

Appendix – II

Experimental Data

Appendix II gives the experimental data for few chosen test runs carried out to study the thermal performance and exhaust gas emission constituents for two different cases, viz., experimental study with diesel, diesel-hydrogen inducted at inlet manifold and diesel/DMM blends and hydrogen inducted at inlet manifold of the compression ignition engine.

Table AII-11 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at NO Load

No.	Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B.Th.}$)						Volumetric Efficiency ($\eta_{vol.}$)							BSEC MJ/kWh	ϕ	T_{exh} (°C)	
			Brake Power (BP)			Input Power (IP)			$\eta_{B.Th.}$ (%)	ρ_{air}			V_{actual}						$\eta_{vol.}$ (%)
(l/min)	$\dot{m}_{H_2} \times 10^6$ (Kg/s)	BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	E_f (kJ)	E_{H_2} (kJ)	IP (W)	$\eta_{B.Th.}$ (%)	T_{amb} (°C)	ρ_{air} (kg/m ³)	S (mm)	$\dot{m}_a \times 10^3$ (kg/s)	$V_{actual} \times 10^3$ (m ³ /s)	$V_{swept} \times 10^3$ (m ³ /s)	$\eta_{vol.}$ (%)				
1	0	0.00	0	0	260	11.06	0.00	11056	0	28.48	1.15	184	18.99	16.50	18.61	88.67	0.20	87.88	
2	1	1.40	0	0	254	10.78	0.17	10943	0	28.36	1.15	184	18.99	16.50	18.61	88.65	0.19	88.27	
3	2	2.79	0	0	251	10.67	0.34	11000	0	28.40	1.15	183	18.94	16.45	18.61	88.41	0.19	88.09	
4	3	4.19	0	0	243	10.33	0.50	10832	0	28.82	1.15	182	18.87	16.42	18.61	88.23	0.19	87.71	
5	4	5.59	0	0	238	10.10	0.67	10772	0	28.65	1.15	181	18.83	16.37	18.61	87.96	0.19	87.66	
6	5	6.98	0	0	234	9.94	0.84	10773	0	28.69	1.15	179	18.72	16.28	18.61	87.48	0.18	88.39	
7	6	8.38	0	0	231	9.81	1.01	10813	0	28.82	1.15	177	18.61	16.19	18.61	87.01	0.18	89.04	
8	7	9.78	0	0	228	9.68	1.17	10853	0	28.88	1.15	175	18.50	16.10	18.61	86.53	0.18	89.90	
9	8	11.17	0	0	224	9.51	1.34	10851	0	28.95	1.15	174	18.45	16.06	18.61	86.29	0.18	90.80	
10	9	12.57	0	0	220	9.34	1.51	10848	0	29.02	1.15	171	18.29	15.92	18.61	85.55	0.18	91.70	
11	10	13.97	0	0	218	9.25	1.68	10924	0	29.09	1.15	170	18.23	15.88	18.61	85.31	0.18	92.50	
12	11	15.36	0	0	215	9.13	1.84	10973	0	29.15	1.15	167	18.07	15.74	18.61	84.56	0.18	93.60	
13	12	16.76	0	0	212	9.02	2.01	11034	0	29.22	1.15	164	17.90	15.60	18.61	83.81	0.18	94.80	
14	13	18.16	0	0	207	8.81	2.18	10990	0	29.29	1.15	163	17.85	15.55	18.61	83.56	0.17	95.60	
15	14	19.55	0	0	203	8.65	2.35	10992	0	29.36	1.15	161	17.73	15.46	18.61	83.06	0.17	96.90	
16	15	20.95	0	0	201	8.55	2.51	11064	0	29.43	1.15	160	17.68	15.41	18.61	82.81	0.17	98.00	
17	16	22.35	0	0	200	8.50	2.68	11181	0	29.50	1.15	157	17.51	15.27	18.61	82.04	0.17	99.40	
18	17	23.74	0	0	199	8.44	2.85	11288	0	29.57	1.15	154	17.34	15.12	18.61	81.26	0.17	100.70	
19	18	25.14	0	0	196	8.34	3.02	11356	0	29.64	1.15	153	17.28	15.08	18.61	81.01	0.17	101.60	

Table AII-12 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 0.5 Amp.

