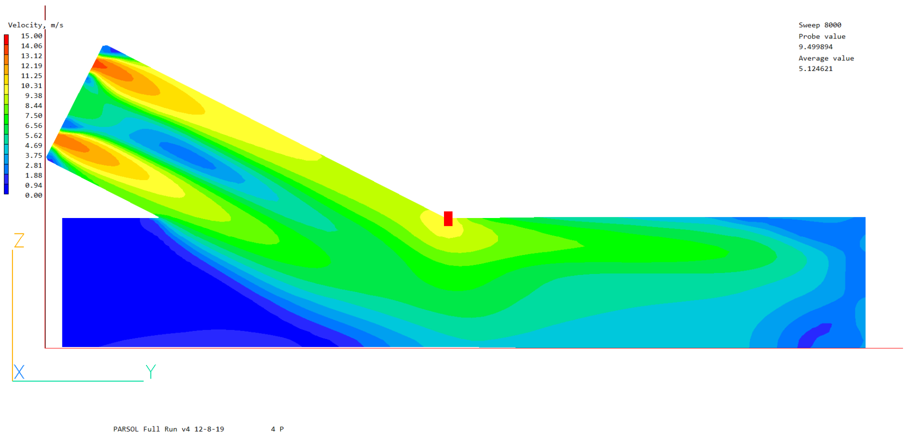
5.1.2 Showing the air concentration profile at the same plane. The length of the likely flame envelope can be clearly seen with little dilution of the flame envelope by excess air. The additional cooling air flow from the burner inlet cooling can be seen at the left.



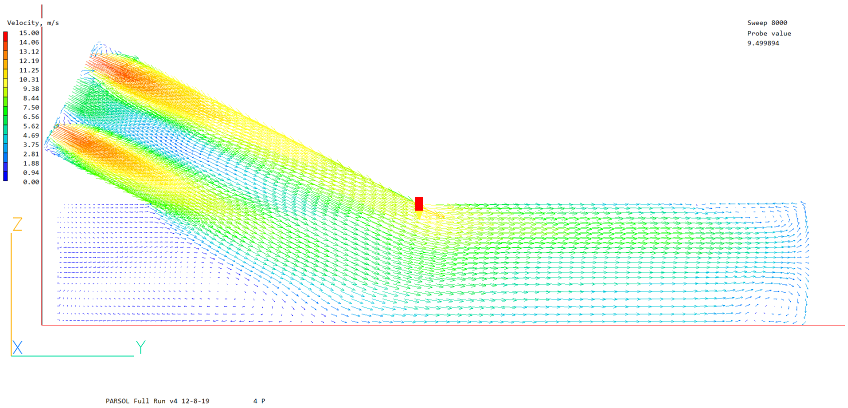
5.1.3 Showing the concentration profile of product gas (flue gas) at the same plane. Again, the long flame shape can clearly be seen, and this correlates well to the predicted temperature profile in 5.1.4 below.



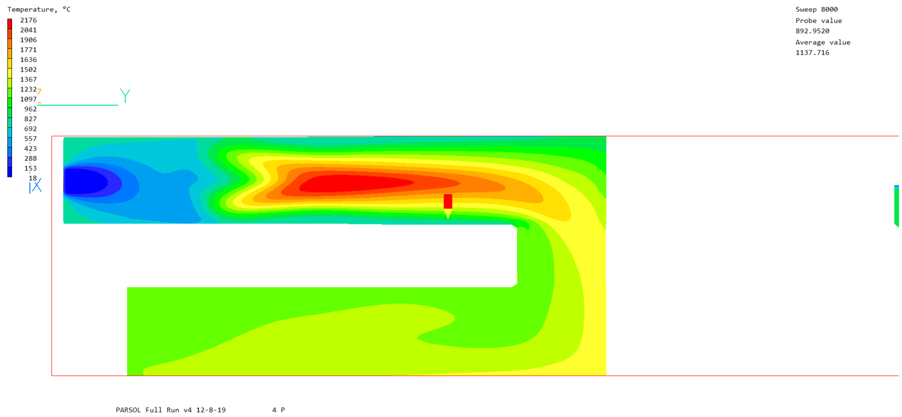
5.1.4 Temperature profile on the X plane centre of the syngas inlet. Temperature corresponds closely to the concentration of pure product (flue) gas. The overall gas temperature falls as the product gas is diluted by excess oxidant (air). Mixing is slow as the design does not include swirl and a long radiant flame is predicted. Mixing is dominated by entrainment by the air and fuel jets and by differences in the adjacent jet velocities.



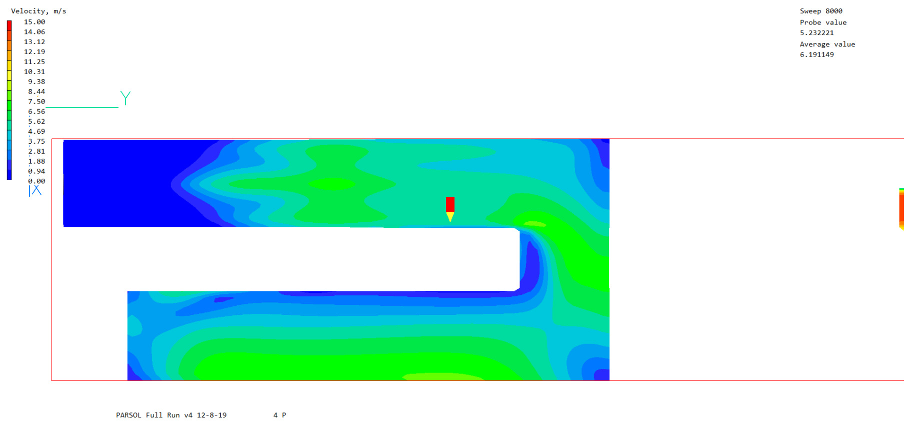
5.1.5 Velocity profile on the same plane. Note that the volume enclosed by the lower limb of the “Y” is unavailable to the residence time model as it is both too cold and largely stagnant.



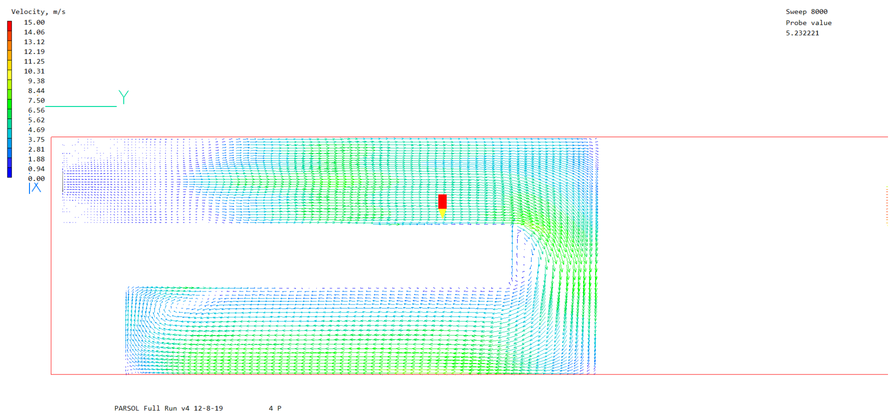
5.1.6 Velocity vectors coloured by magnitude. Recirculating and stagnant volumes can be seen at the left, under the “Y” junction and at the right where the gases strike the wall of the “U” shaped chamber and are forced to flow through 90° into the X axis direction (out of the page).



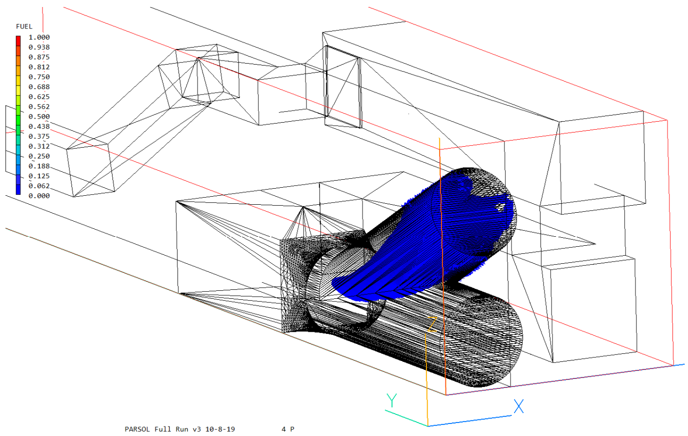
5.1.7 Temperature development at the mid Z plane of the secondary chamber. The flame temperature is rapidly reduced by turbulent mixing of the excess air as the gases are forced to make the 180° turn into the second leg of the volume.



