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An experimental evaluation of toxic gas emissions from vehicle fires

Benjamin Truchot *, Fabien Fouillen, Serge Collet

INERIS, Parc Technologique ALATA, France

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ABSTRACT

Improving fire modelling is a key issue to design efficient safety measures for a safe people evacuation in case of fire. Such an analysis should consider the different impacts of fire on people as temperature, visibility but also toxicity. Most of the standard curves used in tunnel fire studies are based on quite old fire tests without any detailed toxic gas qualification. Very few fire tests were published in that way. Based on those few tests, some standard fire emission factors are available in the literature. The objective of this paper is to review those emission factors considering the different toxic species and dealing with using recent cars. A method is then proposed to define a carbon monoxide equivalent emission factor to consider the different species through their specific threshold. Such an approach can be easily introduced into fire codes.

To meet this objective, two series of tests were performed. The first concerns individual combustible materials of cars as plastics and tyres. The second focusses on full car burning tests including a detailed smoke analysis. Those two series of tests lead to an analysis of the smoke toxicity and a comparison of emission factors with standard ones.

1. Introduction

In case of fire in underground facilities such as tunnels or car parks, while heat release rate (HRR) is crucial for structure behaviour and aerodynamic, impact on people is mainly governed by the smoke toxicity. However, while car fires were largely studied in the past regarding the HRR, few papers were focussed on the toxic gas emissions [1,2]. Since those papers were published, cars were concerned by major improvements as new systems for comfort, that have induced, as far as the topic of this paper is concerned, a major increase of the mass of plastic, or new energy carriers. Each of these improvements could clearly impact the toxic gases emission factors in case of fire.

To evaluate recent cars emission factors, a large scale experimental fire campaign with real cars were performed. Those tests concern several categories of cars. The first is a series of three different recent cars, with several sizes, from small “urban” cars, as Renault Twingo, Citröen C1 or Fiat Panda, to large “familial” cars, as Citroën C5, Volkswagen Passat or Peugeot 508. This first series of tests, compared with existing results in the literature, enables evaluating the impact of embedded comfort system on smoke toxicity. The second series of tests concerns the evolution of the energy carrier using the results from electric cars burning [3]. Tests were also achieved on different materials individually such as fuels, cables and plastics to provide a more detailed analysis. Because carbon monoxide is not the only toxic product that is generated in case of fire, emissions were, during those tests, characterized using a FTIR (Fourier Transform Infra-Red) spectrometer. Such a system enables performing a detailed measurement including the concentration of carbon monoxide, but also of acid gases (hydrogen chloride, hydrogen fluoride, …) or other products as formaldehyde for example. Not only the nature but also the quantity of produced gases during fire are compared.

Regarding those experimental data, made on recent cars in a tunnel like environment, a comparison is proposed with the commonly used fire curves [4] for the emission factor. To let this comparison possible, a CO equivalent source term is defined based on both a simple approach [5], the ISO toxic evaluation standard method [6,7] is also used for toxic consequences evaluation.

2. Vehicle fire source terms available

Considering that most of the toxic gas emission factors from fires are given relatively to the heat release rate (HRR), it appears important to first consider this quantity. Furthermore, the smoke behaviour in a confined or semi-confined infrastructure will highly depends on the thermal gradient that governs smoke stratification.

Regarding HRR, several curves of HRR vs time are available in the literature. Those curves were obtained using different measurement

* Corresponding author.
E-mail address: benjamin.truchot@ineris.fr (B. Truchot).

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methods that could be calorimetry installation [3,8], tunnel fire tests [9] or external measurement [10]. French nationally recognised document [4] or AIPCR publication [20] also give an overview of available data. The published curves of HRR are based on different values of the total amount of energy released during the fire, i.e. the HRR curve integral. The released energy then varies from 3000 MJ [4] to 12 000 MJ [8]. To provide an example, two HRR curves are plotted hereafter on Fig. 1. The first from Ref. [4], on the left part of the figure, is the standard curve commonly used for fire safety studies in France. It is based on a synthesis of available data. The second, from Ref. [20], on the right part of the figure, is an example of measured HRR curve during the Eureka campaign [9] for an individual car containing plastics.

It must be highlighted that the range of values is quite important, not only in terms of HRR peak value, from 2.5 to more than 8 MW depending of the nature of the car [8], but also regarding the fire kinetic with a peak value reached between 5 [4] and more than 40 min depending on fire test conditions [10].

The important issue regarding toxicity is then the relation between the HRR and the emission factor. This relation is governed by the characteristics of combustible materials that are not so different between small and large cars. While some data are available in the literature regarding the emission rate of carbon dioxide and carbon monoxide, few data exists on the other toxic gases that can be produced during a car fire. One of the most detailed is [2]. Those tests, achieved in 1999, deal with vehicles that are quite old now.

