Gasoline direct injection engines
the effects of deposit control and removal

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Summary

As vehicle manufacturers strive to deliver increased fuel efficiency from their vehicles, Gasoline Direct Injection Gasoline (GDI) engines have becoming globally widespread. Already the majority of European market gasoline engines, in 2017 they will be almost a half of global gasoline engine production.

However, whilst the technology might be more modern than tradition port fuelled engines, the need to control deposits remains as strong as ever, and potentially even more critical, as they rely on the successful presentation of the fuel spray to ensure combustion and emissions are as designed.

This presentation will discuss the growth of the GDI engine and what challenges arise from the deposits in these engines. It will then discuss and show what solutions can be offered by the use of deposit control additives to help protect against and recover deposit formation, and what impact they have on the effective service operation of GDI engines.
Outline

1. About Afton Chemical
2. GDI background
3. Injector deposit test methodology and results
4. Vehicle performance
5. Conclusions
About Afton Chemical
Independent company with 90+ years of excellence in additives

Afton Chemical has been a key player in the lubricant and fuel additive industry for more than 90 years

Formed in 1924 as the Ethyl Gasoline Corporation

Newmarket Corporation formed in July 2004

Present

>$2bn turnover

>1850+ employees
Our footprint and local know-how ensure best service to customers
Offering the leading portfolio of solutions

Gasoline Performance
- Gasoline Performance
- Passenger Car Motor Oils

Diesel Performance
- Combustion Improvers
- Octane Improver
- Finished Fuel Additives

Driveline & Industrial
- Transmission Fluids
- Automotive Gear
- Hydraulic, Tractor
- Slideway, Turbine
- Metalworking
- Industrial Gear
- Grease

AftonChemical.com

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World-Class Innovation Centres – Committed to Technology Leadership

Richmond

Manchester

Suzhou

Ashland

Bracknell

Tsukuba

Afton R&D budget of > $150 million.

More than half our revenue comes from products introduced in the last three years.

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Gasoline Direct Injection background
Gasoline Direct Injection background

What’s driving OEMs towards GDI technology?
- Governmental regulations – FE / CO₂ standards
- Customer demands for fuel economy

Why GDI?
- Improved Fuel Efficiency
  - Better knock resistance / higher compression ratios

Any other benefits?
- Smaller engines with higher power densities
  - Enables engine downsizing
- Works particularly well with pressure charging
  - Many GDI applications are turbocharged
Gasoline Direct Injection background

How rapidly is GDI growing?

- Globally went from 1% to 44% of new gasoline engines in last 17 years
- Will go to 62% in the next 5 years

Source: IHS 2014
Gasoline Direct Injection background

Injector deposits can cause:

- Increased fuel consumption and engine power loss
- Increased engine-out emissions
- Engine malfunction
  - Illumination of MIL light

Injector deposits concern OEMs because they can affect:

- Customer satisfaction
- Vehicle emission compliance
  - Euro 6c / US Tier 3 from 2017
- Warranty claims
Gasoline Direct Injection background

Reports concerning GDI Injector Deposits

International Automotive Technicians Network (iATN)

- Largest network of automotive repair professionals in the world
- More than 80,000 members in 160 countries

Postings have highlighted GDI injector deposits causing caused performance, drivability, and fuel economy issues for customers

ALLDATA

- A source for automotive information from OEMs
- Provides OEM Technical Service Bulletins (TSBs), diagnostic, and repair information.

Several TSBs from OEMs recommend gasoline deposit control additives to remove and prevent GDI injector deposits

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Gasoline Direct Injection background

Injector deposits are an industry concern because:

- There is currently no industry accepted test for GDI deposits
  - EU PFI has CEC F-05-93 and CEC F-20-98

- *It cannot be assumed that additives suitable for PFI engines will protect GDI*

- New GDI engine tests now being proposed
  - US GDI: GM 2.0 litre
  - EU GDI: VW 1.4 litre

- *Tests will require development before use*
- *Likely to be rapidly adopted by fuel marketers / specifiers*
Deposit Control Additives – why must they evolve?

