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Assessment of Emissions and Fuel Economy for Electric Hybrid and Conventional Vehicles: A Case Study of Iraq

A Thesis
Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

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Supervisor Certificate

I certify that this thesis entitled **(Assessment of Emissions and Fuel Economy for Electric Hybrid and Conventional Vehicles: A Case Study of Iraq)** had been carried out under my supervision at the University of Diyala / College of Engineering - Mechanical Engineering Department in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.

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Date: 11 / 3 / 2021

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We certify that we have read this dissertation entitled **(Assessment of Emissions and Fuel Economy for Electric Hybrid and Conventional Vehicles: A Case Study of Iraq)** and as an examining committee examined the student **(Loay Mohammed Mubarak)** in its contents and that in our opinion it meets standard of a thesis and is adequate for the award of the degree of Master of Science in Mechanical Engineering.

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The Researcher

24 / 11 / 2020

Abstract

This study introduces the technology of hybrid electric vehicles (HEVs) and states their benefits in terms of fuel consumption and pollutant emissions. The economic and environmental metrics are the main concerned perspectives when comparing the hybrid electric vehicles to the equivalent conventional vehicle. The speed profile was created by assembling many real-world mini-trips that were recorded by the instrumented vehicles using an on-board diagnose (OBD) data logger. Those speed profiles represent the real-world driving cycles that being simulated to investigate fuel consumption and pollutant emissions. To perform the simulation process and to obtain all the involved performance predictions, advanced vehicle simulator (ADVISOR) is considered. In parallel, a MATLAB code is formulated to emulate the performance and fuel consumption of vehicles. For each case study, three-vehicle configurations (conventional, parallel hybrid, and series hybrid) were conducted under the associated real-world driving cycle as well as under the standard driving cycles. The results are analyzed to evaluate the achieved reduction in fuel consumption and emissions.

Considering fuel consumption predictions in city driving patterns, results showed that the best fuel reduction is achieved by series HEV under the driving conditions of Baghdad city. The simulation process predicted a reduction of 67.9% over the conventional vehicle, while the lowest reduction as 22.6% was achieved by parallel HEV under the driving conditions of Samawah city.

In the case of highway driving, simulation predictions revealed that the highest fuel consumption reduction is induced by series HEV on the highway of Baghdad-Najaf road with a reduction of 30.3%. The lowest reduction on the highway was predicted as 9.2% on the Baghdad-Kirkuk express road by a parallel hybrid powertrain, in contrast, the series hybrid powertrain was reported non-economic in comparison to the conventional one.

Table of Contents

Table of Nomenclatures

Symbol	Description	Units
A	The frontal area of the vehicle	m^2
a	Vehicle acceleration	m/s^2
C_d	Coefficient of drag	-
Cr	Coefficient of rolling resistance	-
$\bar{E}_t$	Total energy consumed	kJ
F	Traction force acting on a vehicle	N
g	Gravitational acceleration	m/s^2
lhv	Lower heating value	kJ/kg
m	Calculated vehicle mass	kg
$\dot{m}_{fuel}$	Fuel mass flow rate	kg/s
p	Total power demand	kW
SOC	State of charge of the battery	%
T	The torque of the engine	N.m
t	The total time of the driving cycle	s
u	The ratio of electric powertrain contribution	±%
V	Energy storage system voltage	Volt
v	Vehicle speed	m/s

Table of Greek Symbols

Symbol	Description	Units
η	The efficiency	%
θ	The slope angle of the road	%
ρ	Air density	kg/m^3
γ	Gear ratio	-
ω	The angular speed of the engine	rad/s

