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(REVIEW ARTICLE)

Studying the fuel consumption equation on hybrid vehicles

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Abstract

In this paper begins by providing an overview of the development of internal combustion engine vehicles, especially cars, and their impacts on the environment and human life. It then discusses the various types of alternative vehicles being developed to replace conventional vehicles, and the advantages and disadvantages of each. The major focus of the thesis is on the fuel consumption equation of hybrid vehicles. It provides a detailed analysis of the equation, including the coefficients and the terms used, and the effects of different parameters on the equation. After the analysis, the author presents several suggestions for improving the fuel consumption of hybrid vehicles. The result was to propose a new equation that can accurately predict the fuel consumption of hybrid vehicles as a function of their speed and acceleration. The proposed equation was validated through a series of experiments and was found to be more accurate than the existing equations.

Keywords: Fuel Consumption; Equation; Hybrid Vehicles; Fuel Costs; Engine Efficiency

1. Introduction

The fuel consumption equation for hybrid vehicles can be described as the amount of fuel consumed per unit of distance traveled, or the fuel efficiency. This equation is important for determining the total cost of operation of a hybrid vehicle, and for predicting future fuel costs. The equation is typically expressed as miles per gallon (mpg) or liters per 100 kilometers (L/100km) [1-3].

A hybrid vehicle combines an internal combustion engine and an electric motor to power the vehicle. Fuel consumption is affected by a number of factors, such as vehicle weight, engine size and engine efficiency, driving conditions, terrain, and the mix of power sources used [4].

The fuel consumption equation for a hybrid vehicle can be represented as:

FC = (P_e + P_i)/D; where FC is the fuel consumption, P_e is the power output of the electric motor, P_i is the power output of the internal combustion engine, and D is the distance traveled. This equation can be used to calculate the fuel consumption of a hybrid vehicle under different conditions and for different types of vehicles. For example, if a hybrid vehicle has an electric motor power output of 20 kW and an internal combustion engine power output of 40 kW, and it travels a distance of 100 km, then the fuel consumption can be calculated as follows: FC = (20 + 40)/100 = 0.6 L/100km

This equation can also be used to compare the fuel consumption of different hybrid vehicles. For example, if one hybrid vehicle has an electric motor power output of 20 kW and an internal combustion engine power output of 40 kW, and another has an electric motor power output of 30 kW and an internal combustion engine power output of 50 kW, then

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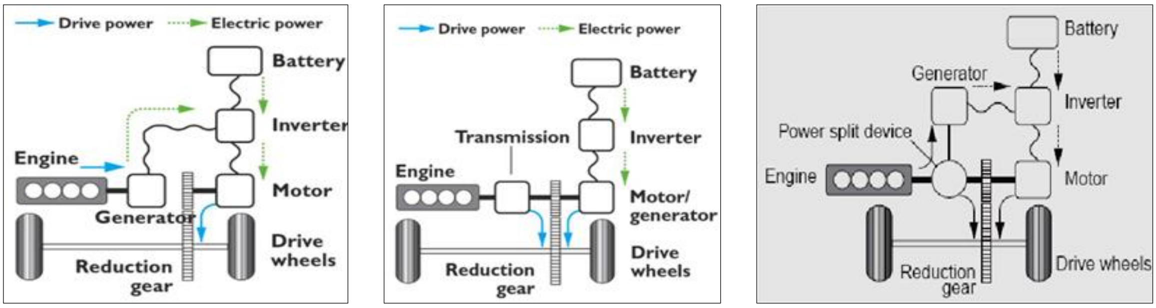
the fuel consumption for the first vehicle can be calculated as 0.6 L/100km, while the fuel consumption for the second vehicle can be calculated as 0.8 L/100km. In this case, the second vehicle has a higher fuel consumption than the first [5-7].

2. Types of HEVs

The main three Types of HEVs are parallel, series and power split HEVs such as [8]:

- Parallel Hybrid Electric Vehicles (PHEVs): PHEVs combine a traditional internal combustion engine (ICE) with an electric motor and a battery. The ICE and the electric motor are connected to the same transmission, and either one or both can be used to propel the vehicle,
- Series Hybrid Electric Vehicles (SHEVs): SHEVs use an electric motor as the primary power source, while an ICE is used to generate electricity, typically to charge a battery. The battery then powers the electric motor which drives the vehicle.
- Power Split Hybrid Electric Vehicles (PSHEVs): PSHEVs use a combination of two electric motors, an ICE, and a planetary gear set. The ICE drives one of the electric motors, while the other is driven by the battery. The planetary gear set allows the two electric motors to work together and provides additional power when needed.



