TRANSFEU

WP2

Report

Influence of gas extraction from the test chamber of ISO 5659-2 on the optical density of smoke measurements – Analysis of data

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SEVENTH FRAMEWORK PROGRAMME

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Content

Introduction

To investigate if continuous extraction of fire effluents from the ISO 5659-2 test chamber during testing has an influence on the smoke measurements, data from previously run tests at SP were collected and analysed. Data from 26 products, each tested in triplicates at three different modes (25 kW/m^2 with pilot flame, 25 kW/m^2 without pilot flame and 50 kW/m^2 without pilot flame) were analyzed. In the tests, gas were continuously extracted from the smoke box for FTIR analysis in the third of the triplicate tests. The objective was to see if a difference in the measured optical density were noticeable in the third test in which gas was extracted compared to the two first tests in which no gas were extracted. The extraction rate in the third test was 2 l/min. The tests were conducted during the years of 2003-2006.

Two methods for analysis of the data were used. A simple comparison of the smoke result in the third test with the average of the triplicate tests, which is presented in Section 3. And a method based on mathematical statistics which is presented in Section 4.

Data

The data is based on results from approximately 230 tests conducted on 26 products. The results in terms of $D_{s,max}$, maximum specific optical density, and D_s10, specific optical density at 10 minutes, were analyzed. The data is presented in Table 1.

Table 1. Optical density results for 26 products.

Product no	Parameter	25 kW/m2 without pilot flame				25 kW/m2 with pilot flame				50 kW/m2 without pilot flame			
		1	2	3*	avg.	4	5	6*	avg.	7	8	9*	avg.
1	Ds max	-	-	321	-	-	-	178	-	266	-	236	251
	Ds 10	-	-	263	-	-	-	163	-	230	-	188	209
2	Ds max	206	212	188	202	239	225	271	245	337	360	346	348
	Ds 10	137	93	126	119	192	194	231	206	275	282	270	276
3	Ds max	138	130	120	129	128	132	140	133	189	177	188	185
	Ds 10	81	62	50	64	70	65	53	63	182	173	183	179
4	Ds max	99	131	113	114	93	117	103	104	92	111	92	98
	Ds 10	83	100	83	89	92	114	102	103	92	110	87	96
5	Ds max	46	44	42	44	63	65	58	62	102	99	102	101
	Ds 10	45	43	42	43	53	52	50	52	93	86	87	89
6	Ds max	-	-	-	-	-	-	-	-	225	-	219	222
	Ds 10	-	-	-	-	-	-	-	-	194	-	195	195
7	Ds max	231	247	250	243	91	104	88	94	233	254	253	247
	Ds 10	146	157	140	148	84	96	76	85	226	244	250	240
8	Ds max	137	142	129	136	129	137	141	136	107	172	187	155
	Ds 10	62	65	57	61	54	44	62	53	94	160	177	144

Product no	Parameter	25 kW/m2 without pilot flame				25 kW/m2 with pilot flame				50 kW/m2 without pilot flame			
		1	2	3*	avg.	4	5	6*	avg.	7	8	9*	avg.
9	Ds max	255	258	281	265	100	100	68	89	220	196	231	216
	Ds 10	169	167	170	169	91	93	67	84	216	161	227	201
10	Ds max	77	74	70	74	55	51	59	55	146	96	145	129
	Ds 10	72	69	67	69	54	50	58	54	119	80	127	109
11	Ds max	165	156	227	183	143	150	190	161	141	123	151	138
	Ds 10	91	76	134	100	79	79	108	89	140	122	150	137
12	Ds max	109	116	110	112	135	94	66	98	56	81	226	121
	Ds 10	86	116	105	102	135	91	49	92	50	74	224	116
13	Ds max	57	54	60	57	62	48	52	54	195	167	187	183
	Ds 10	45	49	44	46	48	47	52	49	180	143	180	168
14	Ds max	143	140	141	141	38	46	43	42	177	150	159	162
	Ds 10	136	132	136	135	32	37	40	36	176	150	157	161
15	Ds max	21	21	20	21	16	16	14	15	34	32	31	32
	Ds 10	8	7	6	7	4	6	6	5	28	26	26	27
16	Ds max	37	34	38	36	31	25	32	29	65	64	65	65
	Ds 10	11	11	10	11	8	7	9	8	59	58	60	59
17	Ds max	197	-	201	199	-	-	84	-	-	-	148	-
	Ds 10	194	-	195	195	-	-	75	-	-	-	135	-
18	Ds max	40	46	49	45	40	47	41	43	86	92	45	74
	Ds 10	37	39	41	39	40	44	40	41	65	72	38	58
19	Ds max	70	67	64	67	53	48	24	42	173	124	184	160
	Ds 10	69	67	64	67	50	47	24	40	164	118	179	154
20	Ds max	282	292	281	285	119	114	133	122	330	327	334	330
	Ds 10	239	274	242	252	108	105	131	115	226	231	252	236
21	Ds max	480	309	470	420	254	224	-	239	380	421	503	435
	Ds 10	399	221	406	342	234	214	-	224	318	354	321	331
22	Ds max	45	46	46	46	26	20	21	22	62	65	57	61
	Ds 10	40	45	45	43	25	15	15	18	43	46	46	45
23	Ds max	45	46	46	46	26	20	21	22	62	65	57	61
	Ds 10	40	45	45	43	25	15	15	18	43	46	46	45
24	Ds max	300	304	322	309	141	293	91	175	265	213	212	230
	Ds 10	195	187	195	192	118	161	87	122	214	206	204	208
25	Ds max	76	177	83	112	-	-	46	-	-	-	183	-
	Ds 10	40	65	68	58	-	-	22	-	-	-	181	-
26	Ds max	367	388	273	343	444	481	555	493	525	633	508	555
	Ds 10	164	173	107	148	358	387	444	396	427	525	423	458

* Gas was extracted from the smoke box with a rate of 2 l/min.

