Air quality measurements of toxic exhaust particles (soot) in Mexico City

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Introduction

Exhaust particles from diesel engines are mainly ultrafine particles ($PM_{0.1}$) i.e. particles with a diameter less than 0.1 micro meter (100 nano meter). These particles are measured in numbers of particles per cm^3. Exhaust particles cause serious health problems in cities by increasing the risk of heart diseases, airway diseases, cancer and thereby premature death. Diesel particles are carcinogenic at the highest possible level according to the WHO[1]. The majority of ultrafine exhaust particles are soot particles (black carbon) being the second most important reason (after CO_2) to global warming. Exhaust particles can be efficiently removed by particulate filters being standard equipment on all new diesel vehicles in Europe, USA, Japan etc. Filters thereby provide people longer and healthier lives.

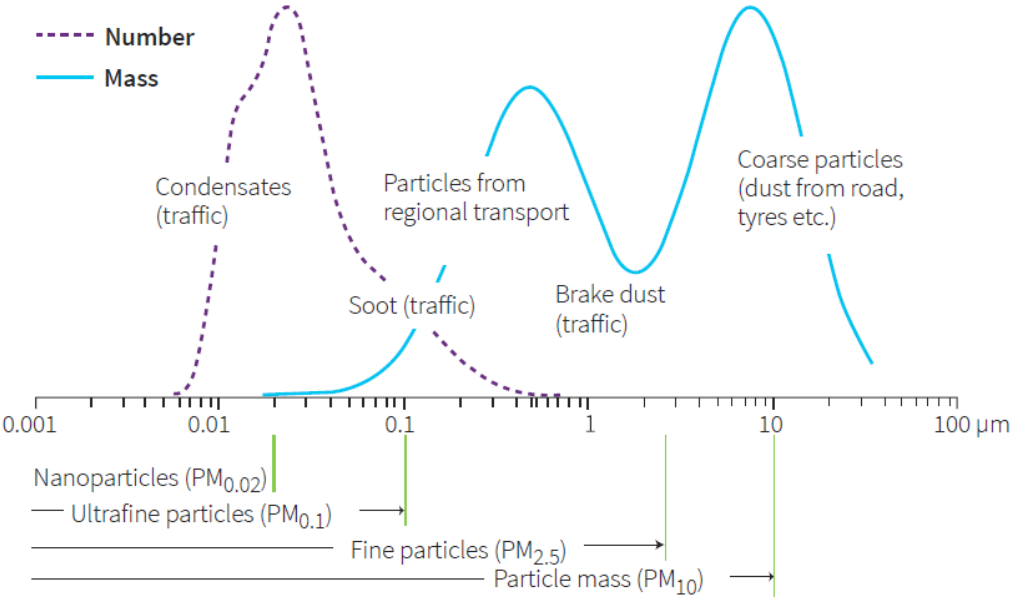
Table 1: Characterization of particle fractions in air

	Diameter in micrometers	Unit of measure
The particle mass (PM_{10})	< 10	µg/m^3
Coarse particles ($PM_{2.5-10}$)	2.5 - 10	µg/m^3
Fine particles ($PM_{2.5}$)	< 2.5	µg/m^3
Ultrafine particles ($PM_{0.1}$)	< 0.1	number/cm^3
Nanoparticles ($PM_{0.02}$)	< 0.02	number/cm^3

Source: **http://www.winkas.dk/wkwebshop/varedetaljer.asp?shopid=851152&funique=244&kat=3&hkat=1**

Particles are characterized according to their aerodynamic diameter, from coarse to ultrafine and nano particles (table 1). Larger particles (PM_{10} and $PM_{2.5}$) account for the majority of particle mass while ultrafine and nano particles account for the majority of the particle number (figure 1). Hence, ultrafine exhaust particles must be measured in numbers.

Figure 1: Particle mass and number characterization



Source: Danish Centre for Environment and Energy, 2012

[1] http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf

Measurements

Ultrafine particles were measured with a P-Trak (Model 8525 Ultrafine Particle Counter).
One measurement was taken every second but minute averages were used in data treatment i.e. one minute represents 60 measuring points and 10 minutes 600 measuring points.
Local wind speed, humidity and temperature were measured with a WindMate-300.
Measurements were performed in Mexico City and Quintana Roo/ Yucatán in January 2015:

1) Inside busses, at bus stops and at the central bus station.
2) At large cross-roads to find the exposure of pedestrians.
3) Inside a car to find the exposure of car drivers.
4) City background in public parks in Mexico City.
5) Natural background in Quintana Roo and Yucatán (Chitzen Itza).

