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AN EXPERIMENTAL ANALYSIS OF THE CONNEXION OF ENGINE FUEL CONSUMPTION AND THE OPERATIONAL FUNCTIONALITY OF ENGINE WITH OR WITHOUT THERMOSTAT

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Abstract

It has become normal practice to remove engine thermostat in an attempt to solve engine overheating problems in Ghana. The aim of this study is to investigate the quality of engine performance and economy in fuel consumption with thermostat-fitted engines as against engines whose thermostat has been removed. The research methodology adopted was the use of experimental research of engine fuel consumption with the presence of an engine thermostat. A laboratory test was conducted for this work. The test was done by fitting an engine with an engine thermostat to see how it impacts on fuel consumption in a vehicle. The research enquired into how internal combustion engine performance characteristics such as engine torque, brake power, indicated power, overall mechanical efficiency and frictional losses are influenced due to the presence of an engine thermostat from an engine. The study established among others that the engine performance, when fan and coolant thermostat were used recorded a progressive change in mechanical efficiency at 52.0% and again engines with thermostat recorded low fuel consumption rate. The study thus recommends that in order to have fuel used efficiently and boost engine performance in motor vehicles, coolant thermostats should not be taken out of the engine in an attempt to address engine overheating problem.

Keywords: *Engine fan; Fuel Consumption; Mechanical Efficiency and Thermostat.*

INTRODUCTION

An internal combustion engine performance is influenced by a number of factors including a controlled cooling system. Whereas control cooling seeks to improve fuel consumption, over-heating may influence engine performance characteristics and possibly increase fuel consumption. (Atkins, 2009). According to Missan, & Keswani (2016) overheating of an engine can be prevented by using an efficient cooling system that assists the vehicle to run at its optimal performance. A study by Tao, & Wagner (2016) indicated that pursuit of greater fuel economy in internal combustion engines requires the optimization of all subsystems including thermal management. They mentioned that reduction of cooling power required by the electromechanical coolant pump, radiator fan(s), and thermal valve demands real time control strategies. It worthy to note that cooling system as a sub management system in engine management plays a

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key role in effective engine performance characteristics. According to Ganesan & Kannan (2018) if effective cooling is not done, it can reduce the efficiency of the engine and in extreme case damage engine by overheating. In a water cooled engine, the coolant temperature is regulated by a thermostat. The thermostat is usually mounted between the engine and the radiator input. When the engine is cold, the thermostat is closed and the coolant is not allowed to flow between engine and the radiator. This allows the engine to heat up as quickly as possible. When the coolant reaches the thermostat valve opening temperature, the thermostats open and allow the coolant to flow between the engine and the radiator.

The coolant temperature is kept fairly constant by allowing more or less coolant to flow through the radiator. Whereas a number of researches are being undertaken to improve upon the performance of water cooled engines others sees the removal of engine thermostat as the solution to engine coolant overheating problem. Wagner, Ghone, Dawson, & Marotta (2002) in their research came out with a smart thermostat and coolant pump to control engine thermal management. A lot of effort have been made by researchers to address the issue of overheating with thermostat control mechanisms. However, in an attempt to address the issue about engine overheating the maintenance practices by the ordinary mechanic should not be left out. This paper, therefore, seeks to assess the influence of the presence of the engine thermostat on fuel efficiency of engines. The study aimed at determining fuel consumption of an engine fitted with fan and water thermostat and finally assessing fuel consumption of an engine fitted with water thermostat. It is a fact that a lot of local garage mechanics removes the engine thermostat in an attempt to solve engine over heating problems. A study by Davis, Sackey & Fanyin-Martin (2018) revealed that the removal of thermostats from automobile engines in Ghana is a wide spread practice. Their study revealed that auto-mechanics practice removal of engine thermostat in an attempt to solve engine overheating problems and also used vehicle importers practice engine thermostat removal to satisfy their customers' wish. Results of their work suggested that the practice of engine thermostat removal affect engine performance, fuel consumption, and cause excessive smoke emission. Undoubtedly, according to Baidoo & Odum-Awuakye (2015) most of these local repair garages serve as an alternative garage to car owners who do not have access to standard automobile service garages. The aim of this research is to investigate the quality of engine performance and economy in fuel consumption with thermostat-fitted engines as against engines whose thermostat has been removed. The emphasis is to find out if there is a scientific basis for these wayside mechanics or non-dealership repair garages to remove the thermostat fitted in an engine by a manufacturer in an attempt to address customer complain such as frequent engine overheating.

