Model Identification and Optimization-based Control Design for Four-Way Catalyst System

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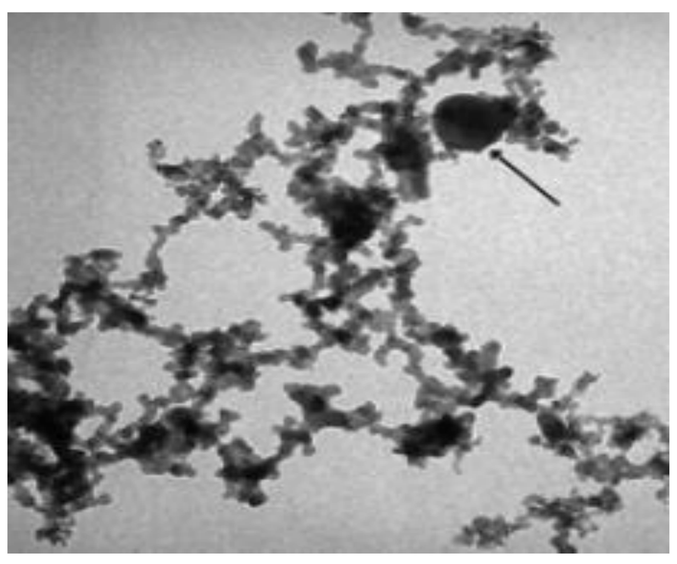
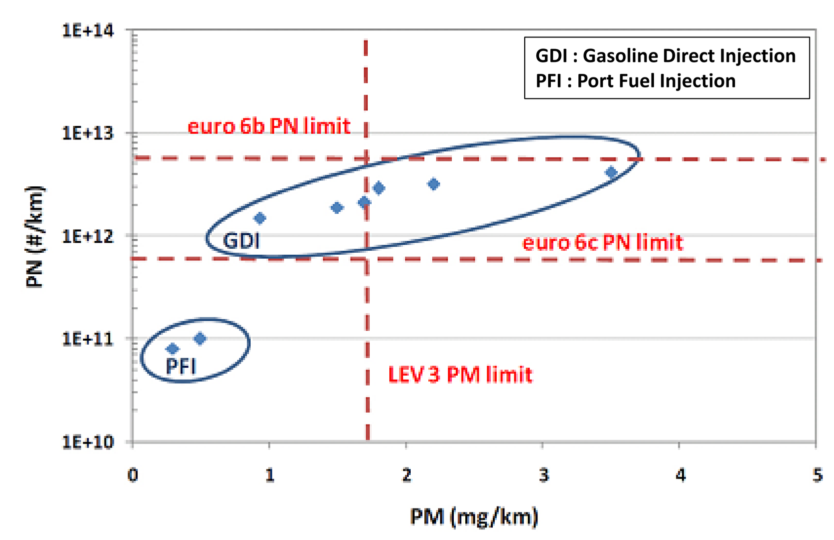
Motivation

- Upcoming Particulate Number (PN) regulations for gasoline vehicles may necessitate the use of Gasoline Particulate Filters (GPF)



Bright-field TEM images of particulate matter [1]



Particulate number and particulate mass regulations for gasoline vehicle [2]

