Conference Summary
42nd International Vienna Motor Symposium, 2021

This is a summary of engine and emissions control related content presented at the 42nd International Vienna Motor Symposium 2021, held in a digital format this year.

Spark Ignition (SI) Engines

Nissan described the improvements in its new “KR15DDT” 1.5L, 3-cylinder turbocharged engine. The engine combines various advanced technologies such as variable compression ratio (CR 8:1 to 14:1), low-P cooled exhaust gas recirculation (c-EGR, up to 20% with exhaust gas extracted after the first catalyst), 350 bar injection and modified intake port and piston for increased tumble flow. Best brake specific fuel consumption (BSFC) of 220 g/kWh achieved. Peak power is 150 kW, or 100 kW/L. The engine is envisioned to be part of Nissan’s “e-POWER” strategy of integrating the engine with an electric powertrain and running it in the highest efficiency region to charge the battery.

Audi presented the steps it took for optimizing combustion for the 2.0L R4 TFSI engine for racing cars, which achieved 42% efficiency at peak output power of 440 kW.

IFP, Valeo and Garrett presented their work on improving the efficiency of SI engines, through a concept they term “SWUMBLE”, which improves engine air charge flow via high levels of swirl and tumble. 1.2L 3-cyl. engine, 350 bar direct injection, VNT, EGR. VNT was used with durability to 980 °C. Peak brake thermal efficiency of 41%, with EGR rates at 25% and peak power of 90 kW/L and lowest BSFC ~ 240 g/kWh. Simulation show ~ 10% reduction in CO₂ on the WLTC for a reference C-segment vehicle.

As more technologies are being added to modern engines, combustion control and variability can be more challenging. Hyundai discussed the use of in-cylinder pressure sensors (ICPS) to address these issues. A new ICPS from Vitesco was applied to the new Smartstream 2.5L GDI engine featuring dual GDI + PMI injection system, Atkinson cycle and cooled EGR. Close-loop combustion control enabled by the sensor led to an improvement in fuel economy by 2 – 5% on the US test cycles.

High pressure injectors are advancing. Marelli gave an update on their 700 bar injectors capable of up to 7 injections of 1 mm³ per cycle with 200 µs dwell time. This has been recently commercialized in Mazda’s spark-controlled compression ignition (SPCCI) engine, enabling operation at high compression ratio (CR) of 16.3 and resulting in an improved fuel consumption – NOx trade-off.

Diesel Engines

Do not discount diesels just yet, they are still improving significantly. On the light-duty side, Punch Torino and GM discussed improvements made to the new 2.0L 4-cylinder diesel engine. The engine is applied to the new Cadillac XT4 SUV and Opel Insignia. The latter emits 121 – 128 g of CO2 per km on the WLTP, a ~ 30 g/km or 18% reduction compared to the previous model year. This is comparable to modern gasoline hybrids. There were several incremental improvements made starting with the previous 1.5L engine, such as the use of steel pistons with optimized bowl design, model based air, boost and EGR control,
use of a variable geometry turbocharger, and optimized combustion modes to address variety of driving conditions. Both high-P and cooled low-P EGR are used. The vehicles are fully compliant with Euro 6d, and after-treatment used is close-coupled DOC and SCR on filter, followed by an underfloor SCR and ammonia slip catalyst. Single dosing is used, showing the potential improvement for Euro 7 with dual dosing.

**Volkswagen** described the improvements in their latest generation of the EA288 engine applied for light commercial vehicles in Europe. The added features help the 2.0L engine comfortably meet the Euro 6d final emission regulations. The fuel injection system has been upgraded to 2500 bar (from the previous 2200 bar) and injectors use solenoid valve technology to deliver up to 9 injections. Both high- and low-pressure cooled EGR is used across most of the engine map. Uncooled HP-EGR is used in the cold start and low load operating points to assist with fast exhaust heat-up. A two-stage high- and low-pressure serial turbocharging system including bypass is used to manage the boosting requirements. An electrical actuator is added to manage the variable turbine geometry of the HP turbocharger. A first for VW’s commercial segment, the emissions after-treatment system includes a close-coupled DOC and SDPF (filter with SCR). This is followed by underfloor SCR and ammonia slip catalysts, with a separate urea dosing system. The accurate metering of urea injection allows for early light-off, fast response to dynamic driving and treatment of NOx during DPF regeneration. The combination of all of the above technologies helps the new vehicles meet Euro 6d final norms comfortably. NOx emissions were reduced by ~ 55% on real-world driving cycles while CO2 emissions were also reduced by 3 – 6% on the WLTP, compared to the previous Euro 6d-temp version.

