Investigating the trade-off between particulate emissions and thermal engine efficiency of a diesel engine

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Motivation and Objective

Motivation

- The development of biofuels compatible with diesel engines

- Need for better understanding of the effect of molecular structure of various fuels to combustion development, exhaust emissions and thermal engine efficiency of a diesel engine.

Objective

- To investigate whether there is a trade-off between particulate matter emissions and engine thermal efficiency

Experimental Setup

Particulates 5-1000nm
- Mass (um/cc)
- Number (N/cc)

Data analysis

DMS 500 Fast Particle Analyzer

Exhaust gas

Fuel injection system

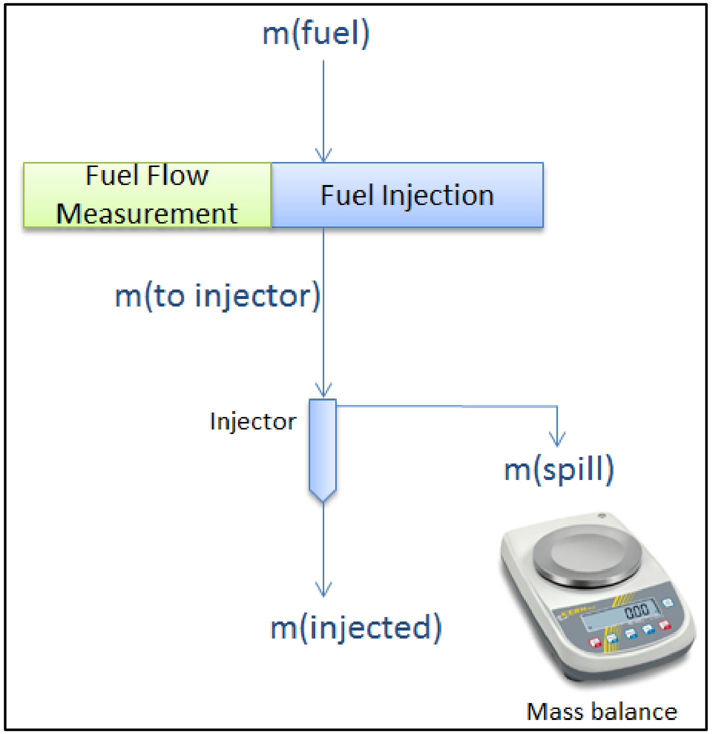
Engine head	Ford Duratorq
Crank case	Ricardo Hydra
Cylinders	1
Bore	86 mm
Stroke	86 mm
Swept volume	499.56 cc
CR	18.2 : 1
Shaft encoder resolution	0.2 CAD

Experimental Setup

- Efficiency measurement

$$\eta_F = \frac{W_C}{m_{injected} Q_{HV}}$$

$$m_{injected} = m_{to\ injector} - m_{spill\ from\ injector}$$



- Engine test conditions
  - 1200rpm engine speed
  - 4 bar IMEP
  - 600 bar injection pressure
  - Injection timing of 7.5 CAD BTDC

Fuel molecules tested

- 46 fuel molecules from 7 functional groups were tested (from C8 to C17)

