

Date	28 June 2018
Time	15:28:25
Test Number	HRSG Test 20
Mixture Composition	100% H2
Ambient Temperature	22 °C
Ambient Pressure	978 mbar
Wind Speed	2 m/s
Wind direction	NE
Relative Humidity	40.00%
Mass Flow	9.5860 kg/s
Equivalence Ratio	0.55

**General Comments: (weather, rig configuration)**

Weather: Sunny and hot, light breeze

Rig configuration: 4 x 3m circular duct; expansion section and HRSG attached. End Plate attached. Igniter 258mm from beginning of 2nd circular duct section

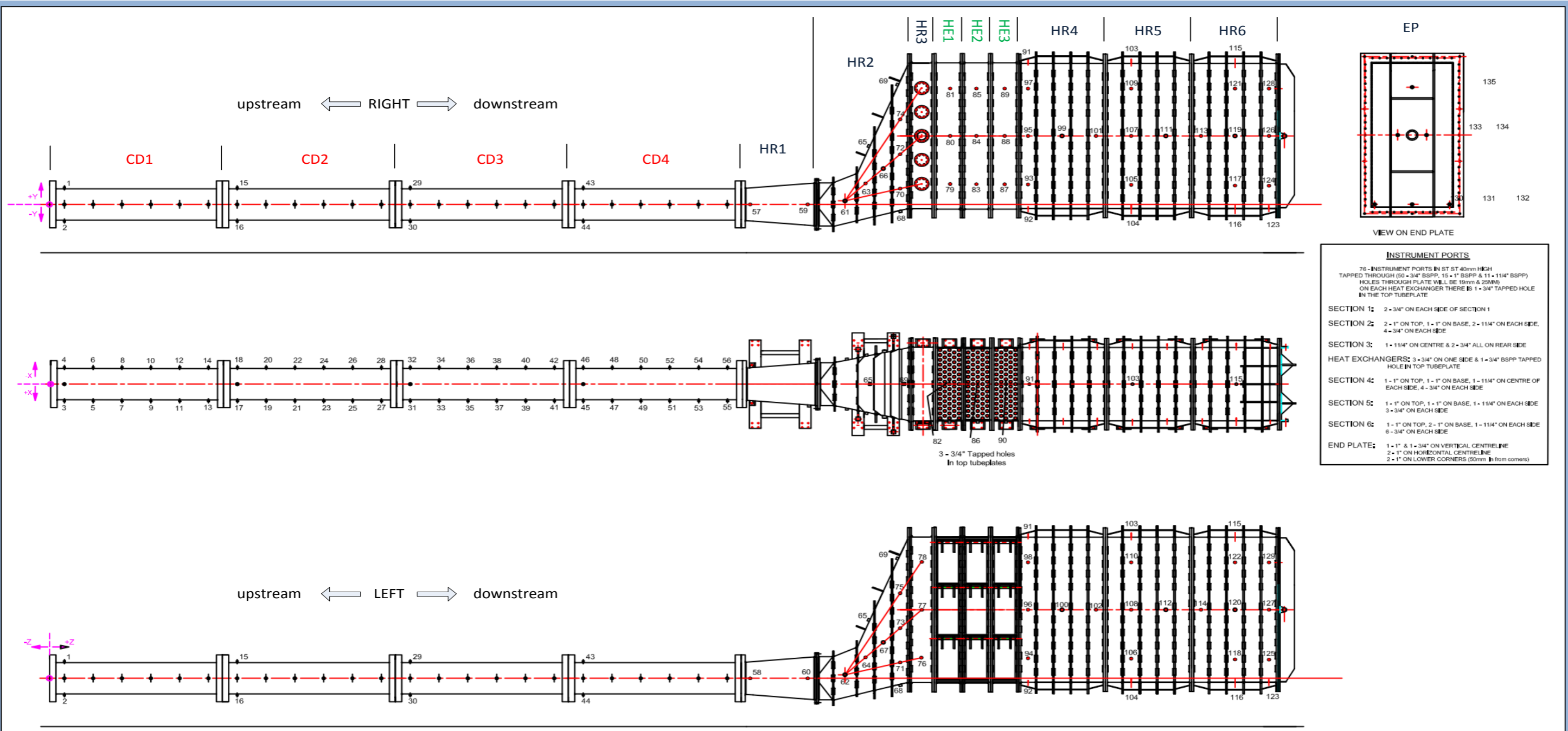
Engine Speed: 40%; 11,800 rpm

Repeat test on 100 % hydrogen at an EQR 0.55

The test gave a moderate combustion event and most sensors provided an identifiable response.

Maximum overpressure of 987 mbar was seen on KU10 near the end plate. All the highest overpressures were seen after the tube bundles in the HRSG.

Max overpressure		Max. gas temperature		Ionisation Probes Max. flame speed		Ionisation Rakes Max. flame speed		Optical Probes Max. flame speed	
	987 mbar		1262 °C		201 m/s		260 m/s		293 m/s
			Initial gas temperature 437 °C						
Location of Max. Overpressure		Location of Max. Temperature		Location of Max. Flame Speed		Location of Max. Flame Speed		Location of Max. Flame Speed	
sensor	KU10	sensor	TC2	sensor	IP1	sensor	RA4	sensor	OP1
label	HR6-L5L	label	CD2-R3	label	HR2-L5L	label	HR4-R3L	label	CD4-R6
distance	21165 mm	distance	4258 mm	distance	14745 mm	distance	17575 mm	distance	11758 mm



**INSTRUMENT PORTS**

76 - INSTRUMENT PORTS IN ST 40mm HIGH TAPPED THROUGH (50 - 3/4" BSPP, 15 - 1" BSPP & 11 - 1/4" BSPP) HOLES THROUGH PLATE WILL BE 10mm & 25mm ON EACH HEAT EXCHANGER THERE IS 1 - 3/4" TAPPED HOLE IN THE TOP TUBEPLATE

SECTION 1: 2 - 3/4" ON EACH SIDE OF SECTION 1

SECTION 2: 2 - 1" ON TOP, 1 - 1" ON BASE, 2 - 1/4" ON EACH SIDE, 4 - 3/4" ON EACH SIDE

SECTION 3: 1 - 1/4" ON CENTRE & 2 - 3/4" ALL ON REAR SIDE

HEAT EXCHANGERS: 3 - 3/4" ON ONE SIDE & 1 - 3/4" BSPP TAPPED HOLE IN TOP TUBEPLATE

SECTION 4: 1 - 1" ON TOP, 1 - 1" ON BASE, 1 - 1/4" ON CENTRE OF EACH SIDE, 4 - 3/4" ON EACH SIDE

SECTION 5: 1 - 1" ON TOP, 1 - 1" ON BASE, 1 - 1/4" ON EACH SIDE, 3 - 3/4" ON EACH SIDE

SECTION 6: 1 - 1" ON TOP, 2 - 1" ON BASE, 1 - 1/4" ON EACH SIDE, 6 - 3/4" ON EACH SIDE

END PLATE: 1 - 1" & 1 - 3/4" ON VERTICAL CENTRELINE, 2 - 1" ON HORIZONTAL CENTRELINE, 2 - 1" ON LOWER CORNERS (50mm from corners)

