

Blow Molding Design Guide

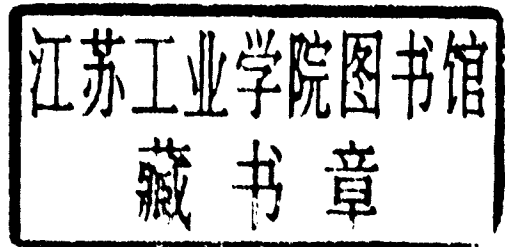


Norman C. Lee



Norman C. Lee

Blow Molding Design Guide



Hanser Publishers, Munich

Hanser/Gardner Publications, Inc., Cincinnati

The Author:

Norman C. Lee, 2705 New Garden Road East, Greensboro, NC 27455, USA

Distributed in the USA and in Canada by

Hanser/Gardner Publications, Inc.

6915 Valley Avenue, Cincinnati, Ohio 45244-3029, USA

Fax: (513) 527-8950

Phone: (513) 527-8977 or 1-800-950-8977

Internet: <http://www.hansergardner.com>

Distributed in all other countries by

Carl Hanser Verlag

Postfach 86 04 20, 81631 München, Germany

Fax: +49 (89) 98 12 64

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 authors 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.

Library of Congress Cataloging-in-Publication Data

Lee, Norman C., 1934–

Blow molding design guide / Norman Lee.

p. cm.

Includes bibliographical references and index.

ISBN 1-56990-227-5

1. Plastics—Molding. I. Title.

TP1130.L44 1998

668.4'12—dc21

97-43193

Die Deutsche Bibliothek – CIP-Einheitsaufnahme

Lee, Norman:

Blow molding design guide / Norman Lee. – Munich : Hanser ; Cincinnati : Hanser/Gardner, 1998

(SPE books)

ISBN 3-446-18255-1

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 1998

Typeset in England by Techset Composition Ltd., Salisbury

Printed and bound in Germany by Kösel, Kempten

Lee

Blow Molding Design Guide

SPE Books from Hanser Publishers

Belofsky, *Plastics: Product Design and Process Engineering*
Bernhardt, *Computer Aided Engineering for Injection Molding*
Brostow/Corneliussen, *Failure of Plastics*
Chan, *Polymer Surface Modification and Characterization*
Charrier, *Polymeric Materials and Processing—Plastics, Elastomers and Composites*
Del Vecchio, *Understanding Design of Experiments: A Primer for Technologists*
Ehrig, *Plastics Recycling*
Ezrin, *Plastics Failure Guide*
Gordon, *Total Quality Process Control for Injection Molding*
Gordon/Shaw, *Computer Programs for Rheologists*
Gruenwald, *Plastics: How Structure Determines Properties*
Lee, *Blow Molding Design Guide*
Macosko, *Fundamentals of Reaction Injection Molding*
Malloy, *Plastic Part Design for Injection Molding*
Manzione, *Applications of Computer Aided Engineering in Injection Molding*
Matsuoka, *Relaxation Phenomena in Polymers*
Menges/Mohren, *How to Make Injection Molds*
Michaeli, *Extrusion Dies for Plastics and Rubber*
Michaeli/Greif/Kaufmann/Vossebürger, *Training in Plastics Technology*
Michaeli/Greif/Kretzschmar/Kaufmann/Bertuleit, *Training in Injection Molding*
Neuman, *Experimental Strategies for Polymer Scientists and Plastics Engineers*
O'Brien, *Applications of Computer Modeling for Extrusion and Other Continuous Polymer Processes*
Progelhof/Throne, *Polymer Engineering Principles*
Rauwendaal, *Polymer Extrusion*
Rees, *Mold Engineering*
Rosato, *Designing with Reinforced Composites*
Saechtling, *International Plastics Handbook for the Technologist, Engineer and User*
Stevenson, *Innovation in Polymer Processing*
Stoeckhert, *Mold-Making Handbook for the Plastics Engineer*
Throne, *Thermoforming*
Tucker, *Fundamentals of Computer Modeling for Polymer Processing*
Ulrich, *Introduction to Industrial Polymers*
Wright, *Injection/Transfer Molding of Thermosetting Plastics*
Wright, *Molded Thermosets: A Handbook for Plastics Engineers, Molders and Designers*

Foreword

The blow molding industry continues to grow and become more sophisticated; however, there is little written about basic blow molding design. The *Blow Molding Design Guide* offers a spectrum of design information useful for someone new in blow molding, learning the basics, as well as someone experienced in blow mold design looking for new approaches to resolve difficult part design issues. The list of references throughout the book is a virtual who's who in the blow molding industry.

