CHAPTER 4

RESULTS AND DISCUSSION

The major purpose of this study was to improve the performance of a two-stroke gasoline engine to match that of a four-stroke gasoline engine with reduced emission using simple modifications. For this purpose, the two engines, a four-stroke spark ignition gasoline engine, and a spark ignition two-stroke gasoline engine were taken and tested for comparison. Further tests were carried out with inlet modified configurations on the spark ignition two-stroke gasoline engine. The test results obtained with various configurations evolved for developing an optimal design are compared in this section. There are three configurations selected for development and testing.

a) Configuration 1 is referred as D4 with a modified inlet having 4 mm orifice diameter in the two-stroke gasoline engine.
b) Configuration 2 is referred as D6 with a modified inlet having 6 mm orifice diameter in the two-stroke gasoline engine.
c) Configuration 3 is referred as D8 with a modified inlet having 8 mm orifice diameter in the two-stroke gasoline engine.

The experiments were conducted with varying percentage of both cooled and uncooled exhaust gas recirculation (EGR).

a) The percentage recirculation for cooled exhaust gas is referred as P5C, P10C, and P15C for 5 %, 10 %, and 15 % cooled EGR respectively.
b) The percentage recirculation for uncooled exhaust gas is referred as P5H, P10H, and P15H for 5 %, 10 % and 15 % uncooled EGR respectively.

Brake Thermal Efficiency, Specific Fuel Consumption, Mass flow Rate, CO, CO_2, NOx and HC Emissions, Scavenging Efficiency, and Trapping Efficiency are the different parameters obtained from the test results of the modified two-stroke engines.

These parameter values varied with changing speed conditions, uncooled and cooled EGR. These variations in values are analyzed and discussed here to determine the best combination of configuration, uncooled or cooled EGR and percentage of EGR to match the performance of a four-stroke gasoline engine.

4.1 Brake thermal efficiency

4.1.1 Brake thermal efficiency for 5 % uncooled and cooled EGR

Brake power vs. Brake thermal efficiency variations in the two-stroke engine using inlet manifold, modified with the orifice of diameters 4 mm, 6mm and 8mm are shown for 5 % uncooled EGR in Fig.4.1 and for 5 % cooled EGR in Fig.4.2. The performance of the two-stroke gasoline base engine without modifications and the reference four-stroke gasoline engine are also plotted in the same graph to get a visual comparison and the level of improvement achieved. There is a variation in brake thermal efficiency as compared to the two-stroke base engine in all the six configurations namely, 2SD4UC, 2SD6UC, 2SD8UC, 2SD4C, 2SD6C and 2SD8C for 5 % EGR.

The efficiency values were observed for the various configurations with 5 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

The brake thermal efficiency is 34.2 % for the two-stroke base engine, and brake thermal efficiency values are 37.7 %, 38.3 % and 37.2 % for 2SD4P5H, 2SD6P5H, and 2SD8P5H respectively. It can be observed that the increment in efficiency values are 3.5 %, 4.1 %, and 3.0 % for 2SD4P5H, 2SD6P5H and 2SD8P5H respectively over the efficiency of two-stroke gasoline base engine.

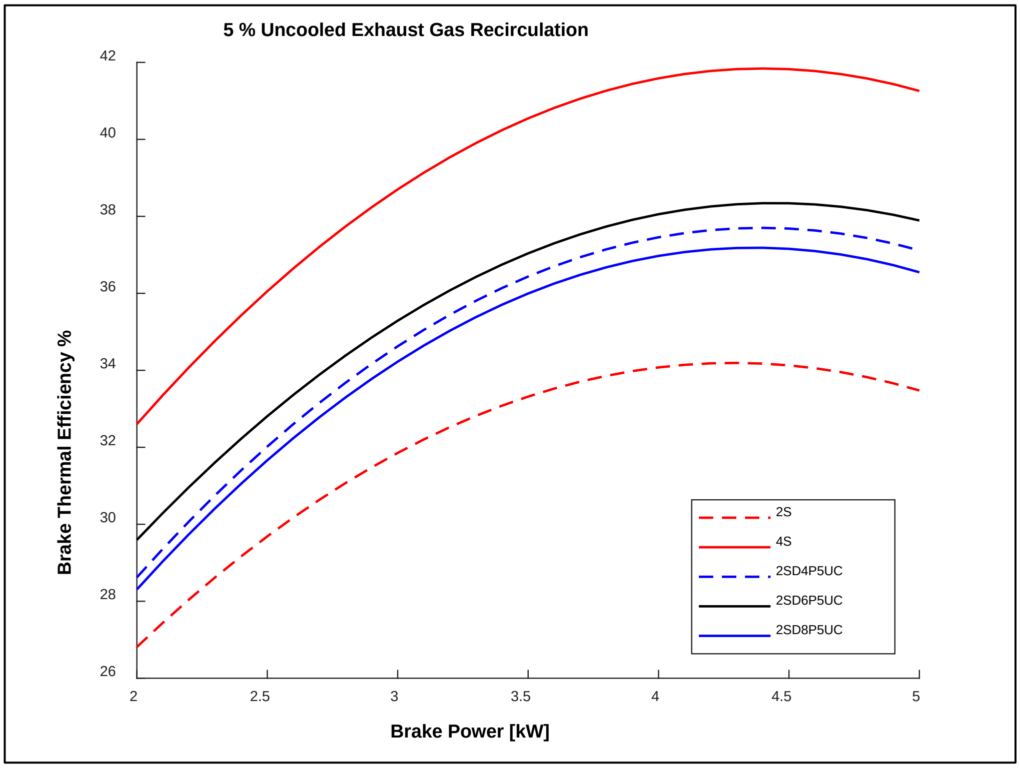

Figure 4.1 Brake Power vs. Brake Thermal Efficiency 5 % Uncooled EGR

Similarly, for cooled exhaust recirculation, the efficiency values were observed for the various configurations with 5 % exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

The brake thermal efficiency is 34.2 % for the two-stroke base engine, and brake thermal efficiency values are 39.6 %, 40.3 % and 39.9 % for 2SD4P5C, 2SD6P5C, and 2SD8P5C respectively. It can be observed that the increment in efficiency values are 5.4 %, 6.1 %, and 5.7 % for 2SD4P5C, 2SD6P5C and 2SD8P5C respectively over the efficiency of two-stroke gasoline base engine.

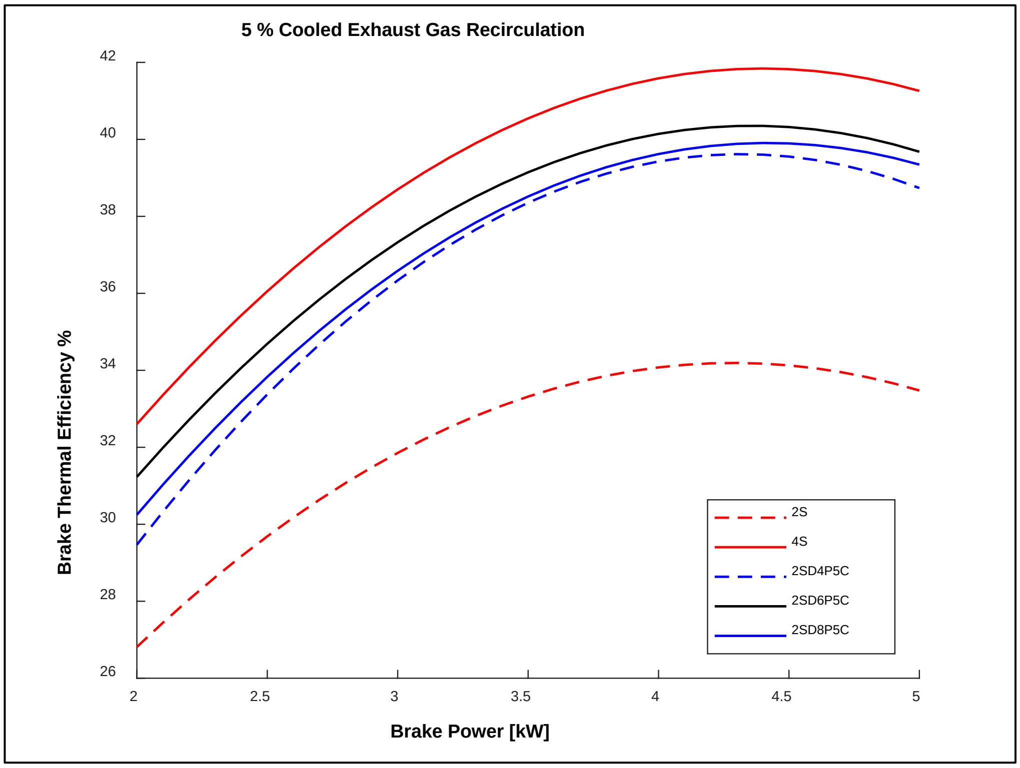

Figure 4.2 Brake Power vs. Brake Thermal Efficiency 5 % Cooled EGR

Maximum increment in efficiency is observed in the case of 2SD6P5C configuration is 6.1 % over that of two-stroke gasoline base engine. Comparing the efficiency values of 38.3 % and 40.3 % observed in 2SD6P5H and 2SD6P5C configurations, it can be observed that there is an increment of 2.0 % efficiency for cooled exhaust recirculation.

It has been concluded from the observations that there is a variation in performance concerning orifice diameters with a maximum improvement of 6.1 % at 6 mm orifice configurations with 5 % cooled exhaust gas recirculation.

4.1.2 Brake thermal efficiency for 10 % uncooled and cooled EGR

Brake power vs. Brake thermal efficiency variations in the two-stroke engine using inlet manifold, modified with the orifice of diameters 4 mm, 6mm and 8mm are shown for 10 % uncooled EGR in Fig.4.3 and for 10 % cooled EGR in Fig.4.4. The efficiency values were observed for the various configurations with 10 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

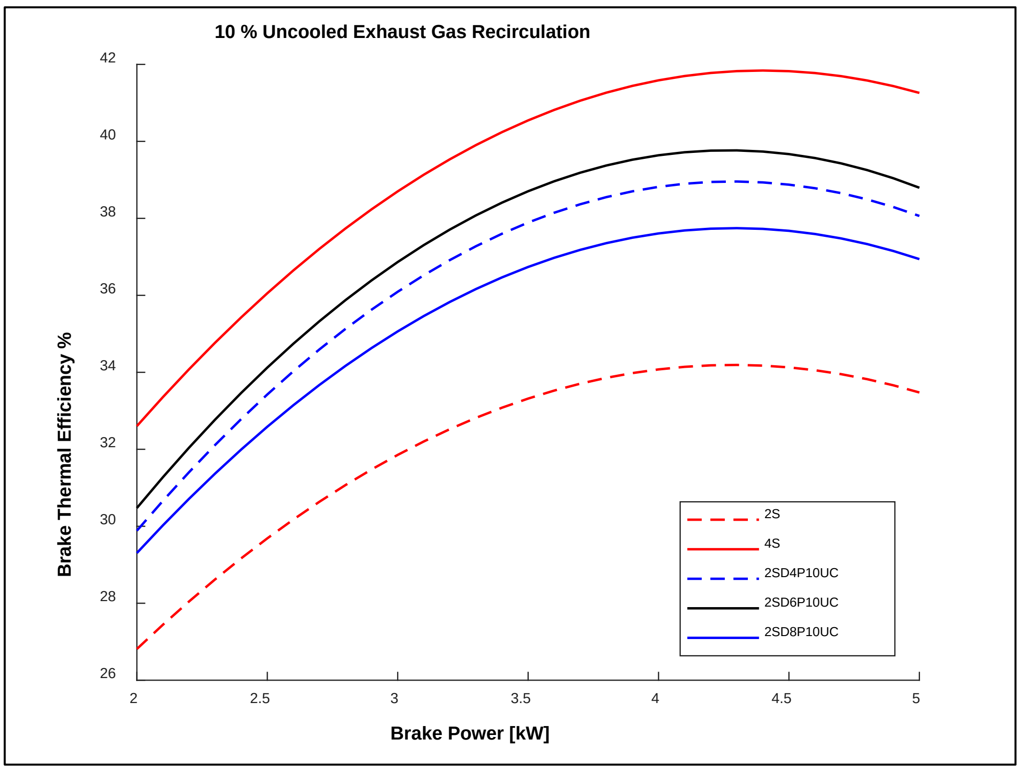

Figure 4.3 Brake Power vs. Brake Thermal Efficiency 10 % Uncooled EGR

The brake thermal efficiency is 34.2 % for two-stroke base engine and brake thermal efficiency values are 38.9 %, 39.8 % and 37.7 % for 2SD4P10H, 2SD6P10H and 2SD8P10H respectively. It can be observed that the increment in efficiency values are 4.7, 5.6, and 3.5 % for 2SD4P10H, 2SD6P10H and 2SD8P10H respectively over the efficiency of two-stroke gasoline base engine.

Similarly, for cooled exhaust recirculation, the efficiency values were observed for the various configurations with 10 % exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

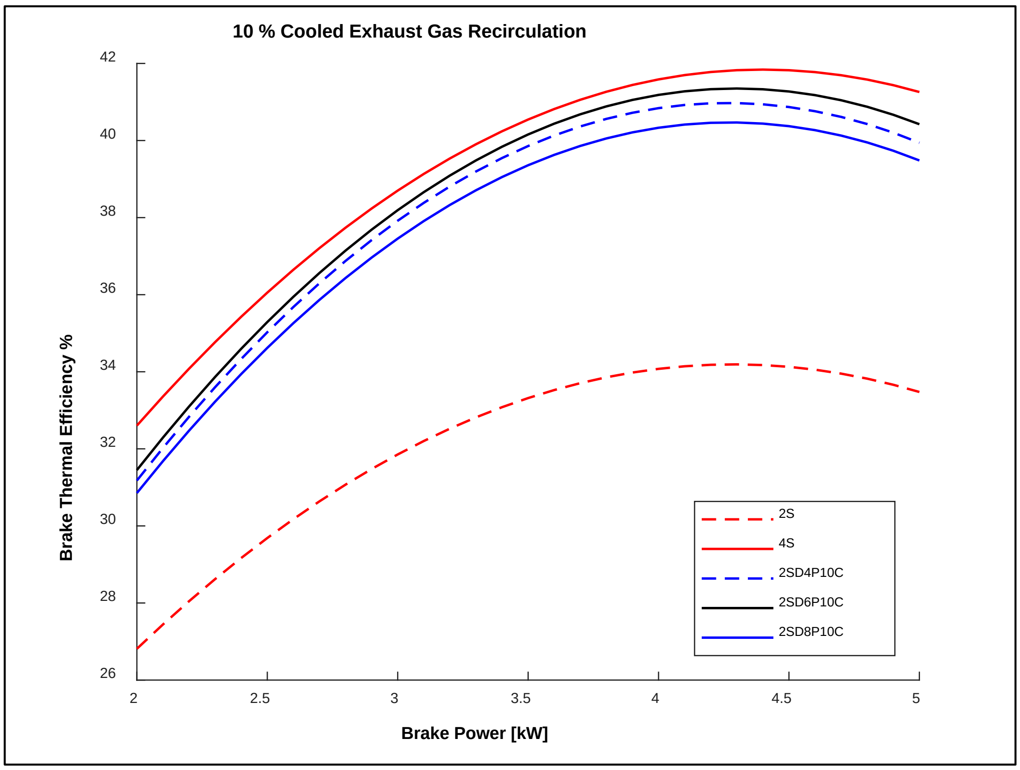

Figure 4.4 Brake Power vs. Brake Thermal Efficiency 10 % Cooled EGR

The brake thermal efficiency is 34.2 % for two-stroke base engine and brake thermal efficiency values are 40.9 %, 41.4 % and 40.5 % for 2SD4P10C, 2SD6P10C and 2SD8P10C respectively. It can be observed that the increment in efficiency values are 6.7, 7.2, and 6.3 % for 2SD4P10C, 2SD6P10C and 2SD8P10C respectively over the efficiency of two-stroke gasoline base engine.

