CHLORINATED POLYVINYL CHLORIDE (CPVC) – An Advanced Engineered Material

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Advances in technology have produced many new engineered materials designed specifically to meet the various needs of our society. For example, strong, lightweight plastics are used in almost every application from cars to valves for artificial hearts, and nano-materials with nano-site structures are the latest advanced engineered materials.

Nevertheless, the production, use and disposal of these materials can affect our environment. Through the concept of sustainable development, many industries worldwide have recognised the need to evaluate materials by carefully balancing their long-term benefits versus risks and hazards.

To achieve sustainable development, some of the relevant issues that need to be addressed are: (i) What natural resources are consumed as raw materials?, (ii) How much energy is used during production?, (iii) What are the generated waste streams?, (iv) What is the product's useful service-life?, (v) What benefits does the product provide for society?, and (vi) How is the product disposed of?

In many developed and developing countries, a highly durable engineered material, chlorinated polyvinyl chloride (CPVC), has been successfully used in many applications, especially those that require very long service-life in high temperature, corrosive environments. When using CPVC, little waste is generated, especially when compared to materials used in disposable product applications.

CPVC is a lightweight yet strong material, based on the relatively low petroleum content, and is produced using a very energy efficient process [1, 2, 3]. Therefore, the need for non-renewable energy sources (such as oil and coal) is low compared with the need when using traditional materials such as polyethylene (PE), polypropylene (PP), polybutylene (PB), copper and steel. So, what is this CPVC material?

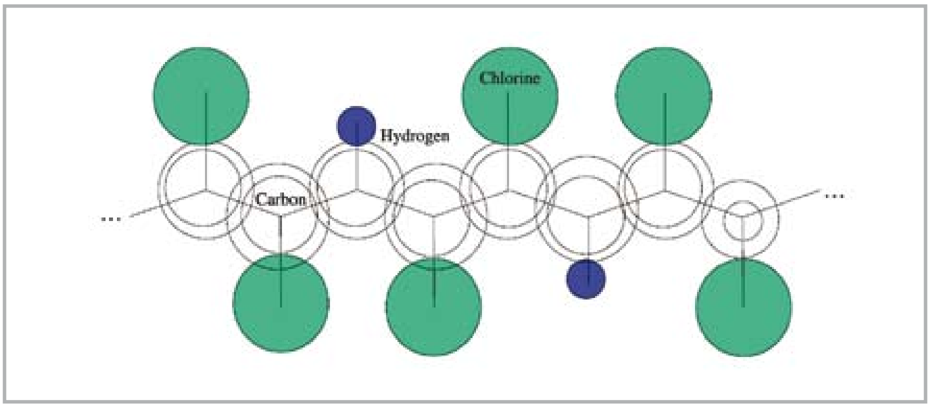

Figure 1: Simplified molecular structure of CPVC polymer

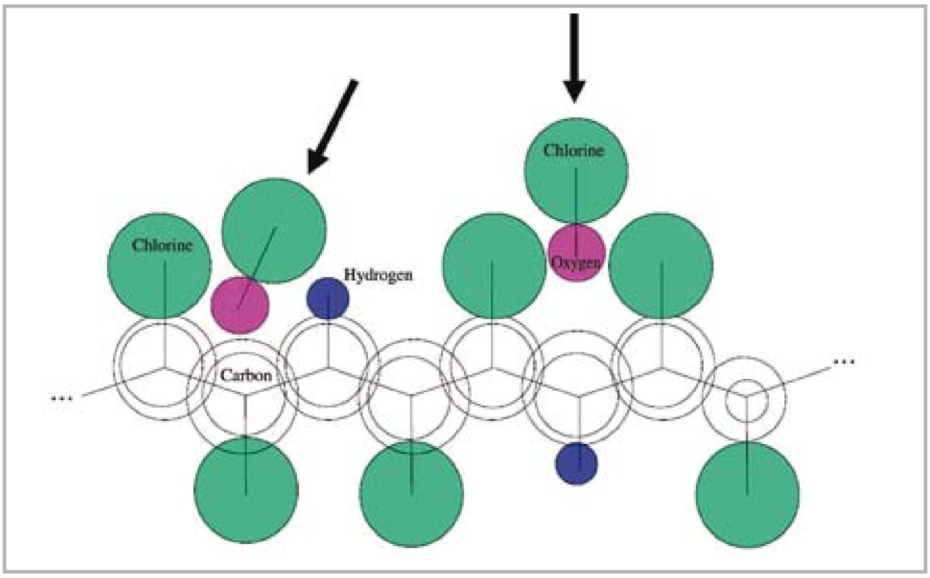

Figure 2: CPVC has excellent natural resistance against hypochlorous acid in water

What is CPVC?

