RAUCHERKENNUNG VON BRÄNDEN MIT NIEDRIGEN TEMPERATUREN DURCH SICHTTRÜBUNGSENSOREN IN STRASSENTUNNEL

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ZUSAMMENFASSUNG

Der 2.7 km lange "Saukopftunnel" in Weinheim, Deutschland ist mit einer Halbquer-/Querlüftung mit zentraler Absaugung ausgestattet. Die Auslösung des Brandalarms und des zugehörigen Brandprogramms erfolgt über ein lineares Temperatur-Meldesystem. Der Brand eines Personenkraftwagens in der Nähe der Ostportals zeigte, dass trotz der Entstehung einer gefährlichen Menge an Rauchgasen der Temperaturanstieg zu klein sein kann, um einen Brandalarm auszulösen.

Der Rauch führte zu einem schnellen Anstieg der Sichttrübung, der von den Sichttrübungsmessgeräten detektiert wurde. Da kein Brandalarm aktiviert wurde, interpretierte die automatische Steuerung der Tunnellüftung die hohen Sichttrübewerte als Fahrzeugemissionen und erhöhte die Lüftungsmenge bis auf das Maximum. Der Rauch breitete sich vom Brandort bis zur Absaugstelle in Tunnelmitte aus.

Ein neues Branderkennungsverfahren wurde entwickelt, das den Anstieg (Gradient) und den absoluten Wert der gemessenen Extinktionskoeffizienten und der CO-Konzentrationen mit einbezieht. Zur Prüfung der Steuerungsparameter und um Fehlalarme zu vermeiden, wurde eine Langzeiterfassung dieser Daten unter Normalbetriebsbedingungen durchgeführt. Die Analyse dieser Daten erlaubte eine tunnelspezifische Optimierung der Grenzwerten für die Raucherkennung.

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SMOKE DETECTION OF LOW TEMPERATURE FIRES IN ROAD TUNNELS USING VISIBILITY SENSORS

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ABSTRACT

The ventilation system of the 2.7 km long "Saukopftunnel" in Weinheim, Germany consists of semi-transverse/transverse ventilation with central extraction. A linear heat detection system is used to activate the fire alarm and the appropriate ventilation programme. A fire in a passenger car near the east portal of the tunnel showed that the rise in temperature can be too small to trigger the fire alarm, even when a dangerous quantity of smoke was produced.

The smoke led to a rapid increase in opacity which was detected by the visibility sensors. Since no fire alarm had been activated, the automatic tunnel ventilation control system interpreted the opacity as vehicle emissions and increased the ventilation to maximum. Smoke was spread from the location of the fire to the extraction point in the centre of the tunnel.

A novel fire detection method was developed using the gradients and the absolute values of measured extinction coefficients and CO-concentrations. In order to examine the control parameters and to avoid false alarms, long-term monitoring of these data under normal operating conditions was undertaken. Analysis of these data has led to optimised and tunnel specific threshold values for smoke detection.

INTRODUCTION

In the event of a vehicle fire in a road tunnel quick detection of fire is essential for the safety of tunnel users. Ventilation requirements during normal operations differ markedly from those for the fire case. During normal operations sufficient air-dilution is required. In the case of a fire maximum smoke extraction near the location of the fire and minimal smoke propagation are important.

Fire detection triggers the automatic operation of tunnel equipment such as ventilation, lighting, traffic lights and ventilation of escape routes. Furthermore alerting the fire brigade, rescue services and an eventual operator in the control room depends on this. Therefore quick detection of a vehicle fire is necessary. On the other hand, false alarms have to be minimized especially for tunnels that are not permanently supervised by operators. Thus the threshold values for fire detection have to be chosen carefully.

The main means for fire detection today are linear, temperature-based systems. These are installed on the ceiling of the tunnel profile and detect unusual increases in the tunnel air temperature. A fire is detected either due to high gradients or high absolute values of the temperature. Since the temperature rise caused by a vehicle fire may be too small to trigger these systems, even if large quantities of smoke are produced, additional detection systems are now being considered and tested.