Maximum increment in efficiency observed in the case of 2SD6P10C configuration is 7.2 % over that of two-stroke gasoline base engine. Comparing the efficiency values of 39.8 % and 41.4 % observed in 2SD6P10H and 2SD6P10C configurations, it can be observed that there is an increase of 1.6 % efficiency for cooled exhaust recirculation.

It has been concluded from the observations that there is a variation in performance concerning orifice diameters with maximum improvement 7.2 % at 6 mm orifice configurations with 10 % cooled exhaust gas recirculation.

4.1.3 Brake thermal efficiency for 15 % uncooled and cooled EGR

Brake power vs. Brake thermal efficiency variations in the two-stroke engine using inlet manifold, modified with the orifice of diameters 4 mm, 6mm and 8mm are shown for 15 % uncooled EGR in Fig.4.5 and for 15 % cooled EGR in Fig.4.6. The efficiency values were observed for the various configurations with 15 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

The brake thermal efficiency is 34.2 % for two-stroke base engine and brake thermal efficiency values are 37.0 %, 37.2 % and 36.4 % for 2SD4P15H, 2SD6P15H and 2SD8P15H respectively. It can be observed that the increment in efficiency values are 2.8, 3.0, and 2.2 % for 2SD4P15H, 2SD6P15H and 2SD8P15H respectively over the efficiency of two-stroke gasoline base engine.

Similarly, for cooled exhaust recirculation, the efficiency values were observed for the various configurations with 15 % exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

The brake thermal efficiency is 34.2 % for the two-stroke base engine, and brake thermal efficiency values are 39.3 %, 39.6 % and 39.0 % for 2SD4P15C, 2SD6P15C and 2SD8P15C respectively. It can be observed that the increment in efficiency values are

5.1, 5.4, and 5.0 % for 2SD4P5C, 2SD6P5C and 2SD8P5C respectively over the efficiency of two-stroke gasoline base engine.

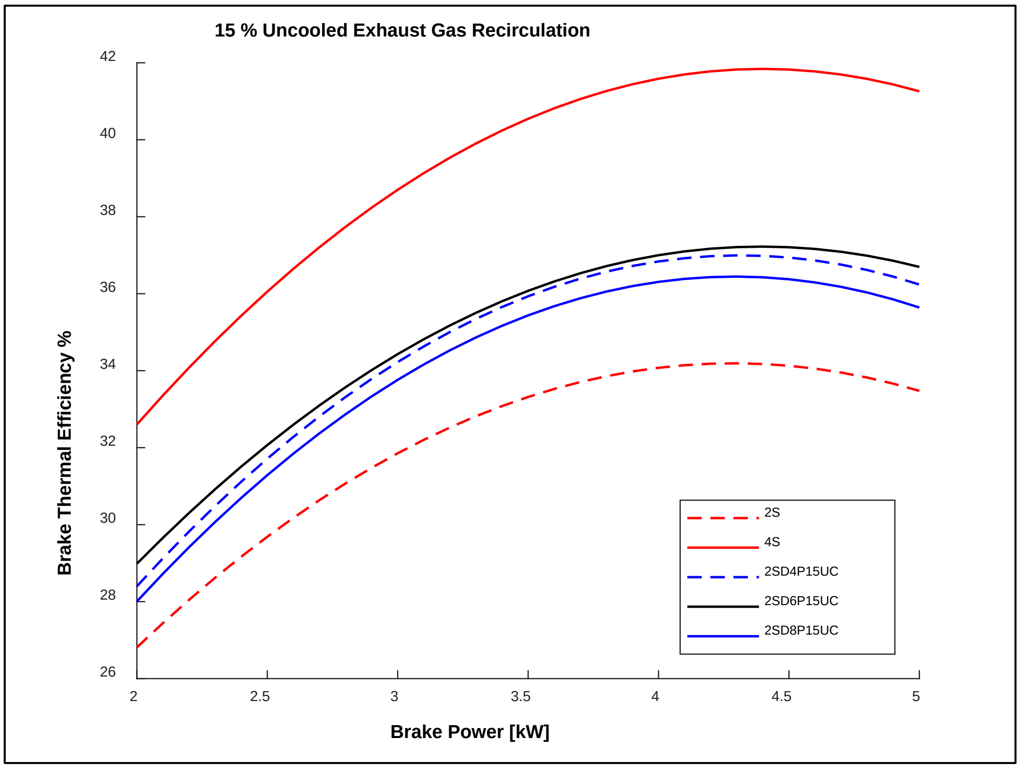

Figure 4.5 Brake Power vs. Brake Thermal Efficiency 15 % Uncooled EGR

Maximum increment in efficiency is observed in the case of 2SD6P15C configuration is 5.4 % over that of two-stroke gasoline base engine. Comparing the efficiency values of 37.2 % and 39.6 % observed in 2SD6P15H and 2SD6P15C configurations, it can be observed that there is an increase of 2.4 % efficiency for cooled exhaust recirculation.

It has been concluded from the observations that there is a variation in performance concerning orifice diameters. Since the maximum improvement of 7.2 % obtained at 6 mm orifice configuration with 10 % cooled EGR, and therefore, 10 % EGR can be considered as the optimum value.

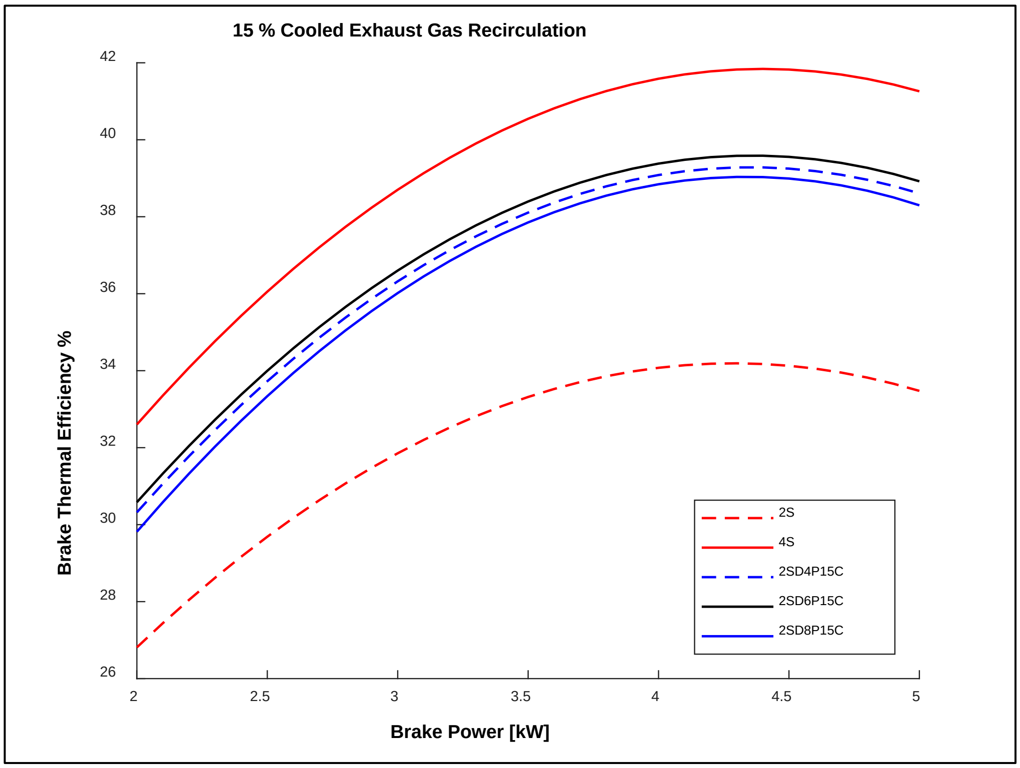

Figure 4.6 Brake Power vs. Brake Thermal Efficiency 15 % Cooled EGR

The brake thermal efficiency increases with increasing orifice diameter up to 6 mm. There is a decrease in the rate of increment beyond 6 mm as seen from the graphs. The performance also increases with increasing EGR flow, and there is a decrease in the rate of increment beyond 10 % EGR as seen from the graphs. Therefore, there is an improvement in efficiency from 5 % EGR to 10 % EGR and decrease in efficiency from 10 % EGR to 15 % EGR. However, there is always an improvement with cooled EGR as compared to uncooled EGR as well as two-stroke gasoline base engine. Further, from the graphs, it can be inferred that increase in performance is comparatively higher with cooled EGR than with uncooled EGR.

4.1.4 Brake thermal efficiency for 6 mm orifice and cooled EGR

Figure 4.7 shows the comparison of efficiency values for the configuration with 6 mm orifice diameter and 5 %, 10 % and 15 % cooled EGR. It gives a comparison of the percentage of recirculation for the optimum orifice diameter configuration.

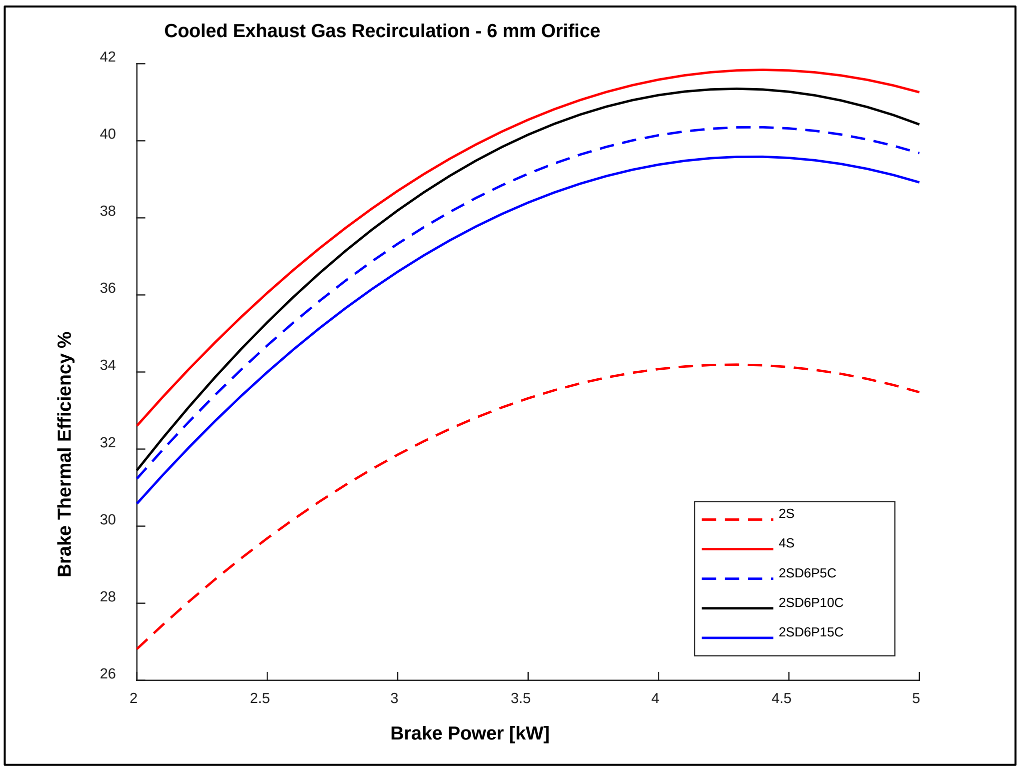

Figure 4.7 Brake Power vs. Brake Thermal Efficiency 6 mm Orifice and Cooled EGR

Though the intended purpose of cooling is to prevent in-cylinder uncooled spark knocking, cooling of EGR also increases mass density entering the crankcase contributing to an increase in trapping efficiency. Therefore, the performance of the engine is more compared to that of uncooled EGR.

In all these cases, since exhaust gas enters first, the fresh air-fuel mixture is prevented from a short circuit in scavenging process. Short circuit prevention retains the air-fuel mixture for complete burning to take place [Raju Hurakadli et al., (2015)]. By recycling the exhaust gas in the combustion chamber, a lean mixture of air-fuel is obtained inside. As the mixture becomes lean, there is a loss of energy and the temperature rise during the combustion becomes less. The lower temperature results in lower specific heat and causes lower chemical equilibrium losses. Due to this brake thermal efficiency of the engine increases when compared to the normal two-stroke gasoline base engine.

Table 4.1 gives the comparison of brake thermal efficiency at optimum brake power for all configurations discussed in this chapter. A maximum improvement of 7.2 % is obtained at 6 mm orifice (2SD6) configuration with 10 % cooled EGR over the normal two-stroke gasoline base engine with no EGR.

Table 4.1 Brake Thermal Efficiency (%) for all configurations at optimum Brake Power

Engine	% EGR	No EGR	P5 UC	P10 UC	P15 UC	P5 C	P10 C	P15 C
	D mm							
4S	-	41.82	-	-	-	-	-	-
2S	-	34.19	-	-	-	-	-	-
2S	D4	-	37.68	38.96	36.99	39.61	40.97	39.28
2S	D6	-	38.31	39.77	37.21	40.34	**41.35**	39.58
2S	D8	-	37.17	37.74	36.44	38.88	40.47	39.03

When uncooled EGR takes place, the temperature inside the combustion chamber increases. At higher temperatures, the compression power required becomes more decreasing the network available from the engine [Miqdam Tariq Chaichan et al., (2016)]. Therefore, the efficiency of the engine becomes low in uncooled EGR case. In the case of cooled EGR, the lower combustion temperature is achieved to obtain more work and efficiency. Thus, there is always an increase in performance when cooled EGR takes place as compared to uncooled EGR in all the cases. With increasing percentage of recirculation beyond 10 %, there is an adverse effect on density and impurity levels resulting in deteriorating efficiency levels. Also, an increase in exhaust flow recirculation is always with a proportional reduction in air-fuel flow and therefore insufficient air mass results in oxygen starvation leading to deficient performance beyond 10 % recirculation and 41.35 % efficiency level. By the method of modifying the inlet manifold using 6 mm orifice and 10 % cooled EGR, we can improve the performance to match that of a four-stroke gasoline engine as shown in Figure 4.7.

4.2 Specific Fuel Consumption

4.2.1 Specific Fuel Consumption for 5 % uncooled and cooled EGR

Brake power vs. Specific Fuel Consumption variations in the two-stroke engine using inlet manifold, modified with the orifice of diameters 4 mm, 6mm and 8mm are shown for 5% uncooled EGR in Fig.4.8 and for 5% cooled EGR in Fig.4.9. The performance of the two-stroke gasoline base engine without modifications and the reference four-stroke gasoline engine are also plotted in the same graph to get a visual comparison and the level of improvement achieved. There is an improvement in Specific Fuel Consumption compared to the two-stroke base engine in all the six configurations namely, 2SD4UC, 2SD6UC, 2SD8UC, 2SD4C, 2SD6C and 2SD8C for 5 % EGR.

