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Improving the Performance of Two-stroke Motorcycle with Tuned Adjustable Exhaust Pipe

O. Obodeh, and A.D. Ogbor
Department of Mechanical Engineering, Ambrose Alli University,
Ekpoma Edo State, Nigeria

Abstract: Engine performance is strongly dependent on gas dynamic phenomena in intake and exhaust systems. Careful design of the manifolds enables the engineer to manipulate the characteristics. The basic exhaust tuning mechanisms was described with respect to a two-stroke single-cylinder engine. Tuned adjustable exhaust pipe for use on two-stroke motorcycle was designed and tested. The dynamometer used incorporated a flywheel of appropriate moment of inertia to simulate the mass of the motorcycle and rider. The test procedure involved measurement of the flywheel speed during an acceleration phase resulting from opening the throttle. Calculation of the instantaneous flywheel acceleration gave a measure of the torque and power characteristics. The airflow based values of delivery ratio; trapping efficiency and charging efficiency were not measured directly but were culled from the fuel flow values and the Spindt computation of the exhaust gas analysis. Experimental test results were presented for power output, specific fuel consumption and engine-out emissions. The tuned exhaust system was found to improve fuel economy of the engine by 12%. The major engine-out emissions, HC and CO were reduced by a minimum of 27.8% and 10.7% respectively. An improved power output of 15.8% increase was achieved. As a bonus, it was also found that the exhaust noise was reduced.

Key words: Tuned exhaust pipe, motorcycle, performance characteristics

INTRODUCTION

Vehicles are one of the dominant sources of urban pollution in developing world that threatens both people's health and economic activities (Vorsic and Weilenmann, 2006; Houston and Ahern, 2007). While this is common to growing urban areas throughout the world, it is particularly severe in Nigeria where majority of vehicles are two-stroke motorcycles (Faluyi *et al.*, 2006). The demand for owning a motorcycle is on a soaring path (Faluyi *et al.*, 2006). This is of course due to a number of social and economic reasons but convenience of avoiding heavy traffic congestions and easy accessibility to remote areas, appear most favorable in Nigeria. It is clearly observed that the population of all types of motorcycles is growing fast to the extent that besides goods and parcels, passengers are also moved by such mode of transportation in Nigerian cities and towns (Faluyi *et al.*, 2006).

Two-stroke motorcycles are more commonly used than four-stroke because they are small and cheap. Because they are less expensive than other vehicles, they play an important role in the country's transport sector. They are very visible in most cities and major towns of the country providing an alternative mode of transport for short distances (Faluyi *et al.*, 2006). The main air pollutants in the exhaust effluent from motorcycles are carbon monoxide (CO), unburned hydrocarbon (HC), oxides of nitrogen (NO_x) and white smoke emitted from two-stroke motorcycles. Two-stroke motorcycles are reported to emit as much as 5 times more HC and 1.5 times more CO emissions per kilometer driven than do four-stroke motorcycles and even cars (Vorsic and Weilenmann, 2006). However, in Nigeria, due to excessive use of poor quality lubricant oil, adulterated gasoline and poor engine maintenance, they emit more (Obodeh *et al.*, 2008).

In recent years, much research work has been conducted to reduce these exhaust emissions so that the engine will conform to all prevailing and future environmental legislations (Sawada *et al.*, 1998; Hanawa, 2004; Kashani, 2004; Korman, 2006; Winkler, 2006). To comply with these emission regulations, stratified scavenging (Bergman *et al.*, 2003; Bergman and Berneklev, 2006) has become one of the most popular design approaches on newly developed small two-stroke engines. Exhaust after-treatment by catalyst (Merkisz and Fuć , 2003; Arnby *et al.*, 2005) is another technique that is used to reduce exhaust emissions. In some cases four-stroke engines (Ahern, 2003) have been substitutes for the two-stroke engine. In future, it is likely that the automobile industry will improve catalytic converters for use on all motorcycles (Maus and Brück, 2005). Currently, BMW and Yamaha both produce a motorcycle that uses a computer controlled catalytic converter (Winkler, 2006). It is still in the early stages of development and improvements to it will likely follow. However, this three-way catalyst system adds approximately one thousand dollar ($1000) to the cost of

Corresponding Author: O. Obodeh, Department of Mechanical Engineering, Ambrose Alli University, Ekpoma Edo State, Nigeria

a motorcycle, and the package does not perform well under vibration (Winkler, 2006).

