FIAT CHRYSLER AUTOMOBILES

UNIVERSITY OF MINNESOTA

Enabling Lean and Stoichiometric Gasoline Direct Injection Engines through Mitigation of Nanoparticle Emissions

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Annual Merit Review and Peer Evaluation Meeting

June 19-21, 2018

Project ID: acs120

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Project Overview

Timeline

Project Start Date: 10/1/2015

Project End Date: 1/15/2019

Percent Complete: 75%

Budget

Total Project Funding:

DOE Share = $1,090,654

Contractor = $221,113

FY 2017 Funding = $262,892

FY 2018 Funding* = $148,262

* through 5/1/2018

Barriers – ACEC Roadmap p.28,29

Dilute Gasoline Combustion:

1) “Particulate matter (PM) emission from dilute combustion gasoline engines is not fully understood.”
2) “…both the engine-out and filter-out particulate mass and number need to be characterized.”
3) “Determine effect of ethanol and fuel chemistry on particulate formation.”

Partners

University of Minnesota

FCA Fiat Chrysler Automobiles

bp

Relevance/Objectives

- **Overall Objectives**

1) Efficiently reduce particle number (PN) and particle mass (PM) emissions of lean and stoichiometric gasoline direct injection GDI engines used in light-duty vehicles to below established worldwide standards using a combination of fuel and lubricant properties and aftertreatment strategies.

2) Develop an accurate method for real-time PM measurement using suspended particle instruments.

- **Objectives in this Period**

1) Evaluate an array of oxygenated fuels to see their systemic effects on PN/PM emissions from a GDI engine under lean and stoichiometric modes using advanced combined three-way catalyst (TWC) and gasoline particulate filter (GPF) aftertreatment.

Milestones

Project Tasks, Milestones, and Go/No-Go Decisions	Budget Period 1					Budget Period 2				Budget Period 3			
	FY16				FY17				FY18				
	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Commission Engine and Test Cell			M1.1	M1.2	M1.3								
2. Regimes of Interest for PM/PN Reduction						D1.1	M2.2						
3. Fuels/Lubricants with High Impact on PM/PN							M3.1	D3.1	M3.3				
4. Synergies with Aftertreatment Technology										M4.1	D4.1		
5. Validate Identified Strategies											M5.1	D5.1	
6. Develop RT PM Measurement Techniques													M6.1

Completed (green) To be Completed (red)

Approach

FY18: Determine Fuel and Lubricant Impact on lean GDI

FY19: Validate Fuel/Aftertreatment Strategy, Real-Time PM

3. Fuel and Lubricant Property Effects — Refine fuel and lubricant impacts on PM/PN from lean GDI

4. Synergy with Aftertreatment — Study GPF-TWC aftertreatment for lean GDI over fuel range

5. Strategies Validated — PM/PN reduction proven during transient operation

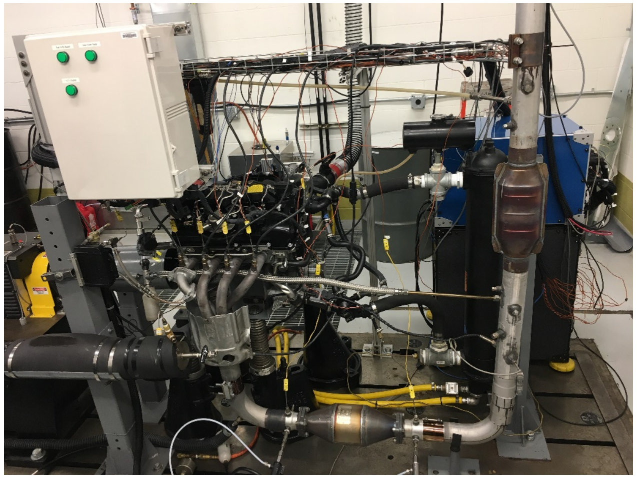
6. RT PM Measurement Techniques — Determine particle effective density for suspended particle instruments