Analysis

Comparing individual results with the average

The measurements from the triplicate tests of each product in each test mode were compared to the average of this test group (consisting of three tests). The comparison was conducted for both the $D_{s,max}$ and D_s10. The difference between the test and the average for the group, expressed as absolute values as well as percentage of the average, is presented in Table 2 to Table 7. The differently coloured cells indicate: 1) tests that have a result lower than the average, 2) tests that have a result equal or higher than average, 3) tests that have a result lower than 90% of the average and 4) tests that have a result higher than 110% of the average. At the bottom of each table the counts of the number of tests complying with the criteria for the coloured cells is presented.

As is seen in the tables below no significant differences or tendencies in counts are shown for the third test in each test group (test 3, 6 and 9) compared to the two previous columns. This indicates that the extraction of gas at a rate of 2 l/min in the third test has no influence on the test results.

As a comparison, it should be noted that according to ISO 5659-2 Section 10.9.2 the criteria for rerunning the series of three tests in one mode is if one test differs more than 50% from the average.

Table 2. Smoke data ($D_{s,max}$) comparison to average. Test condition 1 (25 kW/m^2 without pilot flame).

Product no.		25 kW/m2 without pilot flame									
		Measured data				Diff from avg.			Diff from avg., %		
		1	2	3*	avg.	1	2	3*	1	2	3*
1	Ds max	-	-	321							
2	Ds max	206	212	188	202	4	10	-14	2.0	5.0	-6.9
3	Ds max	138	130	120	129	9	1	-9	6.7	0.5	-7.2
4	Ds max	99	131	113	114	-15	17	-1	-13.4	14.6	-1.2
5	Ds max	46	44	42	44	2	0	-2	4.5	0.0	-4.5
6	Ds max	-	-	-							
7	Ds max	231	247	250	243	-12	4	7	-4.8	1.8	3.0
8	Ds max	137	142	129	136	1	6	-7	0.7	4.4	-5.1
9	Ds max	255	258	281	265	-10	-7	16	-3.7	-2.5	6.2
10	Ds max	77	74	70	74	3	0	-4	4.5	0.5	-5.0
11	Ds max	165	156	227	183	-18	-27	44	-9.7	-14.6	24.3
12	Ds max	109	116	110	112	-3	4	-2	-2.4	3.9	-1.5
13	Ds max	57	54	60	57	0	-3	3	0.0	-5.3	5.3
14	Ds max	143	140	141	141	2	-1	0	1.2	-0.9	-0.2
15	Ds max	21	21	20	21	0	0	-1	1.6	1.6	-3.2
16	Ds max	37	34	38	36	1	-2	2	1.8	-6.4	4.6
17	Ds max	197	-	201	199	-2		2	-1.0		1.0
18	Ds max	40	46	49	45	-5	1	4	-11.1	2.2	8.9
19	Ds max	70	67	64	67	3	0	-3	4.5	0.0	-4.5
20	Ds max	282	292	281	285	-3	7	-4	-1.1	2.5	-1.4
21	Ds max	480	309	470	420	60	-111	50	14.4	-26.4	12.0
22	Ds max	45	46	46	46	-1	0	0	-1.5	0.7	0.7
23	Ds max	45	46	46	46	-1	0	0	-1.5	0.7	0.7
24	Ds max	300	304	322	309	-9	-5	13	-2.8	-1.5	4.3
25	Ds max	76	177	83	112	-36	65	-29	-32.1	58.0	-25.9
26	Ds max	367	388	273	343	24	45	-70	7.1	13.2	-20.3
No of tests lower than average:						12	7	13			
No of tests equal or higher than average:						12	16	11			
No of tests lower than average -10%:									3	2	2
No of tests higher than average +10%:									1	3	2

Colour code:
- Lower than average
- Equal or higher than average
- Lower than average -10%
- Higher than average +10%

* Gas was extracted from the smoke box with a rate of 2 l/min.

Table 3. Smoke data ($D_{s,max}$) comparison to average. Test condition 2 (25 kW/m^2 with pilot flame).

Product no.		25 kW/m2 with pilot flame									
		Measured data				Diff from avg.			Diff from avg., %		
		4	5	6*	avg.	4	5	6*	4	5	6*
1	Ds max	-	-	178							
2	Ds max	239	225	271	245	-6	-20	26	-2.4	-8.2	10.6
3	Ds max	128	132	140	133	-5	-1	7	-4.0	-1.0	5.0
4	Ds max	93	117	103	104	-11	13	-1	-10.9	12.1	-1.3
5	Ds max	63	65	58	62	1	3	-4	1.6	4.8	-6.5
6	Ds max	-	-	-							
7	Ds max	91	104	88	94	-3	10	-6	-3.5	10.2	-6.7
8	Ds max	129	137	141	136	-7	1	5	-4.9	1.0	3.9
9	Ds max	100	100	68	89	11	11	-21	11.9	11.9	-23.9
10	Ds max	55	51	59	55	0	-4	4	0.0	-7.3	7.3
11	Ds max	143	150	190	161	-18	-11	29	-11.2	-6.8	18.0
12	Ds max	135	94	66	98	37	-4	-32	37.3	-4.4	-32.9
13	Ds max	62	48	52	54	8	-6	-2	14.8	-11.1	-3.7
14	Ds max	38	46	43	42	-4	4	1	-10.2	8.7	1.6
15	Ds max	16	16	14	15	1	1	-1	4.3	4.3	-8.7
16	Ds max	31	25	32	29	2	-4	3	5.7	-14.8	9.1
17	Ds max	-	-	84							
18	Ds max	40	47	41	43	-3	4	-2	-6.2	10.2	-3.9
19	Ds max	53	48	24	42	11	6	-18	27.2	15.2	-42.4
20	Ds max	119	114	133	122	-3	-8	11	-2.5	-6.6	9.0
21	Ds max	254	224	-	239	15	-15		6.3	-6.3	
22	Ds max	26	20	21	22	4	-2	-1	16.4	-10.4	-6.0
23	Ds max	26	20	21	22	4	-2	-1	16.4	-10.4	-6.0
24	Ds max	141	293	91	175	-34	118	-84	-19.4	67.4	-48.0
25	Ds max	-	-	46							
26	Ds max	444	481	555	493	-49	-12	62	-10.0	-2.5	12.5
No of tests lower than average:						11	12	12			
No of tests equal or higher than average:						11	10	11			
No of tests lower than average -10%:									4	4	4
No of tests higher than average +10%:									6	6	3