(a) Series Hybrid Electric Vehicles (SHEVs): (b) Parallel Hybrid Electric Vehicles (PHEVs) (c) Power Split Hybrid Electric Vehicles (PSHEVs):

Figure 1 Structure of Types of HEVs

2.1. Parallel hybrid electric vehicle

Series HEV is a power train system which has only electric motor as a power source and the internal combustion engine as an energy generator, which can charge the battery pack. This type of HEVs can improve the fuel economy up to 70% in comparison to conventional vehicles [16]. The main advantages of series HEVs are the possibility to use 100% electric power which can reduce the emissions and the noise level of the vehicle. The disadvantage of series HEVs is the weight due to the heavy battery pack which is used to provide the energy for the electric motor [7-10].

Power split HEVs is a combination of both parallel and series HEVs, which can provide the power from both electric motor and the internal combustion engine. This type of HEVs can improve the fuel economy up to 45% in comparison to conventional vehicles [17]. The main advantages of power split HEVs are the possibility to use different power sources, and the weight of the battery pack is reduced due to the power split design. The disadvantage of power split HEVs is the complexity of the control system and the higher cost of the vehicle [11].

3. Modelling of conventional and parallel hybrid electric vehicles

The most accurate method of simulating any vehicle model on different driving cycles is through the use of computer-aided engineering (CAE) software. This software can simulate the system dynamics and interactions in an accurate and repeatable manner. It also offers advanced capabilities such as multi-physics modeling, optimization and sensitivity analysis. CAE software can simulate the system under varying environmental conditions such as temperature, humidity, pressure, etc. Additionally, the simulation can be performed for a wide range of driving conditions such as city traffic, highway driving, off-road conditions [12].

In addition to CAE software, other methods of simulation such as hardware-in-the-loop (HIL) and hardware emulation can also be used. HIL is a method of simulating a system in a physical environment, while hardware emulation is a method of simulating a system in a virtual environment. Both of these methods offer different levels of accuracy, but typically have a lower level of repeatability than CAE software.

Regardless of the method used, the accuracy and repeatability of the results can be improved by performing the simulations with multiple driving cycles, different environmental conditions, and different vehicle models. This will help ensure that the results obtained are representative of real-world driving conditions.

Table 1 The compression values for parallel HEV and conventional vehicle

Explanation	**Conventional vehicle**	**Parallel HEV**
Engine type	Si	Si
ICE engine power, kW	110	110
Electric motor generator peak power, kW	–	50
Electric motor generator continuous power, kW	–	25
Transmission type	5 speed	5 speed
Final drive ratio	2.563	2.563
Total Vehicle mass, kg	1126	1161
Fuel heating value (kJ)	42,800	42,800
Fuel density (kg/m^3)	0.742	0.742
Vehicle frontal area (m^2)	2.25	2.25
Vehicle drag coefficient (C_d)	0.3	0.3
Tire rolling resistance (μ)	0.008	0.008

The ECU is designed to control the balance between IC engine and electric motor by using the torque and power of the two power sources. The ECU will decide how much power is needed from IC engine and electric motor to meet the driving requirement. The ECU will also control the charging and discharging of the battery pack.

The ECU also monitors the performance of the engine and electric motor and sends signal to the engine and electric motor to adjust the performance based on the driver's demand. For example, in a typical HEV, the ECU will signal the IC engine to reduce power when the vehicle is running at low speed and signal the electric motor to increase power when the vehicle needs more power for acceleration.

Overall, the ECU in a parallel HEV is responsible for balancing the power from the IC engine and the electric motor to provide an efficient and safe driving experience. The Fuel consumption for a unit of distance qd of the car is calculated by the expression.

$$q_d = \frac{100Q}{S^*} \quad \left(\frac{1}{100Km}\right) \text{ [9]................(1)}$$

Q- Fuel consumption (l)

S* - Car travel distance (km).

4. Modelling of Equation of engine fuel consumption.

A car's fuel consumption depends first on the fuel economy of the engine, then on fuel consumption to overcome motion resistance. Building the relationship between q_d with the engine's fuel consumption factor and the moving forces is called the fuel consumption equation. When testing the engine on the test tape, we can determine the fuel consumption over time (kg / h) and the output power of the P_e engine (kW). The fuel consumption over time is determined by the following formula:

$$Gt = \frac{Q\rho_n}{t} \left(\frac{kg}{h}\right) \text{.................(2)}$$

Q : The amount of fuel consumption (l).
ρ_n : density of fuel (kg / l)
t : time (h)

To evaluate the fuel economy of an engine, we use the useful fuel consumption rate g_e

$$g_e = \frac{G_t}{P_e} = \frac{Q.\rho_n}{P_e.t} \left(\frac{kg}{kW.h}\right) \text{...................... (3)}$$

P_e - Useful motor power (kW)

Through the experiments of the engine, we can build the relationship between the engine power and the fuel consumption rate and the number of revolutions of the engine crankshaft.

