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Review

A New Perspective on Hcl Scavenging at High Temperatures for Reducing the Smoke Acidity of PVC Cables in Fires. I: An Overview of Theory, Test Methods, and the European Union Regulatory Status

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Abstract: In the European Union (EU), according to the second basic requirement for construction works of Regulation (EU) N°305/2011 (Construction Product Regulation, or CPR), cables permanently installed in buildings must be classified in terms of their reaction to fire, smoke production, flaming droplets, and acidity. The classification is harmonized at the EU level. Nevertheless, every EU country decides what kind of classification a cable must have to be installed in a specific location depending on its fire risk, following the assumption that the higher the fire risk of the area, the higher the fire performance of the cable. According to CPR, the acidity is indirectly assessed by performing EN 60754-2, giving the additional class based on pH and conductivity measurements. Hydrogen chloride (HCl) is one of the gases PVC cables release when they burn. In some applications out of the scope of CPR, acid scavengers are commonly used in special grade PVC compounds to reduce the emission of acidic smoke. In this first part of the paper, the basic concepts of regulations in the EU on acidity are presented, a review of literature on HCl scavenging is given, and an introduction on acid scavenging at high temperatures is outlined. In the following parts, we will enter more detail about the topic with new data, comparing them with some old ones, mainly from a series of conferences held by some Italian compounders between 2019 and 2022. They were supported in their research and dissemination by PVC4cables, the European Council of Vinyl Manufacturers' (ECVM) platform dedicated to the PVC cables value chain.

Keywords: acid scavengers; PVC; cables; smoke acidity

1. Introduction

HCl is released when a PVC cable burns, making the smoke acidic. Some fire scientists claim that its diffusion in a fire scenario can incapacitate and hinder a safe escape [1]. Nevertheless, many others highlight that its evaluation is not a critical measure in fire safety and that asphyxiant gasses like carbon monoxide (CO) drive the tenability. After flashover, CO becomes the dominant intoxicant in fires [2, 3, 4]. However, the nature and quantity of toxic substances in smoke do not depend on the kind of materials in fires. CO is released by all polymers regardless of their chemical nature (approximately 20% of their weight after flashover) [3, 5]. Consequently, CO reaches the lethal concentration before other intoxicants or irritant substances like HCl can evolve to the gas phase [6].

Furthermore, HCl decays quickly in real fire scenarios, and its content is much less than expected from the stoichiometric value in PVC finished items. HCl is absorbed by "sorptive surfaces," trapped by fillers in PVC compounds, and washed away by water vapors, and its concentration in the gas phase rapidly goes down [2, 3, 7].

The heat released by the finished item, particularly the peak of the heat release rate, is the crucial factor for assessing whether a small and controllable fire can turn into a large and deadly one and, therefore, if the people can escape unharmed before the flashover is reached [8, 9]. Furthermore, the smoke obscuration impedes people from escaping from the fire scenario and being found by rescuers. Therefore, the evaluation of smoke production of finished items is

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another strategic parameter, while the assessment of smoke acidity "has no general validity in fire hazard" [2]. Despite these considerations, since 2006 in the EU, the additional classification for acidity has been introduced in cables permanently installed in buildings, stopping the use of PVC cables in some locations. This paper explains the central principles for creating PVC compounds for cables with extremely low smoke acidity, aiming to get the best classification for acidity.
The paper is divided into five parts. Part I is an introduction on the topic of acid scavenging at high temperatures and gives a review of test methods for assessing smoke acidity, focussing on regulatory status in the EU and particularly on EN 60754-1 and EN 60754-2. It also describes the basic concepts of acid scavenging at high temperatures in the condensed phase and its consequences on flame retardance, smoke production, and acidity.
The following parts show new data clarifying aspects presented in a series of conferences between 2017 and 2022, particularly AMI cables 2019, AMI cables 2020, and AMI formulation 2021: those conferences, regulatory context, and the research on low smoke acidity PVC compounds are well described in this letter [10].
The parts are the followings:
Part II: "Some examples of acid scavengers at high temperature in condensed phase";
Part III: "EN 60754-2 and focus on the species in solution affecting pH and conductivity";
Part IV: "The impact of acid scavengers on flame retardance and smoke emission";
Part V: "Comparison between EN 60754-1 and EN 60754-2: what happens to acidity with the introduction of the thermal profile of EN 60754-1 in EN 60754-2.

