Factor controlling condensed phase emissions from gas engine fired combined heat and power plant (CHP) – a field study

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Background

Fine and ultra fine atmospheric particles are of growing concern from a public health perspective as well as from a climate and air quality management perspective.

Mounting evidence correlates particles smaller than 2.5 µm and adverse health effects[1]

Growing evidence that fine and ultrafine particles are responsible for a significant fraction of these effects[2-5]

Extended suspension times long transport distances and easy penetration into indoor environment -> ubiquitous exposure.

Current knowledge of which properties of particulate matter show the greatest impact on public health, that being size, composition, or source, is still weak and inconclusive.

Background

Previous projects investigating fine and ultrafine particle emissions from combined heat and power plants showed that natural and bio gas fired plants have surprisingly high particle emissions.

It was speculated that a correlation could exists between lubrication oil use/consumption and particle mass and number emissions.

The available data material from these projects was limited and factors that may control the emission level were not investigated and therefore no conclusions as to the origin of these emissions were drawn.

Objective

- to identify the primary causes of fine and ultrafine particles emitted from CHP plants using gas fired engines.
- To identify which operational parameters has the greatest influence on the particulate emission from gas engines

Site	Engine type (Brand)	E-power output (kW)
Plant A	Wärtsilä 18V34SG	6074
Plant B	RR type K	3118
Plant C	RR type K	2066
Plant D	Wärtsilä 18V34SG	4794
Plant E	RR type K	3271

Measured parameters

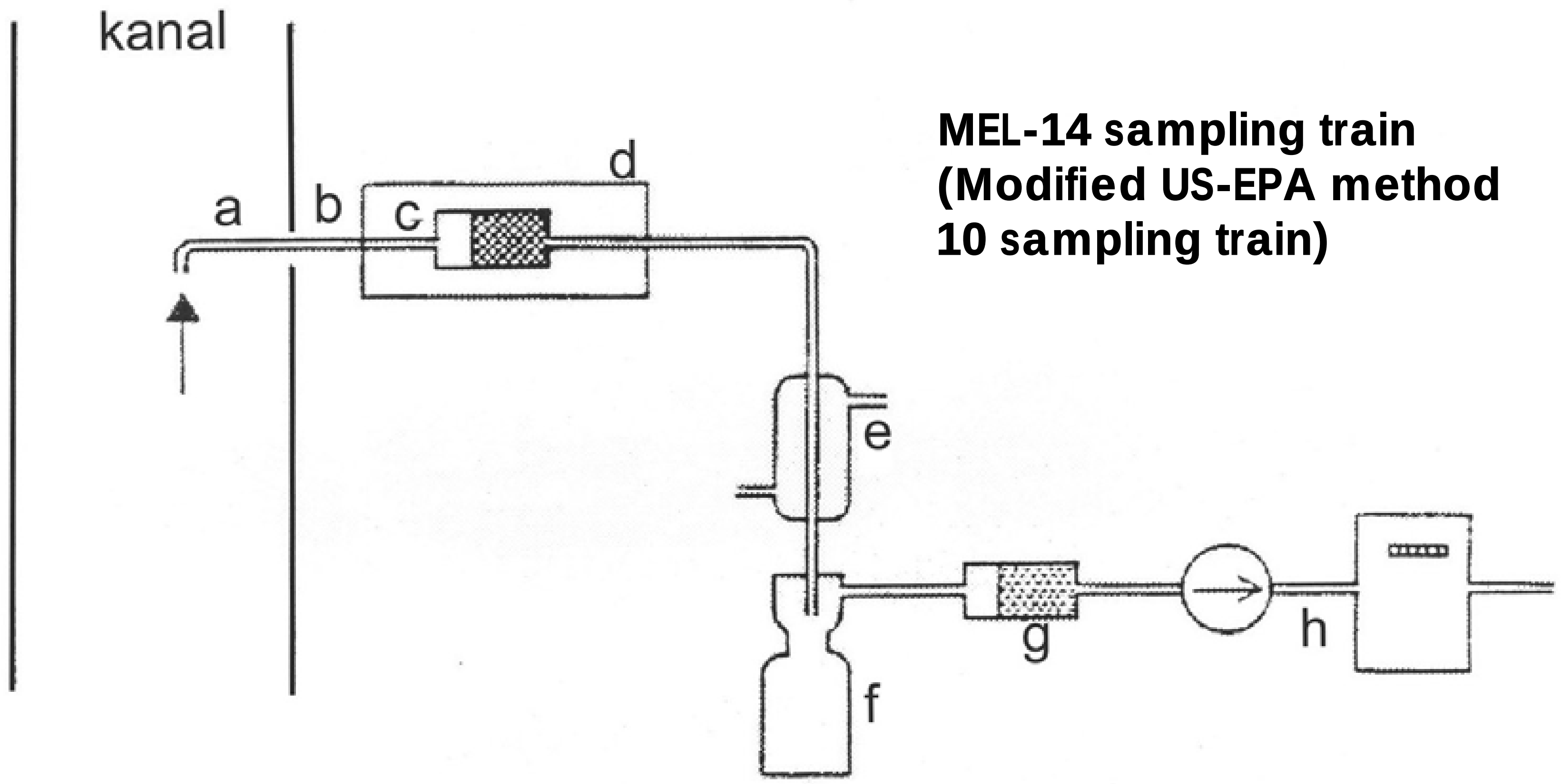
Field test #	Site	Particle number and size distribution	Particulate volatile fraction	Oil mist	UHC	CO	NO_X	O_2	Size resolved elemental analysis	Oil analysis	Stack gas temperature
		ELPI	TD-ELPI	Filter/XAD	FID	NDIR	CLD	ZrO_2	SEM-EDX	AAS/ICP-MS	Thermocouple
1	Plant A	FT	FT	DGC	DGC	DGC	DGC	DGC	FT	Statoil	DGC
2	Plant A	-	-	FT/DGC	-	-	-	-	-	-	DGC
3	Plant B	FT	FT	DGC	DGC	DGC	DGC	DGC	-	Statoil	DGC
4	Plant C	FT	FT	DGC	DGC	DGC	DGC	DGC	-	Statoil	DGC
5	Plant D	FT	FT	DGC	DGC	DGC	DGC	DGC	-	Statoil	DGC
6	Plant E	FT	FT	DGC	DGC	DGC	DGC	DGC	FT	Statoil	DGC
7	Plant E	FT	FT	FT/DGC	DGC	DGC	DGC	DGC	-	-	DGC