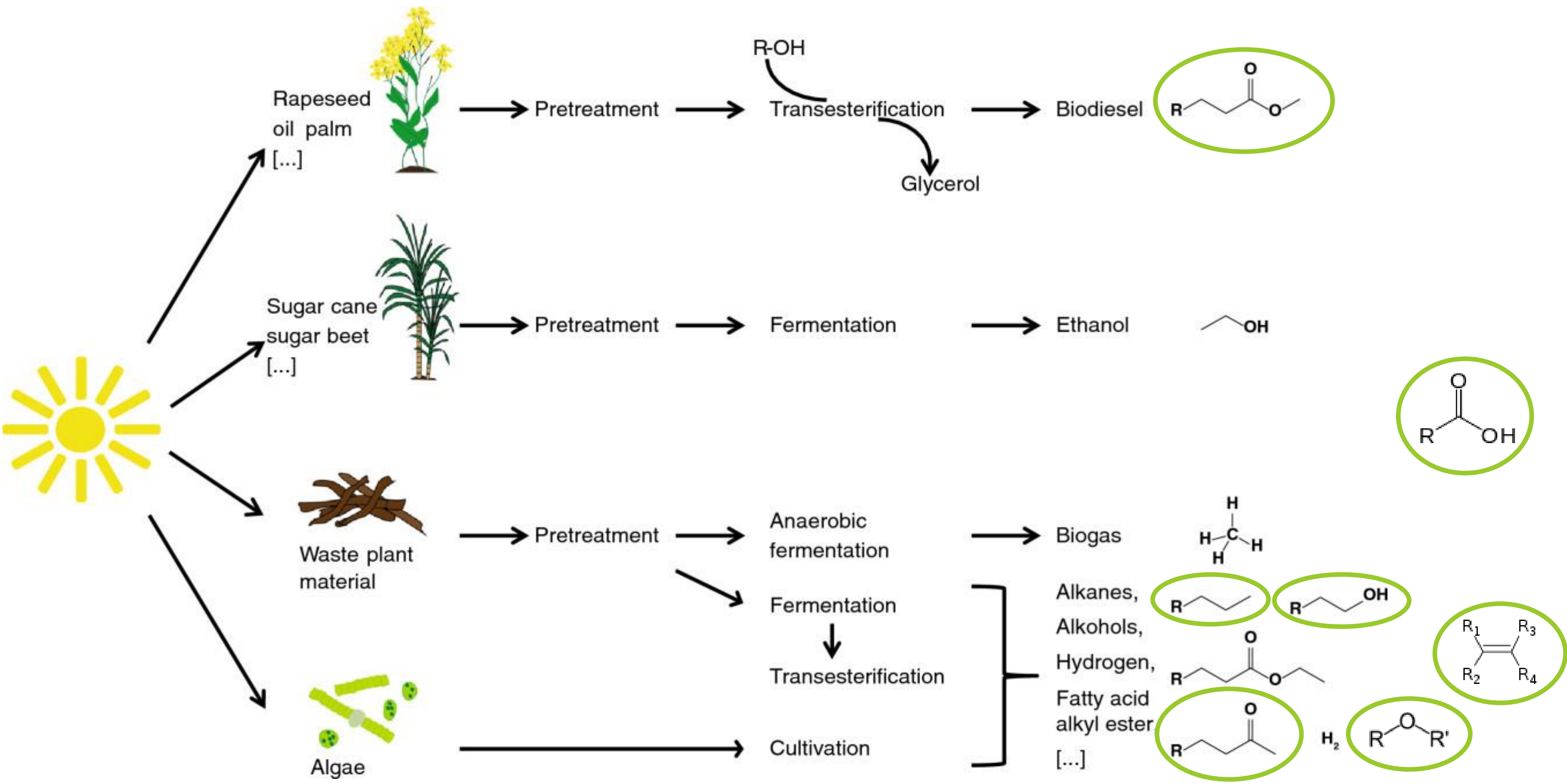
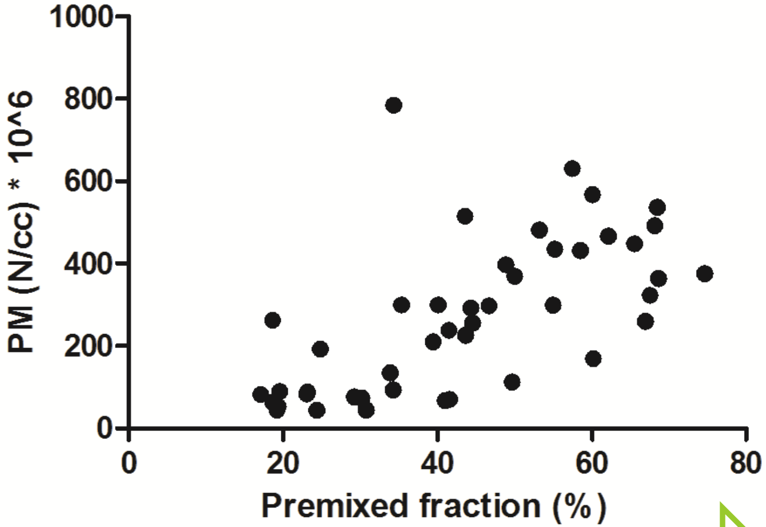
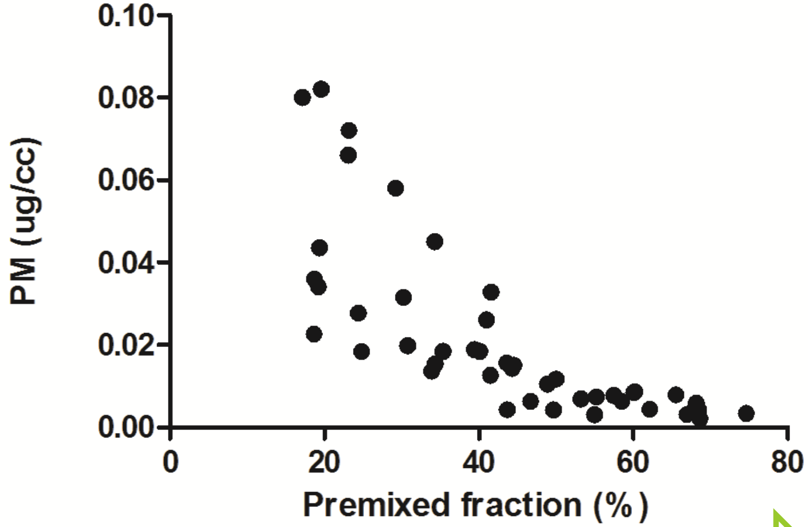


Figure from Overview of the production of first- and second-generation biofuels. Janßen and Steinbüchel *Biotechnology for Biofuels* 2014 7:7 doi:10.1186/1754-6834-7-7