The measurements represent a screening and should be followed by detailed investigations.

Results

Table 2 shows measurements of wind speed, humidity and temperature during measurements. There was no rain during the measurements.

Table 2: Local wind speed, humidity and temperature

	Date	**Wind speed** (m/s)	**Humidity** (%)	**Temperature** (˚C)
Mexico City	January 7th	1-4	40-60	15-25
Mexico City	January 8th	1-3	40-50	15-25
Quintana Roo	January 13th	5	76	26
Yucatán	January 17th	1-2	77	22

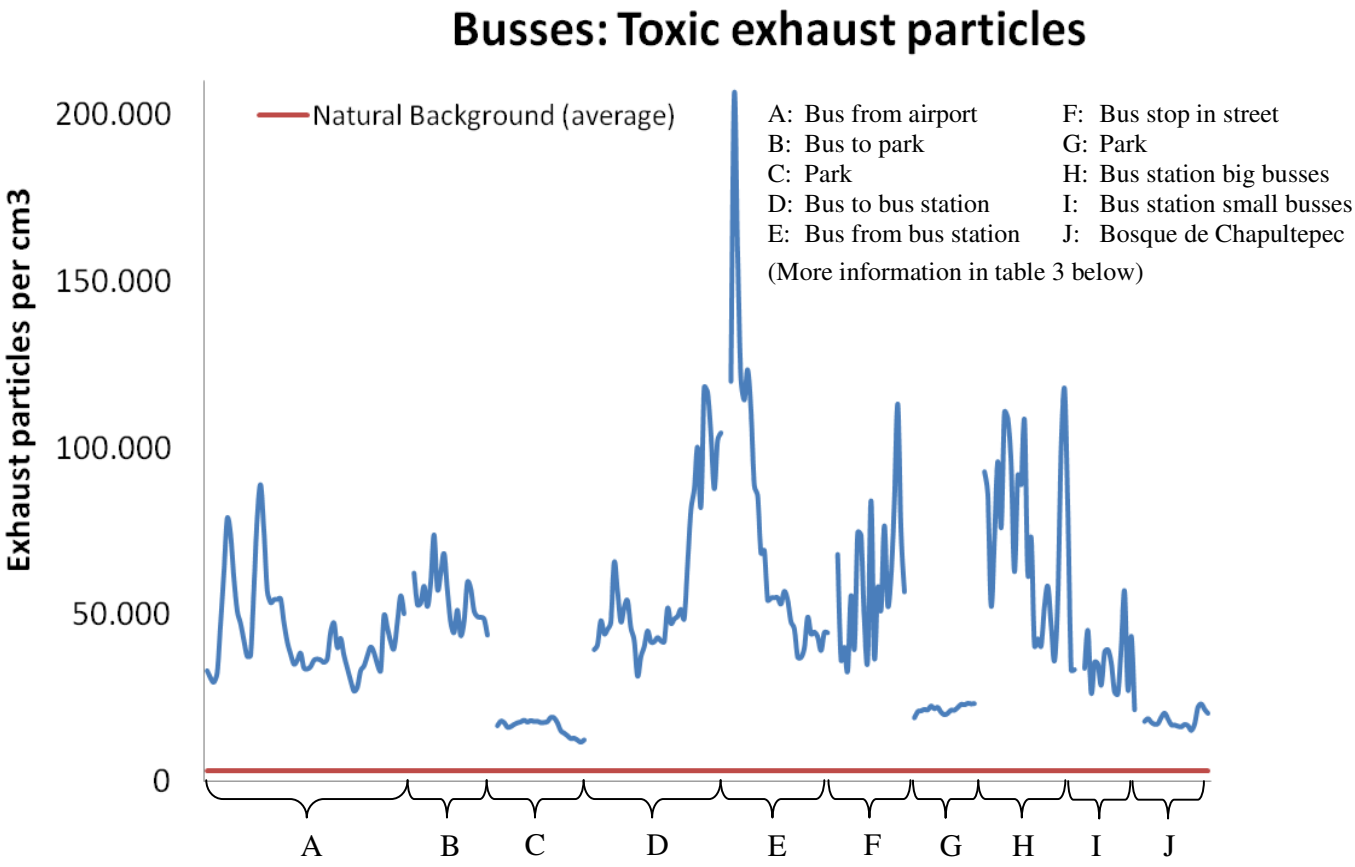
The data in table 2 indicate perfect measuring conditions.

