Sampling Line Loss Experiments 2010

DLR Institute of Combustion Technology

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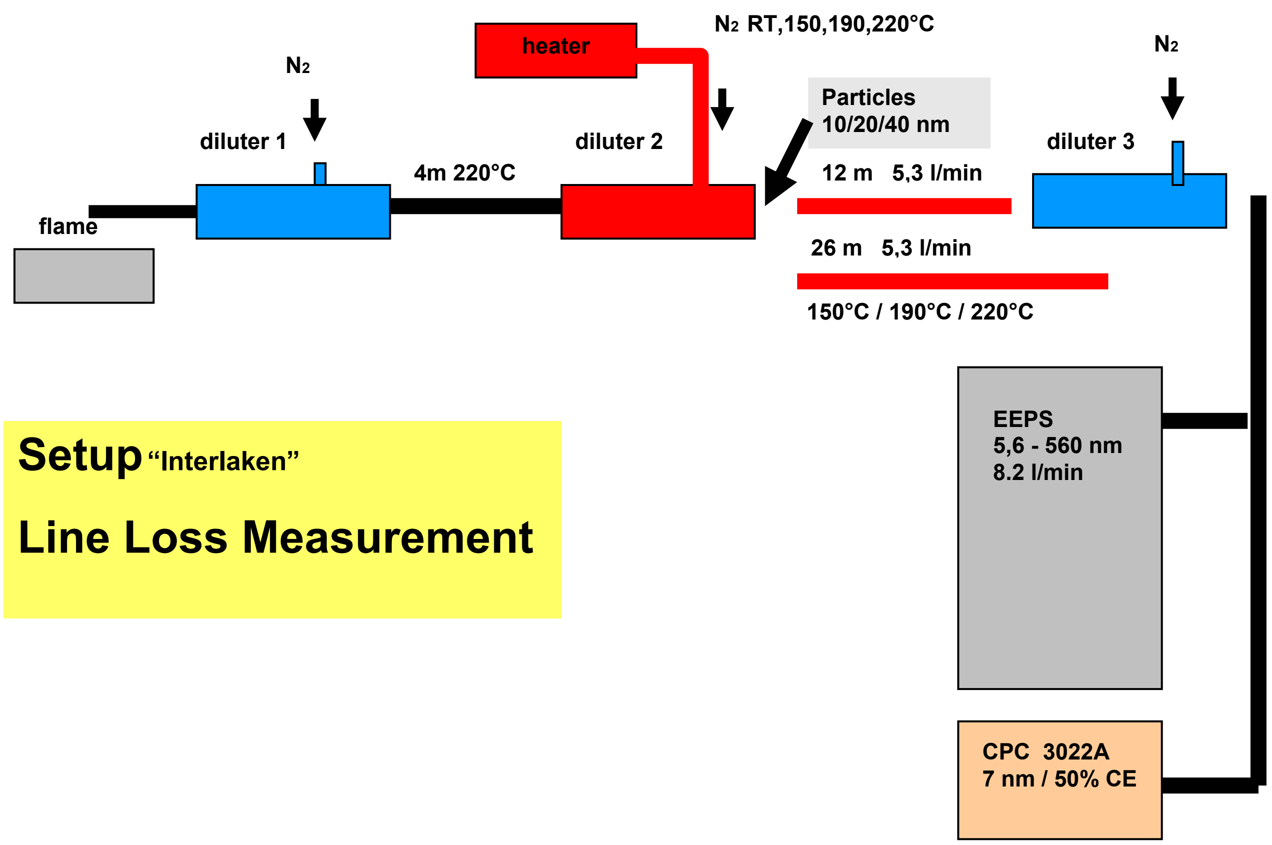
Report: Sampling line loss experiments 2010

Soot source for the line loss experiments was the „DLR premixed soot generator". In this patented soot generator, a stabilized premixed ethylene flame is used as soot source. The particle mean diameter is controlled by air-fuel ratio. The mean diameter of the particle size distribution can be set between 2nm and 200nm.
In the setup 2009, all three diluters worked with N_2 at room temperature. The 4m „conditioning line" was at 150°C, in order to remove volatiles. In this setup, the diluter 2 exit temperature was not equal to the temperature of the tested line.

In the setup 2010 (tests presented at Interlaken), the 4m „conditioning line" was at 220°C. The diluter 2 and the N_2 for diluter 2 was temperature controlled in order have the same temperature at diluter 2 exit and tested sampling line.
At diluter 3 there is always cold dilution in order to bring temperature down to instruments inlet.

In the disscussuion at Interlaken, again the question of volatile particles at exit of diluter 2 araised.
In order to address this concern, the line loss experiments were repeated first with a hot dilution at diluter 1 at 220°C (see figure 6. setup B) and later with the dilution 1 and the 4m preconditioning line both at 300°C (see figure 7, setup C). The measurement results show that the high number losses are not an effect of evaporation of nanoparticles (no number loss increase from setup B to setup C). The non-volatile number loss results for the sampling lines measured with setup C can be considered robust for the given line material at 6mm inner diameter, the given line temperatures and a flow rate of 5.3 liters per minute (see table 2).