Norman Lee has more than 25 years of experience as a design engineer in the blow molding industry. He is well known for his years of service to the plastics industry through leadership in the Society of Plastics Engineers Blow Molding Division and the Plastics Recycling Division. Mr. Lee has demonstrated his commitment to education by service on the SPE Education Committee and by instructing numerous courses in blow molding. Norman Lee was the editor for the first edition of the *Plastic Blow Molding Handbook*, still in print and a resource for many of his classes.

We believe that the *Blow Molding Design Guide* will fill a void in the blow molding industry by condensing a large collection of industry design knowledge into a comprehensive, usable text and reference.

Lewis Ferguson
Chairman
Blow Molding Division
Society of Plastics Engineers

Technical Volumes Committee
Robert C. Portnoy, Chairperson
Exxon Chemical Company

James P. Parr, Reviewer
Exxon Chemical Company

Preface

Designing plastic blow molded parts can be an extremely difficult task because of the complexities of part geometry and the molding processes. It is challenging to even experienced designers. To produce an effective design it should be:

Functional and achieve the objective for which it is intended,
aesthetically pleasing, within the limits of the process,
practical, utilizing the right material, maximizing the benefits of the process,
cost efficient, with consideration of tooling cost and methods and run quantities.

Therefore, the objectives of this book are to give the reader an understanding of plastic blow molding, materials and processes, thus enabling him to design a blow molded part that optimizes the effectiveness of the plastic materials used, process employed, as well as the function of the part. It includes the application of bottles, industrial and structural parts. It is intended to be a no-nonsense, practical hands on book, that forgoes a scientific language that most ordinary people do not understand and concentrates on real life, day to day problems faced by those working to create cost-effective blow molded parts. It is a good introduction to the overall picture, for those who then wish to delve into more detailed and academic aspects of anyone of the many processes discussed.

Because the work includes so many diverse subjects it is not possible for one individual to be an expert in them all, thus, I have relied heavily on experts in their relative fields for information and advice. These of course are acknowledged at the end of each chapter. In many cases I have drawn from the published work. I make no apologies for this, since I am not able to improve on the original work. Also, much of the matter presented is leading edge technology and development by the originators.

I also acknowledge several who have helped me put this manuscript together. Loretta Lee, graduate student at A&T State University, a UNC System in Greensboro, NC, who took it on as a Masters project. Dr. Brent Strong, Brigham Young University, reviewed the manuscript, corrected errors, and made suggestions for changes. The review committee of the S.P.E blow molding division headed by James Parr, Exxon Company, Robert Gilbert, Equistar; and Robert Read, Dow Brands, made valuable suggestions for improvement. Several diagrams were drawn by Sam Huffine, Huffine Associates, Greensboro, NC and Auto-CAD drawings by James Lee, Ashboro, NC.

Norman Lee

Contents

Chapter 1 The Basics of Blow Molding

1

1.1 Definition	1
1.2 The Basic Process	1
1.3 History	2
1.4 Summary of Development	2
1.5 Design Parameters; Benefits, Disadvantages, and Comparisons	8
1.6 References	11

Chapter 2 The Design Process – An Organized Approach

13

2.1 Introduction	13
2.2 Main Structure	13
2.2.1 Six Perspectives on the New Manufacturing Enterprise	14
2.3 Product Design and Development Management System (PD2MS)	16
2.3.1 PD2MS	16
2.3.2 Process Management Tracking System	17
2.3.3 Commitment of Resources	17
2.3.4 Concurrent Engineering	19
2.4 Conclusion	19
2.5 References	25

