

New Generation PVC compounds for cables and safety in case of fire

F. Delchiaro¹, C. Bandinelli¹, I. Bassi¹, M. Piana² and G. Sarti^{1,*}

¹ PVC4Cables, Avenue de Cortenbergh 71, B-1000, Brussels

² PVC Forum Italia, Via Giovanni da Procida, 11, 20149 Milano MI

*gianluca.sarti@fastwebnet.it

Abstract. In public opinion and among the "recognized" experts in the field, there has always been a persistent perception that PVC cables are inherently more "toxic" and less "safe" than their halogen-free counterparts. That perception, rooted mainly in misconceptions and non-scientific data, focuses on the smoke production, toxicity, and acidity of effluents resulting from the combustion of PVC cables. This paper works primarily to confute such false impressions and highlights that acidity is a secondary parameter in fire safety, with carbon monoxide emerging as the leading threat in the effluents produced during a fire. In fact, controlling various parameters, particularly heat release, proves to be the most effective strategy in preventing a minor fire from escalating and causing fatalities, injuries, production halts, property and heritage damage, and environmental impacts. The study also reveals that the smoke production of PVC cables can be significantly mitigated, almost aligning with halogen-free cables, through the strategic use of appropriate flame retardants and smoke suppressants.

Furthermore, this research comprehensively reviews the thermal decomposition and combustion mechanisms of PVC compounds to elucidate the requisite characteristics of flame retardants, smoke suppressants, and specifically acid scavengers at high temperatures, which effectively scavenge hydrogen chloride, lowering the smoke acidity. Finally, the discussion extends to EN 60754-2, the standard employed in the Construction Products Regulation (CPR) to assess indirectly the acidity. Detailed scrutiny reveals the profound impact of varying temperatures and heating regimes on hydrogen chloride emissions in the gas phase, casting doubt on the reliability of EN 60754-2 as a tool for assessing acidity in real fire scenarios.

Introduction

1.1 Fire safety background

Within the fire safety assessment framework, the fire safety objectives are the safety of life, the conservation of specific and adjacent properties, the continuity of business operations, the protection of the environment, and the preservation of heritage. [1] In this context, in addition to the active fire protection and emergency measures, the amount and kind of materials in the fire scenario play a crucial role in fire safety. In fact, item fire performances such as ignitability, flammability, flame spread, heat release, smoke production, and toxicity of its effluents can reduce the fire hazard and casualties in case of fire. Among these parameters, the evaluation of heat release from the article plays a strategic role in understanding if a small fire can become too big to be easily controlled, preventing casualties and damages. In fact, if not well controlled, the fire can impede people from safely escaping the fire scenario and, extending beyond the place of origin, it can involve more locations and people. [2] That is why flame retardants are the essential additives to delay the flashover, the point of no return in a fire (characterized by temperature spanning between 600 – 650 °C), and, therefore, the fully developed stage of a fire. Furthermore, smoke impedes people to escape unharmed from the fire scenario or to be rescued by firefighters. Hence, the smoke production from articles is another crucial parameter to be evaluated, and it can be reduced thanks to the use of smoke suppressants. Some of them are so effective that a new generation of PVC compounds for cables recently developed are even capable of meeting one of the best additional classifications for smoke production (s1b), [3] debunking the myth that PVC releases always black and dense smoke and therefore its use can be a risk in case of fire. Contrary to heat release and smoke production, the nature and quantity of toxic substances in smoke modestly depend on the kind of materials in fires. Before the flashover, narcoleptic substances mainly drive tenability, and even in this context, carbon monoxide (CO) is the main cause of the toxicity of effluents. [1,2] After the flashover, CO becomes the "big toxic killer in smoke," [2] and considering that CO is released from all polymers in the same quantity (20 % of their weight), there is no polymer more toxic

than others in the context of fire. [2] Therefore, dying of toxicity is mainly a consequence of the failure of the fire safety assessment in terms of heat release and in terms of smoke production. In this perspective, the evaluation of the acidity is a non-sense from the point of view of fire safety. For instance, the hydrogen chloride (HCl) from the combustion of PVC items decays quickly (low concentration in the gas phase) and does not travel far from the location where it originates (low mobility). On the contrary, CO reaches the lethal concentration quickly, before other intoxicants do, spreading fast everywhere. [4]

