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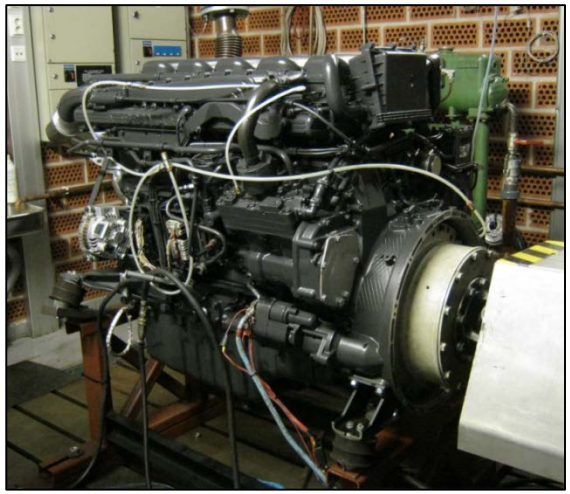

SUMMETH Final Seminar

Methanol with additives for diesel engine – MD95 concept

6th December 2017, Gothenburg, Sweden

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Content

- Objective
- Preliminary screening of fuels
- Test matrix for engine tests
- Emission results
- Cylinder pressure results
- Conclusions

Invisible flame with MD95
Photo: VTT

Objective

- Methanol use is well-proven for otto engines, but **assistance is needed for methanol combustion in diesel engines**, such as glow-plugs, cetane improvers (vs. Scania concept), surface ignition, fumigation, emulsion, pilot fuel (dual fuel), premixed combustion (spark plug or pilot fuel).

- Wärtsilä has a methanol-diesel retrofit concept for marine engines (GD methanol-diesel, diesel as a back-up fuel). MAN has also developed a methanol engine concept.

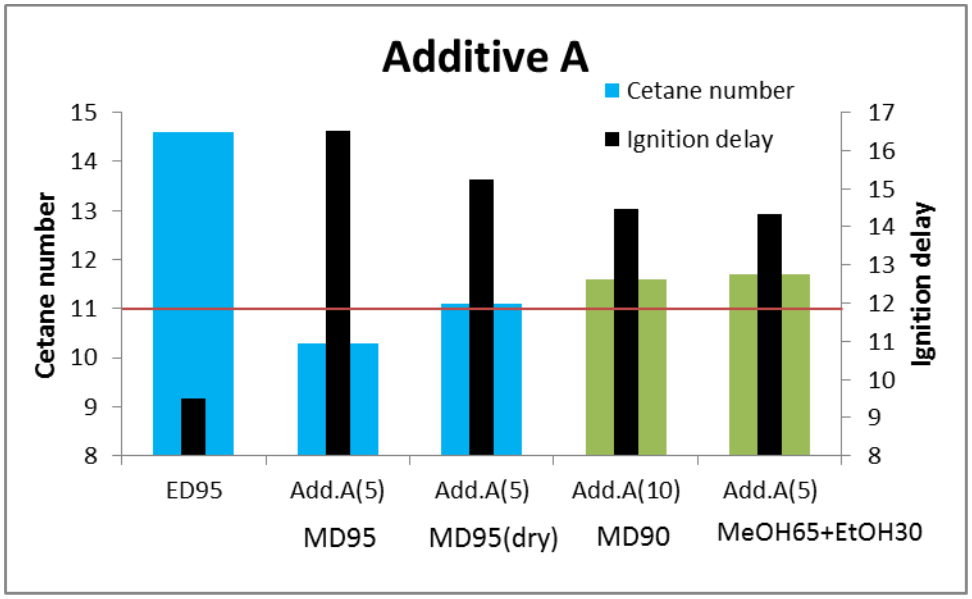
- Scania has an engine capable to use ethanol with ignition improver and lubricity additive (ED95) (commecial since 1985). The modifications of diesel engines include increased compression ratio (28:1), a special fuel injection system and a catalyst to control aldehyde emissions.

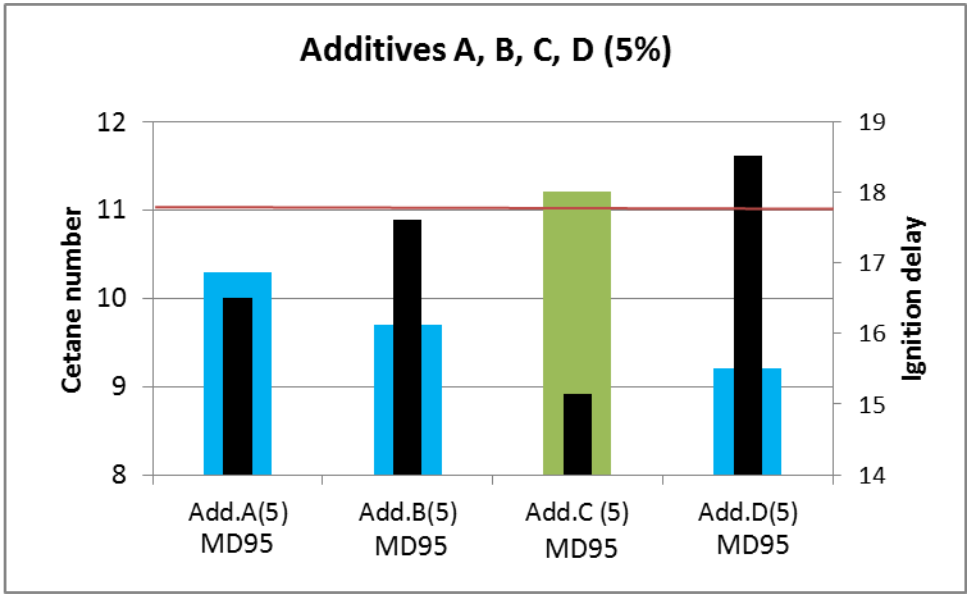
- In this work, **MD95 concept (mimicing ED95) was studied for Scania alcohol engine**.

