“Historically and traditionally it has been the task of the science disciplines to teach about natural things: how they are and how they work. It has been the task of engineering schools to teach about artificial things: how to make artifacts that have desired properties and how to design”

“Of course, engineers are not the only professional designers. Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. Design is the core of all professional training. It is the principal mark that distinguishes the professions from the sciences”

* Nobel Prize in Economics 1978
• The **natural sciences** are concerned with **how things are**.

• **Design** is concerned with **how things ought to be**, with devising artifacts to attain goals.

• Design is much **more complex than optimization**. In fact, the optimization problem, is a standard mathematical one – to maximize a function subject to constraints.
In engineering design we use inequalities—specifications of satisfactory performance—rather than maxima and minima.

- Of course, no one will settle for the satisfactory, good or better if he/she can have the best. But that is not the way the problem usually poses itself in actual design situations. In the real world we usually do not have a choice between satisfactory and optimal solutions.

...hopefully, we can look for a “better” solution...

Herbert Simon tried to introduce the term “SATISFICE” as opposed to “OPTIMIZE”.
EXTRUSION DIE DESIGN CONSIDERATIONS

• FLOW BALANCING: TO PRODUCE UNIFORM OUTFLOW (i.e. film of equal thickness, profiles of desired shape)
• REASONABLE PRESSURE DROP (not too high, not too low)
• NO HOT SPOTS (i.e. avoid excessive viscous heating)
• NO STAGNATION FLOW REGIONS (i.e. all passages streamlined)
IMPORTANT CONCEPTS OF FLOWS THROUGH DIES

1. VELOCITY PROFILES, SHEAR RATE, SHEAR STRESS etc. The equations are simple for unidirectional flow. But, you need finite element simulation for 2-D or 3-D flow analysis.

2. FRICTIONAL HEATING (also called viscous dissipation) due to high viscosity and high velocities.

3. VISCOELASTIC EFFECTS, which might be responsible for extrudate swell, instabilities etc.

4. Conditions at metal/wall INTERFACE (slip? no slip?)
FLOW BALANCING is the most important consideration in the die design. NEED SAME OUTFLOW VELOCITY. The polymer melt has the overwhelming tendency to flow through the areas of least resistance. Let’s explain that, by examining a die having a section with 10% larger gap as shown.

Let’s estimate the outflow velocity
See APPENDIX for flow between parallel plates and gap H=2b

\[ v_{\text{avg.}} = \frac{n}{n+1} \left[ \frac{1}{m} \frac{\Delta P}{L} \right]^{\frac{1}{n}} H^{\frac{1}{n+1}} \rightarrow v_{\text{avg.}} = \text{const} \cdot H^{\frac{1}{n+1}} \]

What does this mean?

**For Newtonian** \((n=1)\) and for the example the outflow velocity ratio will be:

\(1.1^2/1.0=1.21\) (21% faster through the 10% larger gap)

**For a polymer with power-law exponent** \(n=0.33\) and for the example the outflow velocity ratio will be:

\(1.1^{4}/1.0=1.46\) (46% faster through the 10% larger gap)

As the gap **SIZE DIFFERENCE** INCREASES OUTFLOW VELOCITY DIFFERENCE INCREASES → BIG FLOW IMBALANCE
FLOW BALANCING is the most important problem for any kind of die. We want even (uniform) flow for sheet, film, profile, pipe, etc production. Flow passages must be so designed as to deliver even flow amounts to the die lips. But, if the die is O.K. for one polymer it won’t be necessarily O.K. for another. Shear-thinning (expressed by the power-law index $n$) is the defining parameter, the smaller the $n$ the greater the tendency for flow imbalance.
FLAT DIES

Flat dies are used for cast film or sheet or sheet extrusion. Sheet is film thicker than 10 mils (0.25 mm)
PRINCIPLES OF FLAT DIE DESIGN

The purpose of flat dies is to spread the polymer melt and to establish uniform cross section. This is accomplished by:

• proper flow channel design
• lip-adjusting (for fine tuning)
• die body temperature control
FLOW CHANNEL DESIGN

Balancing of flow distribution is accomplished by designing the manifold and preland section so that “each” polymer stream from center to edges exhibits approximately the same resistance to flow: Die width can be from a 2-3 cm (tapes) to perhaps 10 meters (sheet for geotechnical applications)
At least, 2-D simulation software needed for flat die design.
MANIFOLD (i.e. feeding channel)

CROSS-SECTION

T-Slot Dies or Old Coathanger Designs
(linearly diminishing from center to edges to minimize residence time)
preferred for monolayer extrusion

(linearly diminishing from center to edges to minimize residence time)
preferred for feed-block co-extrusion
FOR MORE INFORMATION:


Available for downloading from RESEARCHGATE
SPIRAL DIES

Spiral die design is the most common type of die used in **blown film extrusion**. Spiral dies are also used for the production of **pipe**. The basic requirement is to produce a tubular polymer melt stream of uniform thickness continuously.
Polymer prefers to flow right above the ports

The polymer melt flows from extruder through a melt pipe at the bottom into the runners which guide it to the ports from the where the spirals originate. (From J. Perdikoulias, PhD Thesis U. Waterloo, Canada)

Basic requirement UNIFORM THICKNESS (No more than 5% variation acceptable) Diameter up to more than 1 meter

Polymer prefers to flow right above the ports (Thicker)
Two Design Criteria NEED (needed at least 2D flow simulation)

1. A good die should **NOT** have thickness variation of **more than 5%**
2. There must be flow along the **spiral channel**
Relaxation Chambers

ABOVE THE SPIRALS

During passage through the relaxation chambers the differences due to non-uniform mechanical history are diminished.
Mechanical Drawing of a Spiral Die

“PLUG” WITH RELAXATION CHAMBER

Courtesy BRAMPTON ENGINEERING
influenced by cooling rate and stretching size and morphology of crystals formed determine the end properties of film
Basic Air Ring Designs for bubble cooling

Single Lip Air Ring

Adjustable Dual Lip Air Ring

Coanda Effect

A free jet emerging from a nozzle will tend to “attach” itself and flow along an inclined or offset nearby surface (flat or curved)
Small air ring adjustments may result in significant airflow pattern changes and cooling rates, which affect crystallinity, frozen-in stresses and film properties (V.Sidiropoulos PhD, McMaster U.)
For more information


See also T. Kanai and G. A. Campbell (Editors) “Film Processing Advances” Hanser (2014) Chapter 4 by J. Vlachopoulos and V. Sidiropoulos on modelling.