Site	Field test #	Oil consumption (g/kWh)	NOx (mg/m³)	UHC (mgC/m³)	PN1 #/cm³ (n,ref O2)	Oil fraction (PN1)	PM1 mg/m³ (n, ref O2)	Oil fraction (PM1)	Oil fraction (PM10)	Oil mist on filter (mg/m³)	Oil mist on XAD (mg/m³)	Oil mist on filter+XAD (mg/m³)
Plant A	1	0.160	327	1016	1.66E+06	61%	0.36	3%	42%	0.35	0.29	0.64
Plant A	2	-	-	-	-	-	-	-	-	0.11	0.07	0.18
Plant B	3	0.107	503	1511	1.99E+06	75%	0.72	57%	74%	0.26	0.22	0.48
Plant C	4	0.409	524	1812	1.49E+06	84%	0.19	37%	42%	0.76	0.98	1.74
Plant D	5	0.146	606	1135	1.96E+07	54%	2.08	32%	48%	0.43	3.85	4.28
Plant E	6	0.080	438	1589	1.31E+06	52%	0.17	39%	60%	0.14	0.29	0.43
Plant E	7	-	332	1593	8.81E+06	49%	0.26	39%	46%	0.12	0.05	0.17

Oil mist and oil consumption

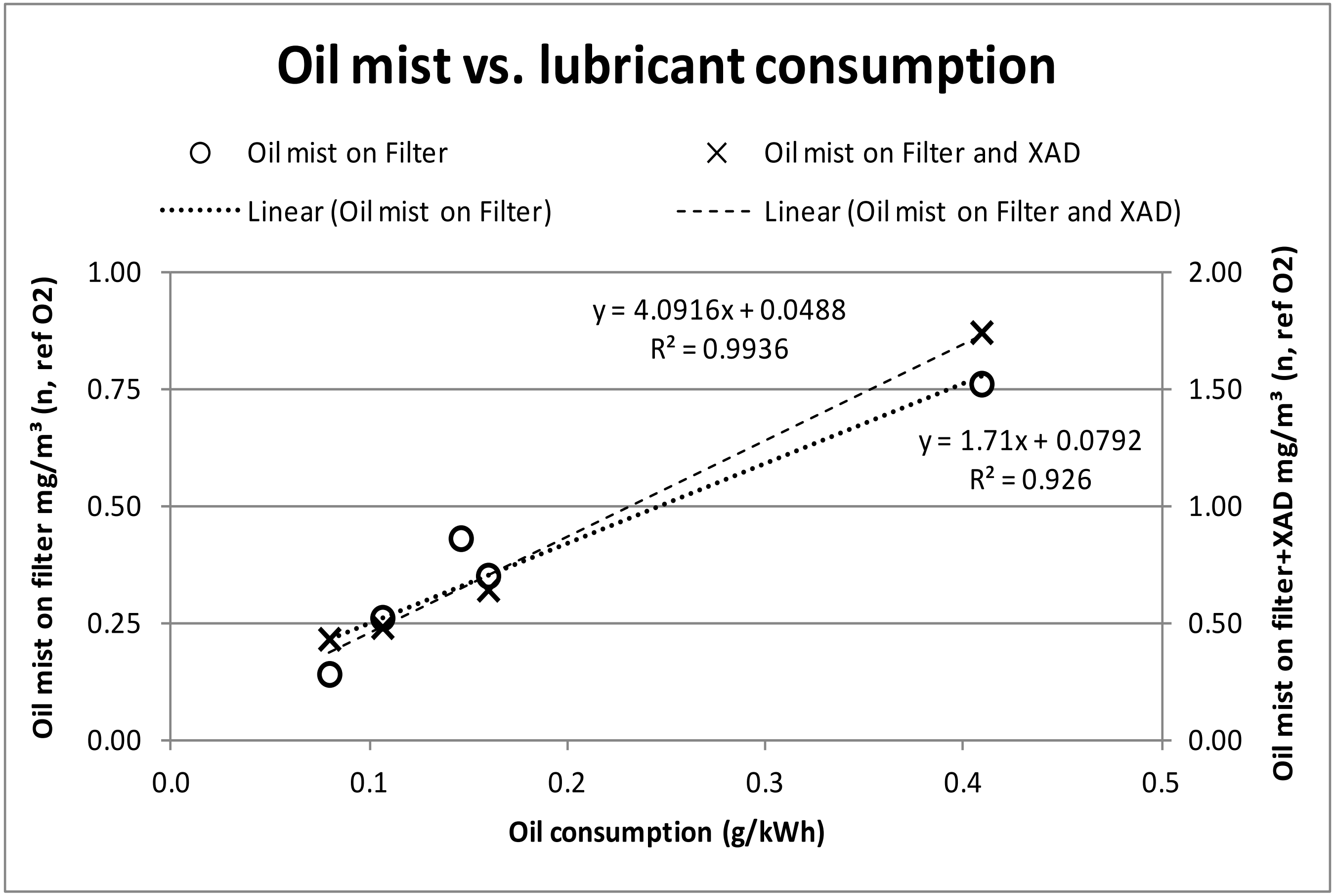
Site	Engine type (Brand)	E-power output (kW)	Engine lubricant (Brand)	Base oil group (API definition)	Oil consumption (g/kWh)
Plant A	Wärtsilä 18V34SG	6074	Shell Mycella	2	0.160
Plant B	RR type K	3118	Geotex PX40	3	0.107
Plant C	RR type K	2066	Geotex PX40	3	0.409
Plant D	Wärtsilä 18V34SG	4794	Mobil 805	3	0.146
Plant E	RR type K	3271	Q8 Mahler	3	0.080

Oil mist and oil consumption



MEL-14 sampling train (Modified US-EPA method 10 sampling train)

