CHAPTER 4

RESULTS & DISCUSSIONS

This chapter deals with the results of engine experimentation as discussed earlier. Engine was primarily experimented with conventional diesel was considered as a baseline data and then extended experimentation with different fuels like; Jatropa based pre-heated straight vegetable oil at 90^{o}C (PHSVO 90), PHSVO 90 supplemented with gaseous hydrogen (GH_2) along with varying injection timings and injection pressures. The results were discussed in the following sub sections of this chapter.

Experimental results are discussed in three categories like; performance parameters exhaust emissions and combustion characteristics with all three fuel combinations.

The results of the conventional diesel were discussed below.

4.1. BASELINE DATA GENERATION WITH CONVENTIONAL DIESEL

4.1.1. Performance Parameters

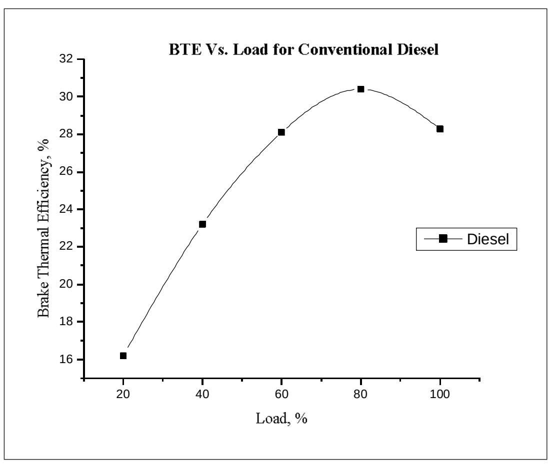


Figure 4.1 BTE Vs. Load for conventional diesel

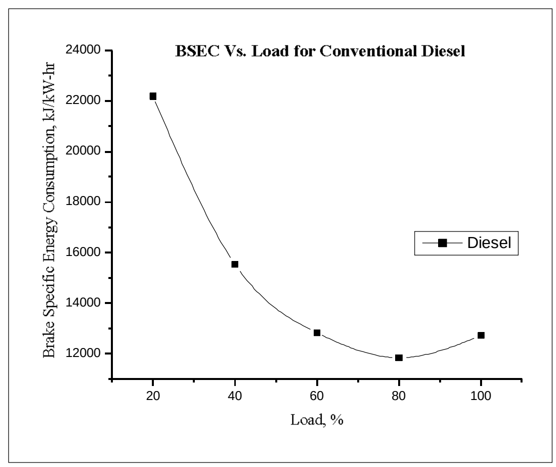


Figure 4.2 BSEC Vs. Load for conventional diesel

Performance parameter results of the engine with diesel fuel are shown in Figure 4.1. From the Figure 4.1, it is clearly seen that, with increasing load, brake thermal efficiency was linearly increased up to 80% load and later starting decreasing. Maximum brake thermal efficiency of 30.42% was experienced at 80% load and at the same point the brake specific energy consumption was 11834.6 kJ/kW-hr is the lowest among all other loading conditions as shown in Figure 4.2. The decrease in brake thermal efficiency at full load is due to higher surface to volume ratio of divided chamber IDI engine, results higher heat transfer compared to open chambers and higher pumping losses and fluid dynamic losses leads to reduction of thermal efficiency at full load conditions.

4.1.2. Exhaust Emissions

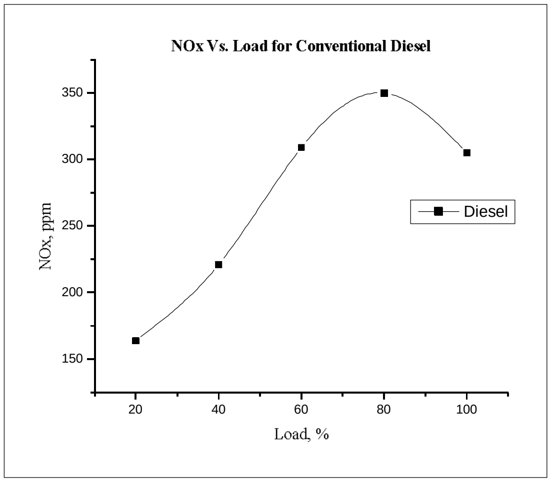


Figure 4.3 NO_x Vs. Load for conventional diesel

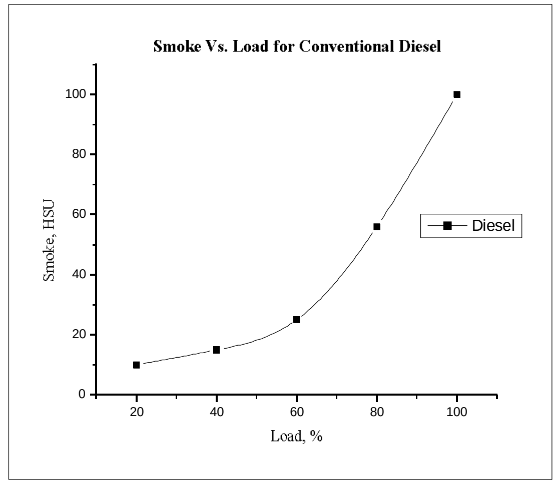


Figure 4.4 Smoke Vs. Load for conventional diesel

Figure 4.3 clearly shown that, as the load increased, NO_x increased up to maximum efficiency point and later the same was decreasing at full load due to deteriorated combustion causing reduction in combustion temperature leads to reduction of NO_x. At maximum efficiency point, NO_x was recorded as 350 ppm. The rise in NO_x is because as load increases, the mixture becomes richer causing rise in combustion chamber temperature, which is a favorable situation to get N_2 to react with O_2 and subsequently forms higher NO_x. Further, as shown in Figures 4.4, 4.5 and 4.6 Smoke, CO and HC were increased with increasing load due to increase of consumption of diesel leads to increase in these emissions. At maximum efficiency point, the smoke is 56 HSU, CO is 0.09% by volume and HC is 10 ppm.

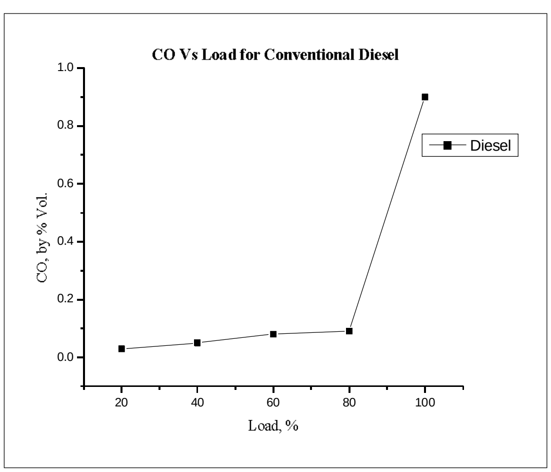


Figure 4.5 CO Vs. Load for conventional diesel

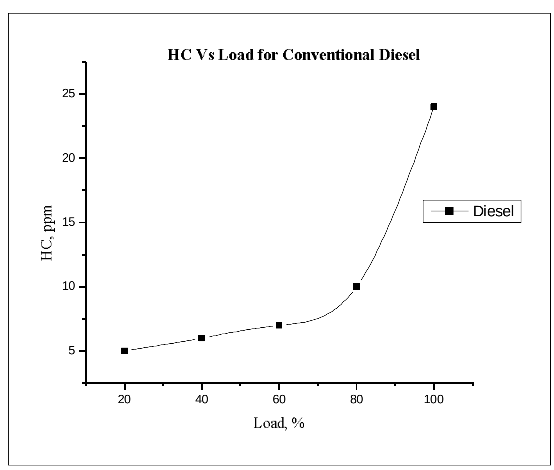


Figure 4.6 HC Vs Load for conventional diesel

4.1.3. Combustion characteristics

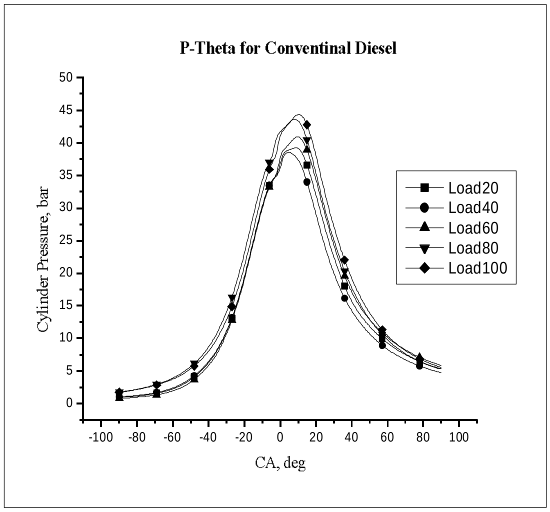


Figure 4.7 Cylinder pressure as function of CA deg. for conventional diesel

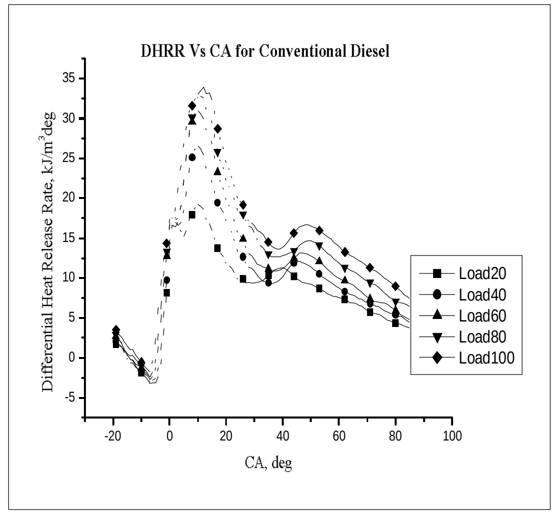


Figure 4.8 DHRR Vs. Load for conventional diesel

From the Figure 4.7 the cylinder pressure is increasing with increased load. At maximum efficiency point, cylinder pressure was observed to be 43.615 bar experienced at 8.5^{o} CA aTDC. Further, with respect to heat release rate as load increases, both pre-combustion and diffusion combustion phases were increased due to increase of mass of fuel burned as showed in Figure 4.8. Whereas ignition delay from Figure 4.9 was decreased with increasing load due to increase of combustion chamber temperature because of increased mass of fuel burned with increased load.

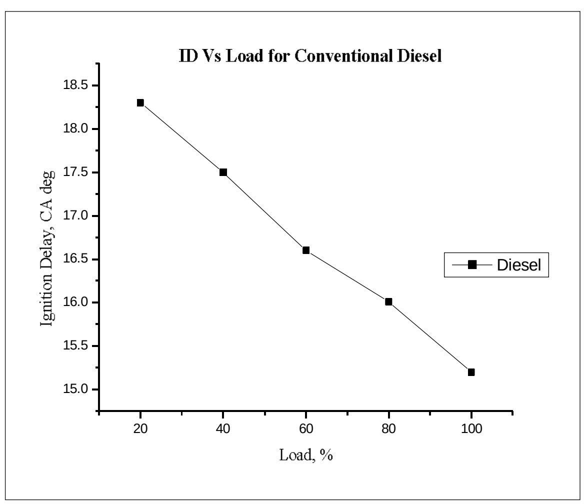


Figure 4.9 ID as a function of load for conventional diesel

It was observed from the above investigation of the selected unmodified engine fuelled with conventional diesel fuel that, maximum brake thermal efficiency was 30.42% at 80% load and at the same point brake specific energy consumption was identified to be minimum of 11834.6 kJ/kW-hr. NO_x was higher at the same maximum efficiency point of 350 ppm. Whereas Smoke, CO and HC were identified that 56 HSU, 0.09% by volume and 10 ppm respectively. Further, both the combustion phases were increased and ignition delay were decreased with increased. At 80% load i.e., maximum efficiency point, ignition delay was recorded as 16.01deg.CA.

4.2. DATA GENERATION WITH PRE-HEATED JATROPA BASED STRAIGHT VEGETABLE OIL AT 90°C (PHSVO 90)

In this section, the same engine was experimented with Jatropa based straight vegetable oil. As the viscosity of the oil is very high at room temperature, the selected straight vegetable oil was pre-heated to 90^{o} C (PHSVO 90) [138], to just make the viscosity comparable to conventional diesel [149] through a heat exchanger connected to the exhaust manifold. The use of straight vegetable oil in this unmodified engine was investigated with respect to performance, emissions and combustion characteristics point of view in the following sections:

4.2.1. Performance Parameters

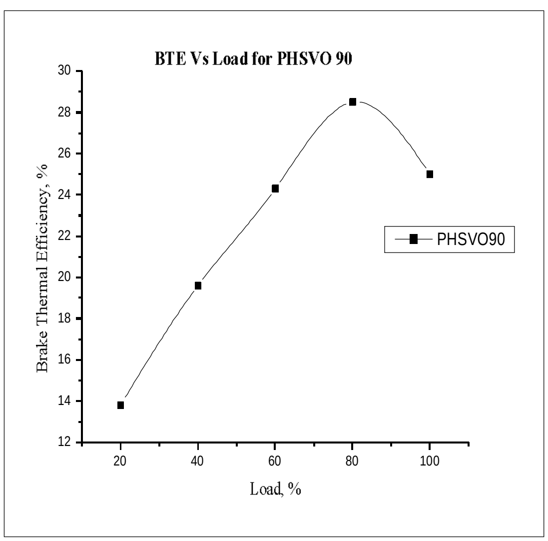


Figure 4.10 BTE Vs. Load for PHSVO 90

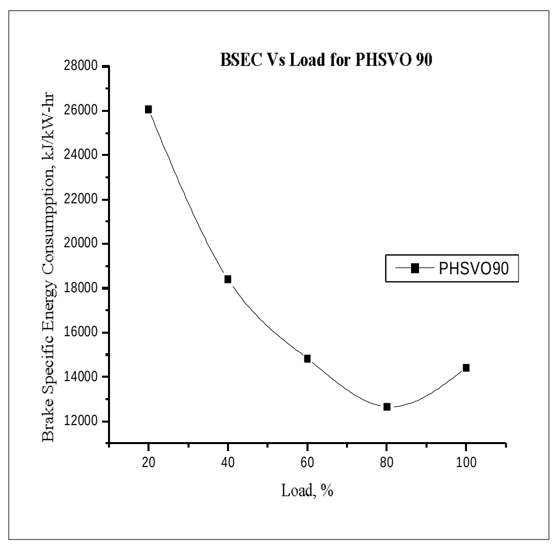


Figure 4.11 BSEC Vs. Load for PHSVO 90

From the Figure 4.10, it was seen that, with increasing load, the brake thermal efficiency was linearly increased up to 80% load and the same was decreased at full load due to high surface to volume ratio of IDI engines. At 80% load, maximum brake thermal efficiency was 28.46% and this point the brake specific energy consumption was 12649.8 kJ//kW-hr as shown in Figure 4.11 is the lowest among others. The reduction in brake thermal efficiency, subsequently hike in BSEC is due to lower heating value and poor combustion caused by the coarser atomization of PHSVO 90.

4.2.2. Exhaust Emissions

From the Figure 4.12 it was seen that, as the load is increased NO_x got increased up to maximum efficiency point and later the same was decreased at full load due to deteriorated combustion causing reduction in combustion temperature leads to reduction of NO_x. At 80% load, i.e., maximum efficiency point, NO_x was recorded as 291 ppm. Further, as shown in Figures 4.13, 4.14 and 4.15 Smoke, CO and HC were increased with increasing load due to increase of consumption of PHSVO 90 leads to increase in these emissions. At maximum efficiency point, the smoke was 67 HSU, CO was 0.2% by vol. and HC was 15 ppm respectively.

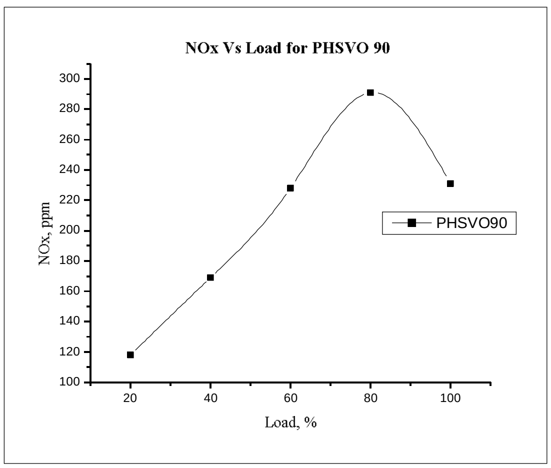


Figure 4.12 NO_x Vs. Load for PHSVO 90

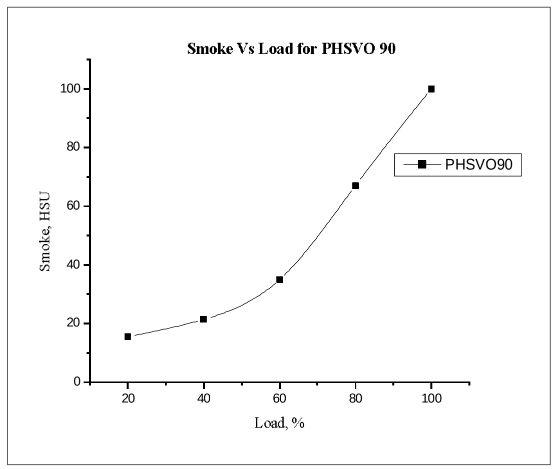


Figure 4.13 Smoke Vs. Load for PHSVO 90

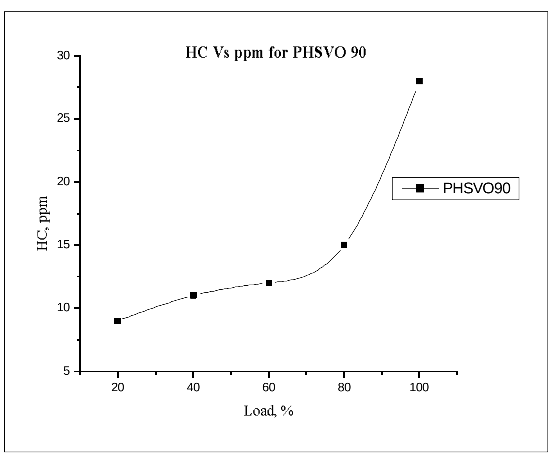


Figure 4.14 CO Vs. Load for PHSVO 90

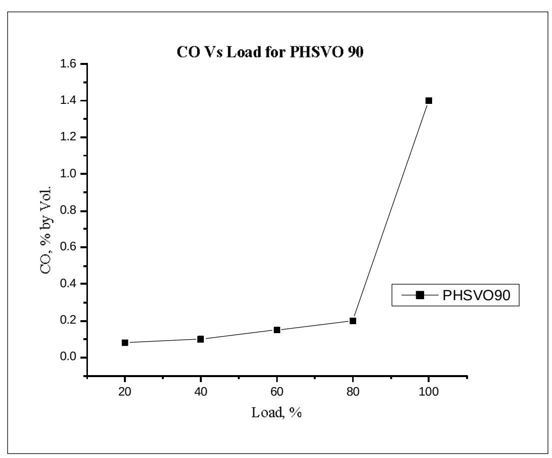


Figure 4.15 HC Vs. Load for PHSVO 90

4.2.3. Combustion Characteristics

From the Figure 4.16, the cylinder pressure is increasing with increased load. At maximum efficiency point, cylinder pressure was observed to be 40.98 bar at 11^{o} CA aTDC. Further, with respect to heat release rate as load increases, both pre-combustion and diffusion combustion phases were increased due to increase of mass of fuel burned as shown in Figure 4.17 Whereas ignition delay as shown in Figure 4.18 was decreased with increasing load due to increase of combustion chamber temperature because of increased mass of fuel burned with increased load.

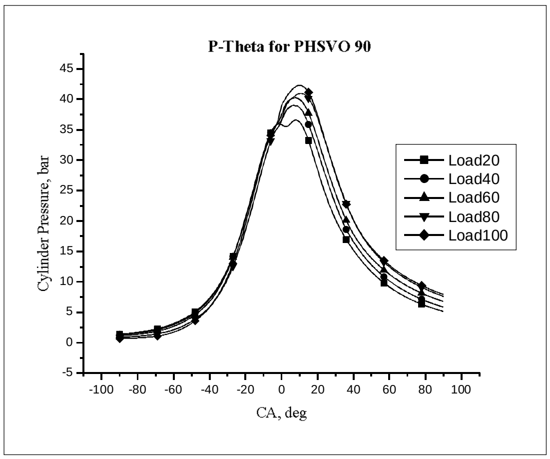


Figure 4.16 Cylinder pressure is a function of CA deg. for PHSVO 90

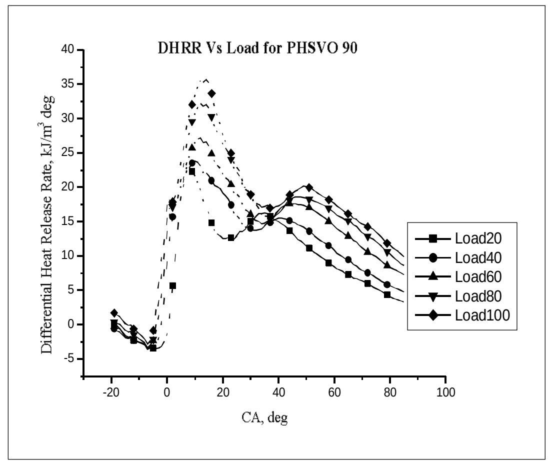


Figure 4.17 DHRR Vs. CA deg. for PHSVO 90

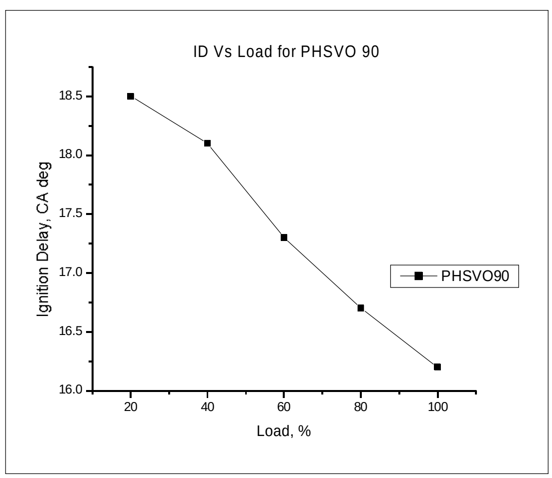


Figure 4.18 Ignition delay is a function of % of Load

It is observed from this investigation of the selected unmodified engine fuelled with conventional diesel that, maximum brake thermal efficiency was 28.46 % at 80% load and at the same point brake specific energy consumption was identified to be minimum of

12649.8 kJ/kW-hr. NO_x also got higher at the same maximum efficiency point of 291 ppm. Whereas, Smoke, CO and HC were identified that 67 HSU, 0.2 % by volume and 15 ppm respectively. Further, both the combustion phases were increased and ignition delay was decreased with increased load. At 80% load, maximum efficiency point, ignition delay was recorded as 16.7 deg.CA.

4.3. COMPARISON OF PHSVO 90 WITH BASELINE CONVENTIONAL DIESEL DATA

4.3.1. Performance Parameters

It is observed from the comparison that, for both conventional diesel and pre-heated straight vegetable oil (PHSVO 90) maximum efficiency of the engine was experienced at 80% load as evident from the Figure 4.19.

