coperion

→ Food Extrusion Seminar *intense* 2026

Nov 11-12, 2026 | Stuttgart/Germany

Presentations



Coperion Food Extrusion Seminar Intense

Agenda – Day 1 – Wednesday, Nov 11, 2026

08:30	Reception | Coperion, Theodorstraße 10, 70469 Stuttgart
9:00	Welcome / Introduction / Organization Stefan Gebhardt & Uta Kühnen, Coperion
	Twin Screw Extruder Basics Uta Kühnen, Coperion
	Types, Forms & Materials of Twin Screw Elements Tobias Gaiser, Coperion
	Coffee Break
	Practical Session: Assembly of Twin Screw Elements Tobias Gaiser & Team, Coperion
12:30	Lunch | Coperion Company Restaurant
	Coperion Test Lab Tour Team, Coperion
	Process Opportunities in Food Extrusion Fabian Specht, Coperion
	Coffee Break
	Expansion & Die Design Christian Hüttner, Coperion
	Feeding of Various Ingredients Fabian Specht, Coperion
17:00	End of Day 1
19:00	Dinner

https://coperion.com/en/food-extrusion-seminar-intense-2026



Coperion Food Extrusion Seminar Intense

Agenda – Day 2 – Thursday, Nov 12, 2026

08:30	Reception | Coperion, Theodorstraße 10, 70469 Stuttgart
09:00	Process Design Uta Kühnen, Coperion
	Recipe Ingredients in Food Extrusion Fabian Specht, Coperion
	Coffee Break
	Practical Session: Extrudate Samples Uta Kühnen, Coperion
	Extrusion Process Examples Uta Kühnen & Tobias Gaiser, Coperion
12:30	Lunch | Coperion Company Restaurant
	Factory & Extruder Assembly Tour Coperion Factory
	Get Your Settings Right – the Impact of Extruder Settings on the Product Properties Christian Hüttner, Coperion
	Coffee Break
	Bring your open questions! Seminar Participants & Coperion Team
16:00	End of Seminar Day 2

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Twin Screw Extruder Basics

Food Extrusion Seminar Intense 2026

Uta Kühnen, Head of Process Technology Food

1 Introduction

2 Extrusion basic mechanisms

3 Geometry outline of twin screw extruders

4 Extruder components

5 Twin Screw Extruder process section

6 Ancillary equipment for process section

7 Pelletizer ZGF

8 Process control system

Introduction

1



Definition

Extrusion (from latin *extrudere* = push out) to press/ squeeze a material by means of force through a small orifice.

Mechanical process

Material (at the die) in is high viscous/flowable aggregate state

Screw extrusion

- A continuous process
- Not always forced through a die
- Not always flowable / high viscous material
- Thermomechanical process

Historical

Food Extrusion

Meat grinder

~ 1830 K. Drais

Maybe oldest and most renewed single screw food extruder



Basic components

- Inlet hopper
- Screw
- Drive
- Die plate
- Knife

Extrusion basic mechanisms

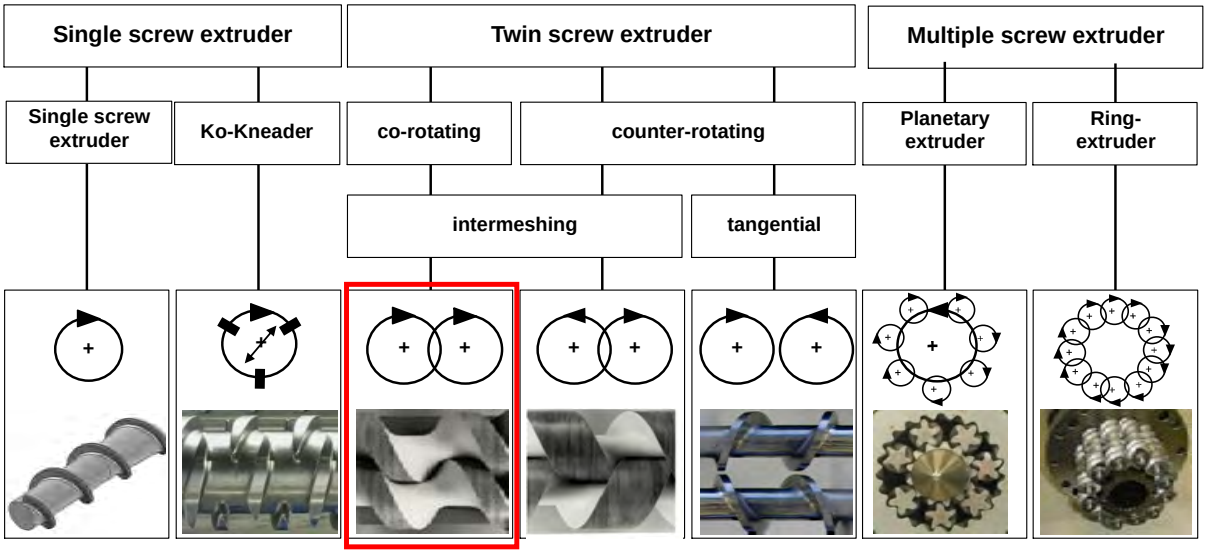
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General Working Principle of screw extrusion machines

Extrusion Systems

Different Concepts



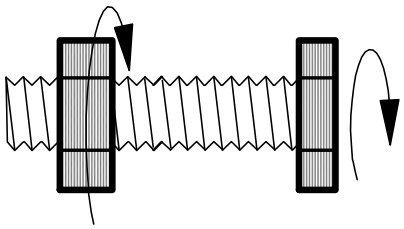
Basics Extrusion systems

Conveying mechanism I

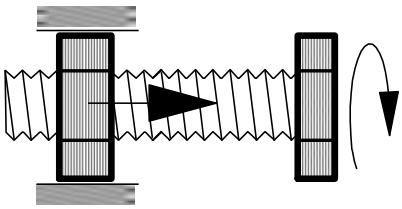
Principle of function

Ratio of friction between product to barrel wall and product to screw element.

$$\frac{\mu\ (prod\ to\ barrel)}{\mu\ (prod\ to\ screw)}$$



No transportation if product sticks to the screw element.



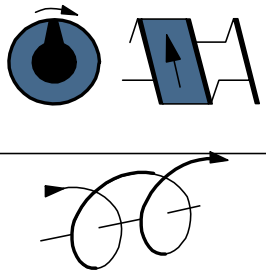
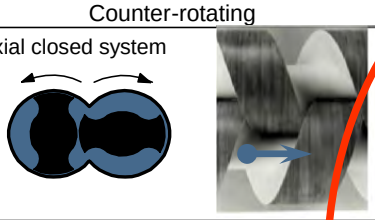
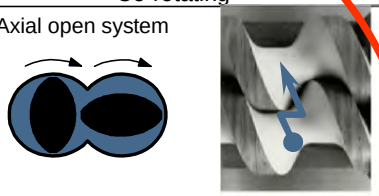
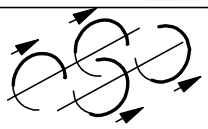
Good product transportation if product sticks to the barrel wall.