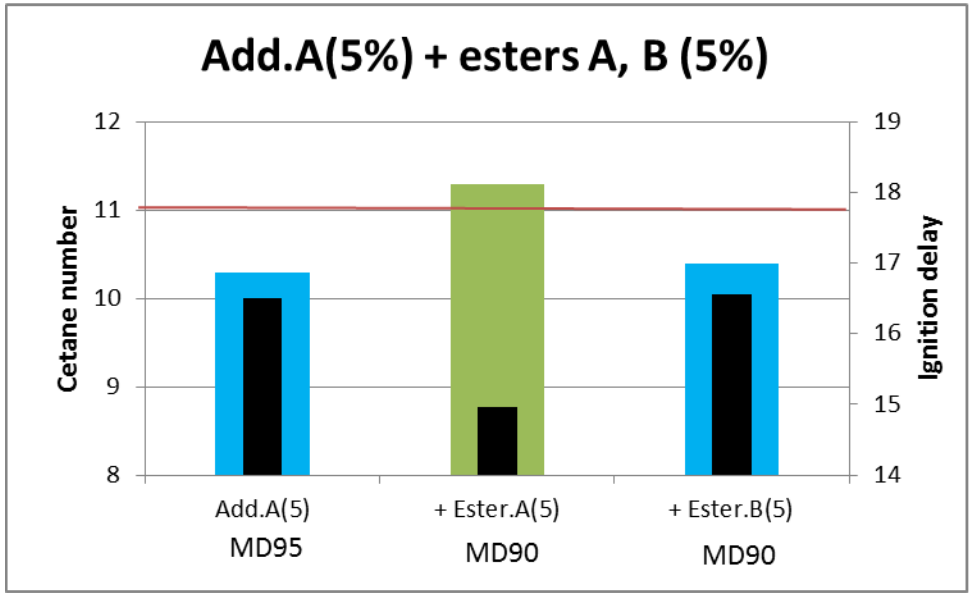
Preliminary screening

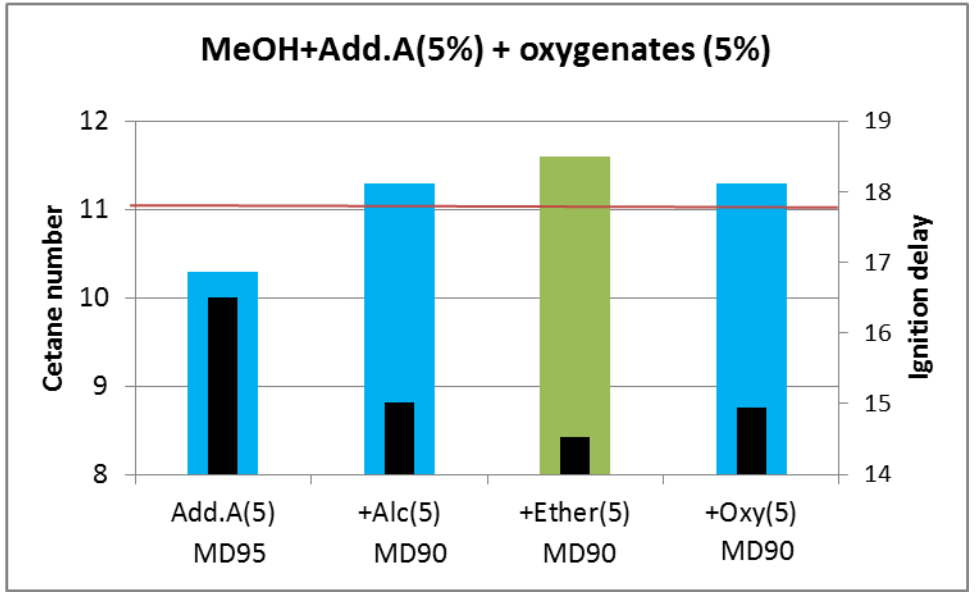
- Solubility of different components to methanol were studied with nine blends.
  - ➢ All components were soluble and no phase separation occurred.

- Ignition quality testing with AFIDA (ASG) with 13 blends.


Additive A
Cetane number
Ignition delay
Cetane number
Ignition delay
15
14
13
12
11
10
9
8
17
16
15
14
13
12
11
10
9
8
ED95
Add.A(5) MD95
Add.A(5) MD95(dry)
Add.A(10) MD90
Add.A(5) MeOH65+EtOH30


Additives A, B, C, D (5%)
Cetane number
Ignition delay
12
11
10
9
8
19
18
17
16
15
14
Add.A(5) MD95
Add.B(5) MD95
Add.C (5) MD95
Add.D(5) MD95


Add.A(5%) + esters A, B (5%)
Cetane number
Ignition delay
12
11
10
9
8
19
18
17
16
15
14
Add.A(5) MD95
+ Ester.A(5) MD90
+ Ester.B(5) MD90


MeOH+Add.A(5%) + oxygenates (5%)
Cetane number
Ignition delay
12
11
10
9
8
19
18
17
16
15
14
Add.A(5) MD95
+Alc(5) MD90
+Ether(5) MD90
+Oxy(5) MD90

Fuels for engine testing

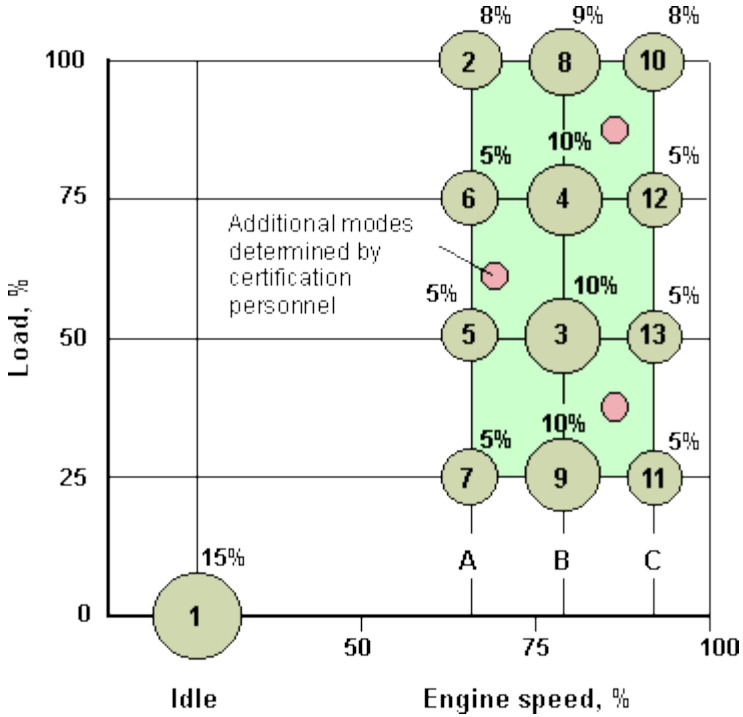
- MD-1: Additive A
- MD-2: Additive C+ester A
- MD-3: Additive C+ester A+ether
- MD-4: Resembles MD-3, but lower additive concentration
- MD-5: Resembles MD-4, but lower additive concentration
- MD-6: Nitrate-based additive
- ED95 as reference

FAME was not fully soluble in the final blends. This could be due to the water content, which was appr. 5.5 %(m/m) for the MD95 blends.