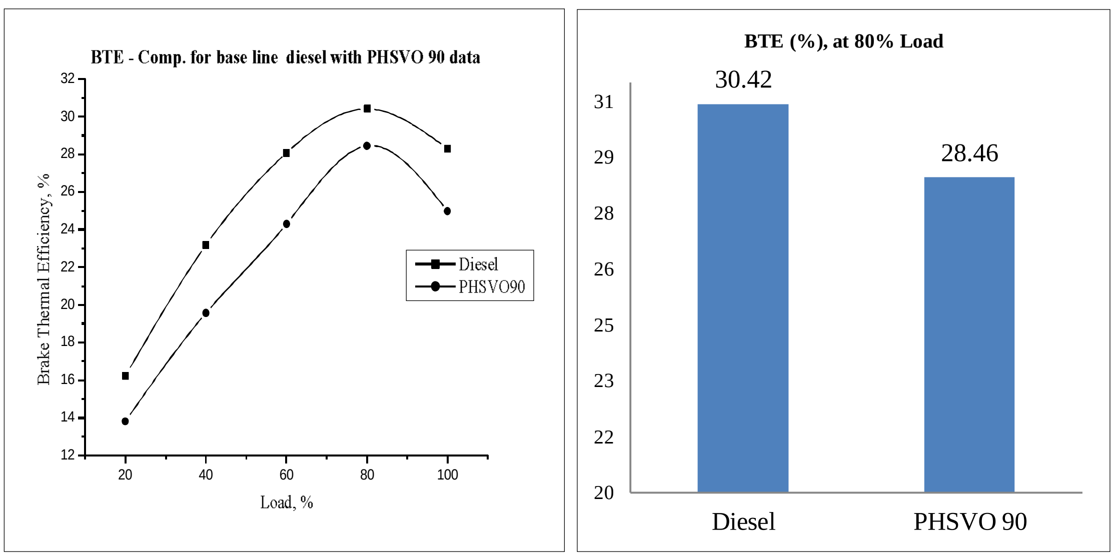


Figure 4.19 Comparison of Brake Thermal Efficiency for base line conventional Diesel with PHSVO 90

Further, brake thermal efficiency of PHSVO 90 is lower than the conventional diesel due to its viscous in nature makes poor atomization, then followed by poor vaporization causes deteriorated combustion and lower calorific value leads to reduction in brake thermal efficiency of PHSVO 90.

From the Figure 4.20, for the both conventional diesel and PHSVO 90, minimum brake specific energy consumption was experienced at 80% load. However, being low viscous and high cetane number of the conventional diesel, causing lowest brake specific energy consumption when compared with PHSVO 90.

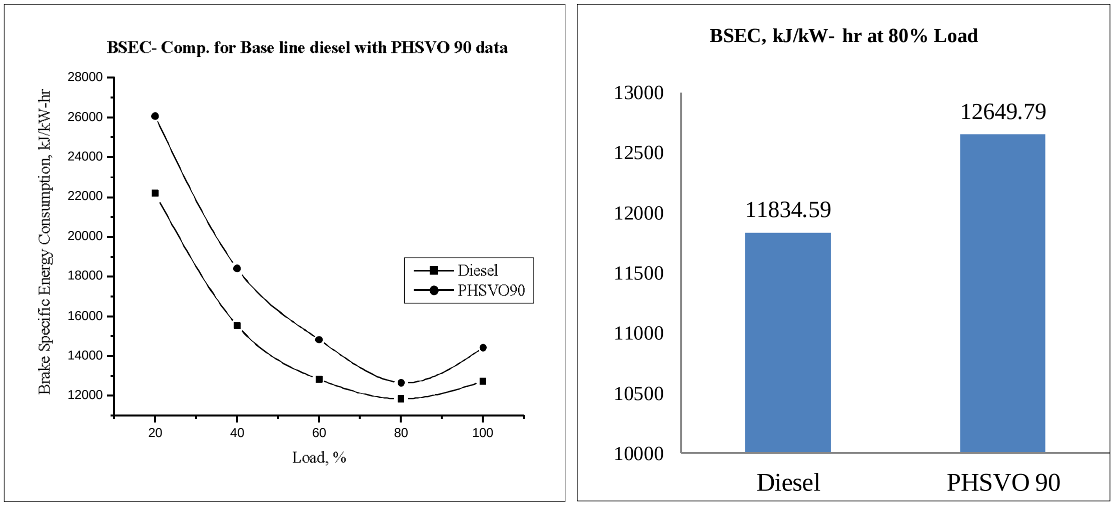


Figure 4.20 Comparison of Brake Specific Energy Consumption for base line conventional Diesel with PHSVO 90

4.3.2. Exhaust Emissions

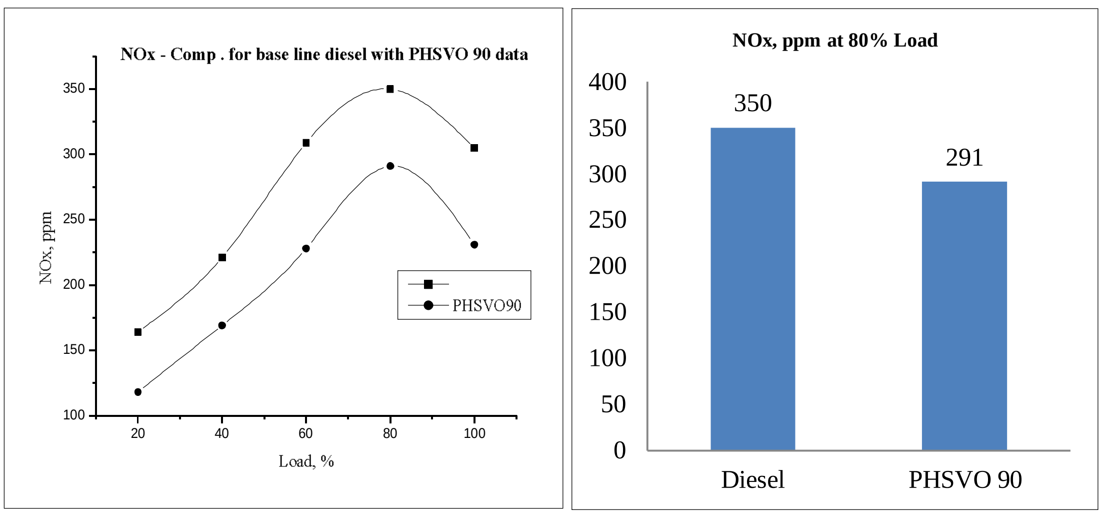


Figure 4.21 Comparison of NO_x for base line conventional Diesel with PHSVO 90

It is observed from the Figure 4.21 that, at all loads NO_x is higher for the conventional diesel when compared to PHSVO 90. Further, NO_x for both the fuels got maximum at 80% load. Due to deteriorated combustion in the case of PHSVO 90 makes lowers the combustion chamber temperatures caused reduction in NO_x when compared to conventional diesel.

From the Figure 4.22, smoke was observed in PHSVO 90 is more than conventional diesel due to its high viscous and density in nature leads to poor combustion causes rise in smoke emissions when compared to conventional diesel. At maximum efficiency point, i.e., 80%

load, PHSVO 90 was reached to 67 HSU which is 11 HSU more than the conventional diesel.

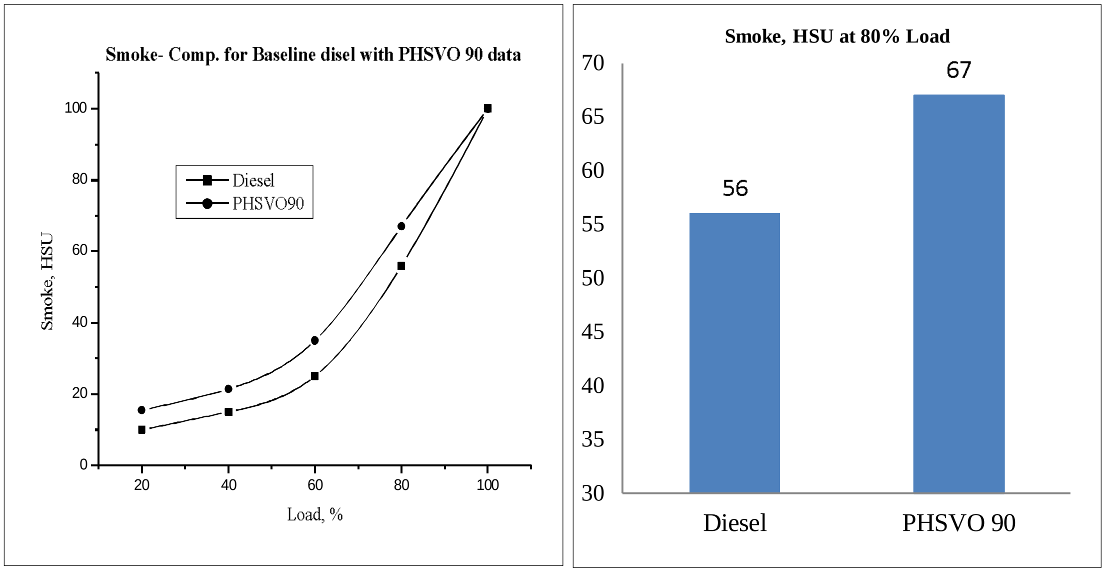


Figure 4.22 Comparison of Smoke for base line conventional Diesel with PHSVO 90

It is observed that, due to deteriorated combustion with PHSVO 90, CO and HC emissions were more when compared to conventional diesel due to high viscous and denser PHSVO 90, as showed in Figures 4.23 and 4.24 respectively. At 80% load, CO and HC emissions of PHSVO 90 is 0.15% by volume and 5 ppm more when compared to conventional diesel fuel respectively.

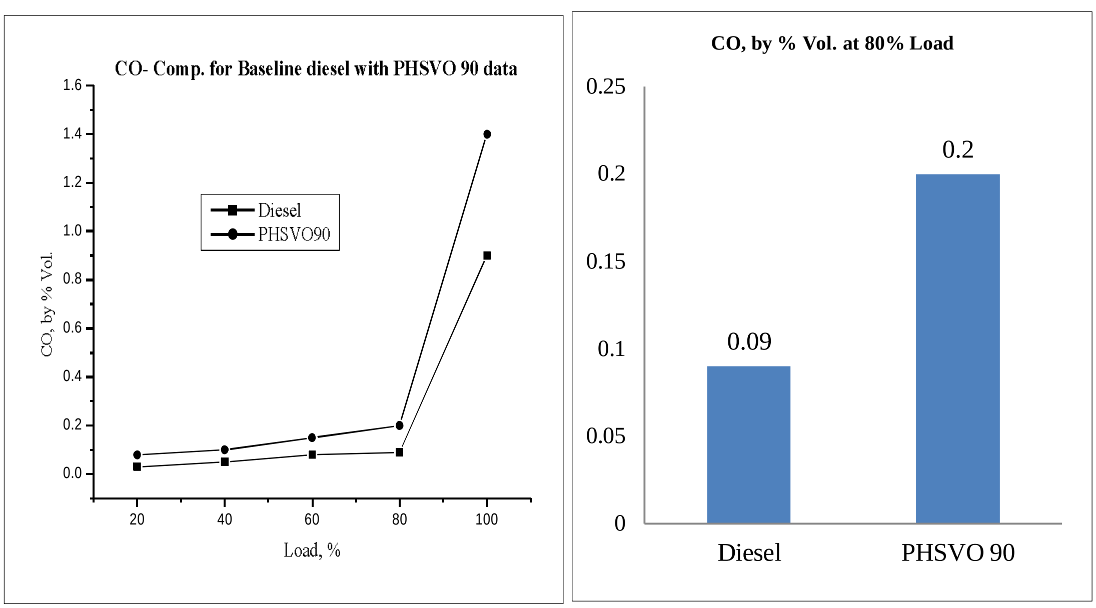


Figure 4.23 Comparison of CO for base line conventional Diesel with PHSVO 90

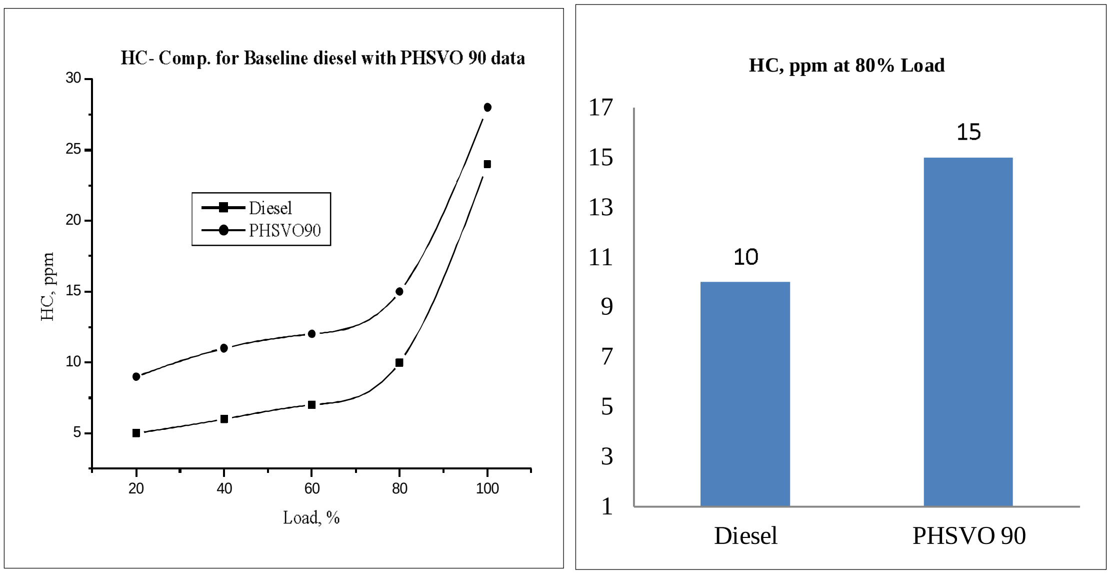


Figure 4.24 Comparison of HC for base line conventional Diesel with PHSVO 90

4.3.3. Combustion Characteristics

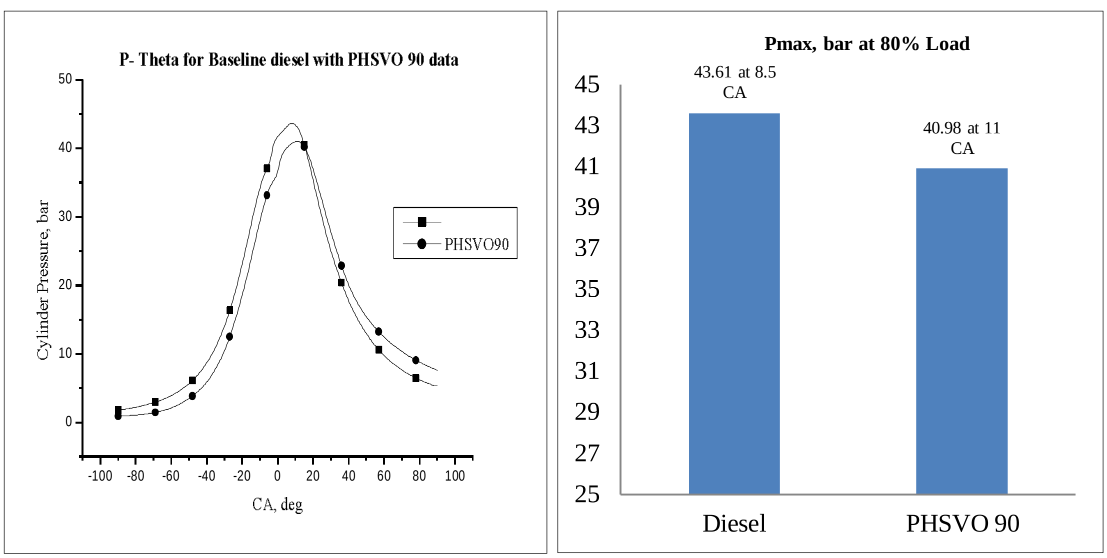


Figure 4.25 Comparison of Cylinder Pressure for base line conventional Diesel with PHSVO 90

Pmax of the conventional diesel was 43.61 bar which is 2.63 bar more than the PHSVO 90 and experienced at 8.5^{o} CA aTDC, when compared to PHSVO 90 experienced at 11^{o} CA aTDC, which is delayed by 2.5^{o} CA.

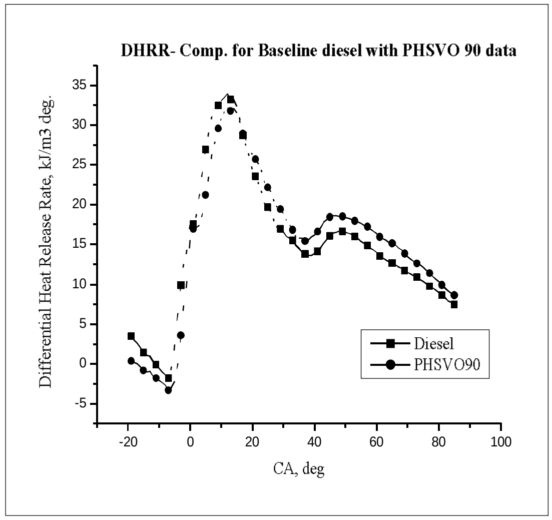


Figure 4.26 Comparison of DHRR of base line conventional Diesel with PHSVO 90

From the Figure 4.26 it is observed that, Pre-combustion phase of the diesel is more when compared to PHSVO 90. But the diffusion phase of the PHSVO 90 was dominated the conventional diesel, due to high viscous nature of the PHSVO 90 is not able to participate during ignition delay which in turn responsible for lower the pre-combustion peak and increase of diffusion phase of the heat release rate diagram.

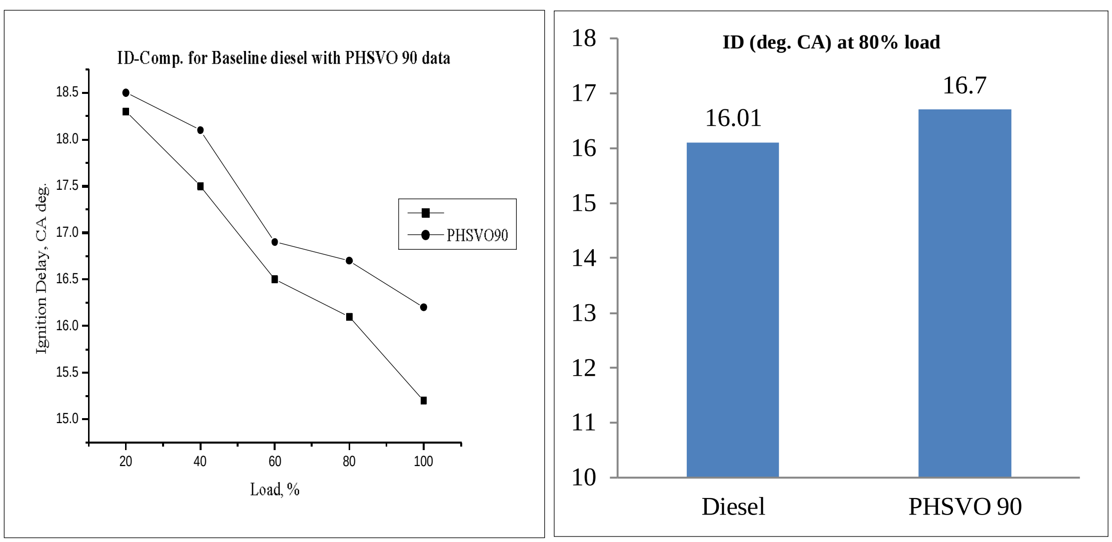


Figure 4.27 Comparison of Ignition delay of base line conventional Diesel with PHSVO 90

In both the fuels, as load increased, ignition delay was decreased. Further, ignition delay of PHSVO 90 was more in all loads when compared to conventional diesel. At 80% load, the ignition delay of the PHSVO 90 is 16.7 deg. CA which is 0.69^{o} CA more than the conventional diesel.

In a nut shell, the poor performance and increased emissions of PHSVO 90 when compared to conventional diesel is due to high viscosity of vegetable oil, leads to poor atomization and further poor vaporization of fuel when compared to conventional diesel made inferior combustion caused poor performance and increased emissions. Further, it was observed from the PHSVO 90 when compared diesel on the basis of performance, emissions and combustion characteristics that, brake thermal efficiency was decreased by 1.96%, BSEC was increased by 815.2 kJ/kW-hr. NO_x were reduced by 59 ppm. Smoke, CO and HC were increased by 11 HSU, 0.11 by % volume, and 5 ppm respectively. Pmax was decreased by 2.635 bar with retarded by 2.5^o CA and Pre-combustion phase was deteriorated and diffusion combustion phase was enhanced.

Therefore, to overcome the above problems and to enhance performance and reduction in emissions, it is very essential to supplement with gaseous hydrogen (GH_2) has high flame speed, wider flammability and higher diffusivity leads to better mixing with the heterogeneous mixture and makes suitable local homogeneous mixture formation for better combustion, discussed in the next section.

4.4. DATA GENERATION WITH PRE-HEATED STRAIGHT VEGETABLE OIL AT 90°C (PHSVO 90) WITH GASEOUS HYDROGEN SUPPLEMENTATION (0.3 gm/min to 1.0 gm/min)

Experimental results are discussed in three categories like; performance parameters, exhaust emissions and combustion characteristics with pre-heated Jatropa based straight vegetable oil at 90^o C supplemented with gaseous hydrogen (GH_2) in the range of 0.3 gm/min to 1.0 gm/min.

4.4.1. Performance Parameters

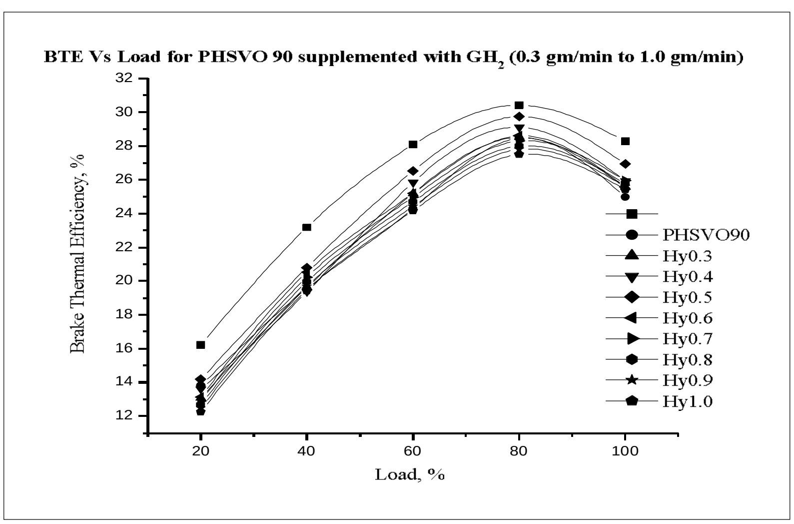


Figure 4.28 BTE Vs. Load for PHSVO 90 with GH_2 Supplementation

It is observed form the Figures 4.28 and 4.29 that, in addition to conventional diesel and PHSVO 90, all hydrogen supplemented PHSVO 90 in the range of 0.3 to 1.0 gm/min also shown that maximum brake thermal efficiency was experienced at 80% load only. Further, at part load, especially in dual fuel operation showed inferior performance due to less quantity of injected pilot fuel, which is not sufficient to burn the high self -ignition temperature of the inducted hydrogen.