Conveying of product

Low friction at the screw, high friction at the barrel wall (bolt / nut effect)

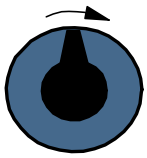
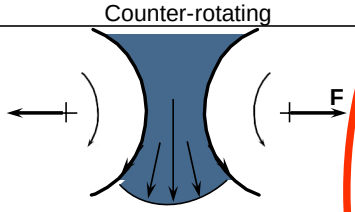
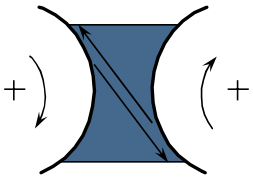
Basics Extrusion systems

Conveying mechanism II

Single screw extruder	Twin-screw extruder	
	Counter-rotating	Co-rotating
Axial open system	Axial closed system	Axial open system
		
		
Conveying due to difference of friction • low friction to screw (crome plating) • high friction to barrel (grooved inner surface) Melt conveying by drag flow	• Closed chamber in intermeshing area of screws. • "Single screw conveying" in other parts of the screw. • good conveying • good pressure build-up • reduced longitutinal mixing	• Open intermeshing area of screws. • "Single screw conveying" in other parts of screw. • reduced conveying • reduced pressure build-up • good longitutinal mixing

Basics Extrusion systems

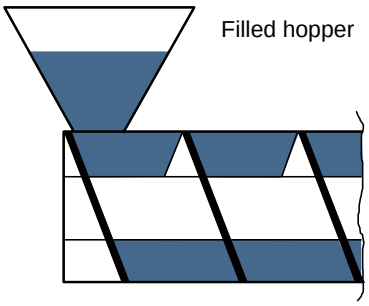
Self wiping (cleaning) effect

Single screw extruder	Twin-screw extruder	
	Counter-rotating	Co-rotating
		
• No self cleaning effect. ⇨ Product can stick to screw without being transported	• No velocity difference between screws • "calander effect„: product sqeezed out of gap ⇨ high forces towards barrel (wear) ⇨ limited screw speed	• Velocity difference between screws • Self-wiping effect • low level forces towards barrel ⇨ High screw speed ⇨ Low wear situation

Basics Extrusion systems

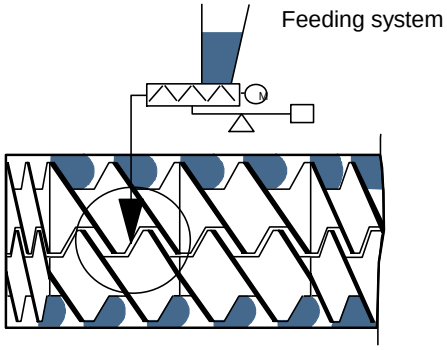
Throughput and Degree of Fill

Single Screw Extruder



- Product feed out of full hopper
- No feeder necessary
- Screw channels completely filled
- Output rate = f (screw speed)

Twin Screw Extruder



- Product feed controlled by feeding system
- Screw channels partly filled
- Output rate independent of screw speed

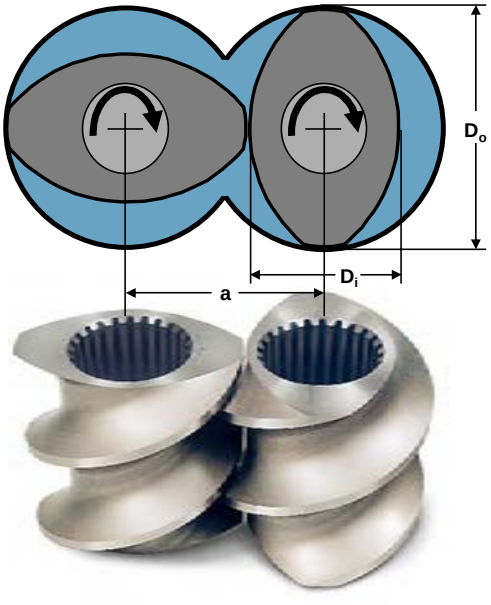
Geometry outline of twin screw extruders

3



Design features of twin screw extruders

Characteristic dimensions



D_o = Outer diameter
D_i = Inner diameter
a = Centerline distance

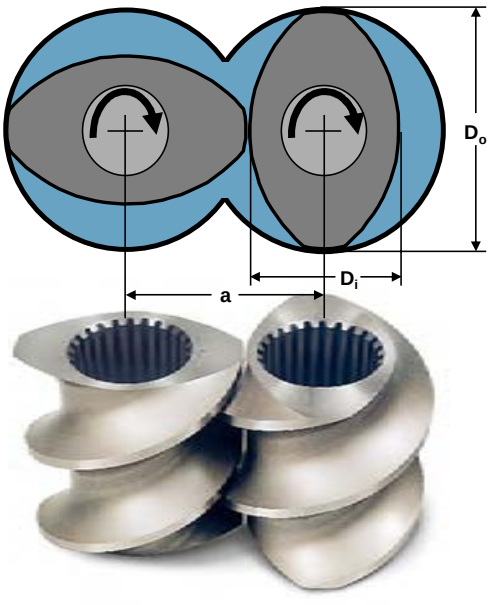
D_o / D_i = Diameter ratio
determines shear, degassing and powder intake