No.	Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B.Th.}$)								Volumetric Efficiency ($\eta_{vol.}$)							BSEC MJ/kWh	ϕ	T_{exh} (°C)	
			Brake Power (BP)				Input Power (IP)				$\eta_{B.Th.}$ (%)	ρ_{air}			V_{actual}						$\eta_{vol.}$ (%)
	(l/min)	$\dot{m}_{H_2} \times 10^6$ (Kg/s)	BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	E_f (kJ)	E_{H_2} (kJ)	IP (W)	$\eta_{B.Th.}$ (%)	T_{amb} (°C)	ρ_{air} (kg/m ³)	S (mm)	$\dot{m}_a \times 10^3$ (kg/s)	$V_{actual} \times 10^3$ (m ³ /s)	$V_{swept} \times 10^3$ (m ³ /s)	$\eta_{vol.}$ (%)					
1	0	0.00	30.21	1091	299	12.70	0.00	12698	8.59	28.82	1.15	184	18.98	16.51	18.61	88.72	0.23	41.89	102.14		
2	1	1.40	30.71	1109	295	12.53	0.17	12699	8.73	28.65	1.15	180	18.77	16.33	18.61	87.72	0.23	41.23	102.78		
3	2	2.79	31.20	1127	294	12.51	0.34	12844	8.77	28.57	1.15	179	18.72	16.28	18.61	87.47	0.23	41.04	102.87		
4	3	4.19	31.69	1144	292	12.41	0.50	12910	8.86	28.57	1.15	178	18.67	16.23	18.61	87.22	0.23	40.62	102.91		
5	4	5.59	32.18	1162	290	12.32	0.67	12995	8.94	28.57	1.15	178	18.65	16.21	18.61	87.10	0.23	40.26	103.04		
6	5	6.98	32.57	1176	284	12.08	0.84	12914	9.11	28.65	1.15	177	18.62	16.19	18.61	86.99	0.22	39.53	104.34		
7	6	8.38	32.86	1187	278	11.82	1.01	12822	9.26	28.69	1.15	176	18.56	16.14	18.61	86.75	0.22	38.89	105.42		
8	7	9.78	33.16	1197	275	11.69	1.17	12865	9.31	28.69	1.15	176	18.54	16.13	18.61	86.65	0.22	38.68	105.94		
9	8	11.17	33.26	1201	272	11.55	1.34	12888	9.32	28.65	1.15	175	18.51	16.10	18.61	86.49	0.22	38.63	104.64		
10	9	12.57	33.35	1205	265	11.26	1.51	12770	9.43	28.65	1.15	174	18.46	16.05	18.61	86.25	0.21	38.17	104.08		
11	10	13.97	33.75	1219	261	11.11	1.68	12784	9.53	28.57	1.15	173	18.41	16.00	18.61	85.99	0.21	37.76	105.51		
12	11	15.36	34.04	1229	260	11.05	1.84	12890	9.54	28.57	1.15	173	18.39	15.99	18.61	85.89	0.21	37.75	105.64		
13	12	16.76	34.14	1233	253	10.75	2.01	12757	9.66	28.59	1.15	172	18.35	15.96	18.61	85.74	0.21	37.25	105.77		
14	13	18.16	34.34	1240	251	10.65	2.18	12824	9.67	28.58	1.15	171	18.30	15.91	18.61	85.49	0.21	37.23	105.90		
15	14	19.55	34.53	1247	247	10.50	2.35	12841	9.71	28.57	1.15	170	18.25	15.86	18.61	85.24	0.21	37.07	106.06		
16	15	20.95	34.63	1251	241	10.26	2.51	12772	9.79	28.57	1.15	169	18.19	15.82	18.61	84.99	0.21	36.76	106.24		
17	16	22.35	34.73	1254	234	9.93	2.68	12611	9.94	28.56	1.15	169	18.17	15.79	18.61	84.86	0.20	36.20	106.42		
18	17	23.74	35.32	1275	230	9.78	2.85	12631	10.10	28.55	1.15	168	18.14	15.77	18.61	84.73	0.20	35.65	106.60		
19	18	25.14	37.08	1339	225	9.56	3.02	12578	10.65	28.55	1.15	167	18.09	15.72	18.61	84.48	0.20	33.81	107.00		

Table AII-13 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
2- Speed: 1500 rpm
3- Load: at 1.0 Amp.

