GÉP

A GÉPIPARI TUDOMÁNYOS EGYESÜLET MŰSZAKI FOLYÓIRATA

2023/2-3.

Nemzeti Kulturális Alap

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AZ EMERSON ÚJRADEFINIÁLJA, HOGYAN HOZZUK MOZGÁSBA A VILÁGOT

SZOFTVEREINK ÉS TECHNOLÓGIÁINK A MODERN ÉLET MOZGATÓRUGÓI

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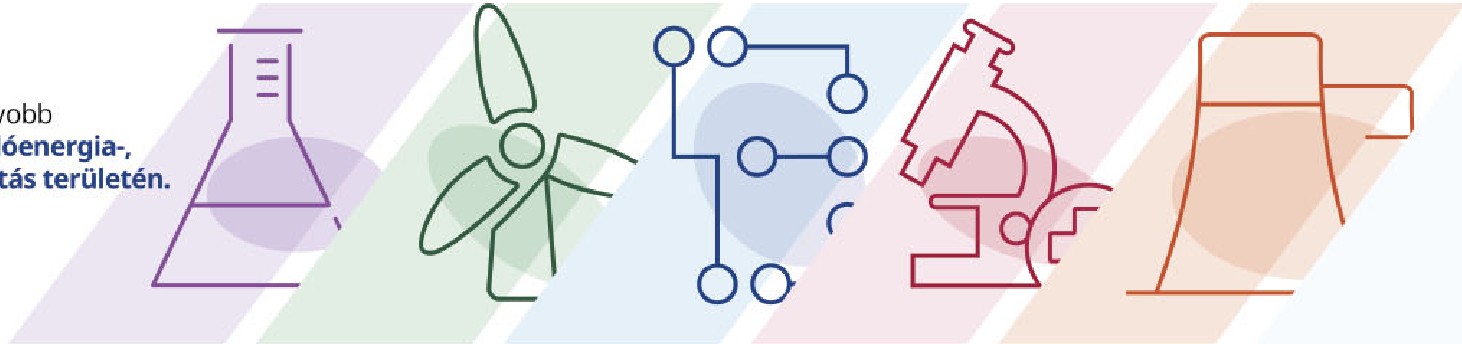

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GÉP

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A 2023 áprilisában hetedik alkalommal megtartott Agria Konferencia Sorozat, InnoVETAS2023 konferenciája egyik szép példája annak a kollaborációs folyamatnak, amelynek során az Emerson Automation FCP Kft. lehetőséget biztosít az egyetemi hallgatóknak, kutatóknak a legfrissebb kutatási eredményeinek bemutatására. A 2023-ban az InnoVETAS2023 konferencia kibővült az 1. Emerson Műszaki Játszótér versennyel, annak zsűrizésével és díjátadójával. A műszaki tudományos előadások mellett a diákok által tervezett és készített eszközök tették színessé az eseményt.

Az InnoVETAS2023 konferencia plenáris ülésén az érdeklődők meghallgathatták Gödri István ügyvezető igazgató úr előadását az egri telephely helyzetéről. Kiemelte a konferencia fejlődésének ívét, amely még szorosabb együttműködést tesz lehetővé hallgatók és az Emerson között. Ezt követően Stéphanie De Boissieu az Emerson Gyártás Automatizálás Stratégia Üzleti Egységének alelnöke tartotta meg nyitóbeszédét. Az Emerson és az üzleti egység bemutatása mellett a mérnök hallgatókat segítette a vállalatok számára értékes készségek, képességek bemutatásával. Rámutatott a mérnöki tudás mellett a „soft skillek", az együttműködés és a nyelvtudás fontosságára.

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BUSZ HŰTÉSI RENDSZEREK ÁTTEKINTÉSE AZ ÁTALAKÍTÁSI FOLYAMATBAN

REVIEW OF BUS COOLING SYSTEMS IN THE CONVERSION PROCESS

*Péter Bencs**

ABSTRACT

The primary objective of this research is to investigate cooling/heating solutions for an urban passenger bus engine and battery plant (for electric drive). A general literature review was conducted to assess the thermal performance expected in a sizing process. In the context of literature, an electrical conversion was also examined to see what cooling system is used for internal combustion engines, what system is replaced and what solution is applied. In the research framework, we tried to find specific thermal performance values for a bus (urban passenger bus) defined in the assignment. The next step of the research was to explore the methods used for cooling internal combustion engines. As a final step in the literature review, the cooling and heating solutions for battery packs used in electrical conversion were considered (maintaining the optimum temperature range of battery packs).

