KONTAKT 2010

Modelování a řízení systémů pro redukci NO_x a pevných částic dieselových spalovacích motorů

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Honeywell

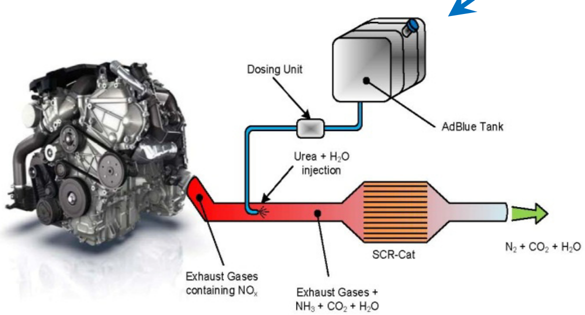
Modelování a řízení systémů pro redukci NO_x a pevných částic dieselových spalovacích motorů

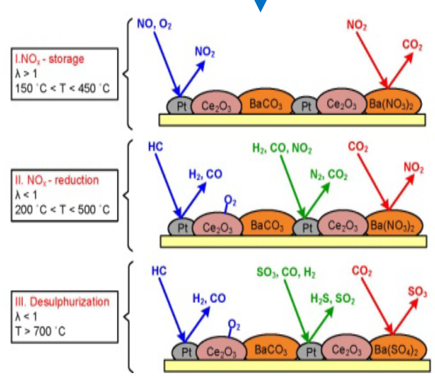
- **Cíle**
  1. Vybrat technologii úpravy spalin – potenciál pro EURO VI
     Vytvořit model systému úpravy spalin této technologie
  2. Navrhnout a aplikovat vhodnou strategii řízení
     Ověřit správnost modelu a strategie

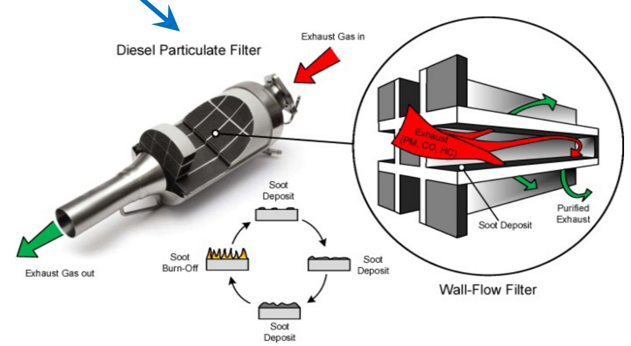
- **Účel** snížit škodlivý obsah výfukových plynů (NO_x, PM, CO, HC, ...)
  → Splnění emisních norem **EURO VI** (EU) a **Tier 2** (USA)

