KICK-DOWN NO_x

INNOVATIVE NO_x MEASUREMENT METHOD FOR CYCLIC EXHAUST EMISSION TESTING

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Inhalt

1. Technology - Chemiluminescence Detection

Our nitrogen oxide (NO_x) detector is based on the method of chemiluminescence detection. The underlying chemiluminescence effect is based on the reaction of nitric oxide (NO) with ozone (O_3).

The reaction of nitric oxide with ozone produces oxygen and excited nitrogen dioxide molecules (NO_2*). During the transition of the molecule into the energetic ground state, light of a certain energy/wavelength is emitted ($E = h\nu$).

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO^2 \rightarrow NO^2 + h\nu \; (Luminescence)$$

The concentration of nitric oxide molecules is proportional to the emitted radiation.
The reaction takes place very rapidly and can be realized with very small sample volume, allowing analysis with response times in the range of milliseconds.

Higher nitrogen oxides

To be able to analyse the concentration of higher nitrogen oxides (e.g. NO_2), a catalyst (NO_x converter) can be used to reduce NO_x to NO.

Due to the high conversion efficiency of up to 98%, an iterative measurement of NO_x and NO can be used to accurately determine NO, NO_x and NO_2 concentrations in the sample gas by difference formation.

For the exhaust emission test, we recommend either to measure NO_x as a sum with converter or even to do without the converter and to calculate from NO via modelling of the thermodynamic equilibrium to NO_x. At the tailpipe, the NO:NO_2 ratio is in the range 90% to 10%.

The advantages of this direct measurement method are a very stable zero point, very fast response times and a high dynamic range.

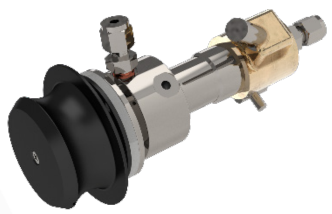


Fig. 1 NO_x converter for the conversion of NO_x to NO

2. Sensor – CLD$_{mini}$ (High-Speed)

The CLD$_{mini}$ sensor is a compact sensor module based on the principle of chemiluminescence. The sensor contains a reaction/measurement chamber in which NO from the sample gas reacts with

O3. The radiation generated by the reaction is amplified and measured using a photomultiplier tube (PMT). The NO concentration is proportional to the amount of radiation.

The ozone required for the measurement is generated from the ambient air by means of an ozone generator. The sensor is pressure and temperature stabilized, so that a constant measurement is possible. By using a very small sample volume, a very low response time can be achieved.

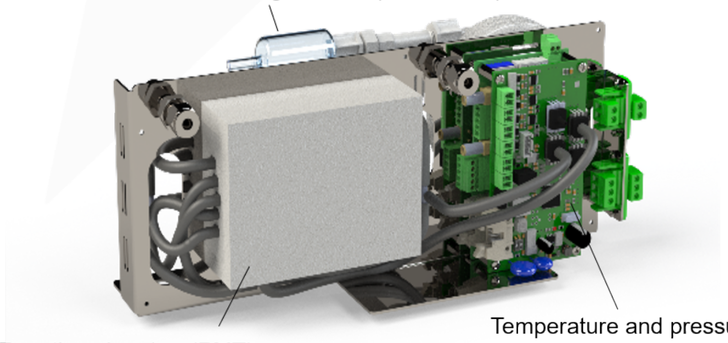


Fig. 2 CLD_{mini} sensor with description of main component

Highlights:

- Very low response time
- Low sample volume
- Reaction chamber with photomultiplier tube (PMT)
- Integrated ozone generator (ambient air)
- Temperature and pressure stabilization

3. „Kick-down NO_x“ measuring device

The measuring device we would like to present contains the CLD_{mini} NO sensor as well as further components for sample gas preparation, control and data evaluation.

From the pump to the ozone destroyer and a display for operation, everything is integrated to perform a location-independent and fast measurement. This allows easy handling and flexible use.