1. INTRODUCTION

Outdoor air pollution, in particular particulate matter less than 2.5 mm (PM2.5), is estimated to cause 3.3 million premature deaths worldwide each year. Exhaust emissions from diesel vehicles are particularly harmful to human health and have been classified as carcinogenic by the World Health Organization.

Generally speaking, the growing knowledge of the negative effects of air pollutants has led to active and continuous regulatory measures to limit emissions and technological improvements in emission control techniques, particularly in road transport. Exhaust emissions from buses and coaches in real-world operations depend on several factors, such as the vehicle's technical condition, the type of vehicle, the type of bus and engine, the type of fuel and lubricant, driving requirements and environmental conditions [1].

Buses, like other vehicles, typically have higher emissions when accelerating from, for example, bus stops. Localized emissions can create air pollution hotspots in parts of a city bus route. Diesel Particulate Filters (DPFs) are typically ceramic filters used in Euro VI diesel vehicles to remove soot particles in the exhaust system of buses. Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR) systems have been used to reduce Nitrogen Oxide (NOx). The use of an ammonia-reducing agent achieves NOx reduction in SCR. Ammonia is usually produced by hydrolysis of a urea solution which is injected into the hot exhaust gas before SCR. As mentioned, current emission control strategies are largely based on exhaust gas after treatment. This strategy offers the possibility of reducing emissions by retrofitting existing buses. Compared to buses with similar DPFs operating under similar driving conditions, buses equipped with DPF-SCRs had 61% and 45% lower NO_2 and NOx emissions, respectively [1].

Electrification of buses is being introduced to reduce carbon emissions by replacing buses using conventional internal combustion engines and diesel fuel as a power source. Trials have shown that battery electric buses can minimize CO_2 emissions by 18.0-23.9% compared to diesel buses using low HVAC. Biofuel and electrified buses can reduce carbon emissions by up to 37%, while full electrification could avoid 52% of carbon emissions. Because of their undisputed benefits in reducing air pollution, electric buses are increasingly being used to replace conventional buses, and many countries are beginning to introduce electric buses into public services to reduce carbon emissions and urban air pollution [2].

Electric buses are emerging as a new transport trend as they have great potential to reduce carbon emissions and avoid severe urban air pollution compared to diesel buses, but there are also barriers to their introduction [2].

The energy storage of electric buses is limited, leading to shorter travel distances for electric buses compared to diesel buses. Increasing battery capacity does not help as it increases not only the cost but also the mass load of the bus. The limited range and energy storage may cause insufficient energy during the service period, as the operating time and travel distance of public buses are fixed [2]. Electric buses also need more time to recharge energy storage than diesel buses. The long charging time for electric buses makes it more challenging to schedule. Forecasting energy consumption is key to estimating the

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energy required by the electric bus and helps in scheduling [2].

In this research study, the cooling and heating solutions used in buses undergoing conversion (conversion of a diesel engine system to an electric motor system) are presented as one of the cornerstones between the two bus types.

2. CONVERSION OF CITY BUSES

The following example shows the conversion options (from diesel to electric system).

e-troFit, a Munich-based in-tech technology company subsidiary, made its debut at the UITP summit in Stockholm, demonstrating retrofitting for city buses. For the time being, the e-troFit kit is only available for the Mercedes Citaro [3].

e-troFit would allow operators to quickly convert conventional diesel buses into electric vehicles. e-troFit has entered into a partnership with ZF Aftermarket: ZF is a system supplier of powertrain components for the e-troFit kit. Specifically, the component is the AxTrax electric motor axle built into the wheel, which Mercedes and Solaris have adopted for their eCitaro and Urbino electric vehicles. ZF is also a partner for retrofitting and servicing, through its global workshop network.

The first demonstration vehicle equipped with the e-troFit kit is a Mercedes Citaro, which has undergone a test period as part of a pilot project with the German municipal operator Stadtwerke Landshut.

The company points out that the first e-troFit conversion kit is already available for the Citaro I Solobus city bus. For city buses, e-troFit kits are planned for the Citaro II Solobus (from mid-2020) and the Citaro II articulated bus (from Q4 2020). e-troFit also plans to offer kits for other city buses from other manufacturers, according to e-troFit.