M_d / a^3 = Specific torque
determines power density and filling degree

n = Screw speed
determines shear and mixing

Design features of Coperion ZSK

MEGAcompounder and MEGAvolume



ZSK Mv

D_o / D_i = 1,8

M_d / a^3 up to 11,3 Nm/cm³

n up to 1800 rpm

ZSK Mc

D_o / D_i = 1,55

M_d / a^3 up to 18 Nm/cm³

n up to 1200 rpm

Geometrically similar design of process section

of the ZSK series



ZSK MEGAcompounder

Screw diameter
18 to 420 mm

ZSK MEGAvolume

Screw diameter
27 to 247 mm

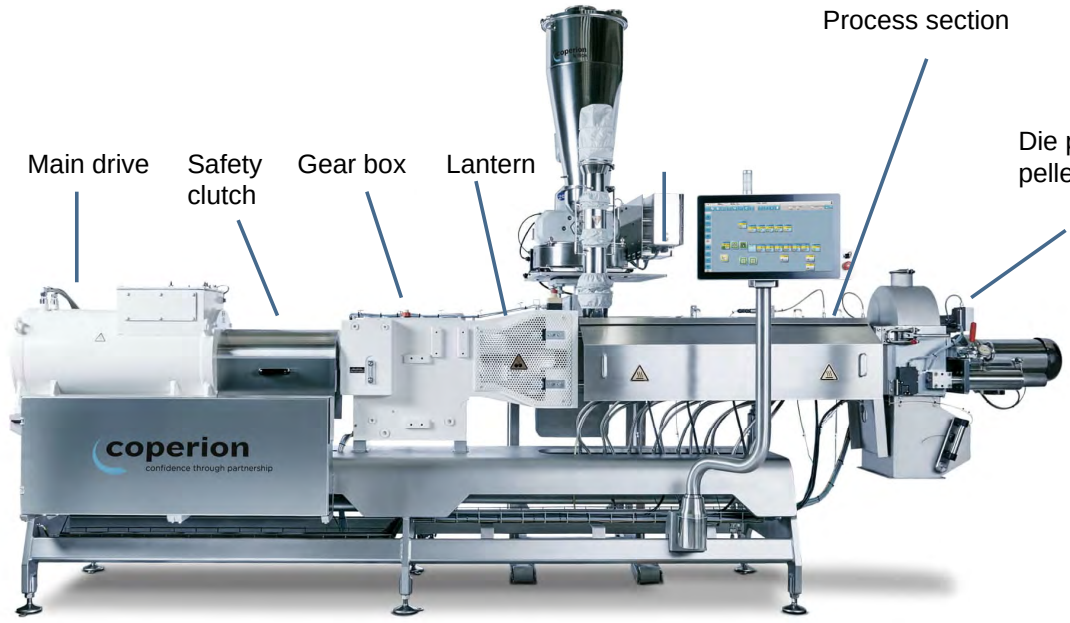
Extruder components

4



Food grade Extruder

Hygienic Design Version



ZSK 54Mv

Main drive

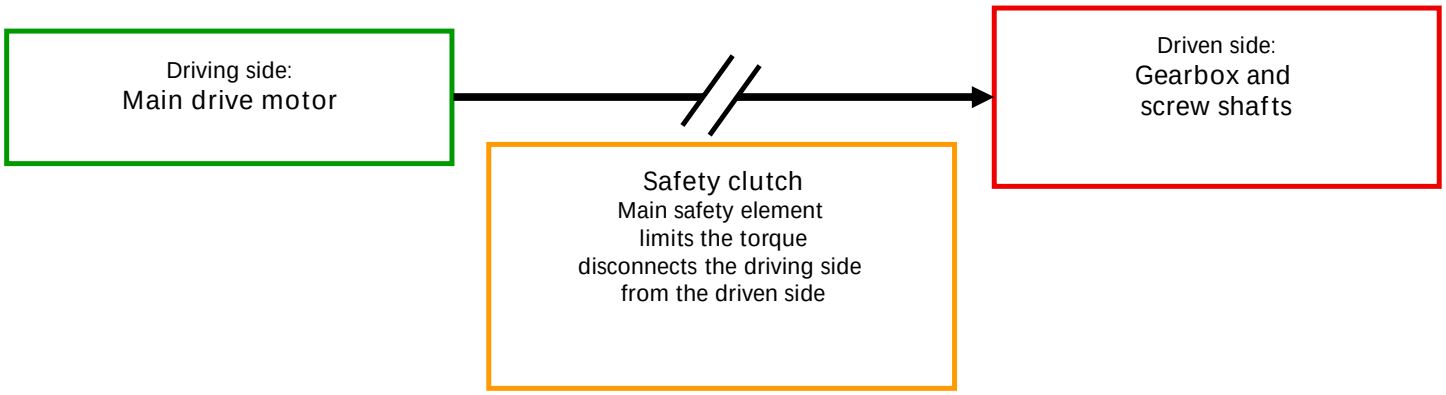
Water cooled main drive

AC drive with frequency converter
Very silent
Hygienic smooth surface
No fan needed
Small footprint



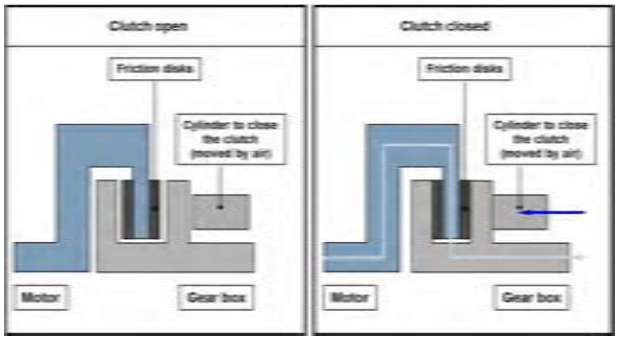
Safety clutch

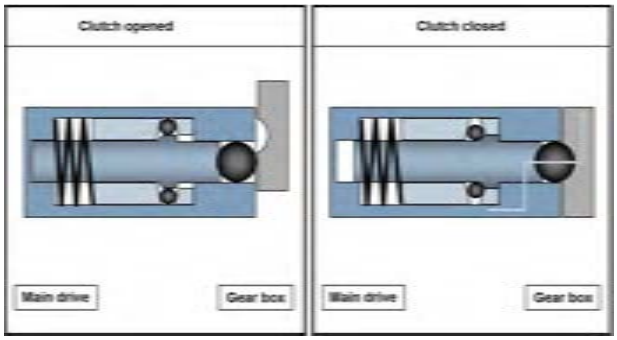
Background



Safety clutch

Air loaded and spring loaded version







Feature

Safety decoupling of gearbox and processing section from main drive if torque is too high