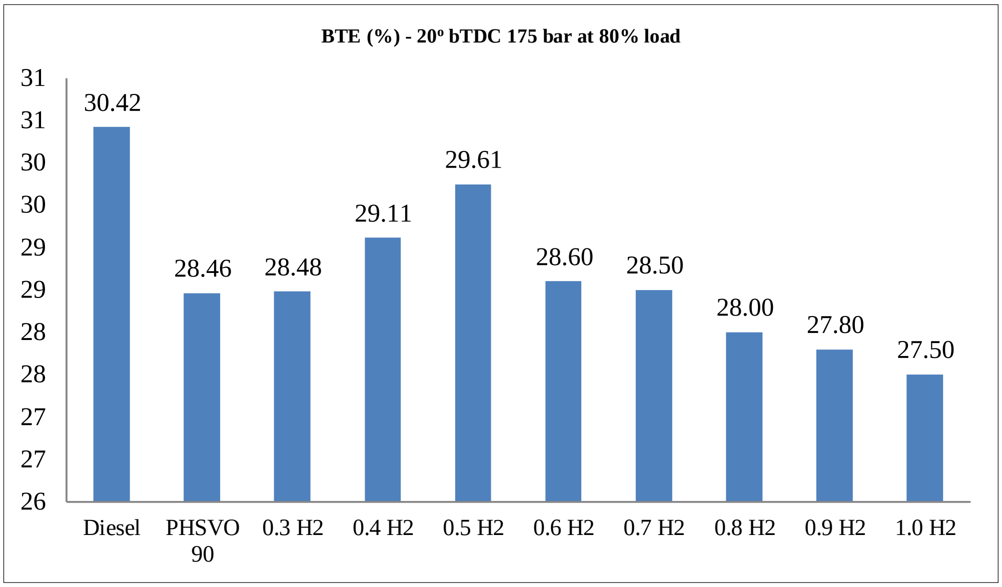


Figure 4.29 BTE Vs. Load for PHSVO 90 with GH_2 Supplementation at 80% Load

Whereas at 80% load, with all doses of supplemented GH_2 showed very good response in increased brake thermal efficiency due to its high flame speed, high burning velocity, wide flammability makes locally homogeneous mixture, causing rapid heat release rate leads to better combustion of available mixture. Further, in the range of 0.4 to 0.7 gm/min hydrogen supplementation showed the enhanced performance when comparing to pure PHSVO 90. However, at higher doses GH_2 supplementation makes an envelope with air which acts as a barrier between inducted air and injected pilot fuel resulted poor combustion and higher energy content leads to reduction in brake thermal efficiency. However, at 0.5 gm/min GH_2 with PHSVO 90 at 80% load, brake thermal efficiency was raised to 29.61%, which is 1.15% higher than pure PHSVO 90.

It was observed from the Figures 4.30 & 4.31 that, up to 0.7 GH_2 supplementation brake specific energy consumption (BSEC) was decreased when comparing to pure PHSVO 90. Further, at higher rates of gaseous hydrogen supplementation, BSEC was increased due to poor combustion. However, at 0.5 gm/min GH_2 supplementation with PHSVO 90 at 80% load showed 548 kJ/kW-hr less when comparing to pure PHSVO 90.

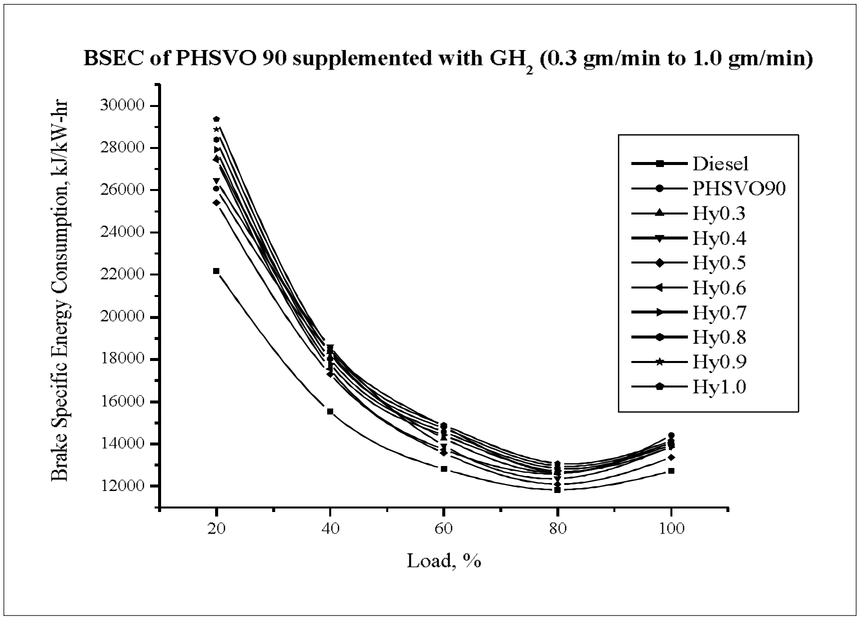


Figure 4.30 BSEC Vs. Load for PHSVO 90 with GH$_2$ Supplementation

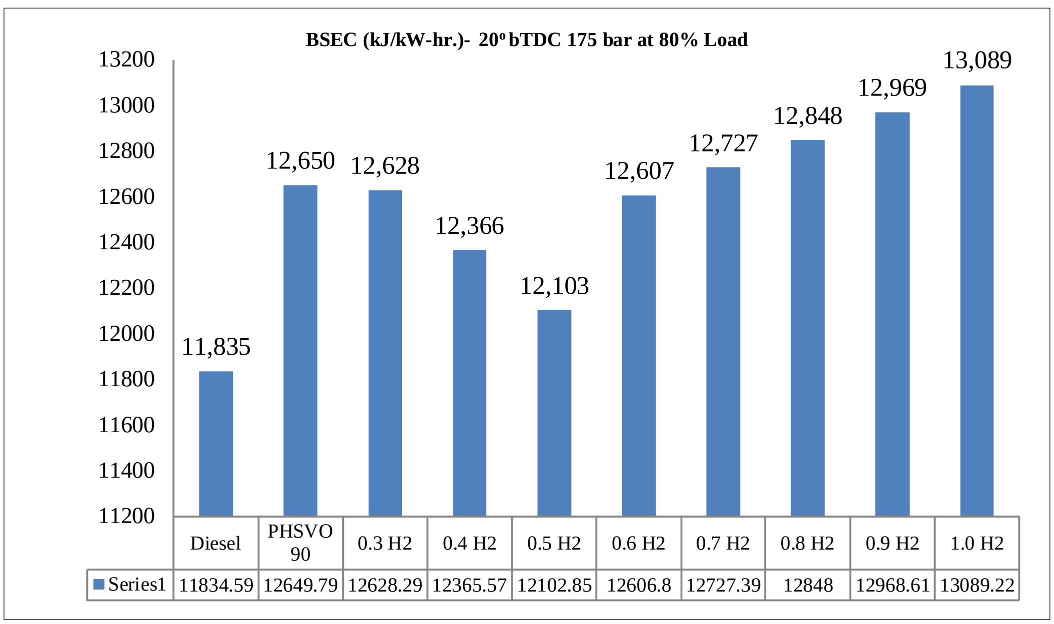


Figure 4.31 BSEC Vs. Load for PHSVO 90 with GH$_2$ Supplementation at 80% Load

4.4.2. Exhaust Emissions

It is observed from the Figures 4.32 and 4.33 that, NO_x was increased with increasing load in all gaseous hydrogen supplemented doses with PHSVO 90. At part loads, as the injected pilot fuel quantity is not sufficient to burn the available inducted GH_2 leads to reduction in combustion chamber temperature caused decreased NO_x. At maximum efficiency point, with 0.5 gm/min GH_2 supplemented PHSVO 90, NO_x was raised to 396 ppm which is 46 ppm higher than the conventional diesel and 105 ppm more than the pure PHSVO 90. This is because of enhanced combustion, increased temperature of the combustion chamber, which is more favorable for formation of NO_x. Further at higher dosages of GH_2 slight reduction of NO_x observed due to envelope formation of GH_2 with air was not able to burn.

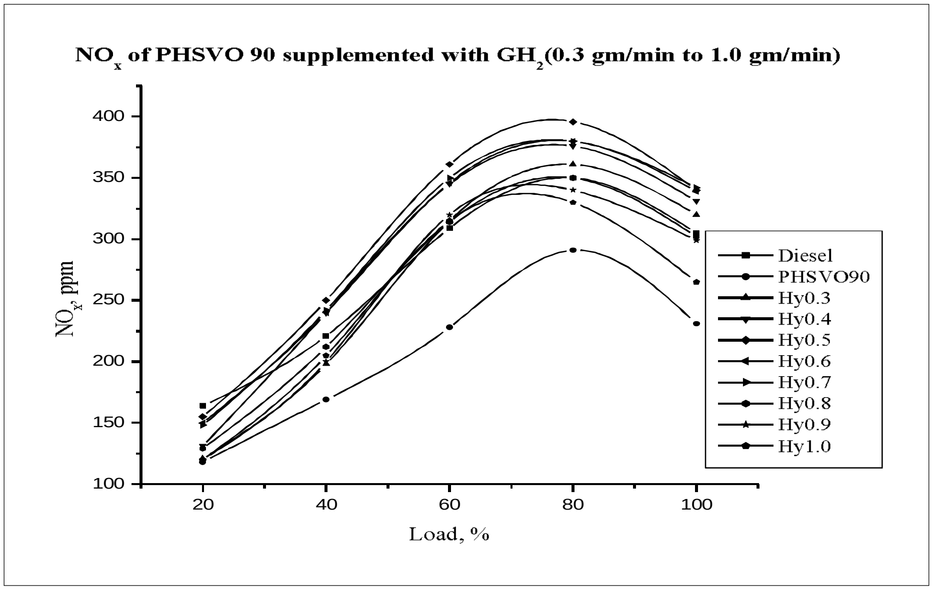


Figure 4.32 NOx Vs. Load for PHSVO 90 with GH_2 Supplementation

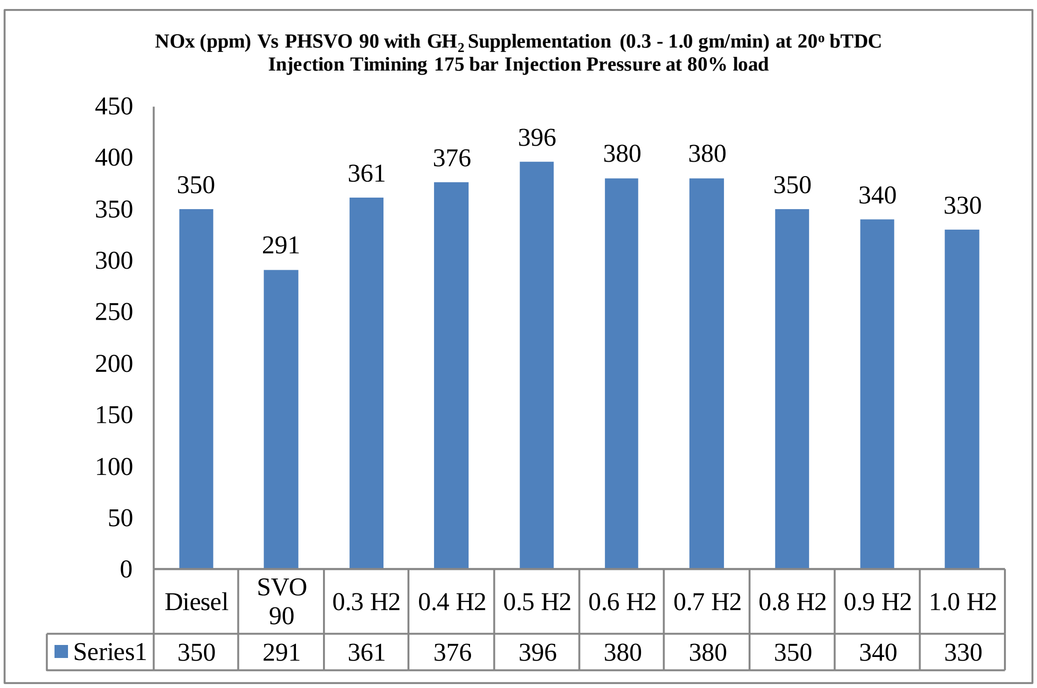


Figure 4.33 NO_x Vs. Load for PHSVO 90 with GH_2 Supplementation at 80% Load

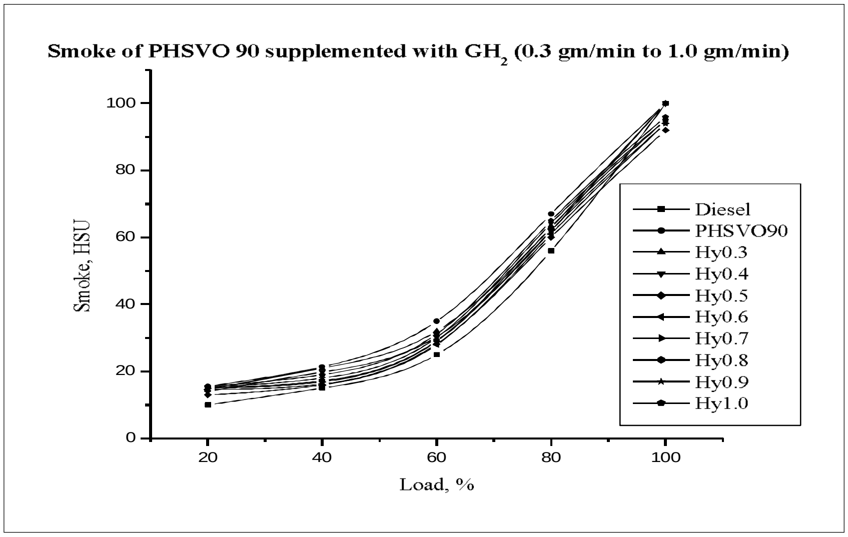


Figure 4.34 Smoke Vs. Load for PHSVO 90 with GH_2 Supplementation

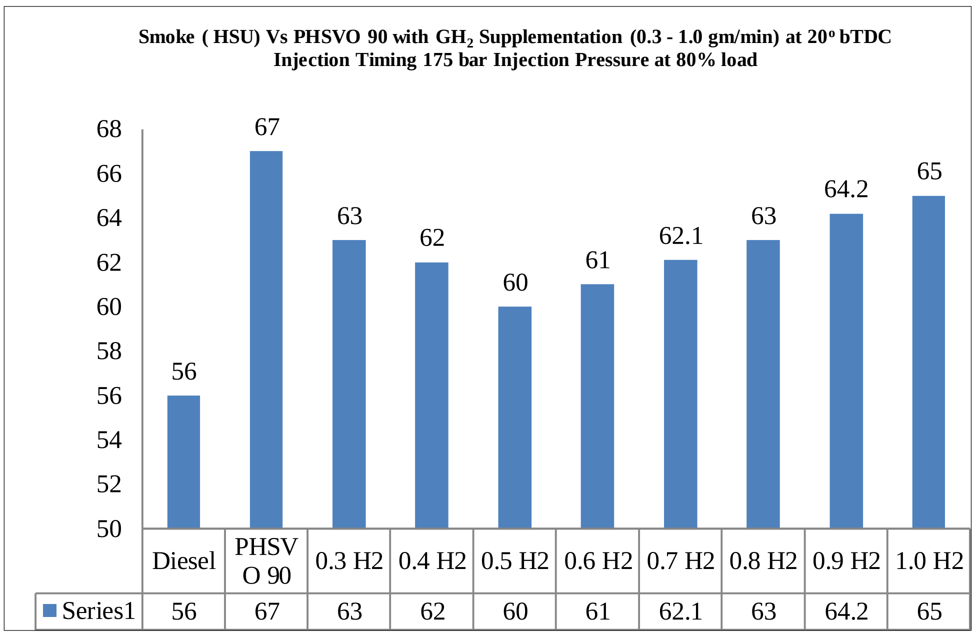


Figure 4.35 Smoke Vs. Load for PHSVO 90 with GH_2 Supplementation at 80% Load

From the Figures 4.34 & 4.35, the smoke opacity was increased with load. Further, with increase in induction of GH_2 up to 0.5 gm/min, smoke was reduced and at later doses, same was slightly increased. At 0.5 gm/min GH_2 supplementation with PHSVO 90 smoke was reduced by 7 HSU when compared to pure PHSVO 90. Whereas with conventional diesel it is still 4 HSU higher. This is due to inducted GH_2 reduces the quantity of injected fuel thereby smoke opacity quantity reduced. Further, it is speculated that inducted GH_2 at 0.5 gm/min and even up to 0.7 gm/min makes homogeneous mixture that burns more rapidly and the overall mixture contains less carbon from which smoke can form. At higher dosage of GH_2, because of improper combustion, smoke level was slightly increased due to GH_2 envelope formation.

It is observed that, with increased load, CO got increased for all fuels starting from conventional diesel to GH_2 supplemented PHSVO 90 including pure PHSVO 90. Further, in the range of GH_2 dose from 0.3 to 1.0 gm/min, up to 0.7 gm/min CO was reduced. Later doses same was slightly increased because of envelop formation of GH_2, and acts as a barrier between injected fuel and inducted air leads to poor combustion by which CO was slightly increased as showed in Figures 4.36 & 4.37.

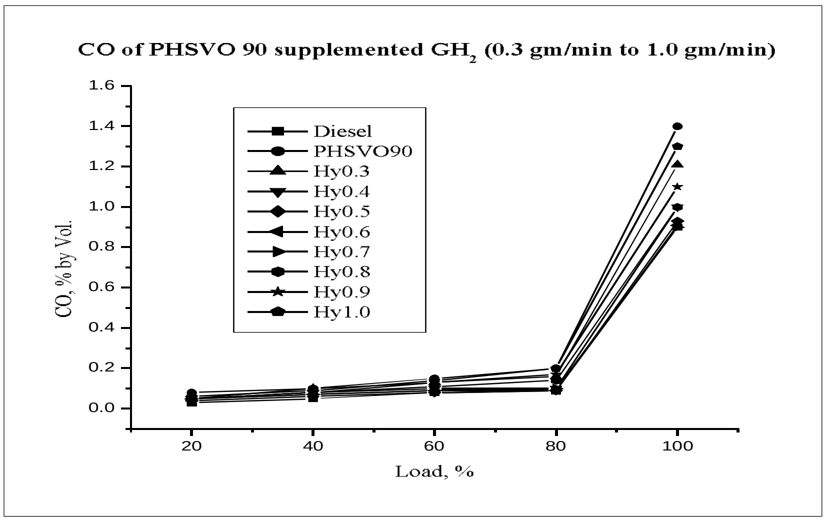
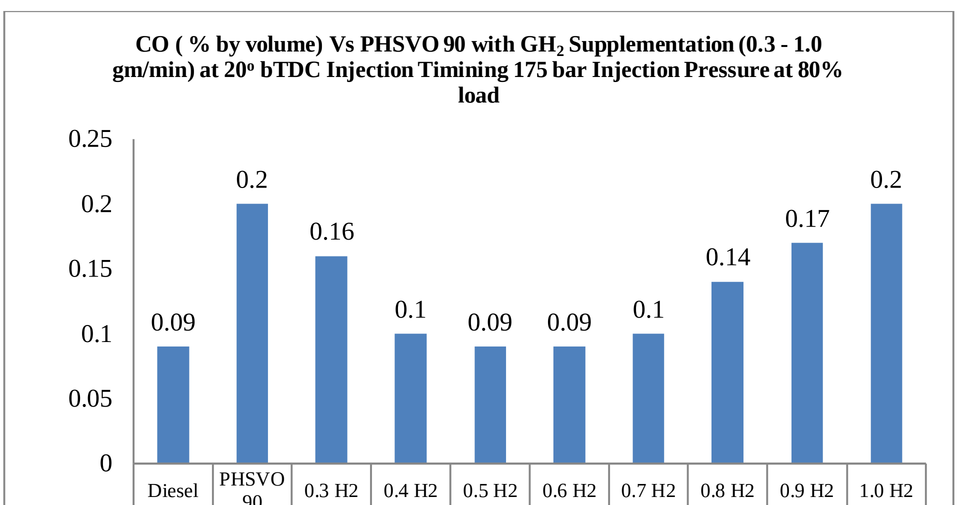


Figure 4.36 CO Vs. Load for PHSVO 90 with GH_2 Supplementation



	Diesel	PHSVO 90	0.3 H2	0.4 H2	0.5 H2	0.6 H2	0.7 H2	0.8 H2	0.9 H2	1.0 H2
Series1	0.09	0.2	0.16	0.1	0.09	0.09	0.1	0.14	0.17	0.2

Figure 4.37 CO Vs. Load for PHSVO 90 with GH_2 Supplementation at 80% load

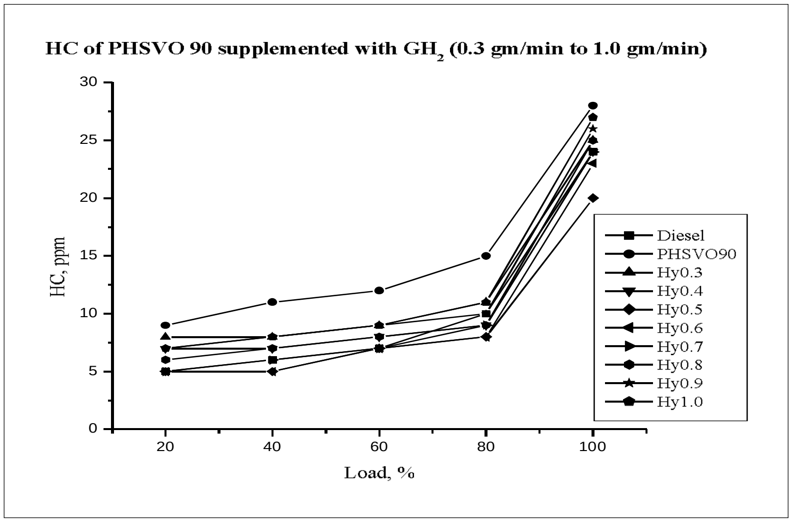


Figure 4.38 HC Vs. Load for PHSVO 90 with GH$_2$ Supplementation

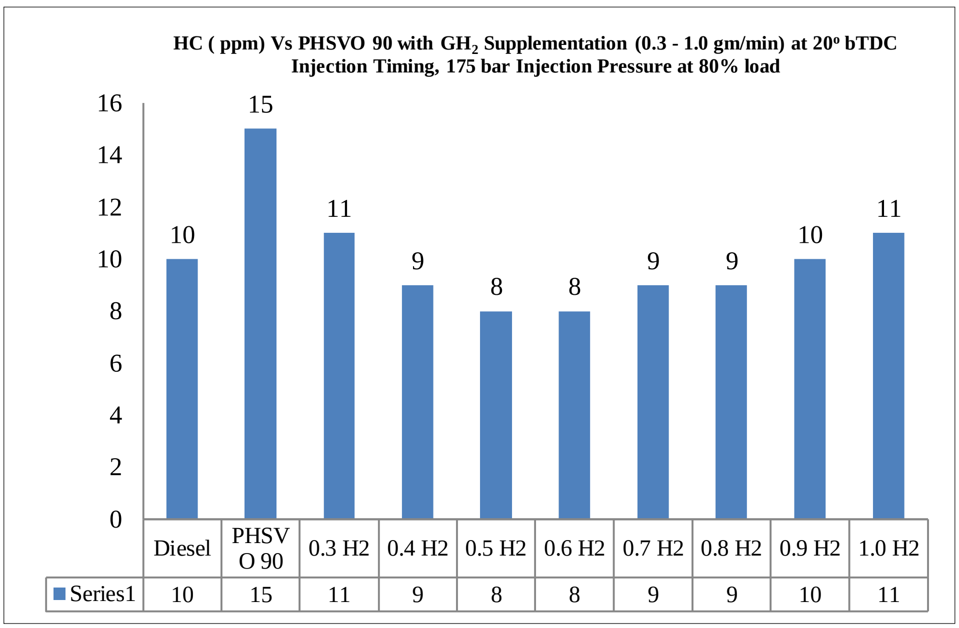


Figure 4.39 HC Vs. Load for PHSVO 90 with GH$_2$ Supplementation at 80% Load

From the Figures 4.38 & 4.39, as load increased, HC emissions were increased. At 80% load HC for conventional diesel was 10 ppm whereas for pure PHSVO 90 recorded as 15 ppm. For 0.5 gm/min GH$_2$ supplemented PHSVO 90 at 80% load with GH$_2$ mass share of 0.5 gm/min HC was reduced to 8 ppm. Which is 2 ppm less than the conventional diesel and 7 ppm less than the pure PHSVO 90. Since, the viscosity and density of vegetable oil is higher than the diesel, spray becomes coarser than the conventional diesel spray leads to poor mixing of pure PHSVO 90 with air as a result of inferior combustion leads to increased HC emissions. Whereas in dual fuel engine as engine inducts the GH$_2$ up to a limit through the inlet manifold as there is no carbon associated with inducted fuel makes the local homogeneous mixture with PHSVO 90 leads to better combustion resulted reduction in smoke emissions. Further, burning of GH_2 increases the combustion temperature and presumably leads to more complete oxidation of injected PHSVO 90. However, at higher doses of inducted GH_2 makes an envelope, and acts as a barrier between injected fuel and inducted air leads to poor combustion by which HC was slightly increased when comparing to conventional diesel. Accordingly, overall HC emissions were reduced with GH_2 supplemented PHSVO 90 when compared to pure PHSVO 90.

