The Review Paper on Exhaust Gas Heat Recovery Using Six Stroke Engine

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ABSTRACT

Six stroke engine is an effective way of recovery of heat lost through the exhaust gases by adding additional steam stroke to a partial exhaust stroke. It can be thought as four stroke Otto or diesel cycle followed by a steam cycle for heat recovery. A partial exhaust is added with water converts the heat from exhaust to the pressure of steam and its expansion is used as another comparatively less powered expansion stroke. To analyze this model an ideal thermodynamic process of exhaust compression water addition and steam expansion is assumed. By changing the closing timing of exhaust valve appropriate amount of exhaust gas can be recompressed to be added water into, to maximize the mean stream expansion pressure (MEP_{steam}). The range of MEP_{steam} calculated for conventional gasoline engine is from 0.75 to 2.5 bars, generally $MEP_{combustion}$of naturally aspirated gasoline engine is up to 10 bars. Hence this concept has big potential to recover the lost heat and improve the efficiency and fuel economy.

1. INTRODUCTION

Traditionally the Otto or diesel cycle has four strokes,

a. Suction stroke
b. Compression stroke
c. Combustion stroke
d. Exhaust stroke

They are represented w.r.t. to the crack angle in the Figure 1.

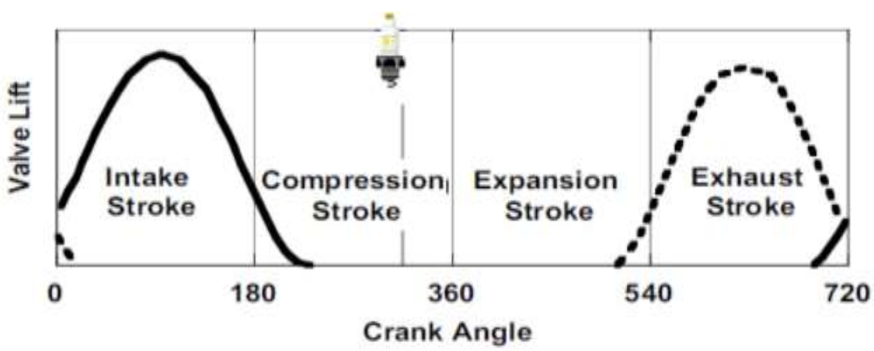

Figure 1: Schematic of typical intake and exhaust valve events for a gasoline engine. [1]

General working cycle of an Otto engine is shown in the following Figure 2.

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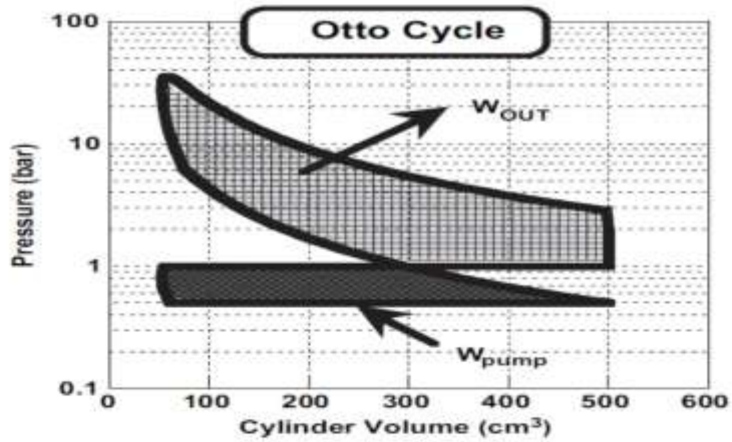

Figure 2: Schematic of pressure vs. volume for a typical gasoline engine Otto cycle. [1]

In generalized gasoline engine running in city conditions, the exhaust gas temperatures rangesbetween 450 to 800 Degrees Celsius. In a study a data collected on Turbocharged SAAB bipower vehicle during federal test protocol (FTP)-75 it was found that total fuel energy consumed during the driving cycle is approximately 58.5MJ, or about 1.7L of unleaded gasoline fuel. The percentage of this total energy consumed to produce driving work is 10.4%. A much larger portion of 27.7% exists the engine in the form of exhaust. While remaining 61.9% energy consists to friction coolants and others. Figure 3 shows the distribution of this power and its distribution w.r.t. time.