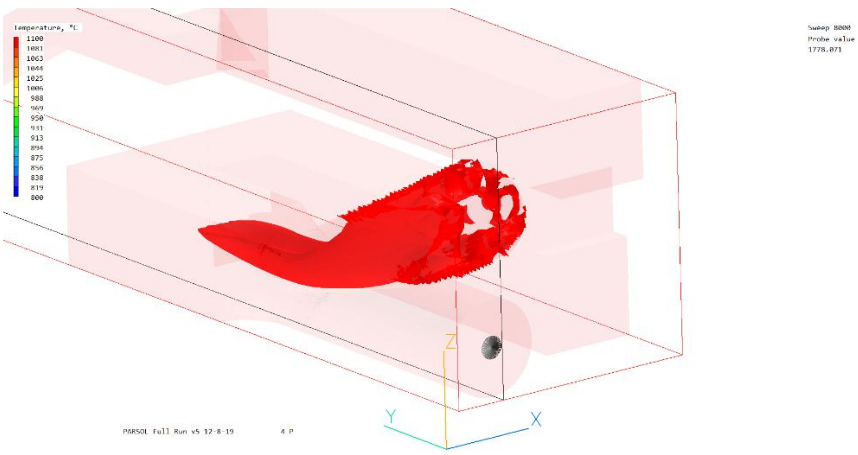
5.1.8 Velocity field at the Z mid plane. The velocity distribution is markedly uneven with stagnation evident where changes of direction occur.



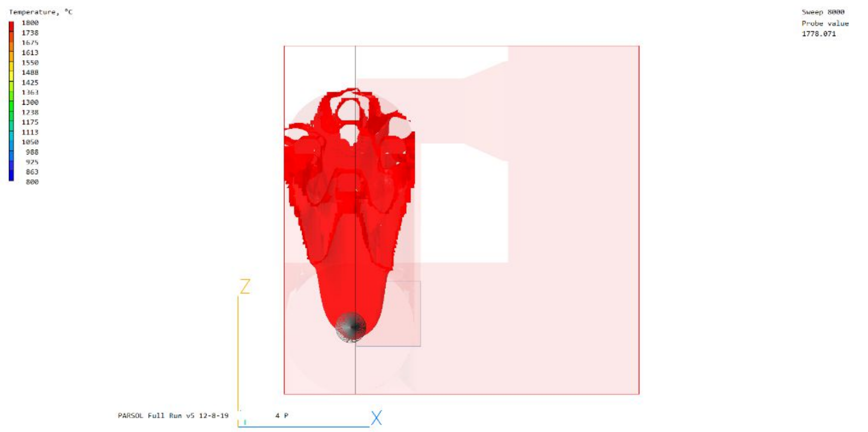
5.1.9 Velocity vectors coloured by magnitude for the same plane as 5.1.8. A distinct area of recirculation in the flow can be seen on the inside of the 180° bend.



5.1.10 Isosurface plot (surface where the selected parameter is a constant) for 0.5% unreacted fuel giving an indication of the flame envelope shape.

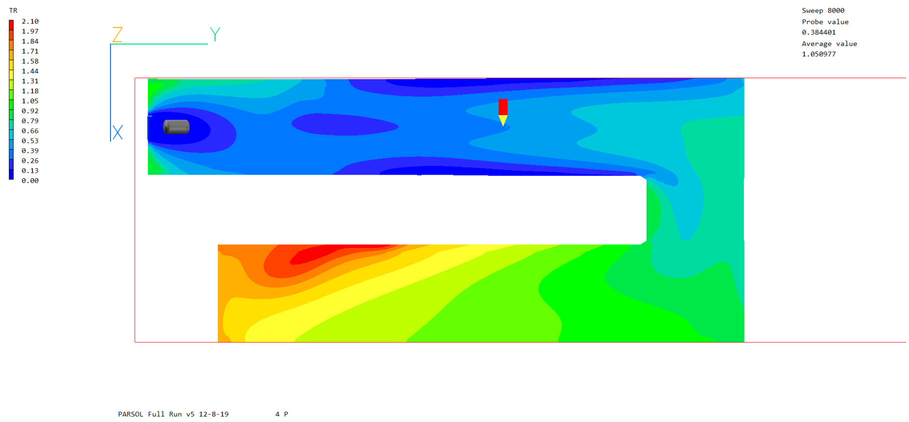


5.1.11 Isosurface plot for the maximum predicted temperature condition. The highest temperatures occur within the angled limb of the “Y” section where mixing between the fuel and air streams occurs, and product gas has the highest concentration. The refractory lining where the two limbs of the “Y” join is likely to see the highest temperature, as the conduction path through the lining at this point is long and the hot face layer thickest.



5.1.12 Isosurface plot as 5.1.11 but looking in the Y axis direction. Showing the likelihood of high wall temperatures in this part of the combustion section.

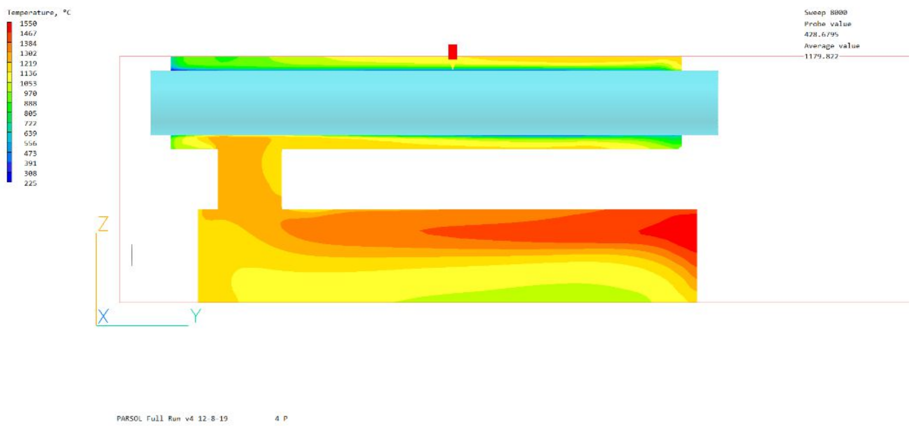
5.2 Residence Time Model



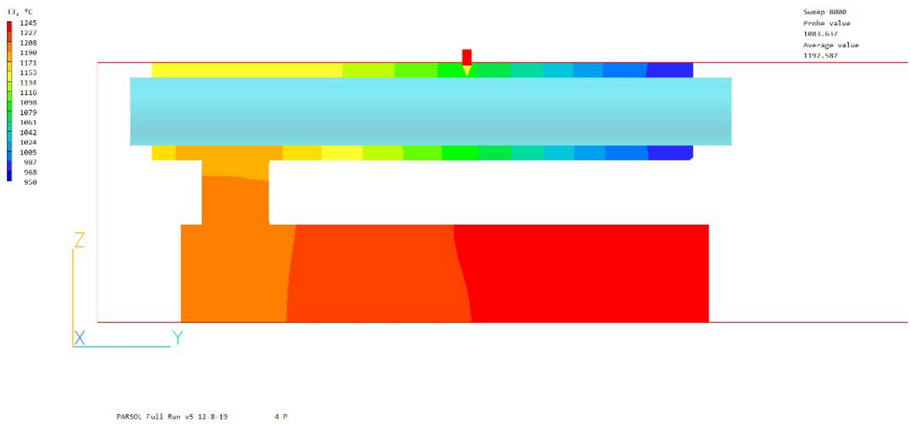
5.2.1 Development of the gas residence time at the mid Z plane of the secondary chamber. Gas in stagnant regions of the volume can accumulate residence time early in their passage through the volume as can be seen in the red / orange region of the contour. Gas passing into a colder region will cease to accumulate further time however.

5.2.2 Temperature field at the mid X plane of the outlet duct. Close to the walls of the duct the gas temperature is predicted to fall below 850°C due to heat abstraction by the lining losses. However the characteristic of the flow regime predicted is that gases in this region have already accumulated sufficient residence time.

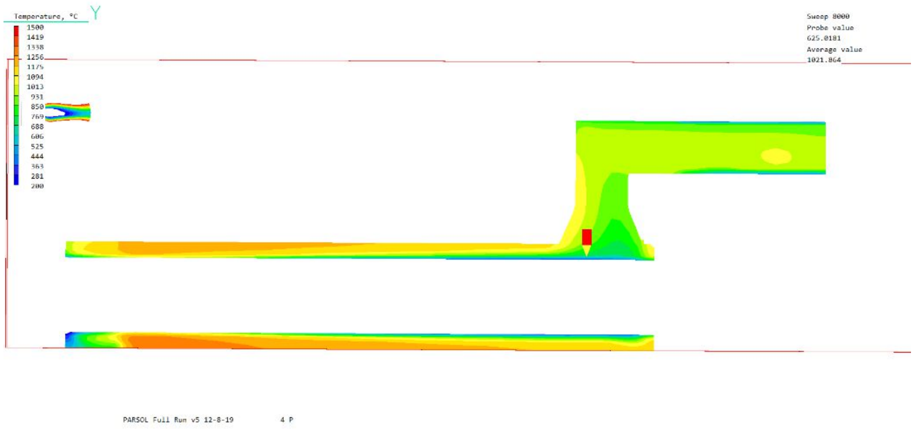
5.2.3 Duct mid X plane residence time development. Note that the average value shown includes parts of the volume towards the front end not shown in the picture, hence is lower. The contour map shows that by the time the gases reach the outlet duct the bulk of the flow has been within the system for 2s at over 850°C.



