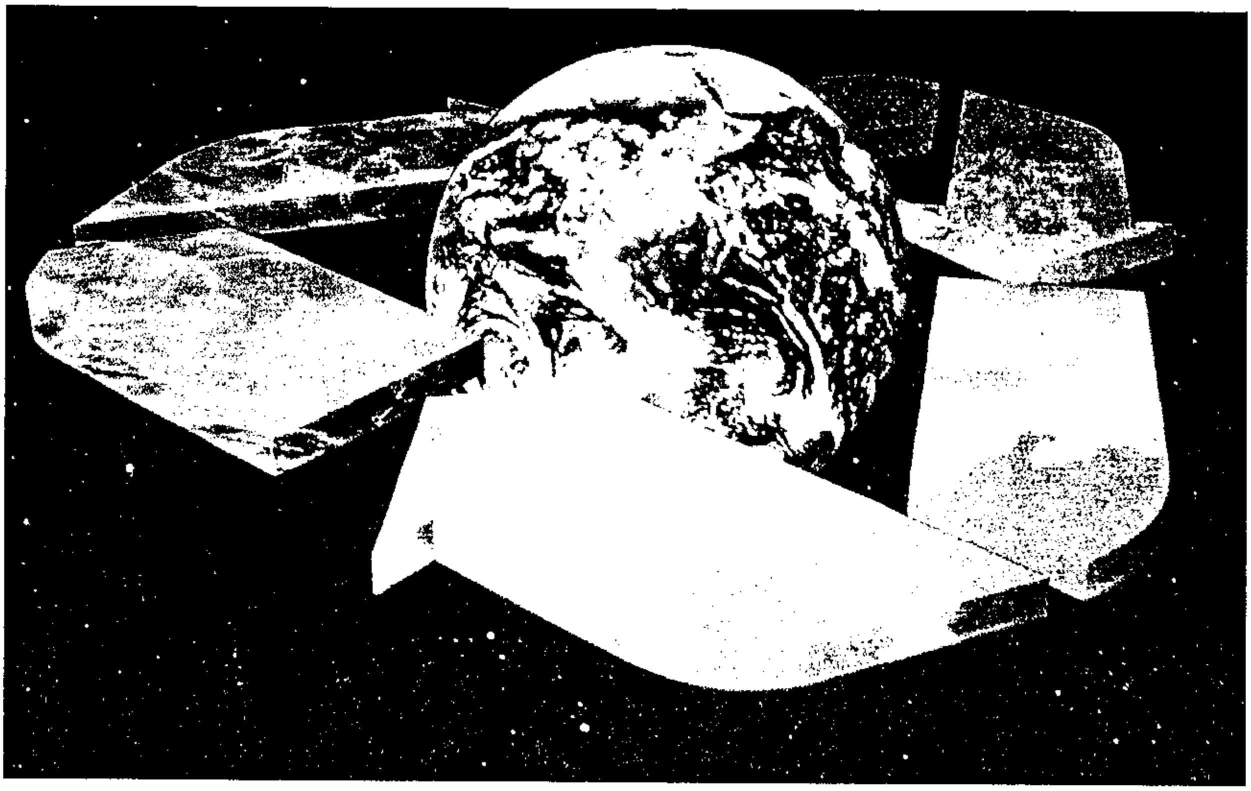
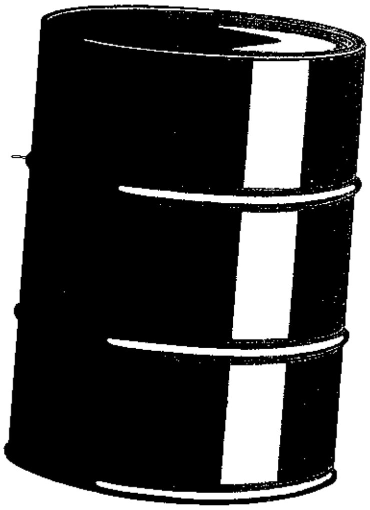


DIESEL FUEL SPECIFICATIONS

Impact on emissions of polycyclic aromatic compounds

Ecotraffic



DIESEL FUEL SPECIFICATIONS

Impact on emissions of polycyclic aromatic compounds

Memorandum for BP Amoco

Ecotraffic ERD[3] AB

Peter Ahlvik
Åke Brandberg

August 2000

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

1 INTRODUCTION AND BACKGROUND

2 LITERATURE INVESTIGATED

As mentioned in the previous memorandum about cancer risk, the fuel specification could have a significant impact on some of the unregulated emissions, i.e. the polycyclic aromatic emission compound (PAC) in particular. In this chapter, a description of some of the test fuels used in Sweden and the effect on PAC emissions in the exhaust is made. Of the available emission test data, three reports are specifically highlighted. These are:

- A report from a project administered by the Swedish Public Transport Association (SLTF) by Brandberg [4]. The report was published (in Swedish) by the Swedish Transport Research Board[1] (TFB, a governmental organization). The report was jointly funded by SLTF, vehicle manufacturers, oil companies and TFB. The testing was carried out on an engine dynamometer of Volvo truck Co. using the US Transient cycle. This report is called the "TFB report" in the following.
- A report from a project by SEPA edited by Westerholm and Egebäck [5]. This report is called the "SEPA report" in the following.
- A report commissioned by SEPA and published by Grägg at MTC [13]. This report is called the "MTC report" in the following.