No.	Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B.Th.}$)						Volumetric Efficiency ($\eta_{vol.}$)						BSEC MJ/kWh	ϕ	T_{exh} (°C)			
			Brake Power (BP)			Input Power (IP)			$\eta_{B.Th.}$ (%)	ρ_{air}			V_{actual}					$\eta_{vol.}$ (%)		
			BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	E_f (kJ)	E_{H_2} (kJ)	IP (W)		T_{amb} (°C)	ρ_{air} (kg/m ³)	S (mm)	$\dot{m}_a \times 10^3$ (kg/s)	$V_{actual} \times 10^3$ (m ³ /s)					$V_{swept} \times 10^3$ (m ³ /s)	
								IP (W)												IP (W)
1	0	0.00	70.63	2551	419	17.80	0.00	17798	14.33	28.52	1.15	182	18.88	16.41	18.61	88.19	25.12	121.75		
2	1	1.40	71.02	2565	412	17.51	0.17	17677	14.51	28.52	1.15	180	18.78	16.32	18.61	87.70	24.81	124.66		
3	2	2.79	71.42	2579	394	16.76	0.34	17094	15.09	28.52	1.15	178	18.67	16.23	18.61	87.21	23.86	125.79		
4	3	4.19	71.61	2586	388	16.49	0.50	16988	15.22	28.52	1.15	176	18.57	16.14	18.61	86.72	23.65	126.01		
5	4	5.59	71.81	2593	382	16.23	0.67	16896	15.35	28.48	1.15	174	18.46	16.05	18.61	86.22	23.45	128.49		
6	5	6.98	72.20	2607	375	15.94	0.84	16777	15.54	28.40	1.15	173	18.41	16.00	18.61	85.96	23.16	130.58		
7	6	8.38	72.59	2622	372	15.79	1.01	16796	15.61	28.48	1.15	172	18.36	15.95	18.61	85.73	23.06	130.84		
8	7	9.78	72.89	2632	369	15.68	1.17	16851	15.62	28.40	1.15	172	18.33	15.93	18.61	85.59	23.05	131.36		
9	8	11.17	73.18	2643	366	15.56	1.34	16901	15.64	28.36	1.15	171	18.31	15.91	18.61	85.46	23.02	130.80		
10	9	12.57	73.48	2654	364	15.46	1.51	16964	15.64	28.36	1.15	169	18.20	15.81	18.61	84.96	23.02	131.10		
11	10	13.97	73.77	2664	361	15.35	1.68	17022	15.65	28.31	1.15	167	18.09	15.72	18.61	84.45	23.00	131.49		
12	11	15.36	73.97	2671	358	15.22	1.84	17067	15.65	28.57	1.15	165	17.98	15.63	18.61	83.98	23.00	134.04		
13	12	16.76	74.26	2682	356	15.11	2.01	17119	15.67	28.52	1.15	164	17.92	15.58	18.61	83.71	22.98	134.97		
14	13	18.16	74.56	2692	353	14.98	2.18	17159	15.69	28.52	1.15	163	17.87	15.53	18.61	83.46	22.94	135.90		
15	14	19.55	74.95	2707	351	14.90	2.35	17246	15.69	28.52	1.15	162	17.81	15.49	18.61	83.20	22.94	136.83		
16	15	20.95	75.14	2714	347	14.75	2.51	17258	15.72	28.52	1.15	161	17.76	15.44	18.61	82.94	22.89	137.76		
17	16	22.35	75.34	2721	344	14.62	2.68	17295	15.73	28.48	1.15	160	17.71	15.39	18.61	82.68	22.88	138.70		
18	17	23.74	76.32	2756	341	14.50	2.85	17349	15.89	28.40	1.15	159	17.65	15.34	18.61	82.41	22.66	139.63		
19	18	25.14	78.48	2834	339	14.42	3.02	17439	16.25	28.48	1.15	157	17.54	15.24	18.61	81.90	22.15	140.56		

Table AII-14 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 1.5 Amp.

Sl. No.	Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B.Th.}$)								Volumetric Efficiency ($\eta_{vol.}$)						BSEC MJ/kWh	ϕ	T_{exh} (°C)
			Brake Power (BP)			Input Power (IP)			$\eta_{B.Th.}$ (%)	ρ_{air}			V_{actual}			$\eta_{vol.}$ (%)			
			BF (N)	BP (W)	$\dot{m}_{H_2} \times 10^6$ (kg/s)	E_f (kJ)	E_{H_2} (kJ)	IP (W)		T_{amb} (°C)	ρ_{air} (kg/m ³)	$\dot{V}$ (mm)	$\dot{m}_a \times 10^3$ (kg/s)	$V_{actual} \times 10^3$ (m ³ /s)	$V_{swept} \times 10^3$ (m ³ /s)				
	(l/min)	$\dot{m}_{H_2} \times 10^6$ (Kg/s)																	
1	0	0.00	166.77	6023	666	28.32	0.00	28321	21.27	25.19	1.16	180	18.88	16.23	18.61	87.22	171.34		
2	1	1.40	167.75	6058	661	28.07	0.17	28240	21.45	25.53	1.16	179	18.82	16.20	18.61	87.02	172.48		
3	2	2.79	168.24	6076	653	27.75	0.34	28088	21.63	25.66	1.16	178	18.76	16.15	18.61	86.80	173.37		
4	3	4.19	168.73	6094	645	27.40	0.50	27899	21.84	25.74	1.16	177	18.71	16.11	18.61	86.57	173.73		
5	4	5.59	169.32	6115	641	27.22	0.67	27892	21.92	26.04	1.16	176	18.64	16.07	18.61	86.37	174.93		
6	5	6.98	169.52	6122	632	26.84	0.84	27677	22.12	26.16	1.16	174	18.53	15.99	18.61	85.89	175.94		
7	6	8.38	169.61	6125	625	26.54	1.01	27547	22.24	26.16	1.16	172	18.43	15.89	18.61	85.89	176.48		
8	7	9.78	169.71	6129	609	25.89	1.17	27065	22.65	26.54	1.16	170	18.31	15.81	18.61	85.40	177.85		
9	8	11.17	169.81	6133	603	25.62	1.34	26961	22.75	26.54	1.16	169	18.25	15.76	18.61	84.95	178.93		
10	9	12.57	170.60	6161	599	25.46	1.51	26970	22.84	25.19	1.16	168	18.24	15.68	18.61	84.26	180.00		
11	10	13.97	171.48	6193	591	25.11	1.68	26781	23.12	25.53	1.16	166	18.12	15.60	18.61	83.80	181.08		
12	11	15.36	171.68	6200	577	24.51	1.84	26357	23.52	25.66	1.16	164	18.01	15.51	18.61	83.32	182.16		
13	12	16.76	171.87	6207	571	24.29	2.01	26298	23.60	25.74	1.16	162	17.90	15.41	18.61	82.82	183.23		
14	13	18.16	172.07	6214	568	24.15	2.18	26323	23.61	26.04	1.16	160	17.78	15.33	18.61	82.35	184.31		
15	14	19.55	172.46	6228	565	24.03	2.35	26377	23.61	26.16	1.16	158	17.66	15.23	18.61	81.85	185.38		
16	15	20.95	172.66	6235	561	23.85	2.51	26360	23.65	26.16	1.16	157	17.61	15.18	18.61	81.59	186.46		
17	16	22.35	173.05	6249	558	23.73	2.68	26409	23.66	26.54	1.16	156	17.54	15.15	18.61	81.38	187.53		
18	17	23.74	173.34	6260	550	23.38	2.85	26223	23.87	26.54	1.16	155	17.48	15.10	18.61	81.12	188.61		
19	18	25.14	174.81	6313	550	23.38	3.02	26395	23.92	26.54	1.16	153	17.37	15.00	18.61	80.59	189.68		
																	190.76		