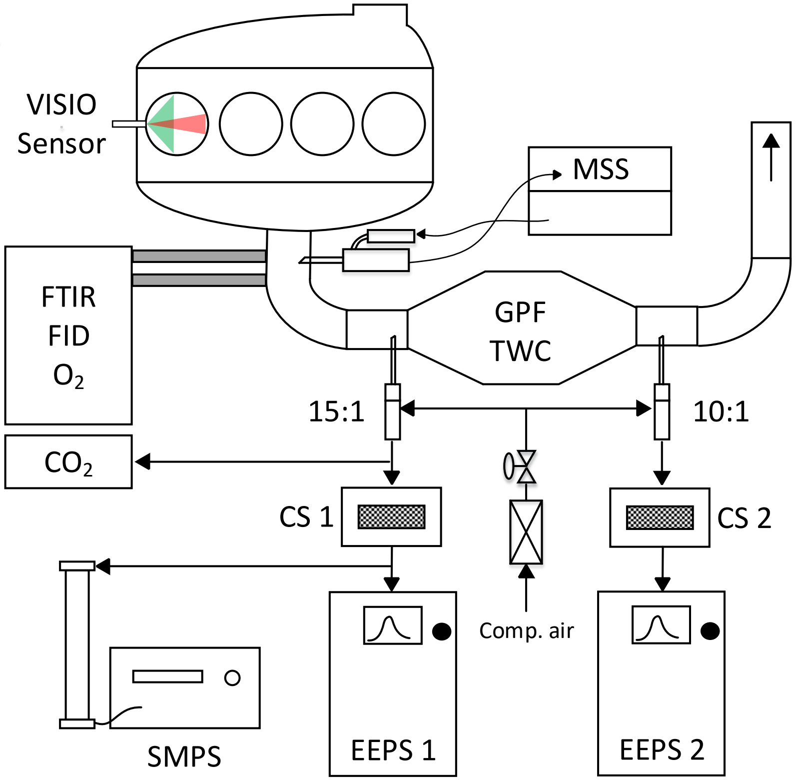
FY18 **FY19**

Technical Accomplishments

Task 1: Engine test stand and all instruments and aftertreatment installed and commissioned in FY17

Model Number	BMW - N43B20
Displacement (cc)	1995
Bore x Stroke (mm)	84 x 90
Compression Ratio	12:1
Rated Power (kW)	125 @ 6700 rpm
Rated Torque (Nm)	210 @ 4250
Induction	Naturally Aspirated
Injection	Central Piezo
Max Rail Pressure (bar)	200





Technical Accomplishments

Task 2: Fuels selected and characterized over range of lean/stoichiometric engine conditions and transient step changes

Engine conditions tested:
S = Stoichiometric, LH = lean homogenous, LS = Lean stratified

Condition	Speed (rpm)	BMEP (bar)	Mode	φ
SS 1	1400	2	S LH LS	1.0 0.67 0.5
SS 2	2000	4	S LH LS	1.0 0.65 0.65
SS 3	2000	7	S LH	1.0 0.69
SS 4	2400	7	S LH	1.0 0.73
Load steps	2000	2-7	S LH	1.0 0.73 – 0.67
Engine start	1000	0	S	1.0

PM Index calculated from GC-MS analysis of fuels

$$PM\ Index = \sum_{i=1}^{n} \left(\frac{DBE_i + 1}{P_{vap,i}(443K)} \times Wt_i \right) \quad [1]$$

Fuel ID	Arom. (%)	T90 (°C)	AKI	EtOH (%)	PM Index
Baseline	27.0	162	90.8	9.9	NA
A-1	22.4	160	90.9	9.9	1.19
A-2	42.9	166	92.6	9.9	1.77
V-1	29.9	129	90.8	9.9	0.70
V-2	29.4	178	91.7	10.0	2.16
E15	28.5	160	93.6	15.2	1.37
E50	16.7	160	96.3	50.0	1.09

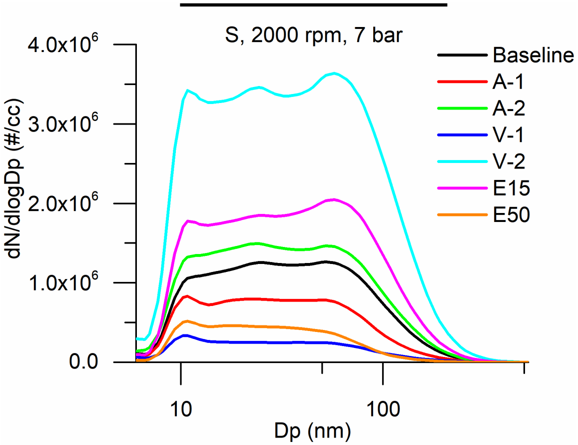
[1] Aikawa et al. Development of a Predictive Model for Gasoline Vehicle Particulate Matter Emissions, SAE Int. J. Fuels Lubr. 3 (2010) 2010-01–2115.

