Internal report

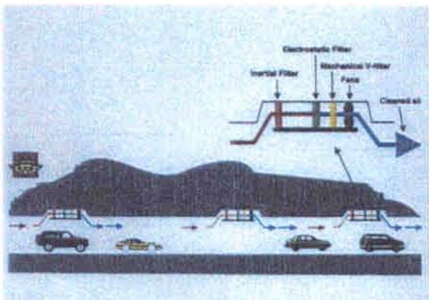
Internal report
no. 2217

Research project:

TUNNELS FOR THE CITIZEN

Sub project H:
Technical installations

Particle Cleaning in Norwegian Road Tunnels



July 2001

Norwegian Public Roads Administration

Road Technology Department

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Particle Cleaning in Norwegian Road Tunnels

Summary:

Norway's road network has become more and more dependent on tunnels. The challenge of planning and construction of road tunnels in urban areas implies an environmentally friendly approach. Particle cleaning of the air in long and heavily trafficked tunnels in densely populated areas have been used in Norway for more than ten years. It has been seen as a possible measure, both for improving the visibility in the tunnels and for reducing the disharge to the air, both inside and outside the tunnels. Three different types of layout system for particle cleaning equipment have been used in Norway. This paper discuss the experience and status for the particle cleaning technology since the opening of the sub-sea "Oslo Tunnel" in 1989. In general, there is no principal difference between the use of a particle cleaning system in ordinary or sub-sea road tunnels.

Key words: *Tunnel, Operation and maintenance, Technical installations, Cleaning plant, R&D, Competence*

Division: *Geology and Tunnel Division*
Author: *Harald Buvik* */ HF*
Date: *July 2001*

Norwegian Public Roads Administration, Directorate of Public Roads
Road Technology Department
P.O BOX 8142 Dep, 0033 Oslo
Telephon: 22 07 39 00 Telefax: 22 07 34 44

INTRODUCTION

An increasing number of complaints from individuals, and invidious coverage in the mass media about poor environment in road tunnels have been noticed in Norway in recent years. In some cases they are more due to ”fear” based on misunderstanding, than to concrete conditions which are injurious to health. Such fears can in the long run be a greater strain on one`s health than tunnel air itself. The majority of people react to visibility because of small particles in the air, and to smell. ”Positive” road-user information is important to create realistic attitudes to the ”environmental risk” which driving in road tunnels represent.

The Norwegian Public Roads Administration has through the R&D project ”Tunnels for the citizen” focused on traffic safety, environment and the long term ownership of tunnels.

Norwegian road tunnels are by no means homogeneous. They exhibit great variation in many key aspects. Factors at variance include tunnel length, traffic volume, subsea tunnels, one or two lane traffic, wall material, road surface material, lighting, air cleaning measures, ventilation, and more. These factors in turn demand different approaches depending on many things, for instance cleaning cycles.

In a road tunnel there occurs - by contrast with road traffic in ordinary streets and on highways - a concentration of traffic pollution in a small volume. Therefore attempts have been made, with variable success, to separate the pollutant particles and gases in the ventilated air before it is released to the surroundings. In general, it must be said that the chances of success are limited, due to the great volumes of air involved, the complexity of the systems, and the high costs.

The ideal goal in the pollution control and environmental protection legislation is to render our surroundings and environment as free from pollution as possible. Measures to counter pollution demand resources in competition with other worthy causes. In special pollution situations, especially those causing local traffic problems, the environmental standards we strive for will be a measure of how much we are willing to pay.

As for traffic pollution and, in particular, suspended particles, this is a problem with aspects special to Norway. In Norway the bulk of the airborne dust is due to road wear from use of studded tyres, and this phenomenon is largely a winter situation.

ENVIRONMENT AND SAFETY ASPECTS

Norway has long experience with longitudinal ventilation of road tunnels. Particle cleaning of the air in long and heavily trafficked tunnels in densely populated areas have been used in Norway for more than ten years. Electrostatic filters with high extraction rate have been seen as a possible measure, both for improving the visibility in the tunnels and for reducing discharge to the air outside. In association with that it has to be mentioned that the demand for particle cleaning in Norwegian road tunnels to a high degree has been politically motivated by environmental reasons.

An evaluation of methods to scrub particles out of air in or issuing from road tunnels in Norway is based on two fundamentally different factors:

1. Safety and environment aspects connected with tunnel users and their perception of reduced air quality. This is particularly apparent in winter when wear by studded tyres and mineral dust combined with exhaust and combustion particles (soot) can severely reduce visibility.