Gearbox

Reduction and distribution

Reduction gears

n1 speed of shaft from main drive

n2 speed of screw shafts

Ratio i

$i = \frac{n1}{n2}$

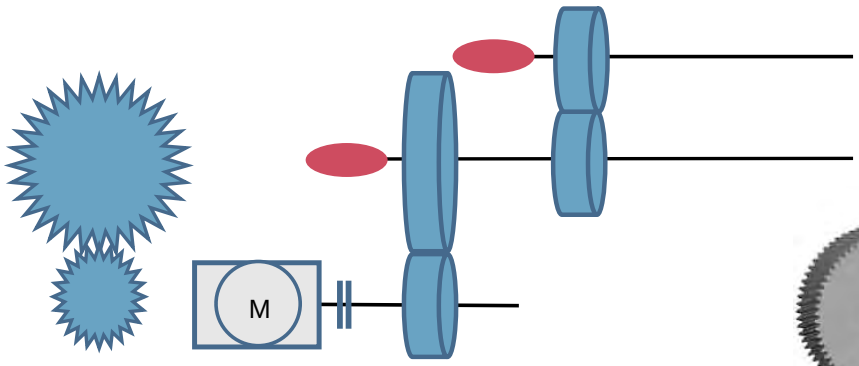
n1 > n2

Distribution gears

Distribution to two shafts

Trust bearing of screw shafts

Only one-sided bearing of screw shafts

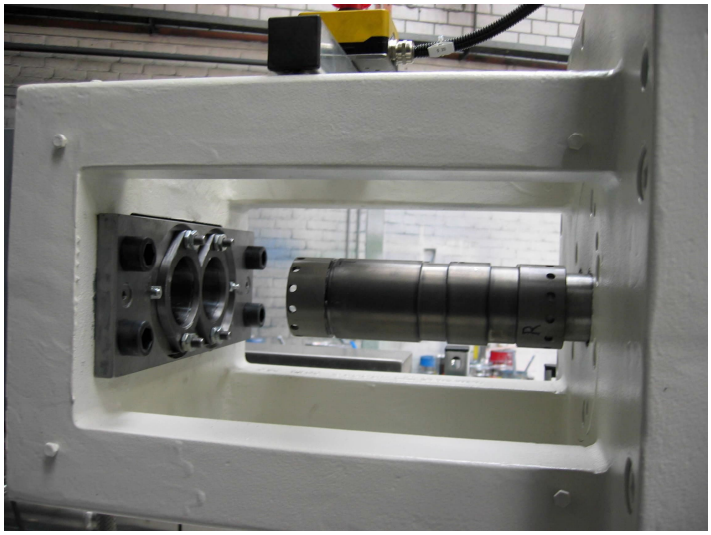




Lantern

Coupling between gear shaft and screw shaft

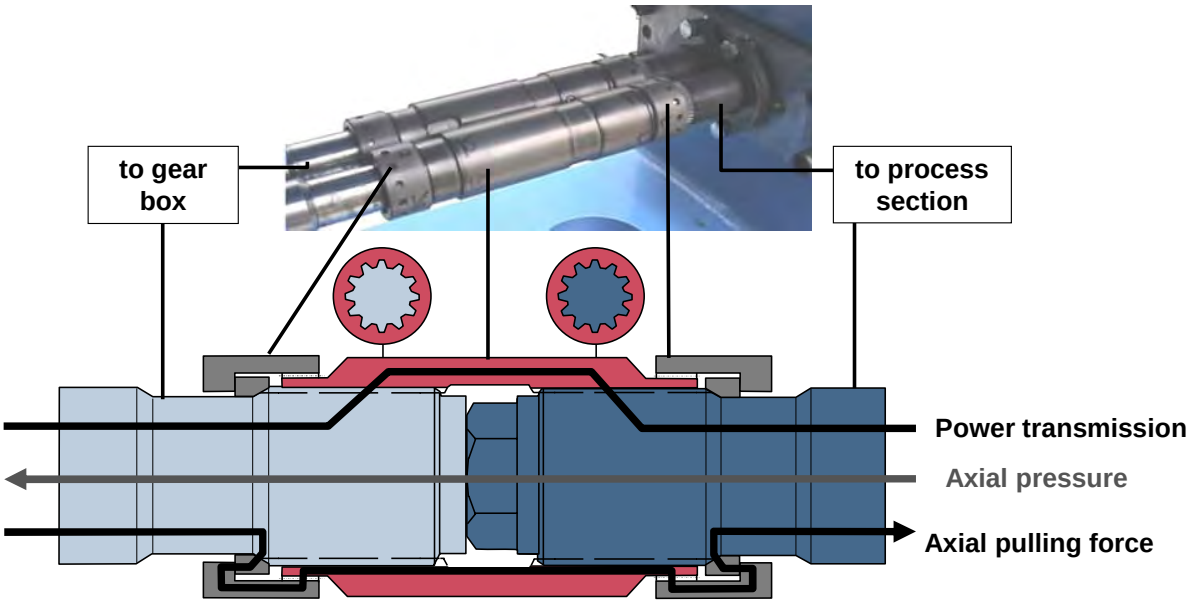
to process section



to gear box

Lantern

Coupling between gear shaft and screw shaft



Hygienic design

ZSK 43Mv in production site

Stainless steel base frame

Open construction

- good access
- avoid dead spaces

Suitable for wet cleaning

Over all IP 54

Easy drainage of cleaning liquids

Clearance from floor



ZSK Food Extruder in Hygienic Design

User, cleaning and maintenance friendly design

Twin Screw Extruder process section

5



Hardware Components – Barrels and Screws

The ZSK Megavolume extrusion system

Modular design and versatility

- ZSK = twin screw kneader
- Modular screws:
  single elements are threaded on a shaft
- Modular barrels:
  single barrels are coupled by flanges or held together by tie-rods
- Each barrel heated / cooled individually

Individual Design

Each extruder mounted with unique configuration of components and parts





Action of the screws

Lookout



Cross section of a ZSK

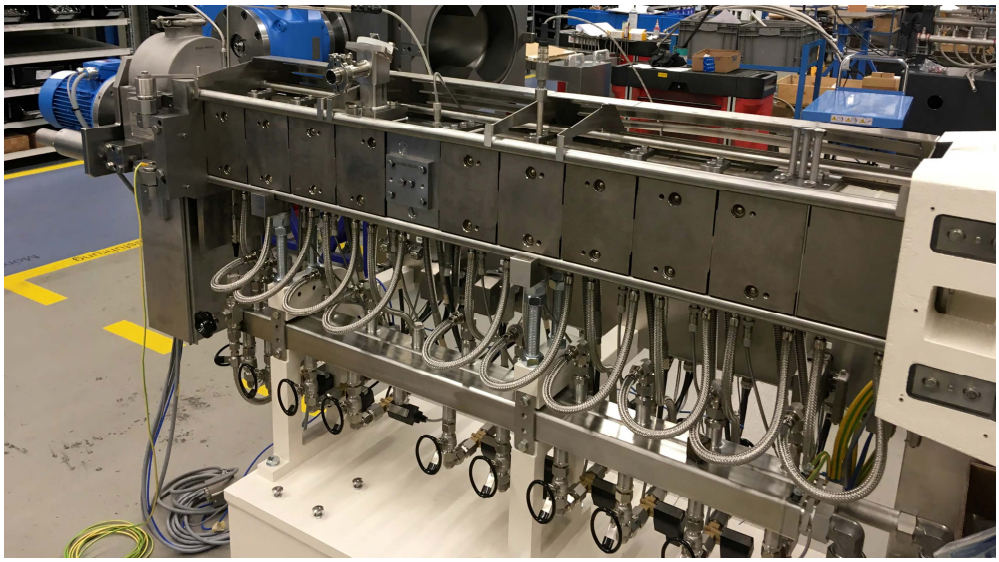
2 lobe system

Deeper insights

In the presentation on screw elements by Tobias Gaiser, Coperion

Modular design of ZSK process section

Example Extruder with tie rods



ZSK 34 barrels fixed with tie rods

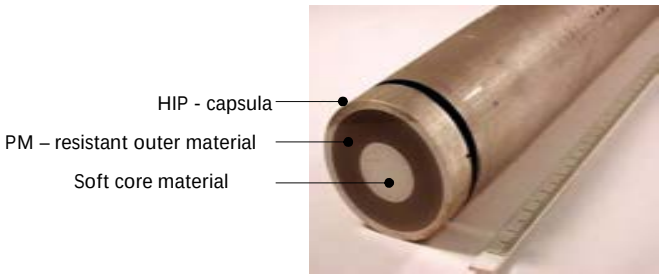
Metallurgical competence

Abrasion and/ or corrosion resistant screw elements

Powder metallurgical element with wear
and corrosion resistant layer with softer core



Raw material for screw elements



High requirements in food extrusion

Corrosive attack: use of water, salt, flavour and aggressive (cleaning) media
Abrasive attack: starch, sugar, minerals... abrasive raw materials
Statutory regulations for food contact

Metallurgical competence

Abrasion and/ or corrosion resistant barrels

Protecion against corrosion and abrasion of Extruder barrels

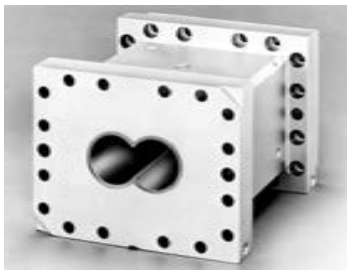
- Extruder barrel with corrosion and abrasion resistant liner

Liner can be exchanged if worn/ barrel body can be safed

- Barrel with special welded layer in 8-boring
- Barrel with special surface
- Complete barrel out of special steel

- Barrel body corrosion resistant for hygienic cleaning of extruder outside





Barrel heating and cooling

Liquid cooling or tempering

Fluid tempering

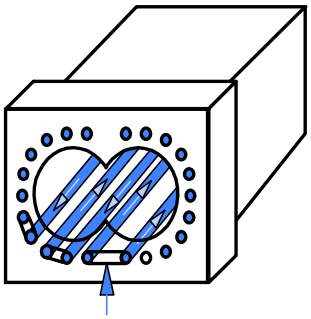
- Water (pressurized max. 200 °C)
- Steam (max. 250 °C)
- Oil (max. 350 °C)

➡ Regulated by external tempering units

Fluid cooling

- Water
- Antifreeze
- Regulated cooling impulses (extruder process control)
- Continuous flow (manually)
- < 100°C by heat transfer
- > 100°C by evaporation enthalpy (much more efficient!!)

Cooling channels in barrel body



Tempering fluid



Barrel heating and cooling

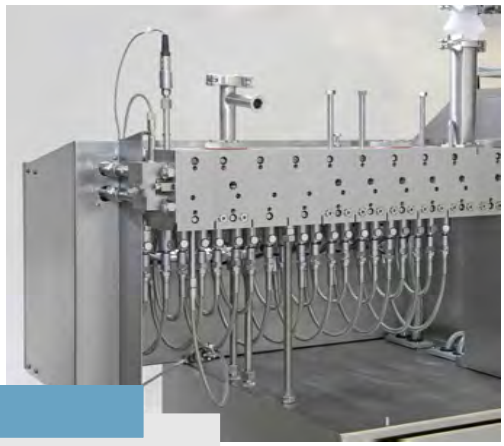
Electrical heating and pulsed water cooling

Temperature control and regulation of each singular barrel

Electrical heating by 2-4 heater cartridges by resistance heating



ZSK 18Mc



Each barrel

Temperature probe
Cooling water inlet/outlet
Heater cartridges

Ancillary equipment for process section

6



Feeder

Integral component of extrusion line

Smooth, reliable, constant infeed to ensure a constinuous consistant extusion process

