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1 Introduction

This book is the second of a set of three being published by the ENERGYWISE Plastics project. The intention is to offer advice on energy efficiency within the polymer industry. The three books come under the main title of *A Practical Guide to Energy Management* and individual titles are aimed at Managers, Processors, and finally the management of Facilities and Utilities.

The ENERGYWISE Plastics project is partly funded by the Leonardo programme which supports the development of skills and training. It funds work placements for trainees, workers and staff, and supports European projects to discuss common issues or develop training materials, courses and frameworks. Leonardo is part of the European Commission's Lifelong Learning Programme.

1.1 The Need for Energy Reduction

The European plastics industry is one of the most important sectors in the European Union (EU), with an aggregate production of almost 40 million tonnes, representing a value of some 250 billion and applications in a vast variety of industries. However, the sector is mainly dominated by small and medium enterprises (SME) who are coming under increasing pressure from low wage economies as well as increases in EU enforced legislation and a rise in the price of energy and materials. While global demand for plastics materials has continued to grow, profit margins of European producers have suffered due to increased expenses for raw materials and energy. Because of the uncertain global economic climate and market pressures on key customer sectors, the main focus of many processors is process optimisation and cost reduction rather than business expansion.

There are many reasons for wanting to improve energy efficiency, however, the most compelling reason for the plastics processing industry is that wasting energy costs money and this is reflected in the bottom line. With rising energy costs, soaring raw material prices and the impacts of climate change, the need to monitor and reduce energy consumption is more important than ever before. As with most industries, controlling costs is critical to sustainability and profitability. However, energy costs can be controlled and often reduced, by implementing measures that do not require significant investment. In many cases improvements can be made for low or no cost, by making slight changes to the way a process or equipment is operated to optimise its performance. Energy efficiency offers short- and long-term benefits and by increasing the efficiency of a business the bottom line can be strengthened. It will be the ability of businesses to make rational and informed decisions about the use of energy on site that will play an increasingly important role in helping to manage the new challenges in a changing business climate.

According to the *European 2008 Environment Policy Review – Annex 1*; 'energy use (including transport) accounts for 80% of all greenhouse gas emissions in the European 15'.

Following agreement at the European Council in 2007, the EU is committed to:

- Achieving at least a 20% reduction in its greenhouse gas emissions by 2020 compared to 1990, or 30% if other developed nations agree to take similar action.
- An increase in the use of renewable energy, to 20% of all energy consumed. This is a binding target. However, the plan allows flexibility in how each country contributes to the overall EU target.
- A 20% increase in energy efficiency.
- An increase in the use of bio-fuels, to 10% of all fuel used in transport.

Energy efficiency and energy management have never been more important themes than now. With the advent of the climate change levy within the UK, companies have found an increasing burden (or incentive!) on them to reduce energy consumption and improve manufacturing processes, without significantly adding to financial burden. In reality of course, there are three major drivers for increased concern with energy – security of supply, legislation and cost.

1.2 The ENERGYWISE Plastics Project

The ENERGYWISE Plastics Project has an objective to develop an elearning platform and training materials for those working with the plastics industry to learn and understand how to manage and reduce their energy consumption. The project uses a blended learning approach, offering interactive on-line modules and supporting hard-copy resources, focusing on the needs of SME. The course has three entry points and is aimed at different levels/grades of staff within an organisation:

2 Injection Moulding

2.1 The Injection Moulding Process

Injection moulding is one of the prime manufacturing processes for making parts from plastic material. It is a fast process and used to produce large numbers of identical items and these can be anything from high precision engineering components to disposable consumer goods. The process involves clamping two moulds together into which a molten polymer is injected. High pressure is used to obtain fast filling speeds and stop the mould being over filled. Once the polymer melt has been set to the shape of the cavity, the mould is opened, the part ejected and the process restarts. **Figure 2.1** shows the six main stages in the injection moulding process.

