

World Harmonized Duty Cycle (WHDC) Test Programme on WHDC Option No. 5

**Final Report
Version 2**

**27th WHDC Meeting
March 2009
Budapest**

PM variables to be investigated - I

- 47 mm vs. 70 mm filter size for
 - TX40 EMFAB (PTFE coated glass fibre) and
 - TEFLON Filter using bonded ring (PTFE membrane)
 - => 70 mm TEFLON filter with ring not commercially available

- Correlation
 - Partial and full flow systems for PM.
 - Full flow sampling and raw gas sampling for gaseous components.

- Sampling probes
 - CVS PM probe with 8 mm internal diameter to be used (min. 12 mm requested by current EC regulation).
 - Partial flow PM probe min. 4mm according to WHDC GTR

PM variables to be investigated - II

Influence of sampling system residence time and filter face velocity

- Requested residence time for dilution systems 1 to 5 seconds from inlet of tunnel until filter face for full flow and partial flow system.
- For CVS at least 0.5 seconds residence time for secondary dilution.
- On CVS (FF) two different CVS flow with one Filter Face Velocity.
- CVS flow constant, FFV variation via Gprobe.
- On partial flow system Gtot variation => FFV / Residence time variation.

Other sampling conditions

- Sample line length for partial flow system as short as possible.
- Dilution ratio minimum at full load between 5:1 – 7:1 with at least 2:1 in pri. tunnel
- Variation in partial flow system via Gdil with Gtot = const. (FFV / FFT = const.)
to archive 5:1 and 10:1 overall dilution ration in the partial flow system

Test engines – Test cycles

- Engine No. 1

- IVECO F4AE with SCRT System, Euro V / EEV
- $V_H = 5883 \text{ cm}^3$, $P = 205 \text{ kW @ } 2500 \text{ 1/min}$

- Engine No. 2

- Mercedes Benz OM501 with SCR System, Euro V / EEV
- $V_H = 11946 \text{ cm}^3$, $P = 350 \text{ kW @ } 1800 \text{ 1/min}$

- WHTC, every first cycle per day cold, all other hot and WHSC

- Each test to be run 7 times (at least)
- Pre-conditioning for the cold cycle to be performed as last cycle per day
- Soak Time to be considered: 10 min

Parameter set-up – Engine I

Full flow / CVS (FF)

variation [-]	filter [mm]	venturi [-]	Gtot [g/s]	FFV [cm/s]	dilution			r [%]
					prim.	sec.	total	
1	47	1+2	0,9	63	3:1	2:1	6:1	0,042
	70			26				
2	47		1,4	98				0,065
			0,9	63				
3	47	1+3	1,4	98	0,072			
4			0,9	63				
				Limitation: max. 100 cm/s	Limitation: min. 2:1	Limitation: 5:1 - 7:1		

CVS	SPC	CVS	SPC	total	CVS flow [kg/h]
Distance: mixer - probe [cm]	Distance: probe inlet - filter [cm]	Residence time [s]			
360	see sheet "Residence time SPC"	0,39	2,02	2,41	~ 4000
			2,29	2,68	
		0,23	1,95	2,34	~ 7000
			1,37	1,60	
			1,30	1,53	
			Limitation: mind. 0,5 s	Requested: 1 - 5 s	

Partial flow (PF)

variation [-]	filter [mm]	Gtot [g/s]	dilution		r [%]
			q [-]	FFV [cm/s]	
1	47	0,9	5	63	0,06
	70			26	
2	47	1,4		98	0,093
		0,9		63	
3	47	1+3	10	98	0,046
4				0,9	
		Limitation by SPC: 0,8 - 2,0 g/s		Limitation: max. 100 cm/s	
	47	0,8		56	
		2,0		139	
	70	0,8		23	
		2,0		57	

SPC	SPC
Distance: probe inlet - filter [cm]	Residence time [s]
see sheet "Residence time SPC"	1,65
	1,93
	1,06
	1,24
	1,65
	1,06
	Requested: 1 - 5 s

Parameter set-up – Engine II

Full flow / CVS (FF)

variation [-]	filter [mm]	venturi [-]	Gtot [g/s]	FFV [cm/s]	dilution			r [%]	CVS Distance: mixer - probe [cm]	SPC Distance: probe inlet - filter [cm]	CVS Residence time [s]	SPC Residence time [s]	total Residence time [s]	CVS flow [kg/h]	
					prim.	sec.	total [-]								
1	47	2+3	0,9 (0,8)	63 (64)	3,4:1	1,8:1	~ 6:1	0,021 (0,019)	360	see sheet "Residence time SPC"	0,16	2,02	2,18	~ 8400	
	70			26								2,29	2,45		
2	47	1,4 (1,22)	98	4:1	1,5:1	~ 6:1	0,033 (0,029)	1,95				2,11			
3	47	1+2+3	0,9				63	0,023				0,14	1,37		1,51
4			1,4				98	0,035					1,30		1,44
							Limitation: max. 100 cm/s	Limitation: min. 2:1				Limitation: 5:1 - 7:1			Limitation: mind. 0,5 s

Partial flow (PF)

variation [-]	filter [mm]	Gtot [g/s]	dilution		FFV [cm/s]	r [%]	SPC Distance: probe inlet - filter [cm]	SPC Residence time [s]
			q [-]	q				
1	47	0,9 (0,8)	5	5	63 (64)	0,034	see sheet "Residence time SPC"	1,65
	70				26	(0,03)		1,93
2	47	1,4 (1,22)	10	10	98	0,052 (0,046)		1,06
3	47	0,9			63	0,017		1,24
4		1,4			98	0,026		1,65
		Limitation by SPC: 0,8 - 2,0 g/s						Limitation: max. 100 cm/s
47	0,8	56	139	23	57			
	2,0							
70	0,8							
	2,0							

TX inner diameter = 40,75 mm
 Teflo inner diameter = 38,25 mm
 (Values for Teflo)

1. Gaseous Components

Overview

NO_x Comparison CVS (FF) vs. raw gas (PF)

CO₂ Comparison CVS (FF) vs. raw gas (PF)

2. PM - Particulate Matter

Overview

Parameter Variations

Teflo vs. TX sampling filter

Results - Engine I - Gaseous Components - Overview 1

All WHTC cold + hot, CoV not to be used

	diluted gas [g/kWh]				raw gas [g/kWh]				perc. dev. (FF as basis)			
	HC	CO	NOx	CO2	HC	CO	NOx	CO2	HC	CO	NOx	CO2
arithmetic mean, all c+h	0,042	0,091	2,517	720,0	0,006	0,103	2,540	724,4	-	18,9	1,3	0,6
standard deviation, all c+h	0,0161	0,0494	0,8416	9,1033	0,0025	0,0506	0,8396	9,5913				
coeff. of variance, all c+h	38,10	54,23	33,44	1,26	43,21	49,31	33,06	1,32				

CVS and raw gas show remarkable good agreement for NO_x and CO₂.

Results - Engine I - Gaseous Components - Overview 2

All WHTC hot (all hot with pre-conditioning, see slide NOx comparison)

	diluted gas [g/kWh]				raw gas [g/kWh]				perc. dev. (FF as basis)			
	HC	CO	NOx	CO2	HC	CO	NOx	CO2	HC	CO	NOx	CO2
arithmetic mean, only h	0,040	0,069	2,050	718,7	0,005	0,077	2,079	722,8		16,2	1,4	0,5
standard deviation, only h	0,0165	0,0142	0,1494	8,1772	0,0011	0,0103	0,1596	8,4496				
coeff. of variance, only h	41,14	20,59	7,29	1,14	24,15	13,36	7,68	1,17				

CoV for CVS and raw gas well below 10 for NO_x and CO₂.

CVS and raw gas show remarkable good agreement for NO_x and CO₂.

Results - Engine I - Gaseous Components - Overview 3

All WHSC (hot)

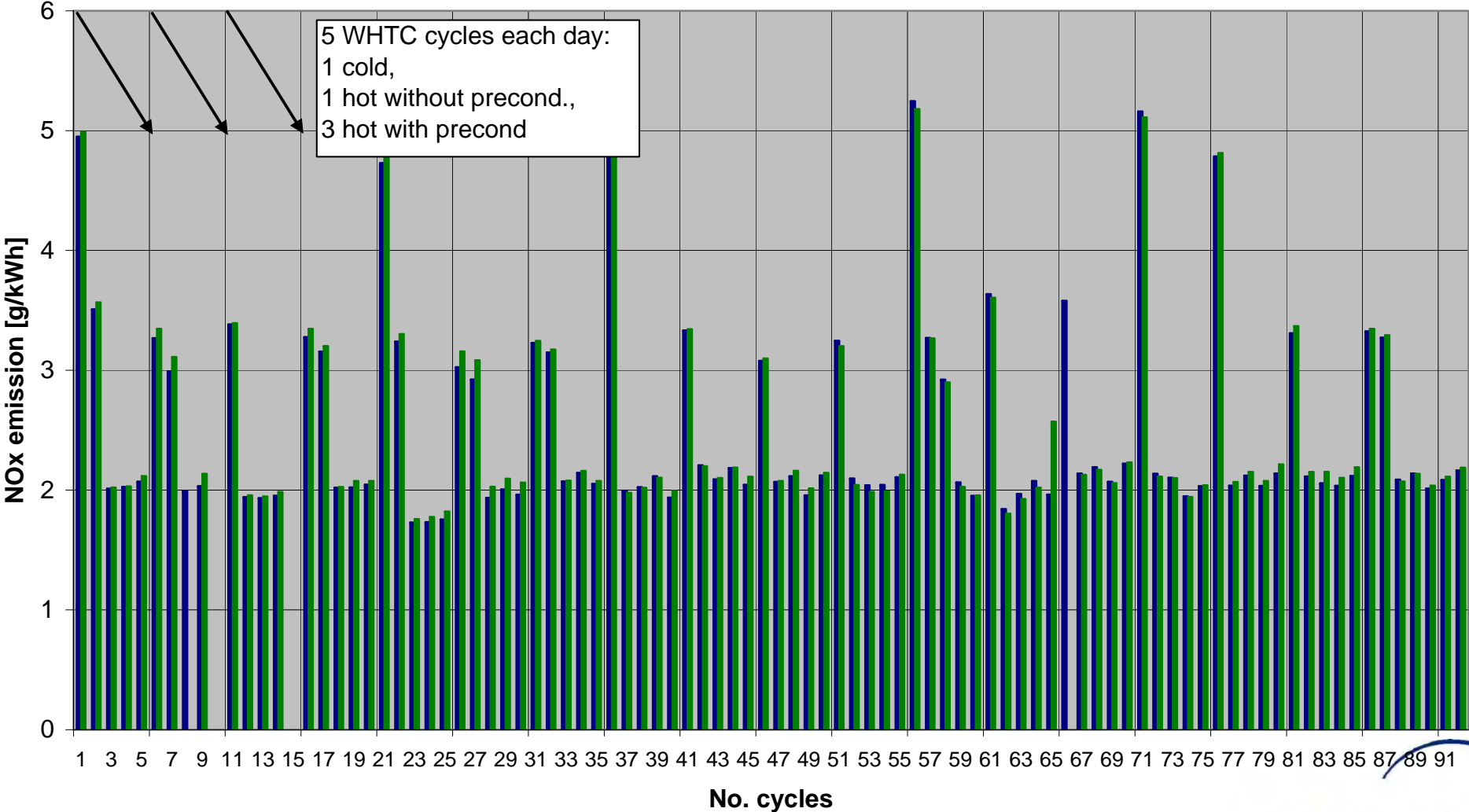
	diluted gas [g/kWh]				raw gas [g/kWh]				perc. dev. (FF as basis)			
	HC	CO	NOx	CO2	HC	CO	NOx	CO2	HC	CO	NOx	CO2
arithmetic mean value	0,028	0,066	2,478	677,2	0,003	0,064	2,546	683,4	-	-0,3	2,7	0,9
standard deviation	0,0106	0,0101	0,0894	5,4621	0,0059	0,0082	0,0811	8,8654				
coefficient of variance	37,97	15,27	3,61	0,81	171,25	12,83	3,19	1,30				

CoV and percentage deviation good to very good for NO_x and CO₂.

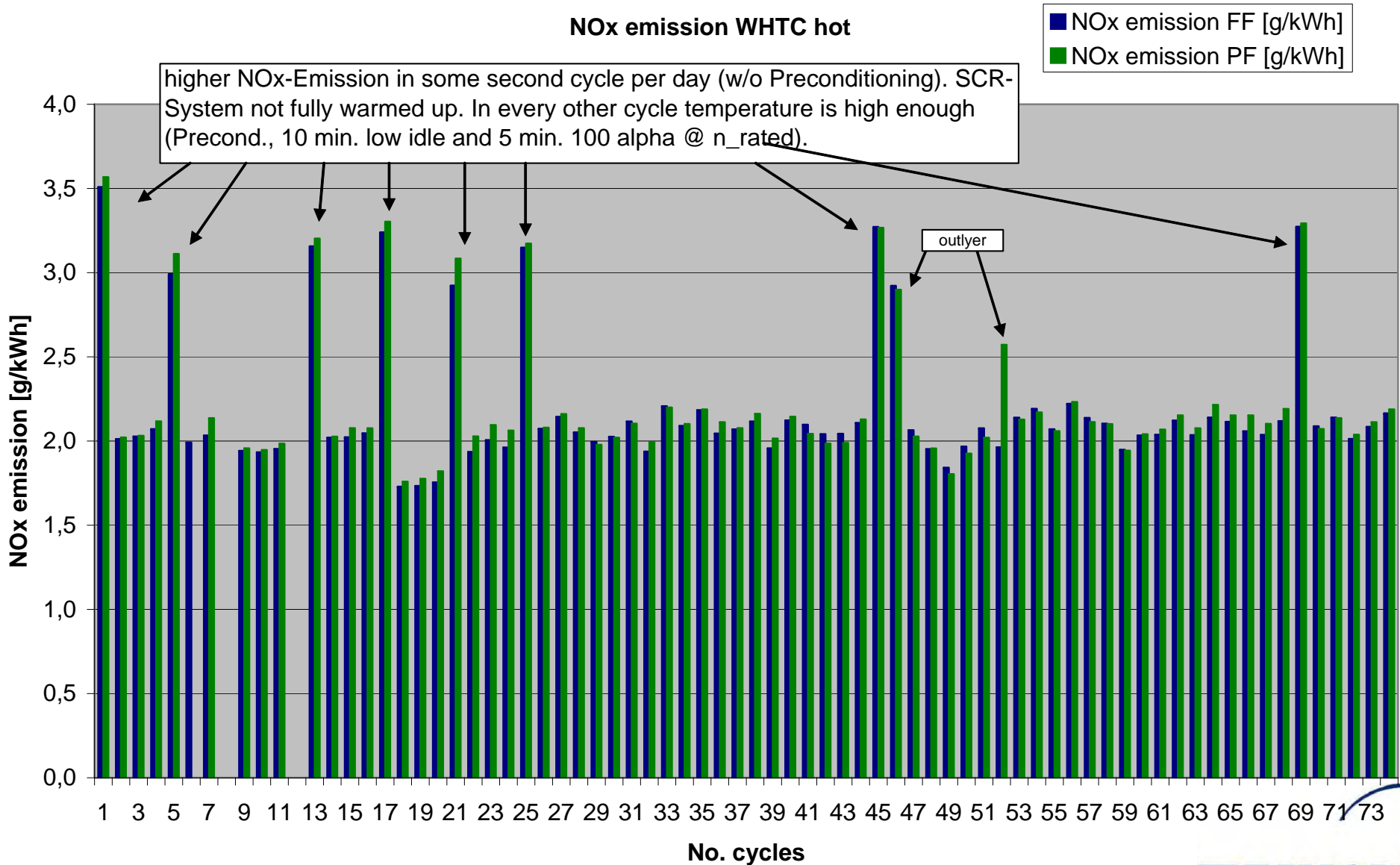
Engine I – Gas. Components - NO_x Comparison CVS (FF) vs. raw gas (PF) - 1

NO_x emission WHTC cold + hot

■ NO_x emission FF [g/kWh]
■ NO_x emission PF [g/kWh]

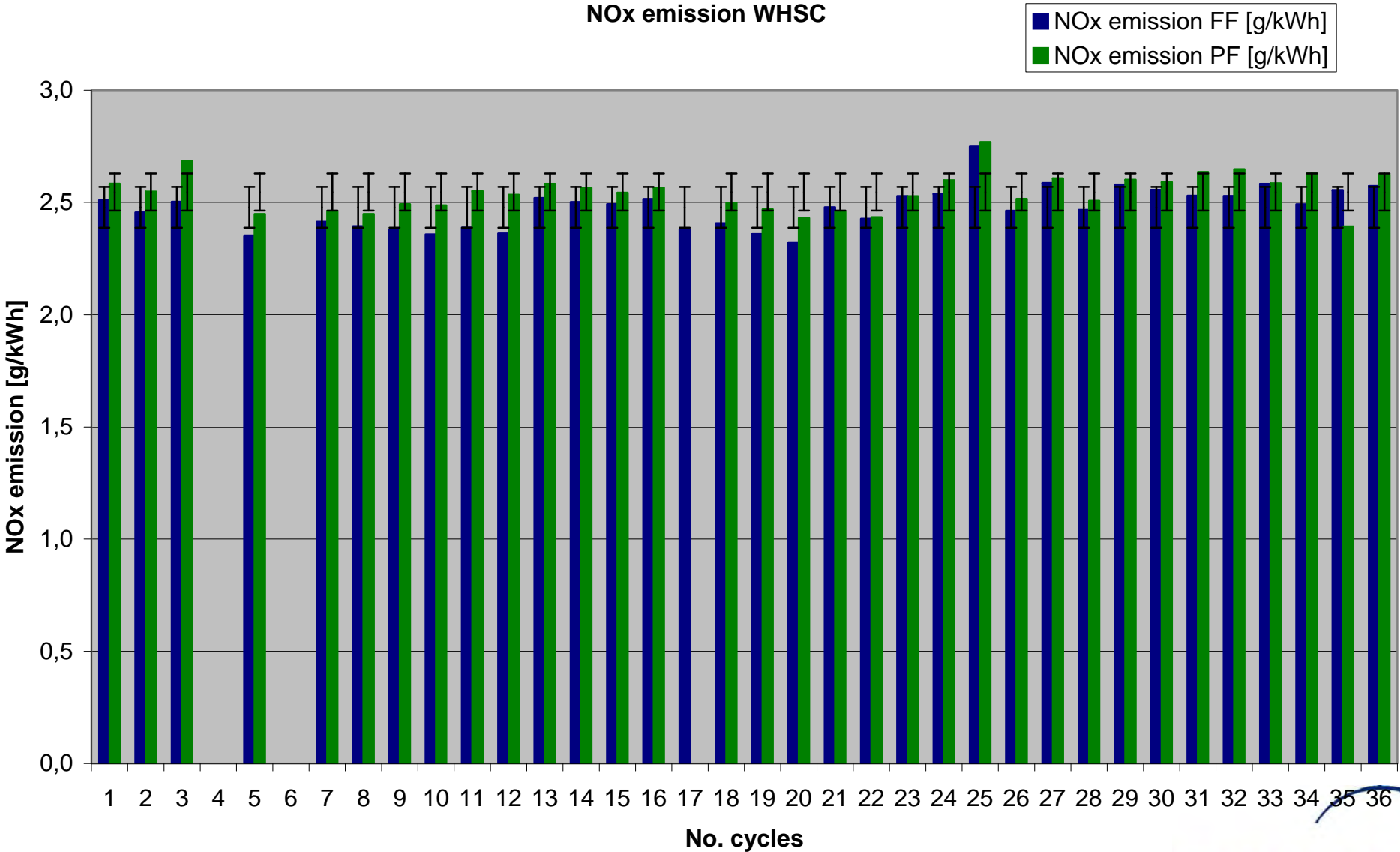


Engine I – Gas. Components - NO_x Comparison CVS (FF) vs. raw gas (PF) – 2



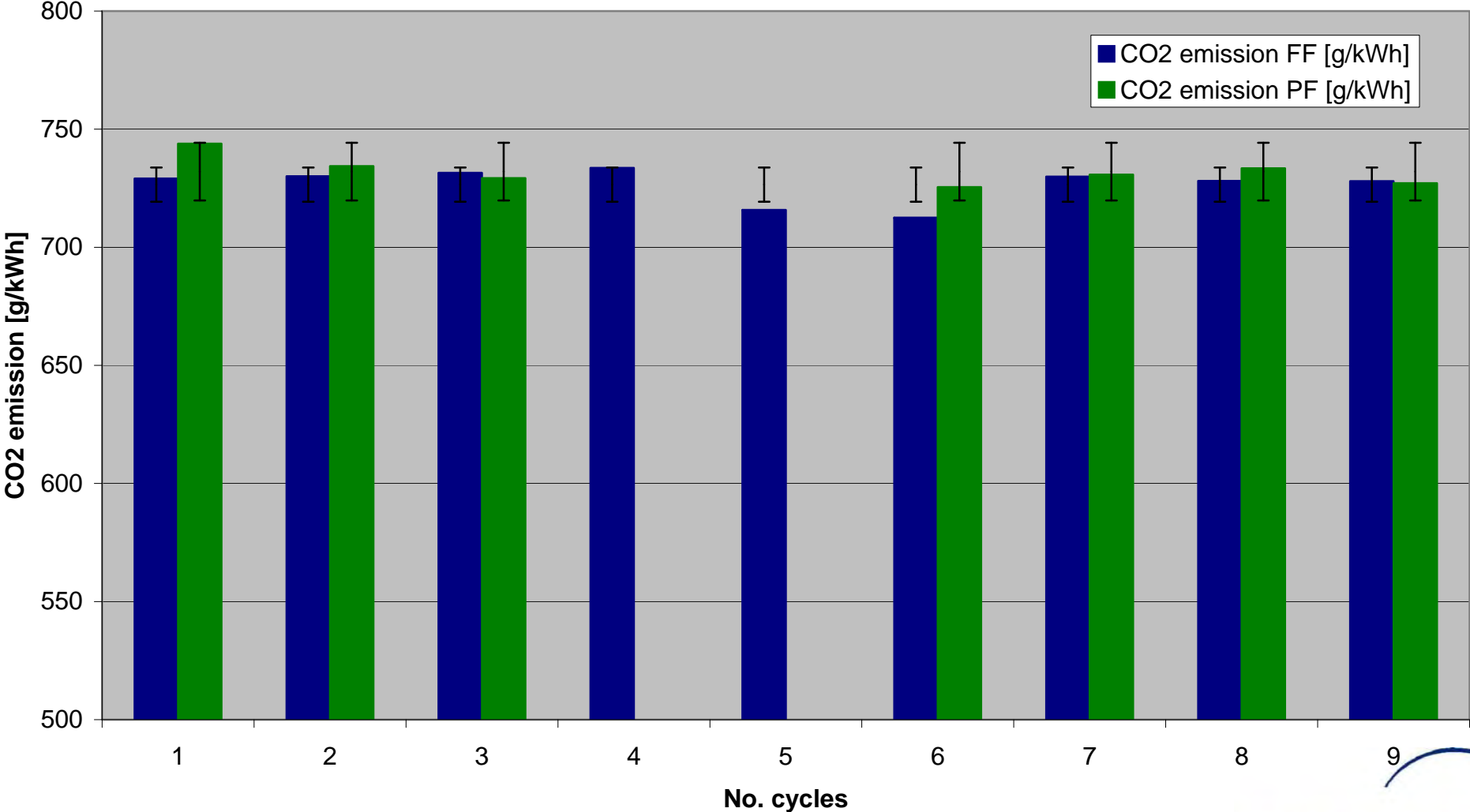
Engine I – Gas. Components - NO_x Comparison CVS (FF) vs. raw gas (PF) – 3