Tests with Scania EEV Ethanol DC9 270 hp

Testing: 2 x ESC test cycle + 3 loads

- CO, HC, NOx, CO2
- Methanol, ethanol, formaldehyde, acetaldehyde using FTIR Gasmet Cr-2000
- Particulate matter (PM), mass emission
- Particle number emissions:
  - ELPI (wet, tunnel)
  - PN-DEED (dry)
- Cylinder pressure, AVL Indicom

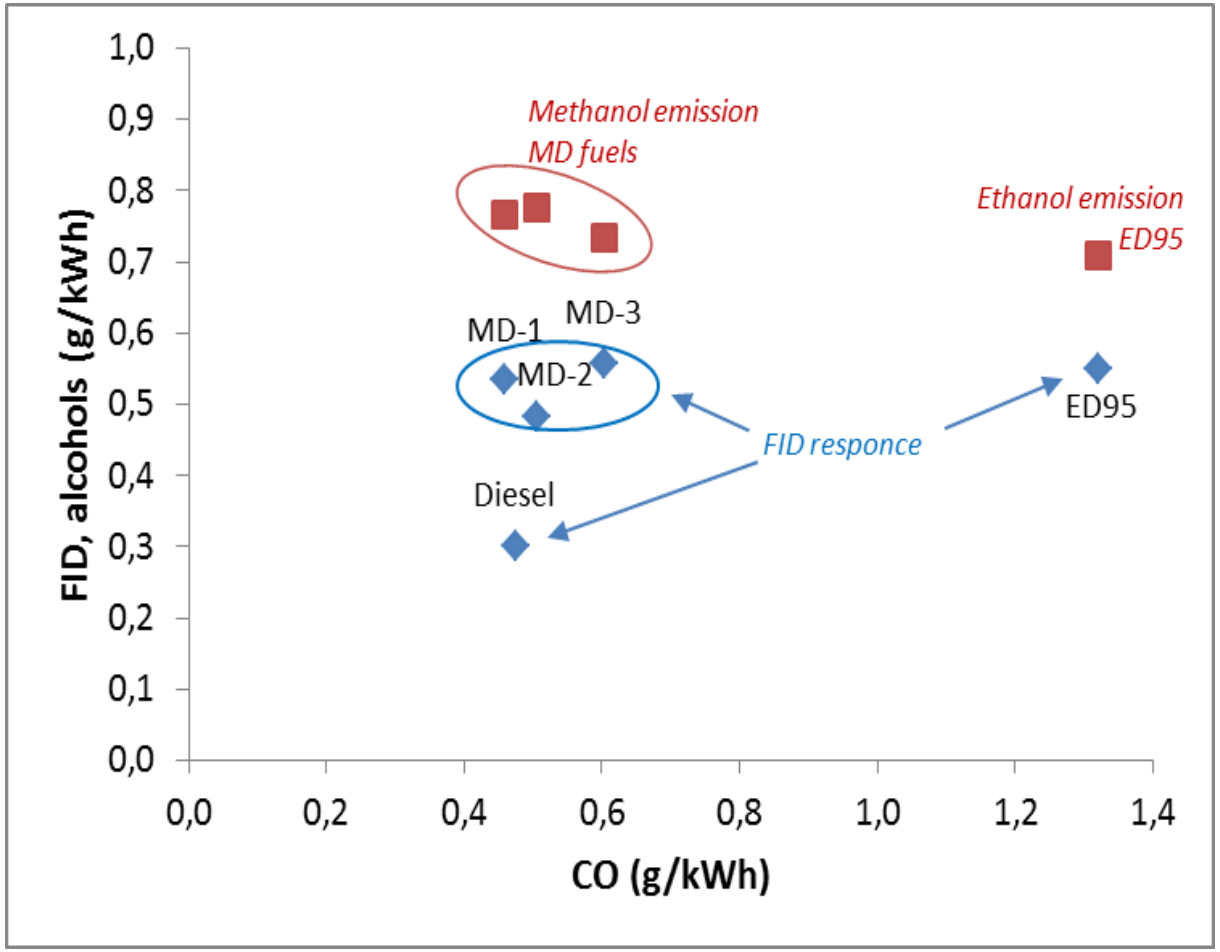


	1	2	3-B50	4	5	6	7	8	9	10	11	12	13-C50
N (min-1)	609	1109	**1439**	1439	1109	1107	1108	1440	1438	1769	1769	1769	**1769**
M (Nm)	25,7	899,2	**438,5**	656,6	467,8	700,7	235,5	876,5	218,2	767,5	192,7	576,1	**384,8**
P (kW)	1,6	104,4	**66,1**	98,9	54,3	81,3	27,3	132,2	32,9	142,1	35,7	106,7	**71,3**

+ three 5 min loads: 1) B50% 2) C50% 3) random 1250 rpm, 500 Nm

CO and HC emissions

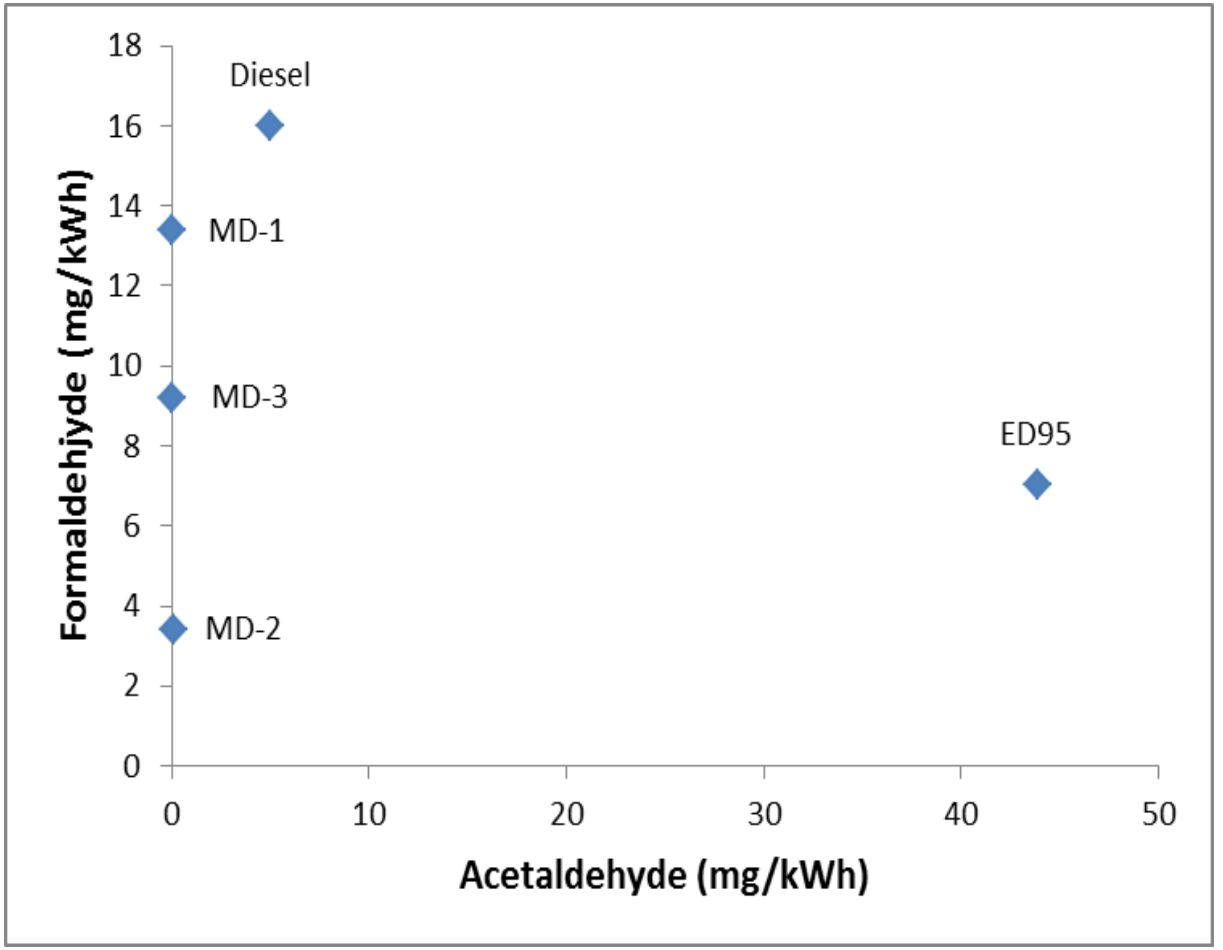
- Lower CO for MD95 than for ED95
- Unburned ethanol and methanol was present in exhaust for ED95 and MD95 fuels. However, differences between different alcohol fuels were relatively small



