SUMMARY, June 9, 2009

## Effects of several biofuels on the particle size distributions of an off-road diesel engine

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One of the greatest challenges of diesel engine development is the reduction of combustion-generated fine particles. There are several technical methods to improve engine combustion and reduce particle formation, such as the increase in the injection and charge pressures, the division of fuel injection into several stages, the improvement of the fuel-air mixing with various means, etc.

The development of fuels also offers a possibility to reduce combustion-generated particles. Animal fat and vegetable oil based fuels contain oxygen and fuels can be burned in diesel engines without major problems. It has been observed that these fuels have an advantageous effect on particle formation of diesel engines.

In this presentation, particle size distributions are presented, recorded in an off-road diesel engine driven with renewable fuels. Waste-derived biofuels were mainly exploited in order not to compete with food production. The studied biodiesels were manufactured from, e.g., fur farming, fish refining and linseed cultivation wastes. As reference fuels, canola oil methyl ester and low-sulfur diesel fuels were used. Spent cooking oil was one fuel option. Furthermore, measurements were also made with crude bio-oils since large engines are able to burn such fuels without notable modifications.

In addition to the basic particle size distributions with different fuels, the effects of EGR, fuel heating and a diesel oxidation catalyst on the particle number emissions are briefly presented.

In the high-speed diesel engine, crude bio-oils often produced more particles of all sizes than DFO. The number of the smallest particles usually increased drastically. Nevertheless, the smallest particles could be effectively reduced by EGR even though the accumulation mode increased. A similar effect was detected when oil was heated.

Of the studied biodiesels, fox methyl ester (FME) from fur farming reduced large particles effectively relative to diesel fuel oil. At some loads, the ultra-fines also decreased. Timing retardation did not impair the results of FME vitally. Fish-based biodiesels were not always as favorable within large particles but showed advantageous ultra-fine results. Linseed methyl ester proved to be beneficial within large particles; it was also competitive within ultra-fines. Canola oil methyl ester tended to increase the number of the smallest particles.

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About the speaker:

Seppo Niemi,

- DTech at Helsinki University of Technology in 1992
- Professor at the University of Vaasa (fixed-term public-service) and Principal Lecturer at Turku University of Applied Sciences, Finland
- Working experience even from
    - Wärtsilä Finland
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    - Helsinki University of Technology
    - Technical Research Centre of Finland (VTT).

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# OUTLINE

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- Objectives
- Experimental setup
  - Engine
  - Fuels
  - Experimental matrix
- Results
- Conclusions

# OBJECTIVES

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- To determine the exhaust PM size distributions with different biofuels
  - Crude bio-oils
  - Biodiesels
  - **Note: not automotive fuels but those for**
    - **Distributed energy production and**
    - **Off-road equipment**
- To compare the results with those of the baseline diesel fuel use
- To analyze the effects of some engine parameters on the PM size distributions

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# ENGINE

| SisuDiesel 420 DSJ | (Agco Sisu Power Inc.) |
|---|---|
| Bore | 108 mm |
| Stroke | 120 mm |
| Swept volume | 4.4 $dm^3$ |
| Combustion chamber | Direct injection |
| Firing order | 1-2-4-3 |
| Turbocharger | Schwitzer S1B |
| Injection pump | In-line, Bosch A |
| Charge air cooler | Air-to-water, 50 °C |

# FUELS

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- Crude bio-oils
  - Vegetable oils
    - Mustard seed oil (MSO)
    - Canola oil (RSO)
  - Animal fat based
    - Rainbow trout oil (StO)

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# CRUDE BIO-OILS

| | | StO | MSO | RSO |
|---|---|---|---|---|
| Density at room temperature | $kg/m^3$ | 918 | 915 | 920 |
| Kinematic viscosity at 40 °C | $mm^2/s$ | 28 | 40.5 | 31.9 |
| Flash point | °C | 297 | 307 | 317 |
| Cetane number | | 49 | | |
| Lower heating value | MJ/kg | 36.9 | 37.9 | 37.3 |
| Stoichiometric air-fuel ratio | kg/kg | 12.3 | 12.7 | 12.5 |
| C | % | 77.4 | 78.8 | 78.2 |
| $H_2$ | % | 11.5 | 11.8 | 11.5 |
| $O_2$ | % | 11.1 | 9.4 | 10.3 |
| $N_2$ | mg/kg | 5.6 | 20 | 15 |
| S | mg/kg | 13 | 40 | 4 |
| Ash | % | 0.004 | 0.007 | 0.002 |
| Lubricity, HFRR, 60 °C | | 150 | | |

# FUELS

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- Biodiesels
  - Animal fat based
    - Fox methyl ester (FME)
    - Salmon methyl ester (SalME)
    - Rainbow trout methyl ester (StME)
  - Vegetable oil based
    - Linseed methyl ester (LinME)
    - Spent cooking oil (UCO)
    - Canola oil methyl ester (RME)

# BIODIESELS

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| | | FME | SalME | StME | LinME | UCO | RME | RME |
|---|---|---|---|---|---|---|---|---|
| Acid value | mg KOH/g | 0.78 | 0.17 | 0.42 | 0.26 | 0.26 | 0.43 | 0.23 |
| Iodine value | | 78 | 142 | 137 | 203 | 98 | 116 | 123 |
| Fatty acid 14:0 | % | 3.2 | 4.2 | 3.5 | | | | |
| 16:0 | % | **18** | **12** | **11** | 4.4 | 5.6 | 3.3 | 3.4 |
| 16:1 | % | 7.6 | 6.1 | 5.3 | | | | 0.2 |
| 18:0 | % | 7.1 | 2.7 | 2.3 | 3.1 | 2.9 | | 1.5 |
| 18:1 cis | % | **48** | **28** | **33** | **14** | **64** | **61** | **57** |
| 18:2 cis ω 6 | % | 10 | 8 | 11 | 14 | 20 | 20 | 23 |
| 20:1 cis | % | | 4.5 | 3.4 | | 1.1 | 1.3 | 1 |
| 20:5 cis ω 3 | % | | 7.2 | 4.2 | | | | |
| 18:3 cis ω 3 | % | | 2.4 | 3.8 | **64** | 2 | 10 | 12 |
| 22:1 cis | % | | 4.2 | 3 | | | 0.4 | 0.1 |
| 22:5 cis ω 3 | % | | 3.6 | 2.1 | | | | |
| 22:6 cis ω 3 | % | | 7.4 | 7.5 | | | | |
| PUF | % | 12 | 34 | | 78 | | 31 | |
| MUF | % | 60 | 44 | | 14 | | 62 | |
| SAF | % | **28** | **22** | | **7.9** | | **7.0** | |
| Lubricity, HFRR, 60 °C | Micrometer | 163 | 162 | 121 | 147 | | 156…159 | |
| Cetane number | | **67** | 54 | 53 | 40 | **61** | 57 | 57 |

# EXPERIMENTAL MATRIX

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| Speed, rpm | Average load, % |
|---|---|
| 1800 | 100 |
| 1500 | 100, 82 and 55 |
| 1300 | 100 |