- **Technologie**

SCR **LNT** **DPF**







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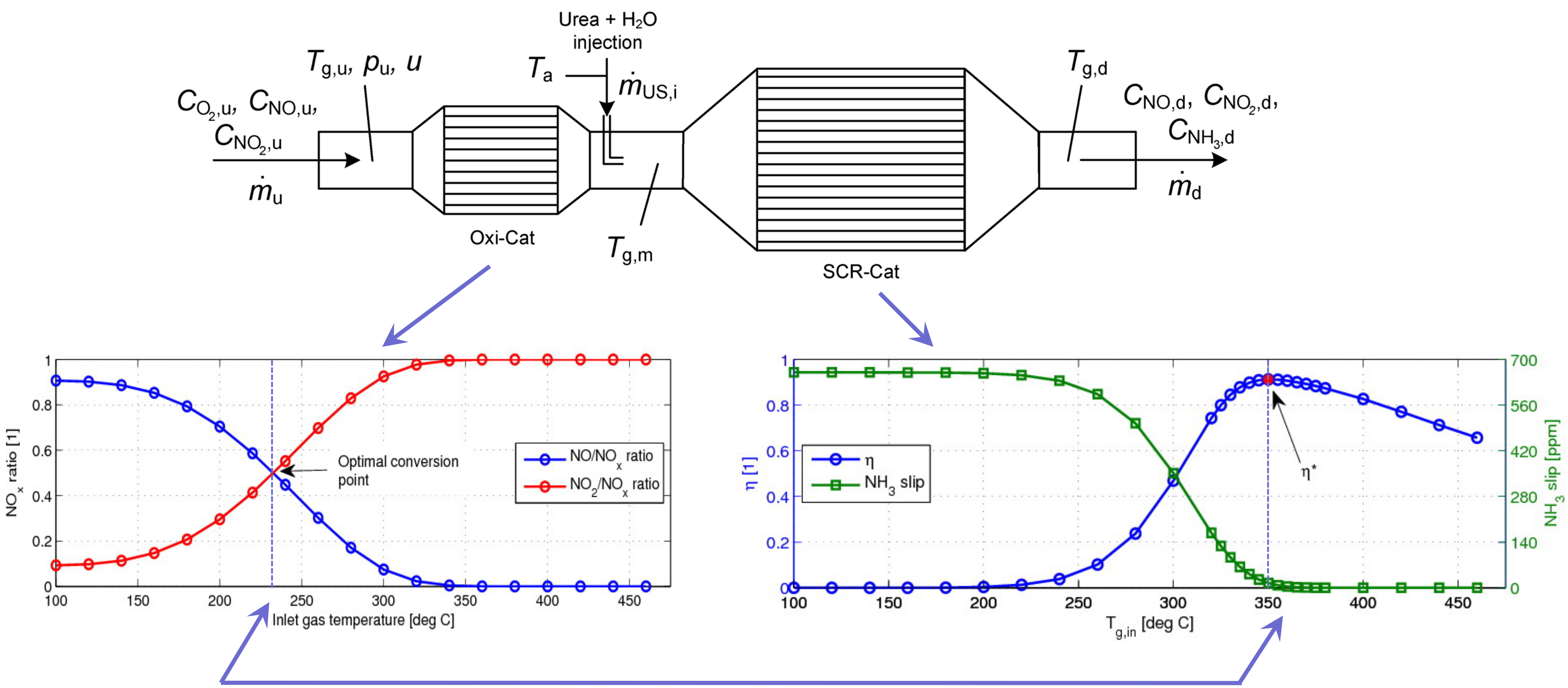
Modelování a řízení systémů pro redukci NO_x a pevných částic dieselových spalovacích motorů

- **Model** – 1D model systému - 3 zařízení (OC, IP a SCR)
  – metoda konečných objemů → 10 buněk na submodel



- Rozdíl v teplotách – nutno upravit parametry katalyzátorů

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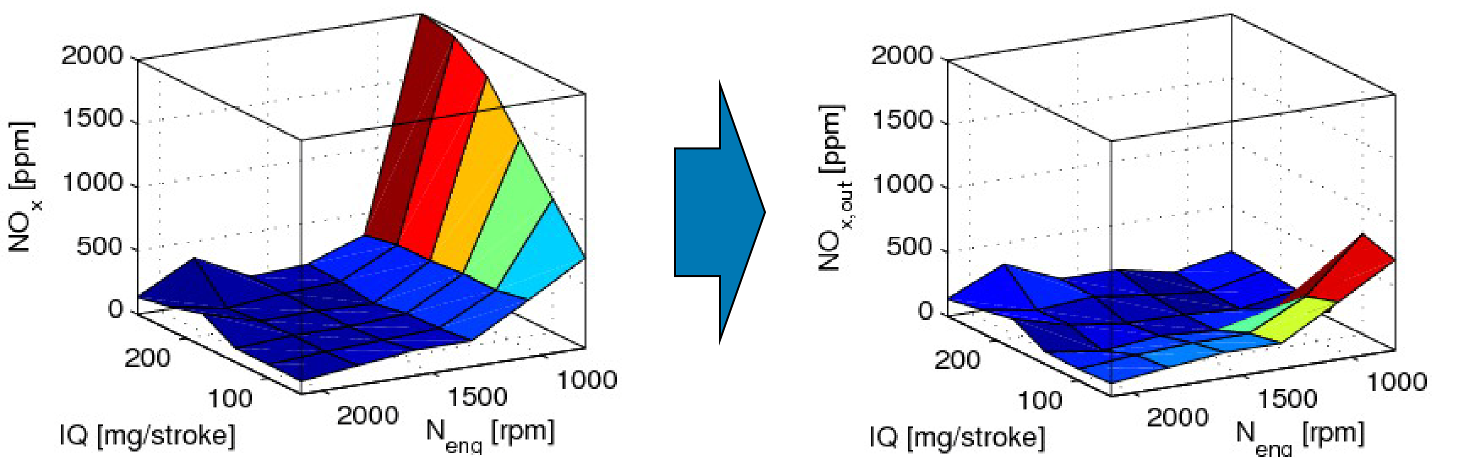
Modelování a řízení systémů pro redukci NO_x a pevných částic dieselových spalovacích motorů