Oil mist and oil consumption

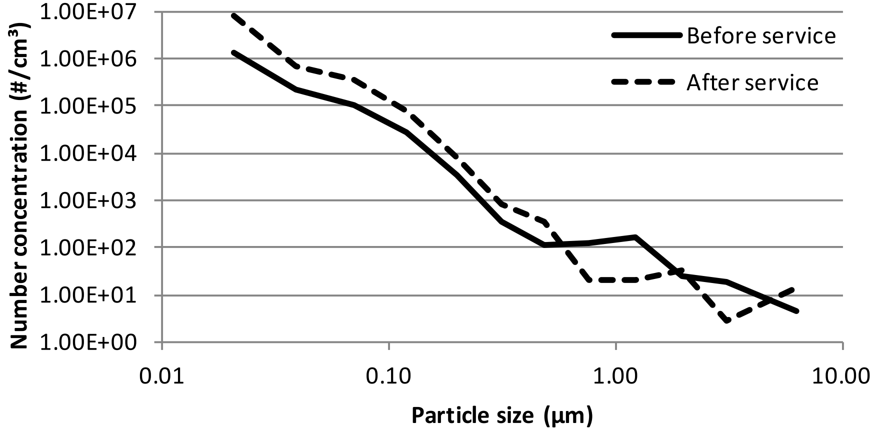


25% - 60% of PM_1

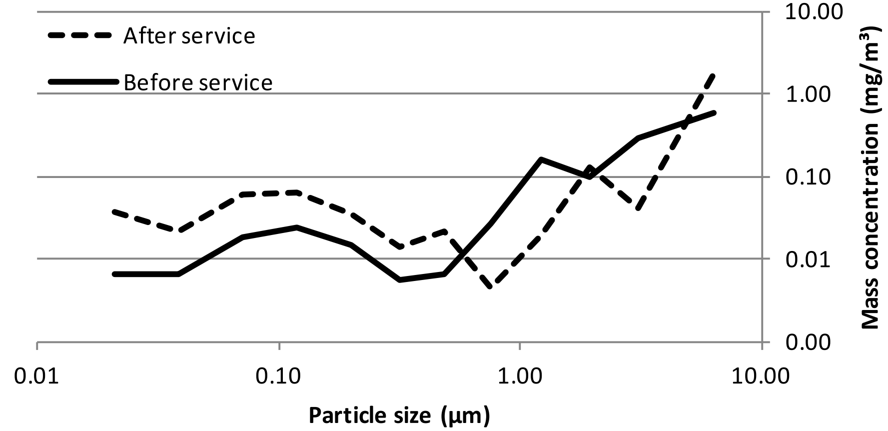
50% - 85% of PM_{10}

Before and after service

Particle number concentration

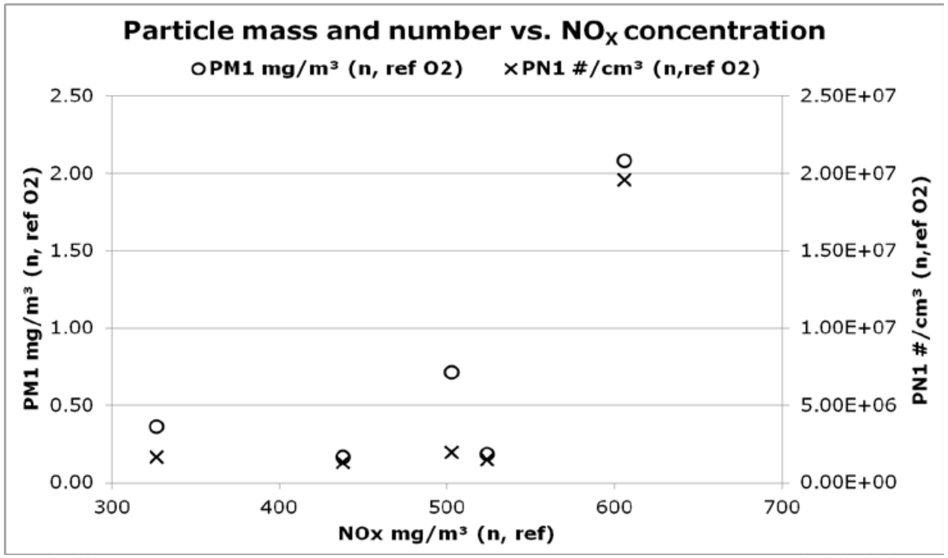


Particle mass concentration



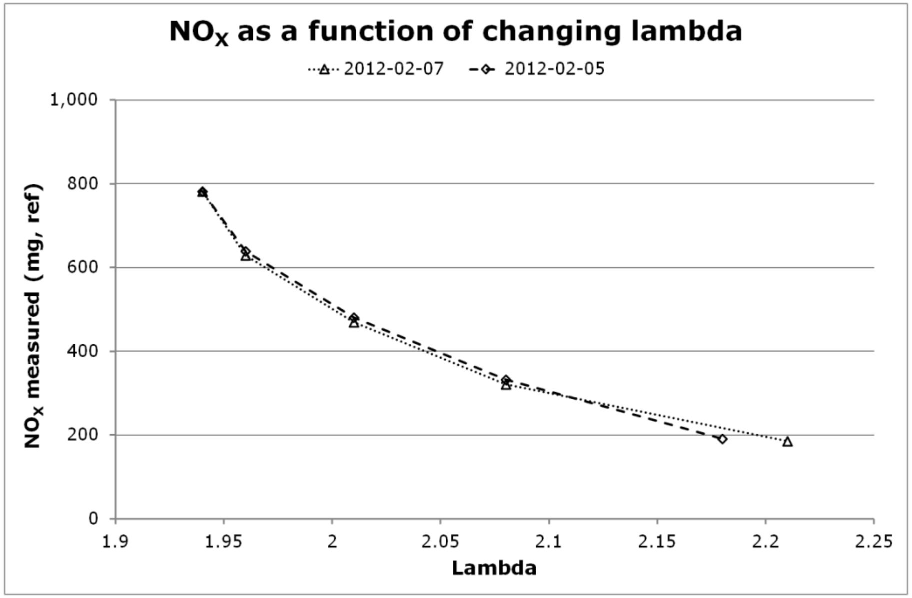
Particle concentration vs NO_X

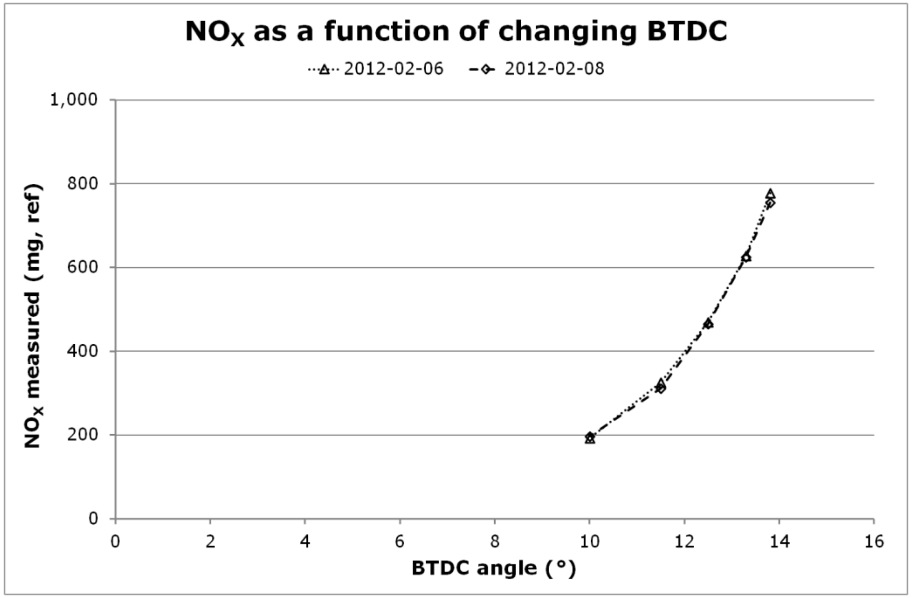
- Results from initial 5 campaigns at the 5 plants show some dependence of particle concentration on NO_X level



- 4 day field campaign at one plant
- No obvious correlation between particle concentration and general NO_X level.