Acetaldehyde and formaldehyde emissions

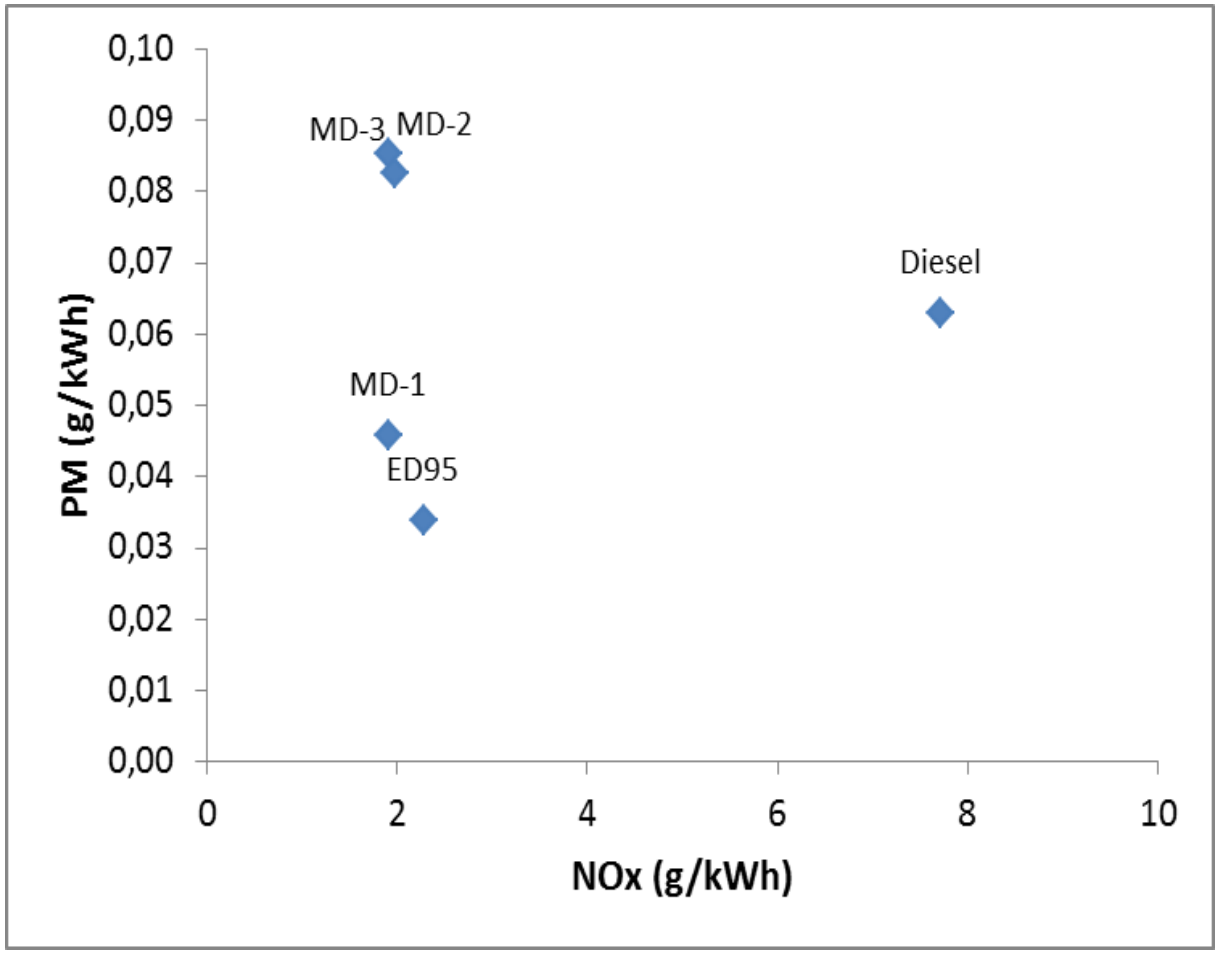
- Clear acetaldehyde emission for ED95
- Formaldehyde was not significantly formed with the MD95 fuels.
- Diesel fuel resulted in the highest formaldehyde emissions.

Transient testing needed to confirm low aldehyde emissions.



