FRI-2.203-1-TMS-12

A REVIEW OF THE POSSIBILITY FOR USING OF ALTERNATIVE FUELS AND BIOFUELS IN HYBRID VEHICLES

Assist. Prof. Krasimir Markov, PhD
Department of Engines and Vehicles
"Angel Kanchev" University of Ruse
Phone: 082 888 373
E-mail: krmarkov@uni-ruse.bg

Abstract: *The electrification of the automotive fleet increases with every year. More and more automotive manufactirers offers hybrid and electric vehicles on the market. It is considered that the hybrid vehicle would occupy a high percentage of the fleet in the near future compared to the electric vehicle. The internal combustion engine in the hybrid vehicle would still be a source of harmful emissions. An interesting and not fully researched question to this vehicle type is the use of alternative fuels and biofuels. For this reason, the subject of this article is an overview of the available literature. In conclusion after the analisys it can be said that the hybrid vehicles which use alternative fuels and biofuels are more environmental friendly than the hybrid vehicles which use conventional fuels.*

Keywords: *Hybrid vehicles, alternative fuels, ethanol, biodiesel, hydrogen, biofuels, emissions.*

INTRODUCTION

The electrification of the automotive fleet increases with every year. More and more automotive manufacturers offers hybrid and electric vehicles on the market. It is widely believed that the hybrid vehicles would occupy a high percentage of the fleet in the near future compared to the electric vehicles. The internal combustion engine in the hybrid vehicles works at the Atkinson cycle and operates mainly in its most efficient region. The engine can be switched on/off when is necessary from the energy management system. The electric motor is used outside this region where the engine has low efficient, high fuel consumption and emissions. The internal combustion engine in the hybrid vehicles has less fuel consumption but it is still be a source of harmful emissions.

The automotive manufacturers conduct the emission tests in laboratories. From practical point of view, however, more important are the real driving tests which include fuel consumption and emissions. There are many authors who investigate the hybrid vehicles in real driving conditions and also compare the results to the conventional vehicles. Most of them take into account the variables which affect the performance of the vehicles such as vehicle configuration, driving style, traffic conditions, energy consumption of the auxiliary devices, road altitude, ambient conditions, etc. The researchers conduct the tests in urban, extra-urban and highway traffic conditions for fully investigation of the hybrid vehicles. The investigations are done on petrol and diesel hybrid electric vehicles.

The fuel consumption of the hybrid vehicles in comparison with the conventional vehicles greatly depends from the vehicle speed. The hybid electric vehicles have about 65% and 50% reduction of the fuel consumption in comparison with the conventional petrol and diesel engines for average speed up to 10 km/h (high traffic conditions) and up to 20 km/h (low vehicle speeds) respectively. According Orecchini et al. the reasons for this reductions are mainly several – the thermal engine efficiency of the Atkinson cycle, the hybid subsystem which allows to run ZEV mode for big part of time for average speeds up to 10 km/h (engine stop, engine never works idle), powertrain management of the hybrid synergy drive system for average speeds up to 20 km/h (engine never works idle or with low power, electric motor aid for transient conditions, engine stop in the absence of power supply to the wheels) and the regenerative braking (Orecchini, F., Santiangely, A., Zuccari, F., Ortenzi, F., Genovese, A., Spazzafumo, G. & Nardone, L., 2018; Huang, Y., Surawski, N.C., Organ, B., Zhou, J.L., Tang, O.H.H. & Chan, E.F.C., 2019). Increasing the speed the fuel consumption of the petrol engine decreases and for average speeds over 50 - 60 km/h the fuel consumption of the hybrid electric vehicles and the pertor/diesel vehicles is similar (Orecchini, F.,

Santiangely, A., Zuccari, F., Ortenzi, F., Genovese, A., Spazzafumo, G. & Nardone, L., 2018; Fontaras, G., Pistikopoulos, P. & Samaras, Z., 2008; Ivanov, Y., Ivanov, R., Kadikyanov, G., Staneva, G. & Danilov, I., 2019). The fuel consumption is 31 – 48% higher than indicated in the technical specification of the vehicle for the extra-urban driving conditions (Ivanov, Y., Ivanov, R., Kadikyanov, G., Staneva, G. & Danilov, I., 2019). Comparison of the fuel consumption of two hybrid electric vehicles and one petrol vehicle in depends of the average vehicle speed is shown in fig. 1.

