ACIDITY ADDITIONAL CLASSIFICATION IN CABLES AND ITS IMPACT ON PVC CABLES COMPOUNDS GROWTH

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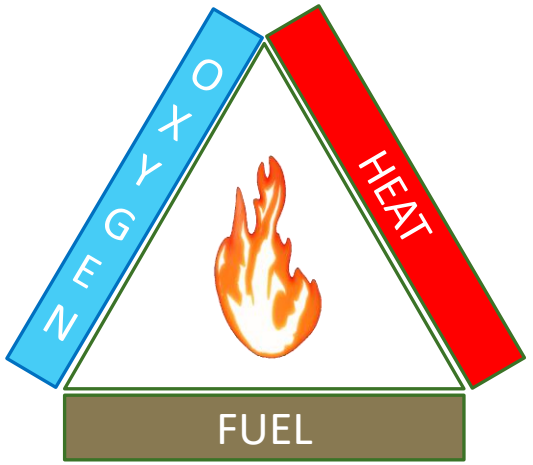
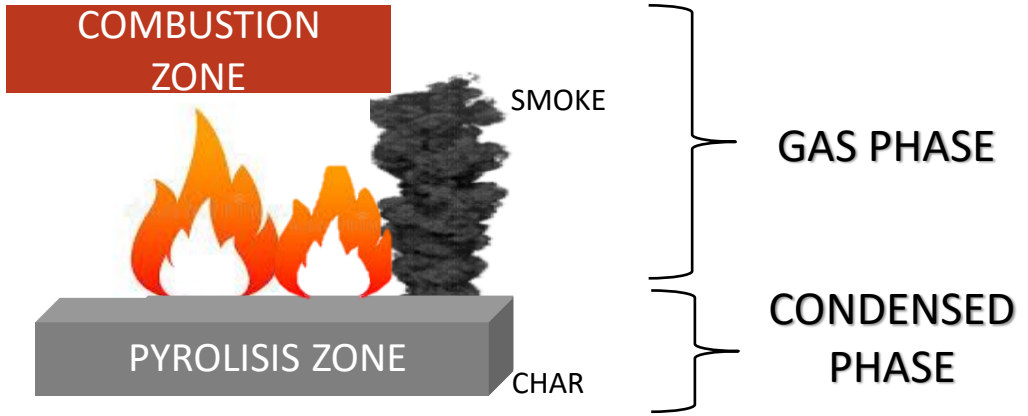
1 General background in the fire behavior of plastics

Fire is a complex phenomenon influenced by several factors. In its most basic form, fire needs the combination of three elements in the right blend: **heat**, **fuel**, and **oxygen**. The removal of at least one of these crucial elements will lead to the extinction of the fire [1].

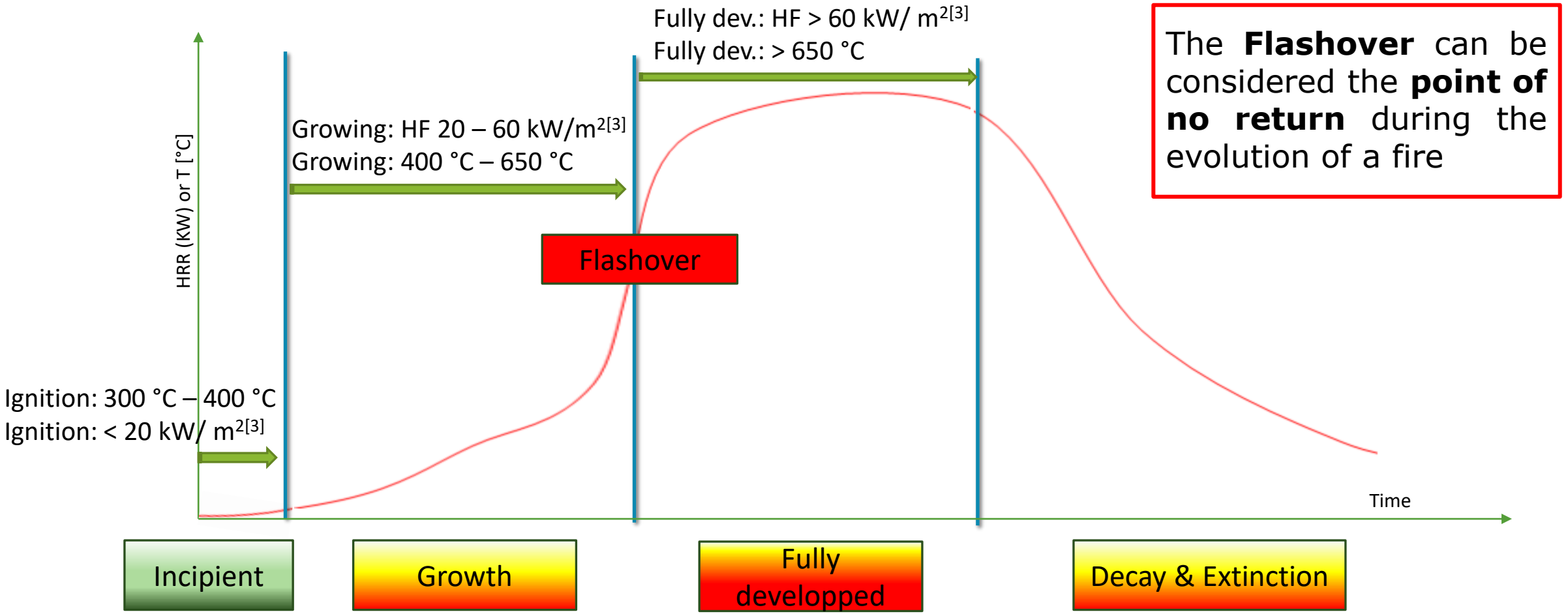


Polymers, when exposed to a source of heat of enough magnitude, tend to degrade and decompose releasing volatile substances. The flame is fueled by radicals as H• and OH• which are the main responsible for the exothermicity of the chain reactions involved such as the oxidation of CO to CO_2 [2].



1 General background in the fire behavior of plastics

The **evolution of** a **fire in a compartment** can be described by **Heat Realese Rate curve**



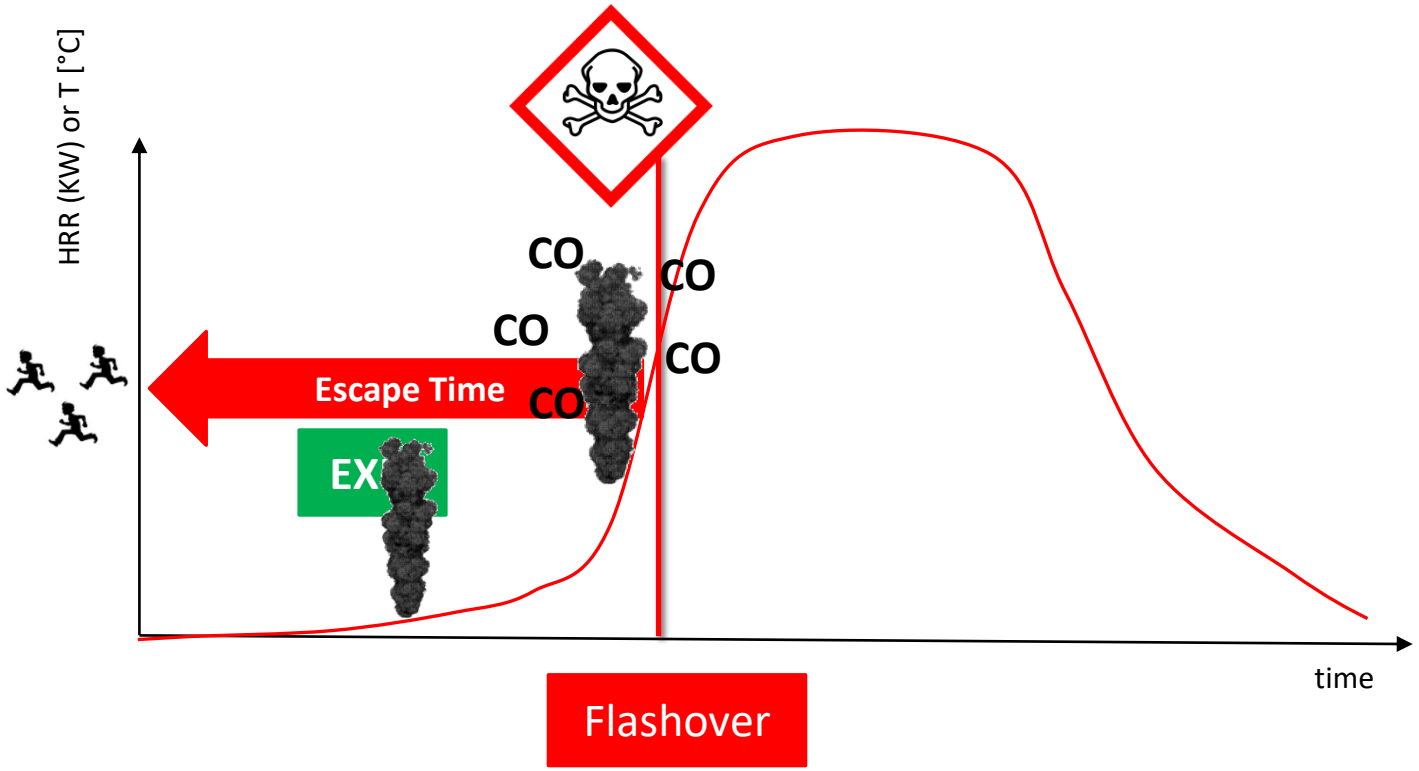
The **Flashover** can be considered the **point of no return** during the evolution of a fire

1 General background in the fire behavior of plastics

Why people die in a fire?

Most **people die** because small, controllable **fires become too big**, having reached the point of no return called flashover [4]

As consequence**, smoke inhalation** is the **main cause of death**



Despite the large number of potentially dangerous components in the gases released in a fire, the **risk comes** mainly **from carbon monoxide** (CO), a toxic and narcoleptic gas that is always **released by all organic burning substances** despite their chemical nature (approx. 20% of their weight after flashover) [5,6]

1 General background in the fire behavior of plastics

Fire protection of a building

Active Protection

Active fire protection (AFP) is based on systems, requiring motion and response to withstand the fire.

Passive Protection

Passive Fire Protection (PFP) tries to contain fires or slow the spread, using fire-resistant walls, doors, floors and materials with higher fire performances.