According to e-troFit, a conversion is on average 50% cheaper than a new vehicle with electric propulsion. So, the operation would cost almost as much as buying a new Euro VI bus. Of course, the price depends on several elements, such as, in particular, the battery capacity (which can be adapted to the operator's needs). The modular lithium-ion battery modules based on NMC (nickel-manganese-cobalt) (60 kWh each, the desired capacity can be achieved by connecting them in parallel) are installed in the former internal combustion engine compartment. If a larger battery capacity is required, part of the battery can be installed on the roof. This would require some reinforcement work on the bodywork [3].

The e-troFit solution has been awarded the German Mobility Prize by the German Federal Ministry of Transport and Digital Infrastructure.

The price of e-troFit retrofit kits, including the electric conversion of diesel buses, ranges from around €300 000 to €360 000, depending on the vehicle model and range requirements.

In Germany, city buses cover an average of 150-180 km per workday. A converted electric bus with a range of around 250 km could replace diesel-powered city buses without restriction. No time-consuming rerouting is needed.

The following components are replaced during the conversion [4]:

Drive train and battery: the diesel engine, gearbox and drive shaft are removed. For the electric drive, a new drive shaft is installed. The ZF (AVE130) electric low-floor portal shaft is used for city buses. It has two electric motors close to the wheels. The battery is installed in the newly won space (engine compartment). If required, additional battery capacity can be installed on the roof.

Auxiliaries: all auxiliaries previously driven by the internal combustion engine, such as the air conditioning system, air compressor, pumps, and radiator, are removed and replaced by electrically driven components. An optimal control system that takes over the operation of these components guarantees the most efficient use of energy.

Driver's cab: An additional display is installed in the driver's cab to inform the driver of the vehicle's status, charge level and any faults.

Figure 1. e-trofit Bus [4]

The electric portal axle of the ZF AxTrax Ave is used in city buses: the drive is provided by a compact, high-speed, and liquid-cooled asynchronous motor per wheel, so that the axle's weight with the integrated motors remains low. The motor has a maximum power of 250 kilowatts and a maximum torque of 22 000 Nm.

Since neither a separate motor nor a cardan shaft is required, space requirements and vehicle weight are reduced. The space saved allows the installation of a more powerful battery or the optimization of the vehicle's interior to carry more passengers. The AxTrax Ave requires no special wheel components. This means that the tire and rim combinations used on conventional buses can be used, as well as conventional disc brakes. The brakes are in the same maintenance-friendly position as on normal axles.

Road registration - a vehicle converted with an e-retrofit kit is delivered ready for operation and road registration [4].

3. COOLING AND HEATING SYSTEM FOR BUSES

A traditional heating and cooling system is shown in the following figure.

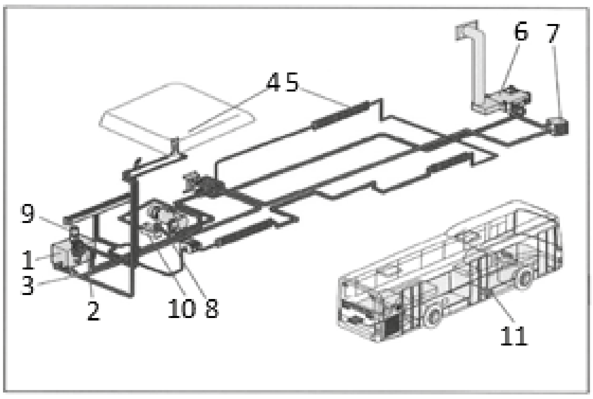

Figure 2. Volvo 7000 bus (Diesel bus) heating and cooling system [5]

The following components are found in a typical bus's heating and cooling system (as shown in Figure 2.).

1 - engine; 2 - heating forward line shut-off valves; 3 - main shut-off valves in the return line; 4 - roof unit; 5 - passenger compartment heaters; 6 - dehumidifier (air mixer for the cab); 7 - heating for the cab; 8 - heating unit; 9 - auxiliary heating system pump; 10- flow-through electric water heater; 11- electric heater

Heating and ventilation example data (Volvo 7900 Diesel – 12 m bus) [6]:

The bus has a water heating system with 2-tube heating radiators and fans, which can be controlled manually or automatically. There is an Additional heater for engine preheating, dehumidification, and passenger compartment heating. The heater has a pre-programmable (7-day programming option) clock. The bus has a built-in heating, ventilation, and air conditioning (HVAC) system to ensure a comfortable temperature.

