Nanoparticle Emissions from an SI Engine Fueled with Gasoline and Methanol Reforming Products

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1. Motivation

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CHALLENGES

- ICE: **main transportation power plant**
  - US road vehicles powered by ICE: over 99% (U.S.EIA, 2015)
- **Fossil fuels** dependence
  - US transport sector usage of fossil fuels: 95% (U.S.EIA, 2015)
- **Climate Change**
  - Global transport sector contribution to CO_2 emissions: 23% (IEA, 2012)
- **Pollutants emissions** from transport sector (EEA, 2009)
  - NO_x: 58% ; CO: 30%
  - PM10: 22% ; PM2.5: 27%

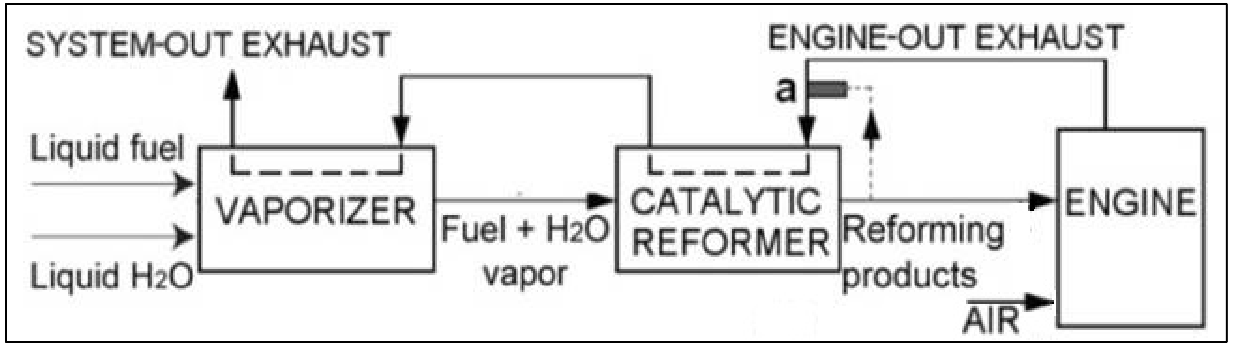
POSSIBLE SOLUTIONS

- Low carbon-intensity, renewable fuels
- Advanced combustion strategies
- Vehicles energy efficiency improvement

1. Waste Heat Recovery by Thermo-Chemical Recuperation

HOW TO INCREASE VEHICLE OVERALL EFFICIENCY?

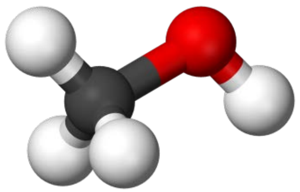
- Exhaust gases: About 1/3 of fuel energy
  - Usually wasted
- Waste heat recovery
- Thermo-Chemical Recuperation
  - Liquid fuel and water supplied to the system
  - They are evaporated and then reformed
  - Gaseous reforming products inserted into the engine and burnt
  - Exhaust gases energy used to reform primary fuel
  - Possible with many liquid fuels
    - Methanol was chosen



1. Why Methanol?

LIQUID METHANOL:

- Low reforming temperatures
- Promising primary liquid fuel
  - Low carbon-intensity
  - Potentially renewable
  - Can produced from natural gas
    - Alternative for oil as a short term solution
- No significant infrastructure change needed



GASEOUS REFORMING PRODUCTS:

- Hydrogen-rich gaseous fuel: $H_2(\approx75\%)+CO_2+CO$
- Better fuel properties
  - LHV increase
  - Increased ON: elevated compression ratio
  - High laminar flame speed
  - Wide flammability limits
- Zero-impact pollutant emissions
- No problems of onboard hydrogen storage

1. Methanol Reforming Drawbacks

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- Intense research on Methanol reforming in the 70's and 80's

DRAWBACKS:

- Backfire
- Pre-ignition
- Reduced maximal power
  - Lower volumetric efficiency
- Startup and transient behavior problems
- **Activities were stopped**

SOLUTIONS:

Backfire, pre-ignition, reduced maximal power → Direct injection of reforming products

Startup and transient behavior problems → Hybrid propulsion system

2. Methodology

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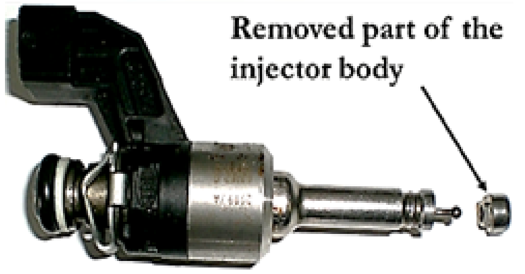
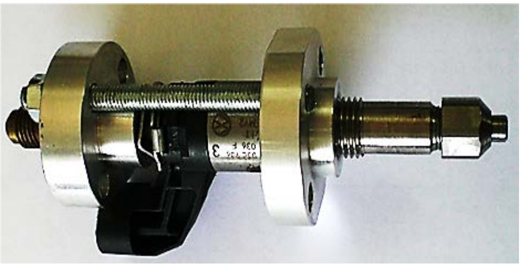
- Testing engine powered by different fuels
  - 95 RON gasoline
  - Syngas imitating methanol reformate products (75% H_2 - 25% CO_2)
- Controlled parameters:
  - Engine Load
  - Injection and Ignition times
  - Air-fuel equivalence ratio (lambda)
- Measured or calculated parameters:
  - Engine performance
  - Combustion quality: in-cylinder pressure
  - Concentrations of gaseous pollutants CO, CO_2, NO_x
  - Particle size distribution and particle number concentration (PN)

2. Experimental Setup: The engine

- Chosen Engine: Gen-set ROBIN EY20-3
- Side-valve engine
  - More space in the cylinder head
    - In-cylinder pressure transducer
    - Fuel injector
- No market-available injectors
  - Direct Injector was developed

Engine	Gen-set ROBIN EY20-3 / SINCRO GP100 2.2 kW AC 230V
Bore x Stroke, mm	67x52
Displacement, cm3	183
Compression ratio	6.3
Power, kW @ speed, rpm	2.2 @ 3000
Lubrication	Splash type
Carburetor	Horizontal draft, Float type
Gasoline feed system	Gravity type
Ignition system	Flywheel magneto
Spark plug	NGK B6HS
Starting system	Recoil starter
Governor system	Centrifugal flyweight type





2. Experimental Setup: Pollutants Measurement Devices

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- Chemiluminescence Teledyne 200EH ($NO/NO_2/NO_x$)
- NDIR CAI 600 (CO/CO_2)
- NanoMet3 - Matter Aerosol (Total PN)
- EEPS 3090 (Particles Size Distribution)