Setup "Interlaken"



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In Fig.2 the line losses in a 12m stainless steel line are plotted vs. particle diameter. Line temperatures are 150°C, 190°C and 220°C. Line losses increase with increasing temperature and with decreasing diameter. In Fig.3 are the same measurements, but losses are plotted vs. temperature. Fig.4 shows the losses measured with CPC 3022A.

Fig.5 shows the differences at 190°C measured with EEPS and CPC. The differences increase with increasing particle diameter.

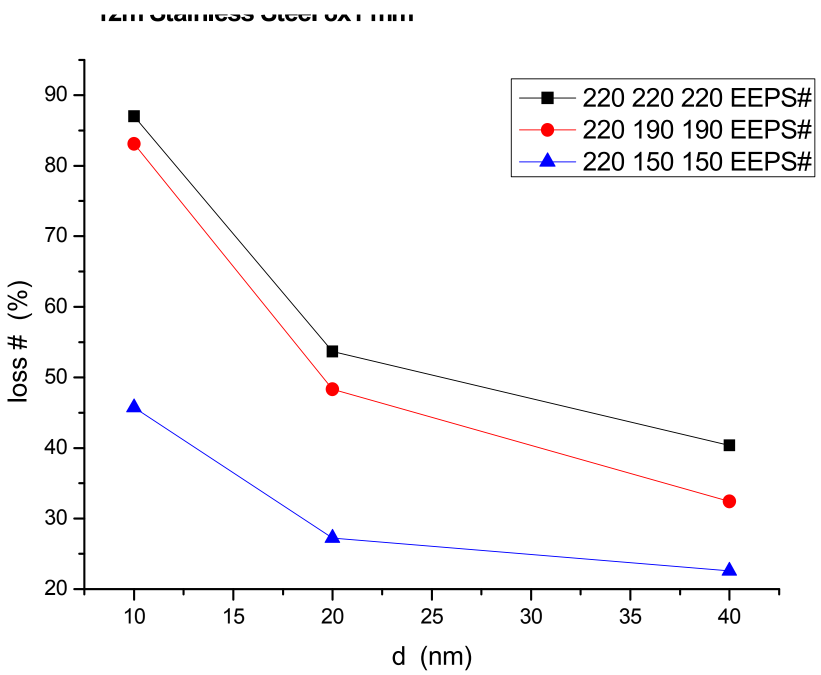

Fig. 2

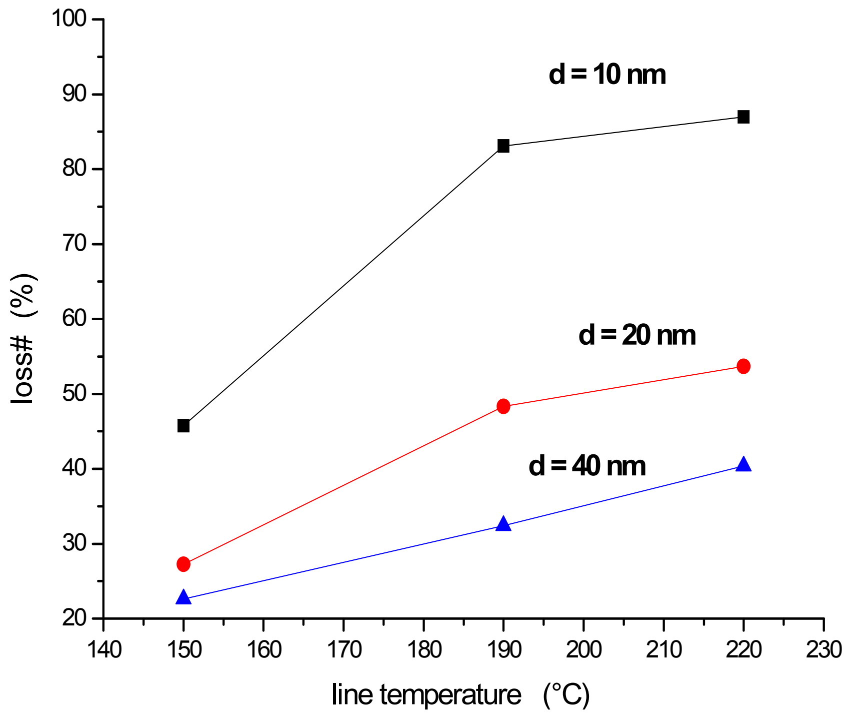

Fig. 3

Fehler! Verweisquelle konnte nicht gefunden werden.

