JRACR

Journal of Risk Analysis and Crisis Response, 2022, 12(3), 143-151
https://jracr.com/
ISSN Print: 2210-8491
ISSN Online: 2210-8505

Review

Poly Vinyl Chloride Additives and Applications - A Review

Abdallah S. Elgharbawy [1,2,*]

[1] Materials Science Department, Institute of Graduate Studies and Research (IGSR), Alexandria University, Alexandria (21526), Alexandria Province, Egypt
[2] The Egyptian Ethylene and Derivatives Company (ETHYDCO), Alexandria (21526), Alexandria Province, Egypt
* Correspondence: ab_pet_88@hotmail.com

Received: February 23, 2022; Accepted: April 16, 2022; Published: September 30, 2022

Abstract: A Pure polyvinyl chloride (PVC) is a white, brittle material and it is the third-largest polymers produced after polyethylene and polypropylene as 40 million tons of PVC are produced yearly. The basic structure of PVC is (C2H3Cl)n and it is produced by polymerization of the vinyl chloride monomer (VCM) with a polymerization degree ranges from 300 to 1500. The chlorine content in PVC is about 57% by weight, which makes it less dependent on hydrocarbon content. In this paper, we are going to reveal the PVC additives and applications.

Keywords: Poly Vinyl Chloride; PVC Application; PVC Additives

1. Introduction

There are two types of PVC which are rigid and flexible. The rigid PVC is a type of PVC that do not contain plasticizers and used in the construction activities. Whereas, the flexible type is made by adding plasticizers to the rigid form and can replace rubber. Flexible PVC can be used in plumbing, electrical cable insulation, imitation leather, and flooring [1, 2].

Rigid PVC is very important type of PVC as it is used in the building construction, piping, signs, roofing sheet material and other products [3]. The types of PVC that are more flexible serve as an alternative to rubber and are widely used in the manufacturing of clothing, footwear/boot grades, upholstery, electrical cable compounds, and many other everyday products [4]. PVC is thermoplastic with a low thermal stability, so the use of PVC polymer is limited in the industry that requires high temperature [5, 6].

Neat PVC polymer is a brittle, not flexible material with limited commercial possibilities. In addition, the PVC processing in its raw form by using high temperature and pressure leads to severe degradation of the PVC structure. Therefore, before using PVC, it must be treated with suitable additives. The most crucial additives are heat stabilizers and lubricants, fillers, processing aids, impact modifiers, pigments, and plasticizers [7, 8]. The role of additives is to improve the mechanical, electrical, thermal, light, color, and clarity properties of PVC. The additives are blended with the PVC via a compounding process [5, 9].

The resin of PVC is categorized by the K-value, which refers to the polymerization degree and the molecular weight [10]. PVC that has a K-value of 57 is a low molecular weight type and it is used in packaging films, blow sheets, bottles and injection shapes. Whereas, PVC that has a K-value of 70-75 is a high molecular weight type has a high mechanical property but it is processed difficultly [11]. This type of PVC is used for flooring, rigid parts, high performance cables, pipes, and profiles. Emulsion PVC is used in the form of plastisol or latex and it is used in special applications such as coatings, multilayer films, and battery separators [12, 13].

Not only does PVC offer the flexibility necessary for medical uses such as blood bags and intravenous therapy (IV) containers, but it can also be relied upon for its strength and durability, even under different temperatures and conditions. PVC can also be easily processed to make IV tubing, thermoformed to make 'blister' packaging, or blow molding to make hollow rigid containers. This versatility is a major reason why PVC is the material of choice for medical product and packaging designers.

In this paper, we will investigate the PVC additives, which are required to improve the PVC properties to be able to perform its functions in the dedicated applications. We will also mention the PVC applications and the mixing techniques.

2. Materials and Methods

2.1. Dry Mixing

The PVC mixing is either dry mixing that uses a very high-speed mixer that blends all the component to produce powder [14, 15].