THE INFLUENCE OF THERMOSTAT ON ENGINE PERFORMANCE

The cooling performance of an internal combustion engine has under gone extensive developments over the past three decades. All in an attempt to address a major setback of influence of engine cooling on engine performance (Stence, 1998; Schöner, 2004). According to Karim, Mehravaran, Lizotte, Miazgowicz & Zhang (2015) in order to maintain the higher power density demand and avoid overheating problem, the cooling system design becomes an important and challenging task. For instance, stratified charge and piston redesign offer improved thermal efficiency through lean combustion, directly resulting in lower fuel consumption and higher power output (Evans, 2006). Further, variable valve timing adjusts engine valve events to reduce pumping losses on a cycle-to-cycle basis (Mianzo & Peng, 2000; Hong, Parvate-Patil, & Gordon, 2004). However, the automotive cooling system has been overlooked until recently (Wagner, Paradis, Marotta & Dawson, 2002). The conventional spark and compression ignition engine cooling systems can be improved with the integration of servo-motor based actuators (Melzer, Hesse, Rocklage & Schmitt, 1999).

Replacement of conventional thermal management components (i.e., wax thermostat mechanical water pump, and mechanical radiator fan) with updated electric and/or hydraulic versions offer more effective operation (Redfield, Surampudi, Gustavo, Montemayor, McKee, Edwards & Lasecki, 2006). In particular, the main function of the thermostat valve (Wanbsganss, 1999) is to control coolant flow to the radiator. Traditionally, this is achieved using a wax-based thermostat which is passive in nature (Allen & Lasecki, 2001) and cannot be integrated in an engine management system (Wagner et al., 2002b). A smart thermostat valve offers improved coolant flow control since it can be controlled to operate at optimal engine conditions (Visnic, 2001). It should be noted that the thermostat valve may be located on the engine block with internal passages for coolant flow or external to the block with supporting hoses. The next generation of internal combustion engines should be designed to facilitate advanced thermal management concepts.

Cooling System configurations and valve operation

The typical automotive cooling system has two main thermal components: engine and radiator. The coolant flow through the engine loop transports excess combustion heat to the radiator loop which dissipates this heat. Controlling and directing coolant flow between these two loops is the main function of most thermostat valves. This functionality may be accomplished through different valve configurations and system architectures (Melzer, et al.,1999). According to Mitchell, Salah, Wagner & Dawson (2009) one important area of cooling system configuration and operation has to do with warm-up, during which fluid flow is regulated between the bypass and radiator loops. The author’s fundamental question has to do with the usefulness of the common thermostat valve. They investigate warm-up behaviours and thermostat valve operations with four different thermostat configurations. However, the efficiency of the cooling and fuel consumption of an engine with or without thermostat need to be looked at to how coolant is regulated.

