WINDSHIELD FOGGING IN ROAD TUNNELS - FINAL RESULTS

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ABSTRACT

When a car enters a tunnel, the occurrence of water condensation on the outside of the front shield is possible if air temperature and/or humidity in the tunnel are higher than outside. Due to cooling of the tunnel air on the surface of the vehicle, the temperature can fall below the dew point and therefore condensation on the surface occurs. Because of sudden appearance and reduction of the driver's view, this phenomenon presents a remarkable potential for danger.

Gruner Ltd. was assigned from the Swiss Federal Roads Authority with the research program "windshield fogging in road tunnels". Tools for predictions have been developed and by means of surveys with tunnel users, theoretical studies, model calculation and measurements in three affected tunnels, measures have been proposed in order to reduce the appearance of windshield fogging. Beside the suggested measures, the final report contains recommendations which have been made to be included in the Swiss guideline "Ventilation of Road Tunnels".

This paper contains selected results from the measurements and the conclusions out of it. The most important measures to reduce the risk associated with windshield fogging are presented.

Keywords: windshield fogging, ventilation design, tunnel safety

1. INTRODUCTION

The phenomena of sudden windshield fogging are known in many two-way traffic road tunnels. The safety risk due to reduction of the driver's view however is not considered in most of the assessments of the safety level of tunnels even though there have been a couple of accidents indisputably caused by windshield fogging.

The Swiss Federal Office of Roads assigned Gruner Consulting Engineers with a research study which was completed in 2004 [1]. First results have been presented in [2]. This paper focuses mainly on the final results.

2. INVESTIGATIONS

2.1. Surveys

Through a survey of the Cantonal (Provincial) Authorities, it was investigated in which tunnels windshield fogging occurs in Switzerland. The phenomenon is reported to occur in a total of 19 Swiss road tunnels. In 9 of these tunnels regular fog formation on windshields are reported. The survey showed that the fogging hazard in two-way traffic tunnels with a length of over 1400 m is distinctly increased. Additionally, for twin-tube single direction traffic tunnels (one-way traffic tunnels) under renovation, where one tunnel tube is operated as a two-way traffic tunnel, time and again fogging of windshields occur.

The correlation between tunnel length and the potential of danger of windshield fogging can be used as simple instrument to determine the probability of windshield fogging in new and existing tunnels. Figure 1 shows the proportion of tunnels with windshield fogging as a function of tunnel length.