Colour code:
- Lower than average
- Equal or higher than average
- Lower than average -10%
- Higher than average +10%

* Gas was extracted from the smoke box with a rate of 2 l/min.

Table 4. Smoke data ($D_{s,max}$) comparison to average. Test condition 3 (50 kW/m^2 without pilot flame).

Product no.		50 kW/m2 without pilot flame									
		Measured data				Diff from avg.			Diff from avg., %		
		7	8	9*	avg.	7	8	9*	7	8	9*
1	Ds max	266	-	236	251	15		-15	6.0		-6.0
2	Ds max	337	360	346	348	-11	12	-2	-3.1	3.5	-0.5
3	Ds max	189	177	188	185	4	-8	3	2.3	-4.2	1.8
4	Ds max	92	111	92	98	-6	13	-6	-6.4	12.9	-6.4
5	Ds max	102	99	102	101	1	-2	1	1.0	-2.0	1.0
6	Ds max	225	-	219	222	3		-3	1.4		-1.4
7	Ds max	233	254	253	247	-14	7	6	-5.5	3.0	2.6
8	Ds max	107	172	187	155	-48	17	32	-31.1	10.7	20.4
9	Ds max	220	196	231	216	4	-20	15	2.0	-9.1	7.1
10	Ds max	146	96	145	129	17	-33	16	13.2	-25.6	12.4
11	Ds max	141	123	151	138	3	-15	13	1.9	-11.1	9.2
12	Ds max	56	81	226	121	-65	-40	105	-53.7	-33.1	86.8
13	Ds max	195	167	187	183	12	-16	4	6.6	-8.7	2.2
14	Ds max	177	150	159	162	15	-12	-3	9.3	-7.4	-1.9
15	Ds max	34	32	31	32	2	0	-1	5.2	-1.0	-4.1
16	Ds max	65	64	65	65	0	-1	0	0.5	-1.0	0.5
17	Ds max	-	-	148							
18	Ds max	86	92	45	74	12	18	-29	15.7	23.8	-39.5
19	Ds max	173	124	184	160	13	-36	24	7.9	-22.7	14.8
20	Ds max	330	327	334	330	0	-3	4	-0.1	-1.0	1.1
21	Ds max	380	421	503	435	-55	-14	68	-12.6	-3.1	15.7
22	Ds max	62	65	57	61	1	4	-4	1.1	6.0	-7.1
23	Ds max	62	65	57	61	1	4	-4	1.1	6.0	-7.1
24	Ds max	265	213	212	230	35	-17	-18	15.2	-7.4	-7.8
25	Ds max	-	-	183							
26	Ds max	525	633	508	555	-30	78	-47	-5.5	14.0	-8.5
No of tests lower than average:						8	14	11			
No of tests equal or higher than average:						15	8	14			
No of tests lower than average -10%:									3	4	0
No of tests higher than average +10%:									3	4	5

Colour code:
- Lower than average
- Equal or higher than average
- Lower than average -10%
- Higher than average +10%

* Gas was extracted from the smoke box with a rate of 2 l/min.

Table 5. Smoke data ($D_{s,10}$) comparison to average. Test condition 4 (25 kW/m^2 without pilot flame).