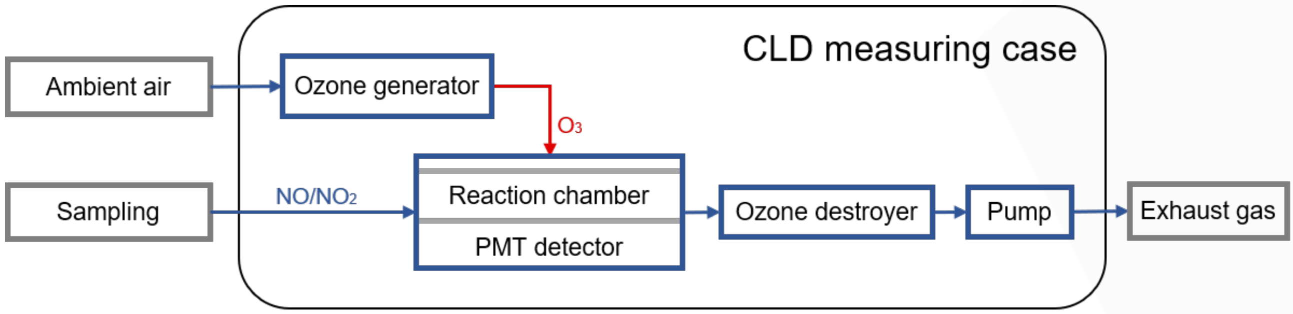
Fig. 3 Kick-down NO_x measuring case with battery and display

No consumables such as gases or the like are required to operate the meter.

Main components:

- CLD_{mini} – NO-Sensor (High-Speed)
- Ozone generator (ambient air)
- Probe for sampling
- Sample preparation (gas filter)
- Temperature and pressure stabilization
- Ozone destroyer
- pump
- Valves with nozzles for span and zero calibration
- Battery for flexible use
-

Gas flow chart measuring case



With the probe, the sample gas can be taken directly from the tailpipe. The measuring device is operated in a vacuum, which is generated by the pump.
After the reaction of NO and O3 in the reaction chamber, the sample gas is freed from ozone in the ozone destroyer before it leaves the measuring device as exhaust gas.
The evaluation of the measurement data is carried out via a data logger on the laptop. This allows easy display and analysis of the concentration values provided via Modbus TCP/IP.

Advantages of the High-Speed Measuring Device

- High sampling rate (100 Hz) and fast response time (milliseconds)
- Exact reproduction of the NO concentration peak despite short measurement duration
- Direct measurement by CLD method
- Mobile and locally independent use due to portable case in battery mode
- Possibility to combine with other sensors (e.g. PN)
- Easy evaluation of measurements via data logger
- Can also be used for stationary measurements
- No consumables
- Measuring device realizable in the cost segment 5000-7000 EUR

Specifications and technical data

Specifications	
Measuring range	0 – 2.500 ppm
Response time t_{10}-t_{90}	< 0,8 s
Detection limit (LOD)	< 0,5 ppm
Measuring frequency	100 Hz
Calibration	one-time - zero adjustment before start

Technical data	
Pressure range ambient	800 - 1.100 mbar
Ambient temperature range	15 – 35°C
Communication	Modbus TCP/IP (others on request)
Supply voltage	~12 V
Dimensions (L x H x W)	ca. 500 x 330 x 180 mm
Weight	approx. 7 kg

KNESTEL TECHNOLOGIE & ELEKTRONIK GMBH
OSTERWALDER STR. 12
87496 HOPFERBACH
+49 (0) 83 72 – 70 80
VETRIEB@KNESTEL.DE
WWW.KNESTEL.DE

4. „Kick-down NO_x“ measuring method

The high-speed sensor, based on the CLD method, can be used in the described measurement kit for the measurement of NO in the vehicle exhaust. This may be necessary in the future for the cyclical exhaust emission test.

In principle, NO/NO_x is produced when the combustion engine is operated under load. This is the case, for example, during real driving or on the test bench. However, the engine also operates under (full) load when the engine's own moment of inertia is accelerated.

This short load phase is used by the method to make a location-independent, stationary and fast measurement possible. This provides reproducible and meaningful measured values without a test stand or test drive. Decisive for a meaningful measurement during the kick-down is the fast sensor principle (100 measured values per second) and the equally fast gas exchange time.

Clarification of terms:

By a kick-down we mean the rapid, full depression of the accelerator pedal starting from idle up to the speed limit. A suitable validation condition for this operation is the specification of the speed change per time. This allows a check to be made that it has been carried out correctly.

$$Validation\ condition: \frac{\Delta\ rotation\ speed}{time}$$

The corresponding data can be read out via the OBD interface of the vehicles.
Speed restrictions in the lower range, e.g. at approx. 3000rpm/min, shorten the measurement period, but provide the same findings, since the measurement procedure is sufficiently fast.

