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EXPERIMENTAL INVESTIGATION OF FACTORS AFFECTING VEHICLE FUEL CONSUMPTION

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ABSTRACT

This paper presents an experimental study of the effect of different factors (tires' conditions, altitudes, passengers' weight and the use of air-conditioning unit (load), vehicle speed, fuel type, maintenance condition) on the vehicles' fuel consumption. These factors should be considered in vehicle regular usage and for check up from time to time to have economical fuel consumption. This study showed that the fuel consumption depends on the altitude at which the vehicles drive. Also it is found that the significant improvements in automotive fuel economy can be obtained by reductions in load, aerodynamic drag and rolling resistance (tire improvements), as well as by improvements in maintenance conditions and using efficient fuel type. The present experimental data concluded that a well-designed diffuser (clearance) underneath the vehicles could decrease the drag, due to the optimized air flow distribution around the vehicle body, which can be achieved by inflating the tires to the optimum pressure.

Keywords; Fuel consumption; vehicles technology; fuel type; tires; wind speed

1. INTRODUCTION

In vehicle development, engineers use a wide range of tools and techniques including on-road tests, wind tunnel investigations, and numerical predictions. Of these, experimental prediction of vehicle fuel consumption has proven to be very challenging. Various studies have been published in recent years demonstrating large potential for drag reduction in contemporary road vehicles, and the resulting fuel savings to be expected have also been assessed. Reducing air drag is shown to be the most efficient way of improving the fuel economy of cars.

In the last twenty years aerodynamics has made a significant contribution to the major changes in the configuration and performance of vehicles. It is essential to the technical future of vehicles that these changes accelerate the development and technology that may, in time, benefit the development of road vehicles manufacturing toward less fuel consumption technology, which can reduce the emissions to the air. Vehicles with hybrid power drive (combustion engine plus electric motor) could be one of the alternatives to reduce fuel consumption and the pollutants.

There have been several studies of wheel drag and lift, but the agreement between results is not particularly good. This is partly because many of the early wind-tunnel tests and early numerical techniques such as those conducted by Cogotti (1983), and Scibor-Rylski (1984) were conducted at low Reynolds numbers (small-scale models at low speeds), and also because the data were sensitive to quit small difference's in tire geometry.

Skea et al (1998, 1999, and 2000) reviews methods within underbody aerodynamics and explores the possibilities with whether or not CFD is the proper tool for this type of engineering problem. There is a clear focus on prediction methods for rotating wheels. Perzon and Davidson (2000) found that the accuracy of computational fluid dynamics, CFD, has improved considerably over the years but still, large errors are present and vehicle parameters such as drag and lift are often poorly predicted. Makowski and Kim (2000) showed that the numerical prediction of the aerodynamics around cars has been one of the rudimentary needs in automotive engineering.

Lift coefficient values also suffer from the fact that it is very difficult to measure the lift on a rotating wheel in contact with the road. Exposed wheels produce high drag coefficients due to the large highly turbulent wake and the presence of strong trailing vortices which increases the fuel consumption (Fukuda et al (1995), Pearson et at (1994), Carr (1982), Mercker (1985)). Cooper et al (1998, 2000) did a study of how drag and lift is affected by under body diffusers. They concluded that a well-designed diffuser could decrease drag. They

also noted that the diffuser might be an efficient down-force producer. Aronson et al (2000) showed however that the rear wheel wake drastically decreases the diffuser efficiency.
The high value of increased drag may be attributable to interference effects; the wheel wake and the flow field interfere with the body flow (Palowski (1930), Mercker (1985)). Another factor, however, is that the wheels are situated in a distorted flow produced by the body. Consequently, the air flow can meet the wheel at a yawed angle.
Experimental data in the present study showed that the flat tire (low air pressure) increased the aerodynamic drag due to the increase of the air flow on the vehicle, which raises the fuel consumption. So that at steady speed on a level road, the total resistance to motion is the sum of two separate contributions; aerodynamic drag and tire rolling resistance.
The fuel consumed by a vehicle depends on the efficiency of the engine, and the transmission system, and on the power required to overcome the resistance to motion. The required power is the product of the total resistance force and the vehicle speed. Brocherts et al (1978), Porter (1997) and Kalm (2007) found that the significant improvements in automotive fuel economy can be obtained by reductions in weight, aerodynamic drag (better streamlining) and rolling resistance (tire improvements), as well as by improvements in engine and power train efficiency.