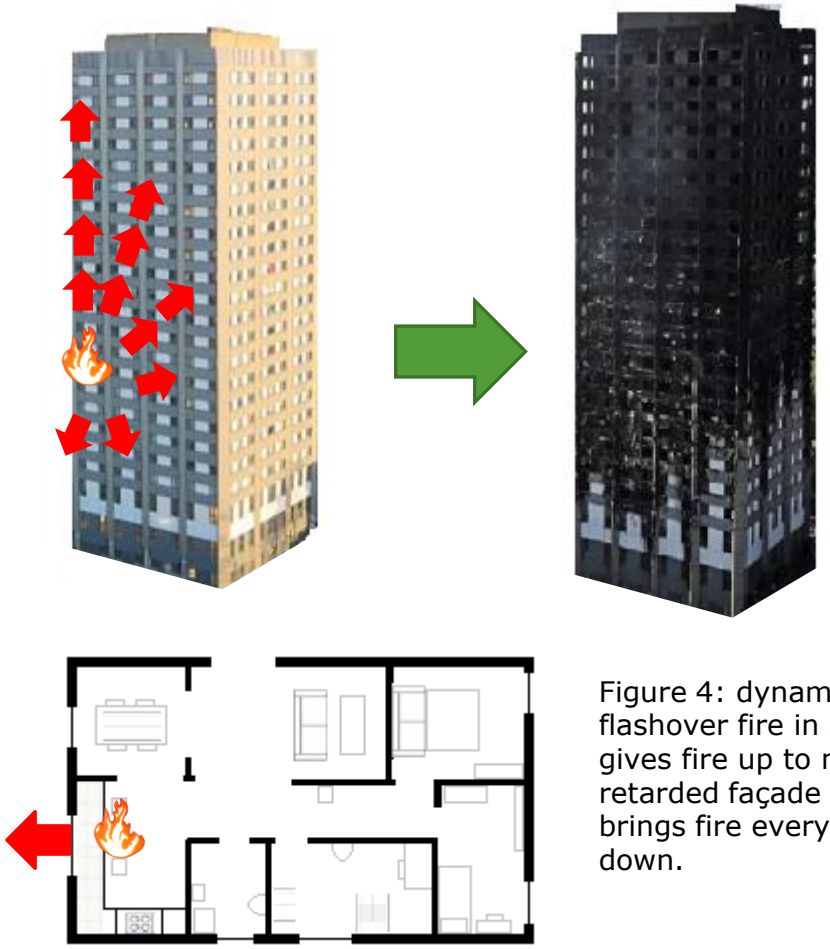
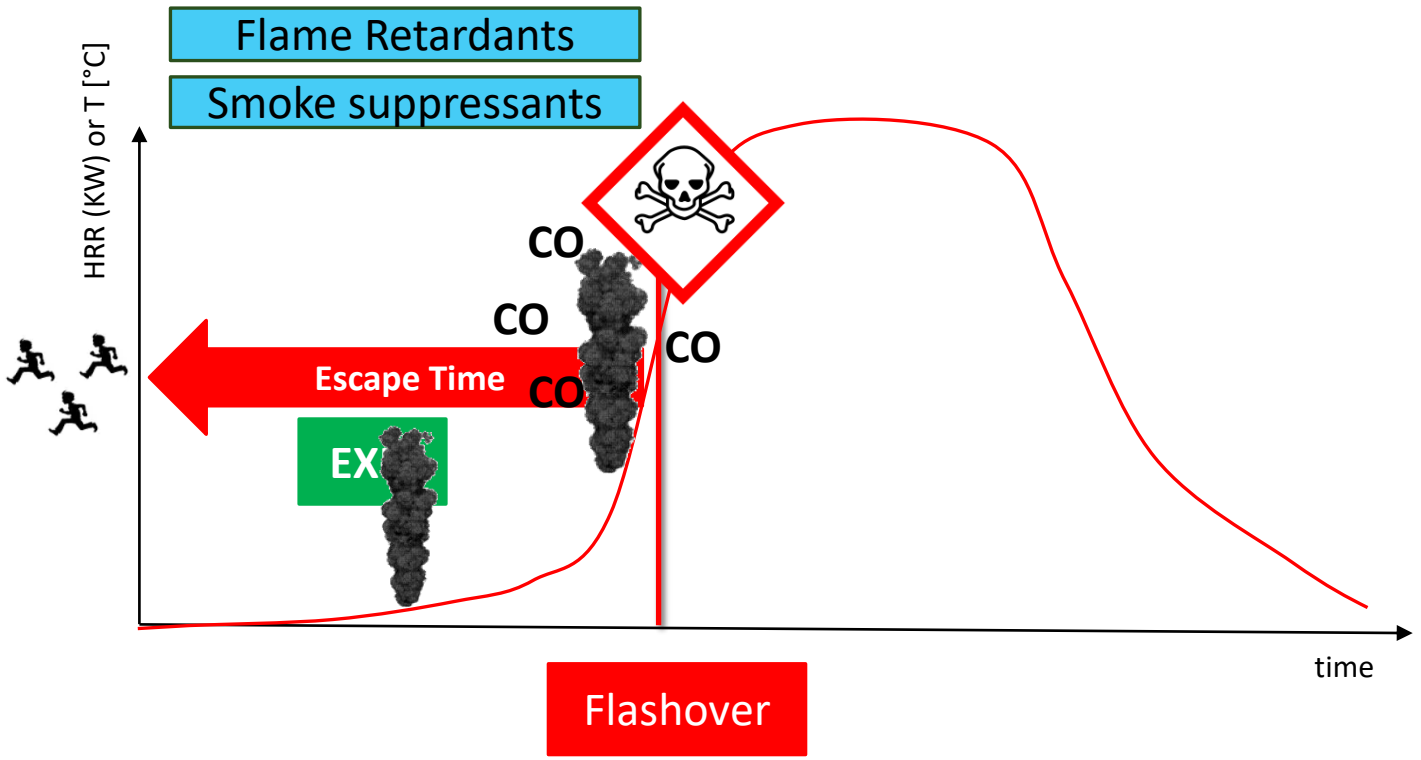


Figure 4: dynamic of a fire. A flashover fire in an apartment gives fire up to not flame retarded façade and this brings fire everywhere up and down.

1 General background in the fire behavior of plastics

Fire protection of a building: passive protection with materials with higher fire performance

The **main goal** in the **construction** of a **building** is defining the **behavior** of the **materials** used for having a good choice of the components.



Actions:

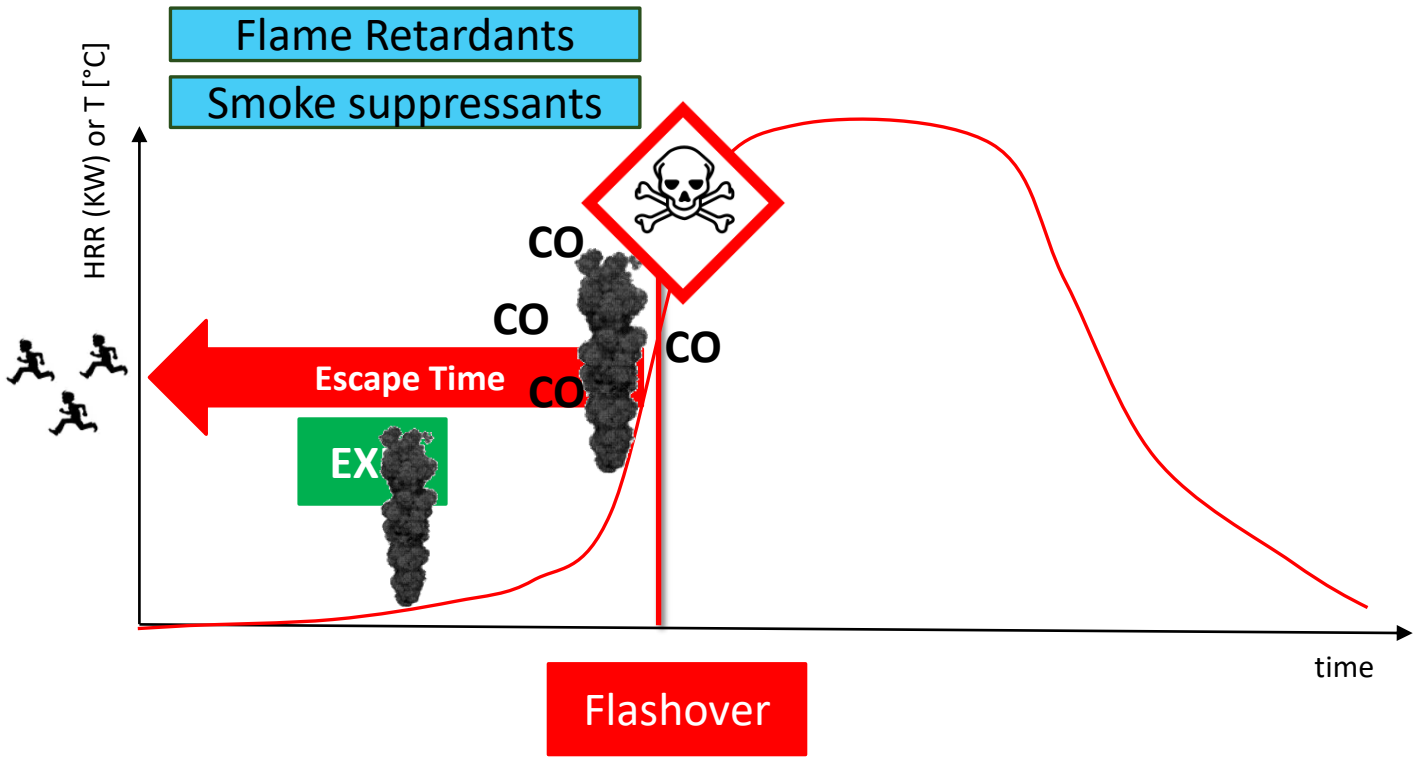
- **Increase time to flashover**
- **Low smoke emission**

The use of **flame retardants** and **smoke suppressants** improves fire performance and the passive protection

2 Parameters to outline the hazard of a fire

The **fire behavior** of a material **is outlined by** these parameters [4]:

These parameters can be related to the HRR curve and smoke emission describing the hazard of a fire



1) IGNITABILITY
2) EASE OF EXTINCTION
3) FLAMMABILITY
4) FLAME SPREAD
5) HEAT RELEASE
6) SMOKE OBSCURATION
7) SMOKE TOXICITY

8) ACIDITY

What does scientists of fire state about the potential hazards related to smoke acidity?

2 Parameters to outline the hazard of a fire

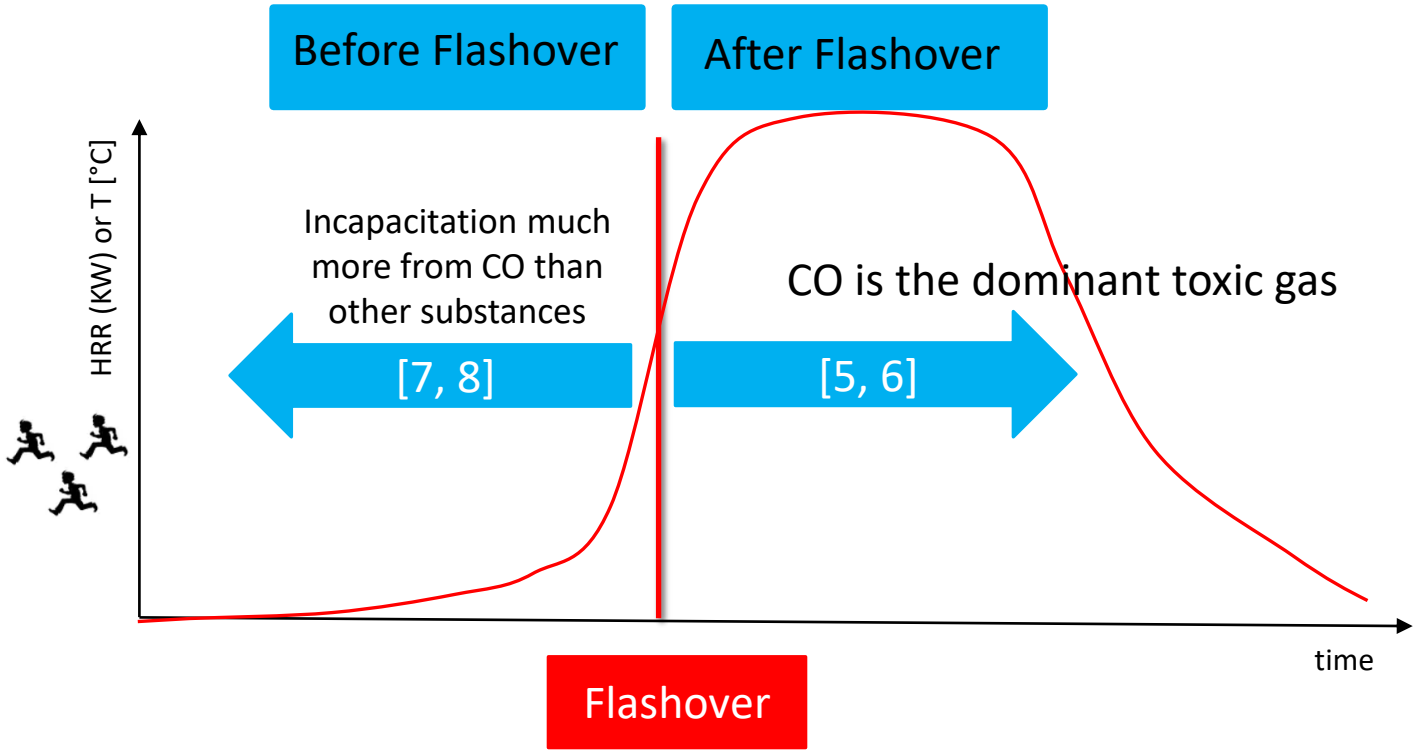
Smoke acidity

- **CO** is a **narcoleptic** substance
- **HCl** is a **corrosive** and **irritating** substance
- **Tenability** is driven mostly by CO