- MSO, RSO and RME within a larger load-speed envelope

# EFFECT OF LOAD, MSO

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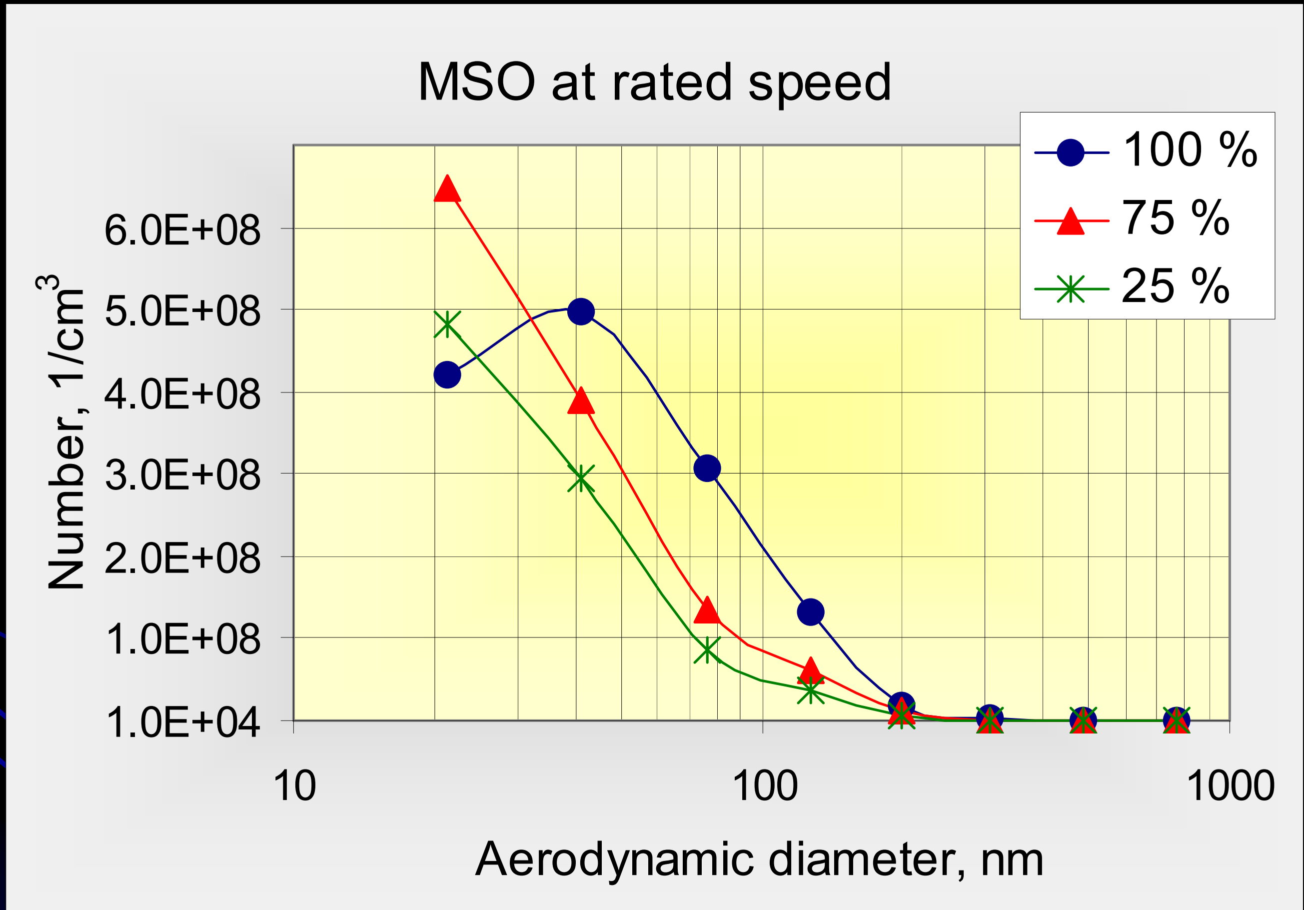

# EFFECT OF EGR, MSO

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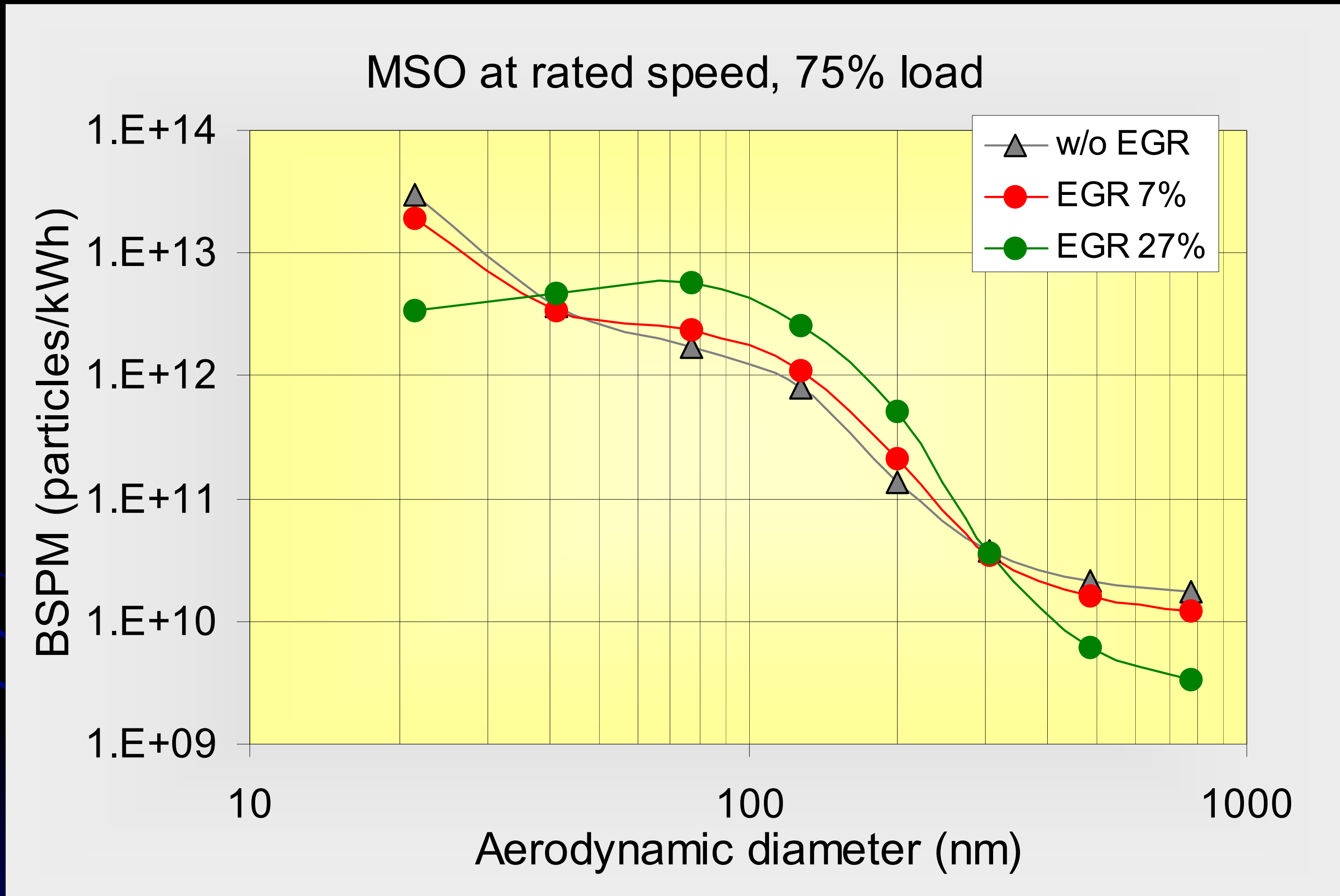