The Specific Fuel Consumption values were observed for the various configurations with 5 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine. The Specific Fuel Consumption is 244 g/kWh for the two-stroke base engine, and Specific Fuel Consumptions are 222 g/kWh, 218 g/kWh and 225 g/kWh for 2SD4P5H, 2SD6P5H, and 2SD8P5H respectively. It can be observed that the decrement in Specific Fuel Consumption values is 22 g/kWh, 26 g/kWh and 19 g/kWh for 2SD4P5H, 2SD6P5H and 2SD8P5H respectively over the Specific Fuel Consumption of two-stroke gasoline base engine.

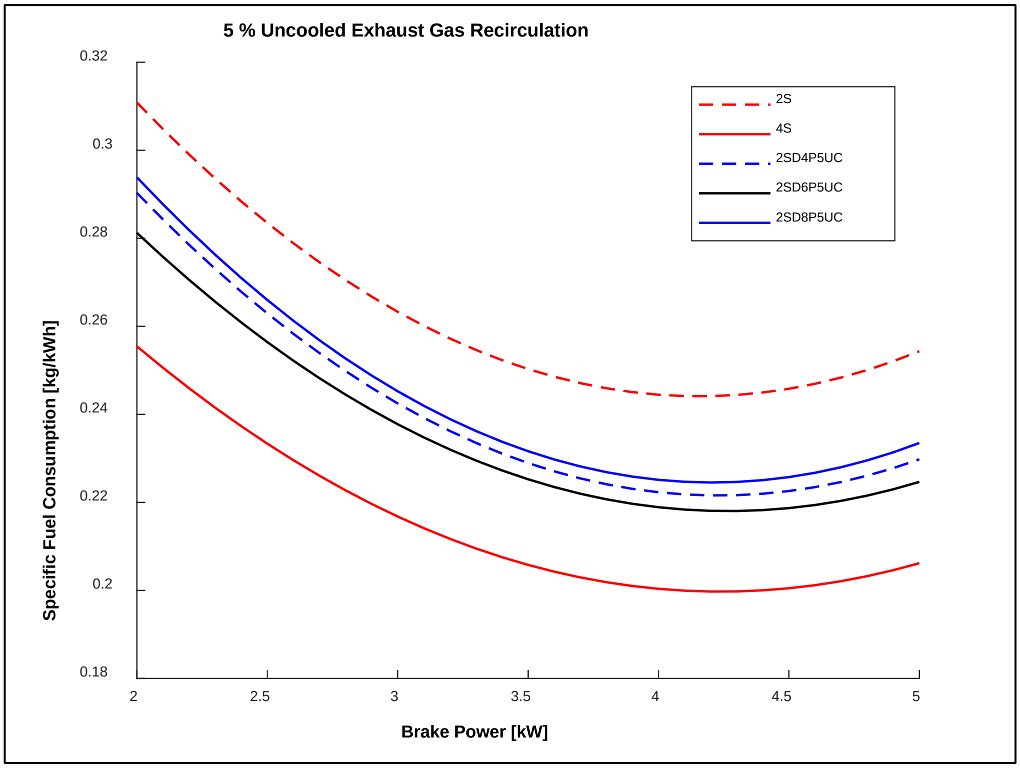

Figure 4.8 Brake Power vs. Specific Fuel Consumption 5 % Uncooled EGR

Similarly, for cooled exhaust recirculation the Specific Fuel Consumption values were observed for the various configurations with 5% exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

The Specific Fuel Consumption is 244 g/kWh for the two-stroke base engine, and Specific Fuel Consumptions are 211 g/kWh, 207 g/kWh and 209 g/kWh for 2SD4P5H, 2SD6P5H and 2SD8P5H for 2SD4P5C, 2SD6P5C and 2SD8P5C respectively. It can be observed that the decrement in Specific Fuel Consumption values is 33 g/kWh, 37 g/kWh and 35 g/kWh for 2SD4P5C, 2SD6P5C and 2SD8P5C respectively over the Specific Fuel Consumption of two-stroke gasoline base engine.

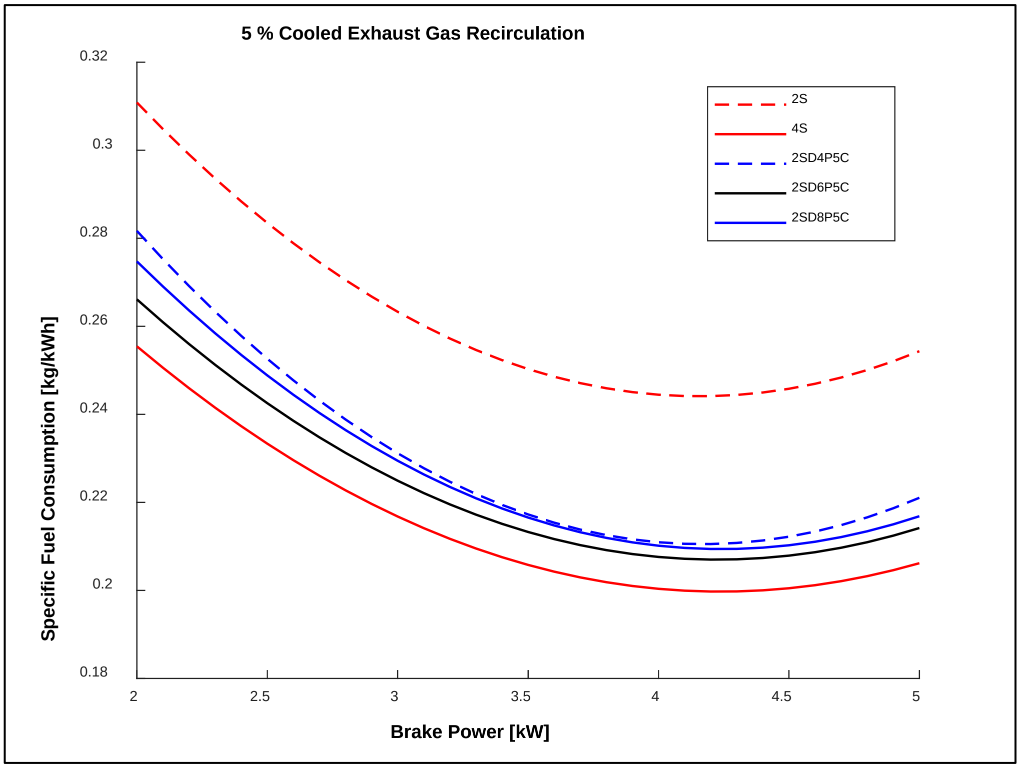

Figure 4.9 Brake Power vs. Specific Fuel Consumption 5 % Cooled EGR

The maximum decrement in Specific Fuel Consumption is observed in the case of 2SD6P5C configuration is 37 g/kWh over that of two-stroke gasoline base engine. Comparing the Specific Fuel Consumption values of 218 g/kWh and 207 g/kWh observed in 2SD6P5H and 2SD6P5C configurations, it can be observed that there is a decrease of 11 g/kWh Specific Fuel Consumption for cooled exhaust recirculation as compared to uncooled exhaust recirculation.

It has been concluded from the observations that there is a variation in Specific Fuel Consumption concerning orifice diameters with a maximum decrement of 37 g/kWh at 6 mm orifice configurations with 5 % cooled exhaust gas recirculation.

4.2.2 Specific Fuel Consumption for 10 % uncooled and cooled EGR

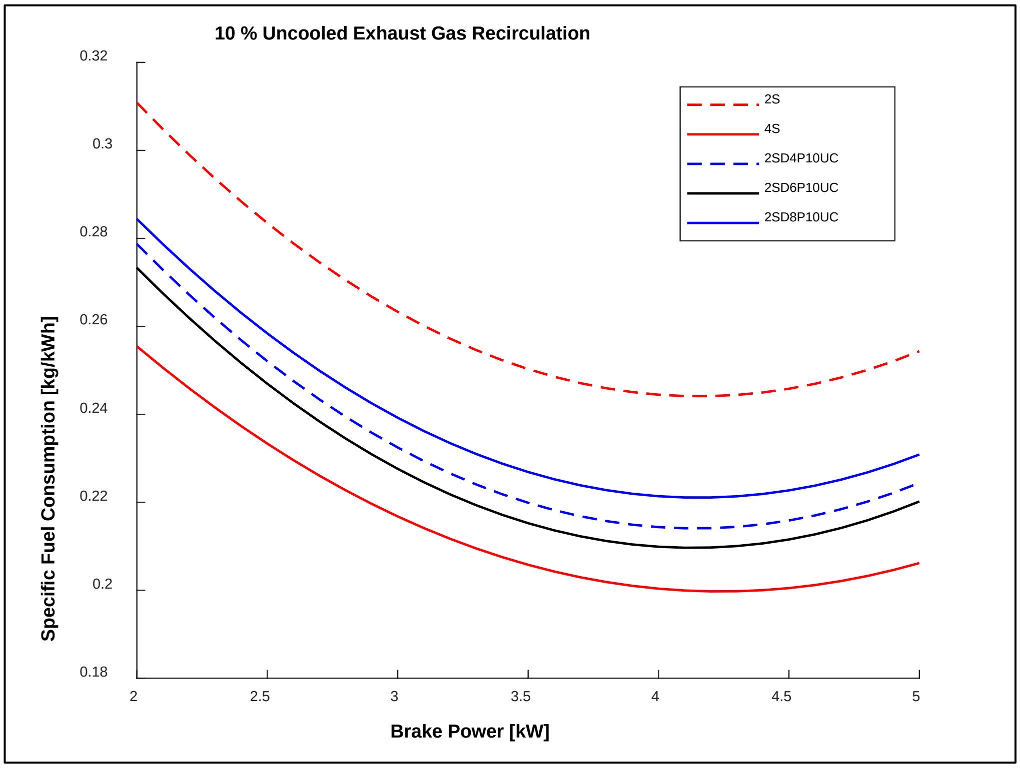

Figure 4.10 Brake Power vs. Specific Fuel Consumption 10 % Uncooled EGR

Brake power vs. Specific Fuel Consumption variations in the two-stroke engine using inlet manifold, modified with the orifice of diameters 4 mm, 6mm and 8mm are shown for 10 % uncooled EGR in Fig.4.10 and for 10 % cooled EGR in Fig.4.11. The Specific Fuel Consumption values were observed for the various configurations with 10 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

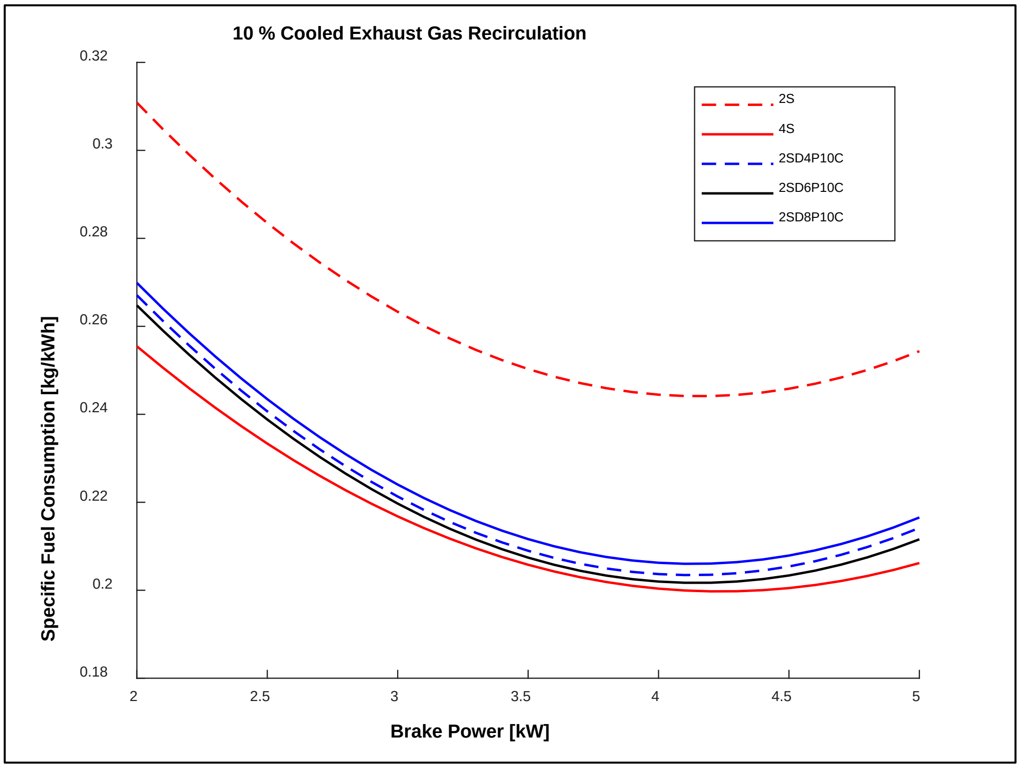

Figure 4.11 Brake Power vs. Specific Fuel Consumption 10 % Cooled EGR

The Specific Fuel Consumption is 244 g/kWh for the two-stroke base engine, and Specific Fuel Consumptions are 214 g/kWh, 210 g/kWh and 221 g/kWh for 2SD4P10H, 2SD6P10H and 2SD8P10H respectively. It can be observed that the decrement in Specific Fuel Consumption values is 30 g/kWh, 34 g/kWh and 23 g/kWh for 2SD4P10H, 2SD6P10H and 2SD8P10H respectively over the Specific Fuel Consumption of two-stroke gasoline base engine.

Similarly, for cooled exhaust recirculation the Specific Fuel Consumption values were observed for the various configurations with 10 % exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

The Specific Fuel Consumption is 244 g/kWh for the two-stroke base engine, and Specific Fuel Consumptions are 204 g/kWh, 202 g/kWh and 206 g/kWh for 2SD4P10C, 2SD6P10C and 2SD8P10C respectively. It can be observed that the decrement in Specific Fuel Consumption values is 40 g/kWh, 42 g/kWh and 38 g/kWh for 2SD4P10C, 2SD6P10C and 2SD8P10C respectively over the Specific Fuel Consumption of two-stroke gasoline base engine.

The maximum decrement in Specific Fuel Consumption observed in the case of 2SD6P10C configuration is 42 g/kWh over that of two-stroke gasoline base engine. Comparing the Specific Fuel Consumption values of 210 g/kWh and 202 g/kWh observed in 2SD6P10H and 2SD6P10C configurations, it can be observed that there is a decrement of 8 g/kWh Specific Fuel Consumption for cooled exhaust recirculation as compared to uncooled exhaust recirculation.

It has been concluded from the observations that there is a variation in Specific Fuel Consumption concerning orifice diameters with a maximum decrement of 42 g/kWh at 6 mm orifice configurations with 10 % cooled exhaust gas recirculation.

4.2.3 Specific Fuel Consumption for 15 % uncooled and cooled EGR

Brake power vs. Specific Fuel Consumption variations in the two-stroke engine using inlet manifold, modified with the orifice of diameters 4 mm, 6mm and 8mm are shown for 15% uncooled EGR in Fig.4.12 and for 15% cooled EGR in Fig.4.13. The Specific Fuel Consumption values were observed for the various configurations with 15 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

The Specific Fuel Consumption is 244 g/kWh for the two-stroke base engine, and Specific Fuel Consumptions are 226 g/kWh, 225 g/kWh and 229 g/kWh for 2SD4P15H, 2SD6P15H and 2SD8P15H respectively. It can be observed that the decrement in Specific Fuel Consumption values is 18 g/kWh, 19 g/kWh and 15 g/kWh for 2SD4P15H, 2SD6P15H and 2SD8P15H respectively over the Specific Fuel Consumption of two-stroke gasoline base engine.

