

# Chapter 18 Forming and Shaping Plastics

## (塑料的成形与成型)

- **18.1 Introduction**
- **18.2 Extrusion**
- **18.3 Injection Molding**
- **18.4 Blow Molding**
- **18.6 Thermoforming**

# 18.1 Introduction

## Outline

- Ø **Two basic types** of plastics:
  - thermoplastics (热塑性塑料/TP)
  - thermosets (热固性塑料/TS)
- Ø **Characteristics** of processing plastics
- Ø **Forms of raw material** of plastics:
  - pellets or powder
  - sheet, plate, rod or tubing
  - liquid

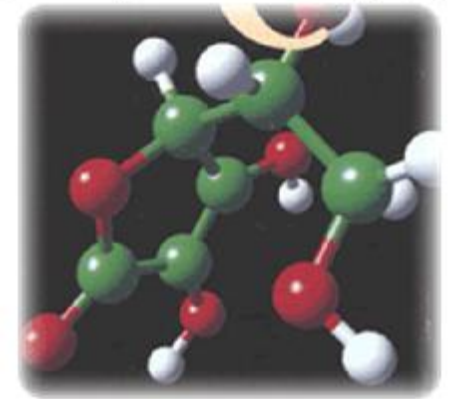
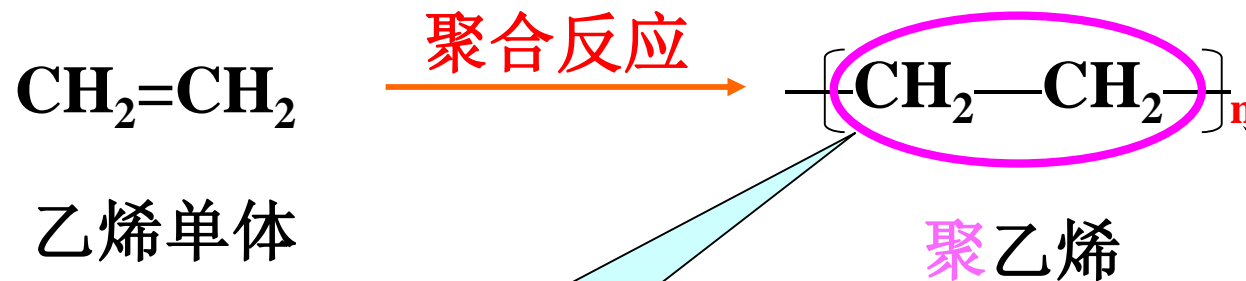
- **Plastics (塑料)**

- Plastics are primarily **polymers (聚合物/高聚物)**, which have **complex and long chain molecules (分子链)**, also called **macromolecules (高分子)**
- The **giant (巨大的) molecule chain** is made up of much smaller **molecules (分子)**, means they are formed by **polymerization (聚合反应)**, that is, by **linking and cross-linking (链接与交联)** of different **monomers (单体)**
- Plastics have **high molecular weight (分子质量)** ( $10^3 \sim 10^5$ )

# \* 高聚物长链结构的形成

以聚乙烯（PE）为例

单体：能合成高分子化合物的小分子物质



链节：高分子化合物中重复出现的结构单元

$n$ ——聚合度

u  $n=1$ , gas

u  $n=6$ , liquid

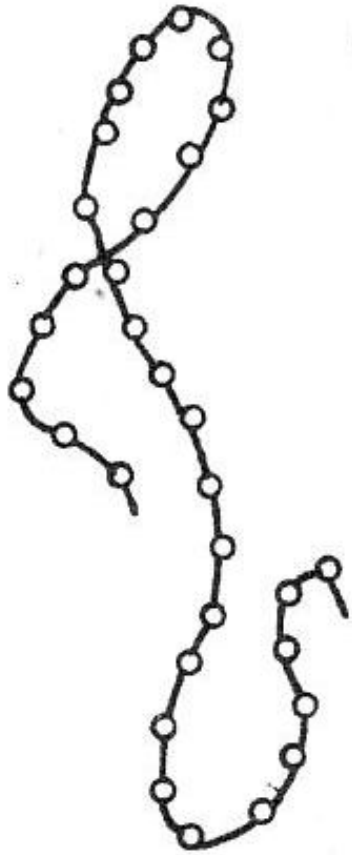
u  $n=35$ , grease (油脂)

u  $n=140$ , wax (蜡)

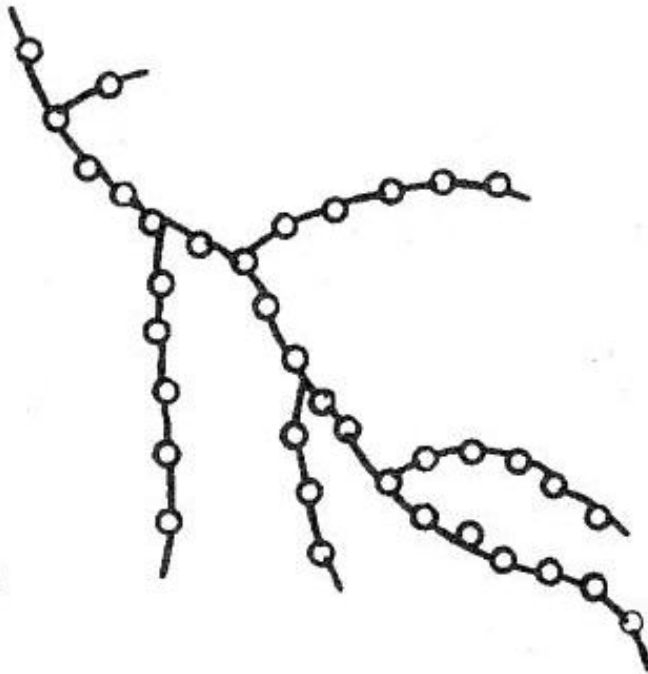
u  $n=1350$ , hard plastic

聚合度： $n$ 值表示高分子化合物中链节的重复次数， $n$ 值越大，相对分子质量越大。

# Two Basic Types of Plastics

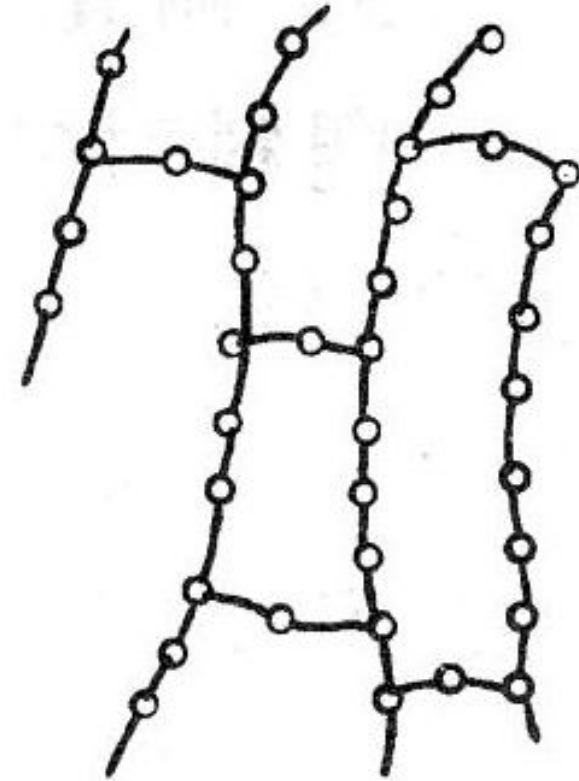


(a)



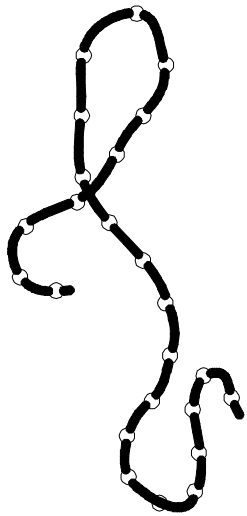
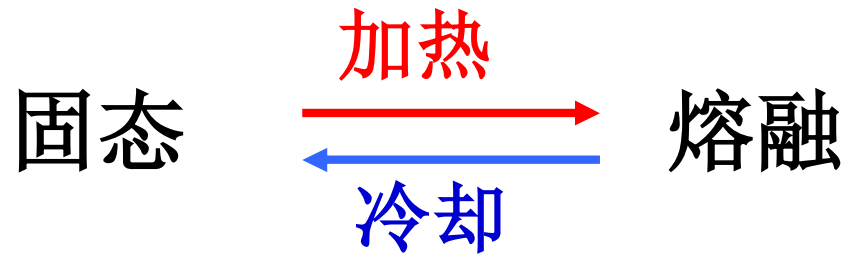
(b)

**Molecular Structure of  
Thermoplastics (TP, 热塑性塑料)**

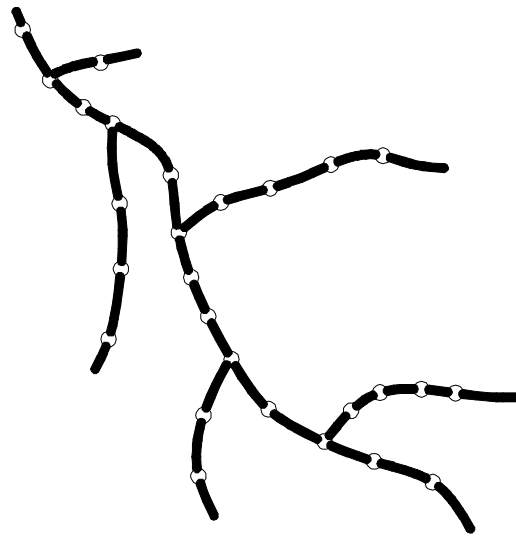


**Molecular Structure of  
Thermosets (TS, 热固性塑料)**

# Thermoplastics (TP/热塑性塑料)



(a)



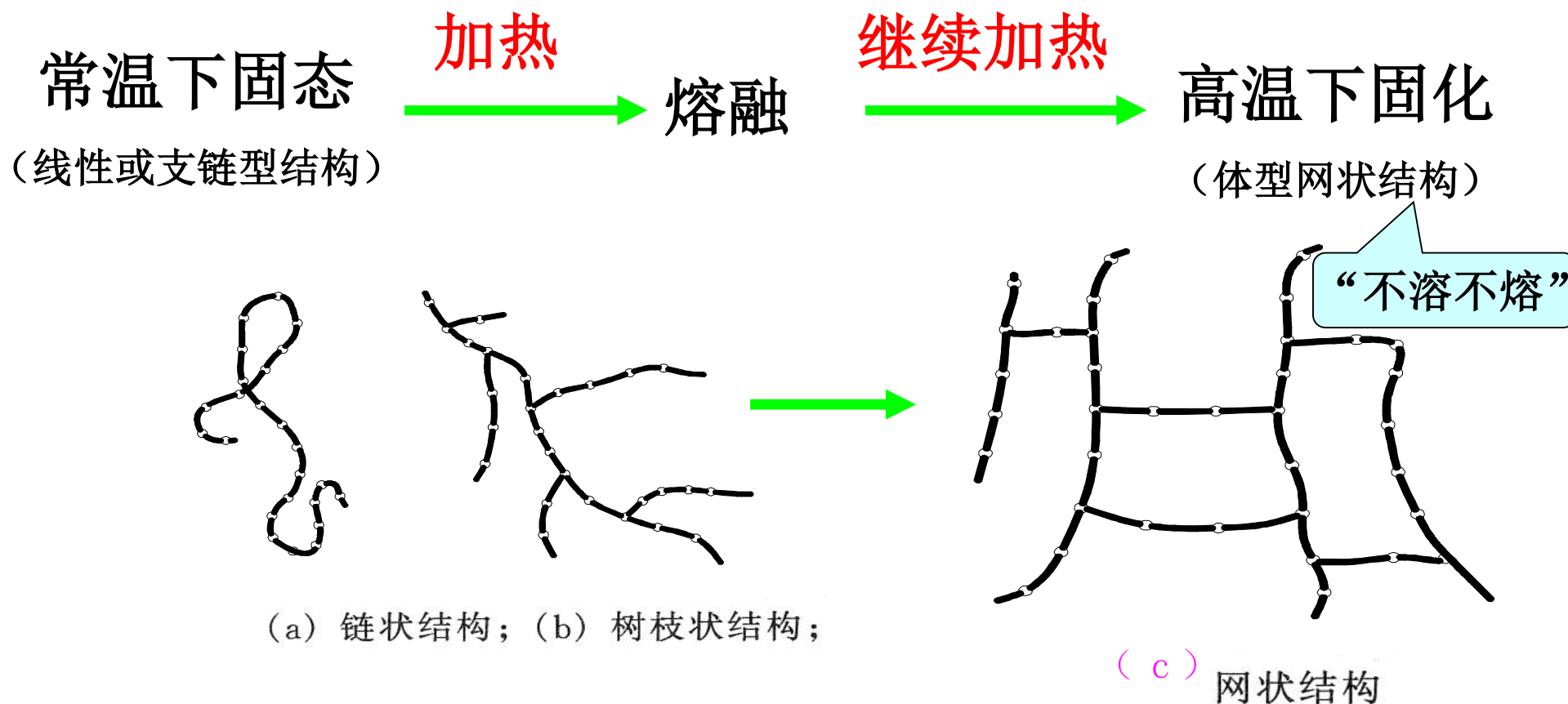
(b)

成型特点:

- 物理反应
- 可逆的 (reversible)

(a) 链状结构; (b) 树枝状结构;

# Thermosets (TS/热固性塑料)



成型特点:

- 化学反应: **cross-linking** (交联反应) / **curing** (固化)
- 不可逆的 (irreversible)

线型的

(a) Linear



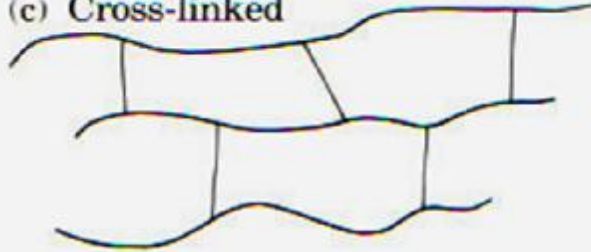
支链型的

(b) Branched



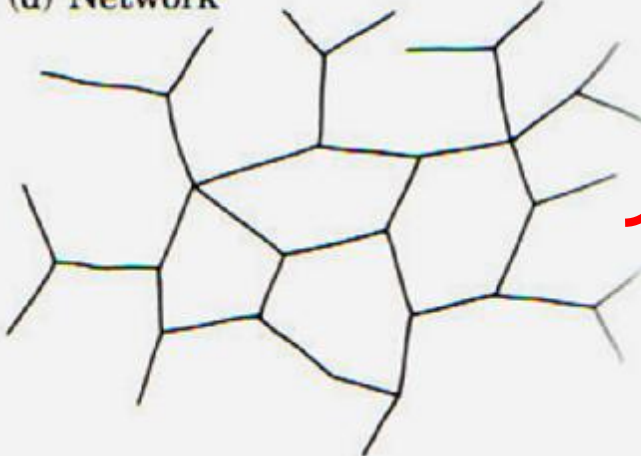
交联的

(c) Cross-linked



网状的

(d) Network



thermoplastics (TP, 热塑性塑料)

For **thermoplastics**, as the temperature is raised above the **glass-transition** (玻璃化转变) temperature or **melting point** (熔点), it becomes easier to form or mold them into desired shapes. After cooling, it returns to its original hardness and strength. In other words, the process is **reversible** (可逆的).

thermosets (TS, 热固性塑料)

When the long-chain molecules in a polymer are cross-linked in a three-dimensional arrangement, the structure becomes one giant molecule with strong covalent bonds (共价键). These polymers are called **thermosetting polymers**, or thermosets. This **curing** (cross-linking) reaction (固化/交联反应) is **irreversible** (不可逆的).



# Processing Operations of Plastics

- **Similar to** those used to form and shape **metals**:
  - Ø **molded** (模塑成型)
  - Ø **cast** (铸造)
  - Ø **formed** (变形/成形)
  - Ø **machined** (机加工)
  - Ø **joined** (连接/焊接)

# Comparison of Processing Plastics to Metals

**plastics**

**metals**

**initial materials**

**pellets,  
powder, or liquid**

**casting ingot or  
sheet, plate**

**difficulty of forming**

**relative ease  
fewer operations**

**relative difficult**

**energy required**

**relative low**

**relative high**

- The **properties** of plastic parts and components are **influenced** greatly by:
  - **method of manufacture** (制造/成型方法)
  - **processing parameters** (工艺参数)

# Forms of Raw Material of Plastics

## ① pellets (颗粒) or powders (粉末)

- then may be **melted** just before the **shaping process**

## ② sheet, plate, rod, and tubing

extrusion/injection molding/  
compression molding/transfer molding

- then may be **formed** into a variety of products.

## ③ liquid plastics

blow molding/ thermoforming

- used especially in the making of **reinforced-plastic**

(增强塑料) parts

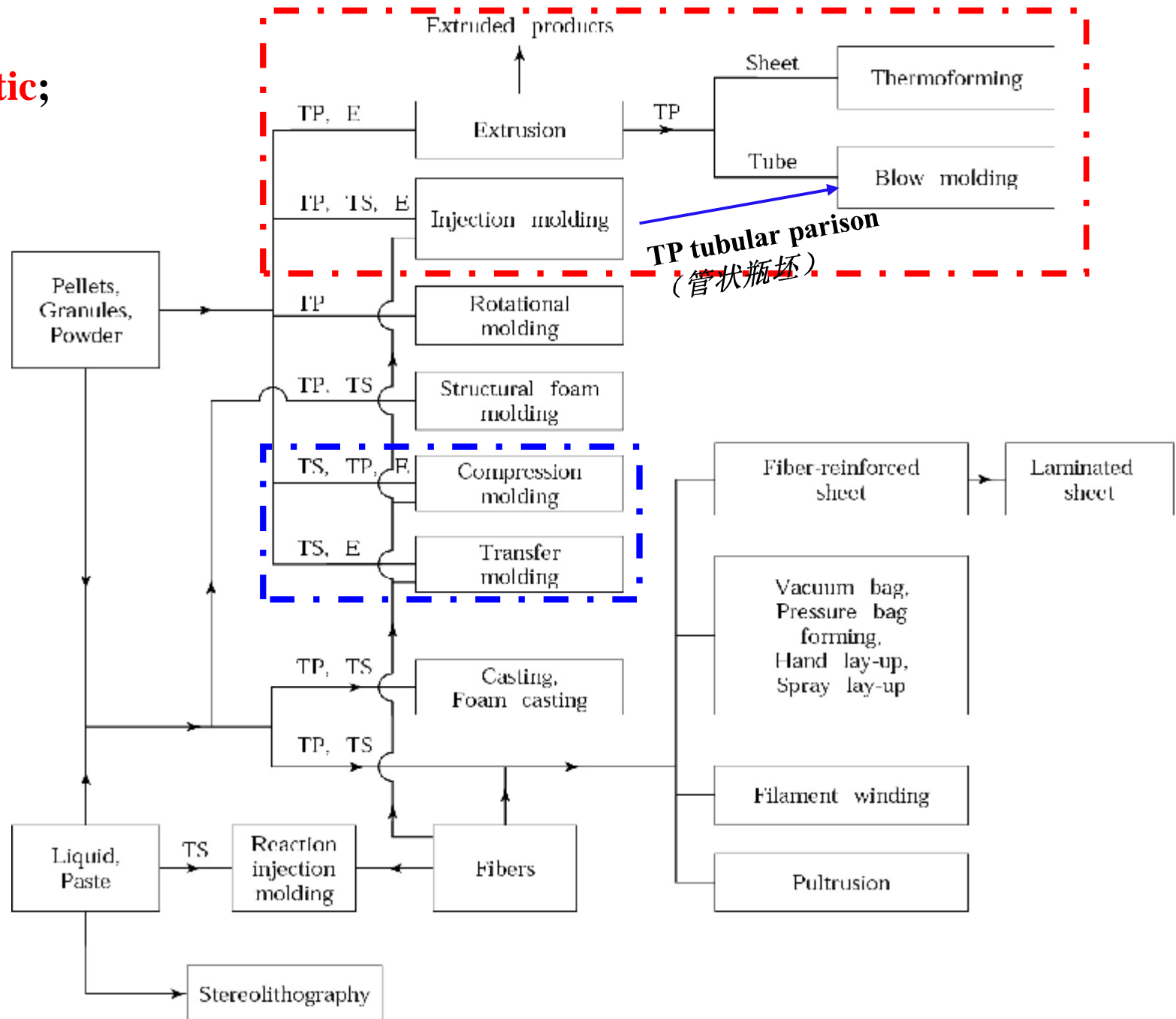
# Characteristics of Forming and Shaping Processes for Plastics and Composite Materials

TABLE 18.1

Process	Characteristics
Extrusion	Long, uniform, solid or hollow complex cross-sections; high production rates; low tooling costs; wide tolerances.
Injection molding	Complex shapes of various sizes, eliminating assembly; high production rates; costly tooling; good dimensional accuracy.
Structural foam molding	Large parts with high stiffness-to-weight ratio; less expensive tooling than in injection molding; low production rates.
Blow molding	Hollow thin-walled parts of various sizes; high production rates and low cost for making containers.
Rotational molding	Large hollow shapes of relatively simple shape; low tooling cost; low production rates.
Thermoforming	Shallow or relatively deep cavities; low tooling costs; medium production rates.
Compression molding	Parts similar to impression-die forging; relatively inexpensive tooling; medium production rates.
Transfer molding	More complex parts than compression molding and higher production rates; some scrap loss; medium tooling cost.
Casting	Simple or intricate shapes made with flexible molds; low production rates.
Processing of composite materials	Long cycle times; tolerances and tooling cost depend on process.

**TP, Thermoplastic;**  
**TS, Thermoset**

# Outline of Forming and Shaping Processes

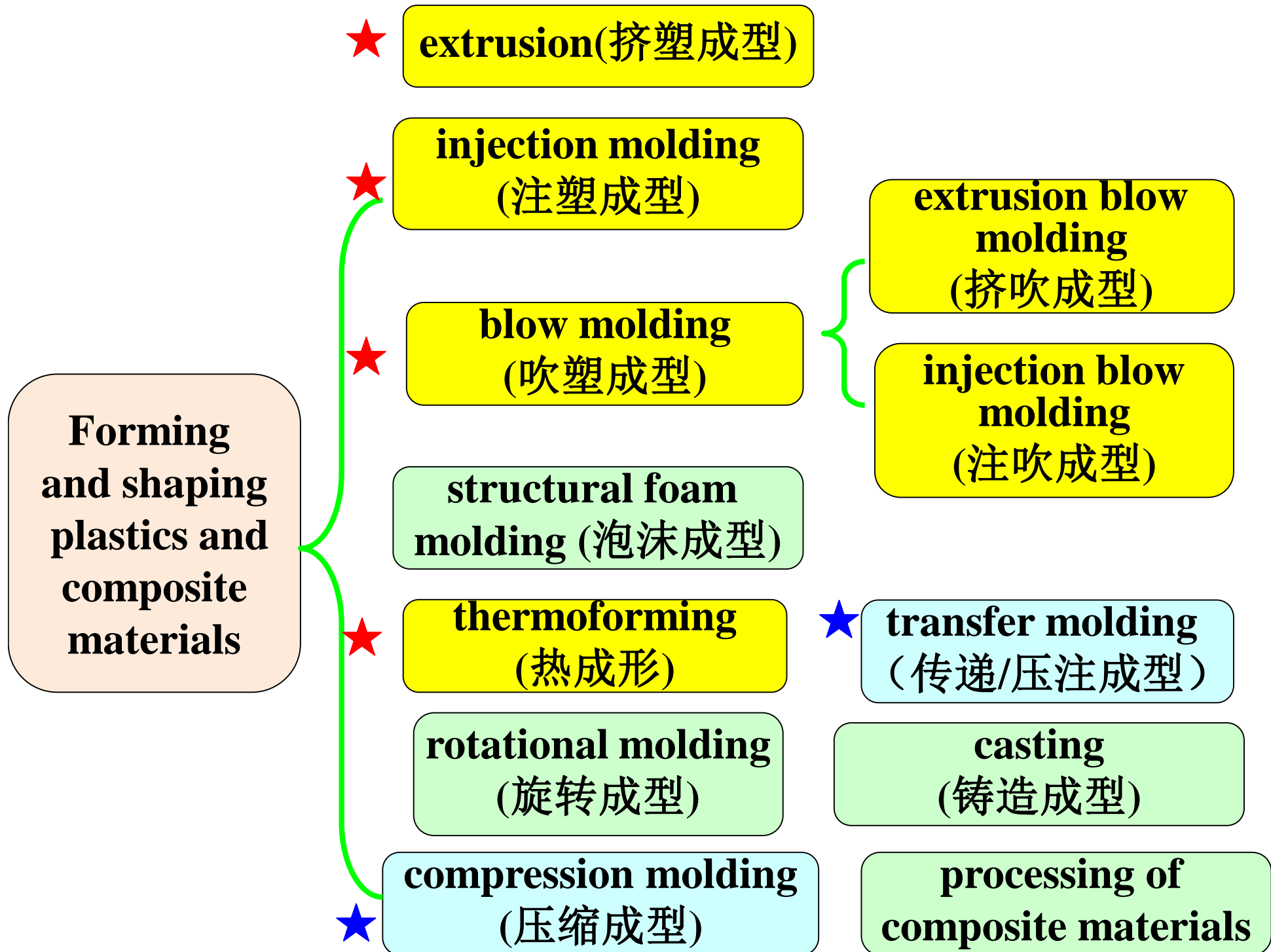


**Figure 18.1 Outline of forming and shaping processes for plastics, elastomers, and composite materials. (E, Elastomer (热塑性弹性体).)**

