Problem analysis of improving the environmental performance of public transport

L A Ugarova, E A Kravtsova and N E Danilina
Togliatti State University, Belarusian Street, 14, Togliatti City, 445020, Samara Region, Russian Federation

E-mail: L.Ugarova@tltsu.ru

Abstract. The transport system of any locality raises a number of environmental problems: atmospheric, hydrological, lithosphere and noise pollution. Due to the fact that the exhaust gas of gasoline engines contains a large amount of harmful substances, many manufacturers of passenger transport do not consider gasoline as the fuel of the future and alternative fuels are increasingly being used in world practice. This paper analyzes the problem of improving the environmental performance of public transport, provides solutions to the problem of air pollution in various developed countries, formulates the most important criteria for the design of environmentally friendly buses and presents a hybrid bus model using an exhaust turbine running on ethanol, based on an analysis of the design city buses of various manufacturing companies.

The growing demand for transport of goods and passengers means an increase in vehicle fleet and an increase in the intensity of its use. As a result, it leads to a rise in amount of toxic substances emitted by motor vehicles, an increase in noise exposure, and further exacerbated energy problem due to limited reserves of petroleum fuels. In this regard, automakers have long been engaged in the creation of electric vehicles (EV) and hybrid vehicles (HV). In almost all developed countries of the world there are state programs for the development of EV and HV. Currently, a large number of electric vehicles of various designs have been created from single mini electric vehicles to electric-powered buses with autonomous energy sources and trucks.

Various modifications of electric drives for electric vehicles of various applications are being created. Work is underway on promising EV using both autonomous energy sources and a combined power plant that provides low toxicity and a significant reduction in fuel consumption in urban traffic.

Convertible electric vehicles (created on the basis of a production car) are of the greatest interest in terms of reducing capital costs, production and operating costs. This is because the main components are produced in series. What is more, for their design and manufacture there is no need to spend large sums of money.

However, some manufacturing companies using modern advances in computer technology design vehicles originally designed as pure electric cars or as cars with a hybrid power unit (HPU).

An example of such a project can be a model of a twelve-meter urban ecobus with a HPU, designed for 80 seats. It was fully developed using computer software by the transnational US-English company Global Products Exchange (GPX).

In many megacities, the use of large trucks and buses in the city center is prohibited by authorities due to the fact that some areas of the city are declared ecological zones.
In this regard, bus manufacturers began the development of an environmentally friendly interurban and suburban vehicle, as its most effective proposal for the use of vehicles in environmental zones.

At the beginning, a model of a clean electric bus with the use of batteries as energy sources and traction electric motors (TEM) was proposed. However, this concept of building an environmentally friendly vehicle imposed a number of limitations on autonomous mileage at a level of approximately 80-100 kilometers. Since, over time, vehicles with gas control systems became more technologically feasible, therefore the concept and approach to the design of environmentally friendly vehicles was changed to the design of a hybrid electric bus. The goal of car manufacturers was to create an environmentally friendly bus that could be produced in large quantities and would meet the expectations of consumers in the field of reliability and environmental friendliness.

In order to meet all the requirements of the authorities and all the expectations of the owners of private bus stations, it was necessary to conduct a survey of passengers, drivers and owners of bus companies in different cities and in different countries. GPX specialists conducted such a marketing research.

For example, in Spain, it was found that the owners of transport companies, due to the large passenger flow, preferred to have buses in which there are twice as many standing seats than seats (for example, in many cities in the USA, most buses have seats for passengers). Bus station owners in Spain explained that in Madrid, for example, they have more than 3,000 city buses to serve more than 3,000,000 passengers. Most of their passengers did not use their personal cars for a week, but used public transport to get from home to work and back, as well as to travel around the city in the evenings.

Based on these studies, GPX specialists formulated the most important criteria for the design of green buses:

- due to the fact that all segments of the population use city buses and usually to travel relatively short distances, fast entry and exit for a large number of people is an important criterion in the convenience of using public transport. This fact forced bus designers to do lower floors;
- sufficiently high bus acceleration rate is an important criterion for traffic safety, allowing the bus to quickly leave the stop and merge into traffic, without being an obstacle to other participants in the movement;
- one of the criteria for passenger and driver comfort is heating, ventilation, and air conditioning, as well as the luggage compartment for suburban buses. However, in order to create the most environmentally friendly bus with a HPU, it is necessary to solve the problem of writing the optimal algorithm for ICE operation, minimizing emissions of harmful substances, and also providing opportunities for using the most environmentally friendly fuel for ICE.

