A
der world PVC demand collapsed in 2008 due to the crisis (-8 % compared to 2007), and declined by a further 2.5 % in 2009, it grew by a good 10 % in 2010 compared to 2009. At 34.8 million t in 2010, it almost reached the 2007 level, which, at 35.4 million t, was a record year for PVC.

World demand for PVC is primarily determined by the construction sector. Globally, the most important applications for PVC are pipes and fittings (43 %), profiles and tubes (18 %), rigid film and sheet (17 %) and cables (8 %) (Fig. 1). Since construction activity in the euro zone and USA is still historically very low, PVC growth in 2010 was primarily supported by intensive building activity in the BRIC states (Brazil, Russia, India and China).

Strong demand growth in China is supported by the construction of local PVC production plants. Over half of world production capacity of 46 million t for PVC (53 %) is now located in Asia. PVC production capacities are shown in Figure 2 according to regions. Investment in PVC production capacities in China will increase in coming years, so Western Europe and North America will continue to decline in relative importance. At almost 17 million t of PVC consumption, Asia is also the biggest market by far, followed by Europe and North America (Fig. 3).

The European market for S-PVC grew by 10 % in 2010. Following the economic crisis, this market has still not picked up, particularly in Western Europe. In Western Europe, S-PVC demand was still 3.9 million t in 2010, and thereby still 1.1 million t below the 2007 level. Spurred on by live-
dy demand for rigid window profiles, the market in the CIS states fared considerably better. The commitment shown by major profile extruders with their own production plants in Russia gave them a significant competitive edge here.

A more dynamic recovery emerged for paste PVC. European growth in 2010 was +18 % compared to 2009. This market recovery is also driven by demand growth in the CIS states, which is covered by further increasing exports by West European producers. Consolidation of the European PVC market is continuing. For example, Kerling, Runcorn, UK, (previously Ineos ChlorVinyls), the European market leader in PVC standard products, took over the PVC and chloralkali activities from the Tessenderlo group.

Universally Applicable. Thanks to PVC’s wide variety of uses and impressive solutions, worldwide demand is still at pre-crisis levels. The new VinylPlus sustainability program builds on the success of the Vinyl 2010 voluntary commitment.
Group, Brussels, Belgium, in August 2011, thereby rising one place in the global ranking. The production capacities of the world’s biggest PVC manufacturers are shown in Figure 4.

Capacity utilization of the European PVC producers, which had fallen to 70 % during the crisis is currently back at 90 %. Besides the partial market recovery described above, this is partly the effect of shutdowns. Of the almost 9 million t of PVC capacity in Europe, approximately 0.6 million t was removed from the market:
- Hellenic Petrol (Thessaloniki, Greece, 100 kt/a); shut down since mid-2008,
- Ineos ChlorVinyls (Barry, UK, 125 kt/a), shutdown since January 2010 and
- Vinyls Italia (Italy) with plants in Porto Marghera (200 kt/a), Porto Torres (65 kt/a) and Ravenna (120 kt/a), shutdown since 2009 (its re-commissioning is still open).

Process Developments

About 90 % of worldwide PVC production capacity is based on the suspension process. On an industrial scale, this is entirely a batchwise process. Vinyl chloride, water, protective colloids and organic peroxide initiators are charged to the reactor, and subsequently polymerized under pressure and stirring. An initiator dosing process has recently also become established. The resulting heat of polymerization is removed via the cooled reactor wall, cooled fittings, such as baffles, and via reflux coolers. By varying the stirring conditions and the protective colloids used, (such as polyvinyl alcohols or cellulose ethers), it is possible to adjust the grain size and the grain porosity, which is important for additive absorption.

Though not yet ready for industrial application, the academic and industrial work on controlled/living free radical polymerization is scientifically interesting. The aim is to influence chain defects in order to improve physical properties. It is also being studied whether there are production advantages to polymerization in non-aqueous media.

On an industrial scale, paste PVC is produced by a batchwise or continuous emulsion process. Various forms of the microsuspension process (batchwise) are also performed. The strategic use of surfactants and surfactant mixtures is essential to the process and the end product. Besides stabilizing the aqueous polymer dispersion, special emulsifier systems can be used to adjust the viscosity of the plastisol (PVC/plasticizer dispersion) and the end product properties as required. New product developments are aimed at reducing the plastisol viscosity in order to reduce the need for processing aids such as organic diluents.

Products and Applications

Thermoplastic Applications: Following the economic col-lapse in 2008/2009, construction-relevant applications only recovered slowly in Europe. Nevertheless, the window profile segment in Europe remained the biggest individual application for PVC. K values between 65 and 68 are mainly used here; copolymers of vinyl chloride and acrylates are also used. The latter can be readily used with other impact modifiers. Standard S-PVC, on the other hand, is used with impact modifiers based on acrylate, chlorinated polyethylene (CPE) or PVC graft copolymers.

