ELECTRIC VEHICLES

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Summary

In 1990, the California Air Resources Board (CARB) in the United States adopted new emission regulations. They required that a minimum of ten per cent (around 20 000 vehicles) of new vehicles sold by major companies in the state in 2003 should be zero emission vehicles (ZEV). Electric vehicles are currently the only practical choice of vehicles with zero tail pipe emissions.

Electric vehicles have been around for a long time. Such vehicles flourished before the rise of the gasoline automobile. Fifty thousand electric vehicles were in use in the United States by 1912. At that time environmental pollution was not a public issue, so they were gradually replaced in major urban, and especially highway, applications by the more competitive gasoline and later – diesel vehicles.

Electric vehicles can be classified into three groups: vehicles with continuous electric supply, vehicles with stored on-board electricity and vehicles with electric energy produced on-board.

Vehicles with continuous electric supply are the only group, which has a significant impact today. Vehicles with stored on-board electricity are used to perform specific jobs. Vehicles with on-board electricity production (hybrid vehicles) emerged as a promising alternative only recently.

The present chapter describes promises and problems facing the development of electric vehicle technology as a means for the practical implementation of zero emission alternatives. The performance of the electric vehicles largely depends on the developments and achievements of battery technology. So, this chapter also outlines several advanced battery technologies that provide hopes for successful achievement of zero emission vehicles goals.

With the increasing worldwide drive towards cleaner environment and sustainable development, vehicles, which use on-board electricity production and/or stored on-board electricity, receive an increasing attention and investment of effort, talent and resources.

1. Introduction

In 1990, the California Air Resources Board (CARB) in the United States adopted new emission regulations. They required that a minimum of two per cent of the sales of the major manufacturing companies in the state in 1998 had to be zero emission vehicles (ZEVs). In 2001, the share of ZEVs was planned to be five per cent, and then reach ten per cent – in 2003. In 1996, the first two milestones were reconsidered compensating the planned reduction of emissions with an increased amount of low emission vehicles. Later, partial zero emission vehicle (PZEV) specifications were defined in order to stimulate a greater impact on California's environment. Electric vehicles are the only practical choice at present, which can be certified as having entirely no tail-pipe emissions.

While today's technology is new, battery-powered vehicles have been around for a long time. Electric vehicles dominated the market before the rise of the gasoline automobile. Some 50 000 electric vehicles were in use in the United States alone by 1912. At that time environmental pollution was not of primary concern, and electric vehicles were gradually replaced in major urban, and especially highway, applications by their more competitive gasoline and later – diesel counterparts.

Electric vehicles can be classified into three groups depending on the means, by which electric energy is produced.

- Vehicles with continuous electric supply receive their energy from an off-board generation system.
- Vehicles with stored on-board energy use electricity, produced off-board.
- Vehicles with electric energy produced on board rely on an electricity generator, which may be also participating in the driving of the wheels.

Vehicles with continuous electric supply are the only group, which managed to retain some of its positions until the present days. Vehicles with on-board electricity production (hybrid vehicles) emerged as a promising alternative only recently. Vehicles with stored on-board electricity (electric vehicles) have been around all these years performing specific jobs. The rapid development of battery technology and vehicles technology as a whole promises much wider and significant contributions to environmental goals in the future.

With the increasing worldwide drive towards cleaner environment and sustainable development, vehicles, which use on-board electricity production and/or stored on-board electricity, receive an increasing attention and investment of effort, talent and resources. The present chapter describes the promises and problems facing the development of electric vehicles towards a powerful zero emissions alternative.

2. Vehicles Powered by Electric Energy

The application of electric energy for generating motion is already present in every day life. It includes mainly electric motors with continuous supply. Such motors are used widely by industry, in agriculture (i.e., pumps for supplying water), for household devices (i.e. vacuum cleaners, lawn mowers), etc. Typical vehicles with continuous electric supply are trams and trolley busses, electricity powered locomotives, etc. Batteries – the primary devices for storing electricity are also everywhere – in watches, portable TV sets, and other appliances, and also – in the automobile. Vehicles using on-board stored electricity have presently very limited application, but hold great promises for the future. Hybrid electric vehicles (HEVs) and fuel cell hybrid electric vehicles (FCHEVs) with on-board electricity production are also a powerful alternative.

2. 1. Vehicles with Continuous Electric Supply

Vehicles with continuous electric supply receive their energy from off-board sources through an overhead wire. They are usually divided into two major groups. The first group is almost entirely represented by trolley busses, which provide urban transport, and their motion is limited only by the existence of the overhead wire system, but not by road. The vehicles in the second group include railroad vehicles – trams and electricity powered locomotives. The latter are used for cross-country destinations, but also in underground transport. All railroad vehicles need rails. They are limited not only by overhead wire, but also by the existence and development of railroad systems.