NO_x emission WHSC



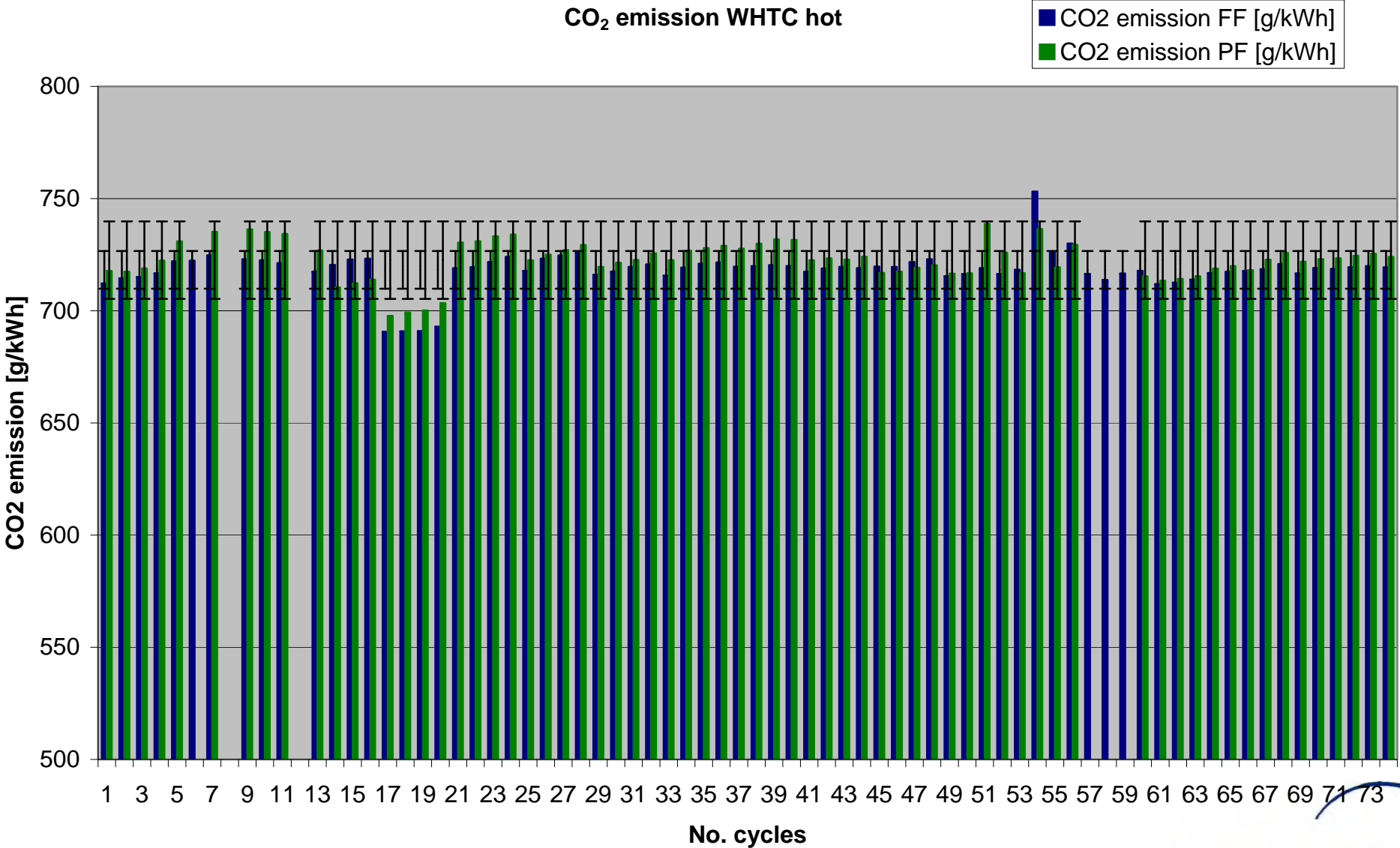
Engine I – Gas. Components - CO₂ Comparison CVS (FF) vs. raw gas (PF) - 1

CO₂ emission WHTC cold



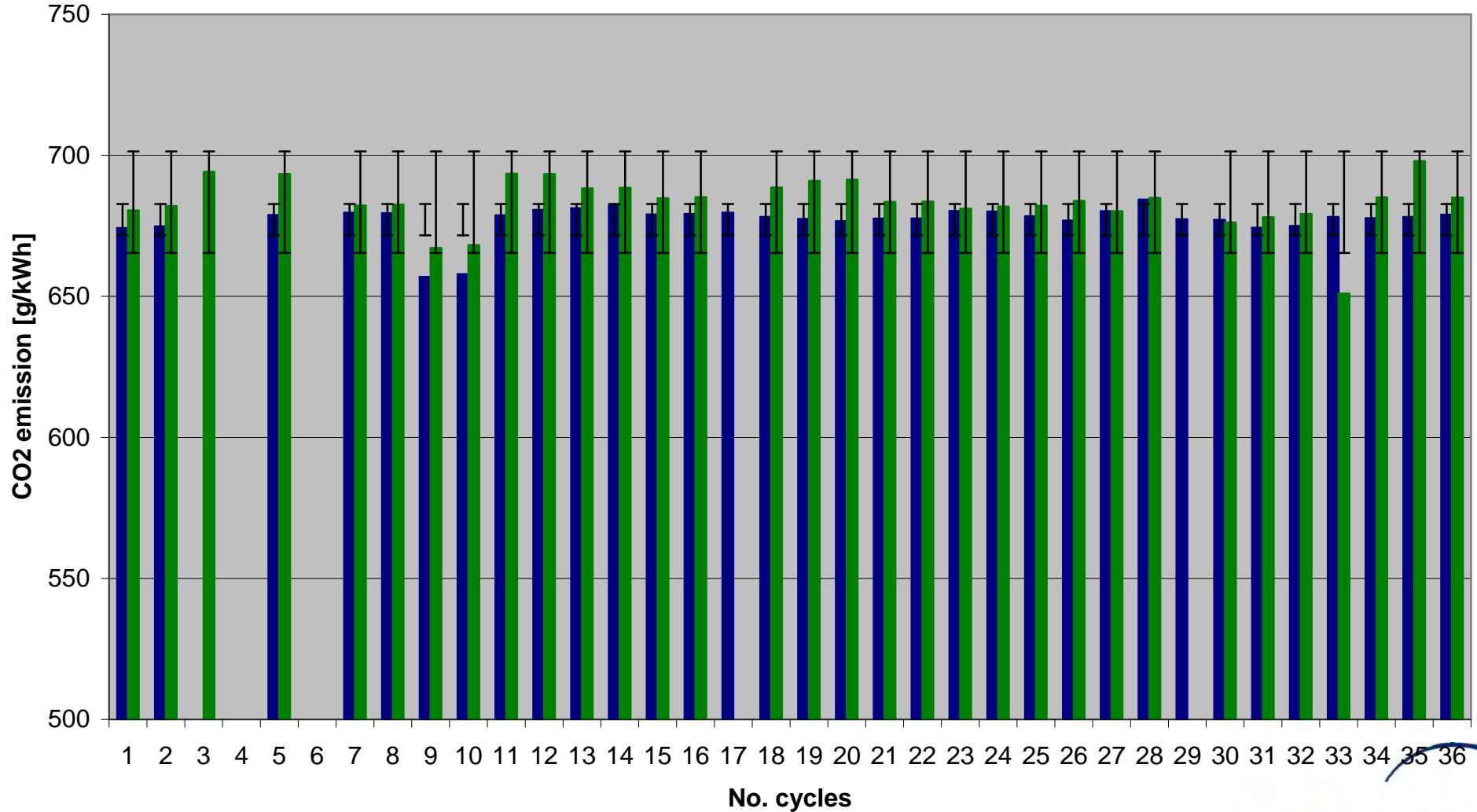
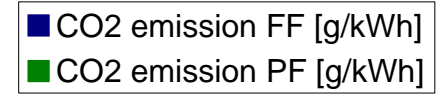
Engine I – Gas. Components - CO₂ Comparison CVS (FF) vs. raw gas (PF) - 2

CO₂ emission WHTC hot



Engine I – Gas. Components - CO2 Comparison CVS (FF) vs. raw gas (PF) - 3

CO₂ emission WHSC



Results - Engine II - Gaseous Components - Overview 1

All WHTC cold + hot, CoV not to be used

	diluted gas [g/kWh]				raw gas [g/kWh]				perc. dev. (FF as basis)			
	HC	CO	NOx	CO2	HC	CO	NOx	CO2	HC	CO	NOx	CO2
arithmetic mean, all c+h	0,047	2,687	2,699	670,4	0,017	2,562	2,770	672,7	-	-4,3	2,5	0,3
standard deviation, all c+h	0,0146	0,1925	1,1863	6,6809	0,0030	0,2001	1,2127	6,4131				
coeffi. of variance, all c+h	31,34	7,16	43,96	1,00	17,63	7,81	43,78	0,95				

CVS and raw gas show good to very good agreement for NO_x, CO and CO₂.

Results - Engine II - Gaseous Components - Overview 2

All WHTC hot (all hot with pre-conditioning, see slide NOx comparison)

	diluted gas [g/kWh]				raw gas [g/kWh]				perc. dev. (FF as basis)			
	HC	CO	NOx	CO2	HC	CO	NOx	CO2	HC	CO	NOx	CO2
arithmetic mean, only h	0,048	2,698	1,822	668,3	0,015	2,584	1,867	671,0	-	-3,8	2,6	0,4
standard deviation, only h	0,018	0,190	0,124	4,1951	0,001	0,170	0,185	4,7255				
coeff. of variance, only h	36,98	7,05	6,82	0,63	6,00	6,57	9,92	0,70				

CoV for CVS and raw gas well below 10 for NO_x, CO and CO₂.
HC CoV much better for PF System.

CVS and raw gas show remarkable good agreement for NO_x, CO and CO₂.

Results - Engine II - Gaseous Components - Overview 3

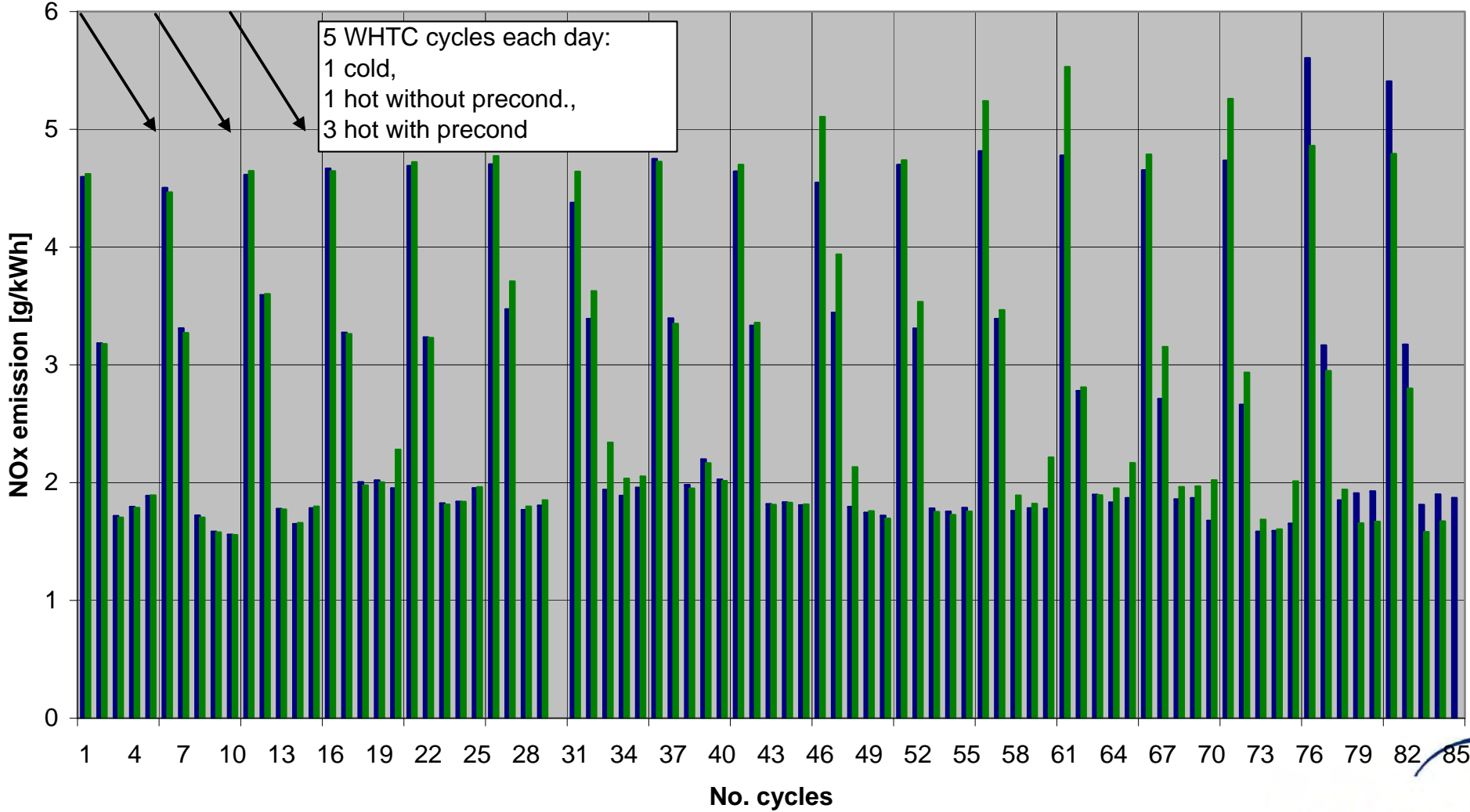
All WHSC (hot)

	diluted gas [g/kWh]				raw gas [g/kWh]				perc. dev. (FF as basis)			
	HC	CO	NOx	CO2	HC	CO	NOx	CO2	HC	CO	NOx	CO2
arithmetic mean value	0,034	0,553	1,301	632,3	0,007	0,539	1,342	629,6	-	-2,3	3,6	-0,4
standard deviation	0,018	0,038	0,090	3,262	0,002	0,014	0,132	3,924				
coefficient of variance	52,84	6,80	6,88	0,52	29,40	2,67	9,85	0,62				

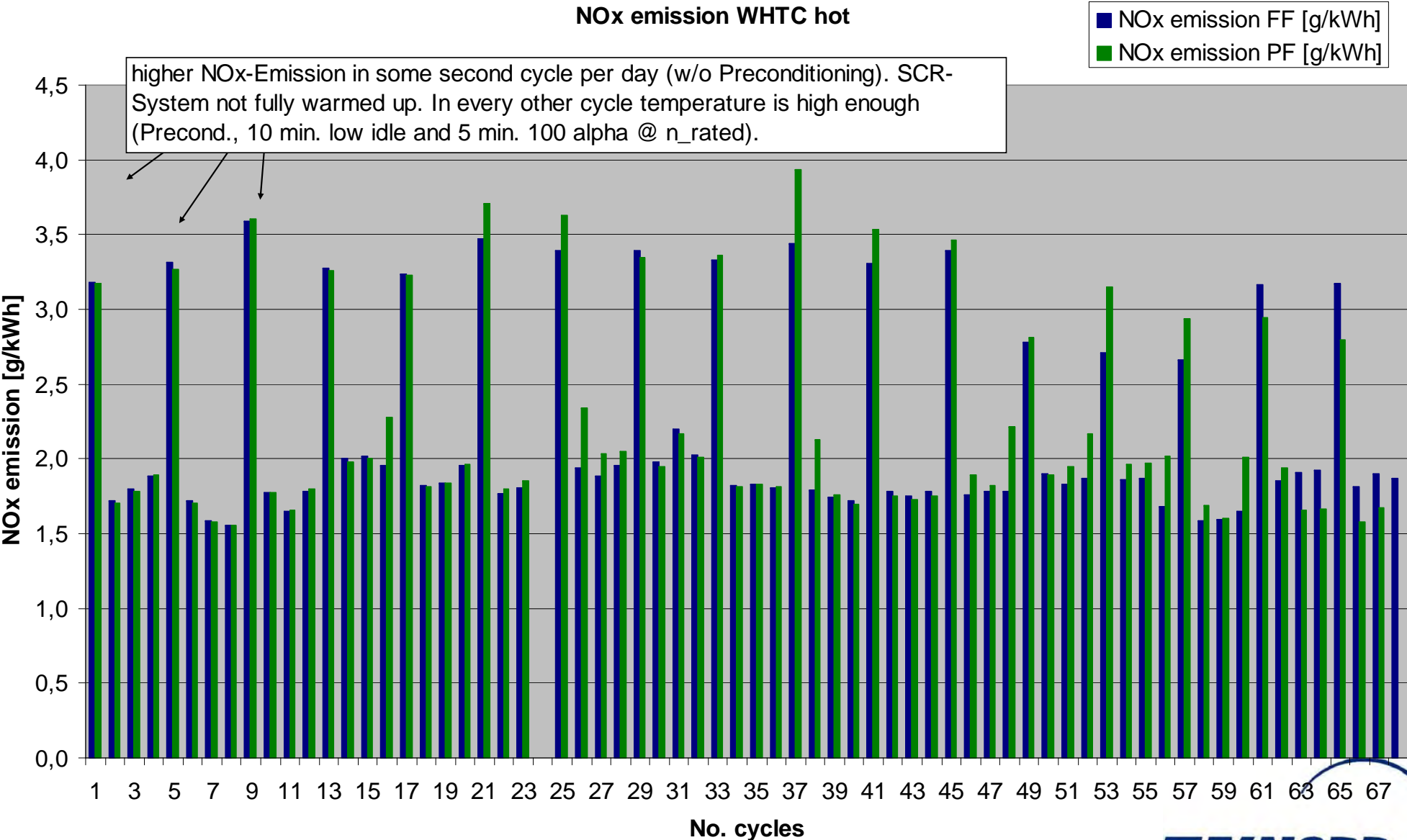
Engine II – Gas. Components - NO_x Comparison CVS (FF) vs. raw gas (PF) - 1

NO_x emission WHTC cold + hot

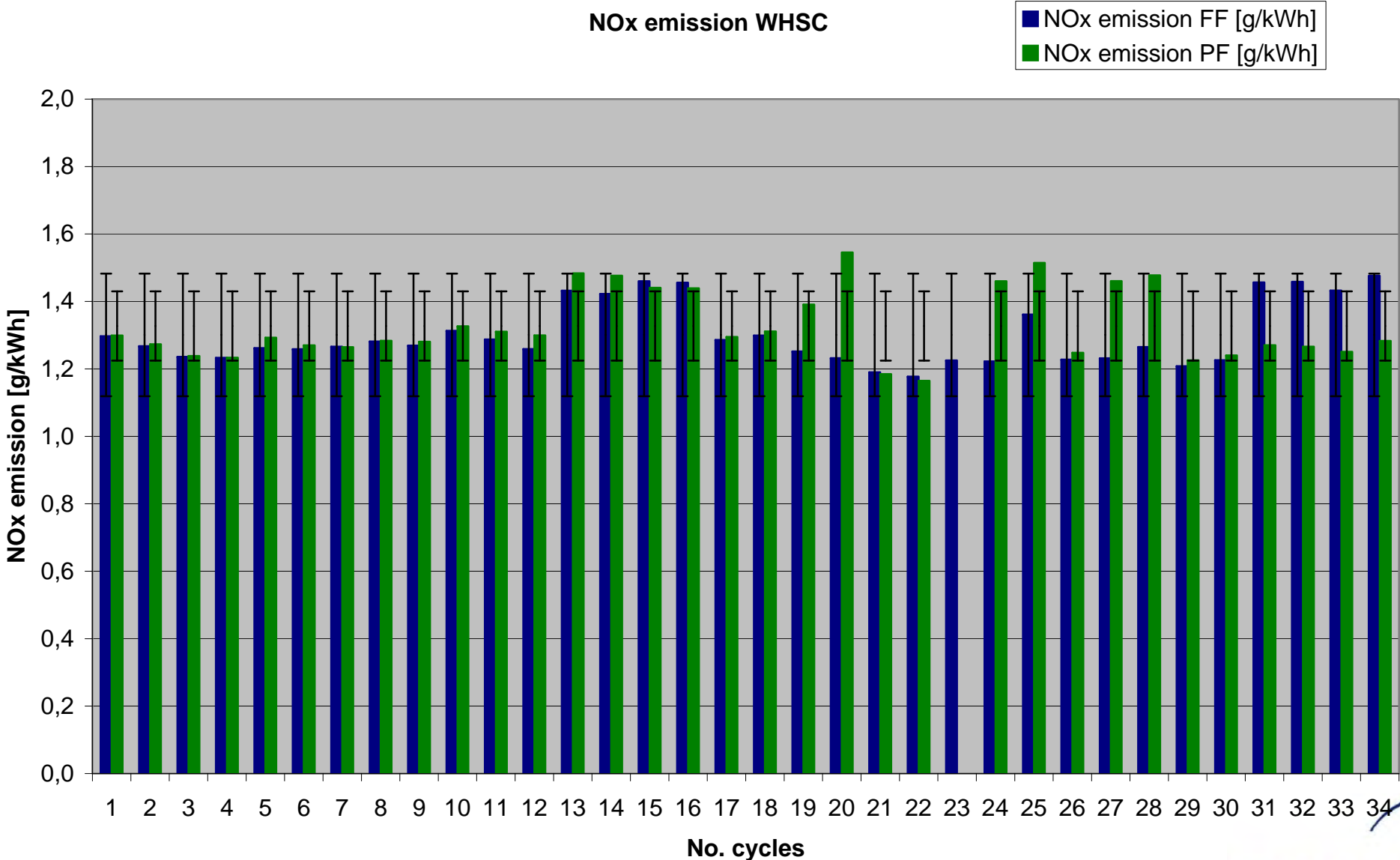
■ NO_x emission FF [g/kWh]
■ NO_x emission PF [g/kWh]



Engine II – Gas. Components - NO_x Comparison CVS (FF) vs. raw gas (PF) - 2



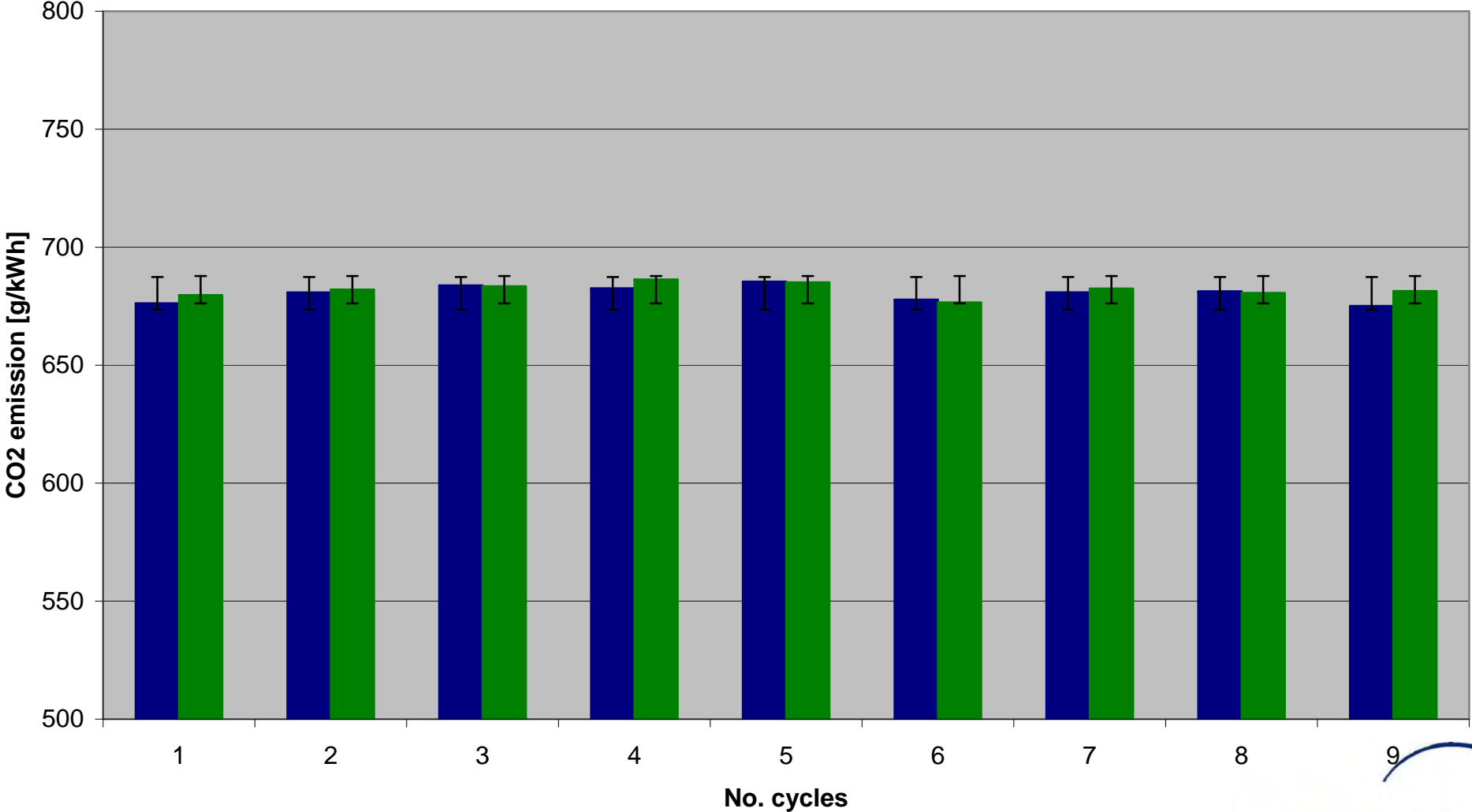
Engine II – Gas. Components - NO_x Comparison CVS (FF) vs. raw gas (PF) - 3