Another technique to reduce exhaust emissions on two-stroke engines that was proposed by Blair (1996) is to use exhaust tuning. Traditionally, exhaust system on an engine was purely to remove exhaust gases from the cylinder and expel them to the environment and also muffle the sound. This traditional type of exhaust system has worked well throughout the years but could be improved. The primary method of doing this is to optimize the way the exhaust gases are able to escape. The main goal of tuned exhaust is to efficiently evacuate the exhaust gases from the cylinder. The bottomline is that with a tuned exhaust system, suctioning out and emptying out of the cylinder are effectively carried out. The engine gets a better complete combustion of fuel. The effect is that it will take less throttle to get the same revolution per minute. This means less fuel flow (Bassett *et al.*, 2001).

The objectives of this work are: firstly to design an adjustable exhaust pipe for use on two-stroke cycle engine which will enable a relatively unskilled operator to tune the engine quickly and reliably for optimum performance. Secondly, to investigate the effects of tuned exhaust system on the performance of a crankcase compression two-stroke cycle engine. This was performed by obtaining experimental data for both the tuned exhaust system and the Original Equipment Manufacture (OEM) exhaust system and make comparison of the potential benefits of the tuned exhaust system relative to the OEM system.

Tuned Exhaust Pipe Design: The periodic charging and discharging of the cylinder, together with pressure increase generated during combustion process, gives rise to highly unsteady flow in the manifolds (Winterbone and Pearson, 1999, 2000; Koehlen and Holder, 2002; Vitek and Polasek, 2002). In two-stroke engine, when the exhaust valve opens, the "blow-down" pressure in the cylinder generates a pressure wave in the exhaust runner (primary) pipe as the piston is still traveling towards bottom-dead-centre (BDC). This pressure-wave propagates towards the end of the pipe and is reflected as a rarefaction-wave (reflected expansion wave) which travels back towards the exhaust. Effective exhaust tuning involves the timing of this low-pressure-wave to arrive downstream of the exhaust valves during the valve overlap period, thereby increasing the scavenging efficiency of the engine via reducing the concentration of trapped residual gas in the engine cylinder (Adair *et al.*, 2006; Gustafsson, 2006).

The critical part of the entire structure design is the determination of what distance must exist between exhaust port baffle portion such that it will return a reflected exhaust gas pressure pulse at just the right moment to prevent loss of fresh air-fuel mixture from cylinder through exhaust port (Fig. 1).

A proper design length of exhaust system allows very precise cut-off between exhaust gas and air-fuel mixture just prior to closing of exhaust port by upward travel of piston in the compression stroke. The critical design can be made when exhaust-open period and the pressure pulse speed inside the exhaust system are known. The following equations were used:

$$V_3 = [401.8(T_{ex} + 273]^{1/2} \text{ m/s} \qquad (1)$$

where

V_3 = Local speed of sound in the pipe (m/s)
T_{ex} = Exhaust temperature (ºC)

$$L_t = \frac{83.3 V_s \theta}{N} mm \qquad (2)$$

where

L_t = uned length
θ = Exhaust port duration in crank degrees
N = Desired rotational speed

$$\pi r^2 L_t = 2C \qquad (3)$$

where

r = Pipe radius
C = Engine capacity per cylinder

θ and N were obtained from the engine specifications (Table 1). Exhaust temperatures ranging from 500-600ºC were used as recommended by Blair (1996). The designs were based at 500 to 600ºC in steps of 20ºC. The exhaust system is shown in Fig. 2 and the parameters of the OEM and tuned exhaust systems are listed in Table 1.

OEM: Original Equipment Manufacture: As reported by Blair (1996), it is preferable to construct the divergent cone to be slightly longer than the convergent cone, an approximate ratio of four to three being suitable. From empirical results, the tailpipe diameter was made slightly less than the diameter of inlet pipe in ratio of 1 to 1.25.

MATERIALS AND METHODS

The engine testing was carried out with a one-cylinder two-stroke cycle motorcycle. The engine specifications are as shown in Table 2. The engine and oil tank of the motorcycle were cleaned to remove old fuel, auto-lube oil and any deposit and refilled with unleaded gasoline and low smoke lube oil (SAE 10W-30 engine oil). The lube oil specifications are shown in Table 3. The speed and load of the engine were controlled independently by dynamometer and fuel control system. The dynamometer incorporates a flywheel which was directly coupled to the engine by a chain. The dynamometer simulates the loading on the engine during acceleration period.