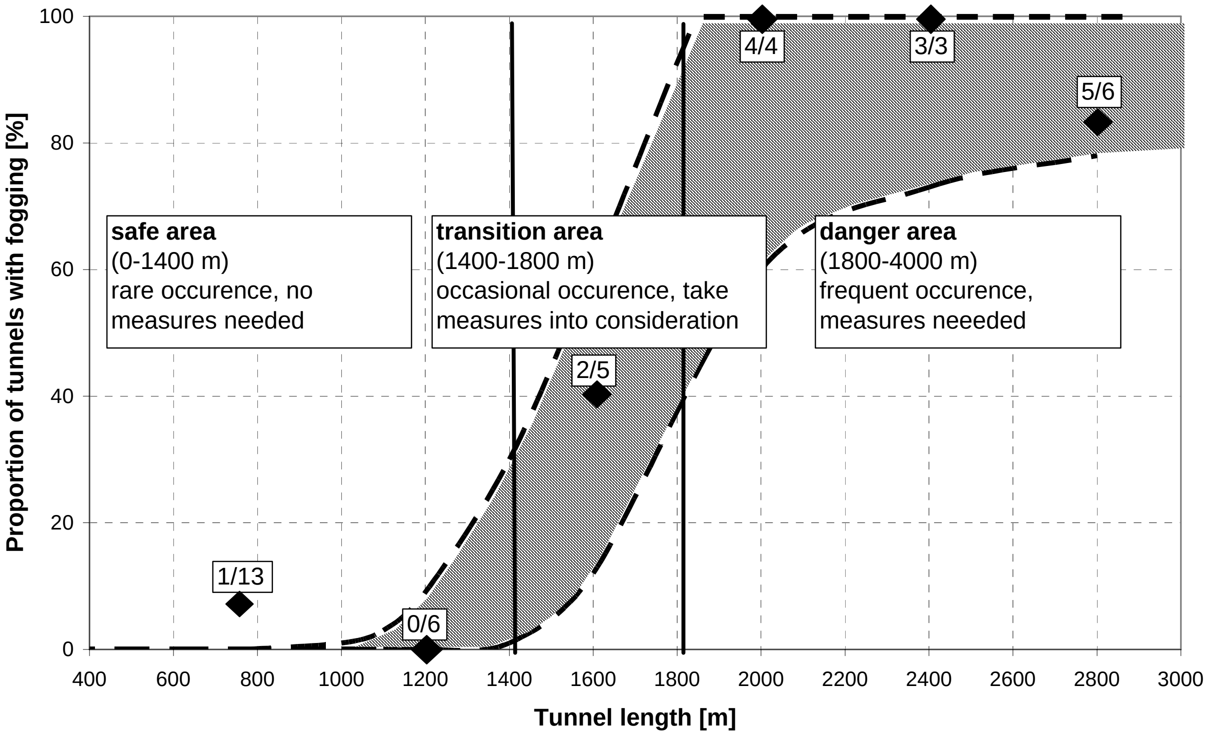

Figure 1: Proportion of concerned tunnels against tunnel length (bi-directional tunnels only)

In the tunnels Vue-des-Alpes (H20, NE, bi-directional traffic, l = 3240 m) and Eggflue (H18, BL, bi-directional traffic, l = 2790 m) a survey of tunnel users was conducted to determine the frequency and intensity of fogged windshields. Obscured windshields were reported on the basis of a three-step scale (light, medium or heavy fogging). Altogether 4770 Vue-des-Alpes as well as 3830 Eggflue tunnel passages were evaluated. The following statements can be deduced:

- In 7% of the tunnel passages (on average) medium or heavy fogging was reported.
- In 92% of the tunnel passages with reported fogging the road surface was wet.
- Fog formation usually occurred shortly after entering the tunnel.

2.2. Measurements

In tunnels Eggflue, Leissigen (A8, BE, bi-directional traffic, l = 2100 m) and Vue-des-Alpes, indoor-air climate measurements were carried out. Besides air temperature and relative humidity, visibility (opacity), air flow velocity and ventilation operation time were additionally recorded. By means of these measurements, it is possible on the one hand to estimate how strongly a tunnel is affected by windshield fogging. On the other hand, the correlation of survey data and measured data allows determining a threshold value for the tunnel dew point temperature above which windshield fogging occurs (see also chapter 3.3 and [2]).

Figure 2 shows results from the climate measurements in the Vue-des-Alpes tunnel. Physically, windshield fogging (on the outside) is possible as soon as the windshield temperature is below the dew point temperature of the outside air. The arrow indicates a corresponding time domain.