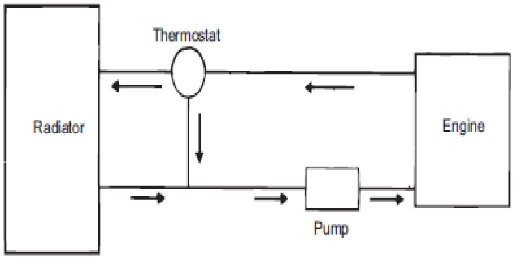

Figure 1: Water cooling system using thermostat valve

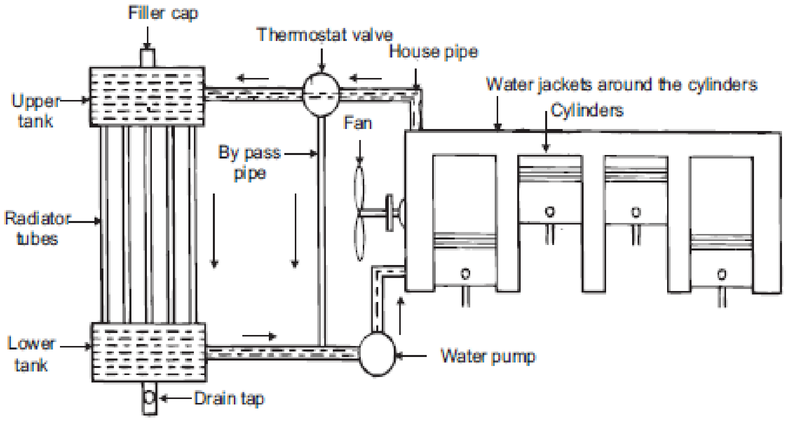

Figure 2: Water cooling system of a 4-cylinder engine

Traditional Thermostat Valve Fluid Control

The common cooling system has key components working to regulate engine temperature: thermostat, water hose/tube water pump, and radiator fan and radiator fins. In operation, when the engine is cold, the thermostat is closed and coolant is forced to flow through an internal engine bypass (usually a water passage parallel to the engine water jackets). Once the coolant reaches the desired operating temperature, the thermostat begins to open and allow coolant to flow through the radiator where excess heat can be rejected. Coolant flowing through the radiator is further cooled by the radiator fan pulling air across the radiator. When the coolant has dropped below the thermostat temperature rating, the valve closes (via spring force) directing the coolant again through the bypass. Conventional thermostats are wax based; their operation depends on the material properties of the wax in the thermostat housing and the coolant temperature surrounding it (Choukroun & Chanfreau, 2001).

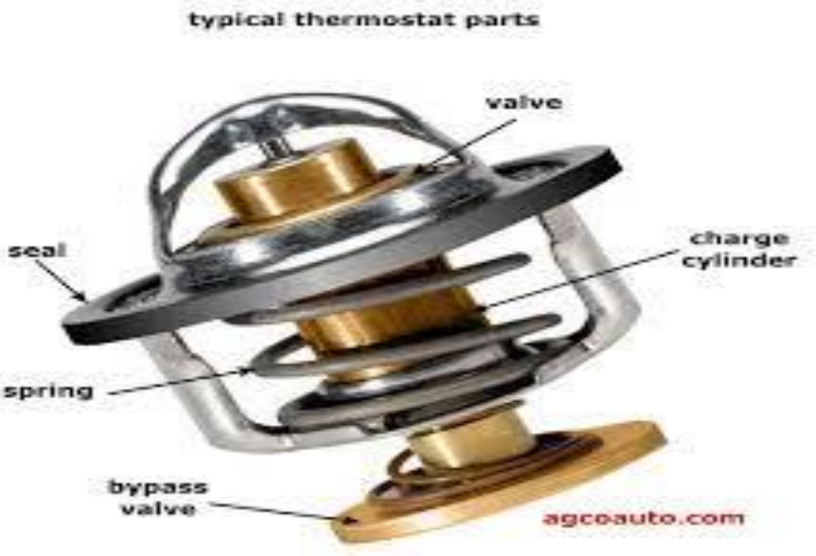

Figure 3: Parts of a Thermostat

Traditional water pumps and radiator fans are generally mechanically driven by the engine's crankshaft. Specifically, the water pump is driven as an accessory load while the radiator fan is often connected directly to the crankshaft with a clutch. Once the coolant reaches the desired operating temperature, the thermostat begins to open and allow coolant to flow through the radiator where excess heat can be rejected. Coolant flowing through the radiator is further cooled by the radiator fan pulling air across the radiator. When the coolant has dropped below the thermostat temperature rating, the valve closes (via spring force) directing the coolant again through the bypass. Conventional thermostats are wax based; their operation depends on the material properties of the wax in the thermostat housing and the coolant temperature surrounding it (Choukroun & Chanfreau, 2001). The failure of cooling system component results in overheating of an engine. Missan & Keswani (2016). Traditional water pumps and radiator fans are generally mechanically driven by the engine's crankshaft. Specifically, the water pump is driven as an accessory load while the radiator fan is often connected directly to the crankshaft with a clutch.