- **Cíl řízení** – maximalizovat účinnost redukce NO_x
  – udržovat skluz amoniaku pod stanoveným limitem
  – kompenzace poruch a nepřenosní fyzického designu
- Kompromisní strategie řízení na bázi PID (soft-omezení)
- Nastavení vah φ a ρ – volba preferencí
- **Výsledky** – redukce NO_x : špičkově 96,7%, průměrně 77% pro relevantní pracovní body motoru
  – skluz amoniaku < 12,5 ppm



Vladimír Dvořák Vladimír Havlena Jaroslav Pekař

Modeling and Control of Aftertreatment Systems for Diesel Combustion Engines

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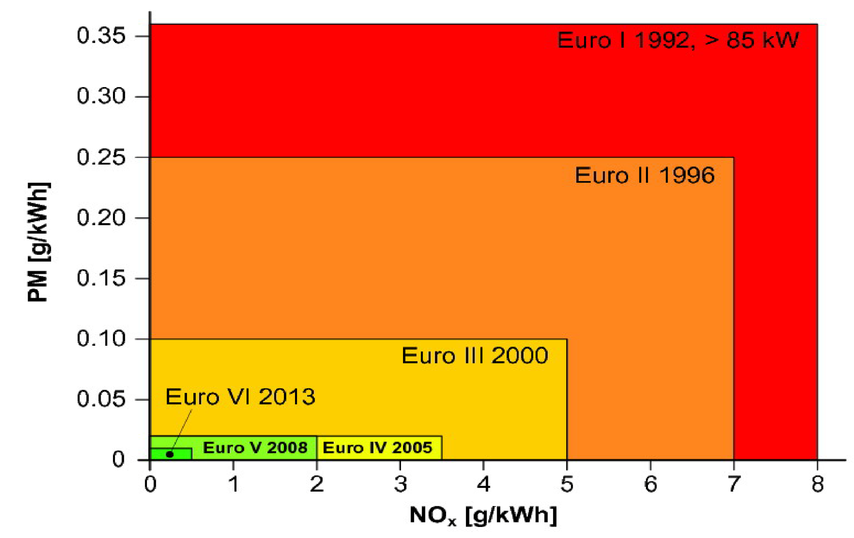
Abstract

The automotive emissions are subject of an increasingly stringent legislation. In order to obey the **emission regulation**, the car manufacturers have to implement technologies for **mitigation of the harmful content** of exhaust gas (mainly **NO_x and PM**) concerning the diesel engines. Two possible **solutions exist**. The first includes prevention of NO_x formation utilizing the **EGR**. The other utilizes an **exhaust gas aftertreatment**, which is in focus of this work.

The goals of this work are:

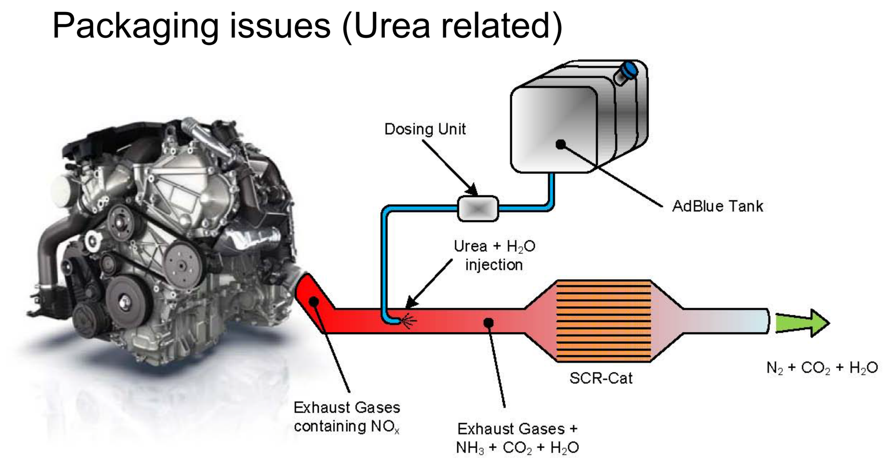
1. to select perspective exhaust gas aftertreatment technology for complying EURO VI for heavy duty automotive application and to **develop a model** of that device
2. to develop and implement a **simple control strategy** for data from a realistic diesel engine model provided by the Honeywell company and **validate both** the control strategy and underlying model.