Product no.		25 kW/m2 without pilot flame									
		Measured data				Diff from avg.			Diff from avg., %		
		1	2	3*	avg.	1	2	3*	1	2	3*
1	Ds10	-	-	263							
2	Ds10	137	93	126	118.7	18	-26	7	15.4	-21.6	6.2
3	Ds10	81	62	50	64	17	-2	-14	25.9	-3.6	-22.3
4	Ds10	83	100	83	89	-6	11	-6	-6.4	12.8	-6.4
5	Ds10	45	43	42	43	2	0	-1	3.8	-0.8	-3.1
6	Ds10	-	-	-							
7	Ds10	146	157	140	148	-2	9	-8	-1.1	6.3	-5.2
8	Ds10	62	65	57	61	1	4	-4	1.1	6.0	-7.1
9	Ds10	169	167	170	169	0	-2	1	0.2	-1.0	0.8
10	Ds10	72	69	67	69	3	0	-2	3.8	-0.5	-3.4
11	Ds10	91	76	134	100	-9	-24	34	-9.3	-24.3	33.6
12	Ds10	86	116	105	102	-16	14	3	-16.0	13.4	2.6
13	Ds10	45	49	44	46	-1	3	-2	-2.2	6.5	-4.3
14	Ds10	136	132	136	135	1	-3	1	1.0	-2.0	1.0
15	Ds10	8	7	6	7	1	0	-1	14.3	0.0	-14.3
16	Ds10	11	11	10	11	0	0	-1	3.1	3.1	-6.2
17	Ds10	194	-	195	195	-1		1	-0.3		0.3
18	Ds10	37	39	41	39	-2	0	2	-5.1	0.0	5.1
19	Ds10	69	67	64	67	2	0	-3	3.5	0.5	-4.0
20	Ds10	239	274	242	252	-13	22	-10	-5.0	8.9	-3.8
21	Ds10	399	221	406	342	57	-121	64	16.7	-35.4	18.7
22	Ds10	40	45	45	43	-3	2	2	-7.7	3.8	3.8
23	Ds10	40	45	45	43	-3	2	2	-7.7	3.8	3.8
24	Ds10	195	187	195	192	3	-5	3	1.4	-2.8	1.4
25	Ds10	40	65	68	58	-18	7	10	-30.6	12.7	17.9
26	Ds10	164	173	107	148	16	25	-41	10.8	16.9	-27.7
No of tests lower than average:						11	9	12			
No of tests equal or higher than average:						13	14	12			
No of tests lower than average -10%:									2	3	3
No of tests higher than average +10%:									5	4	3

Colour code:
- Lower than average
- Equal or higher than average
- Lower than average -10%
- Higher than average +10%

* Gas was extracted from the smoke box with a rate of 2 l/min.

Table 6. Smoke data ($D_{s,10}$) comparison to average. Test condition 5 (25 kW/m^2 with pilot flame).

Product no.		25 kW/m2 with pilot flame									
		Measured data				Diff from avg.			Diff from avg., %		
		4	5	6*	avg.	4	5	6*	4	5	6*
1	Ds10	-	-	163							
2	Ds10	192	194	231	205.7	-14	-12	25	-6.6	-5.7	12.3
3	Ds10	70	65	53	63	7	2	-10	11.7	3.7	-15.4
4	Ds10	92	114	102	103	-11	11	-1	-10.4	11.0	-0.6
5	Ds10	53	52	50	51.67	1	0	-2	2.6	0.6	-3.2
6	Ds10	-	-	-							
7	Ds10	84	96	76	85	-1	11	-9	-1.6	12.5	-10.9
8	Ds10	54	44	62	53	1	-9	9	1.3	-17.5	16.3
9	Ds10	91	93	67	84	7	9	-17	8.8	11.2	-19.9
10	Ds10	54	50	58	54	0	-4	4	0.0	-7.4	7.4
11	Ds10	79	79	108	89	-10	-10	19	-10.9	-10.9	21.8
12	Ds10	135	91	49	92	43	-1	-43	47.3	-0.7	-46.5
13	Ds10	48	47	52	49	-1	-2	3	-2.0	-4.1	6.1
14	Ds10	32	37	40	36	-4	1	4	-11.9	1.8	10.1
15	Ds10	4	6	6	5	-1	1	1	-25.0	12.5	12.5
16	Ds10	8	7	9	8	0	-1	1	0.0	-12.5	12.5
17	Ds10	-	-	75							
18	Ds10	40	44	40	41	-1	3	-1	-3.2	6.5	-3.2
19	Ds10	50	47	24	40	10	7	-16	24.0	16.5	-40.5
20	Ds10	108	105	131	115	-7	-10	16	-5.8	-8.4	14.2
21	Ds10	234	214	-	224	10	-10		4.5	-4.5	
22	Ds10	25	15	15	18	7	-3	-3	36.4	-18.2	-18.2
23	Ds10	25	15	15	18	7	-3	-3	36.4	-18.2	-18.2
24	Ds10	118	161	87	122	-4	39	-35	-3.3	32.0	-28.7
25	Ds10	-	-	22							
26	Ds10	358	387	444	396	-38	-9	48	-9.7	-2.4	12.0
No of tests lower than average:						11	12	11			
No of tests equal or higher than average:						11	10	10			
No of tests lower than average -10%:									4	5	8
No of tests higher than average +10%:									5	6	8

Colour code:
- Lower than average
- Equal or higher than average
- Lower than average -10%
- Higher than average +10%

* Gas was extracted from the smoke box with a rate of 2 l/min.

Table 7. Smoke data ($D_{s,10}$) comparison to average. Test condition 6 (50 kW/m^2 without pilot flame).