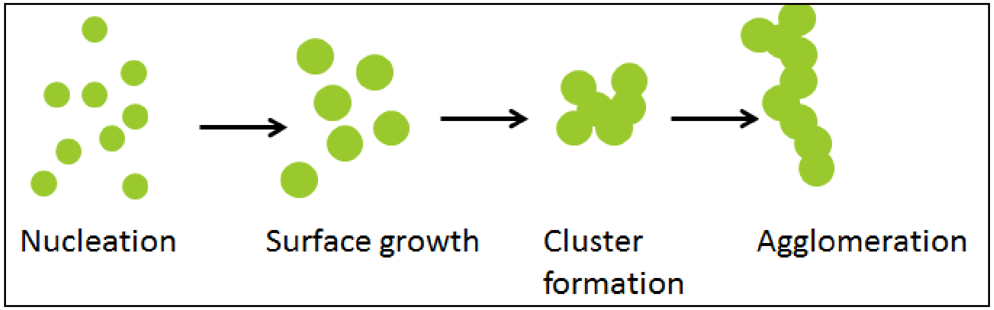
Combustion development



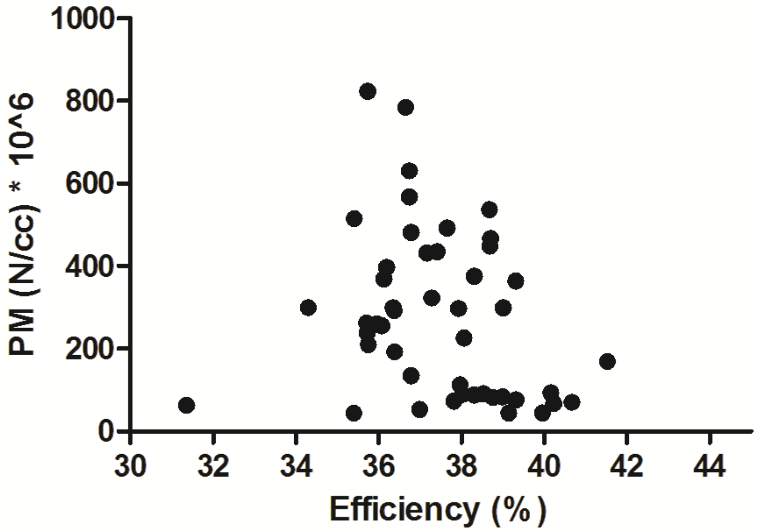
More homogenous mixture

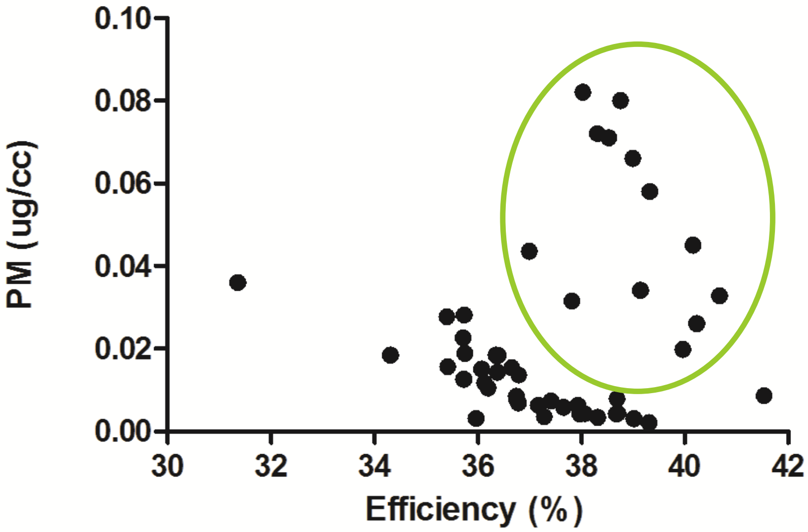


Higher in-cylinder temperature



Thermal Engine Efficiency