## **\* 热塑性弹性体（热塑性橡胶）**

### **Thermoplastic Elastomer/Elastoplastics**

- 热塑性弹性体，简称TPE，是一类在常温下显示橡胶弹性、受热时具有可塑性的高分子材料。
- 它具有普通硫化胶的类似物性，但不需要硫化，可与热塑性树脂一样，采用普通塑料加工方法成型，制品可回收再加工而不失其基本性能。
- TPE新型材料的开发，给橡胶工业带来重大革新。它打破了橡胶和塑料之间的传统界限，在节能、省力和防止环境污染等方面，更具经济和社会效益。然而，TPE的耐热性和机械强度、价格、变形等均不够理想。近年来，除进行改性外，还不断出现新品种。





## 18.2 Extrusion (挤出/挤塑成型)

### Outline

- Ø **Extrusion process**
- Ø **Functions and characteristics of screw (螺杆) in extruder**
- Ø **Typical extruded shapes:**
  - long continuous products with constant cross-section
  - pellets (颗粒)
  - sheet (板材)
  - film (薄膜)
- Ø **Process parameters**
- Ø **Extruder (挤出机)**

# Extrusion (挤出/挤塑成型)

pellets, granules,  
or powder of **TP**

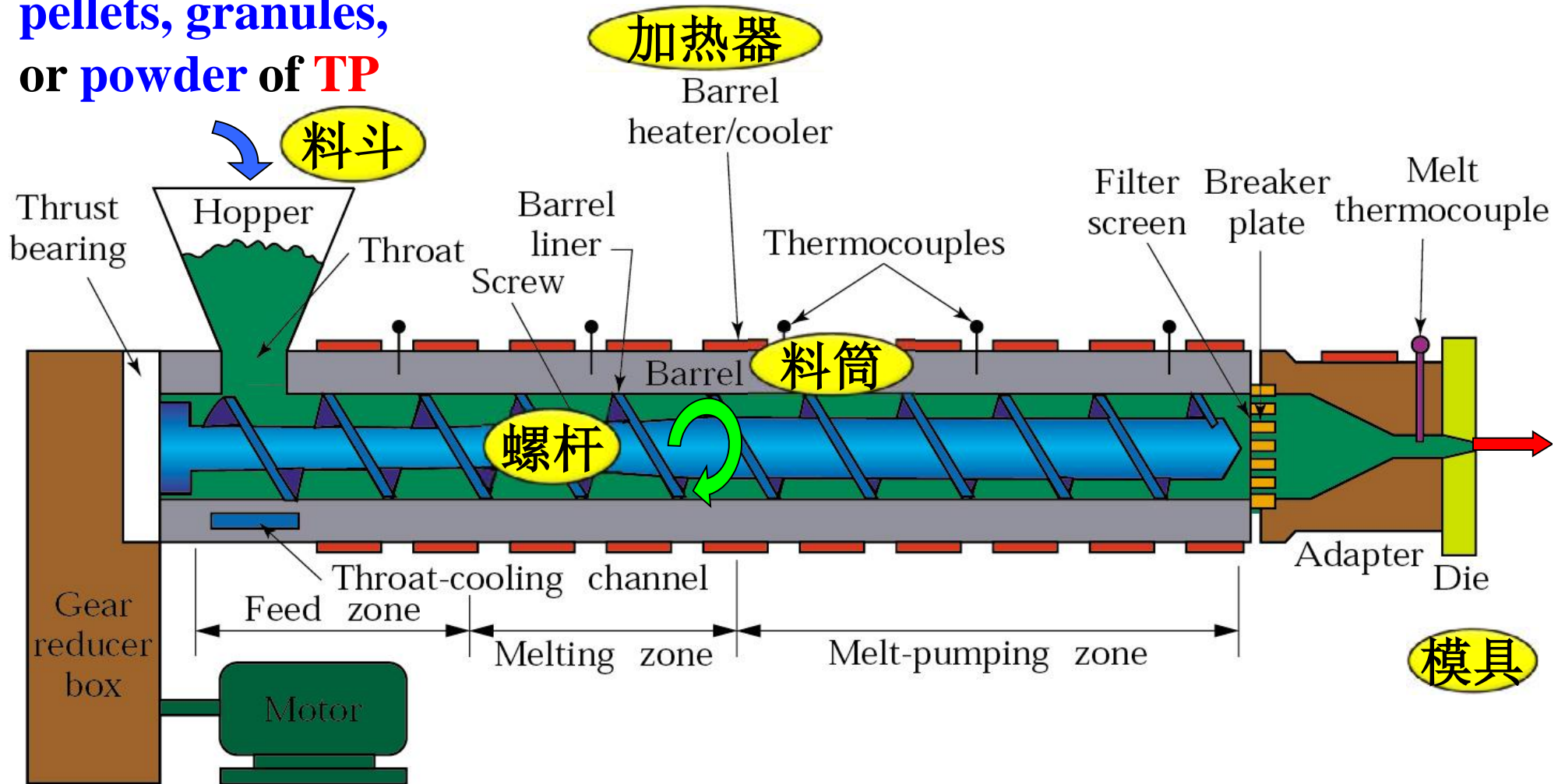
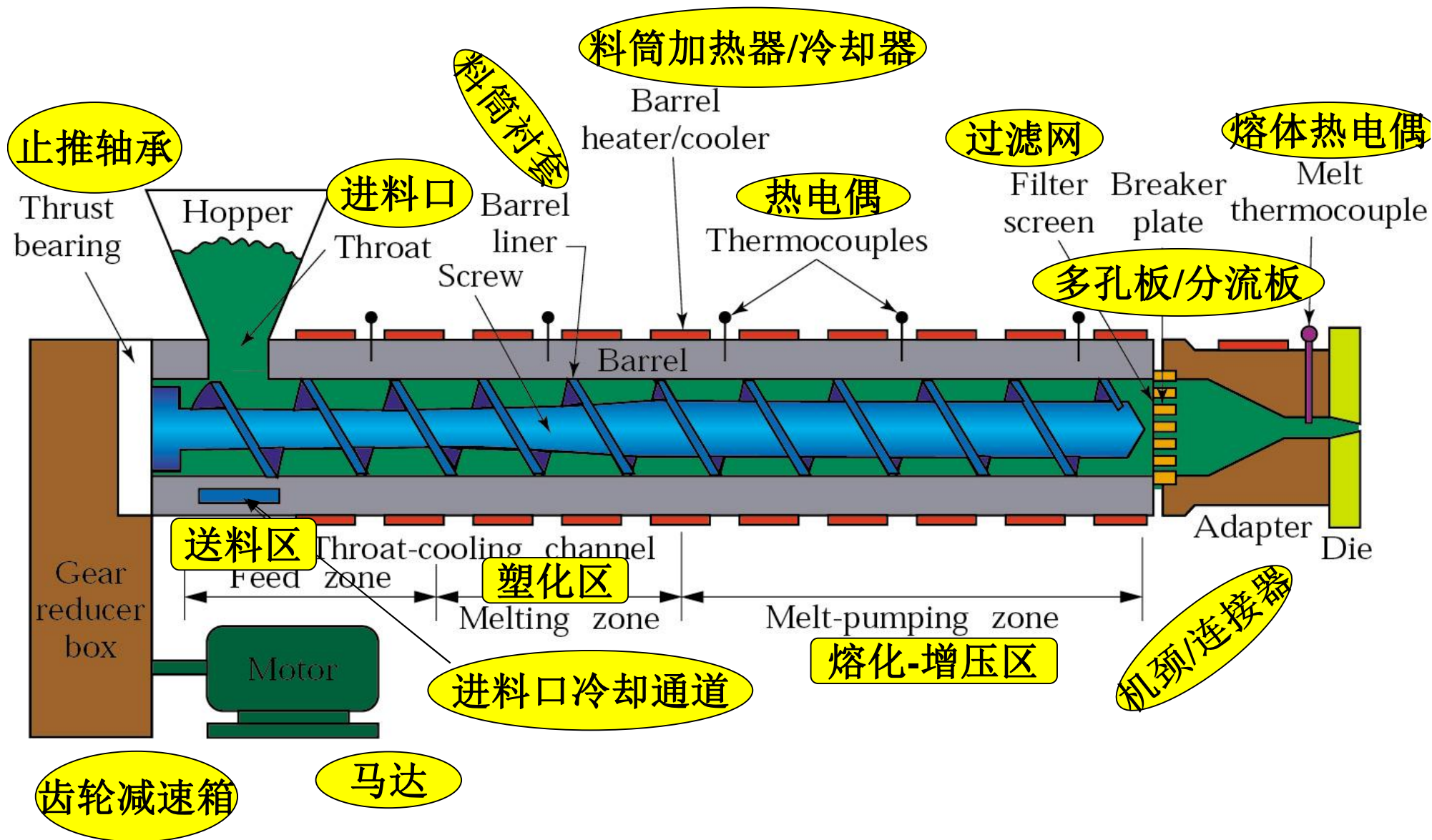
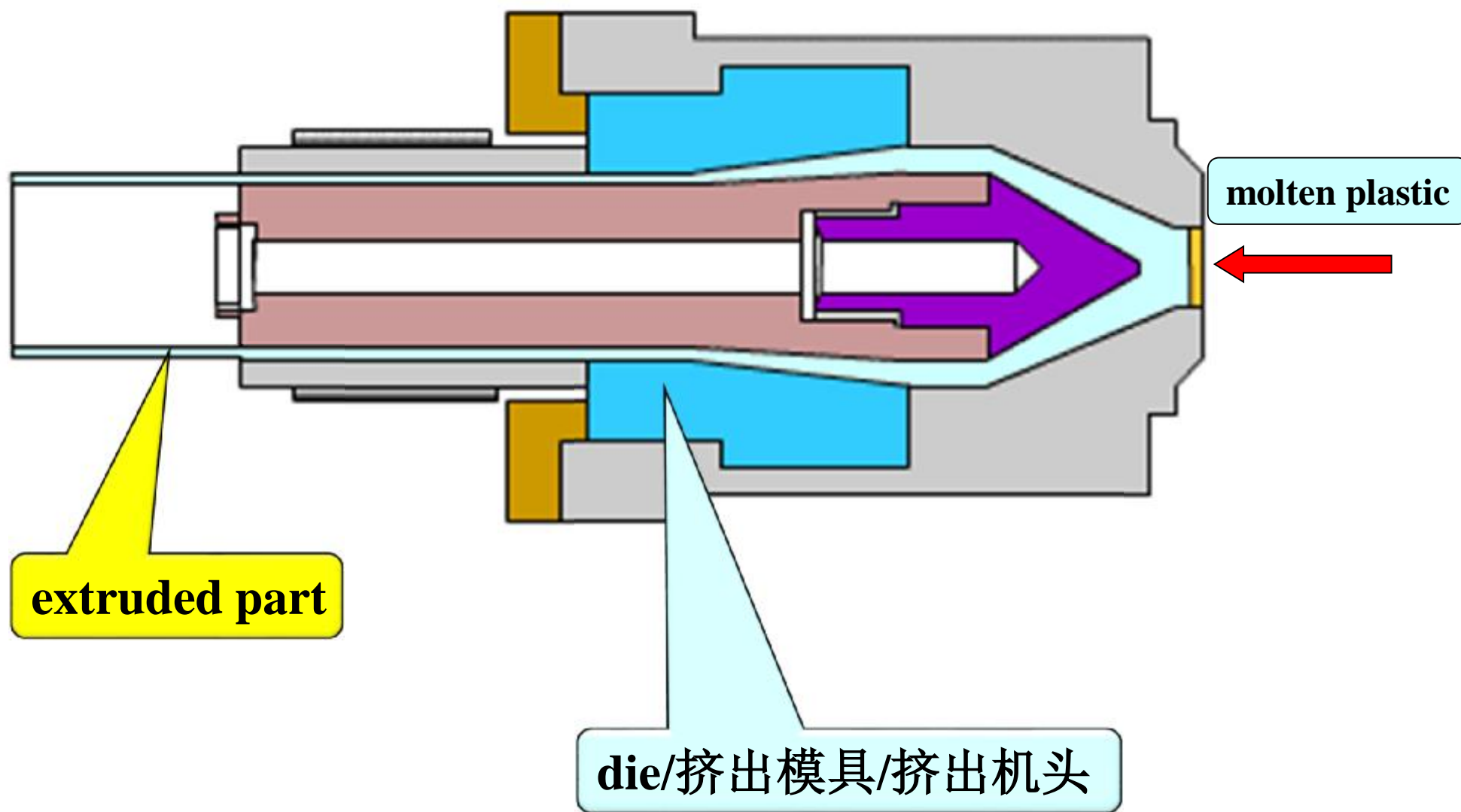


Figure 18.2 Schematic illustration of a typical extruder. *Source: Encyclopedia of Polymer Science and Engineering* (2nd ed.). Copyright © 1985. Reprinted by permission of John Wiley & Sons, Inc.

# Extrusion Process

- Raw materials are in the form of **thermoplastic pellets, granules, or powder**
- They are placed into a **hopper** (料斗/漏斗) and fed into the **extruder** (挤出机) **barrel** (料筒)
- The barrel is equipped with a **screw** (螺杆) that blends the pellets and conveys (传输/运送) them down the barrel
- **Heaters** (加热器) around the extruder's barrels heat the pellets and liquefy (融化/塑化) them
- The **molten plastic** is **forced through a die**, in a process similar to that of **extruding metals**
- Also **suitable for E** (elastomer, 热塑性弹性体/ 热塑性橡胶)





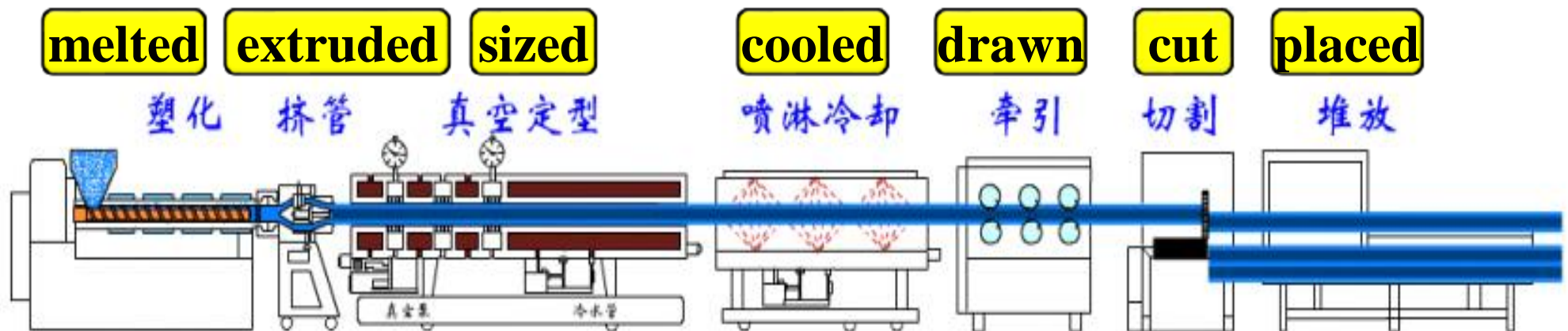
The extruded part is then **drawn** (拉出/牵引) by a puller (牵引装置) :

- ① **sized** (定型)
- ② sufficiently **cooled**
- ③ **coiled** (卷绕) or **cut** into desired lengths.

- **expose** (暴露) it to air
- **pass** it through a water-filled channel

the **rate** and **uniformity of cooling** must be **controlled**:

Ø to minimize product **shrinkage** (收缩) and **distortion** (扭曲/变形)



## How does the raw material melt?

- ① **Heaters** around the extruder's barrel;
- ② **Internal friction** from the **mechanical action** of the **screw**
- **Both** of them **heat** the pellets and **liquefy** them

融化/塑化

# Functions of Screw

- ① To **convey** (传输) the plastics forward.
- ② To help to **melt** (融化) the plastics due to the internal friction from the mechanical action
- ③ To **builds up pressure** (施压/加压) in the barrel.



usually 4Mpa ~ 50Mpa



# Characteristics of Screw

## ① Feed Section (送料区)

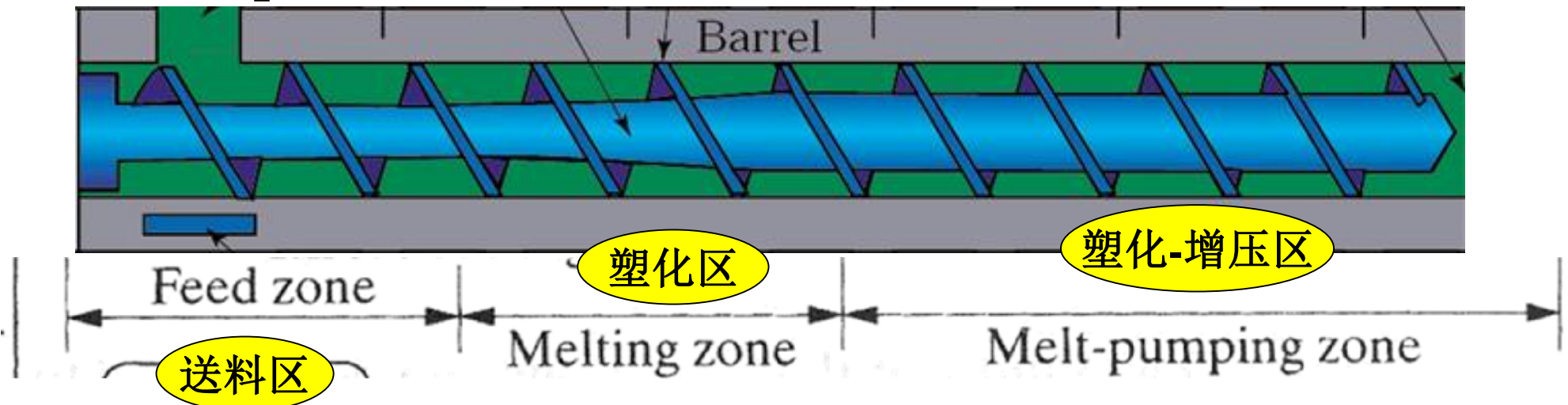
- **conveys** the materials from the hopper area into the central region of the barrel;

## ② Melt, or Transition Section (塑化区/相变区)

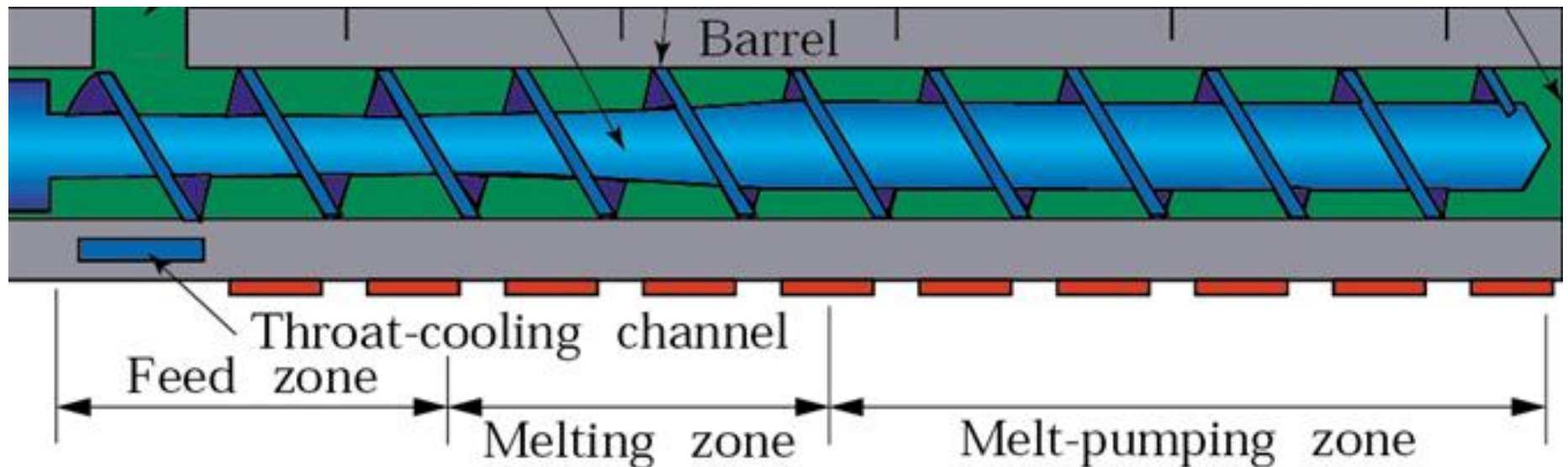
- where the heat generated by the shearing of the plastic and by the heaters causes **melting** to begin;

## ③ Pumping Section (增压区)

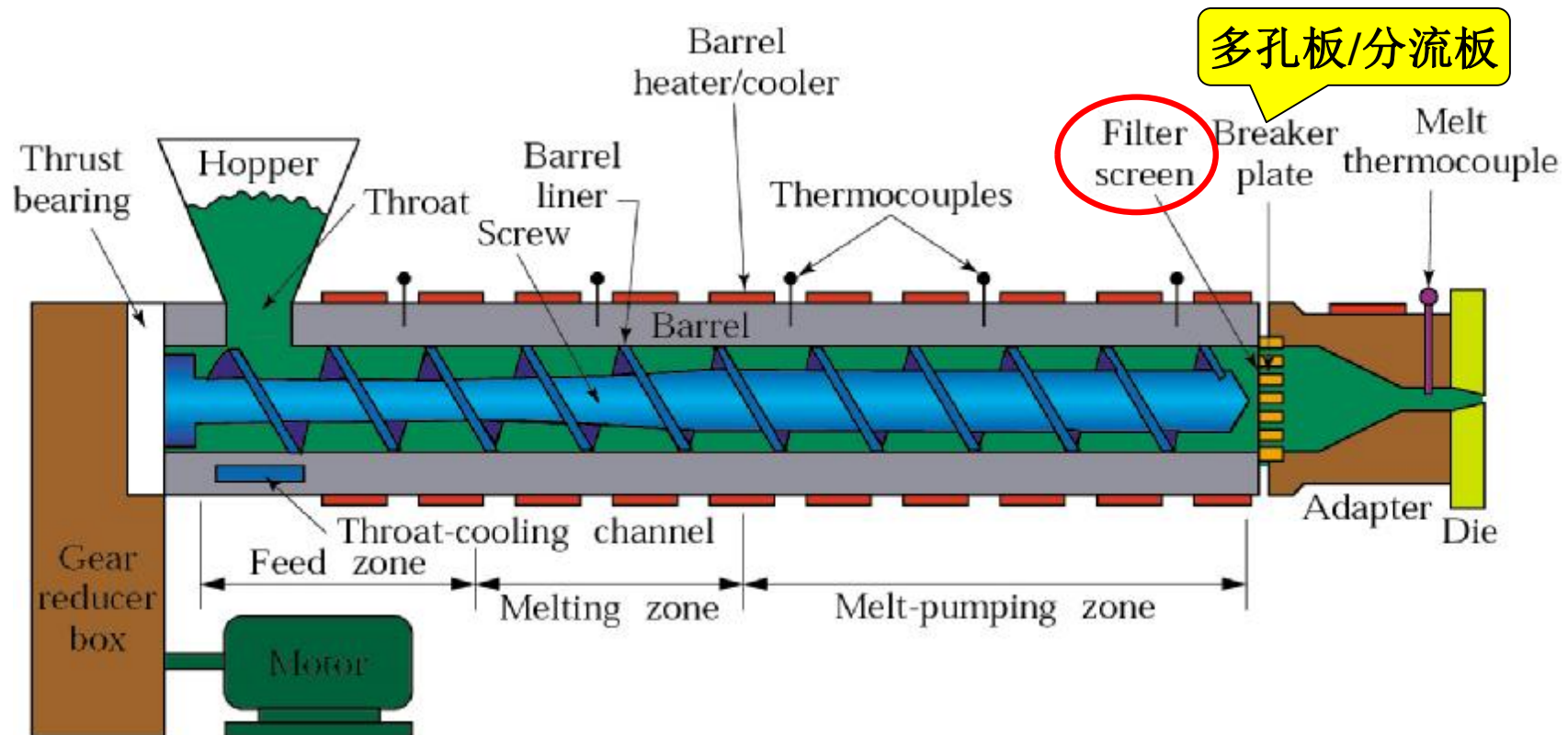
- where additional shearing and melting occurs, with **pressure** build up at the die.



- The **lengths** of these sections can be **changed** to accommodate (适应) the melting characteristics (塑化特性) of different plastics.

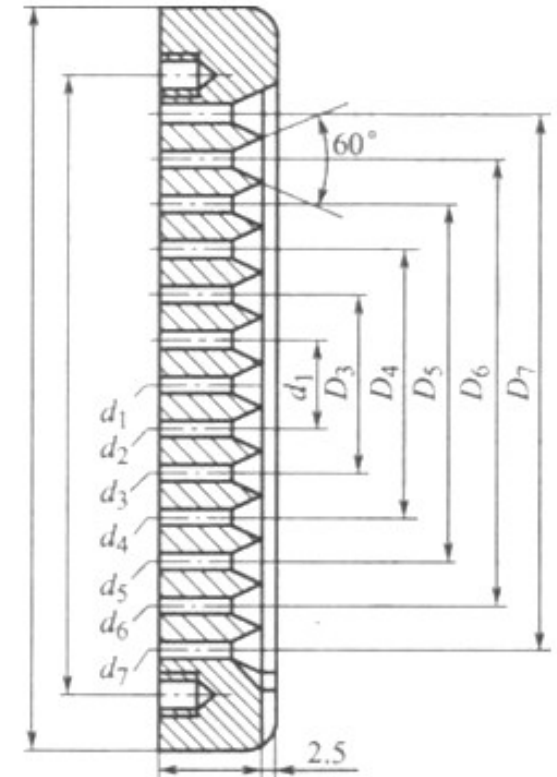


- **Filter Screen** (过滤网/筛)
  - a **metal screen** which is placed before the die
  - to **filter out** unmelted or congealed (凝结的/冻结的) **resin** (树脂/合成树脂/塑料)
  - it is **replaced** (更换) **periodically** (周期性的).