Video based systems may be used to detect irregular vehicle behaviour, occurrence of smoke, flames or temperature rises. Furthermore the deterioration in visibility or a high concentration of carbon monoxide (CO) may be indices of a fire. Since sensors for visibility and CO-concentration are part of the standard equipment for normal operation of a road tunnel, the question arises, could they be used for this purpose too.

TUNNEL SPECIFICATION OF THE SAUKOPFTUNNEL

The Saukopftunnel is on a stretch of federal highway B 38a. It has been in use since 1999 as a two-way tunnel.

The main specifications of the tunnel, which is situated about 150 m above sea level, are as follows:

• Length	2'715 m
• Gradient	1.78 % from West to East
• Number of bores	1
• Traffic	19'000 Vehicles/Day; 6% trucks, bi-directional
• Escape routes	none
• Control centre	unmanned

VENTILATION SYSTEM

An illustration of the semi-transverse/transverse ventilation system with central extraction used in the Saukopftunnel is shown at Figure 1.

Two ventilation ducts are situated above the traffic compartment. The smaller duct (4.5 m^2) is used exclusively to supply fresh-air. Secondary pipes inside the tunnel wall take fresh-air to outlets situated about 1 m above the road surface. The larger duct (8.2 m^2) is used either to supply fresh-air or in the event of fire, to extract smoke by reversal of the direction of flow. For this purpose slots are located in the false ceiling every 10 m.

The tunnel is divided into two ventilation sections, which are supplied from two ventilation buildings, one at the western and one at the eastern portal. The ventilation building in the middle of the tunnel serves as a central extraction unit.

The two end-portal ventilation buildings each contain one fresh air fan with a 1.80 m rotor-diameter providing 52 m^3/s (west) and 55 m^3/s (east) fresh air supply and one reversible fan with 2.24 m rotor-diameter providing either a supply of 104 m^3/s (west) and 110 m^3/s (east) of fresh air or, in extraction mode, extracting 106 m^3/s (west) and 112 m^3/s (east). The central extraction unit consists of two fans with a rotor-diameter of 3.15 m giving a maximum extraction capacity of 275 m^3/s each. All fans are equipped with electro-mechanical blade adjustment to vary the airflow rate during operation.