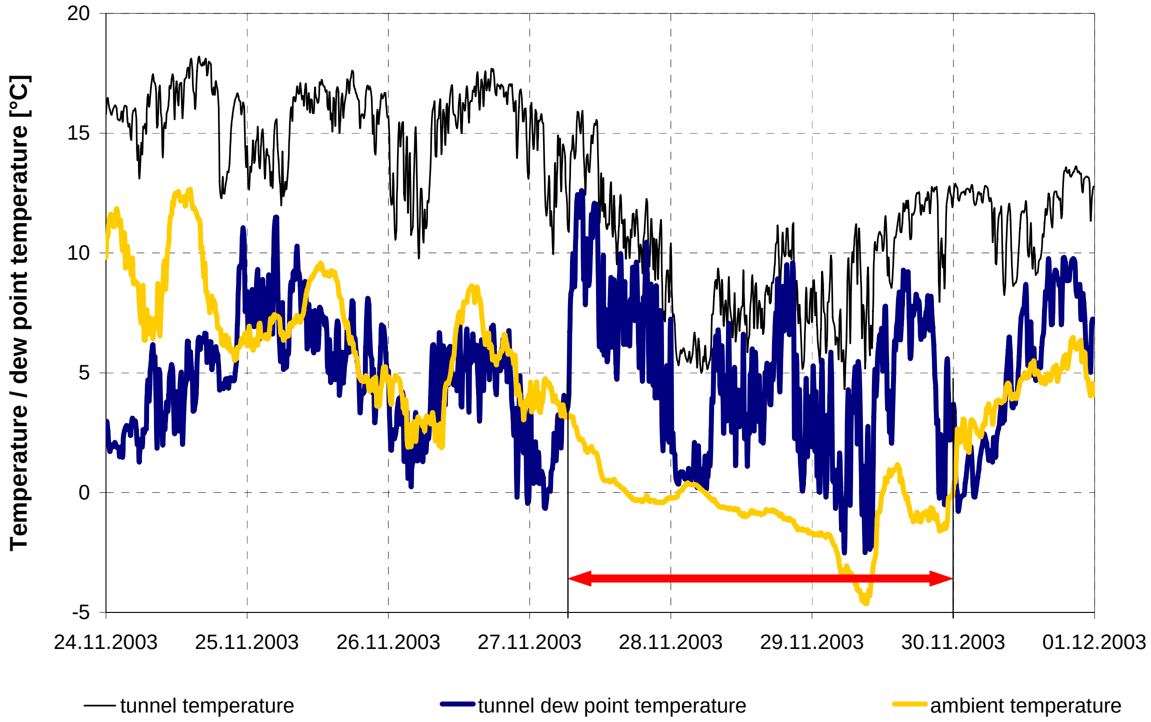

Figure 2: Climate data - the arrow indicates a time domain where the ambient temperature (≈ windshield temperature) is below the dew point temperature in the tunnel.

3. FINDINGS

3.1. Climate

Figure 3 shows the temperature characteristics over one year. Even in summer, the mean tunnel temperatures are - due to heat loss of the vehicles - higher than the ambient temperature.

The following statement can be derived from the measurements and surveys:

- On the basis of stronger emission regulations, or in other words, decreasing noxious emissions from the traffic, a lower air-change rate by the mechanical tunnel ventilation system is to be expected for the future.

Conclusion: Because water ingress into tunnels from automobiles remains approximately constant, an increasing occurrence of windshield fogging is expected.