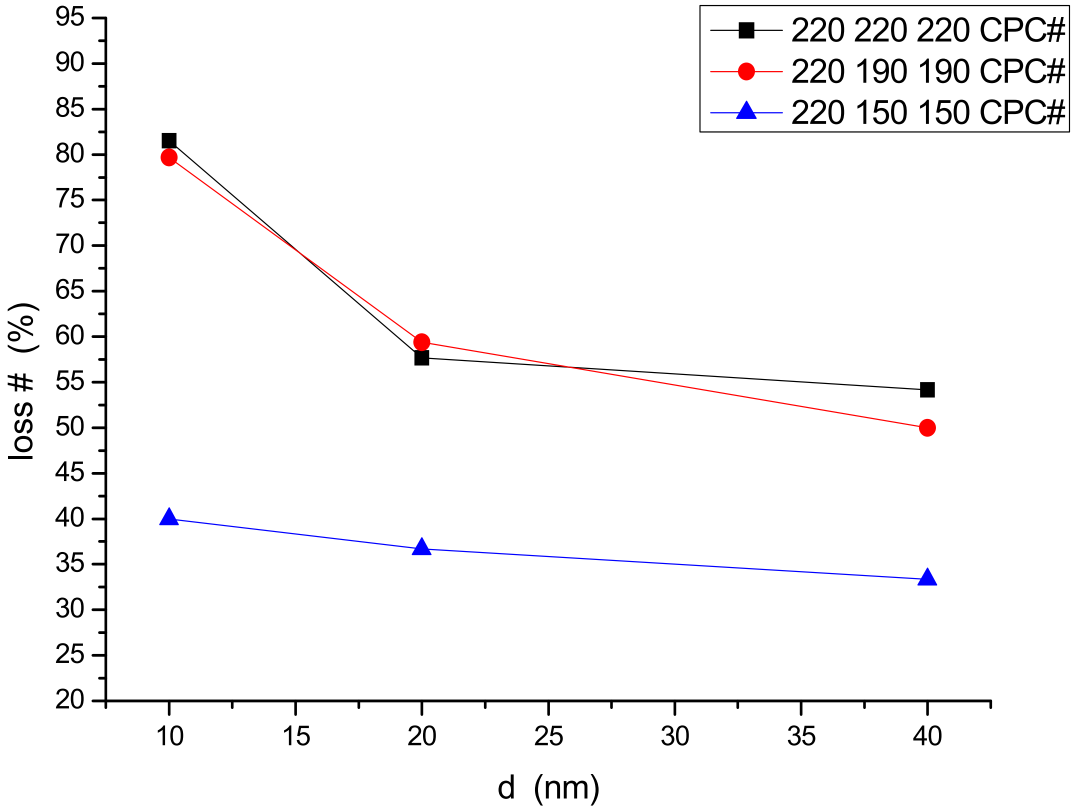
220 220 220 CPC#
220 190 190 CPC#
220 150 150 CPC#
loss # (%)
d (nm)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
10
15
20
25
30
35
40

Fig. 4

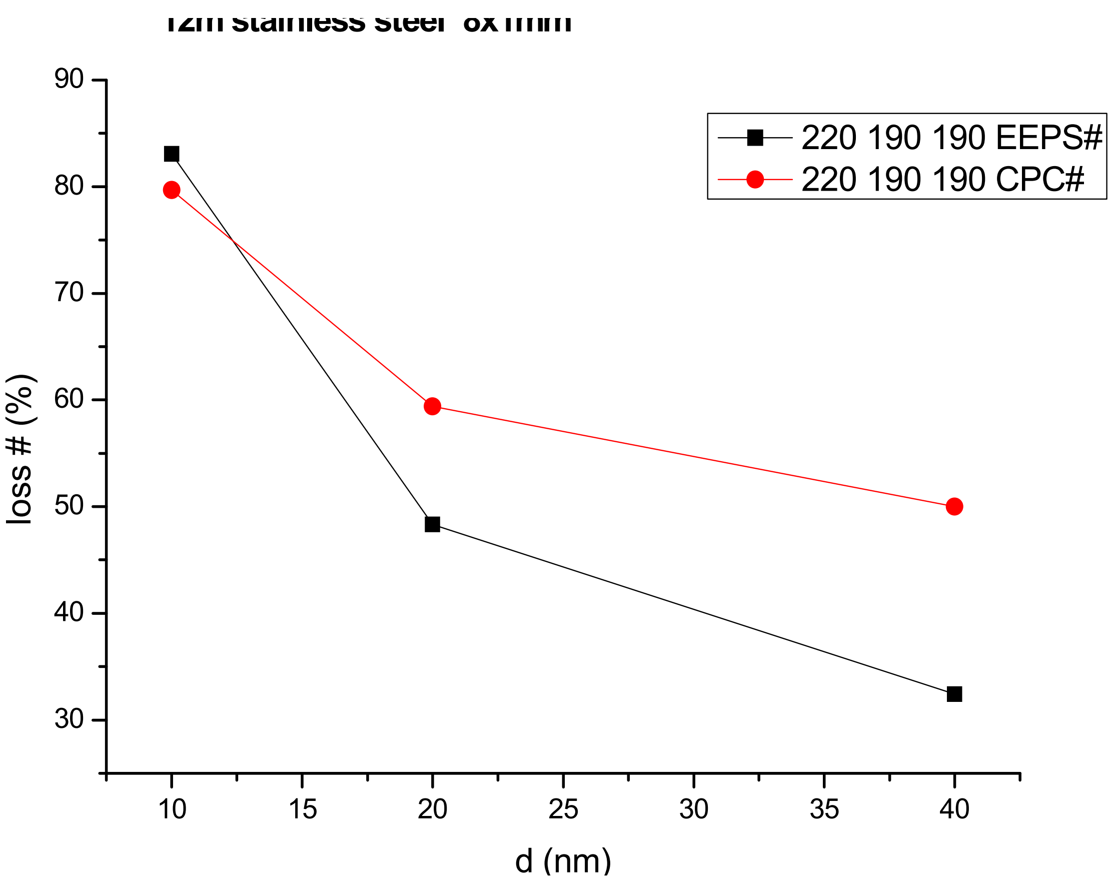
220 190 190 EEPS#
220 190 190 CPC#
loss # (%)
d (nm)
90
80
70
60
50
40
30
10
15
20
25
30
35
40