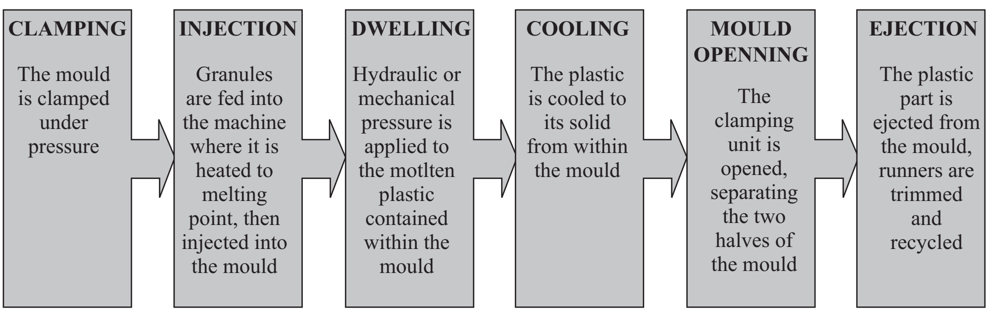

Figure 2.1 The six stages of the injection moulding process. Reproduced with permission from *Low Energy Plastics Processing – RECIPE European Best Practice Guide*, 2006 [1]. ©2006, RECIPE

As the plastic material needs to be heated until it melts, forced into the mould at high pressure and then cooled until solidification, the injection moulding process is quite energy intensive.

2.2 Where and How to Save Energy in the Injection Moulding Process

In an increasingly competitive environment, injection moulders are driven to reduce their costs per part by every available means. There are many other operational elements to consider in achieving this, however, energy consumption is an important factor to address. The energy use in injection moulding can be viewed as occurring in two phases: a high power requirement over a short time as polymer is injected and parts are ejected and a low power requirement over a long period of time as the injected polymer cools.

Energy is required, not just to melt the polymer, and subsequently cool it down again, but to generate the pressure to force the polymer into the mould. Additionally energy is used to open, close and hold the mould under pressure while the part is formed and cooled

Figure 2.2 shows the share of energy used by all the equipment in a typical moulding plant. About 60% of the energy cost can be assigned to the injection moulding machines and their operation presents the greatest opportunity for energy savings.

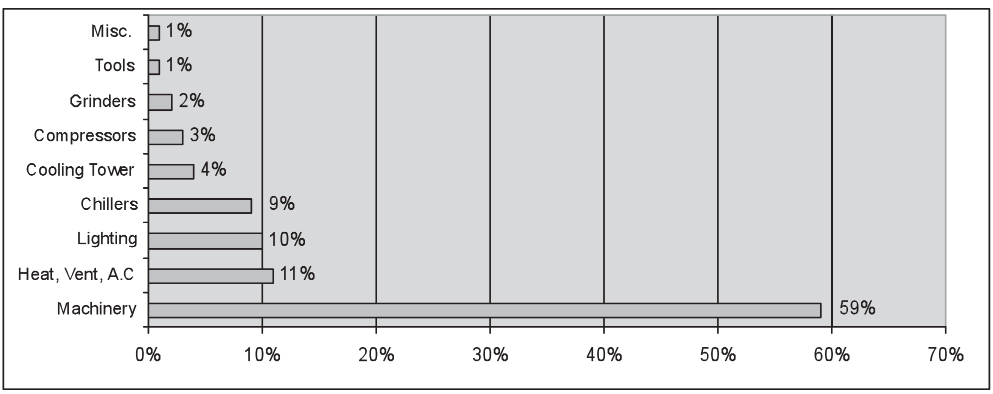

Figure 2.2 Share of energy consumption by typical devices at an injection moulding plant. Reproduced with permission from *Low Energy Plastics Processing – RECIPE European Best Practice Guide*, 2006 [1]. ©2006, RECIPE

The power required to manufacture an injection-moulded part depends on the following factors:

3 Extrusion

This chapter describes some practical ways of improving energy efficiency when processing thermoplastic materials by extrusion. It covers:

- The extrusion process
- Reducing energy consumption in the extrusion process
- Action points for an energy efficient operation
- Case studies illustrating best practice and potential savings

3.1 The Extrusion Process

Extrusion is a continuous process used for the production of semi-finished goods such as films, sheet, profiles and pipes. Extrusion is a very broad technology that includes a great number of very different types of processes. Although the design of the die and some components of an extrusion line differ depending on the type of extruded product, in each case, the same stages of production can be found.

Plastic pellets are fed into an extruder through the hopper or through a gravimetric feeder if blends are used. The material is continuously fed this way into a heated barrel and carried along by a rotating screw. As it is conveyed it is compressed and melted. The screw is moved mechanically by a motor. The softened plastic is then forced out thorough a die, which turns the melt into the required shape, and directly into cool water where the product solidifies. An extrusion line typically involves six main stages (**Figure 3.1**).