Proposal for carrying out the kick-down NO_x measurement

We would like to suggest a simple procedure for carrying out the kick-down NO_x measurement. First, a zero adjustment with ambient air should be made. Then the probe can be inserted into the tailpipe and fixed there with the clamp.

Possible sequence of the measurement:

- Carrying out three kick-downs
- Determination of the peak values of the NO concentration
- Averaging of the three peak values

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WWW.KNESTEL.DE

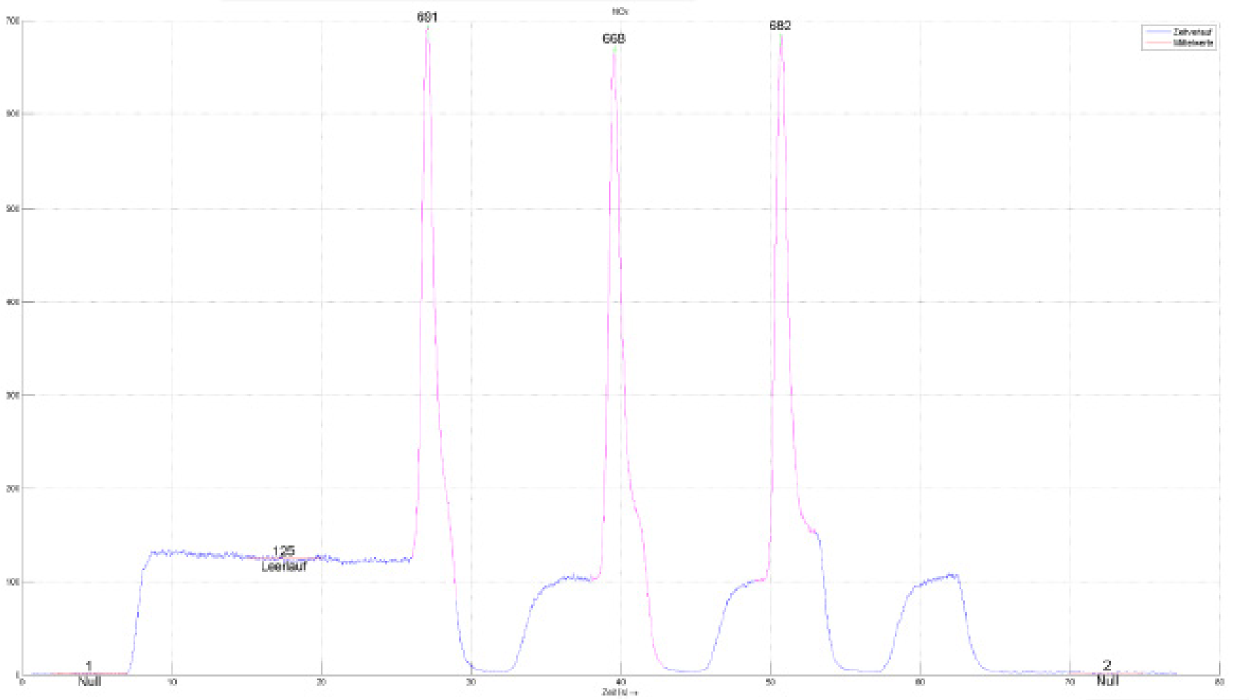

Fig. 4 shows the NO_x concentrations when carrying out the measurement procedure described.

When the measuring probe is inserted into the tailpipe, the NO concentration increases. When performing the three kick-downs, each with a 15s pause in between, one can clearly see the peak when the accelerator pedal is pressed down and the subsequent decrease in NO concentration when the engine coasts down.

The peaks are approximately at the same concentration level when the kick-down is carried out properly. This could be observed consistently in the measurements carried out and speaks for a good reproducibility.

Preparation of vehicle and measuring device:

The vehicle must be warmed up in order to carry out the measurement.

The measuring device requires approx. 30 min warm-up time until all components have reached the optimum operating temperature. For the measuring device we recommend a zero adjustment with ambient air before the measurement. Afterwards, the probe can be inserted into the tailpipe and fixed there with a clamp.

Further options and possible combinations

Due to the fast and flexible measurement, the measuring device can of course also be used to determine the NO_x concentration during other measuring procedures.