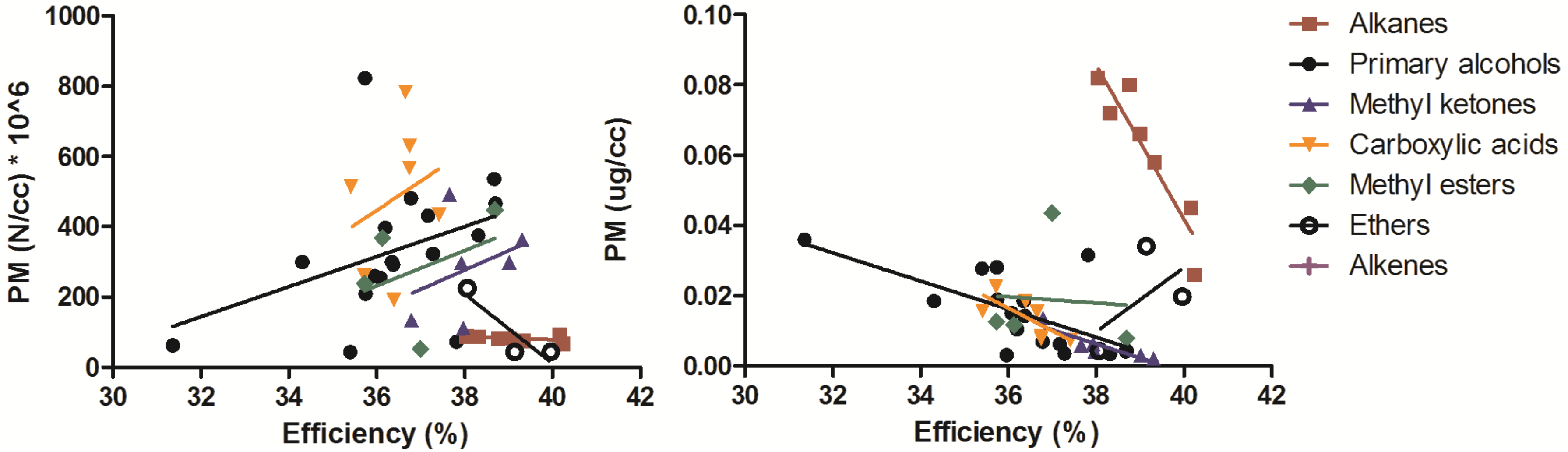




- No correlations, and hence no trade-off was observed

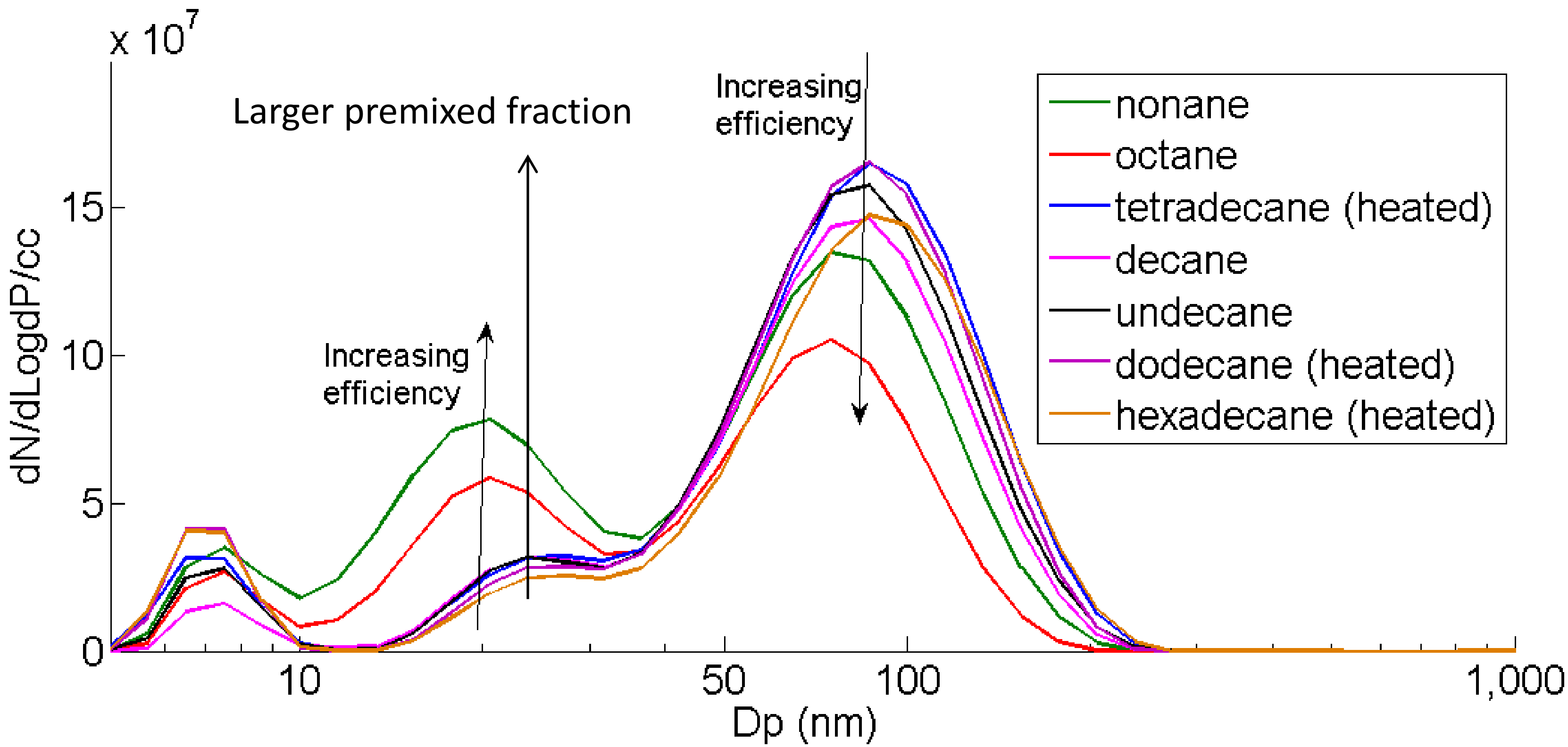
➢ The effect of molecular structure of fuel was investigated in more detail