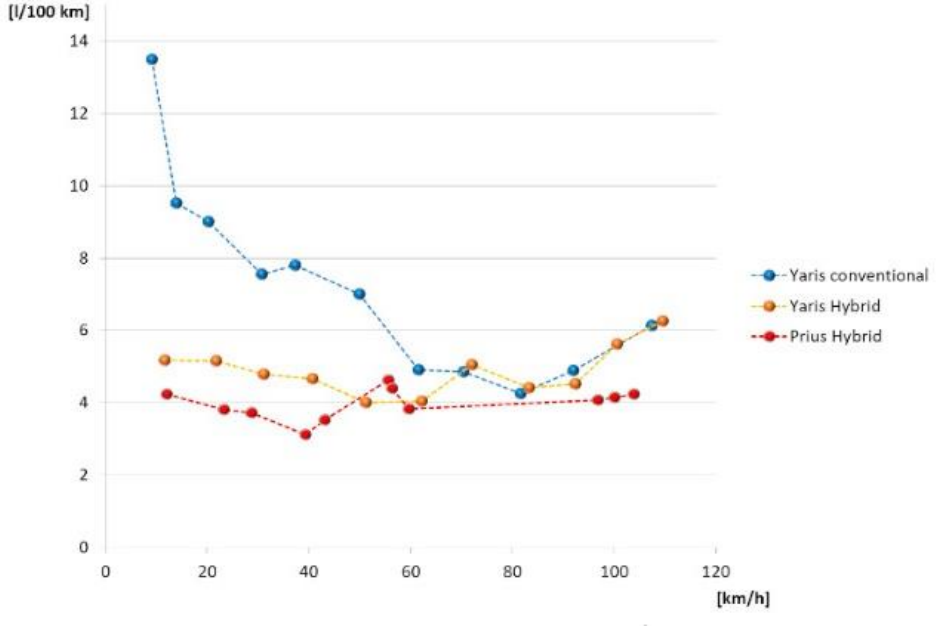

Fig. 1. Comparison of the fuel consumption of two hybrid electric vehicles and one petrol vehicle in depends of the average vehicle speed (Orecchini, F., Santiangely, A., Zuccari, F., Ortenzi, F., Genovese, A., Spazzafumo, G. & Nardone, L., 2018)

Ambient temperature has more significant impact on the fuel consumption of the hybrid electric vehicles under real driving conditions in comparison with the conventional vehicles. The battery capacity is reduced and the air density (aerodynamic resistance) is increased at lower temperatures which affect the fuel consumption (Fontaras, G., Zacharof, N.-G. & Ciuffo, B., 2017; Alvarez, R. & Weilenmann, M., 2012; Fontaras, G., Pistikopoulos, P. & Samaras, Z., 2008). Starting the engine at lower temperature is another important parameter. The effect of the cold start at low temperatures is more pronounced in the hybrid electric vehicles. The fuel consumption of the hybrid vehicles increases between 30 and 107% at low temperatures in comparison with engine starts at high temperatures (Fontaras, G., Zacharof, N.-G. & Ciuffo, B., 2017; U.S. Environmental Protection Agency, EPA; Zahabi, S.A.H., Miranda-Moreno, L., Barla, P. & Vincent, B., 2014). This is much more than the fuel consumption increase of the petrol and diesel vehicles (between 10 and 20% increase at low temperatures). It is also necessary to note the requirement for fully charged battery during cold stard at low temperatures. Otherwise certain amount of fuel would be used for the battery charge and the fuel consumption would increase even more.