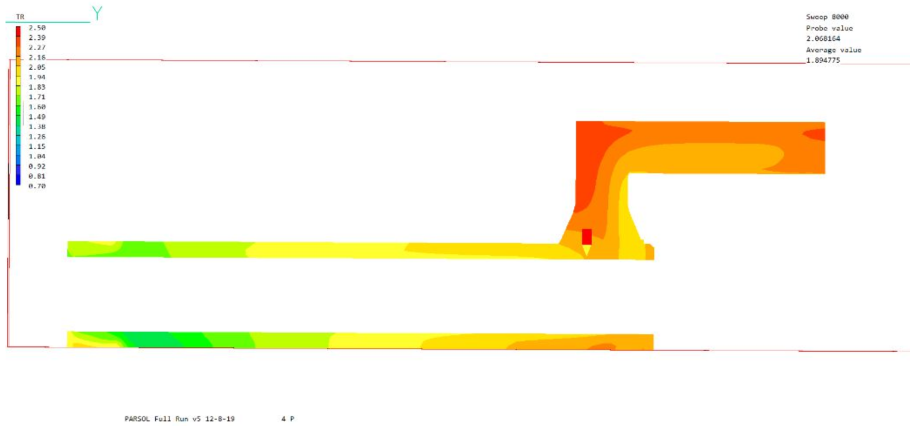
5.2.4 Temperature around the pyrotube at the mid X plane. The cooling effect of the tube can clearly be seen. The raw value of predicted temperature should not be taken as gospel as the tube in reality is rotating, and here has been modelled as a fixed negative heat flux which will tend to exaggerate differences in temperature. The effect of this is conservative with respect to residence time however.



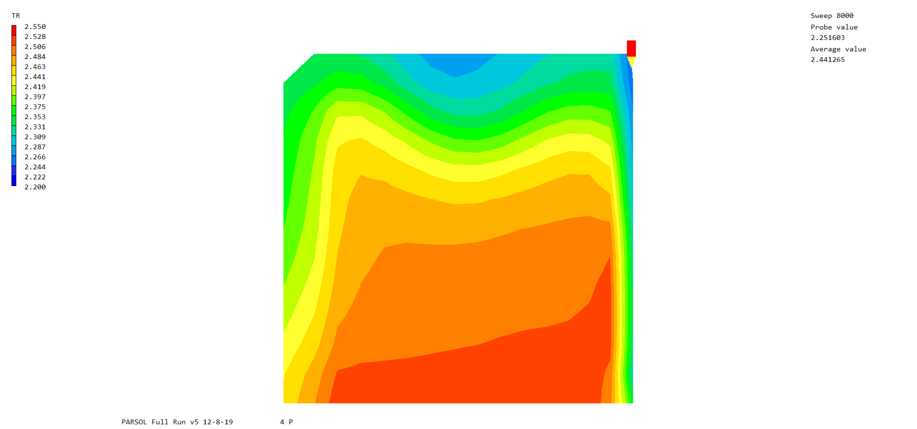
5.2.5 Radiant component of gas temperature. Showing the effective radiant temperature, this is evened out compared with the overall bulk temperature as the heat from hotter parts is passing through the cooler regions and the flue gas is only weakly absorbing, but is included to show that it is over 850°C.



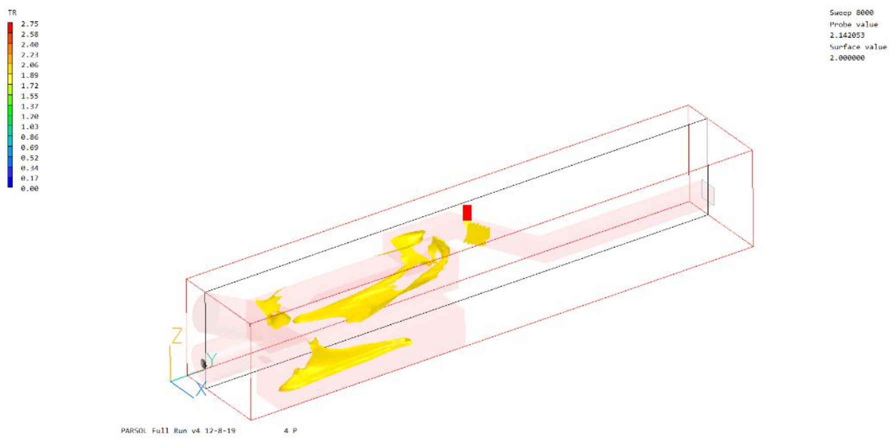
5.2.6 Temperature at the mid Z plane of the muffle furnace containing the pyrotube. The same comments as 5.2.4 apply to the temperature field, but a qualitative indication of the heat absorption by the tube is shown. With the tube rotating the temperature differences will be less pronounced than the model suggests.



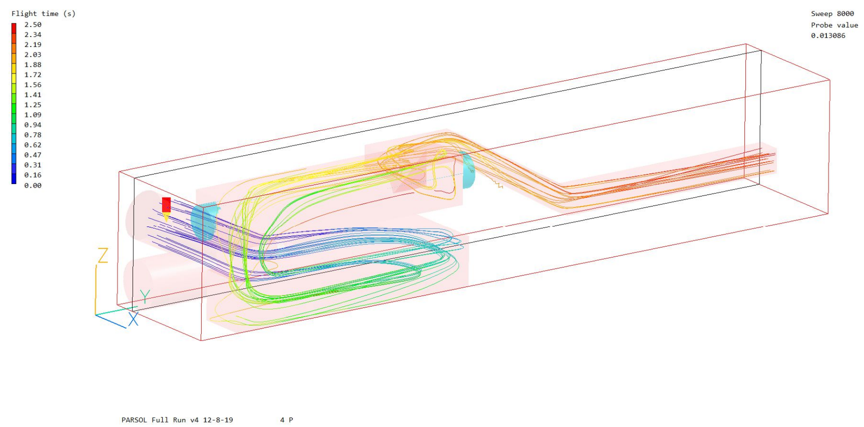
5.2.7 Residence time development at the mid Z plane of the muffle furnace and in the first part of the outlet duct. Gases that have cooled near to the tube are remixed with hotter gases and can then accumulate further residence time above the 850°C threshold. Note that the “average” value applies to the whole field shown.



5.2.8 Outlet plane residence time contour. The probe has been placed in the cell with the lowest accrued residence time, showing a minimum of 2.25 seconds. The maximum value is approximately 2.52 seconds.



5.2.9 Residence time isosurface at 2 seconds. The isosurface shows that all the gases in the volume have attained 2 seconds at over 850°C well before the exit plane of the QSCZ (Qualifying Secondary Combustion Zone). For the modelled working parameters, the legislative requirements for combustion zone residence time have been met, with 10% headroom allowance for increased flow.



5.2.10 Streamlines coloured by flight time. The streamline check creates a virtual flowline through the velocity field. The time shown is greater than the cell-accumulation residence time because the above does not account for the streamline passing through regions of lower temperature.

5.2.11 As the design includes multiple changes of flow direction it is unlikely that a cold short circuit path exists, and the flowline check shows that the flight paths for all the streamlines are of a similar duration. All flowlines take over 2 seconds to complete their journey through the working volume.

6. Discussion and Conclusions

6.1 Combustion Model

6.1.1 The combustion model is a simple mixed is burned scheme where heat release is proportional to the consumption of flue gas and oxidant. It is not a complex chemical model and does not account for heat lost in dissociation, or kinetic considerations in reaction rate. For these reasons the temperature fields will tend to be exaggerated in their range and will err on the high side.

6.1.2 The gas analysis used is a typical measured composition from a plant not dissimilar to the Pyrocore unit, in that the retort temperature is the same and the waste feed (RDF) not dissimilar to many of the constituents of clinical waste. It should be remembered that any waste fuel is highly heterogeneous and can vary substantially from load to load. Because of this, it is not possible to assert that the model will reflect reality under any particular waste composition and the control system employed must stabilise the temperature and flow rate of flue gas within the massflow requirements indicated by the model in order to rely on the predicted residence time.

6.1.3 The shape of the flame and the qualitative temperature distribution is considered reliable, as is the bulk mixed gas temperature prediction within the accuracy allowed by the fixed heat capacity setting. As there is headroom on the temperature, residence time should not be affected by reasonable variations in practice.

6.1.4 100% excess air has been assumed as this approximates to standard conditions for systems burning waste derived substances. This is a conservative assumption as the control system can reduce the air which will reduce the massflow and increase the temperature, both of which will have the effect of increasing the residence time of the flue gases.

6.2 Heat Flux Model

6.2.1 The model is non-adiabatic and contains features to simulate the heat flow lost to the pyrolysis tube and to the ambient environment through the refractory lined walls of the plant. The pyrolysis tube is set to a constant heat flux of approximately 170kW, being the amount of heat calculated to be needed to heat the incoming waste, perform the pyrolysis reactions and account for thermal losses in the tube mechanical arrangement. The input data was customer provided and has not been formally checked, although it is consistent with the experience of the author with similar systems, notably the unit from which the gas analysis data has been taken.

6.2.2 Lining heat flux is simulated by a series of plate features enclosing the walls of the working volume. These have been set to a constant flux per unit area of 0.8 kW/m^2 which is typical for linings enclosing small chambers and ducts where the duct dimensions are the same order of magnitude as the lining thickness. The above figure depends however on the presence of a cold face insulation at least 40mm thick and with a thermal conductivity not exceeding 0.08 W/m/K typical of calcium silicate board. Not all the surfaces are plated due to constraints with the PHOENICS mesh generator.

6.2.3 It is considered that the heat flux modelling method is reasonable in determining the temperature loss in the gases during passage through the working volume and hence the effect on residence time via the temperature threshold.