Engine II – Gas. Components - CO2 Comparison CVS (FF) vs. raw gas (PF) - 1

CO2 emission WHTC cold

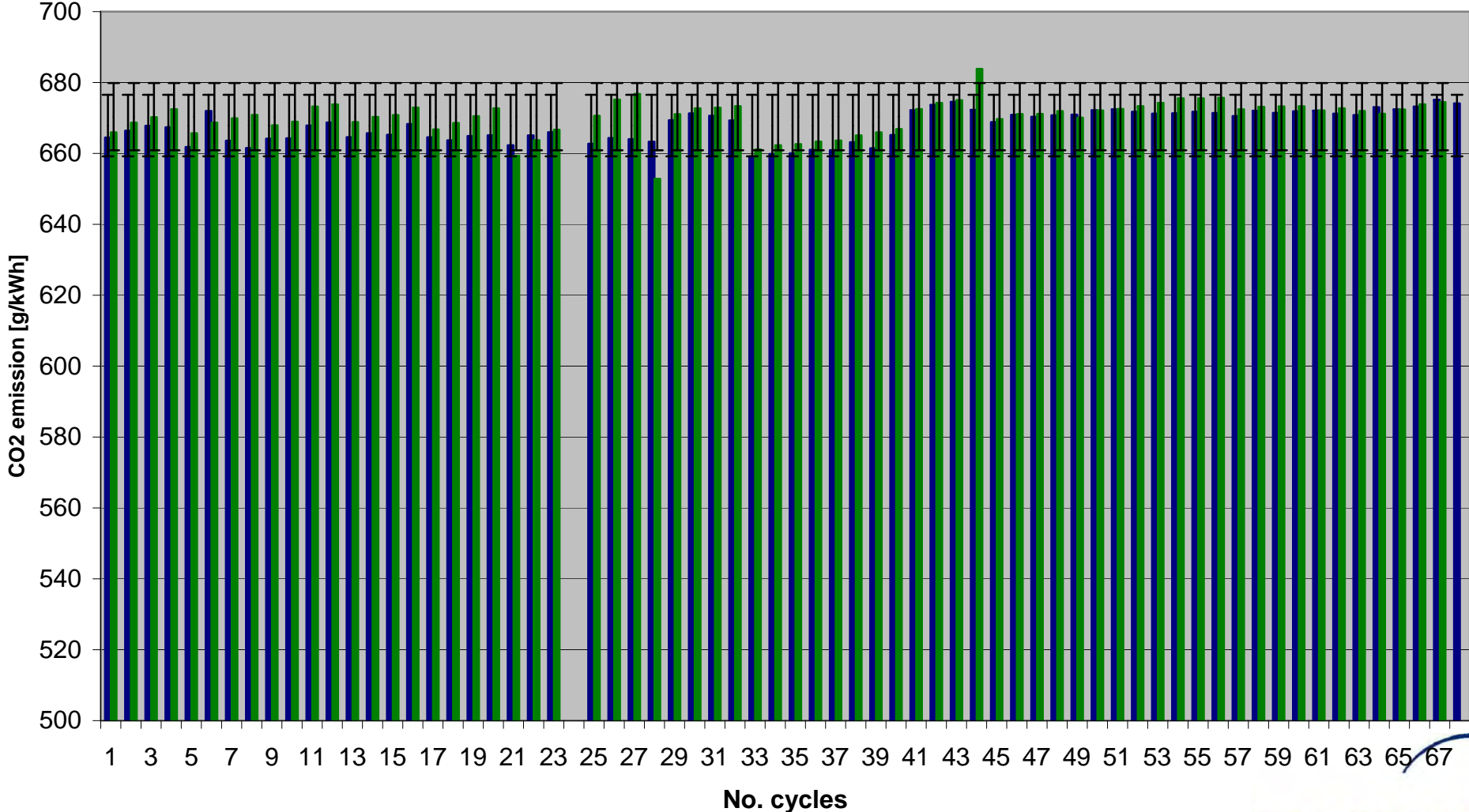
■ CO2 emission FF [g/kWh]
■ CO2 emission PF [g/kWh]



Engine II – Gas. Components - CO2 Comparison CVS (FF) vs. raw gas (PF) - 2

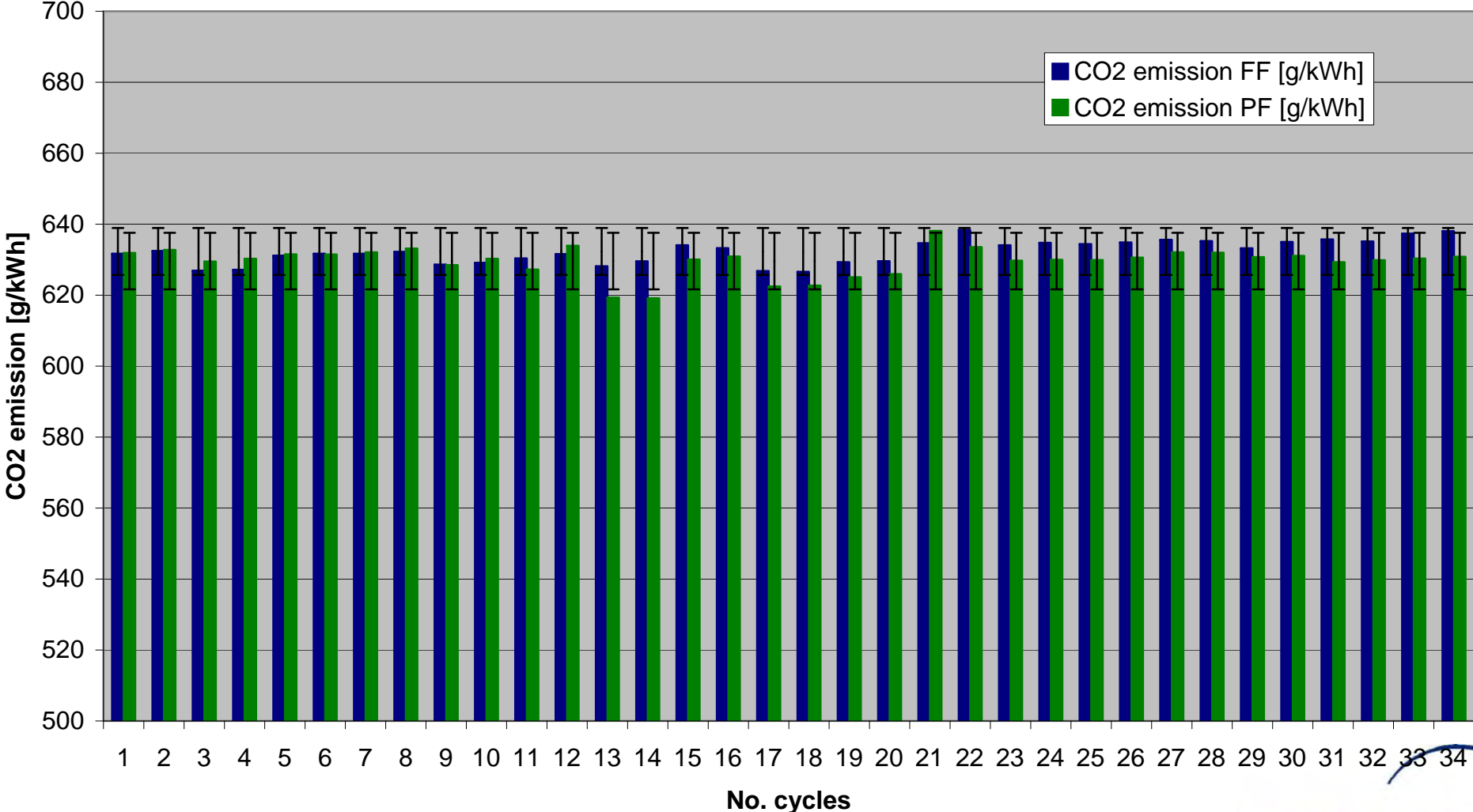
CO2 emission WHTC hot

■ CO2 emission FF [g/kWh]
■ CO2 emission PF [g/kWh]



Engine II – Gas. Components - CO2 Comparison CVS (FF) vs. raw gas (PF) - 3

CO2 emission WHSC



Gaseous Components - Conclusions

The gaseous components NO_x, CO, HC and CO₂ sampled in the raw exhaust according to ISO 16183 respectively GTR No. 4 showed again good to very good agreement when compared to the CVS procedure (sampling in diluted exhaust gas).

The coefficient of variation showed good to very good repeatability. The NO_x and CO₂ CoV's for the raw gas sampling are on the same level as for the CVS.

For the very low emission values of HC and CO (aftertreatment) the raw gas sampling showed better applicability based on the CoV than the CVS.

Since both engines were equipped with SCR systems the pre-conditioning has significant influence on the test-to-test repeatability.

Results - Engine II – Particulate Matter - Overview 1

All mean values over all parameter variations.

Variation	FF	PF	FF						PF				diluted gas, PM FF [g/kWh]		raw gas, PM PF [g/kWh]		
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	PMim 1.	PMim 2.	PMim 1.

results WHTC cold

1	TX47	TX47	0,9	1	2+3	1	0,021	63	1	0,9	5	1	0,034	63	0,021	0,022	0,021	0,022
2			1,4	2	2+3	1	0,033	98	2	1,4	5	1	0,052	98	0,019	0,020	0,020	0,017
3			0,9	1	1+2+3	2	0,023	63	1	0,9	10	2	0,017	63	0,019	0,020	0,020	0,019
4			0,9	1	1+2+3	2	0,023	63	1	0,9	5	1	0,034	63	0,019	0,021	0,020	0,021
5			1,4	2	1+2+3	2	0,035	98	2	1,4	10	2	0,026	98	0,019	0,020	0,020	0,021
6	TX70	TX70	0,9	1	2+3	1	0,021	26	3	0,9	5	1	0,034	26	0,020	0,024	0,026	0,029
7	TEF47	TEF47	0,8	1	2+3	1	0,019	64	1	0,8	5	1	0,03	64	0,020	0,022	0,016	0,015
8			1,22	2	2+3	1	0,029	98	2	1,22	5	1	0,046	98	0,021	0,022	0,020	0,020
9	TX47	TEF47	0,9	1	2+3	1	0,021	63	1	0,8	5	1	0,03	64	0,020	0,022	-	-

results WHTC hot

1	TX47	TX47	0,9	1	2+3	1	0,021	63	1	0,9	5	1	0,034	63	0,022	0,023	0,021	0,022
2			1,4	2	2+3	1	0,033	98	2	1,4	5	1	0,052	98	0,020	0,021	0,021	0,018
3			0,9	1	1+2+3	2	0,023	63	1	0,9	10	2	0,017	63	0,019	0,020	0,024	0,020
4			0,9	1	1+2+3	2	0,023	63	1	0,9	5	1	0,034	63	0,020	0,021	0,021	0,022
5			1,4	2	1+2+3	2	0,035	98	2	1,4	10	2	0,026	98	0,019	0,020	0,023	0,025
6	TX70	TX70	0,9	1	2+3	1	0,021	26	3	0,9	5	1	0,034	26	0,021	0,025	0,023	0,025
7	TEF47	TEF47	0,8	1	2+3	1	0,019	64	1	0,8	5	1	0,03	64	0,024	0,025	0,019	0,019
8			1,22	2	2+3	1	0,029	98	2	1,22	5	1	0,046	98	0,024	0,025	0,019	0,020
9	TX47	TEF47	0,9	1	2+3	1	0,021	63	1	0,8	5	1	0,03	64	0,023	0,024	-	-

results WHSC

1	TX47	TX47	0,9	1	2+3	1	0,021	63	1	0,9	5	1	0,034	63	0,014	0,014	0,012	0,013
2			1,4	2	2+3	1	0,033	98	2	1,4	5	1	0,052	98	0,013	0,013	0,013	0,012
3			0,9	1	1+2+3	2	0,023	63	1	0,9	10	2	0,017	63	0,012	0,013	0,012	0,013
4			0,9	1	1+2+3	2	0,023	63	1	0,9	5	1	0,034	63	0,013	0,013	0,012	0,012
5			1,4	2	1+2+3	2	0,035	98	2	1,4	10	2	0,026	98	0,012	0,013	0,013	0,014
6	TX70	TX70	0,9	1	2+3	1	0,021	26	3	0,9	5	1	0,034	26	0,013	0,015	0,013	0,014
7	TEF47	TEF47	0,8	1	2+3	1	0,019	64	1	0,8	5	1	0,03	64	0,015	0,016	0,012	0,012
8			1,22	2	2+3	1	0,029	98	2	1,22	5	1	0,046	98	0,015	0,015	0,012	0,012
9	TX47	TEF47	0,9	1	2+3	1	0,021	63	1	0,8	5	1	0,03	64	0,012	0,013	-	-

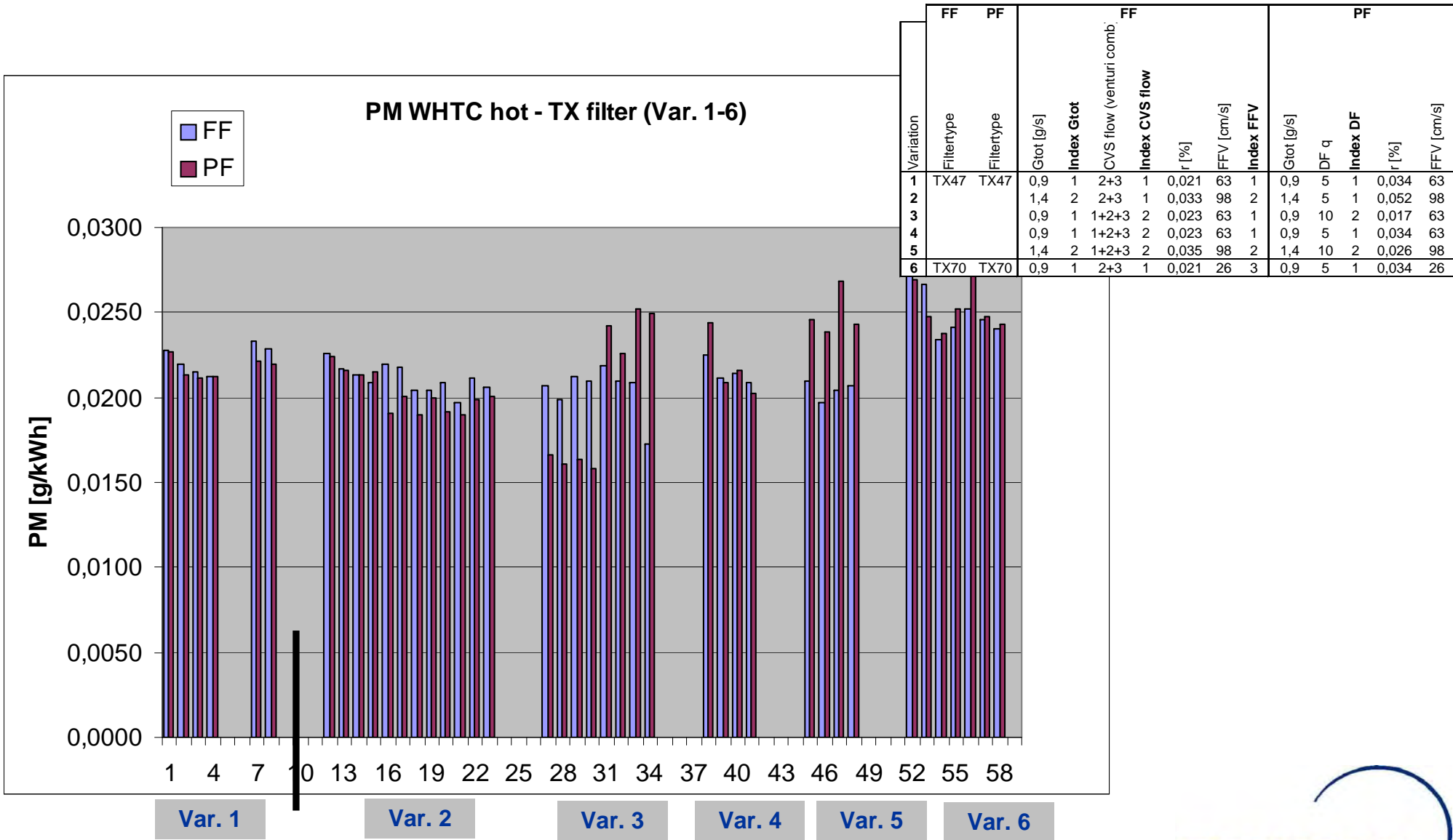
Results - Engine II – Particulate Matter – Parameter variations WHTC 1

Mean values

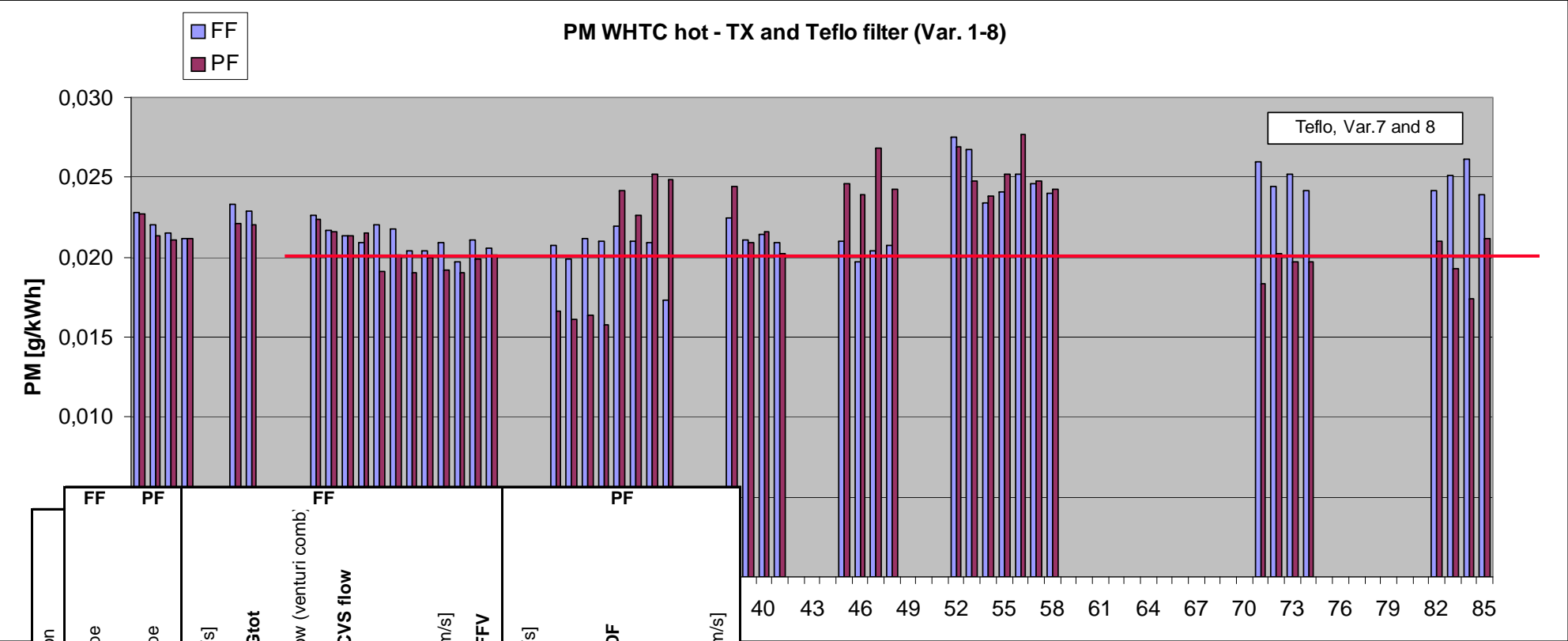
Variation	FF		FF						PF					diluted gas, PM FF [g/kWh]						raw gas, PM PF [g/kWh]						
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	HC	CO	NOx	CO2	PMm 1.	PMm 2.	HC	CO	NOx	CO2	PMm 1.	PMm 2.
1	TX47	TX47	0,9	1	2+3	1	0,021	63	1	0,9	5	1	0,034	63	0,048	2,709	2,095	665,633	0,022	0,023	0,016	2,519	2,083	669,063	0,021	0,022
2			1,4	2	2+3	1	0,033	98	2	1,4	5	1	0,052	98	0,045	2,665	2,244	668,670	0,020	0,021	0,017	2,587	2,314	671,437	0,021	0,018
3			0,9	1	1+2+3	2	0,023	63	1	0,9	10	2	0,017	63	0,052	2,443	2,136	671,022	0,019	0,020	0,016	2,361	2,276	671,505	0,024	0,020
4			0,9	1	1+2+3	2	0,023	63	1	0,9	5	1	0,034	63	0,065	2,694	2,029	671,430	0,020	0,021	0,016	2,623	2,276	675,255	0,021	0,022
5			1,4	2	1+2+3	2	0,035	98	2	1,4	10	2	0,026	98	0,052	2,596	1,872	671,487	0,019	0,020	0,016	2,514	2,058	673,037	0,023	0,025
6	TX70	TX70	0,9	1	2+3	1	0,021	26	3	0,9	5	1	0,034	26	0,054	2,687	2,271	664,536	0,021	0,025	0,014	2,653	2,314	666,919	0,023	0,025
7	TEF47	TEF47	0,8	1	2+3	1	0,019	64	1	0,8	5	1	0,03	64	0,042	2,775	2,242	668,013	0,024	0,025	0,016	2,559	2,213	671,237	0,019	0,019
8			1,22	2	2+3	1	0,029	98	2	1,22	5	1	0,046	98	0,041	2,889	2,193	666,880	0,024	0,025	0,016	2,603	2,123	667,170	0,019	0,020
9	TX47	TEF47	0,9	1	2+3	1	0,021	63	1	0,8	5	1	0,03	64	0,032	2,939	2,294	663,613	0,023	0,024	0,014	2,990	2,512	668,858		

		all 9 variations	arithmetic mean value	0,048	2,711	2,153	667,920	0,021	0,023	0,016	2,601	2,241	670,498	0,021	0,021
			standard deviation	0,0088	0,1398	0,1289	2,8197	0,0016	0,0018	0,0008	0,1591	0,1332	2,5852	0,0017	0,0024
			coefficient of variance	18,31	5,16	5,99	0,42	7,69	8,04	5,45	6,12	5,94	0,39	8,05	11,34
Filtertype TX	Variations 1 to 5	arithmetic mean value	0,052	2,621	2,075	669,648	0,020	0,021	0,016	2,521	2,201	672,060	0,022	0,021	
		standard deviation	0,0069	0,0973	0,1233	2,2594	0,0009	0,0008	0,0005	0,0900	0,1078	2,0413	0,0011	0,0022	
		coefficient of variance	13,09	3,71	5,94	0,34	4,62	3,74	3,11	3,57	4,90	0,30	4,87	10,47	
Filtertype TEFLO	Variations 1 to 6	arithmetic mean value	0,053	2,632	2,108	668,796	0,020	0,022	0,016	2,543	2,220	671,203	0,022	0,022	
		standard deviation	0,0063	0,0921	0,1341	2,8079	0,0009	0,0016	0,0008	0,0957	0,1070	2,6727	0,0010	0,0025	
		coefficient of variance	11,94	3,50	6,36	0,42	4,60	7,34	5,26	3,76	4,82	0,40	4,71	11,50	
Filtertype TEFLO	Variations 7 to 8	arithmetic mean value	0,042	2,832	2,218	667,446	0,024	0,025	0,016	2,581	2,168	669,204	0,019	0,020	
		standard deviation	0,0008	0,0569	0,0243	0,5667	0,0000	0,0001	0,0003	0,0220	0,0448	2,0335	0,0003	0,0001	
		coefficient of variance	1,94	2,01	1,09	0,08	0,16	0,25	1,83	0,85	2,07	0,30	1,72	0,64	
Filtertype TEFLO	Variations 7 to 9	arithmetic mean value	0,039	2,867	2,243	666,168	0,023	0,024	0,015	2,717	2,283	669,088	0,019	0,020	
		standard deviation	0,0043	0,0685	0,0410	1,8656	0,0005	0,0006	0,0008	0,1935	0,1663	1,6683	0,0003	0,0001	
		coefficient of variance	11,21	2,39	1,83	0,28	2,30	2,39	5,54	7,12	7,28	0,25	1,72	0,64	