Manifold temperature and pressures were measured using thermocouples and strain-based pressure transducers, respectively. Exhaust emissions were measured with the aid of pocket gas^{TM}- portable gas

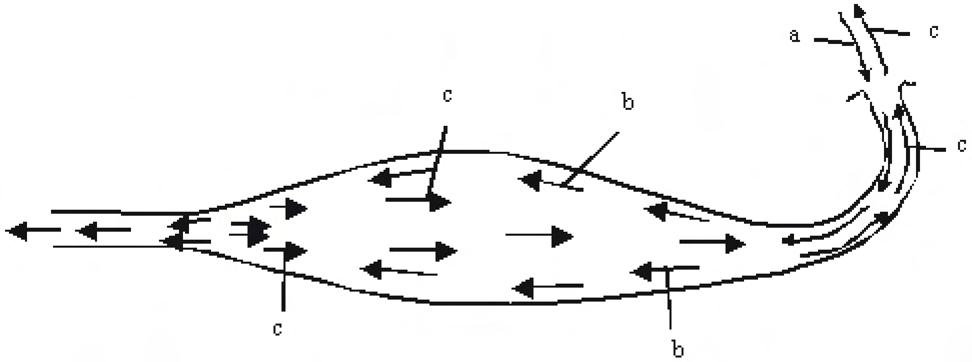

Fig. 1: Gas dynamics in exhaust pipe, a = Exhaust gases; b = Expelled gases; c = Return gases

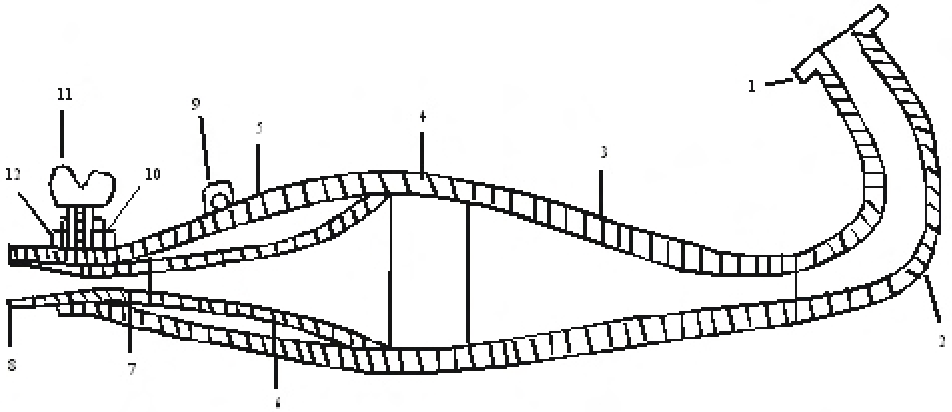

Fig. 2: Optimized adjustable exhaust pipe, 1 = Flange; 2 = Inlet pipe; 3 = Divergent cone; 4 = Cylindrical; 5 = Rear cone; 6 = Convergent cone; 7 = Baffle member; 8 = Tailpipe (slideable); 9 = Attaching lug; 10 = Nut; 11 = Wing; 12 = Securing pipe

Table 1: Parameters of the exhaust systems

Discription		OEM	Redisign
Inlet pipe	Length	200mm	300mm
	Diameter	60mm	45mm
Divergent cone	Length	750mm	320mm
	End diameter	90mm	-
Cylindrical section	Length	-	180mm
	Diameter	-	90mm
Covergent Cone	Length	-	230mm
Tail pipe	Length	30mm(fixed)	60mm(Slideable)
	Diameter	22mm	35mm

analyzer. The exhaust gas analyzer was fitted into the rear tailpipe of the exhaust system.

The testing consisted of three measurement series. In the first, various lengths of the designed exhaust pipes based on the exhaust temperatures were used. The optimum length was determined using charging efficiency as a criterion. The exhaust pipe with optimum length was used in the second test while the third uses the OEM exhaust pipe. The properties of the fuel used are as shown in Table 4.