6.3 Residence time model

6.3.1 Residence time is modelled using the cell-by-cell accumulation method. For a packet of gas within a given mesh cell a residence time scalar is added if the temperature exceeds 850°C. Hence parts of the volume that are not above this threshold do not partake in the residence time calculation. The effective volume is therefore reduced by the volume of regions below the threshold.

6.3.2 Care must be taken where the flow field contains large stagnant or recirculation zones, as mathematical averaging can mix gases with high residence time with those with low residence time creating a situation that departs from reality should this mixed gas then exit through cooler zones. The velocity fields shown indicate that the design only has small recirculation zones and that the flow through the volume is well defined. The streamline model is used as a sense check and shows that the cell-by-cell determination can be relied upon in this design. The predicted cool zones are not connected together from inlet to outlet, and there is therefore no path through only cool zones.

6.3.3 The design places the main heat loss of the muffle furnace with pyrotube downstream of the secondary combustion furnace, and this has sufficient volume to ensure that the residence time of the bulk flow has already attained close to 2s before the gases are partially cooled in the muffle furnace. Due to the many changes in direction, gases that have cooled below 850°C and that have not already acquired sufficient residence have time to remix with hotter gases and attain sufficient further time before exiting. This is shown by the 2s isosurface plot at 5.2.9.

6.3.4 For the input conditions modelled, there is approximately 10% allowance on the minimum predicted residence time at the outlet plane.

6.4 Conclusion

6.4.1 For the inlet conditions assumed, the residence time is between 2.25 and 2.52 seconds at the outlet plane.

6.4.2 The 2 second residence isosurface is contained entirely within the QSCZ and does not approach the outlet boundary.

6.4.3 The streamline check shows a residence time of 2.4 seconds for the streamline positions chosen. No individual streamline shows a flight time less than 2s. The cell-by-cell residence time is considered reliable and realistic.

6.4.4 The legislative requirements for the QSCZ residence time for normal operation are met.

APPENDIX 1

Combustion calculation

Feed Gases	1 mol					**Combustion O2**		**Combustion Products**						
Typical Analysis														
									Mol Ratio			*Products*		
Component	*Formula*	*Mol %*	*Mol Mass*	*Prop mass*	*Prop Cp*	*Stoich*	*Stch Mol*	*CO2*	*H2O*	*N2*	*CO2*	*H2O*	*N2(a)*	*N2(g)*
Hydrogen	H2	14.64	2.02	29.51	4.22	0.5	7.32	0	1	0		14.64		0
Oxygen	O2	0.00	32.00	0.00	0.00	-1	0	0	0	0	0	0		0
Nitrogen	N2	12.00	28.02	336.24	3.50	0	0	0	0	1	0	0		12
Carbon Monoxide	CO	38.42	28.01	1076.14	10.98	0.5	19.21	1	0	0	38.42	0		0
Methane	CH4	16.05	16.04	257.47	5.72	2	32.1	1	2	0	16.05	32.1		0
Carbon Dioxide	CO2	17.27	44.01	760.05	6.41	0	0	1	0	0	17.27	0		0
Ethene	C2H4	1.62	28.05	45.44	0.70	3	4.86	2	2	0	3.24	3.24		0
Ethane	C2H6	0.00	30.07	0.00	0.00	3.5	0	2	3	0	0	0		0
Propane	C3H8	0.00	44.09	0.00	0.00	5	0	3	4	0	0	0		0
	Sum	100	Mass	25.05	1.26	v/v	0.6349	Product Totals			0.7498	0.4998	2.388	0.12
			rho	1.12								20.39184	kJ/mol fract	
Soichiometric Air O2	0.6349			AFR stoich m/m						*mol v/v*	0.1995	0.1330	0.6356	0.0319
Stoichiometric Air N2	2.3884			3.481						*Mass*	32.9987	9.0064	66.9239	3.3624
			rho (650)	0.331						*m/m*	0.2939	0.0802	0.5960	0.0299

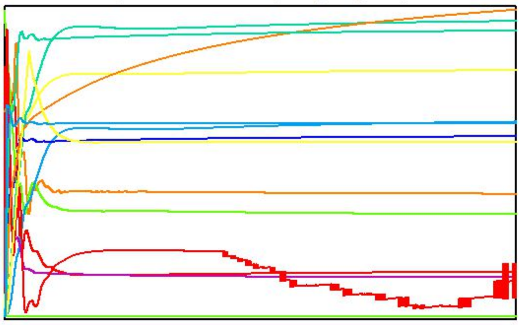
Calculated Raw Gas GCV							
Component	*Formula*	*Mol %*	*kJ/mol*	*kJ/mol fract*			
Hydrogen	H2	14.64	285.66	41.821			
Oxygen	O2	0.00	0	0.000			
Nitrogen	N2	12.00	0	0.000			
Carbon Monoxide	CO	38.42	283.16	108.790			
Methane	CH4	16.05	892.5	143.246			
Carbon Dioxide	CO2	17.27	0	0.000			
Ethene	C2H4	1.62	1421.36	23.026			
Ethane	C2H6	0.00	1575.55	0.000			
Propane	C3H8	0.00	2269.24	0.000			
	Checksum	100	Sum	316.883			
			GCV	**14.138**	MJ/Nm3	**12.65**	MJ/kg
			NCV	**13.228**	MJ/Nm3	**11.84**	MJ/kg

APPENDIX 2

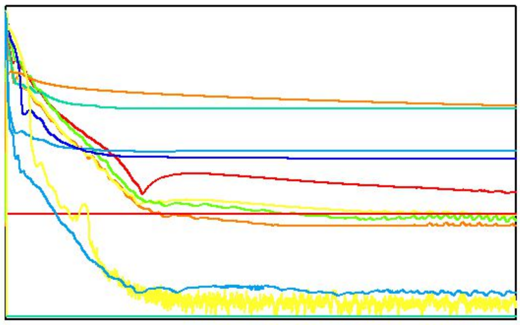
Convergence Plots

PARSOL Full Run v4 12-8-19 4 P 1

Spot Values at (26,131, 12)



% Error - Cut off 1.000E-03 %



Value	Change	Low	High	Variable	Max	% Error	Change
7.21E+00	6.79E-05	0.00E+00	5.00E+01	P1	1.58E+02	8.02E-03	1.21E-06
-8.04E-02	-1.93E-07	-2.00E-01	1.00E-01	U1	6.31E+01	9.34E-04	3.55E-07
1.60E+01	2.24E-05	0.00E+00	2.00E+01	V1	3.16E+02	2.90E-03	-3.09E-06
-2.01E+00	-3.31E-06	-3.00E+00	0.00E+00	W1	3.16E+01	1.06E-03	-1.84E-06
7.70E-01	1.94E-06	0.00E+00	8.00E-01	KE	1.00E+02	5.50E-01	1.06E-05
1.27E+01	4.79E-05	0.00E+00	2.00E+01	EP	3.98E+03	4.21E-01	7.55E-07
1.17E+06	1.80E+00	0.00E+00	2.00E+06	H1	1.58E+02	4.83E-02	-4.70E-06
1.27E-02	1.28E-03	-1.00E+00	7.00E+00	CT3	1.00E+01	1.00E-20	0.00E+00
-1.33E-04	5.69E-04	-1.00E-03	4.00E-03	RT3	1.00E+01	1.00E-20	0.00E+00
8.00E+02	1.27E-02	0.00E+00	8.00E+02	T3	5.01E+01	3.94E-01	3.61E-05
2.27E+00	-3.33E-07	0.00E+00	4.00E+00	TR	1.26E+02	1.79E-03	2.78E-04
0.00E+00	0.00E+00	0.00E+00	1.00E+00	FUEL	1.00E+01	1.00E-20	0.00E+00
9.32E+02	1.45E-03	0.00E+00	1.00E+03	TMP1	1.00E+01	1.00E-20	0.00E+00
1.26E-01	-6.11E-08	0.00E+00	2.00E-01	MIXF	1.58E+02	2.44E-03	-8.98E-06

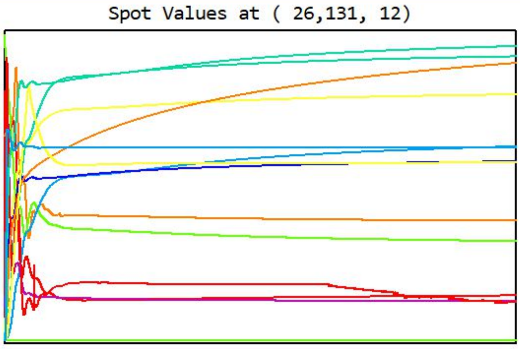
NX NY NZ ISWEEP 8000 Time now 14:04

68 183 78 IZSTEP OFF (h:m) est 14:04

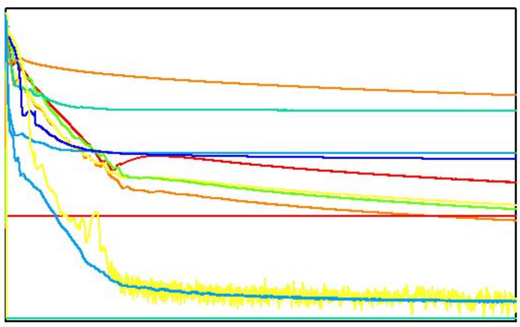
Press a character key to interrupt.