Results - Engine II – Particulate Matter – Parameter variations WHTC 2

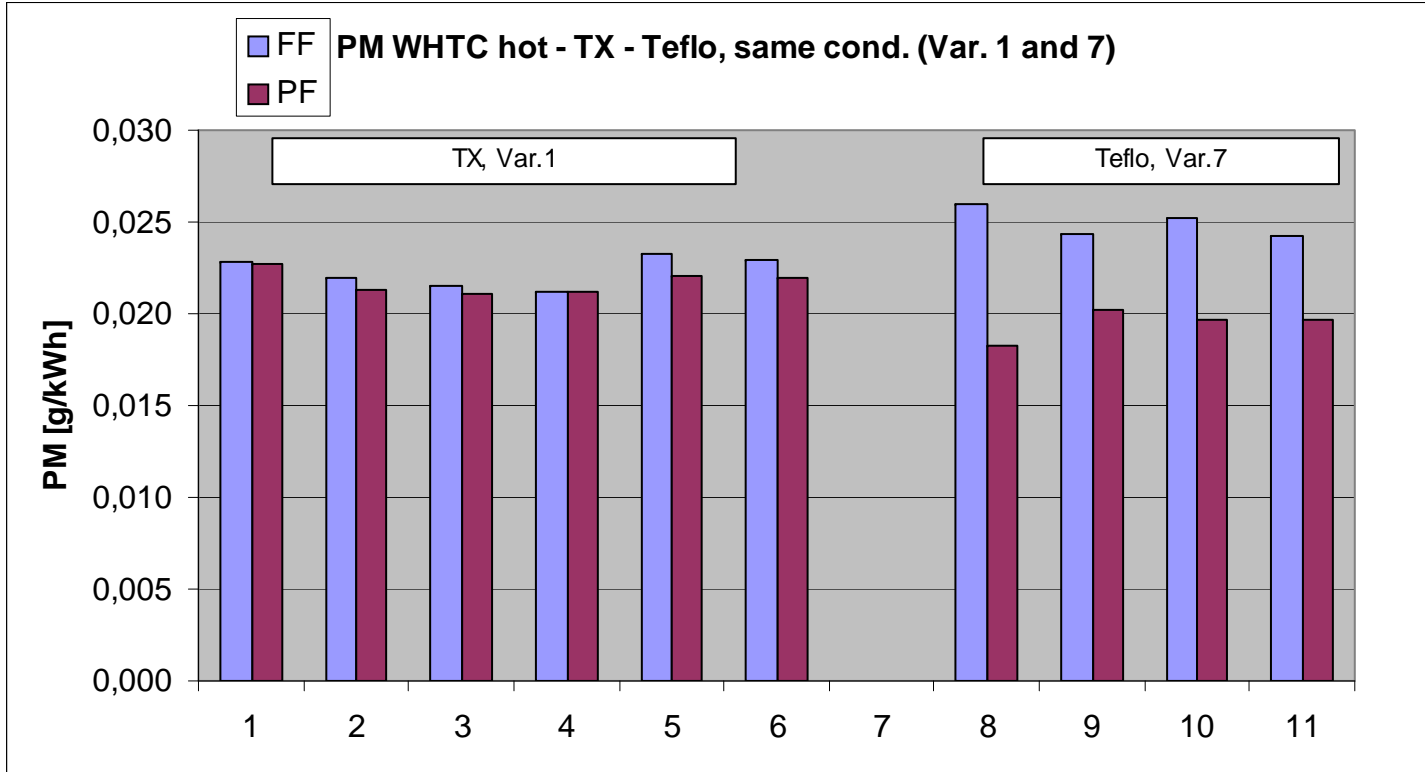


Results - Engine II – Particulate Matter – Parameter variations WHTC 3



Variation	FF		FF							PF				
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]
1	TX47	TX47	0,9	1	2+3	1	0,021	63	1	0,9	5	1	0,034	63
2			1,4	2	2+3	1	0,033	98	2	1,4	5	1	0,052	98
3			0,9	1	1+2+3	2	0,023	63	1	0,9	10	2	0,017	63
4			0,9	1	1+2+3	2	0,023	63	1	0,9	5	1	0,034	63
5			1,4	2	1+2+3	2	0,035	98	2	1,4	10	2	0,026	98
6	TX70	TX70	0,9	1	2+3	1	0,021	26	3	0,9	5	1	0,034	26
7	TEF47	TEF47	0,8	1	2+3	1	0,019	64	1	0,8	5	1	0,03	64
8			1,22	2	2+3	1	0,029	98	2	1,22	5	1	0,046	98

Results - Engine II – Particulate Matter – Parameter variations WHTC 4



Index 1-1-1-1

Var. 1 vs. Var. 7

	PMm 2. FF	PMm 2. PF
	0,0228	0,0227
	0,0220	0,0213
	0,0215	0,0211
	0,0212	0,0212
	0,0233	0,0221
	0,0229	0,0220
	0,026	0,0183
	0,0244	0,0202
	0,0252	0,0197
	0,0242	0,0197

Variation	FF		FF						PF					diluted gas, PM FF [g/kWh]						raw gas, PM PF [g/kWh]						
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	HC	CO	NOx	CO2	PMm 1.	PMm 2.	HC	CO	NOx	CO2	PMm 1.	PMm 2.
1	TX47	TX47	0,9	1	2+3	1	0,021	63	1	0,9	5	1	0,034	63	0,048	2,709	2,095	665,633	0,022	0,023	0,016	2,519	2,083	669,063	0,021	0,022
7	TEF47	TEF47	0,8	1	2+3	1	0,019	64	1	0,8	5	1	0,03	64	0,042	2,775	2,242	668,013	0,024	0,025	0,016	2,559	2,213	671,237	0,019	0,019

Teflo vs. TX / Engine II / Full Flow / Var. 1 and Var. 7

Anzahl der Proben / Number of samples	nR Reference unit FF TX	nC Candidate unit FF Teflo	COV - %
1	0,0228	0,026	9,3
2	0,022	0,0244	7,3
3	0,0215	0,0252	11,2
4	0,0212	0,0242	9,3
5	0,0233		
6	0,0229		
7			
8			
9			
10			
11			
12			
	nR 6	nC 4	

Mittelwert / mean value	xR	xC
	0,02228	0,0250

Standardabweichung / stand. deviation	sR	sC
	0,00084	0,0008

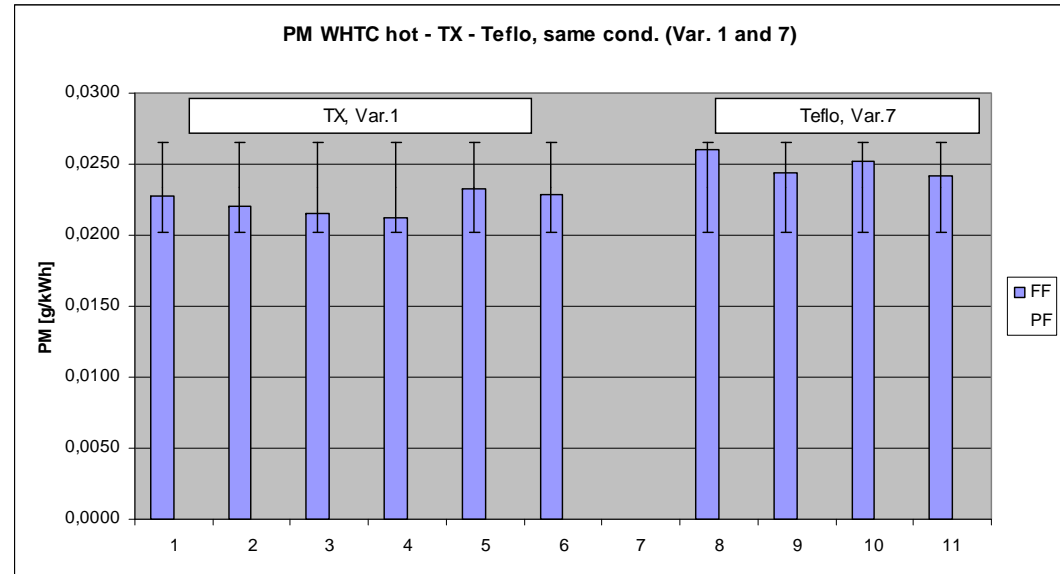
F-test ISO 1,04877 df 5 / 3

t-test ISO 4,94729 df 8

t-test Part 1065 4,97384

Fcrit. 5,3092 $(6-1)/(4-1) = 5 / 3$

tcrit 1,8595 $6 + 4 - 2 = 6$



Teflo vs. TX / Engine II / Partial Flow / Var. 1 and Var. 7

Anzahl der Proben / Number of samples	nR	nC	COV
	Reference unit	Candidate unit	-
	PF TX	PF Teflo	%
1	0,0227	0,0183	15,2
2	0,0213	0,0202	3,7
3	0,0211	0,0197	4,9
4	0,0212	0,0197	5,2
5	0,0221		
6	0,022		
7			
8			
9			
10			
11			
12			
	nR	nC	
	6	4	

	xR	xC
Mittelwert / mean value	0,02173	0,0195

	sR	sC
Standardabweichung / stand. deviation	0,00063	0,0008

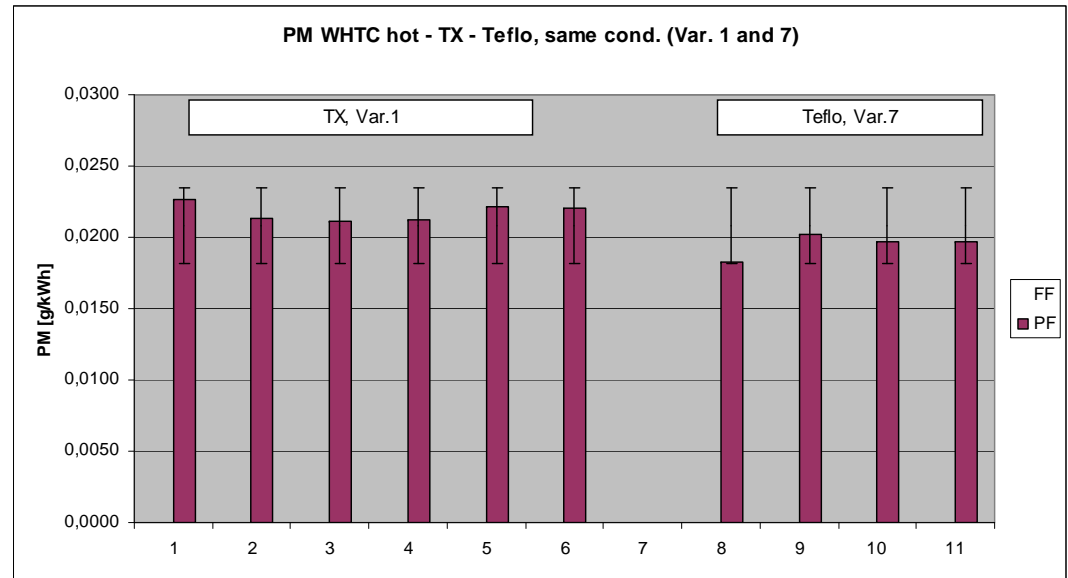
F-test ISO	0,60174	df	5 / 3
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t-test ISO	4,93493	df	8
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t-test Part 1065 4,66452

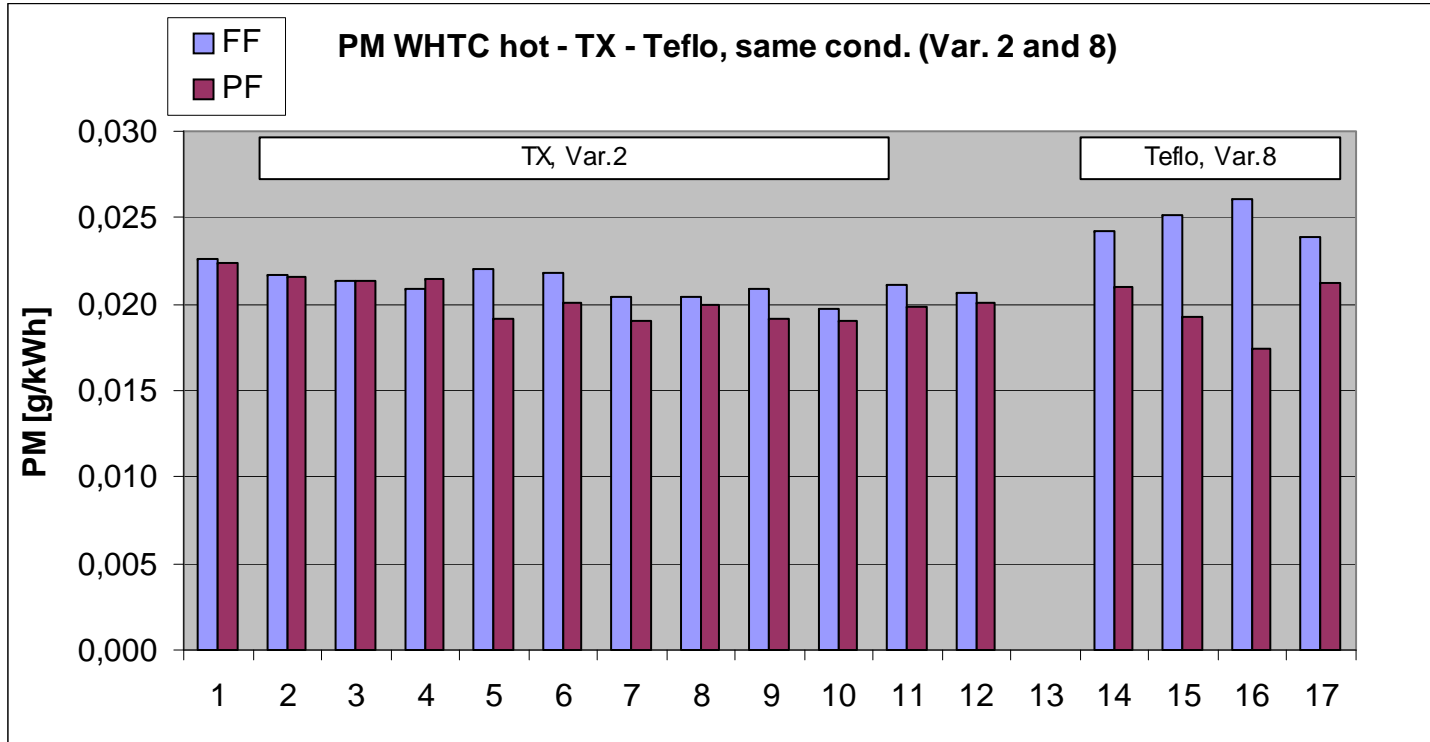
Fcrit.
5,3092 $(6-1)/(4-1) = 5 / 3$

tcrit
1,8595 $6 + 4 - 2 = 8$



90 %
confidence
level

Results - Engine II – Particulate Matter – Parameter variations WHTC 7



Index 2-1-2-1

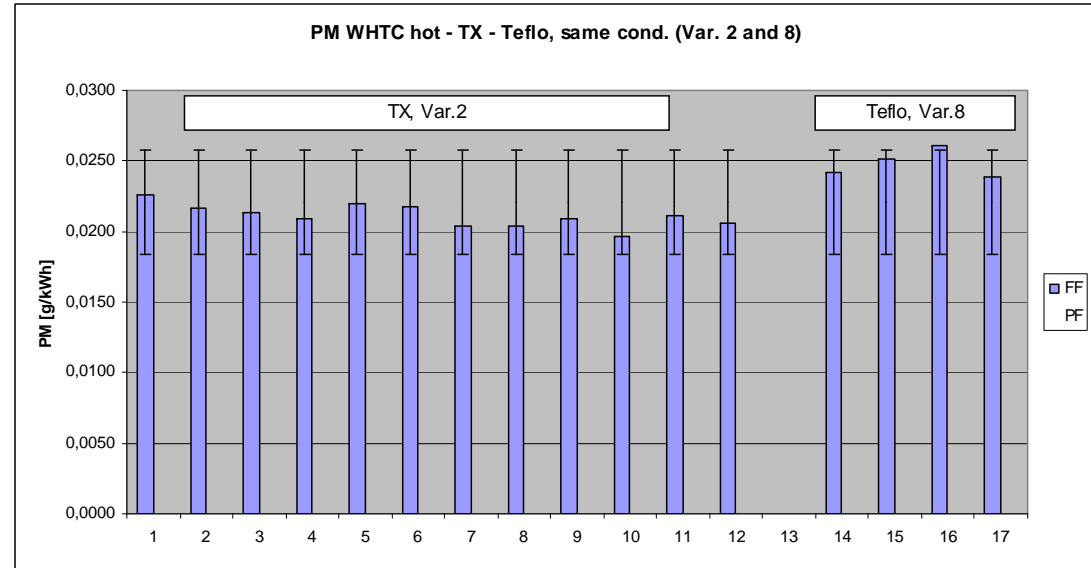
Var. 2 vs. Var. 8

	PMm 2. FF	PMm 2. PF
	0,0226	0,0224
	0,0217	0,0216
	0,0213	0,0213
	0,0209	0,0215
	0,0220	0,0191
	0,0218	0,0201
	0,0204	0,0190
	0,0204	0,0200
	0,0209	0,0192
	0,0197	0,0190
	0,0211	0,0199
	0,0206	0,0201
	0,0242	0,0210
	0,0251	0,0193
	0,0261	0,0174
	0,0239	0,0212

Variation	FF		PF		diluted gas, PM FF [g/kWh]								raw gas, PM PF [g/kWh]													
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	HC	CO	NOx	CO2	PMm 1.	PMm 2.	HC	CO	NOx	CO2	PMm 1.	PMm 2.
2			1,4	2	2+3	1	0,033	98	2	1,4	5	1	0,052	98	0,045	2,665	2,244	668,670	0,020	0,021	0,017	2,587	2,314	671,437	0,021	0,020
8			1,22	2	2+3	1	0,029	98	2	1,22	5	1	0,046	98	0,041	2,889	2,193	666,880	0,024	0,025	0,016	2,603	2,123	667,170	0,019	0,020

Teflo vs. TX / Engine II / Full Flow / Var. 2 and Var. 8

Anzahl der Proben / Number of samples	nR	nC	COV
	Reference unit	Candidate unit	- %
	FF TX	FF Teflo	
1	0,0226	0,0242	4,8
2	0,0217	0,0251	10,3
3	0,0213	0,0261	14,3
4	0,0209	0,0239	9,5
5	0,022		
6	0,0218		
7	0,0204		
8	0,0204		
9	0,0209		
10	0,0197		
11	0,0211		
12	0,0206		
	nR	nC	
	12	4	
	xR	xC	
Mittelwert / mean value	0,02112	0,0248	
	sR	sC	
Standardabweichung / stand. deviation	0,00081	0,0010	
	F-test ISO	df	11 / 3
	1,49758		
	t-test ISO	df	14
	7,53820		
	t-test Part 1065		6,76711



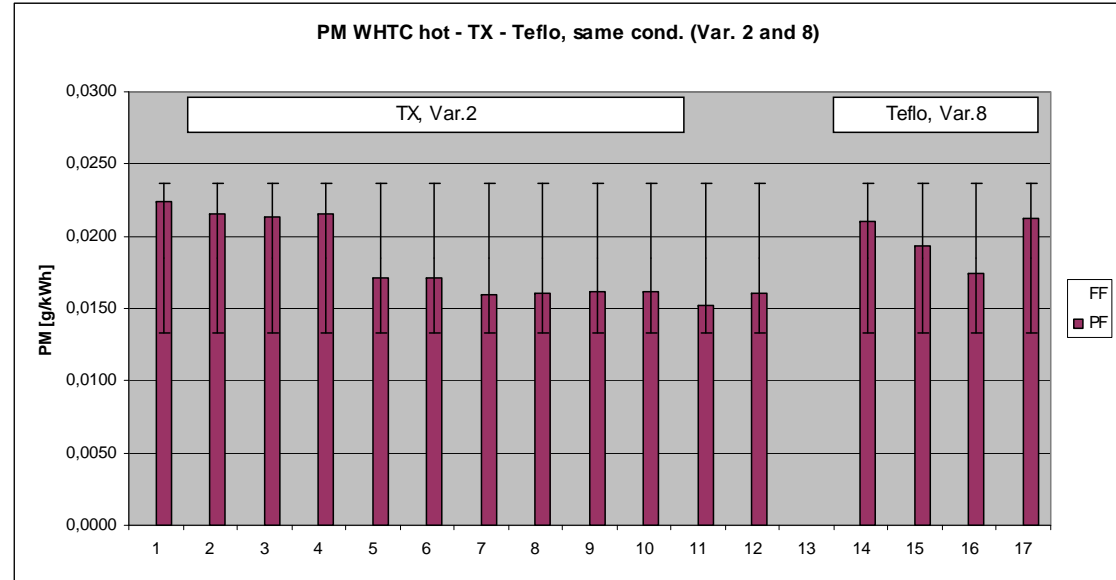
90 %
confidence
level

Fcrit. 5,2224 $(12-1)/(4-1) = 11 / 3$

tcrit 1,7613 $12 + 4 - 2 = 14$

Teflo vs. TX / Engine II / Partial Flow / Var. 2 and Var. 8

Anzahl der Proben / Number of samples	nR	nC	COV
	Reference unit PF TX	Candidate unit PF Teflo	- %
1	0,0224	0,021	4,6
2	0,0216	0,0193	8,0
3	0,0213	0,0174	14,3
4	0,0215	0,0212	1,0
5	0,0171		
6	0,0171		
7	0,016		
8	0,0161		
9	0,0162		
10	0,0162		
11	0,0152		
12	0,0161		
	nR 12	nC 4	
Mittelwert / mean value	xR 0,01807	xC 0,0197	
Standardabweichung / stand. deviation	sR 0,00274	sC 0,0018	
F-test ISO	0,41689	df	11 / 3
t-test ISO	1,12076	df	14
t-test Part 1065	1,39766		



Fcrit.
5,2224 $(12-1)/(4-1) = 11 / 3$

tcrit
1,7613 $12 + 4 - 2 = 14$

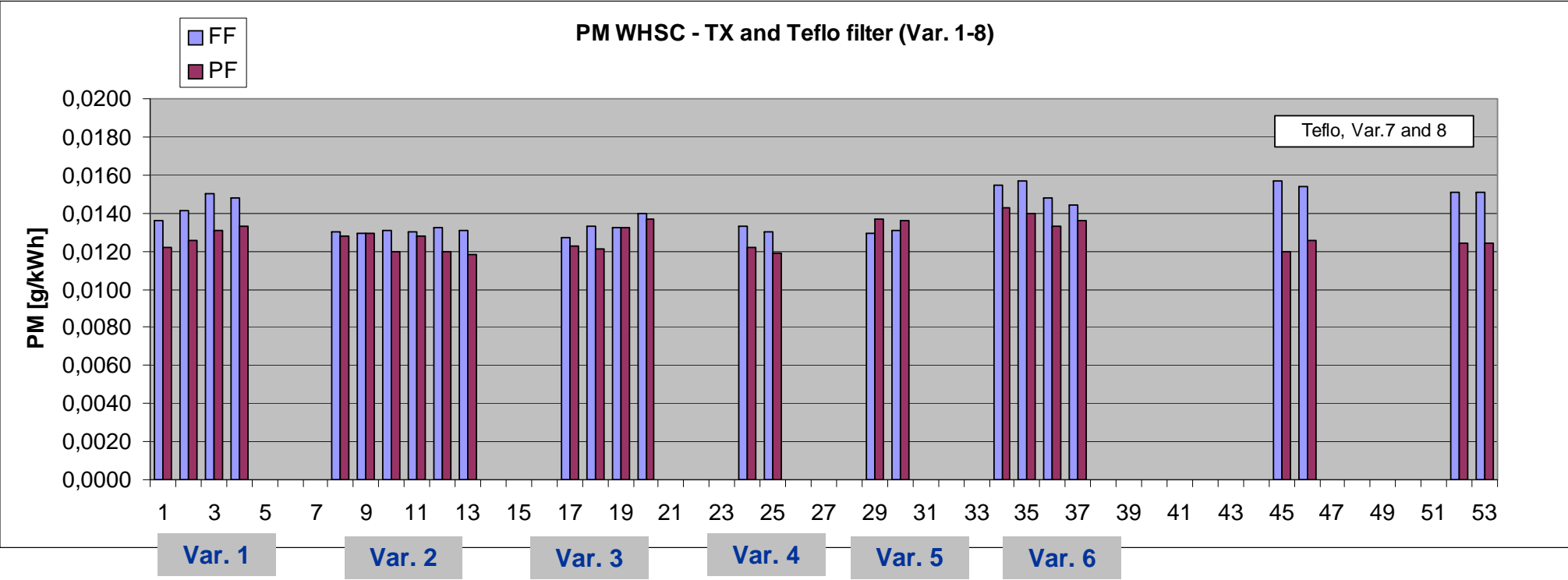
Results - Engine II – Particulate Matter – Parameter variations WHSC 1

Mean values (WHSC)

