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A SHORT DESCRIPTION REGARDING COMBUSTION FACTOR FROM EUROCODE 1-1-2

BY

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Abstract. The aim of this paper is to detail the combustion factor used to calculate the design value of the fire load density in accordance with the European design code. The procedure only states the factor value for the mainly cellulosic materials, like wood, paper, cardboard, naturals fibres (cotton, linen) etc., but it gives no information about other types of fuels, like plastics, flammable liquids, rubber, etc.

Considering the vast types of fuels, for a correct appreciation of the input data used by different fire models, it is necessary to better understand the importance of the combustion coefficient and its appropriate value selection.

The combustion factor directly affects the value of the design fire load density which, in turn, affects the Heat Release Rate. Both parameters are used by different type of natural fire models (like parametric curve, zone models, CFD models) to simulate the fire development and to predict the temperature in the analysed space.

Keywords: combustion factor, fire models, fire load density, chemical heat of combustion, net heat of complete combustion.

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1. Introduction

The design value of the fire load density is computed in accordance with the European design code EN 1991-1-2 Annex E (***). This code states a value of 0.80 [-] to be used in the case of mainly cellulosic materials (like wood, paper, cardboard, natural fibres – cotton, linen, etc.), with no additional information regarding other types of fuels.

This general approach is suitable for the common occupancies, like dwellings, hotels, libraries, schools, theatres, where the main combustible materials are of cellulosic type.

In a specific case, for example a storage room for burning liquids – ethanol, it is necessary to perform a fire load survey and to use the corresponding combustion factor for the main fuel that can burn.

The design value of the fire load density is defined as (***):

$$q_{f,d} = q_{f,k} \cdot m \cdot \delta_{q1} \cdot \delta_{q2} \cdot \delta_n \tag{1}$$

where:

$q_{f,d}$ – design value of the fire load density [MJ/m^2];

$q_{f,k}$ – characteristic value of the fire load density [MJ/m^2];

m - combustion factor [-];

δ_{q1} - factor taking into account the fire activation risk due to the size of the compartment [-];

δ_{q2} - factor taking into account the fire activation risk due to the type of occupancy [-];

δ_n - factor taking into account the different active firefighting measures [-].

Considering the previous Eq. (1), it can be seen that the combustion factor directly affects the design value of the fire load density.

2. Combustion factor

The combustion factor, also called combustion efficiency, in simple terms represents the quantity of the fuel that can burn in case of a real fire. The air and the fuel must mix by the process of diffusion before combustion could occur; the mixing process is relatively inefficient in case of a natural fire. The combustion efficiency is likely to vary from around 0.3÷0.4 for heavily fire-retarded materials to 0.9 or even higher, in case of oxygen-containing products (Fontana *et al.*, 2016).

The combustion behaviour of a material under real fire exposure depends on a lot of variables like: material properties, the surface to volume ratio, the thermal action on the material, geometrical properties (size, shape etc.), oxygen supply, the ability of the material to protect itself against thermal actions (charring of wood), density of the goods storage etc.

The complete combustion is rarely achieved in real fires.

The combustion factor, noted with m [-] in the European legislation or χ [-] in the specific literature, is defined as the ratio between the effective heat released q_{eff} [kJ/kg] and the theoretically maximal possible heat released q [kJ/kg]. Theoretically, the value can be between 0, no combustion, and 1, complete combustion (Fontana *et al.*, 2016). This factor is calculated as:

$$\chi = \frac{q_{eff}}{q} \tag{2}$$

The ratio of the chemical heat release rate to the heat release rate for complete combustion or the ratio of the chemical heat of combustion to net heat of complete combustion is defined as combustion efficiency (Khan *et al.*, 2016):

$$\chi_{ch} = \frac{\dot{Q}_{ch}^{''}}{\dot{Q}_{T}^{''}} = \frac{\dot{m}^{''}\Delta H_{ch}}{\dot{m}^{''}\Delta H_{T}} = \frac{\Delta H_{ch}}{\Delta H_{T}} \tag{3}$$

where:

χ_{ch} - combustion efficiency [-];

$\dot{Q}_{ch}^{''}$ - chemical heat release rate [kW/m^2];

$\dot{Q}_{T}^{''}$ - heat release rate of complete combustion [kW/m^2];

$\dot{m}^{''}$ - mass loss rate [g/m^2/s];

ΔH_{ch} - chemical heat of combustion [kJ/g];

ΔH_{T} - net heat of complete combustion [kJ/g].

The values for ΔH_{ch} [kJ/g] and ΔH_{T} [kJ/g] are determined by experimental means and presented in Table 1 (Morgan and Hurley, 2016) along with the combustion efficiency, computed according to Eq. (2). The fuels and categories of fuels are presented in accordance with Table E.3 from EN 1991-1-2 Annex E (***), for engineer's easy use.

An additional factor is introduced, $m_{avr.}$ [-], which represents the average value of the combustion efficiency for different fuels belonging to the same category.