# EFFECT OF DOC, MSO

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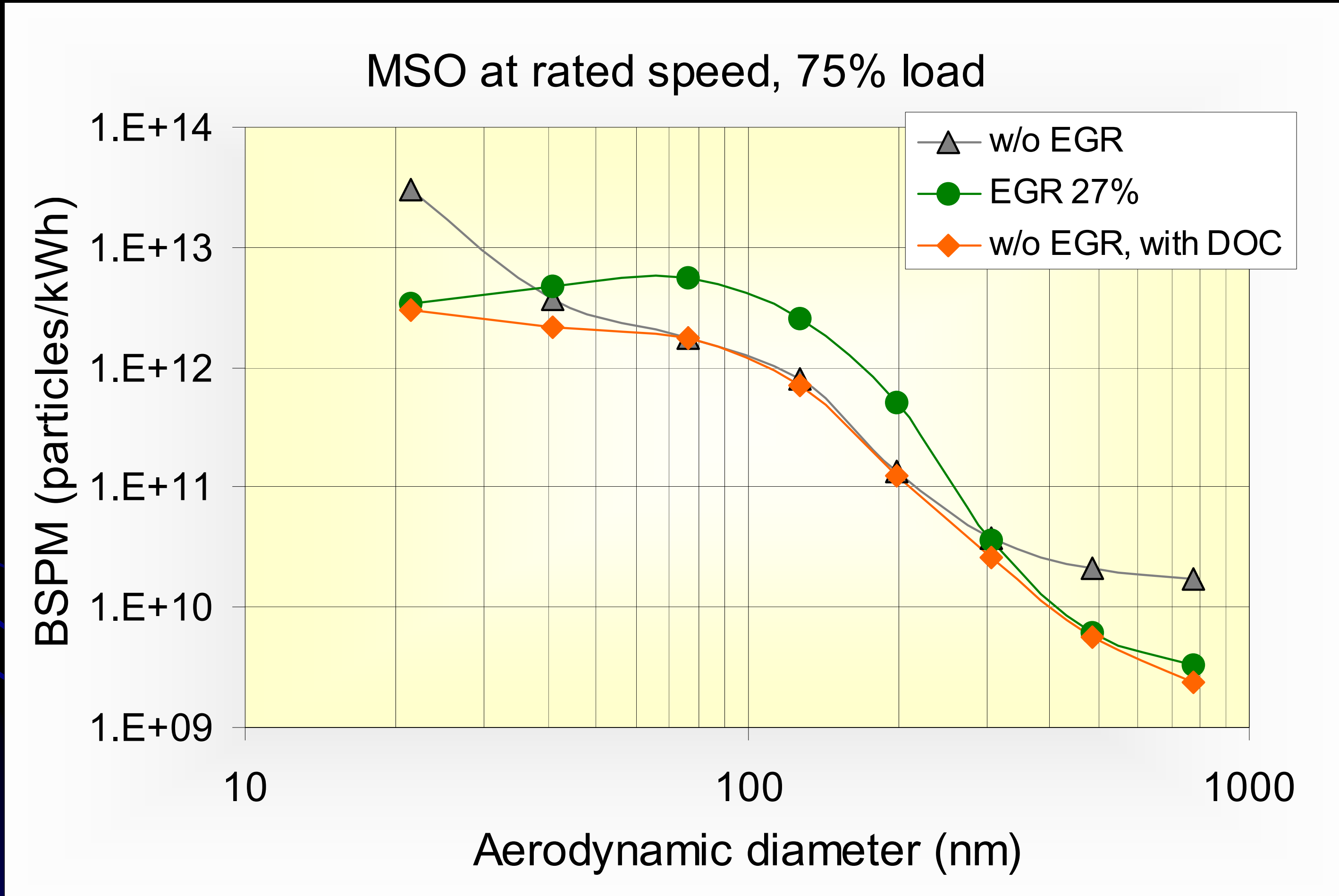

# MSO VERSUS RME

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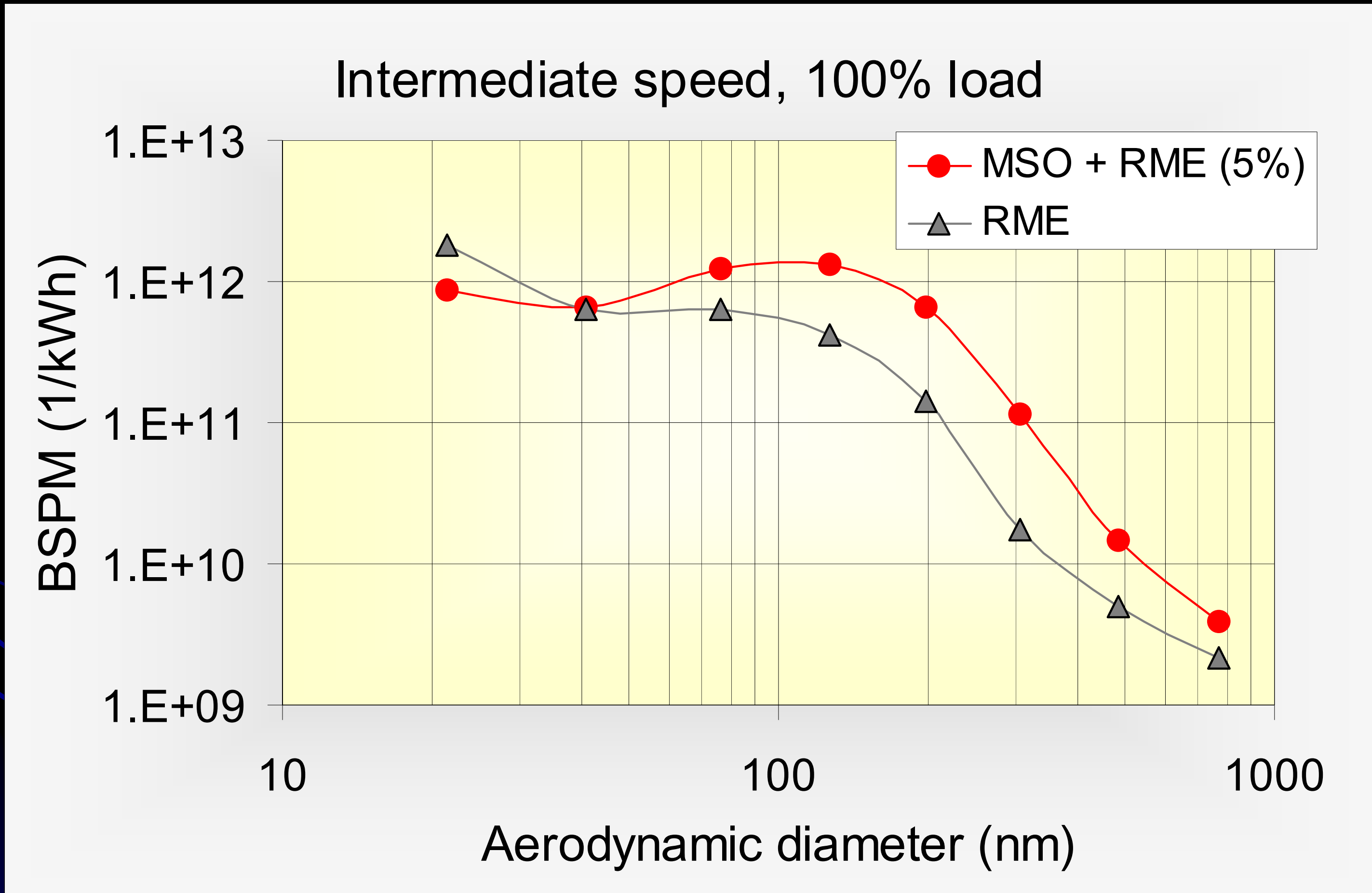