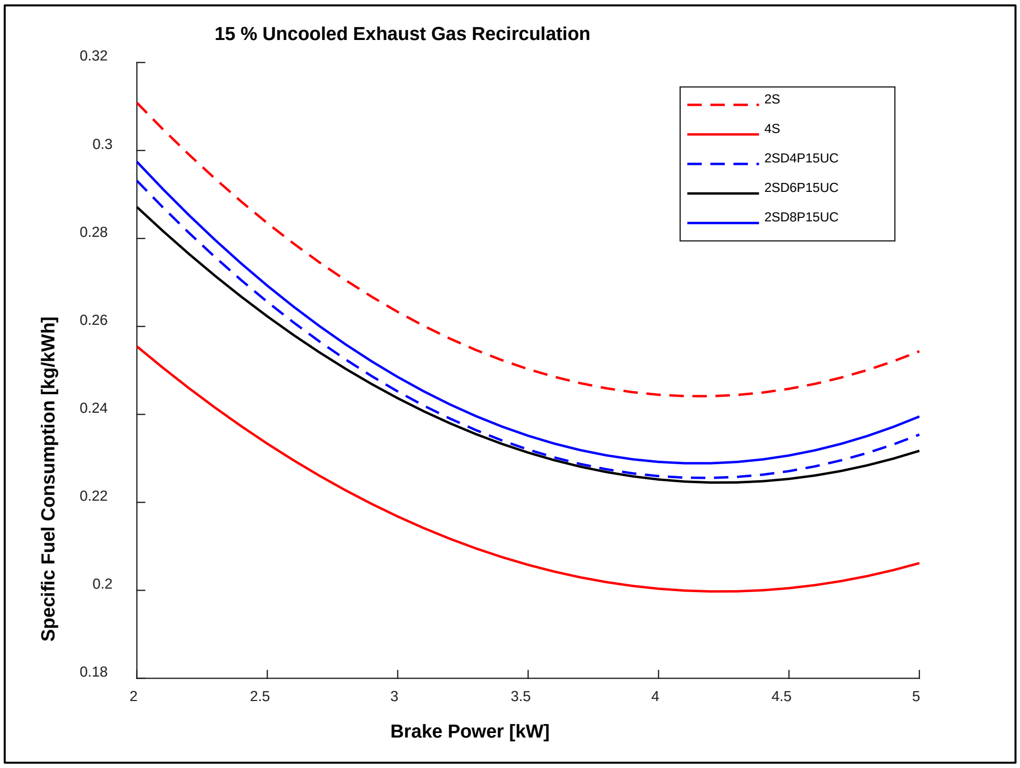

Figure 4.12 Brake Power vs. Specific Fuel Consumption 15 % Uncooled EGR

Similarly, for cooled exhaust recirculation, the Specific Fuel Consumption values were observed for the various configurations with 15 % exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline base engine.

The Specific Fuel Consumption is 244 g/kWh for the two-stroke base engine, and Specific Fuel Consumptions are 213 g/kWh, 211 g/kWh and 214 g/kWh for 2SD4P15C, 2SD6P15C and 2SD8P15C respectively. It can be observed that the decrement in Specific Fuel Consumption values is 31 g/kWh, 33 g/kWh and 30 g/kWh for 2SD4P15C, 2SD6P15C and 2SD8P15H respectively over the Specific Fuel Consumption of two-stroke gasoline base engine.

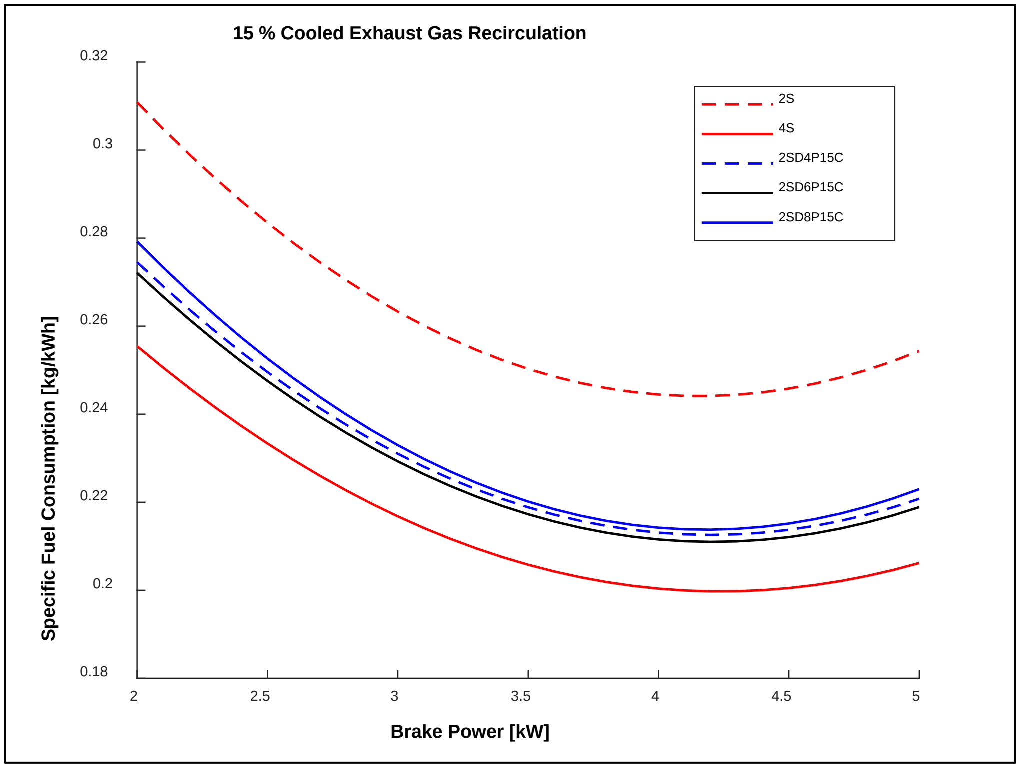

Figure 4.13 Brake Power vs. Specific Fuel Consumption 15 % Cooled EGR

The maximum decrement in Specific Fuel Consumption is observed in the case of 2SD6P15C configuration is 33 g/kWh over that of two-stroke gasoline base engine. Comparing the Specific Fuel Consumption values of 225 g/kWh and 211 g/kWh observed in 2SD6P15H and 2SD6P15C configurations, it can be observed that there is a decrement of 14 g/kWh Specific Fuel Consumption for cooled exhaust recirculation as compared to uncooled exhaust recirculation.

It has been concluded from the observations that there is a variation in Specific Fuel Consumption concerning orifice diameters with a maximum decrement of 33 g/kWh at 6 mm orifice configurations with 15 % cooled exhaust gas recirculation. However, the maximum decrement of 42 g/kWh obtained at 6 mm orifice configuration with 10 % cooled exhaust gas recirculation more than 33 g/kWh obtained here for the same configuration with 15 % cooled exhaust gas recirculation.

The Specific Fuel Consumption decreases with increasing orifice diameter up to 6 mm. Specific Fuel Consumption is increased beyond 6 mm as seen from the graphs. The Specific Fuel Consumption also decreases with increasing EGR flow, and there is an increase in the Specific Fuel Consumption beyond 10 % EGR as seen from the graphs. Therefore, as compared to normal two-stroke gasoline base engine, there is a decrement in Specific Fuel Consumption from 5 % EGR to 10 % EGR and increment in Specific Fuel Consumption from 10 % EGR to 15 % EGR for all configurations. Also, there is always more decrement in Specific Fuel Consumption with cooled EGR as compared to uncooled EGR for all configurations. Further, from the graphs, it can be inferred that improvement in performance over normal two-stroke gasoline base engine is comparatively more with cooled EGR than with uncooled EGR.

It is therefore important to study the comparison of Specific Fuel Consumption at optimum configuration (D6) for varying cooled % EGR to arrive at the best combination.

4.2.4 Specific Fuel Consumption for 6 mm orifice and cooled EGR

Figure 4.14 shows the comparison of Specific Fuel Consumption values for the configuration with 6 mm orifice diameter and cooled exhaust gas recirculation. It gives a comparison of the percentage of recirculation for the optimum orifice diameter configuration.

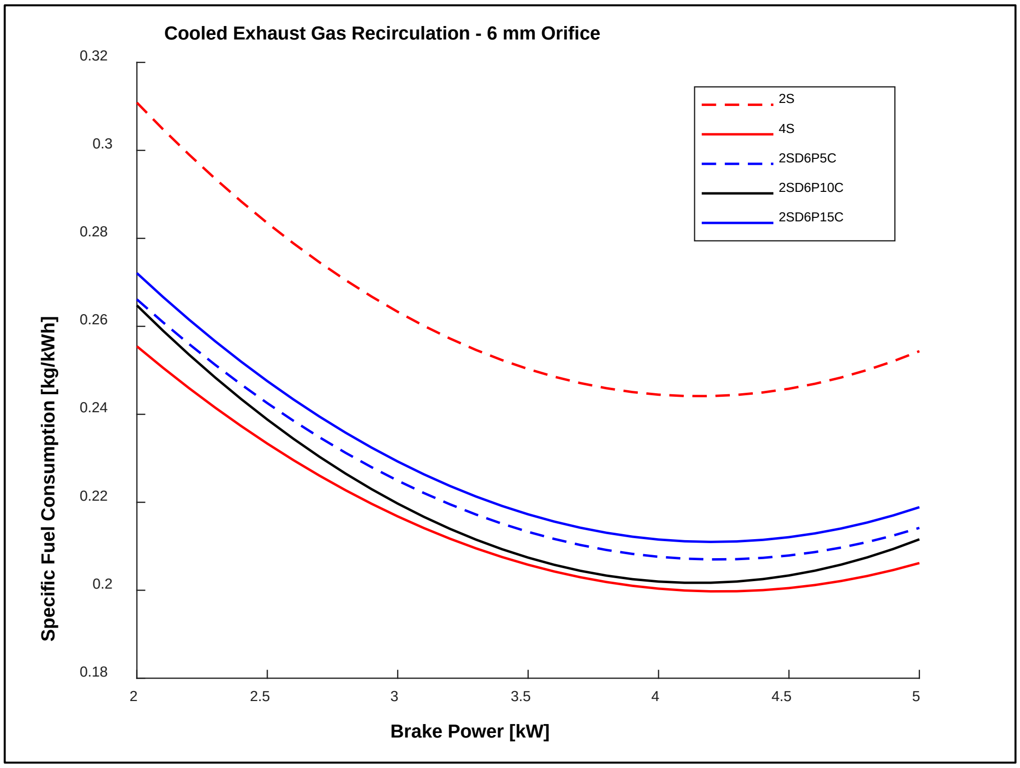

Figure 4.14 Brake Power vs. Specific Fuel Consumption 6 mm Orifice and Cooled EGR

Table 4.2 gives the comparison of specific fuel consumption at optimum brake power for all configurations discussed in this chapter. The maximum decrement in Specific Fuel Consumption observed in the case of 2SD6P10C configuration is 42 g/kWh over the normal two-stroke gasoline base engine with no EGR.

Table 4.2 Specific Fuel (g/kWh) Consumption for all configurations at optimum Brake Power

Engine	Dia D mm	No EGR	P5 UC	P10 UC	P15 UC	P5 C	P10 C	P15 C
4S	-	200	-	-	-	-	-	-
2S	-	244	-	-	-	-	-	-
2S	D4	-	222	214	226	211	204	213
2S	D6	-	218	210	225	207	**202**	211
2S	D8	-	225	221	229	209	206	214

There is always an improvement in performance when cooled EGR takes place as compared to uncooled EGR in all the cases. With increasing percentage of recirculation beyond 10 %, there is an adverse effect on density and impurity levels resulting in deteriorating performance level. Also, an increase in exhaust flow recirculation is always with a proportional reduction in air-fuel flow and therefore insufficient air mass results in oxygen starvation leading to deficient performance beyond 10 % recirculation.

4.3 Mass Flow Rate

The detailed study of variation in brake thermal efficiency and Specific fuel consumption for various configurations have shown that the combination of 6 mm orifice configuration and 10 % cooled EGR provides the optimum performance. To consolidate the findings, tests were continued to plot and study the mass flow rate characteristics for the two cases: (a) Mass flow rate for 10 % cooled EGR and orifice diameters 4 mm, 6 mm and 8 mm; (b) Mass flow rate for configuration with 6 mm orifice diameter and 5 %, 10 %, and 15 % cooled EGR. A close observation of these plots would be sufficient to confirm the conclusion of best combination.

4.3.1 Mass Flow Rate for 10 % cooled EGR

Brake power vs. mass flow rate of air-fuel mixture variations in the two-stroke engine using inlet manifold, modified with the orifice of diameters 4 mm, 6mm and 8mm are shown for 10 % cooled EGR in Fig.4.15. It can be observed that the mass flow rate increases with brake power in all the cases. However, the mass flow rate for all the modified configurations is always lower as compared to that of the two-stroke gasoline base engine.

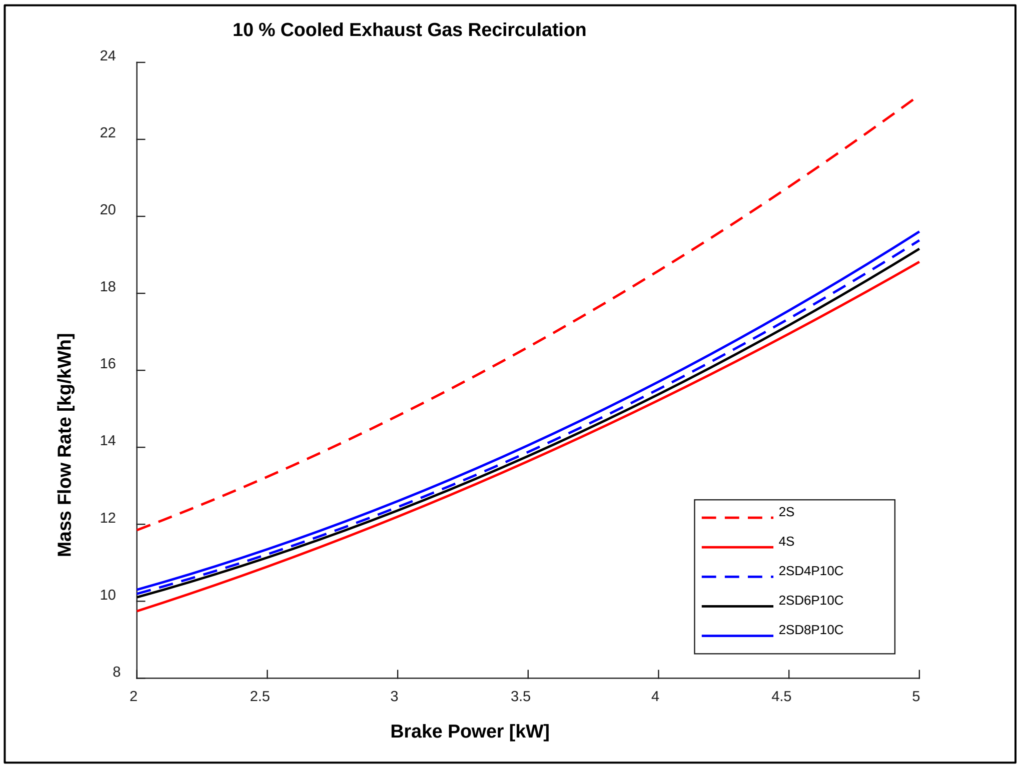

Figure 4.15 Brake Power vs. Mass Flow Rate 10 % cooled EGR

The Mass Flow Rate is 19.815 kg/kWh for two-stroke gasoline base engine, and Mass Flow Rates are 16.537 kg/h, 16.384 kg/h and 16.741 kg/h for 2SD4P10C, 2SD6P10C and 2SD8P10C respectively. It can be observed that the decrement in Mass Flow Rate values is 3.278 kg/h, 3.431 kg/kWh and 3.074 kg/h for 2SD4P10C, 2SD6P10C and 2SD8P10C respectively over the Mass Flow Rate of two-stroke gasoline base engine at the optimum brake power. The maximum decrement in Mass Flow Rate observed in the case of 2SD6P10C configuration is 3.431 kg/h over that of two-stroke gasoline base engine.