## \* 分流板的结构与作用

- 分流板也叫多孔板，安装在机筒的前端，一般情况下，分流板的前面都要加过滤网。
- 分流板与过滤网在挤塑系统的作用是：
  - Ø 把机筒内**旋转运动**的塑化熔料经过分流板后**变成直线运动**，同时阻止熔料中的杂质通过；
  - Ø 分流板与过滤网对料流的阻力也**增加**了熔料流对螺杆的**反压力**，这样使螺杆对原料的**塑化质量**也得到**改进**。
- 分流板的结构比较简单，通常用45、40Cr或2CrB合金钢制造。加工时要注意进料端面不应有料流阻力死角，孔的表面要尽量光滑，以便保证料流通畅。
- 过滤网的使用层数，一般可用1~5层，网的目数为40~120目，用不同目数网组合使用时，要把目数大的网放在中间，目数小的网靠在分流板上支撑目数大的网，以增加目数大的网的工作强度。



# Typical Extruded Shapes

- Complex shapes with **constant cross-section**
- **Long continuous products:**
  - due to **continuous of supply of raw material** on the hopper
  - such as solid rods, channels, tubing, pipe, window frames, architectural components, and sheet
- Rigid plastic **tubing** (刚性塑料管件) :
  - the **die** is **rotated**
  - consequently, the polymer is **sheared** and **biaxially oriented** (双轴取向) during extrusion
  - the tube has higher **crushing strength** (抗碎/抗压强度) and higher **strength-to weight ratio** (比强度) than conventionally extruded tubes.

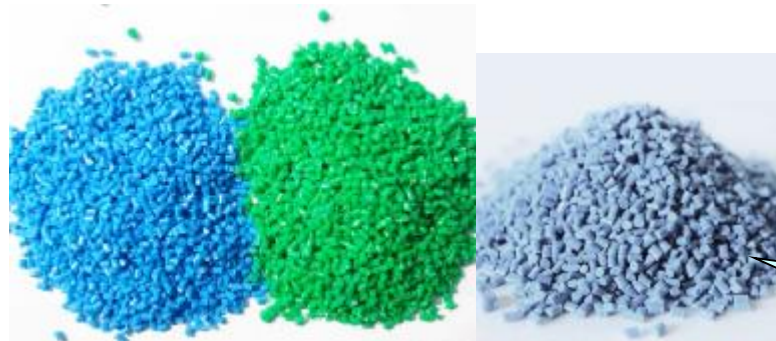


# Typical Extruded Shapes

- Plastic-coated electrical wire, cable, and strips
  - the wire is fed into the die opening at a controlled rate with the extruded plastic in order to produce a uniform coating
- **Pellets** 造粒
  - used for other plastic-processing methods
  - the extruded product is a **small-diameter rod**, which is **chopped** (切断/切碎) into short lengths (pellets) as it is extruded

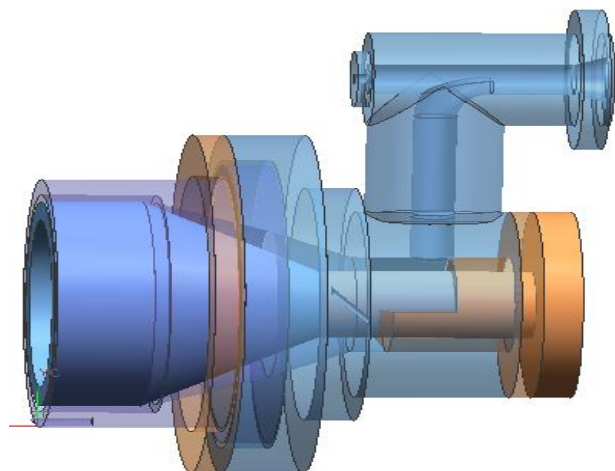


塑料颗粒原色



着色后颗粒

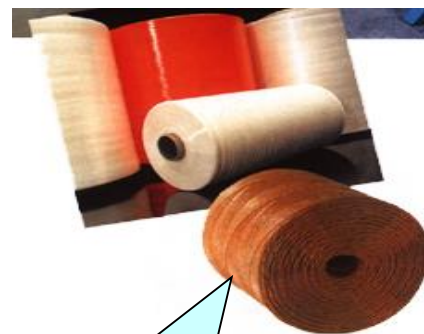
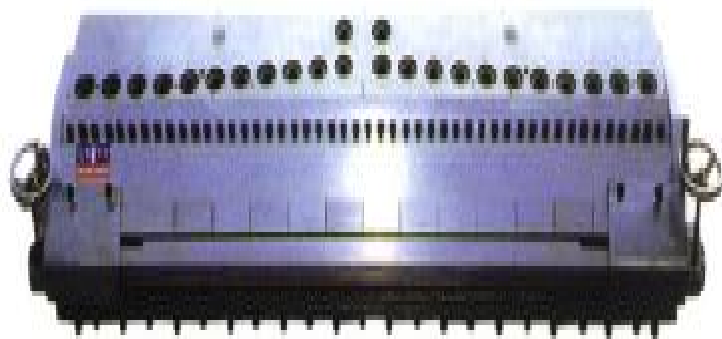
挤出模具（挤出机头）



挤出成型产品



extruded tube



extruded sheet

## Various Shapes with Constant Cross-section





# Process Parameters

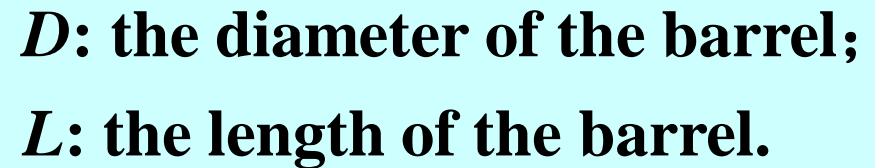
- Ø extruder-screw speed
- Ø barrel-wall temperatures
- Ø die design
- Ø cooling and drawing speeds



**uniform  
dimensional  
accuracy**

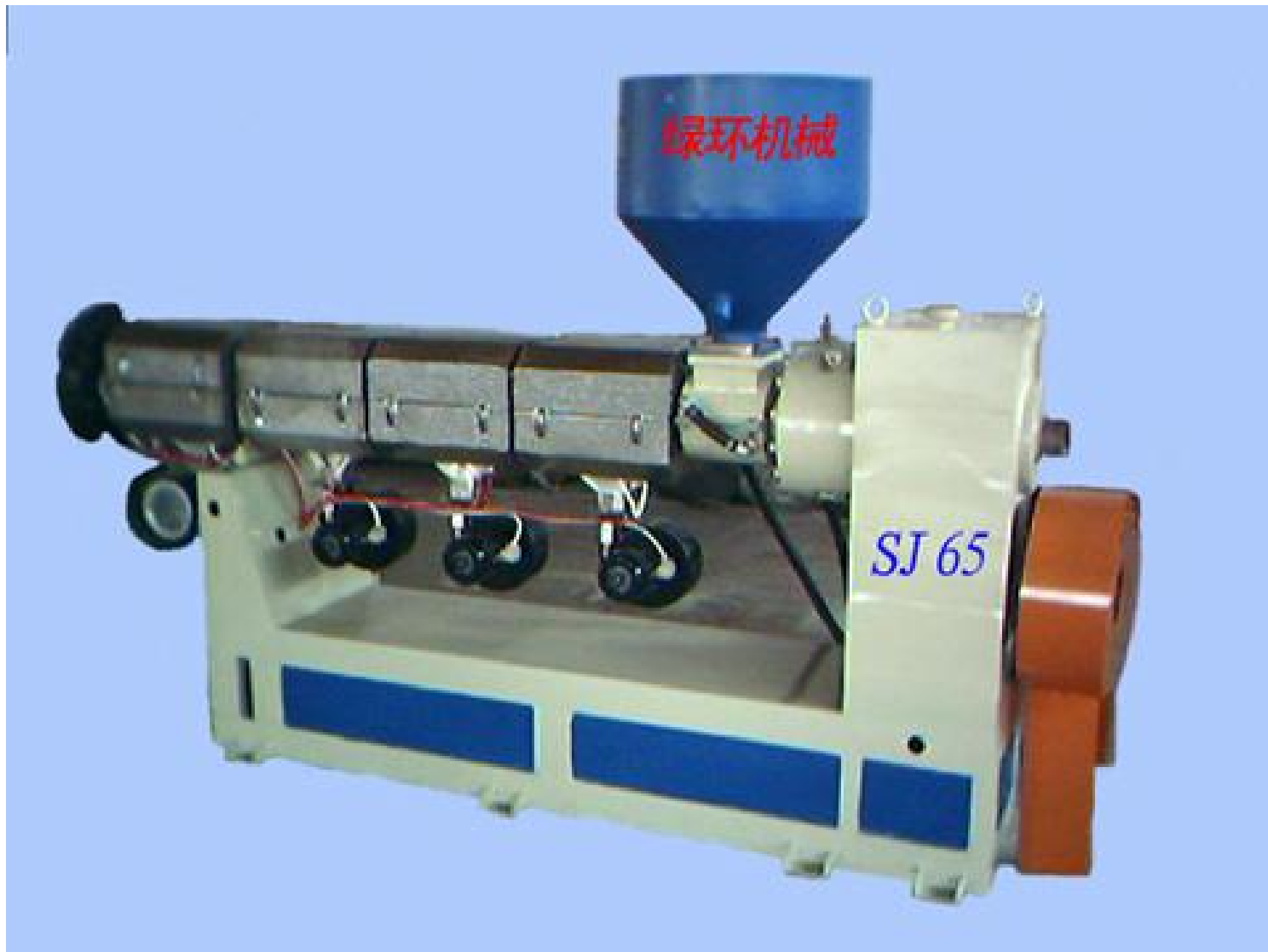
## Extruder (挤出机)

- Extruders are generally **rated** (型号规格等级) by:
  - **$D$** ;
  - **$L/D$  ratio (长径比)**
- Typical commercial units:
  - **$D$ : 25 ~ 200 mm**
  - **$L/D$  ratios : 5 ~ 30**

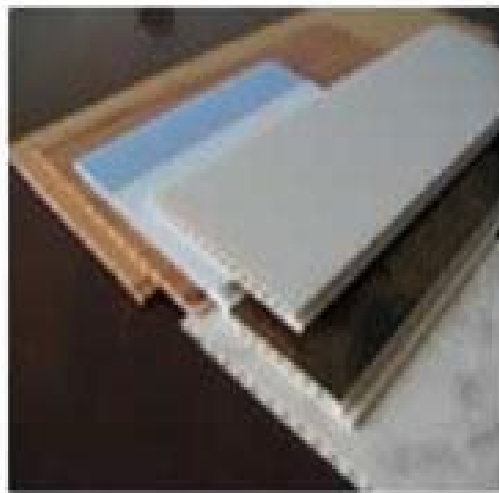


**$D$** : the diameter of the barrel;  
 **$L$** : the length of the barrel.

# Extruder



# Plastics Sheet and Extruder



# Economics of Extrusion

- Relatively **inexpensive tooling**
- Extrusion **equipment costs relatively high**
  - can be on the order of (接近/近似) \$300,000
  - including the cost for the equipment for downstream (下游的) **cooling and winding (卷绕)** of the extruded product.
- **Large production runs** (大批量生产) are generally required to justify such an expenditure

## Sheet Extrusion (板材/片材挤出)

- The polymer is extruded by forcing it through a **specially designed die---a flat extrusion die (T型挤出口模)**
- The extruded sheet is **taken up (卷取)** first on water-cooled rolls and then by a pair of rubber-covered pull-off rolls (牵引辊).

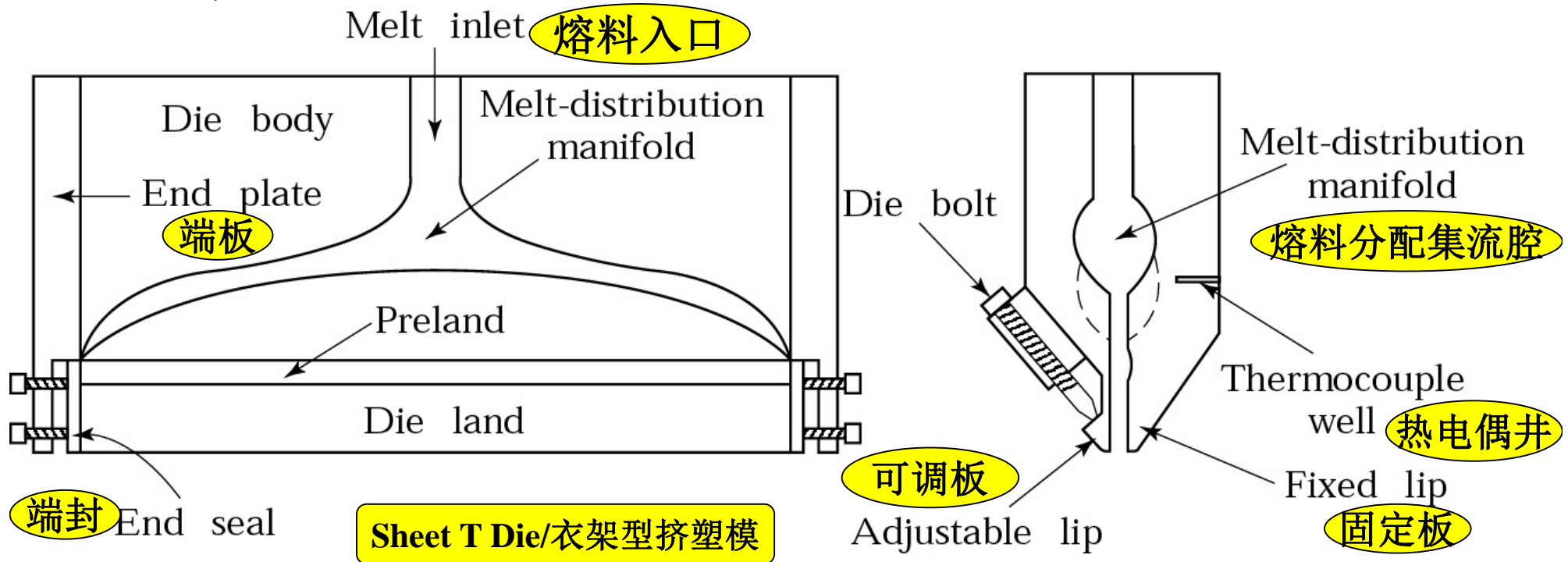


Figure 18.3 Die geometry (coat-hanger die) for extruding sheet. Source: *Encyclopedia of Polymer Science and Engineering* (2d ed.). Copyright © 1985. Reprinted by permission of John Wiley & Sons, Inc.

# Blown Film Extrusion (薄膜挤吹)

- A **thin-walled tube** is extruded vertically upward
- Then **expanded** (扩展/膨胀) into a balloon (气球/bubble/泡管) shape by **blowing air** through the center of the extrusion die until the desired film thickness is reached.
- The balloon is usually **cooled** by air from a cooling ring around it, which can also act as a barrier to further expansion of the balloon to control its dimensions.

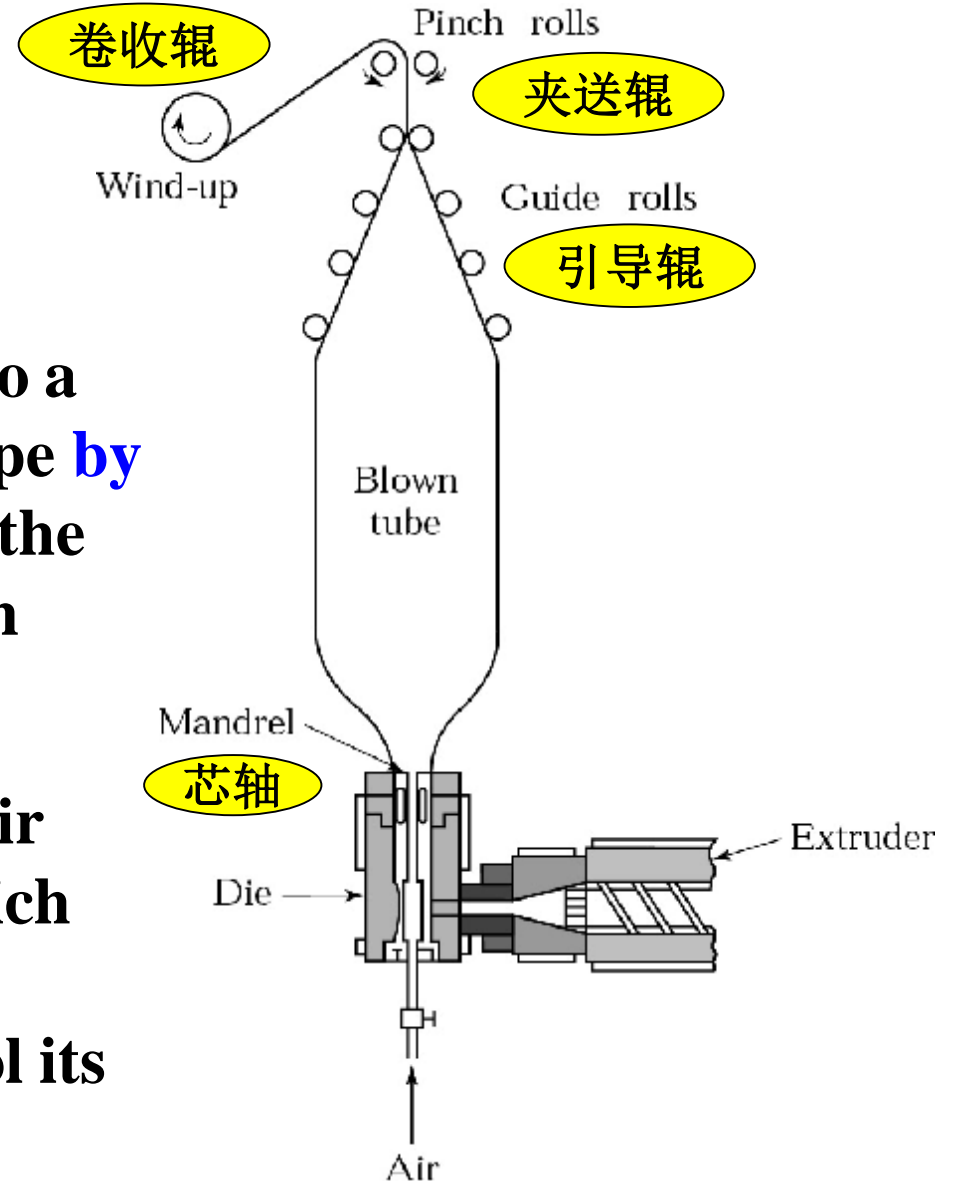


Figure 18.4 Schematic illustration of the production of thin film and plastic bags from tube first produced by an extruder and then blown by air. Source: D.C. Miles and J.H. Briston, *Polymer Technology*, 1975. Reproduced by permission of Chemical Publishing Co., Inc.

## \* Skived Film (旋切薄膜)

- Film is also produced by **shaving** (刮削/切削) **solid round billets** (实心圆棒) of plastic with specially designed **knives**
- Especially polytetrafluoroethylene (PTFE/聚四氟乙烯)

Open the website to see the video if interested.

[https://v.youku.com/v\\_show/id\\_XMzM5MzQ2MjkxMg==.html](https://v.youku.com/v_show/id_XMzM5MzQ2MjkxMg==.html)



# 18.3 Injection Molding (注射/注塑成型)

## Outline

- Ø **Two types** of injection molding processes (machines) :
  - plunger type (柱塞式)
  - reciprocating screw type (往复运动螺杆式)
- Ø **Characteristics** of injection molding
- Ø Typical injection molded parts
- Ø **Injection mold (注射模)** :
  - mold features
  - three basic **types**:
    - cold runner two-plate mold (冷流道两板模)
    - cold runner three-plate mold (冷流道三板模)
    - hot runner mold (热流道模)
- Ø **Injection molding machine (注射机)** :
  - types
  - clamping force (锁模力)
  - capacity

# Injection Molding with Plunger (柱塞式注射成型)

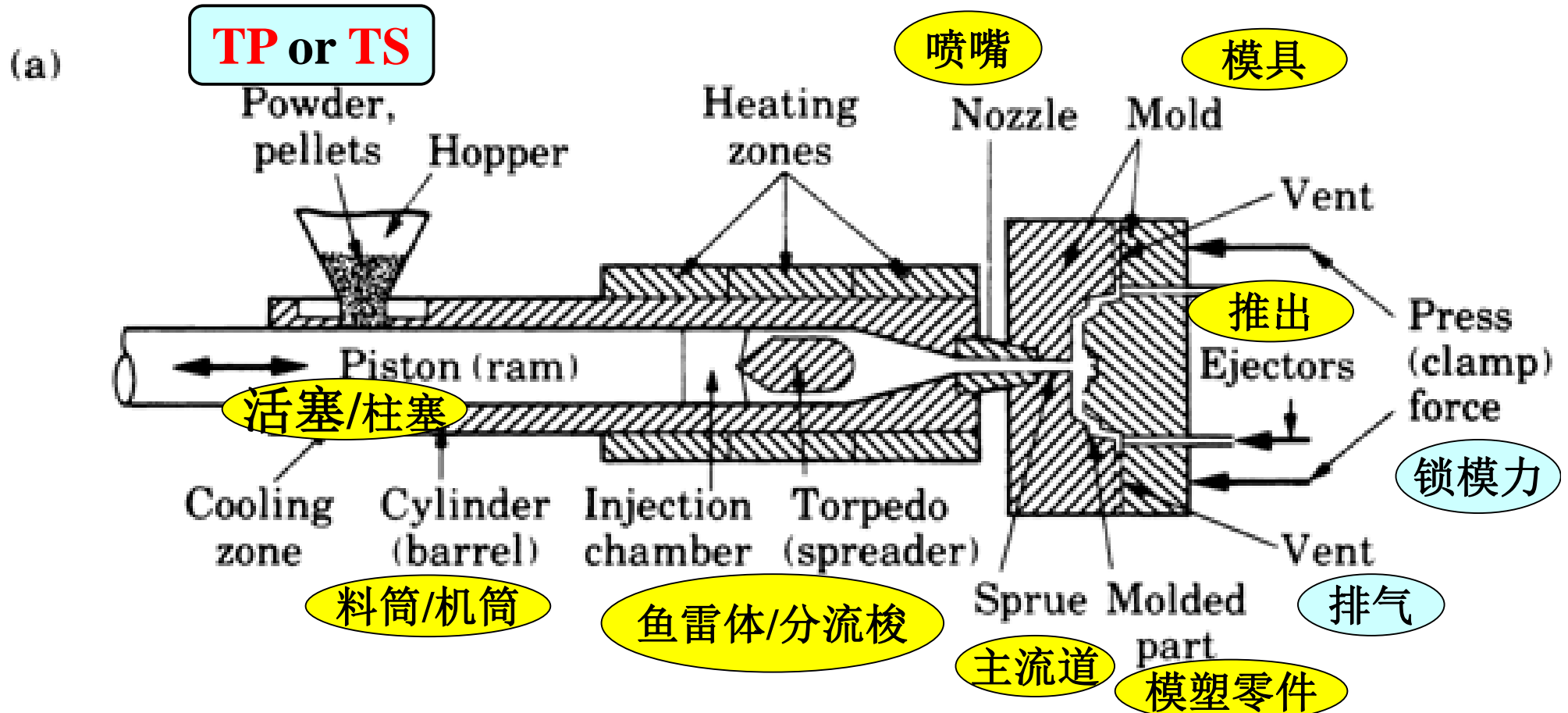
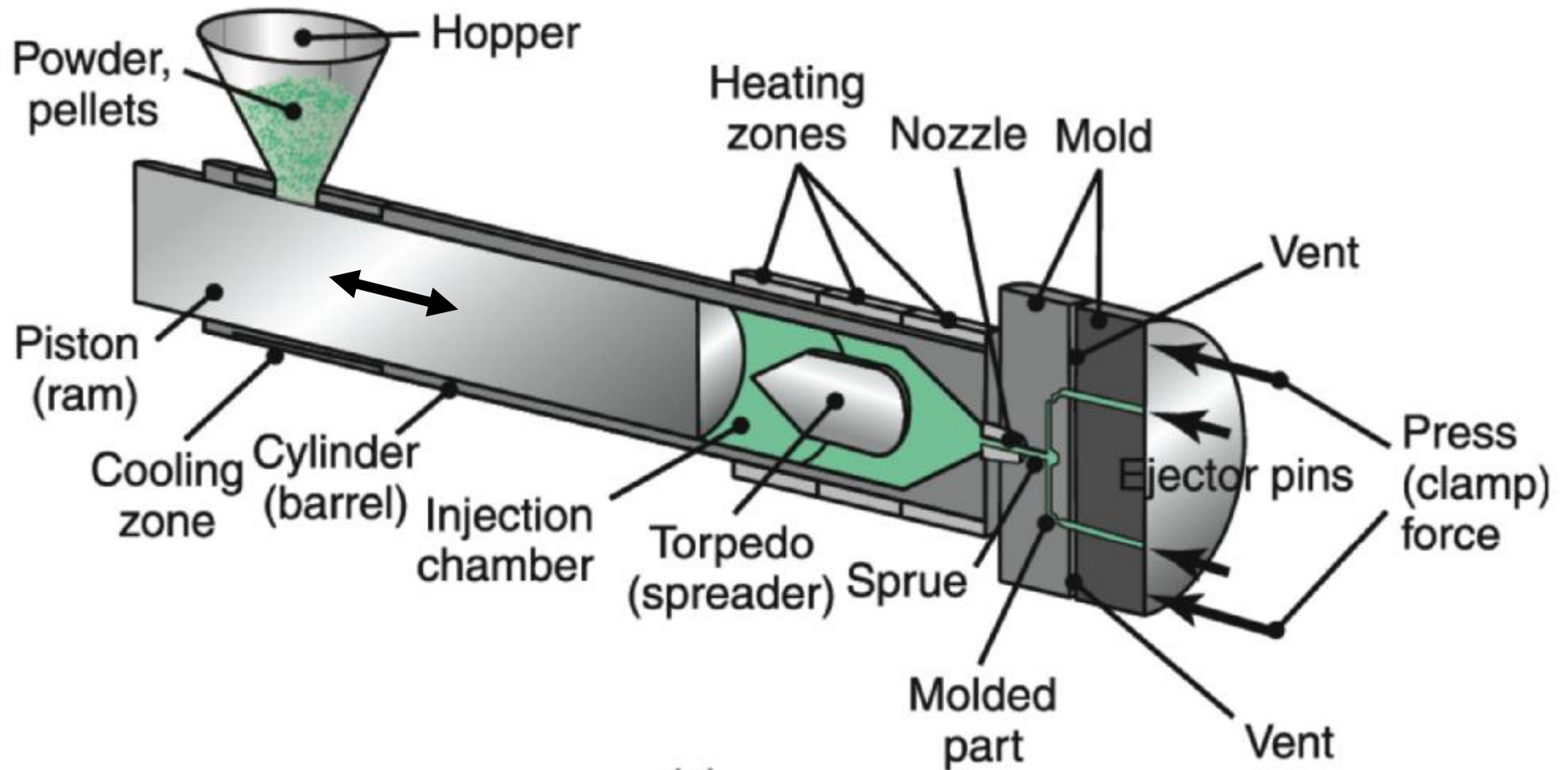