NO LINK WITH TOXICITY: CO IS THE REAL KILLER DURING A FIRE

«ACIDITY IS TOTALLY INADEQUATE AS A REPRESENTATION OF SMOKE TOXICITY»

IN A REAL FIRE SCENARIO HCl TRAVELS NOT SO FAR FROM THE FIRE ORIGIN



HCl emitted in the gas phase:

1) is absorbed by porous walls
2) is diluted by vapour
3) decays in a short time returning to condensed phase

SMOKE ACIDITY IS A SECONDARY AND ANCILLARY PARAMETER IN FIRE SAFETY

3 CPR and additional classification for acidity

Construction Product Regulation (CPR)

In the European Union, the **REGULATION (EU) N. 305/2011,** in force since 2017, establishes harmonized conditions for the marketing of construction products.

Construction products, including those containing plastics, must be tested and classified to verify their fire performance according to the harmonized system of Euro classes.

CPR has 'activated' two technical standards:
- **EN 50575** is a product standard "specifying reaction- to-fire performance requirements, test and assessment methods for electric cables used for the supply of electricity and for control and communication purposes"

- **EN 13501-6** defines classes and additional classes, standards and requirements to obtain them. There are 7 main classifications for reaction-to-fire according to their decreasing performance

Main class to reaction to fire: (from A best to F worst)

Additional classes:
- s1, s2, s3 for smoke
- d0, d1, d2 for flaming droplets
- a1, a2, a3 for acidity

3 CPR and additional classification for acidity

CPR requirements for cables for fixed installations

Electricity has always been one of the **main causes of fires** and the manufacture of **flame retarded electrical cables** suitable to withstand the ignition and to delay the fire spread is a **key factor** for **fire risk prevention**

″Safe electrical cables means to have a safe home″.

EN 13501-6

Main class to reaction to fire: (from A best to F worst)

Additional classes:

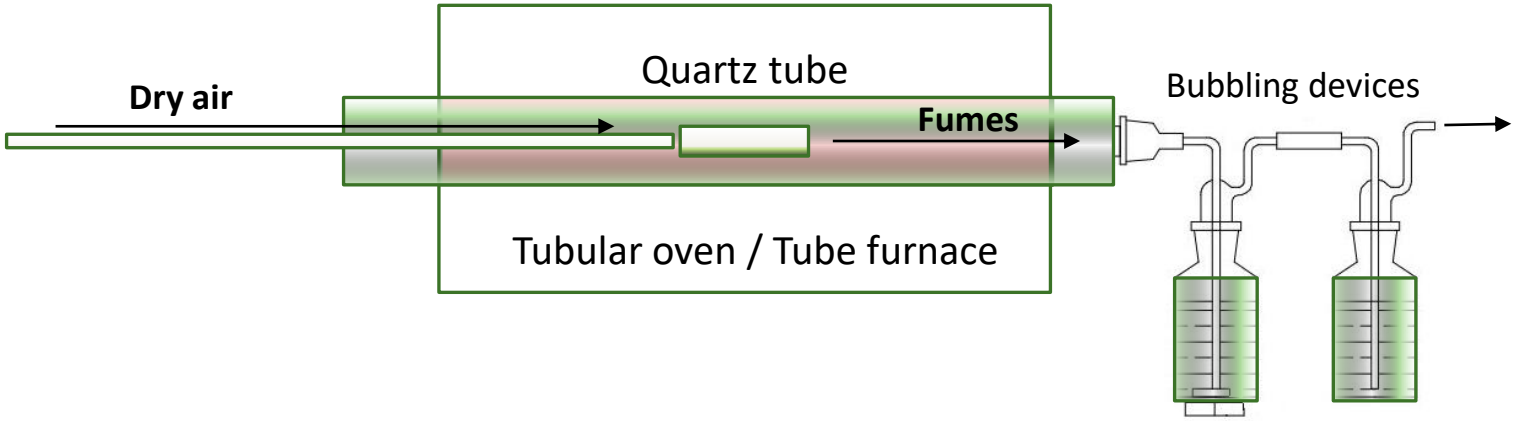
- s1a, s1b, s2, s3 for smoke
- d0, d1, d2 for flaming droplets
- a1, a2, a3 for acidity

Electrical cables are the <u>only construction products</u> **having** the **additional classification for acidity**

Class	Test method(s)	Classification criteria	Additional classification
A_{ca}	EN ISO 1716	*PCS* ≤ 2,0 MJ/kg [a]	
$B1_{ca}$	EN 50399 (30 kW flame source) *and*	*FS* ≤ 1,75 m *and* THR_{1200s} ≤ 10 MJ *and* *Peak HRR* ≤ 20 kW *and* *FIGRA* ≤ 120 Ws^{-1}	Smoke production [b, e] and Flaming droplets/particles [c] and Acidity [d]
	EN 60332–1-2	*H* ≤ 425 mm	
$B2_{ca}$	EN 50399 (20,5 kW flame source) *and*	*FS* ≤ 1,5 m; *and* THR_{1200s} ≤ 15 MJ; *and* *Peak HRR* ≤ 30 kW; *and* *FIGRA* ≤ 150 Ws^{-1}	Smoke production [b, f] and Flaming droplets/particles [c] and Acidity [d]
	EN 60332–1-2	*H* ≤ 425 mm	
C_{ca}	EN 50399 (20,5 kW flame source) *and*	*FS* ≤ 2,0 m; *and* THR_{1200s} ≤ 30 MJ; *and* *Peak HRR* ≤ 60 kW; *and* *FIGRA* ≤ 300 Ws^{-1}	Smoke production [b, f] and Flaming droplets/particles [c] and Acidity [d]
	EN 60332–1-2	*H* ≤ 425 mm	
D_{ca}	EN 50399 (20,5 kW flame source) and	THR_{1200s} ≤ 70 MJ; *and* *Peak HRR* ≤ 400 kW; *and* *FIGRA* ≤ 1 300 Ws^{-1}	Smoke production [b, f] and Flaming droplets/particles [c] and Acidity [d]
	EN 60332–1-2	*H* ≤ 425 mm	
E_{ca}	EN 60332–1-2	*H* ≤ 425 mm	/
F_{ca}	EN 60332–1-2	*H* > 425 mm	/

3 CPR and additional classification for acidity

Standards for acidity classification	CPR	Heating regime	Smoke acidity assessment
EN 60754-1	NO	Heating ramp up to 800°C in 40 min and further 20 min in isothermal conditions at 800°C +/- 10°C	Titration to determine the mg of hydrogen halide per gram of compound
EN 60754-2	**YES**	Isothermal condition at 935 – 965 °C	pH and Conductivity measurements
EN 60754-3	NO	Isothermal condition at 935 – 965 °C	Ion chromatography



EN 60754-2

The classes of smoke acidity are the following:

- Class a1: pH > 4.3, Conductivity [µS/mm] < 2.5
- Class a2: pH > 4.3, Conductivity [µS/mm] < 10
- Class a3: pH ≤ 4.3, Conductivity [µS/mm] ≥ 10

3 CPR and additional classification for acidity

Types of cables for various locations: suggested in Italy

Locations/ Places	Type	Fire Risk
Railways, maritime stations, subways, airport terminals, tunnels, garages	Infrastructures	High
Hospitals, nursing homes, rehabilitation facilities, assisted residences for elderly and disabled	Health	Medium
Cinema, Theatres, discos, sport centers, museums, libraries, shopping centers	Entertainment	Medium
Schools, buildings of every order and degree	Schools	Medium
Hotels, motels, guesthouses, tourist villages, student accommodations, holiday farms, bad &breakfast	Hotels and accommodations	Medium
Residentials, commercials > 24 m	High buildings	Medium
Residential, commercial, industrial buildings < 24 m, bars, restaurants, shops	Others	Low
Other locations with no fire risk	Others	Low

3 CPR and additional classification for acidity

Low acidity PVC cables with EN 60754-2

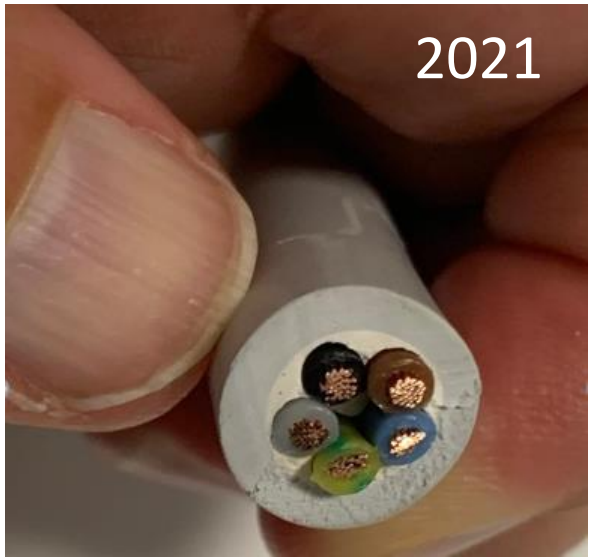
Locations/ Places	Type	Fire Risk	Additional classification for acidity
Railways, maritime stations, subways, airport terminals, tunnels, garages	Infrastructures	High	a1