1.2 PVC thermal decomposition and combustion of PVC compounds: a review

The thermal decomposition stages of PVC and PVC compounds are well described in the Refs. [5-6-7-8-9] The thermal decomposition is defined in Ref. [10]. In summary, when a PVC compound is exposed to temperatures over 220°C, additives commonly found in PVC compounds start decomposing, and furthermore, the kinetic of the evolution of HCl is so fast that one-pack stabilizer in the compound cannot withstand the zip elimination. This causes a massive release of HCl, ending the chemical nature of the PVC compound in a crosslinked black mass. It is well accepted by the scientific community that the stages of thermal decomposition of PVC resin are two. [8] The first is between 220 °C and 360°C where zip elimination yields HCl and polyene sequences, and then polyene sequences can arrange themselves intramolecularly, giving not substituted aromatic hydrocarbon, mainly benzene, competing with intermolecular reactions bringing a crosslinked matrix. The second stage starts around 450 °C, where the crosslinked matrix decomposes partially liberating mainly aliphatic moieties fuels and a char residue. The presence of additives in the compound and oxygen complicates the decomposition pattern. For example, di iso nonyl phthalate (DINP) evaporates around 250°C, enriching the gas phase of flammable fuels, while aluminum trihydroxide (ATH) starts decomposing at around 200 °C, yielding alumina and water. CaCO₃ reacts with HCl, releasing CO₂, and its unreacted quote decarbonates around 850 °C, depending on its particle size. Knowing the decomposition pattern in nitrogen through hyphenated techniques such as TGA-FTIR permits us to understand what can happen in the gas and condensed phase and which additives we can add to a flame-retardant package to improve fire performances, reduce fuels, acidic (HCl) and toxic gases (CO and HCN).

The combustion of PVC compound can be studied by means of the Cone Calorimeter (CC) and the Micro Combustion Calorimeter (MCC), which are powerful tools for measuring parameters through which we can understand the fire behavior of the article. Among them, Fire Growth Rate (FIGRA) and Smoke Growth Rate (SMOGRA) in CC and Fire Growth Capacity (FGC) in MCC are the parameters that "measure" the propensity of the article to withstand or not the fire growth or the smoke production in a real fire scenario. In CC then, incidental heat fluxes are carefully chosen between 20 kW/m² up to 50 kW/m², corresponding to temperatures before the flashover; [11][12][13][14] in this way, we can verify the performances of the flame retardants and smoke suppressants in those conditions when people can escape unharmed from fire scenario. The aim is, actually, to see if, at those temperatures, the flame retardants in the article are performant enough to generate a low FIGRA and, therefore, if they bring less contribution to the growth of the fire. In the same way, at the same temperatures, the propensity of the smoke generations from the article can be evaluated through SMOGRA. Testing flame retardants at the typical temperatures of a fully developed fire is useless in fire safety. In the same way, people who consider the acidity of the effluents a key parameter in fire safety, and the authors of this paper are not part of that perspective, should reflect on the existence of standards for assessing the acidity which involves temperatures above the flashover temperatures (up to 965 °C), conditions where HCl is the minor problem and heat and CO are the primary driver of fatalities and casualties. [2][4]

1.3 The Regulatory Context and Test Methods for Assessing the Acidity

Regulation (EU) No 305/2011 establishes the regulatory framework of building and construction works, commonly known as the Construction Products Regulation (CPR). This regulation establishes harmonized rules for assessing the compliance of items permanently installed in residential and public buildings, considering their impact on the environment, as well as the health and safety of people. [15] Safety in the event of a fire is identified as one of the fundamental requirements for construction works under CPR.

In this context, a harmonized classification system has been adopted concerning the reaction to fire and additional classifications for smoke production, flaming droplets, and acidity. [16] Notably, items such as flooring, linear insulation for pipes, panels, and wall coverings, commonly found in buildings, are exempt from tests and requirements assessing the release of acidic gases in the event of a fire. [16] However, cables stand out as the sole building and construction products, necessitating an additional classification for acidity. [17]

The evaluation of the reaction to fire classification of cables, along with their additional classifications, is outlined in EN 13501-6. [17] EN 60754-2, initially designed to determine corrosivity, is the technical standard for assessing acidity under CPR, with detailed methodology provided in Ref. [18]. The test involves burning 1g of the specimen in a tube furnace, collecting effluents in two bubblers with double deionized water (DDW), and measuring pH and conductivity. Weighted pH and conductivity values for the cable are calculated based on the non-metallic material per unit length of the cable, as per paragraph 8.3 of the standard. [18] Class a₁ cable requires a pH greater than 4.3 and conductivity less than 2.5 $\mu\text{S}/\text{mm}$, class a₂ requires a pH greater than 4.3 and conductivity less than 10 $\mu\text{S}/\text{mm}$, while class a₃ comprises materials that do not fall into class a₁ or a₂. On the other hand, EN 60754-1, the technical standard performed for determining the halogen content in contexts outside CPR [19] is carried out with a heating regime: 40 minutes from room temperature to 800 °C and 20 minutes in isothermal conditions at 800 °C. In EN 60754-1, temperature increases at about 20 °C/min, covering the typical temperatures of ignition and the developing stage of the fire, and after they exceed the typical flashover temperatures (600 °C – 650 °C), reaching 800 °C. It is important to note that EN 60754-2 and EN 60754-1 are conducted as bench-scale tests. They do not encompass all the variables of a real fire scenario that could influence the concentration of HCl in the gas phase.

1.4 The aim of the paper

In the context of the considerations mentioned above, a set of formulations for cables was used to perform the hyphenated technique TGA-FTIR on low smoke acidity compounds and standard grade PVC compounds for jackets to focus on the thermal decomposition pattern and the chemistry of the effluents. CC and MCC were also collected to explore the fire performances of the low smoke acidity compounds and, specifically, MCC and TGA, to understand the thermal degradation pattern of those compounds.