Brake power vs. mass flow rate variations in the two-stroke engine using inlet manifold, modified with the orifice of diameters 6 mm for 5 %, 10 %, and 15 % cooled EGR in Fig.4.16. It can be observed that the mass flow rate increases with brake power in all the cases. However, the mass flow rate for all the modified configurations is always lower as compared to that of the two-stroke gasoline base engine.

4.3.2 Mass Flow Rate for 6 mm orifice and cooled EGR

The Mass Flow Rate is 19.815 kg/h for the two-stroke base engine, and Mass Flow Rates are 16.793 kg/h, 16.384 kg/h and 17.118 kg/h for 2SD6P15C, 2SD6P10C and 2SD6P15C respectively. It can be observed that the decrement in Mass Flow Rate values are 3.022 kg/h, 3.431 kg/h and 2/697 kg/h for 2SD6P5C, 2SD6P10C and 2SD6P15C respectively over the Mass Flow Rate of two-stroke gasoline base engine at the optimum brake power. The maximum decrement in Mass Flow Rate observed is in the case of 2SD6P10C configuration, i.e. 3.431 kg/h over that of two-stroke gasoline base engine.

It is also observed that the configuration 2SD6P10C (i.e., 6 mm orifice diameter with 10 % cooled EGR) gives the best mass flow rate among the following cases, i.e. (a) 5%, 10 %, and 15 % cooled EGR for 6 mm orifice diameter and (b) 4 mm, 6 mm and 8 mm orifice diameters for 10 % cooled EGR.

The mass flow rate improves for all the three configurations compared to the base engine. For all the three configurations, the improvement is significant up to medium load range and is attributed to lower fresh charge losses during scavenging. At higher outputs, more exhaust entry leads to a drop in trapped charge density, and higher combustion temperature counteracts the improvement in mass flow rate.

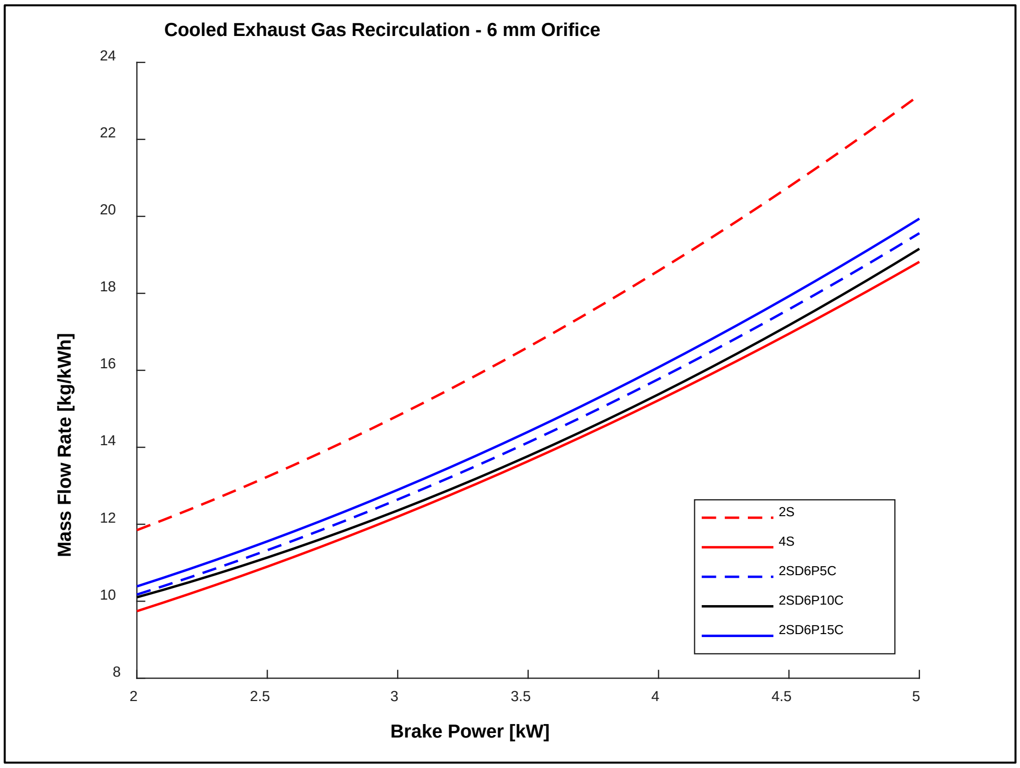

Figure 4.16 Brake Power vs. Mass Flow Rate 6 mm orifice

Table 4.3 Mass Flow Rate (kg/h) for all configurations

Engine	Dia D mm	No EGR	P5 C	P10 C	P15 C
4S	-	16.196	-	-	-
2S	-	19.815	-	-	-
2S	D4	-	-	16.337	-
2S	D6	-	16.793	**16.384**	17.118
2S	D8	-	-	16.741	-

Table 4.3 gives the comparison of the mass flow rate at optimum brake power for 2SD6 configuration, and 10 % cooled EGR (P10C) conditions. For 2SD6 configuration, 10 % cooled EGR (P10C), the mass flow rate is lower as compared to 5 % cooled EGR (P5C), and 15 % cooled EGR (P15C). Concerning configurations, mass flow rate tends to increase with orifice dimensions resulting in variations in pollutants emission.

4.4 Scavenging Efficiency and Trapping Efficiency

The efficiency of an engine depends upon volumetric efficiency. Volumetric efficiency is defined as the ratio of the mass density of the air-fuel mixture drawn into the cylinder at atmospheric pressure (during the intake stroke) to the mass density of the same volume of air in the intake manifold. Since intake and exhaust partly overlap in a two-stroke engine, the term volumetric efficiency as applied to a normal four-stroke engine is replaced by the terms scavenging and trapping efficiency in the case of a two-stroke engine. Scavenging efficiency gives the ratio of the mass of fresh charge retained or trapped to the mass of total charge including residuals trapped. Trapping efficiency gives the ratio of the mass of fresh charge retained or trapped to the mass of fresh charge delivered or ingested.

4.4.1 Scavenging Efficiency for varying cooled EGR

Scavenging efficiency indicates the measure of success in clearing the cylinder of residual gases from the preceding cycle and replacement by the fresh air-fuel mixture. Fig.4.17 shows the variation in scavenging efficiency for the configuration D6 at 5 %, 10 %, and 15 % cooled EGR variations concerning brake power in kW.

The Scavenging Efficiency is 17.3 % for the two-stroke base engine without EGR, and Scavenging Efficiencies are 19.2 %, 20.1 % and 18.9 % for 2SD6P5C, 2SD6P10C and 2SD6P15C respectively. It can be observed that the increment in Scavenging Efficiency values is 1.9 %, 2.8 % and 1.6 % for 2SD6P5C, 2SD6P10C and 2SD6P15C respectively over the Scavenging Efficiency of two-stroke gasoline base engine without EGR for the optimum brake power. The maximum increment in Scavenging Efficiency observed is in the case of 2SD6P10C configuration, i.e., 2.8 % over that of two-stroke gasoline base engine without EGR. With increasing EGR to 15 %, the scavenging efficiency drops down leading to unavailability of enough combustible mixture and thus resulting in the poorer performance of the engine. With 10 % EGR, the temperature conditions and combustion mixture together contribute to a better combustion performance and efficiency.

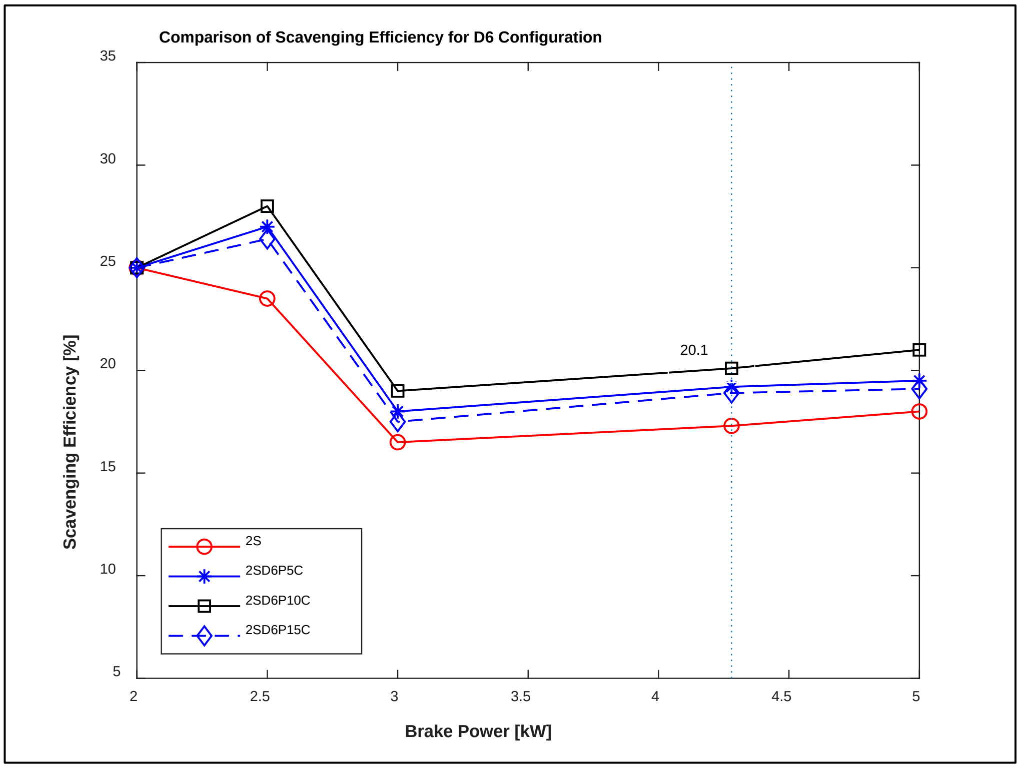

Figure 4.17 Brake Power vs. Scavenging Efficiency 6 mm orifice

4.4.2 Trapping Efficiency for varying cooled EGR

The Trapping Efficiency is 65.4 % for two-stroke base engine and Trapping Efficiencies are 67.9 %, 68.8 % and 67.5 % for 2SD6P5C, 2SD6P10C and 2SD6P15C respectively. It can be observed that the increment in Trapping Efficiency values are 2.5 %, 3.4 % and 2.1 % for 2SD6P5C, 2SD6P10C and 2SD6P15C respectively over the Trapping Efficiency of two-stroke gasoline base engine without EGR for the optimum brake power. The maximum increment in Trapping Efficiency observed is in the case of 2SD6P10C configuration, i.e., 3.4 % over that of two-stroke gasoline base engine.

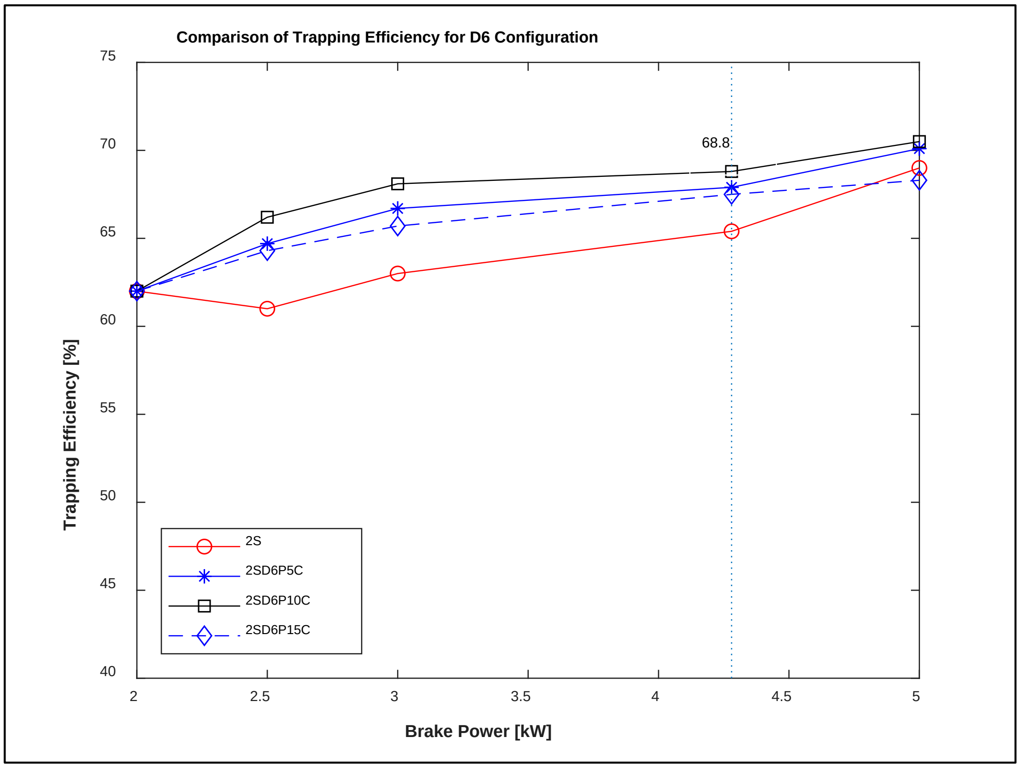

Figure 4.18 Brake Power vs. Trapping Efficiency 6 mm orifice

Since scavenging is mostly done by the recirculated exhaust gas, the fresh mixture is fully retained in the combustion chamber. The kinetic energy of exhaust gas is fully utilized in scavenging. The delivered fresh air mixture is thus trapped to the maximum extent in the combustion chamber [Mohsen Ghazikhani et al., (2016)].

Miqdam Tariq Chaichan (2016) has suggested the shortened ignition delay with an increase in engine load as reasons for the effects. The increasing load increases the residual gas temperature, and the wall temperature raised resulting in higher exhaust gas temperatures. Hence the use of cool EGR will be favourable regarding improved values of thermal efficiency. The same trend can be noticed in Figure 4.4 in which the brake thermal efficiency is found to be maximum at 10 % Cooled EGR. Combining exhaust gas recirculation with lowered EGR temperatures produced better-operating conditions.

Combining oxygenated alternative fuels with exhaust gas recirculation, volumetric efficiency is substantially increased.