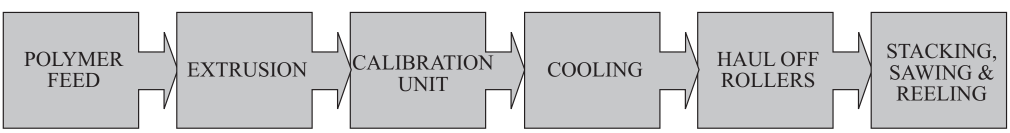

Figure 3.1 The six stages of the extrusion process

The two first stages are practically the same for all extrusion processes, but the other four stages can differ a great deal depending on the type of extrusion process.

From the previous stages, it can be seen that the extrusion process uses electricity in motor drives, extruder line ancillaries (e.g., heaters and handling), and general utilities such as cooling water, vacuum or compressed air. For the extrusion process itself (the process of melting and compressing the polymer in order to be feed it into the die), there are two main ways in which electricity is consumed: for heating and melting the polymer and for moving the molten polymer forward by the use of a screw connected to a motor. In the calibration unit, the main electricity consumption comes from the vacuum systems usually used for calibration and also for heating and cooling.

During the cooling stage, the main electricity consumption comes from the equipments required to keep the temperature of the refrigerating fluid cold (coolers, chillers, and so on). In the other two stages, the haul-off rollers and the stacking, sawing and reeling units - the main electricity consumption comes from the motors used for the movement of the rolls, the compressed air used for closing the rolls and, in some cases, from heating or cooling to keep the rolls at a certain temperature if needed.

3.2 Reducing Energy Consumption in the Extrusion Process

The first step, when implementing an energy reduction programme, is to detect where, when and why energy is being used and how much is being consumed. Producing an energy site map will help discover the points at which the greatest amount of energy is being consumed. In order to carry out this easily, these are some points that can be studied in order to define which areas have the largest energy consumption or where there is more energy waste:

1. Which areas have the largest load?

   The largest extruders are most likely to have the largest motors and create the largest load when used. If it is not possible to reduce energy consumption in every single item or machinery inside a plant, then it is a good option to focus the energy reduction measurements in those areas that contribute the most to the total energy consumption.

2. Are the extruders adequately insulated? If not, why not?

   Insulation prevents the heat from dissipating and therefore improves the efficiency of the heating and cooling systems. Moreover, if the equipment is well insulated, it is easier to keep the melt inside the die at a constant temperature which helps

4 Rotational Moulding

This chapter describes both the rotational moulding process and some practical ways of improving energy efficiency when using rotational moulding.

4.1 The Rotational Moulding Process

4.1.1 Background to Rotational Moulding

Rotational moulding has been used in limited industrial since the 1940s when it was used to manufacture novelties and decorative items such as toys, mannequins, hollow display items and plastic fruits from polyvinylchloride (PVC) plastisols [1]. In 1961 powdered low density polyethylene was demonstrated to the rotational moulding industry followed by grades of polyethylene specifically formulated for use in rotational moulding which resulted in a rapid increase in the use of the rotational moulding process. Today polyethylene still accounts for the vast majority of plastic used in rotational moulding due to its excellent processing characteristics. Rotational moulding competes with blow moulding, thermoforming and injection moulding for the manufacture of hollow plastic products. The ability of rotational moulding to produce stress free products with highly uniform wall thicknesses and complex shapes [2] makes it ideally suited for the production of parts such as bulk containers, tanks, toys, medical equipment and automotive parts.

4.1.2 The Rotational Moulding Technology

Rotational moulding (also referred to as rotomoulding or rotocasting) is production process for manufacturing hollow, stress free parts of virtually limitless size. A powdered plastic is placed in a mould which is then heated to above the melt point of the plastic whilst being biaxially rotated. The molten plastic flows and coats the inside of the mould. It mould is then cooled down whilst still being rotated to produce seamless, hollow plastic parts. The rotomoulding process can be divided into four separate steps:

1. **Loading the Resin into the Mould**: A split, (i.e., two part) metal mould is filled with a predetermined quantity of plastic powder (the 'charge') equivalent in weight to the product to be produced. The mould is then closed, clamped, mounted into a frame and attached to the rotomoulding machine which is then transferred into an oven chamber.