NOx and PM emissions

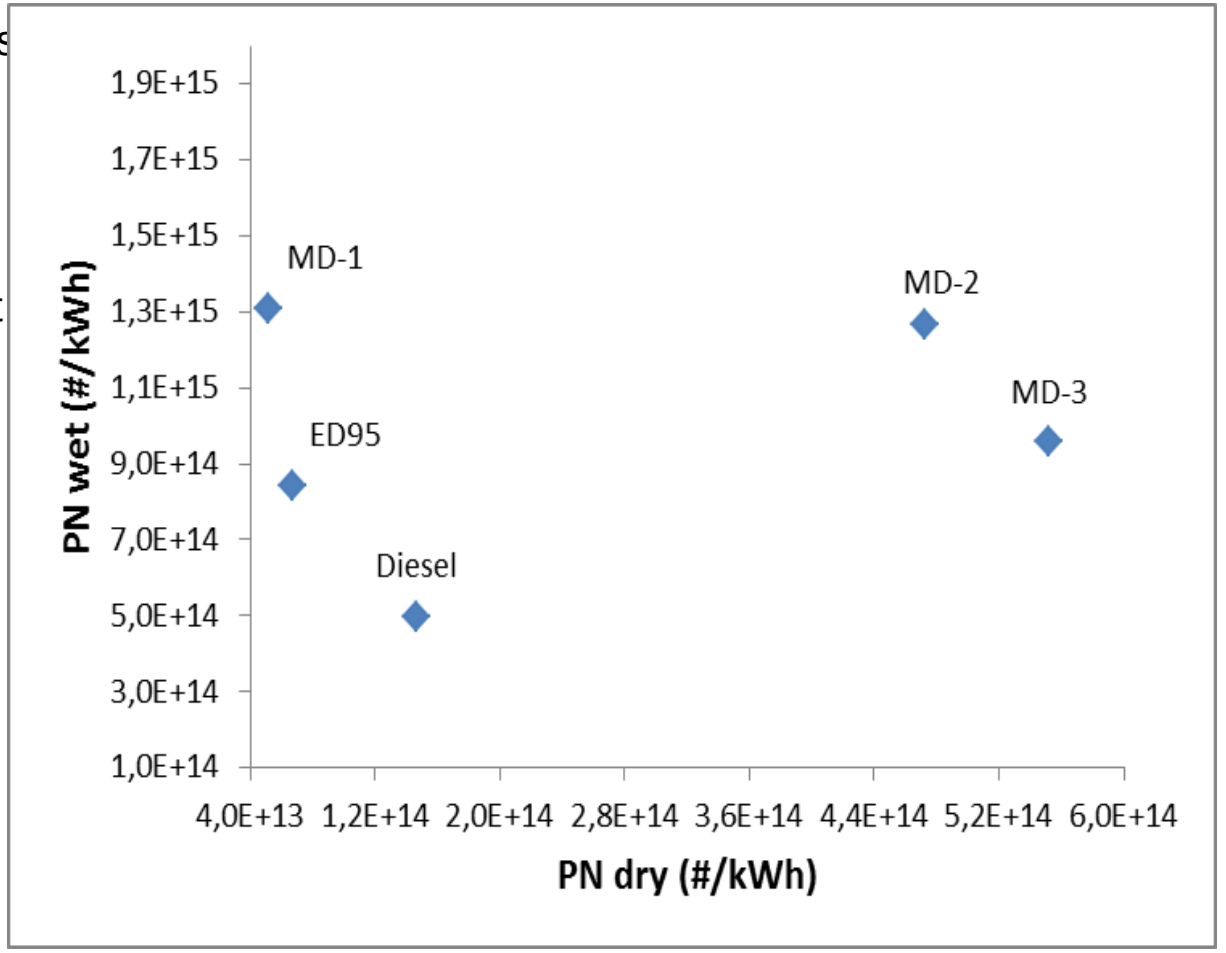
- NOx lower for MD95 than for ED95
- Substantial ”PM” for MD95 and ED95, however, **low ”soot”** is observed. Filters are greyish for ED95, while **filters are totally white for MD-fuels.** Probably ”PM” is
  - semivolatiles originating from the unburned additive
  - For MD-2 and MD-3, also unburned FAME



Particle number emissions

- **Dry PN** (and wet PN) with all fuels several orders of magnitude higher than the Euro VI limit ($8.0x10^{11}$ 1/kWh).
- For MD-1 and ED95, much of volatile particles were removed at 350 °C.
- For MD-2 and MD-3: ”non-volatile” FAME originating particles.

Note: Semivolatile PM can typically be removed by oxidation catalyst.

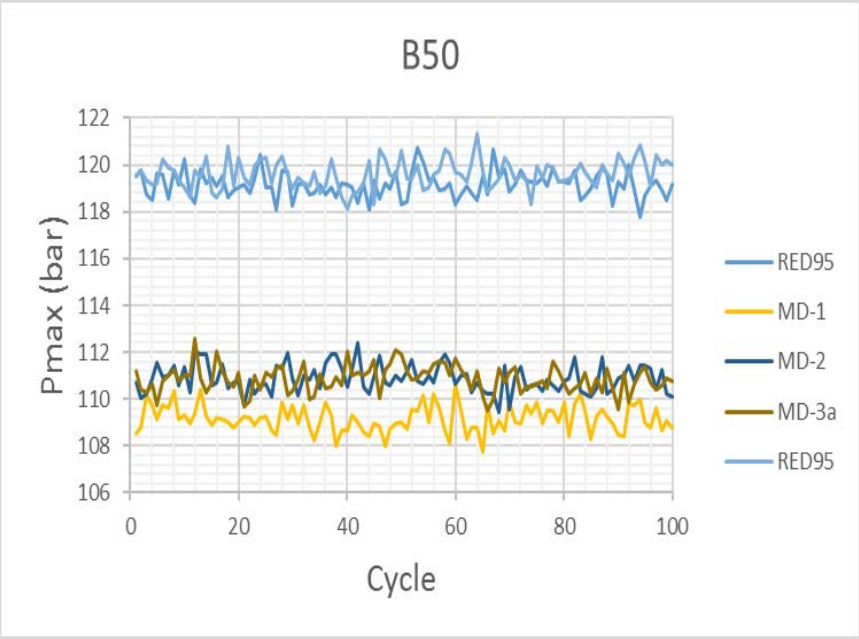


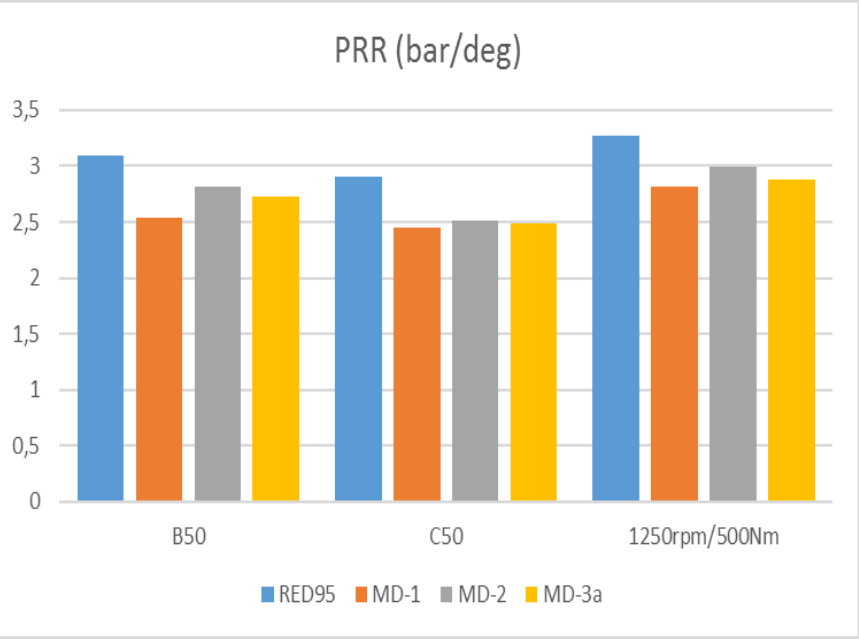
Dry PN acc. to R49 with CPC
- Detects particles >23 nm, removes volatile particles (at 350 °C)