One of the most important pieces of ancillary equipment



ZSK 54Mv

Details & Insights

See presentation on feeding by Fabian Specht

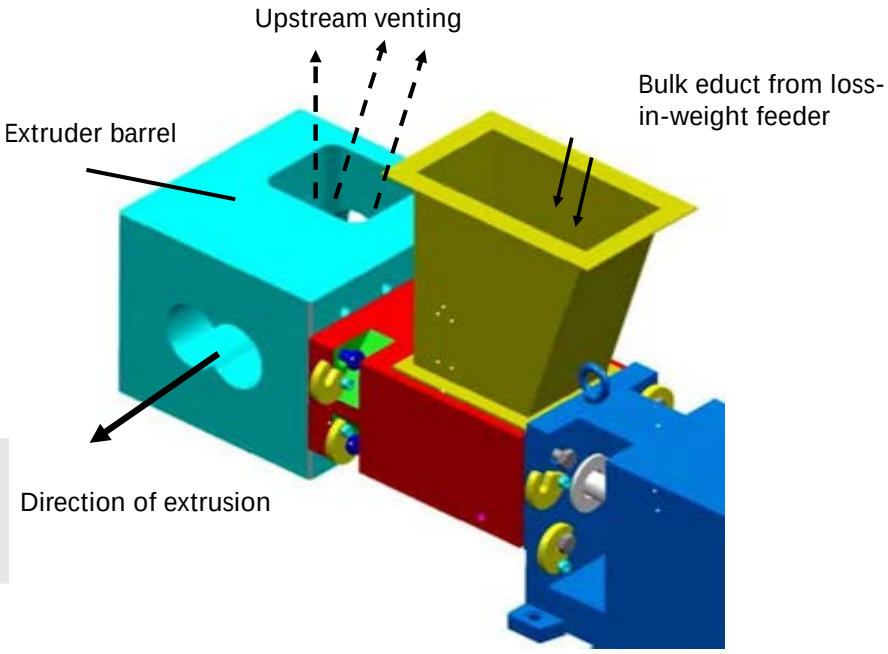
ZS-B twin screw sidefeeder

for bulk material feed

- Increase of powder intake
- Smooth feed in
- Intake into plastified mass
- Integration possible throughout the process section
- Munted to the left (downturning screw)
- Upstream venting

Caution!

Bulk material intake device ZS-B is not a feeder

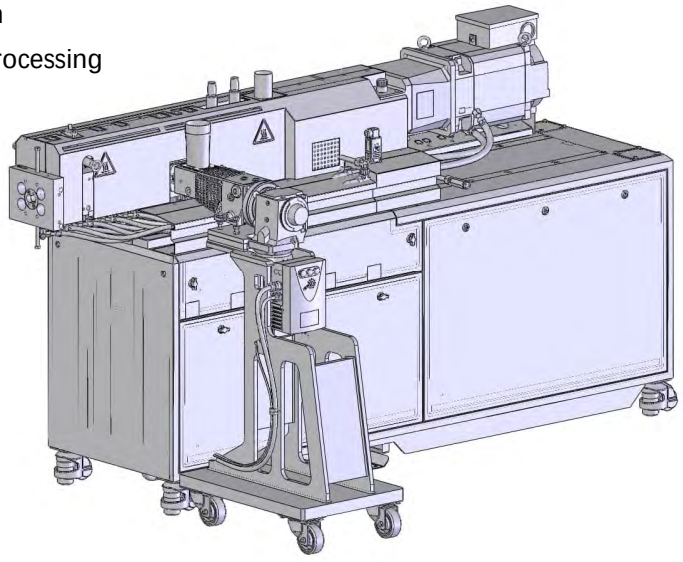


Lab Extruder ZSK 27Mv

with ZS-B 25 sidefeeder

ZS-B sidefeeder in trolley design

Attached to the middle of the processing section



Direct die face cut

7



Discharge for most food extrusion processes

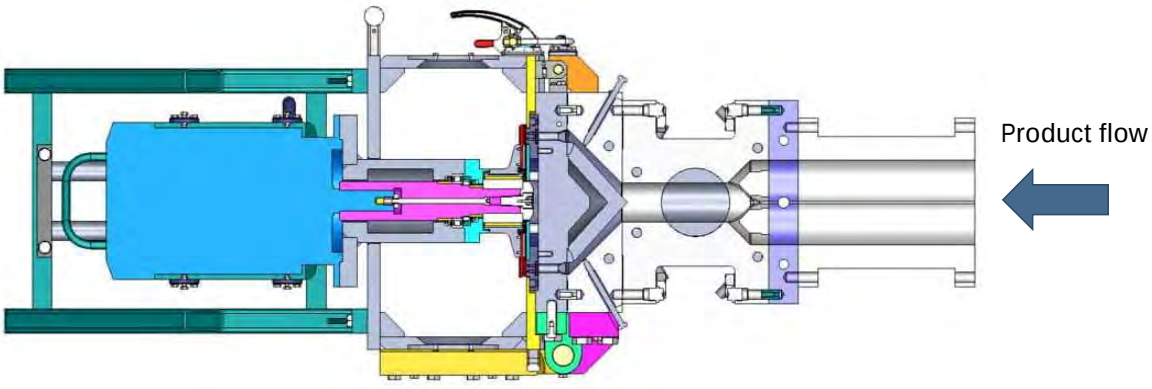
Pelletizer ZGF and Cutter cage SBX

Food pelletizer ZGF

General design

Hinged pelletizer for easy access

Cut view from top

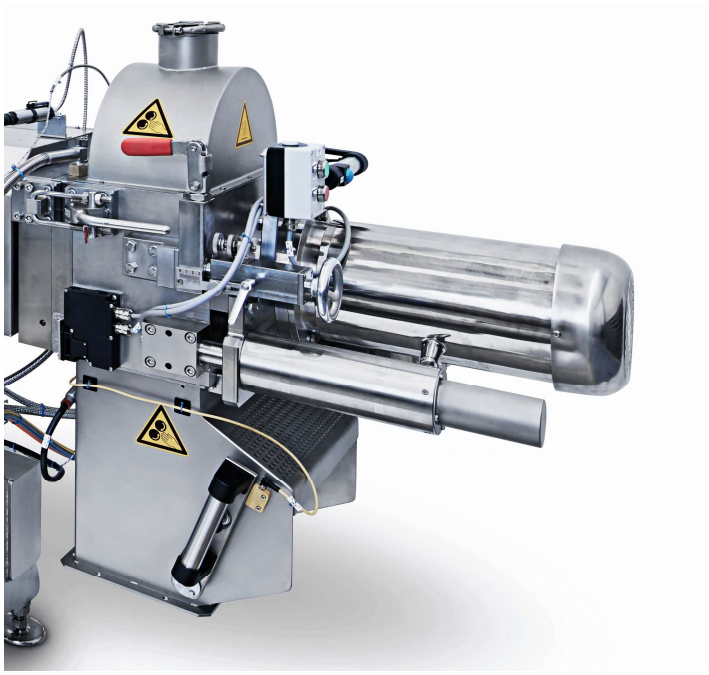


Food pelletizer ZGF

Important features

Easy access to die plate and screws due to hinged design
3-D adjustment of knifes to die plate for very precize cut
Vernier adjustment of knifes/ clearance while running
Sliding pelletizer for easy start up and stop
Full safety sampeling flap
Splash water protected up to IP 65
Different sizes for different products and throughput rates





Pelletizing ZGF 70

Forming by die shape and cutting





Details & Insights about die forming

See presentation on expansion & die design by Christian Hüttner

Pelletizer ZGF 125

Mounted onto ZSK 98

Production of breakfast cereals





Process control system

8



Control cabinet separate from extruder

For better sanitation, apart in separate room

- Control cabinet for extruder and ancillary equipment
- Frequency converter for main drive