2. Experimental Setup: Overall System

Technion Internal Combustion Engine Laboratory

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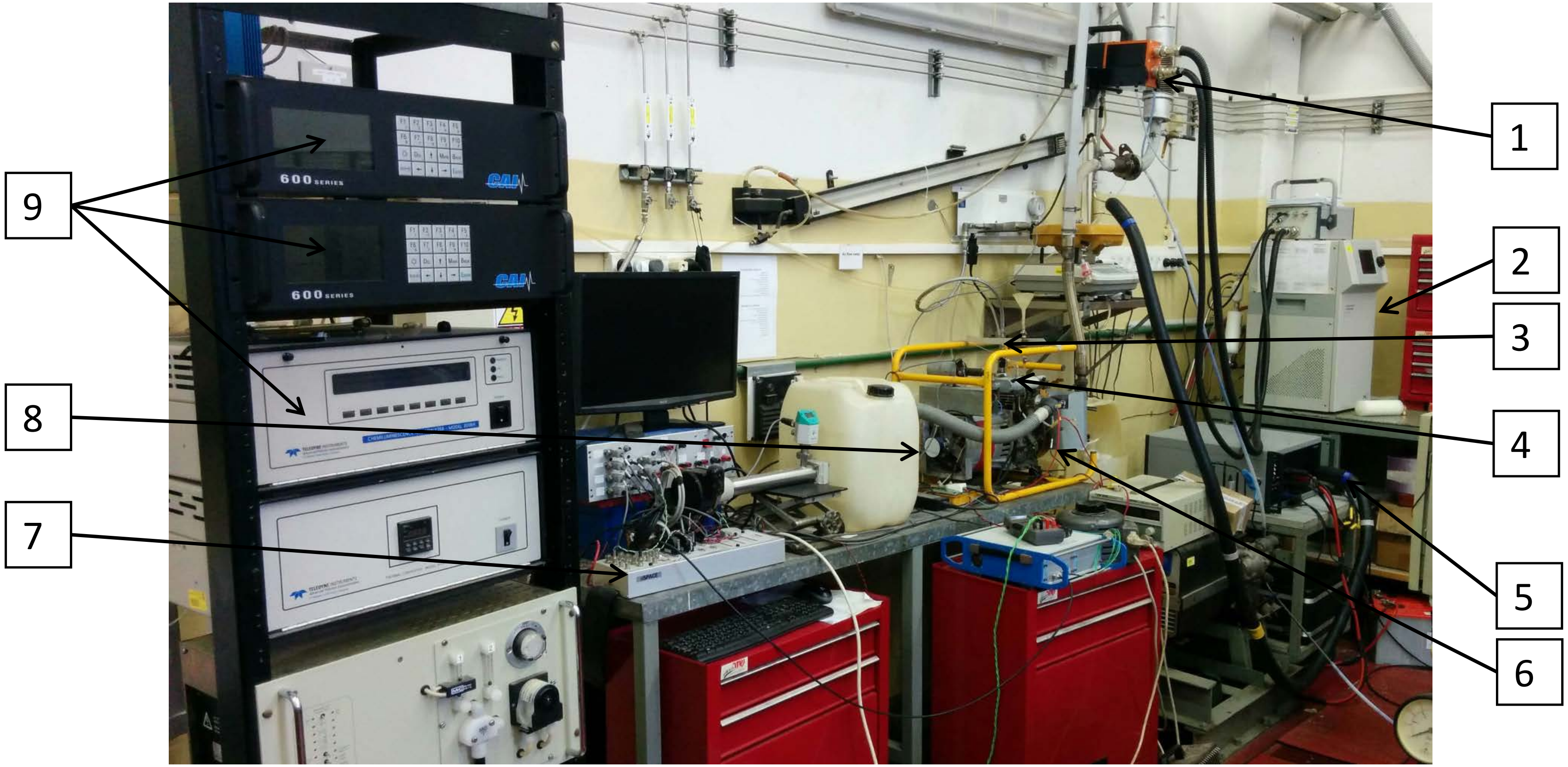

1. Rotating Disk Thermodiluter
2. EEPS3090
3. Reformate Direct Injector
4. In-cylinder Pressure Transducer
5. Nanomet3
6. Engine
7. Control System
8. Crank Angle Encoder
9. Gas Analyzers