FG16OR16 5 X 1,5, cable manufactured according to CEI UNEL 35318 in 2019

Cables Group Italy has **developed more than 100 new compounds** different in terms of fire performance, however the additional classification for acidity is still a_3

$$C_{ca}\ s_1\ d_0\ a_3$$

$$B_{2ca}\ s_1\ d_0\ a_3$$



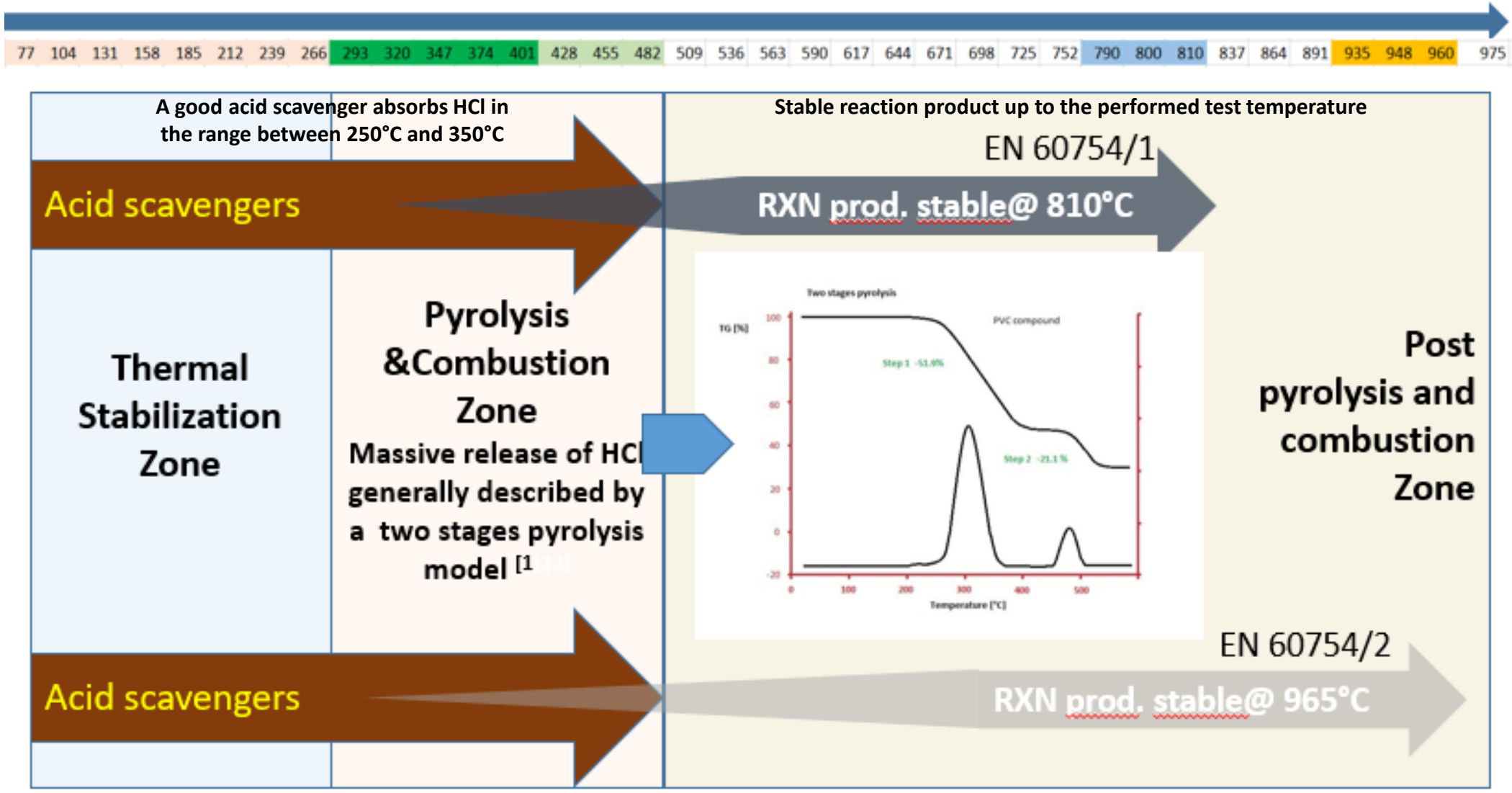
FG16OR16 5 X 1,5, cable manufactured according to CEI UNEL 35318 in 2021

EN 60754-2: WV	Value	Class	Req. a2	Req. a1
pH	**3,77**	a_3	> 4,3	> 4,3
Conductivity [µS/mm]	**16,3**	a_3	< 10	< 2,5

EN 60754-2: WV	Value	Class	Req. a2	Req. a1
pH	**3,80**	a_3	> 4,3	> 4,3
Conductivity [µS/mm]	**13,6**	a_3	< 10	< 2,5

4 The chemistry of acid scavenging

Mechanism of action of acid scavengers



Typical behaviour of an acid scavenger

4 The chemistry of acid scavenging

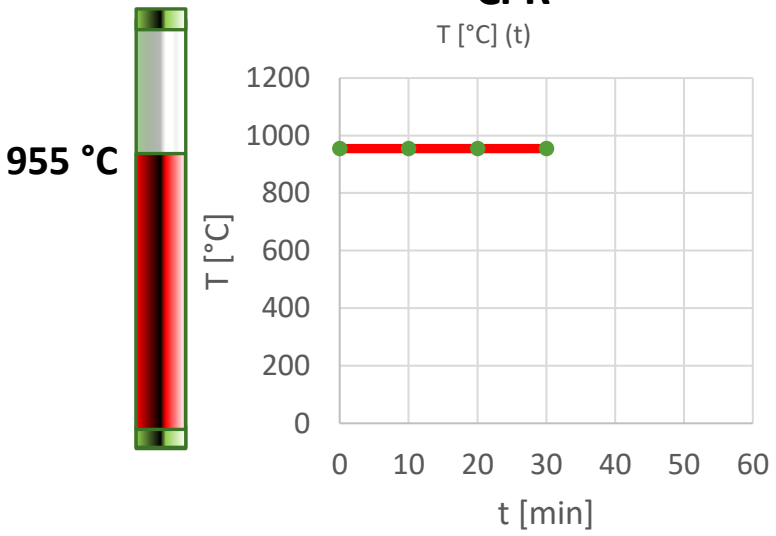
What is the impact of different heating regimes on smoke acidity evaluation?

- **Hirschler 1987** [9]

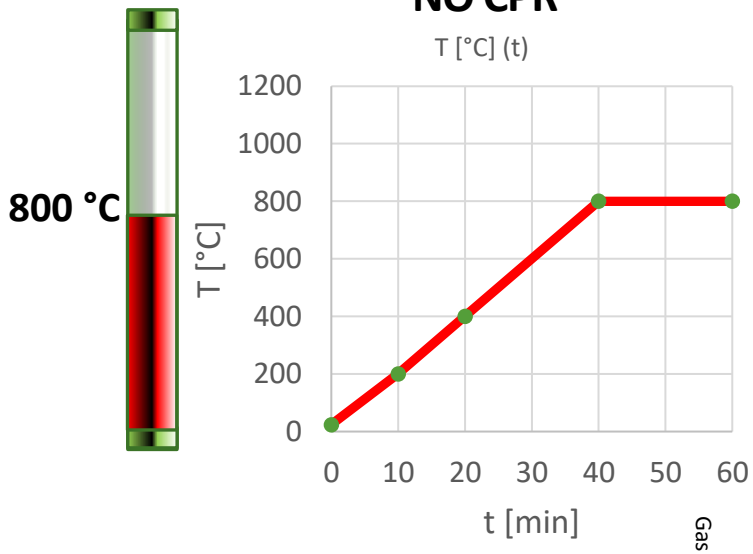
- "It is clear that, **the higher the temperature** at which the tube furnace test is carried out, **the higher the HCl emission** will be

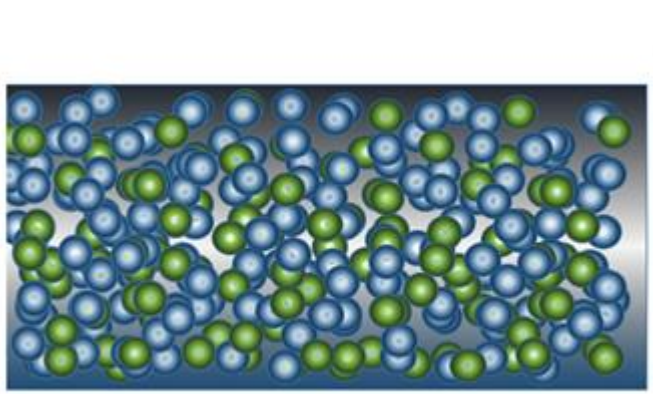
- "On the one hand, **the lower efficiency, during isothermal runs than during gradual heating run** (…), **indicates that there is** a much **greater likelihood of HCl being emitted before it has had the opportunity of reacting with the filler**" (i.e. a ramp gives more time to acid scavenger to do his job)

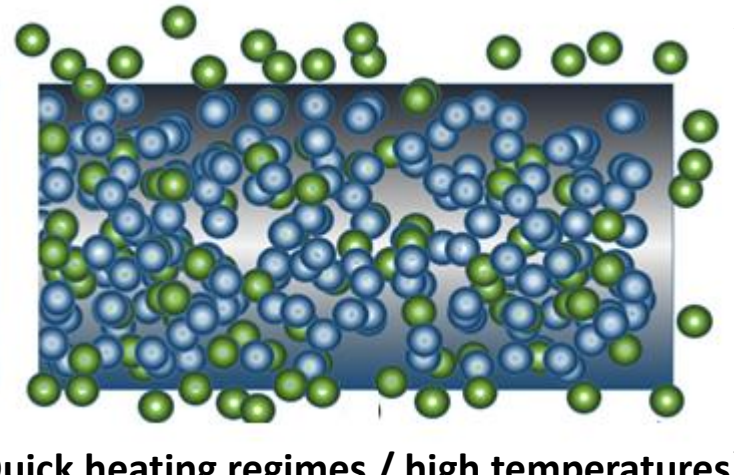
EN 60754-2 isothermal
CPR



EN 60754-1 heating regime
NO CPR







Slow heating / lower temperatures

Quick heating regimes / high temperatures

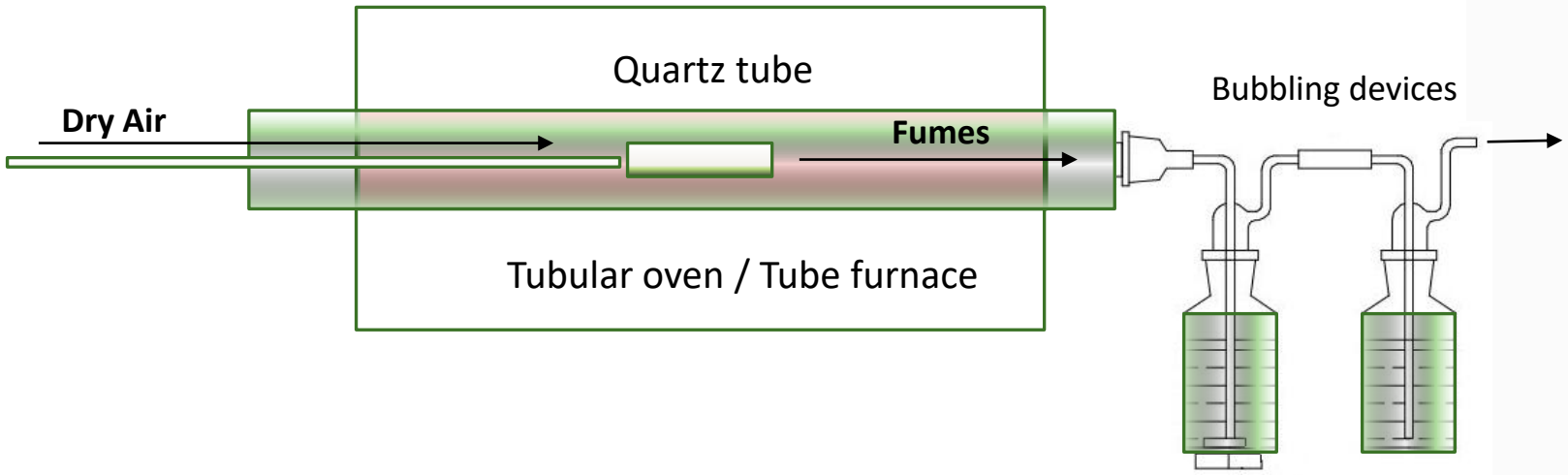
EXPERIMENTAL

A series of experiments were performed applying the EN 60754-2 comparing the heating regime of EN 60754-2 to the heating regime of EN 60754-1

The following data have been produced by:

- **Istituto Giordano;**
- **Iacopo Bassi (Master Thesis University of Bologna);**
- **I-Pool;**
- **Reagens S.p.A.**

5 EN 60754-2 vs. EN 60754-2 with the heating regime of EN 60754-1



EN 60754-2

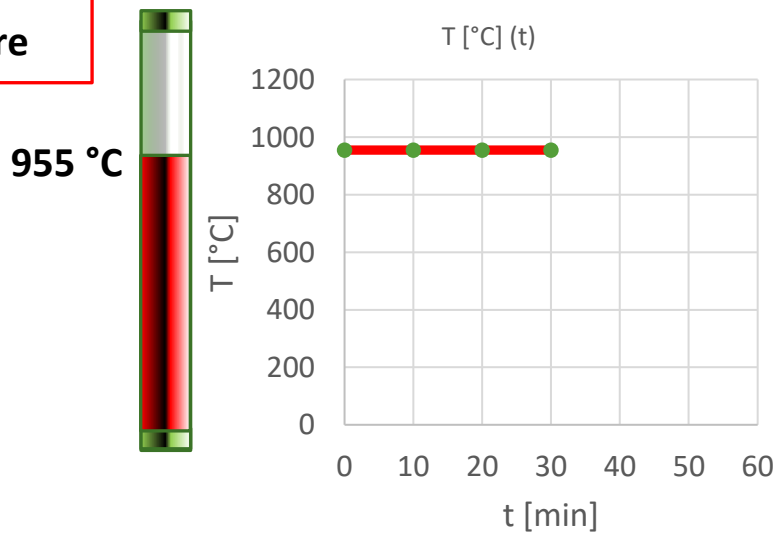
Smoke acidity assessment by pH and conductivity measurements.