Fig.5

Table 1: Setup “Interlaken” // 12m stainless steel // 150°C 190°C 220°C

Φ	Geo.Mean d	Mass	Anzahl EEPS	Anzahl CPC	T_L1	T_ML	Position	Verd.2	T_Abgas VS2	Verluste EEPS	Verluste CPC
[-]	[nm]	[µg/m³]	[#/cm³]	[#/cm³]	[°C]	[°C]		[heiß/kalt]	[°C]	[%]	[%]
1,825	9,9	0,138	1,69E+05	2,5E+05	220	-	tip	heiß	150		
1,975	21,7	14,7	9,17E+05	1,2E+06	220	-	tip	heiß	150		
2,3	42,0	142,5	1,46E+06	2,4E+06	220	-	tip	heiß	150		
1,825	11,3	0,111	9,17E+04	1,5E+05	220	150	exit	heiß	150	45,74	40,00
1,975	24,8	12,8	6,67E+05	7,6E+05	220	150	exit	heiß	150	27,26	36,67
2,3	47,1	131	1,13E+06	1,6E+06	220	150	exit	heiß	150	22,60	33,33

Φ	Geo.Mean d	Mass	Anzahl EEPS	Anzahl CPC	T_L1	T_ML	Position	Verd.2	T_Abgas VS2	Verluste EEPS	Verluste CPC
[-]	[nm]	[µg/m³]	[#/cm³]	[#/cm³]	[°C]	[°C]		[heiß/kalt]	[°C]	[%]	[%]
1,825	10,0	0,17	2,17E+05	3,1E+05	220	-	tip	heiß	190		
1,975	21,0	15,4	1,13E+06	1,7E+06	220	-	tip	heiß	190		
2,3	42,2	149,9	1,48E+06	2,6E+06	220	-	tip	heiß	190		
1,825	10,3	0,0329	3,67E+04	6,3E+04	220	190	exit	heiß	190	83,09	79,68
1,975	22,9	9,29	5,84E+05	6,9E+05	220	190	exit	heiß	190	48,32	59,41
2,3	45,9	111	1,00E+06	1,3E+06	220	190	exit	heiß	190	32,43	50,00

Φ	Geo.Mean d	Mass	Anzahl EEPS	Anzahl CPC	T_L1	T_ML	Position	Verd.2	T_Abgas VS2	Verluste EEPS	Verluste CPC
[-]	[nm]	[µg/m³]	[#/cm³]	[#/cm³]	[°C]	[°C]		[heiß/kalt]	[°C]	[%]	[%]
1,825	9,8	0,126	1,70E+05	2,6E+05	220	-	tip	heiß	220		
1,975	18,9	10,2	9,84E+05	1,3E+06	220	-	tip	heiß	220		
2,3	36,2	97,4	1,32E+06	2,4E+06	220	-	tip	heiß	220		
1,825	9,8	0,0165	2,21E+04	4,8E+04	220	220	exit	heiß	220	87,00	81,54
1,975	20,6	5,28	4,56E+05	5,5E+05	220	220	exit	heiß	220	53,66	57,69
2,3	39,6	64	7,87E+05	1,1E+06	220	220	exit	heiß	220	40,38	54,17