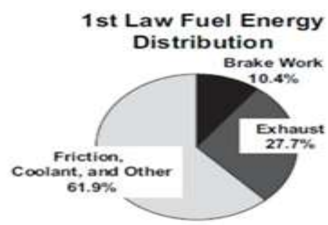

Fig 3.1

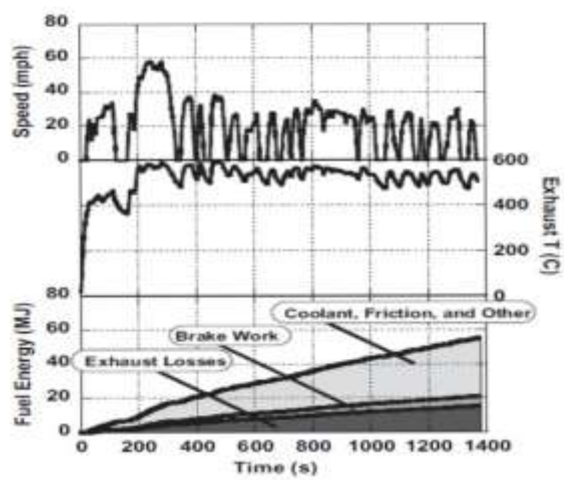

Fig 3.2

Figure 3.1 & 3.2: Federal test protocol (FTP) test cycle for a 2007 Saab Biopower showing speed, exhaust temperature, consumed fuel energy, and recoverable exhaust energy. Experimental data were collected at the ORNL chassis dynamometer facility. [1]

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So to recover the lost heat during this cycle a six stroke cycle is introduced. In six stroke cycle certain amount of exhaust gas in collected into the chamber by prematurely closing exhaust valves and injecting water into it to convert heat into steam to generate work. The duration of each stroke w.r.t. crank angle can be seen in the figure 4.

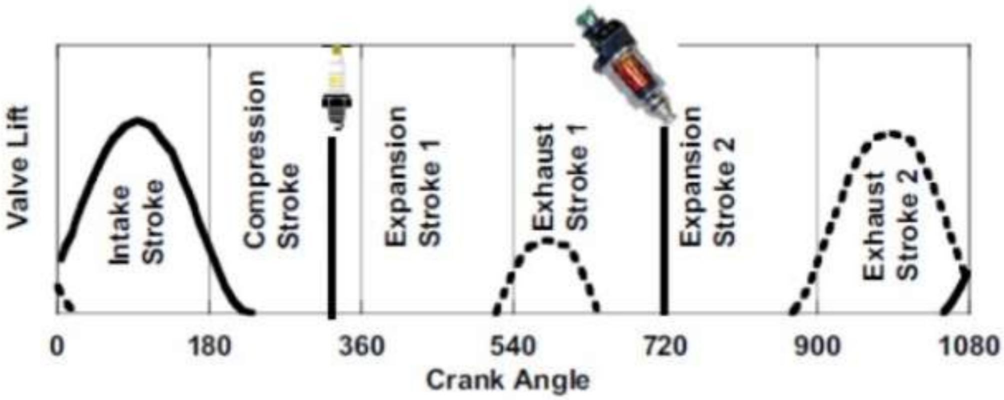

Figure 4: Schematic of typical intake and exhaust valve events for the six-stroke engine cycle. [1]

The cycle of stroke engine with a partial exhaust stroke and injection of water jet for converting heat into the steam for an extra power stroke can be seen in the Figure 5.