Table of Abbreviations

Abbreviation	Definition
A/C	Air conditioner
AC	Alternative current
ADVISOR	Advanced vehicle simulator
AWD	All-wheel drive
BEV	Battery electric vehicle
CO	Carbon monoxide
CO_2	Carbon dioxide
EM	Electric motor
ESS	Energy storage system
EV	Electric vehicle
FC	Fuel consumption
FC_SI	Fuel converter spark ignition
FE	Fuel economy
FWD	Front-wheel drive
GB	Gearbox
GUI	Graphic user interface
HC	Hydrocarbon
HEV	Hybrid electric vehicle
HP	Horsepower
HWFET	High way fuel economy test
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
ISG	The integrated starter-generator system
mpg	Mile per gallon
NOx	Nitrogen oxides
NYCC	New York city cycle
OBD	On-board diagnose
PEV	Pure electric vehicle
PHEV	Plug-in hybrid electric vehicle
r.p.m	Revolution per minute
RWD	Rear-wheel drive
SUV	Sport utility vehicle
UDDS	Urban dynamometer driving schedule

Chapter One
Introduction

Chapter One
Introduction

1.1 Fuel consumption and Emissions

As time goes on, the global demand for fossil fuel grows and gets higher than before. On the contrary, the sources of crude oil nearly reached their peak extraction potentiality. These sources are exhausted because the consumption rate is higher than their expected value in the future; hence, the world may face a deficit in energy sources (Turlapati, 2010). International reports demonstrated that the transportation sector consumes energy with a significantly increased rate since it was documented 23% of total fuel consumption in 1971, however, in 2018, about 35% had been reached (International Energy Agency, 2020). If there are no newly discovered sites of crude oil for satisfying the increased global demand for fossil fuel, fuel production is predicted to be highly reduced within the next few years (Van Mierlo et al., 2006).

Likewise, emissions significantly increased to alarming levels in the last decades (Ganji et al., 2010). These recorded levels depict true threats to human health, environment, and atmosphere (Dawood and Emadi, 2003). More than 4 million premature deaths per year were reported in 2018 all over the world. These deaths were due to polluted air caused by emissions released by different combustion engines (World Health Organization, 2019). Emissions such as carbon monoxide (CO), nitrogen oxides (NOx), carbon dioxide (CO_2), hydrocarbon (HC), and particulate matter, pollute the air directly. The worldwide vehicles emit about 71% of the overall carbon dioxide released globally (Orecchini et al., 2018). Moreover, automobile emissions contribute to pollution by approximately 60% (Ganji et al., 2010). In this context, the internal combustion engine-vehicles (ICEVs) represent a major problem for global warming, greenhouse gas effect (Chau, 2015). For that, by 2050, the transportation sector is required to lower its released emissions; by 60% for meeting the European environmental limitations (Orecchini et al., 2018). Some incentive policies for “zero-emission driving” adopted by the local authorities contributed to that growth. For instance, as an incentive to boost the electric car industry, the UK government intends to grant drivers up to £6000 for substituting their conventional vehicles for electric ones. The UK government has set a 2035 deadline for a ban on new gasoline and diesel cars, but that deadline may be reconsidered to come even earlier. That decision constitutes for meeting the UK "zero-carbon emission targets at 2050" policy. In this context, Norway had managed to ban sales of new petrol cars by 2025, also some cities in China discuss a strategy of banning new petrol cars around 2030 (Technology BBC NEWS, 2020).

1.2 Electric vehicle and Hybrid electric vehicle technology

One of the valuable solutions to the problem of pollution is reviving the electric vehicle technology (Chau, 2015, Reynolds and Kandlikar, 2007), the electric vehicle (EV) if compared with the conventional vehicle (ICEV) it has merits, however, many challenges are also implied. The more prominent challenges are the initial cost is high and the charging infrastructure is not widely available alongside that EV was slower than ICEV on average and EV cannot travel so far in one trip as ICEV does (Chau, 2015). Since EV is restricted by the charging pack and multiple hours are needed for a completely charged battery. Thus, EV fails to be a respectable rival to ICEV (Ganji et al., 2010). These flaws restricted the new electric technology and minimize the consumer desire to buy it as was expected. So, to defeat these restrictions, an ICE was incorporated to the powertrain of EV to extend the driving range and/or to assist propulsion power depending on drivetrain configuration resulting in the hybrid propulsion system. This innovative system combines in one vehicle both the propulsion mechanisms of the conventional ICE propelled by the chemical energy of fuel and the electric motor (EM) propelled by the electricity stored in the battery (Ehsani et al., 2005).

