The Modell PHEM
(Passenger car & Heavy duty emission Model)
Structure and Applications

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CONTENT

• Introduction

• PHEM
  Application
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• Model results versus measured emissions

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Tasks for Vehicle Emission Models

• Emissions on road networks
  from single junction
  to country to EU

  Available data differs from
  speed pattern to traffic situation
  to average speed

• Emissions for defined speed patterns (Efas)

  From speed pattern + road gradient + vehicle loading

  For vehicle categories, actual fleet, technology options,…

  Different models for different tasks
Some main Problems

• Vehicle sample should be large (>10 veh/category)
• Available measurements often from different cycles
• Measured cycles ≠ driving pattern under consideration

etc.
Methods

Emission models have to be based on measurements to reach good accuracy

Emissions measured in various cycles have to be converted into emission levels in new cycles

• Average speed models
• Instantaneous models (e.g. PHEM)
The Model Structure of PHEM

- Driving resistances & transmission losses
- Transient engine maps
- Gear shift model
- Engine load, Fuel consumption, Emissions
- Transient correction functions
- Cold start module

Data bank:
* Single vehicles and engines
* Average vehicles (otto, diesel, EURO 0 to EURO 5) in normalized format
The application of PHEM

User Input: Driving pattern(s)

- Velocity (V(km/h))
- Gradient

Vehicle data:
- Weight
- A * CD
- Fr0, Fr1, Fr4
- Transmission ratios

Maps:
- Hot emission maps
- Cold emission maps
- Warm up polygons
- Full load curves
- Losses in gear box

Driving data:
- Gear shift model
- Start temperatures

Data base or from actual measurements

PHEM

- Driving resistances & transmission losses
- Transient engine maps
- Gear shift model
- Transient correction functions
- Cold start module

Engine load, Fuel consumption, Emissions

Emissions

- NOx
- Power, rpm, normal

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Engine maps can be gained from transient tests

V & running resistance -> engine power

V & transmission & gearshift -> engine speed

Verbrauch
NOx g/h
km/h

Zeit [s]

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But only if measurement data is treated correctly

Potential errors:
- Signal misalignment,
- Signal smoothing.

Mixing of the exhaust gases in the tailpipe
Mixing of the exhaust gases in the CVS
Response time of the analyzers
Smoothing and misalignment in the exhaust line

To be corrected by sophisticated functions
-> Feasible Sources for Emission Factors from PHEM

Microscale Emission model PHEM

- Driving resistances & transmission losses
- Gear shift model
- Fuel Quality
- Transient Correction
- Cold start tool

Engine test beds

NEMO – Network Emission Model

Module: Fleet

Module: Emissions

- Engine load, FC, emissions

Module: Network

\[
\sum_j \left( \sum_i E_i f_i \right) * ADT_j * L_j
\]

chassis dyno (2-wheeler, cars, HDV)

Manually (e.g. future vehicles)

PEMS tests
Vehicles (engines) in the PHEM Data Base

<table>
<thead>
<tr>
<th></th>
<th>SI cars</th>
<th>CI cars</th>
<th>HDV</th>
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<tbody>
<tr>
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<tr>
<td>EURO 5</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
</tbody>
</table>

Next activities: Emission factors for the HBEFA 3
*HDV ~7 EU5 HDV PEMS data from TÜV to be included
*LDV: data collection + measurements (6 veh) for instantaneous data to extend data base for Efas
Emission models have to be selected according to the tasks

**Inventories:**
- good picture of average fleet emissions
- *high number of vehicles in the sample*
- *good picture of average traffic situations*

**Evaluation of measures:**
- good accuracy of relative changes, e.g. due to
- *change in traffic flow (e.g. traffic light control)*
- *change in driving behaviour (e.g. GSI)*
- *change in technologies (e.g. $\eta$-SCR=F(T))*

What can actual models provide?
Simulation results vs. measured fuel consumption
VW Golf GT (Diesel EURO 4)

Fuel Consumption

Messwert
PHEM
Polynomisch (Messwert)

PHEM-data from CADC only!

R² = 0.7929

Fuel Consumption [g/km]

Averag Cycle Speed [km/h]
Measured NOx emissions HBEFA vs. CADC
VW Golf GT (Diesel EURO 4)

Messwert
Polynomisch (Messwert)

CADC-Motorway
R² = 0.6081

HBEFA 1.2
HBEFA 3 urban

NOx [g/km]

0.00 20.00 40.00 60.00 80.00 100.00 120.00

Averag Cycle Speed [km/h]
Simulation results vs. measured NOx emissions

VW Golf GT (Diesel EURO 4)

PHEM-data from CADC only!

\[ R^2 = 0.6081 \]
Similar comparison for EURO 4 CI car fleet
(PHEM data from CADC only)

Fuel Consumption
(Average for 10 EURO 4 diesel cars)

- Measured
- PHEM
- Polynomisch (Measured)

\[ R^2 = 0.756 \]
Similar comparison for EURO 4 CI car fleet
(PHEM data from CADC only)