Table AII-15 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 2.0 Amp.

o.	Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B.Th.}$)									Volumetric Efficiency ($\eta_{vol.}$)						BSEC MJ/kWh	T_{exh} (°C)
			Brake Power (BP)			Input Power (IP)			$\eta_{B.Th.}$ (%)	ρ_{air}			V_{actual}			$\eta_{vol.}$ (%)			
	(l/min)	$\dot{m}_{H_2} \times 10^6$ (Kg/s)	BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	E_f (kJ)	E_{H_2} (kJ)	IP (W)	$\eta_{B.Th.}$ (%)	T_{amb} (°C)	ρ_{air} (kg/m ³)	S (mm)	$\dot{m}_a \times 10^3$ (kg/s)	$V_{actual} \times 10^3$ (m ³ /s)	$V_{swept} \times 10^3$ (m ³ /s)	ϕ			
1	0	0.00	235.44	8503	780	33.13	0.00	33130	25.66	25.19	1.16	177	18.72	16.10	18.61	86.49	0.60	14.03	242.89
2	1	1.40	235.83	8517	773	32.85	0.17	33021	25.79	25.53	1.16	176	18.66	16.06	18.61	86.29	0.60	13.96	245.11
3	2	2.79	236.32	8534	765	32.49	0.34	32829	26.00	25.66	1.16	175	18.60	16.02	18.61	86.06	0.60	13.85	246.92
4	3	4.19	236.22	8531	753	32.02	0.50	32521	26.23	25.74	1.16	174	18.55	15.97	18.61	85.83	0.59	13.72	247.37
5	4	5.59	236.72	8549	745	31.66	0.67	32332	26.44	26.04	1.16	173	18.49	15.94	18.61	85.63	0.59	13.62	247.56
6	5	6.98	236.91	8556	737	31.31	0.84	32144	26.62	26.16	1.16	172	18.43	15.89	18.61	85.40	0.59	13.53	247.99
7	6	8.38	237.30	8570	728	30.95	1.01	31956	26.82	26.16	1.16	171	18.37	15.85	18.61	85.15	0.58	13.42	248.82
8	7	9.78	237.79	8588	723	30.71	1.17	31886	26.93	26.54	1.16	170	18.31	15.81	18.61	84.95	0.58	13.37	250.12
9	8	11.17	237.89	8591	717	30.45	1.34	31793	27.02	26.54	1.16	168	18.20	15.72	18.61	84.45	0.58	13.32	250.99
10	9	12.57	237.89	8591	706	30.01	1.51	31516	27.26	25.19	1.16	166	18.13	15.59	18.61	83.76	0.58	13.21	251.85
11	10	13.97	238.38	8609	702	29.82	1.68	31498	27.33	25.53	1.16	165	18.07	15.55	18.61	83.55	0.58	13.17	252.71
12	11	15.36	238.58	8616	693	29.45	1.84	31297	27.53	25.66	1.16	163	17.95	15.46	18.61	83.06	0.58	13.08	253.58
13	12	16.76	238.78	8623	680	28.90	2.01	30911	27.90	25.74	1.16	161	17.84	15.37	18.61	82.56	0.57	12.90	254.44
14	13	18.16	239.07	8634	668	28.39	2.18	30570	28.24	26.04	1.16	159	17.72	15.28	18.61	82.09	0.57	12.75	255.31
15	14	19.55	240.25	8676	660	28.03	2.35	30374	28.56	26.16	1.16	157	17.61	15.18	18.61	81.59	0.57	12.60	256.17
16	15	20.95	240.93	8701	650	27.61	2.51	30127	28.88	26.16	1.16	155	17.49	15.09	18.61	81.07	0.56	12.46	257.03
17	16	22.35	241.33	8715	641	27.25	2.68	29929	29.12	26.54	1.16	154	17.45	15.07	18.61	80.99	0.56	12.36	257.90
18	17	23.74	242.31	8751	631	26.84	2.85	29686	29.48	26.54	1.16	153	17.37	15.00	18.61	80.59	0.55	12.21	258.76
19	18	25.14	243.68	8800	622	26.45	3.02	29464	29.87	26.54	1.16	151	17.26	14.90	18.61	80.06	0.55	12.05	259.62