As time went on, the HEVs industry prospered and their markets are developing in which their buyers are increased in particular those wanting to "go green". In this context, EVs and plug-in hybrid electric vehicles (PHEVs) sales in Europe had been grown by 72% in the first quarter of 2020 compared to the same period of 2019. By 2035, it is predicted that HEVs occupy about

80% of the automobile markets. The HEV is an alternative car for better fuel economy and fewer emissions (Ganji et al., 2010, Reynolds and Kandlikar, 2007). The technology of hybridization may effectively participate to diminish the transportation sector emissions by 30% as agreed in Paris (Parliament, 2019). The merits of the hybridization technology are listed below (Mansour et al., 2011, Heywood, 2018, Chau, 2015, Guzzella and Sciarretta, 2005):

1- Eliminating the idling.
2- Regenerative braking.
3- Downsizing ICE due to a boosting electric motor involving that maintains the overall propulsion power requirements of the vehicle.
4- The ICE can be imposed to operate at its optimum efficiency by implement such a control strategy.
5- The vehicle can be driven in the purely electric mode as a ZEV.
6- Employing an evolved four-stroke cycle called the "Atkinson cycle" which is of higher efficiency than the Otto cycle (Orecchini et al., 2018), and attains higher functional expansion than compression due to using a variable valve timing. Thus, employing this cycle raises engine efficiency.

1.2.1 Pure electric vehicle (PEV)

Pure electric vehicle (PEV), battery electric vehicle (BEV), or sometimes called zero-emissions vehicle (ZEV) is configured so utilizing only the electricity as an energy source for driving the wheels by an installed electric motor. The most important privileges of fully electrifying vehicles are: firstly, the accumulative efficiency of energy converting processes from well-to-wheel involved in EVs is higher if compared with that of ICEVs as depicted in Figure 1-1. In addition, the regenerative braking utility involved in EV can improve energy efficiency by up to 10% (Chau, 2015). Secondly, adopting EVs that are mostly zero-emissions emitters shifts the pollutant emissions away from urban areas. Nevertheless, EVs encounter many challenges that were mentioned previously. The battery cost is estimated at 30-40% of the PEV price. Another challenge is the end life of the battery cells that are typically limited to about 1500 cycles. The end life of the battery imposes the PEV's owner to renew it at least once if the vehicle's operation life is standardized at 10 years. Meanwhile, HEVs battery is lasting longer because it is not the unique source for energy as in PEVs. On the one hand, the last issue regarding the battery use duration which is actually more for EVs than for HEVs makes the effective cost of EVs is much higher than the initial cost (Chau, 2015).

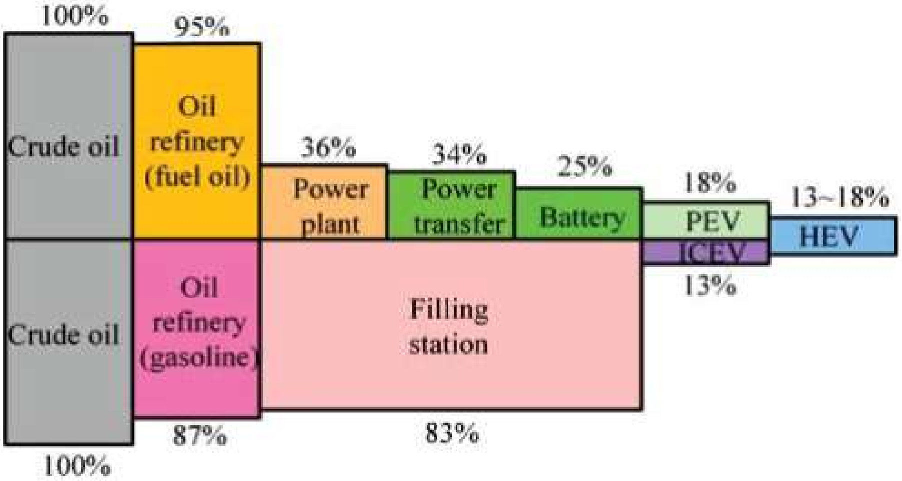

Figure 1-1: Energy efficiency of electrified vehicles (Chau, 2015).