**Naming Convention**

<p>Section Identifier i.e. HE, HR, CD or EP</p> <p>Section Number (1-6) Numbered from downstream to upstream</p>	<p><b>H R 1 - R 1 U</b></p> <p>Side i.e. R, L, T or B</p>	<p>Vertical position in section (sides only) i.e. U, M or L. Absence of letter denotes centreline</p> <p>Longitudinal position in section (numbered from 1)</p>
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**Key**

<b>CD</b> Circular duct	<b>U</b> Upper
<b>HR</b> HRSG	<b>M</b> Middle
<b>HE</b> Heat Exchanger	<b>L</b> Lower
<b>EP</b> End Plate	<b>R</b> Right Side (when viewed downstream from engine)
	<b>L</b> Left Side
	<b>T</b> Top
	<b>B</b> Bottom

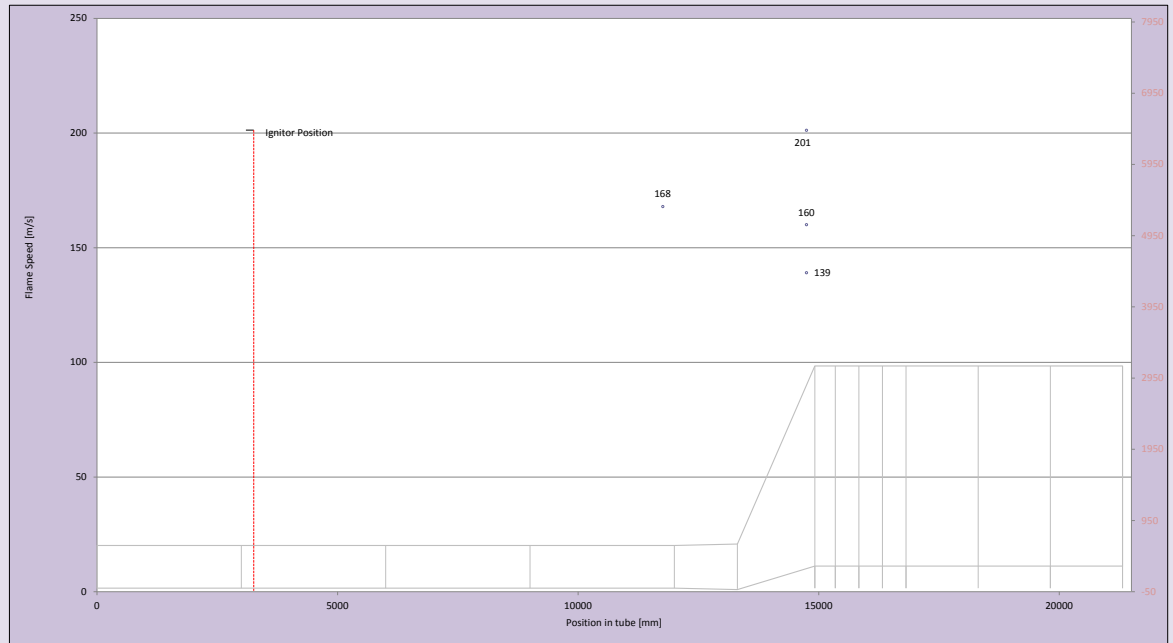
There are 13 sections on the rig

- 4 circular duct sections (CD1 to CD4)
- 6 HRSG sections (HR1 to HR6)
- 3 heat exchanger sections (HE1 to HE3) located between HR3 and HR4

Location of igniter 3258 mm Time of ignition 18.19738 seconds

IP Number	Location label	Data Name	Position in tube (mm)	Flame arrival time (s)	Avg Flame speed from last sensor (m/s)
IP0	CD4-L6	sation probe 0	11758	18.24796	168
IP1	HR2-L5L	sation probe 1	14745	18.26280	201
IP2	HR2-L5M	sation probe 2	14745	18.26913	160
IP3	HR2-L5U	sation probe 3	14745	18.27992	139
IP4	HR3-R1L	sation probe 4	15140	18.26250	
IP5	HR3-R1LM	sation probe 5	15140	18.26379	
IP6	HR3-R1M	sation probe 6	15140	18.26593	
IP7	HR3-R1U	sation probe 7	15140	18.26679	
IP8	HR3-L1U	sation probe 8	15140	18.26779	
IP9	HE2-R1M	sation probe 9	16090	18.26444	
IP10	HR4-L1L	ktion probe 10	16985	18.26506	
IP11	HR4-L1M	ktion probe 11	16985	18.26600	
IP12	HR4-L1U	ktion probe 12	16985	18.26628	
IP13	HR4-R1U	ktion probe 13	16985	18.26565	
IP14	HR4-R3U	ktion probe 14	17575	18.26679	
IP15	HR4-L5L	ktion probe 15	18165	18.26974	
IP16	HR4-L5M	ktion probe 16	18165	18.26909	
IP17	HR4-L5U	ktion probe 17	18165	18.26964	
IP18	HR4-R5M	ktion probe 18	18165	18.26966	
IP19	HR5-L2L	ktion probe 19	18775	18.27119	
IP20	HR5-L2M	ktion probe 20	18775	18.27161	
IP21	HR5-L2U	ktion probe 21	18775	18.26729	
IP22	HR5-R2U	ktion probe 22	18775	18.27198	
IP23	HR6-L1M	ktion probe 23	19985	18.27315	

KEY: ND - not detected - sensor working but flame too weak to be picked up  
 NW - not working - sensor not working

