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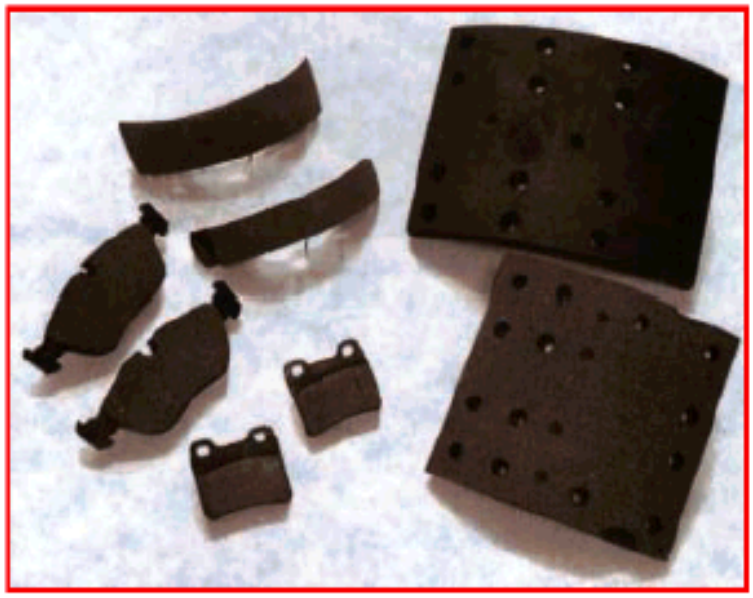
Metal emissions from Stockholm traffic

– WEAR OF BRAKE LININGS



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THE STOCKHOLM ENVIRONMENT AND HEALTH PROTECTION ADMINISTRATION, APRIL 2001

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Foreword

This report has been prepared with funds partly deriving from the Swedish Environment Protection Agency's research area "Metals in Urban and Forest Environment" and partly from the Stockholm Environment and Health Protection Administration's project "Survey of Pollutants in Ground and Sediments in Stockholm".

The environment today is to a great extent affected by diffuse sources. As yet, we do not possess the knowledge necessary to point out connections between sources and conditions in the environment. The study of metal content in brake linings is yet another important part of that work. We would like to thank Rolf Sundberg at Outokumpu Copper whose preliminary calculations of metal emissions from car breaks gave us reason to proceed with this study.

Ulf Mohlander has, on behalf of the Environment and Health Protection Administration, provided views on the design of the project and the report.

A Swedish version of this report was published in 1998, (Rapport Nr 2: 98). This English version is essentially the same but the emission of cadmium has now been estimated and the particulate emission from brake linings has been compared with exhaust emission from diesel and gasoline vehicles in Stockholm.

Stockholm, april 2001

Urban Jonsson

The Department for Environment Protection - The Stockholm Environment and Health Protection Administration

Background and objective

There are elevated, sometimes highly elevated, levels of metal in several of Stockholm's recipients – ground, lakes, Lake Saltsjön and groundwater as well as sludge from sewage treatment plants. Sometimes, the elevated levels in the receiving bodies can affect the biological life.

Metals that are spread to wastewater by way of the combined sewage system and are treated in the wastewater treatment plants cause problems, since the metals contaminate the sewer sludge. This reduces the use of the sludge as a fertiliser on farmland. It is therefore important to reduce metal contamination of wastewater. This is particularly the case with mercury, cadmium and lead, but also with copper as the agricultural utility of the sludge is reduced by the high copper content. Copper water pipes and roofs covered with copper have been identified as large sources for the spread of copper in Stockholm. A further source could be traffic on streets and roads that, due to wear of break linings with copper content, contributes copper to the sewage system, stormwater and ground.

Few studies have been made in Sweden of emissions from wear of brake linings. The Malmö Environmental Health Administration made a study of national cadmium emissions deriving from brake linings in 1993 (ref. 1). This study showed that in Sweden approx. 934,000 kg of brake linings were used per year and that approx. 13 kg cadmium was emitted from traffic.

The objective of the present study is to provide the necessary background for calculating metal emissions in Stockholm that are caused by wear of brake linings.

SGAB Analytica has performed the metal analyses. The method used has been to cut out samples using glass or ceramic material, dissolve the samples in aqua regia or hydrofluoric acid and subsequently analyse with HR ICP-MS.