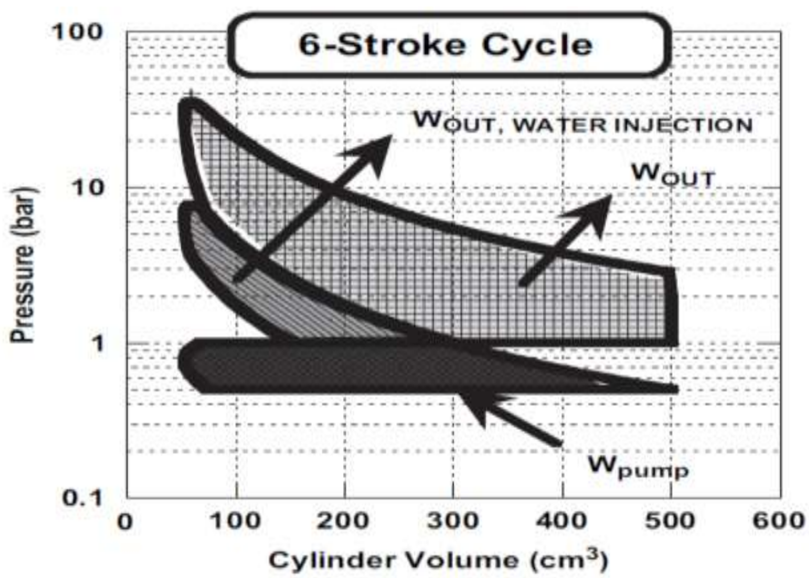

Figure 5: Schematic of pressure vs. volume for a six-stroke engine cycle. [1]

2. OPERATION PRINCIPLE

First three cycles of the engine are same i.e. suction compression and expansion. In forth stroke between 540-720 CA, partial exhaust is cancelled which traps some of the exhaust gas is recompressed. At certain lower in-cylinder pressure of 10 bar water is added to the cylinder through nozzle. Due to this compression of exhaust gas the temperature inside the chamber increases. Addition of water will lead to absorption of heat and lowering the temperature of gases. Therefore, isobaric compression of the gas is expected before 720 CA. absorption of heat leads to isobaric expansion of the steam between 720 CA. now the fifth stroke converts the steam pressure developed into pressure to generate work. Figure 6 shows the gradual progression of this process.

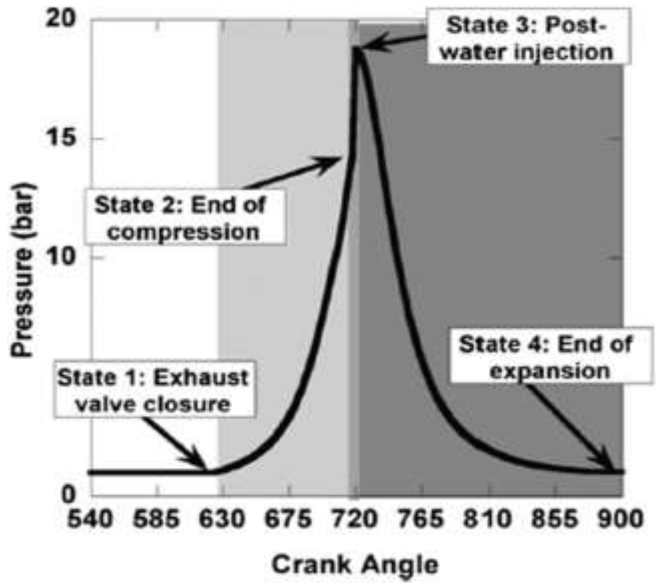

Figure 6: Ideal in-cylinder pressure of present six stroke engine. [3]

3. OPERATION METHODOLOGY

Table 1 and Figure 7 Shows the Positions of cam for this additional stroke.

Valve timing and valve lift	Initial conditions
Inlet advance angle/ Delay angle	12/38
Exhaust advance angle /Delay angle	55/12
Partial exhaust advance angle / Close angle	0/360 CA
Maximum Valve lift of inlet cam	8 mm
Maximum valve lift of exhaust cam	3mm/6mm

Table 1: Initial conditions for cam design of present six stroke engine.[3]

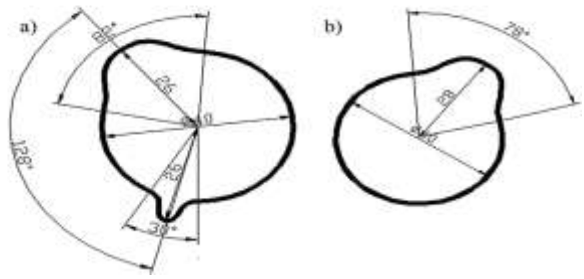

Fig: 7 Cam design for six stroke engine of Conklin and Szybist. [3]

The events occurring in this cycle can be seen in the following Figure 8

First 3 strokes and the valves positons with respect to crank angle can be seen in the following image.