Chapter 3 Basic Blow Molding Part Design

27

3.1 Basic Design Considerations	27
3.1.1 Size Variations	27
3.1.2 Understanding Hollow Structures	27
3.1.3 Draft of Part	29
3.2 Increase Draft as Blow Ratio Increases	30
3.3 Guidelines for Radii	33
3.3.1 Corner and Edge Rounding	35
3.3.2 Chamfers	36
3.4 Molded-in Geometric Configuration	36
3.5 Flanges and Tack-offs	37
3.5.1 Threaded Parts	38
3.5.2 Attachments and Auxiliary Units	39
3.6 Conclusion	40
3.7 Reference	41

Chapter 4
Design for Bottles

43

4.1 Blow Molding Process Basic Shapes.	43
4.2 Simplified Assumptions About Parison Expansion.	44
4.3 Bottle Design Concepts.	44
4.3.1 Ribs: Do Not Always Stiffen	46
4.3.2 Cross-Sections	47
4.3.3 Bottle Neck, Threads, and Openings	48
4.4 Container Volume.	48
4.4.1 Container Volume Measurements	51
4.4.2 Standards	52
4.4.3 Machine Line Mold Volume Correction	54
4.4.4 Source of Error in Volume Correction	54
4.4.5 Package Dairy Mold Volume Correction	54
4.4.6 Production Conditions.	55
4.4.7 Conclusion	56

Chapter 5
Industrial and Structural Part Design

59

5.1 The Blow Molding Process	59
5.1.1 Preferred Process.	59
5.1.2 Hollow Parts	59
5.1.3 Resin/Fiberglass Lay up and Structural Foam Molding	60
5.1.4 Foam-Filled	60
5.2 Kinetic Energy Design Engineering	62
5.2.1 Energy Management Concepts.	62
5.2.1.1 Deformation (of the Surface Skin in the Area of Impact)	62
5.2.1.2 A Sealed Hollow Part	62
5.2.1.3 Foam-Filled	62
5.2.1.4 Crushing	63
5.3 Molded-In Insert of Components	63
5.4 Interlocking Systems	65
5.5 Snap Fits	65
5.6 Multiple/Combination Cavities	66
5.7 Container Configuration Design.	66
5.7.1 Flat Sides	67
5.7.2 Lip	67
5.7.3 Nesting and Stacking	68
5.7.4 Cutting Containers Apart	68
5.8 Conclusion	70
5.9 Reference	72

Chapter 6
Computer Aided Design and Engineering Analysis

73

6.1 Performance Criteria	73
6.2 Computer Software Simulation	73
6.3 Reducing Parison Thickness.	74
6.4 Fluid Flow Finite Element Simulation	76
6.4.1 Modeling	76

6.4.2 Simulation	77
6.4.3 Prediction Example	78
6.5 Polymer Inflation and Thinning Analysis	80
6.5.1 Geometric	80
6.5.2 Understanding Wall Thickness	80
6.5.2.1 Using Normalized Thickness Curves	82
6.6 Conclusion	83
6.7 References	83

Chapter 7 Decorating of Blow Molding Products

85

7.1 Introduction	85
7.2 Surface Treatment	85
7.2.1 Surface Treatment Methods	86
7.2.2 Flame Treatment	86
7.2.3 Corona Discharge	86
7.2.4 Washing with Water-Based Chemicals	88
7.2.5 Solvent Cleaning and Etching	88
7.2.6 Additives Compounded into Resins	89
7.3 Spray Painting	89
7.3.1 Air Atomization and Airless Sprays	89
7.3.2 Masking	89
7.3.3 Vapor Degreasing	90
7.3.4 Mechanical Abrasion-Sanding	90
7.3.5 Chemical Etching	90
7.4 Labels	91
7.4.1 Label Application	91
7.5 Screen Printing	92
7.5.1 Screen Printers	94
7.6 Pad Printing	95
7.6.1 Pad Equipment	96
7.7 Hot Stamping	97
7.7.1 Hot Stamping Foils	99
7.8 Decals	99
7.8.1 Advantages of Heat Transfer	99
7.9 In Mold Labeling	100
7.9.1 In Molding Labeling Equipment	100
7.9.2 In Molding Labeling Process	101
7.9.3 "In Mold" Label Molds	101
7.9.4 Cycle Times	102
7.9.5 Aesthetics	102
7.10 Conclusion	102
7.11 References	102