2. **Heating and Fusion of the Resin**: The complete mould is *heated in the oven* to a temperature above the melting point of the plastic whilst being slowly rotated (typically no more that 12 revolutions per minute) around both the vertical and the horizontal axis. The molten powder lies in the bottom of the mould and as the mould is rotated all the inner surface of the mould comes in contact with the molten polymer which then adheres (*fuses*) to it. This continues until an even layer of molten plastic is formed over the entire inner surface of the mould. By altering the rotation speed around the vertical axis the wall thickness of the product can be controlled.

3. **Cooling**: In the cooling chamber air is blown on to the surface of mould to reduce the temperature of the mould and plastic to below the plastic's melting temperature, (in some rotomoulding configurations water sprays are used to rapidly cool the mould *once the plastic has completely solidified*, see **Section 4.2.2**). Once the plastic has solidified, the mould is then removed from the chamber.

4. **Unloading and Demoulding**: The plastic component is removed from the mould and allowed to finish the cooling process to room temperature unrestricted by the mould.

4.1.3 Advantages and Limitations of Rotational Moulding

Rotomoulding enables the commercial fabrication of single or multi-part hollow plastic parts. It offers a number of advantages and limitations compared to alternative methods such as injection or blow moulding.

The advantages of rotomoulding compared to alternative techniques are:

- **Product Consistency**: Consistent, controllable wall thickness in hollow parts with complex external forms can be repeatably produced enabling optimised material usage and enhanced design freedom.

- **Product Quality**: As the process is virtually shear force and pressure free [3] and avoids inhomogeneous cooling, parts produced by rotomoulding are relatively free of residual stresses, orientation effects and weld lines Thus, reducing defects and improving product service life compared to alternative techniques.

5 Compression Moulding

5.1 The Compression Moulding Process

Compression moulding is one of the oldest plastic moulding methods. The process consists of heating a plastic material, which can be in the form of granules or powder, in a mould that is held in a press. When the material becomes 'plastic' the pressure forces it to conform to the shape of the mould. It is a high volume, high pressure method suitable for moulding complex, high strength fibreglass reinforcements. Products manufactured by compression moulding include bottle caps, jar closures, electric plugs and sockets, toilet seats and trays. In the last few years a lot of new processes for compression moulding – especially direct processes have been developed.

The compression moulding machine comprises of a control unit that manages five main elements:

- A hydraulic alignment controlled high speed press
- A heating and cooling system for the mould
- An extruder or plasticising unit for processing un- and reinforced thermoplastics
- A mould unit
- A transfer unit for putting the plasticised material into the mould

5.2 Reducing Energy Consumption in Compression Moulding

In order to reduce energy consumption and costs, increase productivity and enhance corporate competitiveness, organisations should focus on optimising the manufacturing process in compression moulding.

5.2.1 Control Unit

When processing polymers, the control system has to meet safety requirements to protect the operator from unexpected closure of the press. Process control is necessary for an efficient operation, especially the alignment of the mould parts.

5.2.2 Hydraulic Drive

Hydraulic power is normally generated in a power pack to ensure precise co-ordination and repetition of the machine motions. The power pack provides the power and pressure to work the various motions of the mould. Separate hydraulic drives are needed in most cases for the additional peripheral equipment, including the extruder screws and cutting edges. Stability is maintained by temperature control of the hydraulic fluid, via a heat exchanger connected to a cold water system that offers an opportunity for heat recovery.

5.2.3 Heating and Cooling System

A heating and cooling system provides the controlled supply of thermal oil that flows through the mould and heats up or cools down the mould and the product. The efficiency of the system has a major effect on the overall process time and the energy consumed. When looking to reduce energy consumption across the process, consider using a pendulum storage facility rather than a direct heating and cooling system.

- Pendulum storage:

  For long cycle time and large moulds, it is necessary to use a pendulum storage facility to reuse the heat and energy input to the mould. The principle of the pendulum storage facility is shown in **Figure 5.1**.

At the start of the heating phase the mould is at a lower temperature. The thermal oil is then heated by the heat exchanger with the stored energy in the pendulum storage. The thermal oil and the mould in the press heat up until no further heat flow from the storage facility is possible. The system is switched to direct heating of the thermal oil with the heating system until the final mould temperature is reached.