Consumption of brake linings

Friction material in brake linings for use in passenger cars and heavy goods vehicles/buses consists of compounds where for instance fibres from steel, glass and plastic serve as reinforcements in the material. Cast iron chip can also occur. In addition, some substances have a heat conducting effect. Copper, brass and zinc are also used to conduct heat (ref. 2).

Brake linings in both passenger cars and heavy goods vehicles are usually replaced after approx. 70 % of their total length of life (ref. 2).

The total yearly amount of transports and communication in Stockholm equals approx. 3,000 million vehicle kilometres, out of which passenger cars and light goods vehicles/buses account for 2,880 million vehicle kilometres (96 percent), heavy goods vehicles for 90 million vehicle kilometres (3 percent) and buses for 30 million vehicle kilometres (= 1 percent) (ref. 3).

Passenger cars

Front brake linings in passenger cars that are used in city traffic conditions are normally replaced after 30,000 - 40,000 kilometres, rear brake linings after 60,000 - 80,000 kilometres (ref. 2).

Using the number of passenger cars presently in use in traffic and communications in the City and County of Stockholm as a reference, the average driving distance can be calculated to be 12,000 - 15,000 kilometres per year. The annual driving distance of a passenger car is hereinafter assumed to be 15,000 kilometres. Making the further assumption that both rear and front linings are replaced after 60,000 kilometres driving, this would consequently happen when the car is four years old.

Passenger car linings weigh 0.13 - 0.15 kg at the front of the car and 0.9 - 0.11 kg at the rear (ref. 2). The assumption is made here that new front linings would weigh 0.15 kg, that new rear linings would weigh 0.11 kg, that all linings are used to 70 % of their total length of life before being replaced and that front linings are replaced every 40,000 kilometres (four linings) and rear linings every 60,000 kilometres (four linings). This assumption leads to a brake lining consumption of:

$0.7 * 4 * 0.15/40{,}000 * 2{,}880 * 10^5$ =30,200 kg in the front and
$0.7 * 4 * 0.11/60{,}000 * 2{,}880 * 10^5$ =14,800 kg in the rear, per year.

This would make the total wear of brake linings in passenger cars to 45,000 kg per year.

Goods vehicles

Data referring to the duration of brake linings for heavy goods vehicles vary between 80,000 - 120,000 kilometres (ref. 4) to 100,000 - 120,000 (ref. 5). It will hereinafter be assumed that all brake linings in heavy goods vehicles are replaced every 100,000 kilometres.

The number of linings per wheel varies between make and model. Generally, it can be said that, per wheel, linings weigh 2.4 kg in the front and 3.5 kg in the rear (ref. 2). This means that the total linings of a four-wheel goods vehicle weigh 2 * 2.5 + 2 * 3.5 = 12 kg. The linings are replaced after 70 % of their wear, i.e. when 0.7 * 12 = 8.4 kg has been used.

The total amount of linings consumed per year in goods vehicles would then equal $90 * 10^5$ / 100,000 * 8.4 = 7,600 kg.

Buses

According to data derived from weighing new and worn-out linings provided by Stockholm Transport's bus division, SL Buss AB, (ref. 6), buses use on average 0.00011 kg per kilometre.

This means that buses on a yearly basis use brake linings to a total amount of $30 * 10^5 * 110 * 10^{-5}$ = 3,300 kg.

Metal emissions

In order to calculate emissions from these types of vehicle, it is necessary to measure not just the total amount of brake linings used but also the metal content of brake linings. Content analysis of copper, zinc, chromium, nickel, cadmium and lead has been performed by SGAB Analytica. Metal concentrations have been measured by plasma – emission spectrometry according to EPA– method 200.7 (modified).

Passenger cars

The following “compilation” presents the most frequently represented makes and models in the traffic of Stockholm. The material has been prepared during the autumn of 1997 by the Stockholm branch of the Swedish National Road Administration and is based on random registrations of passenger cars in traffic on Nynäsvägen road, and makes and models have subsequently been checked with the motor vehicle registry. A total of 987 cars were registered.

Table 1 shows the most frequent makes and models and their relative abundance. Only models constituting at least 1 percent of the total amount of cars have been included. It is assumed that the result reflects each model's share of the total passenger car traffic of the city. In all, 63,5 percent of the passenger cars are represented.

Table 1: Abundance of various car models (Source: Swedish National Road Administration, Stockholm regional branch, 1997).