Note that in this memo, the denotation "PAH" is generally used for the polyaromatics in the fuel, and PAC for the polyaromatics in the exhaust. Polycyclic aromatic compounds (PAC) in the exhaust should not be classified as hydrocarbons, since they contain other elements than hydrogen and carbon (e.g. sulfur). These compounds are generally not found, or are found at a very low level, in the fuel. PAH is a subset of PAC and, in fact, most of the PAC in the exhaust is PAH. Furthermore, only the PAH and PAC that could be classified as tri+ aromatics are included in total PAH and PAC respectively. Since, there is not much evidence of carcinogenicity and/or biological activity of di-aromatic compounds, this classification has generally been used in Sweden (in contrast to the practice in several other countries).

Two important questions could be posed regarding the fuel composition. The first question is whether the fuel composition could have some impact on the unregulated emissions and consequently on the health effects from these emissions. Several results from the Swedish projects could be referred to as evidence for this hypothesis. The second question is whether the EC-D fuel introduced by ARCO (now merged into BP Amoco) could have a similar effect on the emissions as the fuels previously tested in Sweden.

The presentation of the results in this chapter is divided into two parts. First, the fuel analysis (incl. PAH speciation) of the tested fuels is shown. Second, the results for the PAC emissions in the exhaust are shown. In the Tables, a checkmark (✓) shows the 14 PAC that has been used in older tests before the presently used test battery of the 29 PAC was introduced[2].

[1] TBF was reorganized and renamed to KFB (the Swedish Communication and Transport Research Board) a couple of years ago.

[2] The analysis of more PAC species (>50) will, most likely, be used in future analysis (R. Westerholm, personal communication).

3 FUEL SPECIFICATION

The fuel specification from the three reports mentioned above is shown in two separate tables, the first for the "ordinary" fuel properties (Table 1 – 3) and the second for the PAH analysis (Table 4 – 6).

Table 1: Fuel specifications for the fuels in the TFB report [4]

		Test fuel				
Fuel property	**Unit**	**S**	**L**	**T**	**F**	**X**
Cetane no.		45+	57	51	54	57
Cetane index (ASTM 0976-80)		n.r.[a]	n.r.	n.r.	n.r.	n.r.
Cetane index (IP 380-88)		n.r.	n.r.	n.r.	n.r.	n.r.
Density @15 °C	kg/m^3	844	815	810	821	812
Viscosity @ 20°C	mm^2/s	3,9	3,3	2,8	3,6	3,3
Distillation IBP	°C	177	214	174	165	192
T5	°C	197	224	193	213	217
T10	°C	206	226	196	216	221
T50	°C	259	241	217	248	245
T90	°C	323	269	301	306	271
T95	°C	338	285	319	319	279
FBP	°C	350	313	330	334	289
H/C		1.82	1.95	n.a.[b]	1.91	2.02
CFPP	°C	-21	-36	-28	-21	-34
Cloud point	°C	n.r.	n.r.	n.r.	n.r.	n.r.
Flash point	°C	n.r.	n.r.	n.r.	n.r.	n.r.
Energy content	MJ/kg	42,9	43,6	43,5	43,1	43,6
Energy content	MJ/l	35,9	35,5	35,3	35,4	35,4
Sulphur content ppm	~~%wt~~	0.1300	0.0015	<0.0001	0.0052	0.0003
Alkenes	%vol	4.5	1	<0.5	7.7	1.4
Total aromatics[c]	%vol	23.5	4.6	- - -	13.8	0.6
PAH (mono)	%vol	n.a.	n.a.	n.a.	n.a.	n.a.
PAH (di)	%vol	n.a.	n.a.	n.a.	n.a.	n.a.
PAH (tri+)	%vol	1.1	0.01	- - -	0.03	- - -
PAH (29)	mg/l	229	37	2.8	172	0.4
Ring analysis Aromatics	%wt	12	1	0	6	0
Naphtenics	%wt	33	32	46	30	33

Notes:

[a] n.r.: not reported.

[b] n.a.: not analyzed

Table 2: Fuel specifications for the fuels in the SEPA report [5]

		Test fuel							
Fuel property	**Unit**	**D1**	**D2**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**
Cetane no.		52.8	50.0	47.2	47.0	48.3	44.7	55.7	52.8
Cetane index (ASTM 0976-80)		52.8	50.0	46.8	48.9	48.3	43.6	42.7	50.6
Cetane index (IP 380-88)		55.5	51.9	47.5	50.1	•[a]	45.7	44.7	52.6
Density @15 °C	kg/m^3	811.7	821.3	832.0	831.3	836.8	808.3	808.7	813.2
Viscosity @ 40°C	mm^2/s	2.11	2.11	2.09	2.26	2.47	1.41	1.44	1.96
Distillation IBP	°C	220	223	221	190	180	180	176	175
T5	°C	n.r.[a]	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
T10	°C	228	231	233	220	205	190	187	205
T50	°C	236	239	241	248	253	206	204	231
T90	°C	251	252	252	289	329	245	243	282
T95	°C	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
FBP	°C	261	260	261	323	364	300	299	301
H/C		n.a.[b]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CFPP	°C	-40	-39	-39	-32	-22	<-40	<-40	<-40
Cloud point	°C	-34	-35	-34	-24	-8	<-40	<-40	<-40
Flash point	°C	87	87	92	75	71	64	64	75
Energy content	MJ/kg	43.20	43.10	42.88	42.98	42.87	43.24	43.24	43.19
Energy content	MJ/l	35.06	35.40	35.68	35.73	35.87	34.95	34.97	35.12
Sulphur content	%wt	<0.01	<0.01	0.29	0.02	0.16	0.02	0.01	<0.01
Alkenes	%vol	1.4	2.0	2.2	1.6	1.0	0.9	0.2	0.7
Total aromatics[c]	%vol	1.8	16.6	23.0	25.1	26.1	20.0	20.5	17.3
PAH (mono)	%vol	1.8	16.2	18.1	21.1	20.2	17.2	17.2	14.5
PAH (di)	%vol	<0.05	0.4	4.9	3.8	4.8	2.7	2.7	2.2
PAH (tri+)	%vol	<0.05	<0.05	<0.05	0.2	1.1	0.1	0.6	0.6
PAH (29)	mg/l	1.6	4.1	1.39	340	1100	230	180	310
Ring analysis Aromatics		2.7	14.7	22.5	26.0	27.7	19.8	19.4	16.0
Saturates		95.9	83.3	75.4	72.4	71.2	79.6	80.4	83.3
Aromatic carbon	%NMR	2.5[a]	8.6	13.7	14.3	15.3	15.2[d]	11.9[d]	9.0