2.2. Extruder Mixing

Extruder mixes the components using a low or high-speed extruder mixer. After that, the mixed components are transferred through heaters to melt the mixture. Eventually, the mixed components are cooled and cut into granules for processing [16, 17].

3. PVC Additives

3.1. Plasticizers

At normal temperature, PVC is naturally rigid. This is due to the short distances between the molecules since there are strong intermolecular forces between them. When plasticizers are added to PVC, the plasticizer molecules make their way between the PVC molecules, preventing the PVC polymer molecules from getting closer to each other. Therefore, the polymer molecules are kept away even at normal temperature and softness is achieved [13, 18].

3.1.1. Primary Plasticizers

Primary plasticizers have a good dispersion inside the PVC resin and used in a large content such as 140-150 parts per hundred (PHR) and it is mainly used for super soft products. All plasticizers are almost liquids and must be absorbed in a suspension resin in heated mixers. Plasticizers are mixed with PVC resin in dry blend in high or low shear mixer [14, 15].

3.1.2. Secondary Plasticizer

Secondary plasticizers have a limited dispersion inside the PVC resin. The main use of secondary plasticizer is to decrease the PVC price [19]. Chlorinated Paraffin wax (CPW) is the most common secondary plasticizers that consist of high viscous wax with a 50 % of chlorine content. The other common secondary plasticizers are chlorinated paraffin oils (CPO) since its viscosity and plasticizing efficiency is much better than CPW [14]. Table 1 summarizes the plasticizers types' performance and specialty [8, 19].

3.1.3. Plasticizing Performance

The Plasticizing performance of di, (2-ethyl hexyl) phthalate (DOP) is 1. The plasticizing performance of any other plasticizer type is calculated as a ratio with DOP for producing a molding of same softness [15, 20]. Table 2 shows the plasticizing efficiency for many plasticizers. For example, if 100 PHR of DOP yields a hardness of 50, and 110 PHR of another plasticizer gives the same hardness, the Plasticizing efficiency of the plasticizer equals:

$$= 100*(100/110) = 91\ \%.$$

3.1.4. Plasticizers for Medical Applications

Dioctyl Phthalate (DOP) is the most common plasticizer used in medical industry due to its high efficiency, availability at high purity and low cost. Other plasticizers such as tri, (2-ethyl hexyl) mellitate (TEHM, also called TOTM), n-butyrul, tri n-hexyl citrate (BTHC) and di (n-decyl), phthalate (DnDP) is used for other medical applications such as the platelets storage [21, 22].

3.2. Stabilizers

The PVC molecule is not stable at high temperature and ultra violet light. Heating PVC leads to the Polymer chains breaking and free the toxic hydrochloric acid gas. The released HCL causes the PVC degradation. The PVC exposure to the UV radiations dissociate the polymer chains but its impact is lesser than the heat degradation [22, 23].

3.2.1. Heat Stabilizers

PVC must be thermally stabilized during its processing at high temperature. Most of heat stabilizers contain metal elements that interact with HCl and prevent PVC degradation. The most common heat stabilizers are metal salts, soaps. Table 3 shows heat stabilizers types [24, 25].

3.2.2. Light Stabilizers

Most of mixed metal stabilizers save PVC from the UV radiation attack. DBL phosphate is a light stabilizer that has some UV resistance properties. Light stabilizers are complex chemicals, very expensive, and are efficient at low amount (0.1-0.3 PHR) [24].

3.3. Fillers

Fillers are inorganic, inactive materials and its main role is to decrease the PVC processing cost and enhance the mechanical properties of PVC such as the fracture strength and impact performance of PVC. It can be used as a pigment and improve the PVC chemical resistance. The most common type of filler is calcium carbonate, titanium dioxide, talc, glass, and calcined clay [26, 27].