4.4.3. Combustion Characteristics

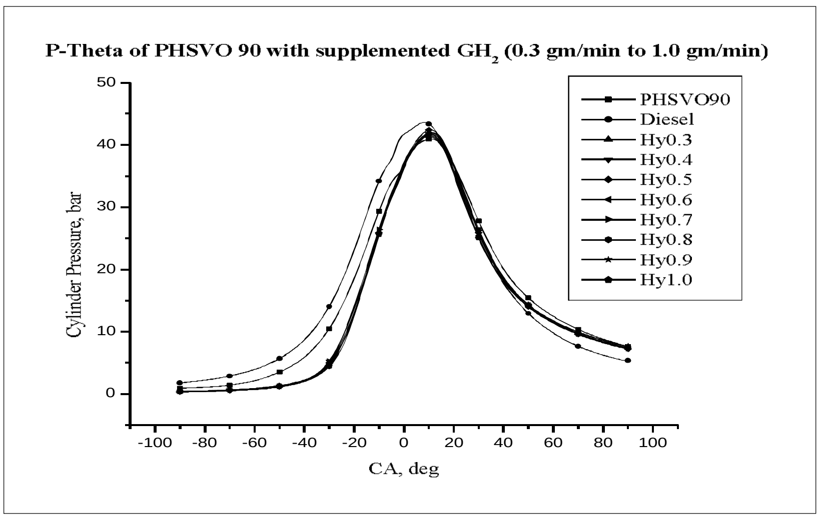
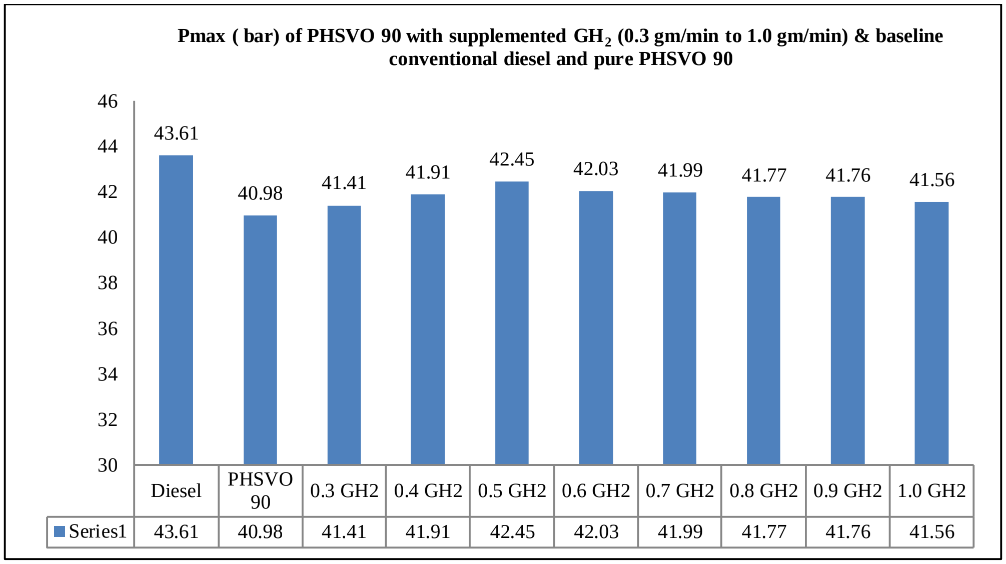


Figure 4.40 P-θ for different GH_2 supplementations of PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20° bTDC Injection Timing and 175 bar Injection Pressure

It was seen that, in all doses of GH_2 supplementation with PHSVO 90, Pmax was increased when compared to pure PHSVO 90 and reaching nearer to conventional diesel. Further, in the range of 0.4 to 0.7 gm/min showed promising growth when comparing to other GH_2 supplementations.

At 80% load, with 0.5 gm/min GH_2 supplementation with pure PHSVO 90, Pmax shown 42.45 bar Pmax experienced at 10.5° CA, which is 1.47 bar more than pure PHSVO 90 and 1.16 bar less than the conventional Diesel. Further, Pmax was advanced by 0.5° CA with this dosage when compared to pure PHSVO 90 and still lagging by 2° CA compared to conventional Diesel. This is because of inducted GH_2 was actively participated in the combustion in the range of 0.4 to 0.7 gm/min. But at higher rate dosages, the inducted GH_2 is becoming an envelope during interaction of injected fuel with inducted air and makes inferior combustion. In all dosages of GH_2 supplementations at 20° bTDC injection timing at 175 bar injection pressure, pre-mixed and diffusion combustion phases were increased when comparing to pure PHSVO 90 and conventional Diesel.



	Diesel	PHSVO 90	0.3 GH2	0.4 GH2	0.5 GH2	0.6 GH2	0.7 GH2	0.8 GH2	0.9 GH2	1.0 GH2
Series1	43.61	40.98	41.41	41.91	42.45	42.03	41.99	41.77	41.76	41.56

Figure 4.41 Pmax for different GH_2 supplementations of PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20^0 bTDC Injection Timing and 175 bar Injection Pressure

Further, during diffusion phase, wavy nature was experienced. This is due to inactive participation of GH_2. At 20^o bTDC injection timing, accumulated pilot fuel was not sufficient to burn the GH_2 there by inferiority in the combustion. Rise of this pre-mixed as well as diffusion combustion phases were mostly for lower dosages of GH_2 rather than at higher side due to envelope formation GH_2 during combustion leads to improper combustion, thereby decreasing thee HRR with pure PHSVO 90 for this engine

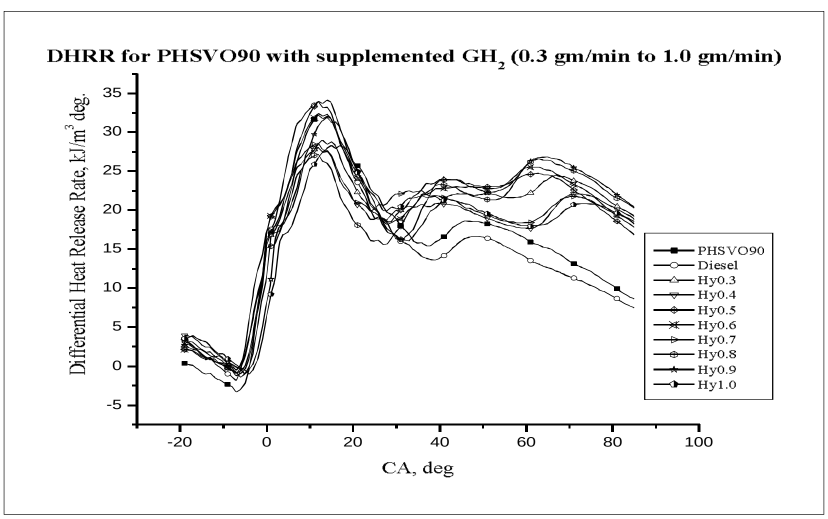


Figure 4.42 DHRR Vs. CA of different GH_2 supplementations for PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20^o bTDC Injection Timing 175 bar Injection Pressure

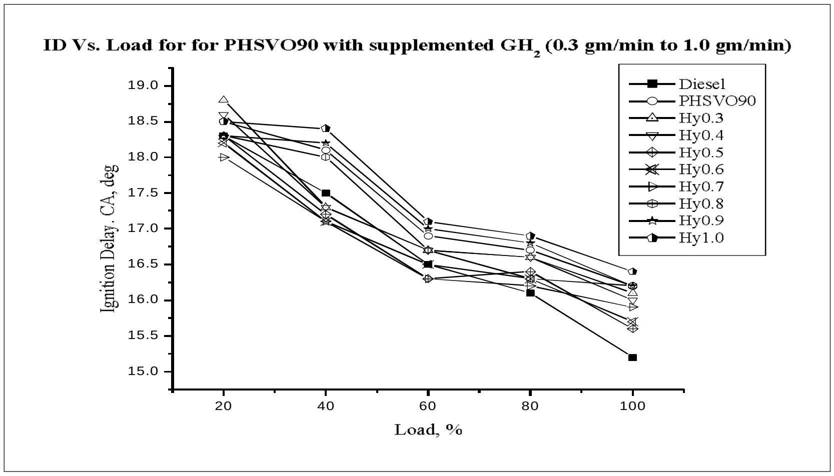


Figure 4.43 Ignition delay Vs. Load of different GH_2 supplementations for PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20^o bTDC Injection Timing 175 bar Injection Pressure

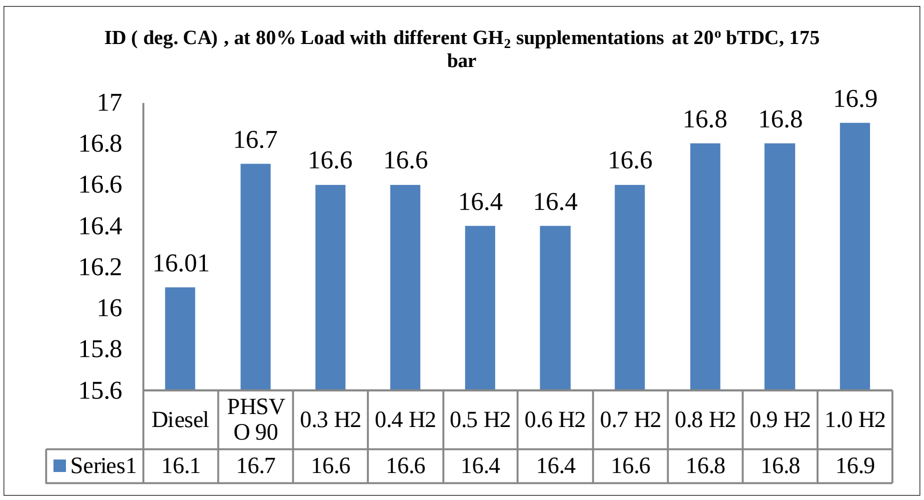


Figure 4.44 Ignition delay Vs. Load of different supplementations for PHSVO 90 and conventional Diesel as well as pure PHSVO 90 at 20^o bTDC Injection Timing 175 bar Injection Pressure at 80% Load

It is observed that, from the Figures 4.43 & 4.44, as the load increases ignition delay increased, further increasing of GH_2 dosage up to 0.6 gm/min ignition delay was decreased and later slightly increased. After 0.6 gm/min the inducted GH_2 becoming an envelope with air and not allowing to properly burn the pilot fuel on time leads to deteriorating the combustion caused by reduction in combustion temperatures by that ignition delay is increased. The ignition delay of conventional diesel at maximum efficiency point is 16.01 deg. CA, whereas for PHSVO 90 this was raised to 16.7 deg. CA because of increase in its physical delay due to viscous and denser vegetable oil. However, at 0.5 gm/min GH_2 share with PHSVO 90 the same ignition delay was reduced to 16.4 deg.CA, because of involved chemical processes consists of pre-combustion reactions in the mixture of air, GH_2 and pilot fuel, which is lesser than pure PHSVO 90 by 0.3 deg.CA, and still 0.39 deg.CA more than the conventional diesel.

4.4.4. Summary of influence of different GH_2 Supplementations with PHSVO 90 on Performance, Emissions and Combustion characteristics

It was observed that, in the given band of GH_2 supplementations ranging from 0.3 to 1.0 gm/min with an increment of 0.1 gm/min at engine manufacturer recommended injection timing 20^o bTDC injection timing and 175 bar injection pressure of a 4 stroke, compression ignition, water cooled, single cylinder IDI, 7.35 kW engine designed and optimized for conventional diesel, fuelled with PHSVO 90 showed inferior performance when compared to conventional diesel fuel because of increase in its physical delay due to viscous and denser vegetable oil which in turn get effects the fuel atomization , vaporization and mixing with air resulted poor combustion leads to inferior performance and increase in emissions. When GH_2 is supplemented with pure PHSVO 90, a promisable change was noticed in the band of 0.4 to 0.7 gm/min.

However, at 0.5 gm/min GH_2 supplemented with pure PHSVO 90, showed a very good response among other the identified GH_2 range when compared to pure PHSVO 90. The Brake thermal efficiency was raised by 1.15%, brake specific energy consumption was reduced by 548 kJ/kW-hr. Smoke was reduced by 7 HSU. HC was reduced by 7 ppm. CO was reduced by 0.11 % by volume. NO_x got increased by 105 ppm. Pmax was increased by 1.47 bar with CA advancement by 0.5^o. Both in pre-mixed as well as diffusion phases peaks were increased. Reduction in ignition delay was by 0.3 deg.CA.

However, in addition to 0.5 gm/min GH_2 supplementation, there is similar potential shown in the range of 0.4 to 0.7 gm/min GH_2 doses. Hence, this range of 0.4 gm/min to 0.7 gm/min with an increment of 0.1 gm/min GH_2 supplementation with PHSVO 90 was selected for further investigation. With this selected range, being vegetable oil is viscous and denser; change of injection timing, i.e., injection advancement with an increment of 2^o CA up to 26^o was seen in the next section. Reason being that, with advancement of injection timing, more fuel is going to be accumulated during the ignition delay period and burning of this fuel intern helps the burning of high self- ignition temperature of GH_2 makes active participation of inducted fuel causing better participation in the combustion. Further, injection advancement was restricted up to 26^o is due to, at higher advancements the accumulated pilot fuel will interact with air for longer time leads to reaching the Lean flame blow out region (LFOR), where equivalence ratio is becoming much leaner which may cause pilot fuel will not initiate the combustion.

4.5. DATA GENERATION WITH PHSVO 90 WITH IDENTIFIED GASEOUS HYDROGEN BAND (0.4 gm/min to 0.7 gm/min) SUPPLEMENTATION UNDER VARYING INJECTION ADVANCEMENTS (20^o – 26^o bTDC) AT 80% LOAD.

Experimental results are discussed in three categories like; performance parameters, exhaust emissions and combustion characteristics with pre-heated Jatropa based straight vegetable oil at 90^o C supplemented with gaseous hydrogen (GH_2) in the range of 0.4 gm/min to 0.7 gm/min with various injection advancements ranging from 20^o bTDC to 26^o bTDC with an increment of 2^o bTDC.

4.5.1. Performance Parameters

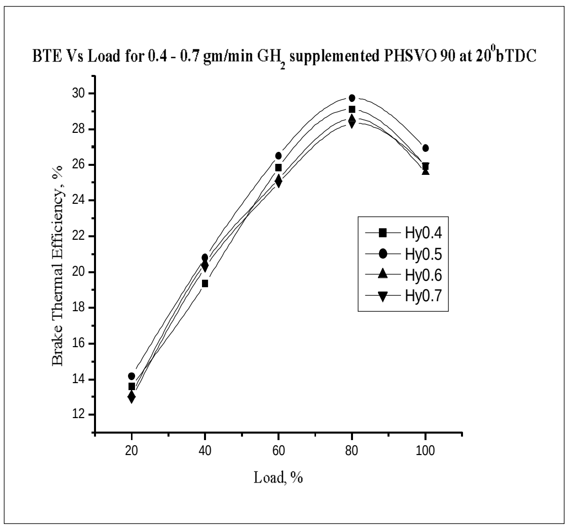


Figure 4.45 BTE Vs. Load, at 20^o bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min)

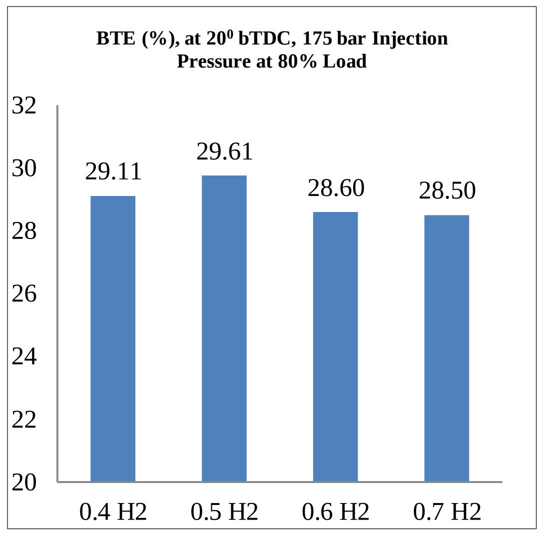


Figure 4.46 BTE Vs. Load, at 20^o bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min) at 80% Load

It is observed from the Figures 4.45 and 4.46 that, brake thermal efficiency was maximum at 80% load, further as GH_2 supplementation increased the brake thermal efficicncy was increased up to 0.5 gm/min and later the same was decreased because of its higher energy content. However at 0.5 gm/min GH_2 supplementation brake thermal efficiency was increased to 29.61%, which is the maxiumum when comparing to all other supplementations.

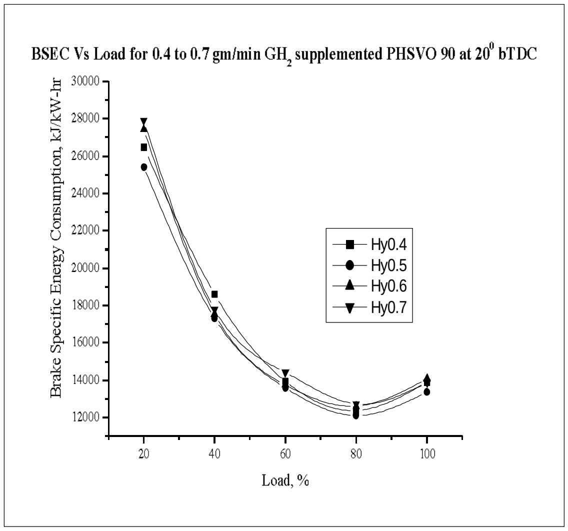


Figure 4.47 BSEC Vs. Load, at 20° bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min)

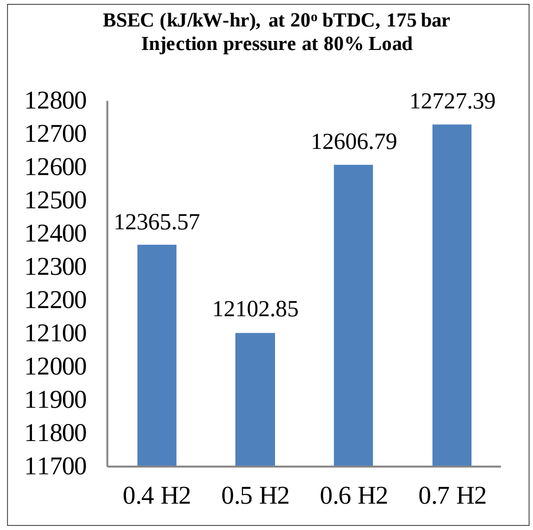


Figure 4.48 BSEC Vs. Load, at 20° bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min) at 80% Load

From the Figures 4.47 and 4.48, brake specific energy consumption was minimum at 80% load, further as GH_2 supplementation was increased BSEC was decreased up to 0.5 gm/min and later was increased due to higher energy content and poor participation of inducted GH_2 leading to inferior combustion. As 0.5 gm/min GH_2 supplementation showed good brake thermal efficiency at the same time BSEC was recorded as 12102 kJ/kW-hr., which is lower than the other GH_2 supplementations.

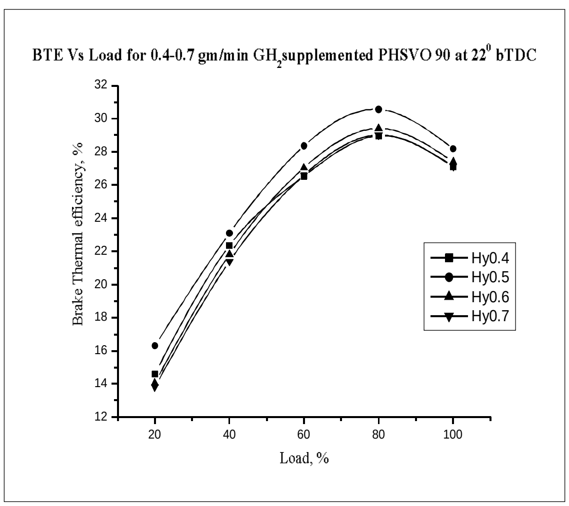


Figure 4.49 BTE Vs. Load, at 22° bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min)

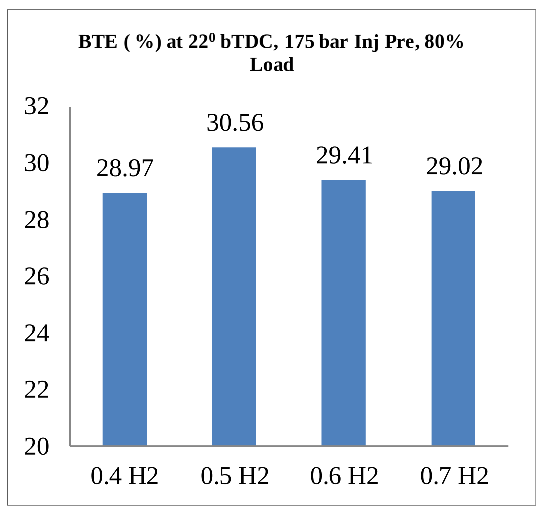


Figure 4.50 BTE Vs. Load, at 22° bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min) at 80% Load

From the Figures 4.49& 4.50, it is observed that, brake thermal efficiency (BTE) was maximum at 80% load, further, as dosage of GH_2 supplementation is increased BTE increased up to 0.6 gm/min and at 0.7 gm/min dosage, same was reduced because of higher energy content. However, at 0.5 gm/min GH_2 supplementation brake thermal efficiency was increased to 30.56% which is more than all other GH_2 supplementation of PHSVO 90 at 22^{o} bTDC injection timing at 175 bar injection pressure.

