JAMES L. WHITE

Twin Screw Extrusion

Technology and Principles

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The Author:
Prof. Dr. James L. White, Institute of Polymer Engineering, University of Akron, Akron, Ohio, USA

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To Yoko, my wife

Preface

Twin screw extruders have become, through the years, an important part of processing technology especially for polymer processing. They are widely used in chemical plants for reactive processing including both polymerization and grafting reactions. In chemical/polymerization plants, they are used for post-reactive processing steps including coagulation and devolatilization. Twin screw extruders are also used in post polymerization plant bulk polymer processing. This includes compounding of particulates, blending and reactive processing of polymers. There are also applications to thermoplastic final shaping operations, particularly for profile extrusion.

No satisfactory book on twin screw extrusion exists. The two existing books on twin screw extrusion, by Janssen ("Twin Screw Extrusion") and Martelli ("Twin Screw Extrusion: A Basic Understanding") are really not comprehensive in their scope and are outdated. More useful than these volumes, actually is the more recent volume by Rauwendaal ("Polymer Extrusion") which is largely about single screw extrusion. It, however, says little about the technology and experimental studies on twin screw extruders. It is also dated in parts.

Twin screw extruders represent not one technology but several. The screws may be co-rotating or counter-rotating. They may be intermeshing, tangential, or separated. Intermeshing screw pairs may or may not be self-wiping. Twin screw extruders may have machined screws or modular constructions. However, the variation in technology arises not simply from differences in mechanical design but from the different flow mechanisms these give rise to. We may roughly divide these technologies into three categories: (i) non-intermeshing counter-rotating, (ii) intermeshing counter-rotating, and (iii) intermeshing co-rotating. In each case, a separate historical and technological development may be discerned as well as specific advantages and disadvantages.

Our purpose in this book will be to attempt to carefully (i) describe each of these three types of machines and the historical development of their technologies, (ii) efforts to understand and model/simulate their flow characteristics, and (iii) experimental studies of the characteristics of these machines. We will begin the book with an introductory section (Chapters 1, 2, and 3) describing useful background for understanding the core part of the book. This includes basic definitions, scientific background, and critical discussions of single screw extrusion. In Chapters 4, 5, and 6, we present these areas for non-intermeshing counter-rotating twin screw machines. Chapters 7, 8, and 9 concentrate on intermeshing counter-rotating twin screw machines. Finally, in Chapters 10, 11, and 12, we summarize the technology and characteristics of intermeshing co-rotating twin screw extruders. We conclude with Chapter 13 contrasting the various types of machines.

Our major intent is to make available to chemists, engineers, and technologists a balanced, but deep, overview of this area including, indeed, its cultural development. The chapters on the development of technology (Chapters 4, 7, 10, and 13) should, alone in themselves, make this book useful.

A second intent relates to developing an understanding of rational design of twin screw extruders. To date, this has largely been done on an intuitive basis. In Chapters 5, 8, and 11 (building on the contents of Chapters 2 and 3), we begin the march to a rational quantitative design.

The author would especially like to thank H. Herrmann (Werner and Pfleiderer), R.J. Nichols (Welding Engineers, now with Farrel), H. Tenner (Leistritz), and D.B. Todd (Baker-Perkins/APV Chemical Machinery) for supplying him with various patents and many helpful conversations. Discussions with M. Ullrich and others with Bayer AG on the origins of the intermeshing co-rotating twin screw extruder were very helpful.

The book was typed by Mrs. Lori Yahner; and Dr. Myung H. Kim was especially helpful in collecting and preparing the figures.

James L. White
June 1990

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Intermeshing Counter-Rotating Twin Screw Extruders

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INTRODUCTION

Chapter 1
Overview of Multi-Screw Extruders

1.1 Introduction

1.2 Screw Geometry

1.3 Classification According to Direction of Rotation and Number of Screws

1.4 Classification According to Contact of Screws

1.5 Classification According to Modularity of Design

1.1 Introduction

Screw extruders represent the major processing machine of the thermoplastics industry, and play an important role in many related industries. Certainly the major continuous processing machine in the polymer industry has always been the single screw extruder. However, we have observed through the years a growing industrial role for multiple screw, especially twin screw extruders. These machines have generally been treated together as a single category and not carefully distinguished. It is our purpose in this book to carefully (i) describe these twin screw extruders and distinguish between them, (ii) indicate how they were developed and their applications, (iii) describe the flow mechanisms which operate in them and present models of this behavior, and (iv) present experimental studies of their performance.