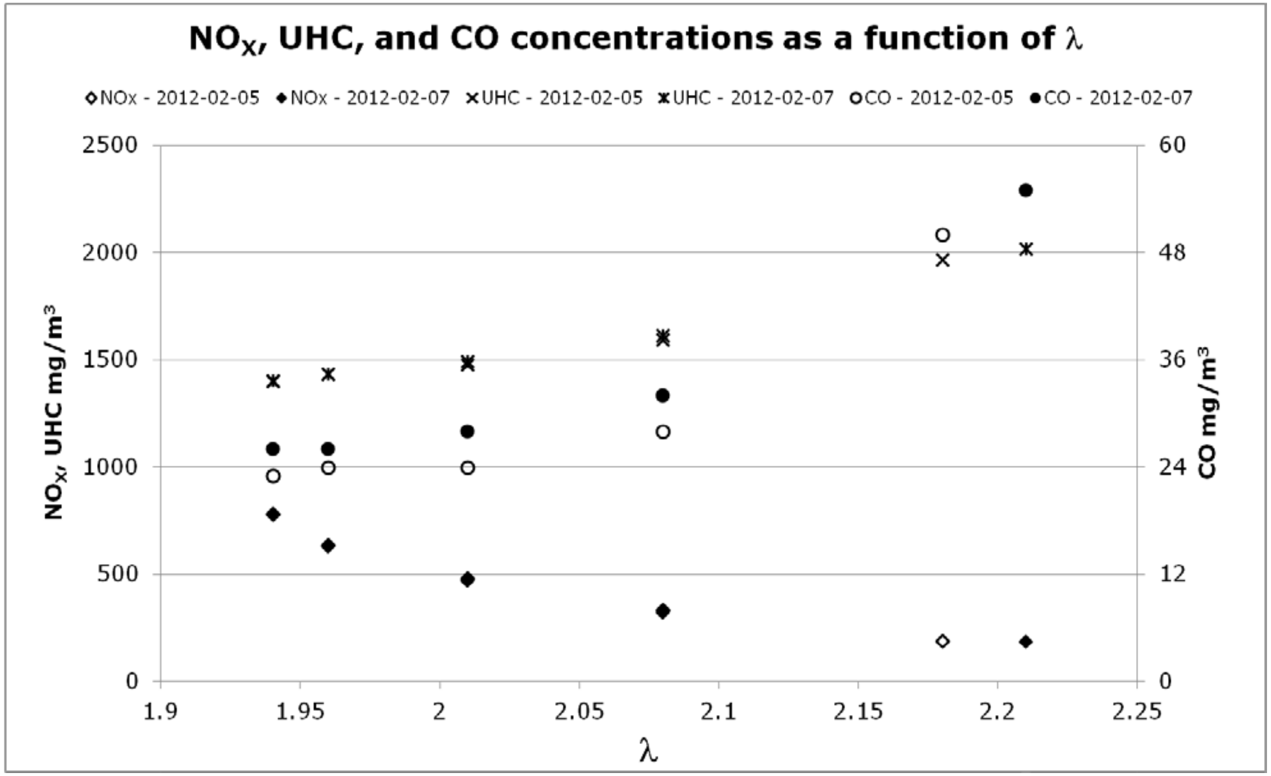
NOX vs λ and BTDC



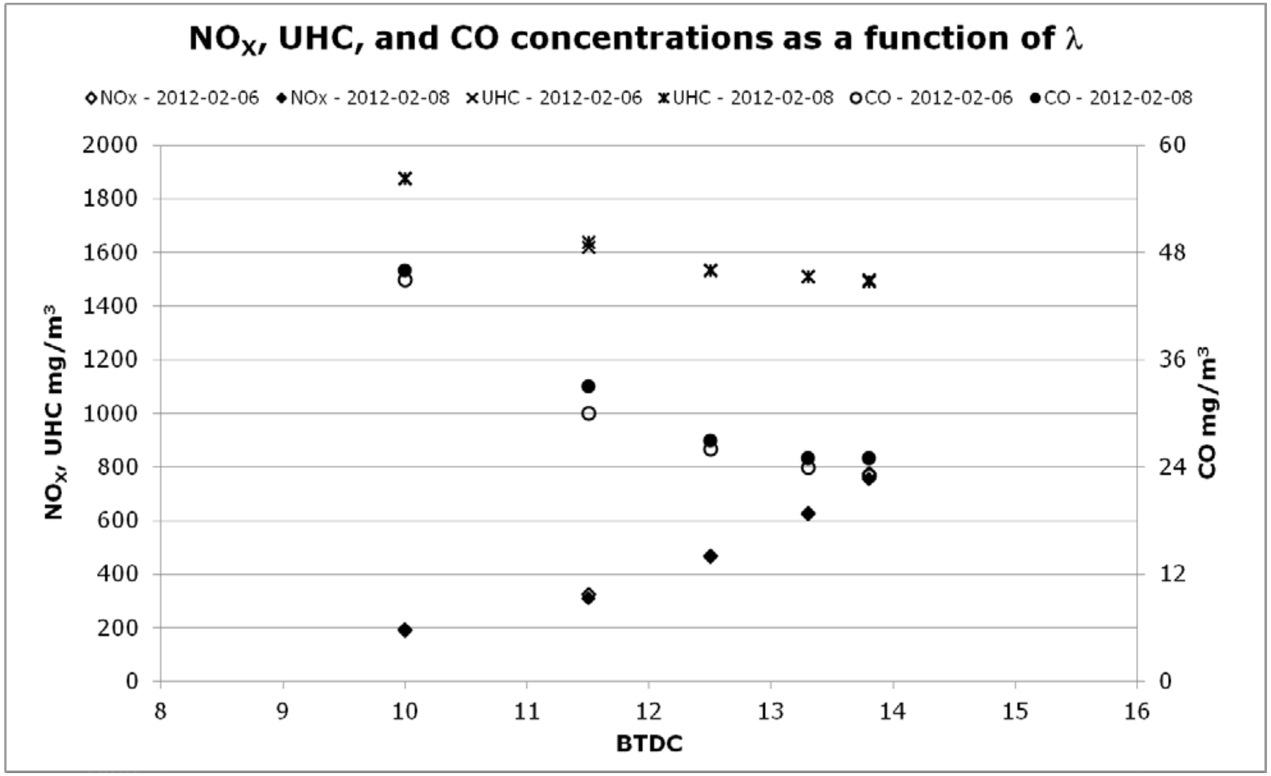


NO_X can be controlled either by changing the air to fuel ratio and thereby the urplus air (λ) or by changing the ignition angle of the cylinder (BTDC)