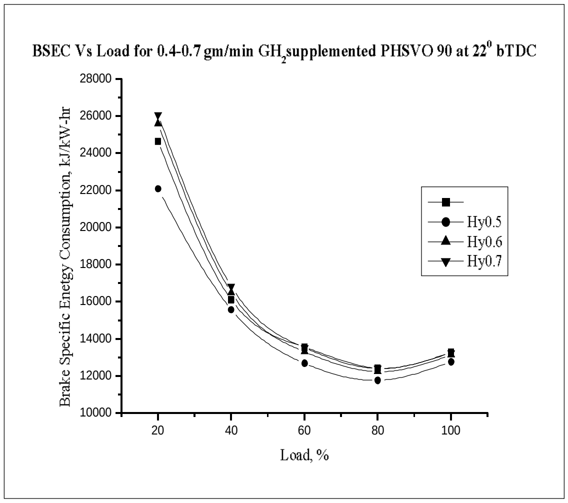


Figure 4.51 BSEC Vs. Load, at 22^{o} bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min)

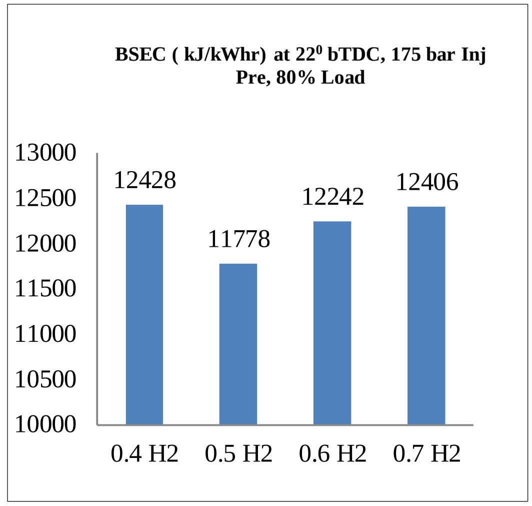


Figure 4.52 BSEC Vs. Load, at 22^{o} bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min) at 80% Load

It is observed from the Figures 4.51 & 4.52 that, brake specific energy consumption (BSEC) was minimum at 80% load, further; as GH_2 dosage is increasing BSEC is decreasing up to 0.6 gm/min and at 0.7 gm/min same was increased because of poor participation of higher content of gaseous hydrogen. However, at 0.5 gm/min GH_2 dosage brake specific energy consumption was decreased to 11778.2 kJ/kW-hr which is, lesser than the all other GH_2 supplementations.

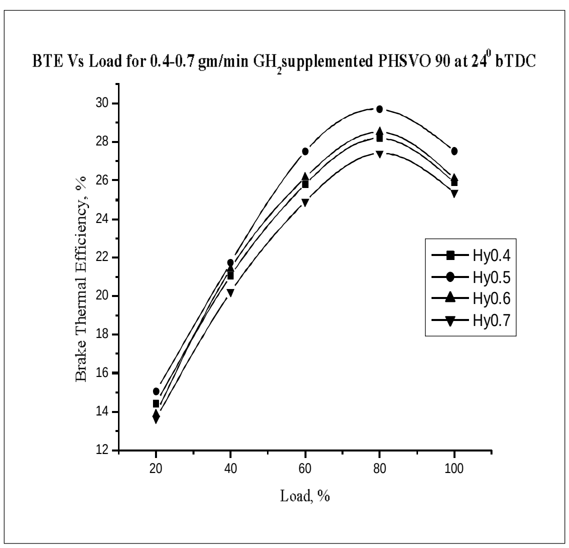


Figure 4.53 BTE Vs. Load, at 24^{o} bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min)

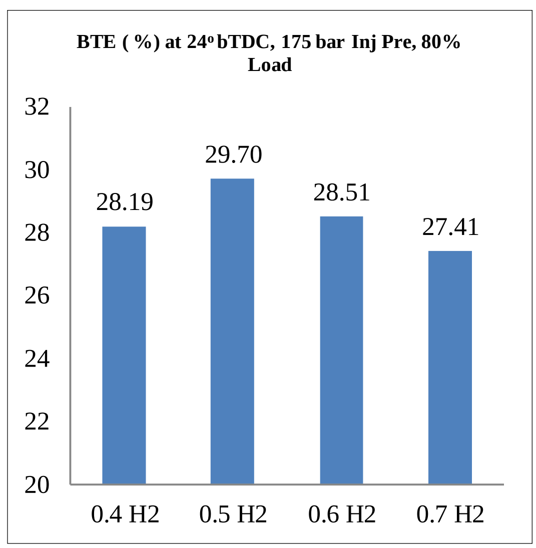


Figure 4.54 BTE Vs. Load, at 24^{o} bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min) at 80% load

It is observed that, brake thermal efficiency (BTE) was maximum at 80% load, further as GH_2 supplementation is increasing BTE is increasing up to 0.6 gm/min and at 0.7 gm/min same was reduced because of higher energy content. However, at 0.5 gm/min GH_2 supplementation brake thermal efficiency was increased to 29.7%, which is more than the all other GH_2 supplementation of PHSVO 90 at 24^o bTDC injection timing and 175 bar injection pressure as showed in Figures 4.53 & 4.54.

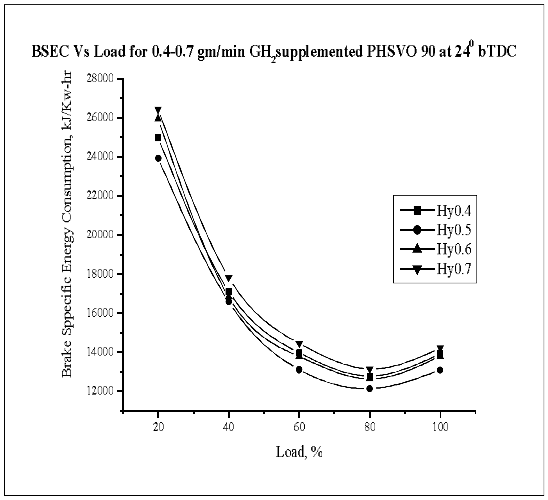


Figure 4.55 BSEC Vs Load, at 24^o bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min)

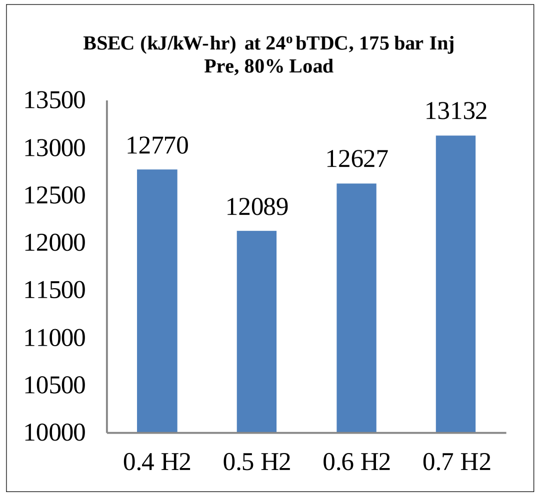


Figure 4.56 BSEC Vs Load, at 24^o bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min) at 80% Load

It is observed from the Figures 4.55 & 4.56 that, brake specific energy consumption (BSEC) was minimum at 80% load, further, as GH_2 supplementation is increasing BSEC is decreasing up to 0.6 gm/min and at 0.7 gm/min same was increased because of poor participation of higher content of gaseous hydrogen during combustion. However, at 0.5 gm/min GH_2 supplementation brake specific energy consumption was decreased to 12089 kJ/kW-hr, which is lesser than the all other GH_2 supplementations.

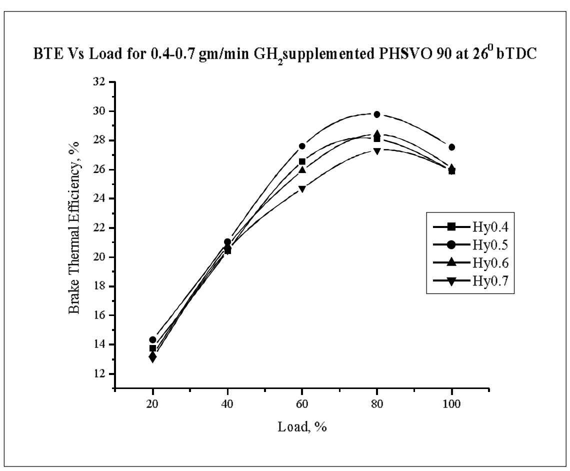


Figure 4.57 BTE Vs. Load, at 26^o bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min)

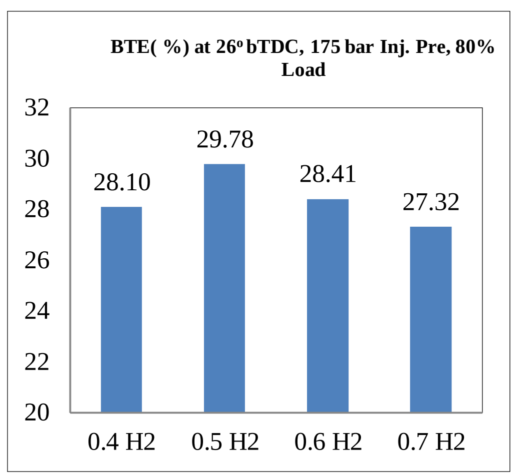


Figure 4.58 BTE Vs. Load, at 26^o bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min) at 80% Load

It is observed that, brake thermal efficiency (BTE) was maximum at 80% load, further, as GH_2 supplementation is increasing BTE is increasing up to 0.6 gm/min and at 0.7 gm/min same was reduced because of higher energy content. However, at 0.5 gm/min GH_2 supplementation brake thermal efficiency was increased to 29.78%. Which is, slightly increased when compared to all other GH_2 supplementations of PHSVO 90 at 26^o bTDC injection timing at 175 bar injection pressure as showed in Figures 4.57 & 4.58.

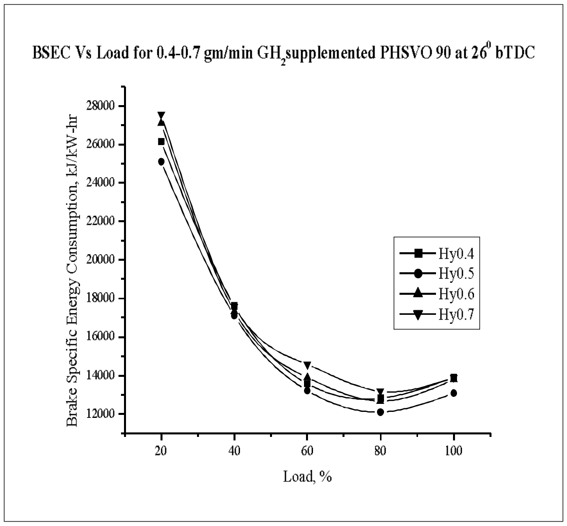


Figure 4.59 BSEC Vs. Load, at 26^{o}bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min)

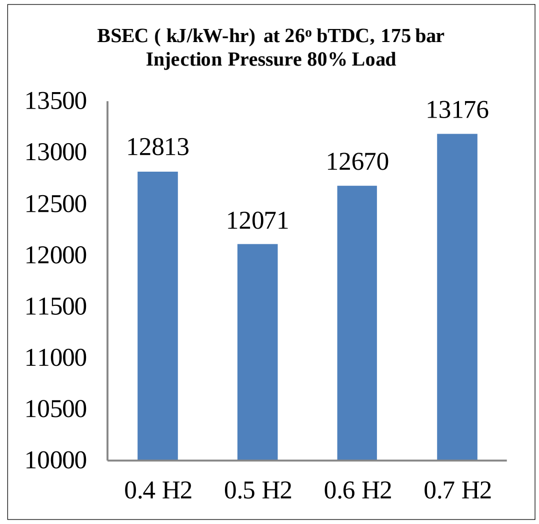


Figure 4.60 BSEC Vs. Load, at 26^o bTDC Injection Timing, 175 bar Injection Pressure and GH_2 supplementation (0.4- 0.7 gm/min) at 80% load

It is observed form the Figures 4.59 & 4.60 that, brake specific energy consumption (BSEC) was minimum at 80% load, further, as GH_2 supplementation is increasing, BSEC is decreasing up to 0.6 gm/min and at 0.7 gm/min same was increased because of poor participation of higher content of gaseous hydrogen. However, at 0.5 gm/min GH_2 supplementation brake specific energy consumption was decreased to 12071 kJ/kW-hr. Which is, lesser than all other GH_2 supplementations of PHSVO 90 at 26^o bTDC injection timing at 175 bar injection pressure.

4.5.2. Comparison of Performance Parameters of different Injection Timings ranging from 20^o bTDC to 26^o bTDC at 175 bar Injection Pressure and 0.5 gm/min GH_2 supplementation with PHSVO 90

It is observed from the advancements of injection timings from 20^o bTDC to 26^o bTDC, 0.5 gm/min GH_2 supplementation at 80% load shown good performance when compared to other GH_2 supplementations. Hence, 0.5 gm/min GH_2 supplementation dosage was considered as optimized dosage for PHSVO 90 at optimized 80% load.

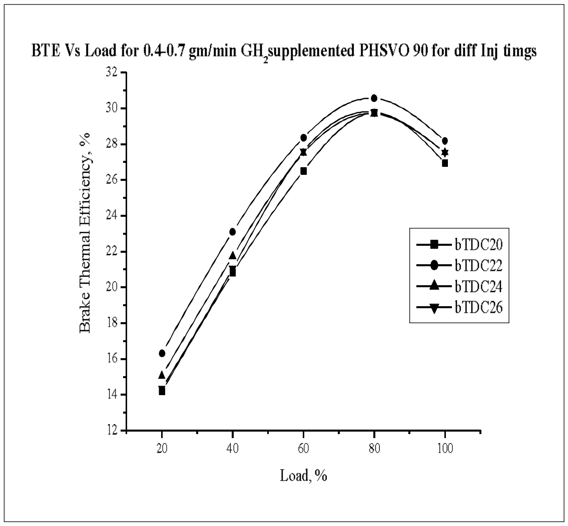


Figure 4.61 BTE Vs. Load Comparison of different Injection Timings (20°-26° bTDC) at 175 bar Injection Pressure for 0.5gm/min GH_2 supplementation with PHSVO 90

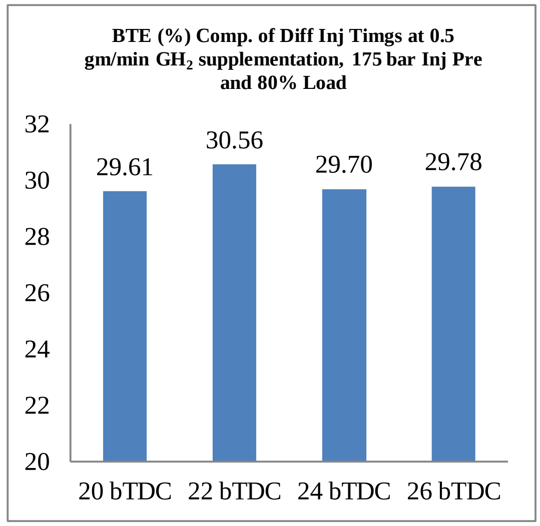


Figure 4.62 BTE Vs. Load Comparison of different Injection Timings (20°-26° bTDC) at 175 bar Injection Pressure for 0.5gm/min GH_2 supplementation with PHSVO 90 at 80% Load

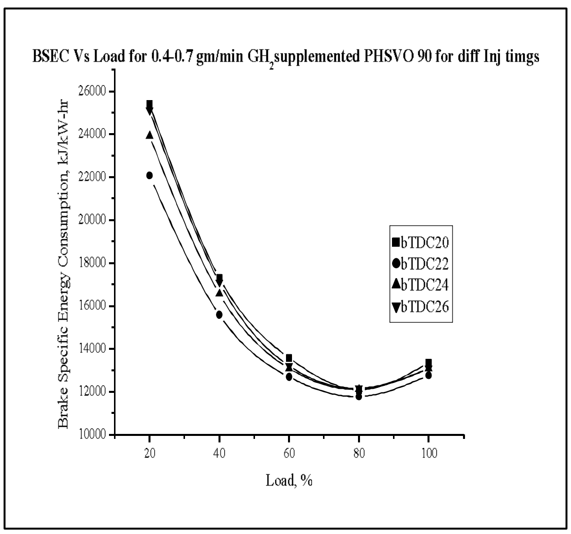


Figure 4.63 BSEC Vs. Load Comparison of different Injection Timings (20°-26° bTDC) at 175 bar Injection Pressure for 0.5gm/min GH_2 supplementation with PHSVO 90

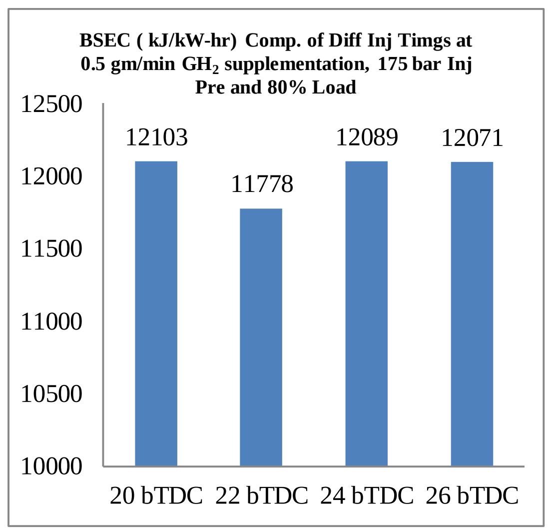


Figure 4.64 BSEC Vs. Load Comparison of different Injection Timings (20°-26° bTDC) at 175 bar Injection Pressure for 0.5gm/min GH_2 supplementation with PHSVO 90 at 80% Load

It was identified that, in all injection advancements starting from 20° bTDC to 26° bTDC, the following observations made:

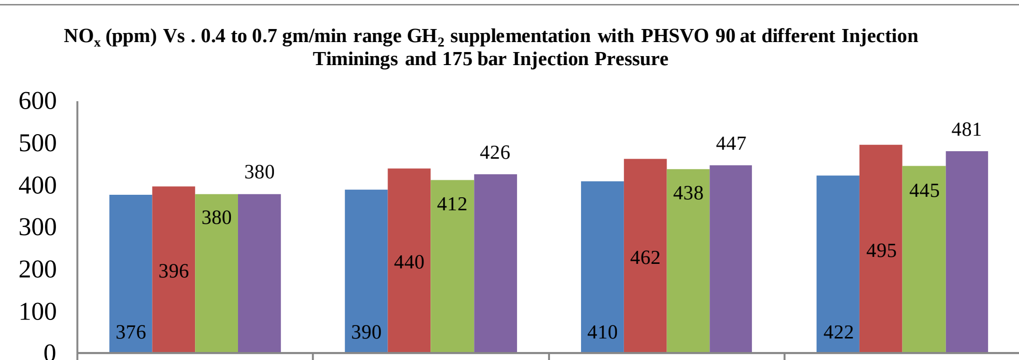
At 22° bTDC injection advancement, the brake thermal efficiency was raised to 30.56% which is 0.95% more than 20° bTDC, 0.86 % more than 24° bTDC and 0.78% more than 26° bTDC as showed in Figures 4.61 & 4.62. The reason being that, during injection advancements to a limit, more fuel is accumulating during ignition delay period, and is sufficient to ignite the high self-ignition temperature of GH_2 by that, gaseous hydrogen actively participating subsequently, pilot fuel consumption reduces there by reduction in brake specific energy consumption leads to increased brake thermal efficiency**.**

4.5.3. Exhaust Emissions at 20°, 22°, 24° and 26° bTDC Injection Timings at 175 bar Injection Pressure at 80% load

It is observed from the conventional diesel fuel to hydrogen supplementation with PHSVO 90 including different injection timings, all results showed that, at 80% load the selected engine shown good performance when comparing to all other loads. Hence all emissions at different injection timings were considered and measured at 80% load and discussed in the following sections.

4.5.3.1. NO_x

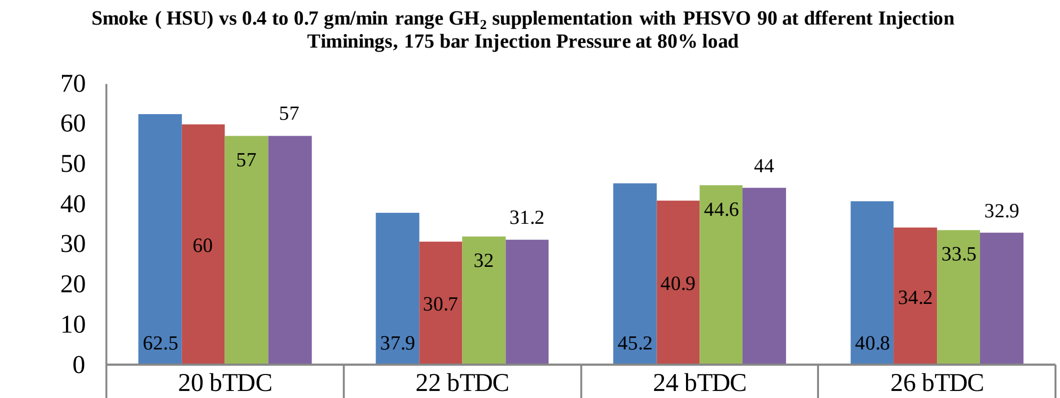
Data was taken at 80% load, for identified GH_2 range, 0.4 to 0.7 gm/min supplemented with PHSVO 90. In general, NO_x got raised with increased dosage of GH_2 and as well as advanced the injection timings. Especially at 0.5 gm/min in all injection advancements NO_x got raised. This is because of heat release rate of GH_2 increases the combustion chamber temperature and is a favorable situation to get react nitrogen with oxygen and forms higher NO_x. Further, as injection timing advanced more amount of fuel got accumulated during the ignition delay and more time is available to burn the same nearer to TDC, where temperature is more favored the formation of NO_x. However, with supplementing the GH_2 with PHSVO 90 diffusion phase peak, discussed in the next section, also got increased. Due to this, the heat remain maintain in overall combustion causes increase of NO_x. At 22° bTDC injection advancement, 175 bar injection pressure with 0.5 gm/min GH_2 supplementation with PHSVO 90, NO_x was raised to 440 ppm.