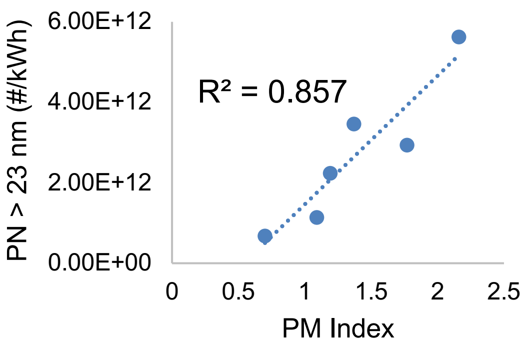
Technical Accomplishments

Task 3: Fuel screening experiments performed to determine the effect of fuel properties on particle emissions

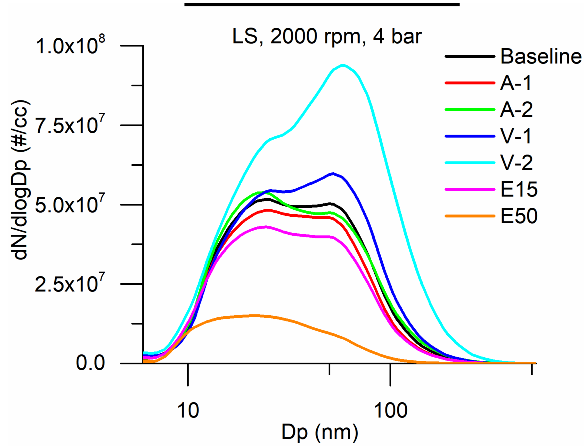
- PM Index - good correlation to stoichiometric conditions but not for lean GDI
- High ethanol (E50) produced excessive PM/PN in lean homogenous modes