# RSO HEATING

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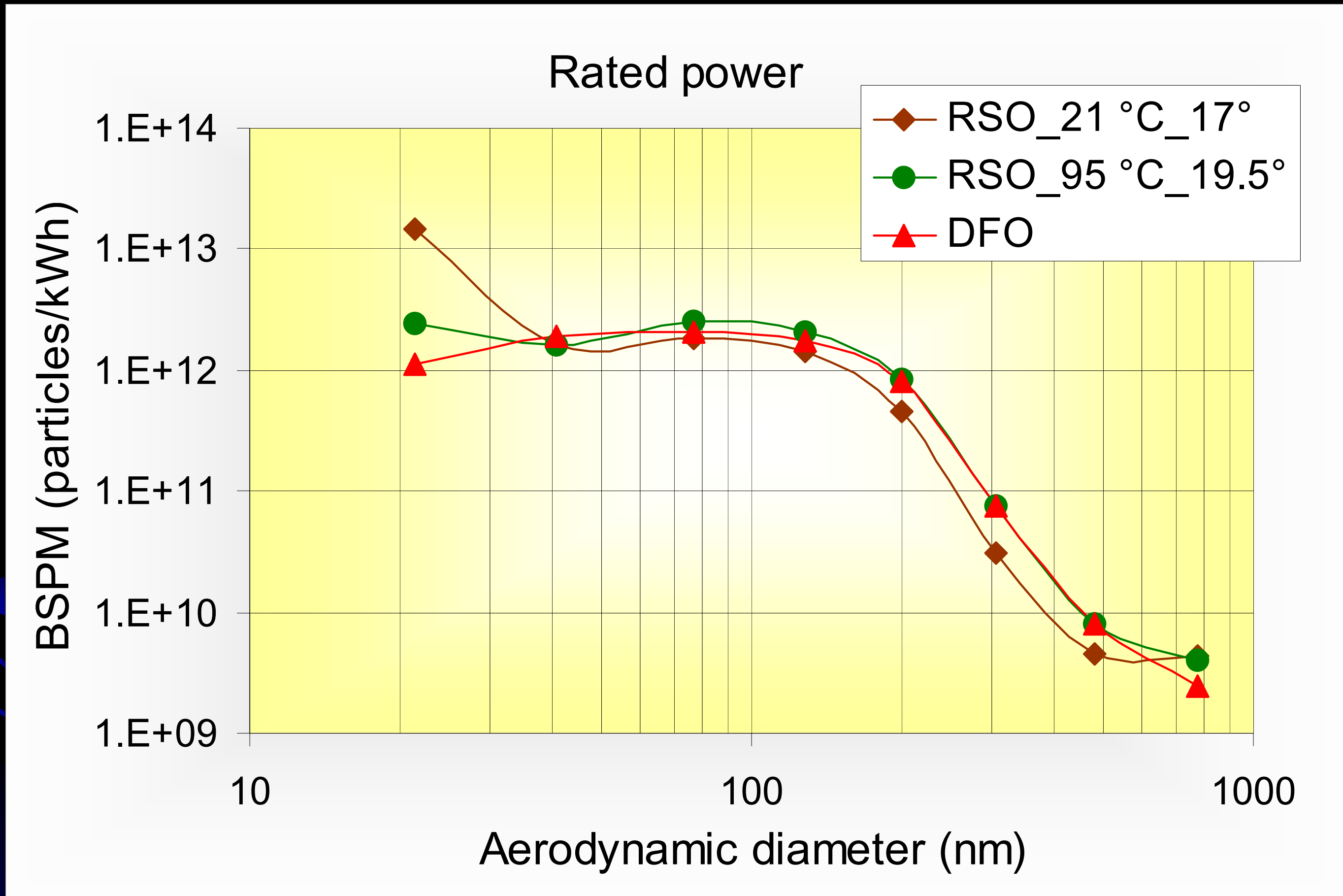

# FOX METHYL ESTER

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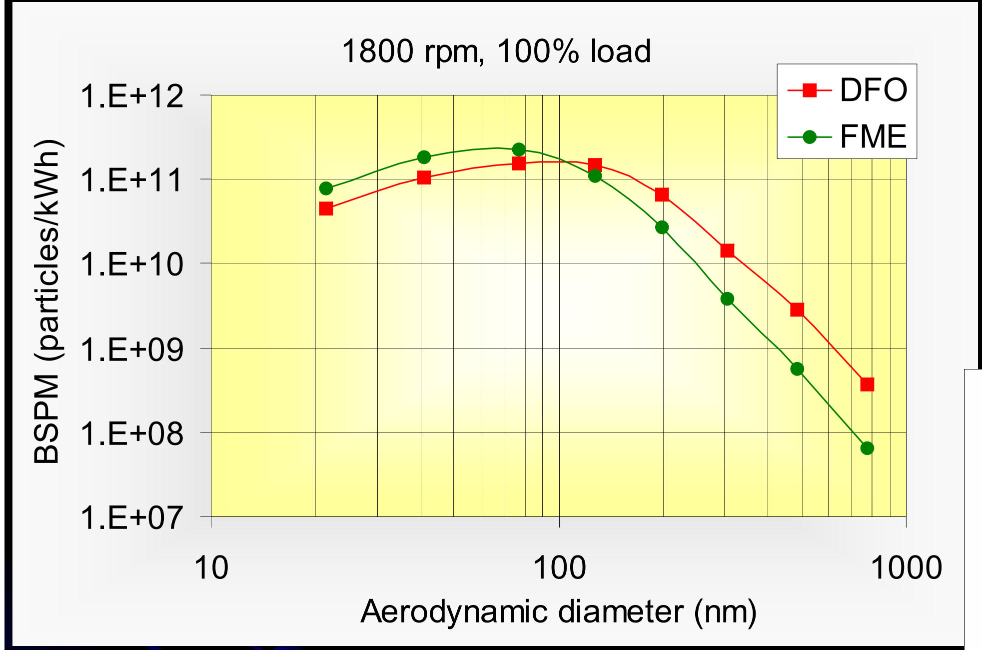