Engine performance tests were performed at 600 to 3600 rpm in steps of 300 rpm with a constant load of 250N to get information about the engine performance characteristics. However, the airflow based values of

Table 2: Engine specifications

Make and model	Kawasaki ZX
Year of manufacture	2004
Engine type	2-Stroke, Carburettor, Air-cooled, Single-cylinder
Stroke x Bore	85mm x 72mm
Displacement	250cm^3
Maximum power @ 4850rpm	16.2kW
Carburettor type	Butterfly
Carburettor venturi diameter	19.8mm
Exhaust port open	110º ATDC
Intake port open	70º BTDC
Scavenge port open	135º ATDC
Induction	Reed valve
Trapped compression ratio	6.1:1
Ignition timing	17º BTDC
Ignition system	Butterfly-fed
Lubrication system	Combined with fuel

Table 3: Lube oil

Characteristics	Unit	Value
Density @ 15ºC	kg/m^3	889
Kinematic viscosity		
@40ºC	cSt	98.2
@100ºC	cSt	11.1
Viscosity Index	-	97
Pour point	ºC	-6
Flash point	ºC	226
Colour	-	Green

Table 4: Fuel Specifications

S/N	Characteristics	Unit	Limit
1	Specific gravity at 15/4	-	0.779
2	Distillation		
	10% evaporated	ºC	70(max)
	50% evaporated	ºC	125(max)
	90% evaporated	ºC	180(max)
	Final boiling point (FBP)	ºC	205(max)
3	Colour	-	Red
4	Odour	-	Marketable
5	Copper corrosion for 3 months at 50ºC	-	No. 1 strip (max.)
6	Total sulphur	%wt	0.20(max.)
7	Residue	% Vol	2(max.)
8	Vapour pressure	Bar	0.62(max.)
9	Ratio T36	ºC	68(max.)
10	Existent gum	mg/100ml	4(max.)
11	Oxidation stability	minute	360(min.)
12	Lead alkyl	g/pb/litre	0.7
13	Knock rating	-	90(min.)

Source: (NNPC, 2007)

250N to get information about the engine performance characteristics. However, the airflow based values of delivery ratio; trapping efficiency and charging efficiency were not measured directly but were culled from the fuel flow values and the Spindt computation of exhaust gas analysis. The definitions of these three variables have been given by Heywood (1988). The accuracy of this approach for the computation of airflow-based values for two-stroke engines has been questioned and discussed by Douglas (1998). The OEM exhaust pipe and the optimized exhaust pipe were used to illustrate the influence of exhaust tuning on two-stroke cycle motorcycle performance characteristics.

RESULTS AND DISCUSSION

Changing the length of the exhaust pipe affects the timing of the wave reflection processes in the exhaust system so as to delay or advance the arrival of the reflected waves at the exhaust valve (Bassett *et al.*, 2001). Timely arrival of the rarefaction wave creates the high pressure required to prevent the fresh charge escaping unburned down the pipe before the exhaust port is fully close (Bassett *et al.*, 2001). This build up pushes the escaping charge back into the combustion chamber. Hence, proper adjustment of the convergent cone and therefore the length of the expansion chamber will cause the reflected wave front of the return gases to arrive at the engine exhaust port at an optimum time which compresses the maximum amount of unburned charges into the cylinder. This improves scavenging of the engine cylinder and therefore charging efficiency. Fig. 3 shows the optimum length of the exhaust pipe to be 1020mm. This gives the highest charging efficiency in the series.

Figure 4 shows the effect of tuned exhaust pipe on the engine delivery ratio. In scavenging process, mixing occurs as the fresh charge displaces the burned gases and some of the fresh charge may be expelled. Two limiting ideal models of the process are: perfect displacement and complete mixing (Heywood, 1988). Perfect displacement or scavenging would occur if the burned gases were pushed out by the fresh gases without any mixing. Complete mixing occurs if entering fresh mixture mixes instantaneously and uniformly with cylinder contents. However, within the cylinder both displacement and mixing at the interface between burned gas and fresh gas are occurring (Heywood, 1988).