The paper also studied the impact on HCl concentration (actually, the acidity as an indirect assessment through pH and conductivity measurements) at temperatures over the flashover (950°C) in isothermal, over the flashover (800°C) applying a heating regime from room temperature, and below the flashover (500°C) in isothermal. The aim was to verify the impact on the acidity of the effluents changing temperatures and heating regimes.

2. Materials and methods

The formulations in Table 1 are intended to explore the fire performances and the thermal decomposition/combustion stages of PVC compounds for cables containing different acid scavengers at high temperatures acting in the condensed phase. Hyphenated techniques were also applied to some of them to verify the kind and type of effluents and the mechanism of decomposition combustion.

Table 1: Formulations FR50.0, FR50.2, FR50.5 and FR50.10. Inovyn 271 PC is a suspension PVC with a K value of 71 from Inovyn. DINP means Di Iso Nonyl Phthalate; Diplast N is the trade name of Polynt S.p.A. ESBO stands for Epoxidized Soy Bean Oil. Reaflex EP/6 is a Reagens trade name. The used antioxidant is Arenox A10, a Reagens trade name, which is Pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate), CAS number 6683-19-8. COS stands for calcium organic stabilizer. RPK B-CV/3037 is a typical stabilizer for 70 °C cables produced by Reagens. Hydrocarb 95 T is ground-milled calcium carbonates, having a stearic acid coating and with a particle size distribution (D50) of 0.7 microns. Winnofil S is a UUPCC having nanoscale mean particle size. AS-6B is a potent acid scavenger in the condensed phase at high temperatures, produced by Reagens S.p.A, having a D50 of 2.0 microns. Ecopyren 3.5 is an uncoated ground-milled MDH produced by Europiren, with a D50 of 3.0 microns.

Raw Materials	Trade Name	FR50.0 [phr]	FR50.2 [phr]	FR50.5 [phr]	FR50.10 [phr]
PVC	Inovyn 271 PC	100	100	100	100.0
DINP	Diplast N	50	50	50	50
ESBO	Reaflex EP/6	2	2	2	2
Antioxidant	Arenox A10	0.1	0.1	0.1	0.1
COS	RPK B-CV/3037	3	3	3	3
CaCO ₃	Hydrocarb 95 T	90			
Mg(OH) ₂	Ecopyren 3.5		90		90
HTAS 2	AS-6B			90	
UUPCC	Winnofil S				30

Tables 2-4 show the acidity measured performing respectively EN 60754-2 in isothermal at 950 °C, with the heating regime of EN 60754-1 and in isothermal at 500 °C. Tables 5-6 show respectively CC and LOI.

Table 2: pH and conductivity of the formulations of Table 1 obtained performing EN 60754-2 in isothermal at 950 °C

Formulation	FR50.0	FR50.2	FR50.5	FR50.10
pH	2.62	2.27	2.79	3.29
SD _{pH}	0.03	0.02	0.02	0.01
Conductivity (μS/mm)	97.3	224.3	70.1	24.2
SD _c	3.7	3.1	2.0	2.1

Table 3: pH and conductivity of the formulations of Table 1 obtained performing EN 60754-2 with the temperature regime of EN 60754-1

Formulation	FR50.0	FR50.2	FR50.5	FR50.10
pH	2.51	2.28	3.29	4.10
CV _{pH}	0.02	0.02	0.02	0.04
Conductivity (μS/mm)	135.7	228.0	22.8	3.9
CV _c	4.4	1.5	0.1	0.3

Table 4: pH and conductivity of the formulations of Table 1 obtained performing EN 60754-2 in isothermal at 500 °C

Formulation	FR50.0	FR50.2	FR50.5	FR50.10
pH	2.48	2.41	3.69	4.55
CV _{pH}	0.04	0.09	0.13	0.13
Conductivity (μS/mm)	139.1	177.3	8.6	1.2
CV _c	1.2	6.2	0.3	0.9