On the other hand, extending the duration of PEV operation so it travels farther may require a doubled or tripled battery capacity, hence, inevitably much higher cost is consequent. The PEVs take around 5-8 hours for a fully charged battery with limited battery charger specifications. To surpass this demerit of long required time superior specifications for the charger must be reconsidered for a quick charging and a state of charge (SOC) of 80% in just about 20-30 minutes. SOC can be introduced as a percentage of the instantaneous level of the battery energy to its full capacity. The fast-charging equipment is at the expense of the installation cost, which is too high. Hence the aforementioned challenges all violate the electric vehicle economic merits (Chau, 2015).

1.2.2 Hybrid electric vehicle (HEV)

Generally, the hybrid vehicle is defined by The International Electrotechnical Commission (IEC) as "one in which propulsion energy, during specified operational missions, is available from two or more kinds or types of energy stores, sources, or converters. At least one store or converter must be on-board. A hybrid electric vehicle (HEV) is a hybrid vehicle in which at least one of the energy stores, sources, or converters can deliver electric energy. A series hybrid is an HEV in which only one energy converter can provide propulsion power. A parallel hybrid is an HEV in which more than one energy converter can provide propulsion power" (Hermance and Sasaki, 1998).

HEV may be a conventional HEV that is fed by a unique external energy source; gasoline or diesel. Also, HEV may be as gridable since it can be recharged with electrical energy via an external port as well as the potentiality to refuel with the operating fuel. The HEV experiences a trade-off between non-zero emissions on the one hand and comparable ICEV driving range and use the available refueling stations on the other hand (Chau, 2015). The classification of electrified vehicles is illustrated in Figure 1-2.

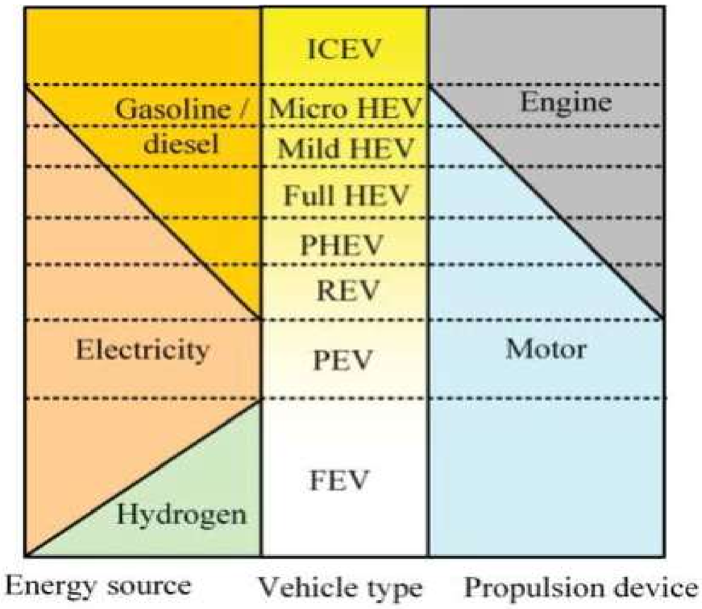

Figure 1-2: Classification of electrified vehicles (Chau, 2015).

1.3 Case study of Iraq

1.3.1 Traffic Intensity in Iraq

The streets of Iraqi cities experienced enormous congestion because of the unlimited importing of all kinds of vehicles since 2003 resulting in high traffic congestion in both the urban areas and on the highways. For instance, “Mohammad Al-Qasim” highway in Baghdad typically undergoes recurrent congestion of about 105,000 vehicles per day (Chaichan et al., 2018). The formal statistics in 2019 showed that the mobility bulk was inflated by more than 400% (Department of Planning. General Directorate of Traffic, 2019).

The inflation in the mobility bulk is associated with the growth of gasoline and diesel fuel supplements in addition to the quantitative and qualitative degradation of paved roads other than the multiplicity of checkpoints for security reasons that influenced mobility congestion.