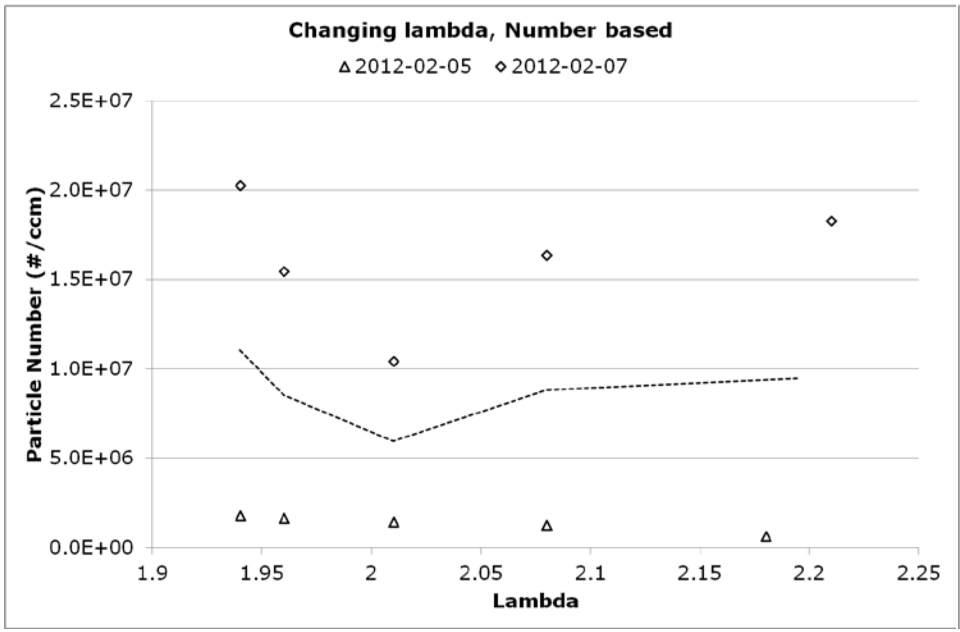
Flue gas parameters I

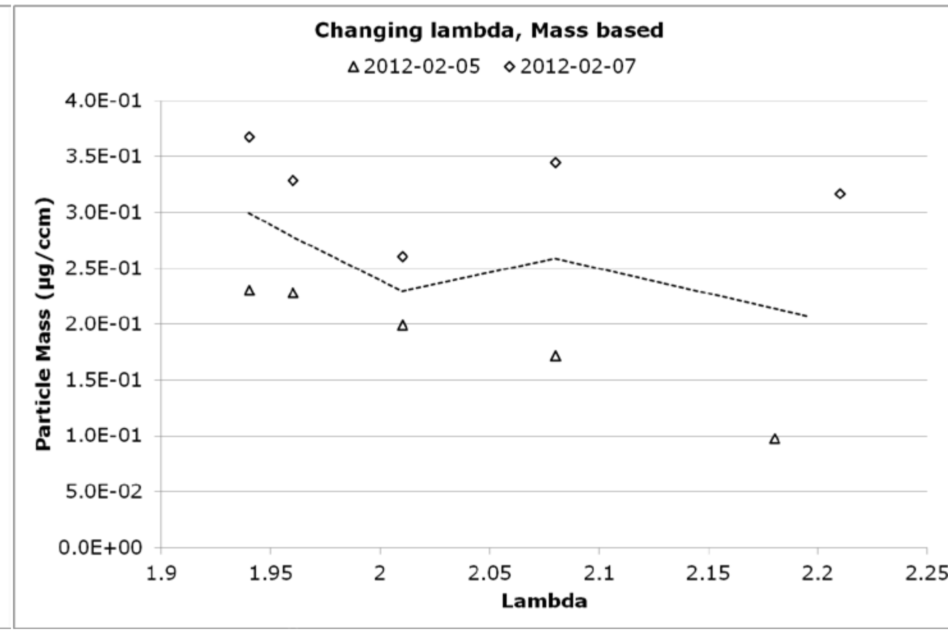


Flue gas parameters II



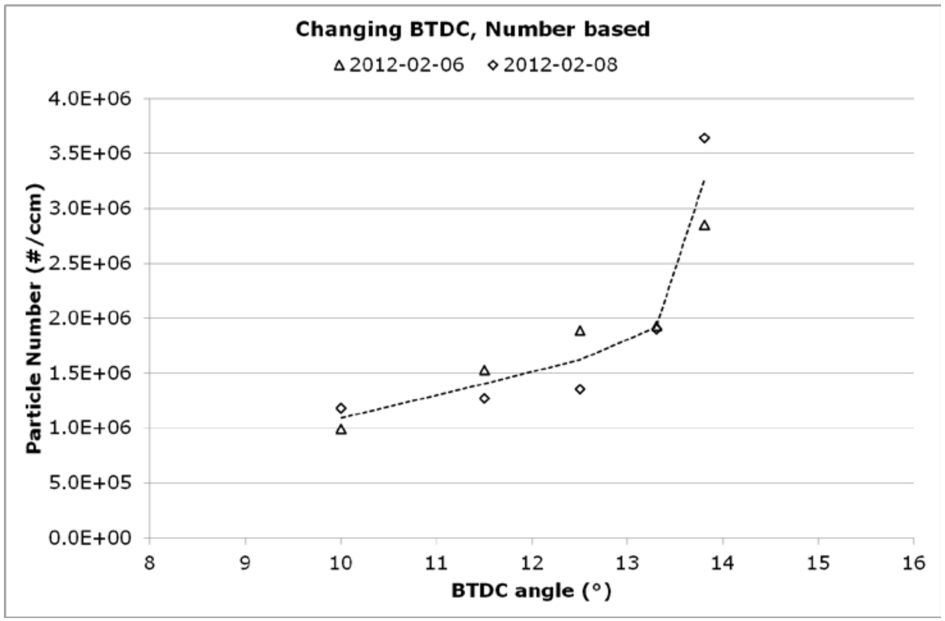
Particle concentration vs λ

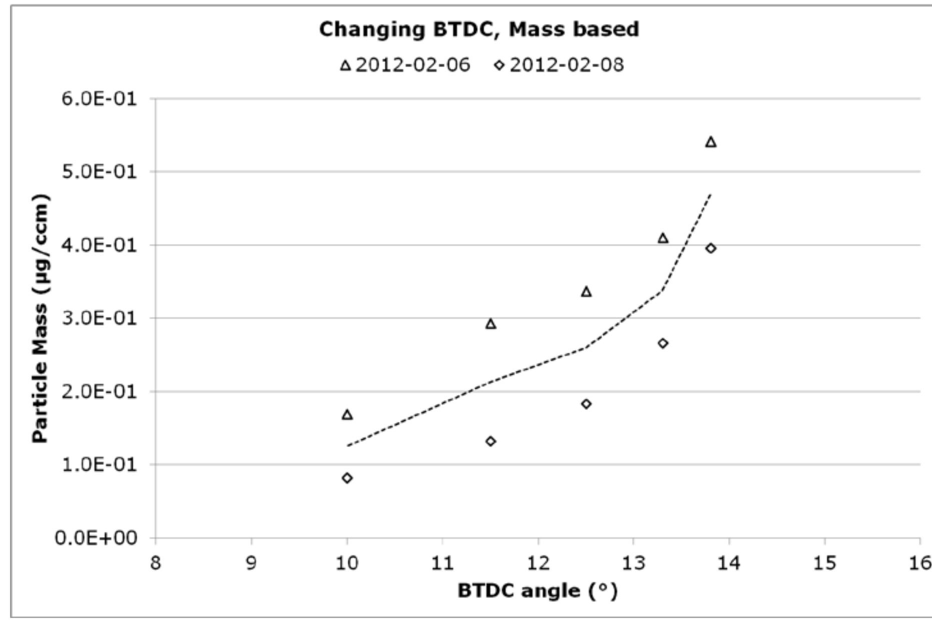




- No obvious trend in data from 2012-02-05
- Data from 2012-02-07 show an ~64% decrease in PN_1 when lambda is changed from 1.94 to 2.18
