Back to basics: revisiting the revolution of thermoplastics

For many pumping applications, the use of metallic materials is undesirable because of problems with corrosion and contamination. In many such cases the use of thermoplastics can provide a successful solution. In this contribution from the USA, Nancy Westcott of Westcott Distribution with Jane Callahan of Fordham University briefly survey the history of the development of thermoplastics and review the different types available, their benefits and industrial applications.

In these uncertain economic times, getting the most for your money in industry is a top priority. The need for a premium pump does not decline with the stock market. Quality, reliability and durability are important to end users as they focus on the lifetime costs of a pump rather than the initial ticket price. A pump that is relatively inexpensive but breaks down after a short period of time will have to be replaced with a new one. Pumps that leak have unseen expenses in inventory loss, cost of labour and material in cleanup, not to mention the ever-present issue of compliance. Pump components that leach into chemicals may affect not only the chemical with which they are being used, but could actually ruin the final product. Compliance has become a priority for supplier and consumer in pump choice. Governments have created and will continue to create stringent standards for chemical use in production; violations can lead to heavy fines.

Corrosion is an enormous problem. The US Federal Highway Administration (FHWA) recently released a breakthrough two-year study on the direct costs associated with metallic corrosion in nearly every US industry sector, from infrastructure and transportation to production and manufacturing. Results of the study show that the total annual estimated direct cost of corrosion in the USA is a staggering US$276 billion – approximately 3.1% of the nation's gross domestic product (GDP), according to the *Flow Control Magazine* website.

Today, pumps and pump parts are manufactured from a full array of traditional metallic and modern thermoplastic materials. Pumps manufactured from carbon steel, stainless steel, nickel alloys and aluminium have been the backbone of industry for a very long time. Of relatively recent origin, synthetic materials offer nearly all of the advantages of metal in combination with wider chemical compatibility and fewer drawbacks – and at a significantly reduced price. With the proliferation of chemicals in industry, manufacturing plants require speciality pumps that can handle a full range of process fluids. When comparing the pros and cons of different pumps, it is always a toss up between quality and affordability. Thermoplastics have become extraordinarily successful because they satisfy both requirements.

Figure 1. This polypropylene drum pump on a plastic container shows the versatility in manufactured shapes.

Brief history of thermoplastics

In order to fully understand the benefits of thermoplastics, it is best to begin at the beginning. The first thermoplastic, discovered in 1862, was cellulose nitrate. It was created by heating a combination of wood fibres and nitric acid to an extreme temperature. This product was then injection moulded and the resulting plastic material was found to be unlike anything in nature. Initially used as insulation for electrical wiring, cellulose nitrate plastic proved to be highly flammable and dangerous to use. The next generation in plastic, formed by compression moulding in 1907, was phenol formaldehyde (PF). Improvements in PF in the 1920s offered translucency and the ability to be pigmented. In the 1930s, polyvinyl chloride (PVC) became available. It was tough, reliable, provided exceptional chemical resistance, and has become a staple in chemical production plants.

In 1954, Natta and Ziegler created the first polypropylene (PP) in Italy by applying endothermic heat and pressure to carbon and hydrogen thus creating a bonding of the elements. This was the first hard plastic created, and it is an especially workable polymer. Once made, the heating and cooling process can be repeated many times without drastically altering the polypropylene's properties. Polypropylene was the first generation of modern plastic materials, and it is still the most popular of all thermoplastics today.

The advent of the semiconductor and computer industries in the 1960s opened the door for the extensive use of thermoplastics. When using metallic pumps, manufacturers of printed circuit boards found that even traces of metallic contamination of the chemicals used in production would ruin the end product. Polypropylene pumps, which had better chemical compatibility than metal, delivered the fluids with no contaminants, making plastics and plastic pumps a mainstay of the manufacturing industry.