Structure of Fuel Molecule



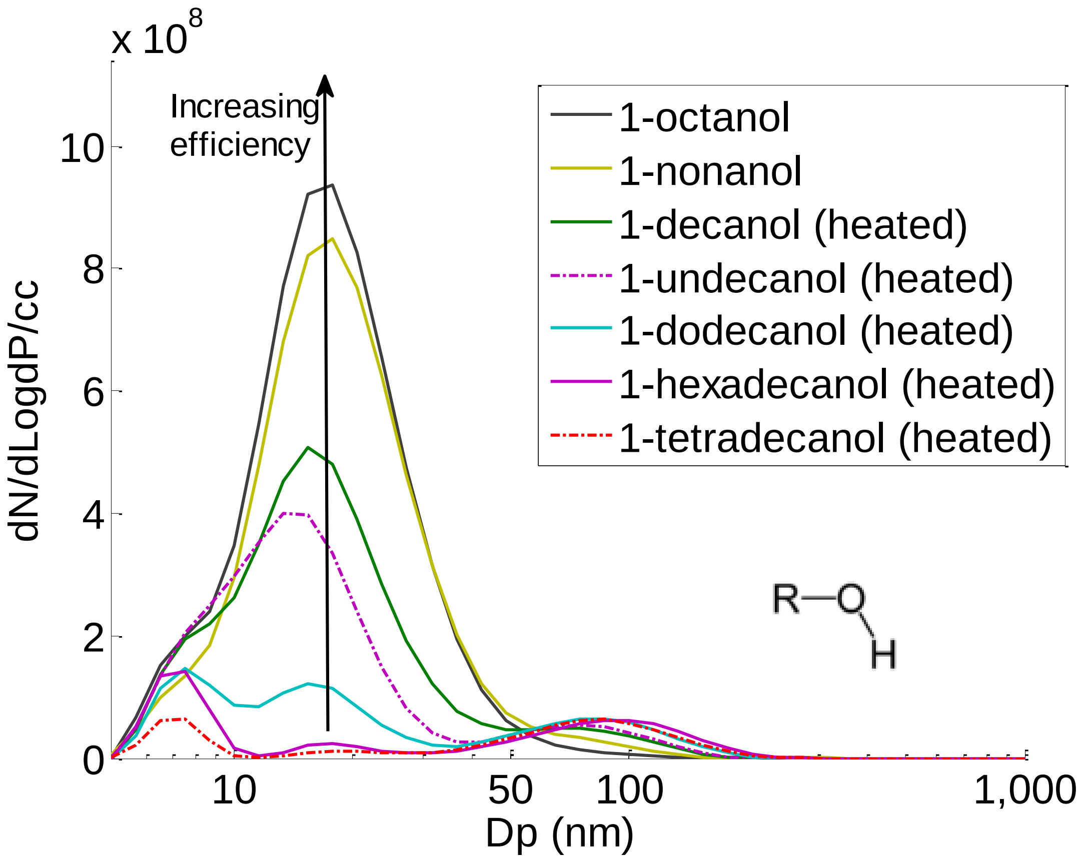
- A shift from heavy agglomeration particles to lighter nucleation particles was observed with increasing thermal engine efficiency

Alkanes



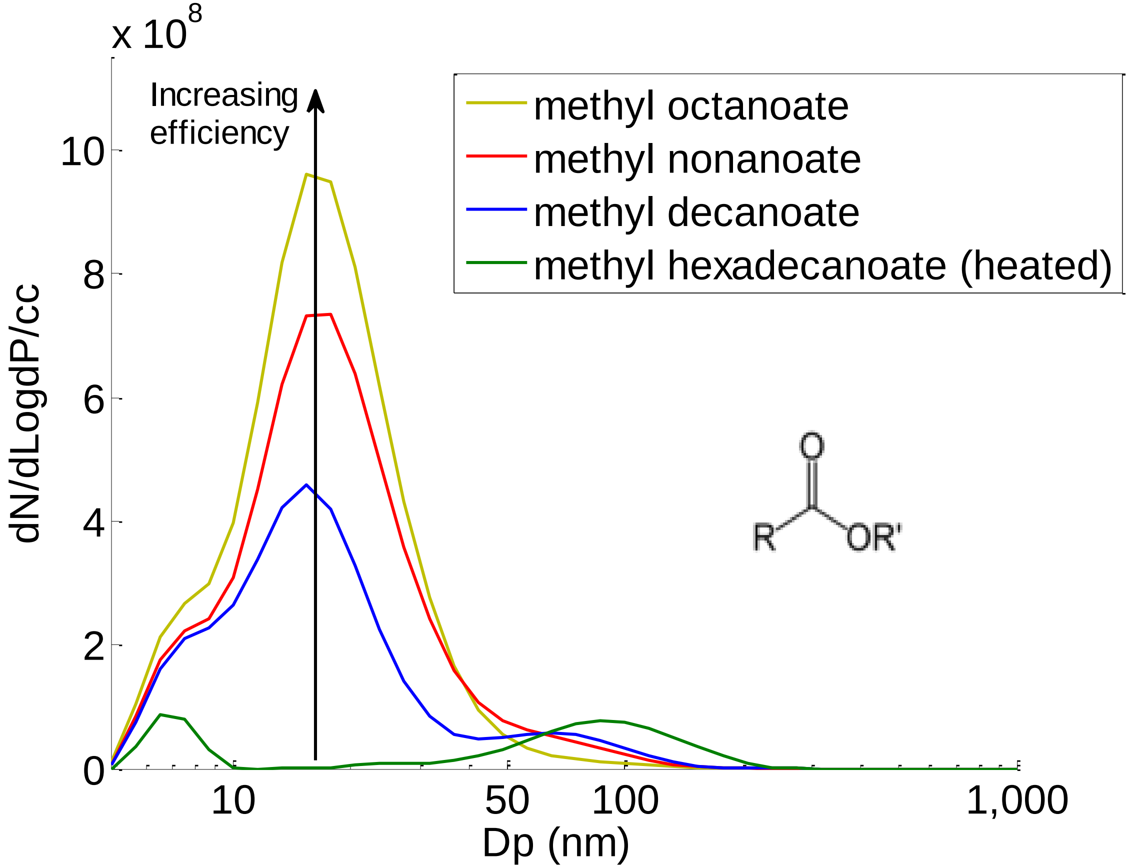
- Trade-off between the amount of light nucleus particles (Dp <50 nm) and thermal engine efficiency