Make	Model	Share %	Accumulated %
Volvo	700, 740, 760	5.8	5.8
	840, 850, S70, V70	5.6	11.4
	940, 960	5.4	16.8
	240	4.7	21.5
	440, 460, S40, V40	2.5	24
	340	1.2	25.2
Saab	900	4.6	29.8
	9000	3.7	33.5
Ford	Escort	3.3	36.8
	Sierra	2.3	39.1
	Scorpio	1.9	41
	Mondeo	1.7	42.7
VW	Golf	2.4	45.1
	Passat	1.3	46.4
	Pick-up	1.2	47.6
Opel	Kadett	2.8	50.4
	Vectra	1.7	52.1
Nissan	Micra	1.4	53.5
	Sunny	1	54.5
Mazda	323	1.8	56.3
	626	1.8	58.1
Audi	100	1.7	59.8
Toyota	Corolla	2.5	62.3
	Carina	1.2	63.5

By including linings from the models above a selection is generated that covers roughly 60 percent of all passenger cars. Samples have been taken from the latest car models and these cars are taken to represent passenger cars impacting on metal emissions from brake linings in the years to come. Front and rear linings for the most sold car models of every make and model/model series. Altogether 48 linings, have been procured.

To arrive at an overview of metals in the brake linings of older passenger cars, samples have been taken of front and rear linings from two downstream market suppliers for Volvo 800 and 400, Saab 900, Ford Escort and VW Golf. The linings, 20 in total, have been procured from

OK and Biltema. To facilitate the calculation of metal emissions passenger cars have been divided into, cars that are up to four years old and are assumed to be equipped with the original linings, and cars that are older than four years and are assumed to be using downstream market linings.

About 40 percent of traffic from passenger cars comes from cars that are four years or younger, while 60 percent derives from older cars (ref. 3).

New passenger cars (original linings, purchased from brand dealers)

Table 2: Metal concentrations in brake linings for new passenger cars, mg/kg.

Make	Model	Front linings						Rear linings					
		Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Ni	Pb	Zn
Volvo	745 GL	<10	156	132,000	151	23,100	28,100	16.2	57.7	172,000	49.1	46,100	26,600
„	854 GLT	<10	169	156,000	217	23,300	29,300	18.2	21.8	216,000	<19.8	53,200	29,800
„	945 S 2.3	<10	156	132,000	151	23,100	28,100	16.2	16.2	172,000	49.1	46,100	26,600
„	245 GL	10.1	123	205,000	-	6,760	26,900	<9.87	<19.7	138,000	<19.7	54,500	11,700
„	400	12.1	128	217,000	186	868	11,800	<9.90	72.8	187,000	138	391	221
„	340	24.2	167	148,000	348	20,600	107,000	<9.62	176	830	144	78.4	870
Saab	900 SE 2.0 T	<9.96	305	168,000	59.3	515	2,650	<9.96	53.4	153,000	97.7	1,240	821
"	9000 150 SE	<10	182	128,000	155	1,370	29,200	<10.1	30.5	229,000	25.5	56,600	35,400
Ford	Escort 1.6 CLX	<9.92	130	87,800	117	175	125	<9.99	46.4	19,000	32.6	403	13,100
"	Sierra 2.0 i GLX	<10.0	120	107,000	108	263	37,200	<9.89	43.2	123,000	32.0	25,300	1,950
„	Scorpio 2.0 CLX	<17.6	132	159,000	159	1,590	17,500	<9.89	43.2	123,000	32.0	25,300	1,950
„	Mondeo 2.0 CLX	<17.6	132	159,000	159	1,590	17,500	<9.95	48.9	107,000	36.7	24,100	2,190
VW	Golf 1.8 GL	10.8	93.2	165,000	109	31,300	27,900	<10.1	197	174	105	310	11,300
„	Passat 1.8 GL	<9.89	127	147,000	113	439	24,100	<9.94	149	142,000	166	22,100	10,800
„	Pick up 2.5	22.5	108	112,000	162	39,700	36,800	19.9	59.6	162,000	132	34,300	37,100
Opel	Astra 1.6 GL	<9.96	158	97,400	121	17,300	32,800	<10.3	248	78,6	131	450	11,800
„	Vectra 1.8	<9.98	118	101,000	113	17,800	34,200	<9.93	43.2	124,000	41.9	375	96,100
Nissan	Micra 1.0	<9.1	76	63.9	80.1	140	6,600	<1.01	27.1	12.7	17.8	<6.06	14.5
„	Sunny 1.6	<9.49	285	234	382	21.3	50,000	<0.974	28.2	14.6	19.1	<5.84	38.3
Mazda	323 S	<0.996	83	17,400	62	160	9,330	<1.00	5.73	17	3.6	9.17	1,900
„	626 2.0 GLX	<0.998	77.9	15,200	61.2	228	7,690	<0.996	123	18,500	106	109	11,900
Audi	A6 1.8	9.86	81.5	43,600	99.4	5 ,970	5,710	11.8	144	126,000	156	784	63,000
Toyota	Corolla 1.6	<0.965	152	98,900	110	36.3	759	<0.974	6.07	108	9.36	<5.84	435
„	Carina 1.8	<0.984	23	234,000	12.4	944	664	<0.974	6.21	25.5	6.12	11.3	370
Mean content		11.6*	137	117,941	141	9 ,052	23,830	8.02	73.4	92,198	69.6	18,655	16,498