HMI close to processing section

Junction boxes at extruder in stainless steel



ZSK 76 Mv in Hygienic Design

Compact extruder

Control cabinet attached to extruder

ZSK 27Mv

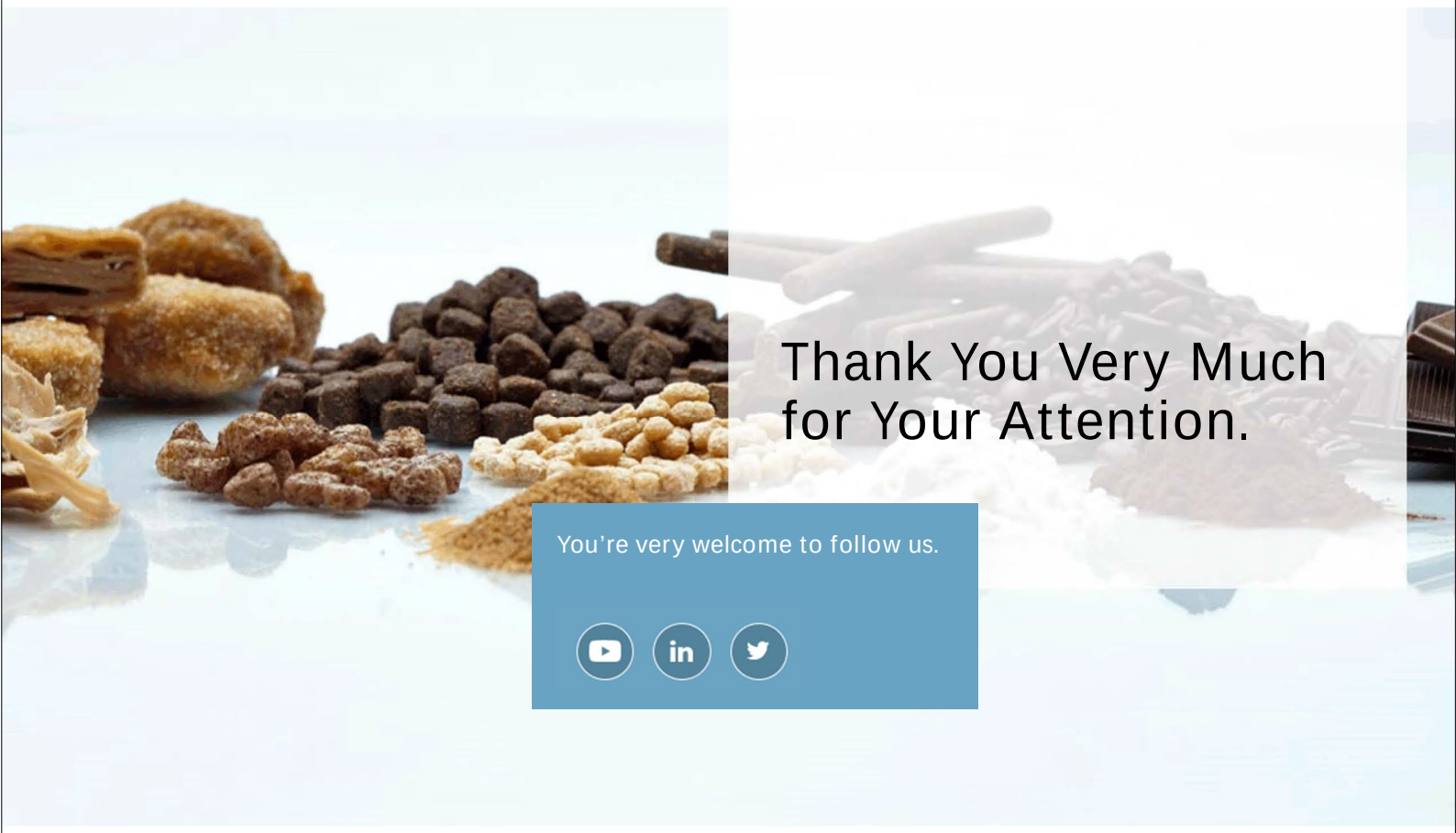
Food and Pharma light version

Control cabinet and frequency converter underneath drive section

Touch screen panel positioned on control cabinet

Ideal for lab purposes and r&d works





Thank You Very Much for Your Attention.

You're very welcome to follow us.



Types, forms and materials of screw elements

Food Extrusion Seminar Intense 2026

Tobias Angres, Process Engineer Food Extrusion

1 General layout of the process section

2 Conveying elements

3 Kneading elements

4 Mixing elements

5 Combining effects

6 Material

General layout of the process section

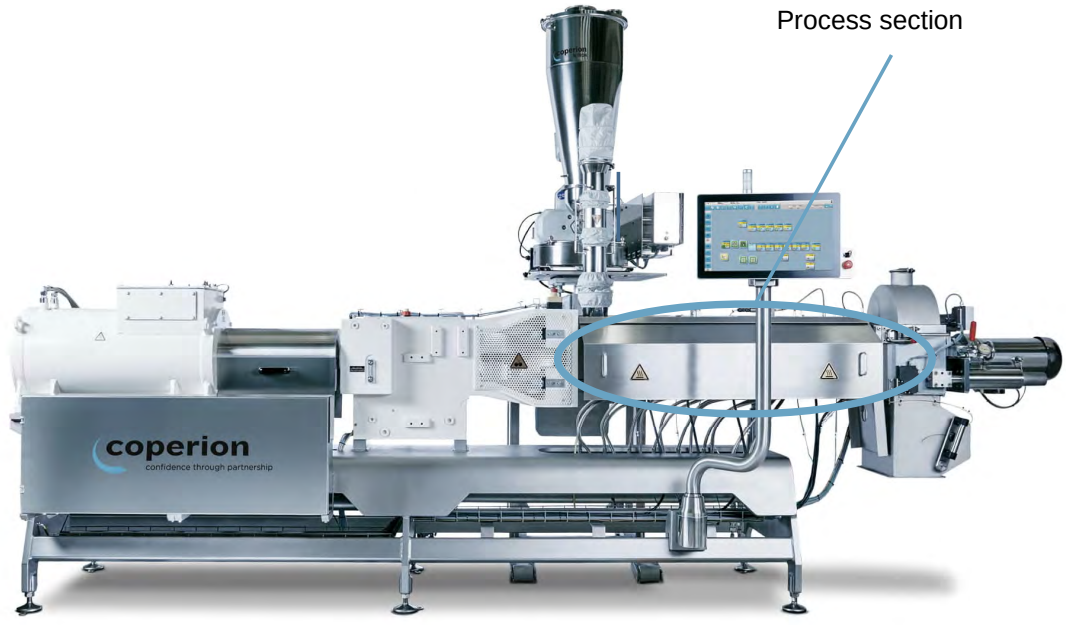
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Types, forms and materials of screw elements