Chapter 8 The Blow Molding Process

103

8.1 Extrusion Blow Molding	103
8.1.1 Understanding the Extruder	104
8.1.2 Blow Molding Technique	106
8.1.3 Continuous Extrusion	108

8.1.3.1 Shuttle System	108
8.1.3.2 Rising Mold	109
8.1.3.3 Rotary Wheel	109
8.1.4 Intermittent Extrusion	110
8.1.4.1 Reciprocating Screw	110
8.1.4.2 Ram.	111
8.1.4.3 Accumulator.	111
8.1.5 Coextrusion	113
8.1.6 Introduction to Head Tooling	114
8.1.6.1 Converging	114
8.1.6.2 Diverging	115
8.1.6.3 Tooling Choices	116
8.1.7 Part Weight and Wall Thickness Adjustment	116
8.1.7.1 Parison Programming	117
8.1.7.2 Die Ovalization	117
8.2 Blow Pins/Needles	119
8.2.1 Needles	119
8.2.2 Pins/Needles	120
8.3 Injection Blow Molding	120
8.3.1 Injection Blow Molding Process	120
8.3.2 The Injection Blow Molding Machine	122
8.4 Stretch Blow Molding	124
8.5 References	126

Chapter 9
New Applications of Blow Molding Technology

9.1 Co-Extrusion Blow Molding of Large Parts	127
9.1.1 Reasons for Coextrusion	127
9.1.2 Typical Structures	129
9.1.3 Intermittent and Continuous Extrusion Blow Molding.	130
9.1.4 Methods of Continuous Coextrusion Blow Molding.	132
9.2 Three-Dimensional Blow Molding	135
9.2.1 Mold Inclining System and Computer Controlled Mold Oscillating Device	136
9.2.1.1 The X–Y Process.	136
9.2.1.2 Formed Parts	136
9.2.1.3 Features of the X–Y Machine	137
9.2.2 Three-Dimensional Technology of Suction Blow Molding	139
9.2.3 Three-Dimensionally Curved Blow Moldings.	141
9.3 Hard-Soft-Hard and Soft-Hard-Soft Technology	142
9.3.1 Axial Extrusion.	142
9.3.2 Preferred Material Combinations	142
9.4 Long-Glass-Fiber-Reinforced Blow Molding	143
9.4.1 Breakthrough	143
9.4.2 15% Long-Glass Fiber	143
9.5 Blow Molding Foam Technology.	144
9.5.1 Advantages	145
9.5.2 Blow Foam Technology Products.	146
9.6 Conclusion	147
9.7 References	147

Chapter 10 Understanding the Mold

149

10.1	Main Characteristic of Mold Halves	149
10.2	Mold Materials	151
10.2.1	Cast Aluminum and Beryllium	151
10.2.2	Aluminum Plate	151
10.2.3	Steel	151
10.3	Importance of Fast Mold Cooling	151
10.3.1	Heat Transfer Rate	152
10.3.2	Cooling	152
10.3.3	Cooling Lines	152
10.3.4	Pinch-Off Areas	154
10.3.5	Blowing Pin	154
10.3.6	Internal Cooling	154
10.4	Cutting and Welding Parison (Pinch-Off)	154
10.4.1	Pinch-Off Section	154
10.4.2	Uniform Weld Lines	156
10.5	High-Quality, Undamaged Mold Cavity Finish	157
10.6	Effects of Air and Moisture Trapped in the Mold-Venting	157
10.7	Injection of the Blowing Air	158
10.8	Ejection of the Piece from the Mold	159
10.9	Bottle Molds	159
10.9.1	Neck Ring and Blow Pin Design	159
10.9.2	Dome Systems	161
10.9.3	Prefinished System	162
10.9.4	Unusual Problems	162
10.10	Injection Blow Molds	164
10.10.1	Parison (Preform) Mold	164
10.10.2	Neck Ring Insert	165
10.10.3	The Core Rod Assembly	166
10.10.4	Materials for Parison Cavity and Core Rods	166
10.10.5	Design Details of the Blow Mold Cavity	166
10.10.6	Vents	167
10.10.7	Neck Ring Insert	168
10.10.8	Bottom Plug Insert	168
10.10.9	Die Sets	169
10.10.10	Injection Blow Molding Tooling Summary	170
10.11	Conclusion	170
10.12	References	172