DOI: https://doi.org/10.54560/jracr.v12i3.335

3.3.1. Nano Fillers

Nano fillers are mixed with polymer from 1 to 10 wt. %. The most common nano fillers are nano fibers such as glass and carbon fibers. The other types of nano fillers are nano-clays, nano-oxides, carbon nanotubes. Nano-clays fillers is a silicate of transition metals and it is natural or synthetic clays. Nano metal oxide such as rutile $TiO2$ is used as a white pigment [27, 28].

3.4. Impact Modifiers

Impact modifiers (IM) should have rubber properties such as acrylic rubber, chlorinated polyethylene, or butadiene styrene. IM are mixed with PVC with an amount of 5-20 wt.% to give the PVC a toughening property [29, 30].

The aim of IM is to enhance the PVC impact resistance and the role of impact modifiers molecules is to absorb the impact energy and eliminate the fracture of the PVC product. The particle size of IM is in the micro range [31].

3.5. Pigments

PVC pigments is a colored material that is insoluble in water generally is categorized into [32]:

- Inorganic.
- Organic.

Pigments for PVC must be thermally and light stable, have good dispersibility, and be compatible within the formulation. Table 4 shows the different types of pigment [33, 39].

4. PVC Applications

4.1. Piping Applications

PVC has been improved for many piping applications such as exterior body trim and molding, chemical resistant trim, gear shifter knobs, hoses, tubing, and interior console covers [14, 34].

4.2. Construction Activities

PVC has been used extensively in a wide range of construction products for more than 50 years. The PVC strength, lightweight, and durability make PVC perfect for many applications as outlined below [35, 36]:

- Window seals.
- Weather-strip and screen spline.
- Concrete water stops.
- Weatherable capstock for exterior trim.
- Dry wall accessories.
- Flooring.
- Roofing.
- Electrical insulators
- Sunroof

4.3. Medical Applications

PVC is used in the medical applications for more than 50 years due to its safety, chemical stabilization, low cost, durability, its resistance to chemical stress cracking, and biocompatibility [37, 38].

4.4. Figures, Tables and Schemes

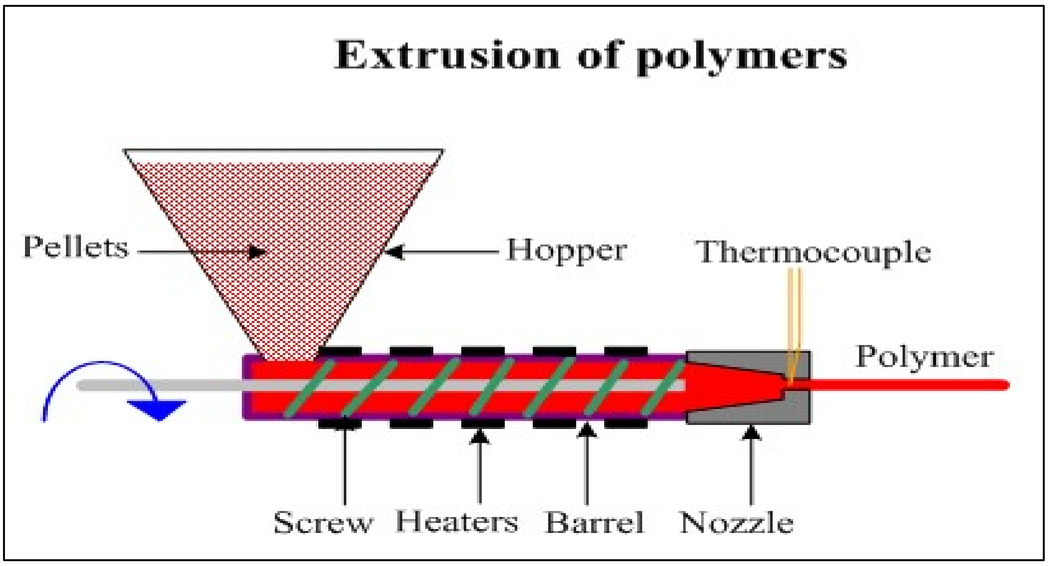

Figure 1. Extruder components.

Table 1. Plasticizers types.