Variation	FF		FF						PF					diluted gas, PM FF [g/kWh]						raw gas, PM PF [g/kWh]						
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	HC	CO	NOx	CO2	PMm 1.	PMm 2.	HC	CO	NOx	CO2	PMm 1.	PMm 2.
1	TX47	TX47	0,9	1	2+3	1	0,021	63	1	0,9	5	1	0,034	63	0,028	0,547	1,258	629,557	0,014	0,014	0,007	0,553	1,261	631,096	0,012	0,013
2			1,4	2	2+3	1	0,033	98	2	1,4	5	1	0,052	98	0,037	0,543	1,295	633,218	0,013	0,013	0,009	0,536	1,361	630,600	0,013	0,012
3			0,9	1	1+2+3	2	0,023	63	1	0,9	10	2	0,017	63	0,044	0,534	1,259	634,522	0,012	0,013	0,007	0,524	1,056	630,048	0,012	0,013
4			0,9	1	1+2+3	2	0,023	63	1	0,9	5	1	0,034	63	0,055	0,559	1,248	635,422	0,013	0,013	0,006	0,549	1,469	632,048	0,012	0,012
5			1,4	2	1+2+3	2	0,035	98	2	1,4	10	2	0,026	98	0,062	0,539	1,217	634,110	0,012	0,013	0,006	0,537	1,233	630,919	0,013	0,014
6	TX70	TX70	0,9	1	2+3	1	0,021	26	3	0,9	5	1	0,034	26	0,030	0,547	1,282	629,929	0,013	0,015	0,005	0,542	1,304	629,990	0,013	0,014
7	TEF47	TEF47	0,8	1	2+3	1	0,019	64	1	0,8	5	1	0,03	64	0,023	0,564	1,330	632,941	0,015	0,016	0,007	0,538	1,274	631,236	0,012	0,012
8			1,22	2	2+3	1	0,029	98	2	1,22	5	1	0,046	98	0,027	0,598	1,373	632,195	0,015	0,015	0,007	0,545	1,285	626,579	0,012	0,012
9	TX47	TEF47	0,9	1	2+3	1	0,021	63	1	0,8	5	1	0,03	64	0,019	0,532	1,427	628,866	0,012	0,013	0,006	0,519	1,480	619,229		

	all 9 variations	arithmetic mean value	0,036	0,552	1,299	632,307	0,013	0,014	0,007	0,538	1,303	629,083	0,012	0,013
		standard deviation	0,0139	0,0193	0,0631	2,2150	0,0010	0,0010	0,0010	0,0104	0,1208	3,7754	0,0004	0,0008
		coefficient of variance	38,38	3,50	4,85	0,35	7,52	7,32	15,30	1,93	9,27	0,60	3,23	6,07
Filtertype TX	Variations 1 to 5	arithmetic mean value	0,045	0,545	1,255	633,366	0,013	0,013	0,007	0,540	1,276	630,942	0,012	0,013
		standard deviation	0,0124	0,0087	0,0248	2,0320	0,0005	0,0005	0,0011	0,0100	0,1379	0,6579	0,0003	0,0007
		coefficient of variance	27,33	1,59	1,97	0,32	4,15	3,82	14,69	1,86	10,81	0,10	2,60	5,67
	Variations 1 to 6	arithmetic mean value	0,043	0,545	1,260	632,793	0,013	0,014	0,007	0,540	1,281	630,783	0,012	0,013
		standard deviation	0,0126	0,0080	0,0247	2,2541	0,0005	0,0008	0,0012	0,0092	0,1263	0,6976	0,0003	0,0008
		coefficient of variance	29,44	1,46	1,96	0,36	3,88	5,81	17,22	1,70	9,87	0,11	2,72	6,31
Filtertype TEFL0	Variations 7 to 8	arithmetic mean value	0,025	0,581	1,352	632,568	0,015	0,015	0,007	0,542	1,280	628,907	0,012	0,012
		standard deviation	0,0019	0,0171	0,0216	0,3731	0,0000	0,0002	0,0000	0,0037	0,0052	2,3286	0,0003	0,0003
		coefficient of variance	7,54	2,94	1,59	0,06	0,17	1,47	0,67	0,69	0,41	0,37	2,71	2,48
	Variations 7 to 9	arithmetic mean value	0,023	0,564	1,377	631,334	0,014	0,015	0,006	0,534	1,346	625,681	0,012	0,012
		standard deviation	0,0033	0,0272	0,0396	1,7713	0,0013	0,0012	0,0004	0,0113	0,0946	4,9428	0,0003	0,0003
		coefficient of variance	14,08	4,81	2,88	0,28	9,02	8,15	6,57	2,12	7,02	0,79	2,71	2,48

Results - Engine II – Particulate Matter – Parameter variations WHSC 2

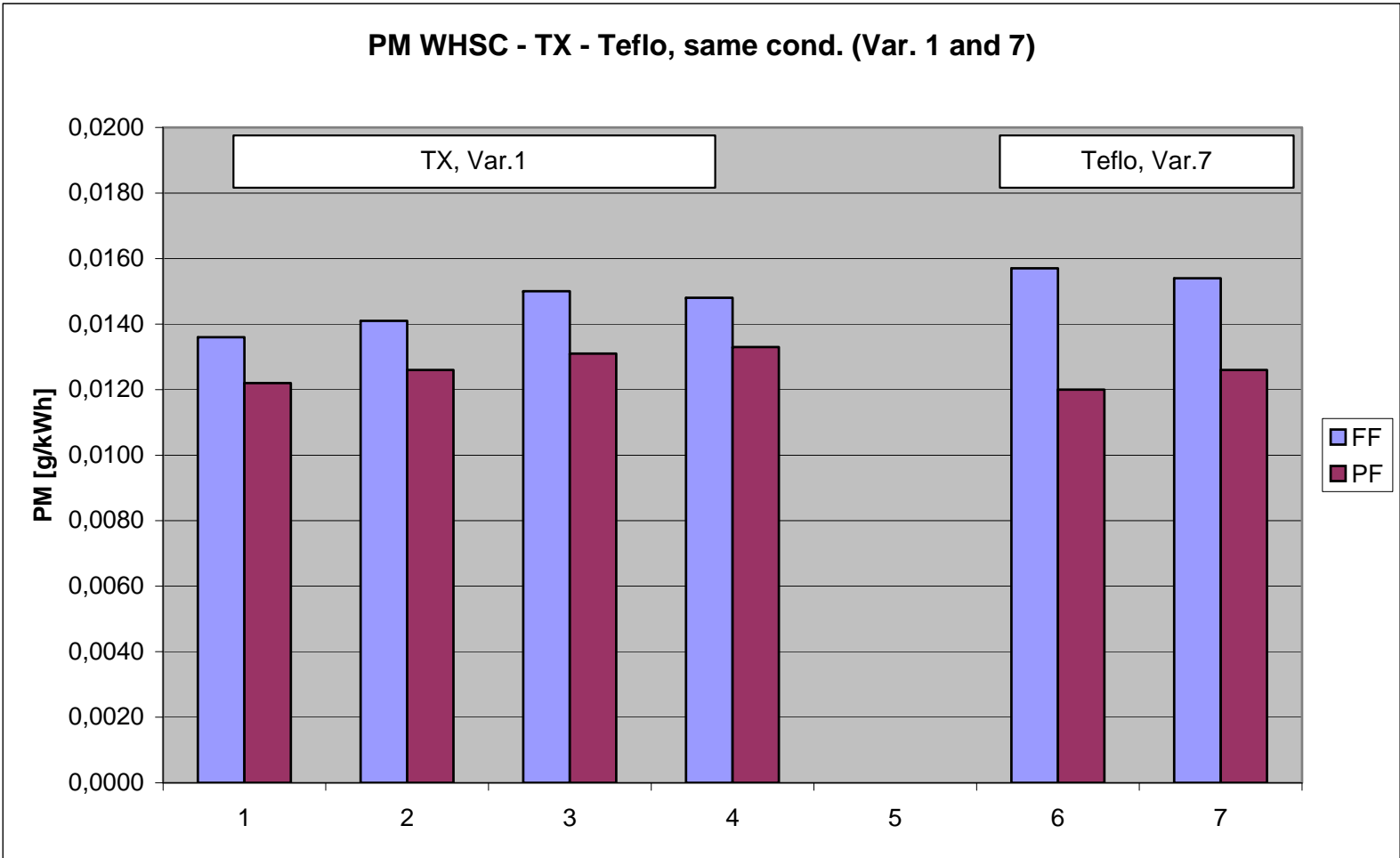


Results - Engine II – Particulate Matter – Parameter variations WHSC 3

Index 1-1-1-1

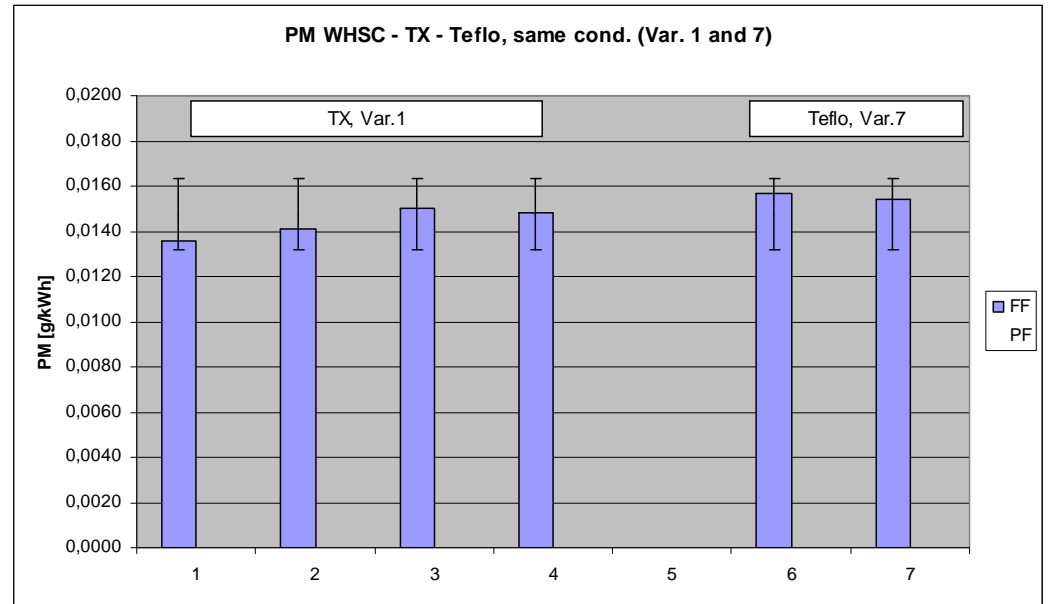
Var. 1 vs Var. 7

PMm 2.	FPMm 2.	PF
0,0136	0,0122	
0,0141	0,0126	
0,0150	0,0131	
0,0148	0,0133	
0,0157	0,0120	
0,0154	0,0126	



Teflo vs. TX / Engine II /Full Flow / Var. 1 and Var. 7

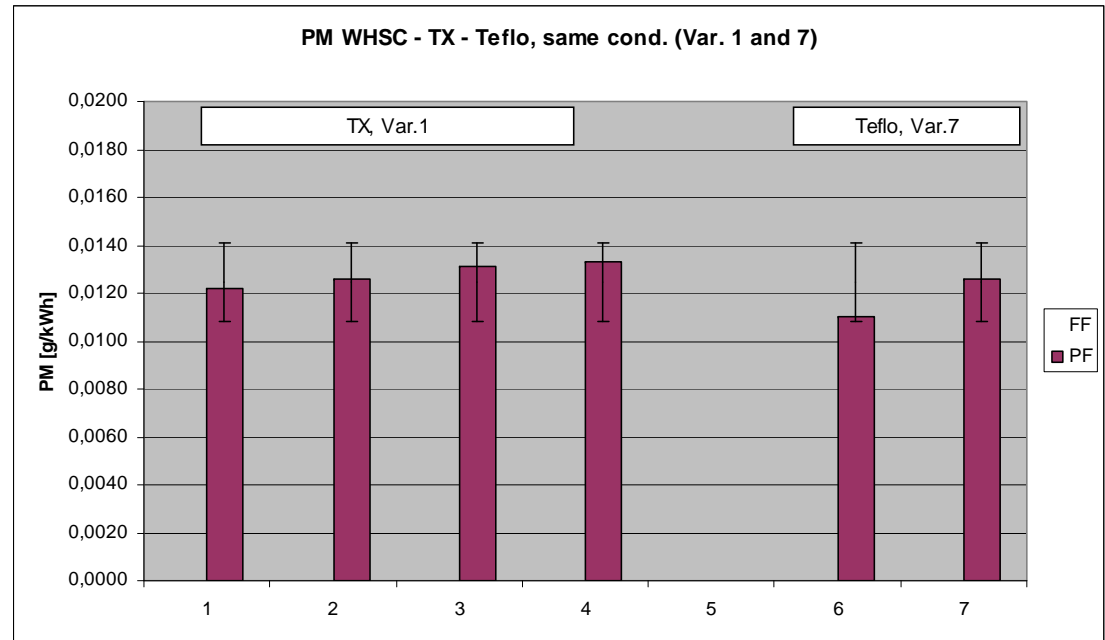
Anzahl der Proben / Number of samples	nR	nC	COV
	Reference unit	Candidate unit	- %
	FF TX	FF Teflo	
1	0,0136	0,0157	10,1
2	0,0141	0,0154	6,2
3	0,015		
4	0,0148		
5			
6			
7			
8			
9			
10			
11			
12			
	nR	nC	
	4	2	
	xR	xC	
Mittelwert / mean value	0,01438	0,0156	
	sR	sC	
Standardabweichung / stand. deviation	0,00064	0,0002	
			90 % confidence level
F-test ISO	9,24074	df	3 / 1
			$(4-1)/(2-1) = 3 / 1$
t-test ISO	2,38683	df	4
			$4 + 2 - 2 = 4$
t-test Part 1065	3,30418		



Teflo vs. TX / Engine II / Partial Flow / Var. 1 and Var. 7

Anzahl der Proben / Number of samples	nR	nC	COV
	Reference unit	Candidate unit	-
	PF TX	PF Teflo	%
1	0,0122	0,011	7,3
2	0,0126	0,0126	0,0
3	0,0131		
4	0,0133		
5			
6			
7			
8			
9			
10			
11			
12			
	nR	nC	
	4	2	
	xR	xC	
Mittelwert / mean value	0,01280	0,0118	
	sR	sC	
Standardabweichung / stand. deviation	0,00050	0,0011	
	F-test ISO	df	3 / 1
	0,19271		
	t-test ISO	df	4
	1,62489		
	t-test Part 1065		1,19381

nR	nC	COV
Reference unit	Candidate unit	-
PF TX	PF Teflo	%
1	0,011	7,3
2	0,0126	0,0
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		



90 %
confidence
level

Fcrit.
53,5932 $(4-1)/(2-1) = 3 / 1$

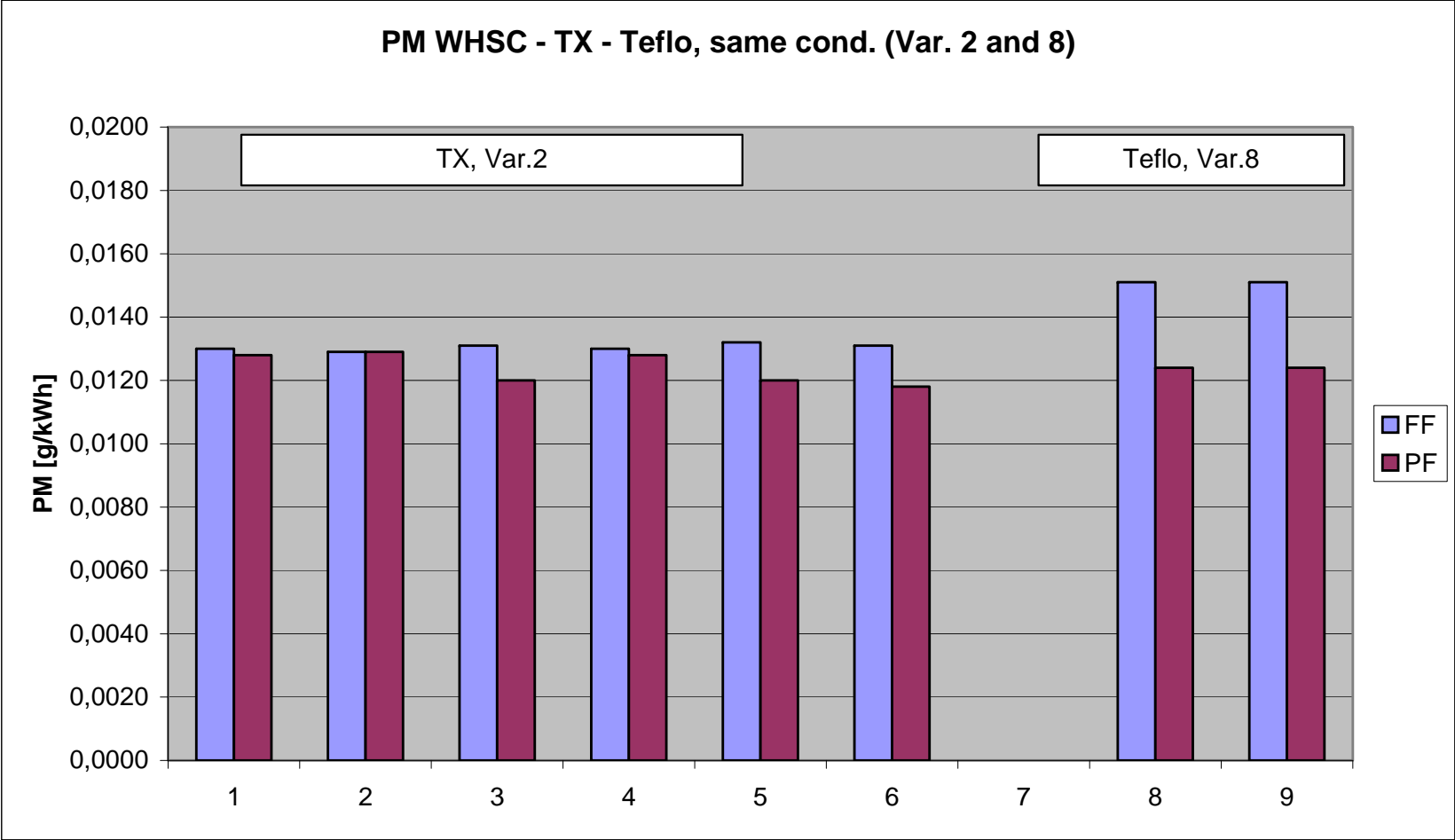
tcrit
2,1318 $4 + 2 - 2 = 4$

Results - Engine II – Particulate Matter – Parameter variations WHSC 6

Index 2-1-2-1

Var. 2 vs. Var. 8

PMm 2.	FF	PMm 2.	PF
0,0130	0,0128		
0,0129	0,0129		
0,0131	0,0120		
0,0130	0,0128		
0,0132	0,0120		
0,0131	0,0118		
0,0151	0,0124		
0,0151	0,0124		



Teflo vs. TX / Engine II / Full Flow / Var. 1 and Var. 7

Anzahl der Proben /
Number of samples

nR

nC

COV

Reference
unit
FF TX

Candidate
unit
FF Teflo

-
%

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

0,013
0,0129
0,0131
0,013
0,0132
0,0131

0,0151
0,0151

10,6
11,1

nR
6

nC
2

xR

xC

Mittelwert / mean value

0,01305

0,0151

sR

sC

Standardabweichung /
stand. deviation

0,00010

0,0000

F-test ISO

#DIV/0!

df

5 / 1

t-test ISO

26,22369

df

6

t-test Part 1065

47,87769

Fcrit.

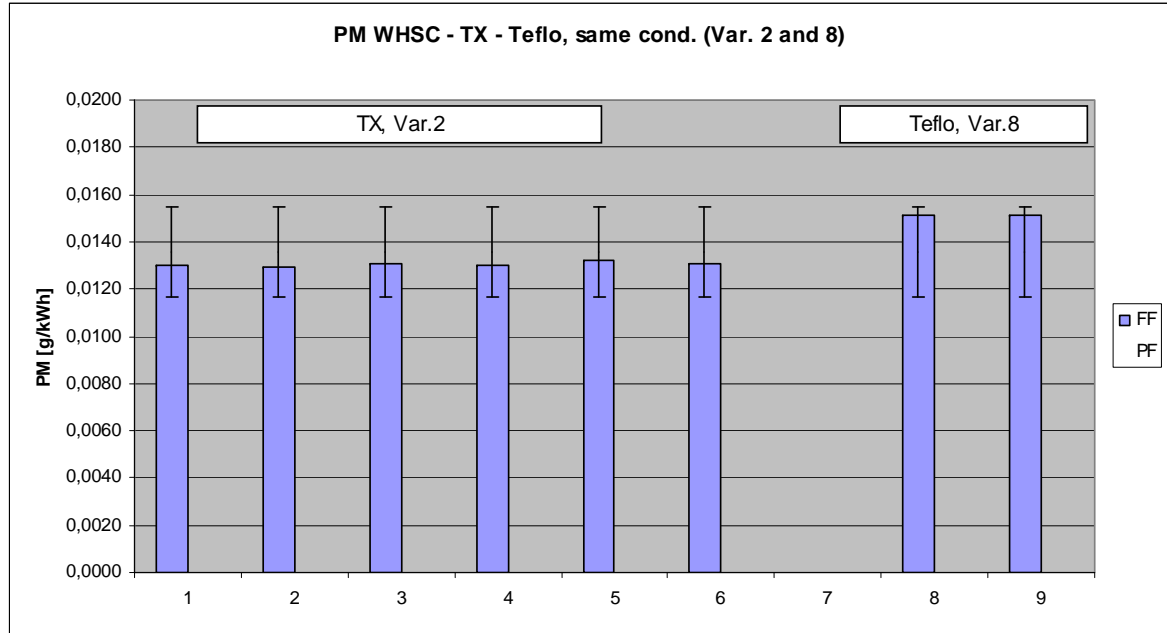
57,2401

$(6-1)/(2-1) = 5 / 1$

tcrit

1,9432

$6 + 2 - 2 = 6$



90 %
confidence
level

Teflo vs. TX / Engine II / Partial Flow / Var. 1 and Var. 7

Anzahl der Proben / Number of samples	nR	nC	COV
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Reference unit	Candidate unit	-
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	PF TX	PF Teflo	
1	0,0128	0,0124	2,2
2	0,0129	0,0124	2,8
3	0,011		
4	0,0108		
5	0,011		
6	0,0108		
7			
8			
9			
10			
11			
12			

nR	nC
6	2

Mittelwert / mean value	xR	xC
	0,01155	0,0124

Standardabweichung / stand. deviation	sR	sC
	0,00101	0,0000

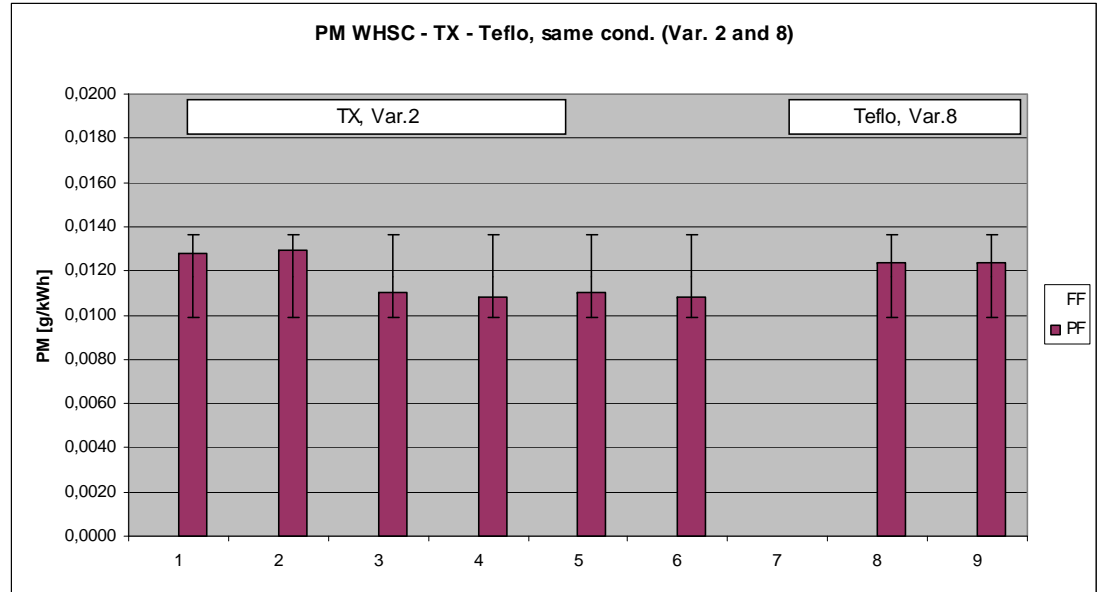
F-test ISO	#DIV/0!	df	5 / 1
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t-test ISO	1,12750	df	6
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t-test Part 1065	2,05853
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Fcrit.
57,2401 $(6-1)/(2-1) = 5 / 1$

tcrit
1,9432 $6 + 2 - 2 = 6$



90 %
confidence
level

Results - Engine I – Particulate Matter - Overview 1

All mean values over all parameter variations.