An experimental design was constructed by Brace, Hawley, Akehurst, Piddock & Pegg (2008) to investigate the effect of water pump throttling, coolant flow control through the oil cooler, and the adoption of a pressure resistive thermostat (PRT). Their research examined cooling system improvement by way of assessing the effect on emissions and fuel economy. Chalgren & Barron (2003) identified two challenges factory cooling systems had. First, large parasitic losses are associated with operating mechanical components at high rotational speeds due to their mechanical linkages. This not only decreases the overall engine power, but increases the fuel consumption. Additionally, these parasitic losses are compounded since the traditional cooling system components are designed for maximum (and often infrequent) cooling loads.

Second, over or under cooling may occur since the water pump speed is directly proportional to the engine speed (again due to the mechanical linkages). At low engine speeds, the water pump may not be circulating coolant fast enough to properly cool the engine at higher loads. Similarly, the water pump may be circulating the coolant too fast, causing the engine to be overcooled and lose efficiency at higher speeds.

Fundamentally, the traditional cooling system is passive and there is no direct control over its operation (Melzer, et al., 1999).

MATERIALS AND METHODS

The experimental set-up consists of a four stroke, twin cylinder carburettor spark ignition (S.I) engine. The engine was coupled to a hydraulic dynamometer for measuring its brake power (b.p). The evaluation method employed in this study was based on a comparison of the outcomes of engines that use thermostat and engines which has it thermostat either removed or defective thermostat. Table 1 and 2 shows the test engine and hydraulic dynamometer specifications respectively.

Table 1: Test engine specifications

Engine Model	FordYSG414
Serial No/Date	E780/183
Build No	D 000 041 403
Bore	70mm
Stroke	90mm
Cubic Capacity	1.6
Compression Ratio	7.4:1
Fuel	Petrol
Engine Lubrication	Wet sump lubrication
Engine Cooling	Water Cooled

Source: Data from Auto Laboratory, Cape Coast Technical University, 2019

Table 2: Hydraulic dynamometer - Specifications

Model	E-50
Motor / pump capacity	KW 1.1, V 220, A 7.7, µF 30
Crank position measurement	By rotary encoder
Water pressure gauge	Bourdon berg gauge
Overall Dimension	3800 x 2500 x 1500

Source: Auto Laboratory Cape Coast Technical University, 2019

Tests conducted for this work were categorised into two groups namely:

Category 1: Engine fitted with thermostat

A petrol engine fitted with thermostat was used to run the test. The test under this category was conducted on an average of four (4) to measure the validity of the result.

Category 2: Engine without thermostat
In this category, a petrol engine with its thermostat removed was used to conduct the test. Again an average of four tests were conducted to look at the validity of the result.

Engine Torque Measurement

The following procedure was followed to carry out the test using the petrol engine coupled to the hydraulic dynamometer:

1. The engine was checked for correct lubrication;
2. The water level in the radiator was checked;
3. The water circulation to the cylinder jacket and to the hydraulic dynamometer was also checked;
4. The ignition system was checked for a good start;
5. The condition of the centrifugal water pump was checked for good performance;
6. Petrol feed from the fuel tank to the carburettor was checked to ensure a continuous flow;
7. Water pressure was raised to about 4bars as directed;
8. The ignition system was switched on while the dynamometer was in the idling position with the control gate closed;
9. The engine was switch on with the throttle at the lowest setting;
10. After a period of 2-5 minutes time, the throttle opening was gradually increased by one notch on the setting and the dynamometer was adjusted to return the rotational speed to about 3000rev/min;
11. Condition was allowed to settle and the brake torque was recorded;
12. With increased throttle openings, continuous increased reading was observed for full throttle to neutral and to the idling position;
13. The cylinders were cut-out in turns and the engine torque was recorded accordingly.
14. Similar procedure was followed for all specimens and their test result was recorded.