Figure 18.5 Injection molding with plunger (柱塞)

# Injection Molding with Plunger

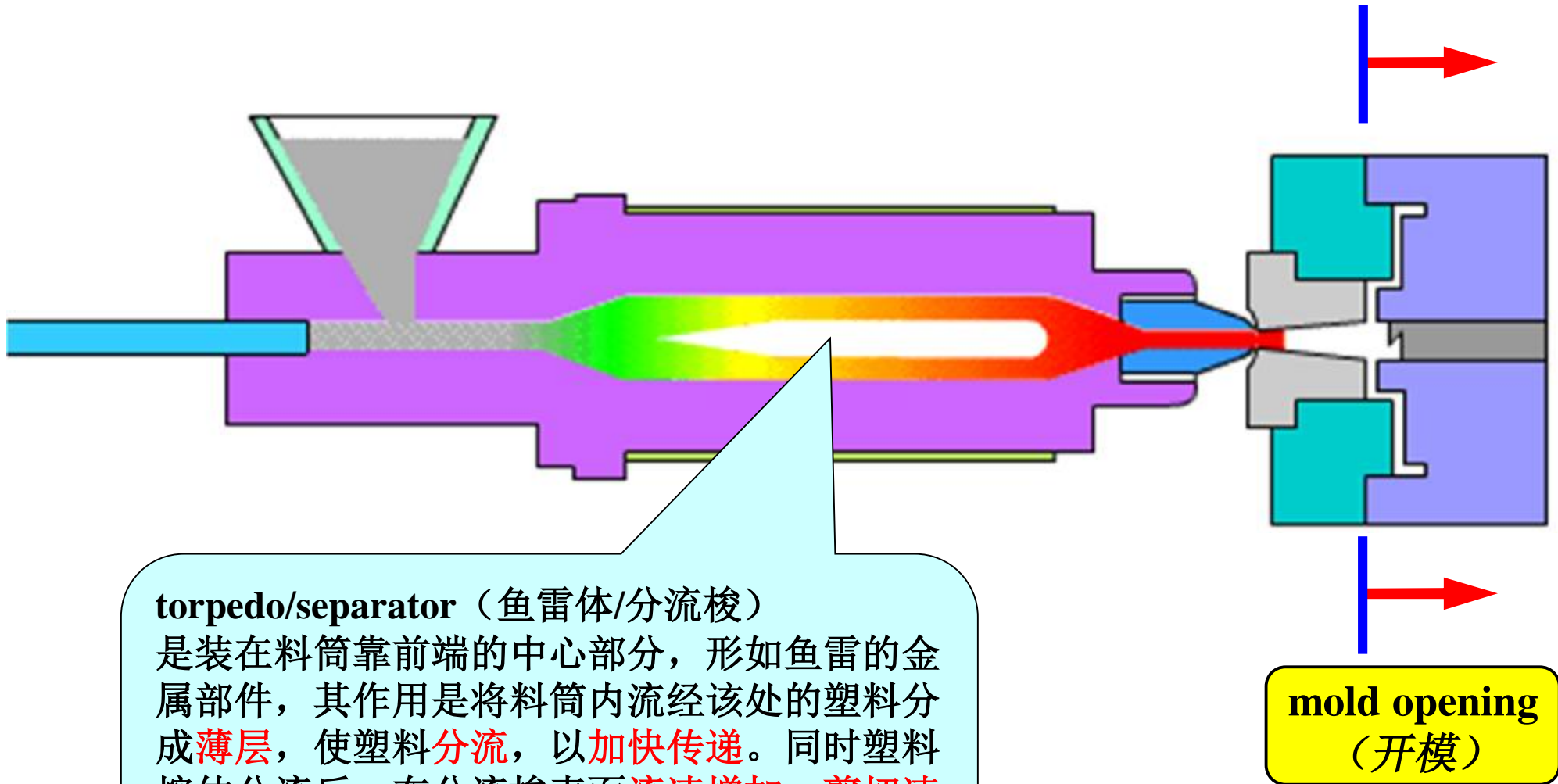
## (柱塞式注射成型)




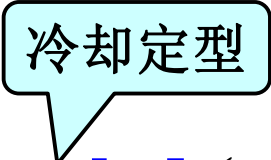
(a)

# 柱塞式注射机工作示意图

## (Injection Molding with Plunger)

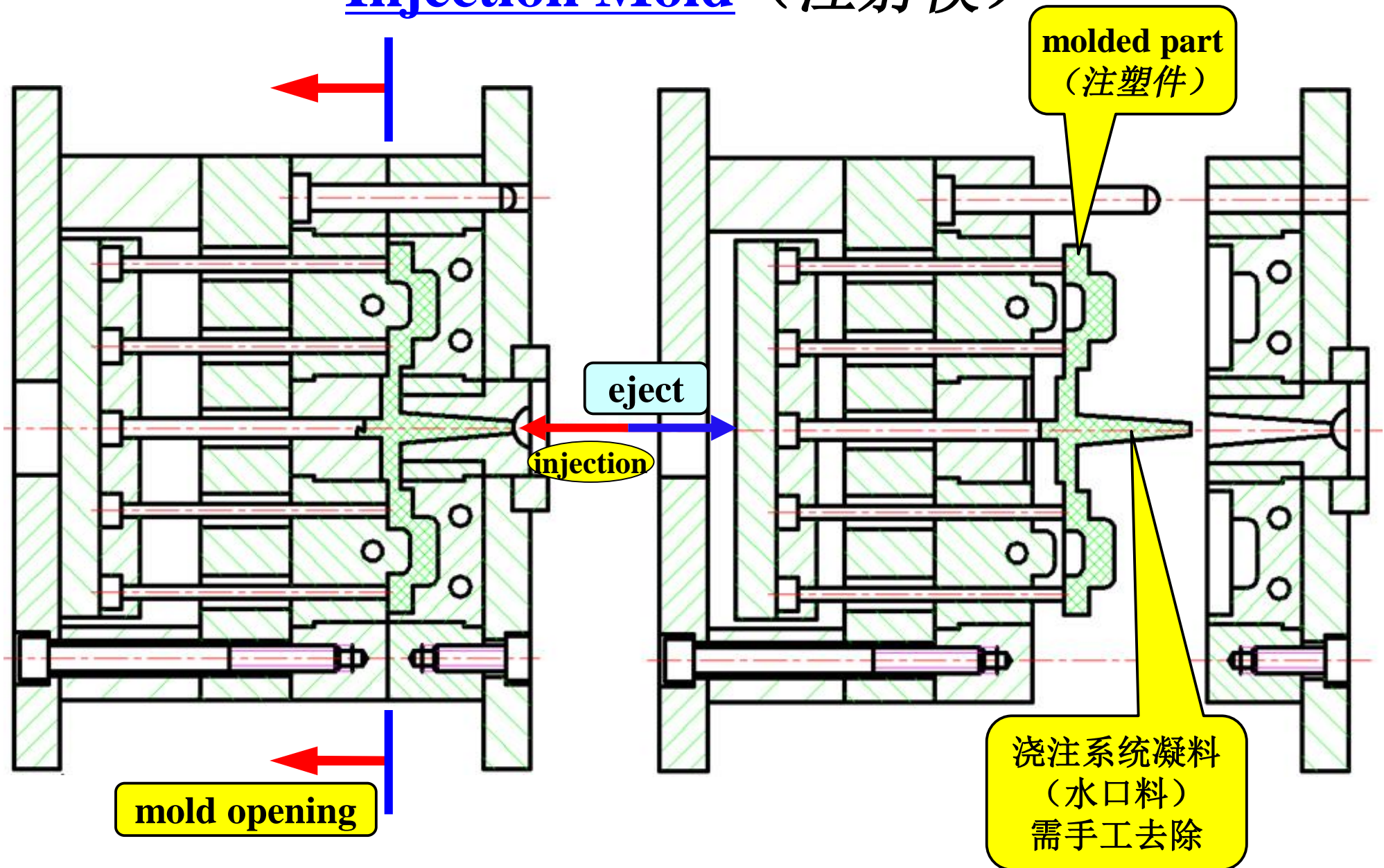


# Injection Molding Process

- The pellets or granules are **fed into** the heated **cylinder** (料筒/机筒) of **injection machine** (注射机/注塑机)
- The melt is **forced into a split-die chamber** (可分开的型腔/模腔) by a hydraulic plunger (柱塞) of the injection machine  

- After part is sufficiently **cooled** (for **TP**) or **cured** (for **TS**), the molds are opened and the part is **ejected** (推出/*knockout*) .
- The molds are then **closed**, and the process is **repeated** automatically



# Injection Mold (注射模)



a) Mold Closed & Injection

b) Mold Opened & Part Ejected

# Reciprocating Screw Type Injection Machine

(往复运动的螺杆式注射机)

- The molten plastic is **conveyed** (传送) to the front of the barrel while **screw rotates**
- As the pressure builds up at the mold entrance, the rotating screw begins to **move backward** under pressure to a predetermined distance
  - this movement controls the volume of material to be injected.
- The screw then **stops rotating** and is **pushed forward hydraulically**, forcing the molten plastic **into the mold cavity**

(b)

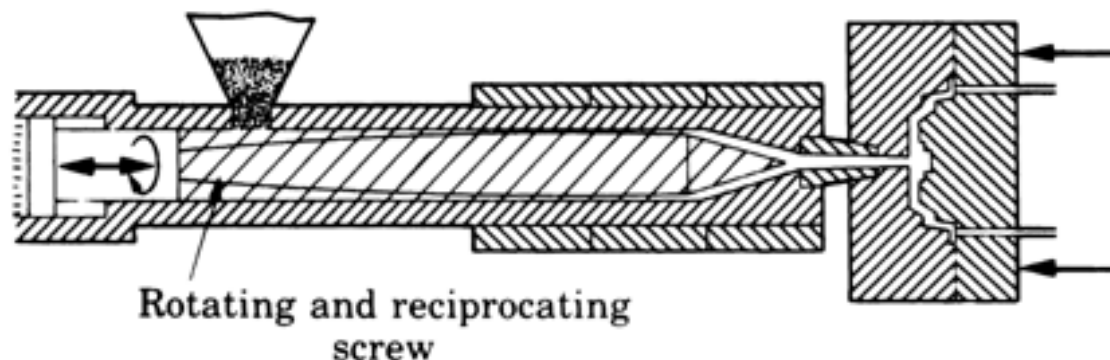
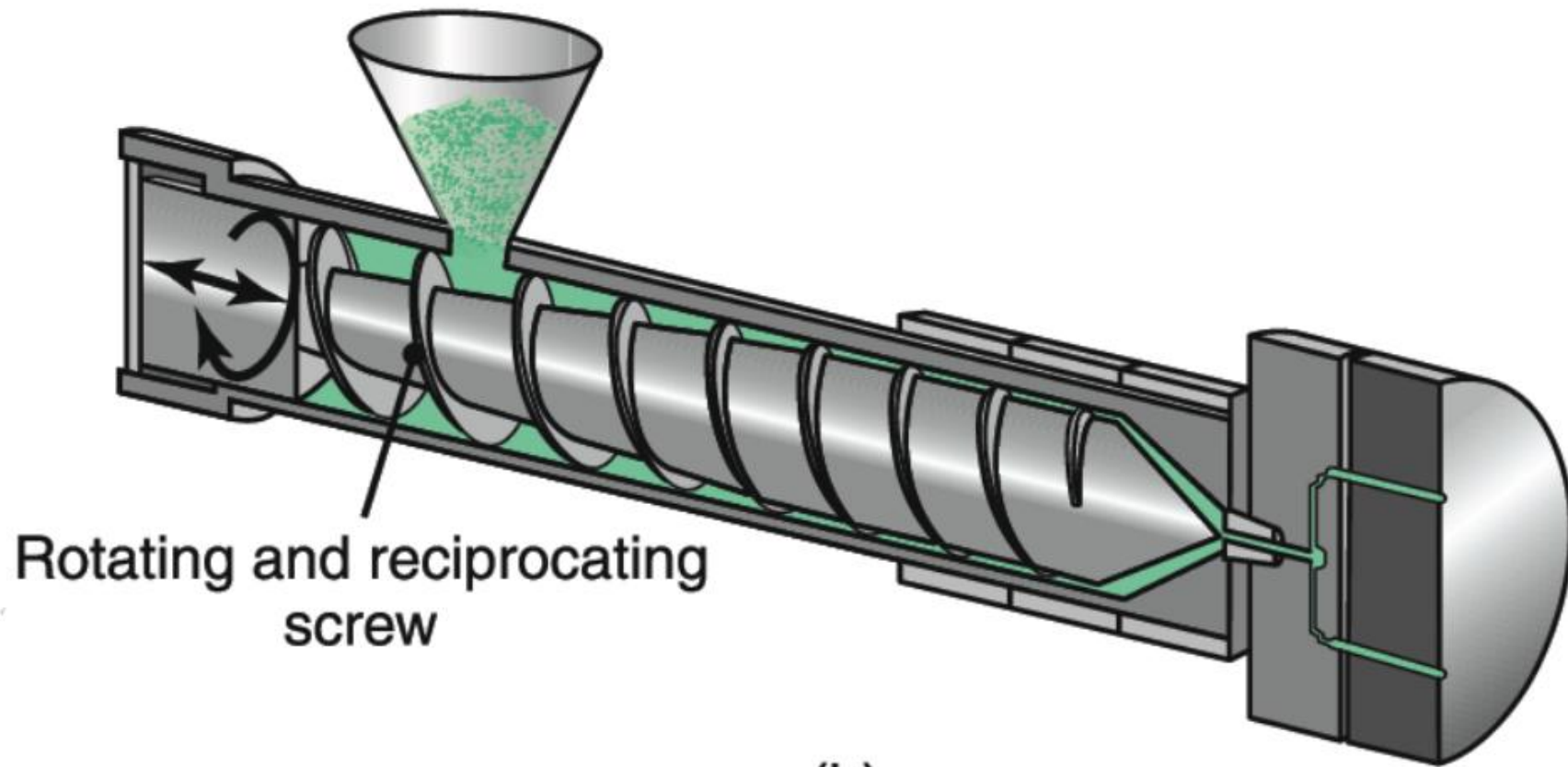


Figure 18.5 Injection molding with reciprocating rotating screw (螺杆)

# Reciprocating Screw Type Injection Machine

## （往复运动的螺杆式注射机）



(b)

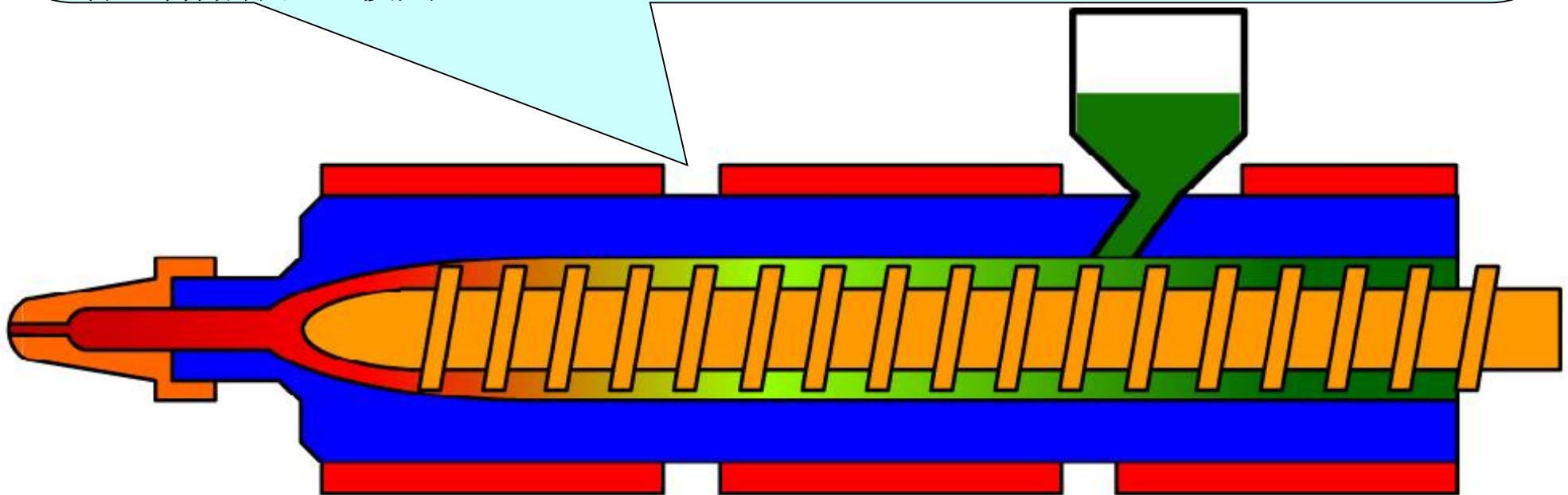


# 往复螺杆式注射机工作示意图

## (Reciprocating Screw Injection Machine)

螺杆即可**旋转**又可**前后移动**，因而能够胜任塑料的塑化、混合和注射工作，作用是送料、压实、塑化与传压。

- 当螺杆在料筒内旋转时，将料斗中的塑料卷入，并逐步将其压实、排气、塑化，并不断地将塑料熔体推向料筒前端，积存在料筒顶部于喷嘴之间，螺杆本身受到熔体的压力而缓慢后退。
- 当积存的熔体达到预定的注射量时，螺杆停止转动，并在液压油缸的驱动下向前推动，将熔体注入模具。



## \* 柱塞式注射机

### — 塑化方式:

∅ 电加热

### — 特点:

∅ 塑化不均匀;

∅ 注射量不宜过大, 一般为  
30~60g;

∅ 不宜用来成型流动性差、  
热敏性强的塑料制品

## \* 螺杆式注射机

### — 塑化方式:

∅ 电加热

∅ 剪切热

由于螺杆旋转、搅拌、  
混合、摩擦生成的热量

### — 特点:

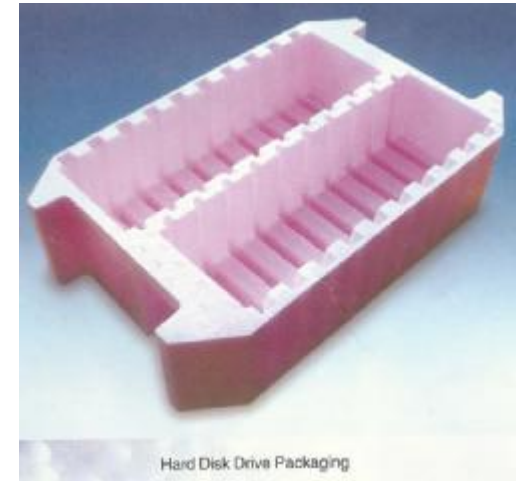
∅ 塑化均匀;

∅ 塑化能力大

# Typical Injection Molded Products (注塑件)

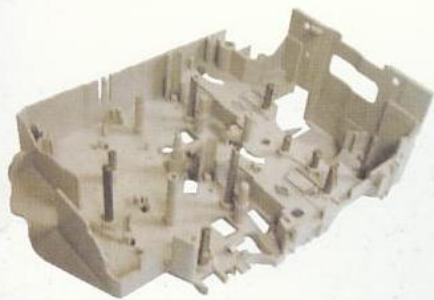
- cups
- containers
- housings (外壳/箱体)
- tool handles
- knobs (把手)
- electrical and communication components (电子及通讯元件)
- toys (玩具)
- plumbing fittings (管道配件)
- etc....

discrete parts

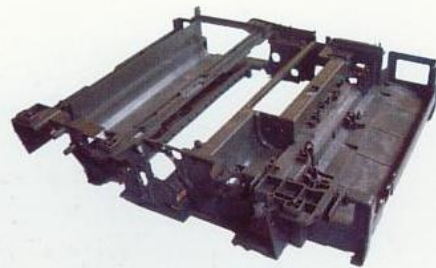


手机模具系列  
Mobile Series





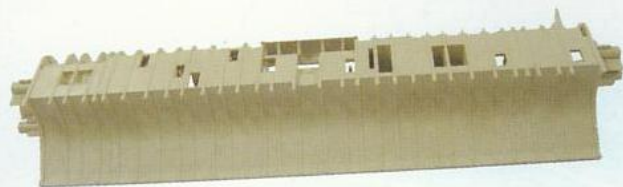
● 日本佳能复印机模具样品  
CANON duplicator sample



● 日本夏普复印机模具样品  
SHARP duplicator sample



● 富士施乐打印机模具样品  
Fuji XEROX printer sample



● 日本理光复印机模具样品  
RICOH duplicator sample



● 富士施乐打印机模具样品  
Fuji XEROX printer sample

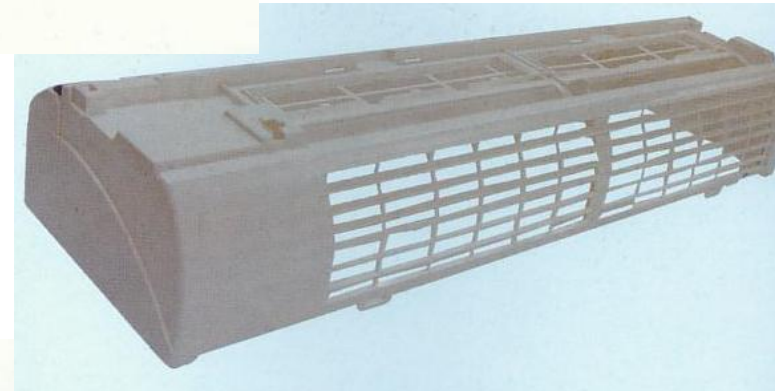


● 吸尘机  
Vacuum Cleaner

### 内饰系统 Interior Trims:

仪表板、门内板、副仪表板、饰柱

Instrument Panel, Door Trims, Console, Pillar Trims



● SONY音响系列  
SONY sound series



● SHARP组合音响  
SHARP combined acoustics

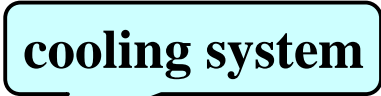



● THOMSON音响支架模具  
THOMSON sound support mo

# Characteristics of Injection Molding

- **The most common used** shaping process of plastic
- Essentially the same process as **hot-chamber die casting**  
(压铸成型)
- Similar to in extrusion, the **barrel** (cylinder) is **headed** to promote melting.
- With injection molding machines, a **far greater portion** of the heat transferred to the polymer is due to **frictional heating** (摩擦热/剪切热)
- Injection-molding pressures: 70MPa  $\sim$  200MPa

# Characteristics of Injection Molding

- **Complex shapes** and **good dimensional accuracy** can be achieved
- Suitable for **TP**, **TS** and E
  - for **TP**: the mold is relatively **cold**
  - for **TS**: the mold is **heated**, where **polymerization** (聚合反应) and **cross-linking** (交联/硬化/固化) take place
- Molds with **moving** (活动的) and **unscrewing** (自动卸螺纹的) **mandrels** (型芯) are also used
  - for molding of parts having **multiple cavities** (多腔模) or **internal** or **external threads** (内螺纹或外螺纹)

molding of parts having  
**external** or **internal** threads



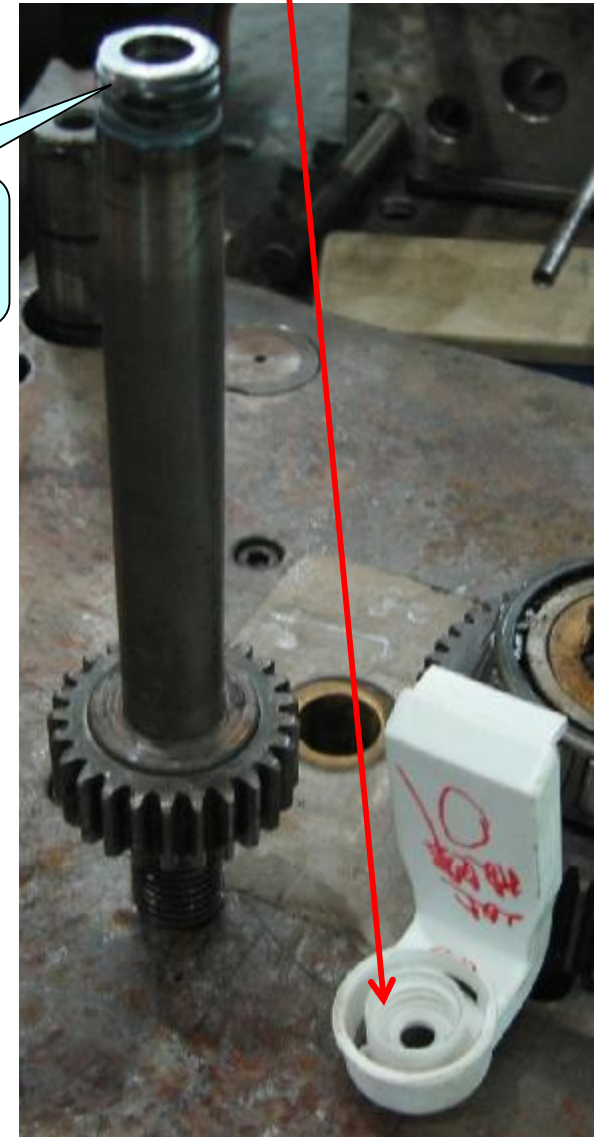
● 精密零件（内外深螺纹）  
The accurate part



screw mandrel  
螺纹型芯



thermoplastic elastomer (TPE/E/热塑性弹性体)  
ice container for refrigerator





# Examples of Injection Molding

一模多件注射

- A number of parts made from **one shot** (一次注射)