Although this research is mainly concerned with vehicles fuel consumption rather than aerodynamics, it is necessary to look at the contribution of different parameters such as tire rolling, altitude location, load, and wind speed on the total resistance. There is limited work on these parameters along with some existing analytical and theoretical descriptions of rolling resistance, drag and load versus fuel consumption. Also the limited agreement between the previously published theoretical studies and the experimental data, along with contradictory published results, indicated that additional work on this topic is needed, Coutermarsh (2007).
The main aim of this study is to investigate the effect of different operating conditions on vehicles fuel consumption. It is possible to estimate the order of fuel savings that would be produced at different speeds by adjusting the affecting factors. A typical medium-sized vehicle with a 1300 and 1600 cc engines and of a C_D of nearly 0.35 returns a fuel consumption figure at a constant speed of 90km/h (56 mph) of around 7.6 litres/100km. However, this study revealed that the fuel consumption dependents on different parameters such as tires' conditions, load and vehicle speed, fuel type and maintenance condition.

2. EXPERIMENTAL SETUP

Experimental work was conducted on four different vehicles, corresponding to different engine sizes (i.e. LADA 1.3cc, LADA 1.6cc, VW 1.3cc and Subaru 1.6cc), Table 1. The diversity of these vehicles is due to the availability of getting the vehicles ready for on-road test.

Table 1 Tested vehicles specifications

Vehicle type	Engine size	Gear type	Model (year)
LADA	1600cc	Normal	1980
LADA	1300cc	Normal	1994
VW(GOLF)	1300cc	Normal	1993
SUBARU	1600cc	Normal	1993

The four vehicles were tested under different conditions such as variable speeds and tires pressures, fuel types, atmospheric conditions (i.e. altitude), and different maintenance conditions (i.e. spark plug functions, air, oil, fuel filters blockage). Some of the tests were conducted under different altitudes in Jordan valley region, which it is the lowest point on earth (~ 420 m under sea level), three different sea levels where chosen (i.e. under, at and above sea level). Furthermore, we have choosed different terrain roads for the vehicles movements to match the rough terrain in Jordan (desert roads).
The distance of 5 km has been chosen for all on-road tests, for the comparison purposes between different conditions.

3. INSTRUMENTATIONS

Different instruments were used for experimental data logging, such as:

Wind speed

A rotating vane anemometer LC6000 (manufactured by airflow, 2001, and approved to ISO 9001) was used. The velocity airflow anemometer display air velocity in Metric or Imperial units ranging from 0.25 to 30m/s or 50 to 6000 ft/min. The instrument utilizes a microprocessor which enables the user to obtain a continually updated average of air velocity over extended periods.

Fuel consumption measuring device

The devices used in the experimental work of the measuring fuel consumption (Figure 1 and 2), consist of an electronic instruments, which consist of a digital screens for sharing fuel consumption L/h (i.e. rate of fuel flow or momentary consumption), in addition to electrical connections, fuel supply pipes and clamps.

Working principle of the fuel consumption measurements

The working principle of the fuel consumption measuring devices depends on the rate of fuel flowing from the main fuel tank in the vehicle to the carburetor through the fuel filter and the pump (Figure 3). As the speed of the car increases, the flow rate will increase and the measuring sensor will record the rate of fuel consumed on the digital screen. The main electrical supply of the devices was taken from the vehicle battery.