Key roles in the fuel consumption of the hybrid vehicle play the kinetic (braking) energy recovery systems, the energy management systems and the battery in-use ageing. Hybrid electric vehicle with higher efficiency kinetic energy recovery system and with properly designed energy management system has lower fuel consumption (Orecchini, F., Santiangely, A., Zuccari, F., Ortenzi, F., Genovese, A., Spazzafumo, G. & Nardone, L., 2018; Sabri, M.F.M., Danapalasingam, K.A. & Rahmat, M.F., 2016). The kinetic energy recovery system is also affected by the low temperatures (U.S. Environmental Protection Agency, EPA). The hybrid vehicle battery has lower total charge output with increase of the mileage. Only fraction of the charge of the battery can be used with increase of the number and depth of the in-use charge/discharge cycles (Alvarez, R., Schlienger, P. & Weilenmann, M., 2010).

The impact of the hybrid electric vehicles over the emissions is unclear in real driving conditions. Some authors report higher emissions of the hybrid vehicles during real driving conditions. Franco et al. report between 150 and 550% exceedance of the regulatory NO_x emissions and between 52 and 178% exceedance of the on-road CO_2 emissions of three diesel-hybrid vehicles during real driving conditions (Franco, V., Zacharopoulou, T., Hammer, J., Schmidt, H., Mock, P., Weiss, M. & Samaras, Z., 2016). Huang et al. report no reduction of the HC emissions and higher CO emissions of two petrol hybrid electric vehicles (Huang, Y., Surawski, N.C., Organ, B., Zhou, J.L., Tang, O.H.H. & Chan, E.F.C., 2019). Another authors report lower emissions of the hybrid electric vehicles during real driving conditions. O'Driscoll et al. report lower CO_2 and NO_x emissions of petrol hybrid electric vehicle in comparison with Euro 5 and 6 petrol and diesel vehicles (O'Driscoll, R., Stettler, M., Molden, N., Oxley, T. & ApSimon, H., 2018). Fontaras et al. report lower CO_2 emissions of diesel hybrid electric vehicle (Fontaras, G., Pistikopoulos, P. & Samaras, Z., 2008).

An interesting and not fully researched question to this vehicle type is the use of alternative fuels and biofuels which can reduce the emissions even more especially for higher vehicle speeds. For this reason, the subject of this article is an overview of the available literature.

EXPOSITION

Hybrid electric vehicles and LPG

The LPG usage at the hybrid electric vehicles could be divided into the passenger vehicles, the light-duty/commercial vehilces and the heavy-duty vehicles. The advantages of the LPG are several – greener cleen burning fuel, cheeper than the petrol and diesel in many countries and it is widespread available in the market. The combination of the hybrid electric vehicle and LPG engine could be very promising but the range of the available LPG engines for hybrid electric vehicles is very small at the present. Researches of LPG hybrid electric vehicles are also not available. Nevertheless, as examples for LPG hybrid electric vehicles could be given Hyundai Elantra LPI-hybrid, Kia Forte LPI-hybrid, Toyota Camry LPG-hybrid, Toyota JPN Taxi LPG-hybrid and are shown in figure 2.

Fig. 2. Examples of LPG hybrid electric vehicles – Hyundai Elantra LPI-hybrid, Kia Forte LPI-hybrid, Toyota Camry LPG-hybrid (WLPGA, 2018)

It has to be noted that all automotive manufacturers of LPG hybrid electric vehicles state there is significant reduction of fuel consumption and emissions but as was mentioned above there is not conducted any scientific reseach of this type of the hybrid vehicles. Nevertheless, there is not-scientific experiment done by the engineers from one of the LPG fuel system manufacturers. The result are shown in fig. 3.

Fig. 3. Comparison of the cost of several types of vehicles (WLPGA, 2018)

Hybrid electric vehicles and ethanol

Another option for use in the hybrid electic vehicles is the ethanol. The first and only up-to now produced ethanol hybrid electric vehicle is Toyota Prius Hybrid FFV (flexible-fuel vehicle). It is designed for the Brazil market where the ethanol is a widespread fuel since Brazil is one of the largest producers of ethanol, mainly from sugarcone. The engine in the vehicle could operate with petrol, with petrol/ethanol blends or with pure ethanol. The automotive manufacturer states there is also significant reductions of the emissions (Toyota Motor Corporation, 2018). Fig. 4 shows the prototype of Toyota Prius Hybrid FFV.