PM
(Average for 10 EURO 4 diesel cars)

\[ R^2 = 0.2821 \]
Similar comparison for EURO 4 SI car fleet
(PHEM data from CADC only)

Fuel Consumption
(Average of 21 EURO 4 gasoline cars)

\[ R^2 = 0.8902 \]
Similar comparison for EURO 4 SI car fleet
(PHEM data from CADC only)

HC Emissions
(Average of 21 EURO 4 gasoline cars)

Relative deviation is high for CO and HC of modern cars (absolute values low)

$R^2 = 0.4316$

- Measured
- PHEM
- Polynomisch (Measured)

Average Cycle Speed [km/h]

0 2 0 4 0 6 0 8 1 0 1 2 1 4 0

HC Emissions

0.000 0.005 0.010 0.015 0.020 0.025

Average Cycle Speed [km/h]
Similar comparison for HDV EURO III
(PHEM data from JRC-PEMS measurements)

1 cycle to set up PHEM data, 17 others simulated for validation

- PHEM setup ECU based
- measurement
- Polynomisch (measurement)

\[ R^2 = 0.3676 \]

average cycle speed [km/h]

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Similar comparison for HDV EURO III
(PHEM data from JRC-PEMS measurements)

1 cycle to set up PHEM data, 17 others simulated for validation

![Graph](image)

- **NOx**
  - PHEM setup ECU based
  - Measurement
  - Polynomisch (measurement)

**$R^2 = 0.3492$**

**average cycle speed [km/h]**

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Link PHEM with Micro Traffic Models

For simulation and optimisation of

*Traffic control measures

*Vehicle to vehicle communication

*vehicle technology options (e.g. hybrid operating strategies)
Method of PHEM Advance

Traffic model
v-trajectories

Evaluation:
*total sum
*acc. to vehicles
*acc. to location

PHEM-Advance
Sorting vehicles to Veh-Id

Sequential simulation of each single veh.
*Attribution of vehicle layer
*Attribution of starting values
(T-cat, T-coolant)

PHEM_Standard

Driving resistances &
transmission losses

Engine load, Fuel
consumption, Emissions

Gear-shift model

Driving Cycle

Transient correction functions

Cold start module
Summary

PHEM has a huge DB for HDE and HDV emissions (HBEFA 1.2, ARTEMIS, COST 346, HBEFA 3)

PHEM was extended to model also emissions from passenger cars, LDV and 2-wheelers

Input data from chassis dyno, engine tests and PEMS can be compiled consistently in a similar quality

Good accuracy is reached for most exhaust gas components. Simulation of CO and HC from modern cars should be improved

The interface with micro traffic simulation may provide a powerful tool for local traffic optimisations towards low emissions

PHEM can not replace inventory models but can provide emission factors to them
Thank you for your attention!
Dynamikkorrektur
"Quasi Stationary Simulation"

4 transient tests

Sec.

CO [g/h]

CO measured

CO PHEM
Quality of the „Quasi Stationary Simulation“

- Good agreement for fuel consumption (<± 5%)
- Acceptable agreement for NO\textsubscript{x} (<± 20%)
- Inacceptable agreement for CO, HC and PM (> 50% to +100%)

Reasons are seen mainly in influences of transient changes in the engine load

Transient correction for quasi stationary emissions is necessary
Demands for Transient Correction

Explain the differences between quasi stationary result and measurement in transient tests

With formulas for quantitative assessment

Method for „quick“ elaboration is essential (many engines with total >3 transient tests each)

Statistical approach selected
Approach for Transient Correction

1) Main differences between steady state and transient operation:
   * inertia of turbo charging + charge air cooling
     \[ \text{inlet air (p, t, V, } \rightarrow \text{ Lambda)} \]
   * Electronic engine control application

2) Statistical analysis which values correlate well with differences simulation - measurement

3) Description of these parameters with „transient parameters“, which can be calculated from engine load changes directly
1) Quasi stationary simulation vs. measurement: $\lambda$ and CO

- $\lambda$ increase in transient load
- CO decrease

- $\lambda$ decrease in transient load
- CO increase
2) Explanation of $\lambda$ differences by transient parameters, e.g.:

- Transient Parameter "Ampl3p3s"

![Graph showing the relationship between Delta $\lambda$ (stat./measured-1) and Transient Parameter "Ampl3p3s".]
3) Correlation CO-differences and transient parameters

$R^2 = 0.6664$
4) Improvement of correlations with multiple regression (up to 3 explaining transient parameters)

\[ F_{\text{trans}} = A \times T_1 + B \times T_2 + C \times T_3 \]

Factors (gained by multiple regression analysis)

Transient parameters (Ampl3p3s, ΔPe2s,...)

Transient corrected emission value:

\[ E_{\text{trans}} = E_{\text{QS}} + P_{\text{Rated}} \times F_{\text{trans}} \]
Model accuracy for the „average“ engine

PM, all EURO 2 engines

PM-meas.  PM-dyn.

ETC  UST  TUG  TNO 7  TNO 12.5

PM [g/h]