- Mold features

Ø Sprue (主流道)

Ø Runners (分流道)

Ø Gates (浇口)

(c)

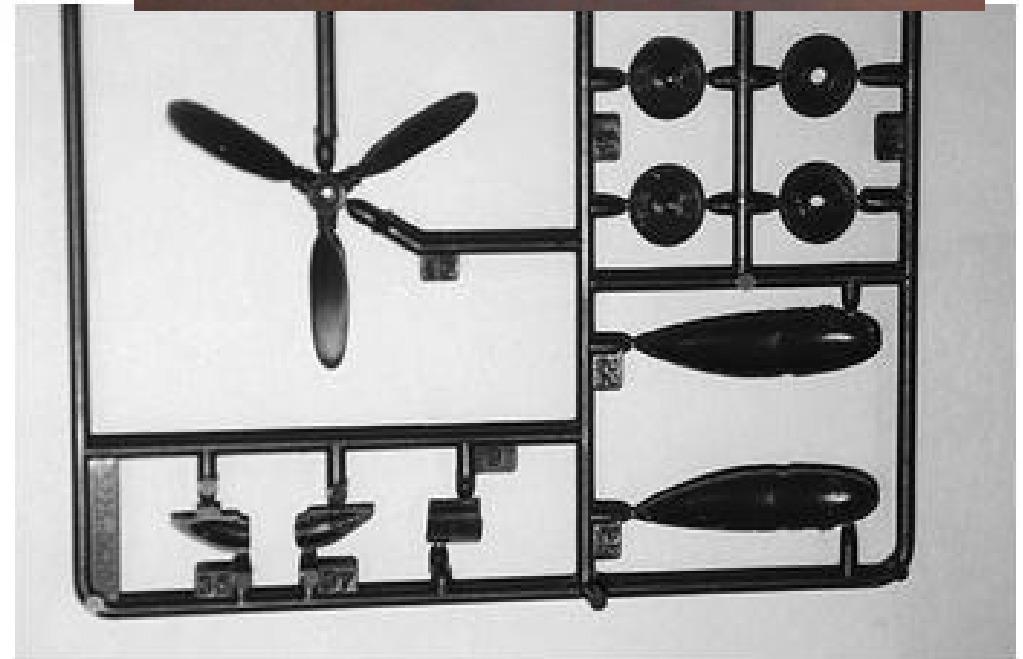
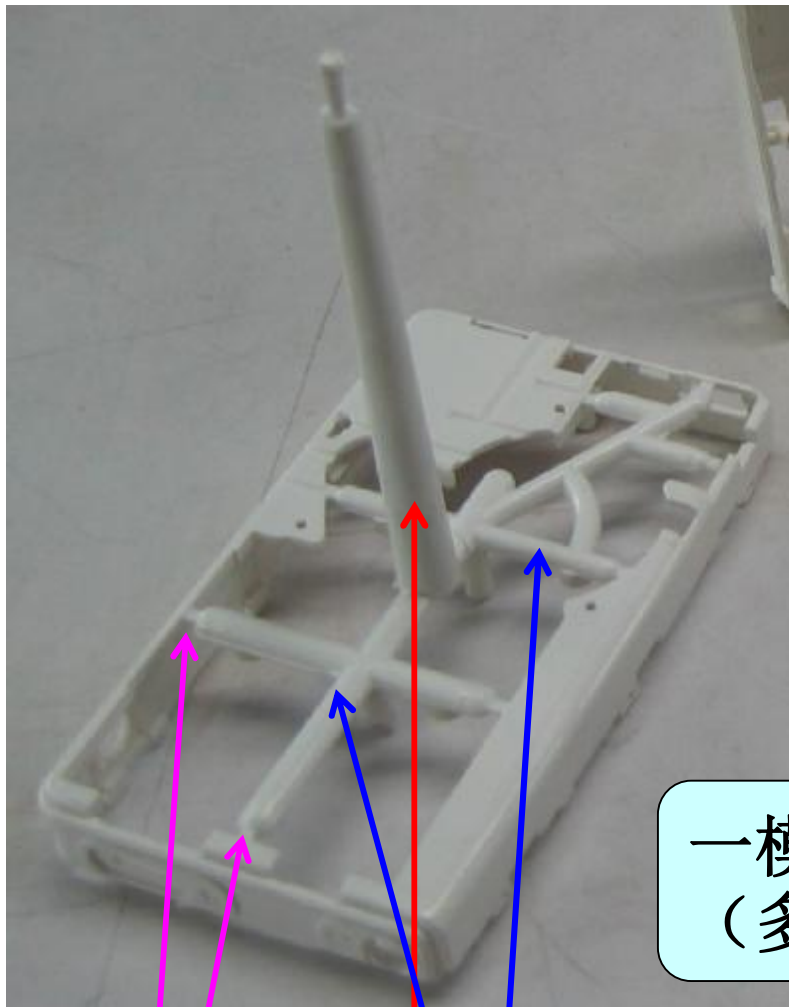


Figure 18.5 Injection molding with (c) a typical part made from an injection molding machine cavity, showing a number of parts made from one shot; note also mold features such as sprues, runners, and gates.





一模一件注射  
(多浇口)



final parts

- Injection molded parts with **mold features**:

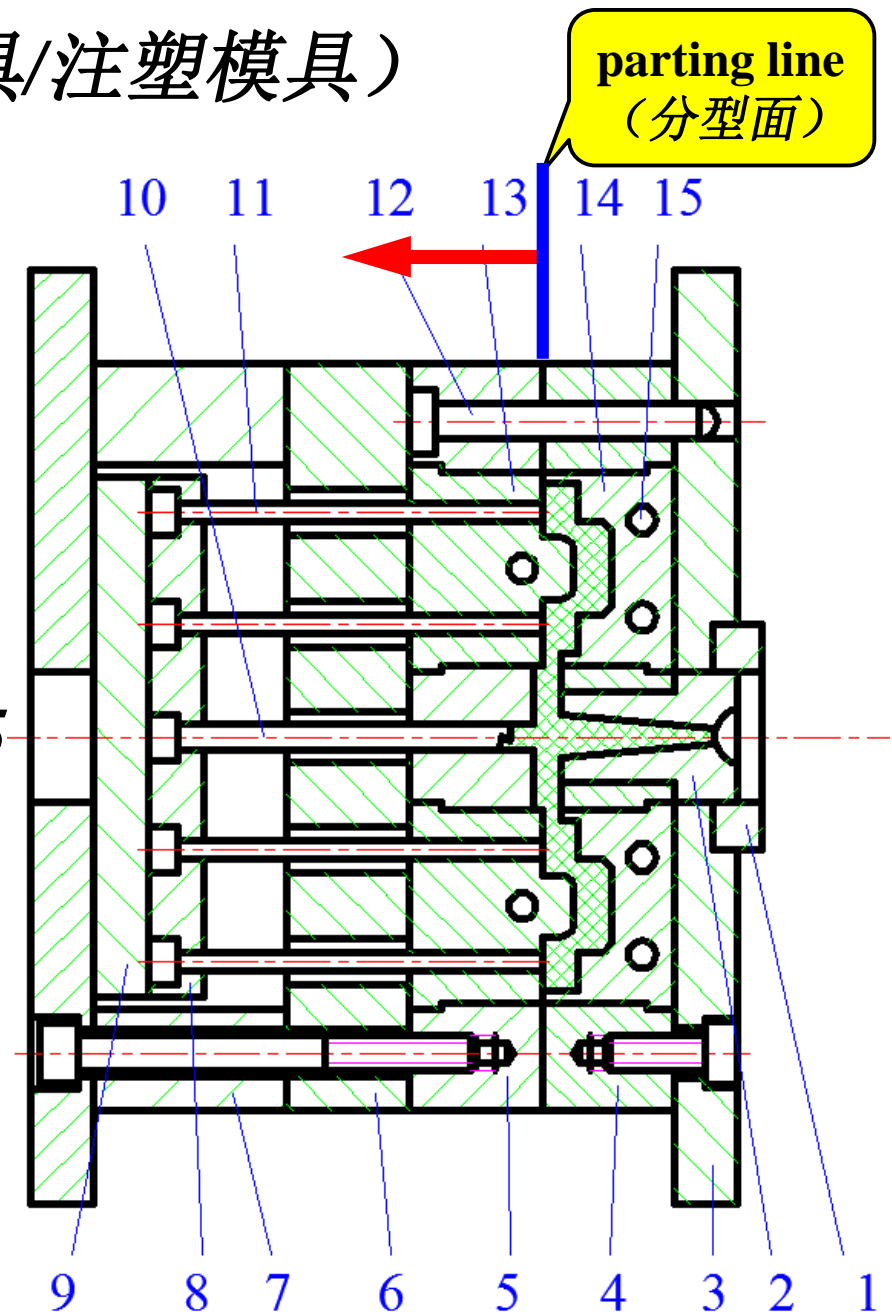
- Ø sprue (主流道)

- Ø runners (分流道)

- Ø gates (浇口)

# Injection Molds (注射模具/注塑模具)

- ∅ runners (浇注系统) 2
- ∅ cores (型芯/凸模) 13
- ∅ cavities (型腔/凹模) 14
- ∅ cooling channels (冷却水道) 15
- ∅ inserts (镶件/镶块)
- ∅ knockout pins (顶杆) 11
- ∅ ejectors (推出元件) 8,9,10
- ∅ mold base (模架/模胚)

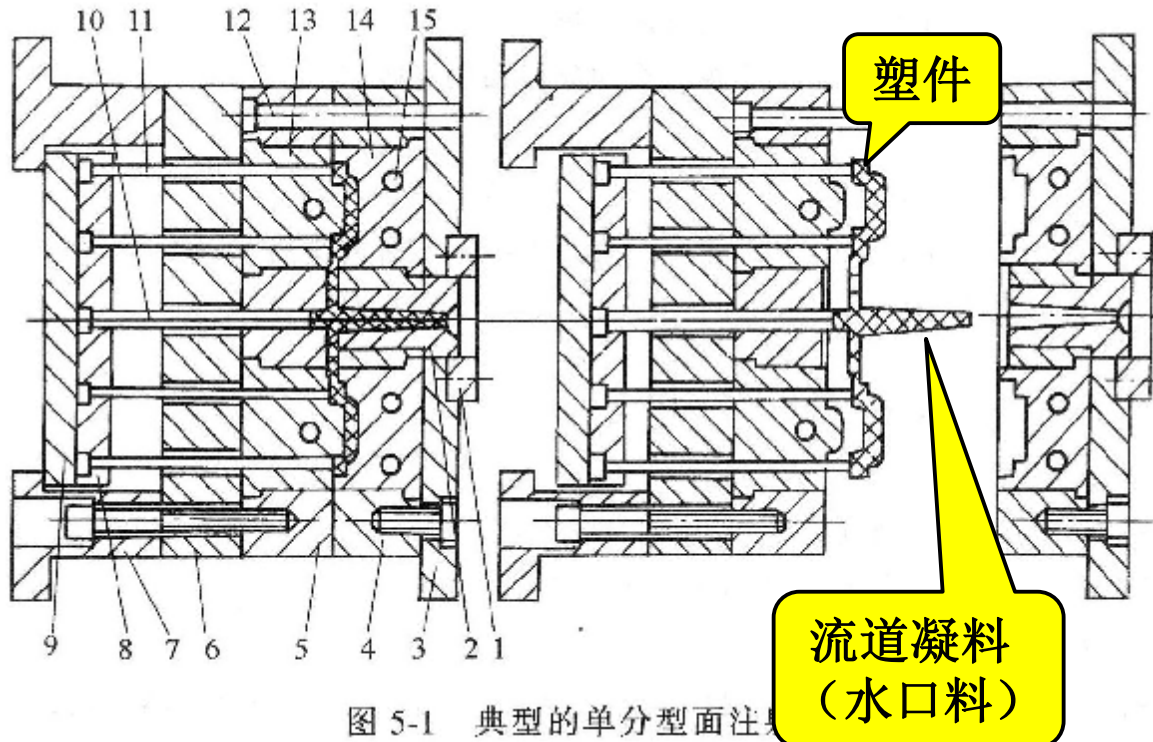


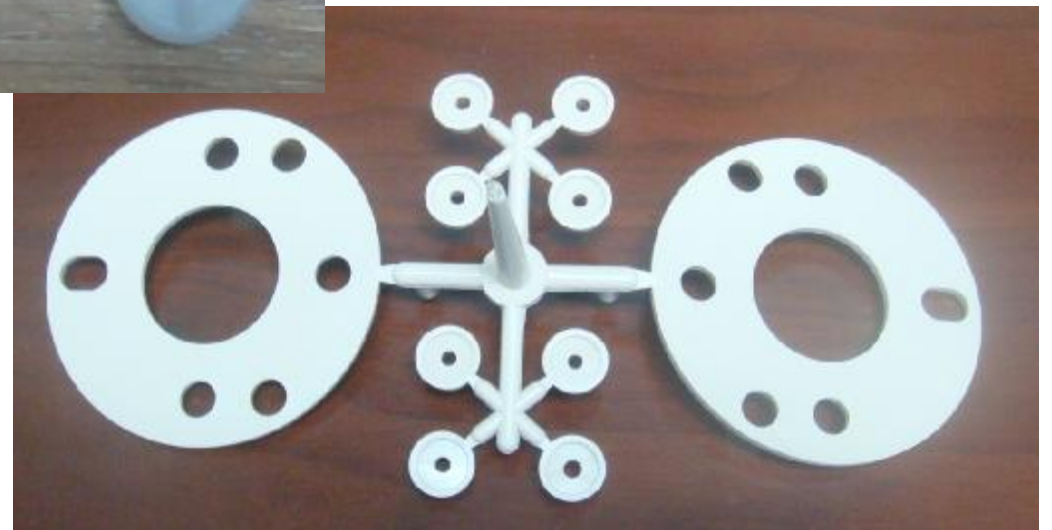
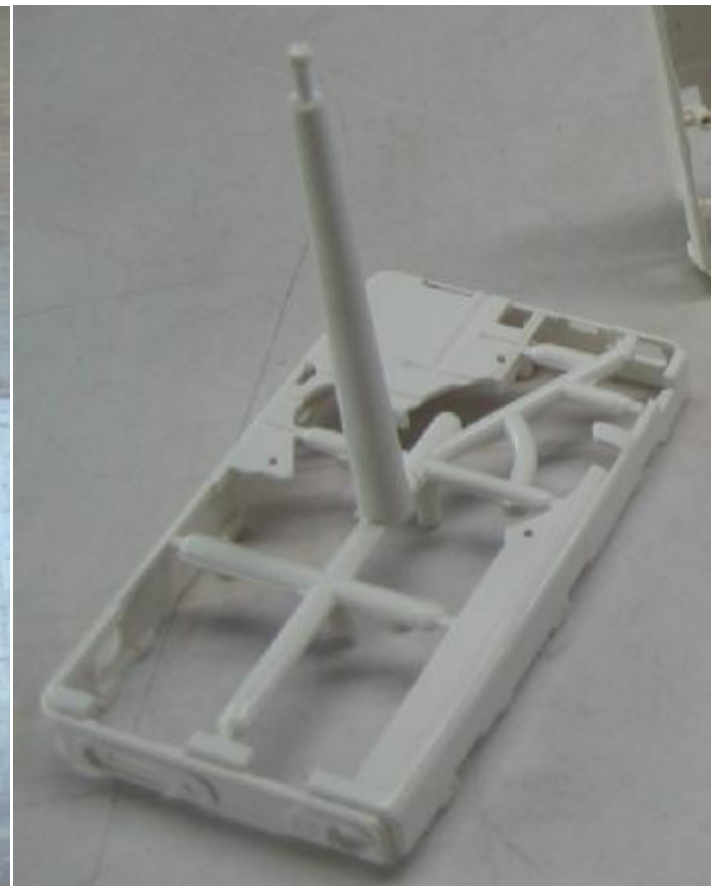
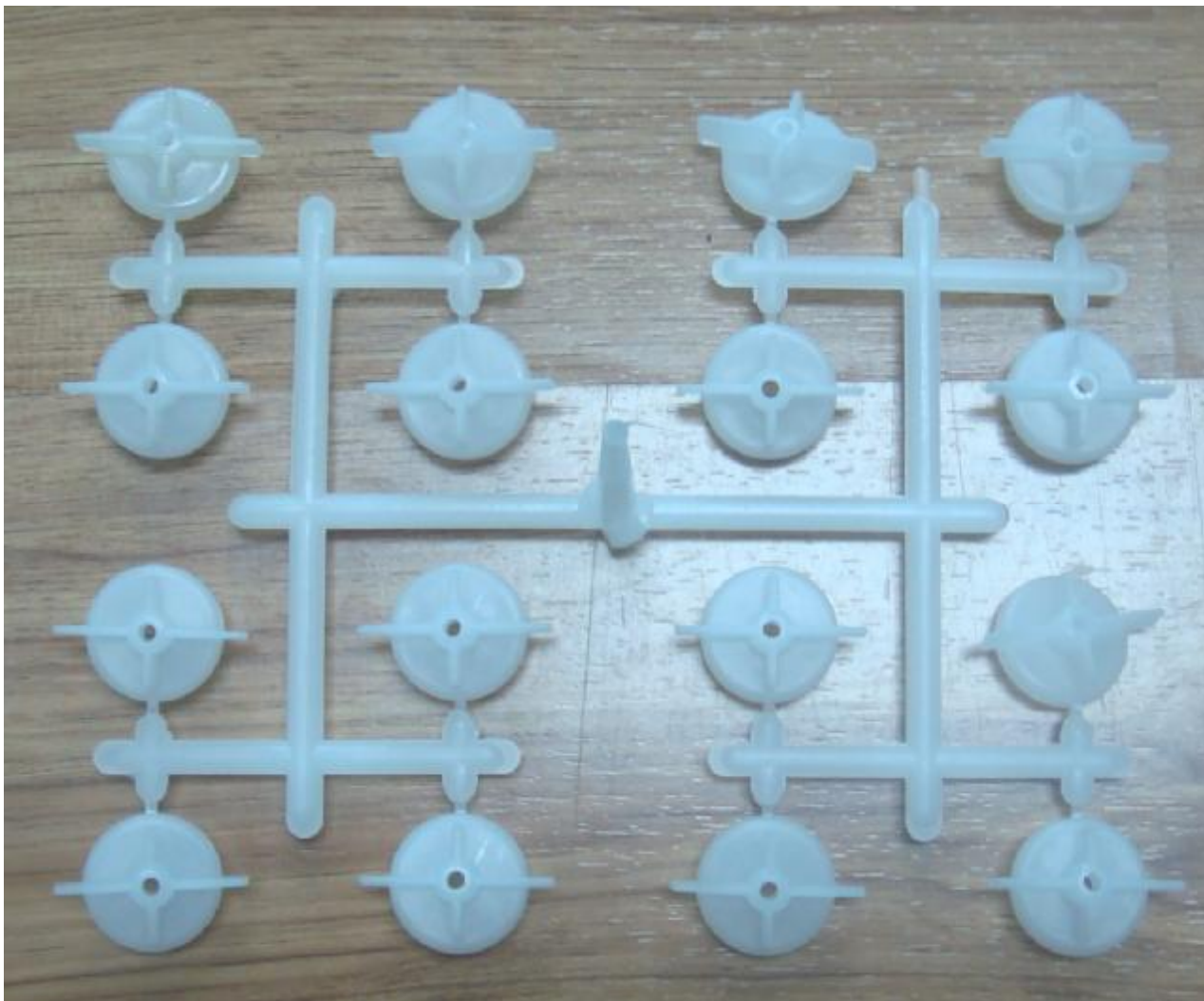
Structure of Injection Mold

# Three Basic Types of Injection Molds

## a. Cold-runner two-plate mold (冷流道两板模)

- the solidified plastic in the channels (流道凝料) that connect the mold cavity to the end of the barrel must be removed, usually by **trimming**
- the simplest mold design







- This **scrap** (废料) can be **chopped** (粉碎/打碎) and **recycled** (再利用).



## b. Cold-runner three-plate mold

(冷流道三板模)

- in which the runner system is **separated** from the part when the **mold opens**;

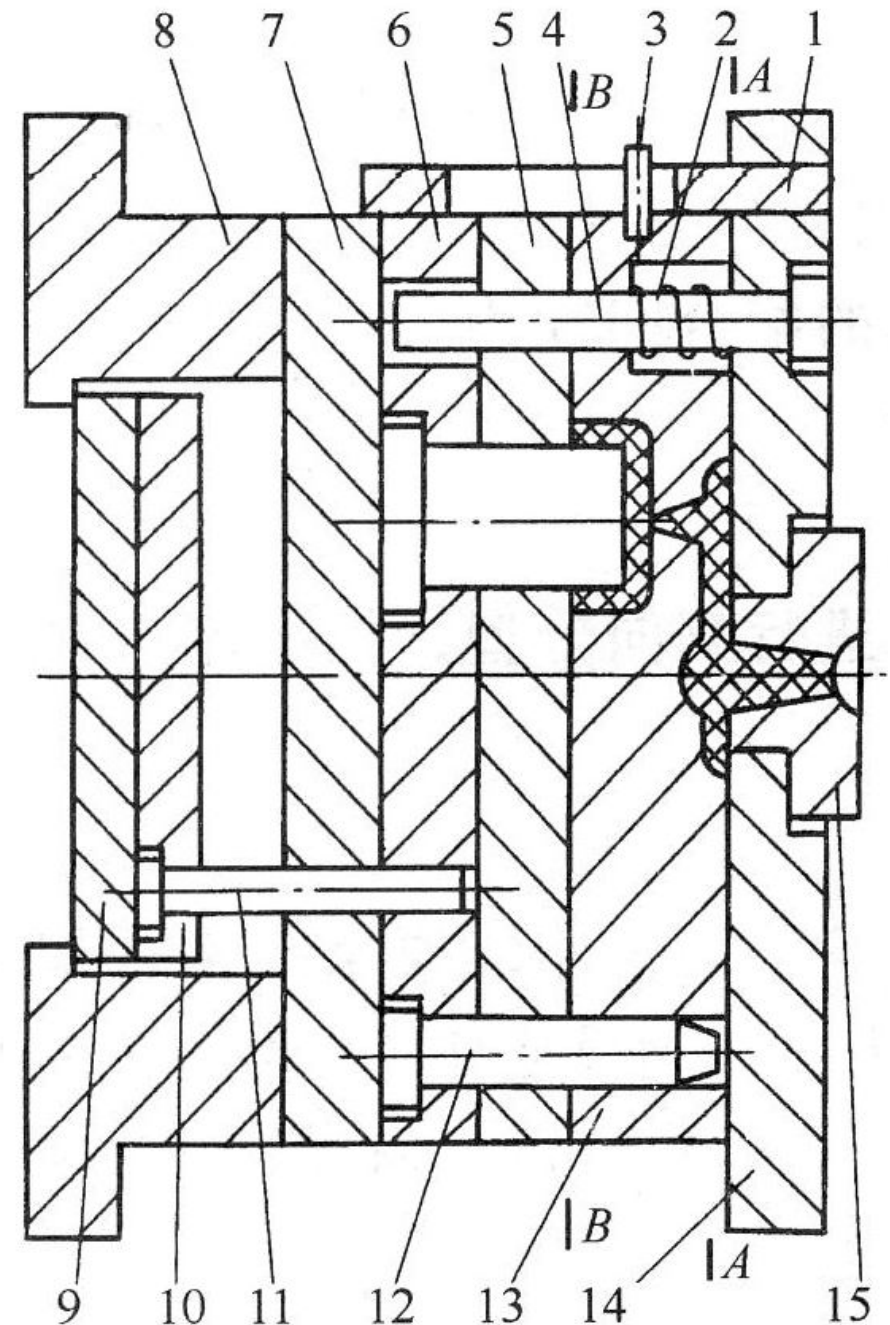
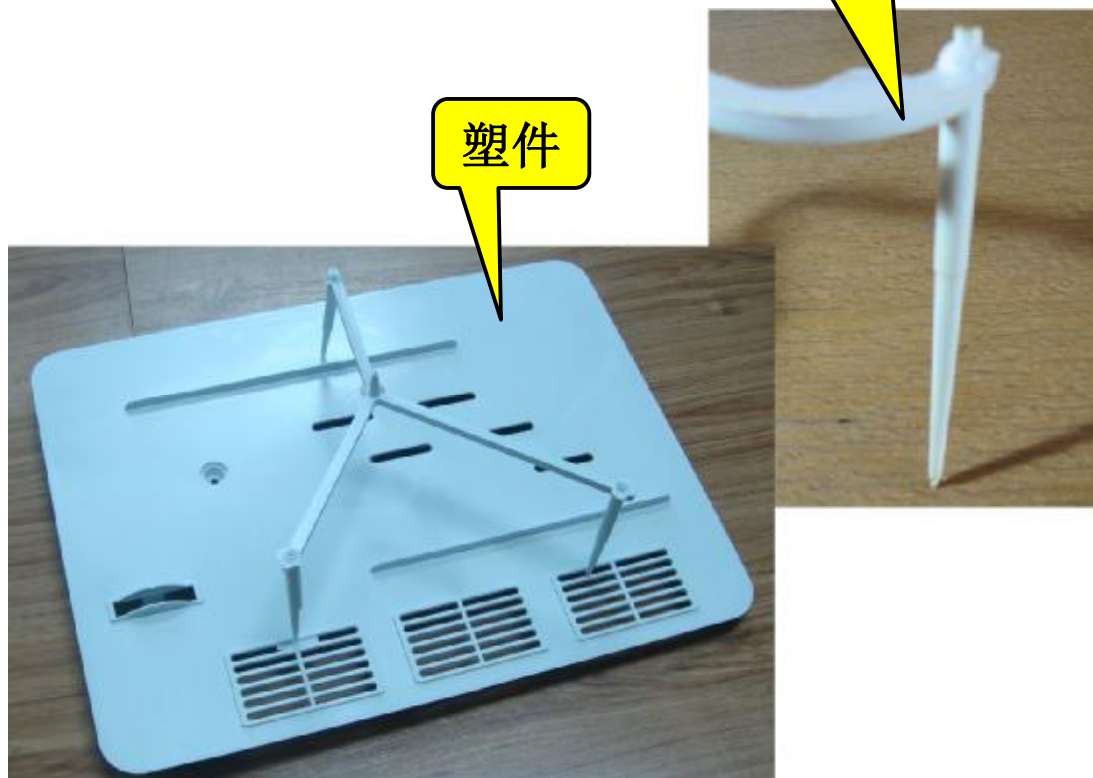


图 5-2 双分型面注射模具

### c. Hot-runner mold (热流道模)

- in which the molten plastic is kept in a **heated runner plate** (热流道板), there are no gates, runners, or sprues attached to the molded part.
- also called the **runnerless mold** (无流道模)
- more **expensive**;
- **cycle times** (成型周期) **are shorter**, because only the injection molded part must be cooled and ejected.