Notes:

[a] This sample was outside the range of the method.

[b] n.r.: not reported.

[c] n.a.: not analyzed

[d] These two samples seem to have shorter chain N-alkyls present or they have been exposed to hexane/heptane.

Table 3: *Fuel specifications for the fuels in the MTC Report [13]*

		Test fuel	
Fuel property	**Unit**	**EC1**	**EPEFE reference**
Cetane no.		53.8	52.7
Cetane index (ASTM 0976-80)		n.r.[a]	n.r.
Cetane index (IP 380-88)		n.r.	n.r.
Density @15 °C	kg/m^3	816.9	839.6
Viscosity @ 40°C	mm^2/s	2.03	2.68
Distillation IBP	°C	188	184
T5	°C	206	210
T10	°C	212	219
T50	°C	239	271
T90	°C	271	320
T95	°C	280	332
FBP	°C	294	345
H/C		1.91	1.76
CFPP	°C	-37	-16
Cloud point	°C	-34	-12
Flash point	°C	67	78
Energy content	MJ/kg	43.2	42,6
Energy content	MJ/l	35,3	35,8
Sulphur content	%wt	0.7	440
Alkenes	%vol	n.a.	n.a.
Total aromatics[c]	%vol	3.6	29.5
PAH (mono)	%vol	3,6	25,5
PAH (di)	%vol	<0,1	3,2
PAH (tri+)	%vol	<0.02	0.8
PAH (29)	mg/l	24	>2100
Ring analysis Aromatics	%vol	1,9	27,2
Naphtenics	%vol	n.r.	n.r.

Notes:

[a] n.r.: not reported.
[b] n.a.: not analyzed

Table 4: PAC speciation for the fuels investigated in the TFB report [4]

#		Compound name	Test fuel[a] – PAH content in mg/lit.					
			S	L	T	F	X	Lube Oil[b]
1		2-Methyl-9H-Fluorene	n.d.[a]	n.d.	n.d.	0.30	n.d.	n.d.
2		Dibenzothiophene	n.d.	n.d.	n.d.	0.01	n.d.	n.d.
3	✓	Phenanthrene	6.4	0.34	<0.01	3.1	0.01	5.8
4	✓	Anthracene	1.7	0.10	<0.01	0.87	n.d.	1.8
5		4-Methyl-Dibenzothiophene	n.d.	0.01	n.d.	0.01	n.d.	n.d.
6		3-Methyl-Dibenzothiophene	n.d.	n.d.	n.d.	0.01	n.d.	n.d.
7		3-Methyl-Phenantrene	24	0.67	n.d.	3.1	0.02	5.3
8		2-Methyl-Anthracene	32	0.81	0.02	3.8	0.01	7.5
9		4 & 9-Methyl-Phenatrene	48	0.79	n.d.	2.7	0.04	11
10		1-Methyl-Phenanthrene	41	0.75	<0.03	2.7	0.02	7.5
11	✓	Fluoranthene	2.5	3.8	0.20	23	n.d.	1.9
12	✓	Pyrene	10	16	1.1	74	0.14	5.1
13		1-Me-7-Isopropylphenanthrene	33	0.19	0.04	0.79	0.01	2.1
14		Benzo(a)flourene	12	0.09	n.d.	0.39	0.01	1.5
15		2-Methyl-Pyrene	6.4	7.3	0.85	31	0.05	2.2
16		1-Methyl-Pyrene	5.0	6.0	0.60	27	0.04	2.2
17	✓	Benzo(ghi)fluoranthene	0.75	0.04	0.07	0.17	n.d.	4.0
18	✓	Cyclopenta(cd)pyrene	0.59	0.01	<0.01	0.07	n.d.	0.98
19	✓	Benzo(a)anthracene	1.5	n.d.	<0.01	0.02	n.d.	0.72
20	✓	Chrysene/Triphenylene	3.8	0.01	<0.04	0.11	n.d.	3.2
21	✓	Benzo(b & k)flouranthene	0.20	n.d.	n.d.	n.d.	n.d.	0.86
22	✓	Benzo(e)pyrene	0.21	<0.01	n.d.	n.d.	n.d.	0.99
23	✓	Benzo(a)pyrene	0.21	0.09	<0.02	0.02	0.03	1.9
24		Perylene	0.14	0.02	<0.03	0.01	n.d.	0.84
25		Indeno(1,2,3-cd)flouranthene	0.12	n.d.	n.d.	n.d.	n.d.	0.18
26	✓	Indeno(1,2,3-cd)pyrene	0.05	n.d.	n.d.	n.d.	n.d.	n.d.
27		Picene	0.00	0.01	<0.01	n.d.	n.d.	0.13
28	✓	Benzo(ghi)perylene	0.12	0.02	n.d.	n.d.	0.02	0.45
29	✓	Coronene	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
		Sum of 29 PAC	229	37	2,8	172	0,41	69

Notes:

a n.d.: not detected.

b Lube oil PAH in µg/g instead of mg/l as for the fuels.