Aftertreatment Technologies

The aftertreatment technologies are divided into two main groups according to the pollutant that has to be mitigated. The $DeNO_x$ technologies are based mainly on a catalytic technologies:

1. **Selective Catalytic Reduction**
   - Ammonia as an additional reagent (Urea-Water solution)
   - Operating temperature range from 200 C to 450 C
   - NO_x reduction efficiency as high as 95%
   - Successful stationary applications for power plants
   - Packaging issues (Urea related)



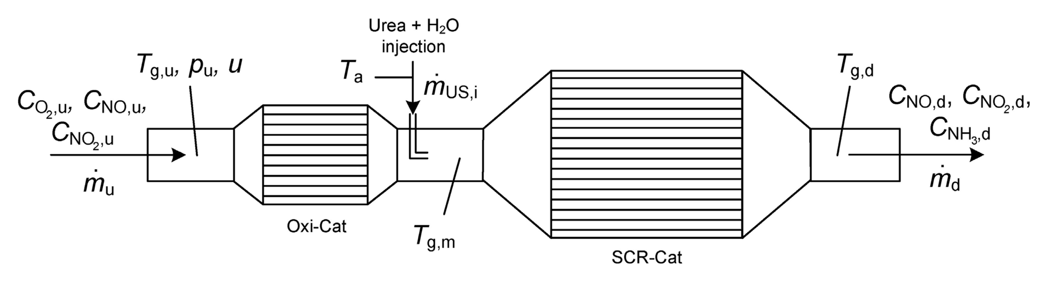
2. **Lean NO_x Trap**
   - Discontinuous operation - 3 phases:
     a. accumulation/adsorbtion
     b. regeneration
     c. desulphurization
   - Operating temperature range from 300 C to 400 C
   - NO_x reduction efficiency as high as 60% to 70%
   - Rapid aging (temperature stress and sulphurization)

The particulate matter abatement technologies utilize both particulate filtration and catalysis:

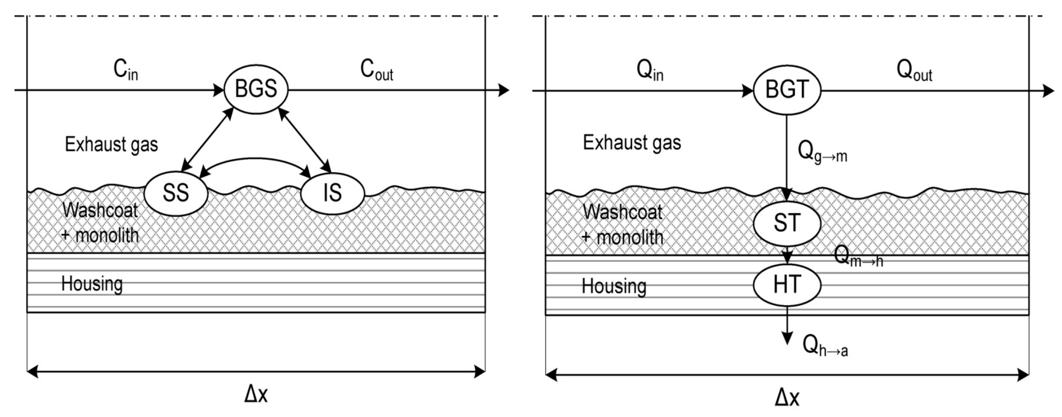
1. **Diesel Particulate Filter** and its derivations
   - Utilizes wall-flow filter
   - Accumulation and regeneration phase
   - PM filtration efficiency >95%
   - High regeneration temperatures reaching 1300 C
2. **Diesel Oxidation Catalyst**
   - Burns-up diesel fuel remains
   - 90% of SOF and 20% of PM removal efficiency
   - Provides synergy when used along with DPF, SCR and LNT due to heat production

Aftertreatment System Model

The **SCR based system** was selected for model development in combination with upstream-placed **Oxidation catalyst** and **Intermediate piping**. The NO_x pathways are assumed as the only pollutant mitigation reduction.