2. Methods, regulatory status in the EU, the pattern to low smoke acidity PVC compounds

2.1 Smoke acidity test methods.

Several bench-scale tests can measure the concentration of acidic gases released during material combustion. They can measure the acid content statically or dynamically. The static test methods have a test apparatus based on a combustion chamber, a conveying system, and trapping devices, where the acidic substance is scavenged, analyzed, and quantified (titration, back titration, pH, conductivity, ion chromatography). Furnace tube tests, such as EN 60754 ff and other "old" proposed in the past [11, 12, 13, 14], are static methods. Different sample quantities, conditions, and test apparatus geometries do not give comparable results.
The dynamic methods follow the concentration of the evolving gas during the combustion of the test specimen. TGA-FTIR, TGA-FTIR-GC-MS, and TGA-MS are the most common ones. FTIR sensors, capable of detecting the released gases and those responsible for making the smoke acidic, can be installed in cone calorimetry test apparatus. In this way, acidic gases can be viewed "dynamically" during the combustion of the matrix.
Furnace tubes are the most common test apparatus for assessing smoke acidity or corrosivity, particularly in some standards, such as EN 60754 series. The sample is introduced in a quartz tube by a combustion boat. According to the standard, the sample is introduced in a quartz tube and subdued to a specific heating regime. A normalized air stream collects the fumes in some bubbling devices, where ions are analyzed: directly by ion chromatography and titrimetric methods or indirectly by pH and conductivity measures. Methods based on furnace test apparatus give an indirect assessment of the smoke acidity generated by the burning sample. Measurements in tube furnaces are strongly affected by sample size. If the dimensions of the slices of the test specimen in combustion boats are too big, passivation can prevent the sample's total combustion, releasing less HCl in the gas phase. The humidity should be carefully checked because moisture in the air flux can bring some chlorides to hydrolysis, freeing the "trapped HCl" in the gas phase. Even the geometry of the quartz tube and its connectors to bubbling devices plays a significant role. The terminal parts of the quartz tube, external to the furnace, are colder than the inner part. Here, the gas-phase substances can condensate and trap HCl, underestimating its concentration in bubbling devices. The release of trapped HCl can "contaminate" the

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successive runs, and therefore, terminals should be introduced in the inner part of the furnace to "evaporate" all condensates.

For the same reason, the tubes, the connectors, the end connectors, and the bubbling devices must be washed carefully, recovering all dissolved HCl. All seals should be well-tightened to prevent the loss of HCl, and tubes must be sized as shorter as possible to recover all analytes easier during the washing procedures. Without those precautions, furnace tube measurements give poor repeatability and reproducibility.

The temperature and the heating rate of the sample strongly affect the emission of HCl in all kinds of bench-scale tests. If the test is performed at different temperatures and heating regimes, the concentration of HCl in the gas phase will differ [14, 15, 16, 17, 18, 19, 20].

2.1 Acidity additional classification in the EU

The CPR entered into force in 2017, laying down harmonized conditions for marketing construction products in the EU. One of the seven basic requirements of CPR is safety in case of fire; therefore, construction products must meet certain specific requirements in terms of reaction to fire. In the countries of the EU, tests, requirements, classification, marking, and controls on construction products must be the same. They must have a harmonized classification according to EN 13501-1 and EN 13501-6.

In 2006, the Commission Decision of 27 October 2006, amending the Decision 2000/147/EC and implementing Council Directive 89/106/EEC, entered into force. It stated that cables permanently installed in the building had to be considered buildings and construction products, and additional classification for acidity had to be assessed. CPR has implemented the indications of CPD in terms of acidity without any modification in requirements or test methods. EN 13501-6 and EN 50575 laid down test methods, requirements for getting the classification, and the additional classifications for cables, CE marking, and declaration of performance (DoP).