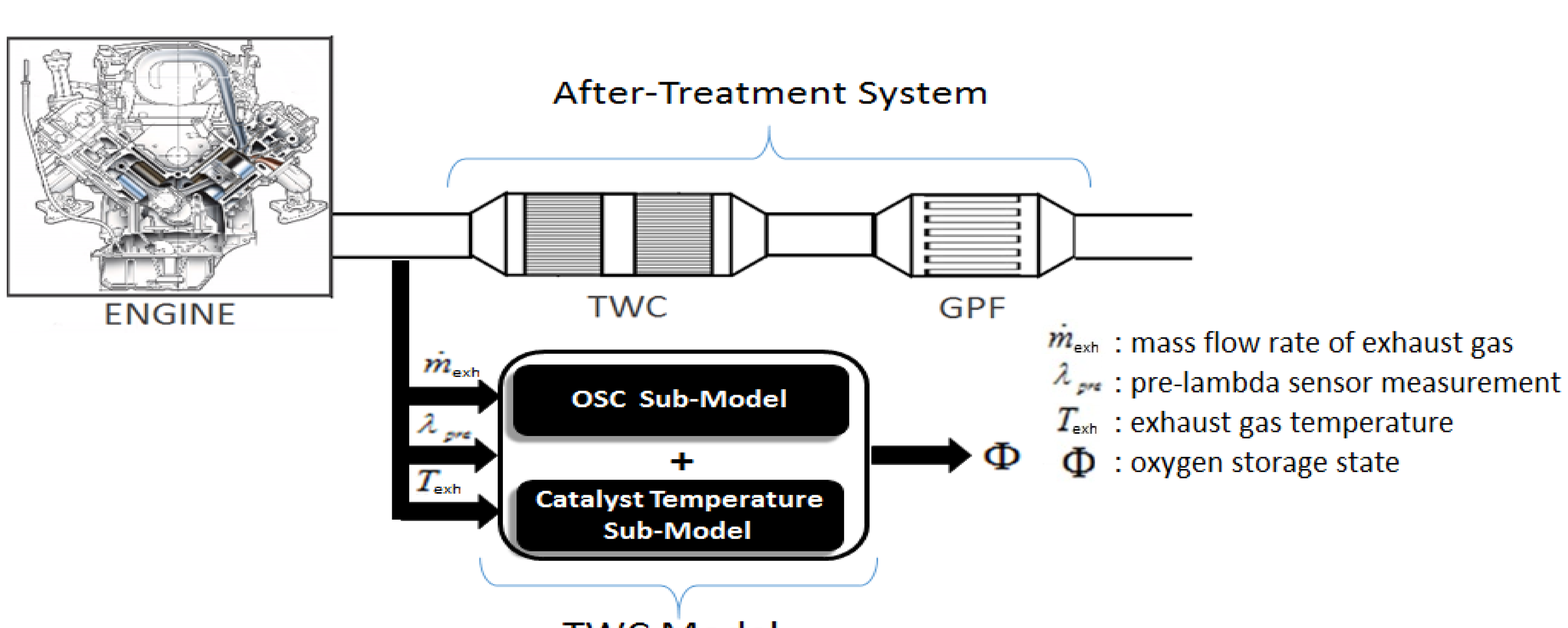
Europe [3]	USA California Air Resources Board (CARB) [4]
Euro 6b => 5 mg/km => 2014	LEV III => 3 mg/mile=> 2017-2021
Euro 6c => 5mg/km => 2017	LEV III => 1 mg/mile => 2025 -2028

PM limit for current and future coming regulations for gasoline vehicle in USA and Europe

GPF Challenges
Particulate accumulation could necessitate GPF regeneration drive cycle dependent
Back-pressure and active regeneration of the GPF affects fuel efficiency
Regeneration requires adequate oxygen, impacting TWC operation

Control Oriented Model of Three Way Catalyst

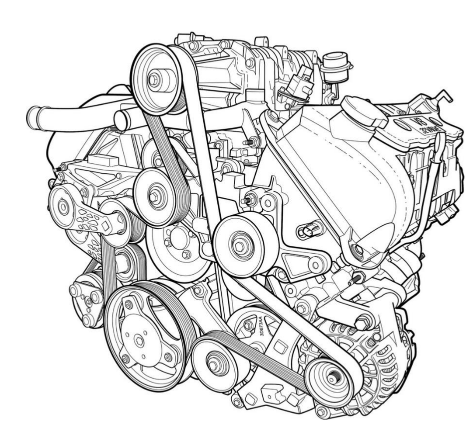
- Semi-empirical oxygen storage model (OSC) including 'catalyst effective capacity (C)' as a function of temperature are being designed
  - Oxygen storage and release to/from the catalyst surface dominate the dynamic behavior of the catalyst
- The control-oriented TWC model is designed as cascade of:
  - Catalyst temperature model
  - Dynamic oxygen storage model



- *'Catalyst Aging'* affects the catalytic activity (efficiency) and this effect can be seen through a decrease in 'catalyst effective capacity (C)'
- Including catalyst temperature dynamics in OSC model provides the opportunity to understand impacts of aging on TWC
- Characterization of catalyst aging will lead to an adaptive online control strategy along the life cycle of the catalyst

Objective

- Simultaneously control the Three Way Catalyst (TWC) and GPF to maintain proper emission levels of CO, HC, NO_x and particulates while minimizing fuel consumption
- A model-based optimization and control approach is used to design a real-time strategy to minimize emissions and fuel consumption
- Experimentally characterize impact of direct injection engine parameters on Particulate Number (PN), Particulate Size (PS), Particulate Mass (PM), and fuel consumption
  - Establish particulate production sensitivities for each parameter
  - Investigate parameter coupling

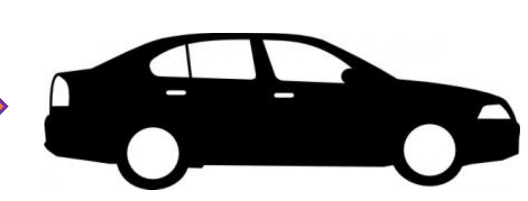


Engine Parameters
Spark Timing
End of injection
Air fuel Ratio
Exhaust valve opening/closing
Intake valve opening/closing