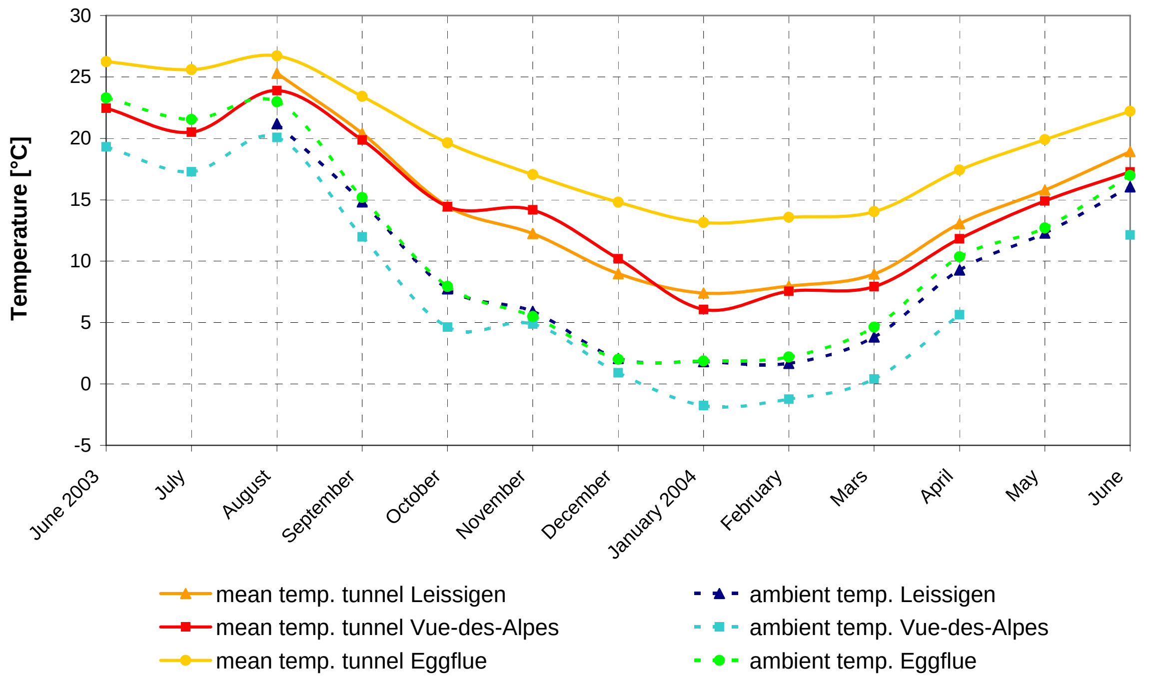

Figure 3: Monthly mean temperatures (ambient and tunnel) for Leissigen, Vue des Alpes, Eggflue[1]. Period: July 2003 to June 2004.

3.2. Ventilation System

The investigation has demonstrated that a tunnel's ventilation system has an impact on the occurrence of windshield fogging.

- When employing a midpoint-extraction ventilation system the dew-point temperature at the tunnel entrance is significantly reduced. This minimizes an abrupt climatic change when entering a tunnel and, as a consequence, reduces the sudden occurrence of windshield fogging. The midpoint-extraction system is well suited to reduce the hazard. Also of critical importance is the correct operation of the dew-point control system.
- With a dew-point controlled semi-transverse ventilation system even with a large expenditure of energy, the fogging hazard can be marginally improved. This system reduces the dew-point temperature at the tunnel entrance just slightly.

Conclusion: Fogged windshields in tunnels are effectively prevented by ventilation systems which aspirate fresh air through both portals. The installation of a dew-point control system is therefore only meaningful when a midpoint-extraction ventilation system (or variable-point extraction system where air is extracted through the plenum above the intermediate ceiling) is implemented. In order to effectively reduce the fogging of windshields, a directional air-flow velocity of greater than 0.5 m/s has to be generated at the tunnel entrance.

[1] For the Vue-des-Alpes tunnel, the temperature is not the average tunnel temperature but the temperature 250 m inside the portal.

3.3. Control Variables for Dew Point Regulation

As control variable, the "supersaturation" of the air in the tunnel [g/m^3] is recommended. Supersaturation is defined as the difference between the absolute humidity in the tunnel and the maximum amount of moisture possible in the tunnel air when the tunnel air is cooled to the outside air temperature. Concerning the threshold value, above which condensate formation occurs, the following statements can be made:

- A comparison of the survey results and the results of measurement shows that with a supersaturation level greater than 3 g/m^3, medium or heavy fogging was reported. With a supersaturation level lower than 0 g/m^3, generally no fogging was reported. In between these two values extends a transition range, in which, depending on circumstances, fogging can occur or not.
- Supersaturation is a good parameter for forecasting the fogging hazard in a tunnel. With a threshold value of approximately 1.5 g/m^3, the best agreement between survey and measurement was achieved. This threshold value was later confirmed by supplementary empirical tests in a wind tunnel.