4.5 Carbon Monoxide Emission

4.5.1 Carbon Monoxide Emission for varying uncooled EGR

Figure 4.19 shows the emission of Carbon Monoxide is observed for 5 %, 10 % and 15 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline engine with configurations 2SD4UC, 2SD6UC, and 2SD8UC.

The Carbon Monoxide emission is 0.14 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Monoxide emissions are 0.17 %, 0.162 % and 0.165 % for 2SD4UC, 2SD6UC and 2SD8UC respectively at 5 % EGR. It can be observed that the increment in emission values are 0.03 %, 0.022 % and 0.025 % for 2SD4UC, 2SD6UC, and 2SD8UC respectively at 5 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Carbon Monoxide emission is 0.14 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Monoxide emissions are 0.185 %, 0.175 % and 0.180 % for 2SD4UC, 2SD6UC and 2SD8UC respectively at 10 % EGR. It can be observed that the increment in emission values are 0.045 %, 0.035 % and 0.040 % for 2SD4UC, 2SD6UC, and 2SD8UC respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

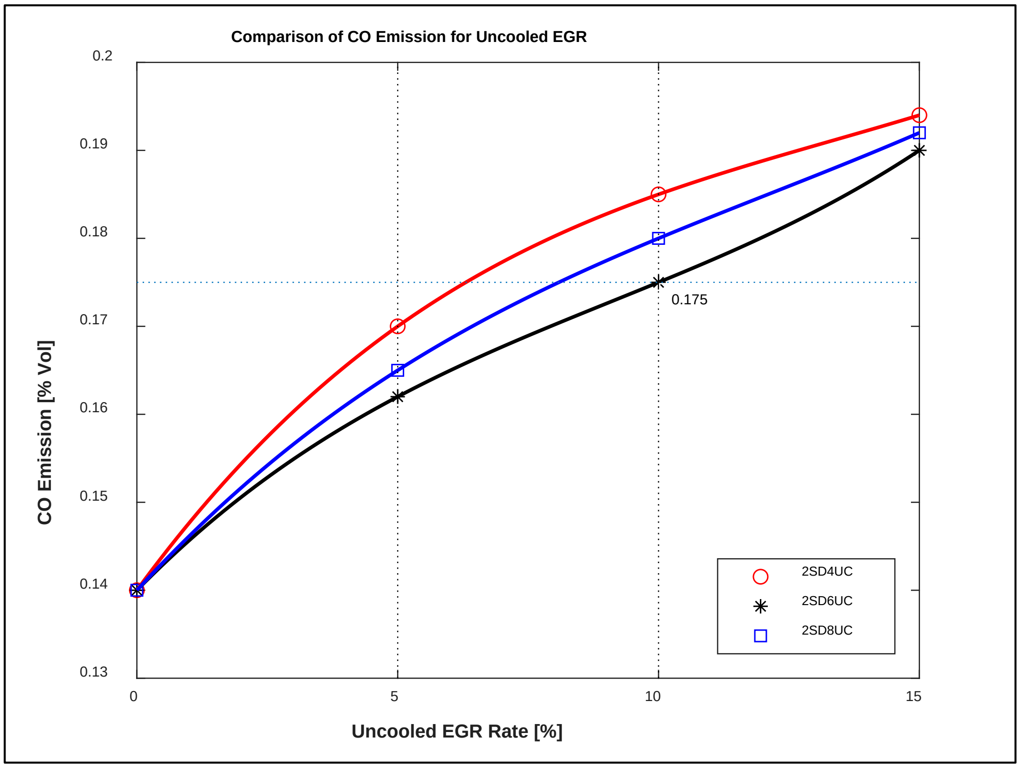

Figure 4.19 EGR Rate vs. CO Emission for uncooled EGR

The Carbon Monoxide emission is 0.14 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Monoxide emission s are 0.194 %, 0.190 % and 0.192 % for 2SD4UC, 2SD6UC and 2SD8UC respectively at 15 % EGR. It can be observed that the increment in emission values are 0.054 %, 0.05 % and 0.052 % for 2SD4UC, 2SD6UC, and 2SD8UC respectively at 15 % EGR over the emission value for two-stroke gasoline base engine without EGR.

4.5.2 Carbon Monoxide Emission for varying cooled EGR

Similarly, the emission of Carbon Monoxide is observed for 5 %, 10 %, and 15 % cooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline engine with configurations 2SD4C, 2SD6C and 2SD8C and shown in Figure 4.20.

The Carbon Monoxide emission is 0.14 % for no EGR conditions for all the configurations. Carbon Monoxide emissions are 0.16 %, 0.145 % and 0.15 % for 2SD4C, 2SD6C and 2SD8C respectively at 5 % EGR. It can be observed that the increment in emission values are 0.02 %, 0.025 % and 0.01 % for 2SD4C, 2SD6C, and 2SD8C respectively at 5 % EGR over the emission value for two-stroke gasoline base engine without EGR.

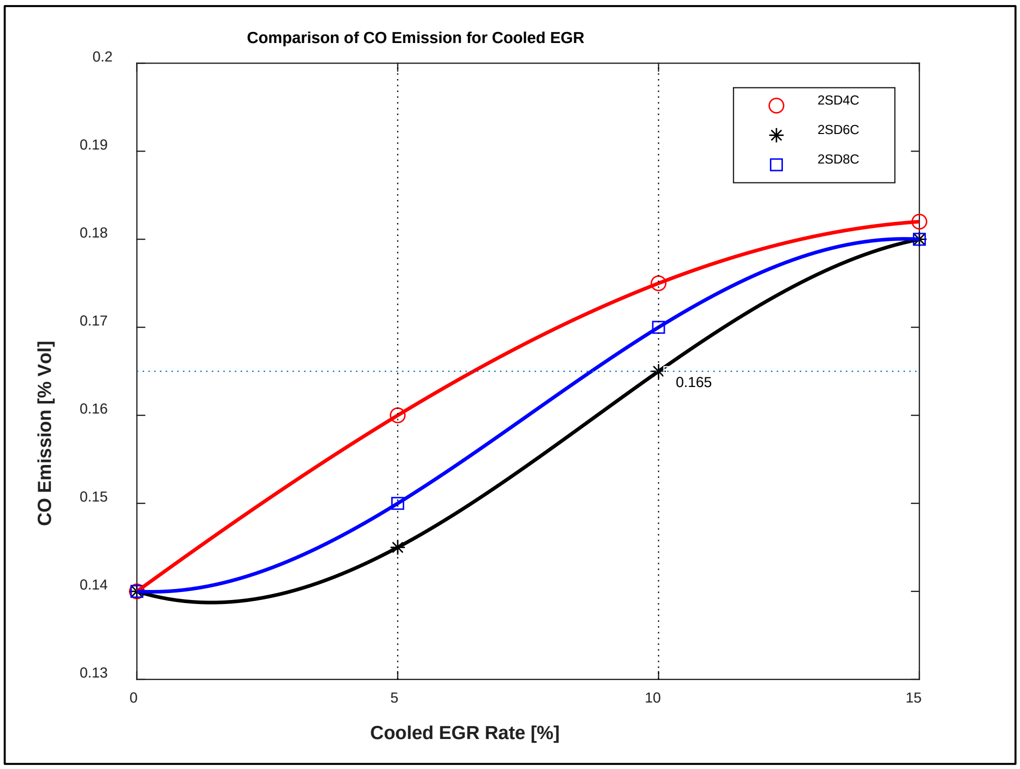

Figure 4.20 EGR Rate vs. CO Emission cooled EGR

The Carbon Monoxide emission is 0.14 % for no EGR conditions for all the configurations. Carbon Monoxide emissions are 0.175 %, 0.165 % and 0.170 % for 2SD4C, 2SD6C and 2SD8C respectively at 10 % EGR. It can be observed that the increment in emission values are 0.035 %, 0.025 % and 0.030 % for 2SD4C, 2SD6C and 2SD8C respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Carbon Monoxide emission is 0.14 % for no EGR conditions for all the configurations. Carbon Monoxide emission s are 0.182 %, 0.180 % and 0.180 % for 2SD4C, 2SD6C and 2SD8C respectively at 15 % EGR. It can be observed that the increment in emission values are 0.042 %, 0.04 % and 0.040 % for 2SD4C, 2SD6C and 2SD8C respectively at 15 % EGR over the emission value for two-stroke gasoline base engine without EGR.

Table 4.4 gives the comparison of Carbon Monoxide emission at optimum brake power for all configurations. The maximum reduction in Carbon Monoxide emission is obtained with 2SD6 configuration at 10 % cooled EGR.

Table 4.4 Carbon Monoxide Emission (%) for all configurations

Engine	**Dia D mm**	**No EGR**	**P5 UC**	**P10 UC**	**P15 UC**	**P5 C**	**P10 C**	**P15 C**
4S	-	-	-	-	-	-	-	-
2S	-	0.140	-	-	-	-	-	-
2S	D4	-	0.170	0.185	194.000	0.160	0.175	0.182
2S	D6	-	0.162	0.175	0.190	0.145	**0.165**	0.180
2S	D8	-	0.165	0.180	0.192	0.150	0.170	0.180

Increasing scavenging efficiency has increased the output, with the corresponding improvement in combustion performance and reduction in specific fuel consumption and CO emission. Khan and Shaikh (2016) have also found the influence of dual spark on the performance of the two-stroke engine and report increase in efficiency experimentally, decrease in fuel consumption and CO emission but increase in NOx emissions with increasing outputs.

Carbon Monoxide(CO) is produced from the partial oxidation of carbon-containing compounds; due to insufficient oxygen present in the combustion chamber and Mohsen Ghazikhani et al., (2013) have reported that the addition of ethanol results in a reduction of CO, HC, and NOx in a two-stroke engine. In the present case, with an increase in EGR rate recirculation exhaust gas results in insufficient oxygen and higher CO emission. Raju Hurakadli et al., (2015) in their experiments on two-stroke SI engines, varied the EGR rate between 0-20% and reported. As per the report, experiments were carried out for mass flow measuring of EGR with simplifying adjustment (manual designed EGR system) on the engine. The performance was measured based on brake thermal efficiency and brake specific fuel consumption. The emission species measured were NOx, unburnt hydrocarbons, and carbon monoxide. The tests were conducted at 2600, 3200 and 4000 rpm. The findings showed that EGR would be one option to increase thermal efficiency and reduce brake specific fuel consumption and NOx concentrations in the engine exhaust, but with a rise in EGR rate beyond the optimum value, the CO and UHC concentrations in the engine exhaust would increase.

4.6 Carbon Dioxide Emission

4.6.1 Carbon Dioxide Emission for varying uncooled EGR

Figure 4.21 shows the emission of Carbon Dioxide is observed for 5 %, 10 % and 15 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline engine with configurations 2SD4UC, 2SD6UC, and 2SD8UC.

The Carbon Dioxide emission is 9 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Dioxide emissions are 10 %, 10.3 % and 9.7 % for 2SD4UC, 2SD6UC and 2SD8UC respectively at 5 % EGR. It can be observed that the increment in emission values are 1 %, 1.3 % and 0.7 % for 2SD4UC, 2SD6UC, and 2SD8UC respectively at 5 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Carbon Dioxide emission is 9 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Dioxide emissions are 11 %, 11.3 % and 10.8 % for 2SD4UC, 2SD6UC and 2SD8UC respectively at 10 % EGR. It can be observed that the increment in emission values are 2 %, 2.3 % and 1.8 % ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

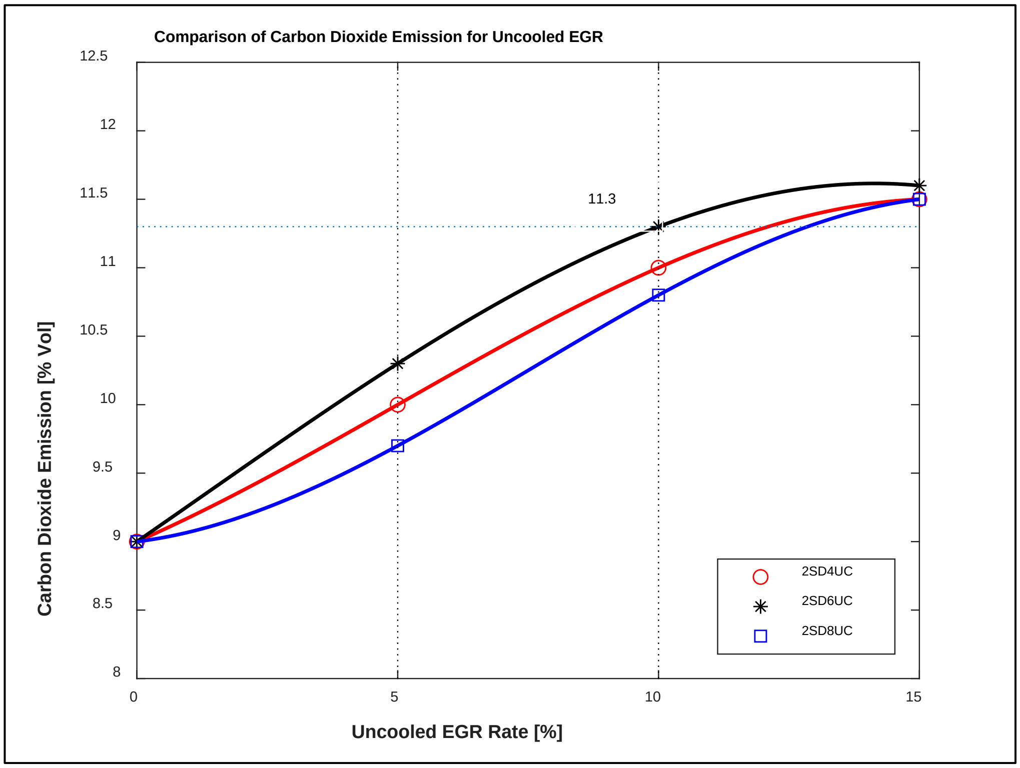

Figure 4.21 EGR Rate vs. CO_2 Emission uncooled EGR

The Carbon Dioxide emission is 9 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Dioxide emissions are 11.5 %, 11.6 % and 11.5 % for 2SD4UC, 2SD6UC and 2SD8UC respectively at 15 % EGR. It can be observed that the increment in emission values are 2.5 %, 2.6 % and 2.5 % for 2SD4UC, 2SD6UC, and 2SD8UC respectively at 15 % EGR over the emission value for two-stroke gasoline base engine without EGR.

4.6.2 Carbon Dioxide Emission for varying cooled EGR

Similarly, the emission of Carbon Dioxide is observed for 5 %, 10 %, and 15 % cooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline engine with configurations 2SD4C, 2SD6C and 2SD8C and shown in Figure 4.22.