Table 1
Combustion efficiency factor for different fuels

Categories of fuels	Fuels	ΔH_T [kJ/g]	ΔH_{ch} [kJ/g]	m [-]	m avr. [-]
Wood	*Beech*	*20.0*	*18.7*	*0.94*	*0.93*
	Birch	*20.0*	*18.7*	*0.94*	
	Douglas fir	*21.0*	*19.6*	*0.93*	
	Maple	*19.1*	*17.8*	*0.93*	
	Red oak	*20.2*	*18.7*	*0.93*	
	Spruce	*21.8*	*20.4*	*0.94*	
	White pine	*19.2*	*17.8*	*0.93*	
Other cellulosic materials	*Clothes*	-	-	-	-
	Cork	*28.0÷31.0*	*26.1*	*0.84÷0.93*	
	Cotton	*16.5÷20.4*	-	-	
	Paper	*16.3÷17.9*	-	-	
	Cardboard	-	-	-	
	Silk	-	-	-	
	Straw	*15.6*	-	-	
	Wool	*26.6*	*20.7*	*0.78*	
Carbon	*Anthracite*	-	-	-	-
	Charcoal	*33.7÷34.7*	*33.2÷34.2*	*0.99*	
	Coal	-	-	-	
Paraffin series	*Methane*	*50.1*	*49.6*	*0.99*	*0.98*
	Ethane	*47.1*	*47.0*	*1.00*	
	Propane	*46.0*	*44.1*	*0.96*	
	Butane	*45.4*	*43.5*	*0.96*	
Olefin series	*Ethylene*	*44.2*	*29.8*	*0.67*	*0.56*
	Propylene	*37.6*	*19.0*	*0.51*	
	Butene	*35.3*	*17.3*	*0.49*	
Aromatic series	*Benzene*	*40.1*	*28.1*	*0.70*	*0.69*
	Toluene	*39.7*	*27.0*	*0.68*	
Alcohols	*Methanol*	*20.0*	*19.4*	*0.97*	*0.96*
	Ethanol	*27.7*	*26.2*	*0.95*	
	Ethyl alcohol	*27.7*	*26.9*	*0.97*	
Fuels	*Gasoline*	*46.8*	*43.7*	-	-
	Diesel	-	-	-	
Pure hydrocarbons plastics	*Polyethylene*	*37.9*	*21.8*	*0.58*	*0.61*
	Polystyrene	*39.2*	*27.0*	*0.69*	
	Polypropylene	*37.0*	*21.1*	*0.57*	
Other products	*ABS*	*35.25*	*33.75*	*0.96*	-
	Polyester	*32.5*	*20.6*	*0.63*	
	Polyisocyanurate	*26.30*	*22.2÷26.2*	*0.84÷1.00*	
	Polyurethane	*23.90*	*22.70*	*0.95*	
	PVC	*16.4*	*5.7*	*0.35*	

Categories of fuels	*Fuels*	ΔH_T [kJ/g]	ΔH_{ch} [kJ/g]	m [-]	m avr. [-]
	Bitumen, asphalt	-	-	-	
	Leather	*18.2÷19.8*	-	-	
	Linoleum	-	-	-	
	Rubber tyre	-	-	-	

NOTE: "-" not data found by the authors.

3. Conclusions

The combustion factor directly affects the design value of the fire load density and, by way of consequence, all the parameters calculated by a fire model, e.g. the temperature of the analysed space.

Its value is given by the ratio between the chemical heat of combustion and net heat of complete combustion, parameters which are determined by experimental means.

It can be seen that the standard value, of 0.8 [-], proposed by EN 1991-1-2 Annex E for cellulosic materials, can lead to wrong results in case of other types of combustible materials. In this case it is mandatory to use the corresponding values. Moreover, even in the case of cellulosic materials the standard value is below the specific value of various wood species.

In the case of a rough, engineering-type analysis, where the exact type of the fuel is not known (e.g. plastic materials), the authors suggest to use average value from the corresponding category of fuels (e.g. pure hydrocarbon plastics).

Another direction of research, proposed by the authors, is the determination of the combustion efficiency factor in case of more fuels found in the analysed space. In this case a possible average value may consider the share in the total fire load density for each type of fuel involved in the fire.

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*** Eurocode 1: *Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire,* EN 1991-1-2:2002, Annex E Fire load densities.

O SCURTĂ DESCRIERE REFERITOARE LA COEFICIENTUL DE ARDERE PRECIZAT DE EUROCODUL 1-1-2

(Rezumat)

Scopul lucrării îl reprezintă detalierea coeficientului de ardere utilizat pentru determinarea valorii de calcul a densității de sarcină termică conform prevederilor Eurocodurilor. Procedura precizează doar valoarea coeficientului în cazul materialelor preponderent celulozice precum lemn, hârtie, carton, fibre naturale (bumbac, in), etc. fără a oferi informații despre alte tipuri de materiale combustibile precum mase plastice, lichid inflamabil, cauciuc, etc.

Considerând diversitatea materialelor combustibile, pentru o apreciere corectă a datelor de intrare specifice fiecărui model de incendiu, este necesară înțelegerea importanței coeficientului de ardere şi utilizarea valorii adecvate.

Coeficientul de ardere afectează direct valoarea de calcul a densității de sarcină termică care, pe cale de consecință, afectează valoarea debitului de căldură degajată; ambii parametri sunt utilizați de diversele modele de incendiu (precum curba parametrică, modele zonale, modele CFD) pentru a simula dezvoltarea incendiilor şi a calcula temperatura în spațiul analizat.