- Convector heating:
  - o Power: 551 W/m.
- Fan heating for cab and front door, baby area and second door: data per fan:
  - o Power: 2.8 kW.
- Total power of convectors (including fans): 2.1-3.4 kW, depending on specification.
- An auxiliary heater heats the passenger compartment, defrosts the windscreen and preheats the engine. A 7-day timer available for programming the heater.
  - o Auxiliary heater capacity: 30 kW.
  - o Fuel consumption: 4.0 kg/h.
  - o Auxiliary heater fuel tank: 40 l.
- Cooling, heating air conditioning system for cooling the passenger compartment.
  - o AC cooling capacity (passenger compartment): 33.7 kW.
  - o Heating power: 46 kW.
  - o Roof-mounted driver air conditioning: 3.5 kW.

It should be noted that the thermal energy demand of the heating system is primarily provided by the cooling system of the internal combustion engine (apart from the auxiliary heating system).

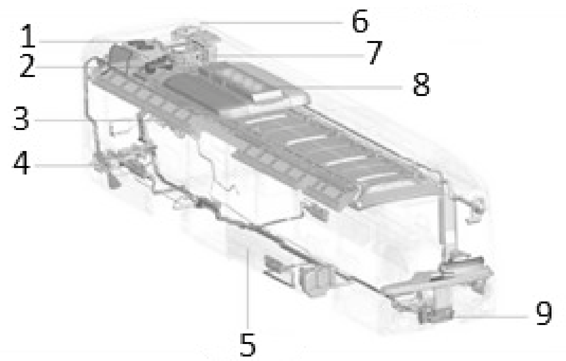

Figure 3. Thermal management architecture of the EvoBus eCitaro (full Electric bus) [7]

The components relevant to the internal heating are the CO_2 heat pump (8) on the top of the bus, the rear brake resistor (3), the rear auxiliary heater (4), the underfloor heating (5) and the front box (9). Additional elements in the system: battery cooler (1), compressor HVAC (2), expansion tank (6) and cold-water chiller (7). The roof-mounted CO_2 heat pump injects heat into the interior via the airflow from above, into the passenger compartment. A braking resistor is used to heat the interior, energy recovery and emergency braking. The auxiliary heater is a fuel heater burning diesel fuel (or biodiesel fuel for second-generation heaters). The auxiliary heater may be used at very low temperatures when the heat capacity of the heat pump is insufficient, and no additional electrical energy is required for heating to maintain the range of the bus. In order to transfer the heat from the brake resistor and the auxiliary heater to the vehicle's interior, both are connected to a coolant circuit. The coolant circuit is connected to the floor heaters in the passenger compartment and to the front box in the driver's cab, which are heat exchangers used to transfer the coolant heat into the passenger compartment [7].

Heating and ventilation example data (Volvo 7900 Electric – 12 m bus) [8].

- Roof mounted HVAC unit (heating, ventilation, and air conditioning, including heat pump function).
- Pipe convectors and air blowers.
- Air blowers at doors.
- Defrosting with air conditioning.
- Auxiliary diesel/electric heater.
- Separate air conditioning zones for drivers and passengers.
- The passenger compartment temperature is controlled by a pre-set optimization function for optimum climate and energy efficiency.
- The temperature in the driver's cabin can be manually adjusted.

Roof heating mode:

- 28 kW Wet heating circuit.
- 9 kW Heat pump (air/air).

AC mode (humidity - 35/40/47%): 25 kW.

Defroster (defrosting):

- Heating (differential temperature: 80 °C) 18 kW.
- Cooling 5,5 kW.

Ducted air conditioning:

- Electric roof-mounted air conditioner connected to the defroster.
- Standard equipment: defroster connected to the passenger compartment air conditioning system.

Auxiliary heating:

- Fuel (Diesel/Biodiesel) 16 kW.
- Electric 14 kW.

Comparing the two data systems shows the difference for the new electric buses (heating/cooling heat demand). It is important to point out that the heat demand for the battery packs needs to be discussed in the context of electric buses.

As battery use has grown, the efficient storage and energy extraction from batteries have become the foreground. Furthermore, among some other parameters, the operating temperature of an electric vehicle battery plays an important role in its performance [9].

Internal heat generation also limits the performance of lithium-ion batteries. The operating temperature range of electric vehicle lithium-ion batteries is between 15°C and 35°C, which is maintained by the battery thermal management system (BTMS).