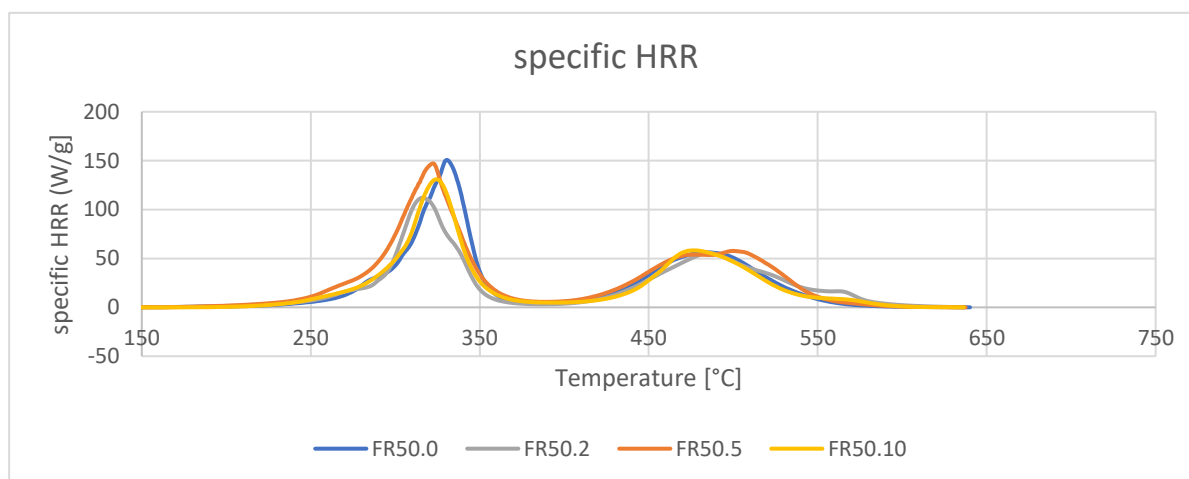
Table 5: CC data of the formulation in Table 1 performing ISO 5660

Formulation	FR50.0	FR50.2	FR50.5	FR50.10
peak HRR (kW/m ²)	192.1	167.7	394.3	254.8
SD	9.5	7.7	13.0	10.7
THR (MJ/m ²)	43.8	39.4	45.5	53.5
SD	1.7	1.9	1.3	3.3
FIGRA (W/s)	2549	1563	5110	3365
SD	458	146	503	255
TSP (m ²)	16.5	10.1	15.3	11.4
SD	1.0	1.5	0.3	0.5

Table 6: LOI data of the formulation in Table 1, performing ASTM D 2863

Formulation	FR50.0	FR50.2	FR50.5	FR50.10
LOI (O ₂ %)	28.0	34.7	23.0	24.0
SD	0.0	0.6	0.6	1.0

Figure 1 shows the specific HRR (T) graphs of formulations in Table 1, and Table 7 shows their MCC



data. Figures 2-4 the Gram-Schmidt curves and the chemigrams of the released gases, obtained following the evolution of their FTIR absorption bands as indicated in Table 8, for compounds FR 50.0, FR 50.2, and FR 50.10.

Figure 1: Specific HRR (T) of data of formulations in Table 1 performing ASTM D 7309

Table 7: MCC data of formulations in Table 1 performing ASTM D 7309.

Formulation	FR50.0	FR50.2	FR50.5	FR50.10
FGC (J/g·K)	88.90	75.81	100.51	92.83
SD	0.70	2.73	3.05	1.20
η_c (J/g·K)	330.20	323.30	322.50	333.03
SD	4.94	13.41	13.23	6.71
Qmax (J/g) stg 1	135.26	109.86	144.00	147.31
SD	0.65	2.13	4.51	2.19
Tmax (°C) stg 1	330.2	323.3	322.5	333.0
SD	0.30	2.30	6.20	0.20
Qmax (J/g) stg 2	51.36	52.62	51.97	59.49
SD	0.50	0.38	1.89	1.29
Tmax (°C) stg 2	483.5	486.8	500.6	478.8
SD	0.16	0.40	1.70	0.90

h _c (J/g) total	9.93	9.15	11.33	10.38
SD	0.12	0.10	0.16	0.08
h _c (J/g) stg 1	5.86	4.74	6.64	6.00
SD	0.08	0.09	0.21	0.06
h _c (J/g) stg 2	4.07	4.41	4.69	4.38
SD	0.16	0.11	0.11	0.10
Y _p (g/g)	0.35	0.34	0.48	0.46
SD	0.02	0.01	0.02	0.02
h _{c gas} (J/g) total	15.30	13.92	21.95	19.08
SD	0.35	0.42	1.11	0.60
h _{c gas} (J/g) stg 1	8.95	7.22	12.86	11.03
SD	0.26	0.20	0.63	0.43
h _{c gas} (J/g) stg 2	6.35	6.70	9.09	8.05
SD	0.09	0.22	0.48	0.17