3. Results: Engine Efficiency

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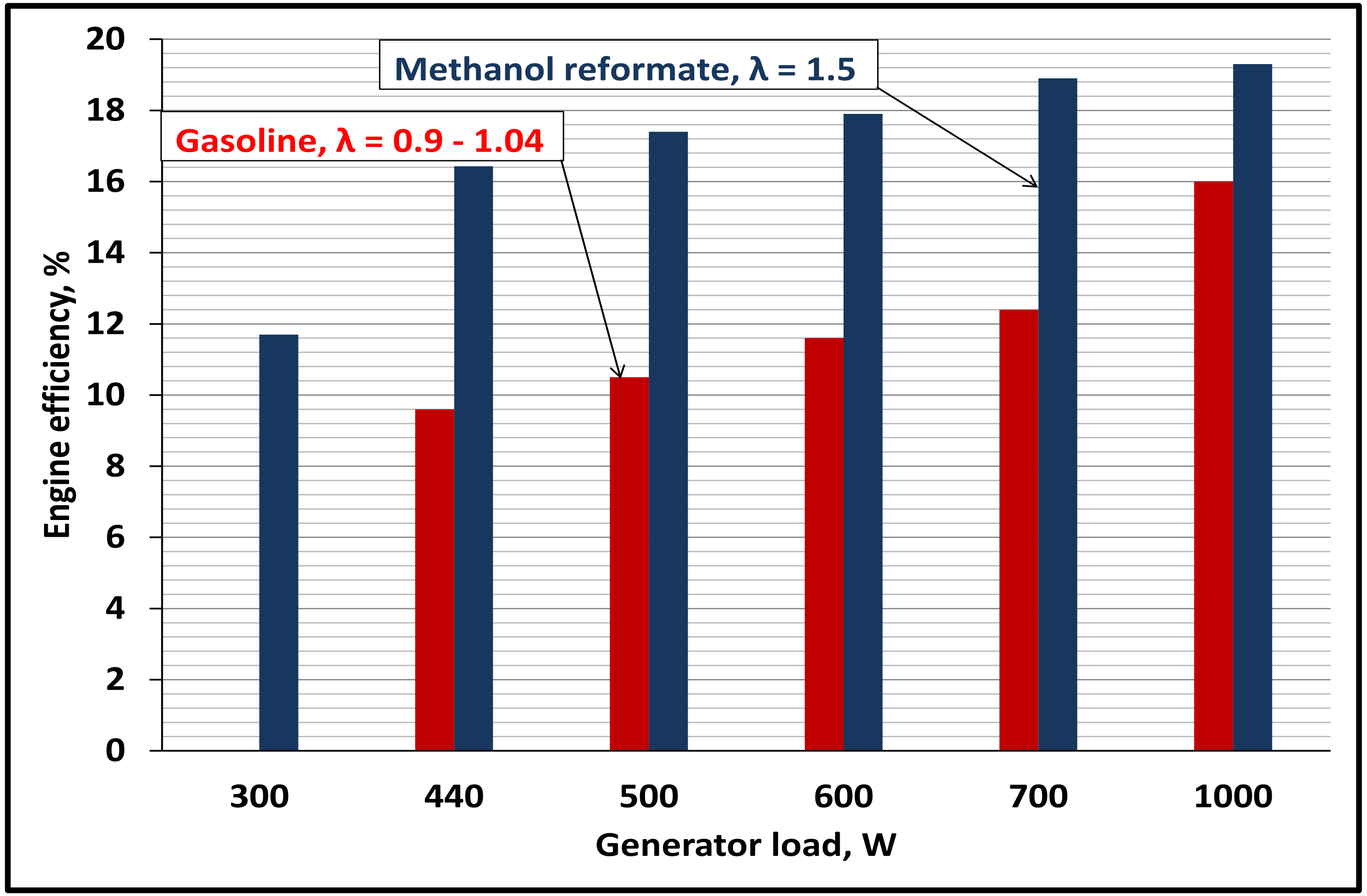