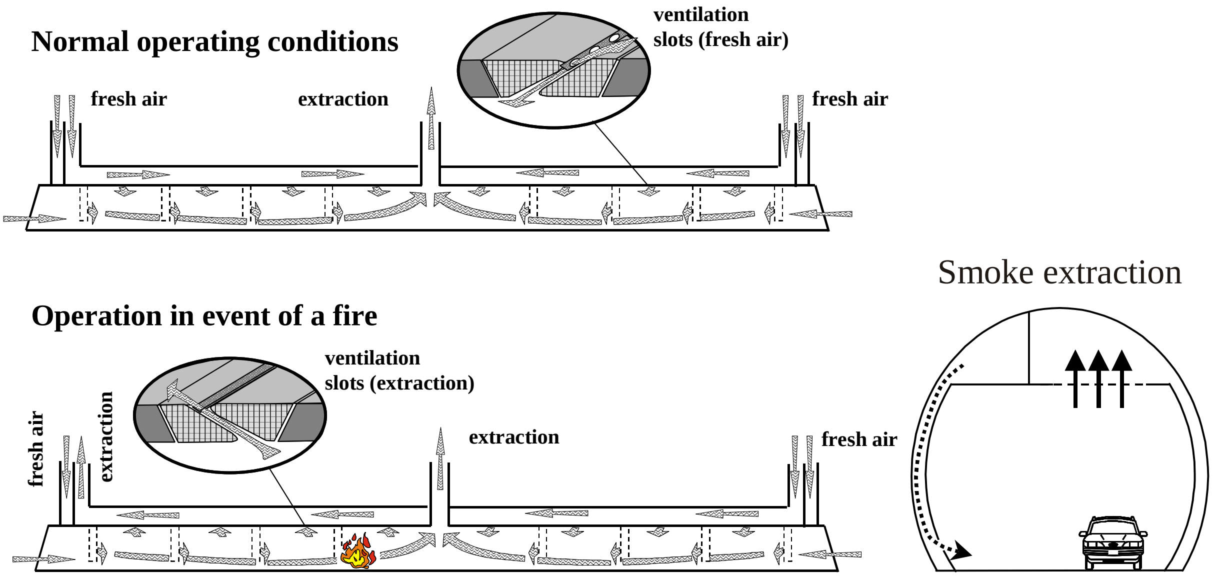
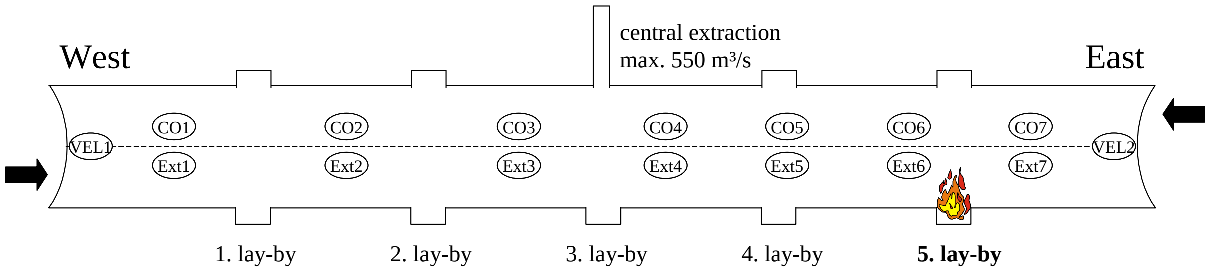


Figure 1: Ventilation system of the Saukopftunnel during normal operating conditions and in event of a fire

ANALYSIS OF THE FIRE INCIDENT ON AUGUST 24, 2000

On August 24, 2000 at about 17.45, a passenger vehicle caught fire in the Saukopftunnel while driving from west to east. The car stopped in the last lay-by before the east portal (see Figure 2). The driver of the car called the emergency number using a mobile phone and informed the police station at Weinheim of the fire.



VEL = Velocity sensor
CO = Carbon-monoxide sensor
Ext = Extinction coefficient Sensor

Figure 2: Plan of the location of the fire and the sensor equipment in the tunnel

The number of vehicles in the tunnel can be estimated from the data provided by the traffic counters at the portals. Between 16.00 and 17.00, 930 vehicles were recorded driving towards Mörlenbach (west to east) including 23 heavy-goods vehicles (2.5 %) and 472 vehicles driving towards Weinheim (east to west) including 28 heavy-goods vehicles (5.9 %). Assuming a vehicle velocity of 60 km/h this would give a figure of about 63 vehicles in the tunnel. Evaluating the traffic data for the last 10 minutes prior to the incident only would result in a similar conclusion.

Figure 3 represents an overview of the measured extinction coefficient K of sensors number 6 and 7 over the whole day. These are located in the eastern part of the tunnel on either side of the site of the fire (see Figure 2). Whereas under normal operating conditions the extinction coefficient only momentarily exceeds the value of 3 km^{-1}, after the fire broke out two distinct peaks occurred. The tunnel was automatically closed to incoming traffic by means of red traffic lights at the portals at the time when the first peak exceeded 12 km^{-1} as required by German regulations [1].