A polymer consists of long chains of atoms, with many thousands of atoms typically in a chain. Some polymers, such as polyurethane or nylon, incorporate nitrogen or oxygen atoms along with the carbon atoms in their backbones. However, vinyls [such as polyvinyl chloride (PVC) and chlorinated polyvinyl chloride (CPVC)] and polyolefins (such as PE, PP and PB) have only carbon atoms in their backbones. It is this primary chain structure that gives each polymer its inherent strength.

Vinyls and polyolefins are distinguished from one another, and gain their individual properties, depending on what is attached to their backbone structure. For example, standard crosslinked polyethylene (Standard PEX) consists of long chains of carbon atoms randomly interconnected,

Table 1: Basic physical properties of CPVC resins
(Courtesy of Lubrizol Advanced Materials; website: www.tempritecpvc.com)

Physical Properties of CPVC	Test Method	Condition	Value
Specific Gravity	ASTM D792	23˚C	1.55 g/cm^3
Water Absorption	ASTM D570	23˚C (100˚C)	+0.03% (+0.55%)
Rockwell Hardness	ASTM D785	23˚C	119 (English unit)
Cell Class	ASTM D1784		23447 (English unit)
Izod Impact (notched bar)	ASTM D256	23˚C	80 J/m o.n.
Tensile Strength	ASTM D638	23˚C	55 N/mm^2
Tensile Modulus	ASTM D638	23˚C	2500 N/mm^2
Flexural Strength	ASTM D790	23˚C	104 N/mm^2
Flexural Modulus	ASTM D790	23˚C	2860 N/mm^2
Compressive Strength	ASTM D695	23˚C	70 N/mm^2
Compressive Modulus	ASTM D695	23˚C	1350 N/mm^2
Coefficient of Thermal Expansion	ASTM D696		1.9×10^{-5} m/m/K
Thermal Conductivity	ASTM C177		0.066 W/m/K
Heat Distortion Temperature	ASTM D648		103˚C
Heat Capacity	DSC	23˚C (100˚C)	0.90 J/g/K (1.10 J/g/K)
Flammability Rating	UL 94	0.157 cm	V-0, 5VB, 5VA
Flame Spread	ASTM E84		15 (English unit)
Smoke Developed	ASTM E84		70 – 125 (English unit)
Limiting Oxygen Index (LOI)	ASTM D2863		60% (English unit)
Dielectric Strength	ASTM D147		492,000 V/m
Dielectric Constant	ASTM D150	60 Hz, -1˚C	3.70
Power Factor	ASTM D150	1000 Hz	0.007%
Volume Resistivity	ASTM D257	23˚C	3.4×10^{15} ohm/cm