Table 5: *PAC speciation for the fuels investigated in the SEPA report [5]. Only the 12 main PAC have been reported.*

#		Compound name	EC 1	D1	D2	D4	D5	D6	D7	D8	D9
				Test fuel[a] – PAH content in mg/liter[b]							
1		2-Methyl-9H-Fluorene	3,8	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
2		Dibenzothiophene	nd	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
3	✓	Phenanthrene	nd	0.17	0.24	0.27	78	110	30	29	84
4	✓	Anthracene	3,5	0.03	<0.05	0.03	3.3	40	3.0	2.7	11
5		4-Methyl-Dibenzothiophene	nd	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
6		3-Methyl-Dibenzothiophene	nd	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
7		3-Methyl-Phenantrene	nd	0.18	0.78	0.11	53	99	29	24	87
8		2-Methyl-Anthracene	4,8	0.18	0.93	0.13	61	160	35	28	83
9		4 & 9-Methyl-Phenatrene	nd	0.12	0.65	0.11	58	300	54	41	17
10		1-Methyl-Phenanthrene	0,7	0.10	0.41	0.11	47	210	45	33	19
11	✓	Fluoranthene	1,1	<0.14	0.06	0.06	7.8	13	4.0	3.7	9.8
12	✓	Pyrene	2,8	0.16	0.30	0.17	9.0	24	6.4	3.3	1.0
13		1-Me-7-Isopropylphenanthrene	nd	<0.01	<0.04	<0.03	3.6	35	4.7	3.1	0.16
14		Benzo(a)flourene	nd	<0.01	<0.01	<0.01	2.6	11	3.5	2.6	<0.08
15		2-Methyl-Pyrene	2,1	0.04	0.16	<0.03	5.2	9.2	3.0	1.9	0.17
16		1-Methyl-Pyrene	nd	0.06	0.17	<0.02	4.6	12	2.2	1.4	0.14
17	✓	Benzo(ghi)fluoranthene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
18	✓	Cyclopenta(cd)pyrene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
19	✓	Benzo(a)anthracene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
20	✓	Chrysene/Triphenylene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
21	✓	Benzo(b & k)flouranthene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
22	✓	Benzo(e)pyrene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
23	✓	Benzo(a)pyrene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
24		Perylene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
25		Indeno(1,2,3-cd)flouranthene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
26	✓	Indeno(1,2,3-cd)pyrene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
27		Picene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
28	✓	Benzo(ghi)perylene		n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
29	✓	Coronene	nd	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
		Sum of 29 PAC	24	1.6	4.1	1.39	340	1100	230	180	310

Notes:

[a] Analysis is the mean value of 3 analyses, except for fuel D1 (4) and D7 (2)

[b] Only the 12 main PAC have been reported in the reference [5]. In all but two cases (D1 & D4) the 12 PAC comprise more than 90% of all 29 PAC.

Table 6: *PAC speciation for the fuels investigated in the MTC report [13]*

			Test fuel (mg/l)	
#		**Compound name**	**EC1**	**EPEFE**
1		2-Methyl-9H-Fluorene	3.8	197.5
2		Dibenzothiophene	n.d.	n.d.
3	✓	Phenanthrene	n.d.	n.d.
4	✓	Anthracene	3.5	14.3
5		4-Methyl-Dibenzothiophene	n.d.	n.d.
6		3-Methyl-Dibenzothiophene	n.d.	n.d.
7		3-Methyl-Phenantrene	n.d.	n.d.
8		2-Methyl-Anthracene	4.8	381
9		4 & 9-Methyl-Phenatrene	n.d.	n.d.
10		1-Methyl-Phenanthrene	0.7	710
11	✓	Fluoranthene	1.1	42.9
12	✓	Pyrene	2.8	236
13		1-Me-7-Isopropylphenanthrene	n.d.	n.d.
14		Benzo(a)flourene	n.d.	n.d.
15		2-Methyl-Pyrene	2.1	251.4
16		1-Methyl-Pyrene	0.6	75.2
17	✓	Benzo(ghi)fluoranthene	n.d.	<50[b]
18	✓	Cyclopenta(cd)pyrene	n.d.	<50[b]
19	✓	Benzo(a)anthracene	n.d.	<50[b]
20	✓	Chrysene/Triphenylene	n.d.	<50[b]
21	✓	Benzo(b & k)flouranthene	n.d.	n.d.
22	✓	Benzo(e)pyrene	n.d.	n.d.
23	✓	Benzo(a)pyrene	n.d.	n.d.
24		Perylene	n.d.	n.d.
25		Indeno(1,2,3-cd)flouranthene	n.d.	n.d.
26	✓	Indeno(1,2,3-cd)pyrene	n.d.	n.d.
27		Picene	n.d.	n.d.
28	✓	Benzo(ghi)perylene	n.d.	n.d.
29	✓	Coronene	n.d.	n.d.
		Sum of 29 PAC	24	>2100

Notes:

[a] n.d.: not detected.