Untreated Fuel
Additised fuel

Untreated = blocked = coarse spray
Additised = clear = fine spray

Carburettor
Port Injector
Model
Year
Component
Temperature
Direct Injection
PFI Inlet Valve
Afton Injector deposit test methodology and results
Potential GDI injector deposit measurement techniques

Visual rating
- May not correlate to change in injector flow performance
  - May be relevant to emissions

Removal and flowing
- Intrusive
  - May change signal

In-situ injector performance
- Long Term Fuel Trim (LTFT)
  - Engine management uses adaptive fuelling to ensure correct stoichiometry as measured by exhaust gas oxygen sensor.
  - As injector nozzle flow rate decreases, injector is held open longer to ensure same volume of fuel is delivered.
  - Percent change can be seen as LTFT
- Relatively simple - can be extracted by interrogating engine diagnostics
- However, not all LTFT correlates to injector flow – OEM specific.
Driving cycle used for mileage accumulation
Injector Plugging Calculated from LTFT

LTFT = Long Term Fuel Trim

Initial drop in LTFT is typical for new injectors – intentional to reduce risk of reaching adaptive limit / clip during normal service.
Validation of LTFT in E10 Vehicle Field Test Fleet

- 67% of the fleet had a LTFT > 10%
- 25% of the fleet had a LTFT > 15%

Histogram Categorized by Adaptive Fueling Parameter
Performance of PFI and GDI additives
Deposits around an injector nozzle hole - visual.

This injector does not have any flow loss

This injector has significant flow loss:
24% LTFT
Gasoline injector deposits and flow loss (GDI)

Dirty

Clean

Flow loss without additive

Flow restoration by additive
Gasoline Injector Face Deposits:

FUEL: Gasoline. No Deposit Control Additive

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Gasoline Injector Face Deposits
FUEL: Gasoline with Deposit Control Additive

Injector 1
1.25 x zoom
3.0 x zoom

Injector 2
1.25 x zoom
3.0 x zoom

Injector 3
1.25 x zoom
3.0 x zoom

Injector 4
1.25 x zoom
3.0 x zoom
Gasoline Direct Injection Deposit Effects
GDI Injector Deposits and Exhaust Particulate Numbers

Increased particulate numbers as injector deposits build up.

Source: University of Birmingham
New GDI test under development by CEC

TDG-F-113

CEC New Test Development – Proposal for a New Engine Fuels Test Procedure

“DISI (Direct Injection spark ignited engine) Injector fouling Test”

It is recognized that this test will need an investigation phase to define a practical and acceptable test. The following guidelines are given and should be discussed and implemented during test development:

General considerations:
- For the evaluation of the performance of an engine, it is necessary to develop a procedure to measure the deposit that is formed in the injector system with a high level of repeatability and reproducibility.
- The procedure should be designed to achieve both high and low quality of performance for fuel injection systems. The proposed test can be used for every operation and durability cycle.
- The procedure should be adequate for both diesel and gasoline engines.
- The test should be designed to measure the injector without affecting the measurement of other parameters.
- The appropriate project timing for each stage of the development and verification of the test is important.

The procedure to generate deposits developed by the CEC is not complicated and the duration is manageable. The variables used for the test are the injection time (Duration), diesel fuel property, and the diesel fuel ratio. The procedure involves three distinct conditions for the test run: diesel fuel ratio, diesel fuel ratio, and diesel fuel ratio. The test runs consist of 40 hours of deposit formation with a continuous measurement of the amount of deposit formed.

A particular requirement exists for the injector design. Each set of injectors needs to have a similar injection behavior. In addition, all injectors have to pass a leakage test. The procedure should be defined during test development. Additional criterion is a visual inspection of spark plug fouling can be included but will not be considered as a limit setting criterion.