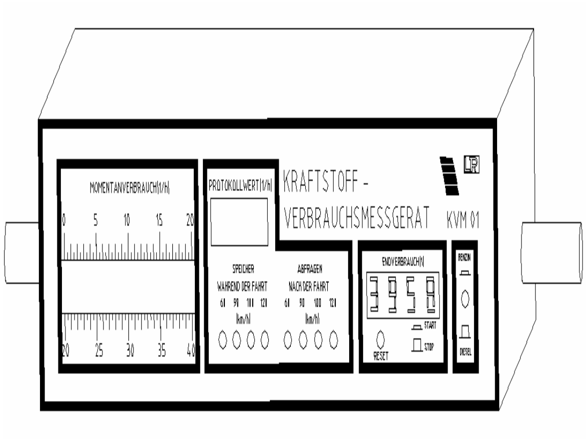


Figure 1 The fuel consumption measuring device installed on each car.

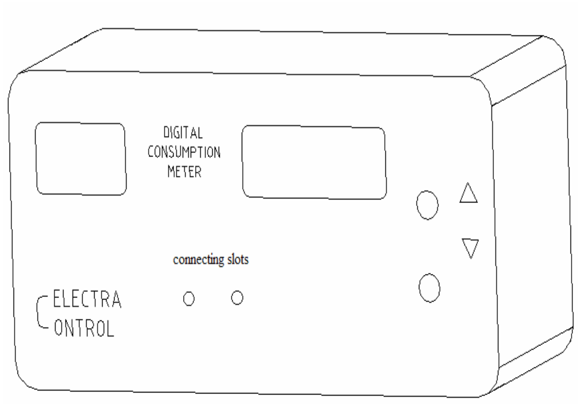
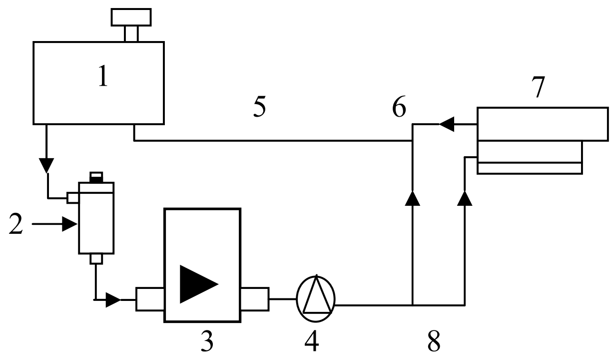


Figure 2 The controller box of the fuel consumption measuring device and its connecting slots.



1.Vehicle fuel tank. 2. Fuel filter. 3. Sensor of fuel flow. 4. Fuel pump 5. Return pipe. 6. Interconnection. 7. Feeder. 8. Fuel pipe lines.

Figure 3 Schematic diagram of the connections of the measuring device with fuel system.

4. RESULTS AND DISCUSSION:

The vehicles were tested under various operating conditions, such as various loads (three or five passengers), different speeds, different sea levels and various maintenance conditions (i.e. spark plug functions, air oil, fuel filters blockage and atmospheric temperature) to find out the effect of these parameters on the fuel consumption. The fuel consumption is measured as a flow rate (liter per hour) as shown in Figures 5 to 10.

Figure 4 shows the flow of air on the car due to the tires inflatory condition (optimum and low pressures). The top of the wheel is moving into the air stream at twice the driving speed, and is trying to drag the air forward against the stream. This will cause the flow to separate very early, and the separation position is usually in the front top quadrant. The consequence is a broad wake and a high drag. The tire width is always less than the diameter, so the flow around the sides is equally important. The side flow has a complicated structure and contains strong vortices which trail downstream, giving high associated drag. From the test results (Fig. 4), it can be concluded that a decrease in the aerodynamic drag would reduce the total resistance (rolling + aerodynamic) by about 23% at optimum speed of 80 km/h. If other factor, such as engine efficiency, vehicle shape, and transmission power, were unaltered, this would represent a reduction in fuel consumption. So that the optimum condition of the tires pressure (as specified by the car manufacturer) will create a proper underneath diffusers that will reduce the total drag of the vehicles. The trend of the result was similar to the findings of Cooper et al (1998, 2000). But direct comparison was not possible due to the use of different vehicle models and atmospheric and operating conditions. Also Cooper et al (1998,