The classes of smoke acidity are the following:

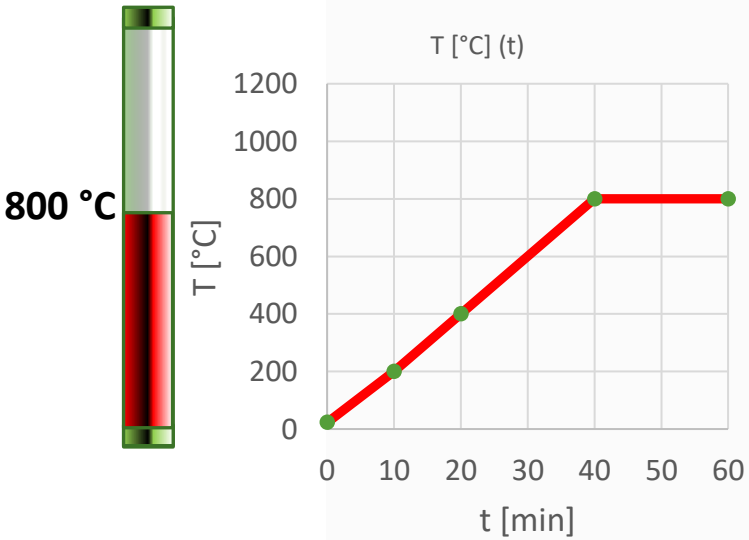
- **Class a1: pH > 4.3, Conductivity [µS/mm] < 2.5**
- **Class a2: pH > 4.3, Conductivity [µS/mm] < 10**
- **Class a3: pH ≤ 4.3, Conductivity [µS/mm] ≥ 10**

- **Isothermal**
- **Higher temperature**

EN 60754-2 isothermal CPR



EN 60754-1 heating regime NO CPR



- **Heating regime**
- **Lower final temperature**

5 EN 60754-2 vs. EN 60754-2 with the heating regime of EN 60754-1

Low smoke acidity compounds for cables

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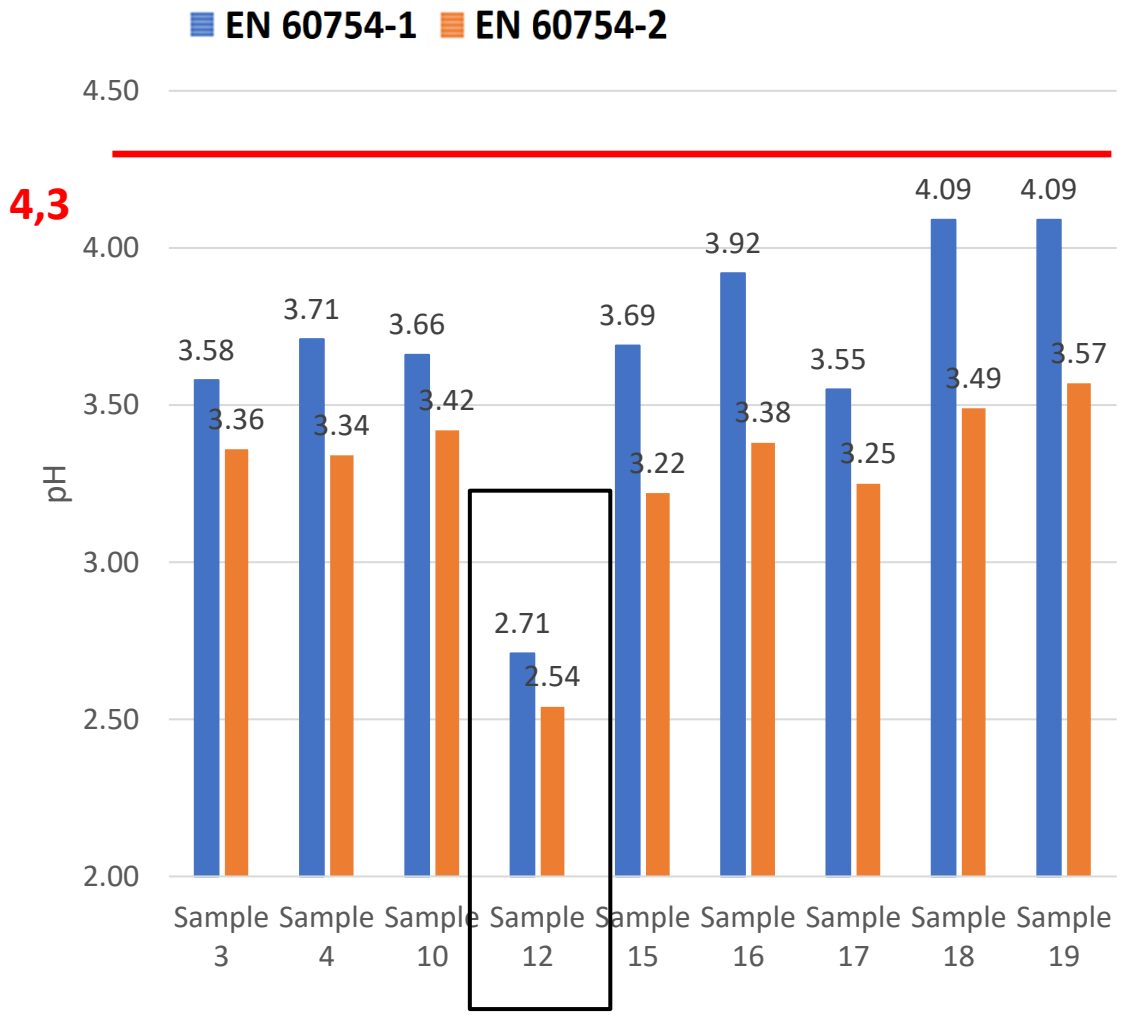
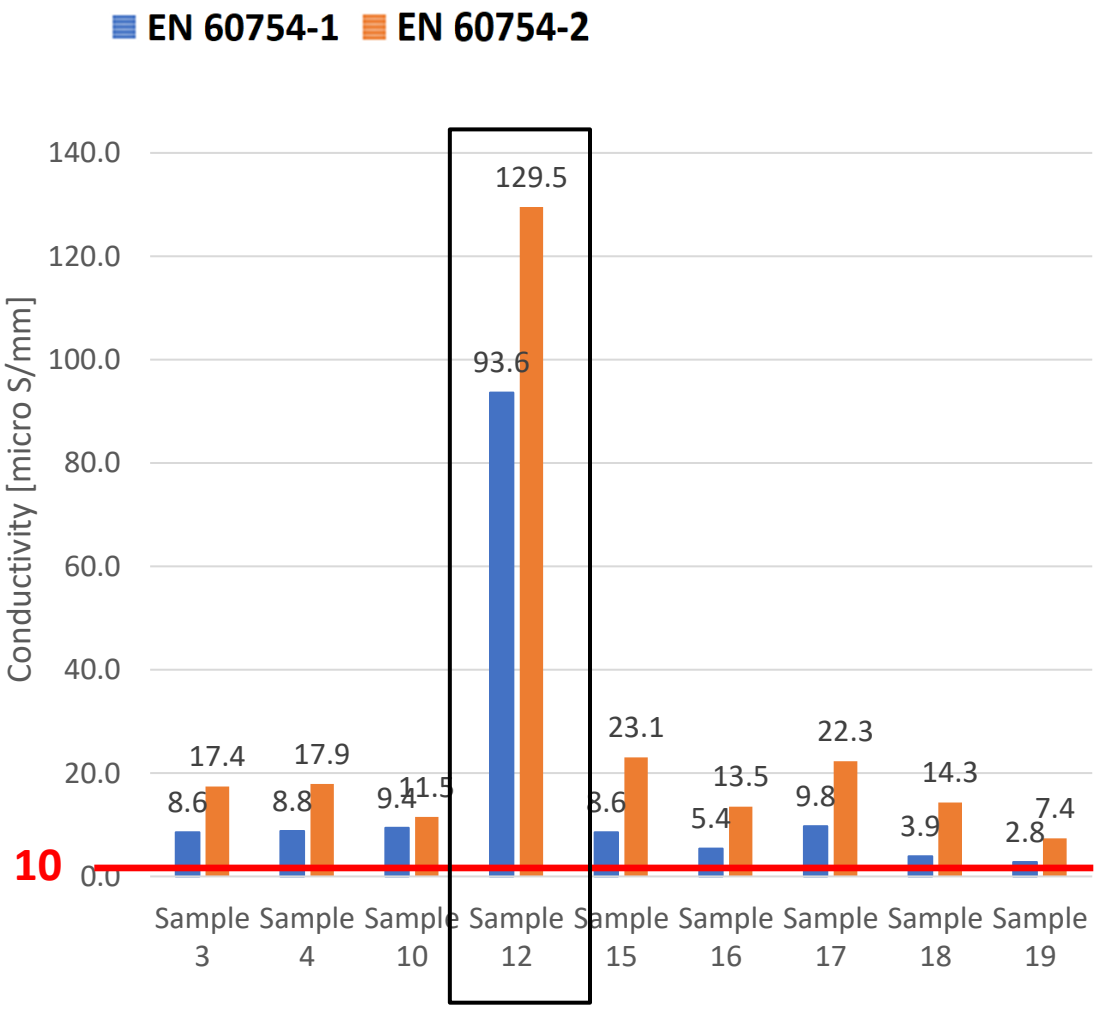
Istituto Giordano: data 2019 [10]