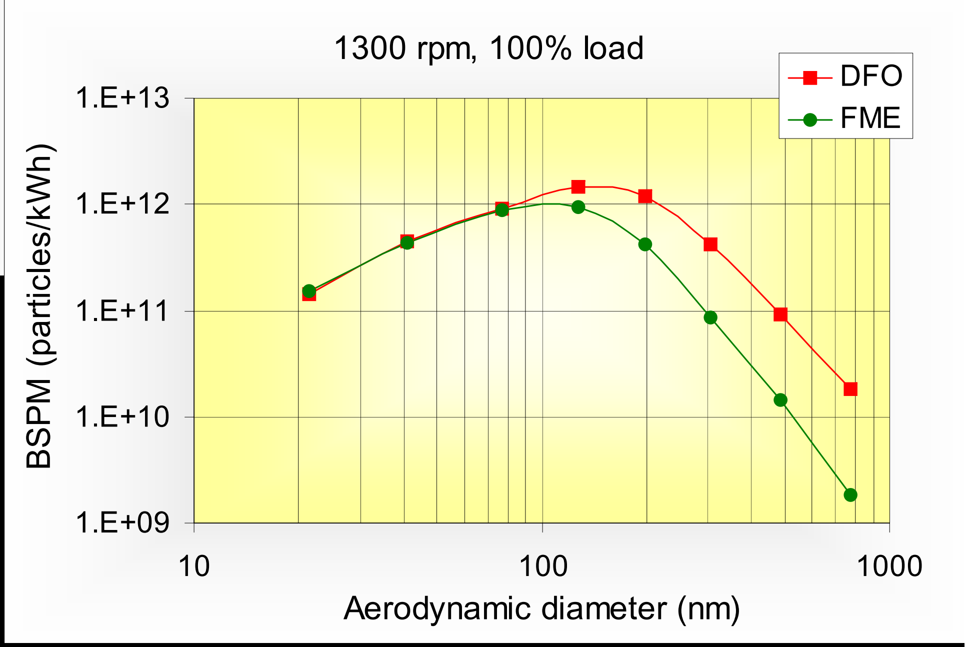

# SalME & LinME

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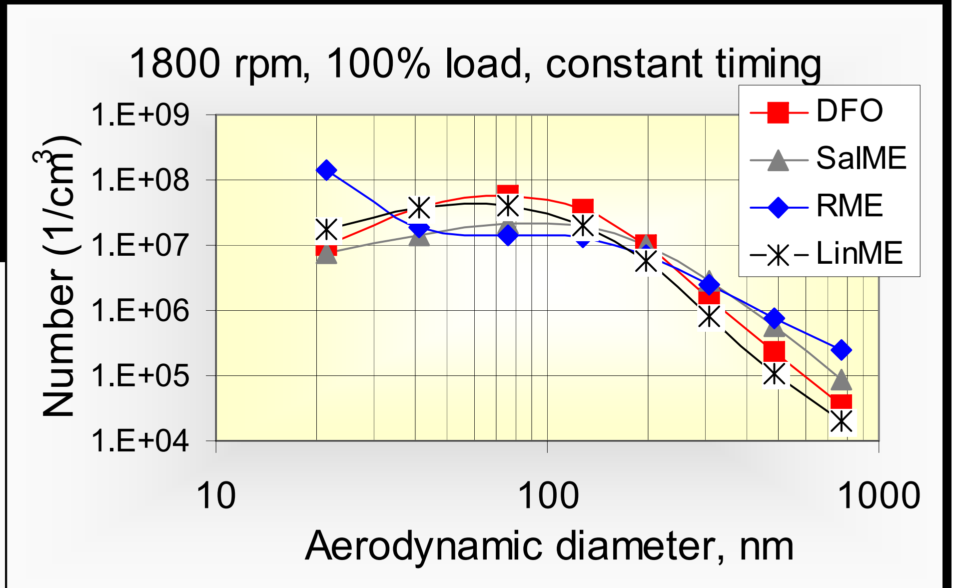


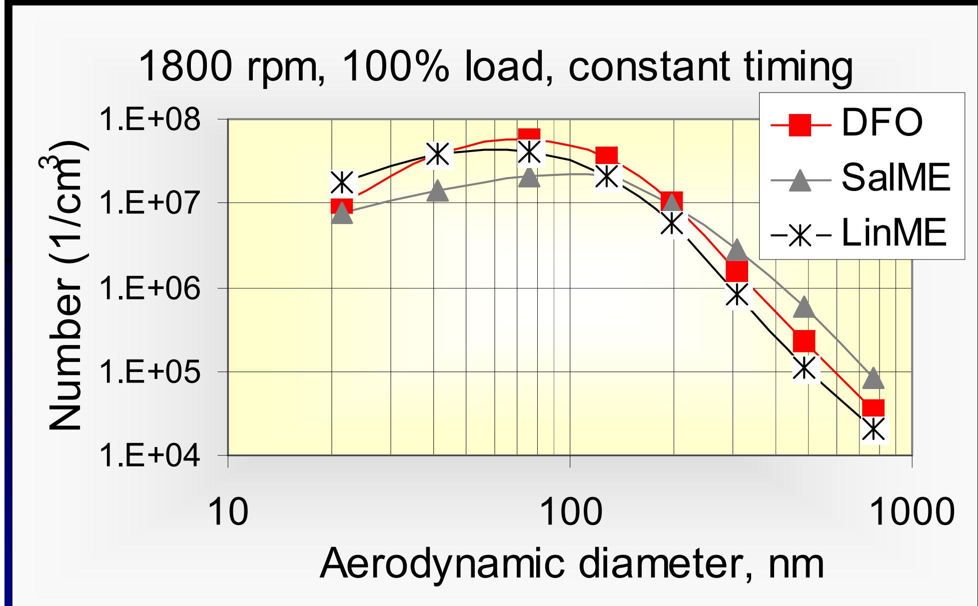

# SalME & LinME

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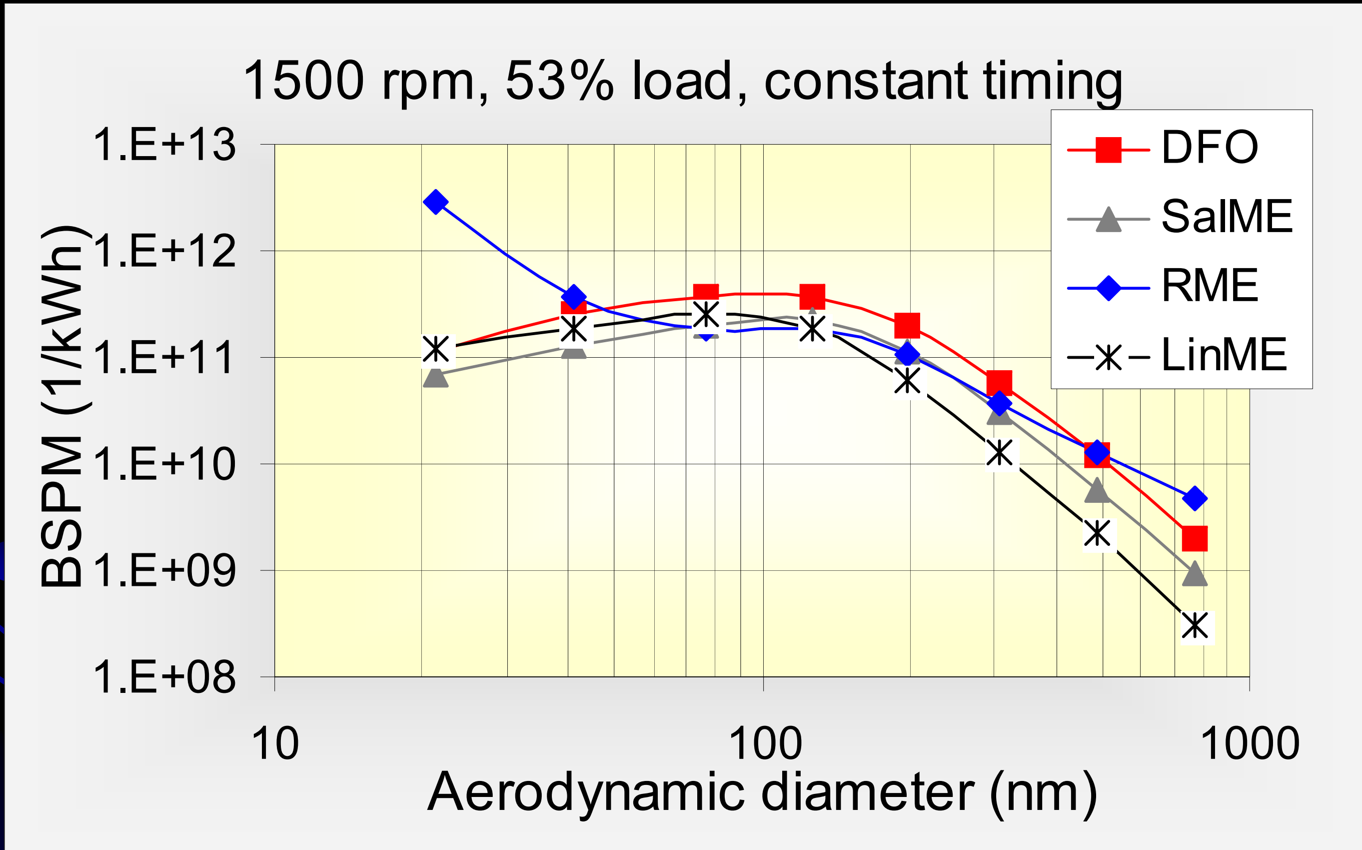