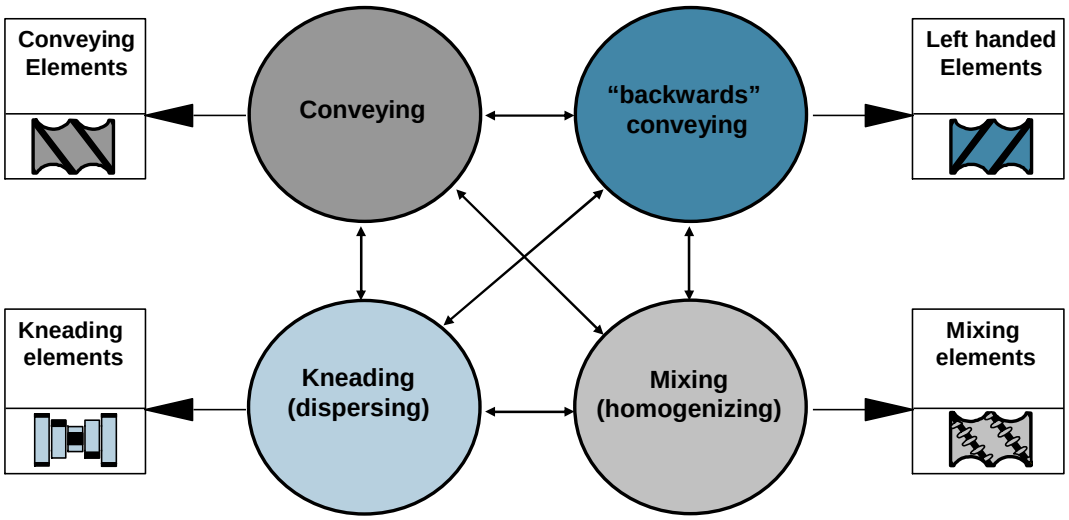
General layout of the process section

General design of the ZSK



General layout of the process section

Basic effects of screw elements



Conveying elements

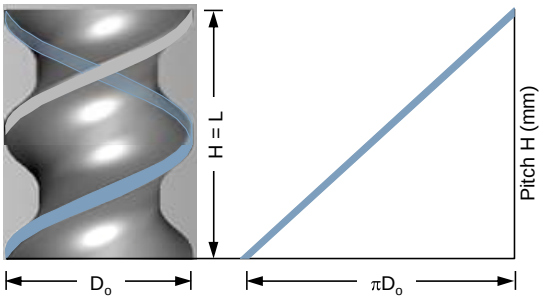
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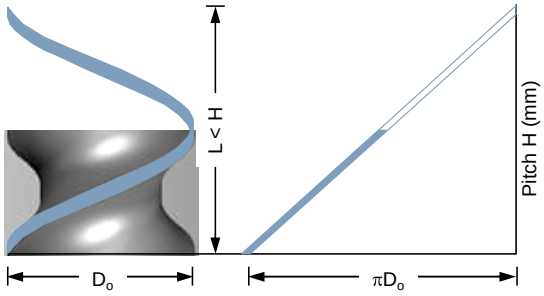
Conveying elements

Definition of pitch and length

Definition Pitch H:
axial length L [mm] required to complete one helix of the screw



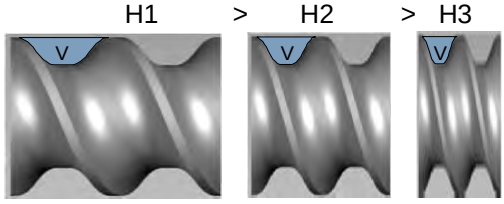
If L<H (e.g. half elements)
the helix has to be completed theoretically in order to get the value of the pitch.



Conveying elements

Free volume in the screw channel

The pitch H of a conveying element determins
- at same cross section of the profile -
the free volume V of the screw channel.



Conveying elements

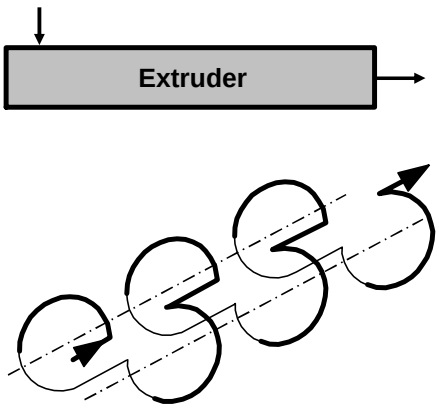
Fill factor



With reduced pitch, the volume in the screw channels is reduced.
As a consequence the fill factor will be increased.

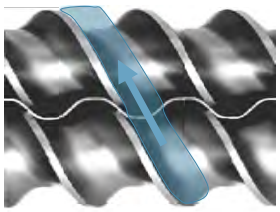
Conveying elements

Product flow



The material moves from one screw to the other (8-shaped flow) as well as in axial direction.

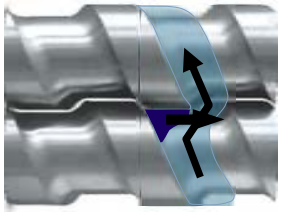
Two-flighted elements



Product mainly moves from one screw to the other one.

This means: reduced transportation of the product in axial direction

Single-flighted elements



Reduced movement of the product from one screw to the other.

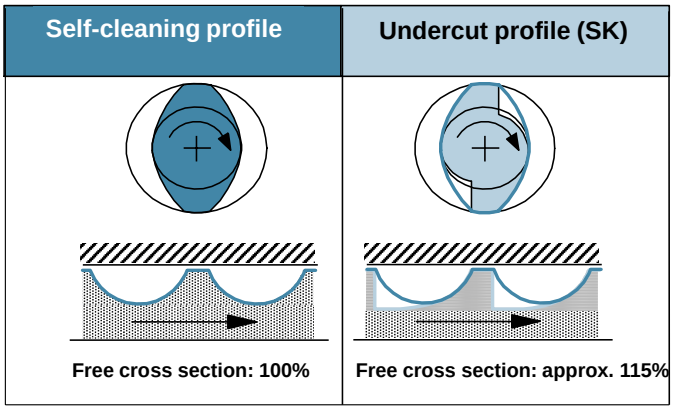
This means: improved transportation of the product in axial direction.

Conveying elements

Increased free volume with special profile

A higher free volume at the same pitch is only possible by giving up the self-cleaning profile.

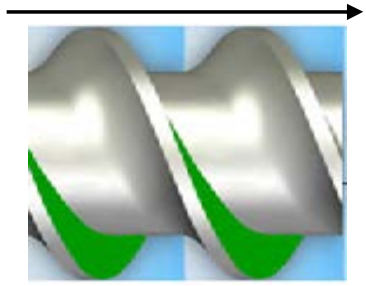
- With sticky products the self cleaning profile might be rebuilt by the product
- In the intermeshing area of the screws there is an open gap which reduces the conveying efficiency

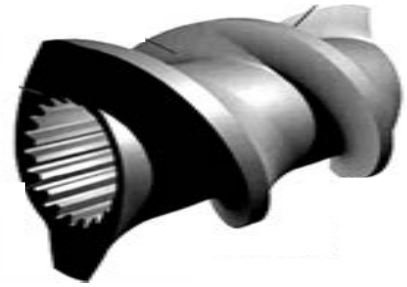


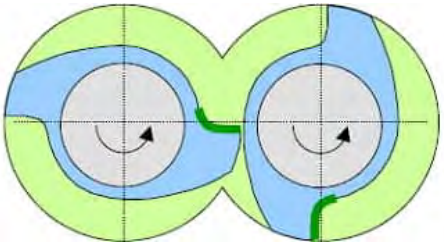
Conveying elements

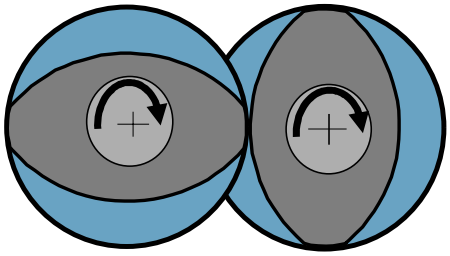
undercut conveying elements

Direction of flow



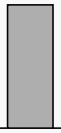
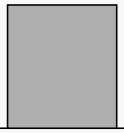
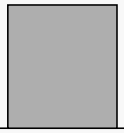
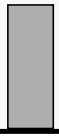