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In order to analyze the proper functioning of the various exhaust gas purification systems, the method can be adapted. A measurement procedure such as that specified by the Capelec EGR test[1] can also be implemented with the NO_x measurement kit.

By extending the test cycle to include a longer phase at idle, the method can also be combined with a particle measurement.

- Adaptation to other test cycles possible
- Combination with particle measurement (PN)

Advantages of the kick-down NO_x measurement method

The load with a roller load of 1000N corresponds at 20/50km/h to a power between 5 and 15 kW. With a kick-down, the engine works almost under full load. Therefore, the kick-down measurement is a possible alternative to the measurement on the test bench.

Compared to other measurement methods (e.g. ASM2050), the kick-down NO_x method does not require a test stand or a test drive. Only the measurement case and a laptop for data evaluation are required. This saves time and costs in carrying out the measurement.

In the CITA II study, the measurement methods presented are evaluated according to certain criteria.[2] These are, for example, the applicability to all vehicles or the time and cost expenditure. The criteria listed in the study can be fulfilled very well by our device and the presented measuring method. The presented measuring method convinces especially by the low effort and the simple execution.

Advantages at a glance:

- Time and cost efficient
- Simple and fast measurement
- Achieving a load on the motor at standstill by kick-down
- Meaningful measurement results comparable with test bench measurement

[1] Final Report: Further Development of Exhaust Emissions Testing (UBA): p.39 Figure 24 and Table 6
[2] CITA II Study: p. 38 Table 15

5. Results of previous Kick-down NO_x measurements

Various tests were carried out to validate the measurement method. Tests were also carried out with a test bench to compare the different methods.

Kick-down compared to measurement on the test bench

For the measured values shown below, the nitrogen oxide concentration was measured during three kick-downs. The vehicle was then driven onto a chassis dynamometer and the NO_x concentration was measured in three phases (acceleration - stationary - coasting). Afterwards, three kick-downs were performed again. An example measurement is shown in Figure 5.

Measurement procedure:

- 3x kick-down measurement
- Drive on test bench (20 km/h, approx. 1,000 N total force)
- 3x kick-down measurement

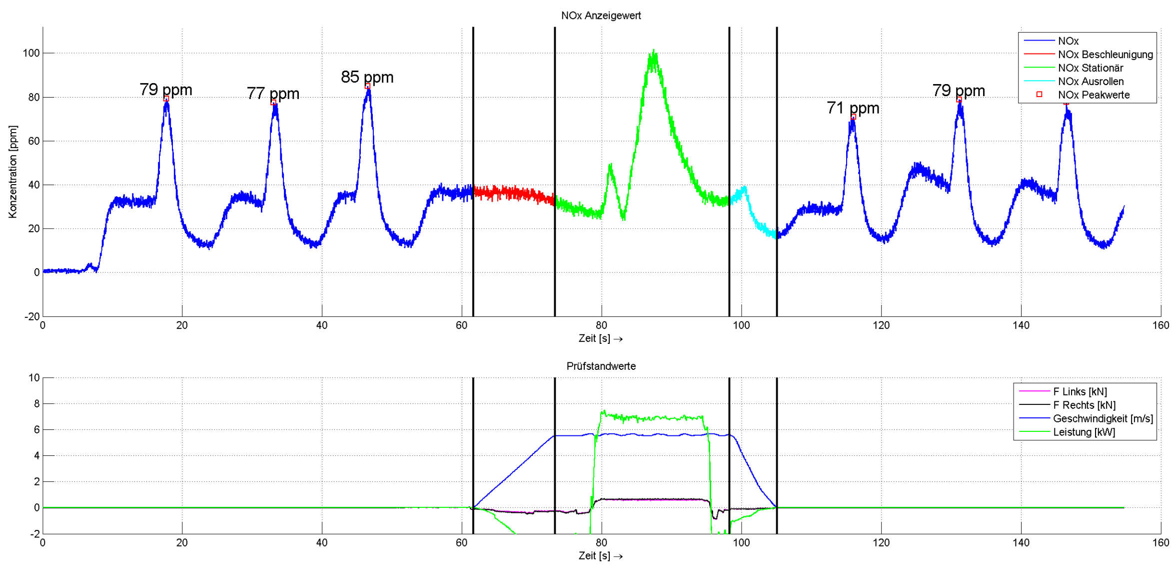


Fig. 5 Comparison between kick-down and measurement on the test bench (passenger car - EURO6b/Diesel)

The measurement shows that the peak concentration at the performed kick-downs is approximately in the range of the NO values on the test bench.