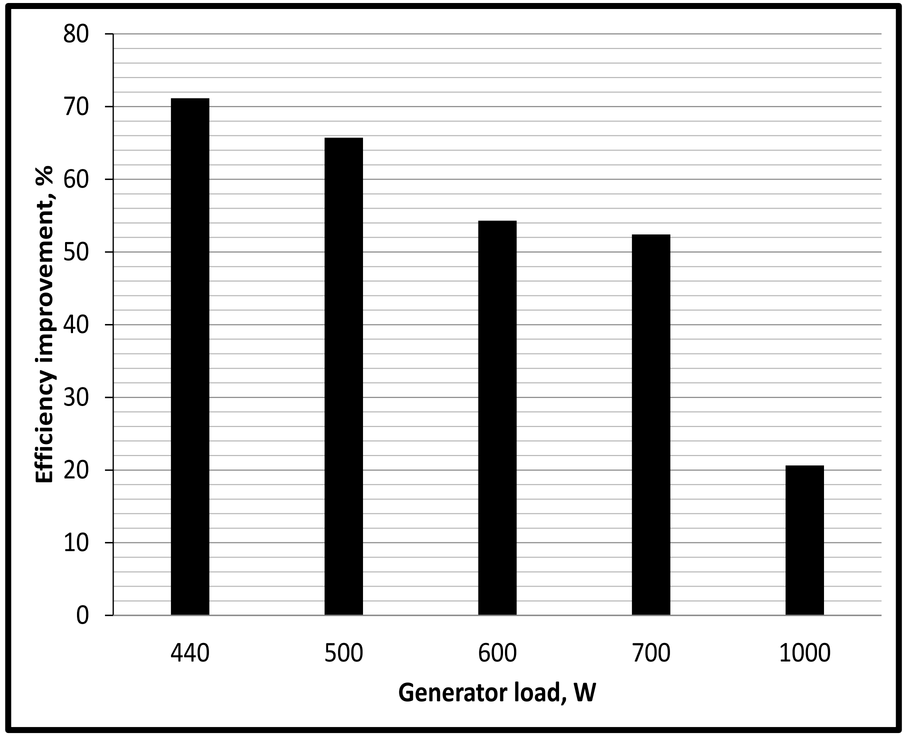

3. Results: Gaseous Emissions