Figure 2 show measurements related to busses in Mexico City. To comparison are shown city background measured inside parks in Mexico City and the natural background measured in Quintana Roo (in quiet beach areas away from streets and other local pollution sources).

From figure 2 is seen that the air pollution with toxic exhaust particles inside busses, at bus stops and at the bus station in Mexico City is many times higher than the natural background pollution in Mexico (outside cities away from local pollution sources) i.e. the pollution is created inside Mexico.

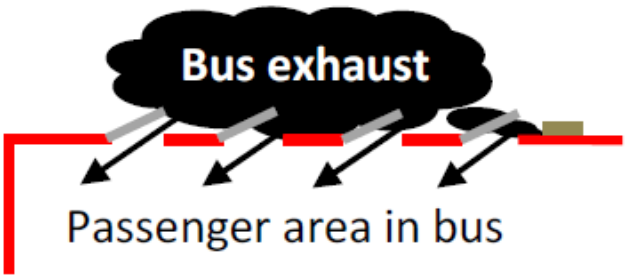
Furthermore, it is seen that the pollution inside busses, at bus stops and at the bus station is much higher than the pollution in parks (C, G & J) in Mexico City i.e. the pollution is mainly generated by the street traffic in Mexico City. The exhaust particles mainly origin from diesel engines i.e. busses, trucks and vans since most private cars are gasoline cars in Mexico. This was confirmed by the measurements at the bus stop (F) where the peaks clearly followed the busses arriving at the bus stop.

Figure 2: Measurement report related to busses in Mexico City



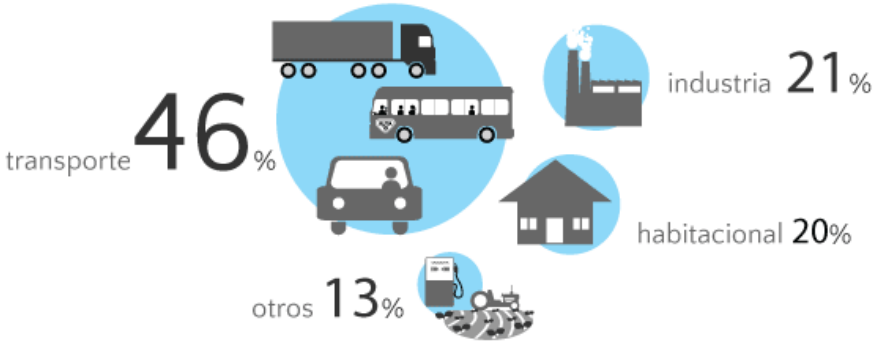
The high pollution inside the busses (A, B, D & E) illustrated in figure 2 is partly due to a bad exhaust system design allowing exhaust from the bus directly to enter the passenger area through the roof ventilation windows (see figure 3) and partly due to polluted street air entering the busses. The extreme high pollution at the bus station with busses (H: Plan Verde) compared to the old small busses (I. Microbús) is due to the fact that the Plan Verde busses are constantly idle running whereas the small busses turn off engines when stopped.

Figure 3



According to the official reports of the Mexico City Secretary of Environment[2] (SEDEMA) the transport is the main source of pollution of ozone precursors and particles in the city and metropolitan area (see figure 4). Diesel trucks and busses emit most of the fine and ultrafine particles. This is confirmed by the measurements in this report.

Figure 4: Mexico City and metropolitan area emissions sources



Source: Secretary of Environment, Mexico City

Table 3 contains measurements related to busses in Mexico City. To comparison are shown city background measured in parks in Mexico City and the natural background measured in Quintana Roo/Yucatán (away from local pollution sources) and measurements from Western Europe (Copenhagen, Denmark) and the former Eastern Europe (Prague, Czech Republic).