Product no.		50 kW/m2 without pilot flame									
		Measured data				Diff from avg.			Diff from avg., %		
		7	8	9*	avg.	7	8	9*	7	8	9*
1	Ds10	230	-	188	209	21		-21	10.0		-10.0
2	Ds10	275	282	270	276	-1	6	-6	-0.2	2.3	-2.1
3	Ds10	182	173	183	179	3	-6	4	1.5	-3.5	2.0
4	Ds10	92	110	87	96	-4	14	-9	-4.5	14.2	-9.7
5	Ds10	93	86	87	88.67	4	-3	-2	4.9	-3.0	-1.9
6	Ds10	194	-	195	194.5	-1		1	-0.3		0.3
7	Ds10	226	244	250	240	-14	4	10	-5.8	1.7	4.2
8	Ds10	94	160	177	144	-50	16	33	-34.6	11.4	23.2
9	Ds10	216	161	227	201	15	-40	26	7.3	-20.0	12.7
10	Ds10	119	80	127	109	10	-29	18	9.5	-26.4	16.9
11	Ds10	140	122	150	137	3	-15	13	1.9	-11.2	9.2
12	Ds10	50	74	224	116	-66	-42	108	-56.9	-36.2	93.1
13	Ds10	180	143	180	168	12	-25	12	7.4	-14.7	7.4
14	Ds10	176	150	157	161	15	-11	-4	9.3	-6.8	-2.5
15	Ds10	28	26	26	27	1	-1	-1	5.0	-2.5	-2.5
16	Ds10	59	58	60	59	0	-1	1	0.0	-1.7	1.7
17	Ds10	-	-	135							
18	Ds10	65	72	38	58	7	14	-20	11.4	23.4	-34.9
19	Ds10	164	118	179	154	10	-36	25	6.7	-23.2	16.5
20	Ds10	226	231	252	236	-10	-5	16	-4.4	-2.3	6.6
21	Ds10	318	354	321	331	-13	23	-10	-3.9	6.9	-3.0
22	Ds10	43	46	46	45	-2	1	1	-4.4	2.2	2.2
23	Ds10	43	46	46	45	-2	1	1	-4.4	2.2	2.2
24	Ds10	214	206	204	208	6	-2	-4	2.9	-1.0	-1.9
25	Ds10	-	-	181							
26	Ds10	427	525	423	458	-31	67	-35	-6.8	14.5	-7.7
No of tests lower than average:						11	13	10			
No of tests equal or higher than average:						13	9	14			
No of tests lower than average -10%:									2	6	2
No of tests higher than average +10%:									2	4	5

Colour code:
- Lower than average
- Equal or higher than average
- Lower than average -10%
- Higher than average +10%

* Gas was extracted from the smoke box with a rate of 2 l/min.

Statistical analysis to find significant differences

The subject to be investigated is whether there is a significant difference between the average of the smoke data from measurement 1 (x_1) and measurement 2 (x_2), and the smoke data in measurement 3 (y). I.e., does the absolute value of the difference significantly deviate from zero. The difference (d) can be expressed as:

$$d = |\bar{x} - y| = \left| \frac{x_1 + x_2}{2} - y \right| \quad (1)$$

In order to investigate if the difference is significant one need to know the variance of the quantity (i.e. of the difference). One can assume that the variance for the random variation of the smoke data is the same in all three individual measurements (here denoted σ^2). The variance of the difference can thus be expressed as:

$$Var[d] = Var[\bar{x}] + Var[y] = \frac{\sigma^2}{2} + \sigma^2 = 1.5 \cdot \sigma^2 \quad (2)$$

The true variance (σ^2) is, however, not known and has to be estimated. If the estimate is denoted s^2 there is a significant difference if:

$$d > t_{1-\frac{\alpha}{2},\nu} \cdot \sqrt{1.5 \cdot s^2} \quad (3)$$

In equation 3, α denotes the level of significance (for example 5%) and ν is the degrees of freedom (N-1) in the estimate of σ^2 . The t-distribution is an approximation of the normal distribution in cases of a limited number of data (N).

There are two alternatives to estimate the variance. The first option is to estimate the variance in the separate tests. This would, however, give us only one degree of freedom (N=2) and the corresponding confidence interval for the *t*-distribution would be very wide and the test would have limited usefulness.

The other alternative is to use all series of tests to get a more accurate estimate of the variance. The assumption made is that the variance is comparable for each group of tests, and the variance is estimated as the average of the variances from the individual series of tests (M). This will result in a much higher degree of freedom for the averaged variance (M-1) and thus a more stringent confidence interval for the *t*-distribution.

However, when investigated (see Tables XX-XX) it is clear that the estimated variances for the individual series of tests is not estimates of a common variance. It is instead proper to use the square root of the coefficient of variance (η^2), i.e. the average weighted variance (see equation 4).

$$\eta^2 = \frac{\sigma^2}{\bar{x}^2} \quad (4)$$

The estimate of η^2 ($\hat{\eta}^2$) is given by taking an average of all individual estimates, i.e.

$$\hat{\eta}^2 = \overline{\eta^2} \quad (5)$$

The difference for each series of test results (d_i) can then be tested against the estimated confidence interval for variance:

$$d_i > t_{1-\frac{\alpha}{2},\nu} \cdot \sqrt{1.5 \cdot \left(\bar{x}_i \cdot \hat{\eta}\right)^2} \quad (6)$$

This test is made for the two parameters $D_{s,max}$ and $D_{s,10}$, individually for the three heat exposure modes in Table 8 to Table 13. A positive residual denote that there is a significant difference between the average of the smoke data from measurement 1 (x_1) and measurement 2 (x_2), and the smoke data in measurement 3 (y).

Of the approximately 156 groups of test data analysed, 12 give a positive value for the residual. It should be noted that of theses 12 groups of tests, 7 have a measurement in the third test that are lower than the average of the first and second tests. For the other 5 the third measurement is higher than the average of the two first tests. This is a contradiction to the hypothesis that if extraction had an effect on the measured optical density it would decrease the measured value. If we for a moment ignore the assumption on which this analysis is based, i.e. the results from test 1 and test 2 are the "right results", it can be noted that the high residual in some test groups (i.e. group 8 in Table 13 and test group 24 in Table 9) are caused by a large discrepancy in test 1 or test 2 compared to the others.

Table 8. Smoke data ($D_{s,max}$) and statistical test. Test condition 1 (25 kW/m^2 without pilot flame).