The **1D model** is developed while incorporating main governing equations according to the relevant phenomena:



Mass balance equations		**Energy balance equations**	
(BGS)	Bulk gas species	(BGT)	Bulk gas temperature
(SS)	Surface species	(ST)	Surface temperature
(IS)	Intermediate species	(HT)	Housing temperature

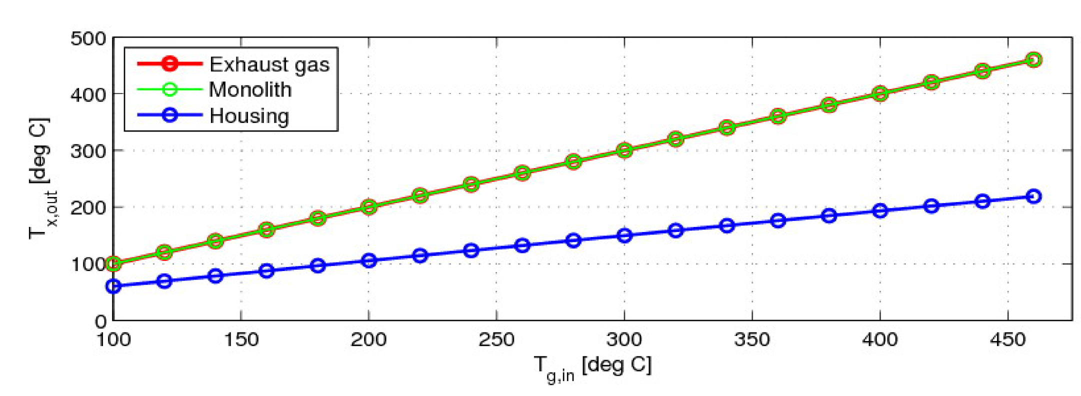
The reaction mechanism utilizes the **Eley-Rideal** surface reaction scheme. A spatial discretization – **finite volumes method** is used to simplify the governing PDEs. The obtained ODEs are solved in MATLAB/Simulink. As a result of discretization, each of three sub models is **divided into 10 cells**.

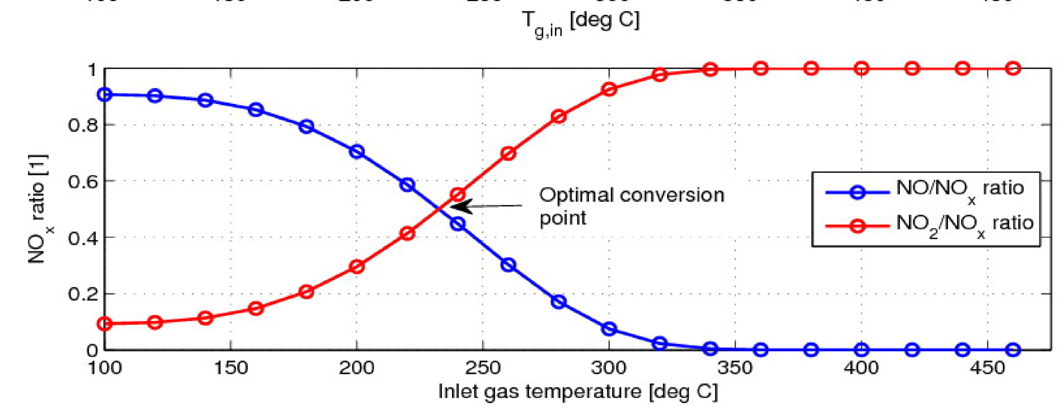
Validation of Submodels

A validation of the aftertreatment model was carried out by putting each of three submodels through series of simulations.

Oxidation catalyst

Basic static characteristic of temperature and NO conversion:

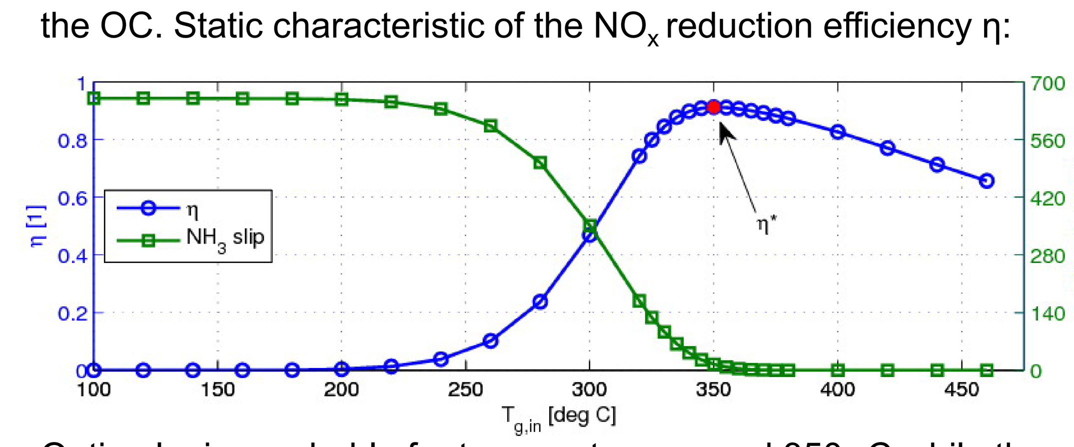




The **optimal NO conversion point** is reachable at a temperature of 232 C.

SCR catalyst

Static characteristic of temperature is the same as in the case of the OC. Static characteristic of the NO_x reduction efficiency η:



Optimal η is reachable for temperature around 350 C while the NH_3 slip is held below 25 ppm. Further **model fitting** is necessary to shift both optimal points closer to each other.

The Control Strategy

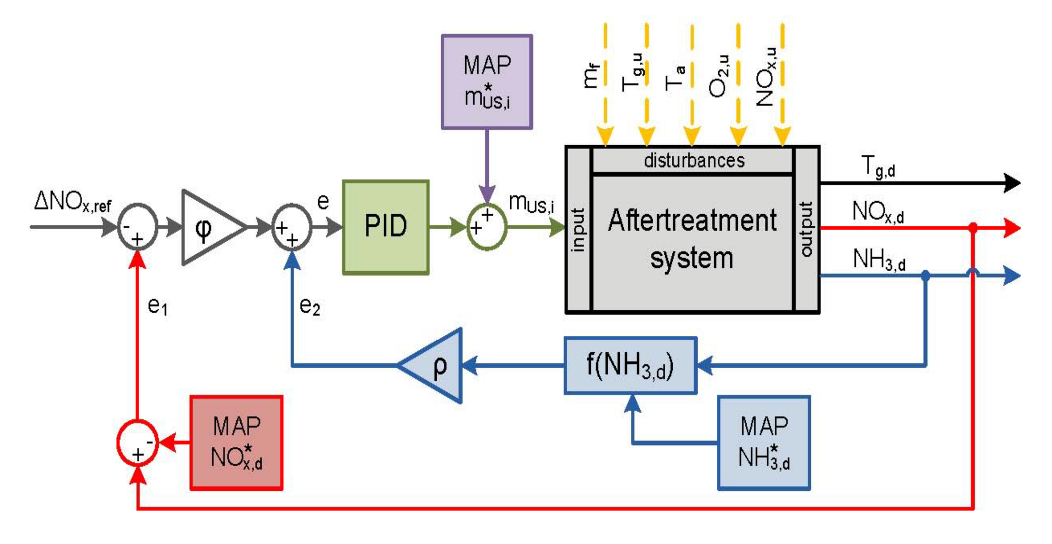
The goals:

- To provide NO_x reference tracking
- To mitigate the inaccuracies of physical design
- To hold the NH_3 slip below limits given by legislation

Feedback control strategies in combination with conservative feed forward control seems to be a suitable solution. Possible controller **solutions** are:

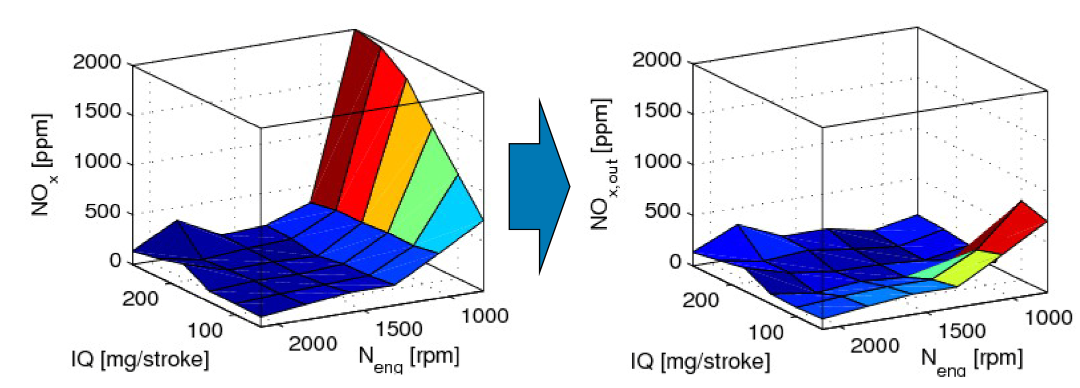
- **An MPC controller** - engine and aftertreatment system treated as a single unit
- **A cascade of PID controllers** – setpoints PID controlling the engine is computed as an output of PID controlling the aftertreatment system.