FINDINGS AND DISCUSSION

Fuel consumption of an engine fitted with fan and water thermostat

Table 3 shows the average result of the experimental test conducted on the engine performance when cooling fan and coolant thermostats were in operational. Whereas the test recorded a progressive change in mechanical efficiency at 36%. moreover, indicated specific fuel consumption was 13.0151kg/kw/h. Brake specific fuel consumption was 36.3636kg/kw/h. the study confirmed that indicated thermal efficiency was 0.0614 and brake thermal efficiency was 0.022 respectively as the cylinders were cut-out in turns, a constant frictional power and losses of 0.00461 kw was recorded throughout the cylinder cut-out. As shown on the table brake power and indicated power recorded similar values at the various cylinder cut-outs in turn. Again it is noticed that a variation of torque output of 0.05, 0.013, 0.36, 0.04, 0.008 and -0.0005Nm respectively was recorded as the cylinders were cut out in turn. The study finding suggested that engines with fan and coolant thermostats have higher mechanical efficiency and low fuel consumption. As shown in figure 4, it will be observed that performance curves for indicated fuel consumption and brake thermal efficiency are not the same. The brake power curve shows that the brake power increases with the speed until the peak is reached. The maximum power output, however, does not occur at the condition for maximum thermal efficiency. The indicated specific fuel consumption occurs steadily against the indicated thermal efficiency and the brake thermal efficiency, respectively. The result of the test suggest that engines with fan and coolant thermostats have higher mechanical efficiency and low fuel consumption.

Table 3 Average Test Result- Engine Performance with Fan and Water Thermostat

Cylinder cut out	**None**	**Number 1**	**Number 2**	**Number 3**	**Number 4**
Speed (N): rev/min	3000	3000	3000	3000	3000
Mechanical torque (Nm)	0.05	0.013	0.04	0.008	-0.0005
Actual torque (Nm): $\frac{Nm}{9550}$	$5.24\ x10^{-6}$	$1.36x10^{-6}$	$4.19x10^{-6}$	$8.38x10^{-7}$	$-5.24x10^{-8}$
Mechanical Efficiency (%)	36	8.5	22.1	5.34	-0.36
Friction power and pumping losses	0.00296	0.00461	0.00461	0.00461	0.00461
Fuel Consumed/kg/hr	0.06	0.043	0.03	0.03	0.023
Brake power developed (W): $\frac{2\pi NT}{60}$	0.00165	0.000427	0.00132	0.000263	- 0.0000165
Indicated power (kw)	0.00660	-0.00175	0.000132	0.000263	- 0.0000165
Indicated specific Fuel Consumption/min	13.0151	8.5317	5.0590	6.1101	
Brake Sp. Fuel Consumption/min	36.3636 0.0614	100 0.0937	22.7272 0.1581	115.38 0.1298	5.0108 -1393.93
Indicated Thermal Efficiency (%)	0.022	0.008	0.0352	0.0069	0.1596 0.0057
Brake Thermal Efficiency (%)					