Table 3: Passenger exposure in busses in Mexico City (MC)

Average, rounded numbers	Date	Particles/cm^3 (time)
A: Bus from airport in MC (*WTC, Del. Benito Juárez*)	**January 7th**	**44,650** (15.34 - 16.33)
B: Bus to park in MC (*Parque Hundido, Del. Benito Juárez*)	**January 7th**	**54,550** (16.44 - 17.06)
D: Bus to bus terminal station in MC (*Indios Verdes*)	**January 8th**	**60,150** (08.45 - 09.23)
E: Bus from bus terminal station in MC (*Col. Roma/Condesa, Del. Cuauhtémoc*)	**January 8th**	**71,000** (09.32 - 10.02)
F: Bus stop in middle of street in MC (*Col. Roma/Condesa, Del. Cuauhtémoc*)	**January 8th**	**59,850** (10.05 - 10.25)
H: Bus station (*Plan Verde*) **in MC** (*Chapultepec, Del. Cuauhtémoc*)	**January 8th**	**72,050** (12.54 - 13.21)
I: Bus station small busses (*Microbús*) **in MC** (*Chapultepec, Del. Cuauhtémoc*)	**January 8th**	**35,100** (13.22 - 13.37)
C: City background (park) in MC (Parque Hundido, Del. Benito Juárez)	**January 7th**	**16,350** (18.07 - 18.33)
G: City background (park) in MC (Parque México, Del. Cuauhtémoc)	**January 8th**	**21,700** (12.15 - 12.33)
J: City background (park) in MC (Bosque de Chapultepec, Del. Miguel Hidalgo)	**January 8th**	**18,850** (14.11 - 14.30)
Natural background (beach in Cancún, Quintana Roo)	**January 9th**	**3,750** (07.25 - 08.02)
Natural background (beach in Akumal, Quintana Roo)	**January 13th**	**2,150** (08.03 - 08.46)
Natural background (Chitzen Itza, Yucatán)	**January 17th**	**1,150** (09.46 - 10.22)
Bus stop Copenhagen in 2013	**October 23rd**	**21,000** (09.26 - 09.38)
Park in central Copenhagen in 2013	**October 23rd**	**11.200** (09.49 – 10.03)
Natural background outside Copenhagen	**Lots of data**	**2-3,000** (morning data)
Bus stop Prague in 2014	**September 8th**	**46,550** (09.42 - 09.58)

[2] http://www.aire.df.gob.mx/

From table 3 is seen that people using the busses in Mexico City are exposed to more than 20 times as many ultrafine particles as people living in clean areas of Mexico inhaling a natural background pollution around 1-3,000 ultrafine particles per cm^3 of air. The exposure both takes place inside busses, at the bus station and at bus stops. Ultrafine particles inhaled in Mexico City are mainly diesel particles consisting of black carbon (soot) making the particles extremely toxic and carcinogenic at the highest possible level. The pollution from the streets spread into parks making the air 50-100 meters inside parks 5-20 times more polluted than the natural background in Mexico. Thereby it is reasonable to assume, that all air in Mexico City is polluted i.e. all the population in the city is exposed; even people living in more quiet areas of the city. Thereby bad outdoor air quality will affect indoor air quality in most of the city.

Furthermore, it is seen that the measured pollution at the bus stop in Mexico City is just about three times higher than at a similar bus stop in Copenhagen (Western Europe) and about 30 % higher than at a similar bus stop in Prague (former Eastern Europe). Even though Copenhagen and Prague have a high share of light diesel vehicles (30-50 % polluting the air at the bus stop as well) whereas Mexico City has almost none. This highlights the high pollution caused by busses (trucks and vans) in Mexico City. Hence, the pollution inside parks in Copenhagen is thereby significantly lower than in parks in Mexico City. However, the natural background pollution in Mexico is the same – or even lower in *Chitzen Itza* - as in Denmark (and other European countries) underlining that the pollution in Mexico City can be reduced to the same low levels as in European cities by introducing low emission zones with filter requirements for diesel vehicles and reducing the sulphur content in the diesel to European levels.