	20 bTDC	22 bTDC	24 bTDC	26 bTDC
0.4 H2	376	390	410	422
0.5 H2	396	440	462	495
0.6 H2	380	412	438	445
0.7 H2	380	426	447	481

Figure 4.65 NO_x Vs. different Injection Timings at 0.4 – 0.7 gm/min GH_2 supplementations and 80% load

4.5.3.2. Smoke



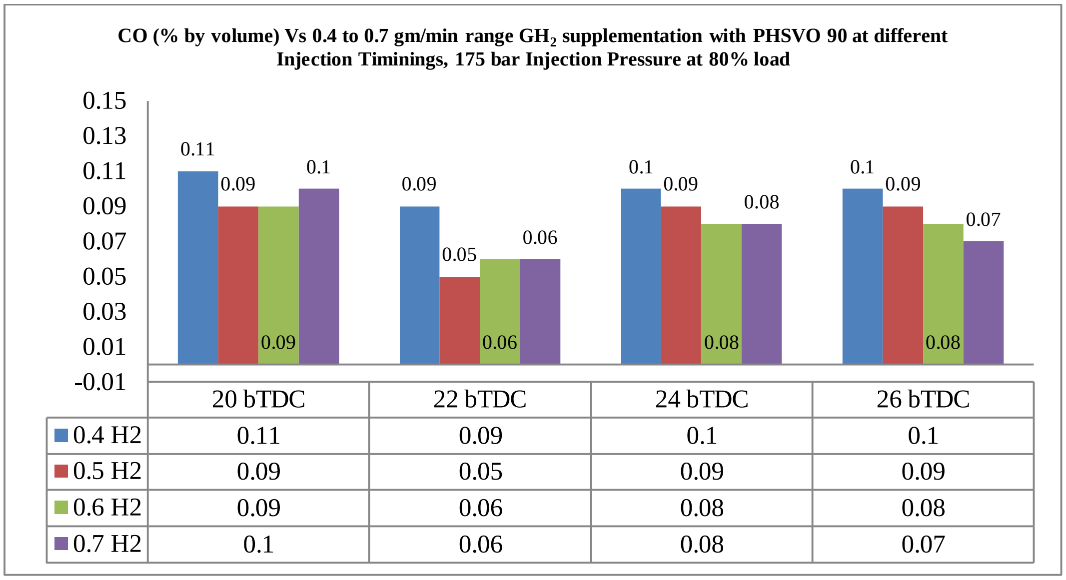
	20 bTDC	22 bTDC	24 bTDC	26 bTDC
0.4 H2	62.5	37.9	45.2	40.8
0.5 H2	60	30.7	40.9	34.2
0.6 H2	57	32	44.6	33.5
0.7 H2	57	31.2	44	32.9

Figure 4.66 Smoke Vs. different Injection Timings at 0.4-0.7 gm/min GH_2 supplementations and 80% load

It is observed from the Figure 4.66, smoke was decreased with advanced injection timings. Due to advanced injection timing, as more time available for soot to got oxidation. Further, inducted GH_2 enhances the combustion, which further enhanced the combustion chamber temperature leads to oxidation of soot. At 22^o bTDC injection advancement, 175 bar injection pressure with 0.5 gm/min GH_2 supplementation with PHSVO 90 at 80% load, Smoke reduced to 30.7 HSU, which is 29.3 HSU lesser than 20^o bTDC and 10.2 HSU lesser than the 24^o bTDC and 3.5 HSU lesser than the 26^o bTDC. As the injection advances smoke is decreasing at 22^o bTDC, very less smoke was observed and followed by 26^o, 24^o and 20^o bTDC injection advancement even at 22^o bTDC, BSEC was also less observed.

4.5.3.3. CO

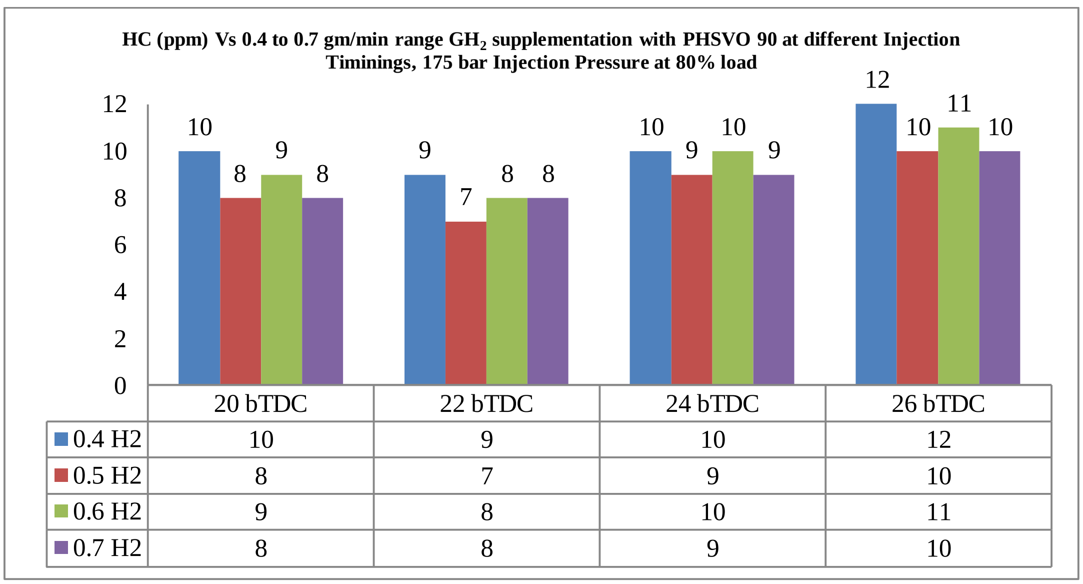
In general, for diesel engines the CO formation is very less because that they operate at lean mixtures. From the Figure 4.67, it was observed that, CO emissions decreasing with increasing GH_2 supplementation with PHSVO 90. Further, as injection timing advanced, more amount of fuel got accumulated during ignition delay was burned nearer to TDC and even burned inducted GH_2 lead to increase the combustion chamber temperature, which reduced the formation of CO. At 22^o bTDC injection advancement, 175 bar injection pressure with 0.5 gm/min GH_2 supplementation with PHSVO 90, CO was reduced to 0.05 % by volume, which is 0.04 by % volume is lesser when comparing to all injection advancements.



	20 bTDC	22 bTDC	24 bTDC	26 bTDC
0.4 H2	0.11	0.09	0.1	0.1
0.5 H2	0.09	0.05	0.09	0.09
0.6 H2	0.09	0.06	0.08	0.08
0.7 H2	0.1	0.06	0.08	0.07

Figure 4.67 CO Vs different Injection Timings at 0.4-0.7 gm/min GH_2 supplementations and 80% load

4.5.3.4. HC



	20 bTDC	22 bTDC	24 bTDC	26 bTDC
0.4 H2	10	9	10	12
0.5 H2	8	7	9	10
0.6 H2	9	8	10	11
0.7 H2	8	8	9	10

Figure 4.68 HC Vs. different Injection Timings at 0.4-0.7 gm/min GH_2 supplementations 80% load

It is seen from the Figure 4.68, with increasing of injection advancement, HC was slightly increased reason being that, during advancements, more time is available for accumulated fuel to get interact with available air leads to overmixing of fuel resulting relatively lean mixture beyond required limit and it will very slightly deteriorate the combustion thereby slightly increasing of HC. At 22^o bTDC injection advancement, 175 bar injection pressure with 0.5 gm/min GH_2 supplementation with PHSVO 90, HC was reduced to 7 ppm, which is 1 ppm lesser than the 20^o bTDC, 2 ppm lesser than the 24^o bTDC and 3 ppm lesser than 26^o bTDC.

4.5.4. Combustion Characteristics

As maximum efficiency of the selected engine was identified at 80% load with all fuel combinations like; conventional diesel, PHSVO 90, PHSVO 90 with different GH_2 supplementations and PHSVO 90 with identified GH_2 band (0.4 gm/min to 0.7 gm/min) with different injection advancements, 80% load was selected to record the combustion data. Further, the data generated from, PHSVO 90 with identified GH_2 band (0.4 gm/min. to 0.7 gm/min), was shown good performance and less emissions at 0.5 gm/min. Therefore to understand the combustion characteristics, 0.5 gm/min GH_2 supplementation and 80% load was selected.

4.5.4.1. P-θ comparison for 20°, 22°, 24° and 26° bTDC Injection Timings at 175 bar Injection Pressure, at 0.5 gm/min and 80% load.

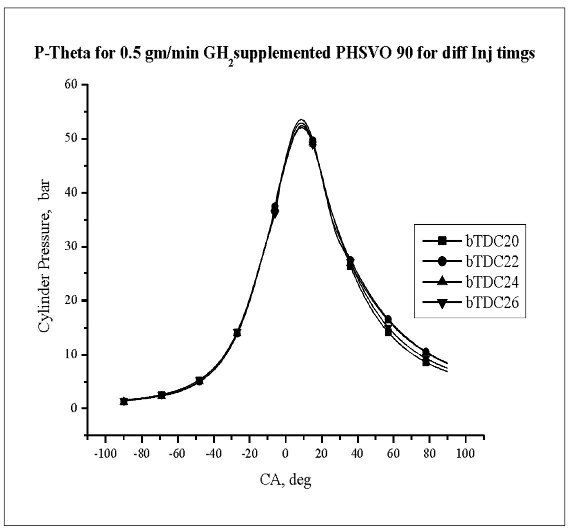


Figure 4.69 P-θ for different Injection Timings

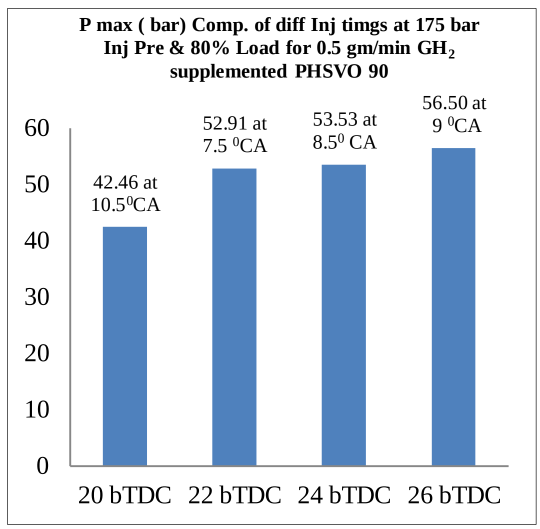


Figure 4.70 Pmax for different injection Timings at 80% load

In observation with advancement of injection timings from 20° to 26° bTDC with GH_2, supplementations as showed in Figures 4.69 & 4.70, Pmax was increased and experienced nearer to TDC. Further, with supplementing the GH_2, also Pmax is increasing. At higher efficiency load, i.e., at 80% load, and 22° bTDC injection advancement, 175 bar injection pressure with 0.5 gm/min GH_2 supplementation with PHSVO 90, Pmax was raised to 52.91 bar experienced at 7.5° CA aTDC, which is 10.45 bar more than the 20° bTDC, 0.62 bar less than the 24° bTDC and 2.97 bar less than the 26° bTDC.

4.5.4.2. Differential Heat Release Rates comparison for 20°, 22°, 24° and 26° bTDC Injection Timings at 175 bar Injection Pressure at 0.5 gm/min and 80% load

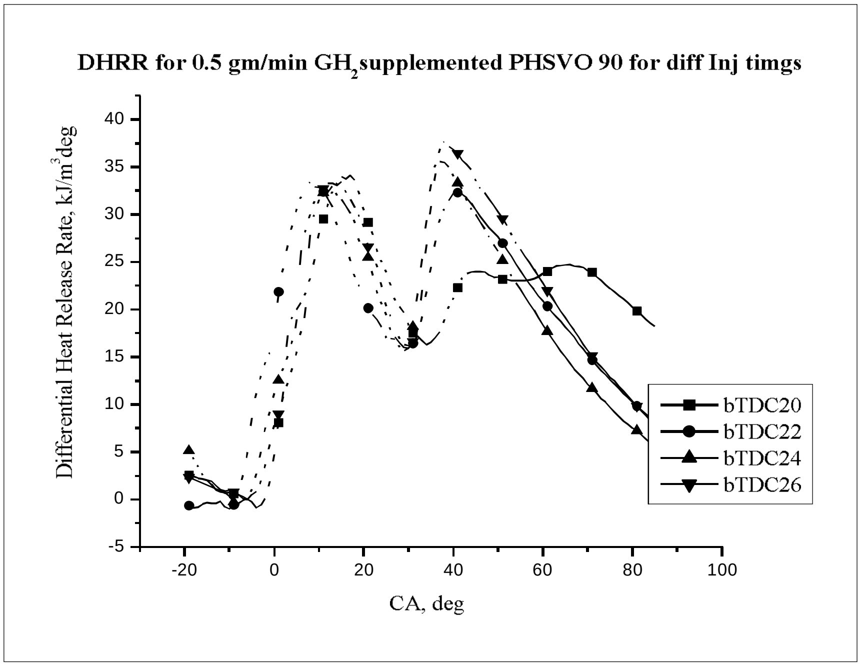


Figure 4.71 Differential Heat Release Rate for differential Injection Timings

It is observed from the Figure 4.71 that, as injection timing advanced, more amount of fuel accumulated during ignition delay period, which is sufficient to burn the high self- ignition temperature of the GH_2. The burned GH_2 increased the pre-combustion phase as well as diffusion combustion phases. Further, the zig-zag manner (wavy nature) of diffusion phase experienced at 20°bTDC due to inactive participation of inducted GH_2 was totally eliminated. Whereas, with 24° bTDC and 26° bTDC injection advancements shown that the diffusion phase peak was sharply raised when compared to all other injection advancements. For the same injection advancements 24° and 26°, pre-combustion phase showed small dip was taken place due to, maximum accumulation of pilot fuel in the combustion chamber reduces the combustion temperature leads to poor burning of GH_2 during pre-mixed combustion phase and later in diffusion phase is participating causing sharp rise in 2nd phase. However, 22° injection advancement was reasonably good in both pre as well as diffusion combustion phases.

4.5.4.3. Ignition delay for 20°, 22°, 24° and 26° bTDC Injection Timings at 175 bar Injection Pressure at 0.5 gm/min and 80% load

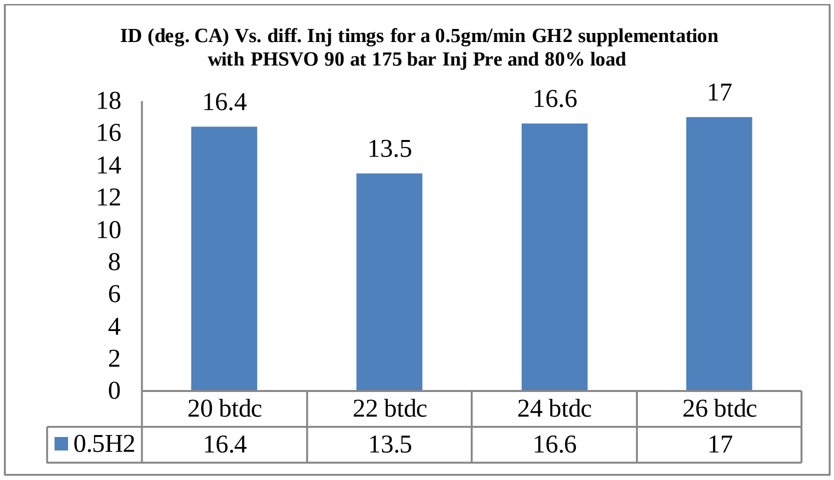


Figure 4.72 Ignition Delay for different Injection Timings

As the injection timing is advanced, more amount of pilot fuel is accumulated; causing reduction in combustion chamber temperatures, and delaying the pre-combustion reactions in the mixture of pilot fuel, and air surrounded with GH_2 and residual gases leads to increase in ignition delay. However, at 22° bTDC, with 0.5 gm/min GH_2 supplemented PHSVO 90 at 80% load, the ignition delay was reduced to 13.5° CA, which is 2.9° CA lesser than 20° bTDC, 3.1° bTDC lesser than the 24° bTDC and 3.5° lesser than the 26° bTDC as showed in Figure 4.72.

4.5.5. Summary of influence of different Injection advancements of 0.5 gm/min GH_2 supplemented PHSVO 90 on Performance parameters, Exhaust emissions and Combustion characteristics.

Being a vegetable oil viscous and denser, it is very essential to provide time to get proper mixture with available air in the combustion chamber. Hence, it is mostly desirable to advance the injection timing for better combustion. Further, GH_2 also have high self-ignition temperature, it is very essential to burn the GH_2 to promote the good combustion there by enhancing the performance and reduction in emissions. In this background, in addition to the manufacturer's optimized injection timing 20° bTDC for the conventional diesel fuel, an attempt was made to advance the injection timing up to 26° with an increment of 2° CA. And the experiments were conducted in the identified GH_2 range started from 0.4gm/min to 0.7 gm/min at 80% loading and 175 bar injection pressure.

In general with advanced injection timings, brake thermal efficiency was raised due to better combustion of accumulated pilot fuel, which intern burns the GH_2 leads to reduction in quantity of the pilot PHSVO 90, leads to reduction of smoke and CO. The same scenario was identified with increasing the GH_2 supplementation also. Whereas with injection advancement HC was slightly raised due to, more time is available for accumulated fuel to get interact with available air leads to overmixing of fuel resulting lean mixture beyond required limit and it slightly deteriorated the combustion thereby increased HC emissions. Further, with advanced injection timings and increased dosage of GH_2 supplementation increased the NO_x level due to, heat release rate of GH_2 increase the combustion chamber temperature which is a favorable situation to get react Nitrogen with oxygen and forms higher NO_x. Further, with advanced injection timing more amount of fuel is being accumulated during the ignition delay and more time is available to burn the same nearer to TDC and enhanced the diffusion combustion in addition to pre-mixed phase increased the combustion temperature, which is favoring the formation of NO_x. With reference to the combustion parameters; with injection advancement as well as increase of GH_2 supplementation will increase the Pmax also. Ignition delay was increased with increasing the injection advancement, because as injection timing advanced, more fuel was accumulated resulting reduction in the combustion chamber temperature leads to delayed the pre-combustion reactions in the mixture.

It was seen that, at 22^o bTDC injection advancement, for 0.5 gm/min GH_2 supplemented PHSVO 90 at 175 bar injection pressure shown following meritorious observations when compared to all other injection advancements including manufactures recommended injection timing and identified GH_2 supplementations.

Brake thermal efficiency was raised to 30.56%, which is 0.95 % more than 20^0 bTDC, 0.86% more than 24^o bTDC, 0.78% more than 26^o bTDC. NO_x was raised to 440 ppm, which is 44 ppm more than the 20^o bTDC, and 22 ppm and 55 ppm less than the 24^o bTDC and 26^o bTDC injection advancements respectively. Smoke was considerably reduced to 30.7 HSU, which is 29.3 HSU lesser than 20^o bTDC and 10.2 HSU lesser than the 24^o bTDC and 3.5 HSU lesser than the 26^o bTDC. CO was reduced to 0.05% by volume, which is 0.04 by % volume is lesser than the 20^o bTDC, 24^o bTDC, and 26^o bTDC. HC emissions were reduced to 7 ppm, which is 1 ppm lesser than the 20^o bTDC, 2 ppm lesser than the 24^o bTDC and 3 ppm lesser than 26^o bTDC. Pmax was raised to 52.911 bar, at 7.5^o CA aTDC, which is 10.454 bar more than the 20^o bTDC, 0.62 bar less than the 24^o bTDC and 3.59 bar less than the 26^o bTDC with CA retardments of 8.5^o and 9^o CA for 24^o and 26^o bTDC injection advancements respectively. Diffusion Heat release rate peaks are sharply increasing, which is not a desirable mode in case of 24^o bTDC and 26^o bTDC when comparing to 22^o bTDC. Ignition delay was reduced to 13.5^o CA, which is 2.9^o CA lesser than 20^o bTDC, 3.1^o bTDC lesser than the 24^o bTDC and 3.5^o lesser than the 26^o bTDC.

With the above merits it was decided that, this selected engine for given range of GH_2 supplementation with PHSVO 90 is optimally working at 0.5 gm/min GH_2 dosage, with injection advancement of 22^o bTDC, and injection pressure of 175 bar at 80% loading.

However, in order to further improve the atomization of selected or identified injection advancement 22^o bTDC, 0.5 gm/min GH_2 supplementation with PHSVO 90 at 80% load was considered to be investigate further by changing the injection pressure. In next session detailed analysis was considered by varying the different injection pressures.

4.6. DATA GENERATION OF PHSVO 90 WITH IDENTIFIED GASEOUS HYDROGEN 0.5 gm/min SUPPLEMENTATION AT 22^o bTDC UNDER VARYING INJECTION PRESSURES LIKE: 175 bar, 205 bar, 235 bar and 265 bar AT 80% LOAD

Further, with increase of injection pressure, shorter injection duration is required for the same nozzle hole size and injection quantity and atomization improves resulting in smaller droplet size enhances the combustion resulting increase in brake thermal efficiency and reduction in smoke emissions.

Experimentation results are discussed in three categories like; performance parameters, exhaust emissions and combustion characteristics with Jatropa based pre-heated straight vegetable oil at 90^oC (PHSVO 90) with identified gaseous hydrogen of 0.5 gm/min supplementation at 22^o bTDC under varying injection pressures like: 175 bar, 205 bar, 235 bar and 265 bar at 80% load.

4.6.1. Performance Parameters

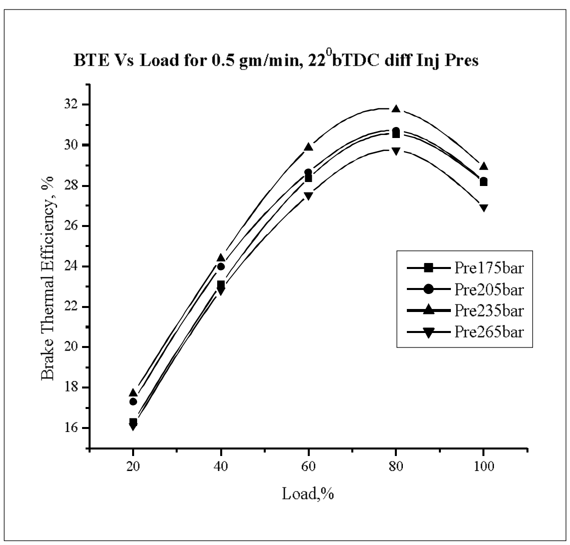


Figure 4.73 BTE for different Injection Pressures at 22^o bTDC Injection advancement, 0.5 gm/min GH_2 supplementation

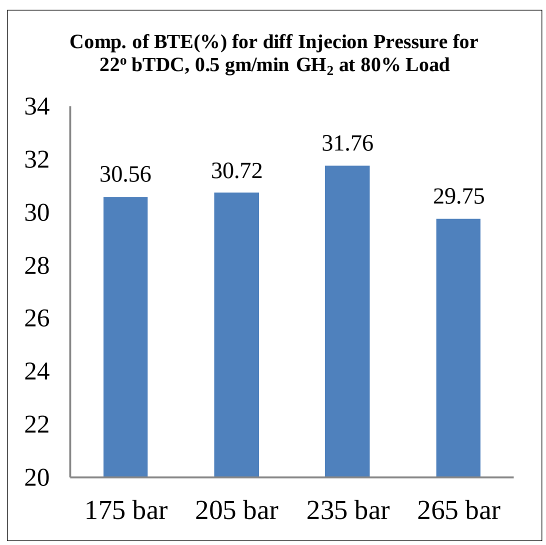


Figure 4.74 BTE for different Injection Pressures at 22^o bTDC Injection advancement, 0.5 gm/min GH_2 supplementation t 80% load

As the injection pressure was increased, shorter injection duration was observed for the given injection quantity that enhanced the fuel atomization resulting in formation of better local combustible mixture. Further, supplemented GH_2 enhanced the combustion mixture, by which consumption of pilot fuel quantity got reduced leading to increase in brake thermal efficiency. Up to 235 bar injection pressure, brake thermal efficiency was increased and maximum at 235 bar injection pressure of 31.76% as showed in Figures 4.73 & 4.47, which is 1.2% and 1.04% higher than 175 bar and 205 bar injection pressures. Whereas, at 265 bar injection pressure, brake thermal efficiency was reduced to 29.75%, reason being that, impingement of fuel sprays on the walls i.e., spray over penetration leads to bulk quenching of combustion chamber temperature, thereby deteriorating the combustion reactions due to cooling of mixture.