Wet PN from CVS tunnel with ELPI
- Tunnel dilution favours nanoparticles
- Detects particles >8 nm

Normal cylinder pressure deviation (SDEV < 1) was experinced in all points

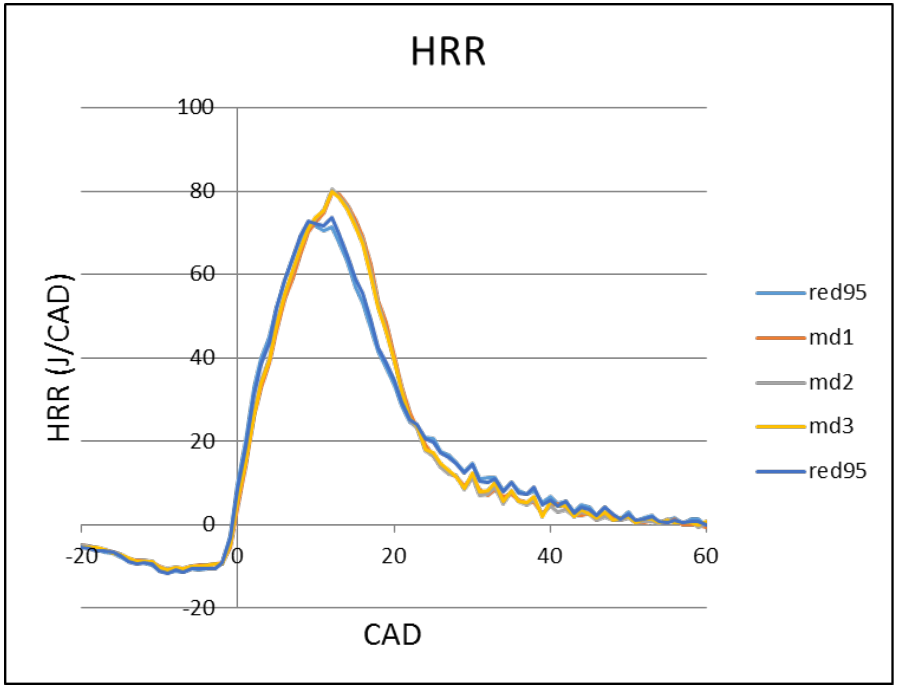
PRR highest using ED95

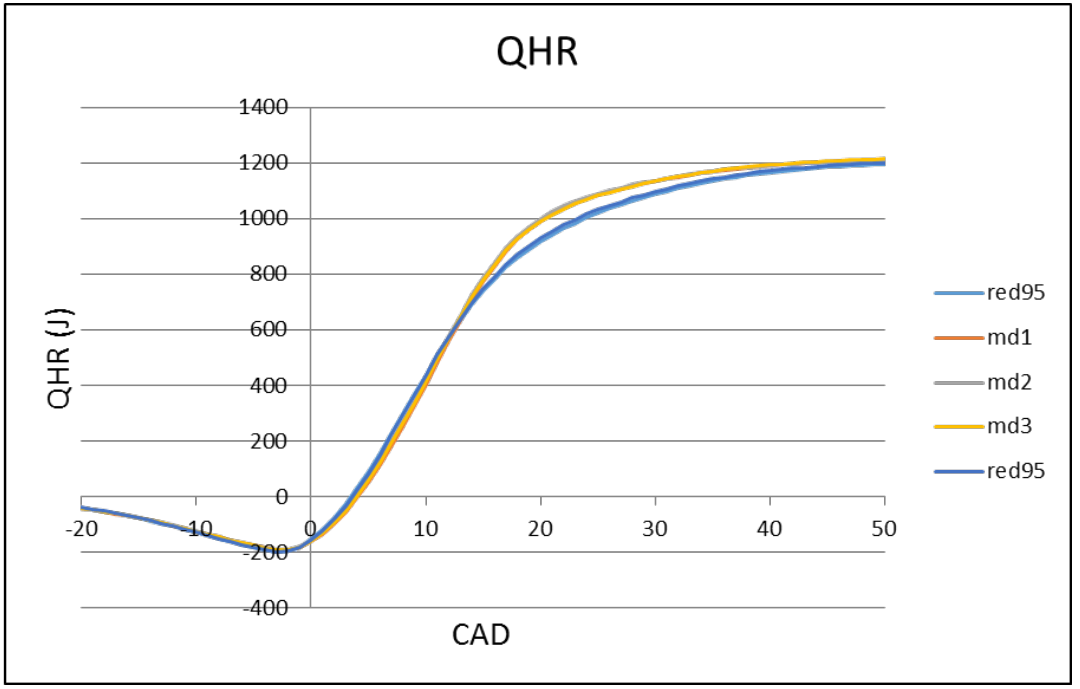




Heat release

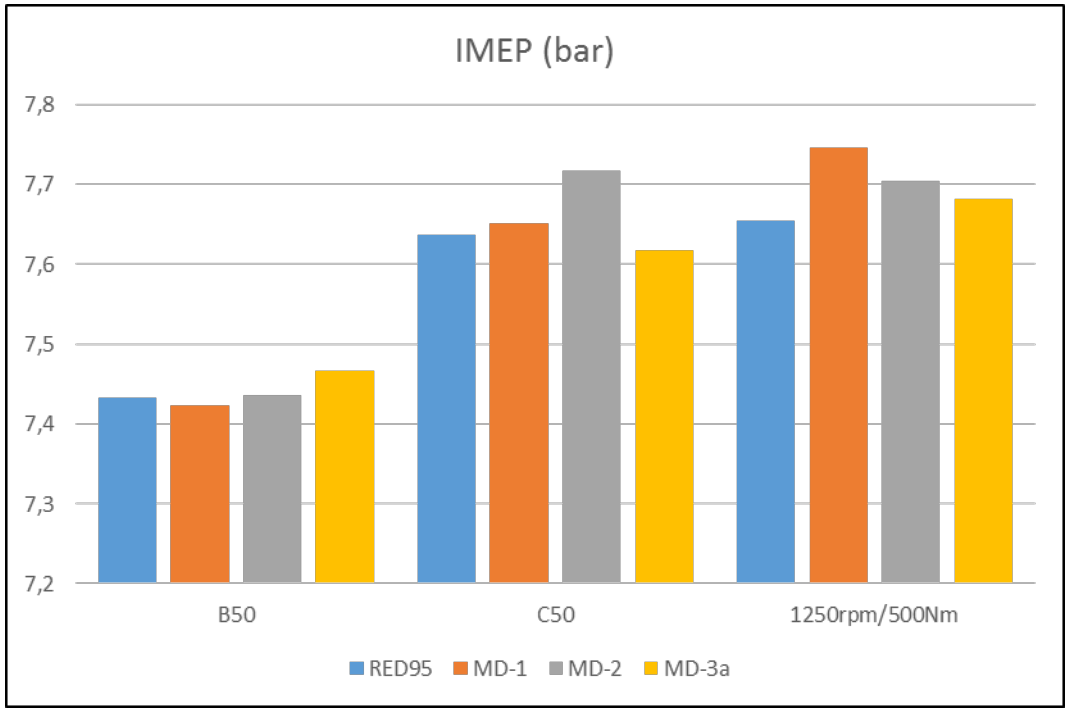
- Due to longer injection duration, **methanol heat release lasts longer**
- **Methanol combustion is faster** caused by the better mixing and higher reaction speed
- ED95 tends to release more heat in the late combustion phase