Our concern in the present chapter is to give an overview and classification of the different types of multiple screw extruders. First, in Section 1.2 we will discuss screw geometry. We then turn to classification of multi-screw machines. In Section 1.3, we consider the relative direction of screw rotation and number of screws in the machine. The manner of contact of the screws is considered in Section 1.4. The question of segmentation and modularity of construction is discussed in Section 1.5.

1.2 Screw Geometry

Before we can discuss twin and multi-screw extruders, we must consider the geometry of individual screws. The geometry of an extruder screw is summarized in Figure 1.2-1a. The screw fits inside of a cylindrical barrel with internal diameter D_B. The distance between the root of the screw and the internal surface of the barrel is H. It should be noted that the value of H varies with position between the flights. The screw root may be curved and the flight need not be perpendicular to the root though it is to the screw axis. The radial clearance between the crest of the screw flight and the inner barrel surface of δ_f.

The axial distance of one full turn of the screw (screw lead or pitch) is S. The axial distance between flights is B, and e is the perpendicular width of the flights. The perpendicular distance between the flights along the helical path of the screw is W. The angle of the helix is ϕ. The distance W may vary (increase) with increasing altitude of the flight. This is associated with a decreasing flight thickness.

The helix angle ϕ will vary with radius because the pitch S is constant and ϕ is defined so as to relate S to the circumference through:

$$S = 2\pi r \tan \phi(r) \qquad (1.2\text{-}1)$$

Thus, at the screw root, we have:

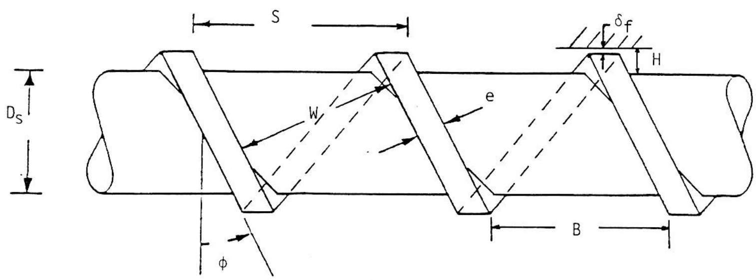

Fig.1.2-1 **(a) Single-flighted extruder screw.**

$$S = \pi D_s \tan \phi_s \tag{1.2-2a}$$

and at the barrel:

$$S = \pi D_b \tan \phi_b \tag{1.2-2b}$$

Angle ϕ decreases as one proceeds from the screw root to the barrel.

The quantities defined above are not necessarily constant along a screw. Quantities such as W, e, and ϕ vary not only then with the screw radius from the screw root to the barrel but along the length of the screw. The pitch can vary along the length of the screw.

Many geometric relationships exist between the quantities defined in the above paragraphs. The pitch S is related to B and e through:

$$S = B + \frac{e}{\cos \phi} \tag{1.2-3}$$

The channel width W is related to B through:

$$W = B \cos \phi \tag{1.2-4}$$

and to pitch S through:

$$W = \left[S - \frac{e}{\cos \phi} \right] \cos \phi = S \cos \phi - e \tag{1.2-5}$$

The relationships given in the above paragraph are for a single-flighted screw as shown in Figure 1.2-1a. More generally, extruder screws are multi-flighted, i.e. fluid added to the inlet will simultaneously travel along two or more parallel flights. A double-flighted screw is shown in Figure 1.2-1b and a triple-flighted screw in Figure 1.2-1c. If a screw has p parallel flights, we have:

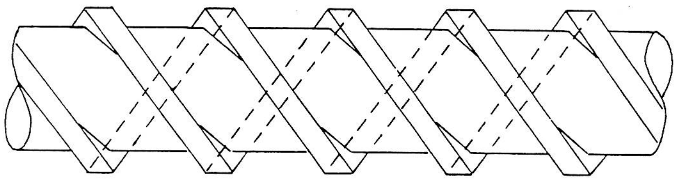

Fig.1.2-1 (b) Double-flighted extruder screw.