Primary alcohols



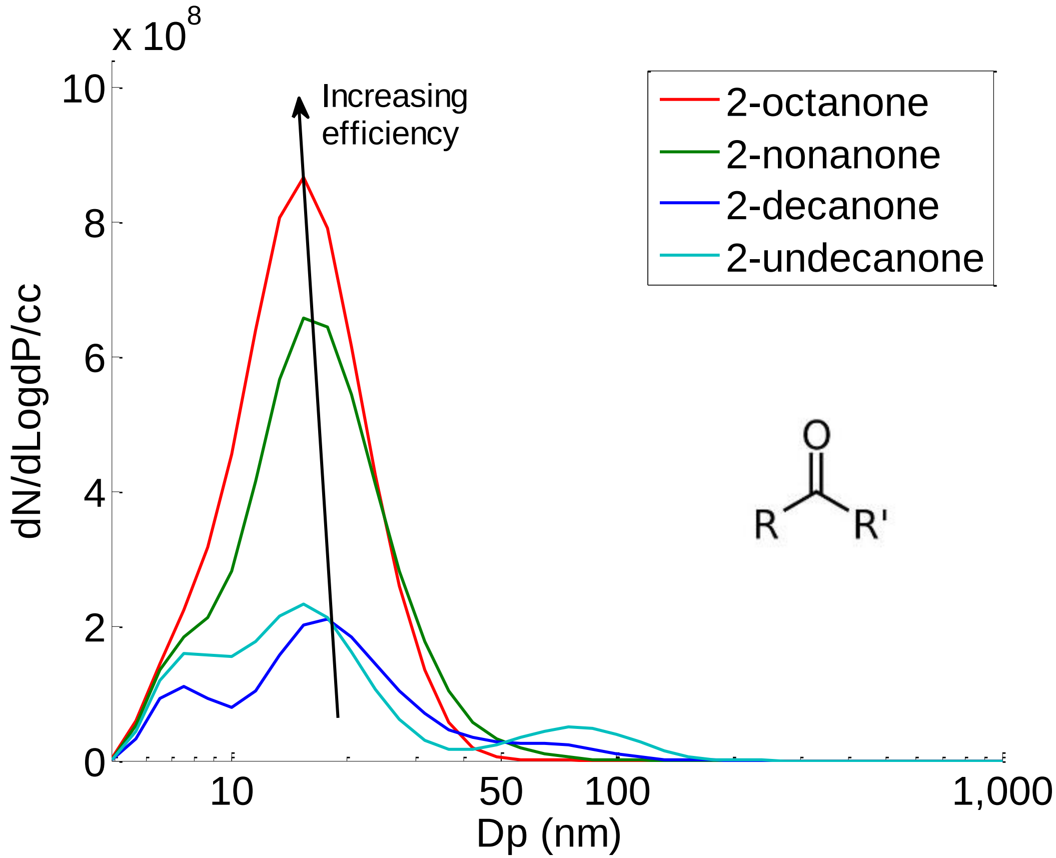
- Trade-off between the amount of light nucleus particles (Dp <50 nm) and thermal engine efficiency

Methyl esters



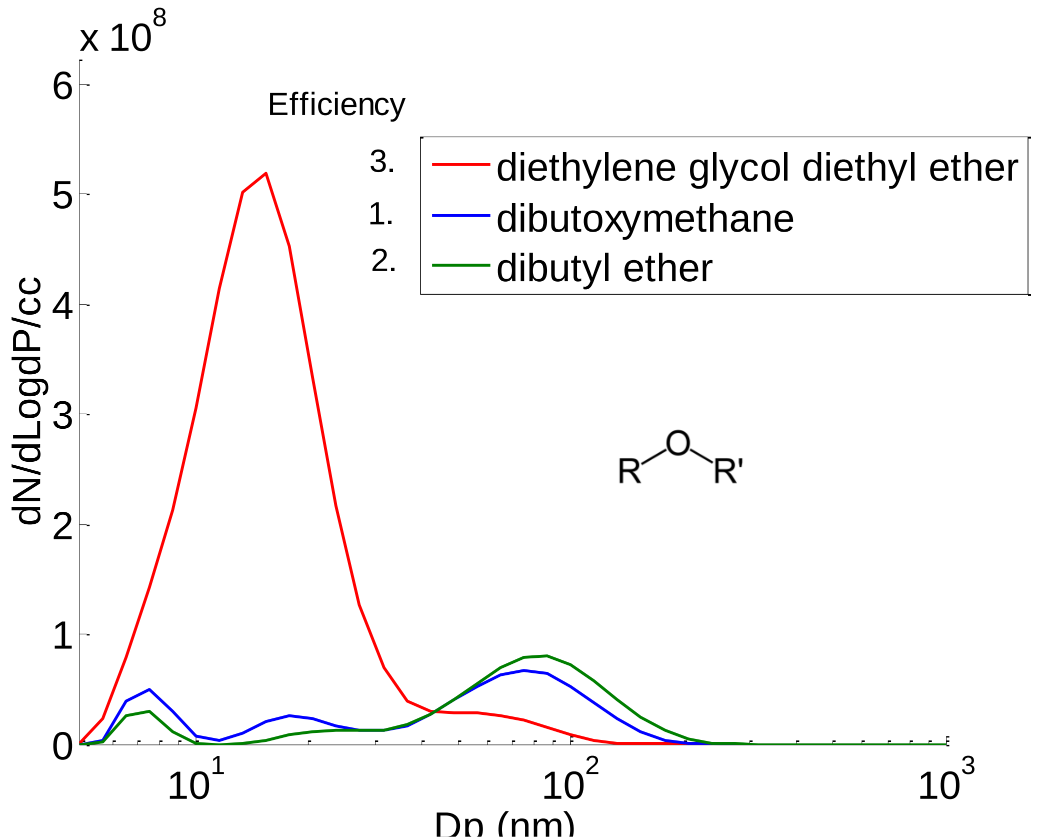
- ➢ Trade-off between the amount of light nucleus particles (Dp <50 nm) and thermal engine efficiency

