

Plastics Pocket Power

Naranjo, Noriega,
Sierra, Sanz

Series editor: Tim A. Osswald

Injection Molding Processing Data

2nd Edition

HANSER

Plastics Pocket Power

Series editor: Tim A. Osswald

Alberto Naranjo C.

Maria del Pilar Noriega E.

Juan Diego Sierra M.

Juan Rodrigo Sanz

Injection Molding Processing Data

2nd Edition

HANSER

Distributed in North and South America by:
Hanser Publications
6915 Valley Avenue, Cincinnati, Ohio 45244-3029, USA
Fax: (513) 527-8801
Phone: (513) 527-8977
www.hanserpublications.com

Distributed in all other countries by
Carl Hanser Verlag
Postfach 86 04 20, 81631 Munich, Germany
Fax: +49 (89) 98 48 09
www.hanser-fachbuch.de

The use of general descriptive names, trademarks, etc., in this publication, even if the former are not especially identified, is not to be taken as a sign that such names, as understood by the Trade Marks and Merchandise Marks Act, may accordingly be used freely by anyone. While the advice and information in this book are believed to be true and accurate at the date of going to press, neither the author nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Cataloging-in-Publication Data is on file with the Library of Congress

ISBN 978-1-56990-666-8
E-Book-ISBN 978-1-56990-667-5

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying or by any information storage and retrieval system, without permission in writing from the publisher.

© Carl Hanser Verlag, Munich 2019
Coverdesign: Stephan Rönigk
Typesetted, printed and bound by Kösel, Krugzell
Printed in Germany

Table of Contents

1	Introduction	5
2	Injection Technology	6
2.1	The Injection Molding Cycle	7
3	Useful Equations and Theory	14
4	Examples	24
4.1	Runner System Balance	24
4.2	Shrinkage Prediction	25
4.3	Cooling Time Prediction	27
4.4	Effect of Process Parameters on Shrinkage	28
4.5	Theoretical Energy Consumption in an Injection Molding Process with PS	29
4.6	Processing Conditions of PA6 Parts and Theoretical Power-Cooling Requirement	30
4.7	Theoretical Water Flow Requirement for a Mold for PA6 Parts	34
4.8	Determining Viscosity Constants from the Curve	35
5	Polymer Data (for Standard Materials without Fillers or Modifiers)	37
5.1	Polyolefins	37
5.1.1	Low Density Polyethylene (LDPE)	37
5.1.2	High Density Polyethylene (HDPE)	41
5.1.3	Polypropylene Homopolymer (PP)	45

5.2	Styrenics	49
5.2.1	Polystyrene Homopolymer (PS)	49
5.2.2	High Impact Polystyrene (HIPS)	53
5.2.3	Styrene/Acrylonitrile Copolymer (SAN)	57
5.2.4	Acrylonitrile/Butadiene/Styrene Copolymer (ABS)	61
5.3	Polycondensates	65
5.3.1	Polyamide 6 (PA6)	65
5.3.2	Polyamide 66 (PA66)	69
5.3.3	Polyethylene Terephthalate (PET)	73
5.3.4	Polybutylene Terephthalate (PBT)	77
5.3.5	Polycarbonate (PC)	81
5.3.6	Polyphenylene Ether Modified (m-PPE)	85
5.3.7	Polyether Etherketone (PEEK)	89
5.3.8	Polyarylsulfone (PSU)	93
5.4	Vinyls	97
5.4.1	Polyvinylchloride (PVC) Rigid	97
5.4.2	Polyvinylchloride (PVC) Flexible	101
5.5	Others	105
5.5.1	Polylactic Acid (PLA)	105
5.5.2	Polymethylmethacrylate (PMMA)	109
5.5.3	Polyacetal (POM)	113
6	Appendix	117
7	Definitions	120
8	Further Reading	123

1 Introduction

Initial processing data given to the engineer or technician before setting up an injection molding machine for a new product can save time and money. To arrive at high-quality products as quickly as possible, the machine settings at the beginning of the injection molding process optimization procedure should be as close as possible to optimal processing conditions. However, one needs to be aware that even with a good educated guess of the processing conditions for a given material, the final conditions are dependent on specific material grades, injection molding machine size, screw wear, part and mold design, and other material-independent variables. For most materials a good starting point is always known and can be found in resin supplier data sheets as well as material data banks such as CAMPUS™. This book compiles important processing data information, such as viscosity, thermal properties, mold temperatures, and suggested heater temperatures for the plasticating unit. Through a set of easy to follow examples, this book shows how the given data can be used to generate important information about a specific material, process, and product.

