energies

Editorial

Diesel and Spark Ignition Engines Emissions and After-Treatment Control: Research and Advancements

Evangelos G. Giakoumis

Internal Combustion Engines Laboratory, School of Mechanical Engineering, National Technical University of Athens, Zografou Campus, 15780 Athens, Greece; vgiakms@central.ntua.gr; Tel.: +30-210-772-1360

Received: 26 October 2017; Accepted: 3 November 2017; Published: 16 November 2017

1. Introduction and Motivation

One of the major risks mankind has encountered during recent years is, without a doubt, the anthropogenic contribution to environmental pollution. This has posed a substantial burden on human health, but also on the global economy. The pollutants that are now widely recognized as the most harmful to humans are particulate matter (PM), nitrogen dioxide (NO_2) and ground-level ozone (smog) [1,2]. Long-term and peak exposures to these pollutants range in the severity of impact, from increases in the risk of non-allergic respiratory symptoms and disease to premature death. In parallel, one relatively recent issue is global warming; the latter is responsible for various environmental impacts such as extreme weather conditions and sea level rise. The main culprit here is excessive green-house gas (GHG) emissions, with carbon dioxide (CO_2) assuming the largest share.

There is a growing awareness that on-road vehicles are among the key contributors to the environmental degradation in both forms mentioned above, i.e., toxic pollutants and CO_2 emissions. For example in Europe, the road transport sector alone (includes, among others, passenger cars, motorcycles, and heavy vehicles) is responsible for emitting 30% of the total nitrogen oxide (NO_x) emissions in 2015, 25% of total carbon monoxide (CO), and 8% of PM 2.5 and NMVOC (non-methane volatile organic compounds). Furthermore, road transport contributes about 20% of the EU's total emissions of CO_2 [1], with the situation being, overall, similar in other major countries such as USA or Japan [3].

It is the internal combustion (I.C.) engines, either in the form of compression ignition (diesel) or spark ignition engines, that have dominated the (automobile and truck) road sector for many decades now, and are thus responsible for many of the aforementioned negative environmental issues. The ability of the internal combustion engine to operate efficiently over a wide speed and load operating range, its good drivability as well as its low initial and maintenance costs have been major contributing parameters for this dominance.

The earliest indication of vehicle-related effects on urban pollution appeared in the 1940s in Los Angeles in the form of the photochemical smog. A few years later in 1959, these developments led to the establishment of the first emission standards from motor vehicles, initially regarding CO and hydrocarbons (HC). The setting of these first limits opened a new chapter in the development of all kinds of engines and vehicles by introducing the terms 'emission level' and, perhaps more importantly, 'emission control'. Following the example of the U.S., other areas, such as Europe and Japan, legislated emission limits from motor vehicles in the late 1960s to the early 1970s, with India, China, Australia, Canada, South Korea and other countries following in the next years. These emission limits were soon expanded to cover NO_x and, during the 1980s, particulate matter too; the latter was motivated by the increasing use of turbocharged diesel-powered trucks, which notoriously emitted black smoke from their exhausts during acceleration or (cold) starting. At the same time, the use of cleaner fuels was initiated, with biofuels appearing in the next decades and playing now an important role in the endeavor towards a cleaner environment [3].

One particular aspect of the vehicular engines' operation, essentially being predominantly responsible for the emitted pollutants from I.C. engines, is their transient operation. The latter can be realized in the form of increasing speed (acceleration), load and/or (cold or hot) starting. Obviously, the continuously changing daily driving conditions are responsible for the automotive engines operating (practically) under constantly dynamic conditions, particularly in urban areas, which are also the most 'sensitive' ones regarding emissions, as these are often densely populated. Acknowledging the importance of transient engine operation to the amount of emitted pollutants (CO_2 too), the authorities have legislated driving (i.e., transient) cycle measurement procedures for the certification of new vehicles/engines. The pioneering country was again the USA, followed by Europe (mostly through UNECE regulations) and Japan. Recently, worldwide driving cycles for light-duty vehicles (i.e., the WLTC cycle and the WLTP procedure), heavy-duty engines (transient WHTC and steady-state WHSC) and motorcycles (WMTC cycle) have been developed too by special UNECE sub-committees, based on measurements and real driving data collected from a variety of regions in the world [3]. These cycles, of higher level and accuracy in terms of representativeness, are being gradually enforced into the legislation of many countries all over the world. Nonetheless, it is rather safe to assume that no (legislated) cycle will ever be fully representative of the real-world driving activity. That is why real driving emissions (RDE) tests are gaining increased attention in the legislation as, for example, the one to be implemented during the EU certification of new passenger cars.