[b] quantification not possible due to interference

4 IMPACT OF FUEL SPECIFICATION ON PAC IN THE EXHAUST

All the sampling of PAC in the exhaust has been carried out both in on the particulate and the semivolatile phase. Furthermore, most of the tests have been repeated several times (3 tests in general). To simplify the presentation, only the sum of the PAC in the particulate phase and the semivolatile phase is shown. Likewise, only the averaged results are shown.

In Table 7, the PAC in the exhaust from the TFB report is shown. The PAC analysis in the exhaust was made for only three of the five fuels.

Table 7: *Speciation of exhaust PAC in the TFB report (µg/bhp-hr) [4]*

			Test fuel / PAC (µg/bhp-hr)		
#		**Compound name**	**S**	**L**	**X**
1		2-Methyl-9H-Fluorene	0,88	<0,005	<0,003
2		Dibenzothiophene	0,35	0,04	0,02
3	✓	Phenanthrene	56,85	3,18	3,45
4	✓	Anthracene	9,58	0,93	1,05
5		4-Methyl-Dibenzothiophene	0,07	<0,003	<0,006
6		3-Methyl-Dibenzothiophene	0,29	0,59	0,02
7		3-Methyl-Phenantrene	39,76	4,57	1,82
8		2-Methyl-Anthracene	44,03	6,09	2,61
9		4 & 9-Methyl-Phenatrene	63,27	10,33	3,80
10		1-Methyl-Phenanthrene	52,37	8,29	3,18
11	✓	Fluoranthene	5,51	3,39	2,93
12	✓	Pyrene	6,52	9,23	3,54
13		1-Me-7-Isopropylphenanthrene	4,51	2,03	0,90
14		Benzo(a)flourene	1,95	0,52	0,26
15		2-Methyl-Pyrene	1,44	2,40	0,38
16		1-Methyl-Pyrene	1,15	1,58	0,27
17	✓	Benzo(ghi)fluoranthene	0,79	0,60	0,46
18	✓	Cyclopenta(cd)pyrene	0,12	0,09	0,10
19	✓	Benzo(a)anthracene	0,56	0,15	0,15
20	✓	Chrysene/Triphenylene	1,57	0,50	0,45
21	✓	Benzo(b & k)flouranthene	0,26	0,04	0,09
22	✓	Benzo(e)pyrene	0,03	0,03	0,06
23	✓	Benzo(a)pyrene	0,17	0,02	0,02
24		Perylene	0,02	0,02	0,02
25		Indeno(1,2,3-cd)flouranthene	<0,006	n.d.	<0,006
26	✓	Indeno(1,2,3-cd)pyrene	0,01	<0,008	<0,003
27		Picene	0,01	<0,005	0,01
28	✓	Benzo(ghi)perylene	0,02	0,01	<0,003
29	✓	Coronene	0,01	0,01	<0,005
		Sum of 29 PAC	297	54	25

Notes:

[a] n.d.: not detected.

The results in Table 7 shows clearly that the two "better" fuels having lower PAH content also gives lower PAC in the exhaust. This correlation was shown already in the TFB report and recently these results have been cited in the so-called "World-Wide Fuel Charter" by the auto and engine industry [19]. However, in this case a later publication than the TFB report was cited as the source. In Figure 7, the correlation mentioned above is shown [19].

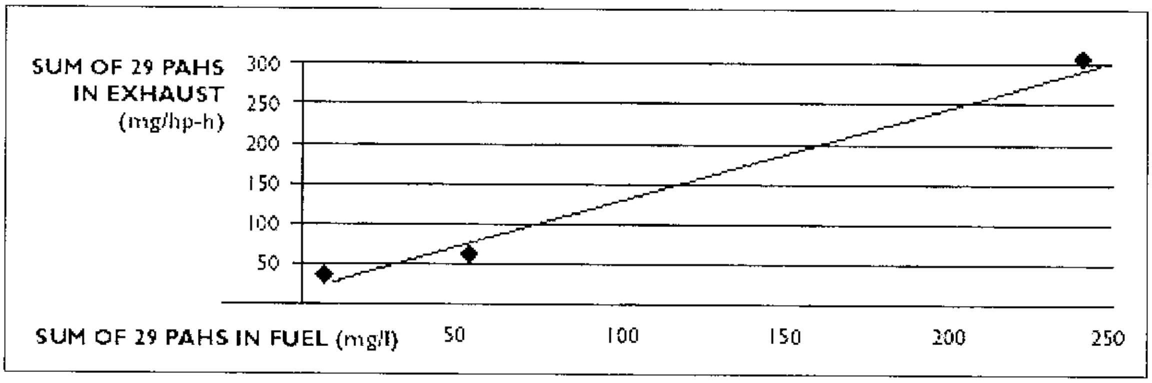


Figure 1: *PAC in exhaust vs. PAH in the fuel [19]*

The fuel specification that best corresponds to the average diesel fuel used in Sweden some 10 years ago appears to be the D6 fuel in the SEPA investigation. This fuel has a tri+ PAH content of some 1100 mg/l. A later report by Grägg compared the EC1 fuel with the EPEFE reference fuel (should correspond to average EU fuel at that time). The fuel analysis showed a PAH content of more than 2100 mg/l for the EPEFE reference fuel. The difference between the D6 fuel and the EPEFE reference fuel could be an indication of that the average Swedish fuel was somewhat better than the European fuel at that time. It is of course a pure speculation to assume the PAH content of the average US (or Californian) fuel, since no similar comparable data are available (or known by the authors). However, other fuel parameters of the US fuel (except sulfur) do not indicate that this fuel should be much better than the D6 or EPEFE reference fuels in this respect.