2 Injection Technology

A modern injection molding machine with its most important elements is shown in Figure 2.1. The components of the injection molding machine are the plasticating unit, clamping unit, control unit, and the mold.

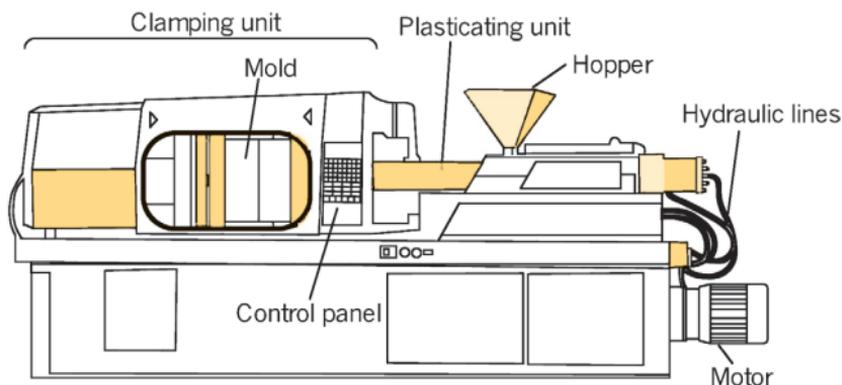


Figure 2.1 Schematic of an injection molding machine. See Figure 2.7 for a more detailed representation of the machine

Today, injection molding machines are classified by the following international convention

Manufacturer type T/P

where T is the clamping force in metric tons and P is defined as

$$P = \frac{v_{\max} p_{\max}}{1000}$$

where v_{\max} is the maximum shot size in cm^3 and p_{\max} is the maximum injection pressure in bar. The clamping force T

can be as low as 1 metric ton for small machines, and as high as 11,000 tons.

There is another classification regarding specific energy consumption (kWh/kg), the Euromap 60.1. There are 10 efficiency classes: Class 1 (> 1.5 kWh/kg) to Class 10 (≤ 0.25 kWh/kg). For small machines (screw ≤ 25 mm) the class definition is different.

2.1 The Injection Molding Cycle

The sequence of events during the injection molding of a plastic part, as shown in Figure 2.2, is called the injection molding cycle. The cycle begins when the mold closes, followed by the injection of the polymer into the mold cavity. Once the cavity is filled, a holding pressure is maintained to compensate for material shrinkage. In the next step, the screw turns, feeding the next shot to the front of the screw. This causes the screw to retract as the next shot is prepared. Once the part is sufficiently cool, the mold opens and the part is ejected. Figure 2.3 presents the sequence of events during the injection molding cycle. The figure shows that the cycle time is dominated by the cooling of the part inside the mold cavity. However, in some cases the plasticating time can be longer than the cooling time, e.g., when the mold cavity number is high for the plasticating unit capacity; the plasticating time is also longer than the cooling time when the parts have thin walls. The total cycle time can be calculated using

$$t_{\text{cycle}} = t_{\text{closing}} + t_{\text{injectionunitforward}} + t_{\text{injection}} + t_{\text{cooling}} + t_{\text{ejection}}$$

where the closing and ejection times, t_{closing} and t_{ejection} , can last from a fraction of a second to a few seconds, depending on the size of the mold and the machine.