Product no.	Smoke data ($D_{s,max}$)			$\bar{x}_i$	$\bar{x}_i^2$	s_i	s_i^2	η	η^2	Variance estimate (95%)	d_i	Residual
	1	2	3									
1	-	-	321									
2	206	212	188	209	43681	4.2	18	0.020	0.0004	77.0	21.0	-56.0
3	138	130	120	134	17956	5.7	32	0.042	0.0018	49.3	14.0	-35.3
4	99	131	113	115	13225	22.6	512	0.197	0.0387	42.3	2.0	-40.3
5	46	44	42	45	2025	1.4	2	0.031	0.0010	16.6	3.0	-13.6
6	-	-	-									
7	231	247	250	239	57121	11.3	128	0.047	0.0022	88.0	11.0	-77.0
8	137	142	129	140	19460	3.5	12.5	0.025	0.0006	51.4	10.5	-40.9
9	255	258	281	257	65792	2.1	4.5	0.008	0.0001	94.4	24.5	-69.9
10	77	74	70	76	5700	2.1	4.5	0.028	0.0008	27.8	5.5	-22.3
11	165	156	227	161	25760	6.4	40.5	0.040	0.0016	59.1	66.5	**7.4**
12	109	116	110	113	12656	4.9	24.5	0.044	0.0019	41.4	2.5	-38.9
13	57	54	60	56	3080	2.1	4.5	0.038	0.0015	20.4	4.5	-15.9
14	143	140	141	142	20022	2.1	4.5	0.015	0.0002	52.1	0.5	-51.6
15	21	21	20	21	441	0.0	0	0.000	0.0000	7.7	1.0	-6.7
16	37	34	38	36	1260	2.1	4.5	0.060	0.0036	13.1	2.5	-10.6
17	197	-	201									
18	40	46	49	43	1849	4.2	18	0.099	0.0097	15.8	6.0	-9.8
19	70	67	64	69	4692	2.1	4.5	0.031	0.0010	25.2	4.5	-20.7
20	282	292	281	287	82369	7.1	50	0.025	0.0006	105.7	6.0	-99.7
21	480	309	470	395	155630	120.9	14620.5	0.307	0.0939	145.3	75.5	-69.8
22	45	46	46	46	2070	0.7	0.5	0.016	0.0002	16.8	0.5	-16.3
23	45	46	46	46	2070	0.7	0.5	0.016	0.0002	16.8	0.5	-16.3
24	300	304	322	302	91204	2.8	8	0.009	0.0001	111.2	20.0	-91.2
25	76	177	83	127	16002	71.4	5100.5	0.565	0.3187	46.6	43.5	-3.1
26	367	388	273	378	142506	14.8	220.5	0.039	0.0015	139.0	104.5	-34.5
				N = 23					$\overline{\eta^2} = 0.02089$			

Table 9. Smoke data ($D_{s,max}$) and statistical test. Test condition 2 (25 kW/m^2 with a pilot flame).

Product no.	Smoke data ($D_{s,max}$) 1	2	3	$\bar{x}_i$	$\bar{x}_i^2$	s_i	s_i^2	η	η^2	Variance estimate (95%)	d_i	Residual
1	-	-	178									
2	239	225	271	232	53824	9.9	98	0.043	0.00182	91.2	39	-52.2
3	128	132	140	130	16900	2.8	8	0.022	0.00047	51.1	10	-41.1
4	93	117	103	105	11025	17.0	288	0.162	0.02612	41.3	2	-39.3
5	63	65	58	64	4096	1.4	2	0.022	0.00049	25.2	6	-19.2
6	-	-	-									
7	91	104	88	98	9506	9.2	84.5	0.094	0.00889	38.3	9.5	-28.8
8	129	137	141	133	17689	5.7	32	0.043	0.00181	52.3	8	-44.3
9	100	100	68	100	10000	0.0	0	0.000	0.00000	39.3	32	-7.3
10	55	51	59	53	2809	2.8	8	0.053	0.00285	20.8	6	-14.8
11	143	150	190	147	21462	4.9	24.5	0.034	0.00114	57.6	43.5	-14.1
12	135	94	66	115	13110	29.0	840.5	0.253	0.06411	45.0	48.5	**3.5**
13	62	48	52	55	3025	9.9	98	0.180	0.03240	21.6	3	-18.6
14	38	46	43	42	1764	5.7	32	0.135	0.01814	16.5	1	-15.5
15	16	16	14	16	256	0.0	0	0.000	0.00000	6.3	2	-4.3
16	31	25	32	28	784	4.2	18	0.152	0.02296	11.0	4	-7.0
17	-	-	84									
18	40	47	41	44	1892	4.9	24.5	0.114	0.01295	17.1	2.5	-14.6
19	53	48	24	51	2550	3.5	12.5	0.070	0.00490	19.9	26.5	**6.6**
20	119	114	133	117	13572	3.5	12.5	0.030	0.00092	45.8	16.5	-29.3
21	254	224	-	239	57121	21.2	450	0.089	0.00788			
22	26	20	21	23	529	4.2	18	0.184	0.03403	9.0	2	-7.0
23	26	20	21	23	529	4.2	18	0.184	0.03403	9.0	2	-7.0
24	141	293	91	217	47089	107.5	11552	0.495	0.24532	85.3	126	**40.7**
25	-	-	46									
26	444	481	555	463	213906	26.2	684.5	0.057	0.00320	181.9	92.5	-89.4
				N = 22					$\overline{\eta^2} = 0.02384$			

Table 10. Smoke data ($D_{s,max}$) and statistical test. Test condition 3 (50 kW/m^2 without pilot flame).