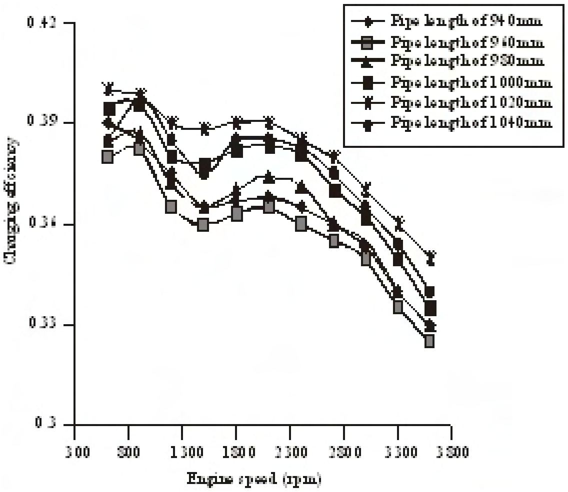

Fig 3: Effect of Pipe length on charging efficiency

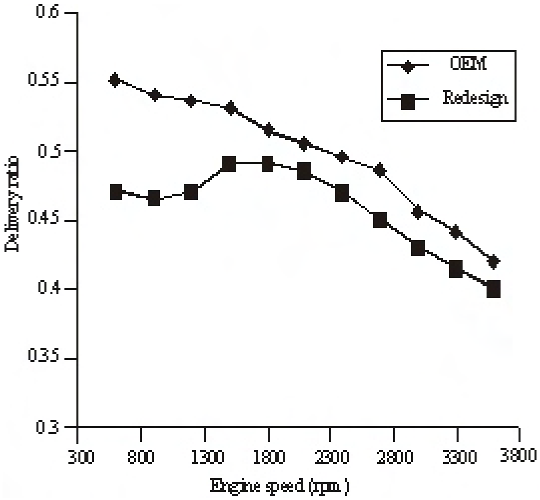

Fig 4: Delivery ratio as a function of engine speed

For the tuned exhaust system, perfect scavenging phase lasts longer. This means that more efficient scavenging (less mixing) is obtained with the tuned exhaust pipe. This is the reason why less fresh charge is required to produce a given speed in an engine with the tuned exhaust system than an engine with OEM. Hence the lower value of delivery ratio at a given engine speeds for tuned exhaust system than OEM as shown in Fig. 4.

The outcome of the scavenging process results in the improvement of the trapping efficiency as shown in Fig. 5. The results show a marked improvement over the OEM exhaust system in the entire speed range. These are shown to have a minimum of 9.7% increase at 2400 rpm and a maximum increase of 11.9% at 600 rpm.

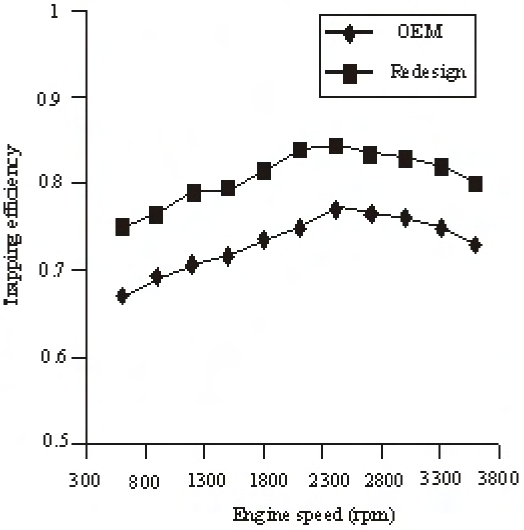

Fig 5: Variation of trapping efficiency with engine Speed

In Fig. 6 are shown the variation of charging efficiency with engine speed. As indicated in Fig. 6, the difference in charging efficiency becomes distinct from 1300rpm. At 600 rpm the tuned exhaust system charging efficiency deteriorated by 2.4% but thereafter improves to attain a maximum of 4% increase at 2100 rpm. The improved charging efficiency was due to better trapping efficiency.

The other advantage of tuning effects is the phasing of suction waves at the exhaust valve during the exhaust stroke thereby reducing the pumping loss of the engine (Adair, 2006). This produces significant improvements in brake mean effective pressure (bmep) and power as shown in Figs. 7 and 8. It is glaring from Fig. 7 that bmep can be improved by the use of tuned exhaust system.

This improvement peaks at about 8.6% at 1800rpm. Fig. 8 shows the variation of power output with engine speed. At 600rpm the tuned exhaust system power output deteriorated by 5.6% and thereafter improves, attaining a maximum of 15.8% increase at 2700rpm.

Comparing Figs. 5 and 9, it is obvious that improvement in trapping efficiency has positive effect on fuel consumption. This implies that with the tuned exhaust system, it takes less throttle to get the same revolution per minute. This means lower specific fuel consumption (sfc), implying better fuel economy. The minimum sfc as shown in Fig. 9 is 460 g/kWhr while that for OEM is 500 g/kWhr. The import of this is that with the tuned exhaust system 12% improvement in fuel economy was achieved.