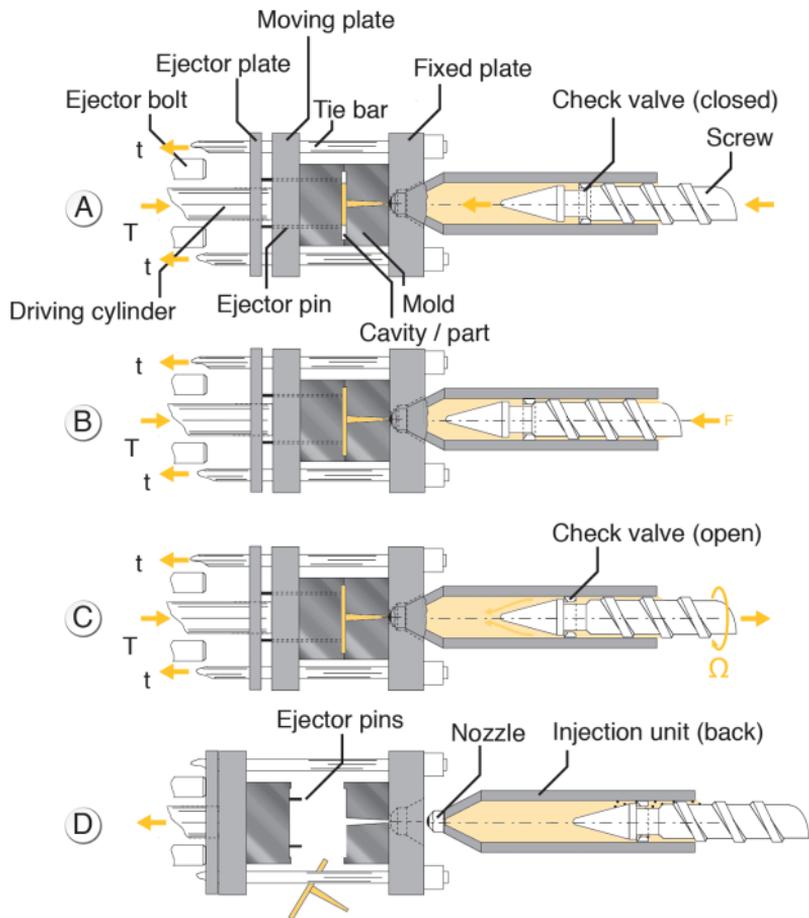


Figure 2.2 Sequence of events during an injection molding cycle

Using the average part temperature history and the cavity pressure history, the process can be followed and assessed using the PVT diagram as depicted in Figure 2.4. To follow the process on the PVT diagram, we must transfer both the

temperature and the pressure at matching times. The diagram reveals four basic processes: an isothermal (constant temperature) injection (0–1) with pressure rising to the holding pressure (1–2), an isobaric (constant pressure) cooling process during the holding cycle (2–3), an isochoric (constant volume) cooling after the gate freezes with a pressure drop to atmospheric (3–4), and then isobaric cooling to room temperature (4–5).

The point on the PVT diagram where the final isobaric cooling begins (4) controls the total part shrinkage, Δv . This