The effect of temperature on battery performance:

Battery cells lost more than 60% of their initial performance after 800 cycles at 50°C and 70% after 500 cycles at 55°C. Cycle life Li-ion battery life at 45°C is 3323 cycles, which drops significantly to 1037 cycles at 60°C. This suggests that temperature has a significant effect on the cycling life and energy capacity of the battery.

The BTMS is the battery's thermal management system, essentially the brain of the battery. BTMS can be classified primarily based on power consumption, heat consumption, heat transfer medium and coolant to battery contact. Air cooling, liquid cooling, and phase change material (PCM) cooling are the conventional techniques [9].

- Air-cooled BTMS
  - Air cooling is the natural method of cooling the battery and can be further classified as free and forced convection cooling. The main advantages are simplicity, low cost, electrical safety, lightweight, no leaks, easier maintenance, etc.
- Liquid-cooled BTMS
  - Liquid cooling gives better thermal performance and cooling efficiency. It is the most common technique for directly or indirectly cooling batteries (used in contact with a coolant).
- PCM-based BTMS
  - Due to the high latent heat, PCMs can absorb a huge amount of heat generated by Li-ion batteries and reduce the temperature of the battery cells while keeping them within the melting range of the PCM.
- Heat-Pipe-based BTMS
  - Heat pipe (HP) based passive TMS have been widely used in recent years for temperature control of batteries. Heat pipes are heat transfer devices filled with small amounts of liquid.
- Hybrid BTMS
  - The literature shows that air, liquid, PCM, HP and ammonia cooling can maintain the thermal management of a battery. Keeping the battery pack within the desired thermal management range has been observed, but it has also been observed that the limitations of a single technique, limit the best possible performance - thermal management. A combination of two or more cooling methods should be used to integrate the advantages and overcome the disadvantages. Cooling systems, called hybrid cooling, have been studied and developed by researchers.
- Other battery cooling techniques
  - More recently, hydrogels, cold hydrogen plates, vortex generators, thermoelectric coolers, etc., have been used to manage the heat in batteries and battery packs.

It is important to note that not only cooling but also heating needs to be given a lot of attention.

A notable feature of Li-ion batteries at sub-zero temperatures is a significantly reduced discharge capacity. At -10°C, a 2.2 Ah capacity of 18650 cylindrical cells could only maintain a discharge capacity of about 1.7 Ah at a discharge rate of 1C, and a lower discharge capacity could be achieved at higher discharge rates (about 0.9 Ah at 4.6C). A reduced discharge capacity would reduce the energy provided by the battery [9].

Different preheating techniques are briefly described below [9].

- Liquid heating
  - Compared to air, liquid has a higher heat transfer efficiency, resulting in better inter-cell temperature uniformity. Therefore, the liquid is widely used as a heat transfer medium in BTMS systems.
- Conduction heating
  - In conductive heating, the heat source elements directly interact with the Li-ion cells or modules. Therefore, the heat generated by the heating elements can be conducted directly to the battery cells and heat them up, reducing heat loss in the heat transfer path.
- Internal heating
  - Internal heating typically takes advantage of the high impedance of low-temperature batteries to generate large amounts of electrochemical heat inside the cells when current is applied.

The issue of heating and cooling solutions for electric buses is more complex. In addition to the driver and the travelling passengers, attention must also be paid to the proper temperature control of the battery pack.

4. SUMMARY

This study investigated the heating/cooling solutions of a conventional combustion engine bus (diesel) and an electric bus. The typical parameters of the heating/cooling solutions under investigation are also presented, which allow an approximate estimation of a new conversion process. The present work is a preliminary study that estimates the heating/cooling requirements for converting an old/conventional internal combustion engine city bus. In addition, the possible solutions between different heating and cooling solutions are of particular interest. In a joint project (unfortunately, due to the specific nature of the project, it contains confidential information, so we cannot describe the conversion process and its parameters in detail in this study), the preliminary design of a heat pump provides complete heating, and the cooling solution was considered. The bus to be converted in this project is of a completely similar size and performance as the buses presented in chapter 3, so we expect very good operating parameters from the selected heating/cooling solution. A particular highlight of the conversion is the possibility of accommodating battery packs. In the case of all-electric buses (new build vehicles), the battery packs have a predefined regular and well-cooled/heated location. However, the project under study has irregularly placed battery pack systems in several locations, so a complex solution for heating/cooling had to be applied. The project involves rebuilding a converted bus that can be used in Hungarian traffic.

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