An average pollution with exhaust particles around 70,000 particles per cm^3 means that people inside busses in Mexico City will inhale about 35 million exhaust particles per breath (½ liter = 500 cm^3). That is 525 million particles inhaled per minute (15 inhalations). About 80-90 % of the particles are deposited in the finest parts of the lungs and transferred to the blood of the passengers. **Hence, the lungs of passengers function as efficient filters inside busses in Mexico City**. People in the busses are thereby heavily exposed to toxic and carcinogenic soot particles. A high share of the air pollution origins from the bus' own exhaust due to bad exhaust system and roof window design (see figure 3). But most important, the busses have no diesel particulate filters. Particulate filters on busses (trucks and diesel vans) would both minimize the pollution inside the busses and in all Mexico City.

Table 4 contains measurements from two sides of a large cross-road (pedestrian exposure) and at the platform of the great *Ángel de la Independencia* roundabout in Mexico City as well as measurements from inside a car (window half open, no mechanical ventilation) driving from Mexico City to the airport (driver exposure). To comparison are shown the natural background pollution measured in Quintana Roo/Yucatán (no local pollution sources) and measurements from Western Europe (Copenhagen, Denmark) and the former Eastern Europe (Prague and Brno, Czech Republic).

Table 4: Pedestrian and driver exposure in Mexico City (MC)

Average, rounded numbers	Date	Particles/cm^3 (time)
A: Cross-road in MC, (*Insurgentes y Río Mixcoac, Del. Benito Juárez*)	**January 7th**	**48,400** (18.57 - 19.17)
B: Cross-road in MC, opposite corner (*Insurgentes y Río Mixcoac, Del. Benito Juárez*)	**January 7th**	**40,950** (19.32 - 19.47)
C: Ángel de la Independencia in MC (*Del. Cuautemoc*)	**January 8th**	**32,050** (15.14 - 15.47)
E: Inside car from MC to the airport	**January 8th**	**64,050** (17.23 - 17.52)
Natural background (beach in Cancun, Quintana Roo)	**January 9th**	**3,750** (07.25 - 08.02)
Natural background (beach in Akumal, Yucatán)	**January 13th**	**2,150** (08.03 - 08.46)
Natural background (Chitzen Itza, Yucatán)	**January 17th**	**1,150** (09.46-10.22)
Most polluted street in Copenhagen	**Lots of data**	**40-45,000** (rush hour)
Cross-road in central Brno, 2014	**September 9th**	**31,750** (08.44 - 09.18)
Inside car in central Prague, 2014	**September 8th**	**31,150** (09.25 - 09.39)

From table 4 is seen that people walking alongside large cross-roads inside Mexico City are exposed to about 15-30 times as many ultrafine particles as people living in clean areas of Mexico inhaling a natural background pollution around 1-3,000 ultrafine particles per cm^3. However, the measured air pollution inside a car driving in Mexico City was 20-60 times as high as the natural background. The pollution inside the car is ventilated into the car through a half-open window (the same would happen if the mechanical ventilation had been on). When the pollution is inside the car it is only slowly removed by dilution when the car drives into less polluted air, i.e. the driver is exposed to high pollution levels for a long time. The pollution measured at the cross-roads was probably lower than in the narrow streets of Mexico City where there are less wind exposure and deep street canyons between the tall buildings. During the measurements at the cross-roads and the *Ángel de la Independencia,* several of the pollution peaks could be directly related to busses, trucks or vans (diesel vehicles) passing by. The measured pollution at cross-roads in Mexico City is at the same level as the most polluted street in Copenhagen even though 30% of light (private) vehicles in Copenhagen are diesel whereas Mexico City has no light diesel cars. The pollution at the *Ángel de la Independencia* is at the same level as at a large cross-road in Brno even though 40-50 % of private vehicles in Brno are diesel whereas the share of private diesel cars in Mexico City is almost none. This underlines the high pollution from diesel busses, trucks and vans in Mexico City. Pollution inside a car in Mexico City is about the double compared to similar measurements in Prague (with 40-50 % private diesel vehicles on the streets) again illustrating how much diesel busses, trucks and vans contribute the driver exposure to exhaust particles in Mexico City.

Current emission technologies being standard in Europe, United States and Japan provide dramatic reductions in diesel particle emission. The technology is closed particulate filters as described in the EPA 2010 standard and European Euro VI standards. About 98%[3] of particle emission (all particle sizes; ultrafine particles as well) is removed using these filters instead of the current Mexican standards for diesel trucks and buses (EPA 2004/EURO IV with no filter requirement). New filters even show reductions above 99.9 % (see pictures on next page). Moreover, European standards contain an emission limit for particle number in the exhaust. It is the use of closed particulate filters that make all the difference and provide more people with longer and healthier lives in the USA, Europe, Japan etc. Furthermore, Mexico needs low sulfur diesel to obtain better air quality and filter efficiency. Mexico City already has this fuel distributed (diesel UBA) with a 15 ppm sulfur. But it's not generally used.