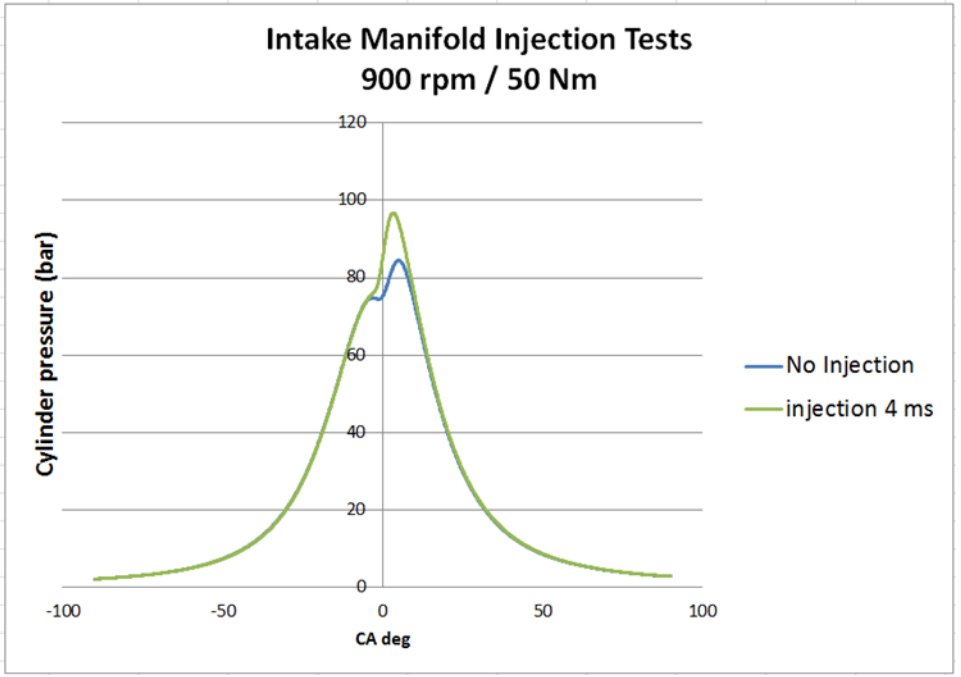
IMEP

- IMEP differences between fuels are small



Intake manifold injection tests

- ED95 fuel was injected in the intake manifold for MD-4 and MD-5, which had reduced ignition improver additive content.
- Utilising manifold injection a fuel blend with poor ignition can be used.
- Green line shows that **much more stable cylinder pressure was achieved with the intake manifold injection** than without (blue line).
- However, in this non-optimized system no exhaust emission benefit was achieved. The system needs improvement in both flow design and main injection functionality to show the potential of the concept.



Conclusions

- **MD95 methanol blends tested were clean burning**, and combustion was good in the Scania EEV Ethanol DC9 270 hp.
- **The best performance for the same type of ignition improver as used in the ED95**.
- **Formaldehyde was not significantly formed** with the MD95 fuels (steady-state tests).
- For MD95 and ED95, high PM observed → **no real soot but rather unburned additives**. This “liquid PM” and particle number emissions can probably be **reduced by catalyst** that belongs to the commercial Scania alcohol engine.
- Fuel injection in the intake manifold allows reducing the concentration of ignition improver additive.

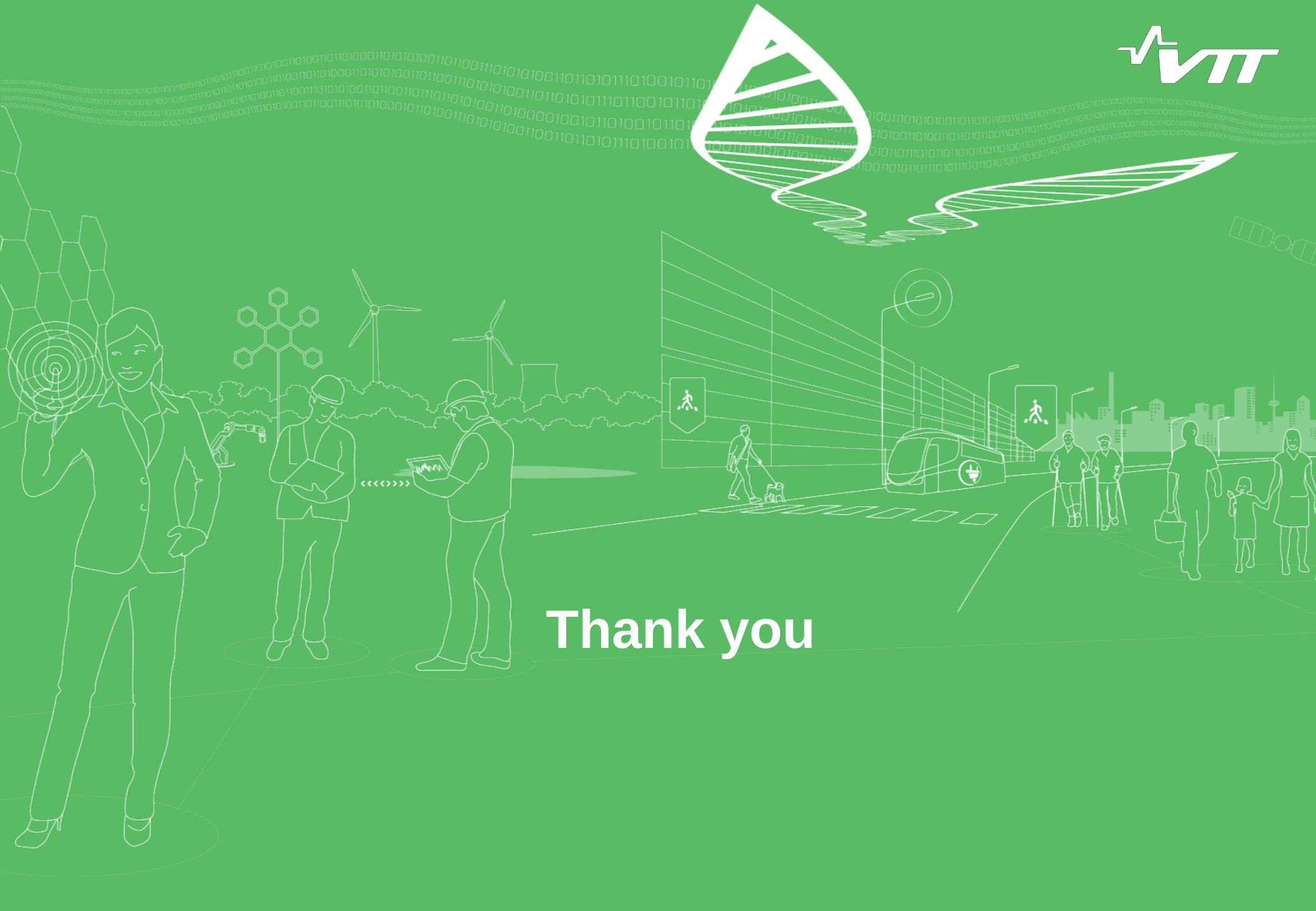
Overall, the results show that the MD95 concept is potential for introducing environmentally friendly renewable methanol for smaller ships on the condition that engine materials and other related issues are handled.