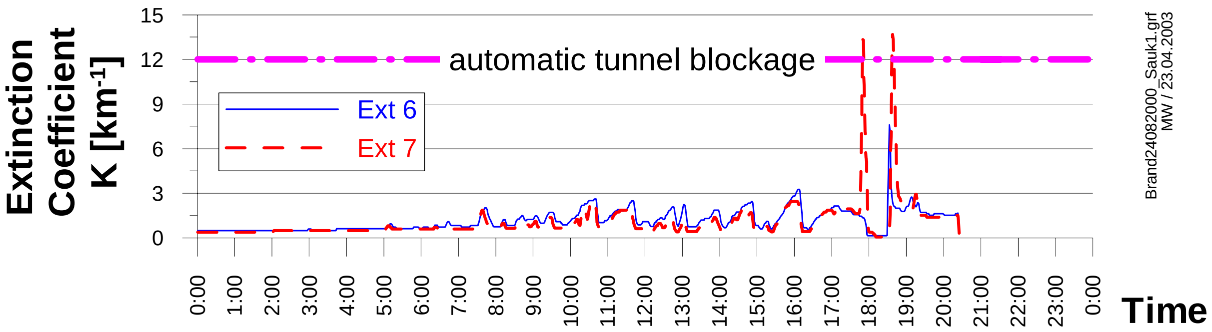


Figure 3: Extinction coefficient recorded by sensors 6 and 7

Figure 4 shows the measured data of the extinction coefficient K from sensors 4 to 7, the air velocity in the tunnel and the fan airflow rates of the central extraction and the eastern fans during the period from 17.00 to 19.00. The fan airflow rates were measured by the inbuilt ventilator measurement systems. The negative values for the reversible fan, indicating extraction mode, have been estimated from the blade angle data.

Just before the fire broke out, the airflow velocity in the tunnel was fairly constant at about 1.1 m/s from west to east. Since at the time no artificial tunnel ventilation system was active, both sensors recorded much the same value. In the first five minutes of the incident, the smoke produced by the fire led to a sharp increase in the extinction coefficient of sensor number 7 up to almost 14 km^{-1}. At about 17.50, the portal traffic lights were automatically switched to red.

As the fire alarm was not triggered by the fire detection cable mounted in the top of the tunnel ceiling the high extinction coefficient was interpreted by the automatic control routine as vehicle emissions. It immediately increased the central extraction and fresh air supply in the eastern part to maximum. Due to this ventilation regime, the velocity in the eastern part of the tunnel changed direction in the following 10 minutes and reached a velocity of about 2.5 m/s from east to west. The velocity in the western part of the tunnel increased up to about 3.0 m/s from west to east. The change of velocity direction in the eastern section caused the high extinction coefficient of sensor 7 to decrease during this period.

Due to the high flow of fresh air in the eastern part (55+104 m^3/s) and the relatively high air velocity, the anticipated consecutive peaks at sensors 6, 5 and 4 are absent or very small.

At 18.02 the opacity values were low and the ventilation shut off automatically. At 18.15 the ventilation control was manually overridden by the fire brigade and the programme for smoke extraction in the eastern part was started. This resulted in a further velocity change in the traffic compartment in the following 10 minutes to about 1.5 m/s from west to east in the eastern section and to about 1.0 m/s from east to west in the western section. Between 18.20 and 18.45 the extinction coefficients of sensors 4, 5, 6 and 7 showed subsequent peaks of about 8 to 14 km^{-1}. The time gap between these peaks corresponds well with the recorded velocity of about 1.5 m/s.

