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Application problems and challenges of low-temperature homogeneous combustion engines

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Abstract Given the efforts towards a complete ban on combustion engines in passenger cars after 2035, many European car manufacturers are shifting their focus to battery electric vehicles. However, the adoption of exceptions for climate-neutral fuels is very good news for the future of the automotive industry in the EU. This is because it will provide a significant alternative to battery electric vehicles in the form of combustion engines utilizing alternative fuels, which are likely to play an important role, especially in sectors where the use of battery electric propulsion is inefficient. Additionally, vehicles with combustion engines continue to be the most popular choice among customers due to their undeniable advantages. Research and development in this field will remain highly relevant as combustion engines are also a significant element of hybrid technologies. Low-temperature combustion of homogeneous fuel mixtures is among the key technologies with strong potential.

Keywords challenges, homogeneous, combustion engines

1. INTRODUCTION

The transportation sector is currently responsible for a significant portion of greenhouse gas emissions and is also a major contributor to pollution in urban areas. This has led to increasing pressure on the automotive industry, which faces constant challenges to significantly reduce emissions and utilize renewable energy sources. Zero-emission propulsion primarily refers to emissions-free operation of the vehicle during its driving stage. However, attention must also be paid to the entire lifecycle of the vehicle, including its production and operation chain. This involves considering the entire supply chain, encompassing the automobile manufacturing, fuel production, vehicle usage stage, and recycling. The lack of infrastructure for charging electric vehicles, as well as the safety and potential cost of battery replacement, can pose challenges. However, vehicles with combustion engines continue to be the most popular choice among customers due to their undeniable advantages. Research and development in this field will remain highly relevant as combustion engines are also a significant element of hybrid technologies. One potential solution could be Low-Temperature Combustion (LTC) technology, which combines the best characteristics of compression ignition and spark ignition combustion, such as high efficiency and low emissions. When coupled with the current application of sustainable synthetic fuels, various LTC variants could represent a potential alternative to electric propulsion.

2. EU EMISSIONS TARGETS

Since the adoption of the first EURO standards, pollutants from car exhausts have been measured according to the New European Driving Cycle (NEDC). This cycle involves a series of tests based on engine acceleration and deceleration in testing facilities. However, it was later revealed that the emissions produced during laboratory tests were significantly different from real-world conditions. Therefore, since 2017, the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) has been implemented. It considers higher speeds, more authentic acceleration and deceleration, allowing for a more accurate and realistic simulation of real-world conditions. The current EURO 6 standard has been gradually modified, receiving an additional letter with each update. Since January 2021, the Euro 6d standard has been in force. According to some sources, emissions such as CO are expected to decrease by half compared to the currently valid Euro 6d standard.

Continuous greening of transportation is necessary, and several countries, such as Austria and Germany, are implementing restrictions on entry into cities for vehicles that do not meet emission standards. This causes inconveniences, especially for owners of older cars [1,2].
Figure 1 depicts a Roadmap illustrating the historical development and planned targets for reducing the carbon footprint. According to available information, the European Union aims to achieve a 37.5% reduction in average CO_2 emissions from new vehicles by 2030. Between 2025 and 2029, cars and vans will be required to emit 15% less CO_2. Since 2030, the CO_2 emissions of new deliveries must be 31% lower on average compared to 2021. At the same time, the plan is to achieve -100% CO_2 emissions for new cars by 2035.

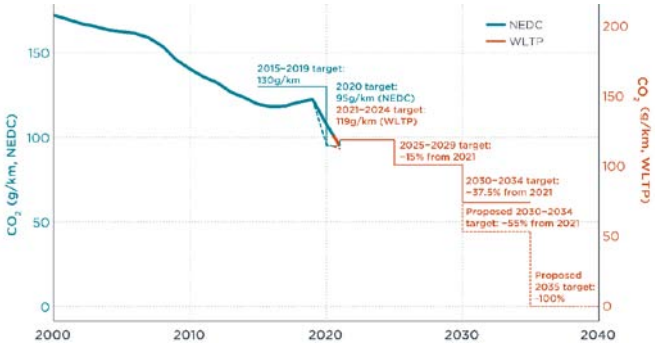

Figure 1 Historical development and planned targets for reducing CO_2 emissions according to NEDC and WLTP [3]