The centenary of Finland's independence culminates in Finland's Independence Day, on 6 December. The the climax of the centenary is built together, and the programme will be rich and memorable. The official celebrations start on Independence Day Eve, on 5 December, and take place in Finland as well as abroad. Finland's birthday week includes numerous acknowledgements to the 100-year-old.

Suomi Finland 100

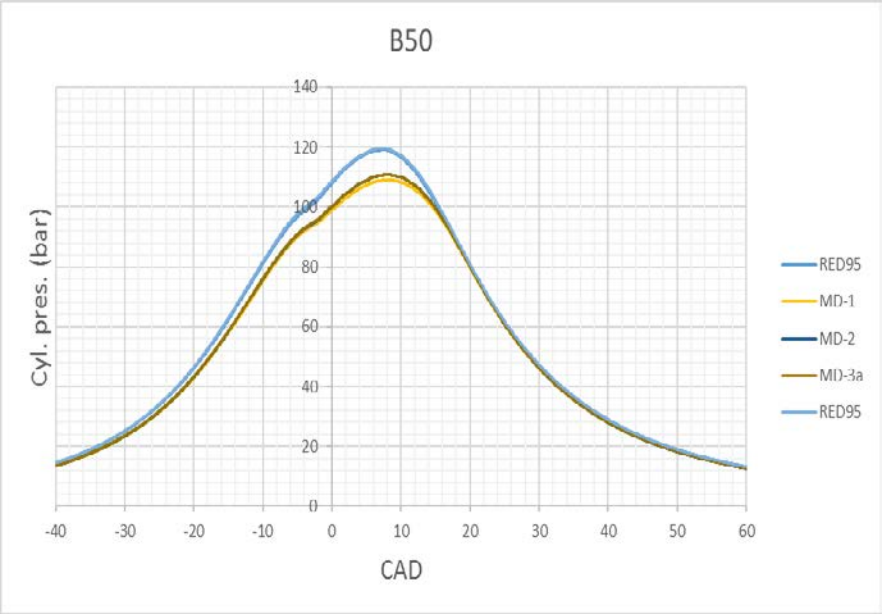
SWEDEN CELEBRATES FINLAND'S 100 YEARS OF INDEPENDENCE WITH A SUBSTANTIAL INVESTMENT INTO FOREST BIOECONOMY RESEARCH

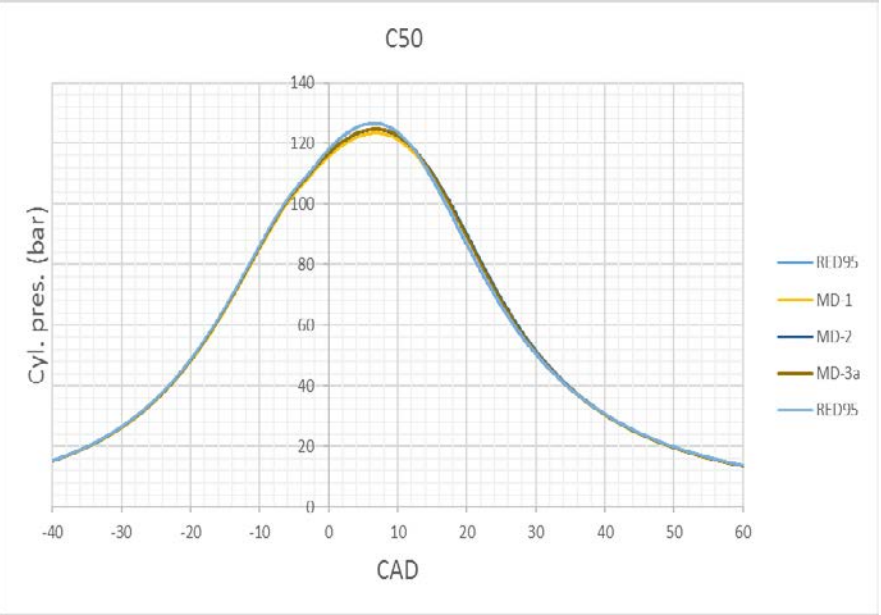
Sweden's 100-year gift to #Finland - Anna Uddenberg's 'Free Fall' - inaugurated at @Hanaholmen by @SwedishPM Löfven & Finland's @juhasipila.


Thank you

Cylinder pressure

- B50, cylinder pres. difference ~10bar, C50 ~3bar between RED95 vs. MD
  - →calc. intake air mass flow 18,5% (B50) respectively 3,2% (C50) lower using methanol
  - →The engine is using different maps on equal load





Particle number emissions

- Clear nucleation but low soot mode for ED95 and MD-1
- For MD-2 and MD-3: higher accumulation (soot) mode (vs diesel) than for the other fuels, but no greyish colour of filters.
- All distributions in Figure show tendency for nucleation, which is expected as tunnel dilution favours formation of nanoparticles.