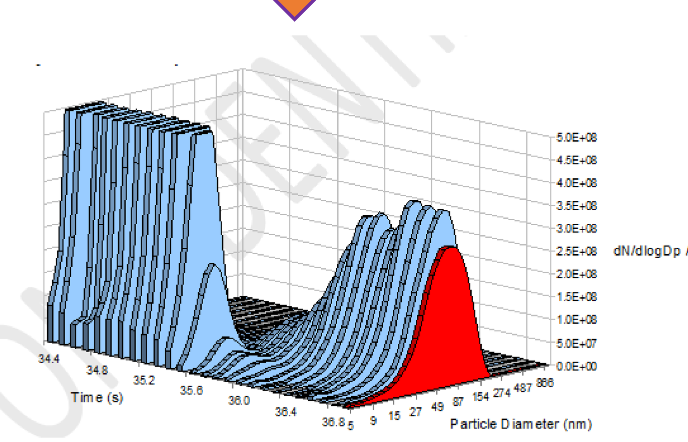
Particulate Number
Particulate Size
Particulate Mass
Fuel Consumption

Chassis Dyno

Test Mule



Particulate Measurement (DMS 500)

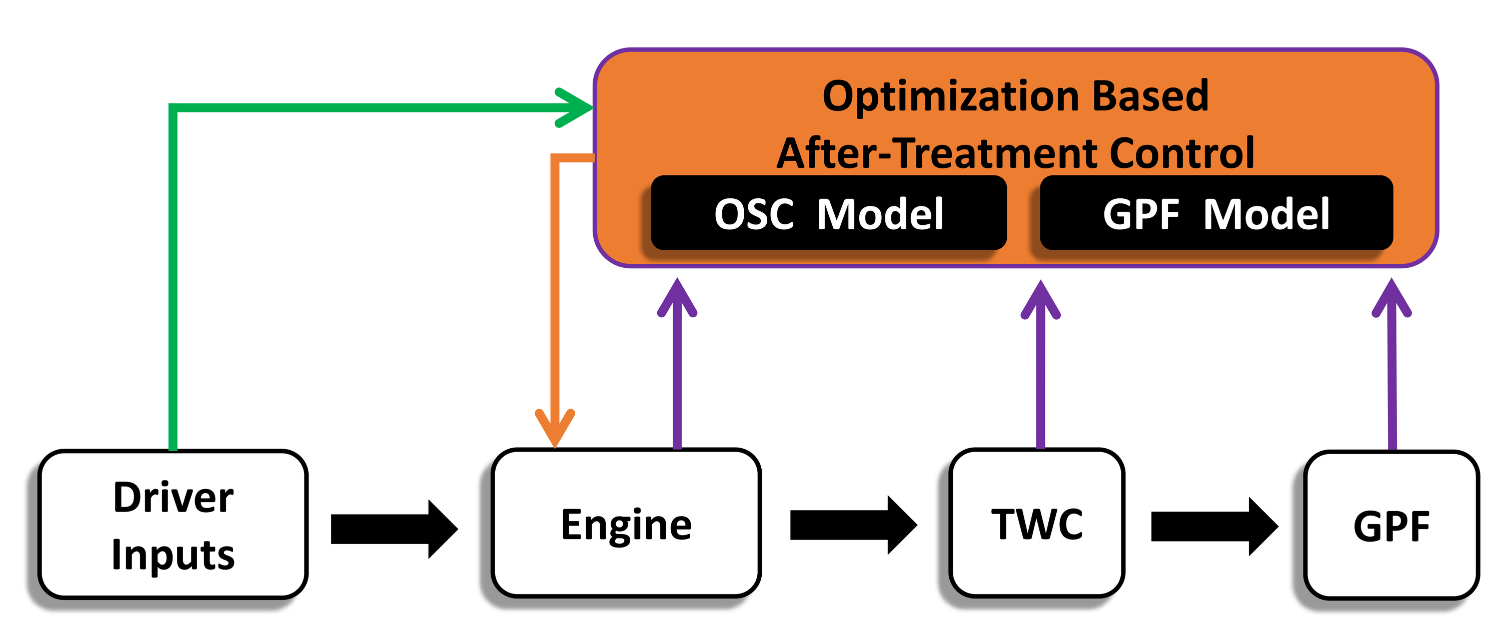


Transient PN distributions obtained through DMS500 [5]

- Transient, system level testing for direct validation of control-oriented models and optimization strategies

Optimization

- Overall system (Engine + TWC + GPF) will be optimized through model-based techniques using a control-oriented model
- Optimization-based control strategy will be designed with the purpose of maximizing fuel economy and validated experimentally



- Designed for real-time implementation
  - Robustness and near optimal performance will be emphasized
  - Experimentally validated over real world drive cycles

References

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[5] Filipi, Z., Hagena, J., and Fathy, H., "Investigating the Impact of In-Vehicle Transients on Diesel Soot Emissions", *Thermal Science*, 2008, Vol. 12, pp. 53-72