2000) wind tunnel investigations were done on very simple car geometry without wheels and wheelhouses.
From Figure 5, it can be seen that when the vehicle air-conditioning system is switched on during driving, it will impart a load on the engine that will decrease the cursing speed and increase the fuel consumption by nearly 7%.
The altitude at which the vehicle operates can affect the fuel consumption. From Figure 6, it can be seen that, when the sea level decreases the engine efficiency will increase due to the increase in atmospheric pressure, so that enhancing the combustion process and leading to a fuel reduction. While at higher sea levels, the atmospheric pressure decreases, leading to a decrease in the air intake through the carburetor and higher enrichment of the fuel-air mixture, thus increasing the rate of fuel consumed. Also the higher attitudes diminish a vehicle's available horsepower, and the vehicle may not perform as well at 1180m as it does at sea level.
Figure 7 shows the effect of vehicle speed on the rate of fuel consumption. It is obvious that as the velocity of the vehicle increases the air velocity around the vehicle will increase causing increases in the aerodynamic drag. The increase of the vehicle speed will create many separated flow regions on the curved surfaces of the vehicle body that will increase the overall drag, and consequently the rate of fuel consumption will be increased. It is noticed from Figure 7 that an increase in vehicle speed by 4% has increased the rate of fuel consumption by nearly 40%, which shows that both parameters are proportional.
The effect of the fuel type on the rate of fuel consumption is also studied. The two common types of fuels used in the Jordanian fuel stations are (Super gasoline, and normal gasoline). The use of the super gasoline which has higher octane number (ON=95) than the normal gasoline (ON=89), will make the combustion process more efficient, so that a 10% reduction in fuel consumption is recorded, as shown in figure 8. Also the figure shows that the consumptions of both fuels will increase as the vehicle speed increases.
The passengers load and the rate of fuel consumption interaction are presented in Figure 9. The present research considered into account the effect of human weight inside the vehicle on the rate of fuel consumption in general.
Load (human weight) can have a direct influence on the fuel consumption. When the number of passengers' increases, more power is needed to overcome the total weight and the wheels frictional interaction with the road, which corresponds to the increase of the frictional contact points. An increase in the number of passengers (from three passengers to five passengers) inside the vehicle can proportionally increase the rate of fuel consumption by ~ 35% (Figure 9).
Figure 10 shows the effect of keeping good maintenance of the vehicle on the rate of fuel consumption. Good maintenance condition means that spark plugs, air, oil, and fuel filters are checked and replaced regularly to keep a well maintained operation (according to the manufacturer's specifications). When the vehicle operating parameter is well maintained, the fuel consumption will be decreased. The figure shows that a saving of 60% in the fuel consumption is possible due to a good maintenance.

5. CONCLUSIONS

The development of passengers' vehicles is characterized by advanced aerodynamics, efficient engine controls, and long lasting operating conditions to reduce the fuel consumption and emissions, and to have proper vehicle driving management. This paper reports on the results of a parametric conditions affects the vehicle fuel consumption. The present study has proved that the best economic speed for the vehicles is around (70-80 km/hr). Although it showed that some of the tests results were different from the manufacturer's specifications. This is attributed to the variation of the atmospheric conditions, the age of the engine, and the roads type. Various altitudes tests showed that the fuel consumption depends on the altitude at which the vehicles drive. As the altitude increases, it will diminish a vehicle's available horsepower. Moreover, the fluctuation in the atmospheric pressure will destabilize the combustion process, causing an increase in the fuel consumption.