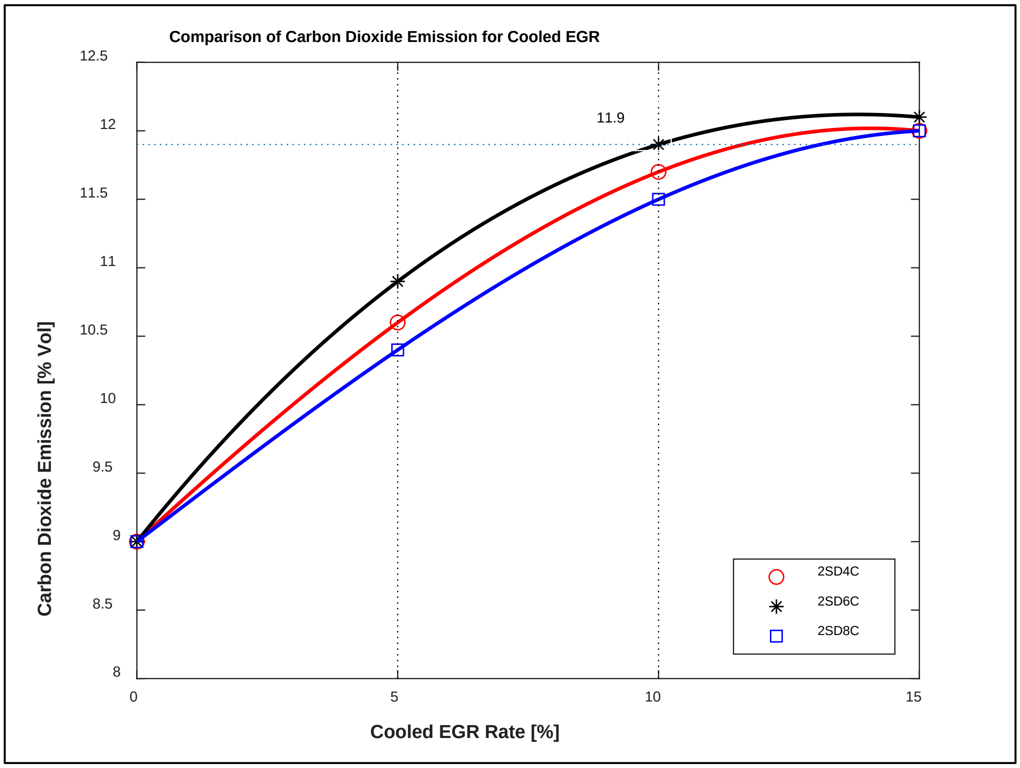

Figure 4.22 EGR Rate vs. CO_2 Emission cooled EGR

The Carbon Dioxide emission is 9 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Dioxide emissions are 10.6 %, 11.7 % and 12 % for 2SD4C, 2SD6C and 2SD8C respectively at 5 % EGR. It can be observed that the increment in emission values are 1.6 %, 2.7 % and 3 % for 2SD4C, 2SD6C, and 2SD8C respectively at 5 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Carbon Dioxide emission is 9 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Dioxide emissions are 10.9 %, 11.9 % and 12.1 % for 2SD4C, 2SD6C and 2SD8C respectively at 10 % EGR. It can be observed that the increment in emission values are 1.9 %, 2.9 % and 3.1 % for 2SD4C, 2SD6C, and 2SD8C respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Carbon Dioxide emission is 9 % for without EGR conditions in the two-stroke gasoline base engine. Carbon Dioxide emissions are 12.4 % for all the configurations i.e. 2SD4C, 2SD6C and 2SD8C at 15 % EGR. It can be observed that the emission value for all the configurations is 3.4 % higher than that of two-stroke gasoline base engine without EGR.

The Carbon Dioxide emission is higher for the configurations 2SD6 as compared to 2SD4 and 2SD8 for both uncooled and cooled exhaust gas recirculation at 5 % and 10 %. There is an increase in thermal efficiency due to the increase in mass density entering the crankcase contributing to an increase in trapping efficiency. Therefore, complete combustion takes place leading to emission of more carbon dioxide and heat release rate. Due to improved scavenging efficiency, the air-fuel mixture is retained for complete burning to take place.

It is also observed that the Carbon Dioxide emission has the same value in all the configurations, i.e. 2SD4, 2SD6 and 2SD8 for both uncooled and cooled exhaust gas recirculation at 15 %. Further increase in EGR beyond 10 % results in an adverse effect on density and impurity levels resulting in deteriorating efficiency levels. The proportional reduction in air-fuel flow leads to insufficient air mass resulting in oxygen starvation and deficient combustion and emission of the product of combustion, carbon dioxide. With the result, a saturation limit is reached for carbon dioxide formation.

Table 4.5 gives the comparison of carbon dioxide emission at optimum brake power for all configurations. Carbon dioxide emission is maximum for 2SD6 configuration with 10 % cooled EGR due to the maximum output produced.

Table 4.5 Carbon Dioxide Emission (%) for all configurations

Engine	Dia D mm	No EGR	P5 UC	P10 UC	P15 UC	P5 C	P10 C	P15 C
4S	-	-	-	-	-	-	-	-
2S	-	9.0						
2S	D4	-	10.0	10.0	11.5	10.6	11.7	12.0
2S	D6	-	10.3	11.3	11.6	10.9	**11.9**	12.1
2S	D8	-	9.7	10.8	11.5	10.4	11.5	12.0

The increase in volumetric efficiency and carbon dioxide emission (from 10 % to 12 %) is also referred in the findings by Nazar Yahya Ibrahim et al., (2015) on SI Engine using 98 % gasoline with 2 % lubricant. The improvement in brake thermal efficiency is also confirmed by the increase in the formation of the product of reaction carbon dioxide. However, after-treatment methods need to be followed to prevent the global warming effect due to this emission from a large number of vehicles plying on the roads.

4.7 Hydrocarbon Emission

4.7.1 Hydrocarbon Emission for varying uncooled EGR

Martin et al., (2012) classified the exhaust gas constituents into three categories, harmful to health, objectionable and potentially objectionable. Among them, the objectionable constituents are either odorous or irritating and include aldehydes and other compounds resulting from the partial oxidation or reaction of the fuel. These compounds appear as smoke. The potentially objectionable constituents are those materials which may react directly or indirectly to form irritating and lachrymating pollutants. Certain hydrocarbons may react in the presence of oxides of nitrogen and ozone to form eye and nose irritants; hydrocarbons must be considered in this classification. Carbon monoxide, oxides of nitrogen, and hydrocarbons are those compounds believed to be of greatest importance to air pollution.

Figure 4.23 shows the emission of Hydro Carbon observed for 5 %, 10 % and 15 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline engine with configurations 2SD4UC, 2SD6UC, and 2SD8UC.

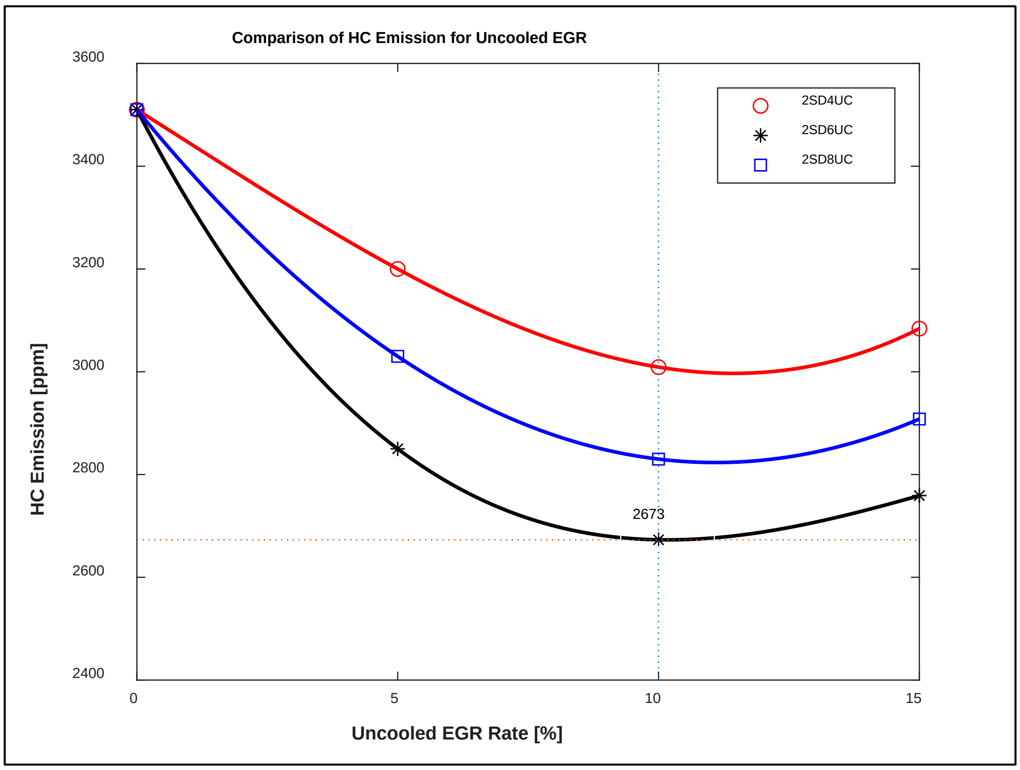

Figure 4.23 EGR Rate vs. HC Emission uncooled EGR

The Hydrocarbon emission is 3510 ppm for without EGR conditions in the two-stroke gasoline base engine. Hydro Carbon emissions are 3200 ppm, 2850 ppm and 3030 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 5 % EGR. It can be observed that the decrement in emission values are 310 ppm, 660 ppm and 480 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 5 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Hydrocarbon emission is 3510 ppm for without EGR conditions in the two-stroke gasoline base engine. Hydro Carbon emissions are 3009 ppm, 2673 ppm and 2870 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 10 % EGR. It can be observed that the decrement in emission values are 501 ppm, 837 ppm and 680 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Hydrocarbon emission is 3510 ppm for without EGR conditions in the two-stroke gasoline base engine. Hydro Carbon emissions are 3084 ppm, 2759 ppm and 2908 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 15 % EGR. It can be observed that the decrement in emission values are 426 ppm, 751 ppm and 602 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 15 % EGR over the emission value for two-stroke gasoline base engine without EGR.

4.7.2 Hydrocarbon Emission for varying cooled EGR

Similarly, the emission of Hydro Carbon is observed for 5 %, 10 %, and 15 % cooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline engine with configurations 2SD4C, 2SD6C and 2SD8C and shown in Figure 4.24.

The Hydrocarbon emission is 3510 ppm for without EGR conditions in the two-stroke gasoline base engine. Hydro Carbon emissions are 3100 ppm, 2750 ppm and 2930 ppm for 2SD4C, 2SD6C and 2SD8C respectively at 5 % EGR. It can be observed that the decrement in emission values are 410 ppm, 760 ppm and 580 ppm for 2SD4C, 2SD6C, and 2SD8C respectively at 5 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Hydrocarbon emission is 3510 ppm for without EGR conditions in the two-stroke gasoline base engine. Hydro Carbon emissions are 2905 ppm, 2566 ppm and 2725 ppm for 2SD4C, 2SD6C and 2SD8C respectively at 10 % EGR. It can be observed that the decrement in emission values are 605 ppm, 944 ppm and 785 ppm for 2SD4C, 2SD6C, and 2SD8C respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

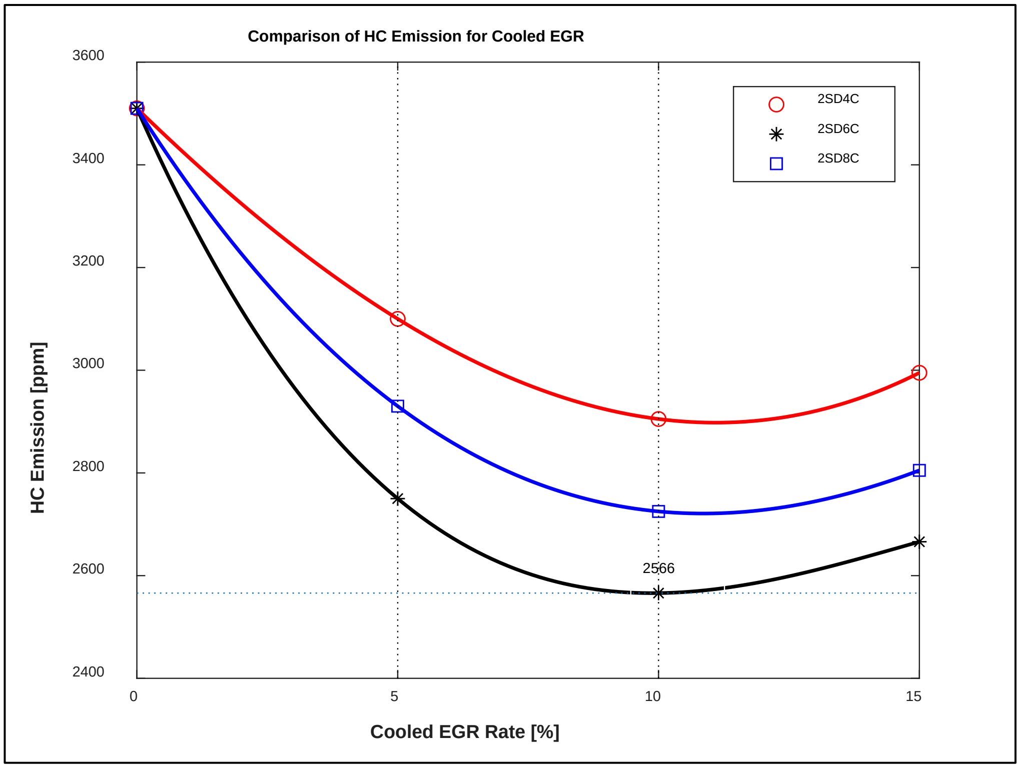

Figure 4.24 EGR Rate vs. HC Emission cooled EGR

The Hydrocarbon emission is 3510 ppm for without EGR conditions in the two-stroke gasoline base engine. Hydro Carbon emissions are 2995 ppm, 2666 ppm and 2805 ppm for 2SD4C, 2SD6C and 2SD8C respectively at 15 % EGR. It can be observed that the decrement in emission values are 515 ppm, 844 ppm and 705 ppm for 2SD4C, 2SD6C, and 2SD8C respectively at 15 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Hydrocarbon emission is lower for the configurations 2SD6 as compared to 2SD4 and 2SD8 for both uncooled and cooled exhaust gas recirculation at 5 % and 10 %. The improved thermal efficiency resulting in maximum utilization of carbon in combustion reaction leaves less unburnt hydrocarbons. At 5 % EGR, the combustion temperature is lower and hence poor combustion with more unburnt hydrocarbons. At 10 % EGR, the temperature is higher, and more oxygen atoms are used for nitrogen oxides formation, and thus unburnt hydrocarbons tend to increase.

Table 4.6 gives the comparison of hydrocarbon emission at optimum brake power for all configurations. The maximum reduction in hydrocarbon emission is obtained with 2SD6 configuration with 10 % cooled EGR.

Table 4.6 Hydrocarbon Emission (ppm) for all configurations

Engine	Dia D mm	No EGR	P5 UC	P10 UC	P15 UC	P5 C	P10 C	P15 C
4S	-	-	-	-	-	-	-	-
2S	-	3510	-	-	-	-	-	-
2S	D4	-	3200	3009	3084	3100	2905	2995
2S	D6	-	2850	2673	2759	2750	**2566**	2666
2S	D8	-	3030	2830	2908	2930	2725	2805

The reduction in HC emission is also due to improved scavenging efficiency with EGR rates yielding more fresh air-fuel mixture for burning in the combustion chamber. Report by Juhi Sharaf (2013) recommends the recycled exhaust to dilute the engine intake mixture lowers the NOx level. During the warm-up period from the starting of the engine, vaporization is slow and requires rich mixture resulting in high HC and CO emission. At part load conditions lean mixtures are permitted thus reducing the HC and CO emissions.