Also comparing Fig. 5 and 10 reveal that high trapping efficiency gives low amount of hydrocarbon (HC) emissions. It can be observed from Fig. 10 that the tuned exhaust system reduces HC emissions. Maximum reduction of 34.6% was obtained at 3000 rpm and minimum of 27.8% at 600rpm.

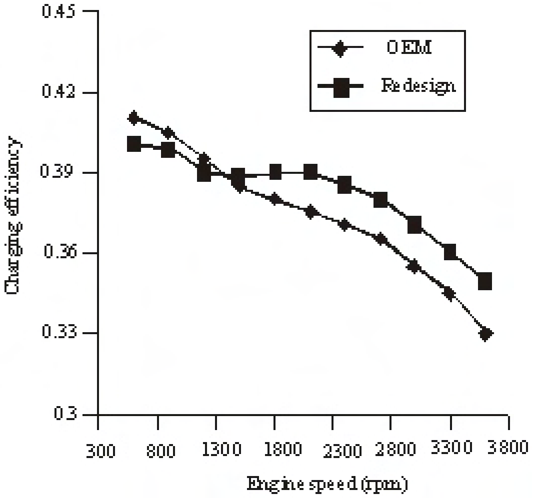

Fig 6: variation of charging efficiency with engine speed

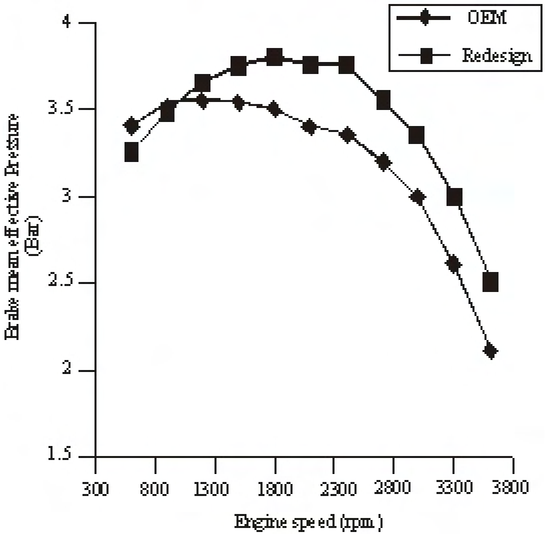

Fig 7: Break mean effective pressure against engine speed

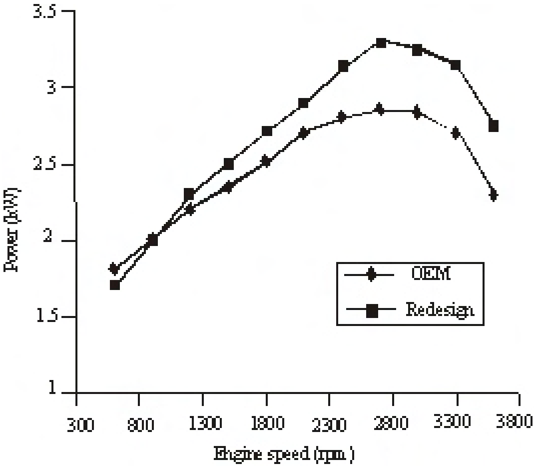

Fig 8: Power as function of engine speed

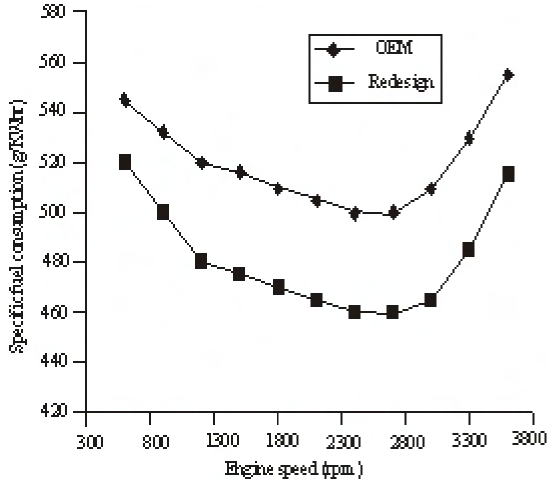

Fig 9: Specific fuel consumption versus engine speed

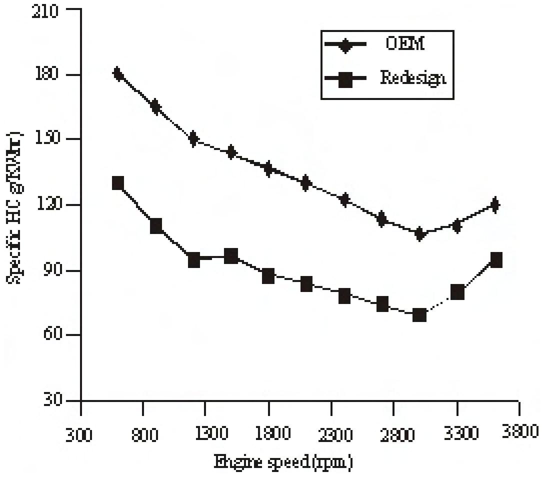

Fig 10: variation of specific HC with engine speed

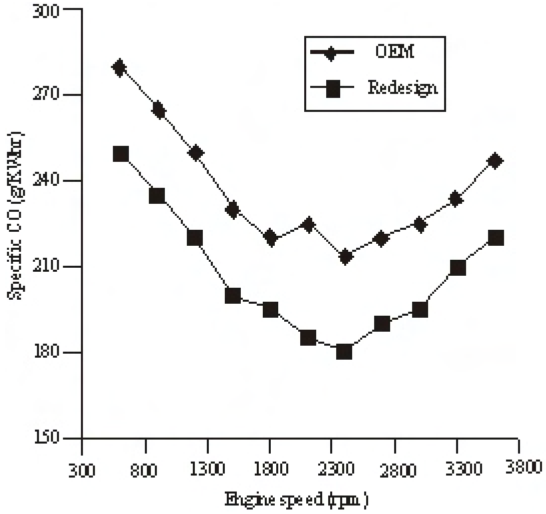

Fig 11: Specific CO as a function of engine speed

In Fig. 11 are shown the emissions of carbon monoxide (CO) as a function of engine speed. With the tuned exhaust system, less diluents were left in the cylinder hence the rate of complete oxidation of the fuel carbon to carbon dioxide (CO_2) was higher due to the presence of more oxygen. This results in the reduction of CO emissions.

However, at higher speeds, the purging of the diluents was less complete (Huang *et al.*, 1999). Maximum reduction of 15.9% was obtained at 600rpm while minimum of 10.7% was obtained at 2400 rpm.

CONCLUSION

Tuned adjustable exhaust pipe for use on two-stroke motorcycle was designed and tested. The optimum length of the tuned exhaust pipe that gives the highest charging efficiency was found to be 1020 mm. The OEM exhaust system and the optimized adjustable exhaust pipe were used to illustrate the influence of tuned exhaust system on the performance characteristics of the engine.

