Heavy-duty vehicle manufacturers are facing the Euro VI legislation, which puts new constraints on in-use vehicle emissions. For development and validation purposes, the new climatic-altitude chamber at TNO offers the unique capability to measure real world emission performance of complete truck configurations under extreme temperatures and altitude combinations. The CA chamber reduces development time and costs and enables more robust emission technology with further reductions in CO₂ emissions.
In 2012, Euro VI emissions legislation for heavy-duty (HD) vehicles will be implemented. This legislation puts the following new demands on diesel emission control systems in two points:

1. optimal performance to meet the more ambitious emission targets for type approval (TA)
2. real-world performance testing at the vehicle level – this sets new robustness requirements, since emissions compliance has to be demonstrated under a broad range of operating conditions.

Both conditions create new demands for the development of robust exhaust-gas aftertreatment systems to assure the optimal operation under a huge number of conditions. The new European In-service Conformity (ISC) legislation requires vehicle manufacturers to measure real life emissions themselves with portable emission measurement systems (PEMS). As illustrated, there is no lower temperature boundary for ISC testing. The tests can be performed under any ambient condition representative of real conditions within the European Union. However, the altitude upper limit for in-use emissions testing is 1600 m.

Compared to the existing requirements for On-Board Diagnostics (OBD), the OBD operation area is extended up to altitudes of 2500 m. The OBD threshold limits are sharpened with Euro VI legislation. In addition, the in-use performance of the OBD system has to be monitored. By using an operation value (In-use Performance Ratio, IUPR), it is checked whether the minimal number of drive cycles with active OBD system are met.

**TEST FACILITIES**

Ensuring that heavy-duty vehicles meet the emission targets during the whole life span of the vehicle under real world conditions is a major challenge. The two traditional diagnostic facilities that are part of testing and developing emission control systems have certain limitations:

1. The engine dynamometer: Extreme temperatures and pressures can be realised on specialised setups. These R&D methodologies have to be proven reliable. However, the engine dynamometer tests do not replace the real-world operation and ambient conditions to validate for ISC requirements. The validity for development and testing of emission control systems for Euro VI are therefore limited.
2. The portable emissions measurement system (PEMS): The currently proposed testing and validation procedures for complete trucks rely on PEMS as an effective means of in use emissions checking. This equipment can be used as a screening tool, but it is not very well suited for development and calibration purposes. This is mainly due to the limited reproducibility of test cycles on the road.

Considering the limitations of the current testing tools, TNO conceived a new testing development and validation methodology. This tool has to enable truck manufacturers to fully comply with the upcoming emission legislation and to maximise the overall powertrain potential.
The new climatic-altitude (CA) chamber at TNO is a facility that combines the best of the engine dynamometer and PEMS testing tools and provides a number of extra features. The facility simulates real-world conditions in a controlled environment for the development of efficient and robust performance of emission control development. The chamber provides a unique combination of:

- extreme ambient conditions: wide range of temperature and altitude combinations
- transient (hub mounted) dynamometer: highly dynamic performance
- emission measurement under extreme ambient conditions
- complete heavy-duty vehicle accommodation.

In Fig. 2, the main features of the CA chamber are compared with the existing test facilities. The chamber can significantly reduce the number of vehicle/test cell iteration loops in the development process.

This reduction is possible thanks to the ability to develop, calibrate and validate a complete truck including the interaction of different subsystems in an integrated powertrain control system. An additional benefit is the possibility to enhance robustness of the emission control system. This creates opportunities for further performance optimisation and calibration for lower CO₂ emissions.

Temperature conditioning for the test chamber is enabled by a circulatory air conditioning unit installed in the test space below the insulated cell ceiling. It comprises a heat exchanger, solid state heating elements and fans ensuring continuous, intensive air circulation for uniform air distribution and temperature conditioning. The powerful conditioning system is able to realise all combinations of extreme conditions in just one day.

### TEMPERATURE CONDITIONING

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**FEATURE** | **CLIMATIC-ALTITUDE CHAMBER** | **ENGINE DYNAMOMETER** | **PEMS**
--- | --- | --- | ---
Transient cycles | + | + | +
Gaseous emissions | + | + | +
Particulate emission | + | + | – *
Reproducibility (driver, climate) | + | + | –
Accuracy | + | + | +/–
Real-world vehicle representation | + | – | +
Installation effort | + | + | +/–
Integrated system analysis | + | – | +/–

*Fig. 2 Comparison of climatic-altitude chamber with existing test facilities engine dynamometer and PEMS (* under development)*

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**CLIMATIC-ALTITUDE CHAMBER**

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**Fig. 3 Scheme illustrating the functionality of the climatic-altitude chamber**
EMISSION MEASUREMENT SYSTEM

The test cell is equipped with a full flow Constant Volume Sampling (CVS) dilution system with a capacity of 120 m^3/min. Direct lines are available for raw exhaust gas measurement. This exhaust measurement system fulfils the current EU emission measurement legislation and can be used at normal temperature and atmospheric pressure. For the emission measurement in extreme ambient conditions, the exhaust mass flow rate is determined using the methods of intake air measurement and air/fuel ratio measurement. For particulate measurements a sample is taken, which is proportional to the exhaust-gas mass flow rate. The dilution rate in the tunnel is set-up by a exhaust-gas mass flow rate signal.