Table AII-36 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at No Load

NO	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
1	0	17.30	0.07	2.67	0.18	23	26	120	146
2	1	17.30	0.12	2.67	0.20	41	32	106	138
3	2	17.30	0.17	2.67	0.21	58	37	92	129
4	3	17.30	0.22	2.67	0.22	82	40	84	124
5	4	17.30	0.27	2.67	0.23	106	43	75	118
6	5	17.30	0.32	2.67	0.25	143	45	70	115
7	6	17.30	0.37	2.67	0.26	179	46	64	110
8	7	17.25	0.41	2.71	0.28	213	47	62	109
9	8	17.20	0.46	2.74	0.29	246	48	60	108
10	9	17.20	0.51	2.74	0.32	288	47	59	106
11	10	17.20	0.56	2.74	0.35	329	46	57	103
12	11	17.20	0.60	2.74	0.38	365	47	57	104
13	12	17.20	0.65	2.74	0.42	400	48	57	105
14	13	17.20	0.70	2.74	0.46	440	48	57	105
15	14	17.20	0.74	2.74	0.50	479	47	57	104
16	15	17.20	0.79	2.74	0.61	521	47	58	105
17	16	17.20	0.84	2.74	0.71	563	47	58	105
18	17	17.15	0.89	2.78	0.91	607	47	58	105
19	18	17.10	0.94	2.82	1.11	650	47	58	105

Table AII-37 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
2- Speed: 1500 rpm
3- Load: at 0.5 Amp.

NO	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
1	0	16.45	0.06	3.30	0.17	14	25	159	184
2	1	16.43	0.10	3.32	0.19	24	31	143	174
3	2	16.40	0.14	3.34	0.20	34	36	127	163
4	3	16.40	0.19	3.34	0.21	53	38	116	154
5	4	16.40	0.23	3.34	0.22	72	41	106	147
6	5	16.40	0.27	3.34	0.23	99	42	99	141
7	6	16.40	0.31	3.34	0.25	127	53	93	146
8	7	16.38	0.36	3.35	0.26	155	54	89	144
9	8	16.35	0.40	3.37	0.27	183	56	86	142
10	9	16.35	0.44	3.37	0.29	215	57	83	140
11	10	16.35	0.48	3.37	0.30	246	57	81	138
12	11	16.35	0.52	3.37	0.33	275	58	80	138
13	12	16.35	0.55	3.37	0.35	303	59	80	139
14	13	16.33	0.59	3.39	0.38	335	60	79	138
15	14	16.30	0.63	3.41	0.41	367	60	78	138
16	15	16.30	0.67	3.41	0.47	401	61	77	138
17	16	16.30	0.70	3.41	0.53	434	61	77	138
18	17	16.25	0.74	3.45	0.64	468	62	76	138
19	18	16.20	0.78	3.49	0.75	502	62	76	138

Table AII-38 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 1.0 Amp.

NO	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
1	0	15.60	0.06	3.93	0.16	5	23	198	221
2	1	15.55	0.08	3.97	0.16	7	31	180	211
3	2	15.50	0.11	4.00	0.17	9	34	161	195
4	3	15.50	0.15	4.00	0.17	24	36	149	185
5	4	15.50	0.19	4.00	0.18	38	40	136	176
6	5	15.50	0.23	4.00	0.18	56	50	129	179
7	6	15.50	0.26	4.00	0.19	74	59	122	181
8	7	15.50	0.30	4.00	0.22	97	62	117	178
9	8	15.50	0.34	4.00	0.22	120	64	111	175
10	9	15.50	0.37	4.00	0.23	142	66	108	174
11	10	15.50	0.40	4.00	0.24	163	68	105	173
12	11	15.50	0.43	4.00	0.25	185	69	104	173
13	12	15.50	0.45	4.00	0.27	206	70	102	172
14	13	15.45	0.48	4.04	0.29	231	72	100	172
15	14	15.40	0.51	4.08	0.30	255	73	98	171
16	15	15.40	0.54	4.08	0.30	280	74	97	171
17	16	15.40	0.57	4.08	0.31	305	75	96	171
18	17	15.35	0.60	4.12	0.32	329	76	95	171
19	18	15.30	0.63	4.15	0.33	353	77	93	170

Table AII-39 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 1.5 Amp.