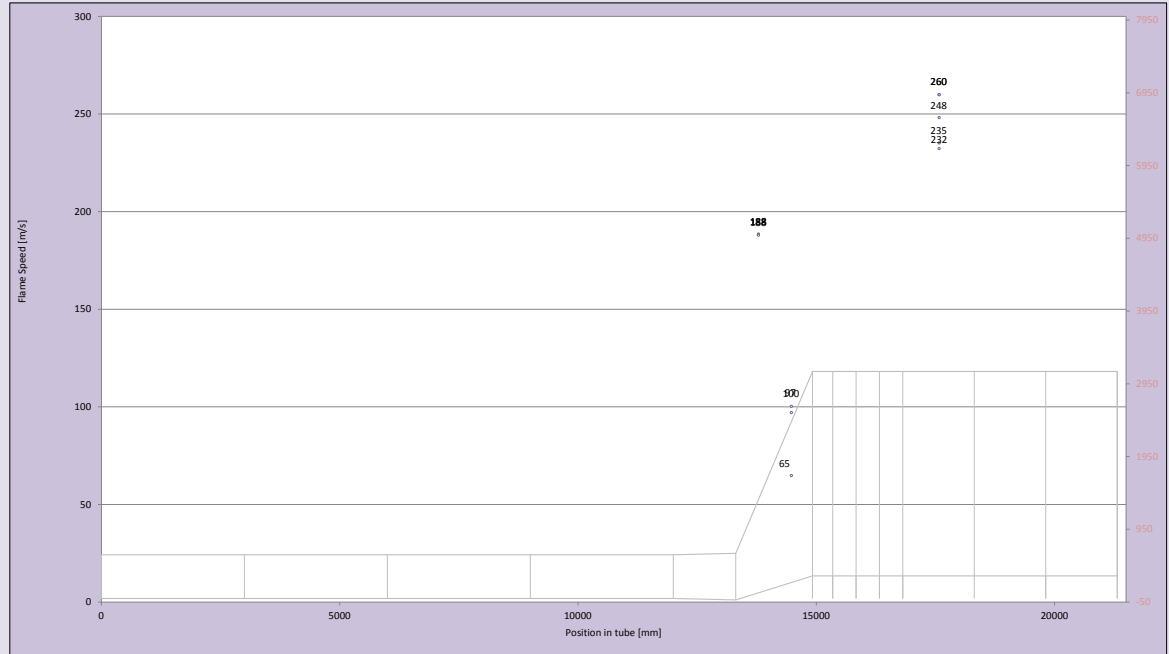


Location of igniter 3258 mm

Time of ignition 18.19738 seconds

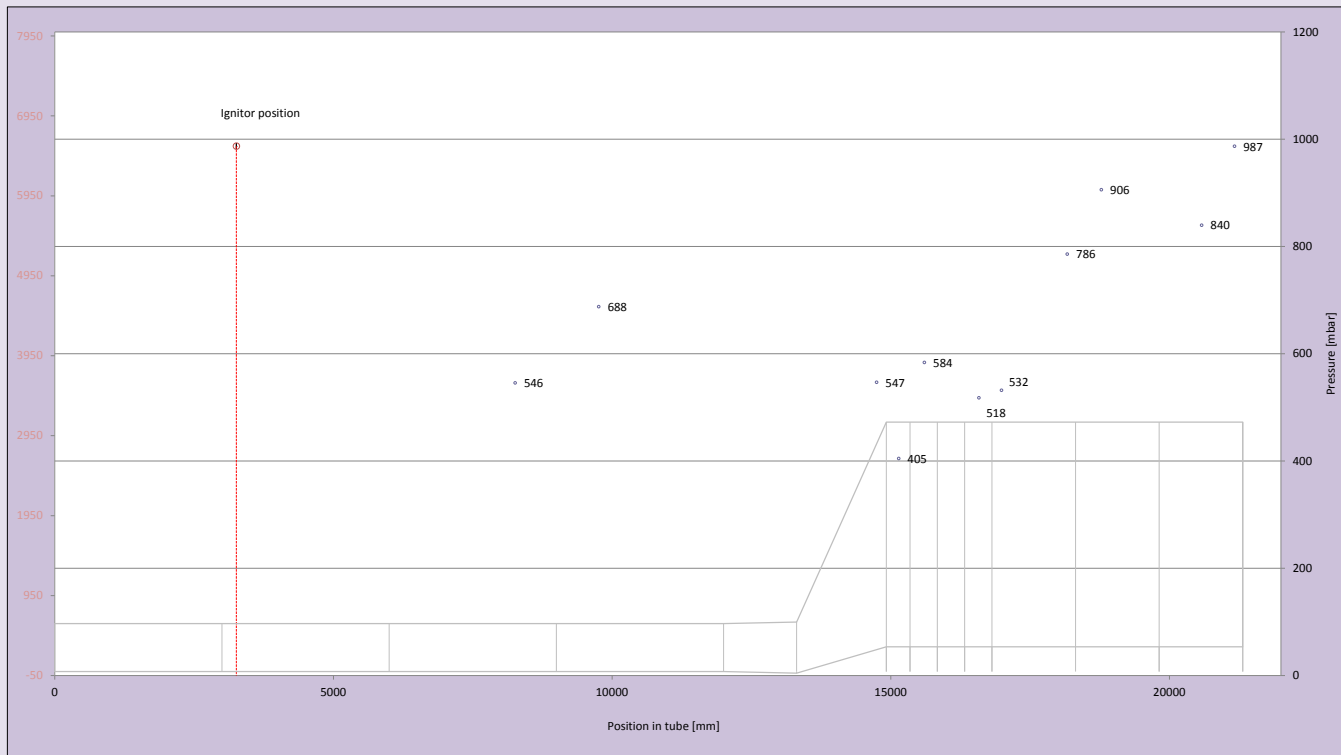
Rake Number	IP Number	Location label	Data Name	Position in tube (mm)	Flame arrival time (s)	Avg Flame speed from last sensor (m/s)
RA1	IP24	HR2-R2M	IP24	13785	18.2532	188
RA1	IP25	HR2-R2M	IP25	13785	18.2532	188
RA1	IP26	HR2-R2M	IP26	13785	18.2534	188
RA2	IP27	HR2-R4M	IP27	14475	18.2601	100
RA2	IP28	HR2-R4M	IP28	14475	18.2603	97
RA2	IP29	HR2-R4M	IP29	14475	18.2639	65
RA3	IP30	HR4-R3M	IP30	17575	NW	
RA3	IP31	HR4-R3M	IP31	17575	18.2735	232
RA3	IP32	HR4-R3M	IP32	17575	18.2733	235
RA4	IP33	HR4-R3L	IP33	17575	18.2726	248
RA4	IP34	HR4-R3L	IP34	17575	18.2720	260
RA4	IP35	HR4-R3L	IP35	17575	18.2720	260

KEY: ND - not detected - sensor working but flame too weak to be picked up  
 NW - not working - sensor not working  
 The signal on IP 30 was noisy - some evidence of response to flame but not possible to pick out exact time of flame arrival