Product no.	Smoke data ($D_{s,max}$)			$\bar{x}_i$	$\bar{x}_i^2$	s_i	s_i^2	η	η^2	Variance estimate (95%)	d_i	Residual
	1	2	3									
1	266	-	236									
2	337	360	346	349	121452	16.3	264.5	0.047	0.00218	124.9	2.5	-122.4
3	189	177	188	183	33489	8.5	72	0.046	0.00215	65.6	5	-60.6
4	92	111	92	102	10302	13.4	180.5	0.132	0.01752	36.4	9.5	-26.9
5	102	99	102	101	10100	2.1	4.5	0.021	0.00045	36.0	1.5	-34.5
6	225	-	219									
7	233	254	253	244	59292	14.8	220.5	0.061	0.00372	87.3	9.5	-77.8
8	107	172	187	140	19460	46.0	2112.5	0.329	0.10855	50.0	47.5	-2.5
9	220	196	231	208	43264	17.0	288	0.082	0.00666	74.5	23	-51.5
10	146	96	145	121	14641	35.4	1250	0.292	0.08538	43.4	24	-19.4
11	141	123	151	132	17424	12.7	162	0.096	0.00930	47.3	19	-28.3
12	56	81	226	69	4692	17.7	312.5	0.258	0.06660	24.5	157.5	**133.0**
13	195	167	187	181	32761	19.8	392	0.109	0.01197	64.9	6	-58.9
14	177	150	159	164	26732	19.1	364.5	0.117	0.01364	58.6	4.5	-54.1
15	34	32	31	33	1089	1.4	2	0.043	0.00184	11.8	2	-9.8
16	65	64	65	65	4160	0.7	0.5	0.011	0.00012	23.1	0.5	-22.6
17	-	-	148									
18	86	92	45	89	7921	4.2	18	0.048	0.00227	31.9	44	**12.1**
19	173	124	184	149	22052	34.6	1200.5	0.233	0.05444	53.2	35.5	-17.7
20	330	327	334	329	107912	2.1	4.5	0.006	0.00004	117.7	5.5	-112.2
21	380	421	503	401	160400	29.0	840.5	0.072	0.00524	143.5	102.5	-41.0
22	62	65	57	64	4032	2.1	4.5	0.033	0.00112	22.8	6.5	-16.3
23	62	65	57	64	4032	2.1	4.5	0.033	0.00112	22.8	6.5	-16.3
24	265	213	212	239	57121	36.8	1352	0.154	0.02367	85.6	27	-58.6
25	-	-	183									
26	525	633	508	579	335241	76.4	5832	0.132	0.01740	207.5	71	-136.5
				N = 22					$\overline{\eta^2} = 0.01979$			

Table 11. Smoke data ($D_{s,10}$) and statistical test. Test condition 1 (25 kW/m^2 without pilot flame).

Product no.	Smoke data ($D_{s,max}$)			$\bar{x}_i$	$\bar{x}_i^2$	s_i	s_i^2	η	η^2	Variance estimate (95%)	d_i	Residual
	1	2	3									
1	-	-	263									
2	137	93	126	115	13225	31.1	968	0.271	0.07319	43.6	11	-32.6
3	81	62	50	72	5112	13.4	180.5	0.188	0.03531	27.1	21.5	-5.6
4	83	100	83	92	8372	12.0	144.5	0.131	0.01726	34.7	8.5	-26.2
5	45	43	42	44	1936	1.4	2	0.032	0.00103	16.7	2	-14.7
6	-	-	-									
7	146	157	140	152	22952	7.8	60.5	0.051	0.00264	57.5	11.5	-46.0
8	62	65	57	64	4032	2.1	4.5	0.033	0.00112	24.1	6.5	-17.6
9	169	167	170	168	28224	1.4	2	0.008	0.00007	63.7	2	-61.7
10	72	69	67	71	4970	2.1	4.5	0.030	0.00091	26.7	3.5	-23.2
11	91	76	134	84	6972	10.6	112.5	0.127	0.01614	31.7	50.5	**18.8**
12	86	116	105	101	10201	21.2	450	0.210	0.04411	38.3	4	-34.3
13	45	49	44	47	2209	2.8	8	0.060	0.00362	17.8	3	-14.8
14	136	132	136	134	17956	2.8	8	0.021	0.00045	50.8	2	-48.8
15	8	7	6	8	56	0.7	0.5	0.094	0.00889	2.8	1.5	-1.3
16	11	11	10	11	121	0.0	0	0.000	0.00000	4.2	1	-3.2
17	194	-	195									
18	37	39	41	38	1444	1.4	2	0.037	0.00139	14.4	3	-11.4
19	69	67	64	68	4624	1.4	2	0.021	0.00043	25.8	4	-21.8
20	239	274	242	257	65792	24.7	612.5	0.096	0.00931	97.3	14.5	-82.8
21	399	221	406	310	96100	125.9	15842	0.406	0.16485	117.6	96	-21.6
22	40	45	45	43	1806	3.5	12.5	0.083	0.00692	16.1	2.5	-13.6
23	40	45	45	43	1806	3.5	12.5	0.083	0.00692	16.1	2.5	-13.6
24	195	187	195	191	36481	5.7	32	0.030	0.00088	72.5	4	-68.5
25	40	65	68	53	2756	17.7	312.5	0.337	0.11338	19.9	15.5	-4.4
26	164	173	107	169	28392	6.4	40.5	0.038	0.00143	63.9	61.5	-2.4
				N = 22					$\overline{\eta^2} = 0.02218$			

Table 12. Smoke data ($D_{s,10}$) and statistical test. Test condition 2 (25 kW/m^2 with a pilot flame).