DYNAMOMETER OF THE TEST BENCH

In contrast to common chassis dynamometer test benches, the dynamometer shaft is connected directly to the two vehicle drive shafts, with no tyre-on-roll contact. This eliminates the risk of tyre slip, which is especially relevant at high engine loads and/or low gear ratios. It enables testing of high load profiles for a longer period compared to a chassis dynamometer. Another reason for the elimination of the tyre-on-roll contact is that the CA chamber is primarily designed as a development tool for emission control systems for heavy-duty vehicles. This enables to run engine emission cycles directly with the vehicle, which facilitates simultaneous type approval and ISC validation.

The CA chamber is an essential tool for both development and validation of future emission control systems. This is illustrated in 3 and is discussed in more detail in the next sections.

CA CHAMBER AS A VALIDATION TOOL

The CA chamber was put into service by TNO in December 2009 in Helmond, The Netherlands. This section describes two case studies that demonstrate the special capabilities of the CA chamber as a validation tool.

CASE 1: REPRODUCIBILITY OF TEST CONDITIONS

In the first case study, the effect of different transmission fluids on fuel consumption was evaluated at the vehicle level. As only small differences were expected, reproducibility of test conditions was crucial. Therefore, the test cycle needed to be reproducible and ambient conditions needed to remain constant.

For this test, the highway part of the European Transient Cycle (ETC) cycle was used. To ensure a good statistical average, each test consisted of 24 load cycles. During two days of testing, the chamber temperature and pressure were kept constant at 20 °C and 950 mbar, respectively. 6 shows both the cycle-to-cycle and day-to-day variation of several key variables for one transmission fluid. This illustrates an excellent overall reproducibility of tests. Over several days, the ambient temperature and pressure in the CA chamber are very well controlled: maximum variation of 0.26 K and 0.11 kPa, respectively.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature range</td>
<td>-45 to +55 °C</td>
</tr>
<tr>
<td>Simulated altitude range</td>
<td>0 to 4000 m (1013 to 628 mbar)</td>
</tr>
<tr>
<td>Adjustment time</td>
<td>0.5 h (from 0 to 4000 m)</td>
</tr>
<tr>
<td></td>
<td>2 h (from 21 to +55 °C)</td>
</tr>
<tr>
<td></td>
<td>8 h (from 21 to -45 °C)</td>
</tr>
<tr>
<td>Airflow speed, nozzle area</td>
<td>120 km/h, 1.25 m × 0.7 m</td>
</tr>
<tr>
<td></td>
<td>40 km/h, 1.6 m × 1.6 m</td>
</tr>
<tr>
<td>Gaseous emissions</td>
<td>NOx, NO, NH3, N2O, CO2, CO, THC</td>
</tr>
<tr>
<td>Particle emissions</td>
<td>PM</td>
</tr>
<tr>
<td>Dynamometers</td>
<td>Full transient, hub mounted</td>
</tr>
<tr>
<td>Inner dimensions of the chamber (length × width × height)</td>
<td>24 m × 10 m × 7 m</td>
</tr>
</tbody>
</table>

• CO₂ and emission reduction
• Active and passive safety
• Mobility and cooperative driving

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⑥ also shows that the brake specific fuel consumption (BSFC) is measured with very high accuracy. A cycle-to-cycle variation of 0.65 g/kWh (0.3 %) was found over all tests. As a result, only small variations in performance can be detected.

CASE 2: EXACT EMISSION MEASUREMENT

The second case study illustrates the benefit of accurate emission measurements in the chamber. For trucks that encounter long overnight idling periods at low ambient temperature conditions, uncontrolled regenerations are observed, which can damage the diesel particulate filter (DPF) system.

In the CA chamber, the overnight idling period was performed with the vehicle under a controlled temperature condition of -30 °C without load and with light load. After a 10 h idling period, a representative drive cycle was started, and the emission behaviour was monitored. ⑦ shows the hydrocarbon (HC) emissions that were measured upstream of the DPF. During overnight idling, HC emission was adsorbed in the diesel oxidation catalyst (DOC). The HC was desorbed during the drive cycle. The unanticipated high levels of HC emissions can cause an excessive exothermic reaction, damaging downstream DPF and SCR-catalyst. Due to this two day test, accurate emission data at various locations in the exhaust system were available. With on-road measurements, it was impossible to analyse this issue in depth.

CA CHAMBER AS A DEVELOPMENT TOOL

In addition to the capabilities as a validation tool, the CA Chamber is a necessary tool in future emission and powertrain control development. With an increasing focus on CO₂ emissions, it will be necessary for manufacturers to fully exploit the synergies between subsystems to optimise powertrain performance. As a first step, the engine and aftertreatment control have to be further integrated. The main focus here is to realise minimal fuel consumption within the in-use emission limits under all driving conditions. To meet the ambitious CO₂ goals [2, 3] in the future, electric driven auxiliary systems, hybrid powertrains and energy recovery systems will be introduced with energy management strategies. This requires an integrated system approach, combining energy and emission management. Due to the growing number of sensors, actuators and subsystems, control development and calibration becomes an increasingly demanding task for manufacturers.

⑧ Cycle-to-cycle and day-to-day variations for a transmission fluid
SUMMARY

By testing the vehicle under a wide range of conditions, the new climatic-altitude chamber at TNO will be essential in the various development stages for the integrated systems approach. The CA chamber allows to efficiently deal with the impact of system configuration and system integration on control performance early in the development process.

Due to the superior measurement accuracy, the combined procedures of fuel consumption and CO₂ emission reduction can be evaluated at the real vehicle level. In summary, CA chamber assisted control development leads to enhanced quality and robustness of emission controls, lower CO₂ vehicle emissions, and reduced control development and calibration time.

REFERENCES


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