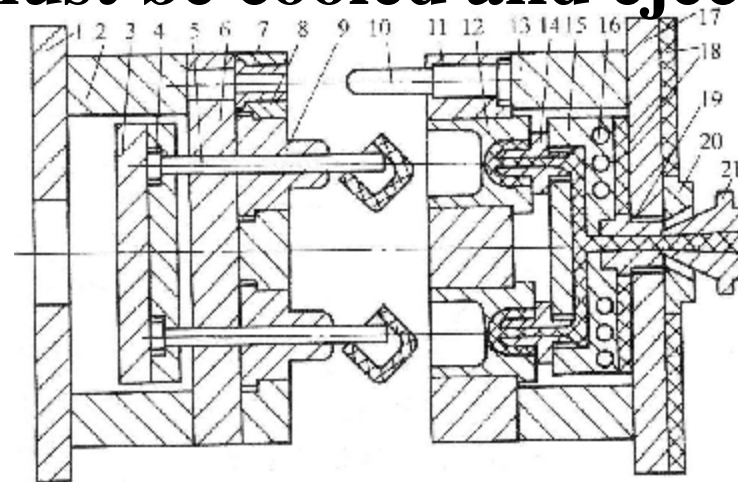
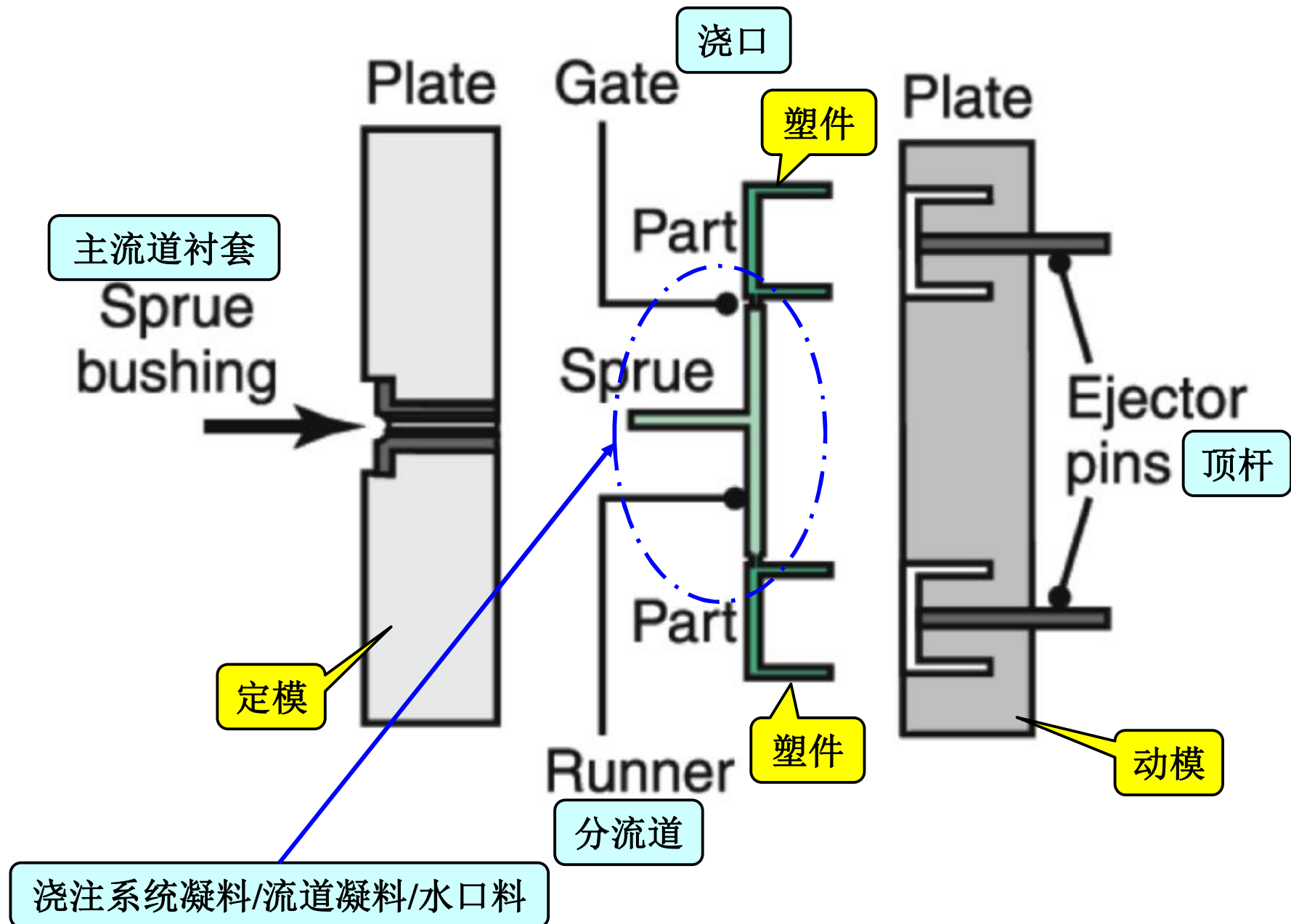


图 5 7 热流道注射模具

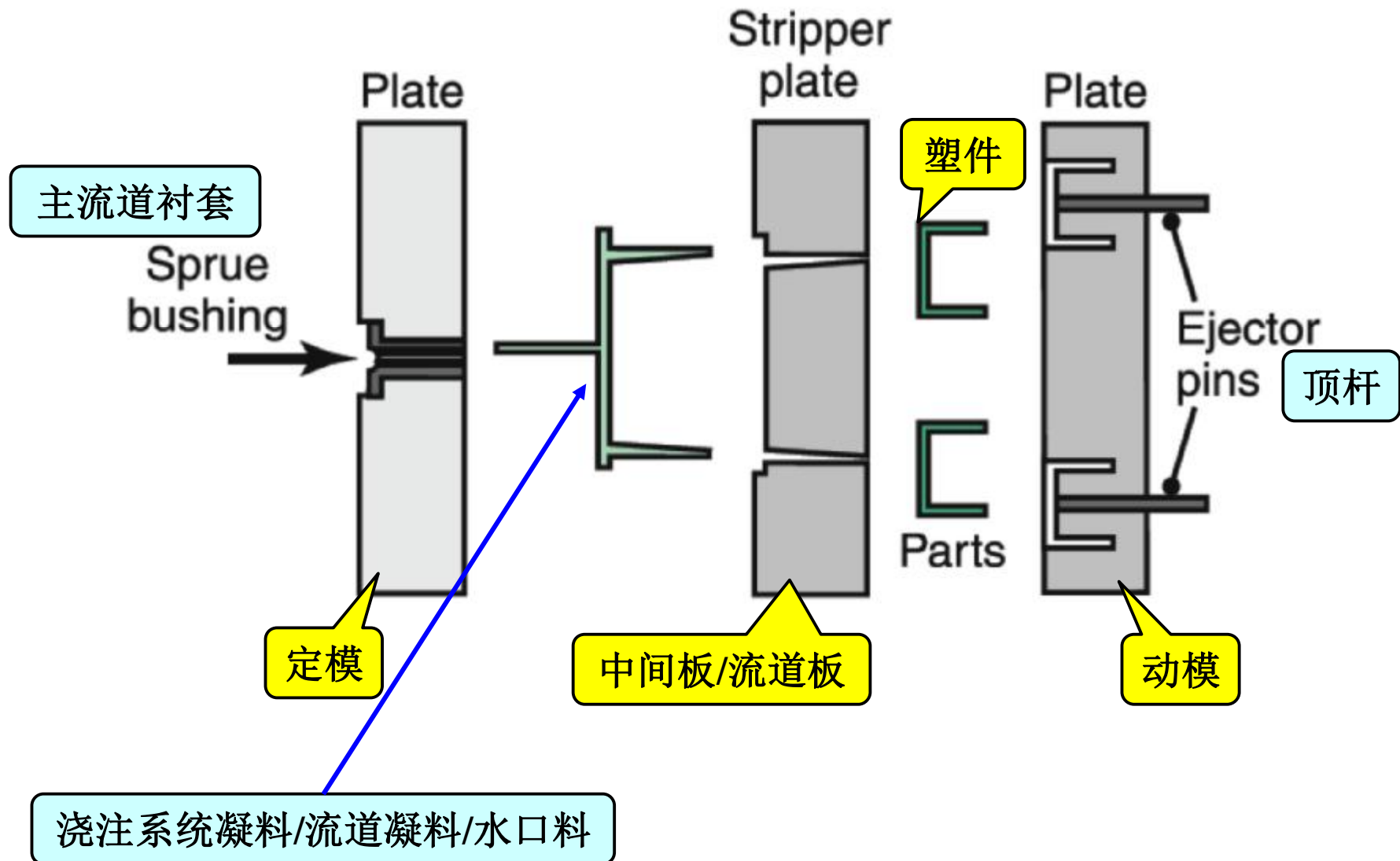


## \* Cold-runner Two-plate Mold 示意图

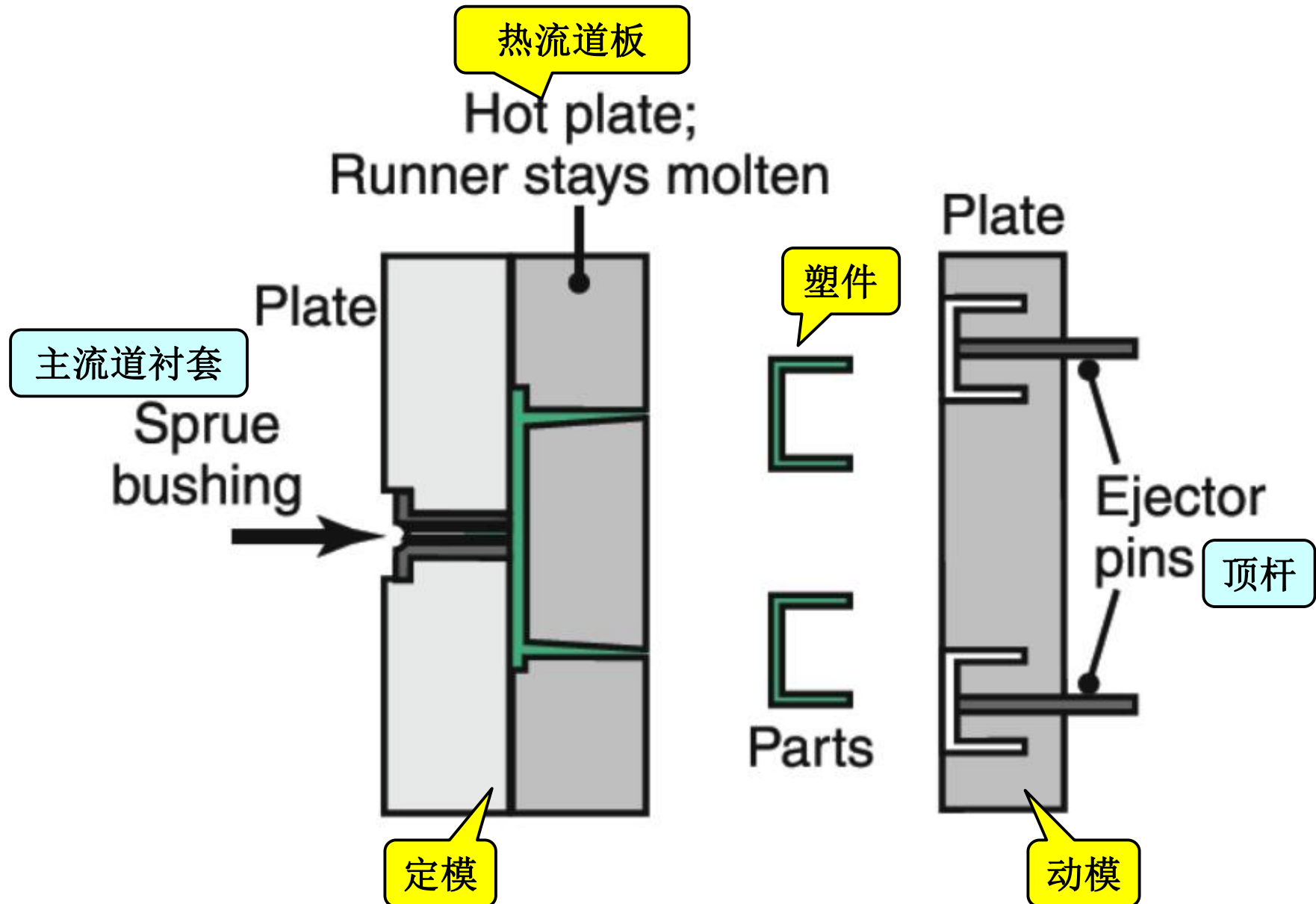




## \* Cold-runner Three-plate Mold 示意图



## \* Hot-runner or Runnerless Mold 示意图



# Process Capabilities

## ① High production rates

- cycle time (成型周期)
  - ∅ TP: 5 ~ 60 seconds
  - ∅ TS: several minutes
- may have multiple cavities (多腔模)

## ② Good dimensional control

## ③ Mold materials:


- tool steels, beryllium – copper (铍铜合金), Al

## ④ Mold cost: can be as high as \$100,000

## ⑤ Mold life:

- steel molds: 2 million cycles
- Al molds: 10,000 cycles

# Important Factors in Quality Control

- **Mold design**
- The control of **material flow** in the die cavities
- Much progress has been made in the **analysis** and **design** of molds and of material flow
- **Modeling techniques** (模流分析技术) have been developed for studying **optimum** (优化) gating systems (浇注系统), mold **filling**, mold **cooling**, and part **distortion** (变形/翘曲);  
 process parameters
- They take into account such **factors** as **injection pressure**, **temperature**, and the **condition of the resin**.
- Software programs are now available to **expedite** (加速) **the design process** for molding parts with good dimensions and characteristics.

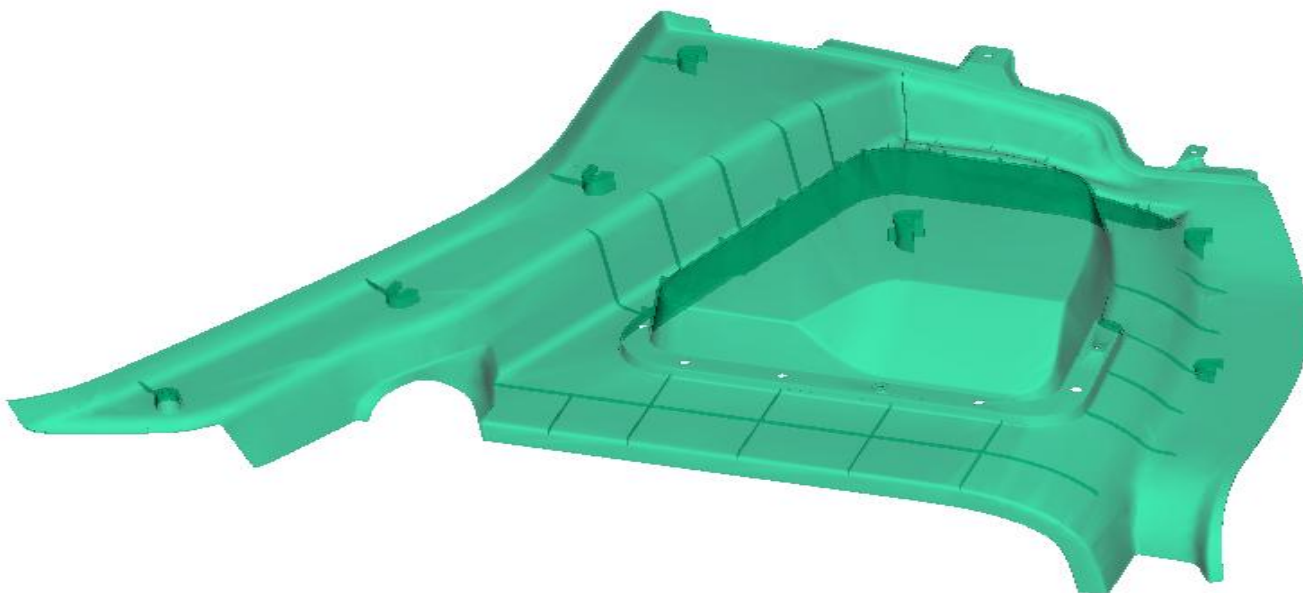
## Example of Modeling Techniques\_1

### \* Optimum of Gating System （浇注系统的优化）

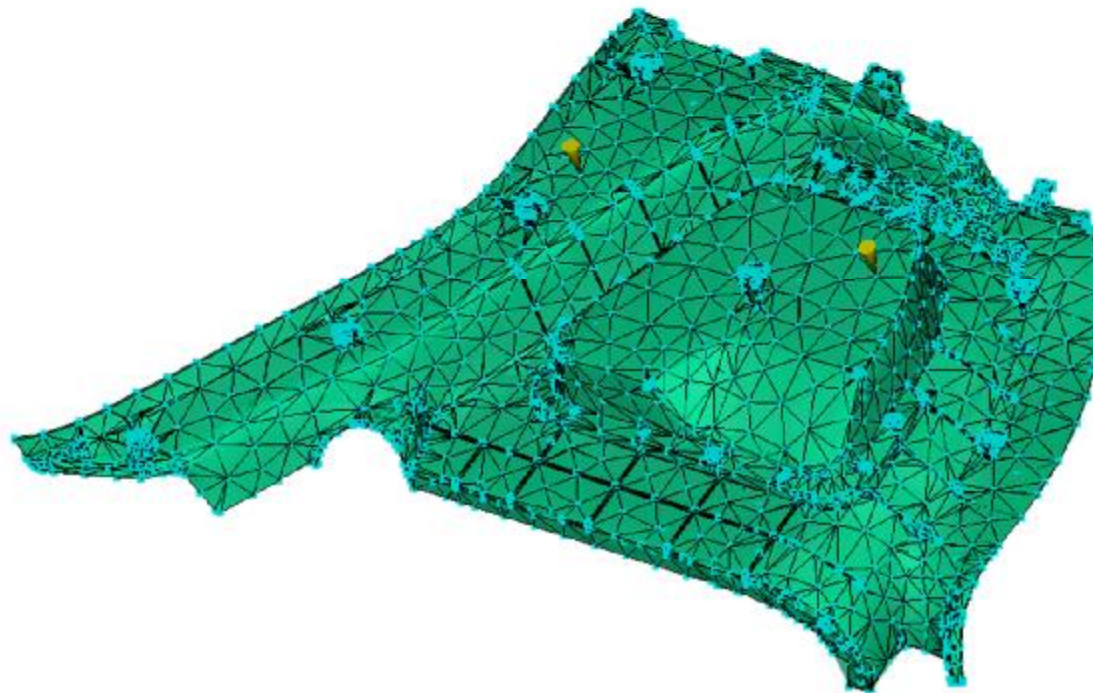
#### β 汽车尾门内饰件

**已知：** 塑件尺寸较大（约 $900 \times 800 \times 250\text{mm}$ ），形状较复杂。

**待求：** 如何选择合适的浇口位置和进浇口数量，才能保证**填充**  
**完满**？



# Solution 1: Two gates



## Analysis Result

欠注  
(short shot/  
incompletely filling)

Filling Analysis  
analysis is beginning ....

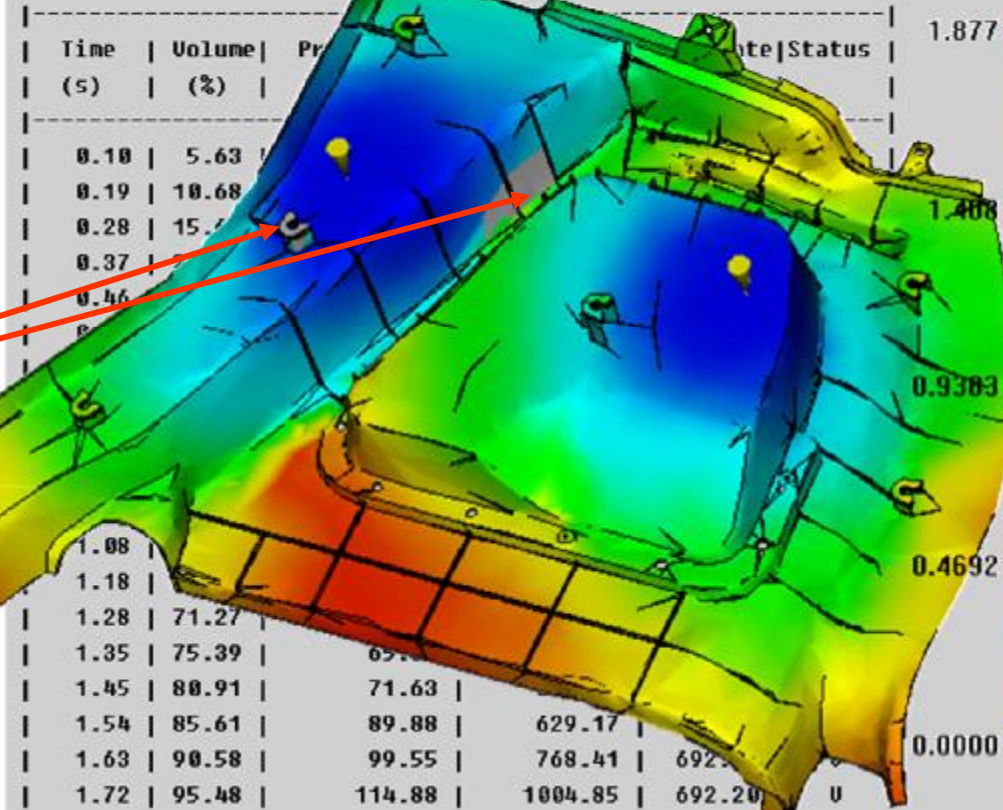
Fill time [Fast Fill]  
= 1.877[s]

Filling phase: Status: U = Velocity control

P = Pressure control

U/P = Velocity/pressure switch-over

[s]



\*\* WARNING 98930 \*\* The required clamp force is greater than the maximum machine clamp force.

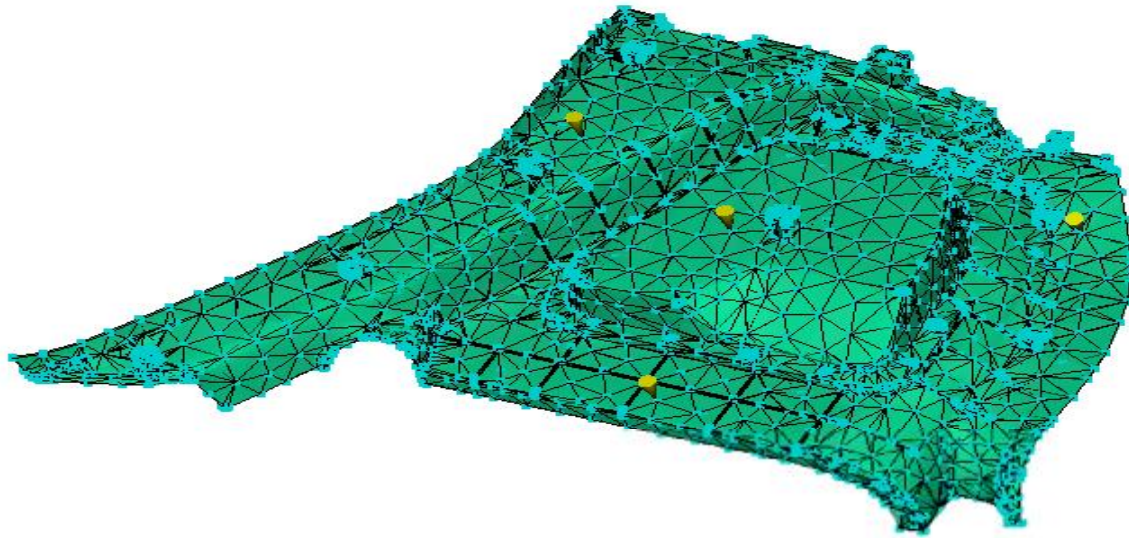
\*\* WARNING 98934 \*\* The maximum machine injection pressure reached at time = 1.76 s; volume = 97.77 %  
Using maximum machine injection pressure

1.80	98.70	180.00	2297.58	267.13	M.M.P
1.82	99.06	180.00	2308.04	258.52	U/P
1.83	99.30	144.00	1886.90	165.49	P

\*\* WARNING 128271 \*\* SHORT SHOT - Frozen melt flow front.