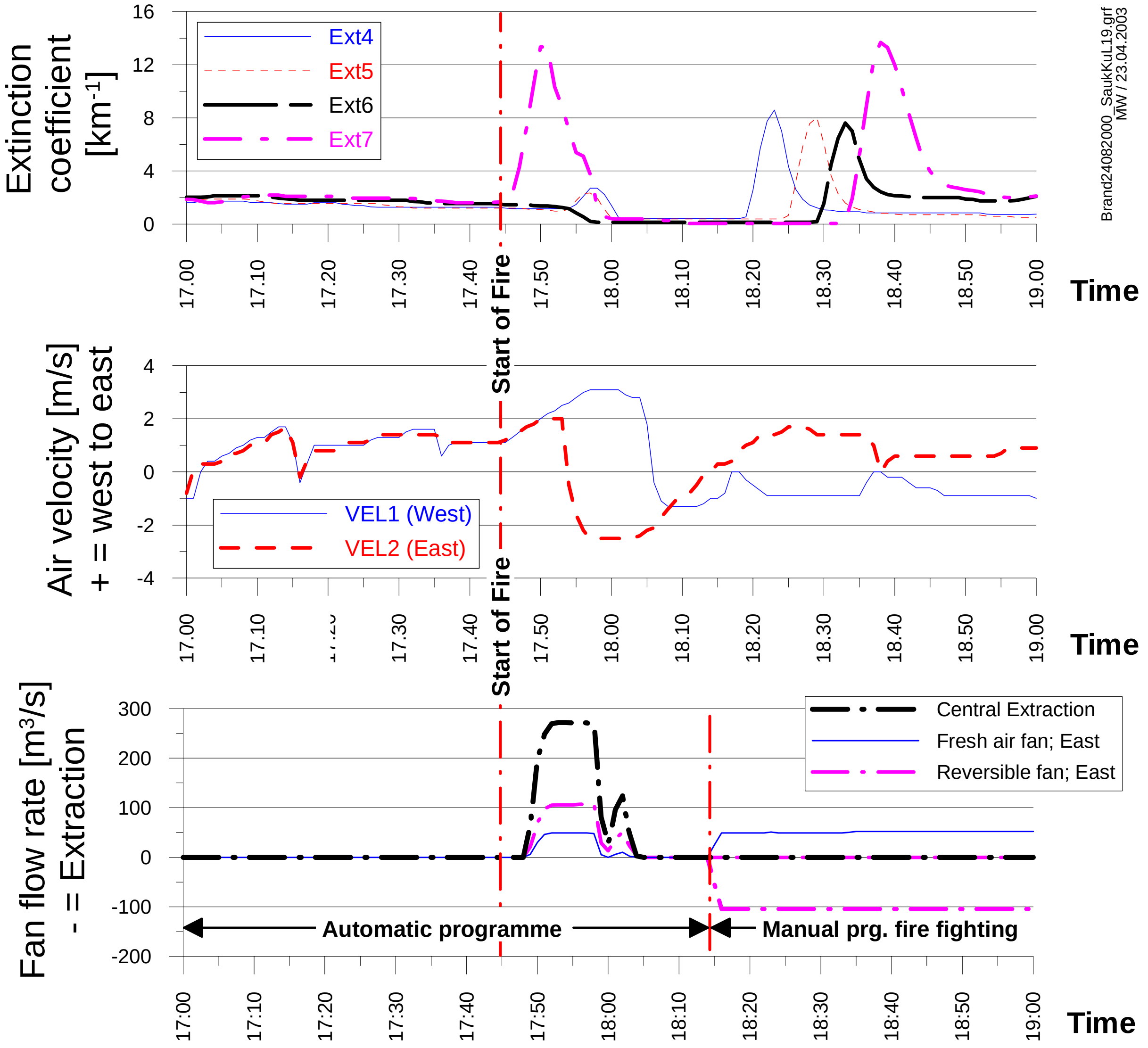


Figure 4: **Extinction coefficients K, recorded by sensors 4 - 7, air velocity and fan flow rate from 17.00 to 19.00**

CONSEQUENCES

As a consequence of this incident a supplementary control routine for smoke detection was proposed in which two conditions should be checked. When the measured value of the extinction coefficient and the gradient exceed given thresholds the fire alarm will be activated.

Hitherto only a small amount of normally short-term data had been collected. To avoid false alarms, a three-month testing period was proposed during which these those two conditions would be recorded without triggering the fire alarm.

DATA ANALYSIS

The raw data of the extinction coefficients and CO-concentrations during the three month period (August 1, 2002 to October 31, 2002) under normal operating conditions have been averaged over one minute. From this the difference between sequential minute average values (gradient) was calculated. The gradients are plotted over the corresponding values in Figure 5 and compared with the values occurring during the fire incident on August 24, 2000. The hatched lines show the threshold values that were applied during the test period in order to examine the potential functionality of the new approach. However these alarms where not interfaced with the control system.