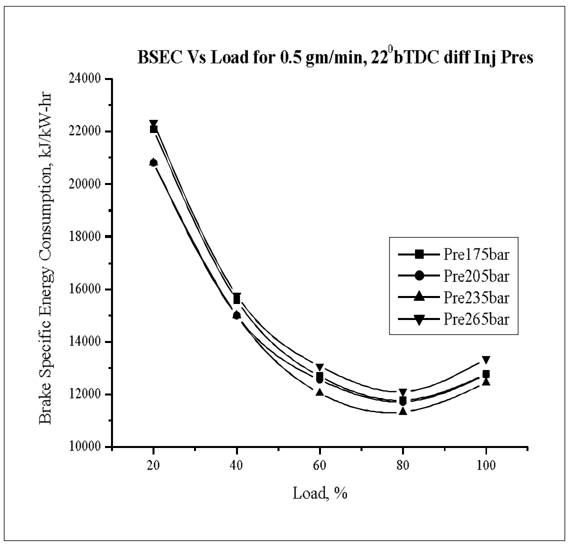


Figure 4.75 BSEC for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min GH_2 supplementation

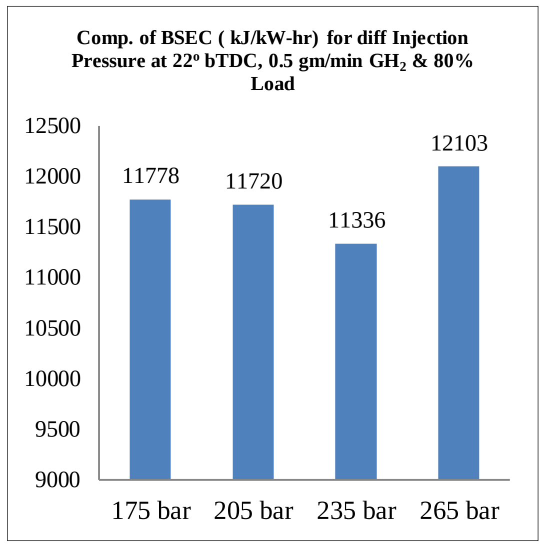


Figure 4.76 BSEC for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min GH_2 supplementation at 80% load

From the Figures 4.75 and 4.76, at 235 bar injection pressure, brake specific energy consumption was minimum when compared to others.

4.6.2. Exhaust Emissions

As the injection pressure increased, atomization resulted smaller droplet size will properly evaporate and form combustible mixture faster resulting in more fuel burning close to TDC, which is favorable situation for Nitrogen to get react with air and forms more NO_x. At 235 bar injection pressure, NO_x got maximum when compared to others. At this injection pressure, NO_x was raised to 492 ppm as showed in Figure 4.77.

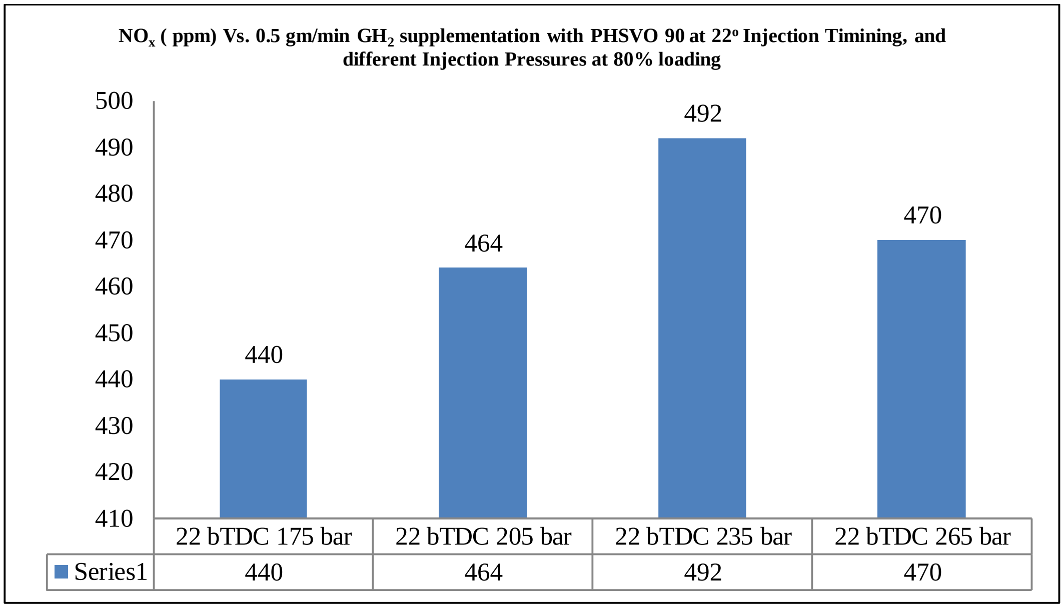


Figure 4.77 NOx for different Injection Pressures at 22^{o} bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load

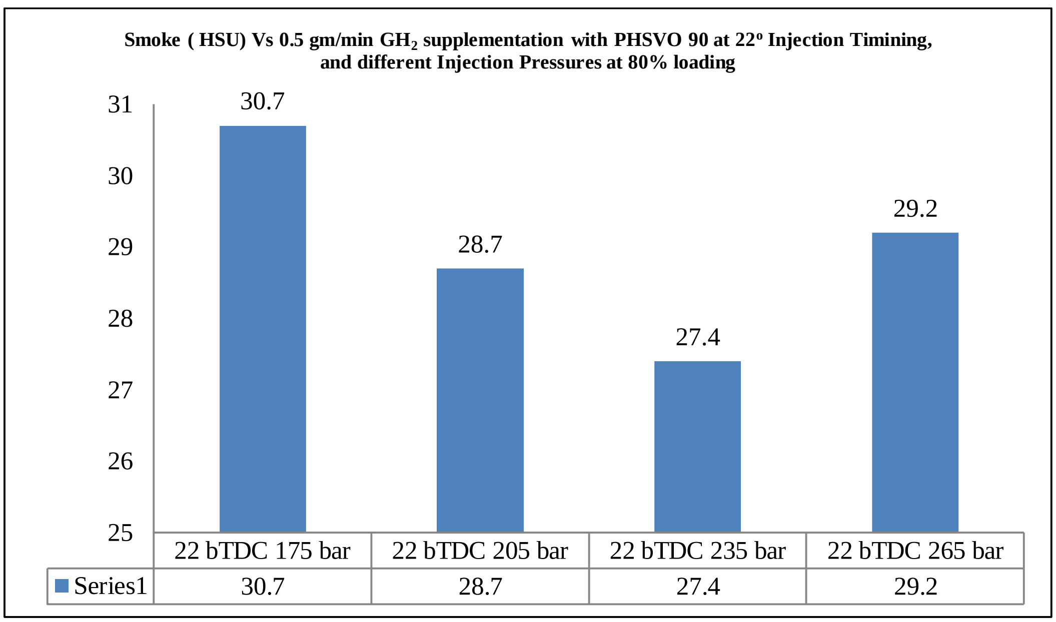


Figure 4.78 Smoke for different Injection Pressures at 22^{o} bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load

At 235 bar injection pressure, Smoke was very less when compared to others. At this injection pressure, the same was reduced to 27.4 HSU. Which is 3.3 HSU and 1.3 HSU lower than the 175 bar and 205 bar injection pressures. Whereas at 265 bar injection pressure, smoke was increased to 29.2, which is 1.8 HSU more than 235 bar injection pressure due to poor combustion as showed in Figure 4.78.

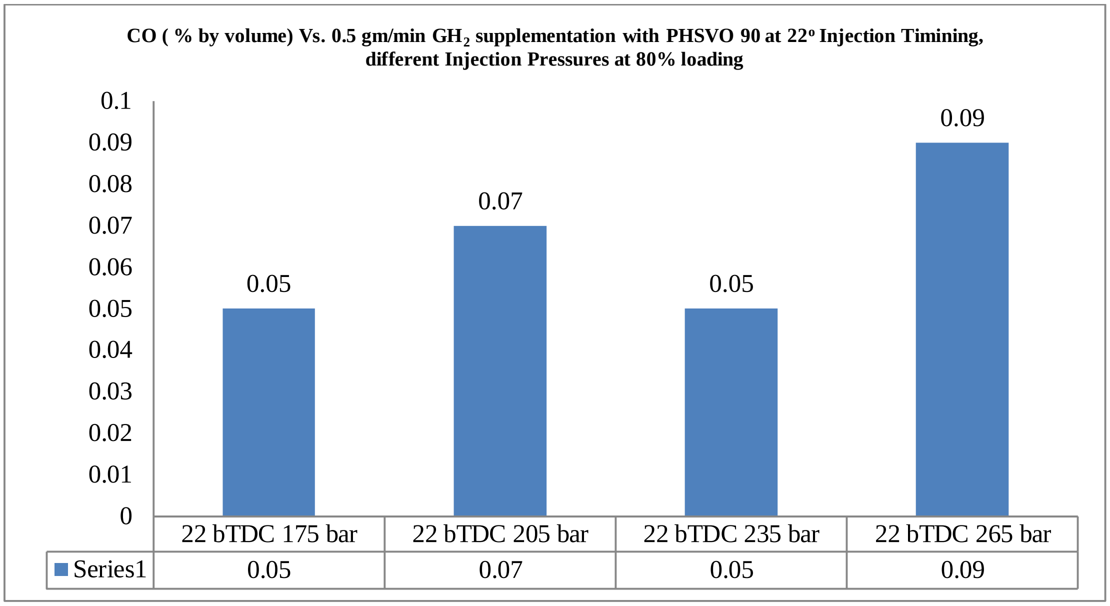


Figure 4.79 CO for different Injection Pressures at 22^{o} bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load

From the Figure 4.79, at 235 bar injection pressure, CO was very less when compared to others. At this injection pressure, the same was reduced to 0.05 by % volume, which remains same with 175 bar injection pressure and at 205 bar and 265 bar injection pressures the same was reduced by 0.02 % and 0.04% by volume respectively.

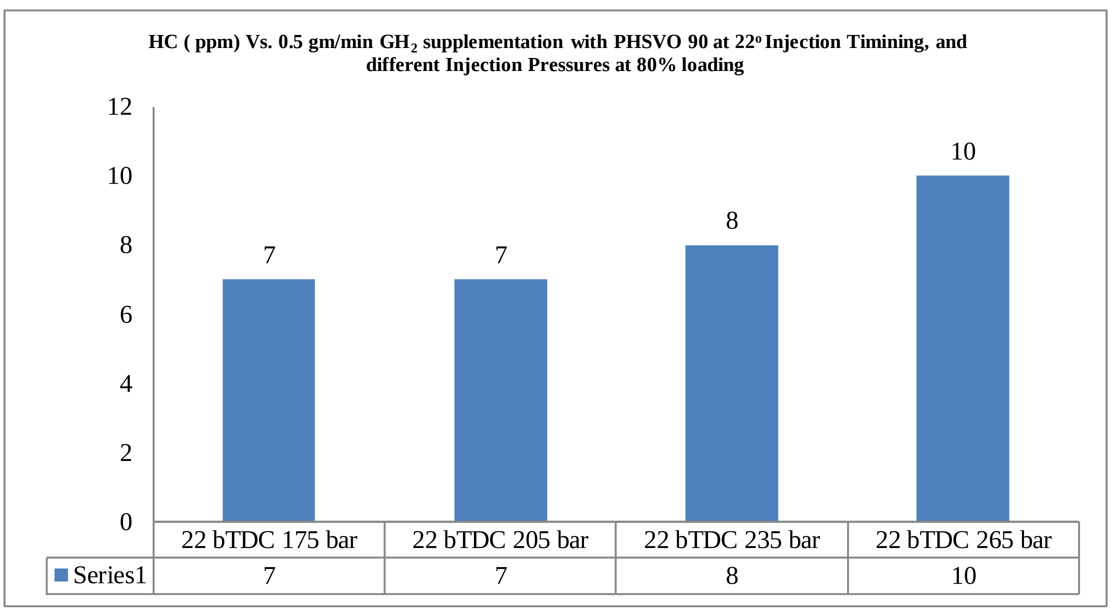


Figure 4.80 HC for different Injection Pressures at 22^{o} bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load

HC was slightly increased with increased injection pressure. At 235 bar injection pressure, HC is 8 ppm. which is 1 ppm higher than the 175 bar and 205 bar injection pressures and 2 ppm lesser than the 265 bar injection pressures. The rise in HC with increase of injection pressure is due to increase of momentum of the fuel vapour, further escaping from valve during valve overlap as a unburned hydrocarbons and impingement of fuel sprays on the walls reduced the combustion chamber temperature made raise in HC emissions.

4.6.3. Combustion Characteristics

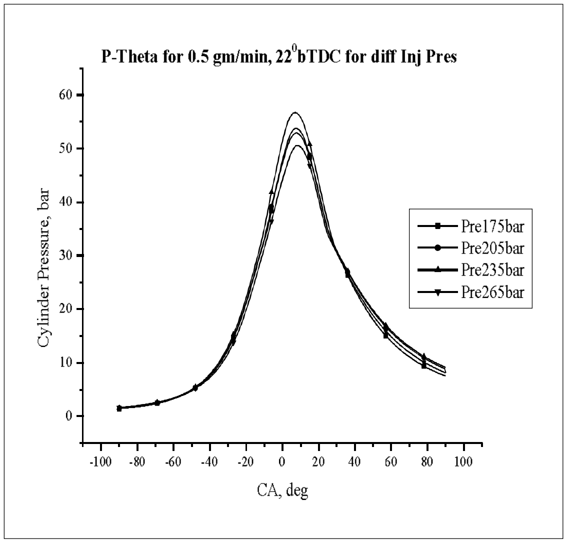


Figure 4.81 Cylinder Pressure for different Injection Pressures at 22^{o} bTDC Injection advancement, 0.5 gm/min hydrogen supplementation

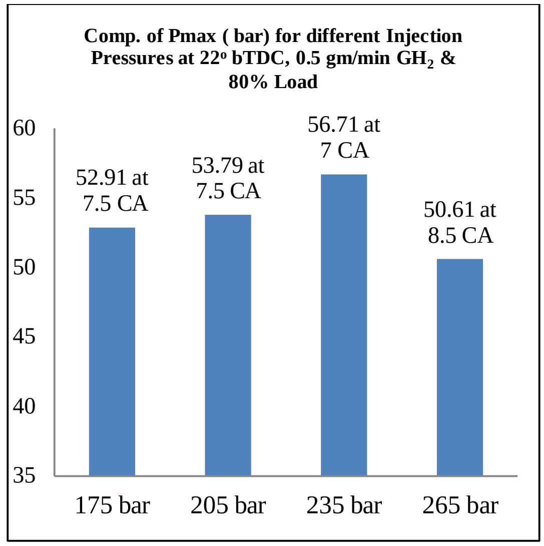


Figure 4.82 Pmax for different Injection Pressures at 22^{o} bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load

With increased injection pressure, as atomization was good resulted smaller droplet size of the injected fuel is easy to get mix with the air and GH_2 caused good combustion. Further, increase in turbulence of the combustion chamber helps to proper mixing of fuel and air with inducted GH_2 which enhanced the Pmax up to 235 bar injection pressure. At higher injection pressure, being an IDI engine, over penetration of fuel causing wetting the combustion chamber, by which combustion chamber temperature reduces leading poor combustion, which effected the Pmax. At 235 bar injection pressure, Pmax was raised to 56.715 bar at 7^{o} CA, which is 3.8 bar, 2.92 bar and 6.11 bar higher than 175 bar, 205 bar and 265 bar injection pressures with CA retardments by 0.5^{o}, 0.5^{o} and 1.5^{o} respectively as showed in Figures 4.81 & 4.82.

As the injection pressure is increased from 175 bar to 265 bar with an increment of 30 bar, it was observed that, up to 235 bar pre-combustion phase and diffused combustion phase were increased. But at high injection pressure, i.e., at 265 bar injection pressure, pre-mixed phase was increased and diffusion phase was dipped when comparing to other injection pressures due to quenching and escaping of fuel from the combustion chamber as showed in Figure 4.83.

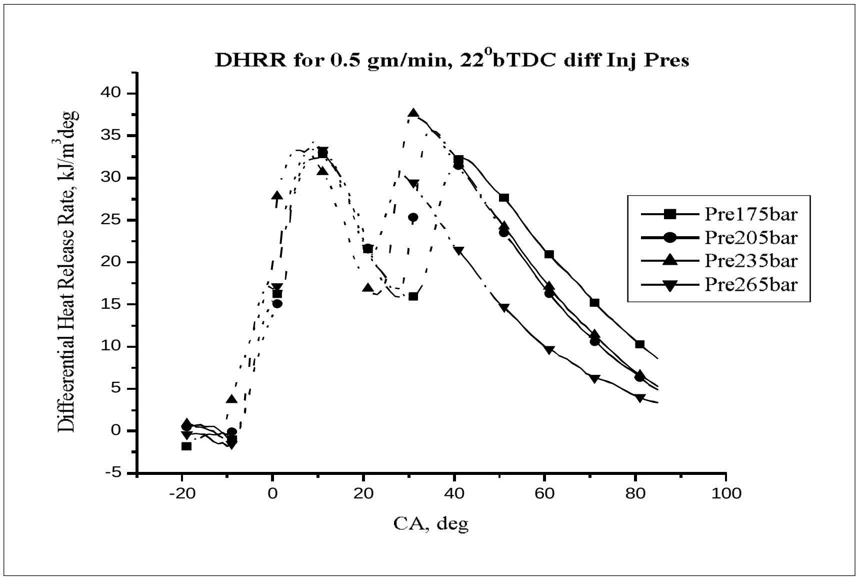


Figure 4.83 DHRR for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load

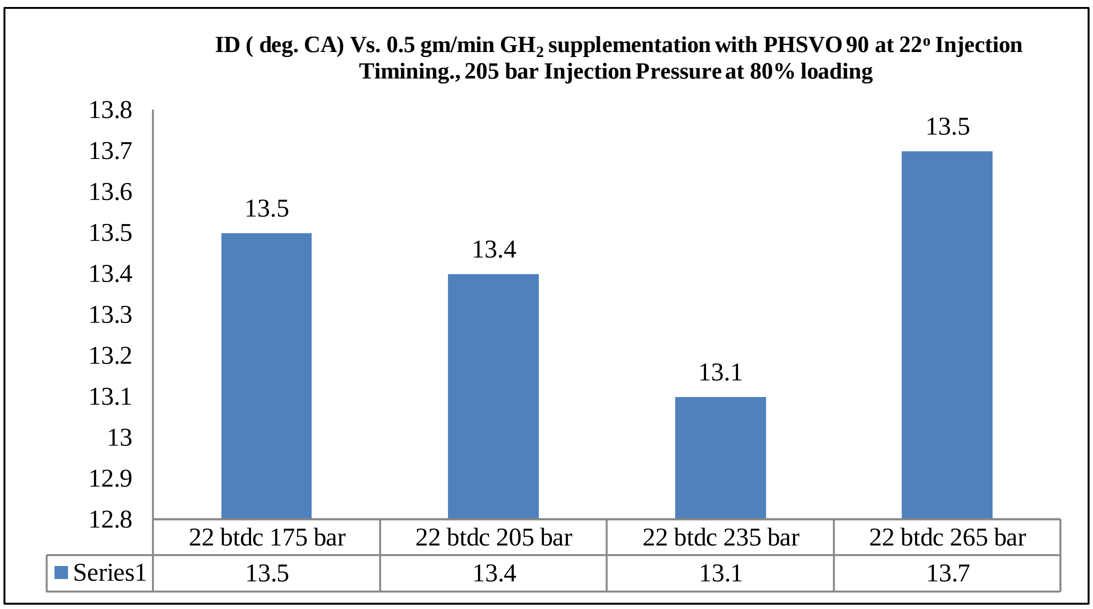


Figure 4.84 Ignition delay for different Injection Pressures at 22° bTDC Injection advancement, 0.5 gm/min hydrogen supplementation at 80% load

From the Figure 4.84, ignition delay was greatly influenced by the injection pressure, at 235 bar ignition delay was reduced to 13.1° CA, which is 0.4° CA and 0.3° CA lower than the 175 bar and 205 bar injection pressures. But at higher injection pressure, the same was increased to 13.5, which is 0.4° CA higher than the 235 bar injection pressure due to over penetration of fuel and subsequently quenching of cylinder walls leads to reduction of combustion chamber temperature.

4.6.4. Summary of influence of different Injection Pressures on 0.5 gm/min GH_2 supplemented PHSVO 90 at 22^o bTDC at 80% load on Performance parameters, Exhaust emissions and Combustion characteristics.

With increase of injection pressure, shorter injection duration is required for the same nozzle hole size, and injection quantity and atomization improves resulting in smaller droplet size enhances the combustion resulting increase in brake thermal efficiency and reduction in smoke emissions.

Experiments were conducted at 0.5 gm/min GH_2 supplemented PHSVO 90 at 22^o bTDC at 80% load with varied injection pressures ranging from 175 bar to 265 bar with an increment of 30 bar. It was observed that, with increased injection pressure up to 235 bar, brake thermal efficiency was enhanced and all emissions were decreased except NO_x. But at higher injection pressure 265 bar, being IDI engine, brake thermal efficiency was deteriorated and emissions were increased except NO_x due to over penetration of fuel causing wetting the combustion chamber, by which combustion chamber temperature reduces leading poor combustion.