Trolley buses are closer than the rest of the vehicles using off-board energy to the electric vehicles being considered in this chapter. Presently the trolley bus systems providing mobility around the world are estimated at nearly 400 with more than 30 000 vehicles. Most of the systems and vehicles are in Central and Eastern Europe, the former Soviet Union and China. The largest system, in Moscow, operates an estimated 2000 vehicles. The Western Hemisphere, including the Americas and Western Europe, accounts for less than one hundred systems. The United States are currently running five systems with a little more than 700 vehicles, the countries in the Western Europe – 52 systems with around 2200 trolley buses. The flexibility of the operation of the trolley buses is limited by the need of overhead wires, which are also vulnerable to accidents. They have relatively high operational and capital costs. Trolley buses at present cost up to 100 per cent more than diesel buses of comparable transportation abilities. Their exploitation is economical only in cities with considerable height differences. Still they are quieter and practically emit no pollutants.

The other group of vehicles with continuous electric supply is that of hybrid vehicles. Fuel supply systems in these vehicles can use fuel cells or on-board stored fuel and oxidizer to produce electricity. This electricity powers the electric motor, which may be complemented with an advanced internal combustion engine. Hybrid vehicles are discussed in detail in *Hybrid Vehicles.*

The vehicles with continuous electric supply are not the subject of the present chapter. However, the experience gathered from their quite prolonged use provides means for evaluation of some of the environmentally related features of electric transport.

2.2. Vehicles with Stored On-board Energy

Battery powered vehicles also have their representatives already working. Forklifts, golf carts, milk delivery vans, etc. are doing a limited but recognized service.

The major advantage of propulsion of vehicles with electricity is that the two major events in realizing mobility – the transformation of the chemical energy of the fuel and the propelling, can be separated. Electric motors can generate high torque at low speed and operate efficiently over a greater range of speeds than internal combustion engines. The drive train of an electric vehicle may be simpler and more efficient than that of an internal combustion engine.

The internal combustion engine of a vehicle has to meet the peak power demand for a much higher acceleration than the one, which is required in normal driving. The typical efficiency of an internal combustion engine is normally less than half of its efficiency at optimal conditions. Under straight and level conditions, these engines produce ten per cent or less of the power they are capable of producing. Moreover, internal combustion engines have to be able to accommodate large and rapid variations of speed and loads, which also results negatively on efficiency and emissions. Although the same principle is valid for electric engines – efficiency is lower at light loads, still the reduction of the efficiency for them is much lower.

An inherent advantage of electric engines is their capacity for *regenerative breaking*. An internal combustion engine not only dissipates the kinetic energy of the vehicle's motion in breaking, but this energy turns into heat and mechanical energy in the brakes and results in their wear. If the electric motor of an electric vehicle is used as a generator, its kinetic energy is turned back into electricity when breaking. If there is sufficient capacity for energy storage on-board that vehicle, up to 80 per cent of that energy can be recovered, at the same time saving wear of the breaks. This is especially important in urban travel (i.e., in buses) where stopping and starting are a substantial part of the mode of transportation.

Other advantages of electric engines include the lack of moving parts and noise, the lower amount of devices, which deteriorate with time, higher safety in case of accidents, etc. Of course, electric engines and electric vehicles have inherent disadvantages as well. The overcoming of these disadvantages is described in the following text.

Electric motors used in electric vehicles are direct current (DC) or alternative current (AC) motors. The AC electric motors may be induction motors or permanent-type synchronous motors. Most electric motors used for road vehicles up to now are of the DC type. Direct current electric motors allow for less expensive and simpler control system.

Compared to AC motors of the same power current DC motors are heavier and less efficient. The need for periodic servicing of the brushes is an additional disadvantage. AC induction and permanent magnet synchronous motors are lighter than DC motors and more efficient. However, they require a sophisticated and expensive system to synthesize variable AC power from battery supplied electricity. Synchronous motors can operate only at a rotational speed that is equal to the frequency of the power source. Induction motors have to use a rotational speed, which is close enough to the frequency of the AC source.

With recent developments in semiconductor technology, the costs of the controllers for variable frequency AC motors are reducing considerably and many of the new electric vehicles have now AC propulsion. Permanent-magnet synchronous motors can provide the highest power density of the three types, but still use rather expensive materials for the magnets.

3. Capabilities of On-board Energy Storage Devices and Direct Conversion Fuel Cells

Electric vehicles are being developed in a very competitive environment. Because of that in many cases, the latest information is of a proprietary nature. A lot of contradictions exist in published data about storage facilities, energy requirements, range of travel, etc. because of intensive advertising and lack of comparative experimental data.

At present electric vehicles use electrochemical rechargeable batteries for storage of the electric energy. Other storage media which may be eventually used in hybrid and electric vehicles in the future are flywheels, ultra capacitors and fuel cells.