Fig 6: **Setup B: Improved Setup / particle preconditioning at 220°C**

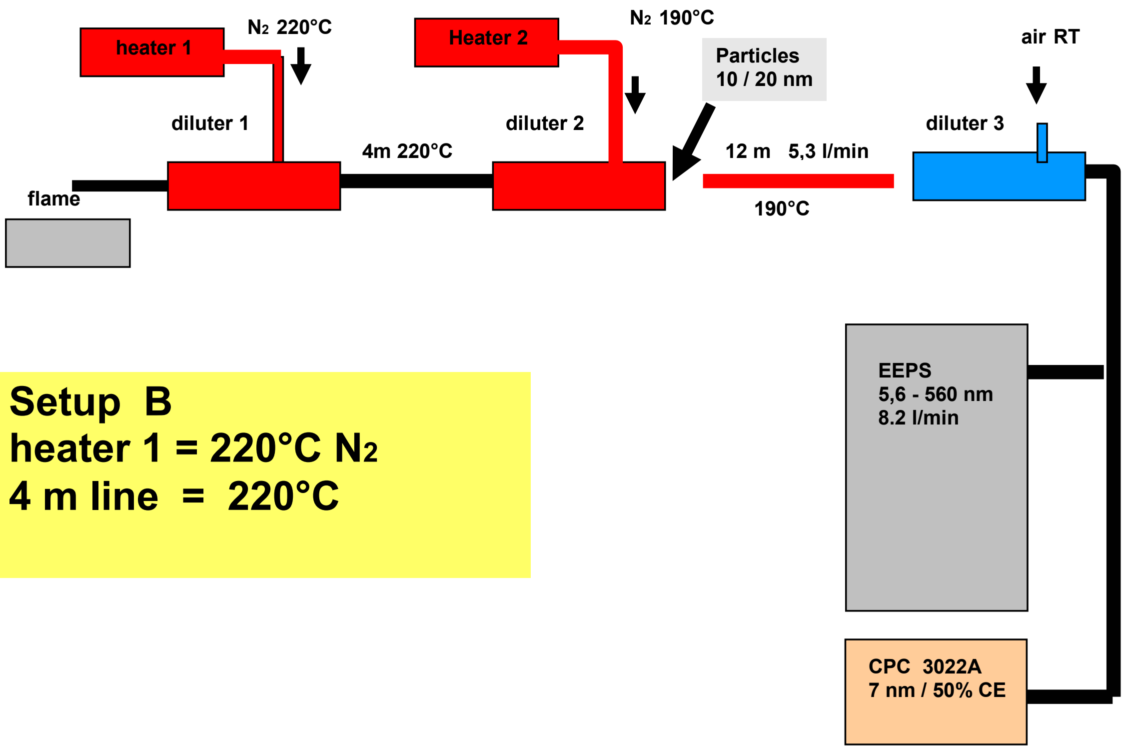

Fig. 7: **Setup C: Improved Setup / particle preconditioning at 300°C**

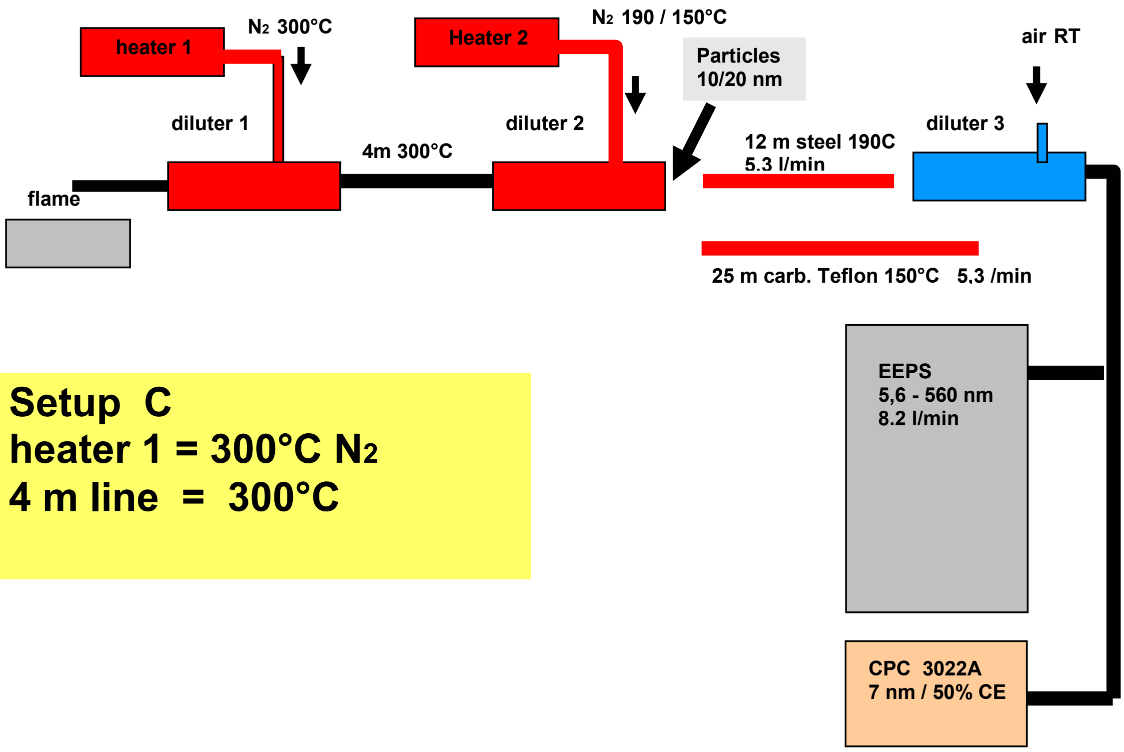

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Table 2: Measurments with setup B and setup C