Family	General purpose	Performance of plasticizers			Specialty plasticizers		
		Strong solvent	Low temperature	Low volatility	Low diffusion	Stability	Flame resistance
Phthalates	P	S	S	S	S		S
Trimellitates			S	P	S		
Aliphatic esters			P				
Polyesters				P	P		
Epoxides			S	S		P	
Phosphates		S	S				P
Extenders		P					
miscellaneous			P	P	P		

P: Primary performance function.

S: Secondary performance function.

Table 2. Plasticizing efficiency for many plasticizers.

Plasticizer	Plasticizing efficiency
Di butyl phthalate	1.05
Di Octyl phthalate	1.00
Di iso Octyl phthalate	1.00
Di nonyl phthalate	0.98
Di Iso decyl phthalate	0.95

Table 3. Heat stabilizers types.

Type	Heat stability	Main applications	Not recommended for
Leads	Very good	Cables, pipes, fittings, sleeves, profiles.	Clear application. Can be toxic.
Tins	Best	Transparent tubing and sheeting, high quality pipes, medical.	Staining with leads
Cd-Zn	Moderate	Electrical cables	For high heat history
BA-Cd	Good	Leather cloth, calendared products, footwear.	Nontoxic applications
Metallic stearates	Low	Co-stabilizer with lubricating action	Sole stabilizer

Table 4. Pigment types.

Inorganic pigments		Organic pigments	
Type	**Color**	**Type**	**Color**
Ultramarine	Blue and violets	Phthalocyanines	Blue, green
Chromes	Yellows, orange	Chromophthals	Red, orange
Cadmiums	Reds, orange, yellow	Azos	Wide range
Iron oxide	Brown, black	Toners	Wide range

5. Conclusions

PVC is categorized into two types: rigid and flexible. Neat PVC uses is negligible and need additives to be more appropriate for many applications such as bags, bottles, toys, construction, petroleum pipes, and medical applications. PVC is mixed with additives through two techniques: dry mixing or extruder mixing. PVC additives are various such as plasticizers, stabilizer, fillers, impact modifier, and pigments. Many research is required to investigate the PVC industry and widen the uses of PVC.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] Elgharbawy, A.S., A Review on High Density Poly Ethylene as Engineering Polymer. Quaestus, 2021(18): p. 455-459.

[2] Allam, E.M., et al., Rare Earth Group Separation after Extraction Using Sodium Diethyldithiocarbamate/Polyvinyl Chloride from Lamprophyre Dykes Leachate. Materials, 2022. 15(3): p. 1211. DOI: https://doi.org/10.3390/ma15031211.

[3] Patrick, S., Practical guide to polyvinyl chloride. 2005: iSmithers Rapra Publishing.

[4] Giacomucci, L., et al., Polyvinyl chloride biodegradation by Pseudomonas citronellolis and Bacillus flexus. New biotechnology, 2019. 52: p. 35-41.

[5] Elgharbawy, A.S.A.A., Review on Corrosion in Solar Panels. International Journal of Smart Grid-ijSmartGrid, 2018. 2(4): p. 218-220.

[6] Elgharbawy, A.S., et al., Maximizing biodiesel production from high free fatty acids feedstocks through glycerolysis treatment. Biomass and Bioenergy, 2021. 146: p. 105997. DOI: https://doi.org/10.1016/j.biombioe.2021.105997.

[7] Ding, L., et al., The photodegradation processes and mechanisms of polyvinyl chloride and polyethylene terephthalate microplastic in aquatic environments: Important role of clay minerals. Water Research, 2022. 208: p. 117879. DOI: https://doi.org/10.1016/j.watres.2021.117879.

[8] Choi, D.-S., et al., Emotion-interactive empathetic transparent skin cushion with tailored frequency-dependent hydrogel–plasticized nonionic polyvinyl chloride interconnections. Chemical Engineering Journal, 2022: p. 136142. DOI: https://doi.org/10.1016/j.cej.2022.136142.