Variation	FF		FF					PF					diluted gas, PM FF [g/kWh]		raw gas, PM PF [g/kWh]		
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	PMm 1.	PMm 2.	PMm 1.

results WHTC cold

1	TX47	TX47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,006	0,006	0,007	0,007
2	0	0	1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,004	0,004	0,004	0,004
3	0	0	0,9	1	1+3	2	0,046	63	1	0,9	10	2	0,03	63	0,006	0,006	0,008	0,006
4	0	0	0,9	1	1+3	2	0,046	63	1	0,9	5	1	0,06	63	0,005	0,004	0,005	0,005
5	0	0	1,4	2	1+3	2	0,072	98	2	1,4	10	2	0,046	98	0,004	0,005	0,006	0,005
6	TX70	TX70	0,9	1	1+2	1	0,042	26	3	0,9	5	1	0,06	26	0,005	0,005	0,008	0,008
7	TEF47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,026	0,030	0,030	0,038
8	0	0	1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,013	0,000	0,023	0,003
9	TX47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,004	0,004	0,045	0,000

results WHTC hot

1	TX47	TX47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,005	0,005	0,006	0,006
2	0	0	1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,004	0,004	0,003	0,003
3	0	0	0,9	1	1+3	2	0,046	63	1	0,9	10	2	0,03	63	0,004	0,004	0,005	0,006
4	0	0	0,9	1	1+3	2	0,046	63	1	0,9	5	1	0,06	63	0,004	0,004	0,005	0,004
5	0	0	1,4	2	1+3	2	0,072	98	2	1,4	10	2	0,046	98	0,003	0,003	0,004	0,004
6	TX70	TX70	0,9	1	1+2	1	0,042	26	3	0,9	5	1	0,06	26	0,005	0,005	0,006	0,006
7	TEF47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,035	0,030	0,025	0,025
8	0	0	1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,013	0,002	0,021	0,002
9	TX47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,004	0,004	0,027	0,013

results WHSC

1	TX47	TX47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,006	0,006	0,006	0,006
2	0	0	1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,004	0,004	0,003	0,003
3	0	0	0,9	1	1+3	2	0,046	63	1	0,9	10	2	0,03	63	0,006	0,006	0,006	0,006
4	0	0	0,9	1	1+3	2	0,046	63	1	0,9	5	1	0,06	63	0,005	0,005	0,005	0,004
5	0	0	1,4	2	1+3	2	0,072	98	2	1,4	10	2	0,046	98	0,003	0,003	0,003	0,003
6	TX70	TX70	0,9	1	1+2	1	0,042	26	3	0,9	5	1	0,06	26	0,009	0,009	0,008	0,008
7	TEF47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,018	0,016	0,013	0,013
8	0	0	1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,006	0,002	0,026	0,002
9	TX47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,005	0,004	0,009	0,001

Results - Engine I – Particulate Matter – Parameter variations WHTC 1 New

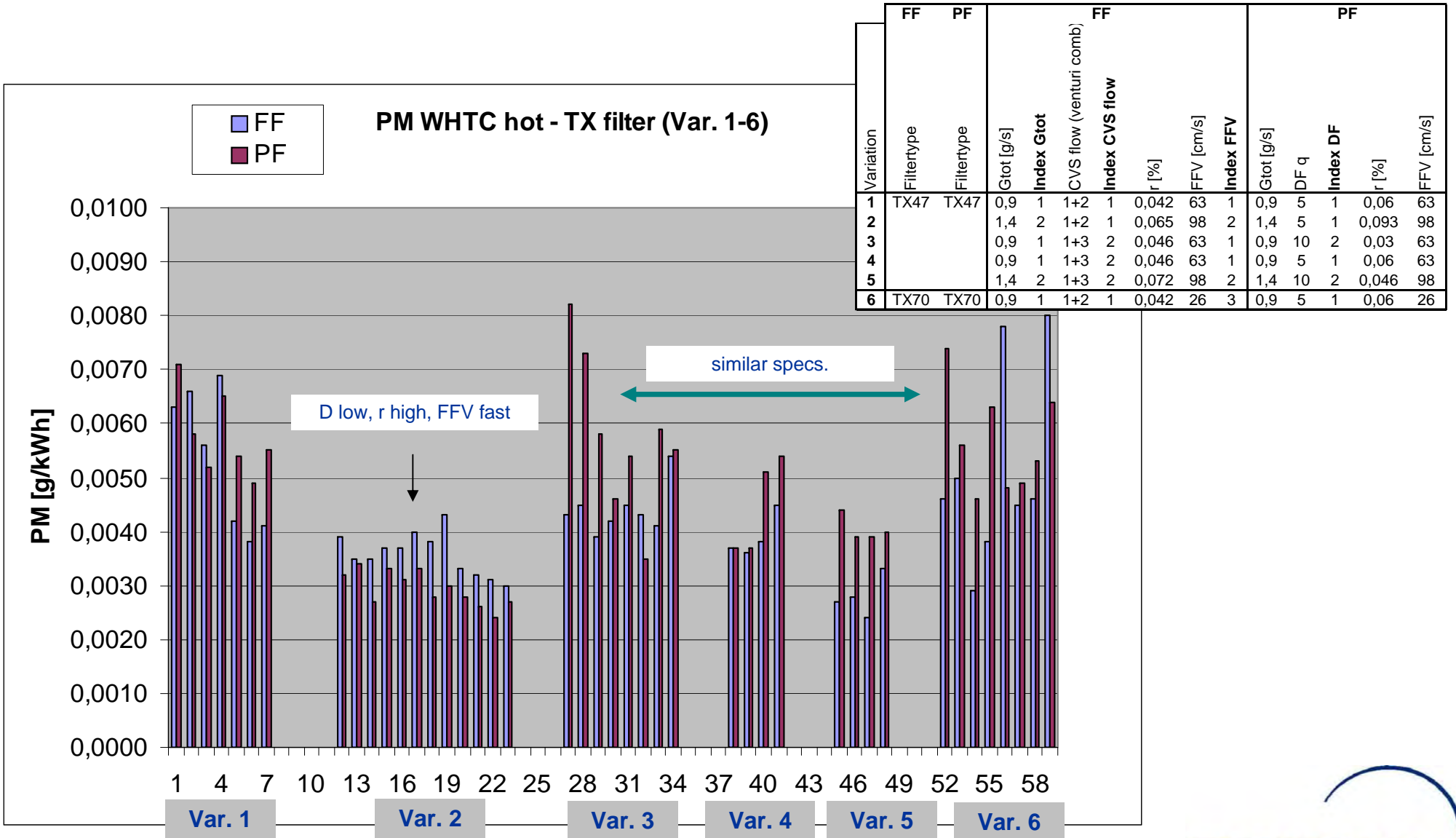
Mean values WHTC hot

Teflo testing repeated

Variation	FF		FF						PF					diluted gas, PM FF [g/kWh]						raw gas, PM PF [g/kWh]						
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	HC	CO	NOx	CO2	PMm 1.	PMm 2.	HC	CO	NOx	CO2	PMm 1.	PMm 2.
1	TX47	TX47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,037	0,067	2,376	718,248	0,005	0,005	0,004	0,077	2,498	723,763	0,006	0,006
2			1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,035	0,069	2,052	719,057	0,004	0,004	0,005	0,084	2,053	725,282	0,003	0,003
3			0,9	1	1+3	2	0,046	63	1	0,9	10	2	0,03	63	0,066	0,055	2,257	718,922	0,004	0,004	0,005	0,087	2,309	721,486	0,005	0,006
4			0,9	1	1+3	2	0,046	63	1	0,9	5	1	0,06	63	0,063	0,071	2,156	731,960	0,004	0,004	0,004	0,084	2,147	725,535	0,005	0,004
5			1,4	2	1+3	2	0,072	98	2	1,4	10	2	0,046	98	0,061	0,085	2,056	716,170	0,003	0,003	0,005	0,076	2,049	715,352	0,004	0,004
6	TX70	TX70	0,9	1	1+2	1	0,042	26	3	0,9	5	1	0,06	26	0,032	0,065	2,161	706,210	0,005	0,005	0,004	0,075	2,241	716,145	0,006	0,006
7	TEF47	TEF47	0,8	1	1+2	1	0,037	64	1	0,8	5	1	0,053	64	0,027	0,088	2,187	710,554	0,009	0,001	0,009	0,069	2,207	712,180	0,001	0,002
8			1,22	2	1+2	1	0,057	98	2	1,22	5	1	0,081	98	0,020	0,086	2,252	710,313	0,005	0,002	0,008	0,075	2,262	714,556	0,004	0,001
9	TX47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,040	0,066	2,218	720,825			0,005	0,082	2,261	723,835		

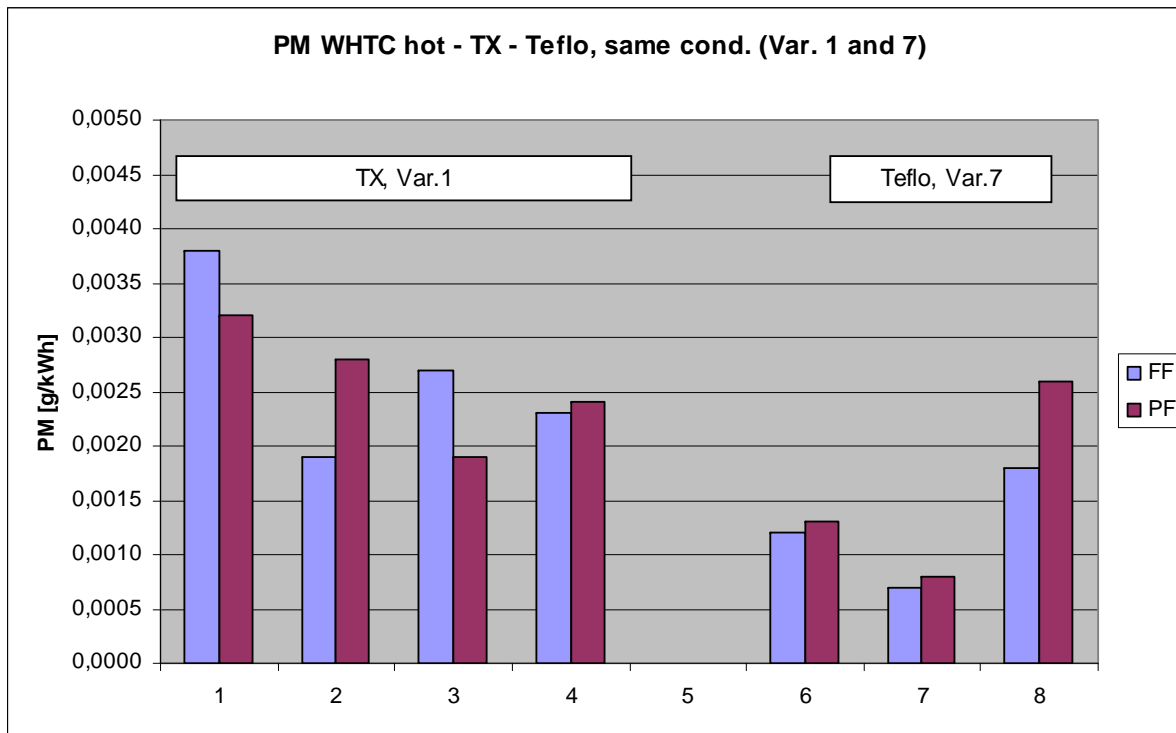
Filtertype	Variations	all 9 variations		Variations 1 to 5		Variations 1 to 6		Variations 7 to 8		Variations 7 to 9				
		arithmetic mean value	standard deviation	arithmetic mean value	standard deviation	arithmetic mean value	standard deviation	arithmetic mean value	standard deviation	arithmetic mean value	standard deviation			
Filtertype TX	all 9 variations	arithmetic mean value	0,042	0,073	2,191	716,918	0,005	0,003	0,006	0,079	2,225	719,793	0,004	0,004
		standard deviation	0,0158	0,0106	0,0960	7,0808	0,0019	0,0014	0,0017	0,0055	0,1295	4,9042	0,0014	0,0017
		coefficient of variance	37,19	14,62	4,38	0,99	38,33	41,33	30,82	6,98	5,82	0,68	33,55	42,73
	Variations 1 to 5	arithmetic mean value	0,052	0,070	2,180	720,871	0,004	0,004	0,005	0,082	2,211	722,284	0,005	0,005
		standard deviation	0,0133	0,0095	0,1240	5,6396	0,0007	0,0009	0,0004	0,0042	0,1714	3,7531	0,0010	0,0011
		coefficient of variance	25,37	13,70	5,69	0,78	18,31	21,24	7,98	5,10	7,75	0,52	21,46	23,44
Variations 1 to 6	arithmetic mean value	0,049	0,069	2,176	718,428	0,004	0,004	0,005	0,081	2,216	721,261	0,005	0,005	
	standard deviation	0,0143	0,0089	0,1134	7,5074	0,0008	0,0009	0,0004	0,0045	0,1568	4,1196	0,0010	0,0011	
	coefficient of variance	29,04	12,89	5,21	1,04	19,59	21,11	7,65	5,60	7,08	0,57	20,83	22,20	
Filtertype TEFLO	Variations 7 to 8	arithmetic mean value	0,024	0,087	2,219	710,434	0,007	0,001	0,009	0,072	2,234	713,368	0,003	0,002
		standard deviation	0,0038	0,0014	0,0327	0,1206	0,0022	0,0001	0,0007	0,0031	0,0273	1,1881	0,0013	0,0001
		coefficient of variance	16,32	1,64	1,47	0,02	29,66	10,57	8,32	4,34	1,22	0,17	50,71	4,44
	Variations 7 to 9	arithmetic mean value	0,029	0,080	2,219	713,897			0,007	0,075	2,243	716,857		
		standard deviation	0,0084	0,0097	0,0267	4,8997			0,0019	0,0056	0,0255	5,0283		
		coefficient of variance	28,98	12,14	1,20	0,69			26,00	7,39	1,14	0,70		

Results - Engine I – Particulate Matter – Parameter variations WHTC 2



Results - Engine I – Particulate Matter – Parameter variations WHTC 3 New

Teflo testing repeated



Var. 1 zu Var. 7

PMm 2. FF	PMm 2. PF
0,0038	0,0032
0,0019	0,0028
0,0027	0,0019
0,0023	0,0024
0,0012	0,0013
0,0007	0,0008
0,0018	0,0026
0,0000	0,0000

Variation	FF		FF								PF					diluted gas, PM FF [g/kWh]						raw gas, PM PF [g/kWh]					
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)		Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	HC	CO	NOx	CO2	PMm 1.	PMm 2.	HC	CO	NOx	CO2	PMm 1.	PMm 2.
1	TX47	TX47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,037	0,067	2,376	718,248	0,005	0,005	0,004	0,077	2,498	723,763	0,006	0,006	
2	TEF47	TEF47	0,8	1	1+2	1	0,037	64	1	0,8	5	1	0,053	64	0,027	0,088	2,187	710,554	0,009	0,001	0,009	0,069	2,207	712,180	0,001	0,002	

Teflo vs. TX / Engine I / Full Flow / Var. 1 and Var. 7

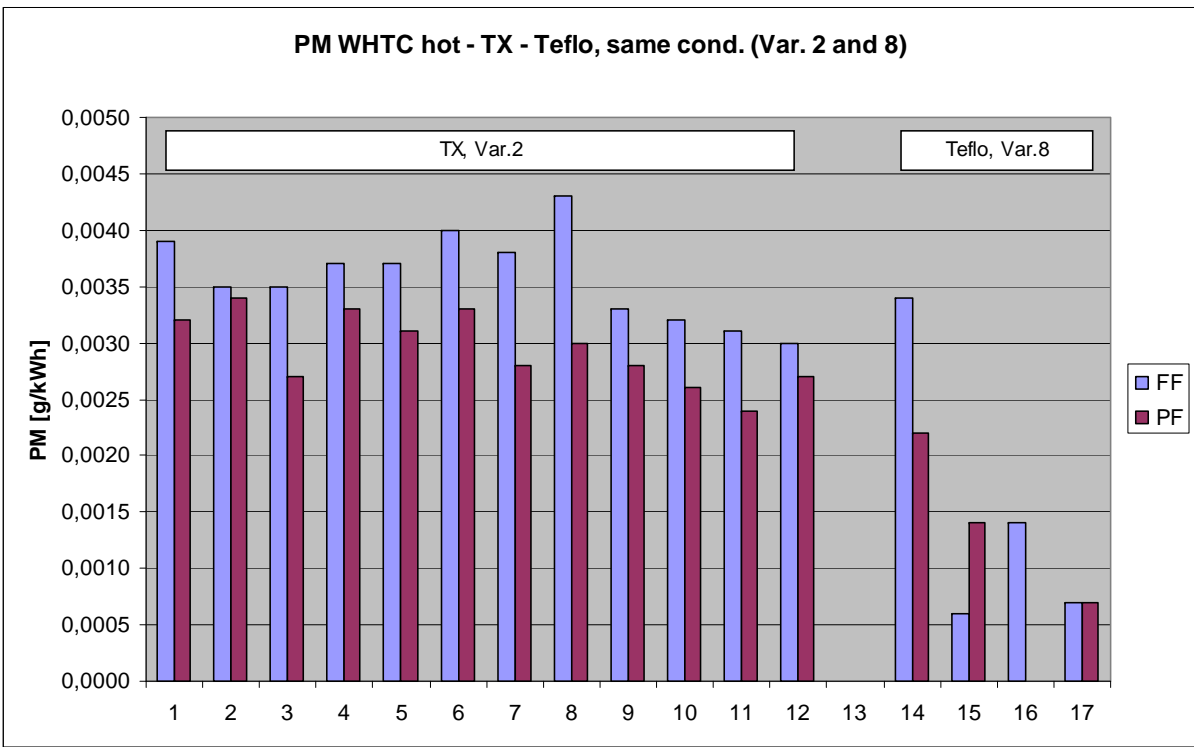
Anzahl der Proben / Number of samples	nR	nC	COV
	Reference unit FF TX	Candidate unit FF Teflo	- %
1	0,0038	0,0012	73,5
2	0,0019	0,0007	65,3
3	0,0027	0,0018	28,3
4	0,0023	0	141,4
5			
6			
7			
8			
9			
10			
11			
12			
	nR 4	nC 4	
	xR	xC	
Mittelwert / mean value	0,00268	0,0009	
	sR	sC	
Standardabweichung / stand. deviation	0,00082	0,0008	90 % confidence level
	F-test ISO	df	Fcrit.
	1,14878	3 / 3	5,3908 $(4-1)/(4-1) = 3 / 3$
	t-test ISO	df	tcrit
	3,12841	6	1,9432 $4 + 4 - 2 = 6$
	t-test Part 1065	3,12841	

Teflo vs. TX / Engine I / Partial Flow / Var. 1 and Var. 7

Anzahl der Proben / Number of samples	nR	nC	COV
	Reference unit PF TX	Candidate unit PF Teflo	- %
1	0,0032	0,0013	59,7
2	0,0028	0,0008	78,6
3	0,0019	0,0026	22,0
4	0,0024	0	-
5			
6			
7			
8			
9			
10			
11			
12			
	nR 4	nC 4	
	xR	xC	
Mittelwert / mean value	0,00258	0,0012	
	sR	sC	
Standardabweichung / stand. deviation	0,00056	0,0011	90 % confidence level
	F-test ISO	df	Fcrit.
	3,84636	3 / 3	5,3908 $(4-1)/(4-1) = 3 / 3$
	t-test ISO	df	tcrit
	2,28746	6	1,9432 $4 + 4 - 2 = 6$
	t-test Part 1065	2,28746	

Results - Engine I – Particulate Matter – Parameter variations WHTC 5 New

PM WHTC hot - TX - Teflo, same cond. (Var. 2 and 8)



Var. 2 and Var. 8

PMm 2. FF	PMm 2. PF
0,0039	0,0032
0,0035	0,0034
0,0035	0,0027
0,0037	0,0033
0,0037	0,0031
0,0040	0,0033
0,0038	0,0028
0,0043	0,0030
0,0033	0,0028
0,0032	0,0026
0,0031	0,0024
0,0030	0,0027
0,0034	0,0022
0,0006	0,0014
0,0014	0,0000
0,0007	0,0007

Variation	FF		PF		diluted gas, PM FF [g/kWh]								raw gas, PM PF [g/kWh]													
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	HC	CO	NOx	CO2	PMm 1.	PMm 2.	HC	CO	NOx	CO2	PMm 1.	PMm 2.
2	TX	TX	1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,035	0,069	2,052	719,057	0,004	0,004	0,005	0,084	2,053	725,282	0,003	0,003
8	TEF47	TEF47	1,22	2	1+2	1	0,057	98	2	1,22	5	1	0,081	98	0,020	0,086	2,252	710,313	0,005	0,002	0,008	0,075	2,262	714,556	0,004	0,001

Teflo vs. TX / Engine I / Full Flow / Var. 2 and Var. 8

Anzahl der Proben / Number of samples	nR Reference unit FF TX	nC Candidate unit FF Teflo	COV - %
1	0,0039	0,0034	9,7
2	0,0035	0,0006	100,0
3	0,0035	0,0014	60,6
4	0,0037	0,0007	96,4
5	0,0037		
6	0,004		
7	0,0038		
8	0,0043		
9	0,0033		
10	0,0032		
11	0,0031		
12	0,003		
	nR 12	nC 4	
Mittelwert / mean value	xR 0,00358	xC 0,0015	
Standardabweichung / stand. deviation	sR 0,00039	sC 0,0013	90 % confidence level
F-test ISO	11,08201	df 11 / 3	Fcrit. 5,2224 $\frac{(12-1)/(4-1) = 11 / 3$
t-test ISO	5,13661	df 14	tcrit 1,7613 $12+4-2 = 6$
t-test Part 1065	3,12086		

Teflo vs. TX / Engine I / Partial Flow / Var. 2 and Var. 8

Anzahl der Proben / Number of samples	nR Reference unit PF TX	nC Candidate unit PF Teflo	COV - %
1	0,0032	0,0022	26,2
2	0,0034	0,0014	58,9
3	0,0027	0,0000	-
4	0,0033	0,0007	91,9
5	0,0031		
6	0,0033		
7	0,0028		
8	0,003		
9	0,0028		
10	0,0026		
11	0,0024		
12	0,0027		
	nR 12	nC 4	
Mittelwert / mean value	xR 0,00294	xC 0,0011	
Standardabweichung / stand. deviation	sR 0,00032	sC 0,0009	90 % confidence level
F-test ISO	8,66199	df 11 / 3	Fcrit. 5,2224 $\frac{(12-1)/(4-1) = 11 / 3$
t-test ISO	6,20855	df 14	tcrit 1,7613 $12+4-2 = 6$
t-test Part 1065	3,88513		

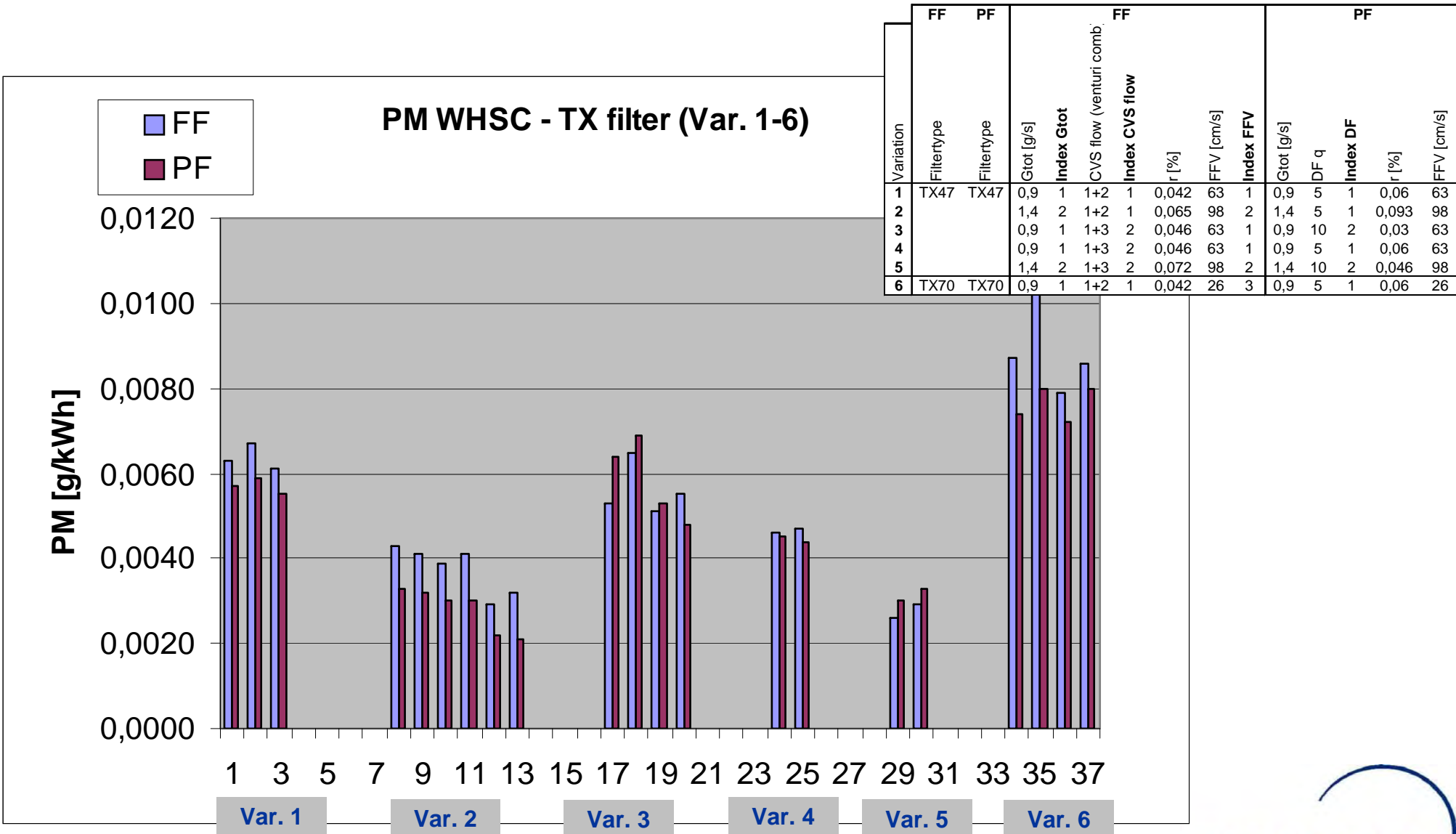
Results - Engine I – Particulate Matter – Parameter variations WHSC 1