Experimental test results were presented for power output, specific fuel consumption and engine-out emissions. The tuned exhaust system was found to have a profound impact on the specific fuel consumption, lowering it by 12%. The major engine-out emissions, HC and CO were reduced by a minimum of 27.8 and 10.7% respectively. An improved power output of 15.8% increase was also achieved. The reason for these was explained by looking at how the tuning pressure wave at the exhaust port was changed due the modification of the exhaust system. The tuned exhaust system indicates that significant reductions of engine-out emissions and gains in engine performance characteristics are possible. The technology of the adjustable expansion chamber exhaust system for use on two-stroke cycle engines is such that a relatively unskilled operator can tune the engine quickly and reliably for optimum performance.

REFERENCES

Adair, J., D.J. Olsen and A. Kirkpatrick, 2006. Exhaust tuning of large bore multi-cylinder engine. Int. J. Eng. Res., 7(2): 131-142.

Ahern, L., 2003. Fuel Economy Advantages on Indian 2-Stroke and 4-Stroke Motorcycles fitted with Direct Injection, SAE Technical Paper No. 2003-26-0019.

Arnby, K., J. Assiks P. Carlsson, A. Palmqvist and M. Skoglundh, 2005. The effect of platinum distribution in monolithic catalysts on oxidation of co and hydrocarbon. J. Catalysis, 233: 176-185.