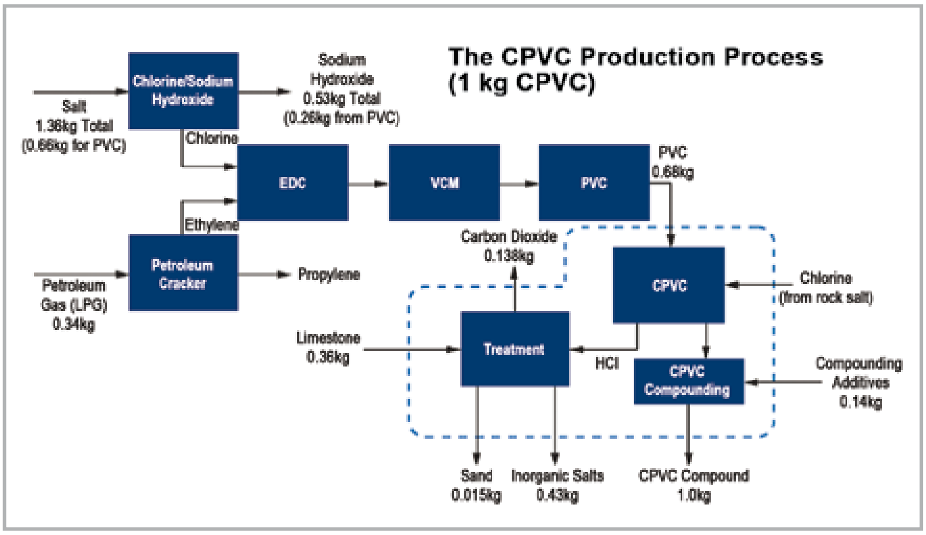

Figure 3: The CPVC production process (courtesy of Lubrizol Advanced Materials)

with all other bonding sites occupied by hydrogen atoms. Silane PEX consists of long chains of carbon atoms randomly interconnected using silane groups. As with standard PEX, all other bonding sites are occupied by hydrogen atoms.

PP has a short one-carbon branch on every third carbon atom in the chain, while PB has a short two-carbon branch on every third carbon atom in the chain. For both PP and PB, all other bonding sites are filled with hydrogen atoms. In CPVC, approximately 80% of the bonding sites on each carbon chain are filled with strategically placed chlorine atoms, and the remaining 20% are filled with hydrogen atom, as shown in Figure 1. It is these strategically placed chlorine atoms that make CPVC many times stronger (both chemically and mechanically) than PE, PP and PB.

When chlorine is added into water for disinfection, it forms hypochlorous acid. Hypochlorous acid is a strong oxidiser, capable of breaking the carbon-to-carbon bonds within polymer chains, thus effectively disintegrating them. The hydrogen atoms surrounding the carbon chains of polyolefins (such as PE, PEX, PP, PPR and PB) are small atoms which are not capable of protecting the chains from attack by the hypochlorous acid in the water [3]. However, the chlorine atoms surrounding the carbon chains of CPVC are large and help to protect the CPVC carbon chains from attack by the hypochlorous acid. This is illustrated in Figure 2.

Moreover, any chlorine atom which actually reaches the carbon chains in the CPVC backbone simply chlorinates the polymer further. This effect is the same as the resin chlorination process, as discussed in the next section of this article. Therefore, in some applications such as hot and cold water piping systems, pipes and fittings made from CPVC material are much stronger and more reliable than those made from other thermoplastics (such as PE, PEX, PP, PPR and PB).

Some of the basic physical properties of commercially available CPVC resins are shown in Table 1. The physical properties of CPVC resins can be further enhanced by compounding with optimum heat stabilisers, impact modifiers, lubricants, processing aids, *etc*.

The Production of CPVC

CPVC material is produced from petroleum (30%-37% of the finished product) and common salt, NaCl (63%-70%), of which there is an almost limitless supply. A simplified CPVC production process is presented in Figure 3. Since CPVC has relatively low petroleum content, its production process uses less of non-renewable hydrocarbon resources compared to most other plastics (such as

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PE, PEX, PP, PPR and PB). As shown in Figure 3, the main raw materials required to produce CPVC resins are polyvinyl chloride (PVC) resins and chlorine.

PVC production begins with petroleum gas being heated in ovens/crackers to produce ethylene and propylene. Ethylene is used in PVC production, while propylene can be used for other industrial processes. Common salt (NaCl) is dissolved in water and split by electrolysis into chlorine and sodium hydroxide (NaOH). NaOH can be used for other processes such as the production of biodiesel, aluminium, paper, soap, *etc*.

The chlorine and ethylene are then reacted to produce ethylene dichloride (EDC), which is then 'cracked' in heated ovens to form vinyl chloride monomer (VCM). VCM is a gaseous material that is strictly regulated by government agencies for health reasons. Nevertheless, in this process, VCM is then transformed into PVC through a one-way polymerisation reaction.