# SalME, FME, UCO

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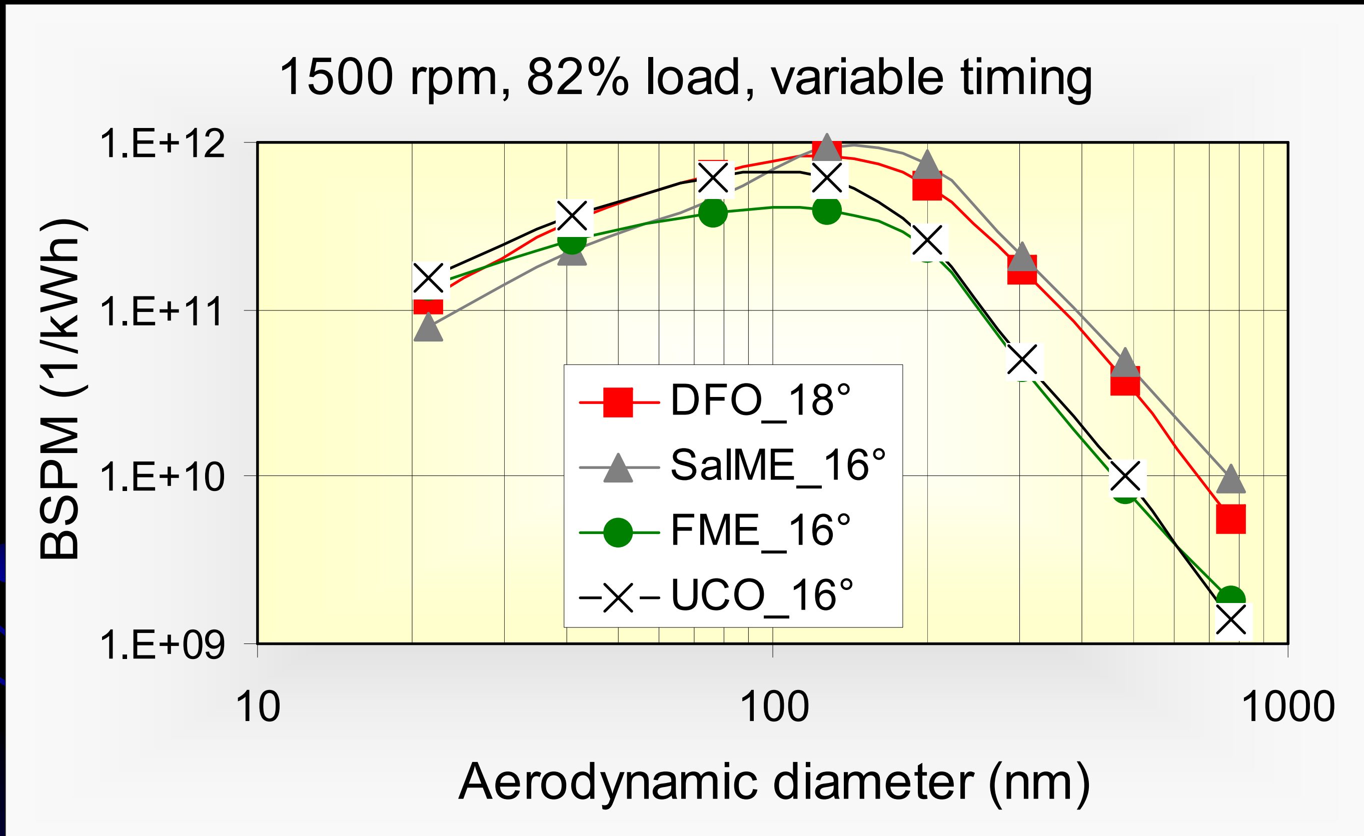

# StO, StME & SalME

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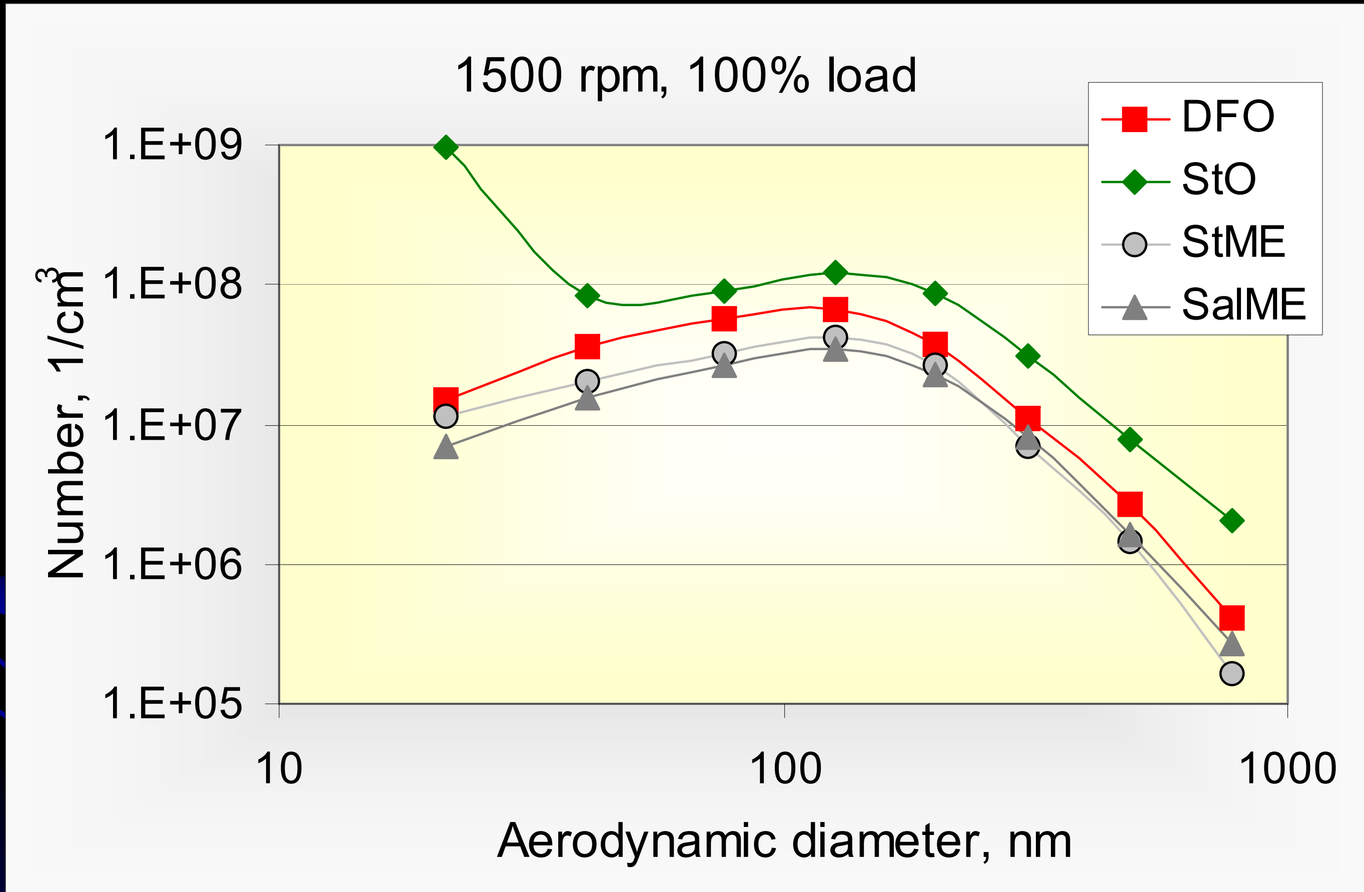