The MPC offers the superior performance. In this case rather simple demonstration control **strategy based on PID** is utilized:

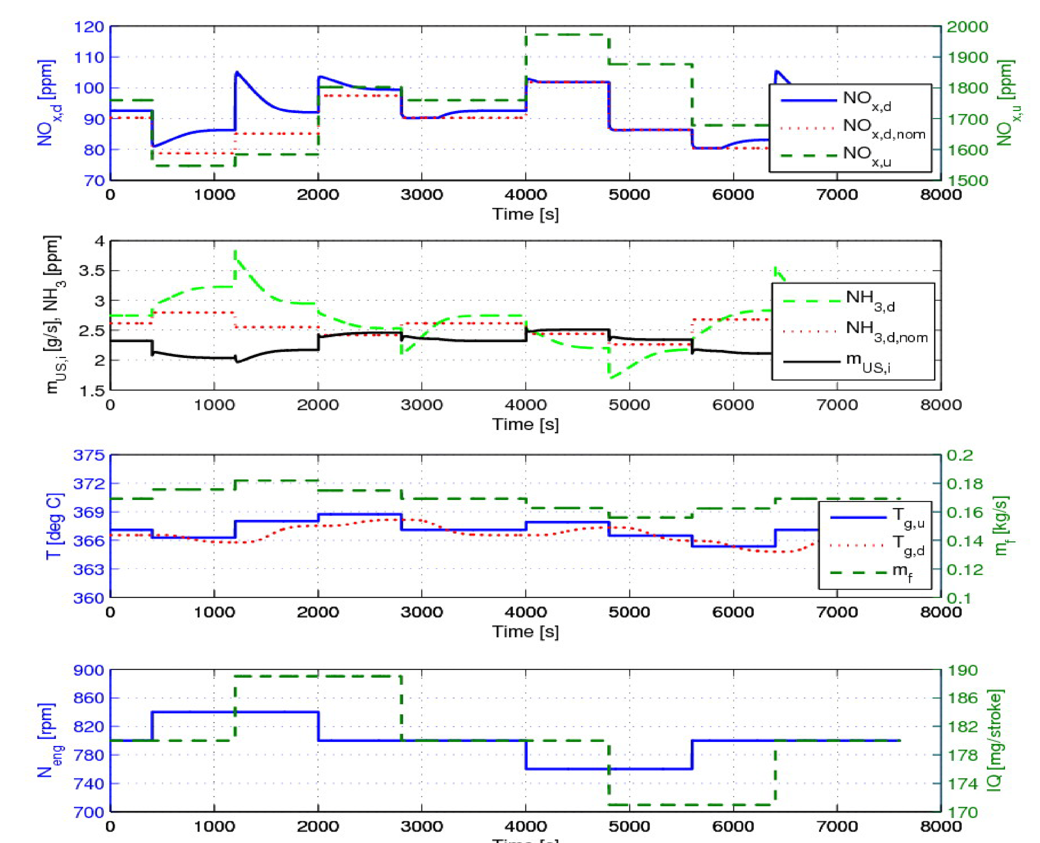


It offers compromise control between NO_x reduction efficiency and NH_3 slip due to **composite control error**.

The control strategy was applied on adjusted aftertreatment system while utilizing data from diesel engine model that was provided by Honeywell company. The engine model has **integrated an EGR**.



The **96.7%** peak NO_x reduction efficiency was reached, while maintaining **77%** average NO_x reduction efficiency for engine operating points within a relevant temperature range. Ammonia slip < 12 ppm. Simulation for validation of control strategy that mimic a simple **drive cycle**:



Acknowledgement

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