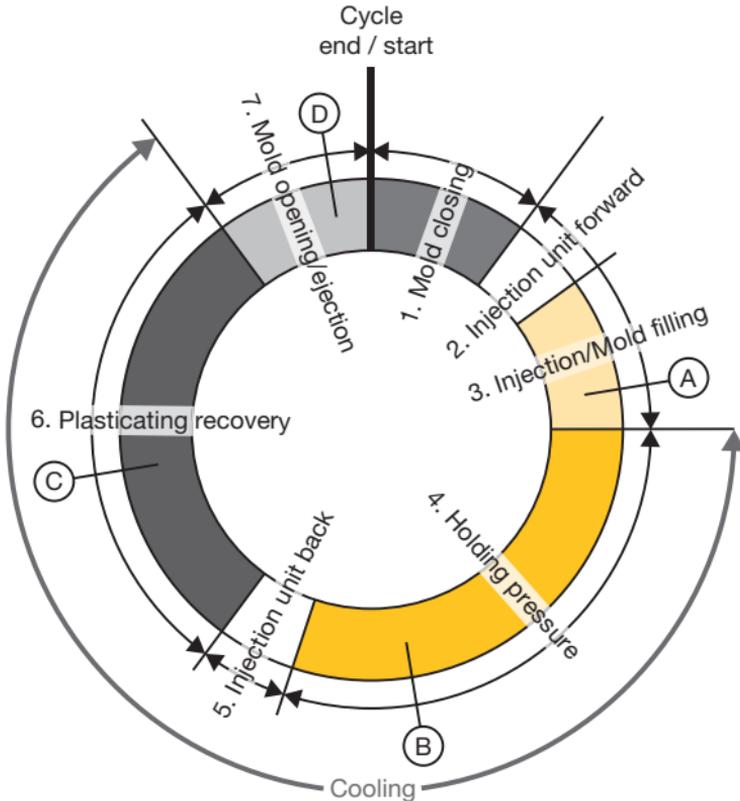


Figure 2.3 Injection molding cycle

point is influenced by the two main processing conditions—the melt temperature, T_M , and the holding pressure, p_H —as depicted in Figure 2.5. Here, the process in Figure 2.4 is compared to one with a higher holding pressure. Of course, there is an infinite combination of conditions that render acceptable parts, bound by minimum and maximum temperatures and pressures.

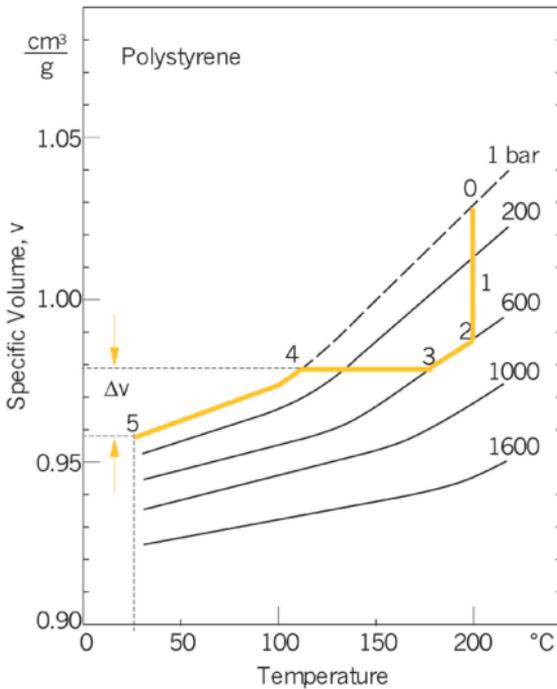


Figure 2.4 Trace of an injection molding cycle in a PVT diagram

Figure 2.6 presents the molding diagram with all limiting conditions. The melt temperature and the injection speed are bound by low values that result in a short shot or unfilled cavity and high values that lead to material degradation. The hold pressure is bound by a low pressure that leads to excessive shrinkage or low part weight, and a high pressure that

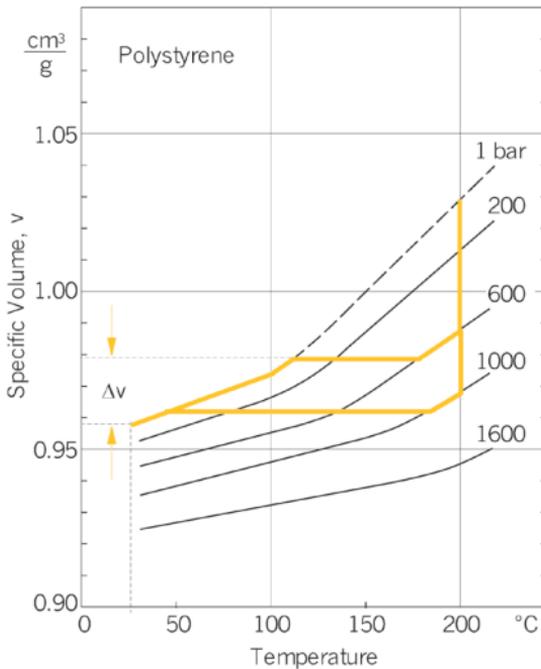


Figure 2.5 Trace of two different injection molding cycles in a PVT diagram

results in flash or jamming. Flash results when the cavity pressure force exceeds the machine clamping force, leading to melt flow across the mold parting line. The holding pressure determines the corresponding clamping force required to size the injection molding machine. An experienced polymer processing engineer can usually determine which injection molding machine is appropriate for a specific application. For the untrained polymer processing engineer, finding this appropriate holding pressure and its corresponding mold clamping force can be difficult. Nowadays there are computer programs for simulation to help them with this critical task. In the following pages some useful equations are presented, and it is explained how to use the physical properties con-