GMD (nm)	Tip / Exit	#EEPS	#CPC	precond. °C	Line °C	
9,6	tip	1,80E+05	1,65E+05	220	190	Steel 12m
10	exit	1,60E+04	3,40E+04	220	190	steel 12m
		91,10%	**79,40%**			
19,7	tip	8,00E+05	9,45E+05	220	190	steel 12m
22,6	exit	4,23E+05	4,00E+05	220	190	steel 12m
		47,10%	**57,70%**			
###						
9,7	tip	4,60E+04	8,50E+04	300	190	steel 12m
10	exit	9,00E+03	1,50E+04	300	190	steel 12m
		80,40%	**82,35%**			
21,2	tip	5,80E+05	6,50E+05	300	190	steel 12m
24,2	exit	3,20E+05	3,10E+05	300	190	steel 12m
		44,80%	**52,30%**			
##						
7	tip	1,00E+03	1,30E+04	300	150	carb teflon 25m
9	exit		9,00E+02	300	150	carb teflon 25m
			93,10%			
8,8	tip	2,00E+04	5,90E+04	300	150	carb teflon 25m
9	exit	3,00E+03	3,30E+03	300	150	carb teflon 25m
		85%	**94,50%**			
9,7	tip	5,70E+04	1,00E+05	300	150	carb teflon 25m
11,5	exit	1,20E+04	1,20E+04	300	150	carb teflon 25m
		78,90%	**88%**			
19,7	tip	5,90E+05	7,10E+05	300	150	carb teflon 25m
23,8	exit	2,30E+05	2,10E+05	300	150	carb teflon 25m
		61%	**70,4**			

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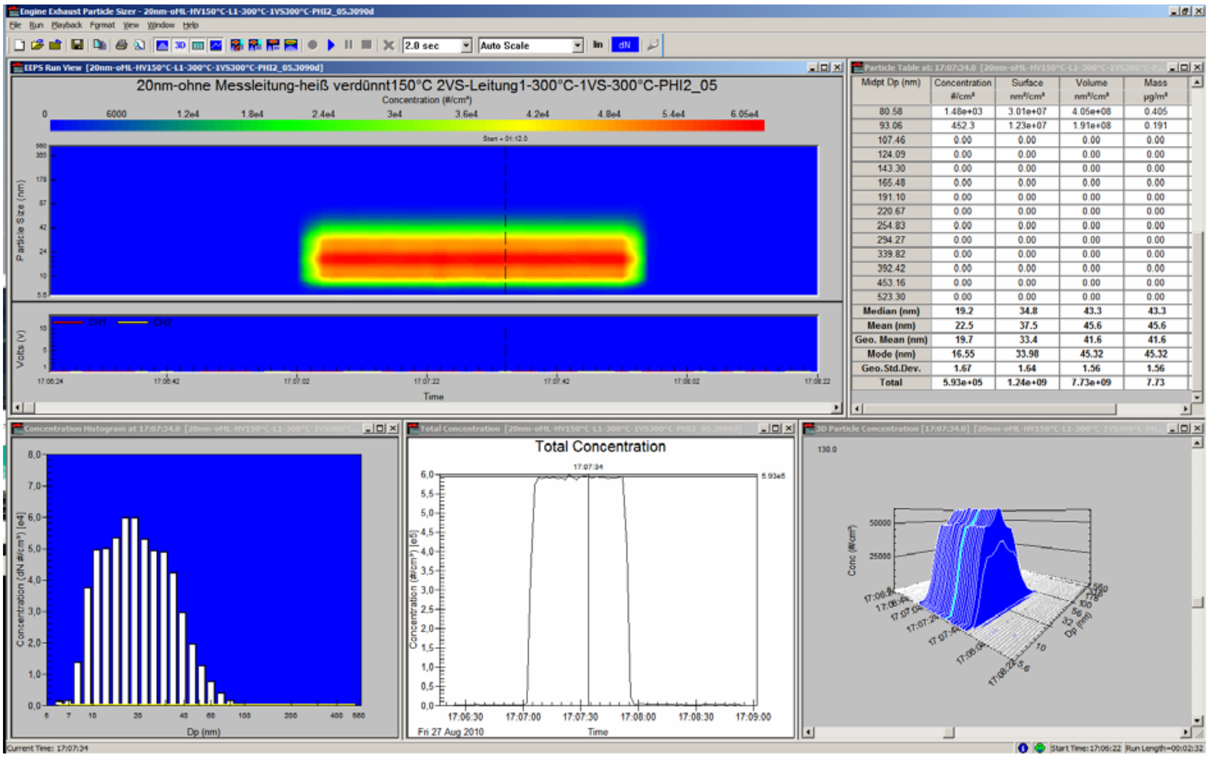
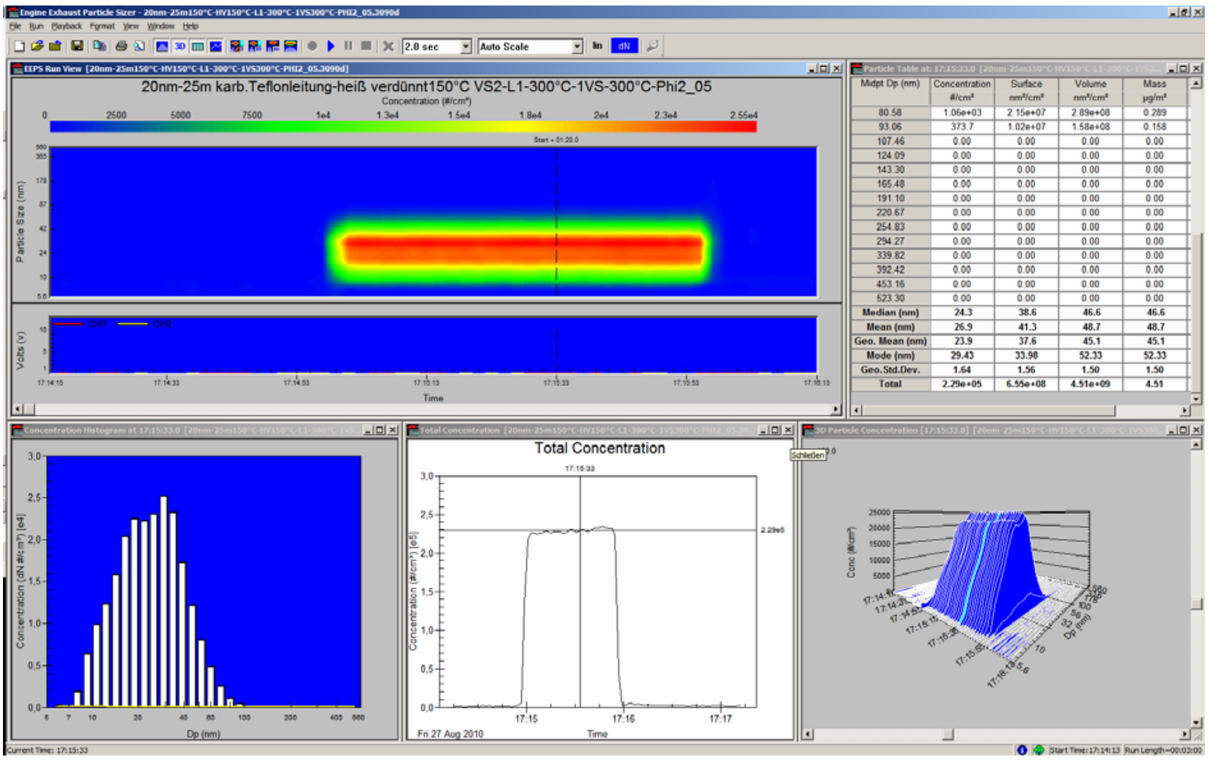
Tip / 25m carb. Teflon // 20 nm Particle diameter // Precond. at 300 °C