- A decrease of ~58% is observed in PM_1

Particle concentration vs BTDC I

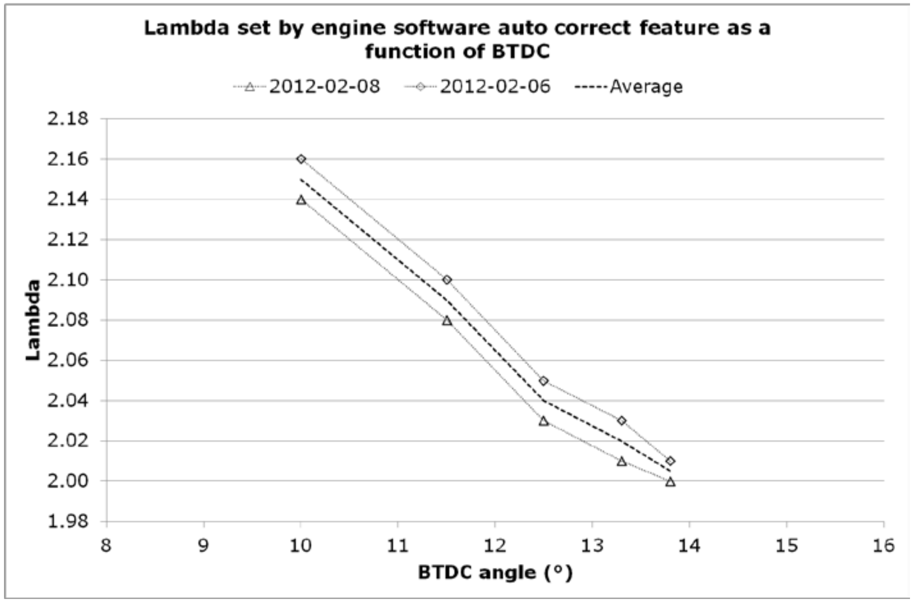




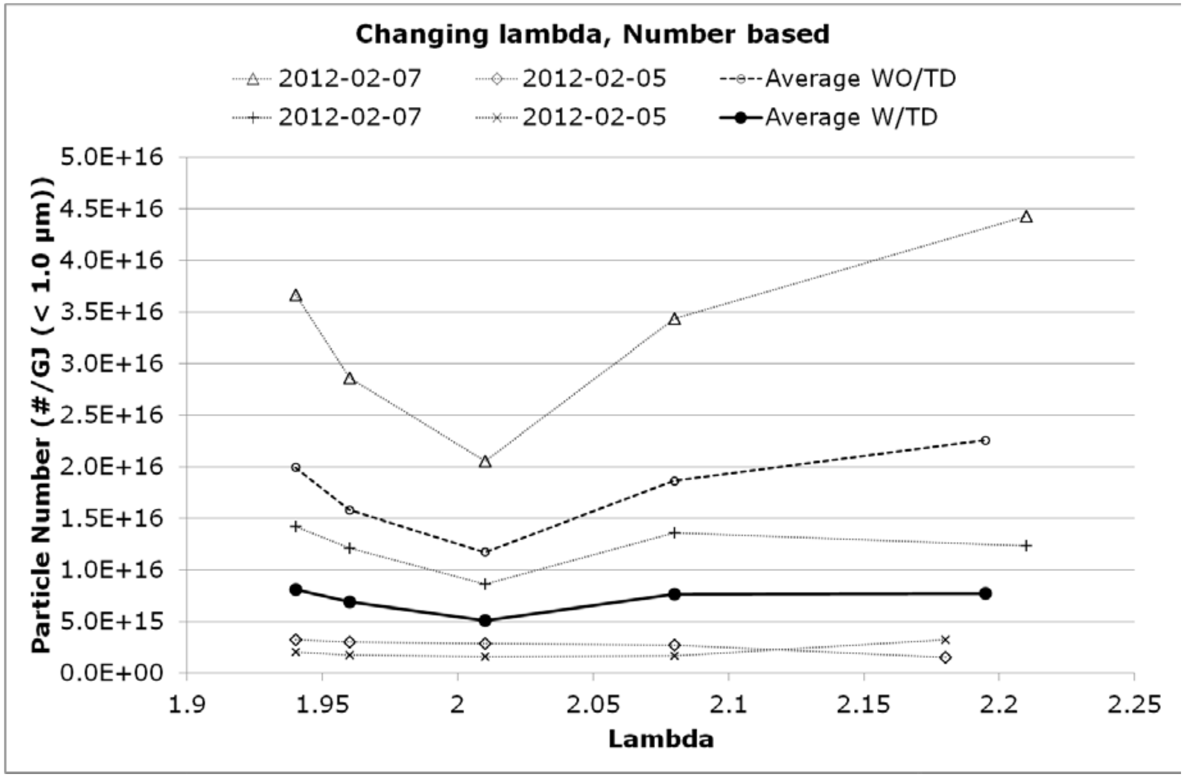
- strong increase in PN_1(by a factor of ~3) with an increase in BTDC from 10 to 13.8 degrees
- The data for PM_1 shows similar trend with a ~3-fold increase in February 6 and a ~5-fold increase on February 8.