2. Particle emissions from high-density tunnels may cause discomfort, irritation over time, and represent a potential health and environment problem for third-parties - particularly groups of persons in the population who are especially vulnerable - and the external environment.

Both these factors come under the heading particle pollution, but the approach is rather different. Depending on the public's perception of such pollution and the real level of risk to health, environment and safety, the authorities may require cleaning of such emissions. Such requirements are statutory and must be taken into account in many situations in Norway, for instance where industrial activities cause particulate pollution.

As for the use of high-efficiency cleaning plants (either combined gas/particle units in tunnels, or each of them on their own), one prior assumption ought to be that the benefit is reasonably proportionate to the total investment and operating costs of the plant. (In some cases these facts have not been the only reasons for the decisions on using electrostatic filters).

The use and level of separation of such cleaning plants must be properly specified and documented. Standards for audit and documentation of the cleaning efficiency of relevant filters, both for laboratory tests and for aftercare in the field are now being worked out. This is decisive for establishing the right guarantee specifications for requirements, and the manner in which tests are conducted.

ELECTROSTATIC FILTERS IN NORWEGIAN ROAD TUNNEL

Important experiences and documentation of cleaning technology with electro filter and mechanical filter in tunnels with traffic both in one and two directions has been gathered. Depending upon what is the object of the cleaning, the electro filter system can be installed in a bypass system, in a shaft connected to the traffic tunnel, or the polluted air can be cleaned at different stages along the length of the traffic tunnel (f.x. electro filter in the ceiling of the tunnel).

Because of the climatic conditions in Norway, extensive use of studded tyres has been practised during the winter. Because of the wear and tear of these tyres the particle concentrations are much higher in winter than in summer. As a result of that the need for extracting particle pollutions (mineral dust and soot) is much higher during the winter than in the summer. Visibility problems are closely linked with the type and quality of road surface, cleaning procedures and running time of fans, in addition to climatic and traffic conditions.

Particle cleaning of tunnel air with the help of a cleaning passage with electro filter was thought to be a possible measure, both for improving visibility and for reducing discharge to the air outside. On the other hand, gas cleaning is an interesting measure, but for the moment considered a lesser possibility in normal road tunnels seen from a cost/usefulness/health risk evaluation. However, the latter can have its use in reducing discharge in special situations.

So far, there has been installed electrostatic filters in three separate tunnels in the Oslo area, one tunnel outside Trondheim and one in Bergen, and not to forget in the world's longest tunnel - the 25 km long Lærdal Tunnel. Particle cleaning systems are also being installed in some other road tunnels.

Three fundamentally different types of solution for the lay-out of particle cleaning systems, with both electrostatic and mechanical filters are chosen in Norway:
The Oslo Tunnel, which is a 2,2 km long two tubes sub-sea highway tunnel below the centre of Oslo, was opened in January 1990. The purpose of the dust cleaning system here was to improve the air quality in the city. The particle separator (mechanical coarse filter and electrostat filter) which is positioned in conjunction with the exit via the shaft tower, will service quantities of polluted air of up to 2,2 mill m^3/hour. Visibility and particle conditions in the tunnel are not affected by the cleaning.

In the Granfos Tunnel (1000 m) and the Ekeberg Tunnel (1500 m) in Oslo, the particle cleaning equipment is installed in a cleaning circuit (bypass system). The main purpose here was to achieve better visibility conditions in the tunnels, but also to reduce the discharge to the air outside the tunnel.

In the Hell Tunnel, which is a 4 km long tunnel with two-way traffic outside Trondheim, the cleaning system was installed at three individual stations in the ceiling of the tunnel, making the distance between the stations approx. 1 km. This concept was based on both improving the visibility by reducing the particle concentration and also reduce the discharge to the environment outside. About 1/3 of the air ventilating the tunnel pass through the cleaning stations.

In the Nygård Tunnel in Bergen (950 m long, one-way traffic) the cleaning of particles is based on electrofilter in the ceiling of the tunnel, like in the Hell Tunnel. 80% (250 m^3/s) of the total air volume is passing through the electrofilter system.

PARTICLE POLLUTION

In a road tunnel, the sight-reducing particles consist of soot and diesel smoke, mineral and metallic particles and mist. Soot and smoke consist of very small and respirable particles. More than 95% of these particles are less than 1 micron

(1/1000 mm) in size. However, they can bunch together gradually and become larger particles. The mineral particles consist of larger particles, 90% larger than 1 micron, including a relatively large portion that is not respirable. The particle concentration and particle size of the mineral airborne dust depends on various things, including what type of rock materials are used in the pavement.
Mist can periodically be a problem, especially near tunnel entrances. The diameter of mist particles is in the region of 10-45 micron. The amount of dust produced and the distribution of particles are directly related to the quality of the road surface, cleaning frequency, ventilation and the traffic situation.