Table 8 and Figure 8 shows the impact of the various fuels in the SEPA report on regulated emissions, PAC and biological tests (Ames and TCDD).

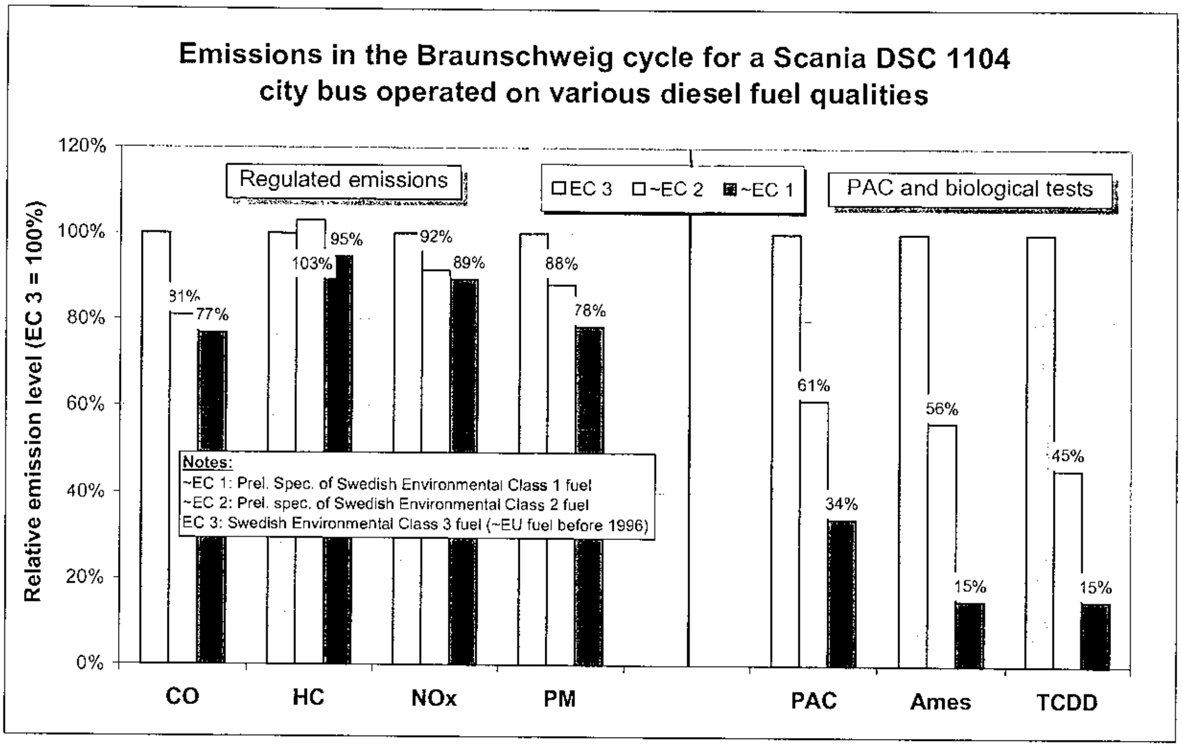


Figure 2: *Impact of fuel specification on emissions and in the biological tests [4]*

For reference, the fuel called "EC3" in Figure 8 is the D6 fuel in the SEPA report and the ~EC2 and ~EC1 are the D9 and the D1 fuels respectively. The denotation (~) before the fuel designation indicates that these two test fuels do not correctly correspond to the standard for the fuels. The standard for the environmentally classified fuels was set later. From the results shown above it is clear that the fuel specification has a considerable impact on the PAC emission as well as the impact in the biological tests. This implies that the use of a single URF for diesel exhaust (as PM) may underestimate the impact of the fuel in this respect.

Table 8: *Speciation of exhaust PAC in the SEPA report [5]*

#		Compound name	Test fuels D1	D2	D4	D5	D6	D7	D8	D9
1		2-Methyl-9H-Fluorene								
2		Dibenzothiophene								
3	✓	Phenanthrene								
4	✓	Anthracene								
5		4-Methyl-Dibenzothiophene								
6		3-Methyl-Dibenzothiophene								
7		3-Methyl-Phenantrene								
8		2-Methyl-Anthracene								
9		4 & 9-Methyl-Phenatrene								
10		1-Methyl-Phenanthrene								
11	✓	Fluoranthene								
12	✓	Pyrene								
13		1-Me-7-Isopropylphenanthrene								
14		Benzo(a)flourene								
15		2-Methyl-Pyrene								
16		1-Methyl-Pyrene								
17	✓	Benzo(ghi)fluoranthene								
18	✓	Cyclopenta(cd)pyrene								
19	✓	Benzo(a)anthracene								
20	✓	Chrysene/Triphenylene								
21	✓	Benzo(b & k)flouranthene								
22	✓	Benzo(e)pyrene								
23	✓	Benzo(a)pyrene								
24		Perylene								
25		Indeno(1,2,3-cd)flouranthene								
26	✓	Indeno(1,2,3-cd)pyrene								
27		Picene								
28	✓	Benzo(ghi)perylene								
29	✓	Coronene								
		Sum of 29 PAC	152	36	37	210	446	135	145	270

"Raw" data not available for the moment

Similar data as in the previous case are shown in Table 9 for the MTC report.