Particle concentration vs BTDC II

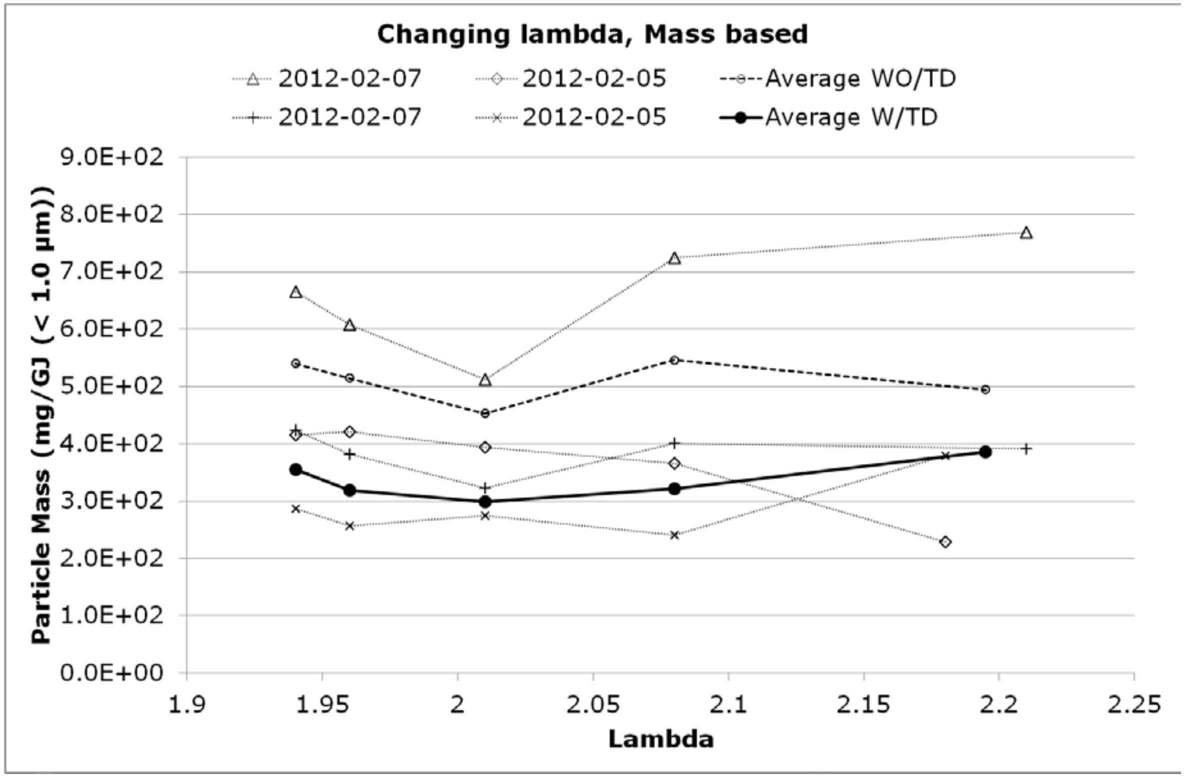
A change in λ from ~2 to ~2.14 yields a decrease of approximately 40-50% (based on the data from February fifth. This works in the same direction as the increase BTDC angle (increasing BTDC → decreasing λ→ increasing PN/PM from λ), but the the contribution from BTDC is much stronger.



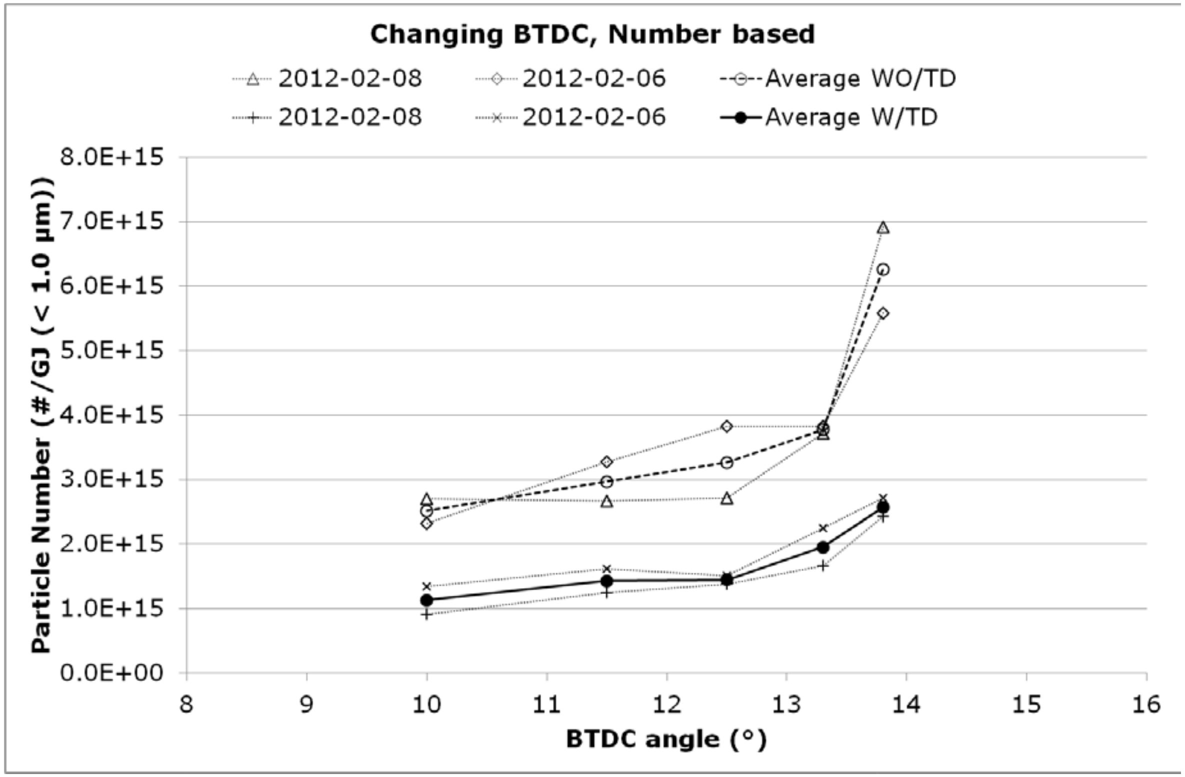
Emissions by energy I (λ)