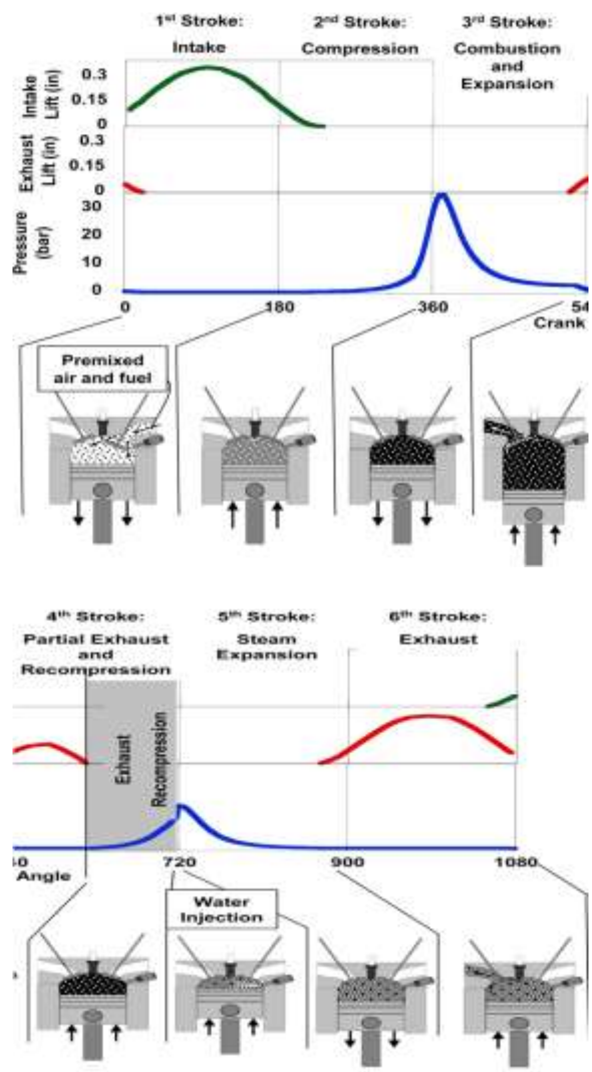

Figure 8: Example of exhaust valve events and cylinder pressure for the six-stroke cycle. [1]

for the testing and verification of the hypothesis a six stroke engine is developed and the schematic and actual engine is shown in the Figure 9. For the water injection system to work properly water injection system has to work by the block diagram shown in the figure 10. [1]

Fig 9A: Working 6 stroke Engine [1]

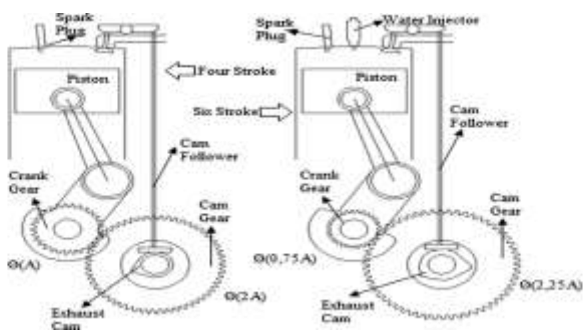

Figure 9B: Schematic and actual design of a six stroke engine [1]

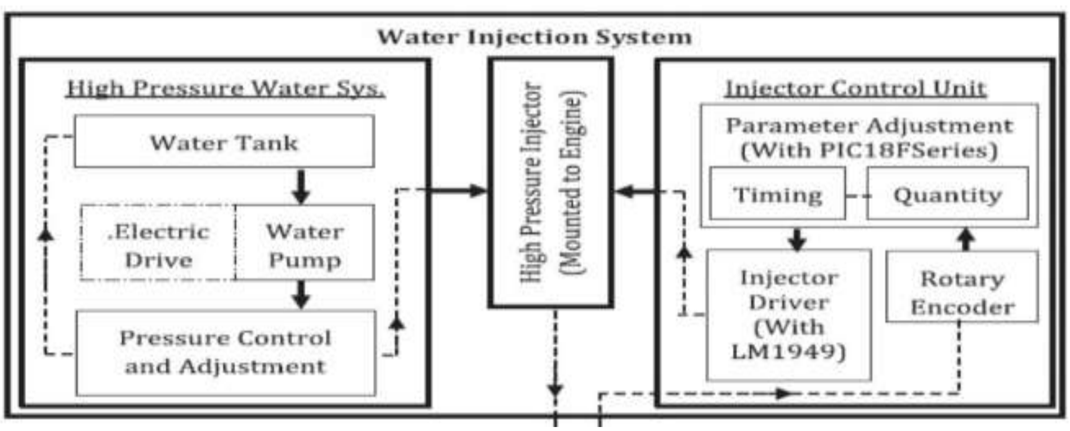

Figure 10: The water injection system operation. [1]