From the magnitude of the readings the SINTEF measurements show that the dust level in road tunnels in winter can consist of some 70-75 per cent by weight of mineral dust and 25-30 per cent by weight of organic materials (soot, non-combusted oil residues, etc). In summer the ratio of mineral to organic dust is roughly reversed. In other words, the mineral complement (inorganic fraction) predominates in winter, whereas products of combustion and other organics predominate in summer. In terms of volumes the organic component is of course equal in summer and winter, assuming the same Annual Traffic Density.

In high-density tunnels with traffic in both directions particulate concentration of total suspended particles (TSP) as measured on cold winter days was up to 18-20 mg/m^3 compared with 1-1.5 mg/m^3 in summer. The very high concentrations of suspended particles in winter are due mainly to the whirling up of large volumes of heavy mineral particles by the air flow (piston effect) when vehicles going in opposite directions pass each other. In tunnels with one-way traffic the dust concentrations are generally lower than in a two-way tunnel under otherwise identical conditions. The relative size of the fine-dust fraction is often higher in one-way tunnels than is the case in two-way tunnels.

MEASUREMENTS AND EXPERIENCES

In the sub-sea “Oslo Tunnel” extensive studies has been carried out by SINTEF over a long period of time. Relation were found between air velocity over the electro filter and the extraction rate. With air velocity as high as 4-5 m/s the extraction rate was remarkably reduced. By increasing the air velocity through the electro filter, without any renouncement of cleaning effectiveness, the filter area necessary to clean the same volume of polluted air will be reduced.

The measurements indicated that during the initial hours after a successful wash, it was possible to achieve a level of separation approaching 90-95 per cent with one shaft fan (of three available) in operation (air velocity 2.8-5 m/s). After 35-40 hours in operation the separation efficiency fell to 50 per cent. With two shaft fans in operation (air velocity 8.5-9.5 m/s) it would no doubt be possible to keep the separation efficiency above 50 per cent for 10-15 hours after a successful wash. Use of the electrostatic filter beyond the times indicated would result in decreasing and essentially "unsatisfactory" separation efficiency.

In all series of measurements a highly variable efficiency was found for the electrostatic filter, and even at different points of the filter area, differences were found. In the first two series at several measurement points the level of particle removal was logged as negative. Part of the reason was that the potential had been applied to the electrostatic filter for a long period without the shaft fans running, and without scouring the filter before readings were taken. There was also a great deal of dust deposited on floors and surfaces in the shaft fan room. Once the fans were turned on during particle readings, large volumes of dust were pulled off the prefilter and electrostatic filter, as well as from the floor of the shaft room. Also significant sparking and electrical discharge were noted during the first two reading series. Faulty connections were also found, causing, in part, some filter sections to be without applied potential.

In the “Oslo Tunnel”, the whole volume of the polluted air from the tunnel passed through the electrostatic filter (square area 70 m^2) before leaving the tunnel through the shafts at the outlet of the tunnel.

The wash-and-dry cycle for the electrostatic filter unit was complex and time-consuming, and represented an operational problem as well as limited the use of the unit. This fact, combined with the designed air velocity above the electrostatic filter being too high, and the lower part of the filter unit being located too close to the roadway, were key reasons why the separation efficiency was unsatisfactory.

In the Ekeberg and Granfos tunnels (one-way traffic) an extention rate (cleaning effect) of 45-50% was calculated on the total air volume passing through the tunnels. The dust measurements showed such low concentrations that, if they were representative, a dust cleaning system would have virtually very little effect on visibility and pollution in the tunnel or on the emission of particles to the external environment. The low dust concentrations must be related to the short tunnel length, which means that the build-up of dust levels from the entrance to the cleaning loop, and thence to the tunnel exit, were modest. This was also what we saw in practice. It was a contributing reason to why we considered the use of a significant amount of energy to clean such small dust quantities an economic non-starter.