# SalME & StME

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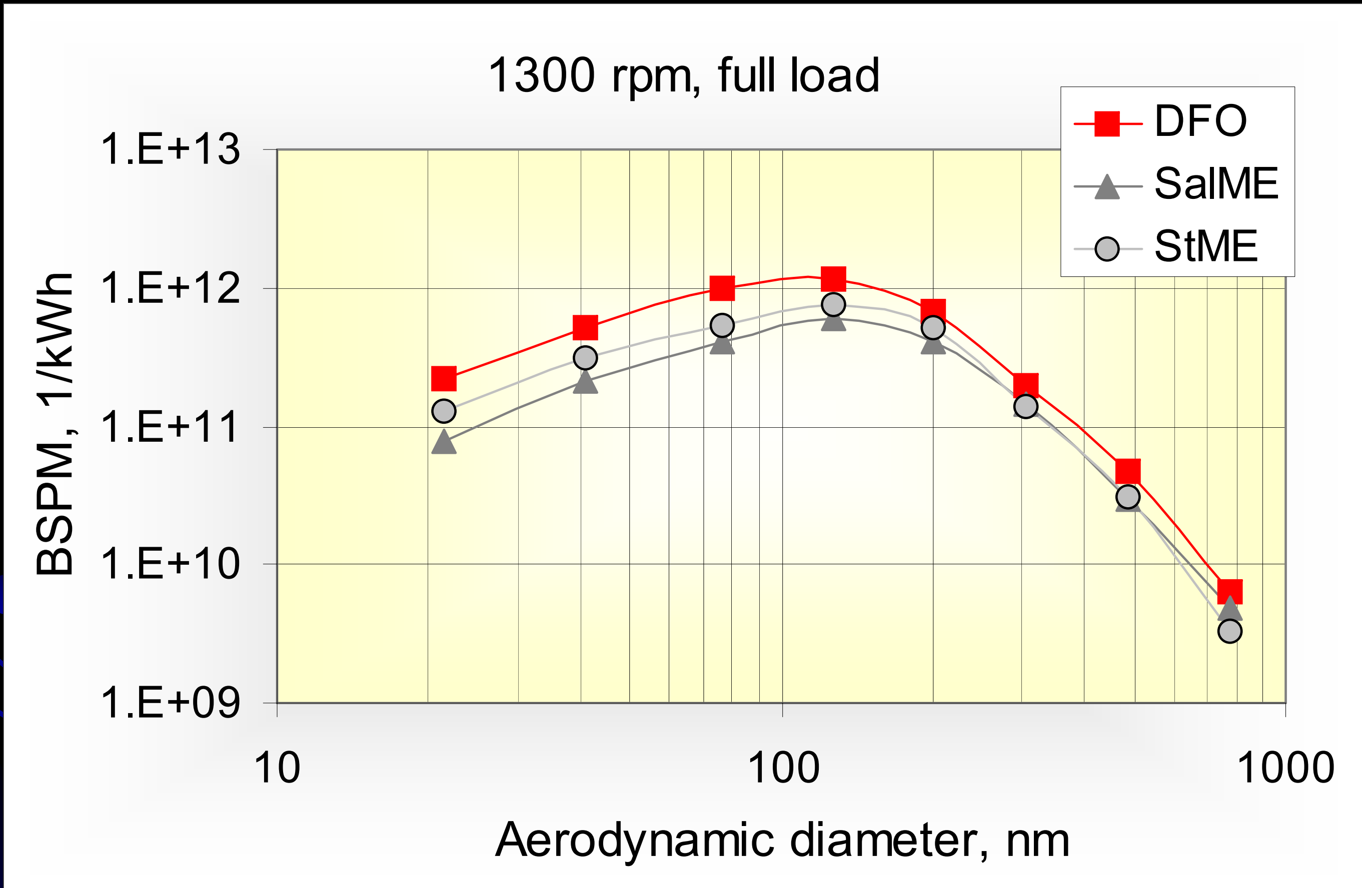
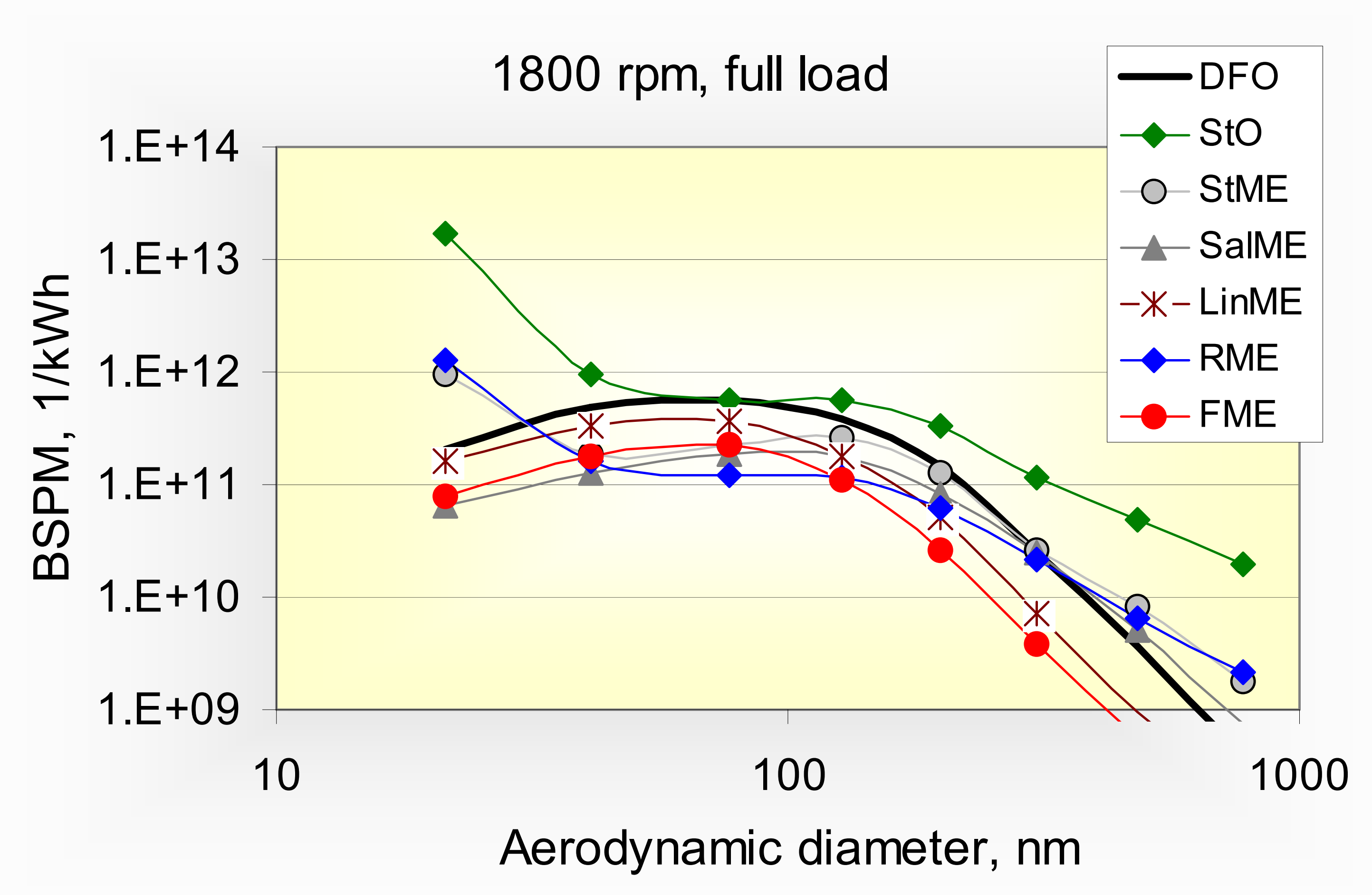