A characterizing feature of the profile sector in recent years has been the changeover of stabilization systems. Now that the phasing-out of cadmium since 2007 (EU-27) is complete, processors have been concentrating on replacing lead-containing stabilizers in accordance with the PVC industry’s self regulation. Most profile extruders have already successfully implemented this. Complex calcium-zinc-based systems are usually used (Fig. 5).

Besides stabilization, the use of recyclates is also playing an ever more important role. In Germany alone, over 25,000 t of old window profiles were collected as part of the Rewindo recycling initiative in 2010 and reprocessed into about 17,000 t of PVC recyclate. These raw materials are processed taking into account the profile design, processing technology and material logistics.

Besides window profiles, PVC is also processed into a wide range of other profile shapes for a wide variety of applications, such as furniture, construction, automotive and electrical accessories. S-PVC with K values between 57 and 68 is used for this. E-PVC with K values of about 70 is used as an effective processing aid for faster gellation and improving the end product properties. This can be used for particularly effective optimization of mechanical properties, surface quality and gloss.

In the second biggest European PVC application segment, pipes and fittings, the use of lead-free stabilization systems is being promoted. PVC is predominantly used for non-pressurized sewer and drainage systems and cable conduit. For pressurized applications, PVC is predominantly used for industrial pipes, but also for supply systems for use with drinking water. As with window profiles, K values of 65 to 68 are usually used. For foam formulations in foam-core pipes, on the other hand, lower K values of 57 to 60 are used. Because of the excellent cost-performance ratio, however, a trend towards traditional solid-walled PVC piping can be seen again. As with window profile, the use of recyclates is increasing in importance in pipes, too.

Rigid PVC sheet is used for a wide range of applications. S-PVC with K values from 57 to 60 is usually used for this. E-PVC with K values of about 60 improves and speeds up gelling and helps to reduce flow lines and increase gloss. In addition, the emulsifiers that are present improve the...
antistatic properties. For high drawing ratios, e.g. in packaging sheet, or good lamination properties (e.g. credit cards), vinyl acetate copolymers are used. Modern food and pharmaceutical packaging places high demands on residual vinyl chloride content, thermal stability and color. To provide these films with functions, such as barriers against oxygen or water vapor and antibacterial properties, they are usually coated or formed from multilayer structures, including combinations with other polymers. For packaging branded articles or pharmaceutically products, films with built-in counterfeit protection are used to prevent product piracy.

Specialties with high K values provide additional functionalities, such as antiblocking behavior, or surface flattening or texturing, depending on the particle size and amount used.

Stabilization of rigid films is still performed using organotin systems. Under REACH no significant changes in methyl or octyl tin stabilizers can be expected, only the use of dibutyltin stabilizers is subject to restrictions, primarily in the case of flexible PVC.

For flexible PVC profiles, cables and tubing, K values of 65 to 80 are used. Higher K values improve the physomechanical properties and heat deflection temperature. For window gaskets with their high elastic recovery requirements, even higher K values are used, usually in combination with acrylate graft copolymers. This allows the amount of plasticizer and migration tendency to be reduced. In addition, these formulations are lightweight and weathering resistant, so that carbon black does not need to be used, and the trend towards light gray shades in window design is supported. Modern (post-) coextrusion processes allow the connection to the PVC profile to be selectively controlled, from firmly welded to non-welded.

Flexible films are produced from PVC with K values from 65 to 70. In the biggest individual segment, waterproofing with roofing sheet and sealing sheets, high resistance to light and weathering must be ensured for long service life. Here, too, plasticizer-free systems based on internally plasticized graft copolymers of VC and ethylene vinyl acetate or acrylate are increasingly being used. A relatively new application field is the coating of vehicles with printed flexible PVC film for decoration or as advertising, known as “car wrapping.”

PVC for Paste Processing:
The PVC paste process permits easy production of a variety of different finished articles. The advantages of paste processing come particularly to play for coating all kinds of substrates and for manufacturing complex molded articles. Large coating widths and multilayer structures, as well as the coating of complicated geometries, can be realized at reasonable effort. Processors have many specialist PVC products available for adjusting the processing and end product properties. With suitable formulation with additives, they offer wide scope for precise adaptation to a diverse range of requirements.

Important application segments for paste PVC include flooring, vinyl wall coverings, artificial leather for fashion articles and leather-look bags, technical coatings (membranes, e.g. for architectural textiles), special synthetic leathers for automotive interiors (Fig. 6), metal coatings (car underbody protection and lid seals) and rotary casting (all kinds of hollow articles, e.g. balls, buoys or fenders).