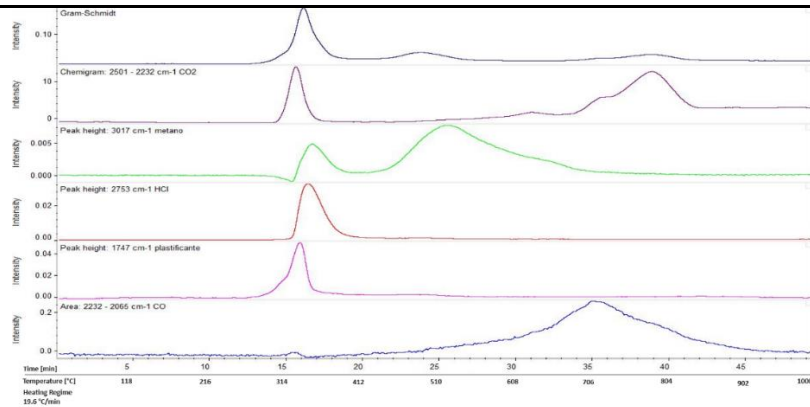


Figure 100 200 300 400 500 600 700 800 900 1000

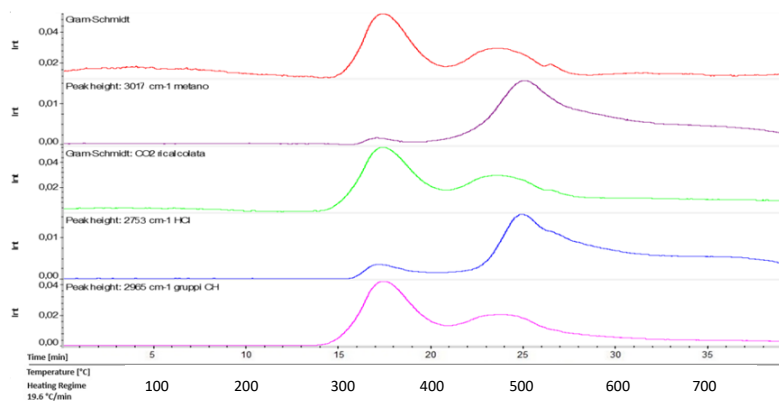


Figure 3. FR50.2 Chemigrams of the emitted gasses and Gram-Schmidt curves.

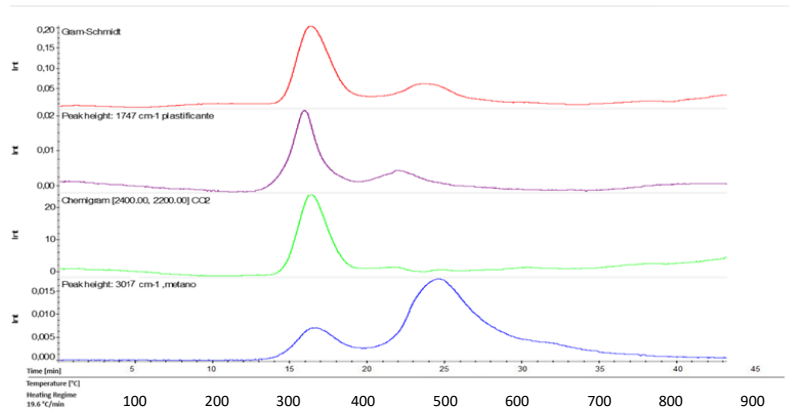


Figure 4. FR50.10 Chemigrams of the emitted gasses and Gram-Schmidt curves.

Table 8: Wavenumbers at which the emitted gas is detected through TGA-FT-IR analysis.

Detected effluents	Wavenumbers (cm ⁻¹)
CO ₂	2500-2200
Methane	3017
HCl	2753
Plasticizer	1747
CO	2232-2065
CH groups	2965

Table 9: Details of the TGA and FTIR test apparatuses adopted.

Test Apparatus	Producer	Model	Additional Information
TGA-FTIR	Perkin Elmer	TGA-IR-GCMS-TL9000	Thermogravimetric analyzer TGA 8000 Acquisition range: [-20; 1200] °C Heating rate from 0.1 to 500°C/min. Spectrophotometer based on DynaScan interferometer, the optical system in KBr – Acquisition range: [8300-350] cm ⁻¹ Signal/noise ratio 14500:1

The procedures for preparing the test specimens and testing the material according to EN 60754-2, ASTM D 7309, and ISO 5660-1 are detailed in Refs. [18,20,21], where instrumentations and operational parameters are reported. The hyphenated methodology TGA-FTIR was conducted with the test apparatus in Table 9 without injecting gases into GC-MS. The procedure is as follows. About 1 mg of sample is weighted in a pan and inserted in TGA at room temperature where 20°C/min of heating regime is set. The nitrogen flow rate was set at 20 mL/min, and it purges the gases coming from the decomposition of the polymer to the FTIR cell through a transfer line with a temperature of 280 °C. FTIR performs four readings with a resolution of 4 cm⁻¹ between room temperature and 1000 °C. The effluent evolution was followed by tuning the wavelengths indicated in Table 8, and the correspondent chemigrams (signal of a substance as a function of temperature) were obtained.

3. Discussion

Tables 2-4 compare pH and conductivity achieved by formulations FR50.0–FR50.2, FR50.5, and FR50.10 of Table 1 when performing EN 60754-2 isothermal at 950 °C (Table 2), EN 60754-2 applying the heat regime of EN 60754-1 (40 min up to 800°C and further isothermal per 20 min at 800 °C, Table 3) and EN 60754-2 isothermal at 500 °C, temperature chosen specifically below the flashover temperature (Table 4). FR50.0 represents a typical non-flame retarded PVC jacket compound for cables and contains ground calcium carbonate, which is a grade not actually good as an acid scavenger. FR50.2 contains 90 phr of MDH, which is a flame-retardant filler but an ineffective acid scavenger at high temperatures, as shown in Ref. [22]. FR50.5 contains a high-temperature performant acid scavenger, and FR50.10 is a performant solution showing the typical synergism between MDH and UPCC. The measurements of acidity in Tables 2-4 and Figure 5 clearly indicate that if we change the heating conditions of EN 60754-2, the HCl emission changes dramatically if a potent acid scavenger is found in the PVC compound (FR50.5 and FR50.10 vs. FR50.2). Regarding FR50.0 containing a grade of

CaCO₃ not performant as an acid scavenger at high temperatures, it can be highlighted that EN 60754-2 at 950 °C isothermal only shows a slightly better smoke acidity compared to EN 60754-2 at 500 °C. The phenomenon has been observed in Ref. [22], and it is probably due to the formation of CaO from CaCO₃, which more likely occurs at 950 °C than in the heating conditions of EN 60754-1 or at 500 °C.