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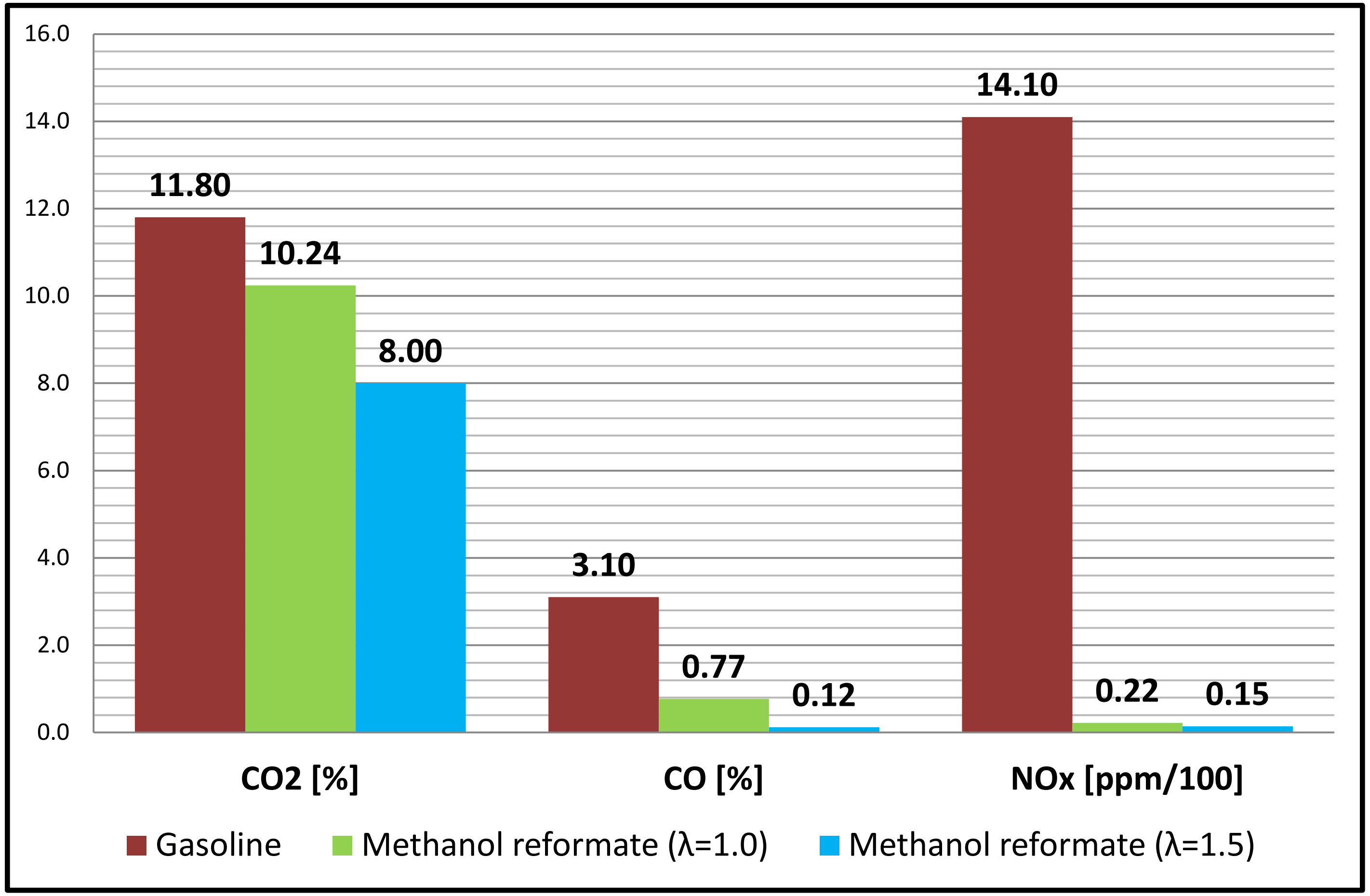