It can be concluded that a well-designed diffuser (clearance) underneath the vehicles could decrease the drag, due to the optimized air flow distribution around the vehicle body. This can be achieved by inflecting the tires to the optimum pressure. Also the fuel economy in vehicles involved reduction of load and aerodynamic losses combined with efficient fuel type. The present experimental data identified the potential of decreasing the fuel consumption to lower the vehicles emissions. The method of establishing the effective parameters such as passenger weight and the use of auxiliary comfortable units (air-condition), aerodynamics drags (tire losses), altitude level is needed in order to get the best vehicle performance.

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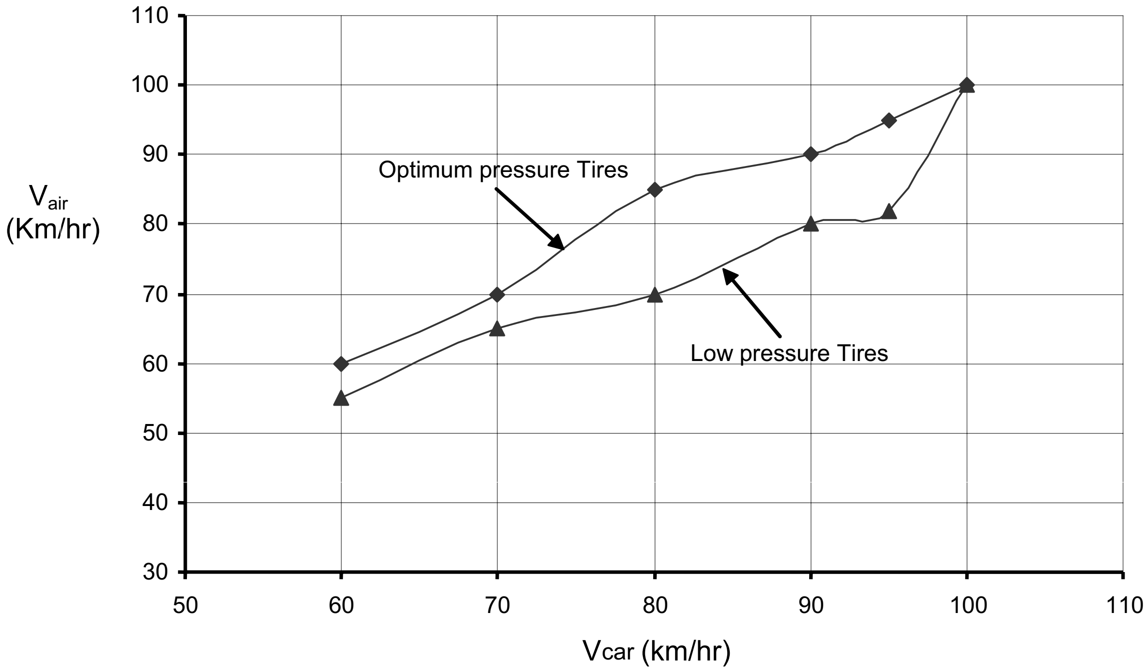

Figure 4 The effect of tires condition on the air flow on car.