Chapter 11 Computer Aided Design and Engineering for Mold Making

173

11.1	Advantages	173
11.2	Systems and Methods	174
11.2.1	Analytical Personal Computer	174
11.2.2	Minicomputer	175
11.2.3	Network Station Approach	175
11.3	Utilizing CAD/CAM in a Mold Making Organization	176
11.3.1	Engineering Activities	176
11.3.2	Manufacturing Activities	179
11.4	Reference	180

Chapter 12 **Polymers and Plastic Materials**

181

12.1	Basic Polymer Chemistry	181
12.1.1	Structure of Matter	181
12.2	Polymers	182
12.2.1	Homopolymers, Copolymers, and Terpolymers	183
12.2.2	Thermoplastic and Thermoset Polymers	183
12.2.3	Amorphous and Crystalline	183
12.2.4	Fundamental Properties	184
12.2.4.1	Average Molecular Weight	185
12.2.4.2	Chain Length Linking	185
12.2.4.3	Morphology	186
12.2.4.4	Additives, Fillers and Reinforcing Agents	186
12.3	Physical Properties	187
12.3.1	Specific Gravity	187
12.3.2	Melt Flow Rate (Melt Index)	188
12.3.3	Moisture	188
12.3.4	Hardness	189
12.3.5	Tensile Strength and Properties	189
12.3.6	Creep	190
12.3.7	Basic Polymer Parameters and Their Effect on Product Properties	190
12.4	Characteristics for Blow Molding	191
12.4.1	High-Density Polyethylene	191
12.4.2	Acrylonitrile-Butadiene-Styrene	191
12.4.3	Polycarbonate	193
12.4.4	Polypropylene	194
12.4.5	Polyphenylene Oxide	195
12.4.6	Polyethylene Terephthalate	196
12.5	Coloring Plastic Materials	196
12.6	Regrind	197
12.6.1	Regrind Specifications	197
12.6.2	Process Performance	197
12.6.3	Physical Properties	197
12.7	Post-Consumer and Industrial Recycled Materials	198
12.8	References	199

Chapter 13 **Cost Estimating**

201

13.1	Introduction	201
13.2	Typical Cost Sheet	201
13.3	Cost Conclusion	204
13.4	Cost Estimating Calculations	204
13.4.1	Part Requirements	204
13.4.2	Cooling of the Part	204
13.4.3	Throughput of the Machine	205
13.4.4	Post-Molding Operations	205
13.4.5	Setup and Purging of Material from Previous Product Run	205

Index

205

1

The Basics of Blow Molding

1.1 Definition

Plastic blow molding is a process used to produce hollow component parts. It is confined to thermoplastic type resins, for example, polyethylene, polyvinylchloride, polyethylene terephthalate, and engineering plastics such as polycarbonate. The three major variants of blow molding to produce blown plastic components are extrusion blow molding, injection blow molding, and stretch molding [2].

1.2 The Basic Process

The production plant for a blow molding process consists of three stages:

1. *Melting and plasticizing*. An extrusion and/or injection machine may be used to produce the melt.
2. *Parison formation* through a head and die/or injection mold.
3. *Blowing and molding*. Auxiliary air compressors provide air and a hydraulic clamp unit holds the mold.