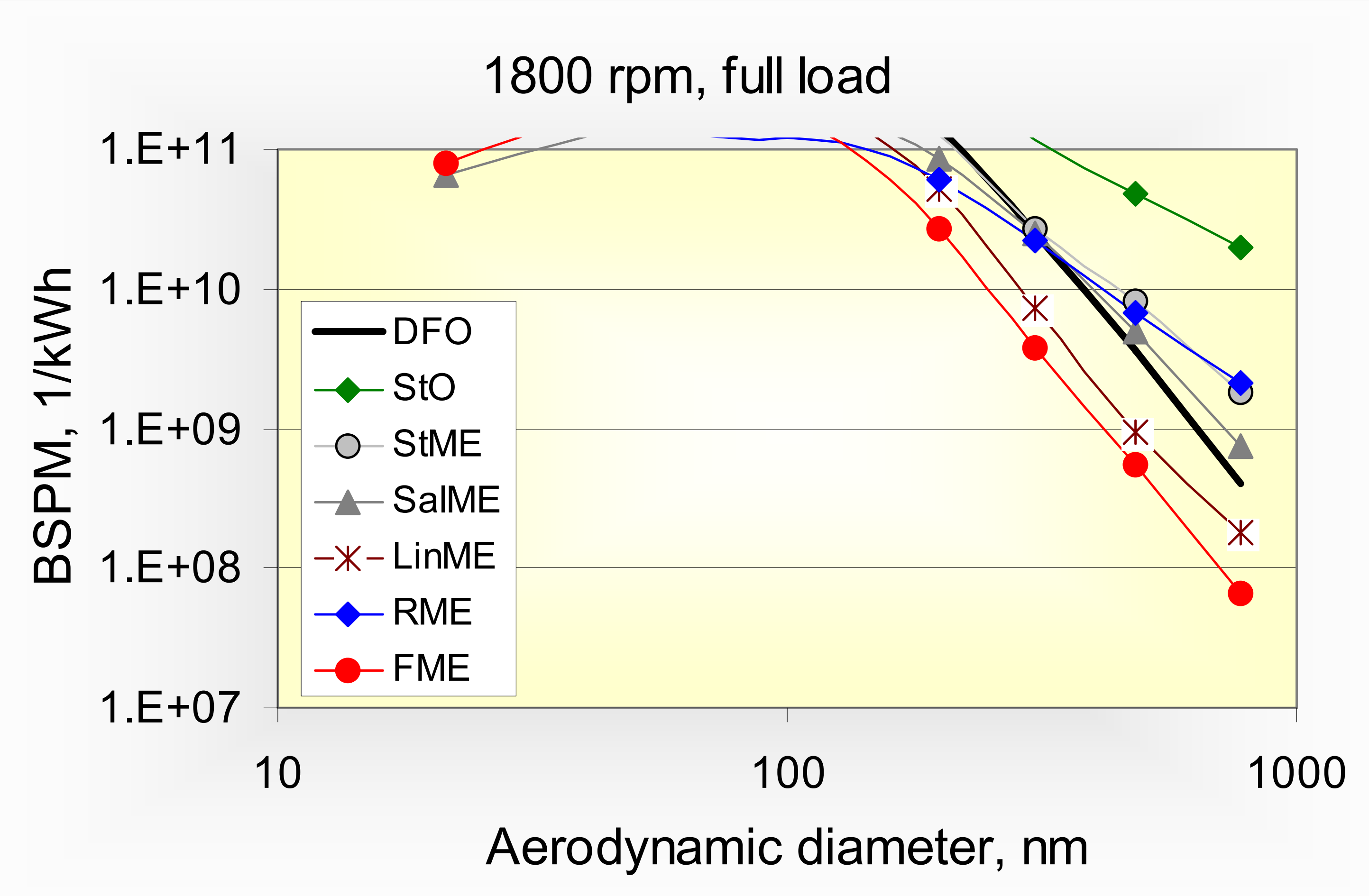
# ALL FUELS



1800 rpm, full load
DFO
StO
StME
SalME
LinME
RME
FME
1.E+14
1.E+13
1.E+12
1.E+11
1.E+10
1.E+09
BSPM, 1/kWh
10
100
1000
Aerodynamic diameter, nm

# ALL FUELS

TUAS



# CONCLUSIONS 1

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- In the high-speed diesel engine, crude bio-oils
  - Often produced more particles of all sizes than DFO
  - Usually increased the number of the smallest particles drastically
  - Nevertheless,
    - The smallest particles could be effectively reduced by EGR even though the accumulation mode increased
      - A similar effect was detected when oil was heated

# CONCLUSIONS 2

TUAS

- Of the studied biodiesels,
  - Fox methyl ester reduced large particles effectively relative to DFO
    - At some loads, the ultra-fines also decreased
  - Fish-based ones were not always as favorable within large particles but showed advantageous ultra-fine results

# CONCLUSIONS 3

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- Of the studied biodiesels,
  - Linseed methyl ester proved to be beneficial within large particles; it was also competitive within ultra-fines
  - Timing retardation did not impair the results of FME vitally
  - RME tended to increase the number of the smallest particles

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# Thank you for your kind attention!