[9] Elgharbawy, A. and A. Sayed, Production of biodiesel from used cooking using linear regression analysis. Journal of Petroleum and Mining Engineering, 2020. 22(2): p. 92-99. DOI: https://doi.org/10.21608/JPME.2020.39252.1044.

[10] Mahmoud, K., et al., Investigation of the gamma ray shielding properties for polyvinyl chloride reinforced with chalcocite and hematite minerals. Heliyon, 2020. 6(3): p. e03560.

[11] Elgharbawy, A., A Review on Vinasse A By-Product from Sugarcane Industry. Trends Petro Eng, 2021. 1(2): p. 1-3. DOI: https://doi.org/10.53902/TPE.2021.01.000506.

[12] Elgharbawy, A. and A. Sayed, A review on natural gas previous, current and forecasting prices and demand. Journal of Petroleum and Mining Engineering, 2020. 22(1): p. 61-64.

[13] Xia, X., et al., Polyvinyl chloride microplastics induce growth inhibition and oxidative stress in Cyprinus carpio var. larvae. Science of The Total Environment, 2020. 716: p. 136479. DOI: https://doi.org/10.1016/j.scitotenv.2019.136479.

[14] Boyle, D., et al., Polyvinyl chloride (PVC) plastic fragments release Pb additives that are bioavailable in zebrafish. Environmental Pollution, 2020. 263: p. 114422.

[15] Farjami, M., V. Vatanpour, and A. Moghadassi, Fabrication of a new emulsion polyvinyl chloride (EPVC) nanocomposite ultrafiltration membrane modified by para-hydroxybenzoate alumoxane (PHBA) additive to improve permeability and antifouling performance. Chemical Engineering Research and Design, 2020. 153: p. 8-20. DOI: https://doi.org/10.1016/j.cherd.2019.10.022.

[16] Sun, Y., et al., Thermal behavior of the flexible polyvinyl chloride including montmorillonite modified with iron oxide as flame retardant. Journal of Thermal Analysis and Calorimetry, 2018. 131(1): p. 65-70. DOI: https://doi.org/10.1007/s10973-017-6117-7.

[17] Bagherinia, M.A., M. Sheydaei, and M. Giahi, Graphene oxide as a compatibilizer for polyvinyl chloride/rice straw composites. Journal of Polymer Engineering, 2017. 37(7): p. 661-670.

[18] Gao, M., M. Wan, and X. Zhou, Thermal degradation and flame retardancy of flexible polyvinyl chloride containing solid superacid. Journal of Thermal Analysis and Calorimetry, 2019. 138(1): p. 387-396.

[19] Zhang, Y., et al., Flotation separation of hazardous polyvinyl chloride towards source control of microplastics based on selective hydrophilization of plasticizer-doping surfaces. Journal of Hazardous Materials, 2022. 423: p. 127095.

[20] Fang, L.-F., et al., Improved antifouling properties of polyvinyl chloride blend membranes by novel phosphate based-zwitterionic polymer additive. Journal of Membrane Science, 2017. 528: p. 326-335. DOI: https://doi.org/10.1016/j.memsci.2017.01.044.

[21] Li, D., et al., Effects of molecular design parameters on plasticizer performance in poly (vinyl chloride): A comprehensive molecular simulation study. Chemical Engineering Science, 2022. 249: p. 117334.

[22] Zhang, H. and J. Zhang, Rheological behaviors of plasticized polyvinyl chloride thermally conductive composites with oriented flaky fillers: A case study on graphite and mica. Journal of Applied Polymer Science, 2022: p. 52186.

[23] Elmahdy, M.M., et al., Tetrabutylammonium tetrafluoroborate electrolyte as poly (vinyl chloride-co-vinyl acetate-co-2-hydroxypropyl acrylate) plasticizer: Thermal degradation and optical characteristics. 2022.