An important topic that is currently occupying processors and additive manufacturers alike is minimizing emissions from the finished article (“low VOC”). This is an important trend for products used in interiors (Title photo). Formulations are optimized to avoid emissions. Processors preferably use emission-free or low-emission additives. Since liquid components are preferably used for the optimization, it can increase the viscosity of PVC, which is often not desirable. Paste PVC with low viscosities and extenders for viscosity reduction are therefore becoming increasingly important. To this extent, “low viscosity” is also gaining in importance among manufacturers of paste PVC. One example of an innovation in this field is Vinnolit EXT, an extender that offers improved viscosity reduction and optimized mechanical properties. Additive manufacturers are also working on this area, and low-VOC →

![Fig. 4. Production capacities of the world’s biggest PVC manufacturers in 2011 (source: Vinnolit)](image)

![Fig. 5. PVC window profiles: changeover of stabilizer system from lead to calcium-zinc-based systems (photo: Inoutic)](image)
and AgBB-compliant additives (stabilizers and viscosity modifiers) are gaining in importance in portfolios of construction products.

Developers are also focusing on plasticizers. There are also efforts to reduce the amount of plasticizer in formulations in order to prevent plasticizer migration. On the other hand, rapid-gelling phthalates (e.g. BBP or DBP) are being replaced with less potentially harmful alternatives. Though the same gelling rate cannot always be achieved. Interest in fast-gelling PVC grades is therefore increasing. Vinyl chloride/vinyl acetate copolymers (as paste PVC and extender) are therefore increasing in importance. These copolymers increase the gelling rate and can compensate for deficits caused by replacement of the plasticizer. Copolymers can also help in reducing plasticizer migration and the amounts used. While copolymer-containing formulations require less plasticizer to achieve a particular flexibility, the plasticizer is more strongly bound to the resin matrix, so that migration is additionally reduced.

Constant optimization is also sought by increasing equipment speed or reducing processing temperatures (to save energy). Here, too, the above-mentioned topics are important. Higher plant speeds require lower viscosities; lower processing temperatures are only possible with adequate gelling. For example, in the car underbody protection sector, in which lower processing temperatures are particularly important, a trend towards increasing the dosage of copolymers is apparent.

**Plasticizer:** Replacement of DEHP, which was the dominant plasticizer for decades, with longer-chain phthalates (DINP and DIDP) is continuing. The market share of DEHP in 2009 was only 11 %, while that of DINP and DIDP had increased to 70 %. Alternatives such as citrates, DINCH or terephthalates are increasing in importance.

**PVC and Sustainability**

This year, the European PVC industry – raw materials manufacturers, manufacturers of stabilizers and plasticizers, as well as PVC processors – presented the concluding report of their self-regulation on sustainable management, and reached or even exceeded all their goals. In 2000, the industry committed itself to Vinyl 2010, a 10-year program with quantitative goals, deadlines and an independent annual audit to further minimize the environmental impact of the manufacture, processing, use and disposal of PVC. The most important successes in the past ten years include, for example

- considerably increasing the recycling of PVC consumer waste to over 260,000 t in 2010,
- exceeding the intermediate goal of 50 % for reducing lead stabilizers in EU-27 (-76 % in 2010, complete phase-out planned by 2015),
- supporting the EU risk assessments for phthalates and shifting phthalate use from low-molecular to (safer) high-molecular phthalate plasticizers (see above), and
- introducing and EU-wide checking of strict emission standards for the production of S-PVC and paste PVC, and EDC and VCM precursors.

Vinyl 2010 has shown that PVC is recyclable on an industrial scale and is being recycled. At the same time, PVC formulations have been modified to improve the reliability and environmental compatibility of PVC applications while maintaining the technical performance. PVC has therefore changed significantly in the last ten years.

In June 2011, the European PVC industry in Brussels, announced new, ambitious goals for sustainable development by 2020. The new VinylPlus sustainability program builds on the success of Vinyl 2010. The new goals are based on five sustainability challenges, which were jointly identified with TNS (The Natural Step), an internationally recognized non-governmental organization active in the field of sustainable development, and have been discussed with external stakeholders. In detail this means making a further quantum leap in the amounts of PVC recycled, and the development of innovative recycling technologies, taking account of widely held concerns about persistent organo-chlorine emissions, use of additives based on acknowledged sustainability criteria, increasing energy efficiency and the use of renewable energies and sustainable raw materials in PVC production, and promoting sustainable development in the entire PVC supply chain.

Sustainable development is a global challenge. The European PVC industry therefore sees an important objective in making the approach of VinylPlus known throughout the world by sharing proven methods with others and encouraging voluntary initiatives of the PVC industry throughout the world.

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