PARSOL Full Run v5 12-8-19 4 P 1

Spot Values at (26,131, 12)



% Error - Cut off 1.000E-03 %



Value	Change	Low	High	Variable	Max	% Error	Change
7.26E+00	6.50E-05	0.00E+00	5.00E+01	P1	1.58E+02	1.55E-02	4.51E-06
-8.32E-02	-2.76E-07	-2.00E-01	1.00E-01	U1	6.31E+01	1.46E-03	-1.77E-06
1.60E+01	5.13E-05	0.00E+00	2.00E+01	V1	3.16E+02	5.85E-03	-3.91E-06
-2.03E+00	-6.28E-06	-3.00E+00	0.00E+00	W1	3.16E+01	2.04E-03	2.61E-06
7.69E-01	4.55E-06	0.00E+00	8.00E-01	KE	1.00E+02	5.65E-01	-3.80E-07
1.27E+01	1.13E-04	0.00E+00	2.00E+01	EP	3.98E+03	4.40E-01	1.38E-06
1.17E+06	4.23E+00	0.00E+00	2.00E+06	H1	1.58E+02	5.46E-02	4.34E-06
1.39E-02	-2.26E-06	-1.00E+00	7.00E+00	CT3	1.00E+01	1.00E-20	0.00E+00
-6.42E-04	1.04E-07	-2.00E-03	9.00E-03	RT3	1.00E+01	1.00E-20	0.00E+00
8.15E+02	1.39E-02	0.00E+00	9.00E+02	T3	3.16E+01	5.37E-01	-5.82E-05
2.32E+00	6.16E-06	0.00E+00	4.00E+00	TR	1.26E+02	2.15E-03	5.56E-04
0.00E+00	0.00E+00	0.00E+00	1.00E+00	FUEL	1.00E+01	1.00E-20	0.00E+00
9.27E+02	3.36E-03	0.00E+00	1.00E+03	TMP1	1.00E+01	1.00E-20	0.00E+00
1.26E-01	-1.36E-09	0.00E+00	2.00E-01	MIXF	1.58E+02	1.90E-03	-7.07E-07

NX NY NZ ISWEEP 8000 Time now 14:02

68 183 78 IZSTEP OFF (h:m) est 14:02

Press a character key to interrupt.

APPENDIX 3

Convergence Quality Reports

CHAM

Convergence information for run completed at 02:57:54 on Tuesday, 13 August 2019

on sweep 8000

Title: PARSOL Full Run v4 12-8-19 4 P

Variable	Source Sum	Residual Error (%)	Max Correction	Location (IX,IY,IZ)
P1 (Continuity)	2.333E-04 (kg/s)	8.020E-03	8.036E-03 (Pa)	(19, 96, 68)
U1 (X Velocity)	N/A	9.337E-04	2.885E-04 (m/s)	(46, 53, 12)
V1 (Y Velocity)	N/A	2.904E-03	4.087E-03 (m/s)	(46, 56, 10)
W1 (Z Velocity)	N/A	1.061E-03	1.189E-04 (m/s)	(68, 39, 29)
KE (Turbulent Kinetic Energy)	N/A	0.550	2.38 (J/kg)	(48, 41, 22)
EP (Rate of Dissipation of KE)	N/A	0.421	64.6 (J/kg/s)	(49, 41, 22)
H1 (Enthalpy)	-1.546E+03 (W)	4.834E-02	4.581E+04 (J/kg)	(64, 18, 64)
T3 (Radiant Temperature)	1.780E+04 (W)	0.394	3.491E-02 (°C)	(35, 96, 71)
TR	2.770E-04	1.789E-03	2.672E-03	(46, 61, 7)
MIXF	2.818E-05	2.438E-03	1.375E-05	(46, 56, 10)

Nett radiative heat source 1.625E+04 (W)

An explanation of the above table is given here.

CPU time of run 50786 s

CHAM

Convergence information for run completed at 23:35:14 on Thursday, 15 August 2019

on sweep 8000

Title: PARSOL Full Run v5 12-8-19 4 P

Variable	Source Sum	Residual Error (%)	Max Correction	Location (IX,IY,IZ)
P1 (Continuity)	4.429E-04 (kg/s)	1.546E-02	7.846E-03 (Pa)	(19, 96, 68)
U1 (X Velocity)	N/A	1.464E-03	2.971E-02 (m/s)	(26, 13, 65)
V1 (Y Velocity)	N/A	5.851E-03	0.118 (m/s)	(27, 14, 66)
W1 (Z Velocity)	N/A	2.043E-03	6.030E-02 (m/s)	(27, 15, 65)
KE (Turbulent Kinetic Energy)	N/A	0.565	2.47 (J/kg)	(48, 41, 22)
EP (Rate of Dissipation of KE)	N/A	0.440	68.8 (J/kg/s)	(49, 41, 22)
H1 (Enthalpy)	-1.210E+03 (W)	5.458E-02	8.926E+04 (J/kg)	(64, 18, 63)
T3 (Radiant Temperature)	2.418E+04 (W)	0.537	4.710E-02 (°C)	(34, 77, 1)
TR	5.751E-04	2.146E-03	1.700E-02	(28, 11, 5)
MIXF	5.632E-05	1.904E-03	2.036E-04	(27, 14, 65)

Nett radiative heat source 2.297E+04 (W)

An explanation of the above table is given here.

CPU time of run 50680 s

APPENDIX 4

Model Output Text File Nett Sources and Sinks for V4 run

```
************************************************************
 Sources and sinks
 !! Zero nett sources are not printed !!!

   Nett Sources have units of mass_per_unit_time * variable
   Average values have units of the variable

   Typically the units of the sources are:
      U1,V1,W1 - Force  - Newtons
      R1       - Mass   - kg/s
      TEM1,H1  - Energy - Watts

 Nett source of U1   at patch named:  OB1     (BLOCK       ) = 5.081877E-02
 Nett source of U1   at patch named:  OB4     (PTUBE       ) = 1.454482E-02
 Nett source of U1   at patch named: OB5      (FLUE        ) = 5.807735E-03
 Nett source of U1   at patch named: IM1D     (PLAT7       ) = 8.291721E-03
 Nett source of U1   at patch named: IM1F     (PLAT9       ) =-6.983258E-04
 Nett source of U1   at patch named: IM20-L   (PLAT10      ) =-5.274837E-03
 Nett source of U1   at patch named: IM21-L   (PLAT11      ) =-7.824196E-03
 pos. sum=0.079463 neg. sum=-0.013797
 nett sum=0.065666

 Nett source of V1   at patch named:  OB1     (BLOCK       ) =-6.520564E-01
 Nett source of V1   at patch named:  OB4     (PTUBE       ) =-2.260184E-01
 Nett source of V1   at patch named: OB5      (FLUE        ) =-6.709145E+00
 Nett source of V1   at patch named: OB6      (AIR_1       ) = 1.096138E+00
 Nett source of V1   at patch named: OB7      (AIR_2       ) = 1.062251E+00
 Nett source of V1   at patch named: OB8      (AIR_3       ) = 1.015830E+00
 Nett source of V1   at patch named: OB9      (AIR_4       ) = 1.000782E+00
 Nett source of V1   at patch named: OBA      (SYNGAS      ) = 3.081807E-01
 Nett source of V1   at patch named: OBB      (BRAIR       ) = 3.764101E-02
 Nett source of V1   at patch named: IM17     (PLAT1       ) = 5.067084E-02
 Nett source of V1   at patch named: IM18-H   (PLAT2       ) =-8.364072E-03
 Nett source of V1   at patch named: IM19     (PLAT3       ) =-3.638924E-02
 Nett source of V1   at patch named: IM1A-H   (PLAT4       ) =-6.339696E-02
 Nett source of V1   at patch named: IM1B     (PLAT5       ) =-8.119610E-03
 Nett source of V1   at patch named: IM1C-L   (PLAT6       ) =-1.086369E-02
 Nett source of V1   at patch named: IM1D     (PLAT7       ) =-6.836343E-02
 Nett source of V1   at patch named: IM1F     (PLAT9       ) = 2.544690E-02
 Nett source of V1   at patch named: IM20-L   (PLAT10      ) = 2.700094E-02
 Nett source of V1   at patch named: IM22-H   (PLAT12      ) =-5.871147E-01
 Nett source of V1   at patch named: IM23-L   (PLAT13      ) =-2.292757E-01
 pos. sum=4.623941 neg. sum=-8.599107
```

nett sum=-3.975166

Nett source of W1 at patch named: OB1 (BLOCK) = 9.862092E-02
Nett source of W1 at patch named: OB4 (PTUBE) =-2.430552E-02
Nett source of W1 at patch named: OB5 (FLUE) = 7.804421E-03
Nett source of W1 at patch named: OB6 (AIR_1) =-5.584358E-01
Nett source of W1 at patch named: OB7 (AIR_2) =-5.412356E-01
Nett source of W1 at patch named: OB8 (AIR_3) =-5.175779E-01
Nett source of W1 at patch named: OB9 (AIR_4) =-5.099109E-01
Nett source of W1 at patch named: OBA (SYNGAS) =-1.544386E-01
Nett source of W1 at patch named: IM17 (PLAT1) =-7.769202E-04
Nett source of W1 at patch named: IM18-H (PLAT2) =-4.680303E-03
Nett source of W1 at patch named: IM19 (PLAT3) =-7.393622E-03
Nett source of W1 at patch named: IM1A-H (PLAT4) =-8.927672E-03
Nett source of W1 at patch named: IM1B (PLAT5) = 3.900600E-04
Nett source of W1 at patch named: IM1C-L (PLAT6) = 4.576193E-04
Nett source of W1 at patch named: IM21-L (PLAT11) = 7.716656E-04
Nett source of W1 at patch named: IM22-H (PLAT12) = 6.414701E-02
Nett source of W1 at patch named: IM23-L (PLAT13) = 2.060284E-01
pos. sum=0.37822 neg. sum=-2.327683
nett sum=-1.949463