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Bibliography

1. *California Air Resource Board Staff Report (1998): 1998 Zero-Emission Vehicles Biennial Program Review*, 46 pp., California Air Resources Board, USA. [A review of the state of zero emission vehicle

technologies,. Can be obtained from the Internet web site of Califronia Air Resources Board – http//www.arb.ca.gov. An executive summary of the year 2000 biennial review can also be obtained from this site.].

2. *California Exhaust Emission Standards and Test Procedures for 2003 and Subsequent Model Zero-Emission Vehicles, and 2001 and Subsequent Model Hybrid Electric Vehicles, in the Passenger Car, Light-duty Truck and Medium-duty Vehicle Classes* (1999), 19 pp., California Environmental Protection Agency, Air Resources Board, USA. [The latest standards concerning electric vehicle testing, which can be obtained from the Internet web site of California Air Resources Board – http//www.arb.ca.gov].

3. *Electric Vehicle Resource Guide* (1998). 6 pp., The U.S. Department of Energy Office of Transportation Technologies National Alternative Fuels Hotline. [A guide which contains information, addresses, etc. of companies, federal agencies, organizations, etc. providing expertise on advanced energy technologies, can be obtained from the Internet address: http//www.nrel.gov].

4. *Electric Vehicle Performance Characterization Summary* (1999). Southern California Edison Company, Electric Transportation Division, California, USA. [Driving test results of electric vehicles sold in USA, can be obtained from the Internet site of California Air Resources Board].

5. Faiz A., Weaver, C. S., Walsh, M. P. (1996), *Air Pollution from Motor Vehicles: standards and technologies for controlling emission*, 250 pp., World Bank, Washington, USA. [A highly informative and comprehensive review on engines, fuels and vehicles, including also comparative results and discussion for electric vehicles].

6. *Final Statement of Reasons for Rulemaking Including Summary of Comments and Agency Response* (1996). 111 pp., State of California Air Resources Board, Public Hearing Date: March 28, 1996, Agenda Item No: 96-2-2. [Questions, answers and comments from the public hearing on the status of the zero emissions vehicle program, reflecting the main reasons for the waiving of the original 1998 and 2001 tasks for introduction of ZEVs in California, USA. Can be obtained from the Internet web site of California Air Resources Board].

7. Kalhammer, F. R., Prokopius, P. R., Roan, V. P.. and Voecks, G. E. (1998). *Status and Prospects of Fuel Cells as Automobile Engines. A Report of the Fuel Cell Technical Advisory Panel*, Section 2, 19 pp., Prepared For State of California Air Resources Board, Sacramento, California, USA. [A report summarizing state of the art FCHEV technology. Can be obtained from the Internet web site of the Air Resources Board].

8. Rand, D. A. J., Woods, R. and Dell, R. M. (1998) 577 pp., *Batteries for Electric Vehicles*. Research Studies Press, Taunton, UK. [Specifically devoted to batteries and battery technologies for electric vehicles].

9. Wakefield, E.H. (1998) History of the Electric Automobile: Hybrid Electric Vehicles. 332 pp., Society of Automotive Engineers (SAE), Warrendale, Pa. USA. [This work describes the development of the electric automobile concept to its present status].

10. Watkins, L. H. (1996), *Air Pollution from Road Vehicles*, 152 pp., 2nd impr., HMSO, London, UK. [Widely cited state of the art review, covering mainly emission testing and air pollution control for road vehicles, but also providing some data on electric vehicles and hybrids].

Biographical Sketch

Georgi St. Cholakov is Associate Professor at the University of Chemical Technology and Metallurgy in Sofia. He received his first hands-on experience of ecological problems during compulsory his military service as the Head of the Fuels and Lubricants Unit of an airbase. His PhD dissertation was on development of replacements for lubricant additives synthesized from the sperm oil, obtained from blue whales. He did a post doctoral specialization in tribology at the University of Birmingham, U.K. Later he specialized in effective and ecological processing and use of petroleum derivatives at Imperial College, London, the French Institute of Petroleum, and other leading universities. The scientific and research interests of G. St. Cholakov are centered around petroleum processing and petroleum derivatives – environmentally compatible processes and products, process and product design for the petroleum industry, chemistry of combustion and ecology, etc. He is teaching advanced courses in related academic disciplines – alternative fuels and lubricants, air pollution management, chemistry of combustion and ecology, additives for fuels and lubricants, technological computation in petroleum processing, etc. He has contributed more than 50 papers in refereed international journals and co-edited the Bulgarian edition of Miall's Dictionary of Chemistry. He is member and has served in elective positions in different Bulgarian and Balkan professional organizations. He has been member of the editorial boards of two journals, published in Bulgaria in the English language.