Source: Field work 2019

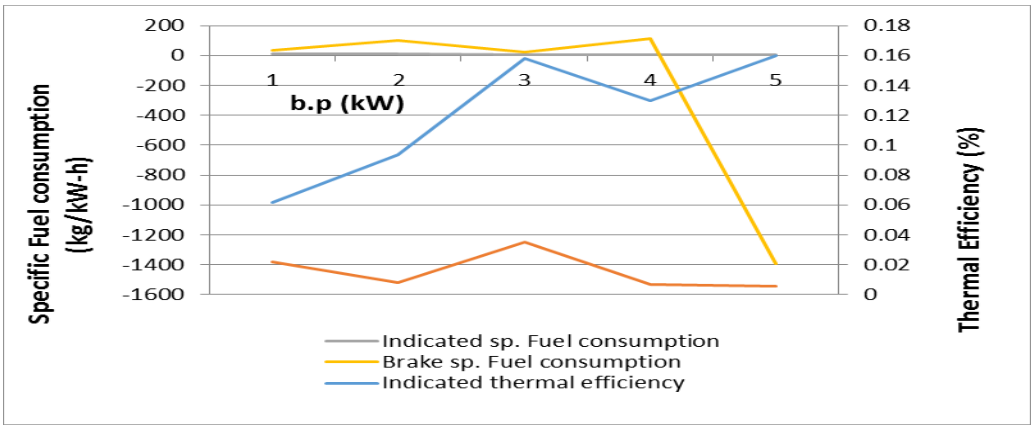

Figure 4: Performance Curves of Engine with Fan and Water Thermostat

Analysis of Fuel Consumption: Engine Specimen without Thermostat

Table 4 shows the average result of the experimental test conducted on the engine performance without thermostat. Whereas the test recorded a regressive change in mechanical efficiency at 26.8%. Moreover, indicated specific fuel consumption was 5.85kg/kw/h. Brake specific fuel consumption was 21.82kg/kw/h. The study confirmed that indicated thermal efficiency was 0.1367 and brake thermal efficiency was 0.0367 respectively as the cylinders were cut-out in turns, a constant frictional power and losses of 0.26kw was recorded throughout the cylinder cut-out. As shown on the table brake power and indicated power recorded similar values at the various cylinder cut outs in turn. Again it is noticed that a variation of torque output of 0.34, 0.02, 0.02, 0.02, 0.02and 0.02 Nm respectively was recorded as the cylinders were cut out in turn. The study finding concluded that engines without thermostats have lower mechanical efficiency and high fuel consumption as compared with the engine fitted with fan and water thermostat. Whereas the mechanical efficiency for engine fitted with both fan and water thermostat recorded 36% that of the engine without fan and water thermostat recorded 26.8%. Again the study recorded different fuel consumption. That of the engine fitted with fan and water thermostat recorded fuel consumption of 0.06kg/h that of engine fitted without thermostat recorded a fuel consumption of 0.24kk/hr respectively. Again figure 5 shows the corresponding performance curve for both indicated specific fuel consumption and that of brake specific fuel consumption respectively.

Table 4. Average Test Result- Engine Performance without Thermostat

Cylinder cut out	None	Number 1	Number 2	Number 3	Number 4
Speed (N): rev/min	3000	3000	3000	3000	3000
Mechanical torque (Nm)	0.34	0.02	0.02	0.02	0.02
Actual torque (Nm): $\frac{Nm}{9550}$	$3.56\,x10^{-5}$	$2.09x10^{-6}$	$2.09x10^{-6}$	$2.09x10^{-6}$	$2.09x10^{-6}$
Mechanical efficiency	26.8	1.56	1.56	1.56	1.56

%					
Friction power and pumping losses	0.03	0.0414	0.0414	0.0414	0.0414
Fuel Consumed/kg/hr	0.24	0.18	0.15	0.14	0.12
Brake power developed (W): $\frac{2\pi NT}{60}$	0.011	0.00066	0.00066	0.00066	0.00066
Indicated power (kw)	0.0410	0.0421	0.0421	0.0421	0.0421
Indicated sp. Fuel Consumption/min	5.85	4.39	3.66	3.41	2.93
Brake Sp. Fuel Consumption/min	21.82	16.36	13.62	12.72	10.91
Indicated Thermal Efficiency (%)	0.1367	0.1866	0.2245	0.2406	0.28077
Brake Thermal Efficiency (%)	0.0367	2.9333	0.0035	0.00352	0.0044