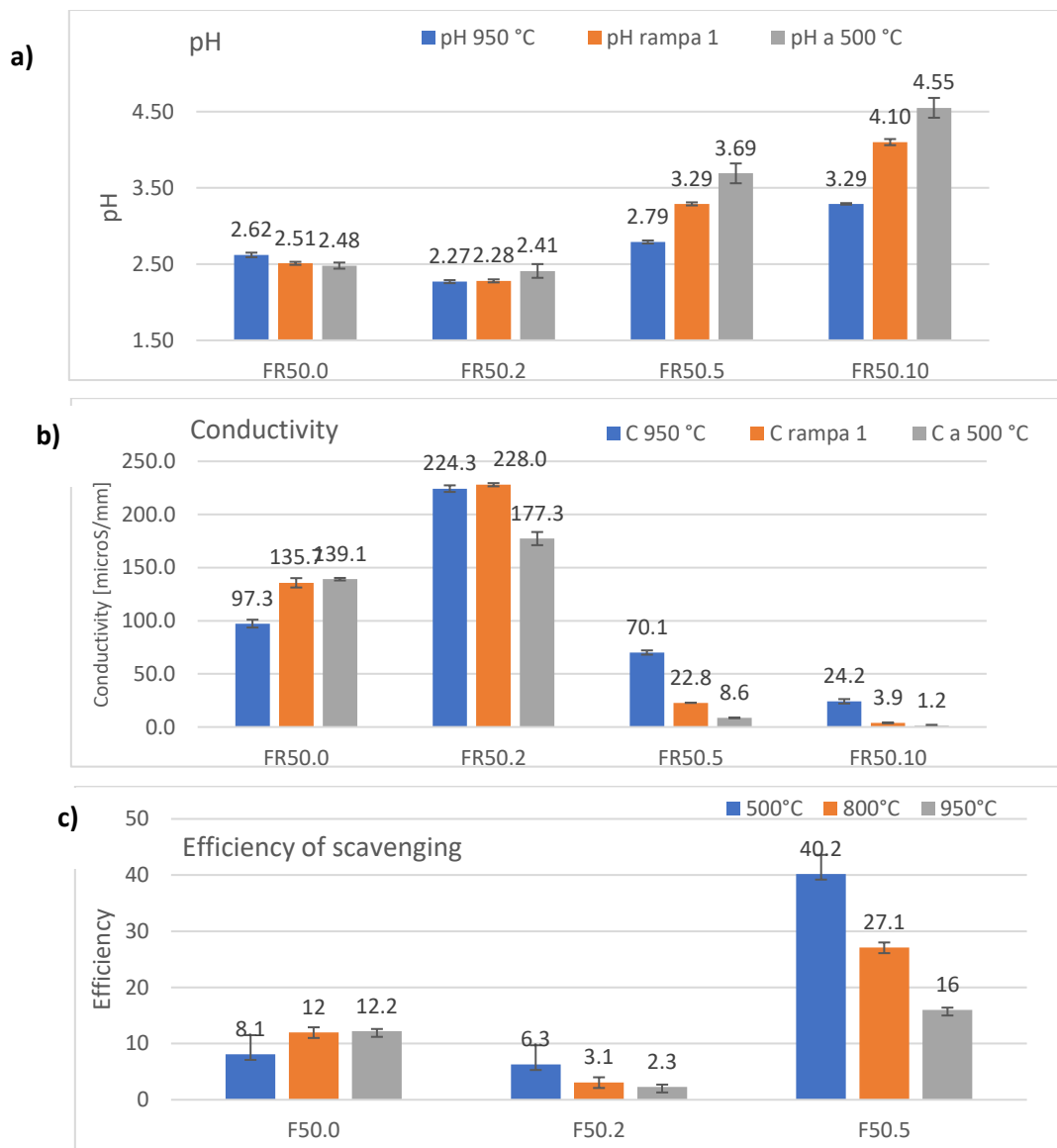


Figure 5. Comparison of pH (a), conductivity (b), and efficiency (c) of formulations of Table 1 measured with EN 60754-2 at 950 °C (blue bars), EN 60754-2 with the heating regime of the EN 60754-1 (orange bars), and EN 60754-2 at 500 °C (gray bars). S.D. is reported. FR50.0 and FR50.2 without efficient acid scavengers, FR50.5 and FR50.10 with efficient acid scavengers.