Table 9: Speciation of exhaust PAC in the MTC report [13]

#		Compound name	Test fuels: EC1	Test fuels: EPEFE
1		2-Methyl-9H-Fluorene	3,8	36,8
2		Dibenzothiophene	2,9	10,2
3	✓	Phenanthrene	39,7	267,3
4	✓	Anthracene	3,1	28,2
5		4-Methyl-Dibenzothiophene	n.r.[a]	n.r.
6		3-Methyl-Dibenzothiophene	n.r.	n.r.
7		3-Methyl-Phenantrene	n.r.	n.r.
8		2-Methyl-Anthracene	9,1	154,4
9		4 & 9-Methyl-Phenatrene	7,7	165,5
10		1-Methyl-Phenanthrene	9,8	98,8
11	✓	Fluoranthene	23,5	82,5
12	✓	Pyrene	70,3	212,7
13		1-Me-7-Isopropylphenanthrene	n.d.[b]	n.d.
14		Benzo(a)flourene	n.d.	n.d.
15		2-Methyl-Pyrene	0,9	10,1
16		1-Methyl-Pyrene	n.d.	n.d.
17	✓	Benzo(ghi)fluoranthene	6,2	14,0
18	✓	Cyclopenta(cd)pyrene	0,5	0,9
19	✓	Benzo(a)anthracene	n.d.	n.d.
20	✓	Chrysene/Triphenylene	0,3	2,6
21	✓	Benzo(b & k)flouranthene	1,5	0,8
22	✓	Benzo(e)pyrene	0,3	0,4
23	✓	Benzo(a)pyrene	0,2	0,7
24		Perylene	n.d.	n.d.
25		Indeno(1,2,3-cd)flouranthene	n.d.	n.d.
26	✓	Indeno(1,2,3-cd)pyrene	n.d.	n.d.
27		Picene	n.d.	n.d.
28	✓	Benzo(ghi)perylene	n.d.	n.d.
29	✓	Coronene	n.d.	n.d.
		Sum of 29 PAC	180[c]	1086[c]

Notes:

a n.r.: not reported.

b n.d.: not detected

c There is a small discrepancy between the sum of PAC in the two reports by Grägg (MTC 9510 [13] and MTC 9517 [15]) where the PAC analysis from these tests is reported. The later report has the level 182 and 1085 respectively, which is very close to the level summed up in the table above. Rounding errors might explain that difference.

As can be seen in Table 9, the EC1 fuel gives much lower PAC emissions than the EPEFE reference fuel.

In Figure 9, the results from the MTC report are shown.

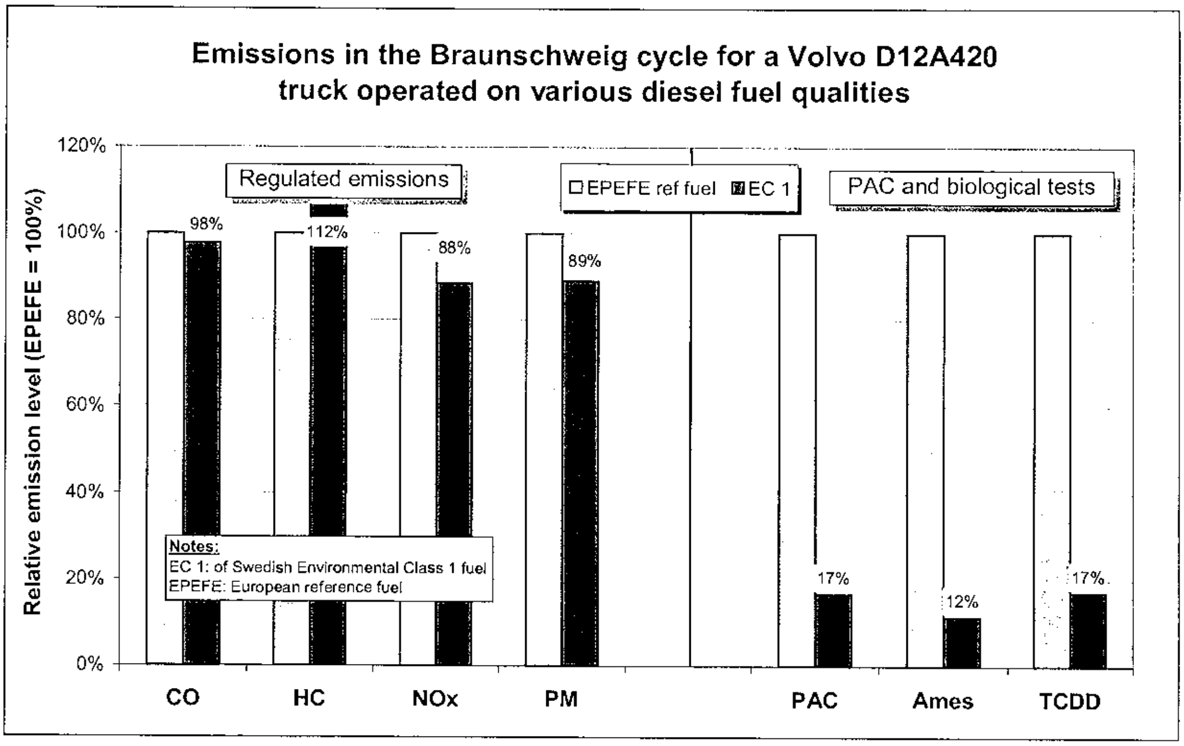


Figure 3: *Impact of fuel specification on emissions and in the biological tests [13]*

As shown in Figure 9 above, the fuel specification has a significant impact on PAC emissions in the exhaust and in the biological tests. The impact on other harmful emission components is not as great as for PAC. As an example the emissions of ethene, propene and 1,3-butadiene was 17%, 33% and 20% lower for the EC1 fuel in comparison to the EPEFE fuel in the MTC report [13]. Benzene could not be detected in either case (below the detection limit).