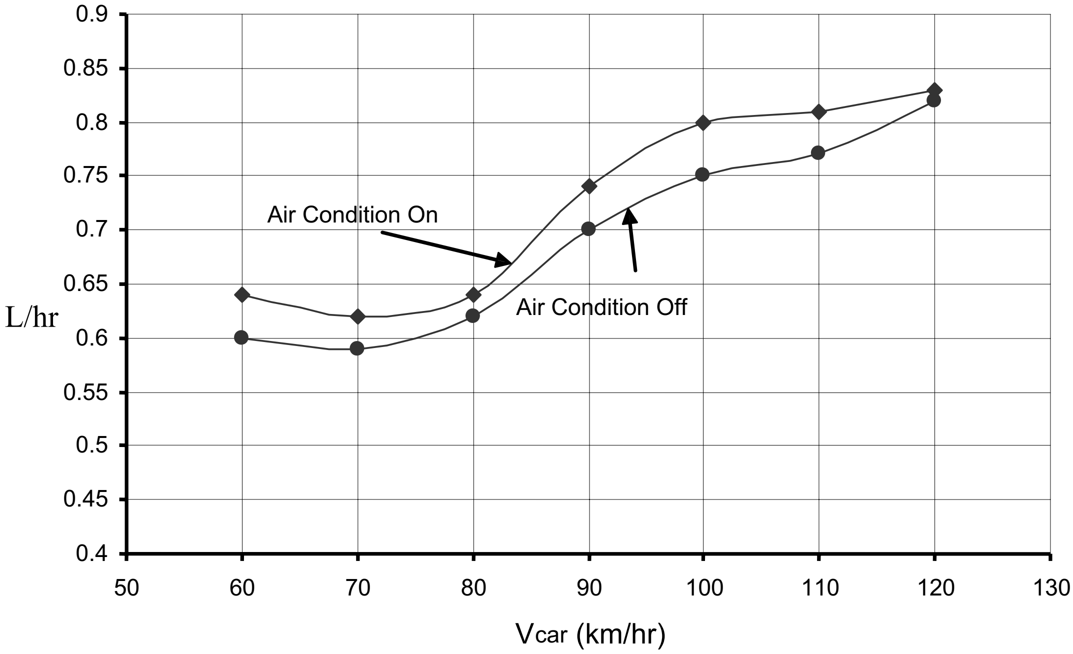

Figure 5 The effect of air-conditioning operation on the rate of fuel consumption.

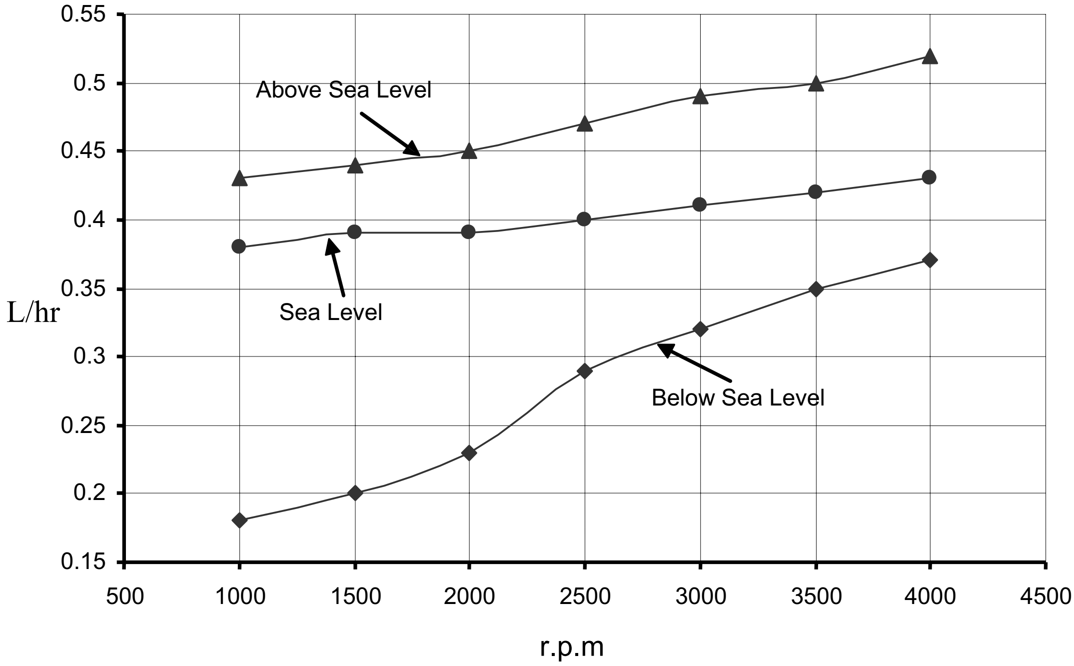

Figure 6 The effect of sea level altitude on the rate of fuel consumption.