After the pressing process, the thermal oil and mould is cooled with the pendulum storage facility until the temperatures are at nearly the same level. The heat in the mould heats up the storage facility and some of the energy is saved for the heating phase of the next cycle. When it is not possible to cool down any further with the pendulum storage, the system is switched to direct cooling of the oil.

With such a system approximately 45% energy savings can be made when producing large parts with long cycle times.

6 Moulds and Tooling

The mould, tool and die industry is one of the most important sectors in the European Union (EU) dominated by Small and Medium Sized Enterprises (SME), but is currently facing major challenges. Reducing overheads through energy saving can help with increasing cash flow, and in times of economic uncertainty this can be a great benefit. Furthermore, the increasing amounts of new legislation make it even more important.

Moulds, tools and dies are involved in the design and manufacturing supply chain of almost all industrial products from aeronautical and automotive to electronics and household products. They are on the critical path of the product development process and are the key to a short 'time to market'.

Increased pressure from low cost countries, new technologies and the demand for short cycle time and limited quantities are putting pressure on an intensively competitive industry.

Energy and environmental management are important issues that are already on the agenda for many leading European businesses. There are many ways to improve the energy and environmental impact of organisations but for many companies the financial benefit is the key motivator.

6.1 Introduction

Despite the amount of information available in the literature, rapid heating and cooling of moulds does not represent a well-developed area of practice. Development of suitable techniques for rapidly heating and cooling a mould with the relatively large mass is technically challenging because of the constraint set by the heat transfer process and the endurance limits set by the material properties.

The ideal condition is to have a hot mould during the filling stage and a cold mould during the cooling stage [1]. A large number of strategies for cooling injection moulds can be used - these include those relating to mould technology, equipment technologies and process technologies.

The research makes clear that there are many unanswered questions surrounding variable mould temperature control. They range from basic work in the field of heat transfer to practical aspects such as: How does the cost/benefit analysis work out? What temperature should be provided for a particular material and a defined quality improvement?

What temperature difference is still acceptable on economic grounds? Cooling time, alone, consumes up 60 to 80% of the cycle time.

The mould heating methods can be classified into four categories depending on the type of heat supply (see **Figure 6.1**).

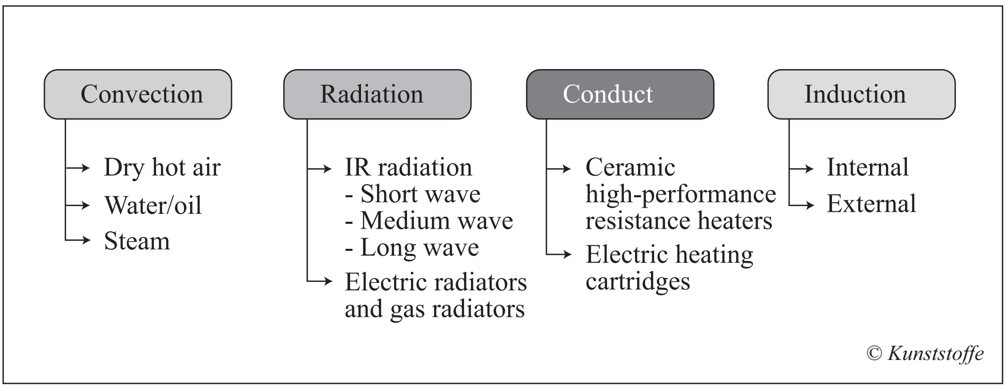

Figure 6.1 Mould Heating Methods. Reproduced with the permission from H. Ridder and H.P. Heim, *Kunststoffe International*, 2009, **99**, 5, 12 [1]. ©2009, Carl Hanser Verlag, Munich, Germany

6.2 Variable Temperature Control

Variable temperature control involves heating the mould cyclically for the injection phase and cooling it down for the cooling phase [1].

The baseline temperature level of the injection mould is determined by the material used and should be as low as possible in the interests of a short cycle time as far is permitted by the required part properties. The maximum required heating temperature of the cavity surfaces can only be determined by considering the particular application

7 Other Processes

This chapter discusses briefly other processes not already covered in this book such as thermoforming, blow moulding, and expanded polystyrene (EPS) foaming.