Product no.	Smoke data ($D_{s,max}$)			$\bar{x}_i$	$\bar{x}_i^2$	s_i	s_i^2	η	η^2	Variance estimate (95%)	d_i	Residual
	1	2	3									
1	-	-	163									
2	192	194	231	193	37249	1.4	2	0.007	0.00005	79.0	38	-41.0
3	70	65	53	68	4556	3.5	12.5	0.052	0.00274	27.6	14.5	-13.1
4	92	114	102	103	10609	15.6	242	0.151	0.02281	42.1	1	-41.1
5	53	52	50	53	2756	0.7	0.5	0.013	0.00018	21.5	2.5	-19.0
6	-	-	-									
7	84	96	76	90	8100	8.5	72	0.094	0.00889	36.8	14	-22.8
8	54	44	62	49	2401	7.1	50	0.144	0.02082	20.0	13	-7.0
9	91	93	67	92	8464	1.4	2	0.015	0.00024	37.6	25	-12.6
10	54	50	58	52	2704	2.8	8	0.054	0.00296	21.3	6	-15.3
11	79	79	108	79	6241	0.0	0	0.000	0.00000	32.3	29	-3.3
12	135	91	49	113	12769	31.1	968	0.275	0.07581	46.2	64	**17.8**
13	48	47	52	48	2256	0.7	0.5	0.015	0.00022	19.4	4.5	-14.9
14	32	37	40	35	1190	3.5	12.5	0.102	0.01050	14.1	5.5	-8.6
15	4	6	6	5	25	1.4	2	0.283	0.08000	2.0	1	-1.0
16	8	7	9	8	56	0.7	0.5	0.094	0.00889	3.1	1.5	-1.6
17	-	-	75									
18	40	44	40	42	1764	2.8	8	0.067	0.00454	17.2	2	-15.2
19	50	47	24	49	2352	2.1	4.5	0.044	0.00191	19.8	24.5	**4.7**
20	108	105	131	107	11342	2.1	4.5	0.020	0.00040	43.6	24.5	-19.1
21	234	214	-									
22	25	15	15	20	400	7.1	50	0.354	0.12500	8.2	5	-3.2
23	25	15	15	20	400	7.1	50	0.354	0.12500	8.2	5	-3.2
24	118	161	87	140	19460	30.4	924.5	0.218	0.04751	57.1	52.5	-4.6
25	-	-	22									
26	358	387	444	373	138756	20.5	420.5	0.055	0.00303	152.4	71.5	-80.9
				N = 22					$\overline{\eta^2} = 0.02579$			

Table 13. Smoke data ($D_{s,10}$) and statistical test. Test condition 3 (50 kW/m^2 without pilot flame).

Product no.	Smoke data ($D_{s,max}$)			$\bar{x}_i$	$\bar{x}_i^2$	s_i	s_i^2	η	η^2	Variance estimate (95%)	d_i	Residual
	1	2	3									
1	230	-	188									
2	275	282	270	279	77562	4.9	24.5	0.018	0.00032	106.4	8.5	-97.9
3	182	173	183	178	31506	6.4	40.5	0.036	0.00129	67.8	5.5	-62.3
4	92	110	87	101	10201	12.7	162	0.126	0.01588	38.6	14	-24.6
5	93	86	87	90	8010	4.9	24.5	0.055	0.00306	34.2	2.5	-31.7
6	194	-	195									
7	226	244	250	235	55225	12.7	162	0.054	0.00293	89.8	15	-74.8
8	94	160	177	127	16129	46.7	2178	0.367	0.13504	48.5	50	**1.5**
9	216	161	227	189	35532	38.9	1512.5	0.206	0.04257	72.0	38.5	-33.5
10	119	80	127	100	9900	27.6	760.5	0.277	0.07682	38.0	27.5	-10.5
11	140	122	150	131	17161	12.7	162	0.097	0.00944	50.1	19	-31.1
12	50	74	224	62	3844	17.0	288	0.274	0.07492	23.7	162	**138.3**
13	180	143	180	162	26082	26.2	684.5	0.162	0.02624	61.7	18.5	-43.2
14	176	150	157	163	26569	18.4	338	0.113	0.01272	62.3	6	-56.3
15	28	26	26	27	729	1.4	2	0.052	0.00274	10.3	1	-9.3
16	59	58	60	59	3422	0.7	0.5	0.012	0.00015	22.4	1.5	-20.9
17	-	-	135									
18	65	72	38	69	4692	4.9	24.5	0.072	0.00522	26.2	30.5	**4.3**
19	164	118	179	141	19881	32.5	1058	0.231	0.05322	53.9	38	-15.9
20	226	231	252	229	52212	3.5	12.5	0.015	0.00024	87.3	23.5	-63.8
21	318	354	321	336	112896	25.5	648	0.076	0.00574	128.4	15	-113.4
22	43	46	46	45	1980	2.1	4.5	0.048	0.00227	17.0	1.5	-15.5
23	43	46	46	45	1980	2.1	4.5	0.048	0.00227	17.0	1.5	-15.5
24	214	206	204	210	44100	5.7	32	0.027	0.00073	80.2	6	-74.2
25	-	-	181									
26	427	525	423	476	226576	69.3	4802	0.146	0.02119	181.9	53	-128.9
				N = 22					$\overline{\eta^2} = 0.02250$			

Summary of results

According to the comparison of the individual measurements to the average of each test group (section 0) there are no sights of systematic influence on the optical density measurements when gas is extracted from the smoke chamber at a rate of 2 l/min.

The supplementary statistical analysis shows that for 12 test groups (out of approximately 156) there is a significant difference between test 3 compared to the average of test 1 and test 2. Of these 12 test groups, 7 test groups have a measurement in the third tests that are lower than the average of the first and second tests. For the other 5 test groups the third measurement is higher than the average of the two first tests.