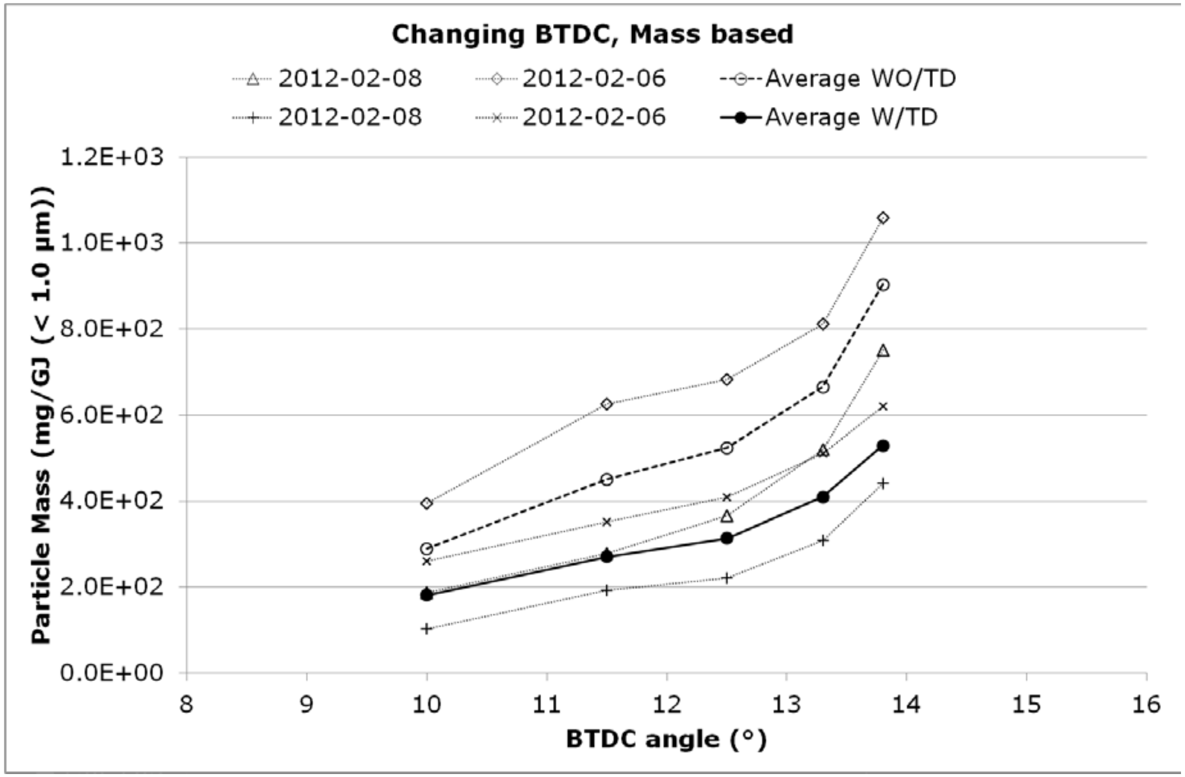
Emissions by energy II (λ)



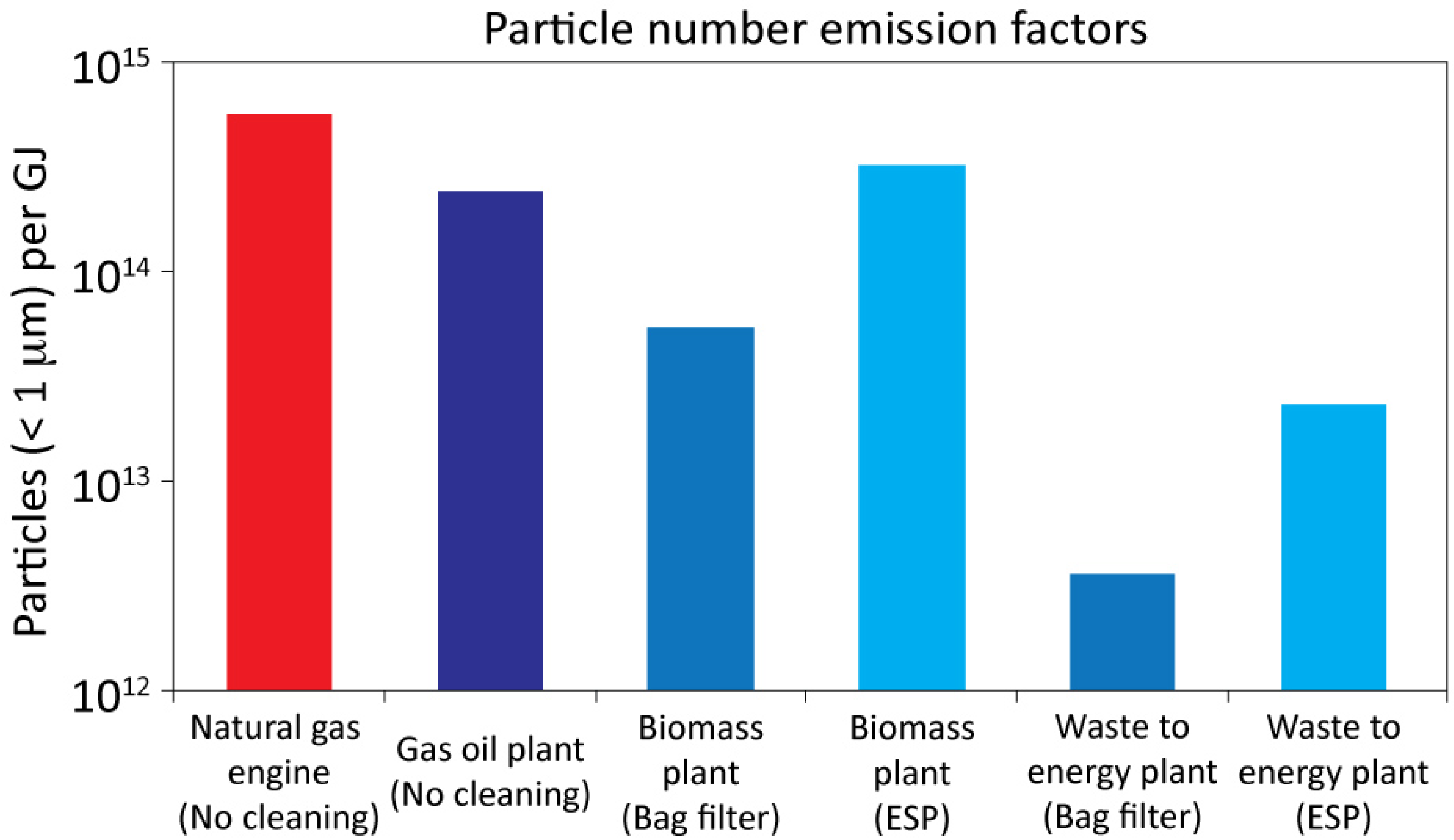
Emissions by energy III (BTDC)



Emissions by energy IV (BTDC)



Gas fired CHPs compared to CHPs using other types of fuel



Take home messages

- Strong correlation between oil consumption and oil mist measured
- Volatile fraction ~50% (25% - 85% depending on size and conditions)
- Volatile fraction did not show dependence on engine parameters
- Correlation between λ and particle concentration
- Very strong Correlation between BTDC and particle concentration
- Gas fired combined heat and power plants emit on the same order or more particulate matter than other types of CHPs, but they do not yet employ any particle emission abatement technology.

- THANK YOU FOR YOUR ATTENTION