On the test bench, the quality of the driver has a decisive influence on the measurement result. It is visible that NO_x is only emitted when the vehicle is actually loaded (power below in green). Since the NO concentration is power-dependent, we therefore assume that the load during kick-down corresponds to that on the test bench.

When working correctly, meaningful and comparable results can be obtained with both the test stand and the kick-down method.

Further kick-down measurements (car/truck - different exhaust gas classes)

The method described can be applied to passenger cars of different exhaust gas classes and fuel types. The method has also been successfully tested on trucks. Fig. 6 and Fig. 7 show exemplary measurements on trucks.

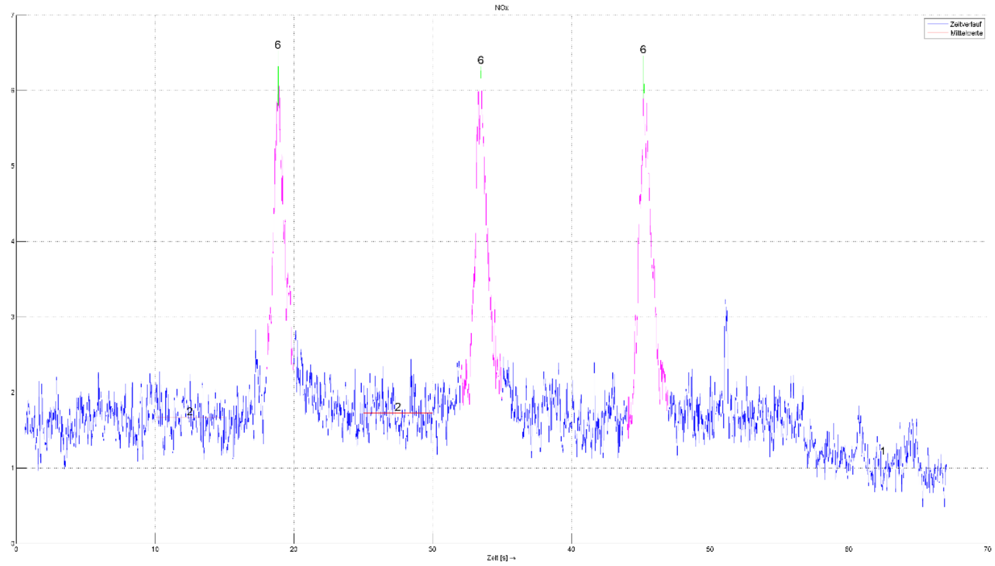
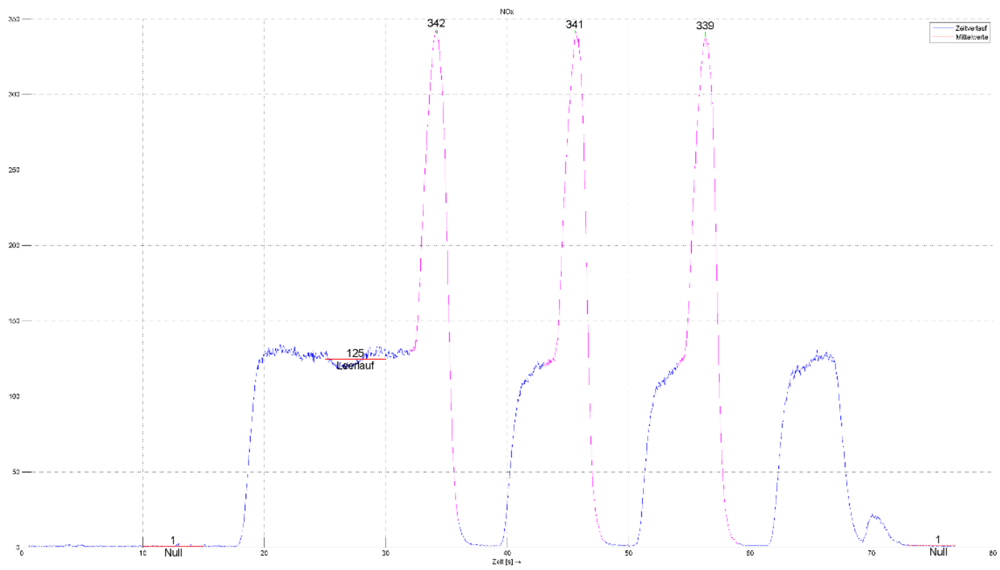


Fig. 6 EURO VI truck - representation of the NO concentration at three kick-downs and at idling speed

When the EURO VI vehicle is idling, almost no NO emissions are measured. Despite the low concentrations, the peaks are clearly visible at the three kick-downs.