Once PVC resin has been produced from VCM, it is not possible to revert back to VCM. As a result, PVC contains only trace amounts of unreacted VCM. Raw PVC, in white powder form, is obtained after drying. CPVC production begins by mixing PVC and water, and chlorine gas is then introduced into the slurry mixture, under controlled temperature and pressure conditions. In the process, the gas is decomposed into free radical chlorine which is then reacted with PVC, essentially replacing a portion of the hydrogen in the PVC with chlorine.

When PVC is converted into CPVC via a free radical chlorination reaction (typically initiated by thermal or UV energy inputs), the level of residual VCM is reduced even further, until almost undetectable in the final CPVC resins. Therefore, there is virtually no employee exposure to residual VCM from proper handling and processing of CPVC materials using Good Manufacturing Practice (GMP) procedures. The final CPVC slurry is then dried and compounded with ingredients (such as heat stabilisers, impact modifiers, pigments, processing aids and lubricants) necessary for the desired properties and further processing as illustrated in Figure 4.

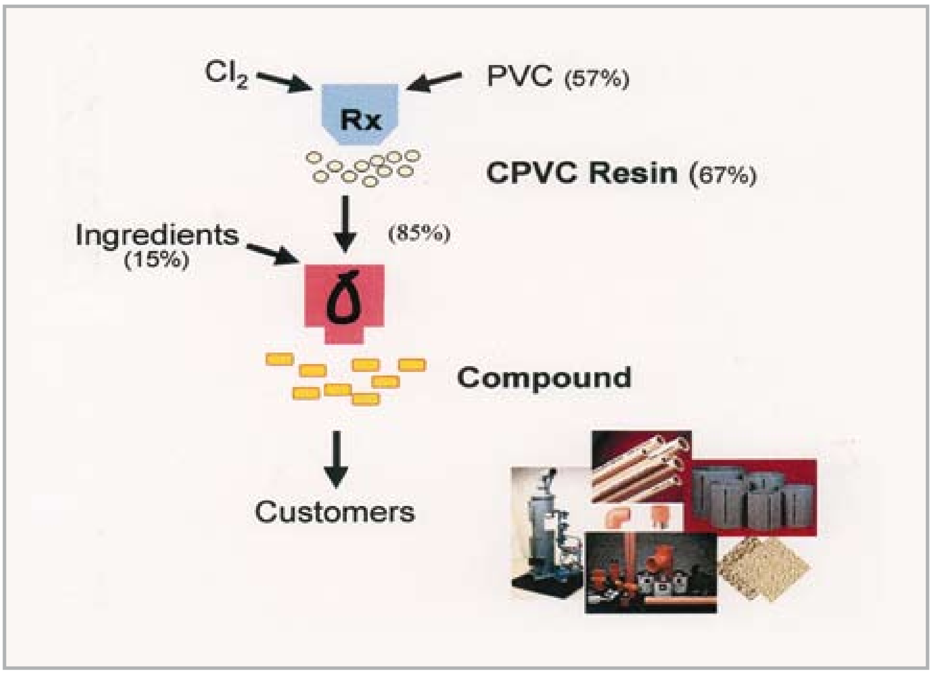

Figure 4: Specialty chemical ingredients added during CPVC compounding process (courtesy of Lubrizol Advanced Materials)

Depending on the chlorination method, a varying amount of chlorine is introduced into the polymer, thus allowing for a measured way to fine tune the final properties. The chlorine content may vary from the base PVC of 56.7% to as high as 74%, although most commercial CPVC resins have 63%-69% chlorine content. As the chlorine content in CPVC material is increased, its glass transition temperature (T_g) increases significantly, thus giving the CPVC material a higher temperature and pressure performance, improved fire retardancy and chemical corrosion resistance.

The Benefits and Performance of CPVC

Being an advanced engineering material, CPVC has excellent chemical and mechanical strength. CPVC is also readily workable, including machining, welding and forming.

Due to its excellent corrosion resistance at elevated temperatures, CPVC is ideally suited for self-supporting constructions where temperatures of up to 93°C are present. The ability to bend, shape and weld CPVC enables its successful use in a wide variety of long service-life process applications such as hot and cold water plumbing systems [4], fire sprinkler piping systems [5], industrial piping and process equipment [6], sheets, tanks, scrubbers, ventilation systems, valves, pumps, profile extrusion and custom injection moulding products [7].