As for the LPG hybrid vehicles, there are not any scientific researches of the ethanol hybrid electric vehicles in real driving conditions but there is just one simulation research of diesel-ethanol series hybrid with LTC which indicate reduction of NO_x and soot emisions but double increase of CO and HC emissions (Garcia, A. & Monsalve-Serrano, J., 2019).

Fig. 4. Example of ethanol hybrid electric vehicle – Toyota Prius Hybrid FFV (Toyota Motor Corporation, 2018)

Hybrid electric vehicles and biodiesel

Another type of biofuel which can be used in the diesel hybrid electric vehicles is the biodiesel. There are not produced any hybrid vehicles which operates with biodiesel. Again as for the previous two fuel types there is not any scientific researches of the biodiesel hybrid electric vehicles in real driving conditions but there is one simulation research of this biofuel type used in the hybrid vehicles. The simulation model describes the hybrid electric vehicle components with mathematical forms, it uses the biodiesel made by cottonseed oil and evaluate the performance of the diesel hybrid electric vehicle in urban driving conditions. The results show that the usage of the biodiesel in this vehicle type contribute to reduce the emissions and increase the fuel economy (Mourad, M., Mahmoud, K., Mohamed, F. & Noah, A., 2014).

Hybrid electric vehicles and hydrogen

The hydrogen is alternative fuel which could be used for both petrol and diesel hybrid electric vehicles. This can happen mainly as additive to the conventional fuel. There are only two investigations that are reported in the literature for both diesel and petrol hybrid electric vehicle.

There is simulation investigation for diesel hybrid vehicle that use 8% hydrogen addition by volume. The hydrogen is injected in the intake manifold in the simulation model. The hydrogen enriched diesel hybrid electric vehicle has better performance and emission characteristics in comparison with the conventional diesel hybrid vehicle and the conventional diesel vehicle (both with the same engine). The results show 4,26% improvement of the power and torque, 14,32% reduction of the combined fuel consumption, 15% reduction of the NO_x emissions and 33% reduction of the CO_2 emissions in comparison with the conventional diesel vehicle with the same engine (Arat, H., 2019).

There is another investigation for petrol hybrid electric vehicle that use 10% hydrogen addition by volume. The investigation has been conducted by simulation. The simulation includes also the Vibe combustion model. The result of the simulaton are compared to spark ignition petrol engine which also has hydrogen enrichment. The hydrogen enriched petrol hybrid vehicle has better performance and emission characteristics in comparison with the hydrogen enriched conventional petrol engine – 2,38% increasement of the power, 3,6% increasement of the torque, 12,6% reduction of the cumulative fuel consumption, 14% reduction of the NO_x emissions, 29% reduction of the CO_2 emissions and 33% reduction of the HC emissions (Arat, 2019). Nevertheless, a disadvantage of the study is the chosen conventional petrol engine for comparison. It would be better if it was petrol hybrid electric vehicle.

CONCLUSION

The hybrid vehicles would occupy a high percentage of the fleet in the near future compared to the electric vehicles. The internal combustion engine in the hybrid vehicles has less fuel consumption but it is still be a source of harmful emissions. In real driving conditions, the fuel consumption of the hybrid vehicles depends from the average speed, the ambient temperature amd the level of electrification. The impact of the hybrid electric vehicles over the emissions is unclear in real driving conditions. Some authors report higher emissions while another authors report lower emissions. Because of this reasons, the usage of the alternative fuels and biofuels is considerable.

Despite the few scientific researches, it can be concluded from the analysis that the hybrid electric vehicles which use alternative fuels and biofuels are more environmental friendly than both conventional vehicles and hybrid electric vehicles. Despite the reported advantages in the literature, more studies need to be conducted to confirm the results from the available investigations.

ACKNOWLEDGMENT

The investigation is conducted with the support from Project **ФНИ РУ 2019-ФТ-01**.

REFERENCES

Alvarez, R. & Weilenmann, M. (2012). Effect of low ambient temperature on fuel consumption and pollutant and CO_2 emissions of hybrid electric vehicles in real-world conditions. *Fuel* 97 (2012), 119-124.