The classes in terms of reaction to fire are the following. Aca, B1ca, B2ca, Cca, Eca, and Fca (A is more performant than F). The additional classifications for smoke (s1a, s1b, s2 and s3, s3 less performant), flaming droplets (d0, d1, and d2, d2 less performant), and acidity (a1, a2 and a3 less performant) complete the classification of the cable.

EN 13501-6 requires that acidity is indirectly assessed by performing EN 60754-2. The test apparatus of EN 60754-2 is a tube furnace where the sample is introduced and burnt for 30 minutes in isothermal conditions at temperatures between 935 °C and 965 °C. Two bubbling devices collect the smoke, and pH and conductivity are measured. Table 1 gives the classification, pH, and conductivity requirements for getting a specific additional class for acidity according to CPR.

Table 1: additional classification for acidity and requirements according to EN 13501-6

Class	Requirement performing EN 60754-2
Class a_1	pH > 4,3, Conductivity < 2.5 [μS/mm]
Class a_2	pH > 4,3, Conductivity < 10 [μS/mm]
Class a_3	not a_1, not a_2

If the classification is harmonized at the European level, national codes and regulations of the countries in the EU define the classes the cables should have to be placed in locations depending on their specific fire risk. Thus, cables for medium and high fire risk locations must have the best classes regarding reaction to fire, smoke production, flaming droplets, and acidity. Infrastructures, health and care facilities, educational facilities, commercials, industrials, and residentials have different fire risks. For example, in Italy, according to CEI UNEL 35016 and CEI 64-8 V4, cables in class B2ca s1a d1 a1 are needed for high fire risk locations. High-risk locations are infrastructures such as air terminals, railway stations,

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marine stations, subways, road tunnels longer than 500 m, and railway tunnels over 1000 m long. In medium fire risk locations, like health and care facilities such as hospitals, nursing homes, assisted residences, entertainment, educational facilities such as cinemas, theatres, discos, schools, museums, and residentials with more than 24 m height, cables Cca s1b d1 a1 are needed. Other locations like residentials and commercials less than 24 m height (houses, bars, restaurants, shops, and medical offices) need bunched cables in class Cca s3 d1 a3 and single wires in class Eca. PVC compounds are suitable for manufacturing cables to match the class B2ca, s1, d0, a3 [17, 18, 19, 20], but nowadays, there is no PVC compound for cables in class a1 or a2. Therefore, PVC cables are excluded in medium and high fire risk locations. According to CPR, cables are the only buildings and construction products with an additional classification for acidity. The same is not required for other finished items like flooring, linear insulation for pipes, and all finished items ruled by EN 13501-1.

In the EU, the market share of PVC compounds for wire&cable was 65 % in 2000, which will be 35 % in 2023, as forecasted in [21]. CPR has driven the growth of halogen-free cables [21], but other standard products, excluding a priori PVC compounds, do the same. The research in developing PVC compounds with low smoke acidity lies in this regulatory context.

2.2 Definition of acid Scavengers at high temperatures

An acid scavenger is a "tool" for trapping acid substances through a reaction or a physical absorption, and it can even be designed to trap specific acidic substances. Acid scavengers discussed in this paper are specific to HCl. Acid scavengers acting as co-stabilizers for processing PVC compounds can be organic and inorganic substances. However, for working at high temperatures, the acid scavenger must be inorganic and stable during and after the combustion of the finished item. HCl scavengers have two main action mechanisms, scavenging in the gas phase and scavenging in the condensed phase.

An alkaline gas, neutralizing HCl, can reduce smoke acidity in the gas phase, yielding products able to be transported by convention in the gas-phase stream. If EN 60754 series are performed, these products can reach bubbling devices and dissolve electrolytes. In this kind of acid scavenging, the conductivity is therefore severely affected by the dissolved electrolytes. An example of this scavenging is when some precursors of NH_3 (like melamine, urea derivatives, and ammonium octamolybdate) are used as flame retardants. In halogen-free systems, TPU typically gives this kind of behavior, high pH but extremely high conductivities when EN 60754-2 is carried out due to specific flame retardants and charring agents releasing ammonia. Some TPU jacked needed to be flame retarded to pass standard according to EN 50620 and IEC 62893 and cannot reach conductivities less than 10 µS/mm.