With each succeeding decade, extensive research has brought substantial improvements to old plastics and the development of new plastics, both thermoplastics and thermosets. PP, PVC, polyethylene (PE), polyester, Teflon, Kynar, epoxy and Kevlar are regularly used in place of metal across all industries.

Benefits of plastics

Overall, plastics have more chemical compatibility than steel and therefore a manufacturer can use a plastic pump with a wider range of fluids for a longer time period. Industries ranging from food production through pharmaceuticals to electronics require that many fluids be pure or ultrapure to meet Government regulations and manufacturing criteria. Contamination is a big issue. Due to their physical properties, thermoplastics and thermosets rarely leach contaminating extractables into fluids. Many fluids will absorb moisture from the environment making them corrosive towards vulnerable metals. This can cause rusting in a non-stainless steel metal pump, and the eroded materials can flake into the fluid content and contaminate it. While stainless steel is an excellent product for fluids transfer, oxidation of non-stainless steel in food production can ruin the end product. Polypropylene, PVC and Kynar are very resistant to alkali materials, which makes them very useful with strong lyes, detergents and soaps. It is unlikely that ionized water, a very aggressive fluid, will destroy polypropylene. In addition, when a gritty material is being pumped through a plastic, it will not abrade or erode the plastic as it might do with a soft metal such as aluminium.

Thermoplastics are inexpensive in many ways: they are inexpensive to produce and, in most circumstances, they are very durable. With a view to lifetime costs, a well-produced plastic pump will need to be replaced less often. The overall repair and maintenance costs will be significantly reduced because the parts do not degrade over time. Thermoplastics also deliver the advantage of translucence should that be desired, and various colours can be added during the moulding process.

The process

The word 'plastic' comes from the Greek word *plastikos*, which means 'able to be shaped or moulded by heat'. Because thermoplastics are highly malleable, pumps can be made with various wall thicknesses and shapes. This allows for more flexibility in how the pump can be moulded. The most popular process is **injection moulding**, in which the plastic is heated and forced into a closed mould by a plunger. This process delivers products in a full range of textures, depending on the tooling, from a mirror polished surface for the inside of a pump to a textured surface for an aesthetically pleasing external surface. And, injection moulding allows the creation of very complex – or simple – parts, which are reproduced with precision accuracy.

Another option is **blow moulding**, which is derived from glass blowing. Compressed air is blown into the shape of the tool: the most common product is the PE soda bottle. **Rotational moulding** is ideal for thick-walled products. The plastic is placed in a closed mould, heated, rotated, and then set with cold air. **Extrusion** is a process that can be compared with squeezing ketchup from a container. The heated plastic is forced through a hot barrel, through a die and then cooled with water. The process of **compression moulding** is forcing a heated polymer into a shape by compressing it with a pressure that

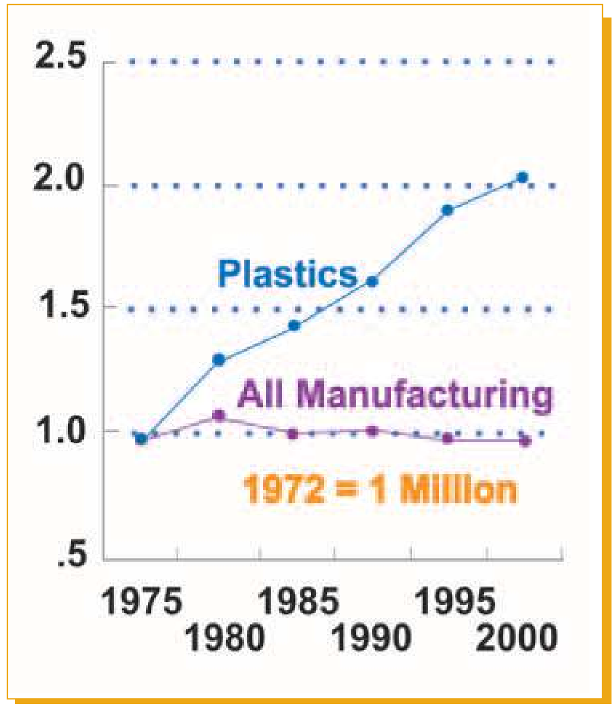

Figure 2. From 1975 to 2000 employment in plastics manufacturing grew 3% per year while overall manufacturing employment was flat. (Courtesy of the Society of the Plastics Industry, Inc, www.plasticsdatasource.org)