4. RESULTS AND DISCUSSION

Six stroke engine provides the exhaust gas heat to convert to work which would have otherwise wasted to the atmosphere. The experiments conducted to test the optimum injection timing and pressure i.e. 20, 50,75 and 100 bars and timing Before TDC, TDC, after TDC, to compare the results the engine was firstly run without water injection and the output was compared with the data from water injected engine. Figure 11 shows the collected data.

As can be seen higher break torque values were registered for the water injected system. It is also shown that engine temperature and exhaust gas temperature are significantly lower. Which is due to recovery of the otherwise lost heat. Fuel consumption is seen to be increasing with increasing RPM but a more suitable figure for comparisonBrakeSpecific Fuel Consumption is seen to be decreasing. brake power can also be seen increasing with water injection. It can be explained that with or without the water injection the fuel consumption would be same but noted decrease in specific fuel consumption could be linked to recovered heat from the exhaust gases to produce power. The injected water also leads to absorption of heat from cylinder walls which further leads to decrease in engine temperature. Which states that heat lost to otherwise cooling is recovered to produce work.

Following data shows the effects of water injection on modified brake power versus engine speed. As the water injection quantity increased, brake power increased until maximum power engine speed. It can be also said that maximum water injection should occur at maximum power engine speed. It was seen that there was a good accordance with brake power and water injection.

Due to recovery of heat thermal efficiency of engine can be seen increasing. The decrease of 18.23% is recorded foe rpm of 3000. The quantity of hydrocarbons and NOx in the exhaust can also be seen decreasing.