The mechanism in the condensed phase is triggered by a solid acid scavenger trapping the gaseous HCl in a solid or liquid reaction product. This scavenging minimizes the contribution of other electrolytes in bubbling devices, except for not scavenged HCl. Therefore, in this mechanism, HCl is the driving force of pH and conductivity.

This paper discusses the mechanism of scavenging in the condensed phase.

2.4 Acid scavenger at high temperatures in condensed phase: failures and success

2.4.1 Where, when, and how

When a PVC compound is subjected to heat flux, temperature increases, and three main zones can be identified: a) pre pyrolysis and combustion zone, b) PVC pyrolysis and combustion zone, and c) post pyrolysis and combustion zone. Scheme 1 visually represents the three main zones.

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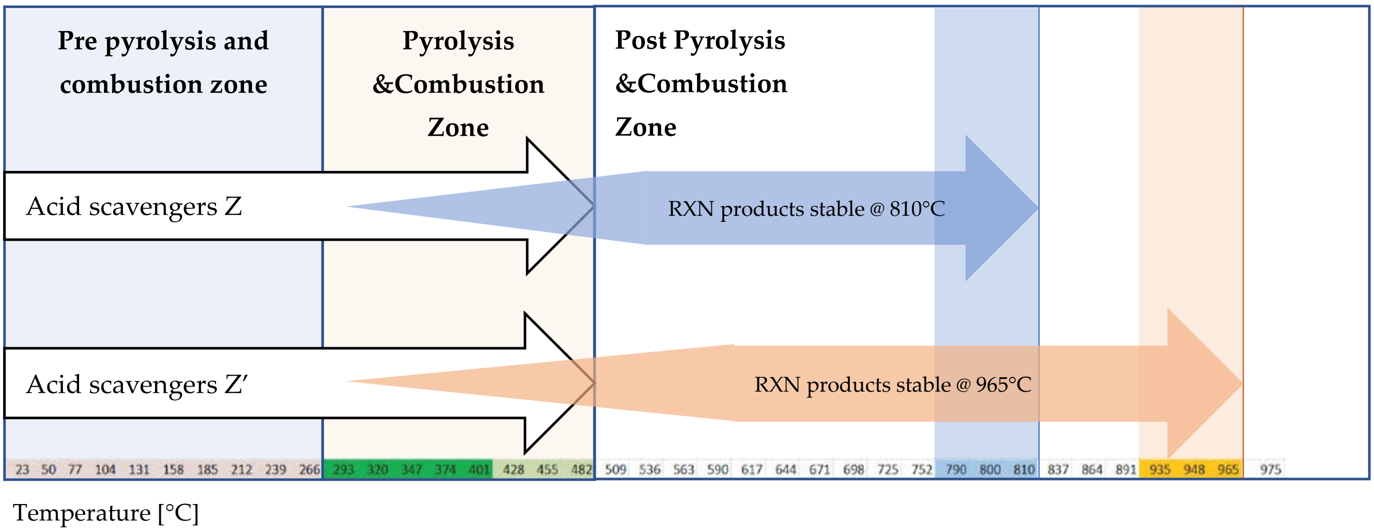
Scheme 1: identification of the three main zones. Blu zone is the temperature range of EN 60754-1, the orange one of EN 60754-2



Pre pyrolysis and combustion zone is where thermal fluxes are low, and stabilizers play their fundamental role in preventing thermal degradation through HCl's well-known "zip elimination" [22]. In scheme 1, the ranges of this zone are determined by all ingredients affecting the stabilization of the compound, thus mainly stabilizers, but also the PVC resins, flame retardant fillers, plasticizers, and fillers. As temperature increases over 270 °C – 300 °C, stabilizers end their action, PVC compound starts the pyrolysis, and evolving gasses start their combustion. PVC compound contains organic and inorganic additives. When they pyrolyze, they make free flammable and not flammable volatiles. Flammable volatiles burn, and the fire is supported by species like ·H and ·OH, bringing energy to the flame. HCl is the primary, not flammable substance in the gas phase and plays a strategic role in trapping those radicals [23]. This phenomenon is common for all halogens and is called "flame poisoning." It is the reason for the inherent flame retardancy of halogenated polymers.