4. Reference Fuels

The TDG will select the reference fuels either from existing CEC reference fuels or from similar development of new reference fuels that will achieve:
- Reproducibility for injector study to define (+/- 3%)
- Low reference fuels for the reference fuels that will be used in the reference fuels.

The reference fuels shall be defined and approved by the CEC.

For this running process, the fuel with the diesel fuel ratio tends to be recommended. This test can be the same as the 48 Reference Fuel.

Reference Fuel: The TDG will select the reference fuel that meets the criteria for diesel fuels for this engine.

5. CEC Management Board Approval

Following CEC Management Board approval of the Test Procedure, the test development methodology will be selected through the CEC testing process. A request for approval will be made using the test proposal process.

Considerations should be made by the TDG to determine whether additional processes are required to select a reference fuel supplier and/or a reference oil supplier.

The TDG must submit a data showing test repeatability based on a reference is given by the CEC. Management Board to process the test development to phase 2, which includes the installation of the test at additional test laboratories.

6. Proposed timeline:
- 12/2017
  - CEC QRB – translation and prior approval of terms of reference
  - Information published on CEC website on the basis of testing proceeds according to CEC Guidelines 10
  - 10/2017
    - Selection of test fuel
      - Provision and selection of fuel
    - Selection of TDG Chair
  - 12/2017
    - Development of protocol for test
    - Development of protocol for test
    - Development of protocol for test
  - 12/2017
    - End phase 1 and approval from CEC Board
    - End phase 2 and approval from CEC Board

Extracted from:
http://www.cectests.org/public/info_/g003/Appendix%201_CEC%20New%20Test%20Development%20-%20%20Terms%20of%20Reference%20-TDG-F-113.pdf
New GDI test under development by CEC

6. Proposed timeline
- 09/2016:
  o CEC MB – finalization and approval of terms of reference
  o Information published on CEC website and start of tendering process according to CEC Guidelines 10
- 10/2016
  o Organization pre-tender meeting
- 11-12/2016
  o End of tender and selection of lead lab
  o Call for sponsors
  o Selection of TDG Chair
- 1/2017
  o Installment of TDG and start of work according to CEC Guidelines 11
  o Start Phase 1
- 12/2017
  o End Phase 1 and approval from CEC Board
- 1/2018
  o Start Phase 2
- 9/2018
  o End phase 2 and approval from CEC Board

Extracted from: http://www.cectests.org/public/info_/g003/Appendix%201_CEC%20New%20Test%20Development%20-%20Terms%20of%20Reference%20TDG-F-113.pdf
Example results expected from new GDI test

Further information to be presented at TAE, Esslingen, 27-29 June 2017
Vehicle performance
Example vehicle performance benefits

**Torque / power**
- Power and Torque before & after dirty-up
- Dirty-up - base fuel, no additive (10% Plugging)
- Torque after cleanup (0% Plugging)

**Fuel Consumption**
- High mileage field vehicle
- Fuel consumption before & after clean-up
- NEDC fuel consumption

**Torque – Start and End of Test**
- Torque loss & recovery

**Torque – Middle of Test**

**Fuel Consumption Reduction**
- NEDC fuel consumption before & after clean-up

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Conclusions
Conclusions

▲ GDI sales and fleet continue growing fast globally

▲ GDI engines vulnerable to injector deposit formation
  ▲ Evidence of GDI deposit issues in the field
  ▲ OEM concern about customer / regulator impact
    • OBD / MIL issue / Particulate emission effect
    • Euro 6c Emissions Sept 2017 – Particulate number limit reduction

▲ New CEC GDI test being developed

▲ Fuel additives can address GDI injector deposits
  ▲ Offers cost effective way to enable fuel and engines to evolve
  ▲ Advanced additives must address GDI as well as PFI / IVD

▲ Additive use offers significant potential for power, fuel economy and emissions maintenance / improvement.
Thank you.
Any questions?

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