* Cd content is below the detection limit in most linings. It is well known that cadmium and zink goes together as they belong to the same group in the periodic system. In order to estimate mean content of Cd in table 2, the relation between Cd and Zn has been calculated for those linings in which both elements has been analysed. The mean value for this relation is 0,49 milligrams of Cd per gram of Zn. This relation has been used to calculate mean concentrations of Cd in the tables 2 and 3.

The metal concentrations are consistently lower in some linings when compared with others. This is for instance the case with rear linings for Volvo 340 and rear and front linings for Nissan Micra.

Old passenger cars (downstream market linings purchased at OK and Biltema)

Table 3: Metal concentrations in brake linings for old passenger cars, mg/kg.

Make	**Supplier**	**Front linings**						**Rear linings**					
modell		Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Ni	Pb	Zn
Volvo	OK	<9.9	83.9	123,000	87.6	46,500	23,900	41.4	91.4	100	81.9	629	17,400
850	Biltema	<10.1	53.2	121,000	62.4	67.2	38.8	<10.1	96.8	123,000	109	<60.7	185
Volvo	OK	<9.99	151	37,300	164	35,900	26,900	<9.99	31.2	143,000	36	62,100	12,100
440	Biltema	<10.2	102	120,000	118	<61.0	158	<19.1	83.0	4,050	78.4	<115	16,500
Saab	OK	<9.97	74.9	76,500	491	3560	51,000	<1.98	48.0	77.9	34.7	94.1	212
900	Biltema	<10.4	84.5	132,000	110	96.4	29.1	<10.1	237	122,000	248	97.2	218
VW	OK	<1.99	69.8	100	66.6	227	239	<9.87	234	45.5	117	354	12,600
Golf lll	Biltema	12.5	60.9	33,000	164	1,700	22,600	<10.2	274	120,000	302	130	210
Ford	OK	11.8	150	31,400	295	33,200	21,300	<10.1	252	43.4	138	366	12,500
Escort	Biltema	14.2	89.6	45,600	257	1,610	30,800	<2.03	164	87.9	73	<12.2	38.3
Mean content		8.60*	92.0	71,990	182	13,651	17,696	3.50*	151	51,240	122	9,110	7,197

* See footnote in Table 2.

A measurable cadmium content was only found in a small number of the linings. The metal content is low in linings for several car models, particularly among those purchased at OK. This is the case with for instance front and rear linings for VW Golf as well as with rear linings for Volvo 850, Saab 900 and Ford Escort. All these linings were manufactured by BBA Friction Sweden AB.

The annual metal emissions are calculated as the amount of brake lining used per year times metal content. As a measure of the metal content, the mean value is used for each metal. Rear and front brake emissions are calculated separately and added.

Table 4: Metal emissions per year for new and old passenger cars, kg.

	Cd	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
New	0.19	2.1	1,971	2.1	220	386
Old	0.23	3.0	1,760	4.4	329	385
Sum	0.42*	5.1	3,731	6.5	549	771

* See footnote in Table 2.

Goods vehicles

There are large variations within the goods vehicle group as regards total weight, with a range between 3.5 tonnes to over 24 tonnes. The group is represented by Volvo and Scania, the two dominant makes among distribution goods vehicles with a weight of 10 tonnes or more. The relationship between the number of Volvo and Scania goods vehicles in the national lorry fleet is approx. 60/40 (ref. 7). This relationship will be used hereinafter.

Brake linings have been procured for Volvo FL 614 and Scania P9, the most abundant distribution vehicles in Stockholm from each make, and the front and rear brake linings share the same composition (ref. 4 and 5). One brake lining from each model has been analysed.