Nett source of R1 at patch named: OB5 (FLUE) =-4.476667E-01
(Mass Out -4.476667E-01 In 0.000000E+00)
Nett source of R1 at patch named: OB6 (AIR_1) = 9.091000E-02
Nett source of R1 at patch named: OB7 (AIR_2) = 9.091000E-02
Nett source of R1 at patch named: OB8 (AIR_3) = 9.091000E-02
Nett source of R1 at patch named: OB9 (AIR_4) = 9.091000E-02
Nett source of R1 at patch named: OBA (SYNGAS) = 5.626000E-02
Nett source of R1 at patch named: OBB (BRAIR) = 2.800000E-02
pos. sum=0.4479 neg. sum=-0.447667
nett sum=2.333406E-04

Nett source of KE at patch named: KESOURCE =-1.499495E+01
Non-linearised source for KE at: KESOURCE = 1.970879E+01
Nett source of KE at patch named: OB5 (FLUE) =-3.228562E-01
(Ave Out 7.211778E-01 In 0.000000E+00)
Nett source of KE at patch named: OB6 (AIR_1) = 4.156945E-02
(Average 4.572594E-01)
Nett source of KE at patch named: OB7 (AIR_2) = 3.908548E-02
(Average 4.299360E-01)
Nett source of KE at patch named: OB8 (AIR_3) = 3.574404E-02
(Average 3.931805E-01)
Nett source of KE at patch named: OB9 (AIR_4) = 3.469291E-02
(Average 3.816182E-01)
Nett source of KE at patch named: OBA (SYNGAS) = 5.314098E-03
(Average 9.445606E-02)
Nett source of KE at patch named: OBB (BRAIR) = 7.793083E-05
(Average 2.783244E-03)
Nett source of KE at patch named: IM17 (PLAT1) = 1.001103E-06

Nett source of KE at patch named: IM18-H (PLAT2) = 6.688554E-07
Nett source of KE at patch named: IM19 (PLAT3) = 3.431107E-07
Nett source of KE at patch named: IM1A-H (PLAT4) = 9.236068E-07
Nett source of KE at patch named: IM1B (PLAT5) = 1.177182E-08
Nett source of KE at patch named: IM1C-L (PLAT6) = 1.519584E-07
Nett source of KE at patch named: IM1D (PLAT7) =-9.219793E-07
Nett source of KE at patch named: IM1F (PLAT9) =-7.433230E-07
Nett source of KE at patch named: IM20-L (PLAT10) = 1.508635E-06
Nett source of KE at patch named: IM21-L (PLAT11) = 7.970770E-07
Nett source of KE at patch named: IM22-H (PLAT12) =-1.841441E-05
Nett source of KE at patch named: IM23-L (PLAT13) = 1.369084E-05
pos. sum=19.865291 neg. sum=-15.317831
nett sum=4.54746

Nett source of EP at patch named: KESOURCE =-7.419844E+02
Non-linearised source for EP at: KESOURCE = 6.829645E+02
Nett source of EP at patch named: OB5 (FLUE) =-6.930283E+00
(Ave Out 1.547008E+01 In 0.000000E+00)
Nett source of EP at patch named: OB6 (AIR_1) = 1.084451E+00
(Average 1.192884E+01)
Nett source of EP at patch named: OB7 (AIR_2) = 9.736035E-01
(Average 1.070953E+01)
Nett source of EP at patch named: OB8 (AIR_3) = 8.326480E-01
(Average 9.159036E+00)
Nett source of EP at patch named: OB9 (AIR_4) = 7.902714E-01
(Average 8.692898E+00)
Nett source of EP at patch named: OBA (SYNGAS) = 2.860558E-02
(Average 5.084532E-01)
Nett source of EP at patch named: OBB (BRAIR) = 9.007790E-05
(Average 3.217068E-03)
Nett source of EP at patch named: IM17 (PLAT1) = 3.248829E-05
Nett source of EP at patch named: IM18-H (PLAT2) = 2.501673E-05
Nett source of EP at patch named: IM19 (PLAT3) = 3.111149E-05
Nett source of EP at patch named: IM1A-H (PLAT4) = 7.235385E-05
Nett source of EP at patch named: IM1B (PLAT5) =-8.400647E-07
Nett source of EP at patch named: IM1C-L (PLAT6) =-3.257772E-07
Nett source of EP at patch named: IM1D (PLAT7) =-8.152208E-05
Nett source of EP at patch named: IM1F (PLAT9) =-4.441598E-05
Nett source of EP at patch named: IM20-L (PLAT10) = 1.421020E-04
Nett source of EP at patch named: IM21-L (PLAT11) =-4.230650E-06
Nett source of EP at patch named: IM22-H (PLAT12) =-1.566864E-02
Nett source of EP at patch named: IM23-L (PLAT13) =-2.149136E-03
pos. sum=686.674468 neg. sum=-748.932588
nett sum=-62.258121

Nett source of H1 for absorption & emission = 0.000000E+00
Nett source of H1 at patch named: OB1 (BLOCK) =-1.782538E+04
Nett source of H1 at patch named: OB4 (PTUBE) =-1.625204E+05
Nett source of H1 at patch named: OB5 (FLUE) =-5.029383E+05
(Ave Out 1.123469E+06 In 0.000000E+00)

```
Nett source of H1   at patch named: OB6     (AIR_1      ) = 2.715936E+03
         (Average  2.987500E+04)
Nett source of H1   at patch named: OB7     (AIR_2      ) = 2.715936E+03
         (Average  2.987500E+04)
Nett source of H1   at patch named: OB8     (AIR_3      ) = 2.715936E+03
         (Average  2.987500E+04)
Nett source of H1   at patch named: OB9     (AIR_4      ) = 2.715936E+03
         (Average  2.987500E+04)
Nett source of H1   at patch named: OBA     (SYNGAS     ) = 7.121953E+05
         (Average  1.265900E+07)
Nett source of H1   at patch named: OBB     (BRAIR      ) = 8.365000E+02
         (Average  2.987500E+04)
Nett source of H1   at patch named: IM17    (PLAT1      ) =-1.834989E+03
Nett source of H1   at patch named: IM18-H  (PLAT2      ) =-1.494384E+03
Nett source of H1   at patch named: IM19    (PLAT3      ) =-2.296188E+03
Nett source of H1   at patch named: IM1A-H  (PLAT4      ) =-1.725654E+03
Nett source of H1   at patch named: IM1B    (PLAT5      ) =-1.212564E+03
Nett source of H1   at patch named: IM1C-L  (PLAT6      ) =-7.575590E+02
Nett source of H1   at patch named: IM1D    (PLAT7      ) =-2.360672E+03
Nett source of H1   at patch named: IM1F    (PLAT9      ) =-1.840779E+03
Nett source of H1   at patch named: IM20-L  (PLAT10     ) =-1.527245E+03
Nett source of H1   at patch named: IM21-L  (PLAT11     ) =-9.639665E+02
Nett source of H1   at patch named: IM22-H  (PLAT12     ) =-1.279568E+04
Nett source of H1   at patch named: IM23-L  (PLAT13     ) =-1.334739E+04
pos. sum=7.238956E+05 neg. sum=-7.254411E+05
nett sum=-1545.533242

Nett source of T3   for absorption & emission          = 0.000000E+00
```

Gas radiation ignored on v4 see v5

```
Nett source of T3   at patch named: OB1     (BLOCK      ) = 1.779611E+04
pos. sum=1.779611E+04 neg. sum=0.
nett sum=1.779611E+04

Nett source of TR   at patch named: TRS     (RESIDOB    ) = 1.074537E+00
Nett source of TR   at patch named: OB5     (FLUE       ) =-1.074260E+00
         (Ave Out  2.399677E+00 In  0.000000E+00)
pos. sum=1.074537 neg. sum=-1.07426
nett sum=2.76951E-04

Nett source of MIXF at patch named: OB5     (FLUE       ) =-5.623182E-02
         (Ave Out  1.256109E-01 In  0.000000E+00)
Nett source of MIXF at patch named: OBA     (SYNGAS     ) = 5.626000E-02
         (Average  1.000000E+00)
pos. sum=0.05626 neg. sum=-0.056232
nett sum=2.817706E-05


*************************************************************
Checking IMMERSOL energy balance
for T3 and H1 together
```

nett: T3=1.779611E+04 H1 =-1545.533242
nett sum=1.625058E+04

****

Summary of sources from all Objects/Patches at sweep 8000

Variable	Inflow	Outflow	Nett
P1	4.479000E-01	-4.476667E-01	2.333406E-04
U1	7.946305E-02	-1.379736E-02	6.566569E-02
V1	4.623941E+00	-8.599107E+00	-3.975166E+00
W1	3.782200E-01	-2.327683E+00	-1.949463E+00
KE	1.986529E+01	-1.531783E+01	4.547460E+00
EP	6.866745E+02	-7.489326E+02	-6.225812E+01
H1	7.238956E+05	-7.254411E+05	-1.545533E+03
T3	1.779611E+04	0.000000E+00	1.779611E+04
TR	1.074537E+00	-1.074260E+00	2.769510E-04
MIXF	5.626000E-02	-5.623182E-02	2.817706E-05