Also interesting is the analysis of the formulation FR50.2 data containing MDH. Conductivity and pH in isothermal at 500 °C vs. ramp at 800 °C and isothermal at 950 °C show that at 500 °C the efficiency of MDH is higher. That is probably because MgCl₂, from the reaction between MDH and HCl, decomposes in MgO and HCl at 950 °C and 800 °C, not wholly at 500 °C. In fact, its decomposition starts around 450 °C, as indicated in Ref. [23].

The fire performances measured with CC, LOI, and MCC bring the following considerations. As acid scavengers increase their efficiency (FR 50.5 and FR50.10), FIGRA in CC increases (FR50.0, 2549 W/s vs. FR50.5 5110 W/s vs. FR50.10 3365 W/s). In FR50.10, which contains MDH as a flame retardant, the FIGRA increase is less evident, while FR50.2, having a not performant acid scavenger but a decent flame-retardant filler, shows the best value (1563 W/s). LOI in Table 6 and MCC measurements in Table 7 (particularly the most indicative ones like FGC, Q_{max}, h_c, and h_c gas) follow the same trends. All

this indicates that HCl scavenging drops the flame retardance of the system, and the higher the acid scavenger efficiency, the higher the collapse of flame retardance. The impact of the HCl sequestration on smoke production is less indicative because the formulations do not contain smoke suppressants acting in the condensed phase, which potent acid scavengers would have switched off. [24]

MCC (Figure 1) and TGA-FTIR (Figure 2-4) also give a good overview of the thermal decomposition and combustion of PVC compounds in Table 1. All formulations start to release HCl, plasticizer, and CO₂ around 275 °C, and therefore, in the first stage of the thermal decomposition/combustion: plasticizer through evaporation, HCl from zip elimination and CO₂ due to the reaction between HCl and CaCO₃. In the first stage, polyene sequences (PES) are formed, benzene is yielded from their intramolecular arrangement (but it has not been traced in our study), and the crosslink of the matrix from their intermolecular rearrangement occurs. In the second stage, only "methane" is released. The chemigram in Figure 2 follows the evolution of the signals typical for methane released from the breakdown of the crosslinked matrix. Adding 90 phr of MDH the thermal degradation pattern (line gray in Figure 1, chemigrams in Figure 3) changes. MCC shows how the specific HRR decreases in stage 1 of combustion/decomposition due mainly to the release of water and the heat sink of thermal decomposition around 300 °C. The main highlight is the chemigram of HCl. MDH works extremely fine as an acid scavenger in the first stage. However, here we face a strong release of HCl in the second stage around 450 °C – 600 °C due to the decomposition of formed MgCl₂. This explains the chemistry of MDH as an acid scavenger at high temperatures and why it is ineffective, as highlighted in the following Refs. [22-24] The chemigram of HCl for the FR50.10 in Figure 4 shows another interesting fact. The HCl signal falls below the limit of detection (LOD) of the hyphenated technique, vanishing in both the first and second stages. This phenomenon can be elucidated as follows: in the initial stage, MDH and UPCC act to scavenge HCl, with MDH, being a robust base, proving more effective than UPCC. In the second stage, MgCl₂ releases HCl through the decomposition, as mentioned earlier, likely at a slower rate than PVC, which undergoes zip elimination and autocatalysis in the first stage. This sets the stage for UPCC to efficiently scavenge HCl in the second stage of decomposition/combustion. The relay of HCl between MgCl₂ and UPCC may explain the synergistic effect of these two acid scavengers at high temperatures. [25]

4. Conclusion

Low smoke acidity PVC compound for cables can be studied through MCC, CC, acidity test apparatuses at different temperatures, and hyphenated techniques to verify the performances and why some acid scavengers at high temperatures work better than others.

The paper highlighted that HCl is released in the first stage of thermal decomposition/combustion of PVC compounds, and the acid scavengers at high temperatures acting in the condensed phase should work efficiently, generating stable reaction products up to the temperatures of the acidity test.

The efficiency of the acid scavenger drops as temperature increases, and at 950 °C the most performant acid scavengers have reduced efficiencies of almost a trivial ground calcium carbonate, around 16 %. [22]

EN 60754-2, according to CPR, should be performed at 950 °C where most of the acid scavengers fail and a temperature typical of a fully developed fire. The paper shows how the concentration of HCl drops in the gas phase when the ramp of EN 60754-1 or the isothermal at 500 °C is applied.

It is important to note that room fires exhibit varying stages with distinct temperatures and heat flows. During the ignition and developing fire phases, temperatures may elevate from 300 °C to 600 °C, eventually reaching 650 °C to 1100 °C in the fully developed stage. [11,12,13,14] As indicated in this study and in Ref. [26], the temperatures and heating characteristics outlined in EN 60754-2 nullify the effectiveness of potent HCl scavengers in low-smoke acidity compounds for cables. Conversely, acid scavengers demonstrate an optimal efficiency, potentially up to 10 - 20 times better depending on used acid scavengers, when subjected to a heating regime or pre-flash-over temperatures (see Figure 5 (c) FR50.5 and FR 50.10).