It is now becoming apparent that air pollution in many large cities arises primarily from the exhaust gases emitted by internal combustion engines. Smoke from factories and plants, which has been the predominant source of air pollution worldwide, have been largely cleared over the past few decades. Reducing air pollution caused by diesel engines is receiving increasing attention. There is serious medical evidence for the association of particulate smoke from burnt diesel fuel, lung cancer, and respiratory diseases. Daniel S. Greenbaum, the president and chief executive officer of the Health Effects Institute (Los Angeles), showed that approximately 40 experimental observations were made and, almost every one of them, showed a positive link between particulate diesel smoke and cancer.

The problem of reducing air pollution by cars in developed countries is being addressed in different ways. For example, Japanese automakers unveil their HPU vehicle, which they named SULEV (Super Ultra Low Emission Vehicle). In this car, the internal combustion engine of the HPU worked at constant speeds, and a high-speed microprocessor was used to regulate the completeness of combustion of the fuel-air mixture by means of controlling the stoichiometric composition of the mixture using feedback from a sensor installed in the exhaust system.
Due to the fact that the exhaust gas of gasoline engines contains a large amount of harmful substances, it means that gasoline as a fuel of the future is also undesirable. Therefore, the use of alternative fuels is increasingly being used in world practice.

For example, in the USA, bus manufacturers in this regard have to seriously consider the application of California law, which was aimed at restricting the use of diesel fuel in buses, including hybrid vehicles. In California, a rule has come into force that applies to public bus fleets operating in this State, and it reads as follows: “... this Rule is designed for public transportation (in California) and requires transport company owners to buy heavy vehicles with propulsion systems using an alternative type of fuel in order to reduce air pollution by exhaust gases. To comply with this rule, it is necessary to apply heavy-payload vehicle with propulsion units on alternate fuel - a truck, bus, which uses compressed or liquefied gas, propane, methanol, electricity, fuel cells or other advanced techniques that do not involve use of diesel fuel in general” [1].

The zero emission vehicles now and in the future undoubtedly have a hydrogen fuel cell configuration. The oxidation of hydrogen fuel produces energy and water. However, at present, the cost of a hydrogen fuel cell bus is approximately $700,000 per kilometer, which is not comparable to the cost of a diesel bus of the same size and characteristics.

In order to obtain a more complete combustion of the fuel - the mixture must use propane, known as liquefied petroleum gas. Propane (C\textsubscript{3}H\textsubscript{8}) is a hydrocarbon molecule consisting of three carbon atoms to which eight hydrogen atoms are attached. As a result of the complete oxidation of propane or any other hydrocarbon fuel, carbon dioxide (CO\textsubscript{2}) and water (H\textsubscript{2}O) are released [2]. Currently, a large number of buses use compressed natural gas (CNG) as an alternative fuel to obtain the most complete combustion and reduce exhaust toxicity. Such CNG is hydrocarbon methane (CH\textsubscript{4}), which consists of one carbon atom with four hydrogen atoms. Since the propane molecule has more carbon atoms and more hydrogen atoms than methane (CH\textsubscript{4}), the energy released during the oxidation of the propane molecule is greater. Thus, a propane tank provides four times more energy than a methane tank of the same volume. In addition, propane is stored in liquid form in tanks at a pressure of about 14 at and methane is stored in compressed form in relatively large tanks at a pressure of more than 150 at. The costs of developing a bus refueling infrastructure with methane are significantly higher than the same infrastructure for refueling a bus with propane. And finally, propane is affordable gas all over the world at its low cost.

In the manufacture of gas control systems, the use of a piston internal combustion engine as a generator drive is not mandatory. The company Volvo Car Group (Volvo) has produced an 18-ton city bus for traffic in the city of Gothenburg. It is equipped with a 110 kW exhaust turbine and 130 kW an asynchronous generator connected in series with the turbine. The lead-acid battery is connected to the power system via a buck - boost converter. During the acceleration of the bus, the HPU is able to realize a maximum power of 190 kW, which is the result of the combined operation of an exhaust turbine and a lead-acid battery. The exhaust turbine runs on ethanol, which enables to get the least toxicity. As the number of stops in the city increases: the efficiency of an electric drive is better than the efficiency of a bus drive with an automatic transmission. In the case of steady motion, mechanical gears are more efficient.

As a hybrid bus drive, two asynchronous traction electric motors connected through their own inverters were used. Torque is supplied to the wheels from traction motor 1 and traction motor 2 through a mechanical gearbox and differential [3]. HPU consisting of an exhaust turbine and, directly connected with it, a high-speed electric generator produces electricity in the form of direct current. The lead-acid battery is connected to the generator via a power cable through a block of rectifiers and converters. The lead-acid battery also feeds the auxiliary system, which includes chargers for 12 V and 24 V batteries, a compressor and a hydraulic pump for power steering.