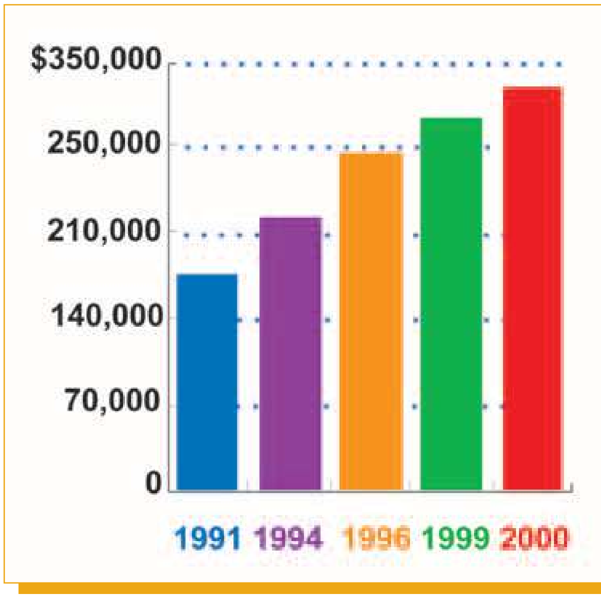

Figure 3. US plastics shipments, including captives, from 1991–2000 in millions of US dollars. Shipments of plastics grew 6.5% per year over this period, compared to overall manufacturing growth of only 1.8% per year. (Courtesy of the Society of the Plastics Industry, Inc, www.plasticsdatasource.org)

can be the equivalent of up to several hundred tonnes. Finally, in **vacuum moulding**, air is drawn out from under a softened plastic sheet, and the plastic forced over a mould by a surrounding pressure. All of these processes are quick, prolific and good for high-volume production. The components of thermoplastics make these processes successful. The chemicals are joined together by heat, bond, and then harden upon cooling.

Industry applications

The fact that thermoplastics can be heated and cooled many times without damage makes them ideal for recycling. Polypropylene has the lowest environmental impact of any material, including both synthetic and traditional, because it is the easiest to reuse. While recycling thermoplastics is positive for the environment, it is also an opportunity for the manufacturer. PP is non-hazardous, which allows employees to work in safety and without irritation. Weight is also a consideration. PP pumps are particularly lightweight, resulting in minimized packaging and reduced shipping costs. This source reduction also means that the manufacturer can put more contents in each pump since the pump itself accounts for very little weight. In production, copolymers can be coated without organic solvents or the evaporation of water, thereby reducing both energy requirements and emissions into the atmosphere.

Obviously, choosing a thermoplastic pump has many more advantages than optimal recycling. One of the most attractive aspects about thermoplastics is their wide variety, with each type having unique applications. The specific benefits and disadvantages of each polymer seem customized for different types of applications. One common drawback found in most plastic pumps is that the temperature maximum is lower than metallic pumps. The exception is Teflon; however, Teflon is the most expensive of the plastics and can be more expensive than steel.

Thermoplastics can be categorized into two groups: low-priced/high-tonnage material, such as PVC, PE, polystyrene and PP; and higher-priced/lower-tonnage materials such as acrylic, ABS, nylon, polycarbonate and thermoplastic polyesters. With the exception of ABS, nylon and acrylic, these materials offer higher temperature ranges.

PVC is self-extinguishing, making it a good tool for cable insulation.