Location of igniter  mm

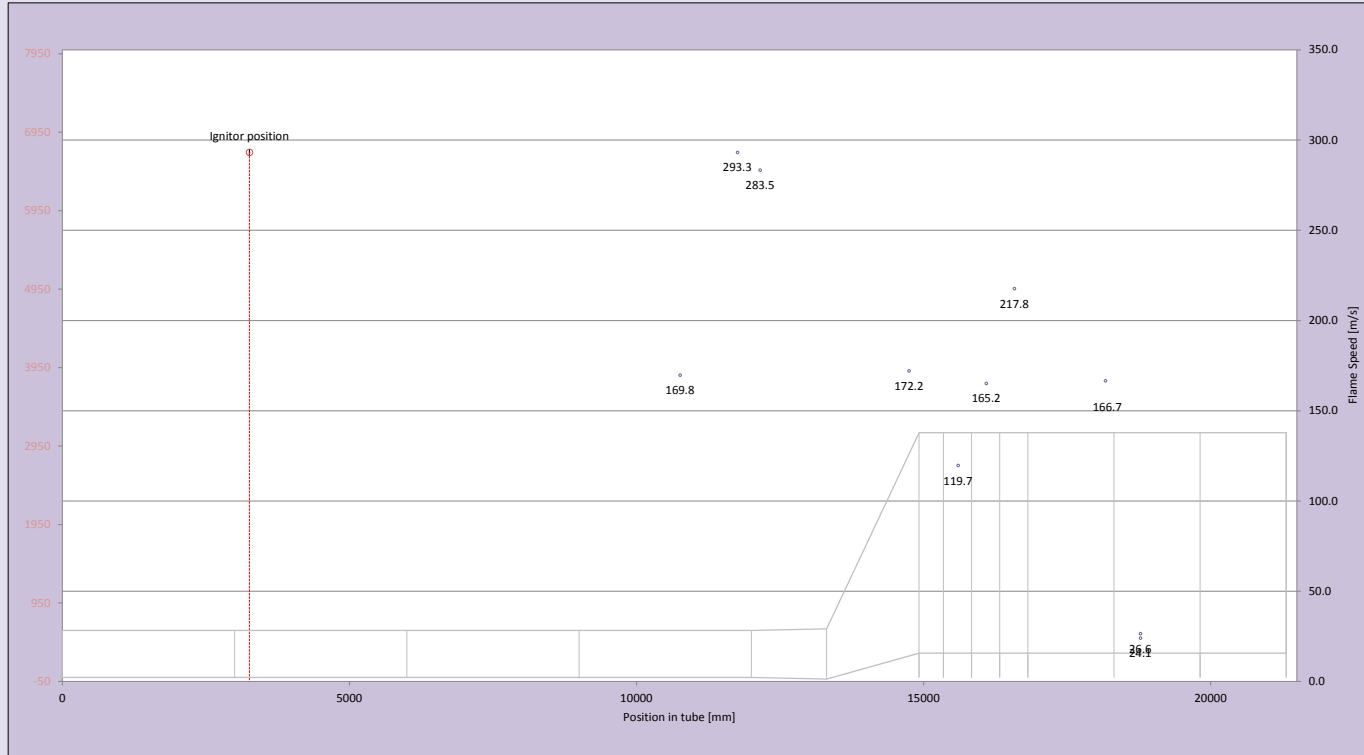
Transducer number	Location	Position in tube [mm]	$P_{max}$ [mbar]	Time $P_{max}$ [sec]
KU0	CD3-R5	8258	546	17.9495
KU1	CD4-R2	9758	688	18.2946
KU2	HR2-T5	14745	547	18.2873
KU3	HR3-L1L	15140	405	18.2712
KU4	HE1-R1U	15600	584	18.2689
KU5	HE3-R1L	16580	518	18.2859
KU6	HR4-R1L	16985	532	18.2681
KU7	HR4-R5U	18165	786	18.2821
KU8	HR5-R2L	18775	906	18.2829
KU9	HR6-R3L	20575	840	18.2800
KU10	HR6-L5L	21165	987	18.2790



Location of igniter  mm      Time of ignitio  seconds

OP Number	Location label	Position in tube (mm)	Flame arrival time (s)	Average flame speed (m/s)
OP0	CD4-L4	10758	18.2416	169.8
OP1	CD4-R6	11758	18.2450	293.3
OP2	HR1-R1	12152	18.2463	283.5
OP3	HR2-R5M	14745	18.2614	172.2
OP4	HE1-T1	15600	18.2685	119.7
OP5	HE2-T1	16090	18.2695	165.2
OP6	HE3-T1	16580	18.2718	217.8
OP7	HR4-T1	16985	18.2682	-112.2
OP8	HR4-R1M	16985	18.2685	-123.9
OP9	HR4-R5L	18165	18.2756	166.7
OP10	HR5-T2	18775	18.2986	26.6
OP11	HR5-R2M	18775	18.3009	24.1

KEY: ND - not detected - sensor working but flame too weak to be picked up  
 NW - not working - sensor not working  
 OP4 signal was slightly noisy but did give an identifiable and quantifiable response.



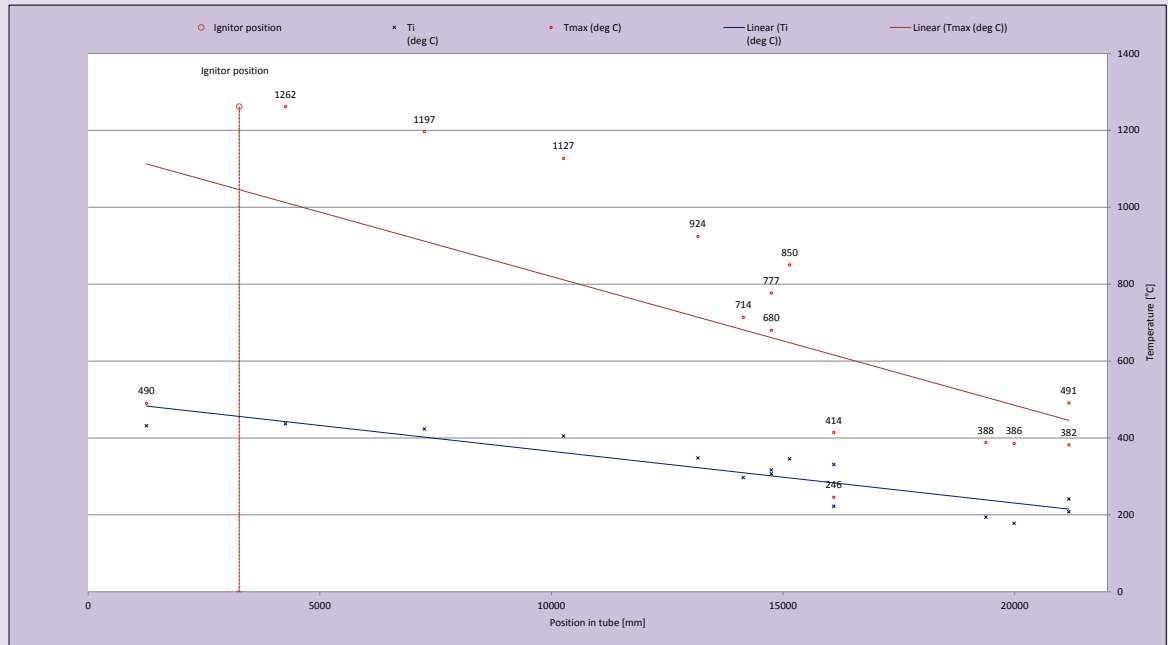
Location of igniter  mm      Time of ignition  seconds