$Pe = f(ne); ge = f(ne)$

$$q_d = \frac{100 g_e P_e t}{S^* \rho_n} = \frac{100 g_e P_e}{v \rho_n} \left(\frac{1}{100km}\right) \text{................ (4)}$$

From the formula (1) and (4) we can draw the expression to determine the fuel consumption level as follows:

$$q_d = \frac{100 g_e P_e t}{S^* \rho_n} = \frac{100 g_e P_e}{v \rho_n} \left(\frac{1}{100km}\right) \text{.................. (5)}$$

When a car is in motion, the power generated by the engine is needed to overcome motion resistance and is indicated by the power balance equation as follows.

$$P_e = \frac{\left(F_\psi + F\omega + F_j\right)}{1000_\eta} \ (kW) \text{................ (6)}$$

F_ψ; F_ω; F_j - Force of resistance (N) .... (7)

v - Car speed (m / s)

Thus, the fuel consumption of a car depends on the useful fuel consumption of the engine and the power consumed to overcome the motion resistance.

From the formula (5) and (7) we have the formula for calculating fuel consumption:

$$q_d = \frac{0.36 g_e \left(F_\psi + F\omega + F_j\right)}{\rho_n.\eta} \text{................(8)}$$

Equation (8) is called the rating equation fuel consumption for cars with unstable movements. When the car has stable movement, $F_j = 0$, the consumption rate car fuel:

$$q_d = \frac{0.36 g_e \left(F_\psi + F\omega\right)}{\rho_n . \eta} \quad \text{.............(9)}$$

5. Results and discussion

Energy transmission line diagram on Hybrid car: The transmission line diagram on a hybrid car would consist of the following components: Battery – The battery is the main source of power for a hybrid car, storing electrical energy and supplying it to the electric motor when required. Electric Motor – The electric motor is used to convert the stored energy in the battery into torque which helps the car move forward. Internal Combustion Engine – The internal combustion engine is used to generate power to supplement the power supplied by the battery. Power Electronics – The power electronics are used to control the flow of power from the battery to the electric motor. Transmission System – The transmission system is responsible for transferring power from the battery. The transmission line diagram of a hybrid car will typically include a motor that is connected to the wheels via a drive shaft, a generator connected to the motor, an inverter connected to the generator and the motor, a battery connected to the inverter, and a controller connected to the battery. All of these components are connected in a loop so that energy can be transmitted through the system. Shown in Figure 2

The power transmission in a hybrid car is typically based on a combination of mechanical and electric power. The motor will use electric power to propel the vehicle forward and the drive shaft will provide mechanical power when the car is in motion. An inverter is used to convert the electric power from the battery into mechanical energy that can be used to drive the wheels. The power transmission system also includes a controller, which monitors the power flow throughout the system and adjusts the power as needed. The capacity of the electric motor in a hybrid car will depend on the size of the vehicle and its power needs. Generally, the larger the vehicle and the more power it requires, the larger the motor capacity needs to be. However, the exact capacity required will vary depending on the model and make of the car. Shown in Figure 3