It was observed that maximum brake thermal efficiency and minimum emissions were recorded at 235 bar injection pressure, 22^o bTDC injection timing and at 80% load. Those observations are as follows:

Brake thermal efficiency was increased to 31.76%, which is 1.2% ,1.04% and 2.01% higher than 175 bar, 205 bar and 265 bar injection pressures. Smoke, was reduced to 27.4 HSU, which is 3.3 HSU, 1.3 HSU and 1.8 HSU lower than the 175 bar, 205 bar and 265 bar injection pressures. CO was reduced to 0.05 by % volume, which remains same with 175 bar injection pressure and at 205 bar and 265 bar the same was increased by 0.02 % and 0.04 % by volume respectively. HC was slightly increased to 8 ppm, which is 1 ppm higher than the 175 bar and 205 bar injection pressures and 2 ppm lower than the 265 bar injection pressure. NOx was increased to 492 ppm, which is 52 ppm, and 28 ppm higher than 175 bar, 205 bar and 22 ppm lower at 265 bar injection pressures. Pmax was increased to 56.715 bar at 7^0 CA, which is 3.8 bar, 2.92 bar and 6.11 bar higher than 175 bar, 205 bar and 265 bar injection pressures with CA retardments by 0.5^o, 0.5^o and 1.5^o respectively. Both Pre-mixed combustion and Diffused combustion peaks were improved as injection when comparing to 175 bar and 205 bar injection pressures. Ignition Delay was decreased to 13.1^o

CA, which is 0.4° CA, 0.3° CA lower than the 175 bar, 205 bar and remain same as of 175 bar at 265 bar injection pressures.

But, with higher injection pressure, i.e., at 265 bar, the brake thermal efficiency was reduced to 29.75%. Smoke, CO and HC were increased by 1.8 HSU, 0.04% by volume and 2 ppm respectively when comparing to 235 bar injection pressure. Whereas NO_x was decreased by 22 ppm. The reason being for deteriorating of performance and increase in emissions is impingement of fuel sprays on the walls i.e., spray over penetration leads, sometimes escaping from the valves, to bulk quenching of combustion chamber temperature, thereby deteriorating the combustion reactions due to cooling mixture.

4.7. COMPARISON OF OPTIMIZED DATA WITH CONVENTIONAL DIESEL AND JATROPA BASED PHSVO 90 DATA.

Experimental results discussed earlier were compared in three categories like; performance parameters, exhaust emissions and combustion characteristics of optimized injection timing, optimized injection pressure at optimized gaseous hydrogen supplementation of 0.5 gm/min with base line conventional diesel and PHSVO 90 at 80% load.

4.7.1. Performance Parameters

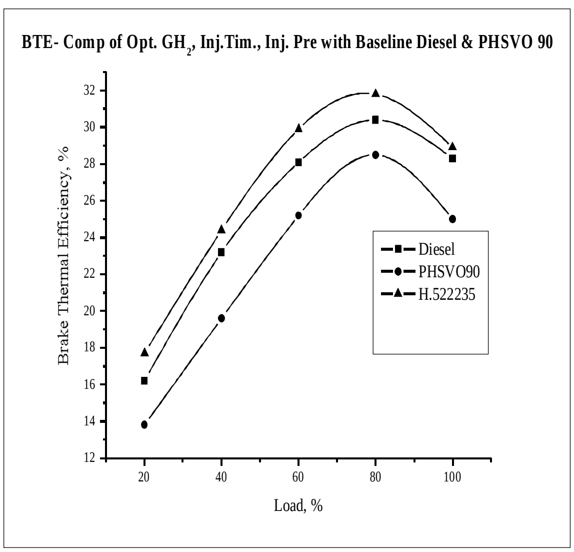


Figure 4.85 Comparison of BTE of optimized data with base line data

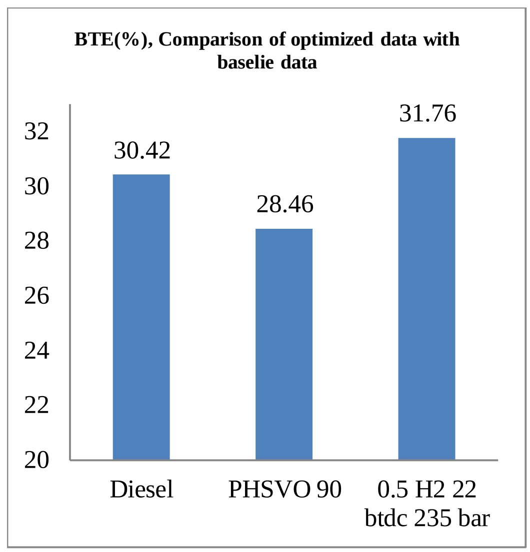


Figure 4.86 Comparison of BTE of optimized data with base line data at 80% load

It is observed that, at 22° bTDC injection advancement, 235 bar injection pressure of 0.5gm/min GH_2 supplemented PHSVO 90 was showed higher brake thermal efficiency of

31.76%, which is 1.34% higher than the conventional diesel, 3.3% higher than the pure PHSVO 90 at 80% loading as showed in Figure 4.85 & 4.86.

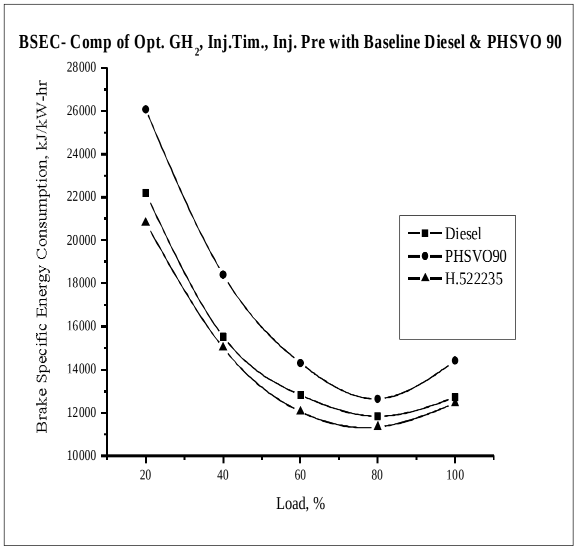


Figure 4.87 Comparison of BSEC of optimized data with base line data

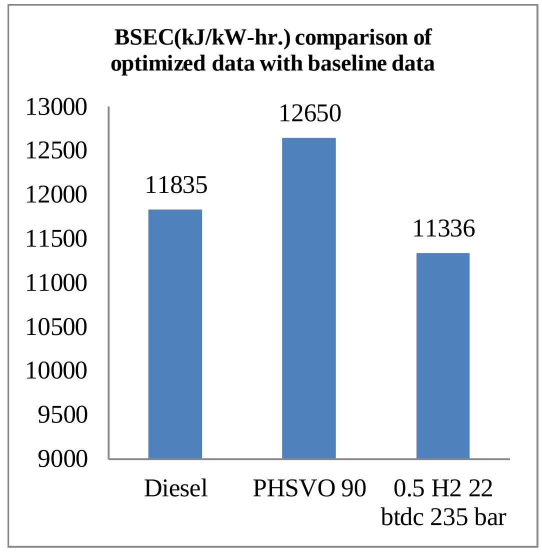


Figure 4.88 Comparison of BSEC of optimized data with base line data at 80% load

From the above Figures 4.87 and 4.88 it was identified that, at 22^{o} bTDC injection advancement, 235 bar injection pressure of 0.5 gm/min GH_2 supplemented PHSVO 90 was shown lower brake specific energy consumption of 11336.2 kJ/kW-hr, which is 499 kJ/kW-hr lesser than the conventional diesel, 1314 kJ/kW-hr, lower than the pure PHSVO 90 at 80% loading.

4.7.2. Exhaust Emissions

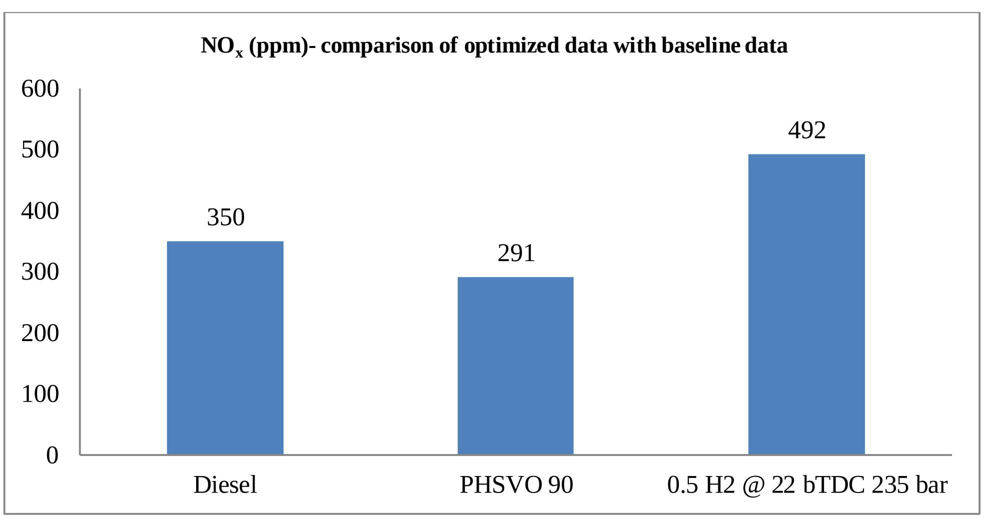


Figure 4.89 Comparison of NO_x of optimized data with baseline data

From the Figure 4.89, 22^o bTDC injection advancement, 235 bar injection pressure of 0.5 gm/min GH_2 supplemented PHSVO 90 was shown higher NO_x of 492 ppm, which is 142 ppm higher than the conventional diesel, 201 ppm higher than the pure PHSVO 90 at 80% loading. From the Figure 4.90, it was observed that, at 22^o bTDC injection advancement, 235 bar injection pressure of 0.5 gm/min GH_2 supplemented PHSVO 90 was shown lower smoke of 27.4 HSU, which is 28.6 HSU lesser than the conventional diesel, 39.6 HSU, lower than the pure PHSVO 90 at 80% loading.

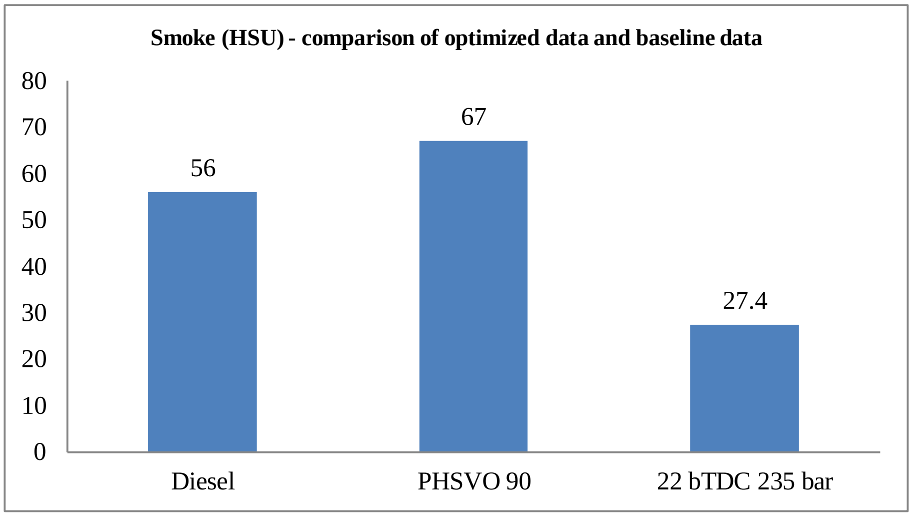


Figure 4.90 Comparison of Smoke of Optimized data with baseline data

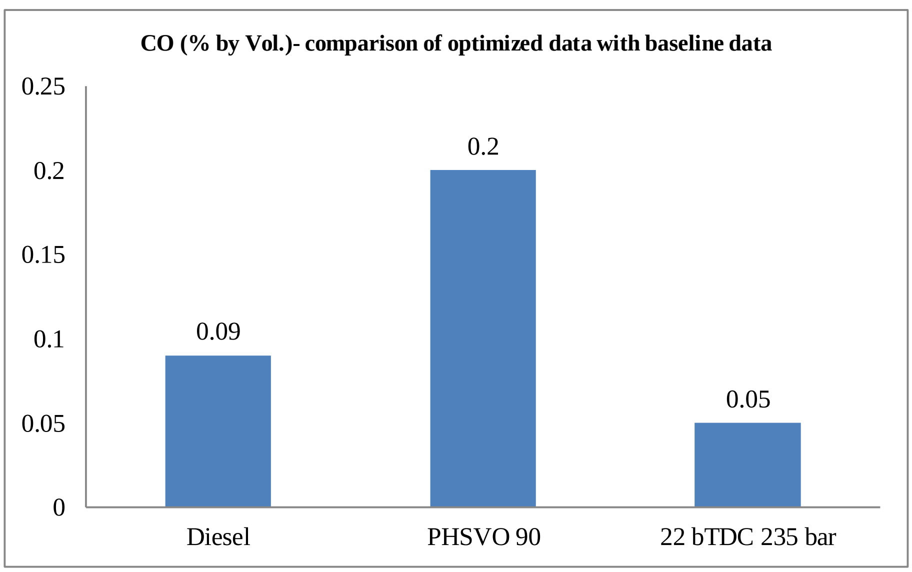


Figure 4.91 Comparison of CO of optimized data with baseline data

From the Figure 4.91, it is seen that, at 22^o bTDC injection advancement, 235 bar injection pressure of 0.5 gm/min GH_2 supplemented PHSVO 90 was shown lower CO of 0.05 % by volume, which is 0.04 % by volume lesser than the conventional diesel, 0.15 % by volume, lower than the pure PHSVO 90 at 80% loading.

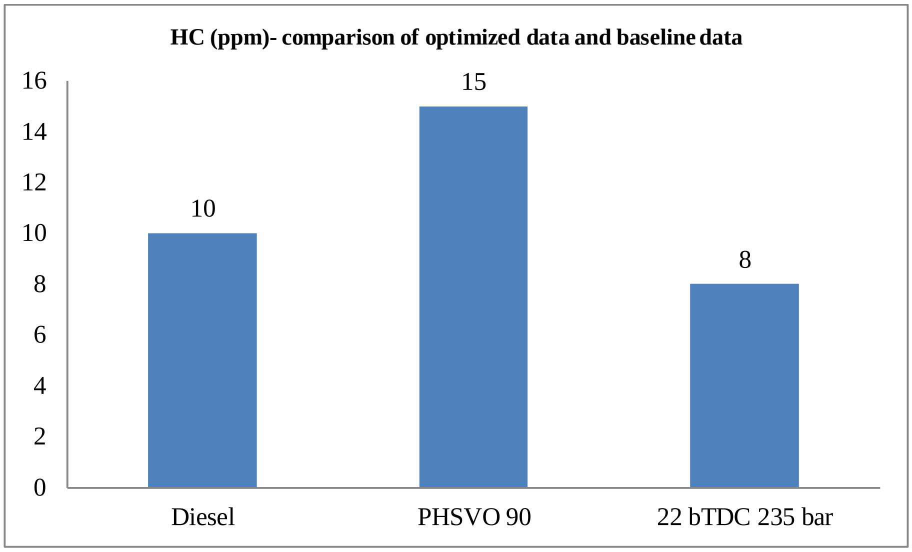


Figure 4.92 Comparison of HC of optimized data with baseline data

From the above Figure 4.92, it was observed that, at 22° bTDC injection advancement, 235 bar injection pressure of 0.5 gm/min GH_2 supplemented PHSVO 90 was shown 8 ppm, which is 2 ppm lesser than the conventional diesel, 7 ppm lower than the pure PHSVO 90 at 80% loading.

4.7.3. Combustion Characteristics

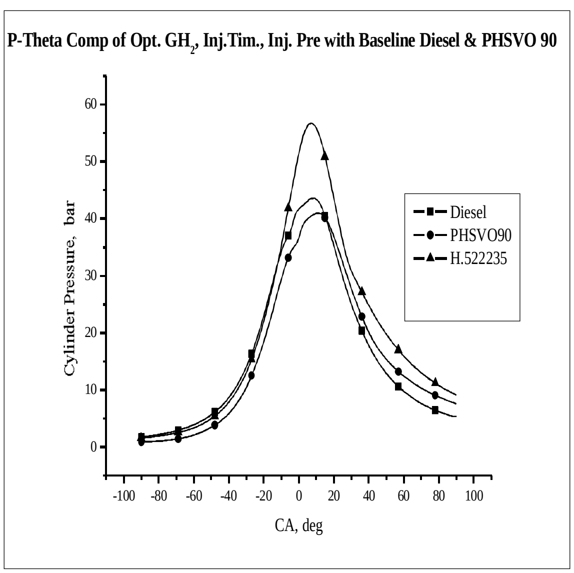


Figure 4.93 Comparison of P-θ of optimized data with Baseline data

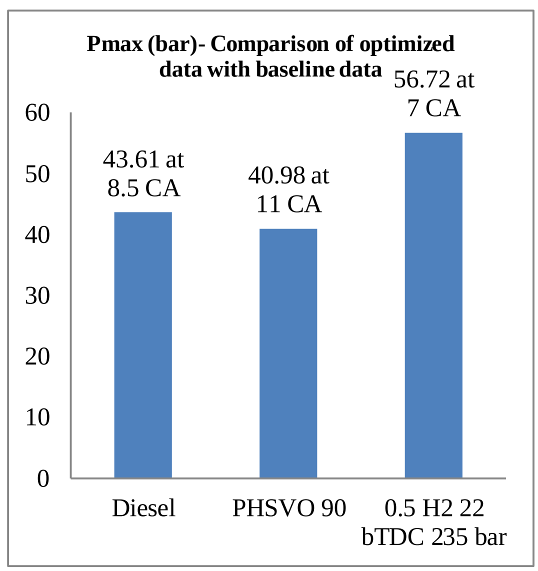


Figure 4.94 Comparison of P-θ of optimized data with Baseline data at 80% load

From the above Figure 4.93 and 4.94, with 22^{o} bTDC injection advancement, 235 bar injection pressure of 0.5 gm/min GH_2 supplemented PHSVO 90 showed higher Pmax of 56.71 bar at 7^{o} aTDC, which is 13.1 bar higher than the conventional diesel with advanced CA by 1.5^{o}, 15.73 bar higher than the pure PHSVO 90 with advanced by 4^{o} CA. at 80% loading.

It is observed from the Figure 4.95 that, with supplementation of GH_2, the diffusion phase was appreciably increased when comparing to base line conventional diesel, and pure PHSVO 90 fuels. Further, with 0.5 gm/min GH_2 supplementation with PHSVO 90 at 22^{o} bTDC injection advancement, 235 bar injection pressure both pre-mixed as well as diffusion phase were moderately increased when comparing to others.

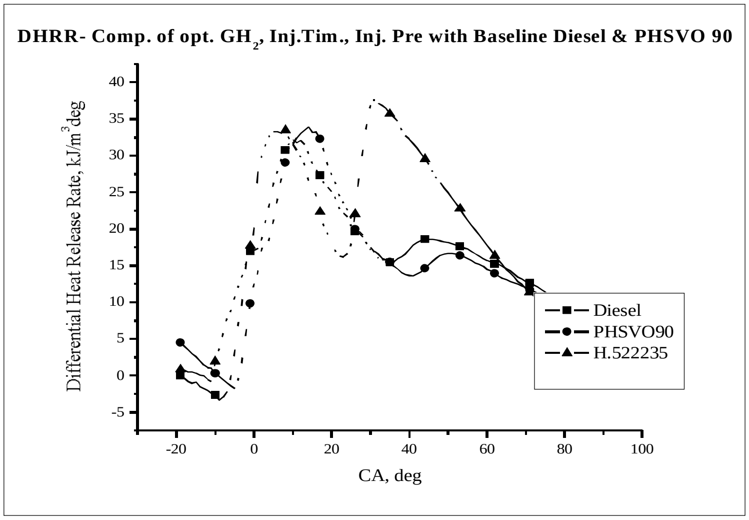


Figure 4.95 Comparison of Differential Heat Release Rate of Optimized data with baseline data

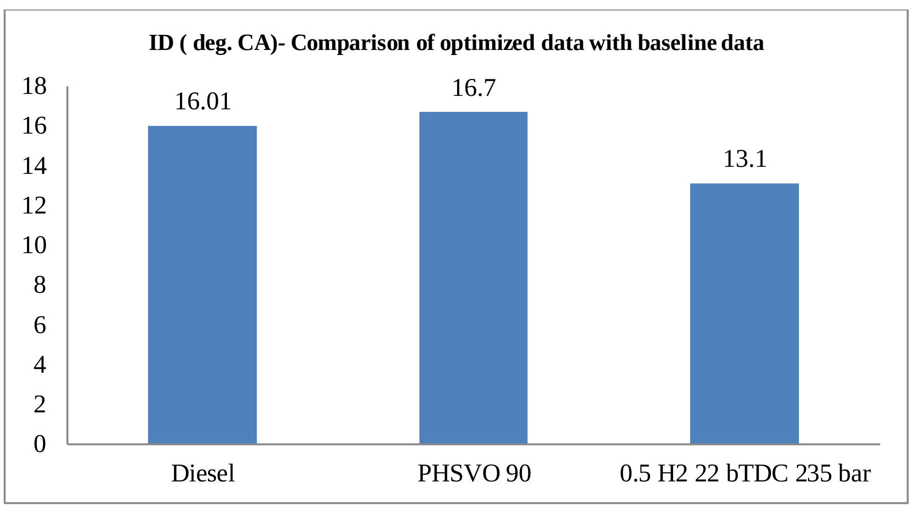


Figure 4.96 Comparison of Ignition Delay of Optimized data with base line data

From the Figure 4.96, it was observed that, at 22^o bTDC injection advancement, 235 bar injection pressure of 0.5 gm/min GH_2 supplemented PHSVO 90 was shown lower Ignition delay of 13.1^o CA, which is 2.9^o CA lesser than the conventional diesel, 3.6^o CA lesser than the pure PHSVO 90 at 80% loading.

4.7.4. Summary

With optimized injection advancement 22^o bTDC, injection pressure 235 bar, GH_2 of 0.5 gm/min supplementation in PHSVO 90 and optimized load at 80%, the following observations were made:

Brake thermal efficiency was increased to 31.76%, which is 3.3% more than pure PHSVO 90 and 1.34% more than conventional diesel. Smoke was reduced to 27.4 HSU, which is 39.6 HSU lower than pure PHSVO 90 and 28.6 HSU lower than conventional diesel. CO was reduced to 0.05% by volume which is 0.15% lower than pure PHSVO 90 and 0.04% lower than conventional diesel. HC was reduced to 8 ppm, which is 7 ppm lower than the pure PHSVO 90 and 2 ppm lower than the conventional diesel. NO_x of 492 ppm, which is 142 ppm higher than the conventional diesel, 201 ppm higher than the pure PHSVO 90, Pmax was increased to 56.71 bar at 7^o aTDC which is 15.73 bar more than the pure PHSVO 90 and 13.1 bar more than the conventional diesel with CA advancement of 4^o and 2.5^o with pure PHSVO and conventional diesel respectively. Further, heat release rate, both pre-mixed as well as diffusion combustion peaks were improved when comparing to pure PHSVO 90 and conventional diesel. Ignition delay appreciably reduced to 13.1^o CA, which is 3.6^o CA lower than the pure PHSVO 90 and 2.91^o lower than the conventional diesel.