A presentation by **Darmstadt University of Technology, Umicore** and other collaborators showed simulation results for pre-turbo catalysts for passenger cars. Either a DOC + SCR or an SCR only system was evaluated with overall pre-turbo catalyst volume ~ 3 – 5L. The former system benefits from high NO2 make on the DOC while the latter enjoys faster SCR heat-up. This concept is expected to work in a mild hybrid ecosystem which provides for electric boosting to make up for lost transient response from the turbocharger.

**Bosch** presented their view on achieving Euro 7 / VII and zero-impact emissions. It was shown that for both gasoline and diesel, light- and heavy-duty vehicles, it is possible to significantly lower the tailpipe emissions over a wide range of very dynamic driving conditions. Use of large catalyst volumes, improved engine control, electrically heated catalyst (EHCs), burners and other measures will be helpful. For diesels, the use of a light-off SCR was discussed (DOC + SCR + SCR on DPF + SCR + ASC) along with increased SCR size was shown to reduce NOx by 36% on a challenging drive cycle. Mild hybridization was shown to further reduce NOx by 36%. Still it was cautioned that boundary conditions of upcoming regulations should be set to cover the practical diving conditions, while setting limits for the combination of extreme conditions could lead to a very high cost to benefit ratio.
Heavy-duty diesel engines are also improving, faced with both tightening NOx and CO2 regulations. Daimler showed the features on its new Detroit DD15 inline 6-cylinder engine launched for the US market for Class 8 trucks in 2021. Peak cylinder BTE > 48% is achieved over a wide operating area of the engine map. Compared to the previous baseline, the new engine has 3.4% lower fuel consumption and meets the 2024 Phase 2 GHG requirements. Several improvements were cited, including redesigned piston bowl, 10-hole injectors, turbochargers with ball bearing rotors for lower friction and oil consumption, and a unique EGR valve which allows up to 50% EGR and also asymmetric injection for improved thermal management and keeping post turbine exhaust hot for high SCR conversion. The after-treatment consists of DOC, DPF and dual SCR/ASC catalysts in parallel. NOx was reduced by 60% on FTP. Compliance to current NOx standards is ensured to 435,000 miles while including a margin for variability in fuel quality.

Umicore and Scania described the key characteristics of a new twin-SCR after-treatment with two possible configurations: SCR-DPF-SCR or DOC-SCR-DPF-SCR, for its new inline V8 heavy-duty engines. The twin SCR system helps with lower NOx emissions and improved N2O-NOx trade-off. A new vanadia-based catalyst is being developed for its resistance to N2O formation, sulfation and chemical poisoning.

The Association of Emissions Control by Catalyst (AECC) gave an update on a demonstration project for lowering NOx emissions from heavy-duty trucks in Europe. The vehicle chosen was a Daimler Actros 4x2 with a 13L Euro VI-C compliant engine. The stock after-treatment was replaced with a state-of-the-art system comprised of a close-coupled DOC and SCR, followed by another DOC, a DPF and an underfloor SCR and ASC. Twin dosing was implemented. The emissions were measured on 3 on-road driving routes covering urban, rural and motorway driving, ambient temperatures from 1 to 16 °C, and 10% and 50% payloads. Test results showed that tailpipe emissions were in the range of 42 – 187 mg/kWh under low speed urban driving conditions (note that Euro VI limit is 460 mg/kWh), and were 98% reduced compared to engine-out emissions.

H2 Internal Combustion Engine (H2-ICE)