3. LOW - TEMPERATURE COMBUSTION TECHNOLOGY

At a certain level of air-fuel ratio, the combustion rate decreases and the combustion stability deteriorates during flame propagation combustion. In the pursuit of finding a compromise between fuel consumption and combustion stability, it is necessary to find a way to reliably execute the combustion process. This technology is referred to as Low-Temperature Combustion (LTC) and has been primarily developed as a solution for reducing NOx emissions. NO_X formation can mostly be prevented by maintaining the local temperature below approximately 2200 K. This condition can be achieved by burning an extremely lean fuel mixture. The LTC concept can also be extended to the concurrent reduction of particulate matter, depending on the local equivalence ratio. LTC combines the best characteristics of diesel and spark-ignition combustion, namely high efficiency and low emissions. The main concept is to create a very lean mixture, preferably homogeneous, capable of potentially autoigniting at a single moment and throughout the entire volume. Solving the entire issue is quite complex. Figure 2 illustrates the challenges that must be overcome for the successful implementation of the entire LTC concept [4].

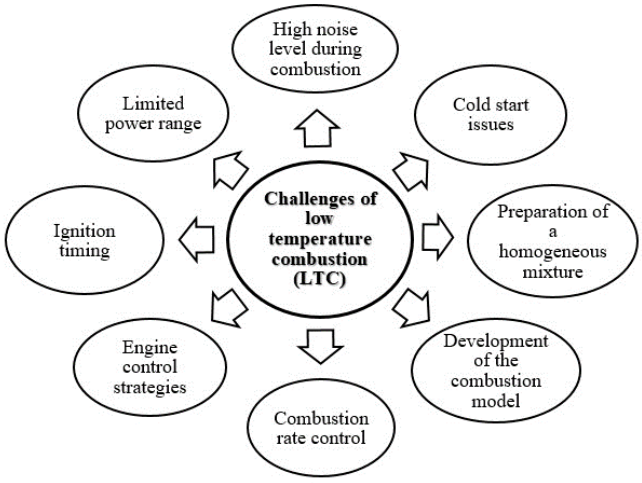

Figure 2 Application issues and challenges of low-temperature combustion engines.

Several combustion technologies can be classified as LTC, which are subject to development aiming for long-term reliability. They mainly differ in the fuel-air mixture preparation process and ignition concept. The homogeneous lean mixture that reduces both NO_X and PM emissions also poses a problem during ignition [5,6].

Relevant LTC technologies with development and application potential include:

- HCCI (Homogeneous Charge Compression Ignition),
- PCCI (Premixed Charge Compression Ignition),
- SCCI (Stratified Charge Compression Ignition),
- RCCI (Reactivity Controlled Compression Ignition),
- SACI (Spark Assisted Compression Ignition).

Several automakers, such as General Motors (GM), Mazda, Mercedes Benz, and Hyundai, are investing in the development of LTC technologies, and the current emission challenges confirm the validity of this step. Mazda, in particular, considers an engine utilizing LTC as a pathway to a better electric future: "We believe it is essential to pursue the ideal internal combustion engine," stated Mazda's Head of Research and Development, Kiyoshi Fujiwara. "Electrification is necessary, but the internal combustion engine should take precedence."

4. CONCLUSIONS

Low temperature combustion (LTC) is the latest engine technology that can simultaneously reduce nitrogen oxides (NOx) and soot emissions while maintaining higher thermal efficiency. Over the past decades, various engine strategies have been employed to reduce exhaust emissions and increase thermal efficiency. Exhaust gas recirculation, variable valve timing (VVT), and advanced fuel injection technologies are adapted to achieve the LTC mode in combustion engines, resulting in improved outcomes. Along with sustainable synthetic fuels, LTC provides a solid foundation for further development and the achievement of carbon neutrality goals [7-9].

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