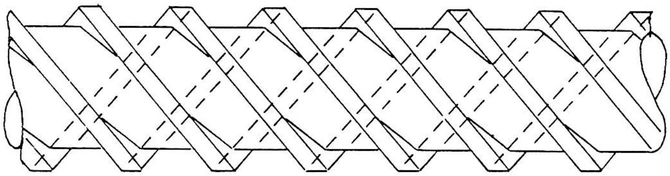

Fig.1.2-1 (c) Triple-flighted extruder screw.

$$|S| = p\left(B + \frac{e}{\cos\phi}\right) \tag{1.2-6}$$

and

$$W = \frac{|S|}{p}\cos\phi - e \tag{1.2-7}$$

Screw elements may be forward or backward pumping (often described as right-handed and left-handed when screw rotation is in a clockwise direction). This is shown in Figure 1.2-2. Backward pumping screws have negative helix angles ϕ and pitch S. It is for this reason that absolute values are used in Eqs. (1.2-6) and (1.2-7).

Single screw extruders and twin screw extruders also contain elements which are not true screws. In twin screw extruders, these are often assemblies of discs or other rotor designs intended for kneading and mixing. However, the discs may be arranged in such a way as to approximate forward or backward pumping screws. They then act as screws in practice.

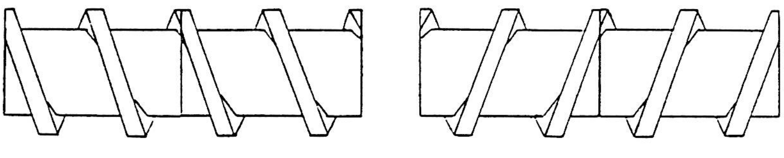

Fig.1.2-2 Forward pumping (right-handed) and backward pumping (left-handed) screws.

1.3 Classification According to Direction of Rotation and Number of Screws

We now turn to twin screw extruders. The most obvious classification in such a machine is whether the two screws rotate in the same or opposite directions. This is shown in Figure 1.3-1. Both co-rotating (in German gleichlaufigen) and counter-rotating (in German gegenlaufigen) are of great industrial importance and are manufactured thoughout the world.

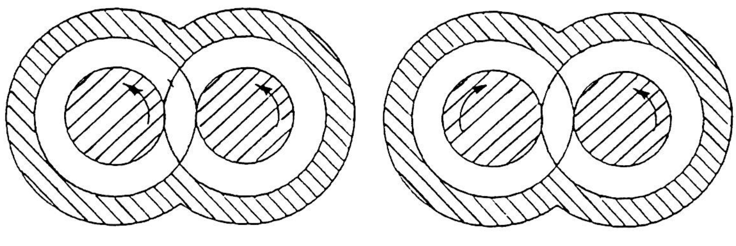

Fig.1.3-1 Co-rotating and counter-rotating twin screw extruders.

Let us consider multiple screw extruders. Descriptions of extrusion machines with not only 2, but 3, 4, 5, 6, 7, 8, etc. screws are contained in the patent literature. The screws may be arranged in various geometric manners. Figure 1.3-2 presents drawings from patents by Robert Colombo (1-3) one of the pioneers of this technology (see Chapter 10) which contains designs for multiple screw extruders. The arrangements of the screws may be seen to vary. The 3 and 5 screw machines are set up in a linear manner. The 6 and 8 screw machines are set up in a circumferential manner. The 4 screw machine has a control screw and 3 spurs. These screw arrangements are in no sense unique. Other arrangements are discussed in the patent literature. V-shaped 3 screw arrangements are described for example by various authors (4, 5). Figure 1.3-3 shows such an arrangement given by Meskat and Erdmenger (5).

With multiple screw extruders, one may have either have co-rotation, counter-rotation, or mixed situations. The screws of Colombo's (1-3) 3, 4, 5, 6, and 8 screw extruders all rotate in the same direction. Meskat and Erdmenger's (5) design is also co-rotating. However, multiple screw extruders may be counter-rotating as well. The first 3 screw extruder is described in Pfleiderer's 1881 patent (4). It was counter-rotating. Figure 1.3-4 shows 3, 4, and 5 screw counter-rotating machines taken from the patent literature (4, 6-8). It is also possible to have both co- and counter-rotating screws in the same multiple screw machine. This is seen in Erdmenger and Oetke's (9) 4 screw machine shown in Figure 1.3-5.