Relative Improvement (from gasoline)	CO_2 [%]	CO [%]	NO_x [%]
Methanol reformate (λ=1.0)	13.2	75.2	98.4
Methanol reformate (λ=1.5)	32.2	96.1	99.0

Engine operation: 1kW @ 2800 rpm

3. Results: Nanoparticle Size Distribution

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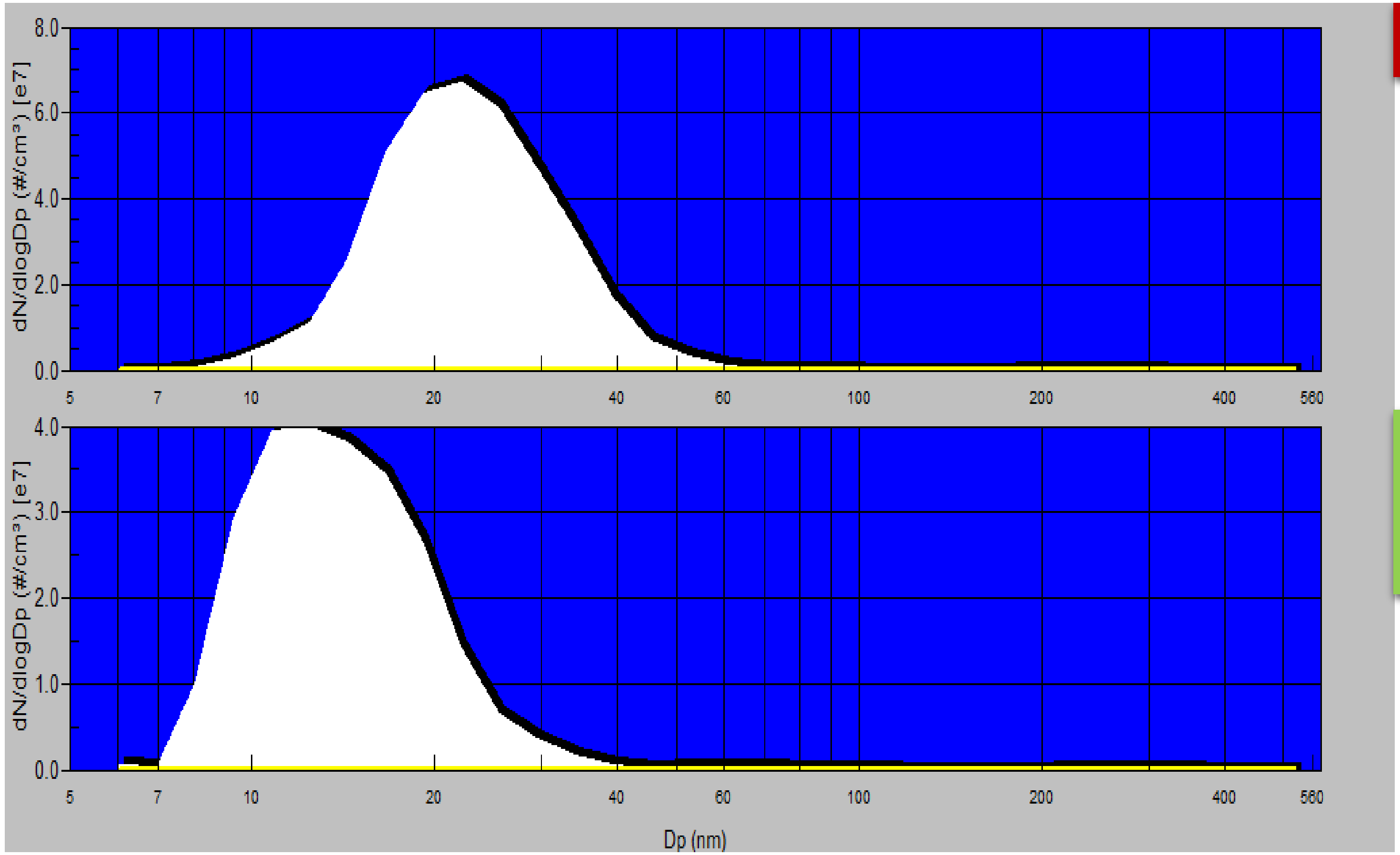

GASOLINE

Methanol reformate (λ=1.0)

- Similar pattern, methanol reformate nanoparticles slightly smaller
- Influence of Volatiles compounds