In our view, the implications of these findings and considerations regarding room fire temperatures underscore the limitations of EN 60754-2 in indirectly assessing acidity in a real fire scenario. It appears to be an inadequate tool for predicting whether the material of an item poses a substantial risk in terms of releasing HCl in the gas phase. This inadequacy arises not only because, in real fire scenarios, HCl undergoes decay, resulting in less acidity than expected and travels only a short distance from the fire origin. [27] Additionally, EN 60754-2 evaluates acidity at typical temperatures of fully developed fires when HCl evaluation is useless from the point of view of a fire risk assessment. Conducting full-scale fire tests to compare HCl evolution from PVC cables of different classes, particularly the new generation of cables produced with the new low smoke acidity compound [28,29,30], could definitively clarify this aspect.

References

1. ISO DTR 20118. *Guidance on fire characteristics and fire performance of PVC materials used in building applications*. ISO: Geneva, Switzerland, 2019. Available online: <https://www.iso.org/standard/67071.html>
2. Hirschler M. *Fire safety, smoke toxicity, and acidity*. In *Proceedings of the Flame Retardants—Interscience Communications, London, UK, 14–15 February 2006*
3. Cardelli C 2022 *AMI CABLES CPR classification of cables and fire safety: contribution of innovative PVC and Halogen free compounds*
4. Guillaume E et al. 2014 *Fire Safety Journal*, **70** 81-97
5. Starnes W.Het Edelson D 1979 *Macromolecules*, **12** 797–802 [CrossRef]
6. Starnes W.H et al. 2007 *In Polymer Additives. Polymer Science and Technology* **26** 237–248 [CrossRef]
7. Montaudo G and Puglisi, C 1991 *Polym. Degrad. Stab.* **33** 229–262 [CrossRef]
8. Wu C.H et al. 1994 *Can. J. Chem. Eng.* **72**
9. Anthony G.M. 1999 *Polym. Degrad. Stab.* **9** 64 353–357 [CrossRef]
10. ISO 13943:2023 Fire Safety Vocabulary
11. Hirschler M 2017 *Fire and Materials*. **41** (8) 993–1006
12. Babrauskas V and Peacock R.D.1992 *Fire Saf. J.* **18** 255–272 [Google Scholar] [CrossRef]
13. Schartel B and I.T.R. 2007 *FAM* 2007 **31** 327–354 [CrossRef]
14. Babrauskas V 1995 *Fire Mater.* **19** 243–252 [CrossRef]
15. Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.
16. EN13501-1:2018; Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests. CEN: Brussels, Belgium, 2019.
17. EN 13501-6:2018; Fire classification of construction products and building elements. Classification using data from reaction to fire tests on power, control and communication cables. CEN: Brussels, Belgium, 2018. Available online: <https://store.uni.com/>
18. EN 60754-2:2014/A1:2020; Test on Gases Evolved during Combustion of Materials from Cables— Part 2: Determination of Acidity (by pH Measurement) and conductivity. CENELEC: Brussels, Belgium, 2020. Available online: <https://my.ceinorme.it/home.html>
19. EN 60754-1; Test on Gases Evolved during Combustion of Materials from Cables—Part 1: Determination of the Halogen Acid Gas Content. CENELEC: Brussels, Belgium, 2014. Available online: <https://my.ceinorme.it/home.html>
20. ISO 5660-1:2015; Reaction-to-Fire Tests—Heat Release, Smoke Production and Mass Loss Rate—Part 1: Heat Release Rate (Cone Calorimeter Method) and Smoke Production Rate (Dynamic Measurement). ISO: Geneva, Switzerland, 2015. Available online: <https://www.iso.org/standard/57957.html>
21. ASTM D 7309:2019; Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using Microscale Combustion Calorimetry. ASTM International: West Conshohocken, PA, USA, 2019. Available online: www.astm.org
22. Sarti G 2022 *Fire* **5** 142 <https://doi.org/10.3390/fire5050142>
23. Laoutid F et al 2009 *Mater. Sci. Eng. Rep.* **63** 100–125 [CrossRef]
24. Bassi I, Delchiaro F, Bandinelli C, Mazzocchetti L, Salatelli E and Sarti G 2023 *Fire* **6** 259 <https://doi.org/10.3390/fire607025910>
25. Sarti G 2022 *Fire* **5** (5) 127 <https://doi.org/10.3390/fire5050142>
26. Bassi I, Bandinelli C, Delchiaro F, Piana M, Sarti G 2023 *Fire* **6** 326. <https://doi.org/10.3390/fire6080326>
27. Chandler L.A and Hirschler Smith GF 1987 *Eur. Polym. J.* **23** 51–61
28. Istituto Giordano 2019 Unpublished Report commissioned by PVC4cables
29. I-Pool. 2022 Unpublished Report commissioned by PVC4cables
30. LS Fire. 2023 Unpublished Report commissioned by PVC4cables