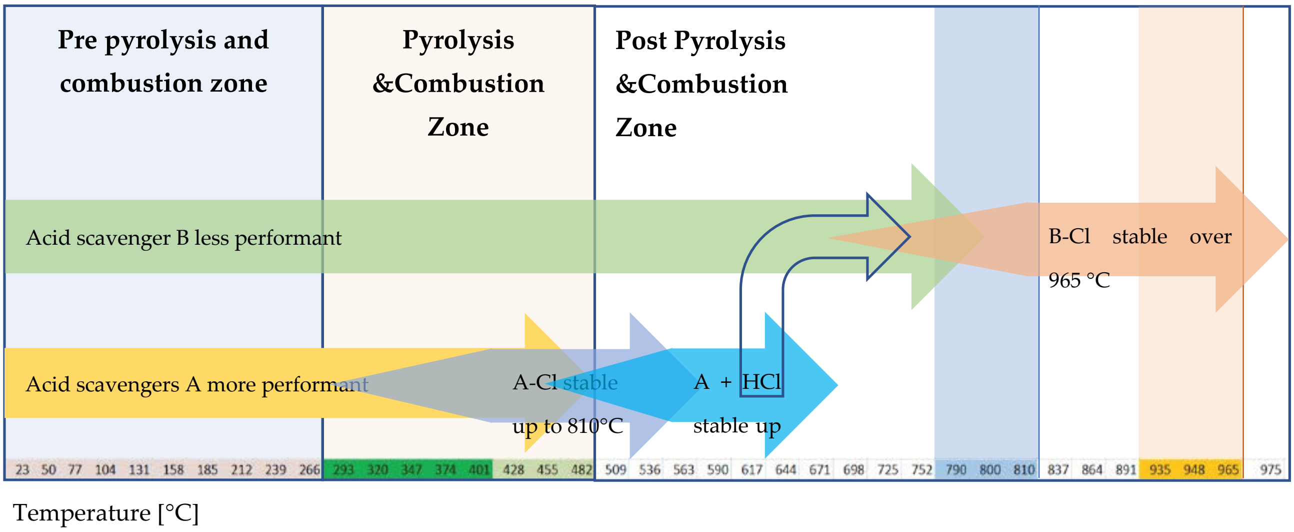
Wu and others have described the pyrolysis mechanism of PVC resin by a two-stage pyrolysis model [24]. However, the pyrolysis and combustion of PVC compounds for cable are made more complex by the presence of some additives. The kind and quantity of the volatiles released in the gas phase depend on the ingredients in the compound. The volatiles in the first stage of the degradation are mainly plasticizers, HCl, CO_2, CO, and benzene, while aliphatic hydrocarbons, CO_2, and CO are released in the second stage. If there is $CaCO_3$, another step centered at 750 °C – 850°C is visible, related to its decarbonation. When all organic substances are entirely burnt, the post-pyrolysis zone starts, where the stability of reaction products coming from the reaction of acid scavengers with HCl is crucial for getting low values of smoke acidity. Therefore, a substantial reduction of smoke acidity depends on the effectiveness of acid scavengers in holding and trapping HCl in solid ashes without any decomposition up to the maximum temperature required by the acidity test method. Performing EN 60754-1, the reaction product must be stable up to 810 °C and up to 965°C if EN 60754-2 is carried out (Scheme 1).

2.4.2 Single-step reaction versus multiple-step reaction

[16, 17] claimed that acid scavengers could react through single- and multiple-step reactions. In their opinion, a single-step response involves just one acid scavenger following Scheme 1.