****

Model Output Text File Nett Sources and Sinks for V5 run

```
**********************************************************
Sources and sinks
!! Zero nett sources are not printed !!!

  Nett Sources have units of mass_per_unit_time * variable
  Average values have units of the variable

  Typically the units of the sources are:
    U1,V1,W1 - Force  - Newtons
    R1       - Mass   - kg/s
    TEM1,H1  - Energy - Watts

Nett source of U1   at patch named:  OB1     (BLOCK       ) = 4.996613E-02
Nett source of U1   at patch named:  OB4     (PTUBE       ) = 1.450832E-02
Nett source of U1   at patch named: OB5      (FLUE        ) = 6.029619E-03
Nett source of U1   at patch named: IM1D     (PLAT7       ) = 8.418249E-03
Nett source of U1   at patch named: IM1F     (PLAT9       ) =-6.278613E-04
Nett source of U1   at patch named: IM20-L   (PLAT10      ) =-5.245589E-03
Nett source of U1   at patch named: IM21-L   (PLAT11      ) =-7.841418E-03
pos. sum=0.078922 neg. sum=-0.013715
nett sum=0.065207

Nett source of V1   at patch named:  OB1     (BLOCK       ) =-6.460458E-01
Nett source of V1   at patch named:  OB4     (PTUBE       ) =-2.242719E-01
Nett source of V1   at patch named: OB5      (FLUE        ) =-6.725676E+00
Nett source of V1   at patch named: OB6      (AIR_1       ) = 1.096138E+00
Nett source of V1   at patch named: OB7      (AIR_2       ) = 1.062251E+00
Nett source of V1   at patch named: OB8      (AIR_3       ) = 1.015830E+00
Nett source of V1   at patch named: OB9      (AIR_4       ) = 1.000782E+00
Nett source of V1   at patch named: OBA      (SYNGAS      ) = 3.081807E-01
Nett source of V1   at patch named: OBB      (BRAIR       ) = 3.764101E-02
Nett source of V1   at patch named: IM17     (PLAT1       ) = 5.066997E-02
Nett source of V1   at patch named: IM18-H   (PLAT2       ) =-7.528788E-03
Nett source of V1   at patch named: IM19     (PLAT3       ) =-3.594590E-02
Nett source of V1   at patch named: IM1A-H   (PLAT4       ) =-6.319040E-02
Nett source of V1   at patch named: IM1B     (PLAT5       ) =-7.432306E-03
Nett source of V1   at patch named: IM1C-L   (PLAT6       ) =-1.041015E-02
Nett source of V1   at patch named: IM1D     (PLAT7       ) =-6.810599E-02
Nett source of V1   at patch named: IM1F     (PLAT9       ) = 2.508586E-02
Nett source of V1   at patch named: IM20-L   (PLAT10      ) = 2.728017E-02
Nett source of V1   at patch named: IM22-H   (PLAT12      ) =-5.836133E-01
Nett source of V1   at patch named: IM23-L   (PLAT13      ) =-2.240344E-01
pos. sum=4.623858 neg. sum=-8.596255
nett sum=-3.972397

Nett source of W1   at patch named:  OB1     (BLOCK       ) = 9.795552E-02
```

Nett source of W1 at patch named: OB4 (PTUBE) =-2.415655E-02
Nett source of W1 at patch named: OB5 (FLUE) = 7.986807E-03
Nett source of W1 at patch named: OB6 (AIR_1) =-5.584358E-01
Nett source of W1 at patch named: OB7 (AIR_2) =-5.412356E-01
Nett source of W1 at patch named: OB8 (AIR_3) =-5.175779E-01
Nett source of W1 at patch named: OB9 (AIR_4) =-5.099109E-01
Nett source of W1 at patch named: OBA (SYNGAS) =-1.544386E-01
Nett source of W1 at patch named: IM17 (PLAT1) =-5.133882E-04
Nett source of W1 at patch named: IM18-H (PLAT2) =-4.474201E-03
Nett source of W1 at patch named: IM19 (PLAT3) =-7.552506E-03
Nett source of W1 at patch named: IM1A-H (PLAT4) =-8.775416E-03
Nett source of W1 at patch named: IM1B (PLAT5) = 3.040440E-04
Nett source of W1 at patch named: IM1C-L (PLAT6) = 3.457908E-04
Nett source of W1 at patch named: IM21-L (PLAT11) = 9.590925E-04
Nett source of W1 at patch named: IM22-H (PLAT12) = 6.208607E-02
Nett source of W1 at patch named: IM23-L (PLAT13) = 2.030473E-01
pos. sum=0.372685 neg. sum=-2.327071
nett sum=-1.954386

Nett source of R1 at patch named: OB5 (FLUE) =-4.474571E-01
(Mass Out -4.474571E-01 In 0.000000E+00)
Nett source of R1 at patch named: OB6 (AIR_1) = 9.091000E-02
Nett source of R1 at patch named: OB7 (AIR_2) = 9.091000E-02
Nett source of R1 at patch named: OB8 (AIR_3) = 9.091000E-02
Nett source of R1 at patch named: OB9 (AIR_4) = 9.091000E-02
Nett source of R1 at patch named: OBA (SYNGAS) = 5.626000E-02
Nett source of R1 at patch named: OBB (BRAIR) = 2.800000E-02
pos. sum=0.4479 neg. sum=-0.447457
nett sum=4.429027E-04

Nett source of KE at patch named: KESOURCE =-1.494334E+01
Non-linearised source for KE at: KESOURCE = 1.970038E+01
Nett source of KE at patch named: OB5 (FLUE) =-3.176277E-01
(Ave Out 7.098310E-01 In 0.000000E+00)
Nett source of KE at patch named: OB6 (AIR_1) = 4.156945E-02
(Average 4.572594E-01)
Nett source of KE at patch named: OB7 (AIR_2) = 3.908548E-02
(Average 4.299360E-01)
Nett source of KE at patch named: OB8 (AIR_3) = 3.574404E-02
(Average 3.931805E-01)
Nett source of KE at patch named: OB9 (AIR_4) = 3.469291E-02
(Average 3.816182E-01)
Nett source of KE at patch named: OBA (SYNGAS) = 5.314098E-03
(Average 9.445606E-02)
Nett source of KE at patch named: OBB (BRAIR) = 7.793083E-05
(Average 2.783244E-03)
Nett source of KE at patch named: IM17 (PLAT1) = 1.022457E-06
Nett source of KE at patch named: IM18-H (PLAT2) = 6.620735E-07
Nett source of KE at patch named: IM19 (PLAT3) = 3.415879E-07
Nett source of KE at patch named: IM1A-H (PLAT4) = 9.267509E-07

Nett source of KE at patch named: IM1B (PLAT5) = 1.040851E-08
Nett source of KE at patch named: IM1C-L (PLAT6) = 1.483255E-07
Nett source of KE at patch named: IM1D (PLAT7) =-9.058283E-07
Nett source of KE at patch named: IM1F (PLAT9) =-7.401029E-07
Nett source of KE at patch named: IM20-L (PLAT10) = 1.473826E-06
Nett source of KE at patch named: IM21-L (PLAT11) = 7.912924E-07
Nett source of KE at patch named: IM22-H (PLAT12) =-1.814704E-05
Nett source of KE at patch named: IM23-L (PLAT13) = 1.419244E-05
pos. sum=19.856886 neg. sum=-15.260989
nett sum=4.595897

Nett source of EP at patch named: KESOURCE =-7.334408E+02
Non-linearised source for EP at: KESOURCE = 6.752483E+02
Nett source of EP at patch named: OB5 (FLUE) =-6.875866E+00
(Ave Out 1.535549E+01 In 0.000000E+00)
Nett source of EP at patch named: OB6 (AIR_1) = 1.084451E+00
(Average 1.192884E+01)
Nett source of EP at patch named: OB7 (AIR_2) = 9.736035E-01
(Average 1.070953E+01)
Nett source of EP at patch named: OB8 (AIR_3) = 8.326480E-01
(Average 9.159036E+00)
Nett source of EP at patch named: OB9 (AIR_4) = 7.902714E-01
(Average 8.692898E+00)
Nett source of EP at patch named: OBA (SYNGAS) = 2.860558E-02
(Average 5.084532E-01)
Nett source of EP at patch named: OBB (BRAIR) = 9.007790E-05
(Average 3.217068E-03)
Nett source of EP at patch named: IM17 (PLAT1) = 3.588307E-05
Nett source of EP at patch named: IM18-H (PLAT2) = 2.495448E-05
Nett source of EP at patch named: IM19 (PLAT3) = 3.023990E-05
Nett source of EP at patch named: IM1A-H (PLAT4) = 7.110323E-05
Nett source of EP at patch named: IM1B (PLAT5) =-8.550401E-07
Nett source of EP at patch named: IM1C-L (PLAT6) =-4.330121E-07
Nett source of EP at patch named: IM1D (PLAT7) =-7.956730E-05
Nett source of EP at patch named: IM1F (PLAT9) =-4.419395E-05
Nett source of EP at patch named: IM20-L (PLAT10) = 1.354225E-04
Nett source of EP at patch named: IM21-L (PLAT11) =-4.143834E-06
Nett source of EP at patch named: IM22-H (PLAT12) =-1.572455E-02
Nett source of EP at patch named: IM23-L (PLAT13) =-2.150730E-03
pos. sum=678.958306 neg. sum=-740.334715
nett sum=-61.376409