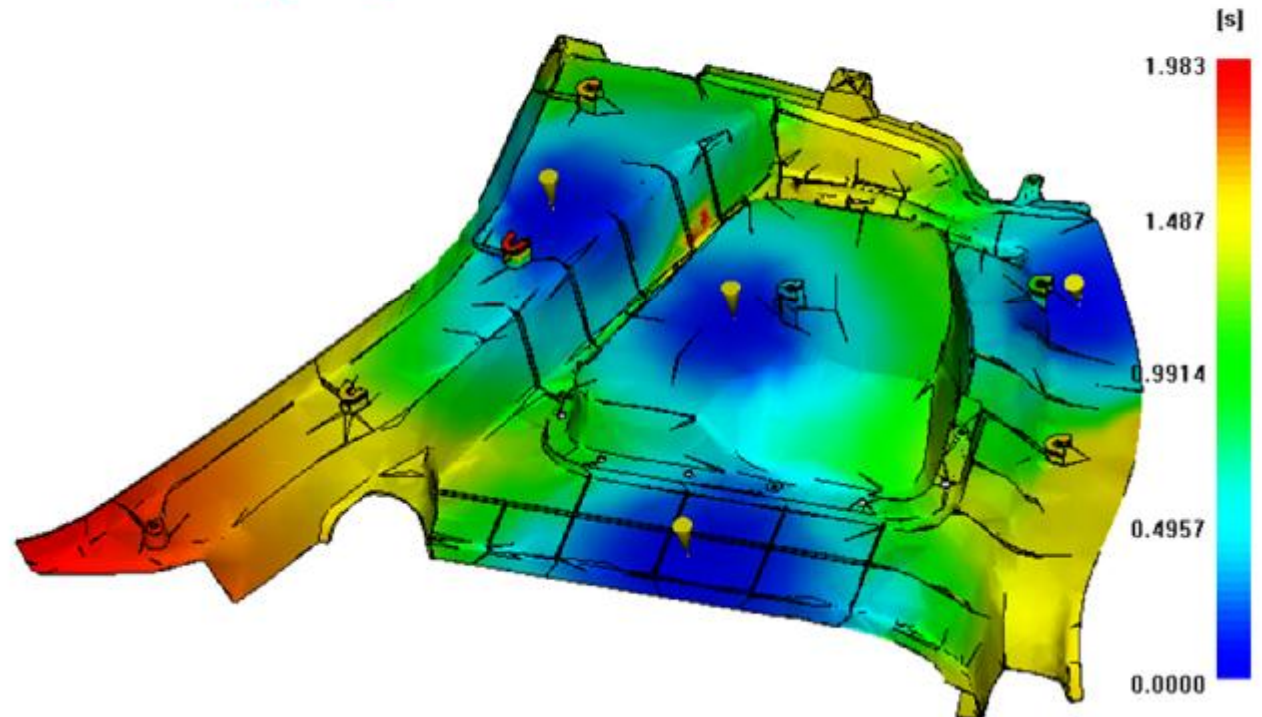
## Solution 2: Four gates



Analysis Result

填充完整  
(Full Filling)

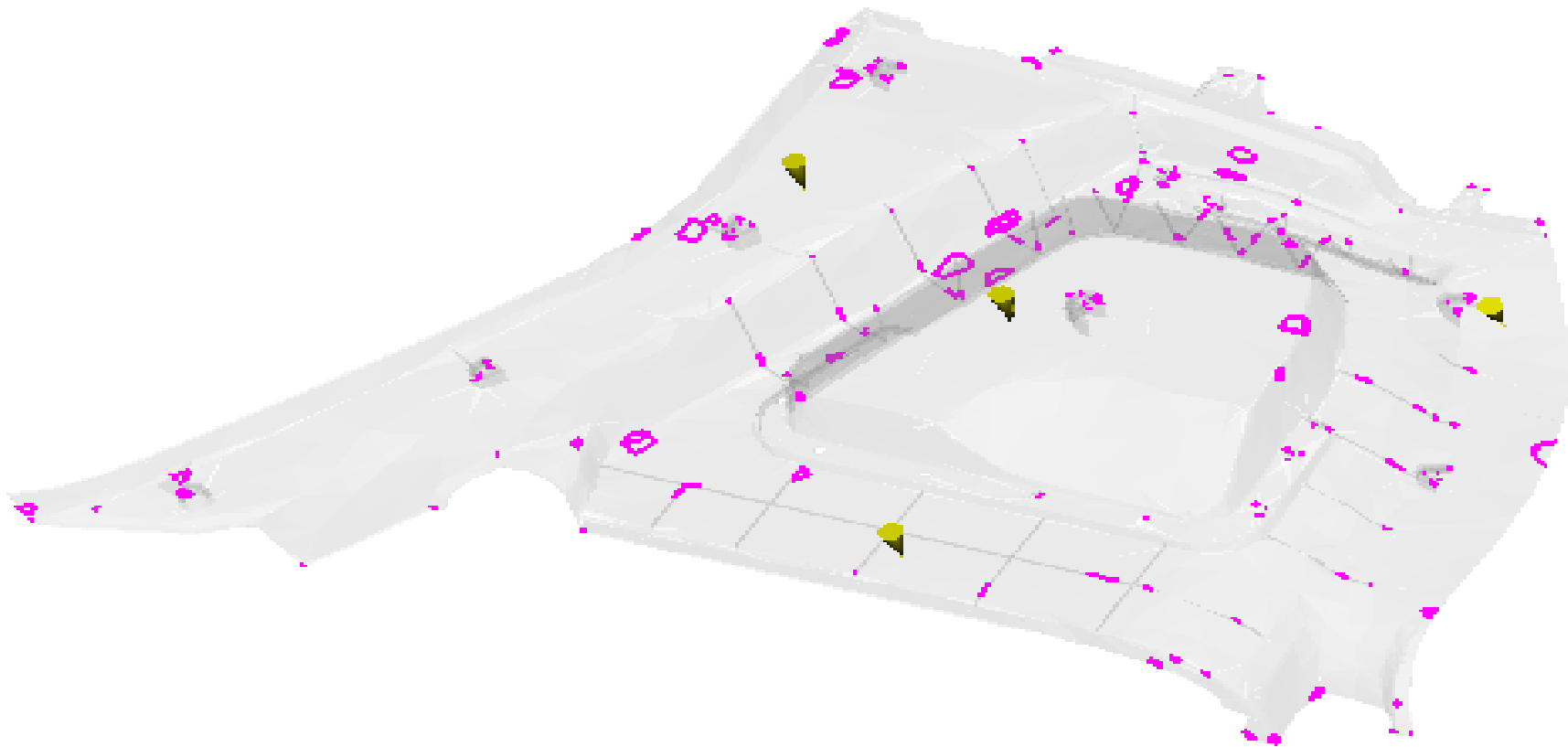
Fill time\_1  
= 1.983[s]





## Example of Modeling Techniques\_ 2

\* **Moldflow**预测成型缺陷\_Air traps（困气）



# Injection-molding Machine (注射机/注塑机)

- Horizontal Injection Machine (卧式注射机)
  - the most common used type
- Vertical Injection Machine (立式注射机)
  - used for making small close-tolerance parts
  - for insert molding (嵌件生产)



## \* 卧式注射机

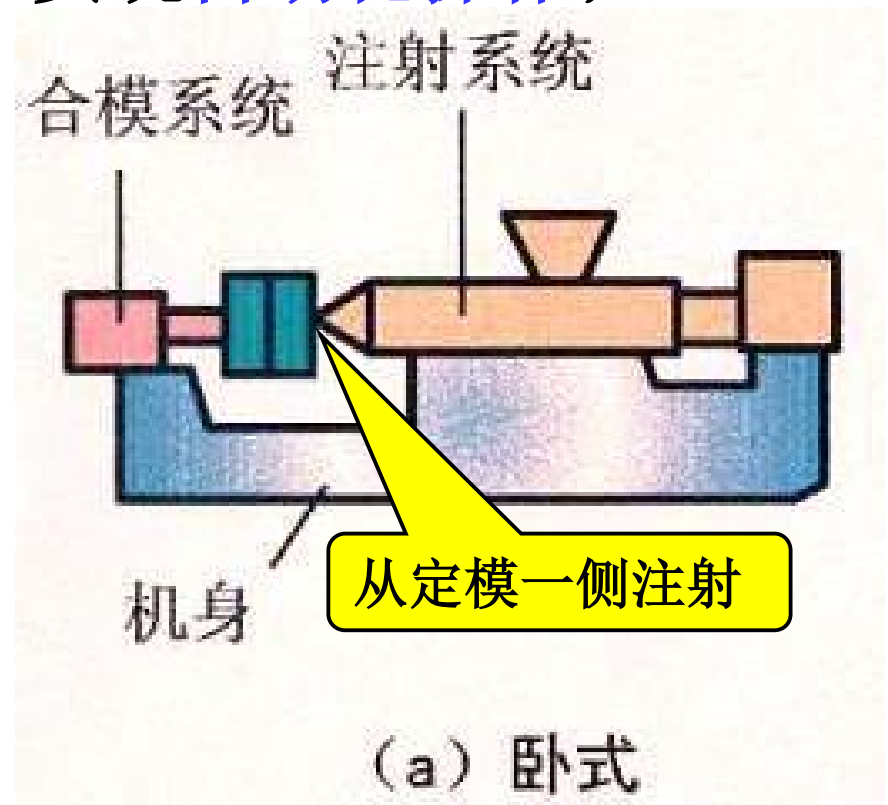
### (Horizontal Injection Machine)

#### 优点:

- Ø 机体较矮、容易操作加料;
- Ø 制品顶出后能自动落下, 便于实现自动化操作;

#### 缺点:

- Ø 设备占地面积大;
- Ø 模具安装比较麻烦。



## \* 立式注射机

### (Vertical Injection Machine)

#### 优点:

- Ø 设备占地面积小;
- Ø 模具拆卸方便;
- Ø 安装嵌件和活动型芯筒便可靠

#### 缺点:

- Ø 不易自动操作;
- Ø 只适用于小注射量的场合, 一般注射量为10~60g。

靠自重安放在  
动模(下模)

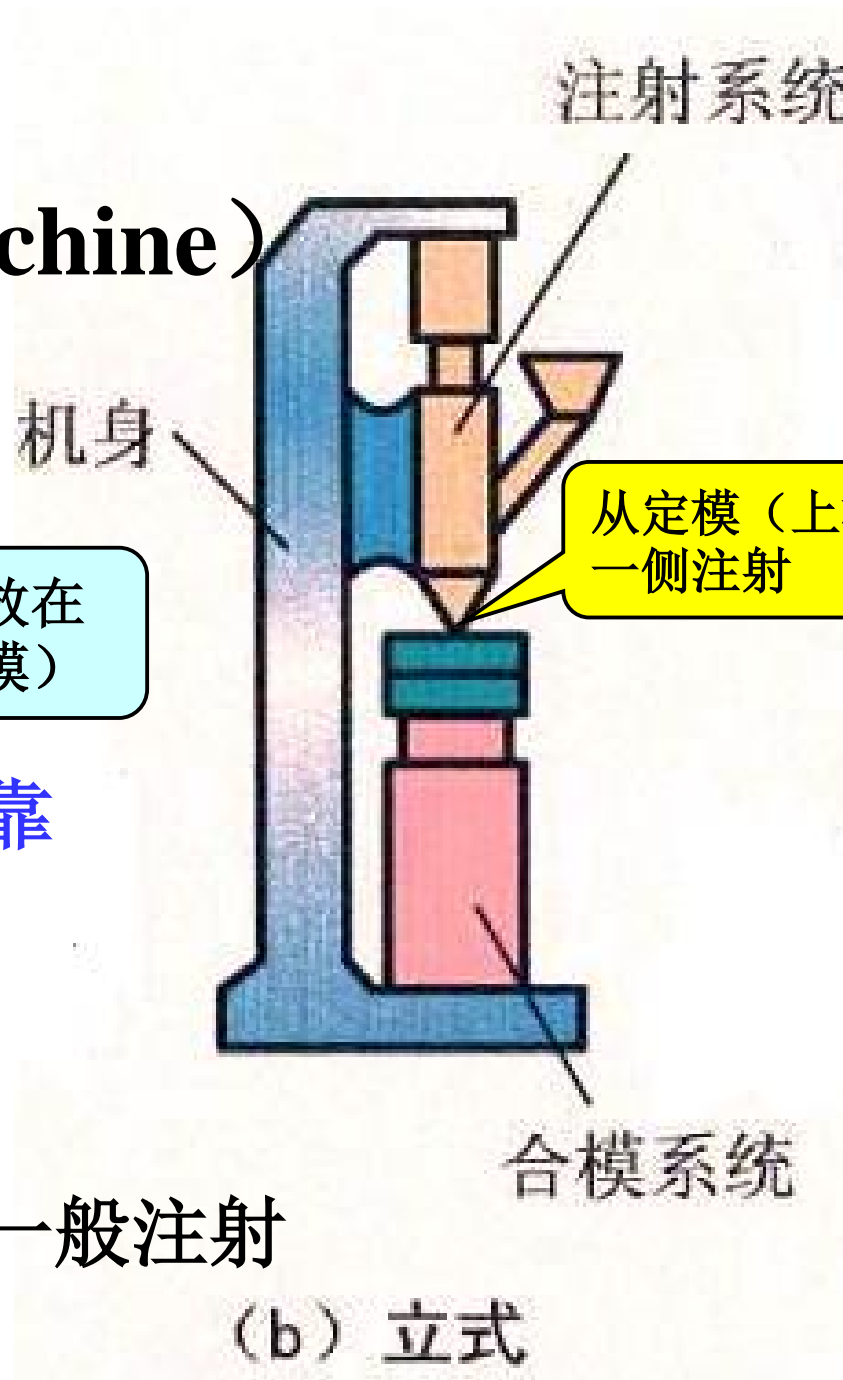
注射系统

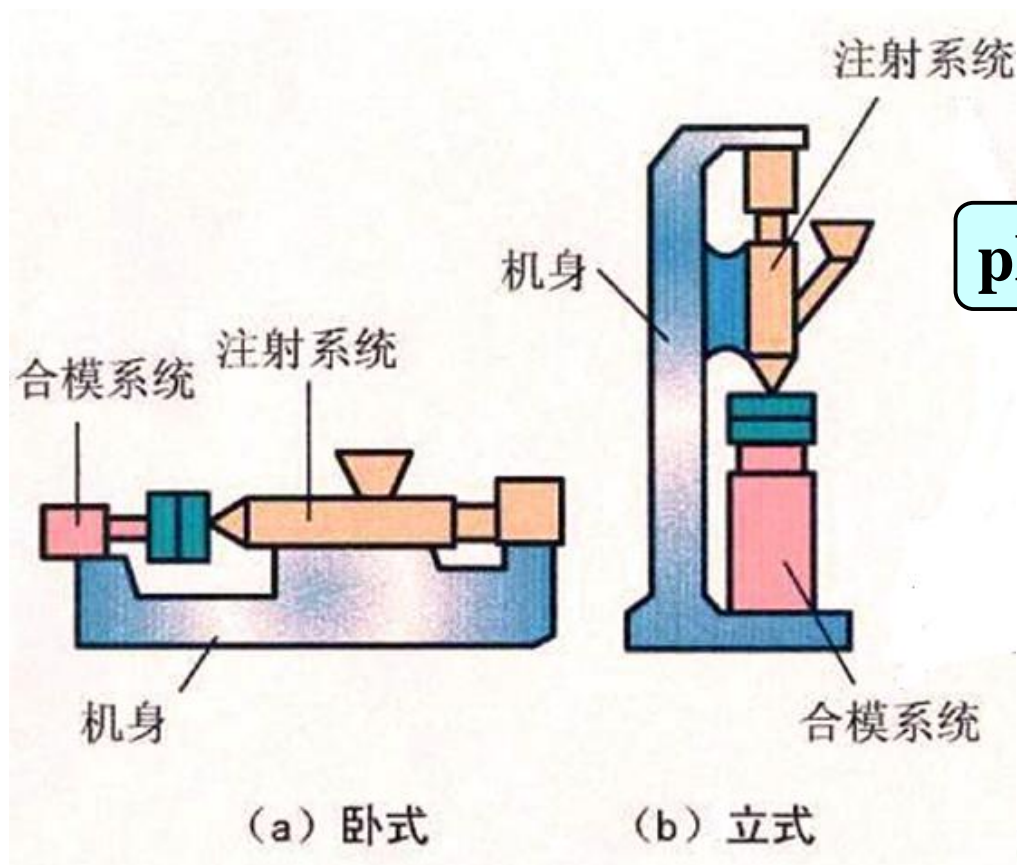
机身

从定模(上模)  
一侧注射

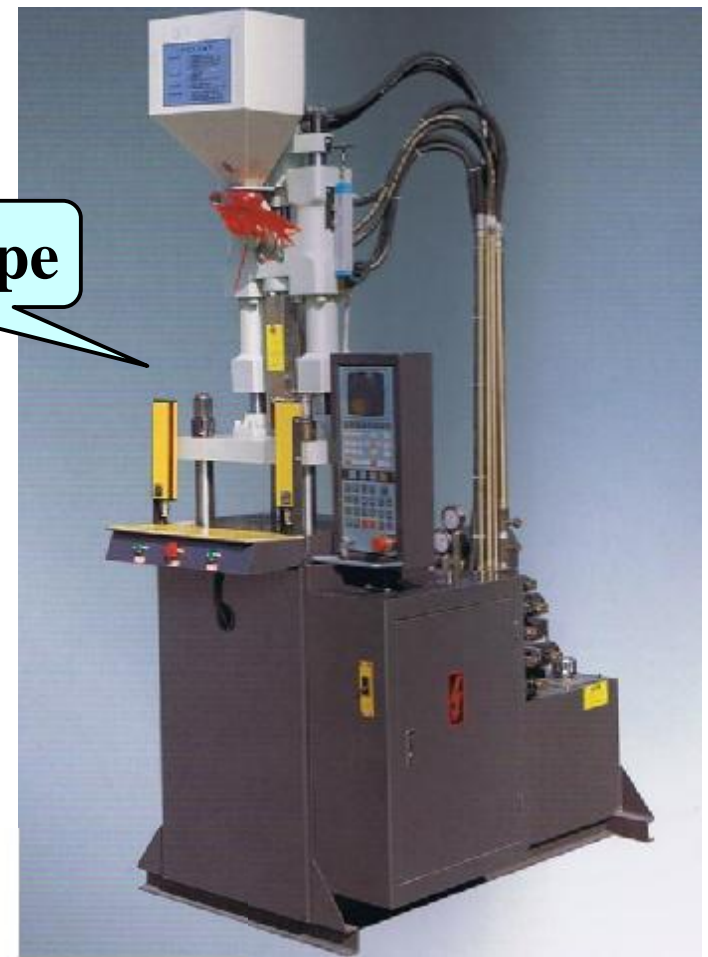
合模系统

(b) 立式



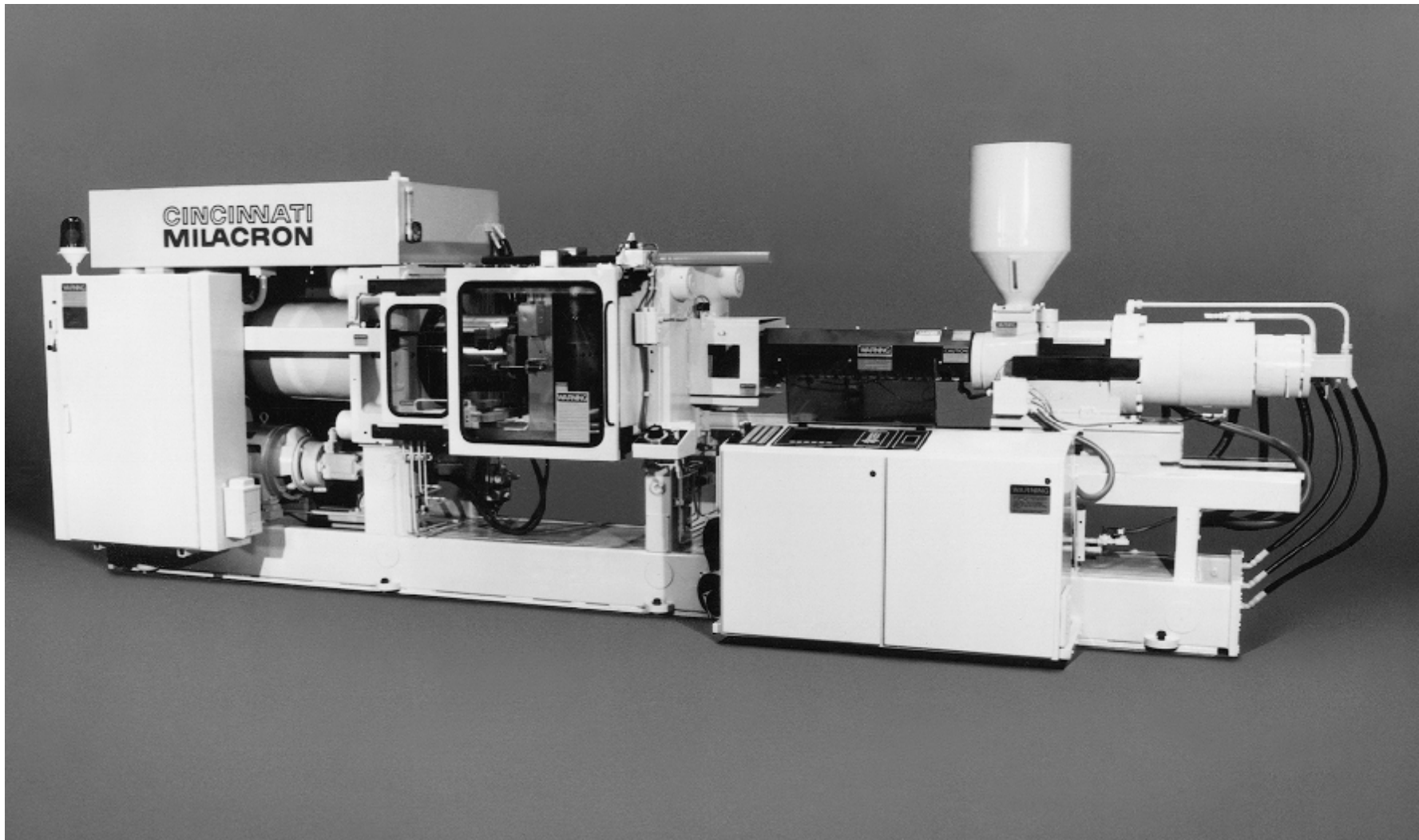


plunger type



screw type

# Injection-molding Machine



**Figure 18.7** A 2.2-MN (250-ton) injection-molding machine. The tonnage is the force applied to keep the dies closed during injection of molten plastic into the mold cavities. *Source:* Courtesy of Cincinnati Milacron, Plastics Machinery Division.



# Clamping Force (锁模力) of Injection Machine

- A force applied to **close the molds** during injection, to **prevent the molten plastics** from **flowing outward** of the cavity and forming **flash** (飞边/溢料)
- Two types are now available :
  - hydraulically driven models (液压式)
  - **electrically** driven models (电动式)

Ø weigh less

Ø quieter



# Machine Capacity

Injection-molding machines are **rated** according to :

## ① Capacity of the mold (最大注射量)

- can produce parts weighing: 100 ~ 600 g ( can be as high as 25 kg)

## ② Clamping force (最大锁模力)

- usually ranges: 0.9 ~ 2.2 MN (100 to 250 tons)
- largest machine: 45 MN (5000 tons)



## \* 国产注射机型号规格

- XS-ZY**500**，即表示**最大注射容量** $\leq 500\text{cm}^3$ 的螺杆式（Y）塑料（S）注射（Z）成型（X）机；
- XZ-**63/50**，表示**最大注射容量** $\leq 63\text{cm}^3$ 、**合模力** $\leq 50$ 吨（ $50 \times 10\text{kN}$ ）的塑料成型（X）注射机（Z）。
- 海天商用注射机：HTF**450**X/1
  - ∅ **合模力**为450吨（4500kN）
  - ∅ **最大注射容量**为1860 $\text{cm}^3$



# Economics of Injection Molding

- Ø For a 100-ton machine: \$60,000 ~ \$90,000;
  - Ø For a 300-ton machine: \$85,000 ~ \$140,000;
  - Ø For dies: typically \$20,000 ~ \$200,000.
- 
- So, **high-volume production** (大批量生产) is necessary to justify such an expenditure.

- Modern machines are equipped with **microprocessors** (微处理器) and **microcomputers** (微机) in a **control panel** (控制面板) and **monitor** (监控) all aspects (方面) of the operation.