Moreover, CPVC is very light weight compared with most alternative materials, especially metals. This means energy savings when transporting both raw CPVC for processing and the finished CPVC-based products. For example, because of its light weight, high mechanical strength and natural flame retardant properties, CPVC material has been successfully used for the internal cabin compartments of commercial airliners [7].

Furthermore, CPVC has made several ecological and safety-related applications, such as air pollution control and residential fire sprinkler systems, more practical and affordable in many countries. For example, the total energy required to produce a given weight of CPVC pipe is much less than that needed to make an equivalent amount of copper pipe, ranging from 35% to 70% less energy, depending on the pipe diameter. Moreover, CPVC engineered polymer piping systems have been produced to the requirements of ANSI/NSF Standard 14, ANSI/NSF Standard 61, ASTM D2846, ASTM F402, ASTM F437, ASTM F439, ASTM F441, ASTM F493, ASTM F656, CSA B137.6, CSA B137.16, and other related standards [4, 5, 6].

The wide applications for CPVC engineering material are due to the combination of its many inherent excellent chemical and mechanical properties, especially the following:

a) High resistance to corrosion and chemical attack
In many applications, products made from CPVC have often replaced metallic products to provide longer service-life in handling corrosive materials and chemicals such as aggressive water, strong mineral acids, caustics and other corrosive aqueous solutions [6]. As a result, CPVC improves the safety and performance of many process industry applications. Moreover, some materials may be adversely affected by the chlorine contained in the water supply which can cause breakdown of the polymer chains and potential leaks. In this respect, CPVC piping system is unaffected by the chlorine present in potable water supply [7, 8].

b) High purity
CPVC materials [7] have been approved for potable hot and cold water applications worldwide by several organisations, such as the NSF International (USA), Deutscher Verein des Gas-und Wasserfaches (Germany), Water Research Council (UK), Canadian Standards Association (Canada) and Keuringsinstituut voor Waterleidingartikelen (Holland). These approvals are based on extraction studies which have verified that ingredients such as heat stabilisers do not migrate from CPVC at levels that would be unsafe [7, 8]. In Malaysia, CPVC piping systems [4] have been approved by SIRIM QAS, IKRAM and various state water agencies, such as PBA Pulau Pinang, JBA Negeri Sembilan, JBA Negeri Pahang, Jabatan Air Negeri Sabah, Syarikat Air Melaka Bhd, Syarikat Air Johor Holdings and Syarikat Air Terengganu.

c) Flame resistance and low smoke generation in fires
Because of its low petroleum content, CPVC is self-extinguishing and has a relatively low smoke generation. CPVC has a much higher Limiting Oxygen Index (LOI) value than many other common materials of construction. Therefore, CPVC does not support combustion under normal atmospheric conditions. Moreover, any smoke generated by CPVC is no more toxic than that from traditional building materials such as Douglas Fir [7, 9].

d) Good mechanical strength at high temperatures
Compared with many other thermoplastics, CPVC has excellent mechanical strength over a broad temperature range. This enables CPVC to be used in pressure piping applications for up to 50 years at temperatures as high as 95°C [4, 5, 6].

e) Low bacteria build up
Many studies [10, 11, 12] have shown that biofilm and bacteria build up (such as Legionella bacteria) in CPVC piping system are far lower than with alternative piping materials such as copper, steel and other thermoplastics.

Conclusion

In our present economic environment, consumers as well as industries have to use critical value judgement on any investment made which requires extensive evaluation of its cost-performance values. In the field of engineering materials, advanced engineered CPVC offer a unique and previously unattainable alternative to plastics processors and consumers. Environmental friendly CPVC materials have been successfully used for many applications, such as hot and cold water plumbing systems, fire sprinkler piping systems, industrial piping and process equipment, sheets, tanks, scrubbers, ventilation systems, valves, pumps, custom profile extrusion and injection moulding products.

In the near future, the author will contribute more articles on the various technical aspects (such as chemical resistance compatibility, mechanical properties and case application references) of CPVC materials. ■

For more information on CPVC engineering materials, the author can be contacted by email at johneow@hotmail.com.

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