It is then interesting to evaluate the impact of vehicle improvements between previous and current tests in terms of chemical species generated by the fire but also in terms of emission factor.

3. Tests on individual elements

Before going any further in the description of full scale fire tests on vehicles, it is important to analyse emission factors for different individual materials. This topic was previously addressed in the literature [12–15]. It is important to note that results presented in this paper are focussed only on chemical species that could induce acute toxicity.

3.1. Brief description of experimental facilities

This series of tests was achieved in the INERIS 80 m^3 room, a 5 m long, 4 m width and 4 m height concrete building. Ventilation in this room is made through a 1 m^2 extraction duct located in the center of the roof. Air inlet is also a 1 m^2 opening in one of the walls, it is located just above the ground. The ventilation flow rate was set to 10 000 m^3/h, this flow rate was chosen to prevent any under ventilation effect on the fire.

During those tests, combustible samples were placed in the center of the room, in a metallic cylindrical container placed over a sand insulation layer. Ignition was achieved with an 80 kW propane burner applied during 1 min. To ensure long duration tests, fires were refueled during the measurement period.

3.2. Main results

During this experimental campaign, four combustible materials from real cars were burnt individually: gasoil, plastics, tyres and cables. Those elements were taken from commercial cars to be representative of real materials. Plastics and tyres were previously crushed. Main results are summarized in Table 1. Of course, many other chemicals were measured but not all can be detailed in the present paper, more details can be found in Ref. [16]. It was chosen here to focus on the most relevant products regarding acute toxicity. For each material, the total duration of the tests was longer than 3 h.

Considering that the main toxicity contribution is not necessarily for the larger produced quantity because of the important ratio of toxic thresholds, those emission factor values should be considered carefully. This can be illustrated through the non-reversible toxic threshold for 60 min exposure that is 40 ppm for HCl against 800 ppm for CO, this means that producing 20 times less HCl than CO will lead to similar consequences, i.e. potential non-reversible impact on human beings. Those preliminary tests clearly indicate that all toxic gases emissions should be considered for evaluating the toxic impact of a fire and not only CO. This table also shows that some materials are responsible of some specific emissions such as tyres for SO_2 or plastics and cables for HCl.

4. Full scale car burning

4.1. Brief description of experimental facilities

Full scale fire tests were achieved in the INERIS fire gallery. This fire gallery was described in some previous papers [17] but relevant details are given hereafter. This gallery, made with concrete, is 50 m long with a 3 m width and 3.3 m maximum height section. It is equipped with fans that can be controlled to manage the air flow in the tunnel. Photography of INERIS fire facilities is presented on Fig. 2.

One of the main features of this installation consists in the smoke treatment system installed downstream. This system, of a similar design as a garbage furnace, enables capturing not only the accute toxic products as carbon oxides or acid gases but also chronical toxic species, as dioxin or PAH (Polycyclic Aromatic Hydrocarbons) too [18].

Table 1
Synthesis of individual combustible material fire tests.

	Gasoil	Plastics	Tyres	Electric cables
Mass of product burn [kg]	131	48	49	36
Emission factors [mg/g] or [g/kg]				
CO_2	2823	2034	1469	728
CO	31	20	42	9.1
HCl	–	2.2	0.2	2.1
HF	–	0.014	0.003	0.11
NOx	1.2	5,0	2.8	2.5
SO_2	0.1	–	10	–

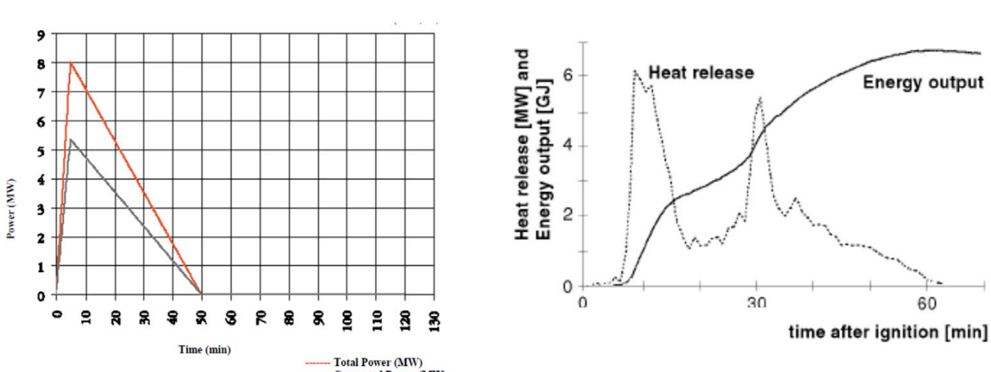

Fig. 1. Two examples of HRR curves from French ce documentation, 12 000 MJ [4] (left) and form PIARC reference, 7000 MJ [20](right).