In these major processes the first step involves the production of the tube, widely known as the parison, a term borrowed from the glass industry. The parison may be produced either by an extrusion or an injection machine. In the latter case it is usually referred to as a preform [3].

The heated parison or preform is placed inside the blowing mold, which closes and clamps around it and then the heated tube is blown against the wall of the mold molten plastic, or resin is then set to shape by being cooled, and after this cooling stage the product is ejected. In many cases the product requires subsequent finishing operations, for example, the removal of flashing, printing and labeling, filling the product, etc. Robotic handling equipment may be used to finish parts using boring and milling operations. For the basic process see Fig. 1.1 [4].

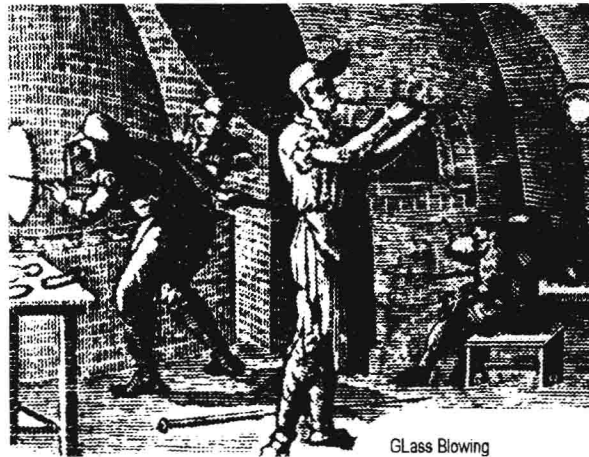


Figure 1.1 Glass blowing

1.3 History

Glass, plastics, and aluminum are three classes of raw materials existing today which are blown to form molded parts. The techniques of modern blow molding plastics grew from the art of glass blowing (Fig 1.1). The method is attributed to Syrian glass workers in the first century BC, who realized that a glass bulb on the end of a blow pipe could be shaped to many useful hollow forms, with handles and feet and decorated adjuncts added at will. During the Middle Ages, chiefly in Great Britain and elsewhere in Europe, the process was refined and sophisticated, becoming an important commercial industry [1].

1.4 Summary of Development

The modern plastic blow molding process (Fig. 1.2) originated in the 1930s, when the initial patents were granted to Plax Corporation and Owens of Illinois for automated equipment based on glass blowing techniques (Fig. 1.3). But the high cost and poor performance of plastic materials at that time discouraged rapid development. The plastic bottles offered no advantage over glass bottles; however, the introduction of low-density polyethylene in the mid-1940s (developed by ICI of England) provided the advantage of squeezability which glass could not match. In 1950 Elmer Mills was granted a patent for a continuous extrusion rotary blow molder used privately by Continental Can. In the late 1950s high-density polyethylene and commercially available molding equipment were developed and the industry rapidly expanded [4].