Engine operation: 700W @ 2800 rpm
Measured with EEPS3090. DF=104.76 / T=150C

3. Results: Total Particle Number

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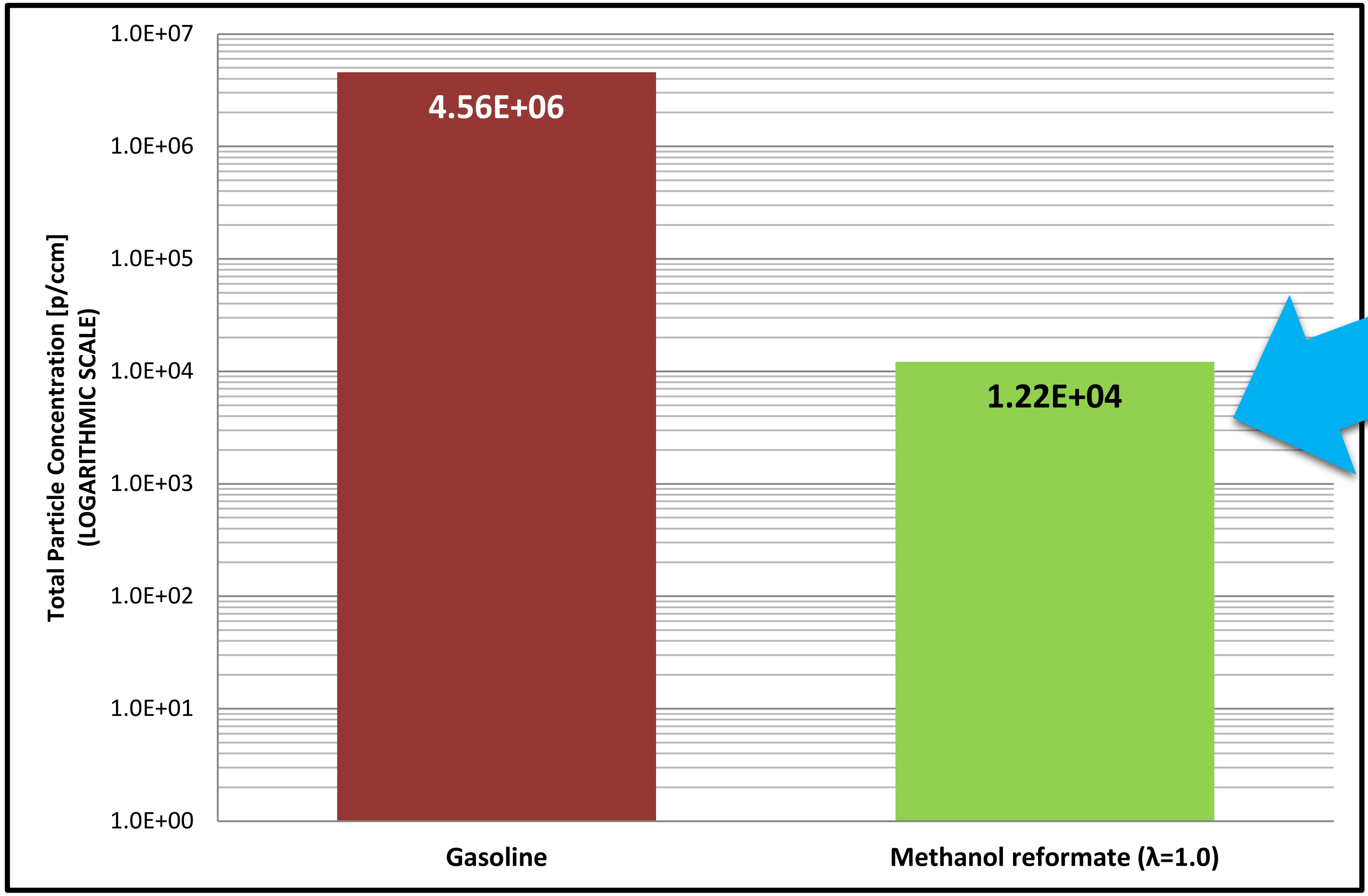

Total PN Reduction: 99.7%

Possible nanoparticle formation from engine oil

Engine operation: optimum ignition timing
Measured with Nanomet3. DF=100

4. Conclusions

- Engine efficiency improvement: from 20% to 60%
- Gaseous pollutants reduction:
  - CO_2: 13% (stoichiometric); 32% (lean)
  - CO: 75% (stoichiometric); 96% (lean)
  - NO_x: over 98%
- Similar nanoparticle size distribution profile. Methanol reformate: Slightly smaller
- **Total Particulate Number reduction of 99.7%**

5. Future steps

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- Develop the reformer
- Different reforming compositions
- Study the influence of engine oil
- Study size distribution at Thermodilution Temperature of 300C

Acknowledgements

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- The project was financially supported by:
  - Israeli Ministry of Environmental Protection
  - Israeli Ministry of National Infrastructures, Energy and Water Resources
  - Israel Science Foundation
  - The Nancy and Stephen Grand Technion Energy Program (GTEP)
- Special Thanks to:
  - Matter Aerosol
  - Prof. Dr. J. Czerwinski (BFH/AFHB, Biel)
  - Dr. A. Mayer/TTM
    - For borrowing the Nanomet3

Thank you!

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