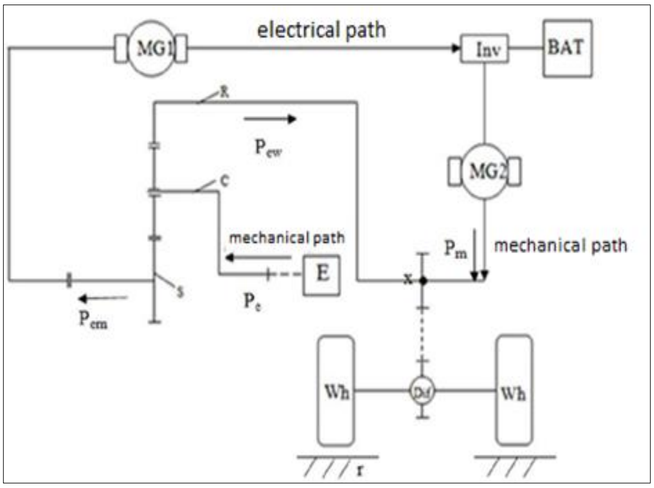


Figure 2 Energy transmission diagram

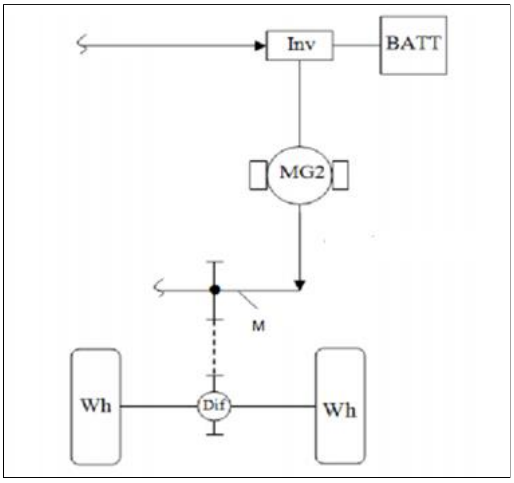


Figure 3 Power transmission diagram of M-axis

The M-axis is the axis that generates power from the MG2 electric motor, so the parameters on the axis will be determined through the external characteristics of the MG2 electric motor.

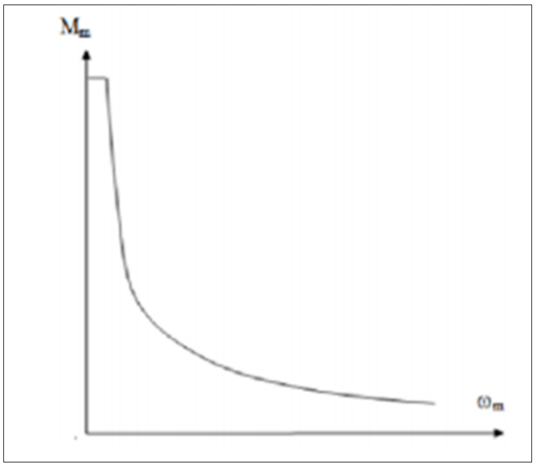


Figure 4 Characteristic line outside electric motor [3]

$$P_m = M_x * \omega_x$$

$$M_k = M_x i_{xr} \eta_{xr}$$

$$M_X = \frac{M_k}{i_{xr}\eta_{xr}} \text{ .... (10)}$$

M_k: Torque at the active wheel

$$F_k = \frac{M_k}{r} = O_f + O_w \pm O_a \text{ ....(11)}$$

$$\omega_x = \omega_x i_{xr} = \frac{v}{r} i_{xr}$$

5.1. The capacity of the battery

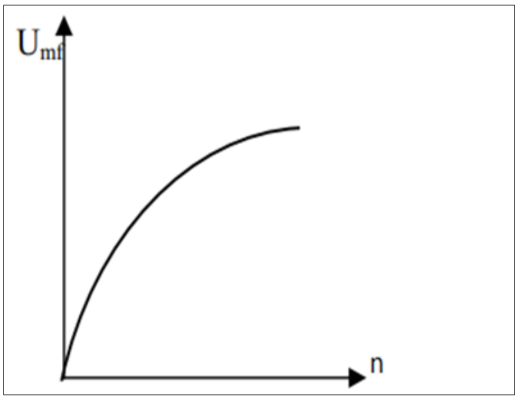


Figure 5 Characteristic line outside battery

$$P_m = P_{em}\eta + P_{aq}\eta_{aq}$$

$$\eta = \eta_{mf} * \eta_m$$

$$P_{em} = \frac{P_m - P_{aq}\eta_{aq}}{\eta}$$

$$P_{ew} = P_k - P_m$$

$$P_e = P_{ew} + P_m$$

P_{aq}: Capacity of the battery

P_{ew}: The power from the gasoline engine goes to the wheels
P_m: Power from the electric motor to the wheel
P_{em}: The capacity that the gasoline engine uses to pull the generator
η: efficiency of the energy transmission line

5.2. The road features fuel economy when the car is moving stably

Based on engine experiments on the test bed to plot the useful fuel consumption of the engine according to the power usage of the engine $g_e = f(Y_p)$ corresponding to different revolutions of the engine. (Figure 6)

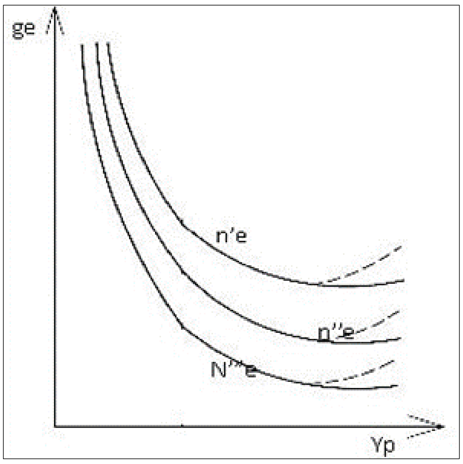


Figure 6 Chart of load characteristics of the engine [7]