Conclusion: Supersaturation is proportional to the windshield fogging occurrences in a tunnel and can therefore be used as the dew-point ventilation system control variable. The recommended threshold level is 1.5 g/m^3.

3.4. Windshield Fogging Hazard

On the basis of the data from the tunnels Vue des Alpes and Eggflue and the described threshold value, it can be stated that over a year in 7 % (Eggflue) resp. 9 % (Vue des Alpes) of the time, sudden windshield fogging has to be expected. Figure 4 shows the seasonal variation of the fogging. Fogging occurs mainly during fall and winter.

Conclusion: Windshield fogging presents a significant safety risk for a road tunnel. With the traffic data of the Swiss tunnels where the phenomenon is known, one can estimate that 2000 tunnel users per day are affected by sudden windshield fogging in Switzerland[2].

[2] Beside the occasional complaints from tunnel users about fogging, there have been a couple of accidents in Switzerland in close coherence with the occurrence of windshield fogging in tunnels.

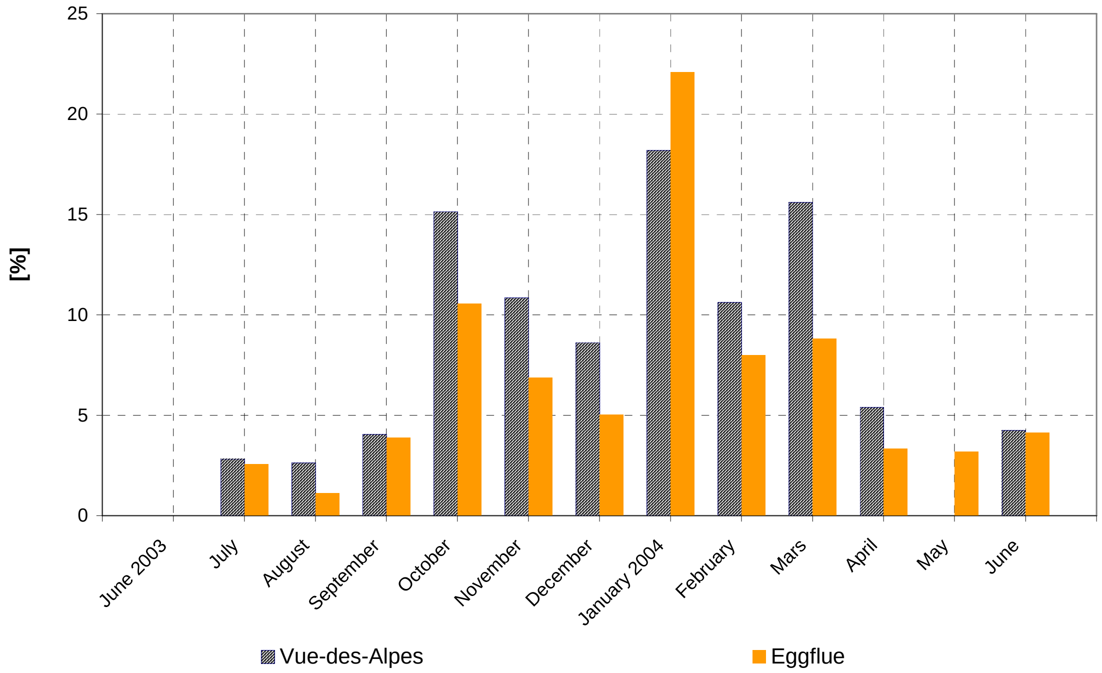

Figure 4: Time slices during which windshield fogging has to be expected based on measured data and a threshold value of 1.5 g/m^3 (Vue-des-Alpes and Eggflue). Period: July 2003 to June 2004.