During the early years of emission standards, internal measures were usually adequate, and therefore adopted by the manufacturers, to cope with the emitted pollutants. As the standards became increasingly stricter, internal measures alone were not sufficient anymore. Sophisticated after-treatment devices was the next logical step towards cleaner exhausts. Nowadays, conventional, port fuel injected, SI-powered vehicles are equipped with three-way catalytic converters for the mitigation of CO, HC and NO_x. The most advanced, in terms of after-treatment, diesel engines, on the other hand, employ a much more complicated emissions abatement scheme incorporating a diesel oxidation catalyst (for CO and HC emissions control), diesel particulate filter (DPF—for particulate matter control) and, recently, a deNO_x catalyst, usually in the form of a SCR (selective catalyst reduction) or lean NO_x trap. In any case, internal measures have not been abandoned, with EGR (exhaust gas recirculation) for NO_x control being the most prominent one.

2. Outline of the Submitted Works

The articles contained in the Special Issue "Automotive Engines Emissions and Control" [4–13] were published online by *Energies* between September 2016 and October 2017; they deal with various issues of automotive engines emissions and after-treatment control. Both diesel and spark ignition engines are covered, under stationary and transient conditions. Most of the works investigate in-cylinder emission mechanisms, and the effect of engine parameters on them from an experimental or simulation point of view.

There are four papers that incorporate in their analysis the effects of biofuels [4–7], two on diesel and two on SI engines operation. This is actually a very timely subject, as biofuels, being by nature renewable, can offer distinctive advantages over conventional fuels. For example, they support local agricultural industries, reduce the countries' dependence on oil imports, and offer benefits in terms of sustainability and reduced carbonaceous pollutant emissions; further, from an economic point of view, they are more evenly distributed than fossil or nuclear resources, since they can be produced domestically. A wide range of biofuels is studied in this Special Issue, namely biodiesel, ethanol, butanol and dimethyl ether. More specifically, Yu et al. [6] experimentally investigate wall film distribution effects of dimethyl ether-diesel blended fuels, with the aim of reducing the pollutants formed during spray wall impingement. Tziourtzioumis and Stamatelos [7] focus on biofuel blends injection and combustion effects of a single cylinder, direct-injection (DI) diesel engine applying a spray visualization system and Laser Doppler Velocimetry. In this paper, various blends of biodiesel (consisting of rapeseed oil, soybean oil and recycled cooking oils) with diesel fuel are under consideration, ranging from 20 to 100% (neat biodiesel). Two other papers focus on SI engine operation; Papagiannakis et al. [5] report on the theoretically-studied effects of spark timing on the performance and emissions of a single-cylinder, four-stroke, light-duty SI engine running under gasoline, (neat) ethanol or (neat) butanol fuel operating modes. Unlike their conventional counterparts, direct injection SI (DISI) engines, being characterized by partially premixed combustion resembling that of the compression ignition engine, are not exempt from PM emissions; actually this is something that has been reflected in the European legislation beginning with the Euro 5 emission standard. To this aim, Merola et al. [4], applying cycle-resolved flame imaging, study the effects of fuel injection strategy on the carbonaceous structure formation and nanoparticle emission of a single-cylinder, optically accessible DISI engine fueled with butanol.

After-treatment matters of diesel engines constitute another important component of this journal edition. The focus in [8] and [9] is on selective catalyst reduction (SCR) operation. SCR, being the most recent development regarding diesel engine after-treatment technologies, is required by the Euro 6/VI emission standards, which has taken effect in Europe and other countries from 2013. More specifically, Leistner et al. [8] developed a procedure for liquid-ion exchange of SAPO-34 with Cu in a SCR. By studying the impact of copper loading on NH_3-SCR, oxidation reactions and N_2O formation over Cu/SAPO-34, an in-depth analysis of SCR operation mechanisms is offered to the interested reader. On the other hand, Li et al. [9] propose and report on a dynamic injection system of urea-water solution for a vehicular SCR running on the ETC (European Transient Cycle, applied for the certification of heavy-duty engines in the EU during the Euro III, IV and V standards, as well as in China, India and other countries). The aim was to inhibit ammonia slip from a six-cylinder medium-to-heavy-duty DI diesel engine, while maintaining high NO_x conversion efficiency; a remarkable 91% reduction in the NH_3 slip is reported.

The critical issue of transient engine operation is mainly dealt with in [10], as regards both pollutants (NO and soot) and carbon dioxide emissions from a large diesel-powered van. In this paper, the effects of driving cycle schedules are also discussed. The newly developed WLTC driving cycle for light-duty vehicles is under investigation (to be implemented in Europe from September 2017), further compared to the NEDC employed for vehicle certification in Europe (1992–2017) and other countries such as Australia, China and India. Apart from [10], the issue of CO_2 emissions is also investigated in [11]; Andwari et al. report on another very timely subject, namely organic Rankine cycle (ORC) waste-heat recovery (WHR). A six-cylinder, heavy-duty diesel engine is in the focus of their research, and two WHR strategies, namely ORC and turbo-compounding, are studied and compared on a simulation basis using the GT-Power® software.