5 EN 60754-2 vs. EN 60754-2 with the heating regime of EN 60754-1

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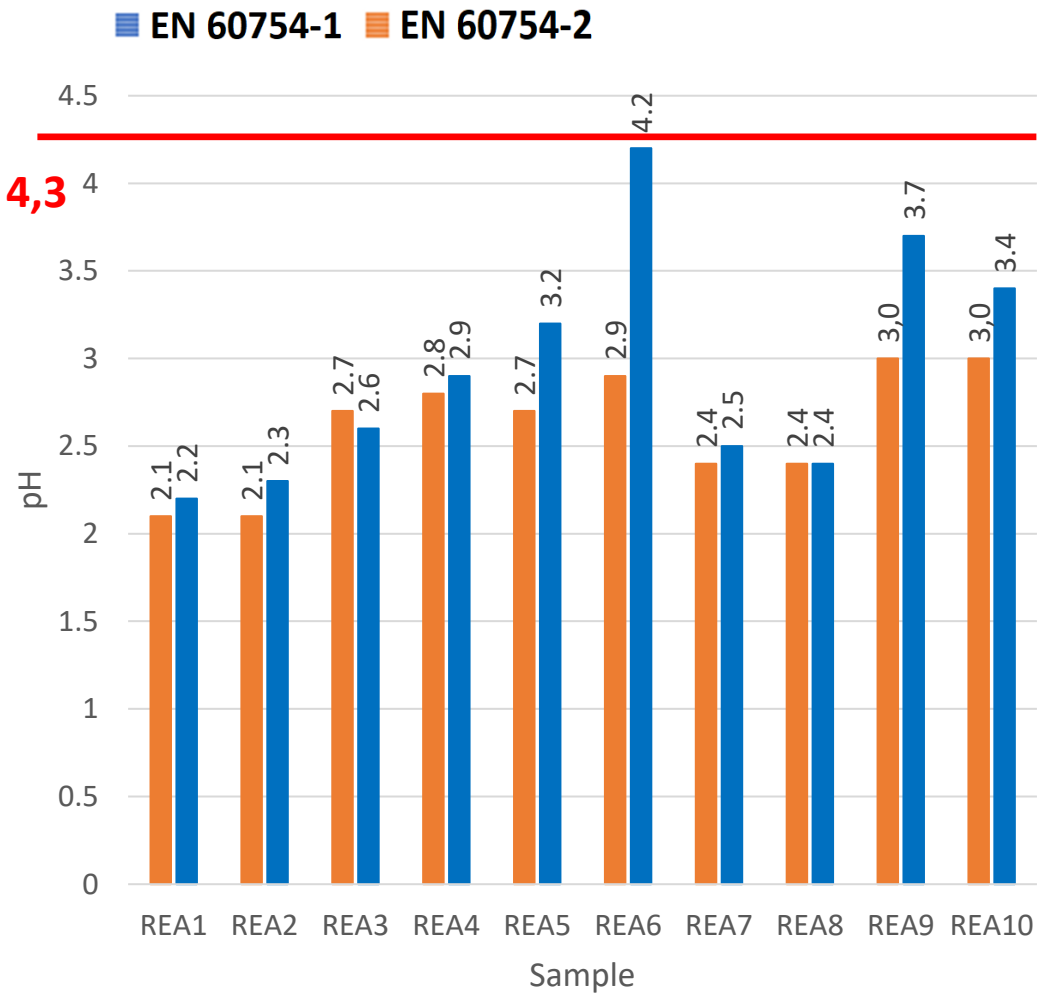
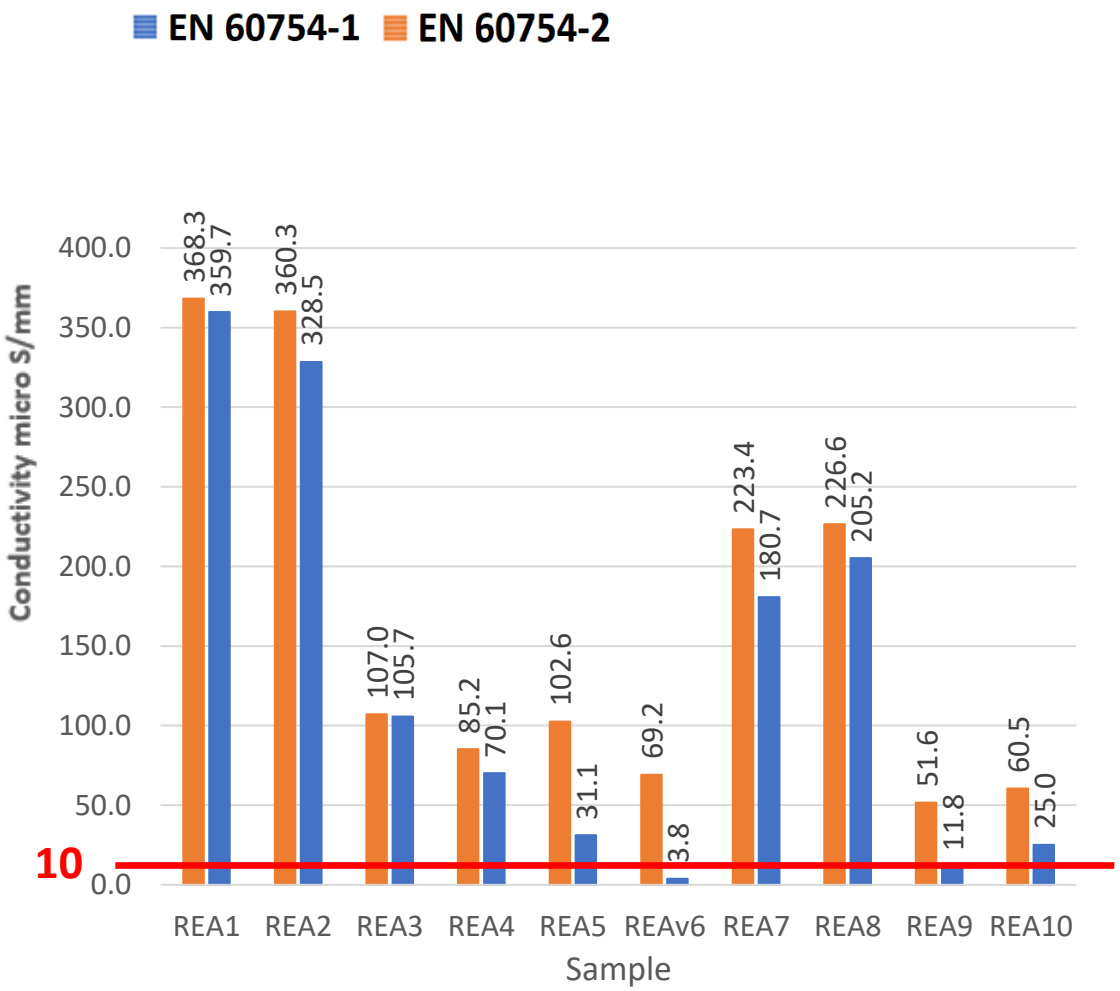
Iacopo Bassi: data 2021 [11]





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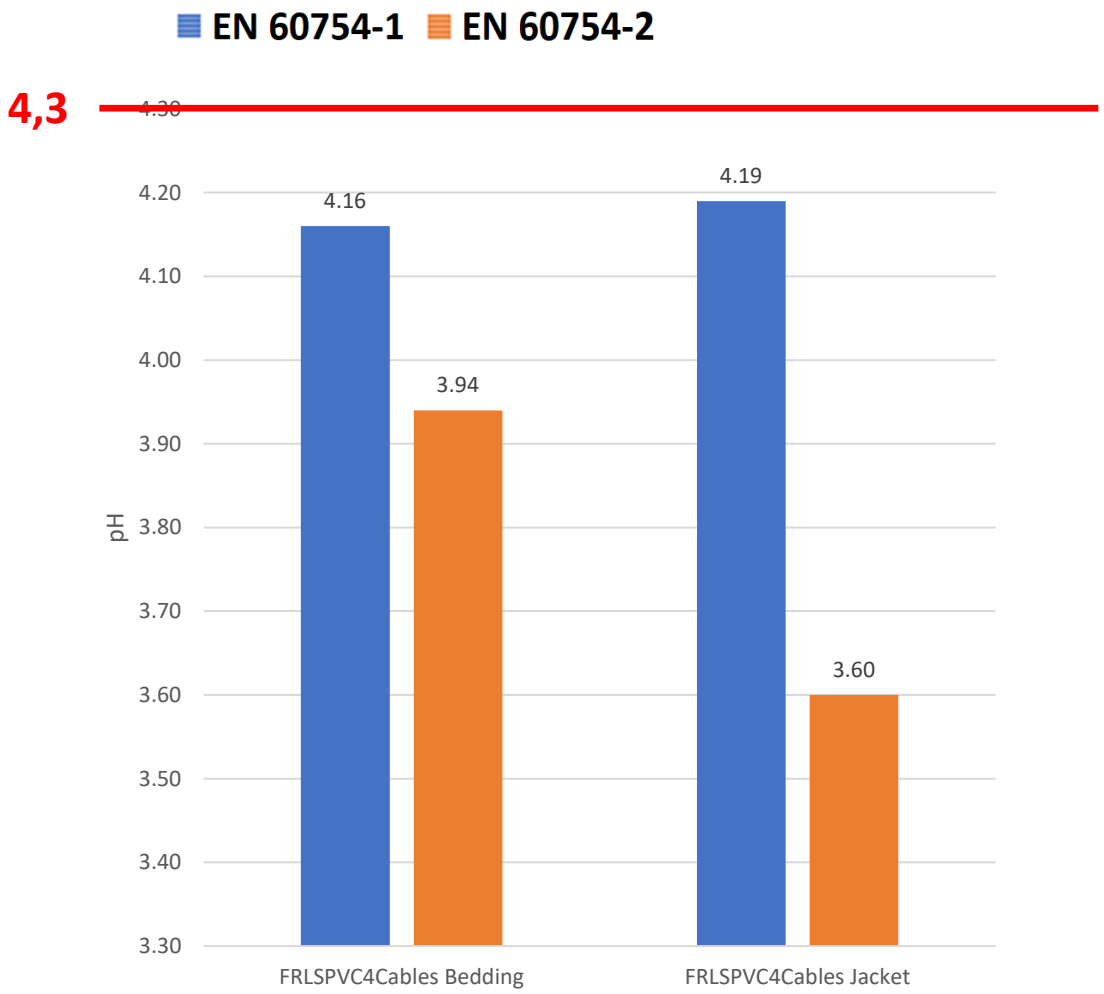
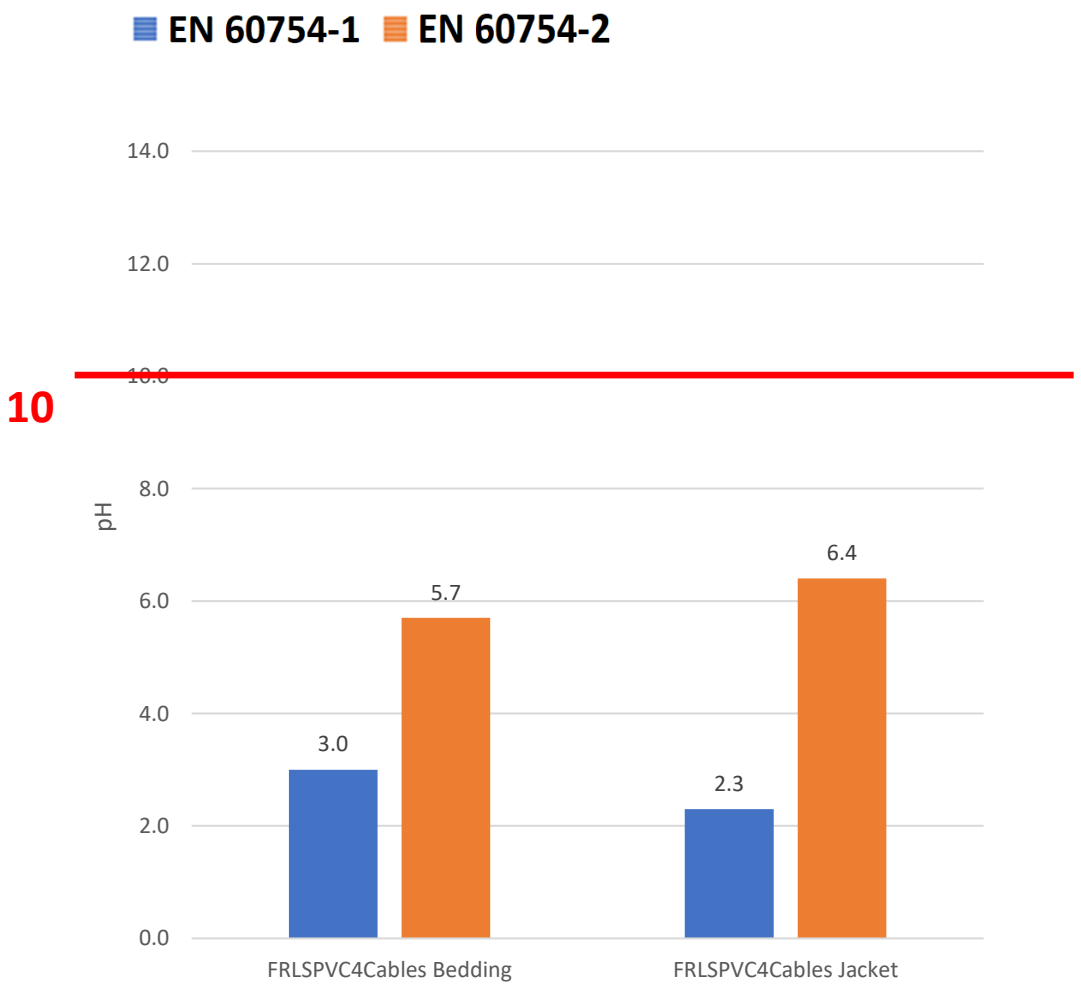
I – Pool: data 2022 [12]