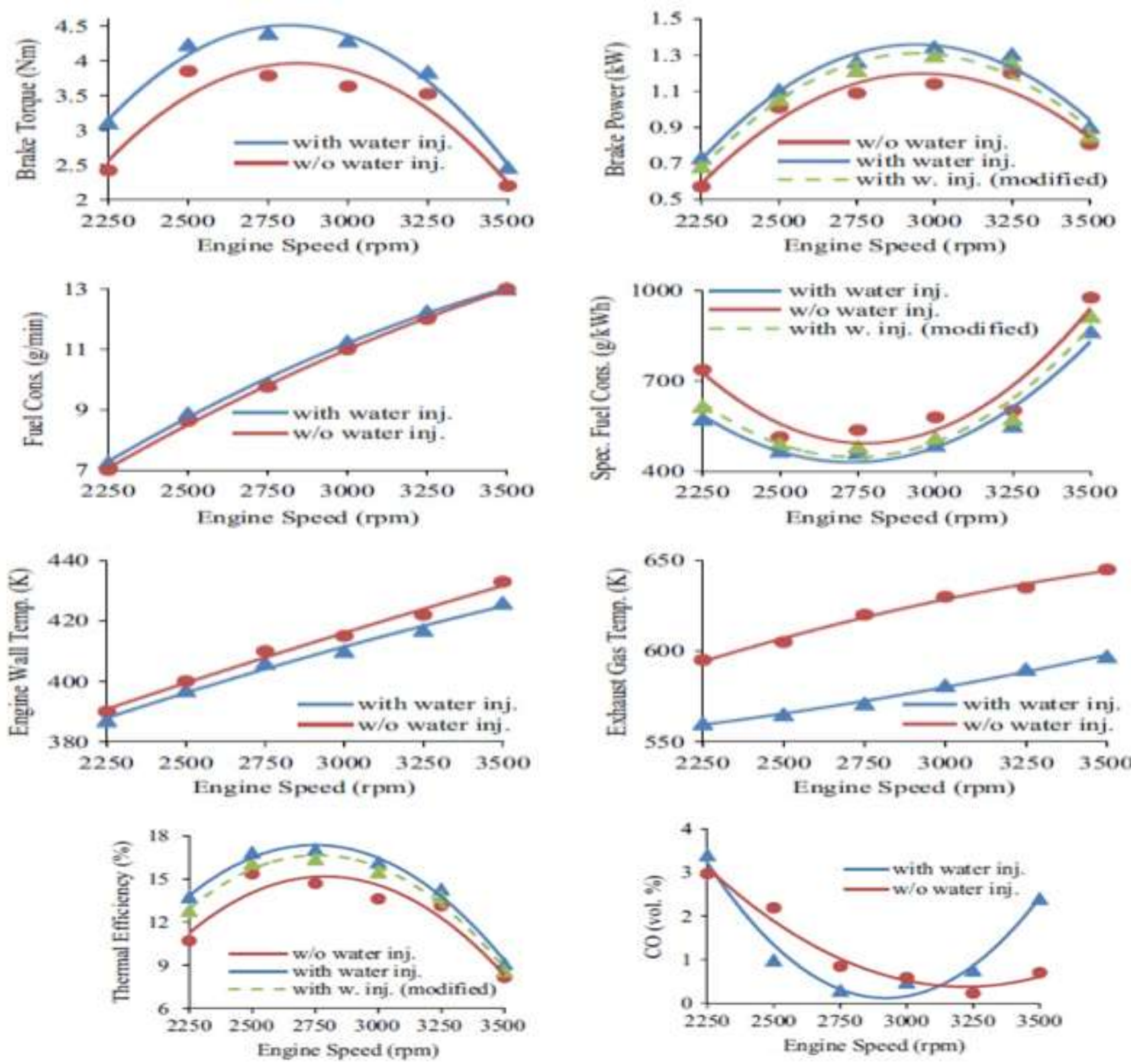

Fig 11 Engine Performance Data [1]

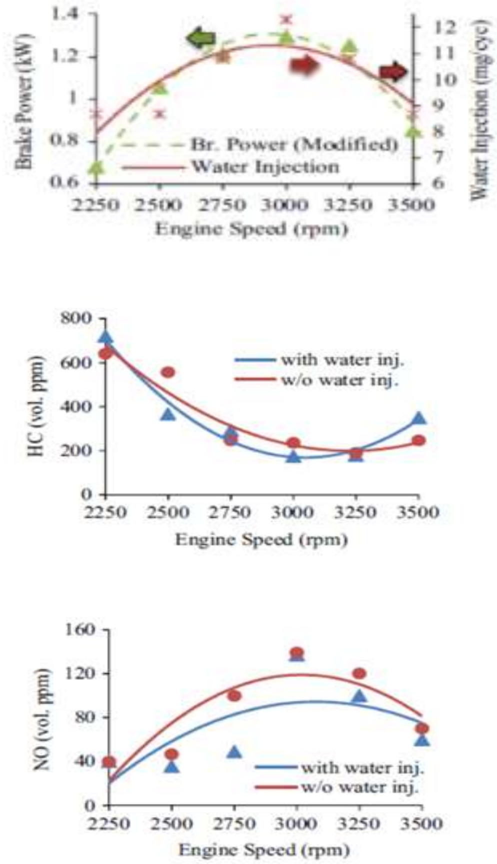

Fig 11: Engine performance data [1]

5. CONCLUSION

Thermal energy lost to exhaust gases and coolants is recovered to improve engine performance significantly the overall improvement of engine performance is given below.

i. Exhaust gas temperature and engine wall temperatures decreased 7% and 2% respectively with water injection. Moreover, volumetric efficiency increased owing to cooling effect of water.
ii. Brake power increased 10% with water injection. In contrast, specific fuel consumption decreased 9%.
iii. The biggest effect of the water injection was observed between 2750 and 3250 rpm engine speed on engine performance. More water was injected between 2750 and 3250 rpm engine speed.
iv. The test results showed that injection timing should be advanced with the increase of engine speed. There is no remarkable effect of the water injection quantity and injection advance on engine performance at lowest (2250 rpm) and highest (3500 rpm) engine speeds.
v. The thermal efficiency and engine performance improve with the proper water injection quantity and injection timing compared to without water injection in six stroke engine.
vi. CO and HC emissions decreased 21.97% and 18.23% until 3000 rpm respectively. NO emissions decreased with water injection as the temperature decreased at the end of cycle.
vii. It was deduced that lower NO emissions are the result ofexhaust heat recovery in six stroke engines. NO emissions substantially decreased due to lower cylinder temperature.

It is hoped that this study contributes the effects of water injection on engine performance and exhaust emissions in six stroke engines.

6. ACKNOWLEDGEMENT

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