Nett source of H1 for absorption & emission =-2.206478E+04
Nett source of H1 at patch named: OB1 (BLOCK) =-2.114512E+03
Nett source of H1 at patch named: OB4 (PTUBE) =-1.625204E+05
Nett source of H1 at patch named: OB5 (FLUE) =-5.048480E+05
(Ave Out 1.128265E+06 In 0.000000E+00)
Nett source of H1 at patch named: OB6 (AIR_1) = 2.715936E+03
(Average 2.987500E+04)

Nett source of H1 at patch named: OB7 (AIR_2) = 2.715936E+03
(Average 2.987500E+04)
Nett source of H1 at patch named: OB8 (AIR_3) = 2.715936E+03
(Average 2.987500E+04)
Nett source of H1 at patch named: OB9 (AIR_4) = 2.715936E+03
(Average 2.987500E+04)
Nett source of H1 at patch named: OBA (SYNGAS) = 7.121953E+05
(Average 1.265900E+07)
Nett source of H1 at patch named: OBB (BRAIR) = 8.365000E+02
(Average 2.987500E+04)
Nett source of H1 at patch named: IM17 (PLAT1) =-1.834989E+03
Nett source of H1 at patch named: IM18-H (PLAT2) =-1.494384E+03
Nett source of H1 at patch named: IM19 (PLAT3) =-2.101705E+03
Nett source of H1 at patch named: IM1A-H (PLAT4) =-1.656163E+03
Nett source of H1 at patch named: IM1B (PLAT5) =-1.030273E+03
Nett source of H1 at patch named: IM1C-L (PLAT6) =-6.261162E+02
Nett source of H1 at patch named: IM1D (PLAT7) =-2.127005E+03
Nett source of H1 at patch named: IM1F (PLAT9) =-1.840779E+03
Nett source of H1 at patch named: IM20-L (PLAT10) =-1.527245E+03
Nett source of H1 at patch named: IM21-L (PLAT11) =-9.419905E+02
Nett source of H1 at patch named: IM22-H (PLAT12) =-9.022043E+03
Nett source of H1 at patch named: IM23-L (PLAT13) =-9.354986E+03
pos. sum=7.238956E+05 neg. sum=-7.251054E+05
nett sum=-1209.774439

Nett source of T3 for absorption & emission = 2.206478E+04
Nett source of T3 at patch named: OB1 (BLOCK) = 2.110681E+03
pos. sum=2.417546E+04 neg. sum=0.
nett sum=2.417546E+04

Nett source of TR at patch named: TRS (RESIDOB) = 1.096906E+00
Nett source of TR at patch named: OB5 (FLUE) =-1.096331E+00
(Ave Out 2.450150E+00 In 0.000000E+00)
pos. sum=1.096906 neg. sum=-1.096331
nett sum=5.750694E-04

Nett source of MIXF at patch named: OB5 (FLUE) =-5.620368E-02
(Ave Out 1.256068E-01 In 0.000000E+00)
Nett source of MIXF at patch named: OBA (SYNGAS) = 5.626000E-02
(Average 1.000000E+00)
pos. sum=0.05626 neg. sum=-0.056204
nett sum=5.632325E-05

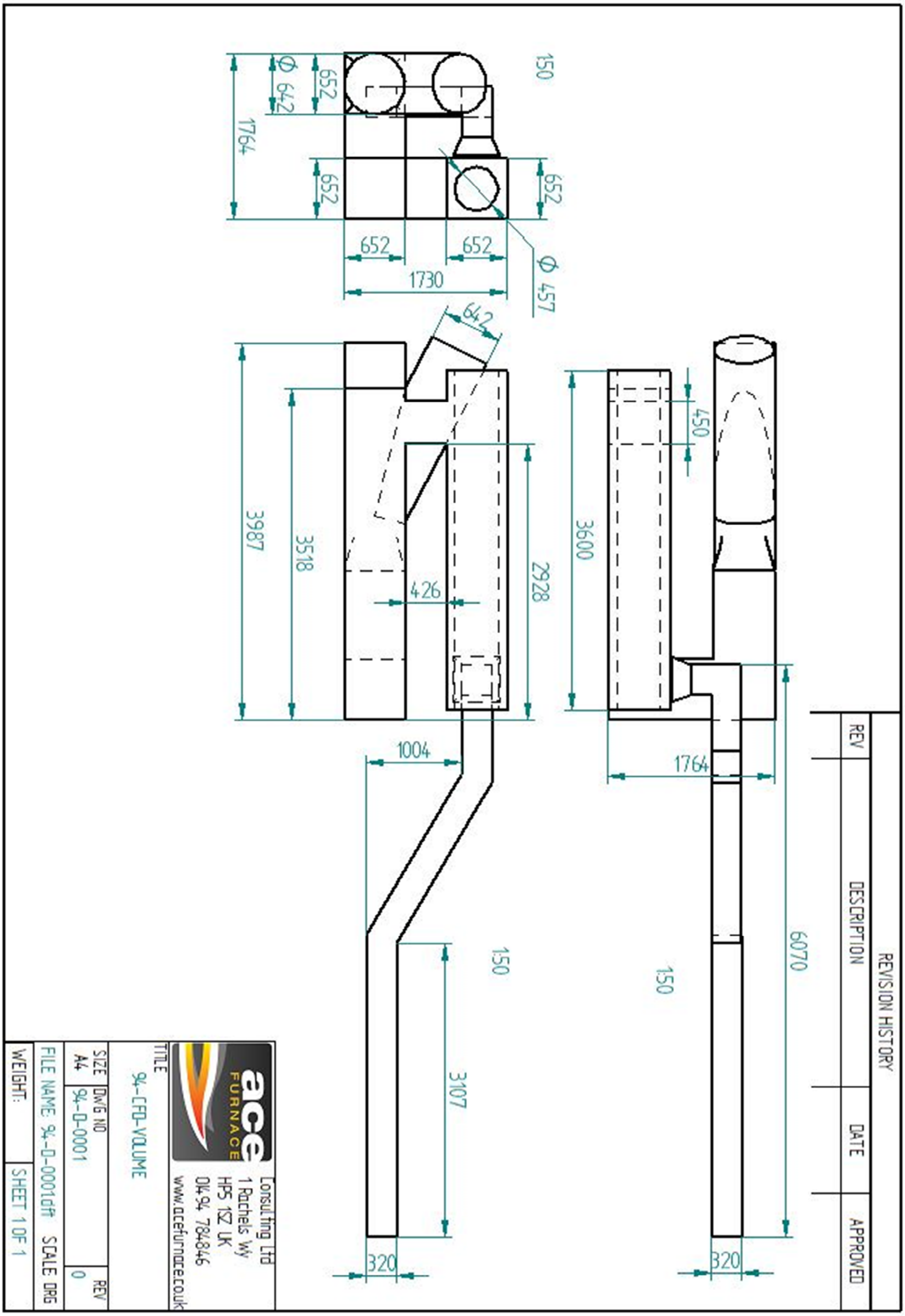
****

Checking IMMERSOL energy balance
for T3 and H1 together
nett: T3=2.417546E+04 H1 =-1209.774439
nett sum=2.296569E+04

```
*************************************************************
Summary of sources from all Objects/Patches at sweep  8000
  Variable     Inflow       Outflow       Nett
    P1      4.479000E-01 -4.474571E-01  4.429027E-04
    U1      7.892231E-02 -1.371487E-02  6.520745E-02
    V1      4.623858E+00 -8.596255E+00 -3.972397E+00
    W1       3.726846E-01 -2.327071E+00 -1.954386E+00
    KE      1.985689E+01 -1.526099E+01  4.595897E+00
    EP      6.789583E+02 -7.403347E+02 -6.137641E+01
    H1      7.238956E+05 -7.251054E+05 -1.209774E+03
    T3      2.417546E+04  0.000000E+00  2.417546E+04
    TR      1.096906E+00 -1.096331E+00  5.750694E-04
    MIXF     5.626000E-02 -5.620368E-02  5.632325E-05
*************************************************************
```

APPENDIX 4

VOLUME DRAWING


TITLE
94-CFD-VOLUME
Consulting Ltd
1 Rachels Wy
HP5 1SZ UK
01494 784846
www.acefurnace.co.uk
SIZE
A4
DWG NO
94-D-0001
REV
0
FILE NAME: 94-D-0001cfd
SCALE: DRG
WEIGHT:
SHEET 1 OF 1
REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
1764
Φ 642
652
150
1730
Φ 457
642
3987
3518
2928
426
3600
450
1004
1764
6070
3107
320