Polyethylene is exploited for its toughness, flexibility, chemical resistanceand low density, and is used in anything from electrical applications to furniture.

Nylon materials have the benefits of thermoplastic strength but also absorb moisture, which ultimately affects their stiffness and slows their ability to dry.

Polycarbonate has strength but is mostly used for its high transparency, which makes it suitable for use in glazing and street light fittings.

Figure 4. A variety of plastics in a typical industrial environment.

Modified polyphenylene ethers are tough and are primarily used for electrical insulating, office machine and washing machine parts. When blended with polystyrene, they have more advantageous properties at a lower cost than alone.

Polysulphones can endure high temperatures and are used in smoke hazard avoidance. These two characteristics make them ideal in the production of electronic equipment and aircraft ducting.

Thermoplastic **polyesters** have especially good abrasion resistance. They are widely used in film form for packaging and photographic applications.

Polypropylene is the most versatile and durable of all thermoplastics. Its combination of strength, long-time performance, stiffness and chemical and temperature resistance is offered at a low price. Among other uses, this plastic is useful both for transporting and containing a full range of process chemicals and then also for decanting them from the container when needed. Polypropylene also has a superior tensile creep reduction rate, which means it has the ability to resist warping under a constant load applied over time. It has the lowest density of all thermoplastics and thus has the lightest weight. For its weight, it is the most durable plastic on the market.

Summary

When comparing the pros and cons of different pump materials, it is almost always a toss-up between quality and affordability. Thermoplastics like polypropylene have become extraordinarily successful because they satisfy both requirements, delivering reliable and durable performance throughout their life. With a view to lifetime costs, a well-produced plastic pump will need to be replaced less often than its metal counterpart. The only products that create demand for more of the same are the ones that work, that deliver and that satisfy. This can be said for thermoplastics. The extensive use of thermoplastics today prove that their applications in industry are effective. Continuing R&D will contribute to future industrial efficiencies and safer, more effective fluid handling.

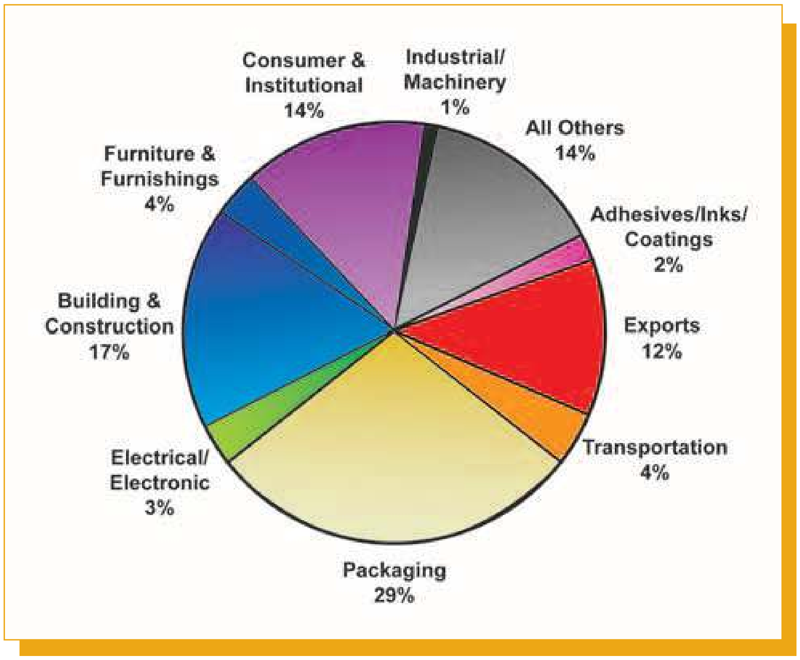

Figure 5. Major markets for thermoplastics in 2001 derived from plastic resins sales volumes and captive use data as compiled by VERIS Consulting. (Courtesy of American Plastics Council, Plastics Industry Producers Statistics Group; modified.)

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