## 18.4 Blow Molding (吹塑成型/中空成型)

- Blow molding is a **modified** extrusion- and injection-molding process:
  - **extrusion blow molding** (挤出吹塑成型)
  - **injection blow molding** (注射吹塑成型)

# 1. Extrusion Blow Molding (挤出吹塑/挤吹成型)

- a **tube** is first **extruded**
- then **clamped into a mold** with a cavity much larger than the tube diameter
- finally **blown** outward to fill the mold cavity
- blowing pressure : 350 kPa  $\sim$  700 kPa

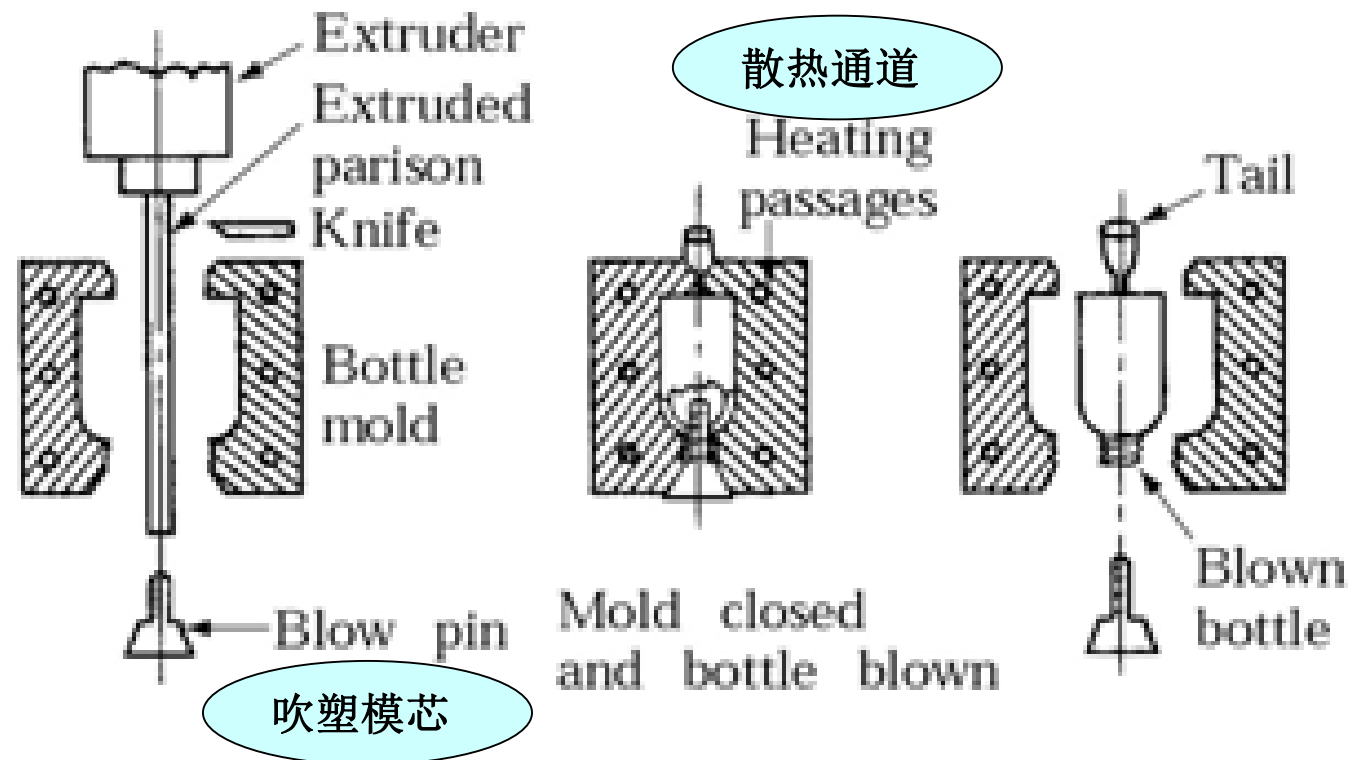


Figure 18.9 Schematic illustrations of (a) the blow-molding process for making plastic beverage bottles

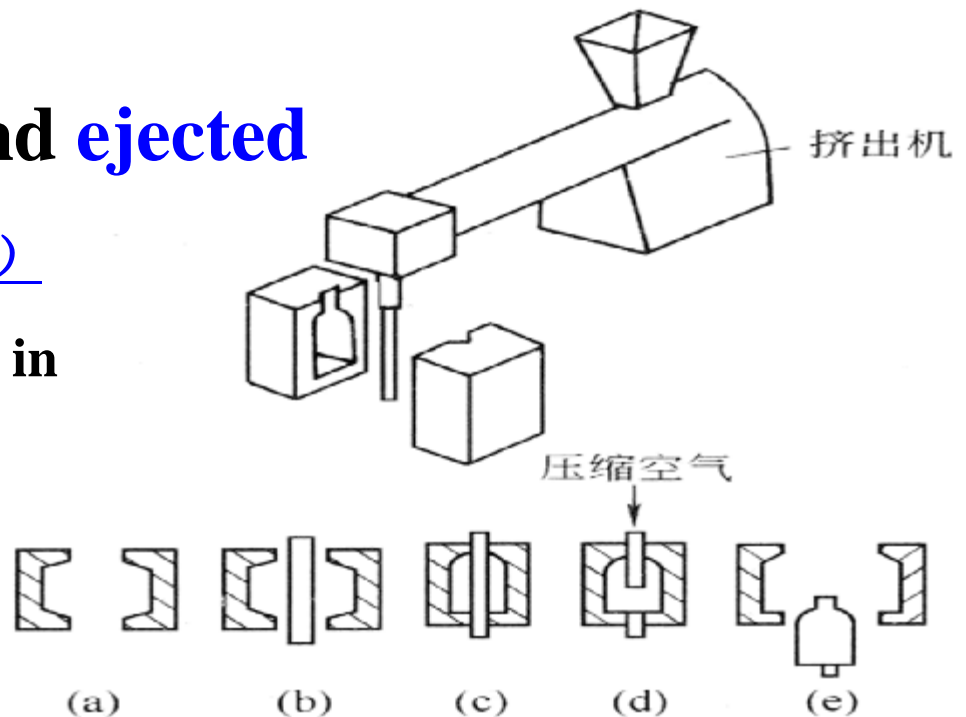
# Extrusion Blow Molding





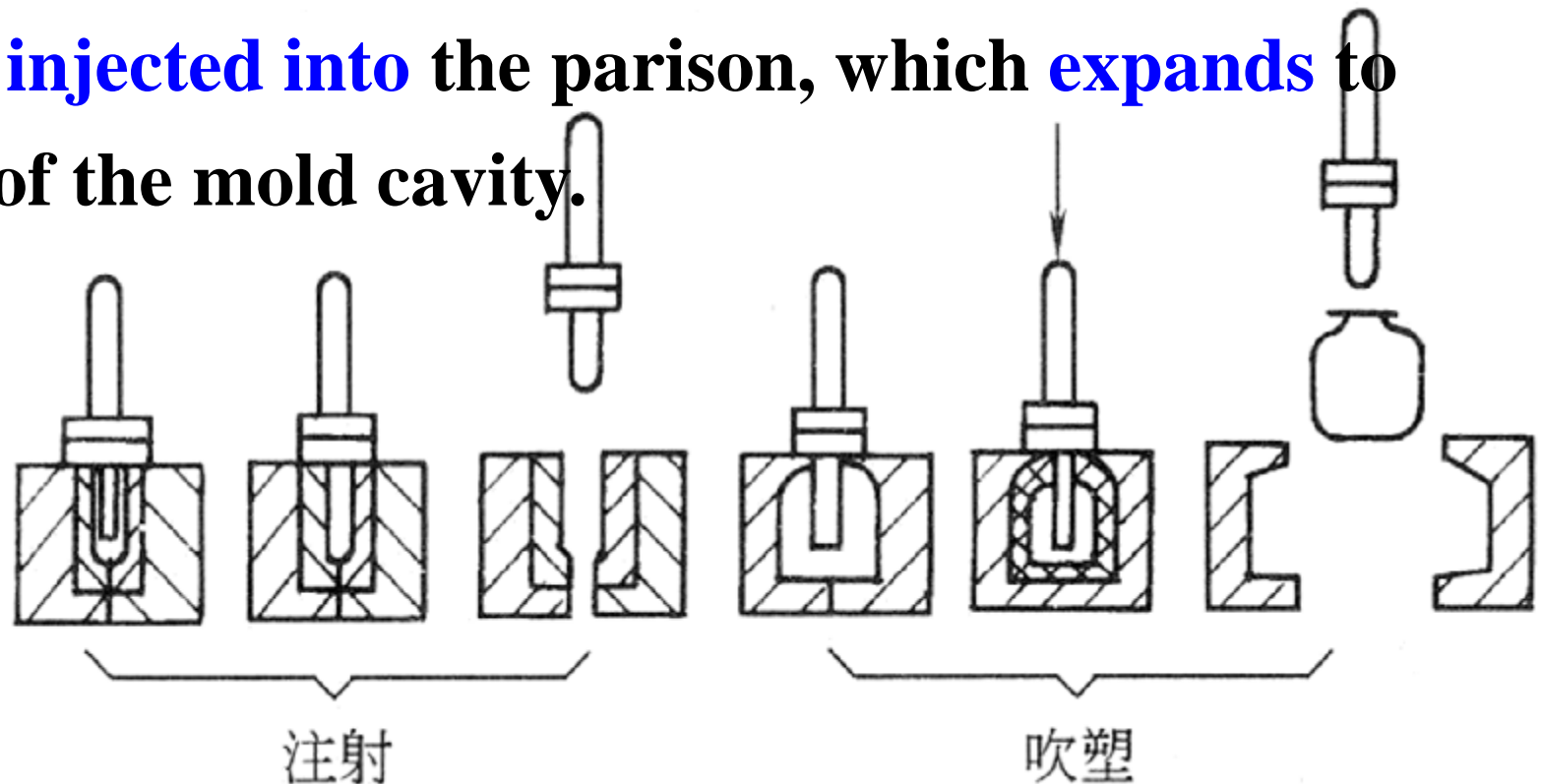
# Continuous Extrusion Blow Molding

- The **extrusion** is **continuous** and the **molds move** with the tubing:
  - the molds **close** around the tubing, close off both ends (thereby breaking the tube into sections)
  - then **move away** as **air is injected** into the tubular piece
  - the part is then **cooled** and **ejected**
- Corrugated pipe and tubing (波纹管) are made by continuous blow molding in which the pipe or tubing is **extruded horizontally** and blown into **moving molds**.



## 2. Injection Blow Molding (注射吹塑/注吹成型)

- A short **tubular piece** (**parison**, 瓶坯/管坯) is first **injection-molded**.
- Dies then open
- Parison is **transferred** to a **blow-molding die**
- **Hot air** is **injected into** the parison, which **expands** to the walls of the mold cavity.



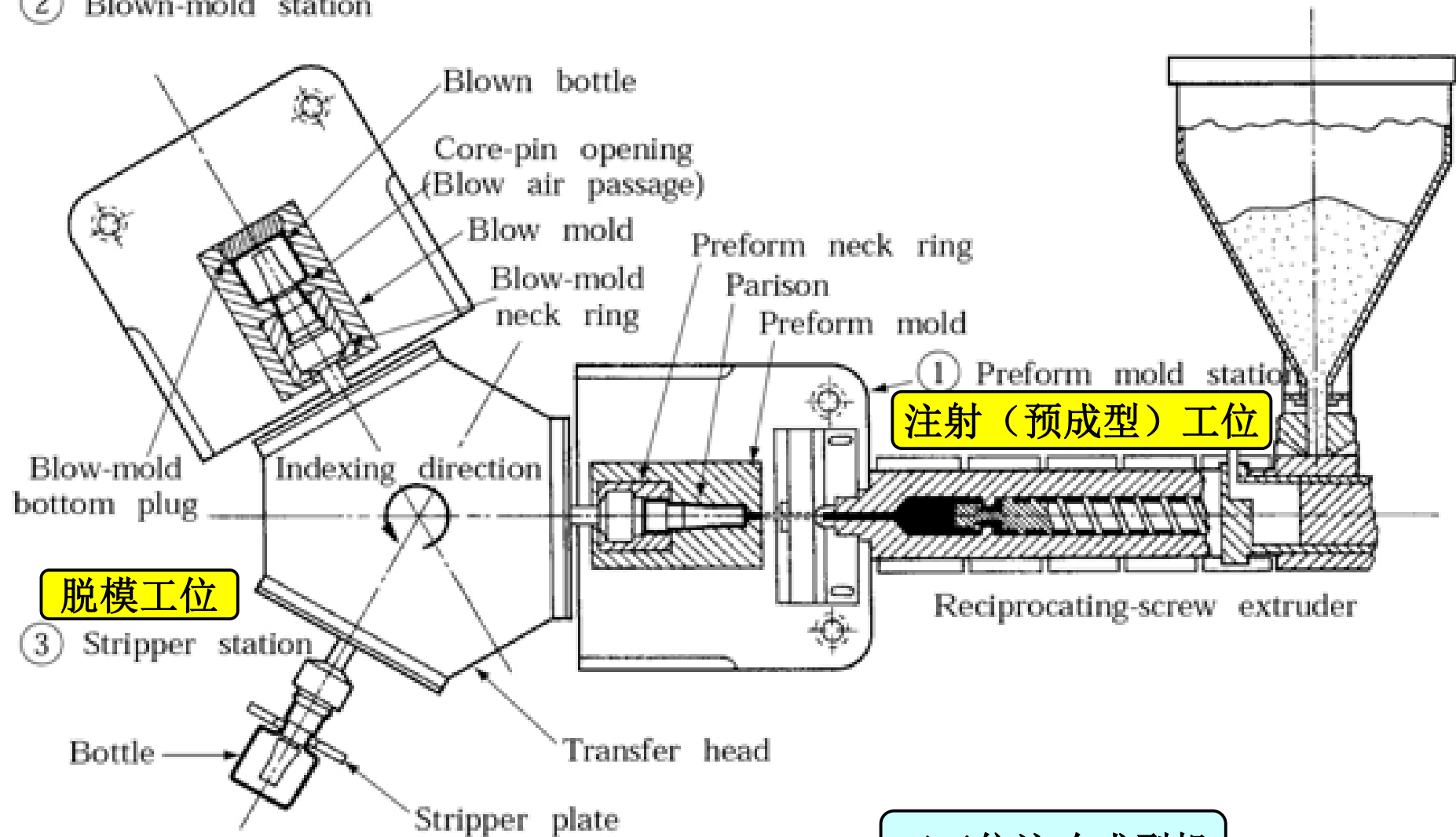
# Blow Molding



(b)

吹塑工位

② Blown-mold station



三工位注吹成型机

Figure 18.9 Schematic illustrations of (b) a three-station injection blow-molding machine. Source: *Encyclopedia of Polymer Science and Engineering* (2d ed.). Copyright ©1985. Reprinted by permission of John Wiley & Sons, Inc.

# Typical Blow Molded Products

- beverage **bottles**
- **hollow** containers



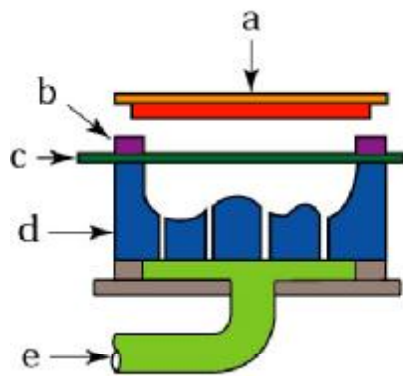
## 18.6 Thermoforming (热成形)

- A series of processes for **forming** (变形) **thermoplastic sheet** or **film** (片材) over a **mold**, by means of the application of **heat** and **pressure**.
  - a **sheet** is **heated** in an oven to the **sag** (松弛/软化) **point** (**softening** but not to the melting point)
  - the sheet is then removed from the oven, placed over **mold**, and **forced against the mold** through the application of a **vacuum** (真空)
  - The mold is usually at **room temperature**, hence the shape of the plastic becomes **set** (定型) upon contact with the mold.



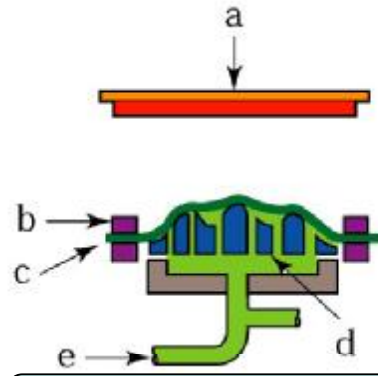
# 吸塑成型

## Thermoforming Processes



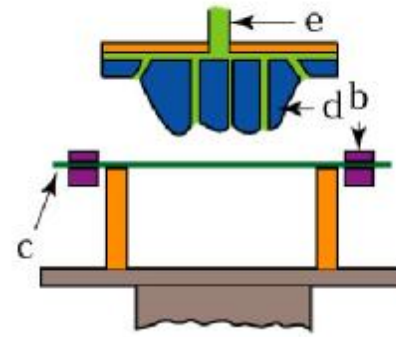
1. Straight vacuum forming

凹模抽真空成形

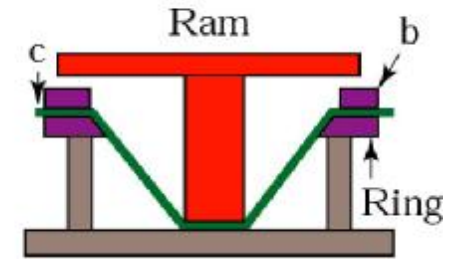


2. Drape vacuum forming

凸模抽真空成形



3. Force above sheet



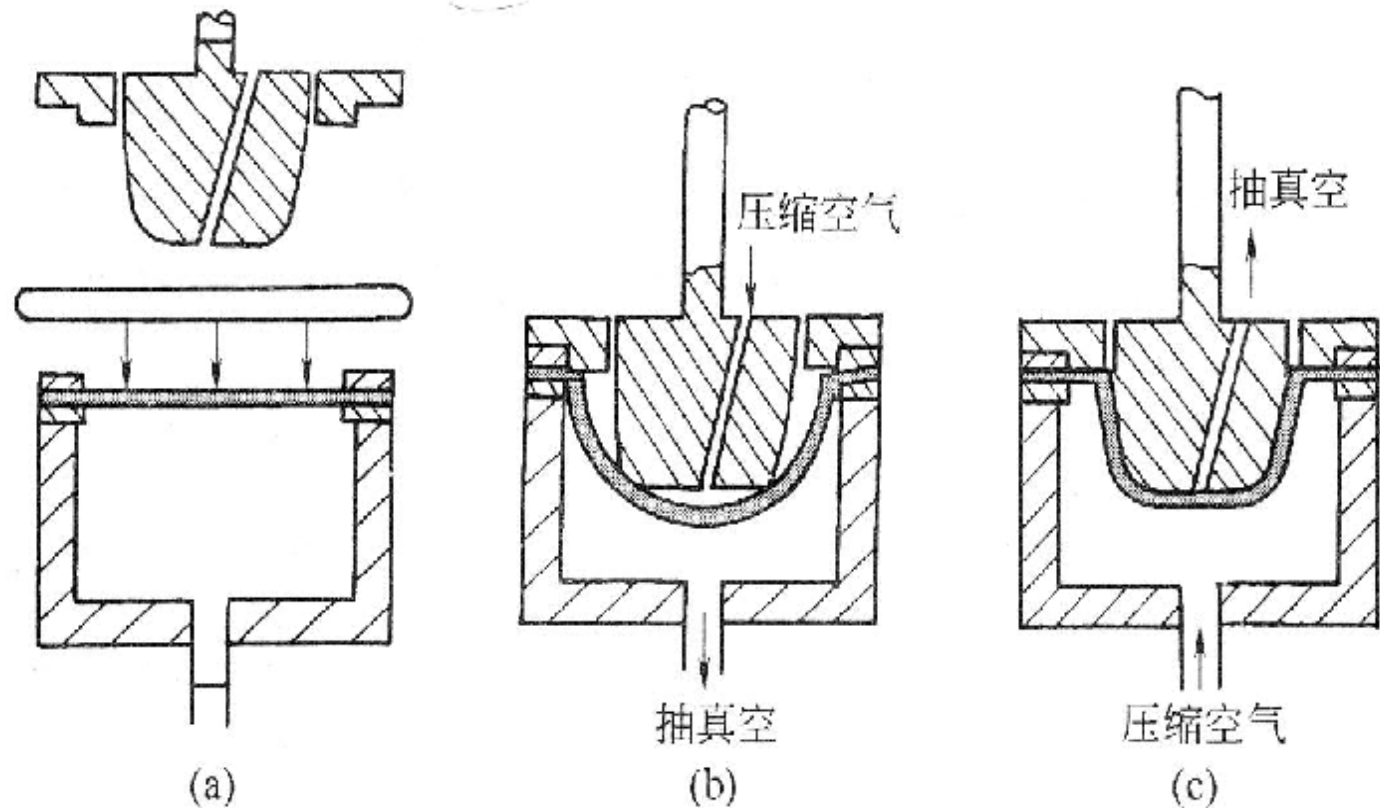
4. Plug and ring forming

- a. Heater
- b. Clamp
- c. Plastic sheet

- d. Mold
- e. Vacuum line

Figure 18.11 Various thermoforming processes for thermoplastic sheet. These processes are commonly used in making advertising signs, cookie and candy trays (托盘), panels for shower stalls, and packaging.

- Because of the **low strength** of the materials formed, the **pressure differential (压力差)** caused by the vacuum is usually **sufficient** for forming
- **Air pressure** or **mechanical means** are also applied for some parts.



# Typical Thermoformed Parts

- advertising signs (广告标志)
- refrigerator liners (冰箱衬层)
- panels for shower stalls (淋浴间隔板)
- packaging (包装)
- appliance housings (外壳)



# Characteristics of Thermoforming

- Thermoforming is a **drawing and stretching operation**, much like **sheet-metal forming**
  - the material should exhibit **high uniform elongation**, otherwise, it will **neck** and **fail**.
  - thermoplastics have **high capacities for uniform elongation**, by virtue of their **high strain-rate sensitivity exponents** (应变速率敏感指数),  $m$ .
- The **sheet** used in thermoforming are made by sheet extrusion.
- **Parts with openings or holes CANNOT** be formed by this process, because the pressure differential cannot be maintained during forming.

# Quality Considerations

- **Tearing**
- **Nonuniform (不均匀的) wall thickness**
- **Improperly filled molds**
- **Poor part definition (清晰度差) (surface details)**

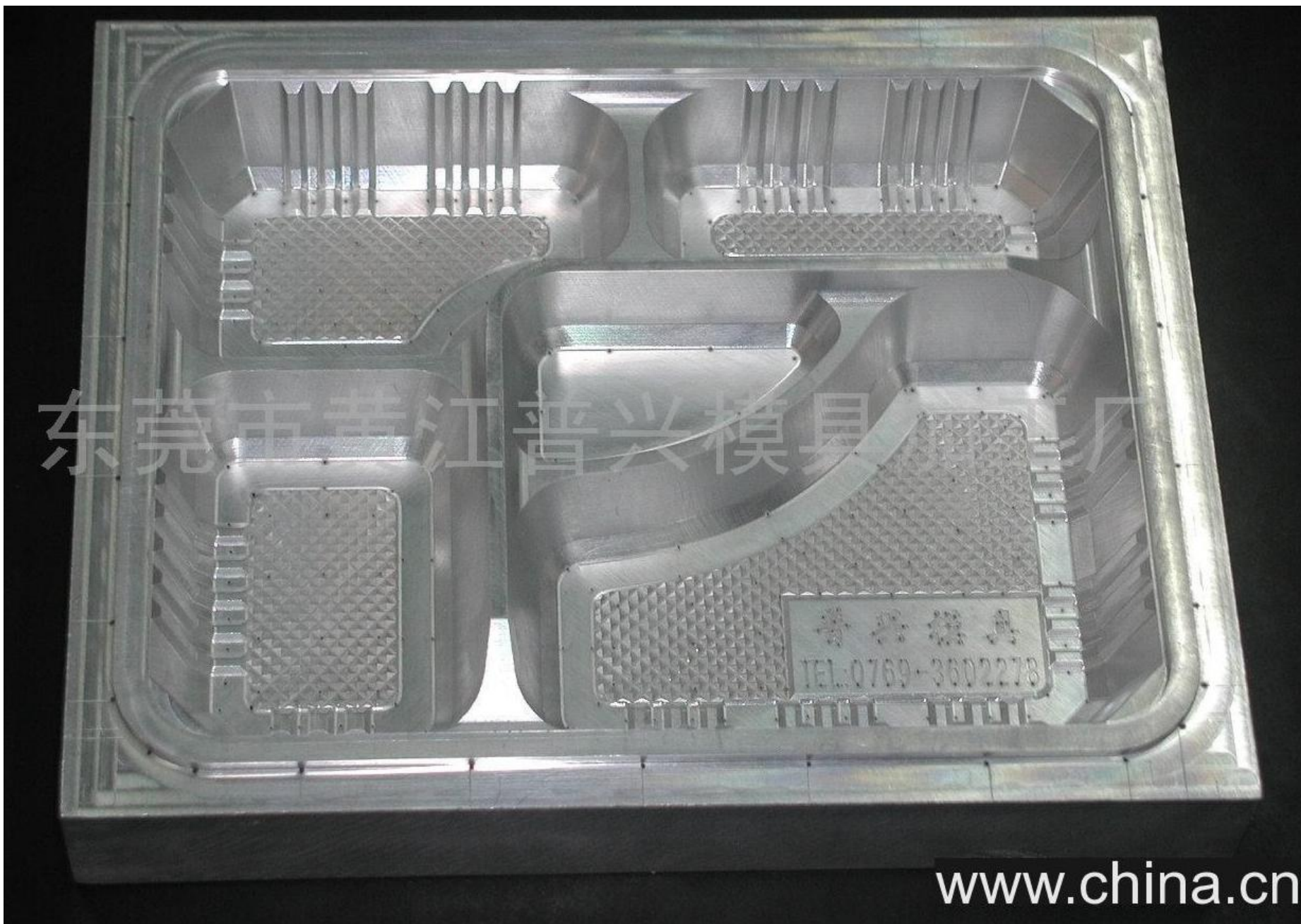
# Thermoforming Molds

- Usually made of **aluminum**
  - does not require high strength
- **Holes** in the molds are usually **less than 0.5mm**
  - to **pull a vacuum**
  - **not to leave any marks** on the formed parts.
- Tooling is **inexpensive**



## Mold Used in Thermoforming

吸塑模



[www.china.cn](http://www.china.cn)

# KEY TERMS

**compression molding** 压缩成型/压制成型

**extrusion** 挤出成型

**extrusion blow molding** 挤出—吹塑成型

**injection molding** 注射成型/注塑成型

**inserting molding** 嵌件成型

**overmolding** 包胶注射成型

**parison** （玻璃或塑料等的）型坯

**pellets** 球状，颗粒状

**thermoforming** 热成形

**transfer molding** 传递成型，压注成型

# **Review Questions**

- 1. What are plastics?**
- 2. What are the two basic types of plastics?**
- 3. How to process plastics?**
- 4. What are the advantages of processing plastics compared to metals?**
- 5. What are the forms of the raw material of plastics?**
- 6. Describe the process of extrusion of plastics.**
- 7. What are the functions of the screw in extruder?**
- 8. What are the three distinct sections of screw in extruder?**

**9. Describe some typical extruded shapes.**

**11. How to rate extruders?**

**12. Describe the process of injection molding.**

**13. What are the three basic types of injection molds?**

**14. What is clamping force of injection-molding machine?**

**15. How to rate injection-molding machines?**

**16. Describe the process of extrusion blowing molding.**

**17. Describe the process of injection blowing molding.**

**18. Give some examples of plastics products made by thermoforming.**