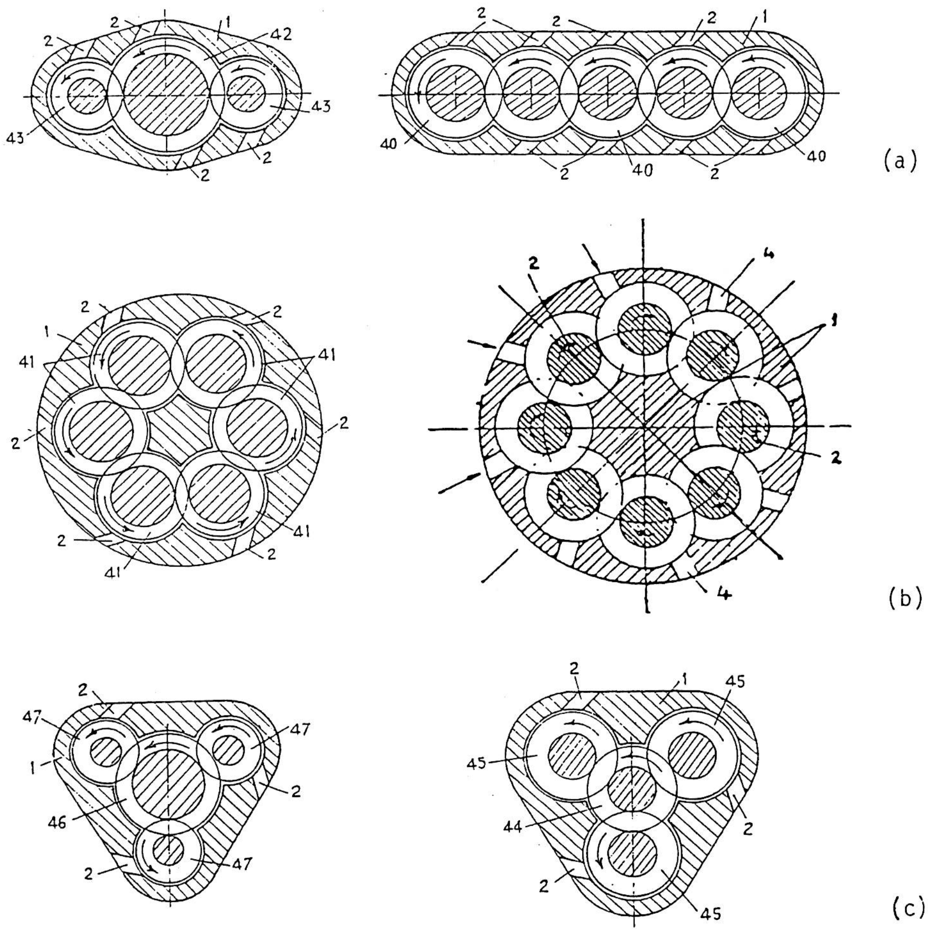

Fig.1.3-2 Multiple co-rotating screw extruders after Colombo (1-3) indicating (a) 3 and 5 screw linear arrangements, (b) 6 and 8 screw circumferential arrangements, and (c) 4 screw arrangement with contact spurs.

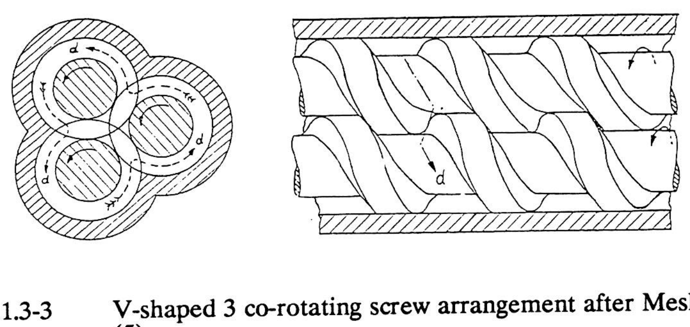

Fig.1.3-3 V-shaped 3 co-rotating screw arrangement after Meskat and Erdmenger (5).