

LIST OF FIGURES

Figure 1.1	Agriculture cultivation in India [1].....	1
Figure 1.2	Sequence of compression, combustion and expansion processes of a naturally aspirated compression ignition engine [3].....	2
Figure 1.3	Common types of Combustion Chambers of Direct Injection Systems	3
Figure 1.4	Common types of Combustion Chambers in IDI engines	4
Figure 1.5	Swirl type Combustion Chamber of selected IDI engine.....	6
Figure 1.6	Adiabatic flame temperature for H ₂ -Air mixture [13-15]	10
Figure 1.7	Laminar flame velocity for (—) hydrogen, oxygen and nitrogen mixtures and (°, - -) gasoline and air mixtures [13-15].....	10
Figure 1.8	Minimum Ignition energy of H ₂ –Air mixture	11
Figure 2.1	Cecil developed hydrogen engine	25
Figure 2.2	BTE vs. Hydrogen mass share of a Jatropa based SVO	29
Figure 2.3	Variation of SEC with Load.....	30
Figure 2.4	Variation of BTE with Load	30
Figure 2.5	Variation of HC with Load	30
Figure 2.6	Variation of Smoke with Load	30
Figure 2.7	Variation of CO with Load	31
Figure 2.8	Variation of Peak Pressure with Load	31
Figure 2.9	Apparent Heat release rate curve showing the fraction of heat release corresponding to pre-mixed burn	36
Figure 2.10	Effect of H ₂ addition on heat release rate at 70% Load.....	38
Figure 2.11	Cylinder pressure and rate of heat release for ULSD.	39
Figure 2.12	Minimum ignition energy of hydrogen in air as a function of air composition by % volume.....	41
Figure 2.13	Typical cylinder and intake manifold pressure traces with pre-ignition (solid lines), compared to regular pressure traces (dotted lines) [30].....	41
Figure 2.14	Continuous carburetion technique	43
Figure 2.15	Manifold induction or injection technique.....	44
Figure 2.16	Direct cylinder injection technique.....	45
Figure 3.1	Schematic diagram of experimental set up	58
Figure 3.2	Photographic view of experimental set up	59
Figure 3.3	Pictorial representation of selected engine.....	59
Figure 3.4	Cantilever based self-starting system	60
Figure 3.5	The cut sectional view of eddy-current dynamometer.....	60
Figure 3.6	Rack control mechanism to run the engine at constant speed.....	61
Figure 3.7	Smoke Meter and 5 Gas Analyzer.....	63
Figure 3.8	Schematic diagram of sampling system.....	63
Figure 3.9	Photographic view of sampling system	63
Figure 3.10	Fuel line Modifications	64
Figure 3.11	GH15DK Pressure Transducer	65