Construct a graph of vehicle power balance with stable motion with drag coefficients ψ of different types of road surface to find the level of using different capacity of Y_p engine. We construct a graph of $P_e = f(v)$ for a transmission ratio of the powertrain. Based on the car's power balance equation when motion is stable, we have:

$$P_e = \frac{1}{\eta}\left(P_\varphi - P_\omega\right)$$

Create a curve of the engine output of $P_e = f(v)$, derived from this curve, build on its bottom a curve representing the power dissipation for air resistance and take into account the power dissipated for friction in the drivetrain.

$$\frac{P_\omega}{\eta} = f(v) = \frac{0.63 C_x v^3 S}{\eta}$$

Based on Figure 7, we can determine that Y_p corresponds to a number of revolutions of the engine, ie corresponding to a speed v at a given gear and depends on the road.

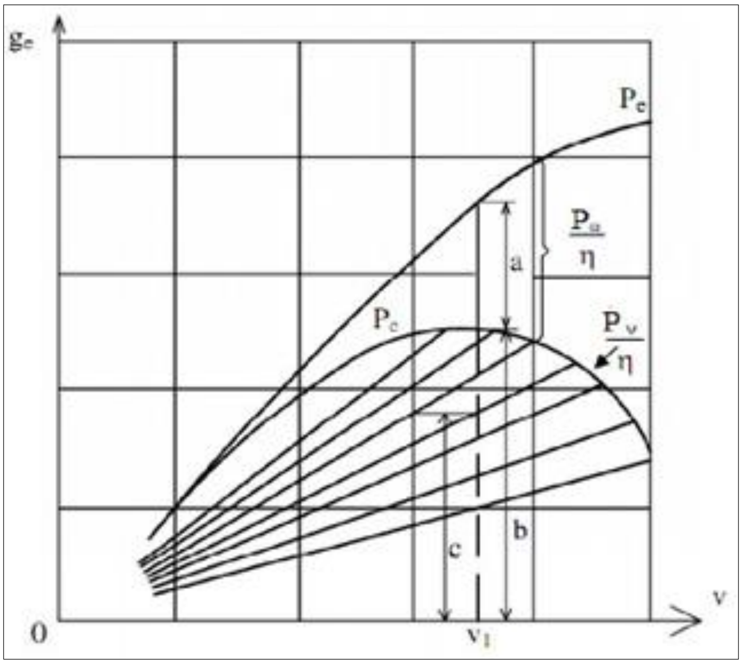


Figure 7 Car capacity balance graph with different drag coefficient of road surface [9]

From equation (9), we determine the value of fuel consumption and construct a curve of the fuel consumption of the car when the motion is stable.

Proceed with many different types of lines, we have a set of curves. This figure is a graph of fuel economy in steady motion (Figure 8)

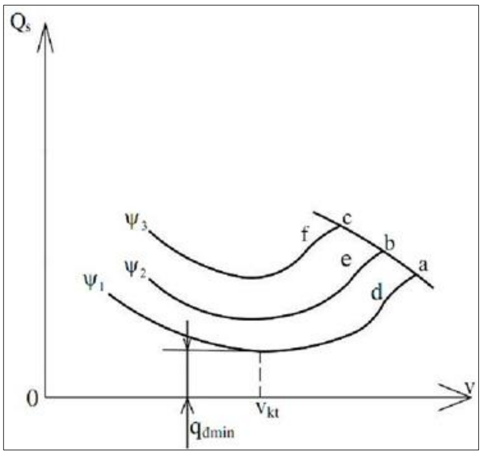


Figure 8 Graph of vehicle fuel consumption characteristics

6. Conclusion

In this study, the comparison of fuel consumption between Hybrid and traditional gasoline vehicles, the impact of hybrid technology on fuel consumption, the benefits of hybrid technology on fuel consumption, the effects of other factors such as driving habits and environmental conditions on fuel consumption, and the economic implications of using hybrid vehicles. Additionally, the study also covers any government regulations and incentives that are related to hybrid vehicles and fuel consumption. Finally, the study also analyzed the current and future trends of hybrid vehicles and fuel consumption.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

All authors contributed positively to the writing of this manuscript and there no conflict of interest as agreed to the content of this research.

Statement of informed consent

Informed consent was obtained from all individuals respondents included in the study.

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