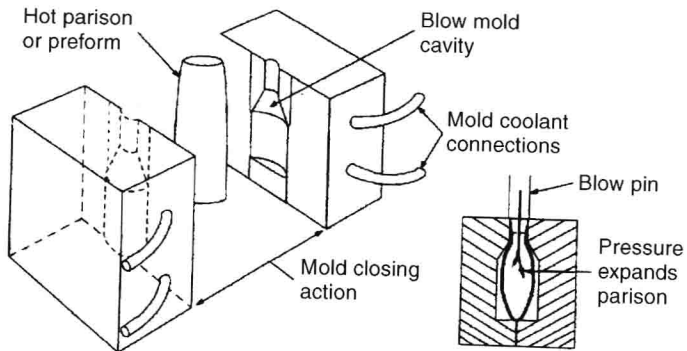


Figure 1.2 Basic blow molding process

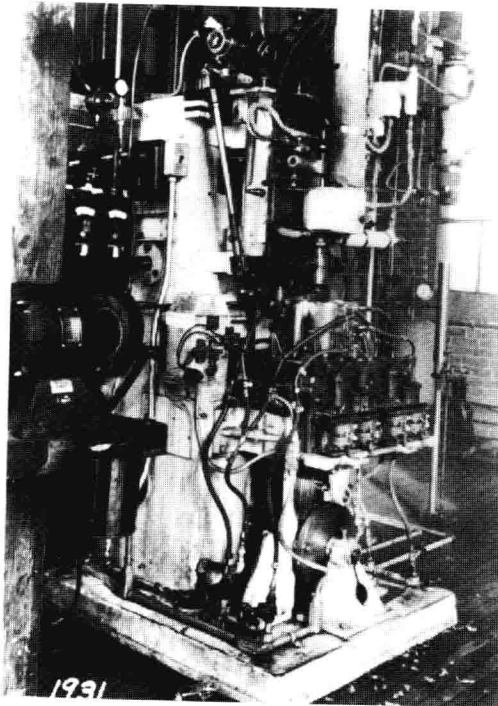


Figure 1.3 An extrusion blowmolder developed by Plax Corporation in the mid 1930s for the production of cellose acetate bottles

High-density polyethylene added considerable breadth to the design capabilities of plastic bottles; most importantly bottles could be lighter and stiffer. Commercial equipment broadened the opportunities for blow molding. Until that time, blow molding was being performed by only a few companies using proprietary technology. Because of the closely held patent situation in the United States most of the equipment development was taking place in Europe, principally in Germany. The first commercial equipment for blow molding in the United States came from Europe, and was shown at the National Plastic Exhibition in 1958. Empire Plastic, a toy company, bought a Fischer Blow Molding machine to make toy bowling pins. The engineers at Empire also converted a Reed–Prentice injection molding machine to make toy baseball bats by moving the injection cylinder up over the platen and building a head with a die and bushing. (Fig. 1.4). A later step was to build a twin head with a Rotec valve to operate and divert the material flow from one side to another (Fig 1.5). Midland Ross–Hartig gained permission from Empire to use this design to build six machines for making doll bodies for Ideal Toy Company. These were the first blow molding machines built by Hartig, which manufactured extrusion machines. The company later became Waldron–Hartig, then Battenfield–Hartig, and are now owned by Davis Standard. In that same period Paul Marcus designed and built twin head machines called Auto-Blow. During 1960 ZARN Inc. was formed in North Carolina and made milk bottles for Borden Dairy, in conjunction with Uniloy (now Johnson Controls), who built the machines and molds. To eliminate the freight cost of transporting empty bottles, in-line bottle blowing was started by a dairy in Burlington, North Carolina using the Uniloy machines and molds [3].

Of all the plastic materials that can be blown like glass, polyethylene is used in greater volume than all others combined. Although mainly still used for bottles, blow molding is increasingly used for industrial parts such as automotive rear deck air spoilers, seat

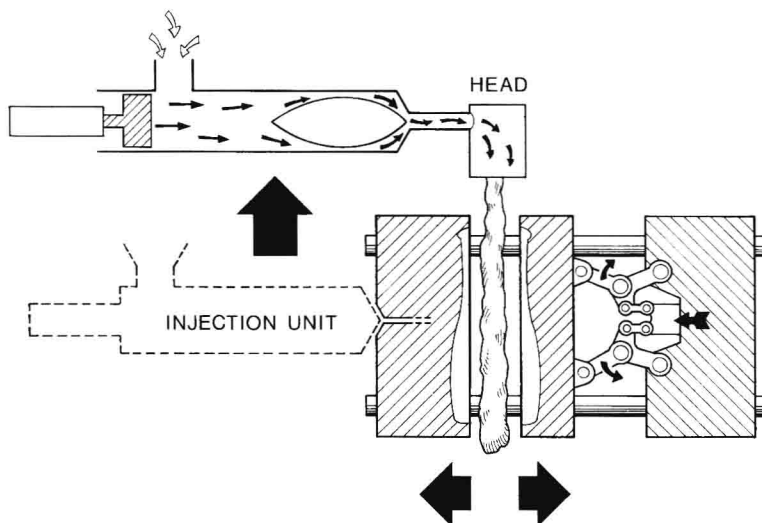


Figure 1.4 Cross-section through converted injection molding machine