Thermocouple number	Location	Position in tube (mm)	Flame arrival time (s)	Average flame speed (m/s)	T <sub>max</sub> (deg C)	T <sub>i</sub> (deg C)
TC0	CD1-R3	1258	20.803		490	432
TC2	CD2-R3	4258	18.231	30	1262	437
TC4	CD3-R3	7258	18.242	90	1197	423
TC6	CD4-R3	10258	18.246	144	1127	405
TC8	HR1-R2	13160	18.276	126	924	348
TC16	HR2-R3M	14140	18.270	150	714	297
TC17	HR2-R5L	14745	18.279	141	777	317
TC18	HR2-R5U	14745	18.295	118	680	307
TC19	HR3-L1M	15140	18.293	124	850	346
TC20	HE2-R1L	16090	18.302	123	414	331
TC21	HE2-R1U	16090	18.297	129	246	222
TC22	HR5-R4M	19375	18.340	113	388	194
TC23	HR6-R1M	19985	18.368	98	386	178
TC24	HR6-R5L	21165	18.481	63	382	208
TC25	HR6-R5U	21165	18.449	71	491	241

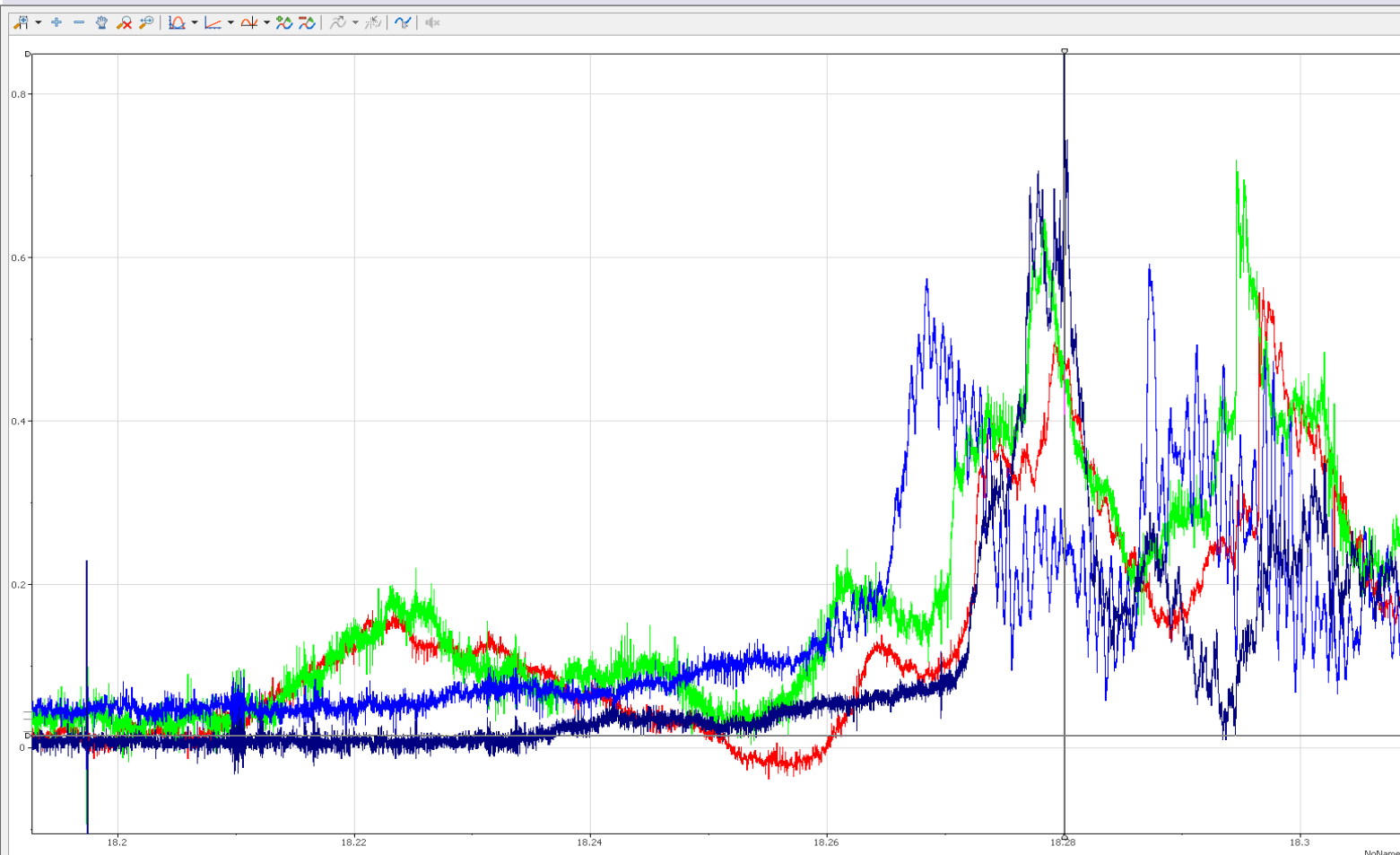
surface thermocouples [not plotted]

TC	Location	Position in tube (mm)	T <sub>max</sub> (deg C)	T <sub>i</sub> (deg C)	
TC1	CD1-T2	1508		123	110
TC3	CD2-T2	4508		107	97
TC5	CD3-T2	7508		52	50
TC7	CD4-T2	10508		84	78

The flame arrival time is measured as the time when the thermocouple registers a 10 °C increase from its baseline value.