Figure 3.12	Photographic view of the Pressure Transducer mounting position on the cylinder head of the engine	66
Figure 3.13	Cut –Sectional view of Pressure Transducer mounting position on the cylinder head of the engine	66
Figure 3.14	Crank Angle Encoder	67
Figure 3.15	Mounting of AVL CA Encoder on Engine	67
Figure 3.16	AVL Indi smart 612 advanced combustion analyzer.....	67
Figure 3.17	Schematic diagram of gaseous hydrogen supply system	68
Figure 3.18	Pictorial representation of gaseous hydrogen supply system	68
Figure 4.1	BTE Vs. Load for conventional diesel.....	74
Figure 4.2	BSEC Vs. Load for conventional diesel	74
Figure 4.3	NO _x Vs. Load for conventional diesel	75
Figure 4.4	Smoke Vs. Load for conventional diesel	75
Figure 4.5	CO Vs. Load for conventional diesel	75
Figure 4.6	HC Vs Load for conventional diesel	75
Figure 4.7	Cylinder pressure as function of CA deg. for conventional diesel	76
Figure 4.8	DHRR Vs. Load for conventional diesel	76
Figure 4.9	ID as a function of load for conventional diesel.....	76
Figure 4.10	BTE Vs. Load for PHSVO 90.....	77
Figure 4.11	BSEC Vs. Load for PHSVO 90.....	77
Figure 4.12	NO _x Vs. Load for PHSVO 90	78
Figure 4.13	Smoke Vs. Load for PHSVO 90	78
Figure 4.14	CO Vs. Load for PHSVO 90.....	78
Figure 4.15	HC Vs. Load for PHSVO 90.....	78
Figure 4.16	Cylinder pressure is a function of CA deg. for PHSVO 90	79
Figure 4.17	DHRR Vs. CA deg. for PHSVO 90.....	79
Figure 4.18	Ignition delay is a function of % of Load	79
Figure 4.19	Comparison of Brake Thermal Efficiency for base line conventional Diesel with PHSVO 90.....	80
Figure 4.20	Comparison of Brake Specific Energy Consumption for base line conventional Diesel with PHSVO 90	81
Figure 4.21	Comparison of NO _x for base line conventional Diesel with PHSVO 90	81
Figure 4.22	Comparison of Smoke for base line conventional Diesel with PHSVO 90.....	82
Figure 4.23	Comparison of CO for base line conventional Diesel with PHSVO 90	82
Figure 4.24	Comparison of HC for base line conventional Diesel with PHSVO 90	83
Figure 4.25	Comparison of Cylinder Pressure for base line conventional Diesel with PHSVO 90	83
Figure 4.26	Comparison of DHRR of base line conventional Diesel with PHSVO 90	84
Figure 4.27	Comparison of Ignition delay of base line conventional Diesel with PHSVO 90	84
Figure 4.28	BTE Vs. Load for PHSVO 90 with GH ₂ Supplementation.....	85

Figure 4.29	BTE Vs. Load for PHSVO 90 with GH ₂ Supplementation at 80% Load	86
Figure 4.30	BSEC Vs. Load for PHSVO 90 with GH ₂ Supplementation	87
Figure 4.31	BSEC Vs. Load for PHSVO 90 with GH ₂ Supplementation at 80% Load.....	87
Figure 4.32	NO _x Vs. Load for PHSVO 90 with GH ₂ Supplementation	88
Figure 4.33	NO _x Vs. Load for PHSVO 90 with GH ₂ Supplementation at 80% Load.....	88
Figure 4.34	Smoke Vs. Load for PHSVO 90 with GH ₂ Supplementation	89
Figure 4.35	Smoke Vs. Load for PHSVO 90 with GH ₂ Supplementation at 80% Load.....	89
Figure 4.36	CO Vs. Load for PHSVO 90 with GH ₂ Supplementation.....	90
Figure 4.37	CO Vs. Load for PHSVO 90 with GH ₂ Supplementation at 80% load	90
Figure 4.38	HC Vs. Load for PHSVO 90 with GH ₂ Supplementation.....	91
Figure 4.39	HC Vs. Load for PHSVO 90 with GH ₂ Supplementation at 80% Load	91
Figure 4.40	P-θ for different GH ₂ supplementations of PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20° bTDC Injection Timing and 175 bar Injection Pressure.....	92
Figure 4.41	Pmax for different GH ₂ supplementations of PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20° bTDC Injection Timing and 175 bar Injection Pressure	93
Figure 4.42	DHRR Vs. CA of different GH ₂ supplementations for PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20° bTDC Injection Timing 175 bar Injection Pressure.....	93
Figure 4.43	Ignition delay Vs. Load of different GH ₂ supplementations for PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20° bTDC Injection Timing 175 bar Injection Pressure	94
Figure 4.44	Ignition delay Vs. Load of different supplementations for PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20° bTDC Injection Timing 175 bar Injection Pressure at 80% Load.....	94
Figure 4.45	BTE Vs. Load, at 20° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min)	96
Figure 4.46	BTE Vs. Load, at 20° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min) at 80% Load.....	96
Figure 4.47	BSEC Vs. Load, at 20° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min)	97
Figure 4.48	BSEC Vs. Load, at 20° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min) at 80% Load.....	97
Figure 4.49	BTE Vs. Load, at 22° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min)	97
Figure 4.50	BTE Vs. Load, at 22° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min) at 80% Load.....	97
Figure 4.51	BSEC Vs. Load, at 22° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min)	98