Source: Field work 2019

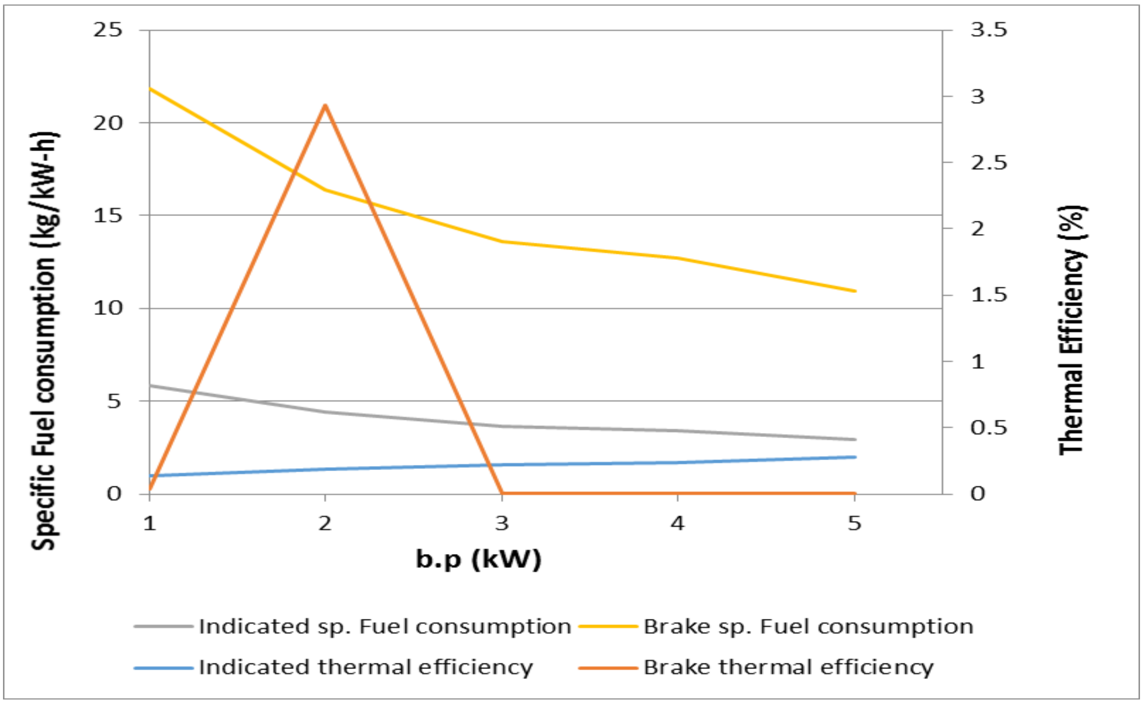

Figure 5: Performance Curves of Engine without Thermostat

Key Findings of the Study

The objective of this study was to evaluate the engine performance of thermostat engines and engines without thermostat. The following observations were made, that:

1. The engine performance when fan and coolant thermostat were used recorded a progressive change in mechanical efficiency at 52.0%.
2. Engines with thermostat recorded low fuel consumption rate.
3. The thermal efficiency of engines with thermostat was high.
4. The brake thermal efficiency of engines with thermostat was 0.1377, this means that engines with fan and coolant thermostats have higher mechanical efficiency and low fuel consumption.
5. The experimental test conducted on the engine performance without thermostat recorded a regressive change in mechanical efficiency at 26.8%. Moreover, indicated specific fuel consumption was high.
6. The engines without thermostat recorded low thermal and mechanical efficiency. The study finding holds that engines without thermostats have lower mechanical efficiency and high fuel consumption.

CONCLUSION

Base on the findings the following conclusions may be drawn that; there is significant change in engine performance characteristics when fan and coolant thermostat are fitted in an engine. Engines with thermostat has a low fuel consumption rate compared with engines which has its thermostat removed or defective.

Recommendation

Thermostat fitted in an engine plays a vital role when it comes to amount of fuel used by the engine. It is recommended that auto mechanics should replace any defective or faulty thermostat removed from an engine. Non-defective thermostat should not be remove in an attempt to solve engine overheating problem.

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