The last two papers focus on engine control issues closely related to engine emissions. In [12], a methodology is presented to adjust the electronic control system of a reciprocating I.C. engine test bench, and the effects the control parameters have on the emissions from a four-cylinder, light-duty turbocharged diesel engine are presented and discussed; this paper too focuses on transient engine operation. Lastly, in [13], the authors outline a procedure for the computer-controlled calibration of a thermodynamic simulation model of a turbocharged I.C. engine with the aim to determine input parameters of the simulation model in such a way to achieve the smallest difference between the results of the measurements and the results of the numerical simulations. This procedure too may prove beneficial with regard to modeling emissions from I.C. Engines.

3. Conclusions

Diesel and SI engines combustion and emissions have been in the focal point of research for many years now, owing to the automobile engines playing a key role in the transportation sector and, at the same time, contributing heavily to pollutants and CO_2 emissions. The present Special Issue, focusing on various emissions-related subjects of I.C. engines operation, such as in-cylinder emission mechanisms, use of biofuels, SCR after-treatment control, transient operation and WHR schemes, was conceived with the aim to contribute towards a better understanding of the underlying (anti)pollution mechanisms, and it is hoped that, at least in part, this aim has been fulfilled.

Acknowledgments: The author would like to thank Energies, MDPI for giving him the chance to organize the Special Issue "Automotive Engines Emissions and Control". Special thanks are due to the staff at Energies for their continuous support. The Editor is also grateful to all contributors; without their high-quality research, this project could not have been realized. The gratitude is extended to the referees of the submitted papers for conducting thorough and detailed reviews that have contributed to the high scientific level of the published articles.

Conflicts of Interest: The author declares no conflict of interest.

Nomenclature

NH_3	Ammonia
UNECE	United Nations Economic Commission for Europe
WHSC	Worldwide Harmonized Steady-state Cycle
WHTC	Worldwide Harmonized Transient Cycle
WLTC	Worldwide harmonized Light-duty driving Test Cycle
WLTP	Worldwide harmonized Light-duty vehicles Test Procedure
WMTC	Worldwide harmonized Motorcycle Test Cycle

References

1. European Environment Agency Website. Available online: http://www.eea.europa.eu (accessed on 23 October 2017).
2. WHO Regional Office for Europe. *Economic Cost of the Health Impact of Air Pollution in Europe: Clean Air, Health and Wealth*; WHO Regional Office for Europe: Copenhagen, Denmark, 2015.
3. Giakoumis, E.G. *Driving and Engine Cycles*; Springer International Publishing: Cham, Switzerland, 2017.
4. Merola, S.S.; Irimescu, A.; Di Iorio, S.; Vaglieco, B.M. Effect of fuel injection strategy on the carbonaceous structure formation and nanoparticle emission in a DISI engine fuelled with butanol. *Energies* **2017**, *10*, 823. [CrossRef]
5. Papagiannakis, R.G.; Rakopoulos, D.C.; Rakopoulos, C.D. Theoretical study of the effects of spark timing on the performance and emissions of a light-duty spark ignited engine running under either gasoline or ethanol or butanol fuel operating modes. *Energies* **2017**, *10*, 1198. [CrossRef]
6. Yu, H.; Liang, X.; Shu, G.; Wang, X.; Wang, Y.; Zhang, H. Experimental investigation on wall film distribution of dimethyl ether/diesel blended fuels formed during spray wall impingement. *Energies* **2016**, *9*, 949. [CrossRef]
7. Tziourtzioumis, D.N.; Stamatelos, A.M. Experimental investigation of the effect of biodiesel blends on a DI diesel engine's injection and combustion. *Energies* **2017**, *10*, 970. [CrossRef]
8. Leistner, K.; Brüsewitz, F.; Wijayanti, K.; Kumar, A.; Kamasamudran, K.; Olsson, L. Impact of copper loading on NH_3-selective catalytic reduction, oxidation reactions and N_2O formation over Cu/SAPO-34. *Energies* **2017**, *10*, 489. [CrossRef]
9. Li, L.; Lin, W.; Zhang, Y. A new dynamic injection system of urea-water solution for a vehicular select catalyst reduction system. *Energies* **2017**, *10*, 12. [CrossRef]
10. Giakoumis, E.G.; Zahiotis, A.T. Investigation of a diesel-engined vehicle's performance and emissions during the WLTC driving cycle—comparison with the NEDC. *Energies* **2017**, *10*, 240. [CrossRef]
11. Andwari, A.M.; Pesiridis, A.; Esfahanian, V.; Salavati-Zadeh, A.; Karvountzis-Kontakiotis, A.; Muralidharan, V.A. Comparative study of the effect of turbocompounding and ORC waste heat recovery systems on the performance of a turbocharged heavy-duty diesel engine. *Energies* **2017**, *10*, 1087. [CrossRef]
12. Payo, I.; Sánchez, L.; Caño, E.; Armas, O. Control applied to a reciprocating internal combustion engine test bench under transient operation. Impact on engine performance and pollutant emissions. *Energies* **2017**, *10*, 1690. [CrossRef]
13. Prah, I.; Trenc, F.; Katrašnik, T. Innovative calibration method for system level simulation models of internal combustion engines. *Energies* **2016**, *9*, 708. [CrossRef]