[3] The International Council on Clean Transportation, *Working paper: Revising Mexico's NOM 044 standards: Considerations for decision-making*, 2014

Closed diesel particulate filters are standard on all road vehicles in the USA, Europe, Japan etc.
These filters remove more than 99.9 % of all particle sizes in the exhaust when they are new. Over the filter lifetime above 98 % of particles are removed by the filter. But the filter must, of course, be maintained just like other parts of a vehicle. However, to get the best filter results, Mexico in general needs to use the low sulfur diesel already being on the marked.
(Pictures: Particle measurement in Denmark: Truck with new filter.)

Air quality limit value

Ultrafine exhaust particles have a small critical size allowing them to enter the finest and most sensitive parts of the lungs and penetrate directly into the blood stream. Thereby the particles (and the PAHs and heavy metals attached to their surfaces) can reach all critical parts of the human body. About 80-90 % of the inhaled ultrafine exhaust particles are deposited in the human organism and may cause serious health problems e.g. heart diseases, airway diseases, cancer and thereby premature death. Hence, there is no lower exposure limit being safe for ultrafine exhaust particles (like smoking: One cigarette a day is not safe – but less damaging than 10 cigarettes a day). The less exposure the less is the risk concerning the harmful effects. Thereby it is difficult to set an air quality limit value for ultrafine exhaust particles. However, based upon measurements and detailed assessments from many European cities the Danish Ecological Council recommends the following air quality standards:

Yearly average: Max. 7,000 particles per cm^3 (particles from 20-100 nano meters).

Hourly average: Max. 20,000 particles per cm^3 (may be exceeded up to 20 days per year).

These limits should be achievable in Mexico City since light vehicles in Mexico are gasoline (in many EU countries up to 50 % of light vehicles are diesel) i.e. only heavy vehicles (busses and trucks) and vans needs to have particulate filters to minimize the pollution. Finally, soot particles from exhaust contribute significantly to global warming that will threaten the existing economic growth in Mexico. Filters will both solve a serious health and climate problem.

Conclusion

People in Mexico City are heavily exposed to toxic ultrafine exhaust particles (soot) when using the busses, walking or driving cars. This exposure significantly increases the morbidity and mortality in the population. In addition, pollution inside busses and cars is a serious health problem for professional drivers (working environment) spending many hours in the traffic every day. The main reason for the very high pollution is diesel vehicles (trucks, busses and vans) without particulate filters. The natural background pollution in Mexico (measured in Quintana Roo and Yucatán) is the same as the natural background pollution in Europe – or even lower. The pollution in Mexico City can thereby be reduced to the same low level as in European cities by introducing low sulphur diesel and low emission zones requiring filters on diesel vehicles like it is done in European Cities.

Recommendations

I. Reduce the general sulphur limit in Mexican diesel to max. 15 ppm (or 10 ppm) and monitor (enforce) the quality of diesel.

II. Replace busses with the Euro VI standard or equivalent technology (EPA 2010) with closed particulate filters: Either buy new busses or retrofit existing busses with filters.

III. Introduce low-emission zones with filter requirements for diesel trucks, busses and vans.

IV. As the first country Mexico should introduce a limit value for particulate number (size 20-100 nm): Yearly average max. 7,000 particles/cm^3 and hourly average max. 20,000 particles/cm^3. This would lift Mexico to the leading elite regarding air pollution control.

V. Prohibit idle running (more than 1 min.) and design the exhaust system and roof window system of busses so exhaust is not ventilated directly into the passengers in the busses.

VI. Investigate the possibility to use gas (LPG/LNG) for trucks, busses and vans.

VII. The screening measurements above should be followed by more detailed investigations covering longer measuring intervals on more days and documenting the effect of filters installed on vehicles.

Further information

http://www.winkas.dk/wkwebshop/varedetaljer.asp?shopid=851152&funique=244&kat=3&hkat=1

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