1.3.2 Fuel consumption and Emissions in Iraq

It is disappointed that the company of oil products distribution had refused to provide the researcher with the information and some real data concerned in this study. The Iraq-associated statistics that certainly enrich this work include; the annual consumption increase rate at the fuel stations all over Iraq for the last decade, the well-to-wheel cost for the gasoline and diesel fuels, and other environmental issues.

Unfortunately, there are no inclusive standard limits for the green-house gases (GHGs) in Iraq, but for HC and CO emissions that were reported violated by a 30% increased concentrations. The experimental test was conducted under limited conditions that inequivalent to the real driving emissions (RDE) of the European testing standards, in which the vehicles were tested while idle mode (Abd Al-Razaq and Fuad, 2018).

1.3.3 Electrified Vehicles in Iraq

Hybrid electric vehicles (HEVs) can be considered rare cars in Iraq; although the first efficient HEV in the world (Toyota Prius) was manufactured since 1997, the first-ever EV in Iraq was only imported and registered by traffic authorities in 2016. Moreover, EV or HEV is unknown and is seldom available across the streets of Iraq. Only 22 electrified vehicles (9 EVs and 13 HEVs, none of them was documented in the city of Baqubah where this study is supervised) against more than 1 million light-duty conventional vehicles were registered until the last month of 2019 (the statistics only includes the passenger car and the 5–7 passenger SUV. The Kurdistan region of Iraq is also not included) (Department of Planning. General Directorate of Traffic, 2019).

The unfamiliarity of the new smart technology (hybridization) may be attributed to the high price of HEV, the relatively low-cost fuel in Iraq (where the price for ordinary gasoline is approximately 0.38 US$ per liter and about

0.63 US$ per liter for super gasoline), and the common misconception. This misconception is justified by the mistrust of the rechargeable appliance for recent considerations related to poor-quality applications. Therefore, in November 2019, the Iraqi government legislated to reduce the custom tariff for HEVs by 100% as an incentive for prompting citizens to own this economic and low-emissions vehicle (Council of Ministers, 2019).

1.4 Objectives of the Present Work

1- The study aims to compare the performance of HEVs, in terms of emissions and fuel consumption (FC) in the first place with their conventional counterpart.

2- The comparison includes also the energy consumption within each component in the powertrain and the efficiencies of them as well as the overall system efficiencies.

3- The case studies of Iraqi cities and highway roads in forms of real-world driving cycles-that conducted in the research to predict fuel economy and emissions-are introduced in this study.

These real-world driving conditions are representing the daily driving routine of:

a) Vehicle of a governmental employee in the University of Diyala.
b) Passenger cars travel on the most important highway roads in Iraq (express roads that linking-in the southern, western, northern, and eastern provinces to Baghdad city).
c) Taxi cars in target-selected cities.
d) Randomly appointed trips.

1.5 Outline of Thesis

The thesis consists of six chapters and three appendices.

Chapter One: outlines-globally and locally-facts about fuel consumption and emissions that both motivate to conduct research in the field of electrified vehicles. The general concepts and the types of hybrid vehicles are also presented with their merits and challenges as well as the objectives of the study.

Chapter Two: introduces a historical overview for the electrified vehicle and the main component that involved in the diverse conducted configurations. The simulation software is presented as well other than reviewing the most associated literature.

Chapter Three: explains; the road load equation, other governing equations, and the energy transition and energy loss using the quasi-static approach. The chapter introduces also the procedures of building the models and shows the governing equations during each operating mode.

Chapter Four: presents the research methodology of the thesis, the instrumentations, and the procedure on which the real-world driving cycles were selected. The modeling and simulation process is also presented as well as the MATLAB coding process. The validation process for the results is explained as well.

Chapter Five: Results includes; fuel consumption, emissions, energy usage reports, and engine efficiency map are introduced and discussed according to three categories: urban, extra-urban, and highway driving conditions. The MATLAB code outputs are introduced and discussed as well.

Chapter Six: concludes the most interesting results and presents recommendations regarding the finding of this research.