Exit / 25m carb. Teflon // 20 nm Particle diameter // Precond. at 300 °C

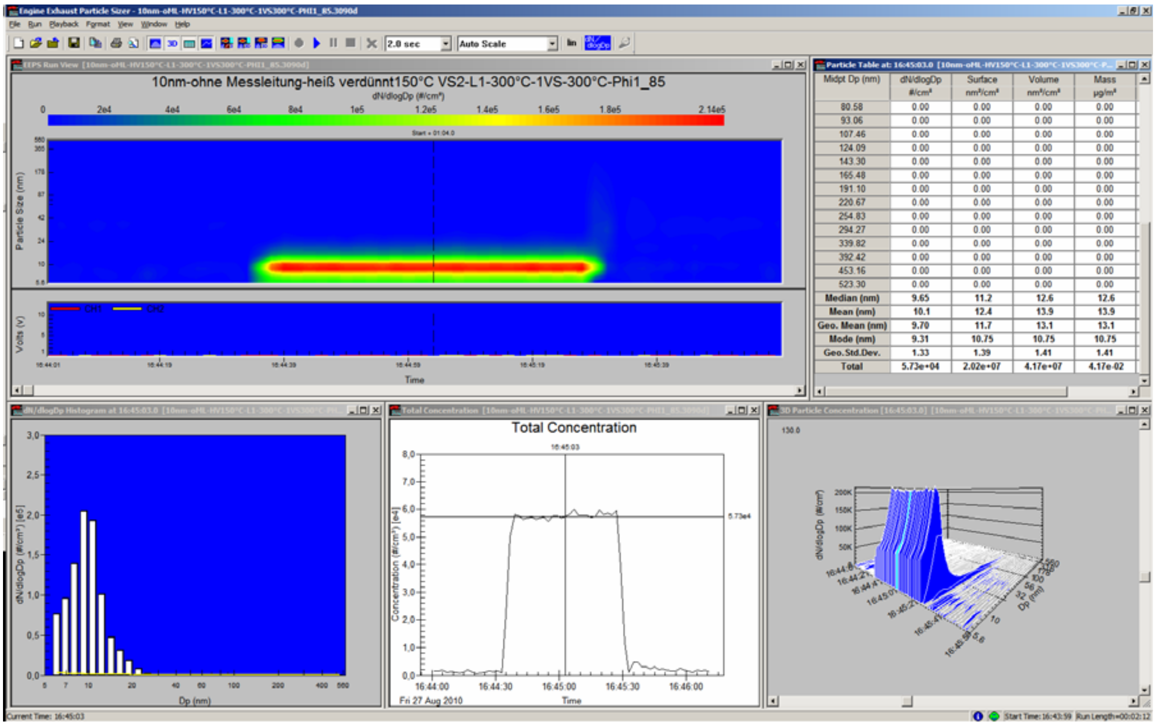


25m carb. TEFLON® 150°C // 20nm particle diameter // particles preconditioned at 300°C