Mean values (WHSC)

Variation	FF		FF						PF					diluted gas, PM FF [g/kWh]						raw gas, PM PF [g/kWh]						
	Filtertype	Filtertype	Gtot [g/s]	Index Gtot	CVS flow (venturi comb.)	Index CVS flow	r [%]	FFV [cm/s]	Index FFV	Gtot [g/s]	DF q	Index DF	r [%]	FFV [cm/s]	HC	CO	NOx	CO2	PMm 1.	PMm 2.	HC	CO	NOx	CO2	PMm 1.	PMm 2.
1	TX47	TX47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,028	0,069	2,490	674,513	0,006	0,006	0,002	0,059	2,605	685,575	0,006	0,006
2			1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,022	0,062	2,433	677,920	0,004	0,004	0,003	0,071	2,484	686,566	0,003	0,003
3			0,9	1	1+3	2	0,046	63	1	0,9	10	2	0,03	63	0,046	0,061	2,570	678,905	0,006	0,006	0,003	0,071	2,603	682,236	0,006	0,006
4			0,9	1	1+3	2	0,046	63	1	0,9	5	1	0,06	63	0,041	0,066	2,526	682,253	0,005	0,005	0,003	0,069	2,557	682,578	0,005	0,004
5			1,4	2	1+3	2	0,072	98	2	1,4	10	2	0,046	98	0,044	0,071	2,568	677,228	0,003	0,003	0,003	0,064	2,596	676,201	0,003	0,003
6	TX70	TX70	0,9	1	1+2	1	0,042	26	3	0,9	5	1	0,06	26	0,021	0,057	2,372	668,543	0,009	0,009	0,002	0,058	2,516	680,554	0,008	0,008
7	TEF47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,028	0,075	2,444	677,459	0,018	0,016	0,002	0,056	2,528	683,102	0,013	0,013
8			1,4	2	1+2	1	0,065	98	2	1,4	5	1	0,093	98	0,023	0,070	2,479	678,732	0,006	0,002	0,002	0,062	2,505	690,532	0,026	0,002
9	TX47	TEF47	0,9	1	1+2	1	0,042	63	1	0,9	5	1	0,06	63	0,029	0,069	2,524	679,882	0,005	0,004	0,011	0,063	2,590	678,234	0,009	0,001

Filtertype	Variations	all 9 variations						Variations 1 to 5						Variations 1 to 6						Variations 7 to 8						Variations 7 to 9												
		arithmetic mean value	standard deviation	coefficient of variance	arithmetic mean value	standard deviation	coefficient of variance	arithmetic mean value	standard deviation	coefficient of variance	arithmetic mean value	standard deviation	coefficient of variance	arithmetic mean value	standard deviation	coefficient of variance	arithmetic mean value	standard deviation	coefficient of variance	arithmetic mean value	standard deviation	coefficient of variance	arithmetic mean value	standard deviation	coefficient of variance													
Filtertype TX	all 9 variations	0,031	0,067	2,489	677,270	0,007	0,006	0,003	0,064	2,554	682,842	0,009	0,005	0,0092	0,0054	0,0617	3,6620	0,0041	0,0040	0,0026	0,0054	0,0441	4,1036	0,0069	0,0033	29,48	8,13	2,48	0,54	n.a.	n.a.	79,73	8,41	1,73	0,60	n.a.	n.a.	
		0,036	0,066	2,517	678,164	0,005	0,005	0,003	0,067	2,569	682,631	0,005	0,004	0,0096	0,0039	0,0514	2,5114	0,0013	0,0013	0,0003	0,0046	0,0460	3,6238	0,0012	0,0013	26,55	6,00	2,04	0,37	26,53	27,81	12,72	6,91	1,79	0,53	26,72	28,66	
		0,034	0,064	2,493	676,560	0,005	0,005	0,002	0,065	2,560	682,285	0,005	0,005	0,0104	0,0049	0,0716	4,2559	0,0019	0,0020	0,0004	0,0054	0,0464	3,3974	0,0016	0,0017	30,90	7,57	2,87	0,63	35,13	37,21	17,85	8,23	1,81	0,50	31,80	33,89	
	Filtertype TEFO	Variations 7 to 8	0,026	0,072	2,461	678,095	-	-	0,002	0,059	2,517	686,817	-	-	0,0029	0,0027	0,0176	0,6364	-	-	0,0001	0,0034	0,0117	3,7151	-	-	11,41	3,79	0,71	0,09	n.a.	n.a.	6,02	5,83	0,46	0,54	n.a.	n.a.
			0,027	0,071	2,482	678,691	-	-	0,005	0,060	2,541	683,956	-	-	0,0028	0,0028	0,0328	0,9896	-	-	0,0040	0,0035	0,0360	5,0569	-	-	10,68	3,94	1,32	0,15	n.a.	n.a.	79,05	5,77	1,42	0,74	n.a.	n.a.
			0,026	0,072	2,461	678,095	-	-	0,002	0,059	2,517	686,817	-	-	0,0029	0,0027	0,0176	0,6364	-	-	0,0001	0,0034	0,0117	3,7151	-	-	11,41	3,79	0,71	0,09	n.a.	n.a.	6,02	5,83	0,46	0,54	n.a.	n.a.
		0,027	0,071	2,482	678,691	-	-	0,005	0,060	2,541	683,956	-	-	0,0028	0,0028	0,0328	0,9896	-	-	0,0040	0,0035	0,0360	5,0569	-	-	10,68	3,94	1,32	0,15	n.a.	n.a.	79,05	5,77	1,42	0,74	n.a.	n.a.	
		0,026	0,072	2,461	678,095	-	-	0,002	0,059	2,517	686,817	-	-	0,0029	0,0027	0,0176	0,6364	-	-	0,0001	0,0034	0,0117	3,7151	-	-	11,41	3,79	0,71	0,09	n.a.	n.a.	6,02	5,83	0,46	0,54	n.a.	n.a.	
		0,027	0,071	2,482	678,691	-	-	0,005	0,060	2,541	683,956	-	-	0,0028	0,0028	0,0328	0,9896	-	-	0,0040	0,0035	0,0360	5,0569	-	-	10,68	3,94	1,32	0,15	n.a.	n.a.	79,05	5,77	1,42	0,74	n.a.	n.a.	

Results - Engine I – Particulate Matter – Parameter variations WHSC 2



TX Filter vs. Teflo Filter

- **Both filter materials came from same supplier.**
- **Teflo filter is hard to handle.**
 - => e.g. sticks to filter holder form PF system**
- **Teflo weighing results on engine I not reliable.**
 - => less filter weight / much higher filter weight
(electrostatic charge not completely removed)**
- **Teflo filter showed further remarkable details such as:**

Particulate Matter – Conclusions and Findings

The partial flow particulate matter measurement according to ISO 16183 respectively GTR No. 4 showed again good to very good agreement in comparison to the CVS procedure.

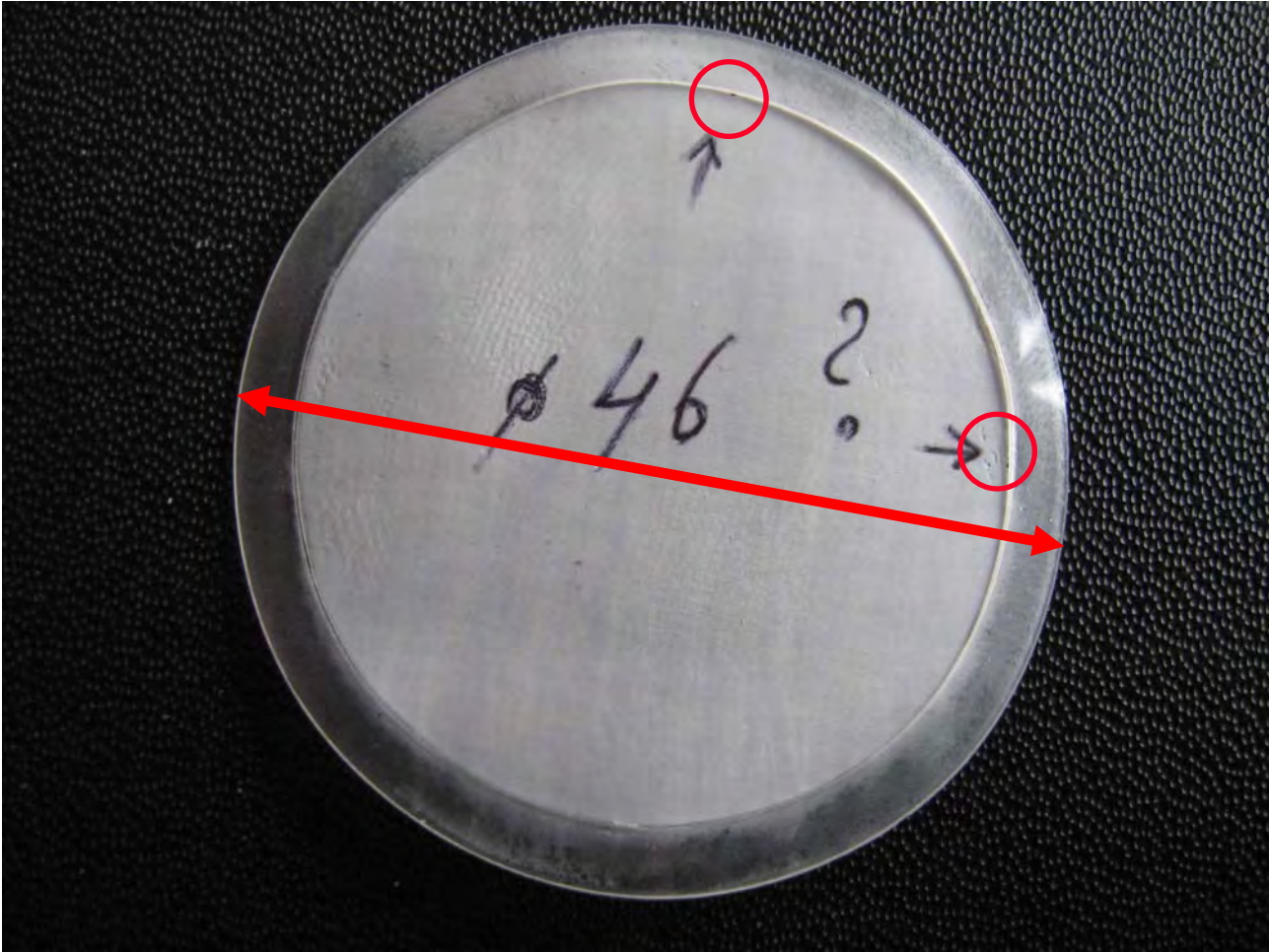
Lowest variability was observed with low dilution ratios and high filter face velocities.

Filter diameter influence was not observed. Teflo filter in 70mm with bonded ring not commercially available.

Teflo filter results slightly higher with FF than with PF on Engine II (SCR). Equivalency for TX and Teflo only given on PF using recommended settings. With PF system no influence of the filter material (Teflo vs. TX) was observed on Engine II (SCR).

On Engine I (SCRT) Teflo filter always showed lower values than TX filter. Filter equivalency according to statistical methods could not be shown.

Teflo Filter - I



Several filters show small perforation at the edge between filter and ring as delivered.

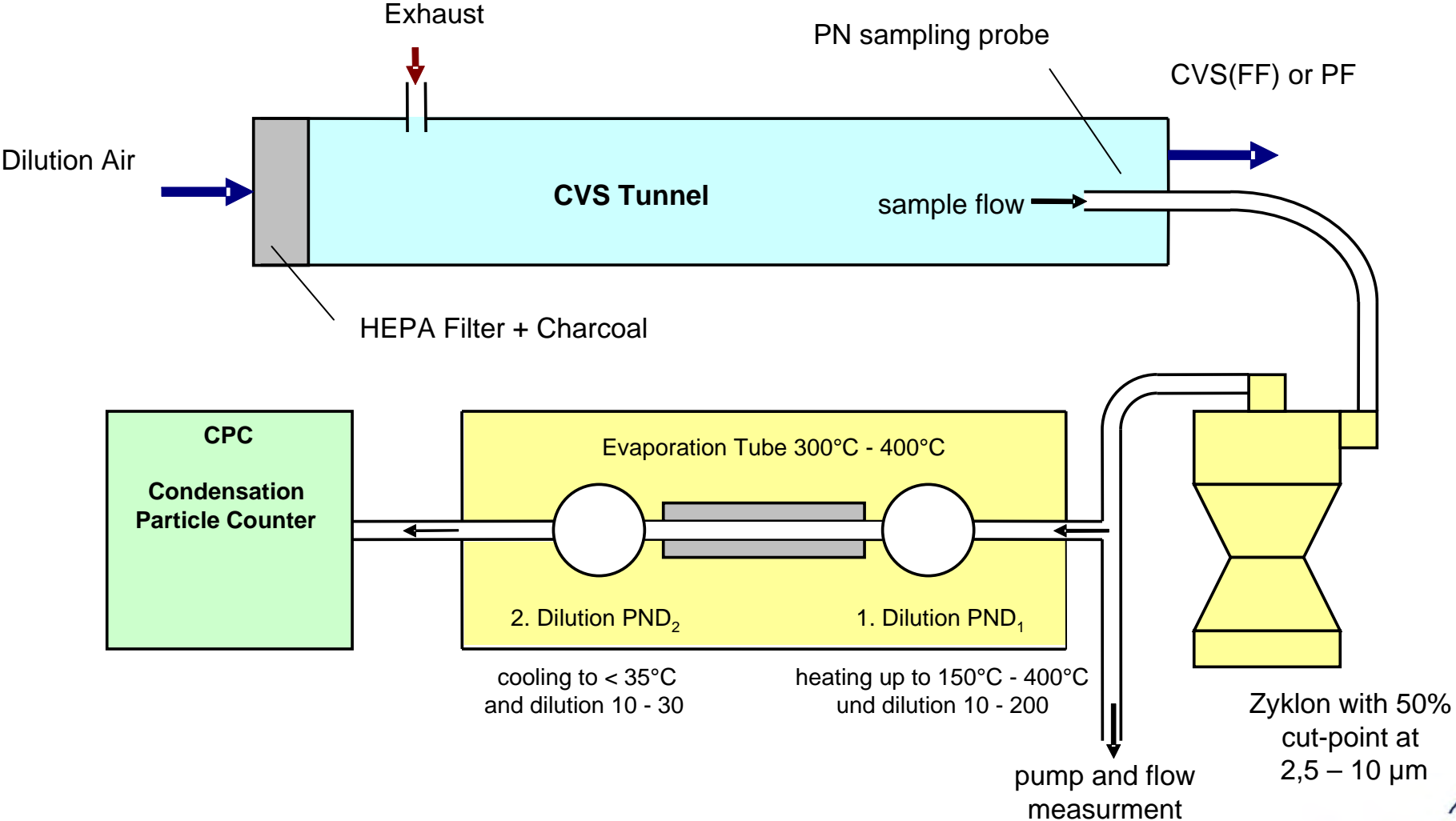
Teflo Filter – II, Discharging essential



§1065.190 PM-stabilization and weighing environments for gravimetric analysis.

- (6) We recommend that you neutralize PM sample media (e.g. filter) to within ± 2.0 V of neutral. Measure static voltages as follows:
- Measure static voltage of PM sample media (e.g. filter) according to the electrostatic voltmeter manufacturer's instructions.
 - Measure static voltage of PM sample media (e.g. filter) while the media is at least 15 cm away from any grounded surfaces to avoid mirror image charge interference.

Particulate number measurements – System layout - 1

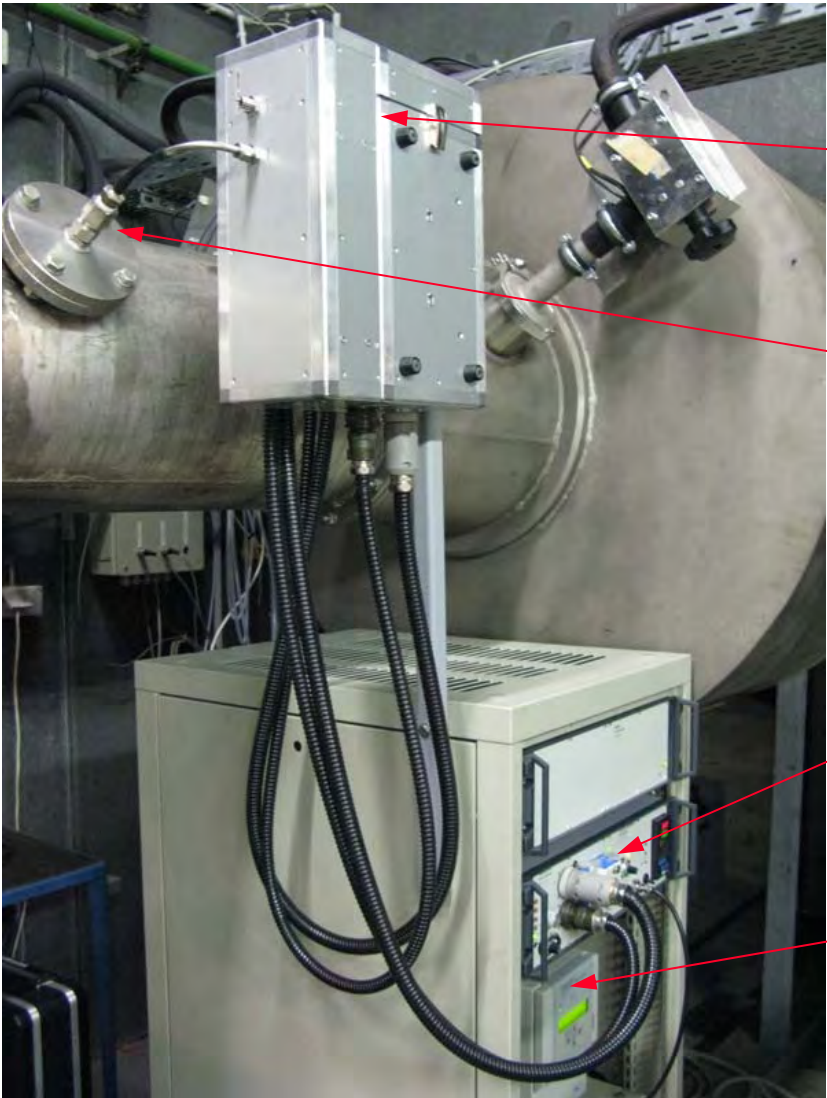


Particulate number measurements – System layout - 2



HEPA and
charcoal filter
on tunnel inlet

Particulate number measurements – System layout - 3



PND₁

PN sample probe

PND₂

CPC

Particulate number measurements – System setting – example Engine II

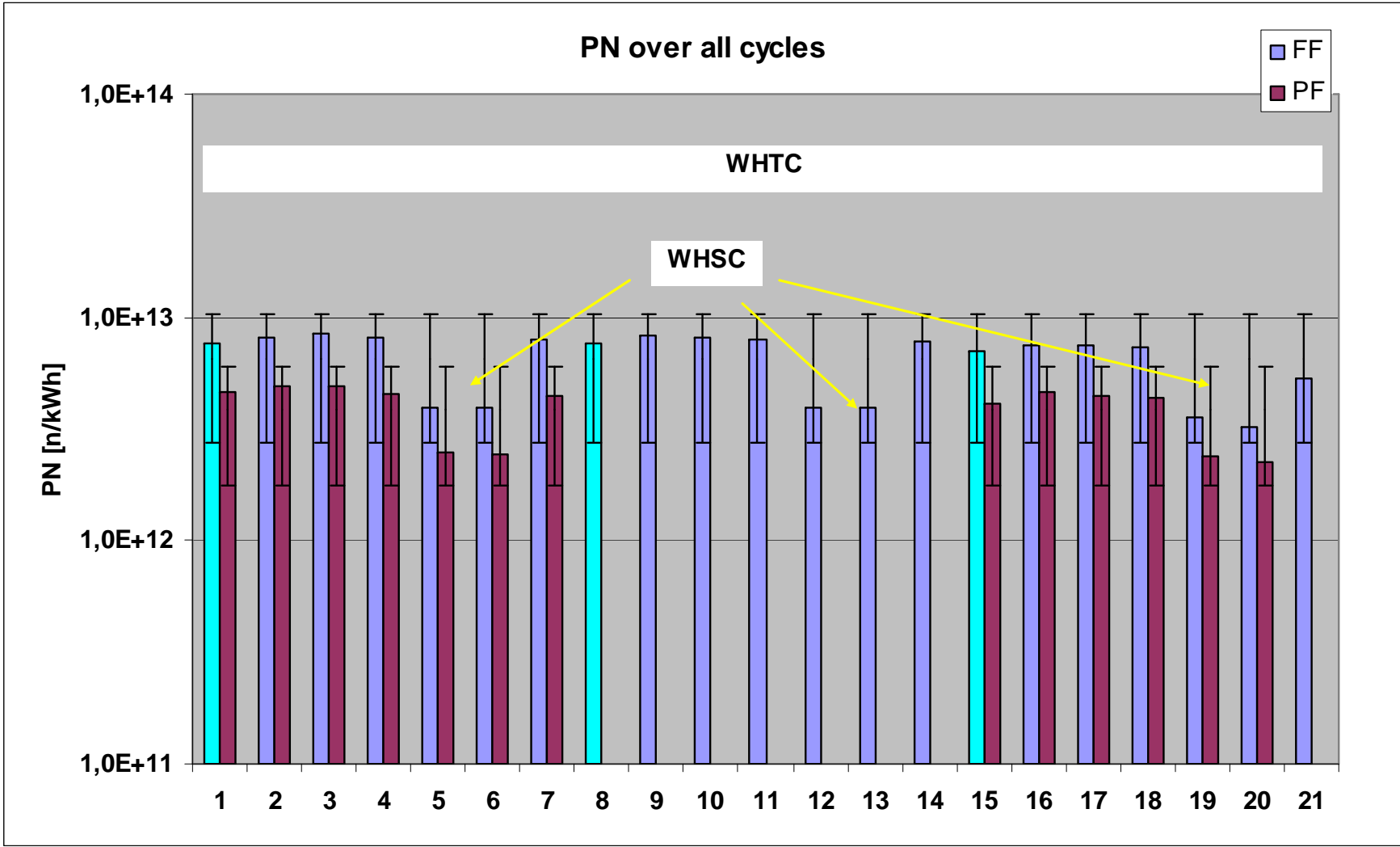
Partial Flow System

Avg DF PND1	[-]	24,57	average dilution factor upstream evaporation tube (rotating disc)
Avg DF PND2	[-]	9,99	average dilution factor downstream evaporation tube
DF3	[-]	245,57	total dilution factor
PC	[n/m ³]	1,354E+09	mean measured particle number concentration
ρ_{Luft} (20°C)	[kg/m ³]	1,204	density of diluted exhaust
M_{TOT}	[kg/test]	0,03612	with 1 l/min suction by CPC and 30 min cycle time
N_p	[n/test]	9,973E+09	particle number count recorded over cycle
M_{SAM}	[kg/test]	0,14448	with 4 l/min suction by CPC (at tunnel) and 30 min cycle time
M_{TOTW} (G_{edf_korr})	[kg/test]	2229,201	total mass of diluted exhaust gas

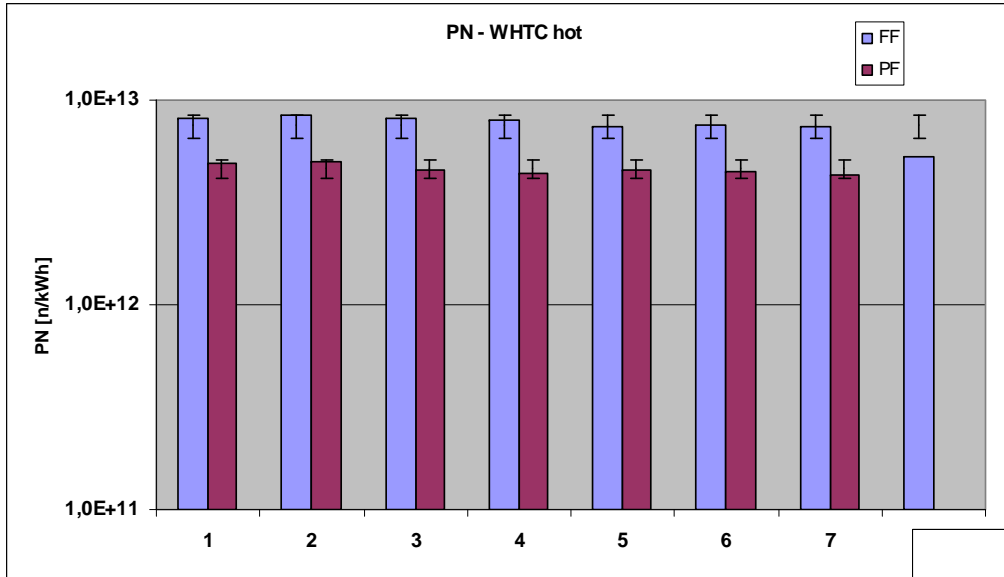
Full Flow System

Avg DF PND1	[-]	25,04	average dilution factor upstream evaporation tube (rotating disc)
Avg DF PND2	[-]	10,00	average dilution factor downstream evaporation tube
DF3	[-]	250,53	total dilution factor
PC	[n/m ³]	1,199E+09	mean measured particle number concentration
ρ_{Luft} (20°C)	[kg/m ³]	1,204	density of diluted exhaust
M_{TOT}	[kg/test]	0,03612	with 1 l/min suction by CPC and 30 min cycle time
N_p	[n/test]	9,010E+09	particle number count recorded over cycle
M_{SAM}	[kg/test]	0,14448	with 4 l/min suction by CPC (at tunnel) and 30 min cycle time
M_{TOTW} (CVSist)	[kg/test]	4113,572	total mass of diluted exhaust gas