[16, 17] claimed that in PVC compounds, depending on the kind of ingredients, it is possible to have also multiple-step reactions involving more than a single teammate, following the "relay race scheme" in Scheme 2. Here the performant acid scavenger A can react with HCl creating A-Cl. If A-Cl is unstable, the second less performant acid scavenger B gets HCl from A-Cl decomposition. If this HCl release is slower than that coming from PVC, and if B-Cl is stable, this "relay race scheme" brings a synergistic effect and increases scavenging efficiency. Acid scavenger B can be added to the dry blend, or a precursor of B can yield B during the combustion. Multiple-step reactions can use more than two teammates. The part II of this paper will enter more into the details of multiple-step reactions, bringing some examples.

Scheme 2: multiple step reactions in HCl scavenging at high temperature



2.4.3 Main failure cases

Following the schemes mentioned above, the failure cases generating high smoke acidity should be mainly two: kinetic of the scavenging action by an acid scavenger and the decomposition of the acid scavenger or its reaction products. If an acid scavenger has a slow kinetic in its reaction with HCl and the kinetic evolution of HCl is too fast, most of the HCl quickly reaches bubbling devices.

2.4.3.1 The kinetic

The kinetic is strictly linked to:

- the chemical nature of the acid scavenger;
- its particle size;
- its dispersion properties;
- the test temperature and heating regimes

Chemical nature

The higher reactivity of the acid scavenger, the quicker its reaction with HCl. So strong bases, such as hydroxides or oxides, are more efficient than weak scavengers, such as carbonates.

Particle size

The smaller the particle size, the more efficient the reaction is. Therefore, ground calcium carbonates (GCCs) are less efficient than ultrafine precipitated calcium carbonates (PCCs).

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Dispersion

The better the acid scavenger dispersion, the more intimate contact with PVC, and the quicker the reaction with HCl. Furthermore, the zones in which acid scavenger misses emit massive amounts of HCl. It is worthy of mention that a finer particle size additive can bring a worse dispersion of acid scavenger in the matrix.

Temperature and heating regimes

The higher the temperature, the quicker the evolution of HCl from the burning matrix, and the more complex the chance for a solid acid scavenger to trap a gaseous HCl. High temperatures give a severe drop in efficiency, and the presence of a heating regime and lower temperatures give more time to acid scavengers to trap HCl efficiently.

2.4.3.2 Decomposition of acid scavengers and their reaction products

Suppose an unstable acid scavenger decomposes before the "pyrolysis and combustion zone," or its reaction product decomposes before reaching the test temperature. In that case, we will have an open door allowing HCl to get the bubbling devices. So many common organic acid scavengers used as long-term thermal stabilizers cannot be used as acid scavengers at high temperatures.

2.5 Definition of efficiency of the acid scavenger

O'Mara proposed the Molar Absorption Efficiency (MAE) as a measure of the efficiency of an acid scavenger. MAE is the amount of HCl absorbed divided by the theoretical amount that could be absorbed by each filler [24]. Chandler and others defined efficiency based on the stoichiometry of reaction between $CaCO_3$ and HCl [14]. For calculating the efficiency of an acid scavenger through [24] or [14], we need to know precisely the reaction mechanism of all involved actors. With multiple-step reactions, this cannot be feasible. It is better to a new definition of efficiency, considering not the moles of reactants and products but just the measure of the "effects" of acid scavenging reactions, whatever they are. The best candidates are linear functions of E (x), and E (pH) is a linear one. Thus, performing IEC 60754 ff, we can propose equation 1 as the definition of the efficiency of an acid scavenger at high temperature:

$$\boldsymbol{E} = 100 \times \frac{(\mathbf{pH} - \mathbf{pHs})}{(\mathbf{pHw} - \mathbf{pHs})} \qquad (2)$$

Where pH ∈ [pHw - pHs]

Equation 1 is a straight line, where measured pH cannot stay outside its "existence region" (pHw - pHs). pHs is the minimum pH reachable when the stoichiometric quantity of HCl reaches the bubbling devices. It is a theoretical value and can be calculated directly from the sources of HCl in the formulation. pHw is the double deionized water (DDW) pH, i.e., the maximum reachable pH when HCl comes from the smoke is negligible. If the measured pH equals pHs, the efficiency is "zero," while if the measured pH equals pHw, the efficiency is 100 %.