In the two-way traffic “Hell Tunnel”, like in the “Oslo Tunnel”, there has been carried out extensive measurements over a long period of time to calculate the extraction rate for different operational situations. The total (or effective) extraction rate for the full cleaning station (which means the total cleaning efficiency, equal to the percentage difference in particulate concentration 20 m before and after the cleaning niche) overall was low: on average 15 per cent (variation 0-64 per cent) for all measurement series. The low "effective" extraction rate which in several measurement series was actually negative was due to the piston effect of passing vehicles and unsuitable flow design and smoothing of the cleaning rebate and exit fans. At the same time, we must remember that only a fraction (1/3 - 1/4) of the air volume in the tunnel actually passes the cleaning unit during normal traffic, the rest passes without cleaning. Due to this, the total extraction rate for the electrostatic cleaning plant will be very low. If you f.x. clean 1/3 of the total air volume in a tunnel with an extraction rate of 50%, the total cleaning effect on the total air volume will be only 16%. As low total extraction rate will have very low positive effect on the visibility and particles from the road-users point of view.

Moreover, it seems difficult to identify other connections between ventilation and cleaning plant status and the cleaning efficiency that results. This must be due to the different numbers of power packs that were unserviceable during the different measurement series.

Analysis of dust deposits on corona plates in the electrostatic filter in the winter period when using studded tires showed 86 per cent inorganic/mineral dust and 14 per cent organic (soot). This shows that the percentage share of inorganic/mineral dust deposited in the electrostatic filter is higher than the corresponding ratio in the tunnel air.

The stated maximum dust deposit (saturation load) on each corona plate is 9.9 grams. Samples of deposited dust on the plates at the presumed saturation load showed 5.3 grams per plate, which was lower than the manufacturer's stated saturation load.

Analysis of the dust deposited on the corona plates in the winter period showed that 80 per cent of dust had a particle size of less than 30 microns. Approx 30 per cent of the deposited particles were larger than 20 microns. This is a coarse particle fraction, the level of which should have been reduced more effectively in the prefilter.

CONCLUSION

Valuable and important experience on the use of cleaning equipment (first generation of existing plants with electro filter and mechanical filter) for particles in Norwegian road tunnels have been gathered through different studies and investigations in the period 1989 - 1996. This documentation represents a good basis in projecting and constructing new particle cleaning plants and equipment in road tunnels with traffic both in one and two directions.
The different studies varies much in size and perfomance. In spite of that, some common features have been found:

- As for traffic pollution and, in particular, suspended particles, this is a problem with aspects special to Norway. In Norway the bulk of the airborne dust is due to road wear from use of studded tyres, and this phenomenon is largely a winter situation.
- We have realized that the practical extraction rate (cleaning effect) for some systems (f.x. in the Hell tunnel with two-way traffic) has been lower than expected. The reasons may be incomplete basis for dimentioning assumptions for ventilation needs when planning the project, diffuse and/or different measurement techniques connected to interpretation of guaranteed spesifications, piston effect from traffic, conditions connected to geometric tunnel design etc.
- Under conditions which are in accordance with the dimentioning assumptions there are measurements (f.x. the Ekeberg Tunnel with one-way traffic) that concludes that the extraction rates over periods of times are in conformity with expected theoretically dimentioned rates.
- Break-down of power packs for the electrostatic filter in operational situations have been a problem. That due to abnormal voltage drop and are not related to the electrostatic plant.

- For some electrostatic plants the wash-and-dry cycle (system) have been complex and time consuming, and because of that represents an operational problem.
- Some details in connection with the flow of air passing by or through the particle filter (leakage, resirculation of air, piston effects from traffic and starting fans, location of fans, shaping of bypass-system or niche, increasing/decreasing areas for air stream, etc.) were not optimal.
- From a practical, environmental, and economical point of view our investigations and measurements indicate that the first generation electrostatic filter in the Hell Tunnel (with heavy two-way traffic and with different dimentioning assumptions for ventilation needs than experienced) does not fulfil the expected demands. However, lessons has been learned, and both technical and geometric improvements has been carried out in a similar plant which are going to be installed in a new tunnel. With those improvements we have reasons to believe that this kind of plant will function in accordance with its assumptions and fulfil the expected effect.

The electrostatic filter system in the “Oslo Tunnel”, the “Granfos Tunnel” and the “Hell Tunnel” has not been in use for some time. The reasons for that are not precise and are more complex than the above features shows. In the “Ekeberg Tunnel” the system is also under a cost/usefulness/health-risk evaluation.

New guidelines for evaluation and documentation of extraction rates for electrostatic filters are now beeing worked out based on the information from different studies and measurements.

New projects are looking on alternative measures to electro filters, f.x. using measurements of the visibility and particle concentrations to regulate the ventilation fans.