[*] Report PVC4cables 19-02-2022 - Unpublished

5 EN 60754-2 vs. EN 60754-2 with the heating regime of EN 60754-1

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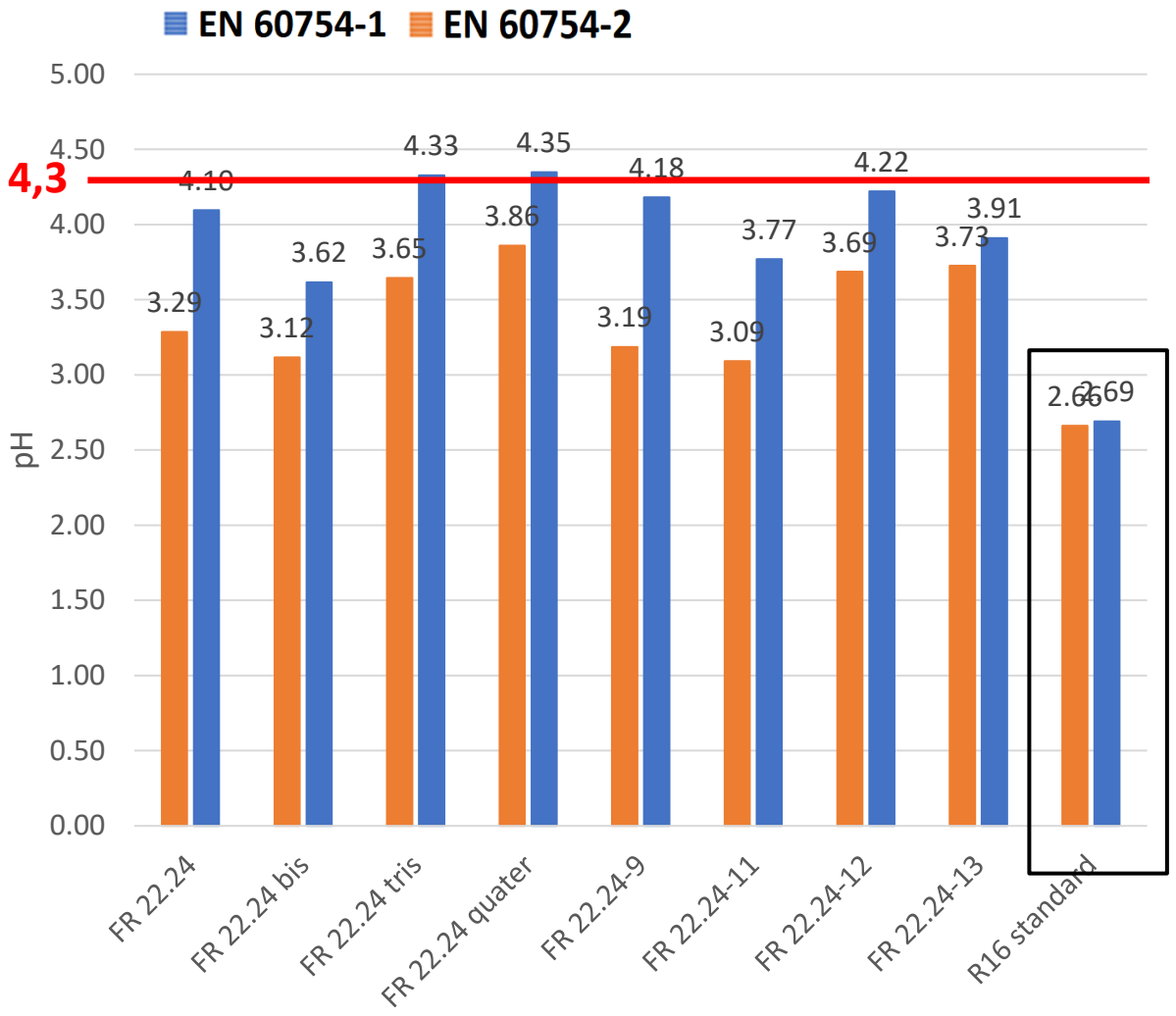
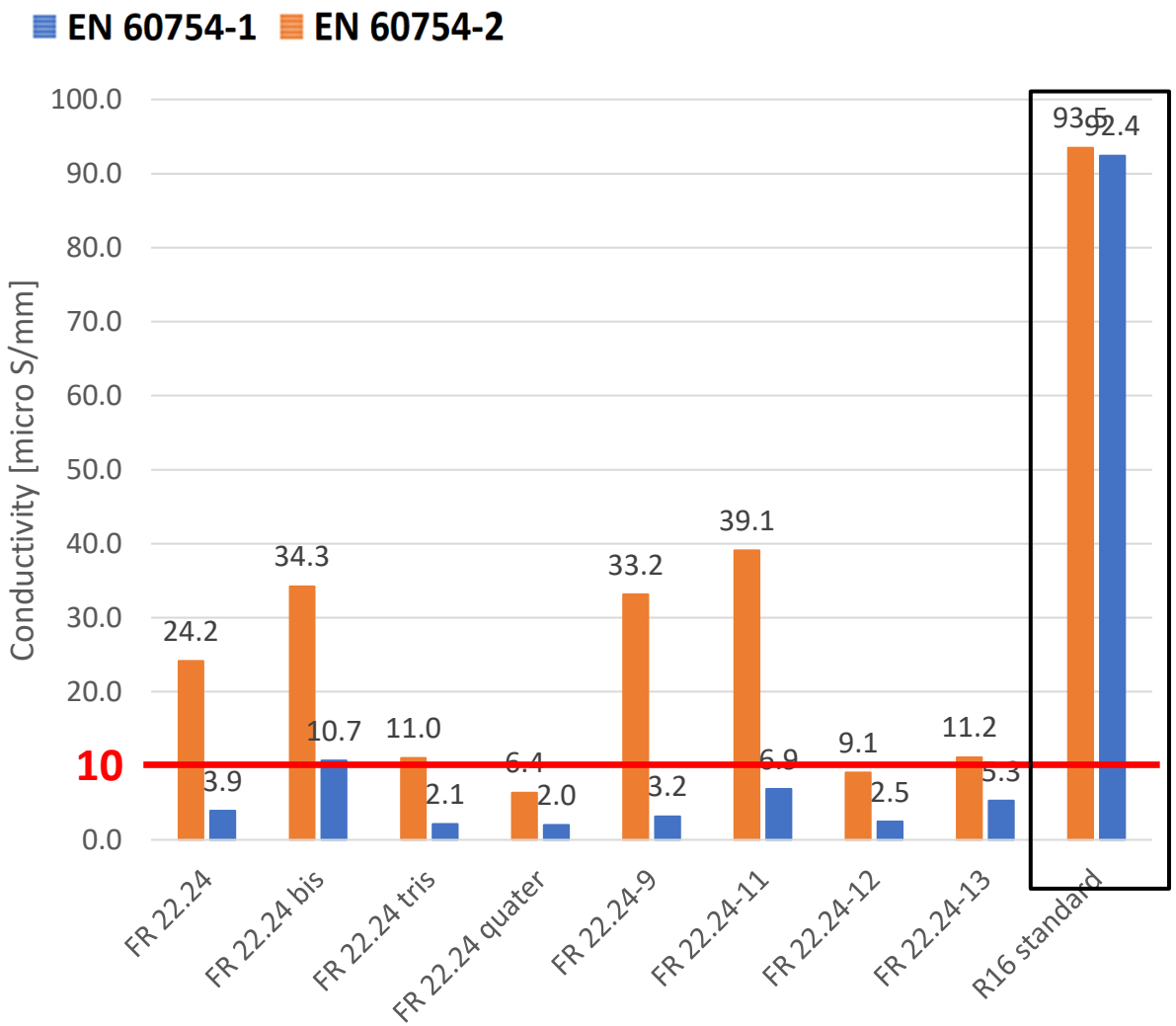
Reagens: data 2022 [13]





[*] Unpublished data

5 EN 60754-2 vs. EN 60754-2 with the heating regime of EN 60754-1

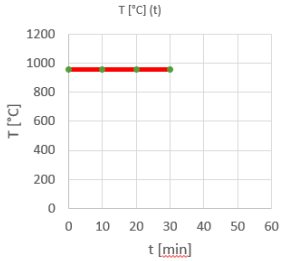
Low smoke acidity PVC cables

B_{2ca} s_{1a} d_1 a_1 **Typical Cable class for high fire risk**

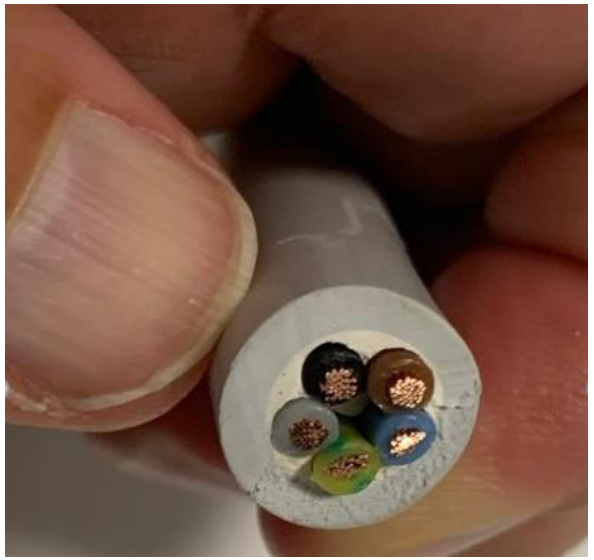
Picture 6: FG16OR16 5 X 1,5, cable manufactured according to CEI UNEL 35318 in 2019.

EN 60754-2
(thermal profile)

C_{ca} s_1 d_0 a_3



B_{2ca} s_1 d_0 a_3



Picture 7: FG16OR16 5 X 1,5, cable manufactured according to CEI UNEL 35318 in 2021.