An exhaust turbine uses ethyl alcohol as a fuel; however, it can also use any type of liquid or gaseous fuel. It has a single-stage radial compressor driven by a single-stage radial turbine with a low toxic combustion chamber and a recuperator. The compressor and turbine are mounted on the same shaft as the rotor of the generator. In this combination, a maximum output power of 85 kW is possible. Power
control was performed taking into account low toxicity, slowly changing the speed in the range of 50,000-67,000 rpm, which corresponds to 30% and 100% of the load, while maintaining the turbine constant temperature of release equal to 620 C.

As another alternative source of energy, some companies consider the significant flywheel masses of a rotating flywheel disk. For example, such an energy storage device was used on a DennisDart hybrid bus. The flywheel is able to accumulate energy equal to 2.5 kW, thereby leveling down the peak loads arising during acceleration and braking [4]. By analyzing the existing designs of hybrid buses, it is possible to formulate general concepts and directions in the layout solutions of various nodes and assemblies.

The chassis and suspension, as a rule, have a spatial design. To provide improved maneuverability, an independent four-wheel drive suspension is used. This makes it possible to have a small turning radius, which is so necessary when driving a bus in dense city traffic flows on narrow streets.

Due to the fact that some buses have an independent suspension, there is no need to make a raised floor to place the rear and front axles across the bus; hence it becomes possible to manufacture a low floor along the entire length of the passenger compartment. The floor can be made at a level of 25-30 cm from the ground, thereby improving bus comfort and allowing people who use wheelchairs to choose the services of public transport. The layout of components and assemblies is made in such a way that there is the possibility of quick and easy access to all systems and components during maintenance of the hybrid bus.

A model of a hybrid bus using an exhaust turbine operating on ethanol was developed at Togliatti State University by means of computer software using computer-aided design systems based on an analysis of the design of city buses of various manufacturing companies. Table 1 shows the general technical specifications of this hybrid bus.

Table 1. Hybrid bus specifications.

| Geometric indicators | Value |
|----------------------|-------|
| Length, m            | 12    |
| Height, m            | 3,2   |
| Width, m             | 2,55  |
| GVW, kg              | 18300 |
| Capacity (seats)     | 68 (34) |
| Floor level, mm      | 320   |

| Technical specifications | Value |
|--------------------------|-------|
| Acceleration time 0-30 km/h, s | 7     |
| Acceleration time 40-60 km/h, s | 13    |
| Acceleration time 0-50 km/h, s | 16    |

| Environmental performance (city route number 85 Gothenburg) | Value |
|-------------------------------------------------------------|-------|
| NOx g / kWh                                                | 1     |
| HC, g / kWh                                               | 0,1   |
| CO g / kWh                                                | 1,5   |

A block diagram of a hybrid bus electric drive is shown in figure 1.
Figure 1. Block diagram of a hybrid bus electric drive.

1 – exhaust turbine; 2 – electric generator; 3 – power module controller; 4 – start inverter; 5 – rectifier; 6 – on-board computer; 7 – throttle pedal and brake pedal; 8 – ignition; 9 – emergency switch; 10 – electronic control unit; 11 – circuit breakers; 12 – converter number 1; 13 – converter number 2; 14 – auxiliary electrical system; 15 – traction battery; 16 – traction battery control unit; 17 – inverter number 1; 18 – inverter number 2; 19 – traction electric motor number 1; 20 – traction electric motor number 2.

Thus, to ensure the improvement of the environmental situation in large cities of Russia, reduce the consumption of petroleum fuels, and reduce the background noise of traffic flows, the widespread introduction of electric vehicles and hybrid vehicles in our country is necessary.

References
[1] Machado T et al. 2015 Int. Conf. on Technologies for Sustainable Development (Mumbai) pp 1-5
[2] Johnson J, Dinesh Kumar K, Praneeth S, Yathiraj and Shankar R 2017 Int. Conf. on Advances in Mechanical, Industrial, Automation and Management Systems (Allahabad) pp 104-9
[3] Bobrowskii A V, Zotov A V, Rastorguev D A, Gorokhova D A and Ugarova L A 2019 Conf. on Materials Science and Engineering pp 320-8
[4] Kazantsev A D, Kravtsova E A 2019 Int. Conf. on Transport. Economy. Social sphere pp 32-4
[5] Chen Y, Gao Q, Su X et al. 2018 Int. J. Syst. Assur. Eng. Manag. 9 1336
[6] Stoll J, Kopf R, Schneider J et al. 2015 Prod. Eng. Res. Devel. 9 225
[7] Chinnamaddaiah K, Lakshmipathi Y, Ravikanth Raju P and Subramanyam B 2017 Int. J. of Mech. Eng. Technol 8 305-11