AVL presented the development of a H2-ICE with zero CO2 tailpipe emissions. Depending on the injection (MPI vs DI), 43 - 47% BTE can be achieved. Transient performance can be a challenge and could require upsizing the engine and/or two stage and electric turbochargers. NOx emissions will occur and require after-treatment system consisting of a DOC and a SCR, either Cu or vanadia based. Another concept is a two stage SCR with the first being a H2-SCR, but which needs further development and has a challenge with respect to N2O emissions. MAN is targeting comparable total cost of ownership compared to diesels by 2030, while carrying over 80% of the components of the diesel engine. A 17L engine which will be put on a demo truck this year. This upsized compared to the diesel 15L reference engine to improve transient response. Compression ratio (CR) is at 11 – 13, and maximum pressure is 170 bar. Direct injection is expected to provide superior efficiency and low-end torque. A single-stage turbo was found to be sufficient to achieve lambda of 2.7 and low engine out NOx. Multi-cylinder testing is ongoing and shows peak BTE of 45%, close to diesels, but while emitting 99% lower NOx at a road-load point. After-treatment will include SCR and ammonia slip catalyst (ASC) only.
FEV showed using CFD calculations and that good mixture formation is critical for achieving low NOx and high efficiency, especially when using a direct injection system. Transient testing was done on a 7.7L medium duty engine with a two-stage turbocharger. Peak efficiency 42% was achieved and exhaust gas temperatures were > 225 °C, sufficient for SCR performance. The combination of air-fuel ratio and ignition timing allowed to calibrate the engine out NOx and exhaust temperature to achieve > 90% NOx conversion, resulting in post-SCR NOx emissions of 50 mg/kWh on warm WHTC.

**Life Cycle Assessment**

The European Commission outlined the path ahead for decarbonization of the heavy-duty transportation sector. Some of the proposed changes to existing legislation on GHG reductions include:

- A review of CO2 emission targets for 2025 and 2030, which currently require 15% and 30% reduction of CO2 compared to a 2019 baseline.
- CO2 standards to be set for 2035 and 2040
- Assessment of the deployment of ZEVs and the incentive mechanisms.
- Role of bio- and e-fuels, CO2 credits for manufacturers and life-cycle assessment of CO2 emissions
- Updates of VECTO simulation tool and extension of CO2 standards to other vehicle categories not included today.

Frontier Economics presented their review of 85 lifecycle studies in the literature and concluded that there is no “single” technology to address climate change and that all powertrain options can contribute to lowering GHG emissions. It was shown that there is a risk of shifting emissions from one option to another, rather than reducing them. Taking an example from a Germany climate package where 10.5M new BEVs are expected to save 10M tons of CO2 by 2030, the analysis showed that only 0.39 Mtons of CO2 will be avoided.

**Synthetic Fuels**

Aramco highlighted that the cost of renewable electricity and electrolyzers is decreasing rapidly so that the cost of producing green hydrogen is also expected to decrease. (Note that a recent power purchase agreement priced solar power at ~ 1 cent per kW [https://www.pv-magazine.com/2021/04/08/saudi-arabias-second-pv-tender-draws-world-record-low-bid-of-0104-kwh/]) Cost of synthetic fuels is expected to reduce < 1 €/l by 2030 when considering CO2 capture from point sources (direct air capture can cost up to 2X higher in that timeframe). Taking Germany as an example, it was shown that net zero carbon emissions can be achieved using either a fully electric fleet powered by renewable energy, or a ~ 50-50 fleet of electric and hybrids with the latter fueled by synthetic fuel. The latter reduces the renewable electricity demand from 120 TW to 60 TW, while requiring 300 billion barrels per day of fuel (by 2050). Such a shift from direct use of renewable electricity to synthetic fuel could be justified by the lack of resources to support the renewable energy demand in Europe and China. In these regions, the synthetic fuels could be transported from other regions such as Africa.
Aachen University and FEV presented engine test results using methanol, which can be potentially synthesized from H2 from electrolysis of water using renewable energy, and captured CO2. Methanol is the first liquid hydrocarbon fuel that can be formed along the synthetic fuel production route. Two routes were chosen for methanol combustion, tested on a 2L engine. One is dual direct injection compression ignition, which requires pilot injection of diesel fuel. This was shown to deliver 49% effective peak BTE but will also require a DPF and SCR for after-treatment. Elevated CO emissions are a concern at low loads. The other was premixed methanol combustion with positive ignition. This mode results in significantly reduced NOx (~ 1g/kWh) and it is foreseen that only a TWC or an oxidation catalyst may be needed to address the HC and CO emissions. Formaldehyde emissions are also one concern and will need to be treated.

Renewable diesel fuel or hydrotreated vegetable oil (HVO) has high cetane number and no aromatics which lends itself to excellent combustion and little particulates. Neste projected that production will grow to 30 million tons by 2025 up by a factor of 3 – 6 across major markets, and all of it from waste and residue (vs. 80% today). A regulatory framework is proposed, in which OEMs can purchase tickets from renewable fuel suppliers, which would count towards the CO2 fleet target.

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