NO	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
1	0	13.20	0.05	5.71	0.15	4	19	240	259
2	1	13.15	0.07	5.75	0.19	5	25	228	253
3	2	13.10	0.08	5.78	0.20	7	30	216	246
4	3	13.13	0.11	5.76	0.20	15	34	207	241
5	4	13.15	0.14	5.75	0.21	23	37	198	235
6	5	13.15	0.16	5.75	0.21	35	41	193	234
7	6	13.15	0.19	5.75	0.22	47	44	189	233
8	7	13.18	0.21	5.75	0.22	60	46	185	231
9	8	13.20	0.24	5.75	0.23	74	48	181	229
10	9	13.13	0.26	5.75	0.23	87	49	180	229
11	10	13.05	0.28	5.75	0.24	100	50	179	229
12	11	13.05	0.30	5.78	0.24	114	52	178	230
13	12	13.05	0.32	5.82	0.25	128	54	177	231
14	13	13.05	0.35	5.82	0.26	143	55	175	230
15	14	13.05	0.37	5.82	0.27	159	57	174	231
16	15	13.08	0.39	5.80	0.28	174	58	173	231
17	16	13.10	0.41	5.79	0.29	190	59	173	232
18	17	13.05	0.42	5.82	0.30	205	58	166	224
19	18	13.00	0.44	5.86	0.31	221	58	158	216

Table AII-40 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
2- Speed: 1500 rpm
3- Load: at 2.0 Amp.

NO	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
1	0	10.80	0.04	7.49	0.13	2	15	282	297
2	1	10.75	0.05	7.53	0.20	3	17	277	294
3	2	10.70	0.05	7.56	0.20	4	19	271	290
4	3	10.75	0.07	7.53	0.20	6	22	266	288
5	4	10.80	0.08	7.49	0.20	8	25	260	285
6	5	10.80	0.10	7.49	0.20	14	27	258	285
7	6	10.80	0.11	7.49	0.20	19	29	255	284
8	7	10.85	0.13	7.49	0.21	24	31	253	284
9	8	10.90	0.14	7.49	0.21	28	33	251	284
10	9	10.75	0.15	7.49	0.21	32	33	252	285
11	10	10.60	0.16	7.49	0.21	36	33	253	286
12	11	10.60	0.18	7.57	0.21	43	35	253	288
13	12	10.60	0.19	7.64	0.21	50	38	252	290
14	13	10.65	0.21	7.60	0.22	56	39	251	290
15	14	10.70	0.22	7.56	0.22	62	41	249	290
16	15	10.75	0.23	7.53	0.23	69	42	250	292
17	16	10.80	0.25	7.49	0.23	75	43	250	293
18	17	10.75	0.25	7.53	0.23	82	40	237	277
19	18	10.70	0.25	7.56	0.23	88	39	223	262

Table AII-61 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel/DMM without and with Hydrogen Induction
2- Speed: 1500 rpm
3- Load: at No Load

Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B.Th.}$)						Volumetric Efficiency ($\eta_{Vol.}$)						ϕ	BSEC MJ/kWh	T_{exh} (°C)	
		Brake Power (BP)		Input Power (IP)				$\eta_{B.Th.}$ (%)	ρ_{air}	V_{actual}			$V_{swept} \times 10^{-3}$ (m ³ /s)				$\eta_{Vol.}$ (%)
		BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	(kJ)	(kJ)	IP (W)			T_{am} (°C)	ρ_{air} (kg/m ³)	S (mm)					
0	0.00	0	0	260	11.06	0.00	11056	0	28.48	1.15	184	18.99	16.50	18.61	88.67	0	87.88
7	9.78	0	0	228	9.68	1.17	10853	0	28.88	1.15	175	18.50	16.10	18.61	86.53	0	89.90
8	11.17	0	0	224	9.51	1.34	10851	0	28.95	1.15	174	18.45	16.06	18.61	86.29	0	90.80
0	0.00	0	0	267*	10.90*	0.00	10909	0	28.34	1.16	77	12.32	10.57	12.41	85.21	0	89.78
7	9.78	0	0	235*	9.59*	1.17	9602	0	28.67	1.15	67	11.46	10.07	12.41	81.13	0	91.12
8	11.17	0	0	231*	9.43*	1.34	9438	0	28.71	1.15	66	11.37	9.99	12.41	80.53	0	92.56

- The Values of m_f , E_f are calculated depends on 90% diesel + 10% DMM

Table AII-62 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel/DMM without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: At 0.5 Amps.

Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B,Th}$)						Volumetric Efficiency ($\eta_{vol.}$)						BSEC MJ/kWh	ϕ	T _{exh} (°C)		
		Brake Power (BP)		Input Power (IP)				$\eta_{B,Th.}$ (%)	ρ_{air}		V _{actual}						V _{swept} $\times 10^3$ (m ³ /s)	$\eta_{vol.}$ (%)
		BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	(kJ)	I (W)	IP (W)				S (mm)	$\dot{m}_a \times 10$ (kg/s)	V _{actual} $\times 10^3$ (m ³ /s)					
$\dot{m}_{H_2} \times 10^6$ (l/min)																		
0	0.00	30.21	1091	299	12.70	0.00	12698	8.59							18.61	88.72	41.89	102.14
7	9.78	32.86	1197	275	11.69	1.17	12865	9.31							18.61	86.65	38.68	105.94
8	11.17	33.16	1201	272	11.55	1.34	12888	9.32							18.61	86.49	38.63	104.64
0	0.00	29.71	1073	307*	12.53*	0.00	12543	8.55							18.61	88.72	42.09	104.45
7	9.78	32.36	1169	283*	11.55*	1.17	11563	10.11							18.61	86.65	35.62	107.13
8	11.17	32.66	1179	280*	11.43*	1.34	11440	10.31							18.61	86.49	34.92	107.00

- The Values of m_f , E_f are calculated depends on 90% diesel + 10% DMM

Table AII-63 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel/DMM without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 1.0 Amps.

Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B,Th}$)						Volumetric Efficiency (η_{vol})						BSEC MJ/kWh	ϕ	T^{exh} (°C)			
		Brake Power (BP)			Input Power (IP)			$\eta_{B,Th}$ (%)	P_{air}			V_{actual}					$V_{swept} \times 10^3$ (m ³ /s)	η_{vol} (%)	
		BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	(kJ)	(kJ)	IP (W)		T_{am} (°C)	ρ_{air} (kg/m ³)	S (mm)	$\dot{m}_{a_3} \times 10^3$ (kg/s)	$V_{actual} \times 10^3$ (m ³ /s)						
(l/min)	$\dot{m}_{H_2} \times 10^6$ (Kg/s)																		
0	0.00	70.63	2551	419	17.80	0.00	17797.59	14.33	28.52	1.15	182	18.88	16.41	18.61	88.19	25.12	121.75		
7	9.78	72.89	3446	369	15.68	1.17	16850.79	20.45	28.40	1.15	172	18.33	15.93	18.61	85.59	23.05	131.36		
8	11.17	73.18	2632	366	15.56	1.34	16900.68	20.47	28.36	1.15	171	18.31	15.91	18.61	85.46	23.02	130.80		
0	0.00	70.13	2533	426*	17.39*	0.00	17405	14.45	29.03	1.15	182	18.88	16.41	18.61	88.19	24.74	123.33		
7	9.78	72.39	2614	376*	15.35*	1.17	15363	16.90	29.34	1.15	172	18.33	15.93	18.61	85.59	21.16	133.12		
8	11.17	72.68	2625	373*	15.22*	1.34	15240	17.10	29.87	1.15	171	18.31	15.91	18.61	85.46	20.90	133.78		

- The Values of m_f , E_f are calculated depends on 90% diesel + 10% DMM

Table AII-64 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 1.5 Amp

Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B.Th.}$)						Volumetric Efficiency ($\eta_{vol.}$)						BSEC MJ/kWh	ϕ	T^{exh} ($^{\circ}C$)	
		Brake Power (BP)		Input Power (IP)				ρ_{air}		V_{actual}			$V_{swept} \times 10^3$ (m ³ /s)				$\eta_{vol.}$ (%)
		BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	(kJ)	(kJ)	IP (W)	$\eta_{B.Th.}$ (%)	T_{atm} ($^{\circ}C$)	ρ_{air} (kg/m ³)	S (mm)	$\dot{m}_{a,3} \times 10$ (kg/s)					
0	0.00	166.77	6023	666	28.32	0.00	28321	21.27	25.19	1.16	180	18.88	16.23	18.61	87.22	16.93	171.34
7	9.78	169.71	6129	609	25.89	1.17	27065	22.65	26.54	1.16	170	18.31	15.81	18.61	84.95	15.90	178.93
8	11.17	169.81	6133	603	25.62	1.34	26961	22.75	26.54	1.16	169	18.25	15.76	18.61	84.70	15.83	180.00
0	0.00	166.27	6005	674*	27.51*	0.00	27538	21.80	26.78	1.16	180	18.88	16.23	18.61	87.22	16.51	173.65
7	9.78	169.21	6111	615*	25.10*	1.17	25128	24.32	26.54	1.16	170	18.31	15.81	18.61	84.95	14.80	180.45
8	11.17	169.31	6114	611*	24.94*	1.34	24964	24.49	26.11	1.16	169	18.25	15.76	18.61	84.70	14.70	180.90

• The Values of m_f , E_f are calculated depends on 90% diesel + 10% DMM

Table AII-65 Thermal Performance Data from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 2.0Amps.