Methyl ketones



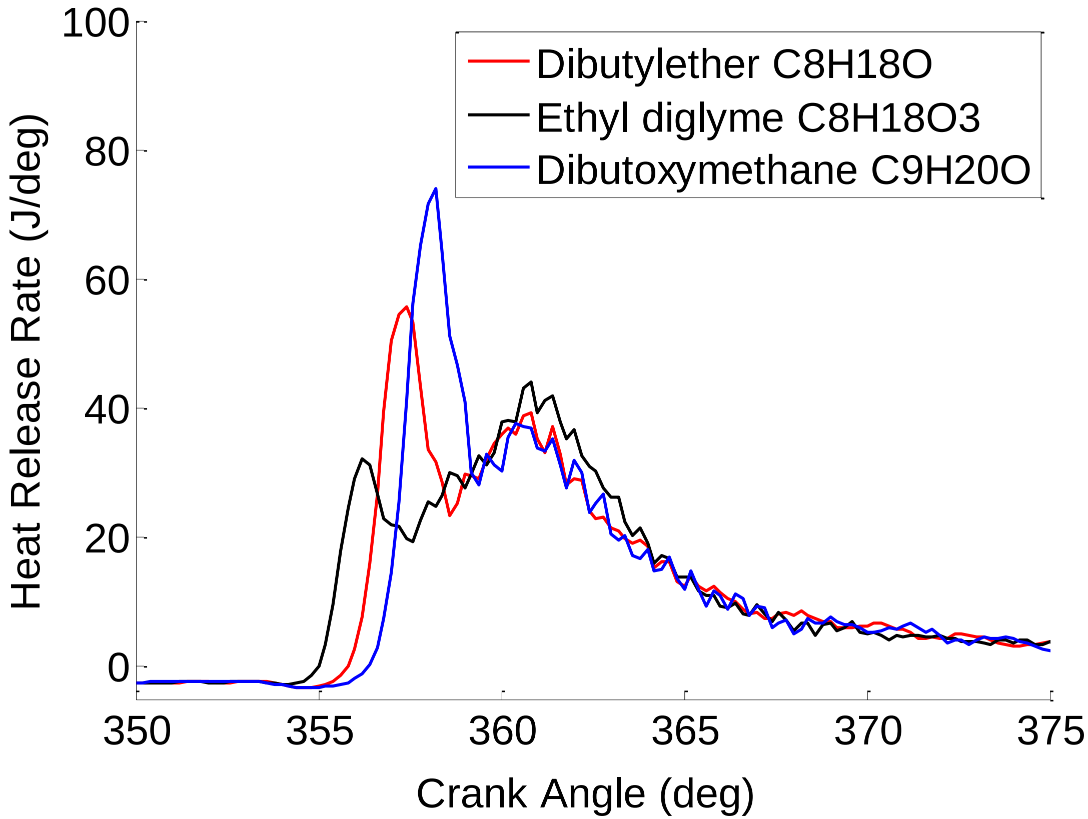
- ➢ Trade-off between the amount of light nucleus particles (Dp <50 nm) and thermal engine efficiency
- Lowest amount of particulates compared to other oxygenated fuel molecules

Ethers



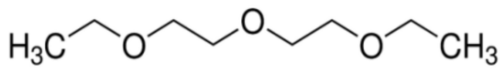
- ➢ Trade-off between the amount of light nucleus particles (Dp <50 nm) and thermal engine efficiency
- Excluding Ethyl diglyme

Ethers



Dibutoxymethane (C9 H20 O2)

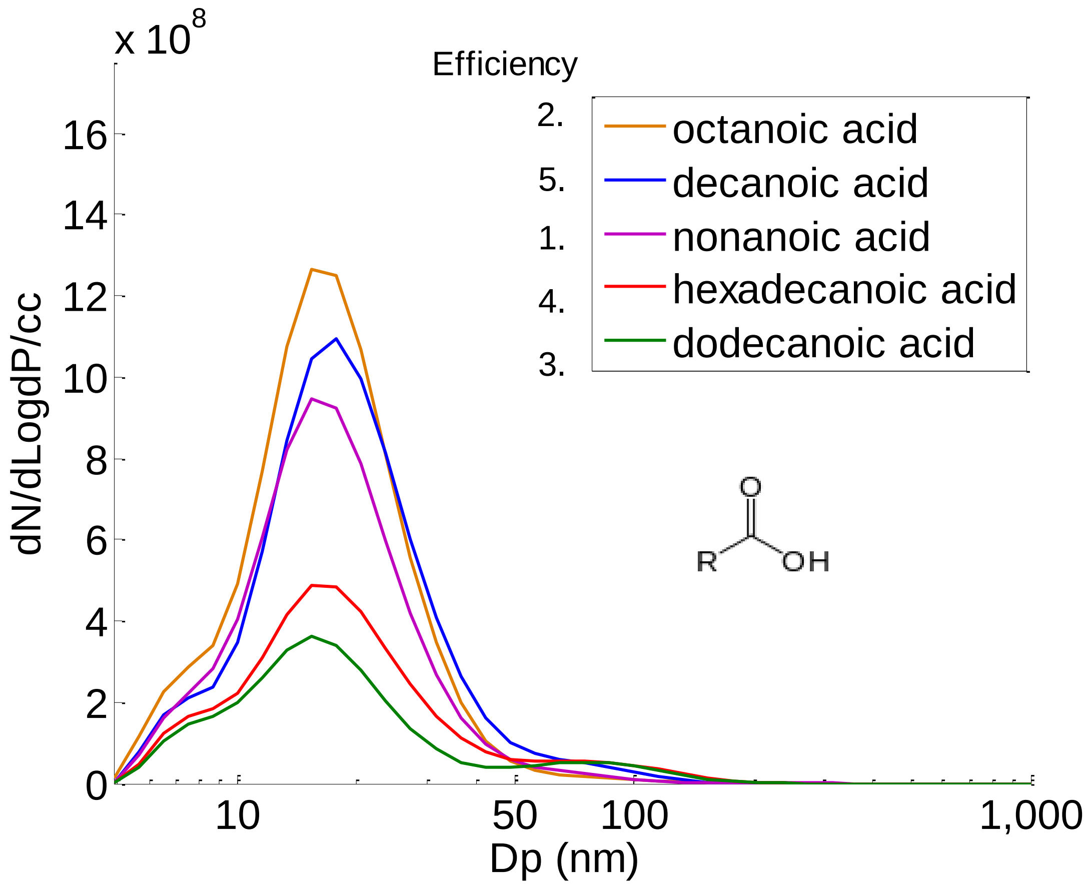
Dibutyl ether (C8 H18 O)