Table 5: Metal content in brake linings for goods vehicles, mg/kg.

	Cd	Cr	Cu	Ni	Pb	Zn
Volvo	<10.3	171	15,000	118	656	14,900
Scania	<1.99	157	76.9	110	158	127

As seen in Table 5 the linings made for Scania (from BBA Friction Sweden AB) show consistently lower metal concentrations than the Volvo linings. This is particularly the case as regards copper and zinc.

Metal emissions from goods vehicle traffic is calculated as the metal content times the amount of brake lining used. As a measure of the metal content a weighted mean value is used according to the 40/60 relationship between Volvo and Scania.

Table 6: Metal emissions per year from heavy goods vehicles, kg.

Cd	Cr	Cu	Ni	Pb	Zn
<0.05	1.3	68	0.9	3.9	68

Buses

Bus traffic in Stockholm is dominated by the bus division of Stockholm Transport, Busslink AB. Their bus fleet consists of 92 percent Scania buses and 8 percent Volvo (ref. 6). The brake linings share the same composition, both rear and front. One brake lining for each bus make has been analysed.

Table 7: Metal content in brake linings for buses, mg/kg.

	Cd	Cr	Cu	Ni	Pb	Zn
Volvo	<10.1	<20.1	27,300	140	1,020	18,500
Scania	<1.98	118	88.3	178	441	172

The content of copper and zinc is many times higher in the brake linings for Volvo, than it is in those for Scania (BBA Friction Sweden AB). The content of chromium and nickel is however higher in Scania's linings.

The metal emissions from bus traffic is calculated as metal content times the amount of brake lining used. As a measure of the metal content in brake linings a weighted mean value is used, in accordance with the relationship 92/8 percent between Volvo and Scania buses.

Table 8: Metal emissions per year from buses, kg.

Cd	Cr	Cu	Ni	Pb	Zn
<0.01	<0.46	76	0.5	3.2	56

Total emissions

Altogether, road traffic is the source of the following amounts of emissions per year due to wear of brake linings as shown in table 9.

Table 9: Traffic emissions in Stockholm, kg per year

	Passenger cars	Goods vehicles	Buses	Approximate total
Cd	0.42	<0.05	<0.01	<0.5
Cr	5.1	1.3	<0.46	<7
Cu	3,731	68	76	3,900
Ni	6.5	0.9	0.5	8
Pb	549	3.9	3.2	560
Zn	771	68	56	900
Brake linings	45,000	7,560	3,300	56,000

Particulate matter, comparison with exhaust emissions

It is also interesting to compare the PM emissions due to wear of brake linings with the direct emissions due to incomplete combustion of diesel and gasoline in vehicles in Stockholm. The average emission factor for heavy-duty vehicles and passenger cars in Stockholm (1996) have been estimated using the emission model EVA (version 2.2) of the National Swedish Road and Transport Administration

Table 10: Comparison of emissions from wear of brake linings and from incomplete combustion of diesel and gasoline. Total emissions have been estimated using the total yearly amount of transports and communication in Stockholm.

Vehicle type	Brake linings emission		Exhaust emission	
	mg/veh km	Tonnes/y	mg/veh km	Tonnes/y
Passenger cars Diesel	17	2	172	20
Passenger cars Gasoline	17	50	11	30
Goods vehicles	84	8	140	10
SUM		60		60

As can be seen from Table 10 the calculated emission per vehicle kilometre due to wear of brake linings from this study is comparable to the fleet average emission from gasoline passenger cars and about a factor 10 lower compared to the exhaust emission from diesel passenger cars. It is also seen that from heavy-duty goods vehicles the emission due to the wear of brake linings is about 60% of that from due to exhaust. The estimate given here for Stockholm is somewhat higher than the US EPA estimate of 8 mg of brake linings per vehicle kilometre for passenger cars (EPA, 1985).

Total particle emissions may then be estimated using the total yearly amount of transports and communication in Stockholm cited earlier. The exhaust particle emissions are calculated to be about 20, 30 and 10 tonnes per year for diesel and gasoline passenger cars, and goods vehicles respectively. These values may then be compared with the particle emissions due to wear of brake linings of 2, 50 and 8 tonnes per year. The total amount emitted is then about equal for these sources. It is important to note that as exhaust emissions decrease in the future due to

renewal of the vehicle fleet, emissions from brake linings may not change and therefore become relatively more important as a source of PM in urban areas.

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