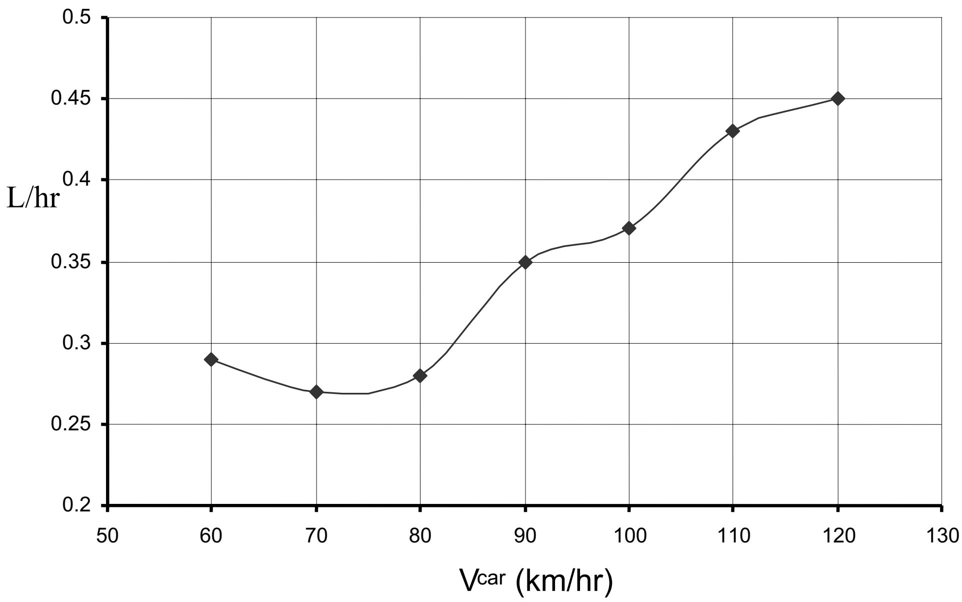

Figure 7 The effect of vehicle speed on the rate of fuel consumption.

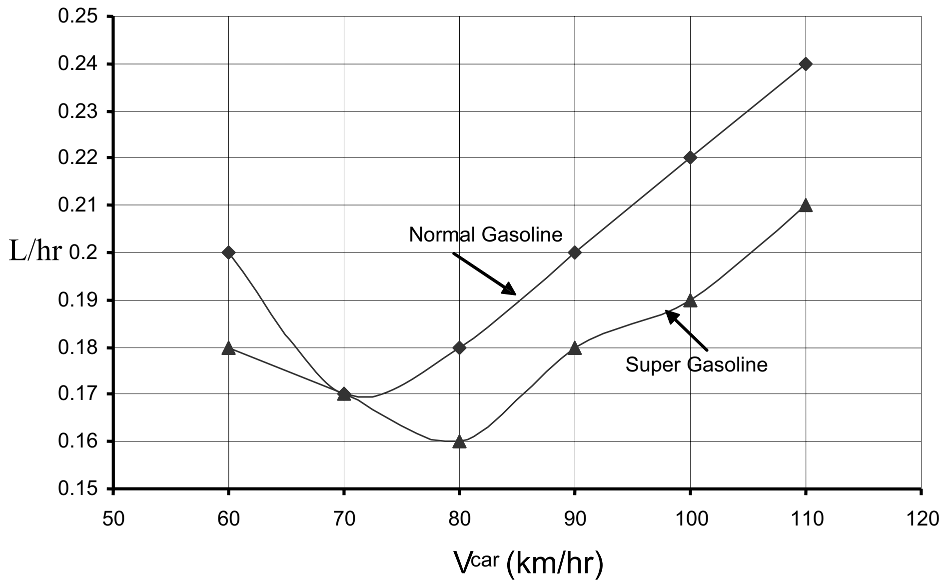

Figure 8 The effect of fuel type on the rate of fuel consumption.