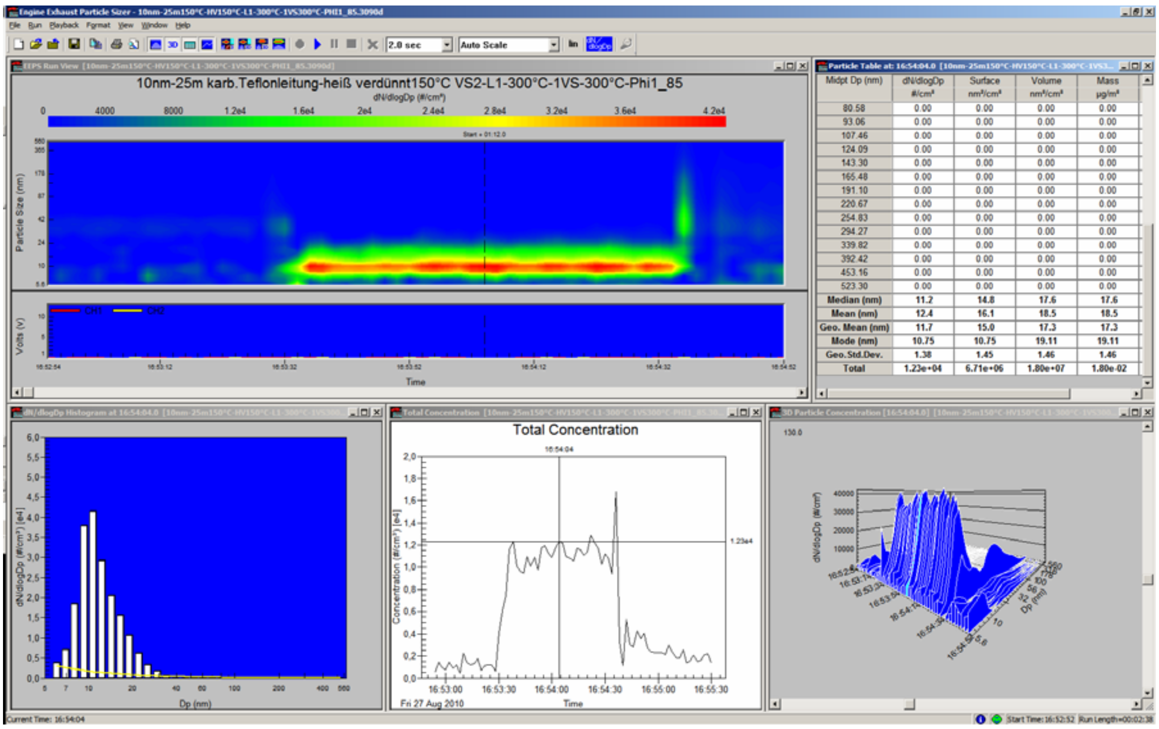
	GMD nm	EEPS conc 1/cm^3	CPC conc 1/cm^3	mass EEPS µg/ m^3
Tip	19,7	5,04e6	6,03e6	65,7
End	23,9	1,95e6	1,78e6	38,3
Loss		**61,3%**	**70,5%**	**41,7%**

(dilution corrected (x8.5))

Tip / 25m carb. Teflon // 10 nm Particle diameter // Preconditioned at 300 °C



Exit / 25m carb. Teflon // 10 nm Particle diameter // Preconditioned at 300 °C



25m carb. TEFLON® 150°C 10nm particle diameter // particles preconditioned at 300°C

	GMD nm	EEPS conc 1/cm^3	CPC conc 1/cm^3	mass EEPS µg/ m^3
Tip	9,7	4,87e5	8,5e5	3,54e-1
Exit	11,7	1,05e5	1,02e5	1,53e-1
Loss		**78,4%**	**88%**	**56,8%**

(dilution corrected (x8.5))

Measurements at 190°C with the carb. Teflon line wasn't possible, because of decomposition of the material.

The losses in mass are less than in number concentration. This is because of agglomeration in the sampling line. The particle diameters are bigger at line exit than at line tip. Agglomeration is a function of number concentration and residence time. Particle number concentration at engine exit can be much higher than the line tip concentrations in this experiment. Small particles at high concentration show very fast agglomeration. Particles of 10nm and a concentration of 10E8/cm^3 can reduce number concentration by 50% because of agglomeration within a part of a second.

Therefore nanoparticle measurement makes only sense, if everybody uses exact the same sampling system. Same length, diameter, temperature, dilution, residence time, material, probe......
Everybody makes the same mistakes, but the results are comparable.

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