Alvarez, R., Schlienger, P. & Weilenmann, M. (2010). Effect of hybrid system battery performance on determining CO_2 emissions of hybrid electric vehicles in real-world conditions. *Energy Policy* 38 (2010), 6919-6925.

Arat, H. (2019). Alternative fuelled hybrid electric vehicle (AF-HEV) with hydrogen enriched internal combustion engine. *International Journal of Hydrogen Energy* 44 (2019), 19005-19016.

Arat, H. (2019). Simulation of diesel hybrid electric vehicle containing hydrogen enriched CI engine. *International Journal of Hydrogen Energy* 44 (2019), 10139-10146.

Fontaras, G., Pistikopoulos, P. & Samaras, Z. (2008). Experimental evaluation of hybrid vehicle fuel economy and pollutant emissions over real-world simulation driving cycles. *Atmospheric Environment* 42 (2008), 4023-4035.

Fontaras, G., Zacharof, N.-G. & Ciuffo, B. (2017). Fuel consumptions and CO_2 emissions from passenger cars in Europe – Laboratory versus real-world emissions. *Progress in Energy and Combustion Science* 60 (2017), 97-131.

Franco, V., Zacharopoulou, T., Hammer, J., Schmidt, H., Mock, P., Weiss, M. & Samaras, Z. (2016). Evaluation of exhaust emissions from three diesel-hybrid cars and simulation of after-treatment systems for ultra real-world NO_x emissions. *Environ. Sci. Technol.* 50 (2016), 13151-13159.

Garcia, A. & Monsalve-Serrano, J. (2019). Analysis of a series hybrid vehicle concept that combines low temperature combustion and biofuels as power source. *Results in Engineering* 1 (2019), 100001.

Huang, Y., Surawski, N.C., Organ, B., Zhou, J.L., Tang, O.H.H. & Chan, E.F.C. (2019). Fuel consumption and emission performance under real driving: Comparison between hybrid and commercial vehicles. *Science of the Total Environment* 659 (2019), 275-282.

Ivanov, Y., Ivanov, R., Kadikyanov, G., Staneva, G. & Danilov, I. (2019). A study of the fuel consumption of hybrid car Toyota Yaris. *Transport Problems* 14, 1 (2019), 155-167.

Mourad, M., Mahmoud, K., Mohamed, F. & Noah, A. (2014). *Influence of biodiesel fuel on performance characteristics of hybrid electric vehicle according to urban driving cycle*. Paper presented at the Vth International Renewable Energy Congress, 25th-27th March 2014, Hammamet, Tunisia.

Orecchini, F., Santiangeli, A., Zuccari, F., Ortenzi, F., Genovese, A., Spazzafumo, G. & Nardone, L. (2018). Energy consumption of a last generation full hybrid vehicle compared with a conventional vehicle in real drive conditions. *Energy Procedia* 148 (2018), 289-296.

O'Driscoll, R., Stettler, M., Molden, N., Oxley, T. & ApSimon, H. (2018). Real world CO_2 and NO_x emissions from 149 Euro 5 and 6 diesel, gasoline and hybrid passenger cars. *Science of the Total Environment* 621 (2018), 282-290.

Sabri, M.F.M., Danapalasingam, K.A. & Rahmat, M.F. (2016). A review of hybrid electric vehicles architecture and energy management strategies. *Renewable and Sustainable Energy Reviews* 53 (2016), 1433-1442.

Toyota Motor Corporation (2018). *Toyota reveals world-first flexible fuel hybrid prototype in Brazil*. News Release, Mar, 20, 2018.

U.S. Environmental Protection Agency (EPA), Fuel Economy in cold weather. https://www.fueleconomy.gov/feg/coldweather.shtml

WLPGA (2018). *LPG Hybrids – Power, Energy, Mobility, Smart Grids – Innovation & Technology*. World LPG Association, 2018.

Zahabi, S.A.H., Miranda-Moreno, L., Barla, P. & Vincent, B. (2014). Fuel economy of hybrid-electric versus conventional gasoline vehicles in real-world conditions: A case study of cold cities in Quebec, Canada. *Transportation Research* Part D 32 (2014), 184-192.