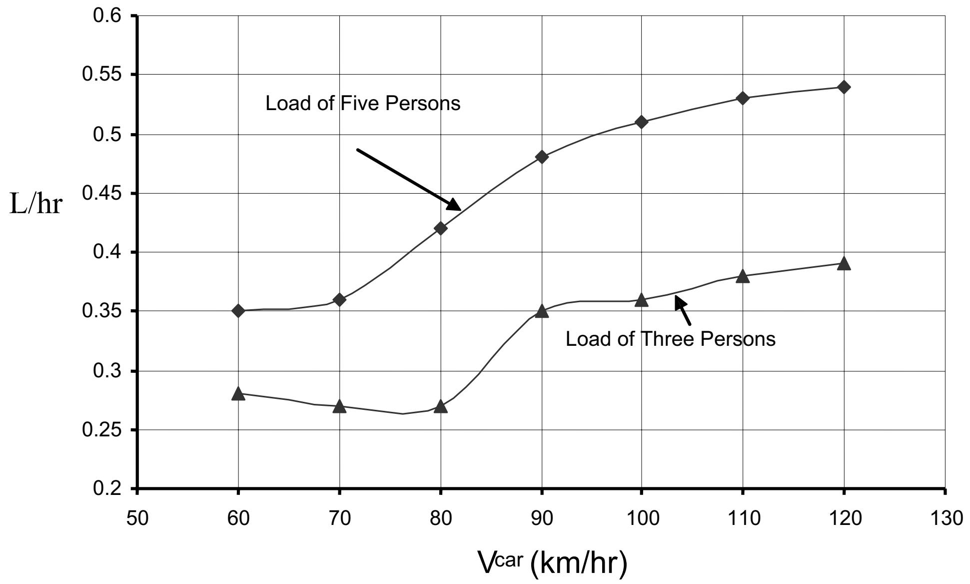

Figure 9 The effect of load on the rate of fuel consumption.

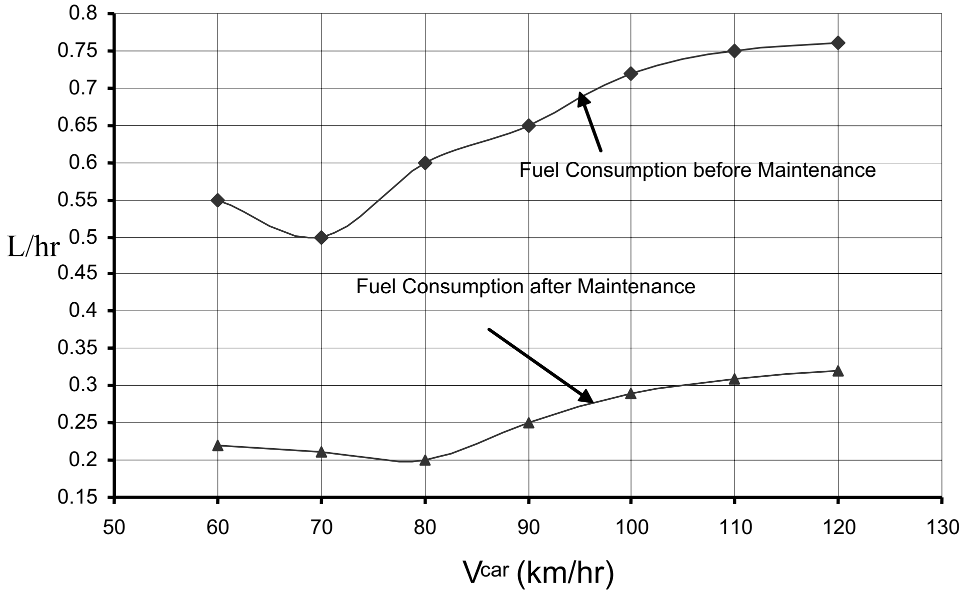

Figure 10 The effect of vehicle maintenance on the rate of fuel consumption.