# Pressure

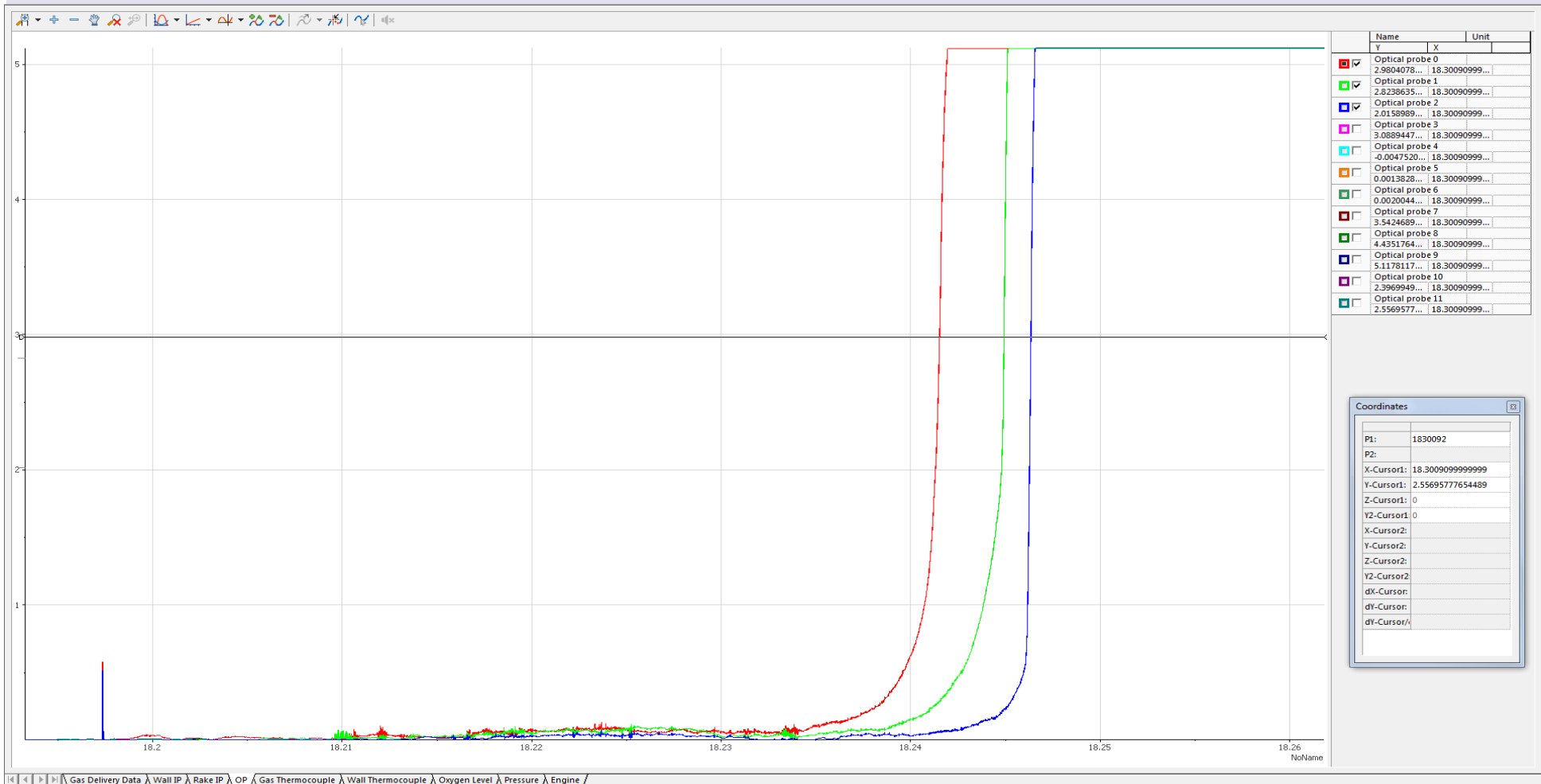


Name	Unit	Y
X	Maximum	Time_Max
<input checked="" type="checkbox"/>	Kulite pressure 0	18.177409... 0.563778925...
<input checked="" type="checkbox"/>	Kulite pressure 1	18.177409... 0.720229027...
<input checked="" type="checkbox"/>	Kulite pressure 2	18.177409... 0.593428218...
<input type="checkbox"/>	Kulite pressure 3	18.177409... 0.412528050...
<input type="checkbox"/>	Kulite pressure 4	18.177409... 0.592138065...
<input type="checkbox"/>	Kulite pressure 5	18.177409... 0.534585590...
<input type="checkbox"/>	Kulite pressure 6	18.177409... 0.551387885...
<input type="checkbox"/>	Kulite pressure 7	18.177409... 0.792983645...
<input type="checkbox"/>	Kulite pressure 8	18.177409... 0.936799471...
<input checked="" type="checkbox"/>	Kulite pressure 9	18.177409... 0.848779037...
<input type="checkbox"/>	Kulite pressure 10	18.177409... 1.017202067...

Coordinates	
P1:	1817742
P2:	1828005
X-Cursor1:	18.1774099999999
Y-Cursor1:	0.015172803397586
Z-Cursor1:	0
Y2-Cursor1:	0
X-Cursor2:	18.28004
Y-Cursor2:	0.848779037579462
Z-Cursor2:	1
Y2-Cursor2:	1
dX-Cursor:	0.102630000000001
dY-Cursor:	0.833606237239703
dY-Cursor/:	8.12244214400948