7.1 Thermoforming

7.1.1 Introduction

Thermoforming is among the oldest of the plastic shaping techniques and is a manufacturing process for thermoplastic sheets or film. The sheet or film is heated to its forming temperature and stretched over, or into, a temperature controlled, single surface mould. The sheet is held against the mould surface unit until cooled and the formed part is trimmed from the sheet. There are several categories of thermoforming including vacuum, pressure, twin-sheet, drape forming, free blowing and simple sheet bending. The five main steps when thermoforming are shown in **Figure 7.1**.

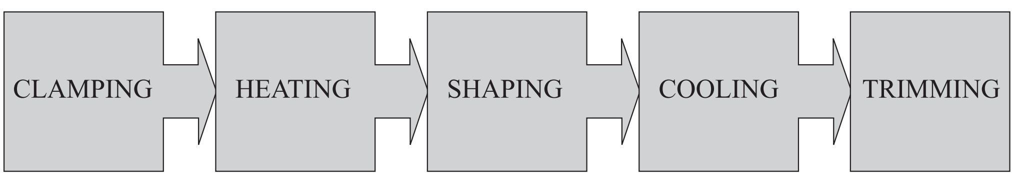

Figure 7.1 The five main steps in thermoforming

7.1.2 Energy Consumption

Thermoforming is an energy intensive business and good energy management is the key to productivity improvement, quality and positive public image. In the benchmarking survey, carried out by the 'RECIPE' project [1], thermoforming was found to be the highest energy consuming process on the basis of kWh/kg of finished product. The survey was conducted in 2005 and included offices and infrastructure in the overall energy figures that were collected. It is also likely that some of the thermoforming companies that responded produced their own sheet, so in reality the specific energy consumption would have included both the sheet manufacture and the thermoforming process. **Figure 7.2** shows how the different processes compared with each other, and in general terms we could say that the extrusion operations were around 1 kWh/kg, injection and compression moulding were 3 kWh/kg, and rotational moulding and thermoforming were 6 kWh/kg. Therefore, even if the sheet extrusion component is deducted from the total, then thermoforming would still have a specific energy consumption of 5 kWh/kg. This high figure is not surprising when we consider that the process includes, individual heating and cooling of each sheet, a large amount of mechanical movement, and subsequent trimming which results in a significant amount of in house recycling, and hence reprocessing of the trimmed material.

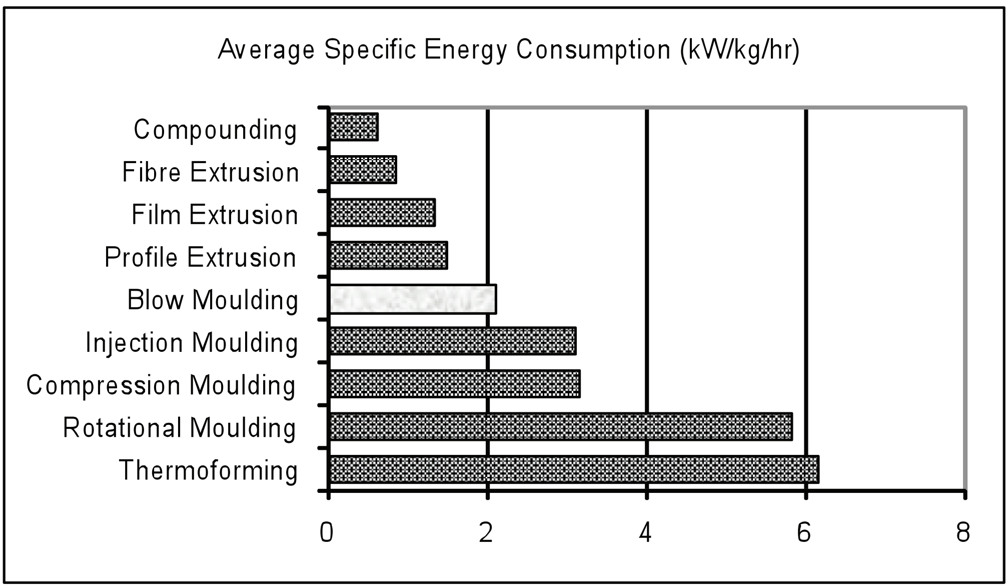

Figure 7.2 Specific energy consumption of a range of processes. Reproduced with permission from the *Low Energy Plastics Processing - European Best Practice Guide*, RECIPE/IEE project, 2006, p.33