Hydrogen Induction Rate		Brake Thermal Efficiency ($\eta_{B.Th.}$)						Volumetric Efficiency ($\eta_{vol.}$)						BSEC MJ/kWh	ϕ	T _{exh} (°C)		
		Brake Power (BP)			Input Power (IP)			$\eta_{B.Th.}$ (%)	ρ_{air}			V_{actual}					$V_{swept} \times 10^3$ (m ³ /s)	$\eta_{vol.}$ (%)
		BF (N)	BP (W)	$\dot{m}_f \times 10^6$ (kg/s)	(kJ)	(kJ)	IP (W)		T _{atm} (°C)	ρ_{air} (kg/m ³)	S (mm)	$\dot{m}_{a_3} \times 10^3$ (kg/s)	$V_{actual} \times 10^3$ (m ³ /s)					
$\dot{m}_{H_2} \times 10^6$ (K·g/s)	(l/min)																	
0	0	0.00	235.44	8503	780	33.13	0.00	33130	25.66	25.19	1.16	177	18.72	16.10	18.61	86.49	242.89	
7	7	9.78	237.79	8588	723	30.71	1.17	31886	26.93	26.54	1.16	170	18.31	15.81	18.61	84.95	250.12	
8	8	11.17	237.89	8591	717	30.45	1.34	31793	27.02	26.54	1.16	168	18.20	15.72	18.61	84.45	250.99	
0	0	0.00	235.04	8488	788*	32.16*	0.00	32196	26.36	26.60	1.16	177	18.72	16.10	18.61	86.49	244.29	
7	7	9.78	237.39	8573	730*	29.80*	1.17	29826	28.74	26.74	1.16	170	18.31	15.81	18.61	84.95	252.42	
8	8	11.17	237.49	8577	725*	29.59*	1.34	29622	28.95	26.84	1.16	168	18.20	15.72	18.61	84.45	252.78	

- The Values of m_f , E_f are calculated depends on 90% diesel + 10% DMM

Table AII-86 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at No Load

	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
Without DMM	0	17.30	0.07	2.67	0.18	23	26	120	146
	7	17.25	0.41	2.71	0.28	213	47	62	110
	8	17.20	0.46	2.74	0.29	246	48	60	110
With DMM	0	17.40	0.06	2.57	0.17	24	27	121	148
	7	17.30	0.28	2.64	0.24	211	47	62	109
	8	17.27	0.30	2.65	0.26	243	48	62	110

Table AII-87 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 0.5 Amp.

	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
Without DMM	0	16.45	0.06	3.30	0.18	14	25	159	184
	7	16.38	0.36	3.35	0.26	155	46	89	135
	8	16.35	0.40	3.37	0.27	183	57	86	143
With DMM	0	16.60	0.06	2.85	0.17	11	26	160	186
	7	16.50	0.31	2.90	0.23	137	44	88	132
	8	16.45	0.35	2.95	0.25	168	55	86	141

Table AII-88 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual

Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 1.0 Amp.

	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
Without DMM	0	15.60	0.06	3.93	0.16	5	23	198	221
	7	15.50	0.30	4.00	0.22	97	62	117	178
	8	15.50	0.34	4.00	0.22	120	64	111	175
With DMM	0	15.70	0.05	3.75	0.14	4	24	195	219
	7	15.60	0.24	3.9	0.19	89	60	116	176
	8	15.50	0.26	3.94	0.20	110	60	112	172

Table AII-89 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual

Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 1.5 Amp.

	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
Without DMM	0	13.20	0.05	5.71	0.15	4	19	240	259
	7	13.18	0.21	5.75	0.22	60	46	185	231
	8	13.20	0.24	5.75	0.23	74	48	181	229
With DMM	0	13.30	0.04	5.64	0.13	3	25	235	260
	7	13.20	0.18	5.68	0.20	56	47	183	230
	8	13.10	0.20	5.68	0.21	71	48	182	230

TableAII-90 Constituent Gases of Exhaust Emission from Compression Ignition Engine Running on Hydrogen – Diesel Dual Fuel

- 1- Fuel: Diesel without and with Hydrogen Induction
- 2- Speed: 1500 rpm
- 3- Load: at 2.0 Amp.

	Hydrogen induction rate (l/min)	O ₂ (%)	CO (%)	CO ₂ (%)	HC (CH ₄) (%)	SO ₂ (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
Without DMM	0	10.80	0.04	7.49	0.20	2	15	282	297
	7	10.85	0.13	7.49	0.21	24	31	253	284
	8	10.90	0.14	7.49	0.21	28	33	251	284
With DMM	0	10.90	0.03	7.44	0.18	1	18	283	301
	7	10.80	0.08	7.45	0.19	22	31	252	283
	8	10.70	0.09	7.45	0.19	24	33	250	283