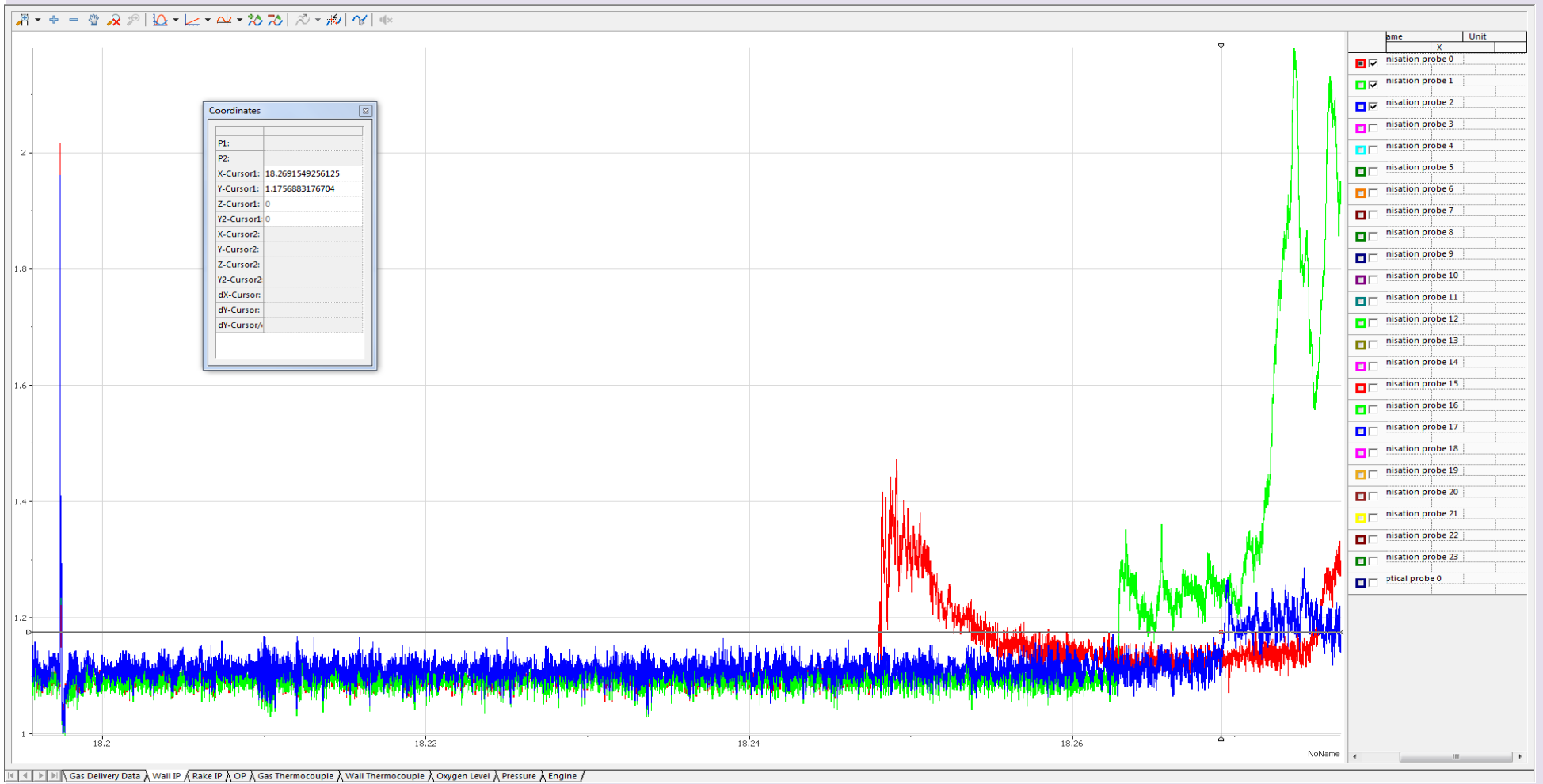


# Optical Probes

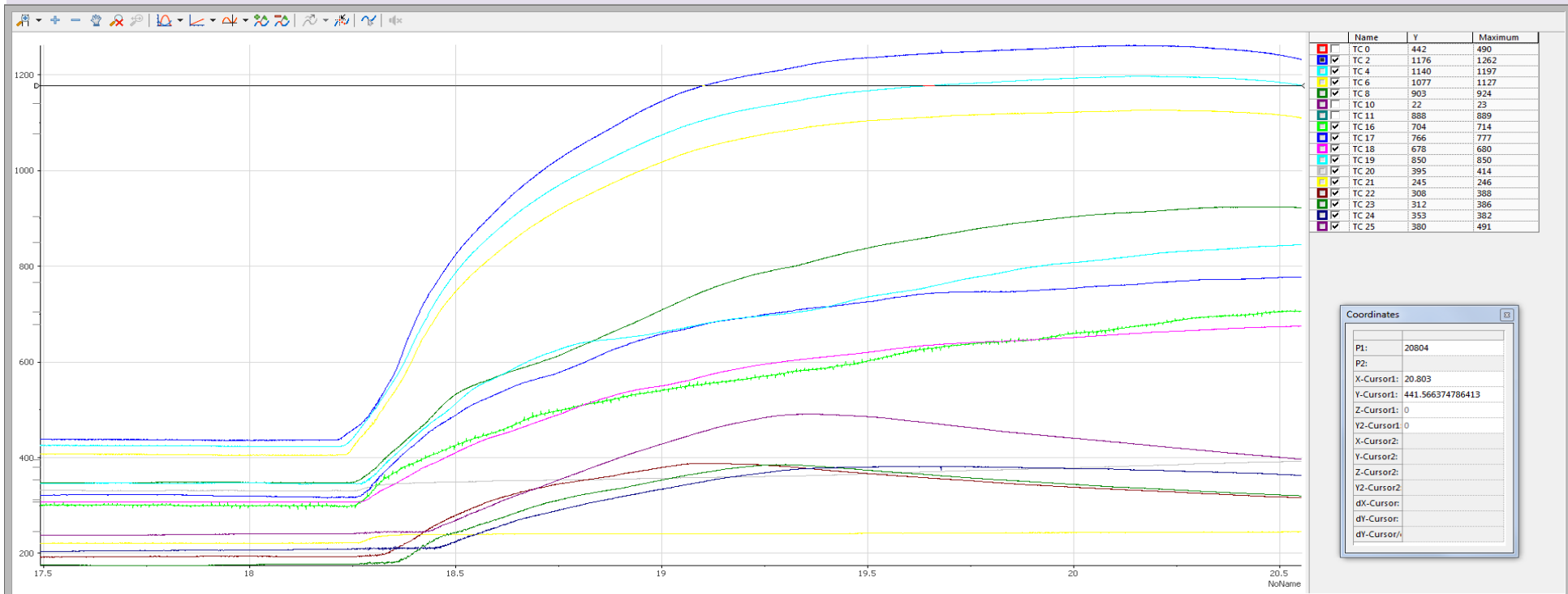


Gas Delivery Data | Wall IP | Rake IP | OP | Gas Thermocouple | Wall Thermocouple | Oxygen Level | Pressure | Engine

# Ionisation Probes



# Temperature



Selected Channels														
Name	TC 0	TC 2	TC 4	TC 6	TC 8	TC 16	TC 17	TC 18	TC 19	TC 20	TC 21	TC 22	TC 23	TC 24
Group name	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature
Length	22300	22300	22300	22300	22300	22300	22300	22300	22300	22300	22300	22300	22300	22300
Unit														
Maximum	490	1262	1197	1127	924	714	777	680	850	414	246	388	386	382
Minimum	432	435	423	404	345	291	315	303	343	330	216	174	157	195
Channel Contents														
20802	441.414104417224	1176.48129739624	1140.22793177734	1077.00188888881	903.534541430815	703.660251609635	766.501316261578	678.364418820135	849.510222025926	395.341266960635	245.317496414896	307.993338818126	312.322911258422	353.75870996
20803	441.37603649749	1176.7009399315	1140.05456795579	1077.08676335	902.84686523539	703.621611731062	766.540476562985	678.325965667185	849.390453158798	395.302934796541	245.197938326835	307.837707432528	312.245189091621	353.48862408
20804	441.566374786413	1176.2616730891	1139.70787209215	1076.57755045118	902.765969897388	703.660251609635	766.422996686175	678.364418820135	849.510222025926	395.341266960635	245.158084284856	307.643158979248	311.973149510476	353.45003955
20805	441.414104417224	1175.29554241903	1139.75120675881	1076.53511971064	902.80641736267	703.930739045713	766.422996686175	678.44132593177	849.470296688341	395.341266960635	245.317496414896	307.643158979248	311.85655390368	353.60437647
20806	441.185694923049	1175.86639523726	1139.66453800706	1076.36540230781	902.84686523539	703.582972148309	766.070575544688	678.402872241647	849.390453158798	395.417930557582	245.158084284856	307.796790562418	311.85655390368	353.60437647
20807	441.147626211445	1175.07601636058	1139.23123440619	1076.91701668612	902.19974815248	703.003413880091	765.835643518435	678.056801112425	849.230766681723	395.072936695428	245.038518122313	307.643158979248	311.778824062502	353.52720841