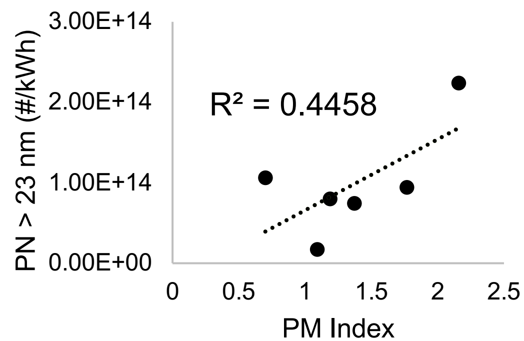
Stoichiometric



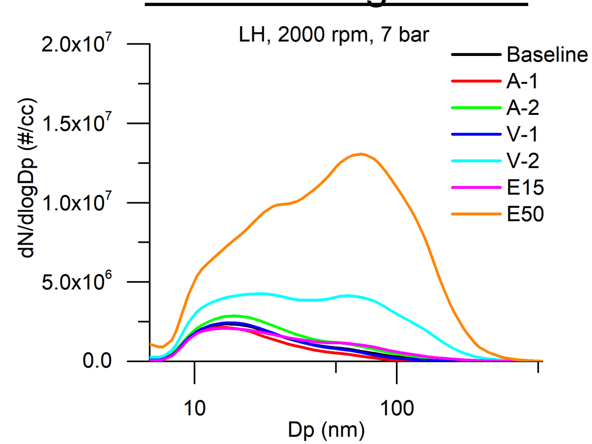


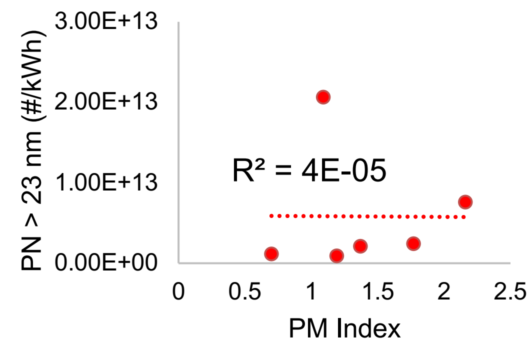
Lean Stratified





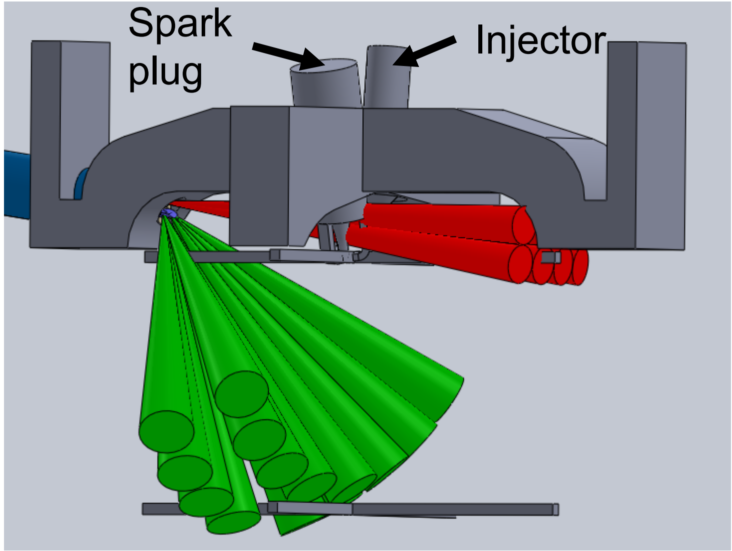
Lean Homogeneous

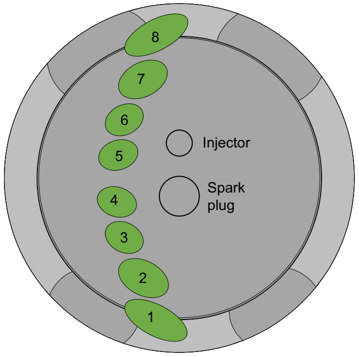




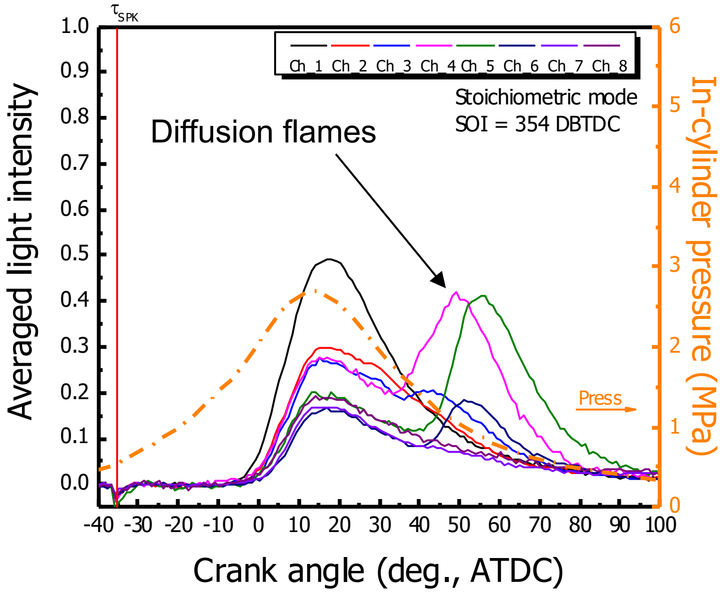
Technical Accomplishments

Task 3: In-cylinder luminosity to determine PM formation causes in lean GDI





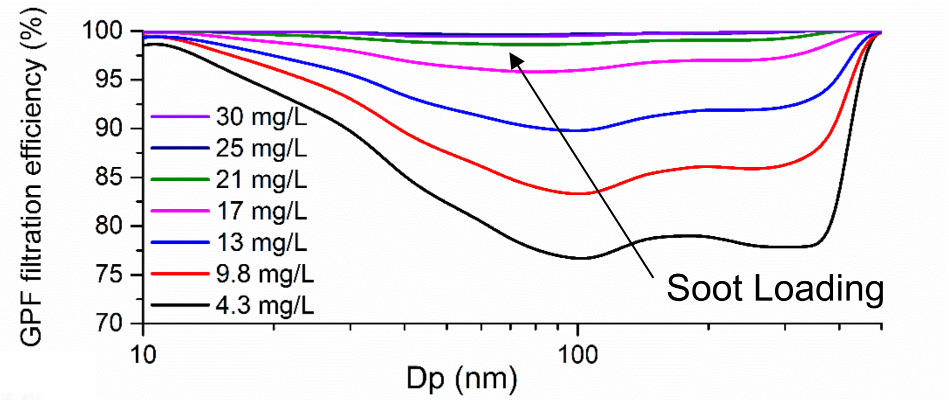
- 24 fiber optic channels - light intensity
- Premixed homogeneous combustion follows in-cylinder pressure trace
- Soot formation occurs in diffusion flames, which incandesce due to soot oxidation
- Diffusion flames are spikes in the light intensity during the expansion stroke