The question of how much the EC-D fuel could improve the unregulated emissions cannot be answered for the moment. No PAH data of the same 29 components analyzed in the Swedish tests is available in the public domain (at the moment). Therefore, it is recommended that such an analysis be carried out. If a PAH analysis is performed at the same laboratory as the Swedish analyses (Stockholm University, Westerholm et al.), valuable information for comparisons could be provided. It is known from the Swedish investigations that deep hydrotreatment with the purpose of reducing sulfur level in the fuel also has a great impact on the higher aromatics (tri+). Therefore, it is likely that the EC-D fuel should be at least as "good" as the Swedish EC2 fuel regarding the PAC emissions. Whether the as low (or lower?) PAC level as for the EC1 fuel could be achieved, remains to be proven.

5 DISCUSSION AND CONCLUSIONS

6 REFERENCES

1. Ahlvik P., and Brandberg Å.: "Relative Impact on Environment and Health from the Introduction of Low Emission City Buses in Sweden." SAE Paper 2000-01-1882, 2000.
2. Törnqvist M., and Ehrenberg L.: "On Cancer Risk Estimation of Urban Air Pollution.", Environmental Health Perspectives, vol. 102, Supplement 4, October 1994.
3. Edited by Möller L. "City Air – A book about the air quality in our cities.", Swedish EPA, ISBN 91-620-1089-1, 1990, in Swedish.
4. Brandberg Å. (Ecotraffic): "Motor fuels for city vehicles – Final Report.", TFB-Message 168, 1990, in Swedish.
5. Edited by Westerholm R., and Egebäck K.-E.: "Impact of Fuels on Diesel Exhaust Emissions – A chemical and biological characterization.", Swedish EPA Report 3968, 1991.
6. Grägg K. (MTC): "Different diesel fuel properties and their impact on the exhaust emissions." MTC Report MTC 9010B, 1991, in Swedish.
7. Grägg K. (MTC): "Low-emission buses, diesel catalyst from Degussa and Volvo's Cityfilter." MTC Report MTC 9006, 1992, in Swedish.
8. Grägg K. (MTC): "Investigation of three diesel fuels regarding the influence of the final boiling point on the exhaust emissions." MTC Report MTC 9109B, 1992, in Swedish.
9. Grägg K. (MTC): "Effects of Environmentally Classified Diesel Fuels, RME and Blends of Diesel Fuels and RME on the Exhaust Emissions." MTC Report MTC 9209B. 1994.
10. Grägg K. (MTC): "Emission measurements with and without a catalytic exhaust muffler." MTC Report MTC 9430A, 1994, in Swedish.
11. Grägg K. (MTC): "Emission measurements on a prototype to a CRT filter." MTC Report MTC 9430B, 1994, in Swedish.
12. Grägg K. (MTC), Westerholm R (SU), and Rannug U (SU): "Chemical analysis and biological tests on the exhaust emissions from tainted and untainted diesel fuel." MTC Report MTC 9431, 1995, in Swedish.
13. Grägg K. (MTC): "Chemical Characterization and Biological Testing of Exhaust Emissions from a Truck Fueled with EC1 and EPEFE Reference Fuel", MTC report 9510, 1995.
14. Hedbom A. (MTC): " Assessments of Test Cycle Proposals – The Transient Cycle and the OICA/ACEA Steady State Cycle with Dynamic Load Response Test.", MTC Report MTC 9511A, 1995.
15. Grägg K. (MTC): "The Effect on the Exhaust Emissions of Changing to a Low Aromatic, Low PAC and Low Sulfur Diesel Fuel", MTC report 9517, 1995.
16. Grägg. K. (MTC): "Testing on a biogas fuelled bus from LITA", MTC Report 9434, 1995, in Swedish.
17. Grägg K. (MTC): "Emissions from two CNG Fueled Buses", MTC report 9405B, 1995.

18. Ahlvik P., and Brandberg Å.: "Exhaust emissions from light-duty vehicles fuelled by different fuels. – Effect on health, environment and energy use." KFB-Report 1999:38, 1999, in Swedish.

19. Edited by ACEA, AAM, EMA, and JAMA: "World-Wide Fuel Charter", www.acea.be, April 2000.

20. IEA Alternative Motor Fuels. "Vehicle Emissions and Cancer Risks." Trends No. 91:3 Aug. 1991.

Ecotraffic

RESEARCH & DEVELOPMENT AB

CONSULTANTS IN ENVIRONMENT,
MOTOR FUELS AND TRANSPORTATION

E-mail eco@ecotraffic.se

Ecotraffic R&D AB

Karlavägen 18 • Box 5671 • S-114 86 Stockholm • Phone +46-8-614 50 56 • Fax +46-8-614 50 08

Ecotraffic Norge AS • P.O. Box 1484 Vika • N-0115 Oslo, Norway • Phone +47-23 11 47 40 • Fax +47-23 11 47 41