Sensor	OLD DESIGNATION	NEW DESIGNATION	Section	Section Number	Side	Horizontal Location	Vertical Location	PORT REF	SIZE	"X"	"Y"	"Z"
-	NS1-1	CD1-R1	CD	1	R	1		3	3/4" BSPP	298	0	258
-	NS1-2	CD1-R2	CD	1	R	2		5	3/4" BSPP	298	0	758
TC0	NS1-3	CD1-R3	CD	1	R	3		7	3/4" BSPP	298	0	1258
-	NS1-4	CD1-R4	CD	1	R	4		9	3/4" BSPP	298	0	1758
-	NS1-5	CD1-R5	CD	1	R	5		11	3/4" BSPP	298	0	2258
-	NS1-6	CD1-R6	CD	1	R	6		13	3/4" BSPP	298	0	2758
-	NS2-1	CD2-R1	CD	2	R	1		17	3/4" BSPP	298	0	3258
-	NS2-2	CD2-R2	CD	2	R	2		19	3/4" BSPP	298	0	3758
TC2	NS2-3	CD2-R3	CD	2	R	3		21	3/4" BSPP	298	0	4258
-	NS2-4	CD2-R4	CD	2	R	4		23	3/4" BSPP	298	0	4758
-	NS2-5	CD2-R5	CD	2	R	5		25	3/4" BSPP	298	0	5258
-	NS2-6	CD2-R6	CD	2	R	6		27	3/4" BSPP	298	0	5758
-	NS3-1	CD3-R1	CD	3	R	1		31	3/4" BSPP	298	0	6258
-	NS3-2	CD3-R2	CD	3	R	2		33	3/4" BSPP	298	0	6758
TC4	NS3-3	CD3-R3	CD	3	R	3		35	3/4" BSPP	298	0	7258
-	NS3-4	CD3-R4	CD	3	R	4		37	3/4" BSPP	298	0	7758
KU0	NS3-5	CD3-R5	CD	3	R	5		39	3/4" BSPP	298	0	8258
-	NS3-6	CD3-R6	CD	3	R	6		41	3/4" BSPP	298	0	8758
-	NS4-1	CD4-R1	CD	4	R	1		45	3/4" BSPP	298	0	9258
KU1	NS4-2	CD4-R2	CD	4	R	2		47	3/4" BSPP	298	0	9758
TC6	NS4-3	CD4-R3	CD	4	R	3		49	3/4" BSPP	298	0	10258
-	NS4-4	CD4-R4	CD	4	R	4		51	3/4" BSPP	298	0	10758
-	NS4-5	CD4-R5	CD	4	R	5		53	3/4" BSPP	298	0	11258
OP1	NS4-6	CD4-R6	CD	4	R	6		55	3/4" BSPP	298	0	11758
OP2		HR1-R1	HR	1	R	1		57	3/4" BSPP	308	0	12152
TC8		HR1-R2	HR	1	R	2		59	3/4" BSPP	393	0	13160
RA1		HR2-R2M	HR	2	R	2	M	61	11/4" BSPP	448	70	13785
TC16		HR2-R3M	HR	2	R	3	M	63	3/4" BSPP	528	410	14140
RA2		HR2-R4M	HR	2	R	4	M	66	11/4" BSPP	598	700	14475
TC17		HR2-R5L	HR	2	R	5	L	70	3/4" BSPP	662	310	14745
OP3		HR2-R5M	HR	2	R	5	M	72	3/4" BSPP	662	975	14745
TC18		HR2-R5U	HR	2	R	5	U	74	3/4" BSPP	662	1660	14745
IP4		HR3-R1L	HR	3	R	1	L	136	3/4" BSPP	700	400	15140
IP5		HR3-R1LM	HR	3	R	1	LM	137	3/4" BSPP	700	868	15140
IP6		HR3-R1M	HR	3	R	1	M	138	3/4" BSPP	700	1335	15140
-		HR3-R1UM	HR	3	R	1	UM	139	3/4" BSPP	700	1802	15140
IP7		HR3-R1U	HR	3	R	1	U	140	3/4" BSPP	700	2270	15140
-		HE1-R1L	HE	1	R	1	L	79	3/4" BSPP	700	400	15600
-		HE1-R1M	HE	1	R	1	M	80	3/4" BSPP	700	1335	15600
KU4		HE1-R1U	HE	1	R	1	U	81	3/4" BSPP	700	2270	15600
TC20		HE2-R1L	HE	2	R	1	L	83	3/4" BSPP	700	400	16090
IP9		HE2-R1M	HE	2	R	1	M	84	3/4" BSPP	700	1335	16090
TC21		HE2-R1U	HE	2	R	1	U	85	3/4" BSPP	700	2270	16090
KU5		HE3-R1L	HE	3	R	1	L	87	3/4" BSPP	700	400	16580
-		HE3-R1M	HE	3	R	1	M	88	3/4" BSPP	700	1335	16580
-		HE3-R1U	HE	3	R	1	U	89	3/4" BSPP	700	2270	16580
KU6		HR4-R1L	HR	4	R	1	L	93	3/4" BSPP	700	400	16985
OP8		HR4-R1M	HR	4	R	1	M	95	3/4" BSPP	700	1335	16985
IP13		HR4-R1U	HR	4	R	1	U	97	3/4" BSPP	700	2270	16985
RA3		HR4-R3M	HR	4	R	3	M	99	11/4" BSPP	700	1335	17575
RA4		HR4-R3L	HR	4	R	3	L	141	11/4" BSPP	700	400	17575
IP14		HR4-R3U	HR	4	R	3	U	142	3/4" BSPP	700	2270	17575
IP18		HR4-R5M	HR	4	R	5	M	101	3/4" BSPP	700	1335	18165
OP9		HR4-R5L	HR	4	R	5	L	145	3/4" BSPP	700	400	18165
KU7		HR4-R5U	HR	4	R	5	U	146	3/4" BSPP	700	2270	18165
-		HR5-R1M	HR	5	R	1	M	NA	SURFACE	700	1200	18455
KU8		HR5-R2L	HR	5	R	2	L	105	3/4" BSPP	700	400	18775
OP11		HR5-R2M	HR	5	R	2	M	107	3/4" BSPP	700	1335	18775
IP22		HR5-R2U	HR	5	R	2	U	109	3/4" BSPP	700	2270	18775
TC22		HR5-R4M	HR	5	R	4	M	111	11/4" BSPP	700	1335	19375

Sensor	OLD DESIGNATION	NEW DESIGNATION	Section	Section Number	Side	Horizontal Location	Vertical Location	PORT REF	SIZE	"X"	"Y"	"Z"
TC23		HR6-R1M	HR	6	R	1	M	113	3/4" BSPP	700	1335	19985
KU9		HR6-R3L	HR	6	R	3	L	117	3/4" BSPP	700	400	20575
-		HR6-R3M	HR	6	R	3	M	119	1 1/4" BSPP	700	1335	20575
-		HR6-R3U	HR	6	R	3	U	121	3/4" BSPP	700	2270	20575
TC24		HR6-R5L	HR	6	R	5	L	124	3/4" BSPP	700	400	21165
-		HR6-R5M	HR	6	R	5	M	126	3/4" BSPP	700	1335	21165
TC25		HR6-R5U	HR	6	R	5	U	128	3/4" BSPP	700	2270	21165