So, we can quickly get the efficiency of a specific acid scavenger in a single-step reaction or a "team" of acid scavengers in a multiple-step reaction by measuring our samples' pH, knowing our samples' pH DDW, and calculating the pHs of the used formulations.

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2.6 The driving force of pH and conductivity in the solution

Equation 2 defines a theoretical model predicting the conductivity values as a pH function for standard HCl solutions. In this case, conductivity and pH are linked by equation 2:

$$c = a \times e^{(-b \times pH)} \tag{2}$$

Suppose the scavenging of HCl is in the condensate phase, and the contribution by the evaporation of reaction products is negligible. Performing EN 60754-2, pHs and conductivities should fit very well the equation 2. Therefore, Ion Chromatography (IC) should measure Cl^- as the main specie and negligible the concentration of other cations and anions. In this context, pH can be derived indirectly through IC measurements.

Part III of this paper enters more into the details of this topic, comparing the theoretical values coming from standard solutions of HCl and the Kohlrausch and Debye–Hückel–Onsager equation [25] with the experimental data coming from EN 60754-2.

2.7 Impact of acid scavengers on flame retardancy and smoke suppressant properties

Acid scavengers interfere with the flame retardant mechanism in the gas and condensed phases, inhibiting flame retardancy. [26, 27, 28] show the impact on the LOI of several calcium carbonates with different particle sizes. In particular, the behavior of 0.1-micron calcium carbonate is better as acid scavengers compared to 14 microns and 1-micron ones. As expected by inert filler, 14-micron calcium carbonate does not affect LOI, and LOI has a slight increase as its concentration increases. However, 0.1-micron calcium carbonate is reactive. Getting in HCl with high efficiency, 0.1-micron calcium carbonate reduces LOI up to its stoichiometric value when the exact quantity of $CaCO_3$ is available for reacting completely with potentially released HCl. After that, it increases again, behaving as an inert filler. 1-micron calcium carbonate shows both characteristics, i.e., a constant trend up to stoichiometric value and a slight increase after. All these confirm that the higher the HCl scavenging, the lower the flame retardance. PVC with acid scavengers loses its inherent flame retardance. The scavenging of HCl also interferes with some common flame retardants used in PVC. Antimony trioxide (ATO) is a common flame retardant working only in the gas phase through the formation of $SbCl_3$, trapping the hot radicals feeding the flame [23]. Since $SbCl_3$ is less volatile than HCl or HBr, it stays longer in the flame, enhancing flame retardancy in PVC compounds. When a powerful acid scavenger is introduced into the compound at high temperatures, all HCl is trapped as chloride in the condensed phase. That prevents the formation of $SbCl_3$ and the reactions trapping the hot radicals. The consequence is a dramatic LOI drop, as reported in [16, 17, 18].

Furthermore, the scavenging of chlorine by acid scavengers interferes with the charring mechanism of some Lewis acid precursors used as flame retardants and smoke suppressants in PVC. Most of these precursors are metal oxides or salts reacting with HCl and yielding chlorides acting as potent Lewis acids. Starnes and co-workers [29, 30], Jianqi Wang and co-workers [31, 32], and Rodolfo and Innocentini-Mei [33] studied some of them. Starnes and others [29, 30] claimed the precursor of Lewis acid as an inhibitor of benzene formation from cis-trans polyene sequences to justify the smoke suppressant properties and the flame retardancy of some molybdenum compounds. Lewis acids seem to advantage parallel reactions yielding to the production of crosslinked solid char through the following steps: the creation of

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preferential pathways bringing to all-trans sequences (pathways 3, 4 in figure 2) and Diels-Alder reactions and Friedel–Crafts alkylations catalyzed by Lewis acid (pathways 5 and 6 in figure 2).