EN 60754-2: WV	Value	Class	Req. a2	Req. a1
pH	**3,77**	a_3	> 4,3	> 4,3
Conductivity [µS/mm]	**16,3**	a_3	< 10	< 2,5

EN 60754-2: WV	Value	Class	Req. a2	Req. a1
pH	**3,80**	a_3	> 4,3	> 4,3
Conductivity [µS/mm]	**13,6**	a_3	< 10	< 2,5

5 EN 60754-2 vs. EN 60754-2 with the heating regime of EN 60754-1

Low smoke acidity PVC cables

$B_{2ca}\ s_{1a}\ d_1\ a_1$ **Typical Cable class for high fire risk**

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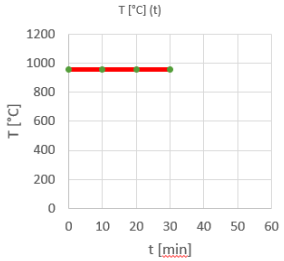
EN 60754-2
(thermal profile)

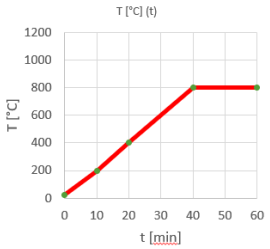
$C_{ca}\ s_1\ d_0\ a_3$



$B_{2ca}\ s_1\ d_0\ a_3$

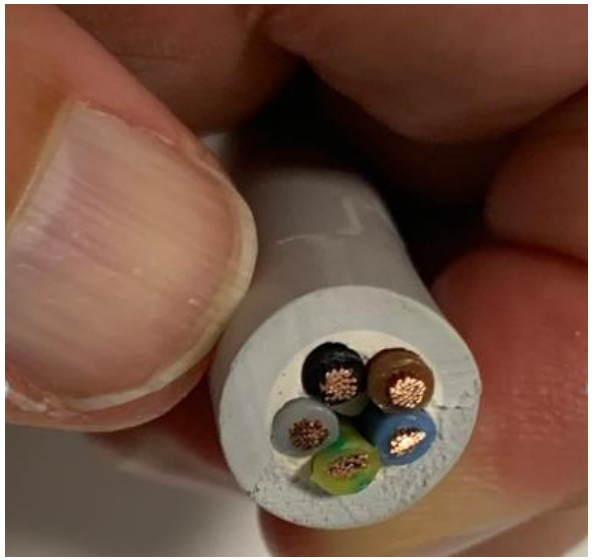
EN 60754-1
(thermal profile)

$C_{ca}\ s_1\ d_0\ a_2$



$B_{2ca}\ s_1\ d_0\ a_2$

Almost a_1



FG16OR16 5 X 1,5, cable manufactured according to CEI UNEL 35318 in 2021.

EN 60754-2: WV	Value	Class	Req. a2	Req. a1
pH	**3,77**	a_3	> 4,3	> 4,3
Conductivity [µS/mm]	**16,3**	a_3	< 10	< 2,5

EN 60754-1: WV	Value	Class	Req. a2	Req. a1
pH	**4,36**	a_2	> 4,3	> 4,3
Conductivity [µS/mm]	**7,4**	a_2	< 10	< 2,5

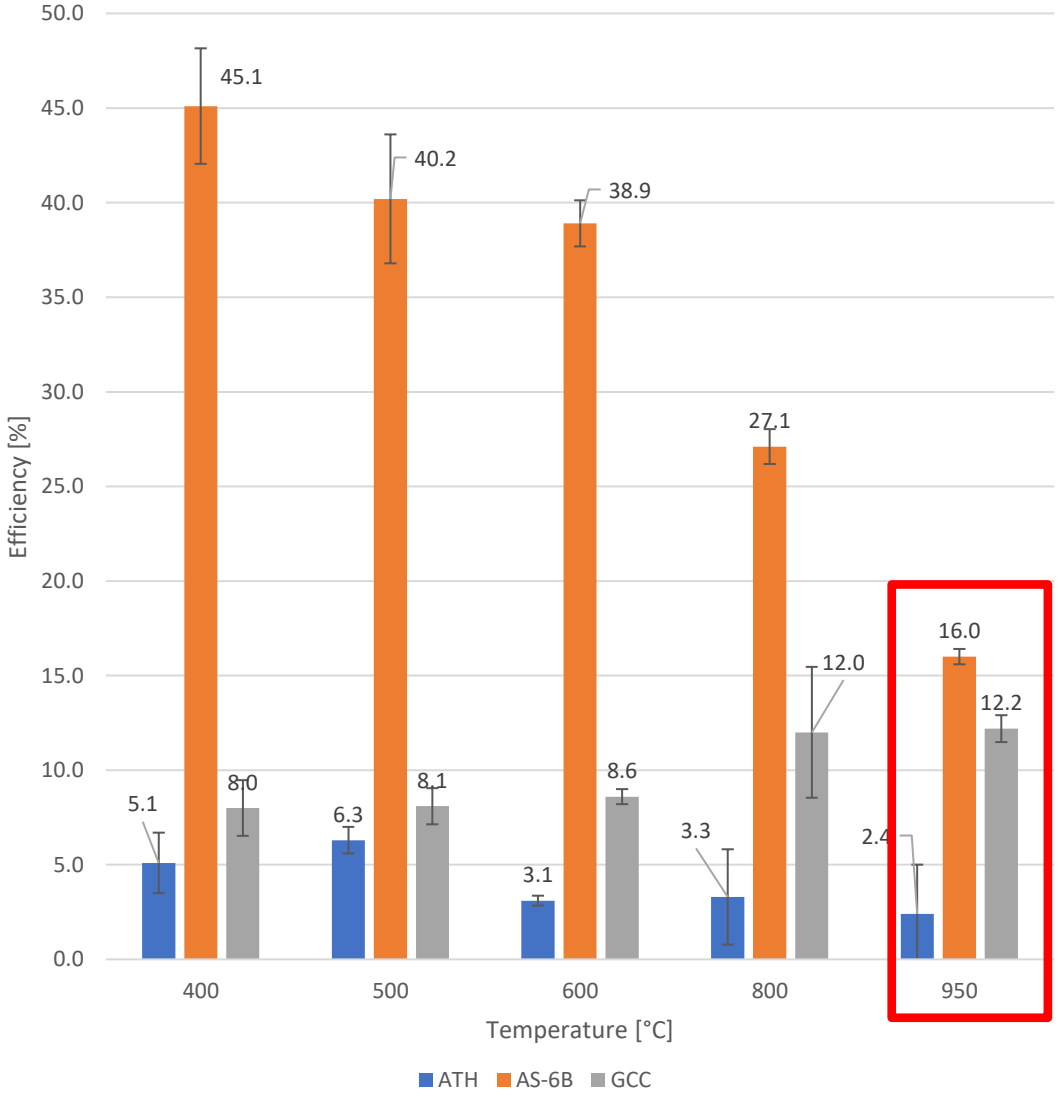
EN 60754-2: WV	Value	Class	Req. a2	Req. a1
pH	**3,80**	a_3	> 4,3	> 4,3
Conductivity [µS/mm]	**13,6**	a_3	< 10	< 2,5

EN 60754-1: WV	Value	Class	Req. a2	Req. a1
pH	**4,44**	a_2	> 4,3	> 4,3
Conductivity [µS/mm]	**2,8**	a_2	< 10	< 2,5

6 EN 60754-2 in the context of fire compartment

Reagens: data 2020 – 2022 [14,15]

Raw Materials	F50.0 [phr]	F50.1 [phr]	F50.5 [phr]
PVC	100	100	100
DINP	50	50	50
ESBO	2	2	2
Antioxidant	0.1	0.1	0.1
Stabilizer	3	3	3
$CaCO_3$	90	-	-
ATH	-	90	-
AS-6B	-	-	90

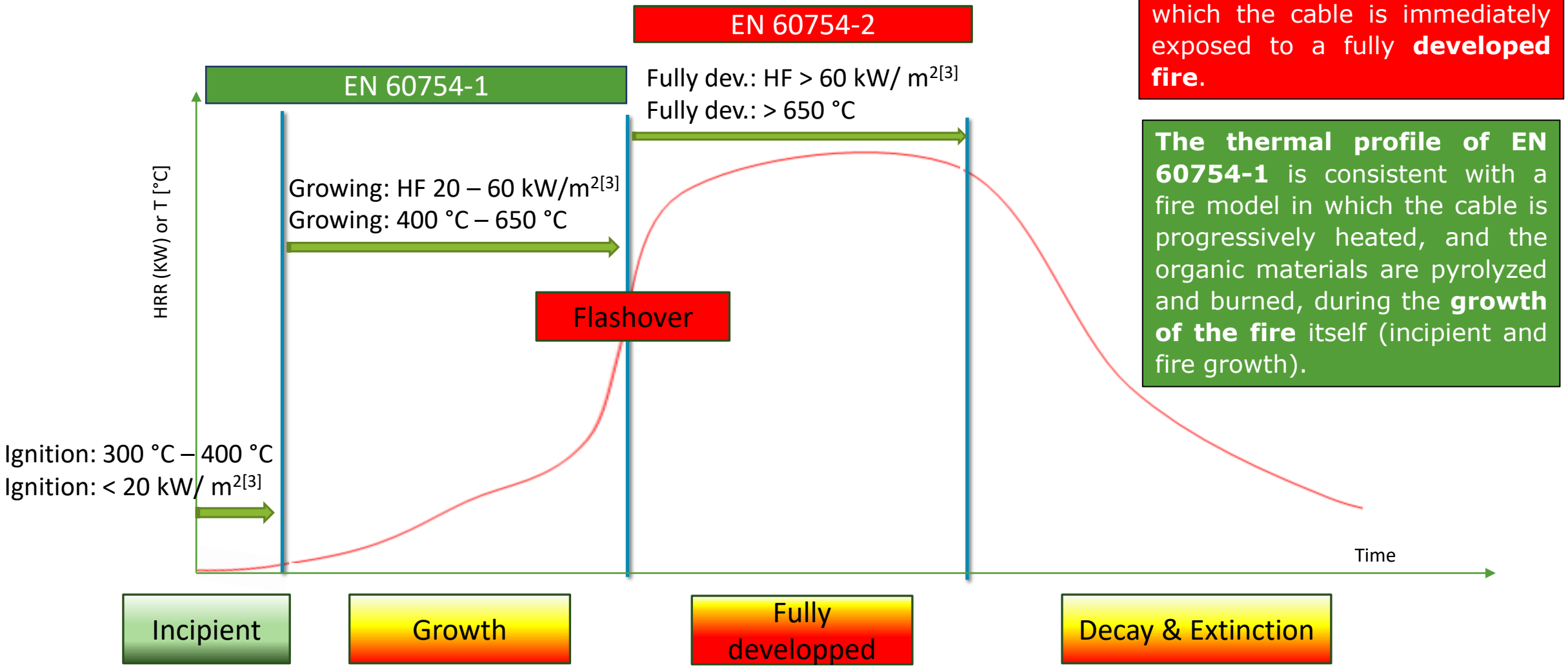


6 EN 60754-2 in the context of fire compartment

In a fire temperature increases with time!

The isothermal condition in EN 60754-2 (T 935-965°C) is consistent with a fire model in which the cable is immediately exposed to a fully **developed fire**.

The thermal profile of EN 60754-1 is consistent with a fire model in which the cable is progressively heated, and the organic materials are pyrolyzed and burned, during the **growth of the fire** itself (incipient and fire growth).



Dynamic of a fire compartment

7 SUMMING UP

- Most **people die** because small, controllable **fires become too big** and, as a consequence**, smoke inhalation** is the **main cause of death;**

- CO is considered to be the real killer in a fire, whereas the **smoke acidity** is seen by most researchers as a **secondary and ancillary parameter** in fire safety.

- **The heating regime of EN 60754-1** matches **better** the **temperatures of the growing stage of a fire**, therefore is **more suitable** for **measuring** the **smoke acidity** and giving to **designers** the chance **to properly evaluate the materials** in terms of fire performance;

- Therefore**, EN 60754-2** should **be updated** with the **introduction** of a **heating regime.**

- The companies belonging to **Cable Group Italy**, thanks to the research on smoke acidity, **can produce PVC cables** with very low emission of acidic smokes.

Thank you for your attention

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Il PVC Forum Italia (www.pvcforum.it) è l'associazione italiana che riunisce le principali aziende di produzione, compoundazione e trasformazione del PVC, i produttori di additivi e di macchine trasformatrici. Con sede a Milano, il PVC Forum è parte del Network europeo dei PVC forum collegati a ECVM (European Council of Vinyl Manufacturers), l'associazione europea dei produttori di PVC, a sua volta divisione dell'associazione dei produttori europei di materie plastiche (PlasticsEurope).

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www.pvc4cables.org

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