Bassett, M.D., R.J. Pearson, N.P. Fleming and M. O'Brien, 2001. Simulating the effects of gas dynamic phenomena on the performance of internal combustion engines. SAE Technical Paper No. SAITS 01187.

Bergman, M. and J. Berneklev, 2006. A novel method of tuning a stratified scavenged wo-stroke engine. SAE Technical Paper No. 2006-32-0055.

Bergman, M., R.U.K. Gustafsson and B.I.R. Jonsson, 2003. Performance evaluation of a 25 cc stratified scavenging two-stroke engine. SAE Technical Paper No. 2003-32-0047.

Blair, G.P., 1996. Design and simulation of two-stroke engines. SAE Technical Paper No. R-161, ISBN 1-56091-685-0.

Douglas, R., 1998. AFR and emissions calculations for two-stroke cycle engines, SAE Trans., 69(16): 209-220.

Faluyi, S.O., S.O. Awoku and S.O. Adebayo, 2006. Comparison of the headway distribution of automobile vehicles and motorcycles plying major roads in Ado-Ekiti, Nigeria. J. Applied Sci., 9(1): 6274-6285.

Gustafsson, R.U.K., 2006. A practical application to reduce exhausts emissions on a two-stroke engine with a tuned exhaust pipe, SAE Technical Paper No. 2006-32-0054.

Hanawa, S.S., 2004. Paradoxical approach to improve fuel economy of small practical motorcycles, SAE Technical Paper No. 2004-01-0989.

Heywood, J.B., 1988. Internal Combustion Engine Fundamentals, McGraw-Hill Books Co., pp: 237-239.

Houston, R. and S. Ahern, 2007. A fresh approach to the design of clean engines for the performance motorcycle market, SAE Technical Paper No. 2007-32-0001.

Huang, R.F., M.P. Hsu W.L. Chen and K. Lee, 1999.On the tuning pipe of a two-stroke engine for scooter motorcycles. J. Mechan. Eng. Sci., 213(8): 861-866.

Kashani, B.O., 2004. The improvement of combustion process and reduction of unburned hydrocarbon emissions in a two-stroke motorcycle. Iran. J. Sci. Technol. Trans. B, 28(B4): 505-508.

Koehlen, C. and E. Holder, 2002. Investigation of post oxidation and its dependency on engine combustion and exhaust manifold design, SAE Trans., 111(3): 260-270.

Korman, M., M. Hirz, K.F. Winkler and W. Kaiser, 2006. Exhaust emission reduction in small capacity two- and four-stroke engine technologies, SAE Technical Paper No. 2006-32-0091.

Maus, W. and R. Brück, 2005. The future of heterogeneous catalysis in automotive applications: Turbulent catalytic for spark-and compression ignition engines. VDI- Fortschritt-Berichte, Reihe, 12(595): 297-319.

Merkisz, J. and P. Fu, 2003. Investigation of catalytic converter from modified catalytic layer (Pt, Pd, Ru, $CeO_{2-0.25}ZrO_{2-0.75}$/Ru) of nanoparticles spherical shape arrangement. J. Kones Int. Combustion Eng., 10(3-4): 201-210.

NNPC, 2007. Warri Refining and Petrochemical Co. LTD, Technical Report, 4: 80.

Obodeh, O., A.C. Ezimokhai and F.C. Nwizugbo, 2008. Investigation of Tailpipe emissions from aging gasoline powered engine. J. Res. Eng., 5(1): 97-102.

Sawada, T., M. Wada, M. Noguchi and B. Kobayashi, 1998. Development of a low emission two-stroke cycle engine, SAE Technical Paper No. 980761.

Vitek, O. and M. Polasek, 2002. Tuned manifold system: Application of 1-D Pipe Model, SAE Trans., 111(3): 271-280.

Vorsic, A.M. and M. Weilenmann, 2006. Comparison of real-world emissions from two-wheelers and passenger cars. J. Environ. Sci. Technol., 40(1):149-157.

Winkler, F., O. Schögl, R. Oswald and R. Kirchberger, 2006. Development of a low emissions two-stroke engine with low pressure fuel injection, SAE Technical Paper No. 2006-32-0065.

Winterbone, D.E. and R.J. Pearson, 1999. Design techniques for engine manifolds. Professional Eng. Public., 12(2): 294-325.

Winterbone, D.E. and R.J. Pearson, 2000. Theory of engine manifold design. Professional Eng. Public., 11(4): 350-364.