AFR yielded reduced hydrocarbons for lean combustion. Ignition timing played a vital part in hydrocarbon emissions for all configurations and was attributed to the effects of enriched AFR's found with ignition retard. Also, Loganathan et al., (2006) confirm the conclusion that at higher loads and speeds, NO levels become higher due to use of leaner mixtures with oxygen availability and higher combustion temperatures. HC emissions are considerably lower in carburetted versions at all speeds.

4.8 Nitrogen Oxides Emission

4.8.1 Nitrogen Oxides Emission for varying uncooled EGR

Figure 4.25 shows the emission of Nitrogen Oxides observed for 5 %, 10 % and 15 % uncooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline engine with configurations 2SD4UC, 2SD6UC, and 2SD8UC.

The Nitrogen Oxides emission is 1250 ppm for without EGR conditions for two-stroke gasoline base engine. Nitrogen Oxides emissions are 1095 ppm, 920 ppm and 1025 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 5 % EGR. It can be observed that the decrement in emission values are 155 ppm, 330 ppm, and 225 ppm for 2SD4UC, 2SD6UC, and 2SD8UC respectively at 5 % EGR over the emission value for two-stroke gasoline base engine without EGR.

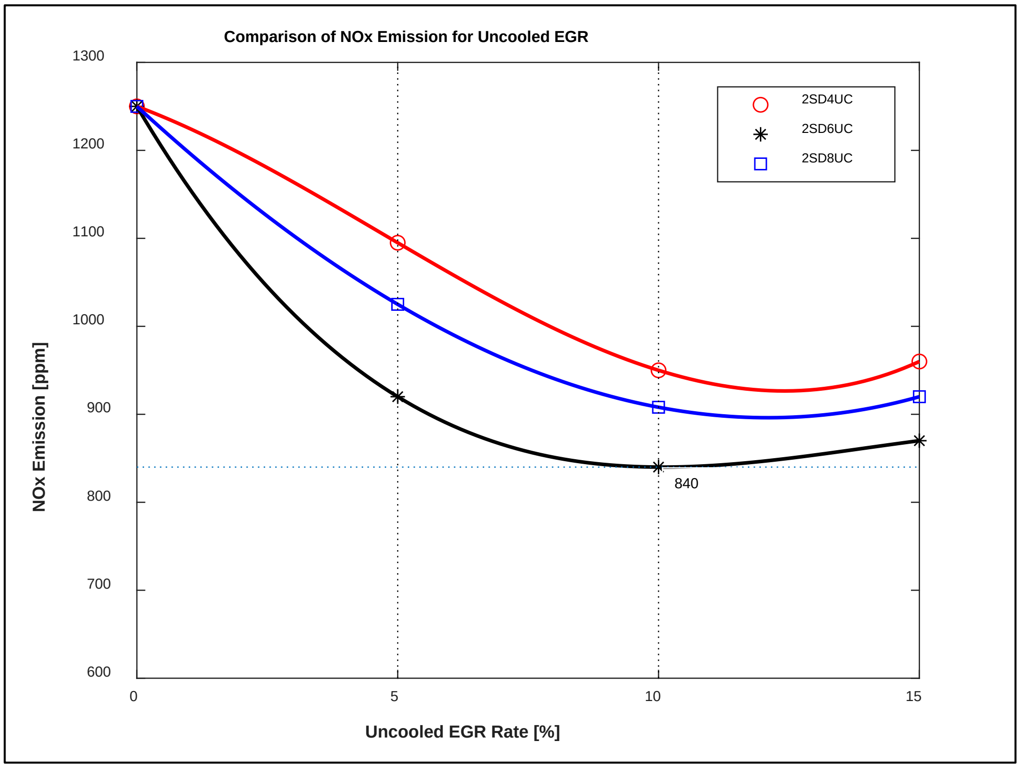

Figure 4.25 EGR Rate vs. NOx Emission uncooled EGR

The Nitrogen Oxides emission is 1250 ppm for without EGR conditions for two-stroke gasoline base engine. Nitrogen Oxides emissions are 950 ppm, 840 ppm and 908 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 10 % EGR. It can be observed that the decrement in emission values are 300 ppm, 410 ppm, and 342 ppm for 2SD4UC, 2SD6UC, and 2SD8UC respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Nitrogen Oxides emission is 1250 ppm for without EGR conditions for two-stroke gasoline base engine. Nitrogen Oxides emissions are 960 ppm, 870 ppm and 920 ppm for 2SD4UC, 2SD6UC and 2SD8UC respectively at 15 % EGR. It can be observed that the decrement in emission values are 290 ppm, 380 ppm, and 330 ppm for 2SD4UC, 2SD6UC, and 2SD8UC respectively at 15 % EGR over the emission value for two-stroke gasoline base engine without EGR.

4.8.2 Nitrogen Oxides Emission for varying cooled EGR

Similarly, the emission of Nitrogen Oxides is observed for 5 %, 10 %, and 15 % cooled exhaust gas recirculation, at the optimum brake power point of 4.287 kW for two-stroke gasoline engine with configurations 2SD4C, 2SD6C and 2SD8C and shown in Figure 4.26.

The Nitrogen Oxides emission is 1250 ppm for without EGR conditions in the two-stroke gasoline base engine. Nitrogen Oxides emissions are 9850 ppm, 820 ppm and 905 ppm for 2SD4C, 2SD6C and 2SD8C respectively at 5 % EGR. It can be observed that the decrement in emission values are 265 ppm, 430 ppm and 345 ppm for 2SD4C, 2SD6C, and 2SD8C respectively at 5 % EGR over the emission value for two-stroke gasoline base engine without EGR.

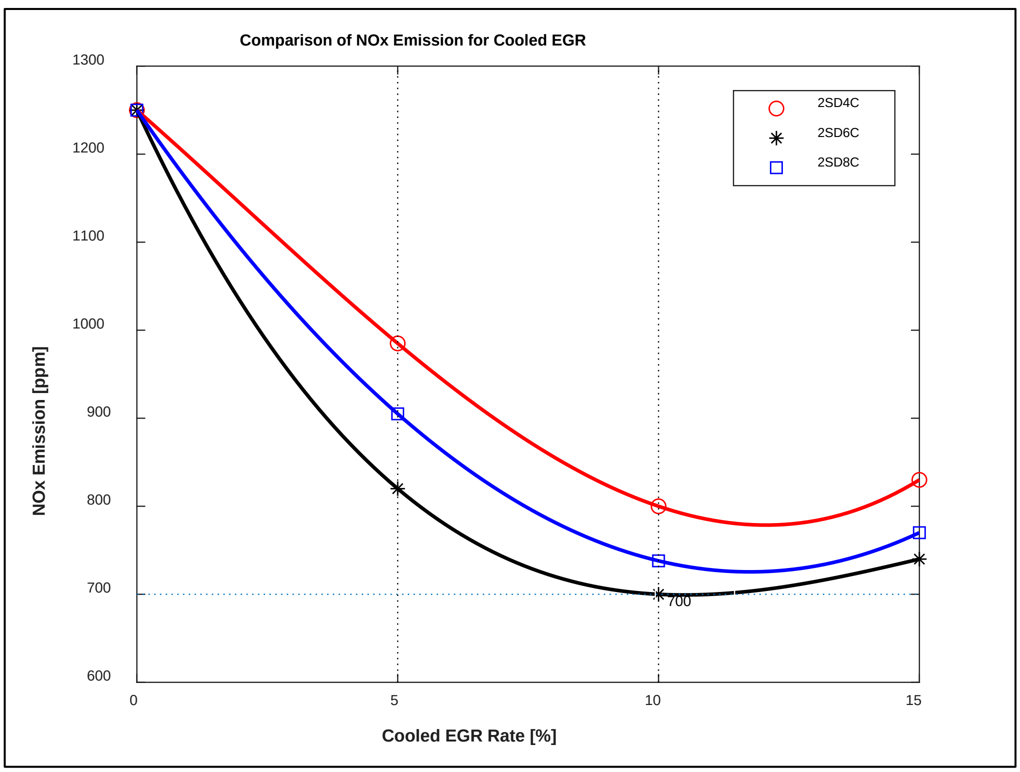

Figure 4.26 EGR Rate vs. NOx Emission cooled EGR

The Nitrogen Oxides emission is 1250 ppm for without EGR conditions in the two-stroke gasoline base engine. Nitrogen Oxides emissions are 800 ppm, 700 ppm and 738 ppm for 2SD4C, 2SD6C and 2SD8C respectively at 10 % EGR. It can be observed that the decrement in emission values are 450 ppm, 550 ppm and 512 ppm for 2SD4C, 2SD6C, and 2SD8C respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

The Nitrogen Oxides emission is 1250 ppm for without EGR conditions in the two-stroke gasoline base engine. Nitrogen Oxides emissions are 830 ppm, 740 ppm and 770 ppm for 2SD4C, 2SD6C and 2SD8C respectively at 10 % EGR. It can be observed that the decrement in emission values are 420 ppm, 510 ppm and 480 ppm for 2SD4C, 2SD6C, and 2SD8C respectively at 10 % EGR over the emission value for two-stroke gasoline base engine without EGR.

Table 4.7 gives the comparison of nitrogen oxides emission at optimum brake power for all configurations. Maximum reduction of 550 ppm in nitrogen oxides emission is obtained with 2SD6 configuration with 10 % cooled EGR over the normal two-stroke gasoline base engine with no EGR.

Table 4.7 Nitrogen Oxides Emission (ppm) for all configurations

Engine	Dia D mm	No EGR	P5 UC	P10 UC	P15 UC	P5 C	P10 C	P15 C
4S	-	-	-	-	-	-	-	-
2S	-	1250	-	-	-	-	-	-
2S	D4	-	1095	950	960	985	800	830
2S	D6	-	920	840	870	820	**700**	740
2S	D8	-	1025	908	920	905	738	770

The efficiency of the EGR in inhibiting the formation of NO and, consequently, reducing the emission of NOx with the engine under the optimum brake power can be observed. Under these circumstances, the recirculation allowed an increase in the pressure, while keeping lower emissions of NOx. Increasing the EGR rate results in dilution, decreased combustion temperature and therefore lower NOx emission was observed. Results indicate that the efficiency on account of the recirculation would be much higher than that for the naturally aspirated base engine without EGR. The trends will be the same, regardless of the orifice diameter, even though the engine emission and hence the performance shows a negative sensibility to the increase of the recirculation beyond 10 %.

Jerzy Kowalski and Wieslaw Tarelko (2009) have dealt with a model of the NOx formation in the combustion chamber of a two-stroke engine. It consists of both the thermodynamic model of a combustion process and the kinetic model of chemical reactions taking place during an engine working process. Engine working parameters are sufficient to work with this model and study the formation of NOx emission. These results have shown lower NOx formation.

Derek Johnson (2016) also reported comparable results by experimental investigations that volumetric EGR rates of 2.5% showed reduced NOx emissions and improved fuel efficiency while rates beyond 5% did not yield NOx reductions in SI engines using alternative fuel. The addition of 2.5% EGR could be used to reduce NOx emissions but increasing to 5% yielded increased NOx emissions. Overall, the addition of EGR improved combustion stability and BSFC apart from limiting the emission. As EGR rate increased, the AFR enriched. AFR enrichment is expected due to the increasing amount of displaced air with increased EGR rates, in addition to increased intake air temperature. At 2.5% EGR, improvements in BSFC and fuel efficiency were prevalent and attributed to increased engine stability. For 5% EGR, the improvements in efficiency and BSFC were not as dramatic in magnitude and were not statistically different.

Dinesh K, Aravind S (2016) also confirms the results of their study reports. Exhaust Gas Recirculation is a very simple method, very useful, and can be modified further to attain better standards. It can be easily fitted to two-wheelers to eliminate Nitrous Oxides gas from IC Engine. From emission test reports in their study, it was concluded that emissions of NOx decrease with increase in % of EGR due to diminished oxygen content and diminished flame temperature in the combustible blend. It was also found that fuel efficiency of the engine increased. These observations were consistent with thermodynamic predictions that lower combustion chamber temperatures restrict the formation of oxides of nitrogen. Driving condition has a marked effect on the emission rate of all constituents. As low as 1 grams per cubic meter to 16 grams per cubic meter during deceleration stage. (12 % to 36 % by weight of fuel).

Ajinkya and Nilesh (2016) have found that Monatomic nitrogen (2N) reacts with oxygen to form NOx. More is the temperature more N2 will dissociate, and more NOx will be formed. At low temperature, less amount of NOx is created. In addition to temperature, NOx formation depends on pressure and air-fuel mixture. At low load condition, the engine requires high EGR ratio because recirculating gases contains a high amount of oxygen and low carbon dioxide while at high load the oxygen in exhaust gas decreases and inert gas constituents star increasing with increased temperature. At high EGR rate of about 44% reduces NO emissions but significantly affect fuel economy. About 2000 ppm of oxides of nitrogen is present in the exhaust of the engine. Mostly this contains nitrogen oxide (NO) and a small amount of nitrogen dioxide (NO_2) and other combinations.

Many of theoretical and experimental investigation shows that the concentration of NOx in the exhaust gas is closely related to peak cycle temperature and available amount of oxygen in the combustion chamber. Any process to reduce cylinder peak temperature and the concentration of oxygen will reduce the oxides of nitrogen. Temperature and oxygen availability suggests some methods are used for reducing the level of nitrogen oxides. Among these the dilution of fuel-air mixture entering the engine cylinder with non-combustible substance is one which absorbs portion energy released during combustion, thereby affecting an overall reduction in combustion temperature and consequently in the NOx emission level.

Exhaust Gas Recirculation done by diverting some exhaust gases back into the inlet port combines with exhaust residual of the previous cycle left in the cylinder to reduce the maximum burning temperature. As the specific heat of EGR is much higher than ambient air, increases the heat capacity of charge and leads to decreasing the temperature rise for the same heat output. EGR displaces fresh air entering the chamber with CO_2 and water vapour present in the exhaust. Hence due to this displacement, amount of oxygen in the air-fuel mixture reduces and reduces the effective air-fuel ratio which influences the exhaust emission substantially. EGR increases the heat capacity of intake mixture, which results in decreasing flame temperature and NOx formation reactions.

4.9 Summary

Controlled combustion temperature and kinematic conditions are very important to achieve optimum performance in an IC engine. Allowing recirculation through orifice flow control device in the inlet manifold is a simple method that can be adopted to achieve this purpose. With increasing orifice dimension, exhaust entry raises to reduce the combustion temperature and improves the performance. If the exhaust is uncooled, then temperature rise occurs defeating the very purpose improving combustion efficiency. At smaller orifice dimension, the exhaust entry being lower, Carbon Monoxide reactions continue to occur even with oxygen present in the exhaust, thus speeding up combustion process. At higher orifice dimension, exhaust at higher temperature enters. Formation of nitrogen oxide at higher temperature is very sensitive preventing the Carbon Monoxide from reacting with oxygen molecules for carbon dioxide formation. Pollution is thus transferred from CO to NO_2. Therefore, there exist optimum limits for orifice diameter as well as percentage EGR rates up to which performance can be improved with low emission.

To summarise the discussion, increased efficiency, with reduced emission levels are obtained in the two-stroke engine with 6 mm orifice introduced in the inlet manifold, and 10 % recirculation cooled exhaust gas. The two-stroke engines are therefore worth reconsidering for usage at select sectors where it would be economical. Stationary engines used in marine and plant applications are a few that fall into this category.