As a result of the tests, the thresholds were redefined as shown in Figure 5 as solid lines. Using this new approach the fire that occurred on August 24, 2000 would have been detected due to high gradients of co-concentrations and/or extinction coefficients.

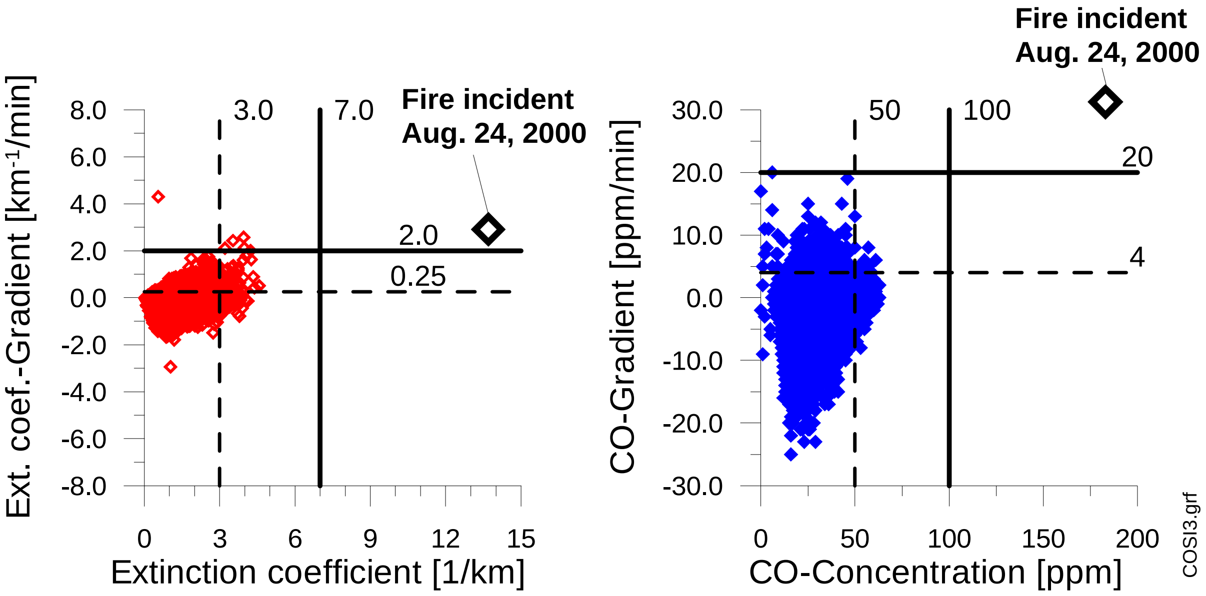


Figure 5: Extinction coefficients K and CO-concentrations under normal operating conditions from August 1, 2002 to October 31, 2002; Gradients plotted over values compared with the values occurring during the fire incident on August 24, 2000.

CONCLUSIONS

The principal conclusions from the current study may be summarised as follows:

1. Linear, temperature based detection systems are state-of-the-art for fire detection in road tunnels. The temperature rise of small fires may be too low to trigger these systems.
2. Even small fires can produce a dangerous quantity of smoke. So rapid fire detection is vital for the safety of tunnel users, automatic adaptation of ventilation, lighting, traffic lights, ventilation of escape routes and alarm activation.
3. The ventilation requirements differ between normal operation and the event of a fire. In the event of high opacity or CO-concentrations, this could result in conditions due to increased normal ventilation which are contradictory to the aim of supporting the evacuation of tunnel users.
4. Sensors measuring the CO-concentrations and the opacity of the air in road tunnels are considered to be standard equipment. Therefore, deterioration of visibility and/or high CO-concentrations should be used for smoke detection. In both cases, two criteria should be used: gradients and absolute values. In order to avoid false alarms, the threshold values for the smoke detection should be chosen carefully. They will depend on the individual characteristics of the tunnel.

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