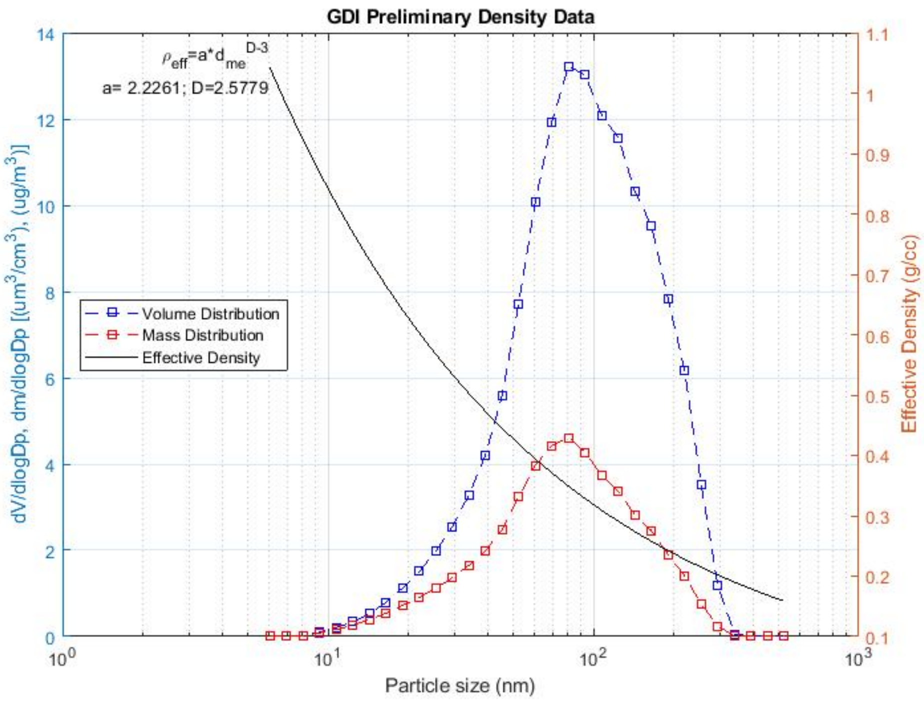


Technical Accomplishments

Task 4: GPF/TWC aftertreatment installed and characterized

- Determining effectiveness over entire fuel and engine operating condition matrix underway





Task 6: Centrifugal particle mass analyzer used to characterize particle density as function of particle diameter

- Can be used for conversion of particle number to mass in real-time

Response to Previous Comments

This is the first year the project has been presented

Partnerships/Collaborations

Partners

FIAT CHRYSLER AUTOMOBILES

- Technical guidance, production vehicle relevance
- Aftertreatment system components

bp

- Technical guidance, fuel products relevance
- Fuels and lubricants with detailed properties

Collaborators

Oak Ridge National Laboratory

- Cycle-to-cycle in-cylinder soot production
- Periodic discussion of BMW N43 engine results

AVL

- In-cylinder Visiolution diagnostics support and collaboration

Remaining Challenges and Barriers

- High solid sub-23 nm diameter nanoparticle concentration unexpected – thought to be ash originating from lubricating oil (Task 3)
- Fuels, lubricants and aftertreatment combinations for meeting worldwide PM/PN regulations for lean and stoichiometric GDI engines incomplete (Task 4)
- Transient segments of driving cycles representative of high PN/PM emissions regions not identified (Task 5)
- Effective density measures not consistent across fuels and engine operation to convert PN to PM (Task 6)

Proposed Future Research

To be completed in FY18/FY19(Q1):

- Detailed characterization of solid nanoparticles in lean GDI modes
  - Correlation with existing knowledge of PM/PN for stoichiometric GDI
  - Sources within combustion chamber using flame luminosity
  - Effect on GPF aftertreatment
  - Fuel-dependent soot oxidative reactivity
- Transient cycle segment experiments including GPF aftertreatment
- Effective density correlations across fuel and operating conditions

Future*:

University of Minnesota and its partners will seek additional funding to continue research on nanoparticle characterization from lean GDI/GDCI engines in support of *ACEC Dilute Gasoline Combustion Roadmap*

*Any proposed future work is subject to change based on funding levels

Thank You

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