Figure 4.52	BSEC Vs. Load, at 22° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min) at 80% Load.....	98
Figure 4.53	BTE Vs. Load, at 24° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min)	98
Figure 4.54	BTE Vs. Load, at 24° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min) at 80% load	98
Figure 4.55	BSEC Vs Load, at 24° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min)	99
Figure 4.56	BSEC Vs Load, at 24° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min) at 80% Load.....	99
Figure 4.57	BTE Vs. Load, at 26° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min)	99
Figure 4.58	BTE Vs. Load, at 26° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min) at 80% Load.....	99
Figure 4.59	BSEC Vs. Load, at 26°bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min)	100
Figure 4.60	BSEC Vs. Load, at 26° bTDC Injection Timing, 175 bar Injection Pressure and GH ₂ supplementation (0.4- 0.7 gm/min) at 80% load	100
Figure 4.61	BTE Vs. Load Comparison of different Injection Timings (20°-26° bTDC) at 175 bar Injection Pressure for 0.5gm/min GH ₂ supplementation with PHSVO 90	101
Figure 4.62	BTE Vs. Load Comparison of different Injection Timings (20°-26° bTDC) at 175 bar Injection Pressure for 0.5gm/min GH ₂ supplementation with PHSVO 90 at 80% Load.....	101
Figure 4.63	BSEC Vs. Load Comparison of different Injection Timings (20°-26° bTDC) at 175 bar Injection Pressure for 0.5gm/min GH ₂ supplementation with PHSVO 90	101
Figure 4.64	BSEC Vs. Load Comparison of different Injection Timings (20°-26° bTDC) at 175 bar Injection Pressure for 0.5gm/min GH ₂ supplementation with PHSVO 90 at 80% Load.....	101
Figure 4.65	NO _x Vs. different Injection Timings at 0.4 – 0.7 gm/min GH ₂ supplementations and 80% load.....	102
Figure 4.66	Smoke Vs. different Injection Timings at 0.4-0.7 gm/min GH ₂ supplementations and 80% load.....	103
Figure 4.67	CO Vs different Injection Timings at 0.4-0.7 gm/min GH ₂ supplementations and 80% load.....	104
Figure 4.68	HC Vs. different Injection Timings at 0.4-0.7 gm/min GH ₂ supplementations 80% load	104
Figure 4.69	P-θ for different Injection Timings.....	105
Figure 4.70	Pmax for different injection Timings at 80% load	105
Figure 4.71	Differential Heat Release Rate for differential Injection Timings	106
Figure 4.72	Ignition Delay for different Injection Timings.....	107

Figure 4.73	BTE for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min GH ₂ supplementation	109
Figure 4.74	BTE for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min GH ₂ supplementation t 80% load.....	109
Figure 4.75	BSEC for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min GH ₂ supplementation	110
Figure 4.76	BSEC for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min GH ₂ supplementation at 80% load.....	110
Figure 4.77	NO _x for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load	111
Figure 4.78	Smoke for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load	111
Figure 4.79	CO for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load	112
Figure 4.80	HC for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load	112
Figure 4.81	Cylinder Pressure for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation	113
Figure 4.82	Pmax for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load	113
Figure 4.83	DHRR for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load	114
Figure 4.84	Ignition delay for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load	114
Figure 4.85	Comparison of BTE of optimized data with base line data.....	116
Figure 4.86	Comparison of BTE of optimized data with base line data at 80% load	116
Figure 4.87	Comparison of BSEC of optimized data with base line data	117
Figure 4.88	Comparison of BSEC of optimized data with base line data at 80% load	117
Figure 4.89	Comparison of NO _x of optimized data with baseline data	117
Figure 4.90	Comparison of Smoke of Optimized data with baseline data	118
Figure 4.91	Comparison of CO of optimized data with baseline data	118
Figure 4.92	Comparison of HC of optimized data with baseline data	119
Figure 4.94	Comparison of P-θ of optimized data with Baseline data at 80% load.....	119
Figure 4.93	Comparison of P-θ of optimized data with Baseline data.....	119
Figure 4.95	Comparison of Differential Heat Release Rate of Optimized data with baseline data.....	120
Figure 4.96	Comparison of Ignition Delay of Optimized data with base line data.....	120