Ethyl diglyme (C8 H18 O3)

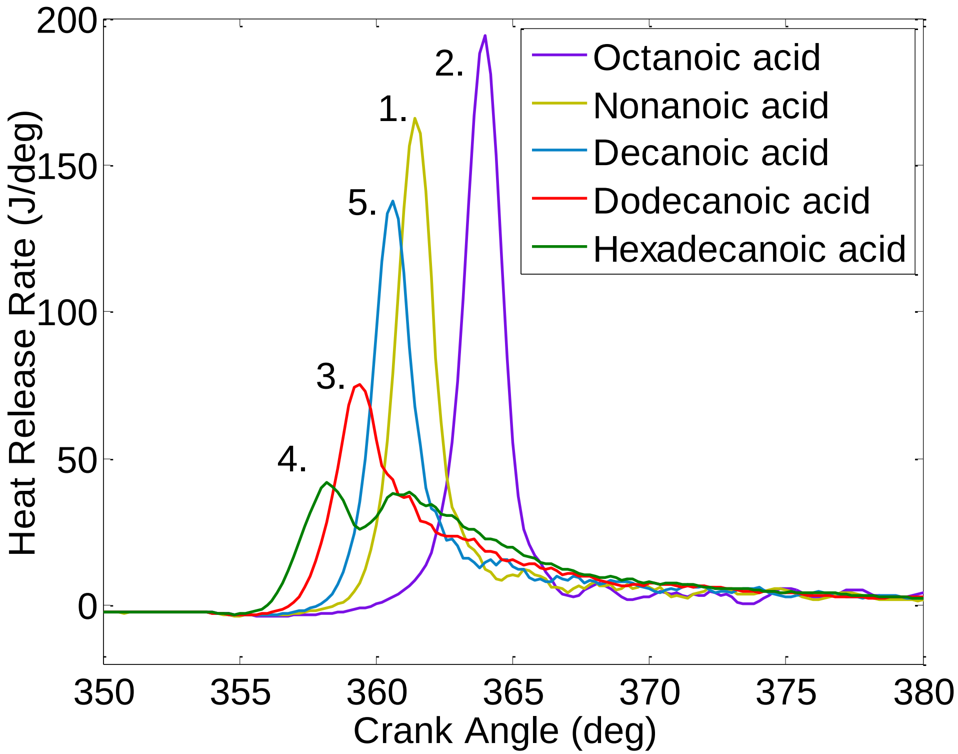
- The increase in the number of particulates for Ethyl diglyme was suggested to be because more fuel was burned in the diffusion controlled phase producing more particulates, as well as leading to lower efficiency

Carboxylic acids



- No correlation between the amount of particulates and thermal engine efficiency

Carboxylic acids



- Large premixed fraction close to TDC resulted in high thermal engine efficiency
- More of the fuel molecules 3. and 4. burned close to TDC compared to fuel molecule 5. making the thermal engine efficiency higher

Regression analysis

- Multivariable regression analysis was done to evaluate the importance of physical fuel properties on the formation of PM emissions

$$\log(PM\ number\ or\ mass) = logC + a * log(ConstantProperty1) + b * \log(property2) + c * \log(property3)$$

↑ Higher sensitivity

Number of particulates (N/cc)	Mass of particulates (µg/cc)
Density at 25c (g/ml)	Density at 25c (g/ml)
Surface tension at 25c (dyne/cm)	Boiling point (°C)
Ignition delay (CAD)	Ignition delay (CAD)
Boiling point (°C)	Surface tension at 25c (dyne/cm)
Dynamic Viscosity at 25c (mPas)	Dynamic Viscosity at 25c (mPas)

Conclusions

- A shift from agglomeration particulates to nucleation particulates occurred with increasing engine efficiency due to more complete combustion
- A trade-off between the amount of particulates (mainly Dp < 50 nm)and engine efficiency was observed within molecular groups
- Oxygen in fuel structure decreases the mass of agglomeration particulates significantly compared to alkanes
- Both chemical and physical properites of the fuel molecule were shown to affect the formation of PM emissions.

Thank you for your attention!

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