[24] Jubsilp, C., et al., Effects of Organic Based Heat Stabilizer on Properties of Polyvinyl Chloride for Pipe Applications: A Comparative Study with Pb and CaZn Systems. Polymers, 2021. 14(1): p. 133. DOI: https://doi.org/10.3390/polym14010133.

[25] Yu, J., et al., Thermal degradation of PVC: A review. Waste management, 2016. 48: p. 300-314.

[26] Dutta, N., S. Hazarika, and T.K. Maji, Study on the role of tannic acid–calcium oxide adduct as a green heat stabilizer as well as reinforcing filler in the bio-based hybrid polyvinyl chloride–thermoplastic starch polymer composite. Polymer Engineering & Science, 2021. 61(9): p. 2339-2348.

[27] Deng, X., et al., Crush behaviors of polyvinyl chloride cellular structures with liquid filler. Composite Structures, 2018. 189: p. 428-434.

[28] Mansour, S.A., R. Elsad, and M. Izzularab, Dielectric spectroscopic analysis of polyvinyl chloride nanocomposites loaded with Fe2O3 nanocrystals. Polymers for Advanced Technologies, 2018. 29(9): p. 2477-2485. DOI: https://doi.org/10.1002/pat.4359.

[29] Khosya, S., S. Kushwaha, and A.A.D. Dung, Polyvinyl Chloride (PVC) Acting as Occupational Hazard in a Factory Worker Presented with Acute Toxic Encephalopathy: A Case Report. J Clin Toxicol, 2018. 8(400): p. 2161-0495.1000400. DOI: https://doi.org/10.4172/2161-0495.1000400.

[30] Hammiche, D., et al., Effects of types of PVC-g-MA on wettability and dynamical behavior of polyvinyl Chloride/Alfa composites. Materials Today: Proceedings, 2021. 36: p. 10-15.

[31] Fakhri, M., E. Shahryari, and T. Ahmadi, Investigate the use of recycled polyvinyl chloride (PVC) particles in improving the mechanical properties of stone mastic asphalt (SMA). Construction and Building Materials, 2022. 326: p. 126780.

[32] Kumar, S., et al., Orange light spectra filtered through transparent colored polyvinyl chloride sheet enhanced pigment content and growth of Arthrospira cells. Bioresource Technology, 2021. 319: p. 124179.

[33] Gangwar, A.K., K. Nagpal, and B.K. Gupta, Triluminescent Functional Composite Pigment for Non-Replicable Security Codes to Combat Counterfeiting. ChemistrySelect, 2018. 3(33): p. 9627-9633.

[34] Wu, P., et al., Adsorption mechanisms of five bisphenol analogues on PVC microplastics. Science of the Total Environment, 2019. 650: p. 671-678.

[35] Mukhamediev, M. and D.Z. Bekchanov, New Anion Exchanger Based on Polyvinyl Chloride and Its Application in Industrial Water Treatment. Russian Journal of Applied Chemistry, 2019. 92(11): p. 1499-1505.

[36] Petrović, E.K. and L.K. Hamer, Improving the healthiness of sustainable construction: example of polyvinyl chloride (PVC). Buildings, 2018. 8(2): p. 28.

[37] Feit, C.G., M.K. Chug, and E.J. Brisbois, Development of S-Nitroso-N-acetylpenicillamine impregnated medical grade polyvinyl chloride for antimicrobial medical device interfaces. ACS Applied Bio Materials, 2019. 2(10): p. 4335-4345. DOI: https://doi.org/10.1021/acsabm.9b00593.

[38] Beveridge, J.M., et al., Covalent functionalization of flexible polyvinyl chloride tubing. Langmuir, 2018. 34(35): p. 10407-10412. DOI: https://doi.org/10.1021/acs.langmuir.7b03115.

[39] Elgharbawy, A.S., & Ali, R.M. (2022). Techno-economic assessment of the biodiesel production using natural minerals rocks as a heterogeneous catalyst via conventional and ultrasonic techniques. Renewable Energy. DOI: https://doi.org/10.1016/j.renene.2022.04.020.