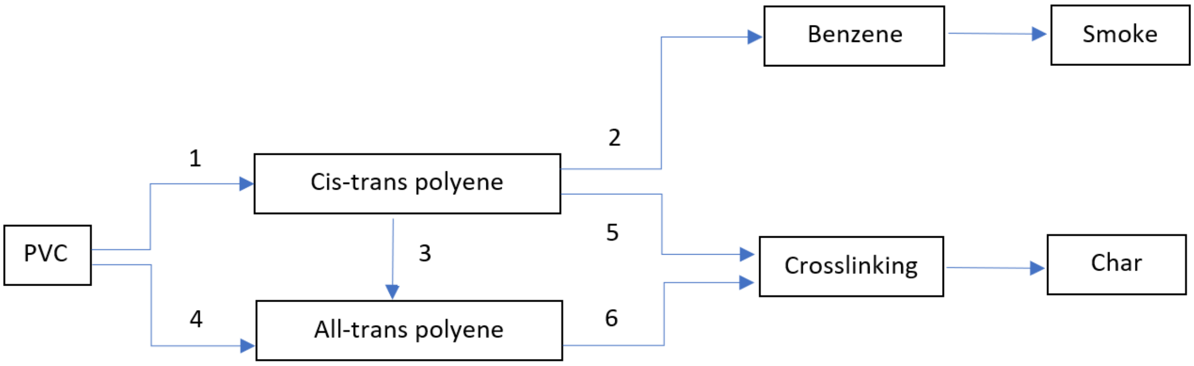

Figure 2: pathways bringing to char and smoke in PVC combustion. From [29]

Without Lewis acid, benzene is produced following patterns 1 and 2 in figure 2. The reaction is an intramolecular cyclization, as described by O' Mara [36]. Benzene is formed during stage 1 of pyrolysis and combustion zone and is a potent source of soot and smoke during PVC combustion.

Therefore, potent acid scavengers, inhibiting the reactions bringing to the formation of metal chlorides, switch off all pathways yielding the char, causing a substantial release of smoke, as reported in these proceedings [14, 15]. All smoke suppressants involving chlorides, acting as Lewis acids promoting char, are, therefore, useless in low-smoke acidity compounds. The smoke suppressants avoiding cationic cracking at high temperatures in large fires [34, 35] lay in that category. This topic will be discussed in detail in part IV of the paper.

3. Conclusions

The acid scavenging at a high temperature of HCl can pass through a single-step or multiple steps reaction in which HCl is released and captured by different actors. Multiple steps reactions can be used to get the advantage of synergism capable of increasing the efficiency of the HCl scavenging. An acid scavenger at a high temperature in a condensed phase can fail or succeed depending on how quickly it reacts with HCl, the thermal stability of its reaction products, and how fast HCl evolves from PVC. Therefore, acid scavenger chemical nature, particle size, how much disperses, test temperature, and heating regimes affect the efficiency of scavenging. This topic will be discussed in detail in part II of the paper.

Particularly, temperature and heating regime are critical parameters influencing the scavenging efficiency. Therefore, EN 60754-2 and EN 60754-2 with thermal profiles of EN 60754-1 have been compared in part V of this paper.

Furthermore, EN 60754-2 is designed for collecting fumes in bubbling devices containing water, and it is strategic to know what species affect pH and conductivity to "design" a good acid scavenger at high temperatures in the condensed phase. Suppose a mechanism of scavenging in the condensed phase is involved, and the volatility of the reaction products is low. In that case, the pH and conductivity are ruled only by the HCl reaching the bubbling device. IC should find Cl- as the predominant specie, ICP and IC should determine the low concentration of all cations in the solution,

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and pH and conductivity should be linked by the mathematical formulation indicated in (2). This topic will be discussed in detail in part III.

Lastly, HCl scavenging inhibits radical trapping and interferes with the char mechanisms of PVC compound in case of fire. Therefore, the low smoke acidity compound will have less fire performance, with low flame retardance and more dense smoke. This drawback highlights the need to introduce a new generation of flame retardants and smoke suppressants if we want to keep the low smoke acidity, high flame retardancy, and minor smoke release together in a PVC compound. This topic will be discussed in detail in part IV.

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