In the case of the vehicle with exhaust gas class EURO V, the NO concentration at idling speed of approx. 125ppm is significantly higher than in the case of the newer vehicles. The peak values at kick-down are also clearly visible here. In both cases the NO peak values on the three kick-downs.

6. Outlook - NO_x measurement without test bench

The kick-down NO_x measurement method for determining the NO_x concentration in the exhaust gas of vehicles offers various advantages. The simple implementation with the measuring case at the tailpipe saves the purchase of expensive test benches and associated measurement technology. The measurement can be carried out quickly and easily with three successive kick-downs.

The measuring device can also be used for measurement on a test bench.

Due to the flexible application possibilities of the CLD measuring case and the advantages in terms of effort and costs, it represents an alternative to other measuring methods. Therefore, this simple method should be considered for the cyclic exhaust emission test.

In summary, the method we present for NO_x measurement in vehicle exhaust is an alternative to previously known methods. The advantage of our method and our measuring device is the fast feasibility, stationary and without test bench. The measurement procedure is simple and quick to implement and can be combined with other measurements such as particle number (PN) measurement.

KNESTEL TECHNOLOGIE & ELEKTRONIK GMBH
OSTERWALDER STR. 12
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WWW.KNESTEL.DE

Appendix

Criteria for NO_x measurement methods

Source: CITA II Study: p. 38 Table 15

Criteria	Spheretech	Capelec	AVL	DT 80	ASM2050	Short Test Ride
Ability to detect failures of different emission systems	X	X	X	XXX	XXX	XX
Over all accuracy of method	X	X	X	XX	XX	X
Applicable for all vehicles	XX	XX	XX	XXX	XXX	XX
Time and Investment needed	XXX	XXX	XXX	X	XX	XX
XXX = very positive **XX** = positive **X** = partially positive						

Table 15- compairisant of test methods – general findings.

Capelec-AGR-Test

Source: Final report: Further development of exhaust emission testing (UBA): p.39 Figure 24 and Table 6

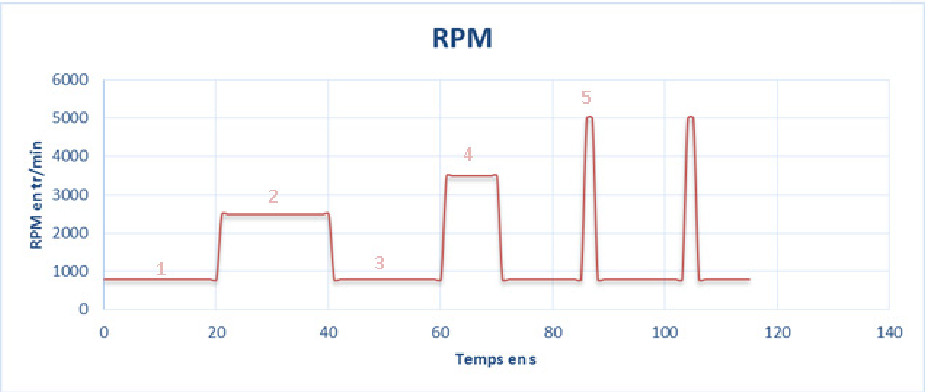

Tabelle 6: Bewertung des Capelec AGR-Test

	Bedingung	Schlussfolgerung
1	p2 < 1	Ventil offen im erhöhten Leerlauf
2	p4 > 1	Ventil geschlossen bei erhöhter Drehzahl
3	NO_x_3 / NO_x_1 > 1.5 oder NO_x_1 < 50 ppm und NO_x_3 < 50 ppm	Wenn die beiden NO_x-Werte in beiden Leerlaufphasen voneinander abweichen, fand wie gewollt ein Umschalten des Ventils statt
4	NO_x_4 / NO_x_2 > 1.2	Höhere NO_x-Werte, wenn AGR-Ventil geschlossen
5	p51, p52 > 1	Ventil geschlossen bei den beiden freien Beschleunigungen

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