4. MEASURES

Various measures are suggested in order to reduce the incidence of accidents caused by the sudden fogging of windshields. A measure can reduce the risk through an improved reaction of the tunnel users and/or through a reduction in the occurrence of fogging windshields. The recommended measures are summed up in the following:

Prevention measures

- Information and training of the drivers: Integration of the topic "Abrupt Fogging of Windshields at Road Tunnel Entrances" in the compulsory circulation theory lessons, carry out campaigns through the Swiss Council for Accident Prevention (bfu), as well as informing the population through publication in journals of automobile clubs and other media (e.g. newspapers).
- Warning system: Installation of a static or dynamic warning sign with a warning light in front of the entrance of affected tunnels. The advantage of the dynamic warning system is that the tunnel user would only be warned when climatic measurements indicate a possible fogging hazard. A pilot project for a dynamic warning system was started for an existing tunnel. The costs for the system were estimated to be about 70'000 euro (without integration in the scada-system). Costs for new tunnels are expected to be lower.

Mitigation measures

- Speed reduction: Implement a speed reduction system (e.g. from 80 km/h to 60 km/h) which combines climatic measurement with a dynamic speed-sign system. The effects of this measure are: reduction of the amount of condensation (condensation is linear to the vehicle speed), increasing of the available reaction time for the driver and due to the lower kinetic energy reduced consequences in case of an accident.

Technical measures

- Dew-point Ventilation System: With a dew-point controlled ventilation system the formation of fogging on windshields can be effectively reduced. This is valid, however, only for tunnels with ventilation systems in which outside air flows into the tunnel entrance (midpoint-extraction ventilation system or variable-point extraction system). Ventilation systems with dew-point controlled ventilation have increased energy consumption. The additional costs strongly depend on the specific climate conditions (tunnel and surroundings). In the Leissigen tunnel, the additional power consumption of the ventilation is about 12 %.

5. RECOMMENDATIONS FOR CODES AND STANDARDS

On the strength of the findings, different recommendations and measures for safety standards are suggested for both road tunnels in the planning stage and for tunnels in service.

For one-way traffic tunnels no safety measures are necessary. For bidirectional tunnels longer than 1400 m, measures are to be implemented. The suggested recommendations for Standardization are summarized in the following:

Tunnels in planning stage

- Two-way road tunnels with a length between 1400 m and 1800 m (transition area of fig. 1): A variable-point extraction system (or midpoint-extraction ventilation system) should be preferred to a semi-transverse or longitudinal ventilation system without extraction. Additionally, care must be taken to ensure the installation of dew-point sensors and a dew-point control module in the tunnel ventilation control system at a later time.
- Two-way road tunnels longer than 1800 m (danger area of fig. 1): At the entrance zone of the tunnel, an appropriate ventilation system has to be installed in order to ensure a directional flow of air into each tunnel entrance zone.

Existing tunnels

- Two-way road tunnels (in service) with a length over 1400 m: The time ratio of how often a fogging hazard condition occurs has to be measured. If critical conditions occur more than 4 % of the time during a year[3], then a dew-point controlled ventilation system is to be installed.

It is recommended to integrate the suggested measures into the existing Swiss standard [3]. Because abrupt fogging of windshields does not only present a problem for traffic safety in Switzerland, international coordination of the above guidelines is advisable.

6. CONCLUSIONS

Windshield fogging represents a significant safety risk for two-way traffic tunnels longer than 1400 m. Due to continuous reduction of mechanical air exchange in underground traffic systems caused by the lower vehicle emissions, it is expected that the occurrence of windshield fogging will further increase in the future.

Different measures (organisational/educational and technical) are recommended to reduce the risk due to the sudden appearance of fogging on the windshield. For tunnels with a ventilation

[3] An appropriate mobile measurement and evaluation system has been defined and is already in use.

system which directs the airflow into the tunnel entrance from outside, dew-point controlled ventilation is a technically effective measure and should thus be taken into account in the design of a ventilation system.

In order to reduce the risk associated with windshield fogging as much as possible especially in new tunnels, the research findings should be integrated into the guidelines and standards for tunnels. International coordination of the proposed guidelines is essential.

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