Particulate number measurements – Engine II - 1



Particulate number measurements – Engine II - 2

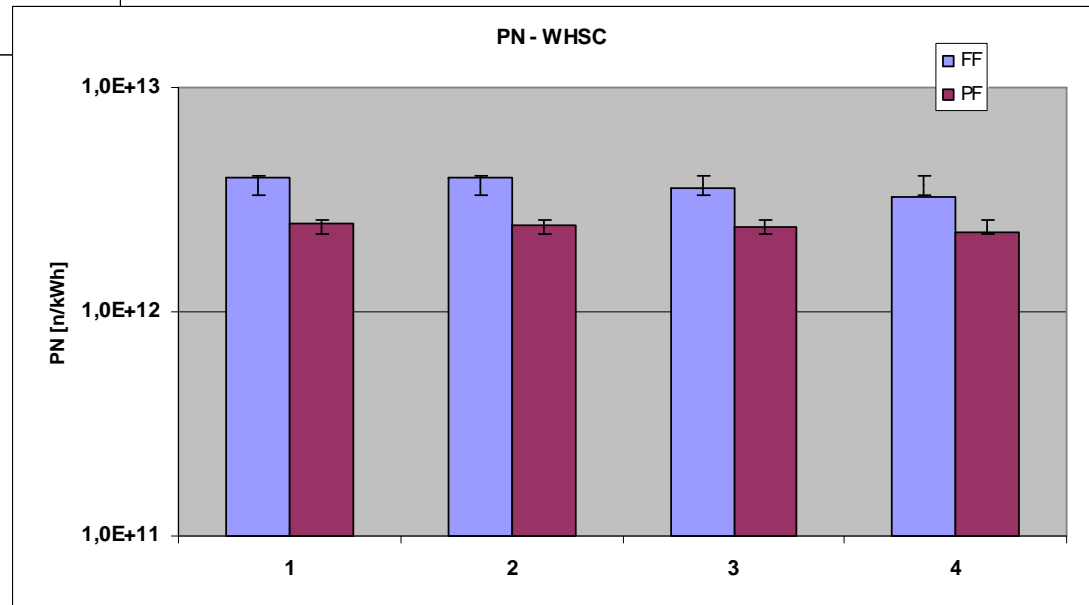


WHTC hot

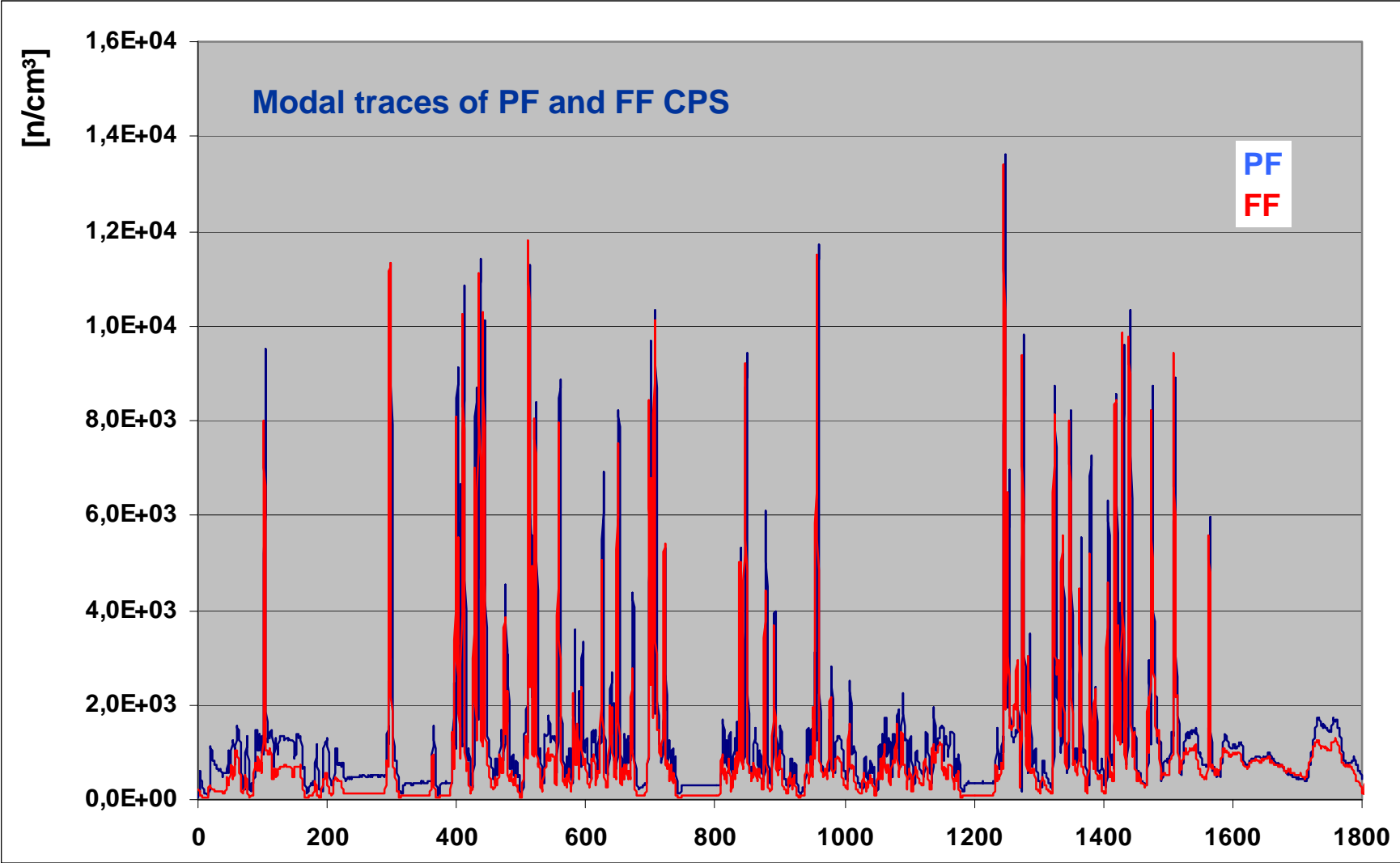
Day	Cycle	Test	PN [n/test]		PN [n/kWh]	
			PMn FF	PMn PF	PMn FF	PMn PF
10	WHTC hot	081021102_WHTC_02	2,7025E+14	1,6271E+14	8,091E+12	4,871E+12
10	WHTC hot	081021103_WHTC_03	2,7983E+14	1,6586E+14	8,378E+12	4,966E+12
10	WHTC hot	081021104_WHTC_04	2,6946E+14	1,5293E+14	8,068E+12	4,579E+12
10	WHTC hot	081021107_WHTC_05	2,6863E+14	1,4761E+14	8,043E+12	4,419E+12
12	WHTC hot	081023102_WHTC_02	2,4868E+14	1,5321E+14	7,445E+12	4,587E+12
12	WHTC hot	081023103_WHTC_03	2,5163E+14	1,4872E+14	7,534E+12	4,453E+12
12	WHTC hot	081023104_WHTC_04	2,4683E+14	1,4517E+14	7,390E+12	4,346E+12
12	WHTC hot	081023107_WHTC_05	1,7664E+14	1,0514E+14	5,289E+12	3,021E+12
arithmetic mean value			2,5149E+14	1,5374E+14	7,5297E+12	4,6031E+12
standard deviation			3,0421E+13	7,2148E+12	9,1081E+11	2,1601E+11
coefficient of variance			12,10	4,69	12,10	4,69

WHSC

Day	Cycle	Test	PN [n/test]		PN [n/kWh]	
			PMn FF	PMn PF	PMn FF	PMn PF
10	WHSC	081021105_WHSC_01	1,8452E+14	1,1475E+14	3,968E+12	2,468E+12
10	WHSC	081021106_WHSC_02	1,8444E+14	1,1341E+14	3,966E+12	2,439E+12
12	WHSC	081023105_WHSC_01	1,6548E+14	1,1133E+14	3,559E+12	2,394E+12
12	WHSC	081023106_WHSC_02	1,5101E+14	1,0514E+14	3,247E+12	2,261E+12
arithmetic mean value			1,7136E+14	1,1116E+14	3,6852E+12	2,3905E+12
standard deviation			1,4081E+13	3,68E+12	3,0282E+11	7,9139E+10
coefficient of variance			8,22	3,31	8,22	3,31



Particulate number measurements – Engine II - 3



Particulate number measurements – System setting – example Engine I

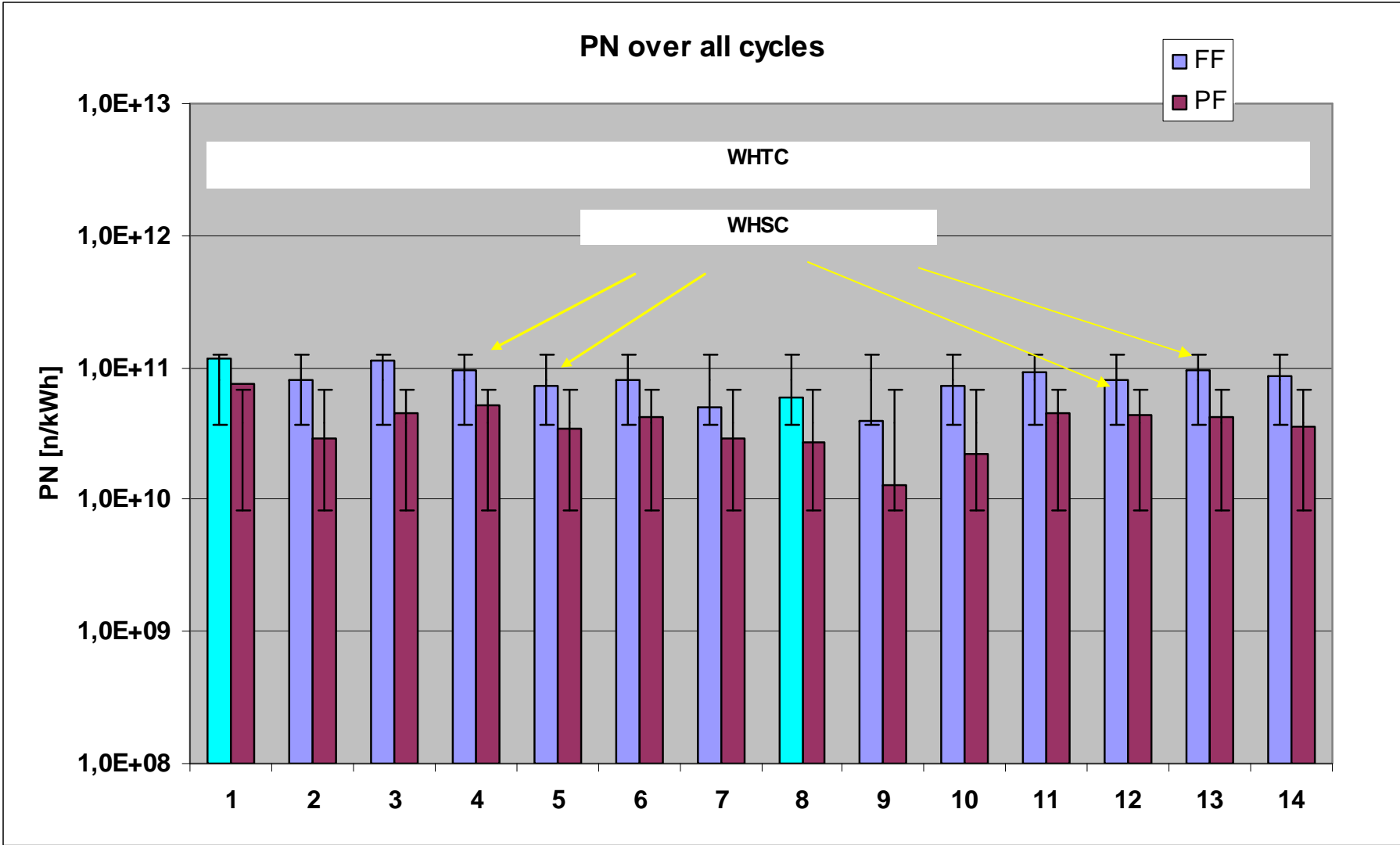
Partial Flow System

Avg DF PND1	[-]	25,15	average dilution factor upstream evaporation tube (rotating disc)
Avg DF PND2	[-]	10,00	average dilution factor downstream evaporation tube
DF3	[-]	251,36	total dilution factor
PC	[n/m ³]	1,092E+07	mean measured particle number concentration
ρ_{Luft} (20°C)	[kg/m ³]	1,204	density of diluted exhaust
M _{TOT}	[kg/test]	0,03612	with 1 l/min suction by CPC and 30 min cycle time
N _P	[n/test]	8,233E+07	particle number count recorded over cycle
M _{SAM}	[kg/test]	0,14448	with 4 l/min suction by CPC (at tunnel) and 30 min cycle time
M _{TOTW} (G _{edf_korr})	[kg/test]	1190,076	total mass of diluted exhaust gas

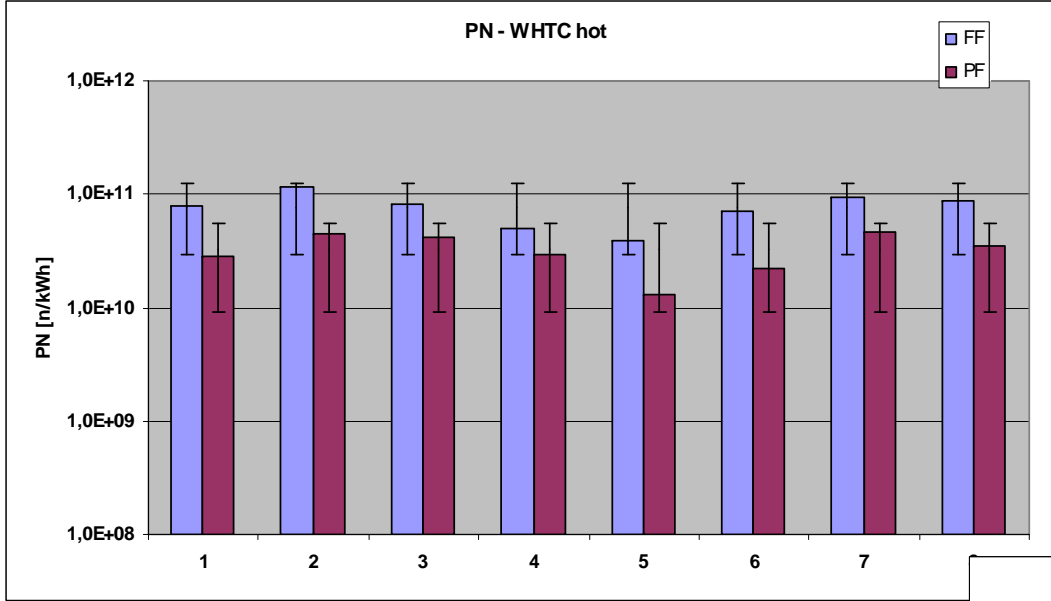
Full Flow System

Avg DF PND1	[-]	25,08	average dilution factor upstream evaporation tube (rotating disc)
Avg DF PND2	[-]	10,00	average dilution factor downstream evaporation tube
DF3	[-]	250,92	total dilution factor
PC	[n/m ³]	1,555E+07	mean measured particle number concentration
ρ_{Luft} (20°C)	[kg/m ³]	1,204	density of diluted exhaust
M _{TOT}	[kg/test]	0,03612	with 1 l/min suction by CPC and 30 min cycle time
N _P	[n/test]	1,170E+08	particle number count recorded over cycle
M _{SAM}	[kg/test]	0,14448	with 4 l/min suction by CPC (at tunnel) and 30 min cycle time
M _{TOTW} (CVSist)	[kg/test]	2065,469	total mass of diluted exhaust gas

Particulate number measurements – Engine I - 1



Particulate number measurements – Engine I - 2

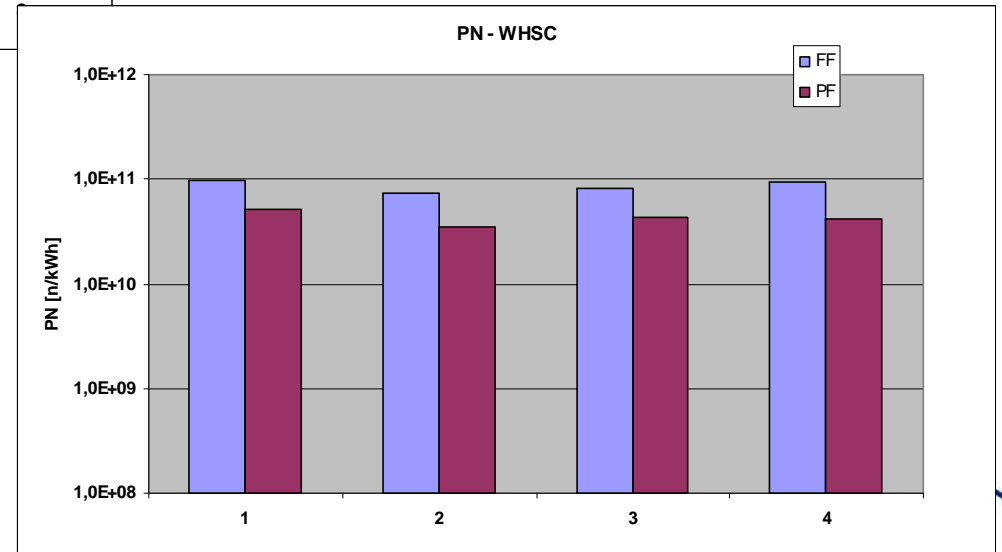


WHTC hot

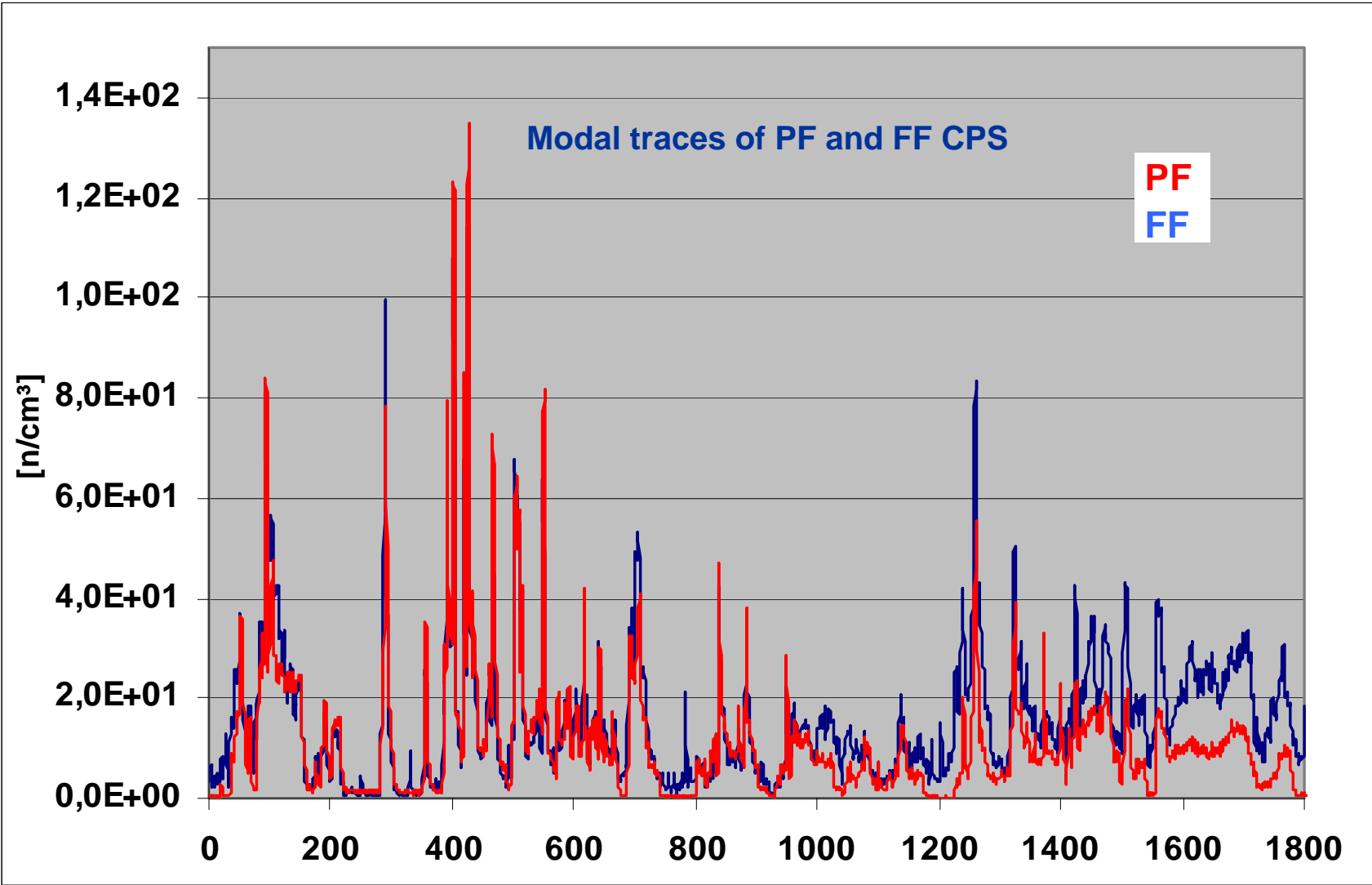
Day	Cycle	Test	PN [n/test]		PN [n/kWh]	
			PMn FF	PMn PF	PMn FF	PMn PF
2*	WHTC hot	090128103_WHTC_03	1,5354E+12	5,5701E+11	7,938E+10	2,880E+10
2*	WHTC hot	090128104_WHTC_04	2,2175E+12	8,8194E+11	1,146E+11	4,560E+10
2*	WHTC hot	090128107_WHTC_05	1,5796E+12	8,1825E+11	8,167E+10	4,230E+10
2*	WHTC hot	090128108_WHTC_06	9,6622E+11	5,5931E+11	4,995E+10	2,892E+10
3*	WHTC hot	090129102_WHTC_02	7,6449E+11	2,5155E+11	3,952E+10	1,301E+10
3*	WHTC hot	090129103_WHTC_03	1,392E+12	4,2681E+11	7,197E+10	2,207E+10
3*	WHTC hot	090129104_WHTC_04	1,8118E+12	8,885E+11	9,367E+10	4,594E+10
3*	WHTC hot	090129107_WHTC_05	1,673E+12	6,7817E+11	8,649E+10	3,506E+10
arithmetic mean value			1,4925E+12	6,3269E+11	7,7163E+10	3,2711E+10
standard deviation			4,3108E+11	2,1297E+11	2,2287E+10	1,101E+10
coefficient of variance			28,88	33,66	28,88	33,66

WHSC

Day	Cycle	Test	PN [n/test]		PN [n/kWh]	
			PMn FF	PMn PF	PMn FF	PMn PF
2*	WHSC	090128105_WHSC_01	2,6019E+12	1,402E+12	9,626E+10	5,187E+10
2*	WHSC	090128106_WHSC_02	1,994E+12	9,4209E+11	7,377E+10	3,485E+10
3*	WHSC	090129105_WHSC_01	2,1847E+12	1,1613E+12	8,082E+10	4,296E+10
3*	WHSC	090129106_WHSC_02	2,5731E+12	1,1307E+12	9,519E+10	4,183E+10
arithmetic mean value			2,3384E+12	1,159E+12	8,6512E+10	4,2879E+10
standard deviation			2,5826E+11	1,6349E+11	9554487906	6048565632
coefficient of variance			11,04	14,11	11,04	14,11



Particulate number measurements – Engine I - 3



Particulate number measurements – findings

COV of number measurements on both PF and FF good to very good on Engine II. COV became higher on Engine I most likely due to less PN counts.

Dilution settings recommended by PMP may to high for very low emissions.

PF number count was always lower than FF number count. No final explanation found yet. May PF dilution settings for PND₁ and PND₂ need to be adjusted.

Both systems (CPC on FF / CPC on PF) showed same emission traces in modal measurement.



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