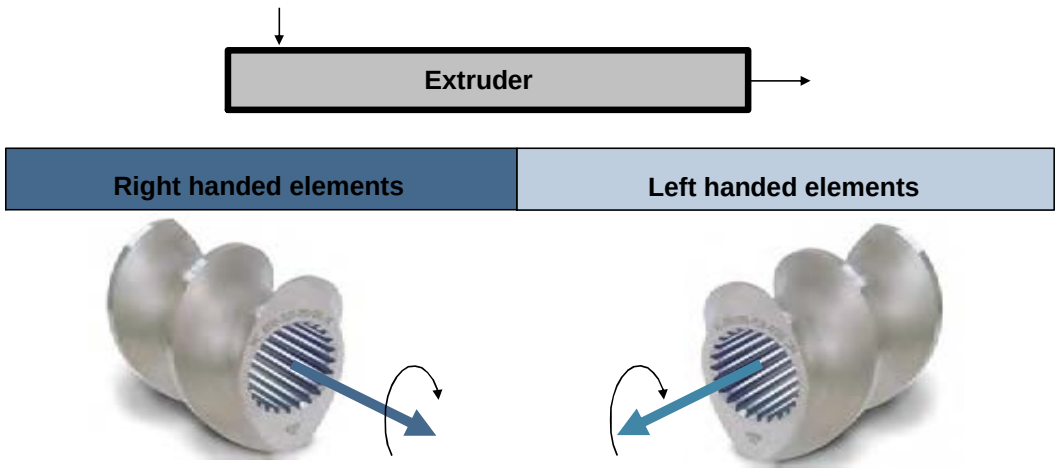
Conveying elements

Free volume and conveying efficiency

Type of element	Free volume	Conveying efficiency
1-flighted element 		
Standard element 		
Undercut element 		

Conveying elements

Conveying direction



Conveying direction of the element
same as
direction of product flow in the extruder

Conveying direction of the element
contrary to
the direction of product flow in the extruder

Kneading elements

3

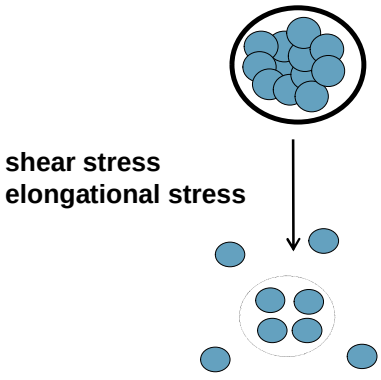


Types, forms and materials of screw elements

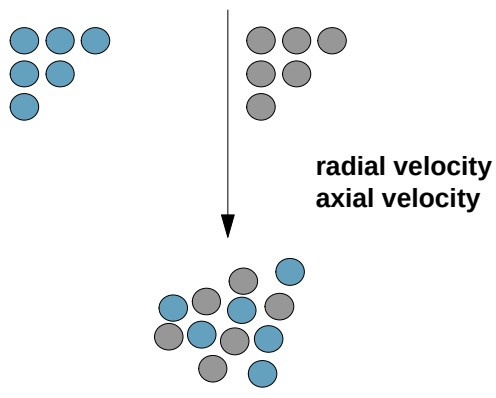
Kneading elements

Mixing mechanisms in twin screw extruders

Dispersive Mixing
=
Break up of agglomerates and aggregates

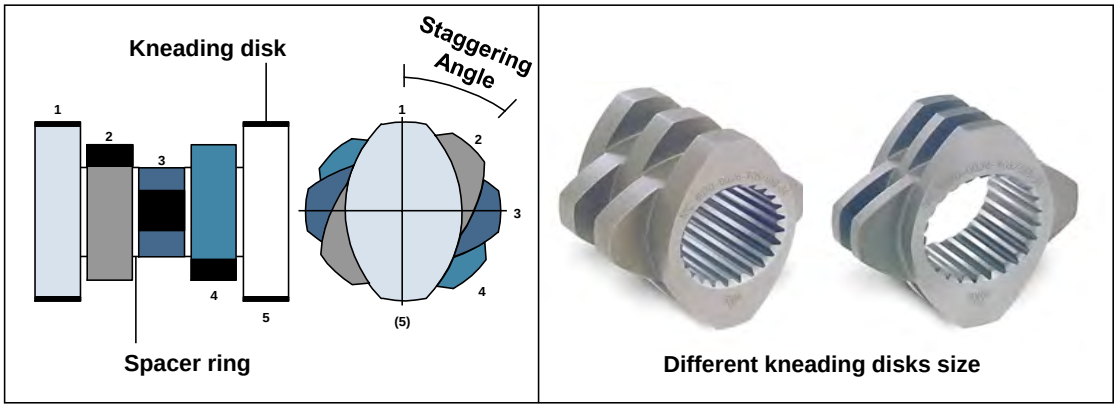


Distributive Mixing
=
Distribution of primary particles



Kneading elements

Overview

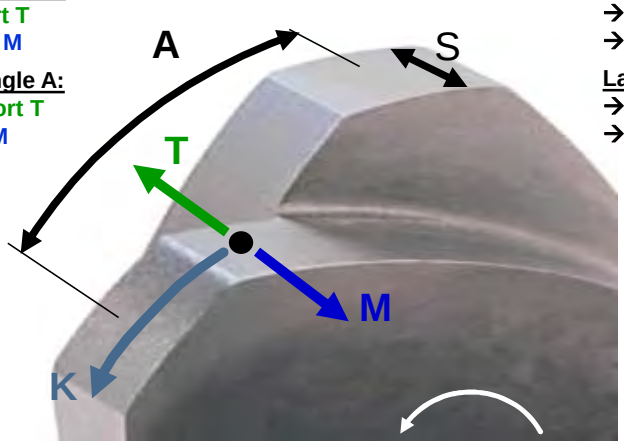


Kneading elements

Working principle

Large staggering angle A:
→ reduced transport T
→ improved mixing M

Small staggering angle A:
→ improved transport T
→ reduced mixing M



Small disk S:
→ improved mixing M
→ reduced kneading K

Large disk S:
→ reduced mixing M
→ intensive kneading K

A... Staggering angle
S ... Thickness of the disk
T ... Transport
M ... Distributive mixing
K ... Dispersive mixing/kneading

Kneading elements

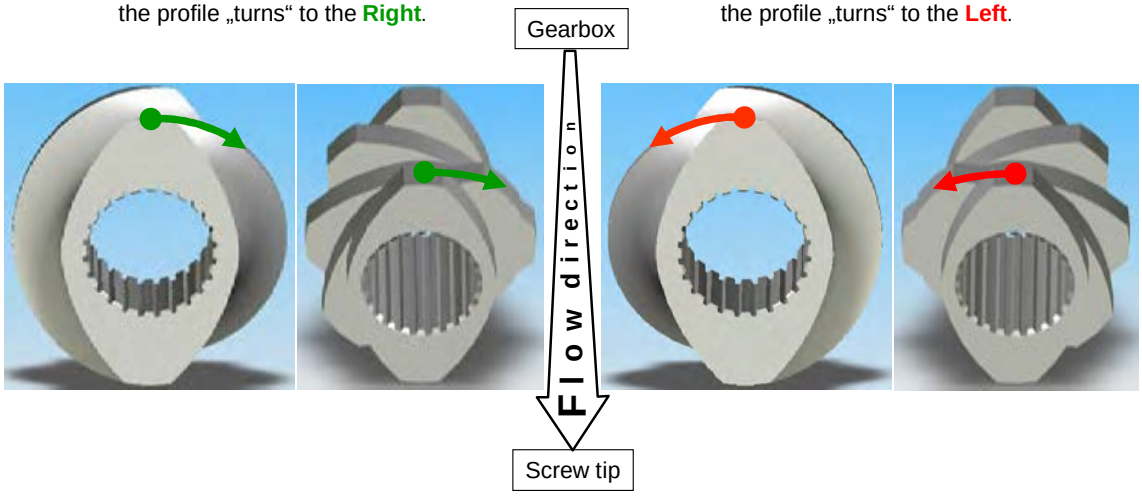
Direction of pitch

Right handed elements

Looking towards the cross section of an element the profile „turns“ to the **Right**.

Left handed elements

Looking towards the cross section of an element the profile „turns“ to the **Left**.



Kneading elements

Direction of product transportation

right handed element	neutral element	left handed element



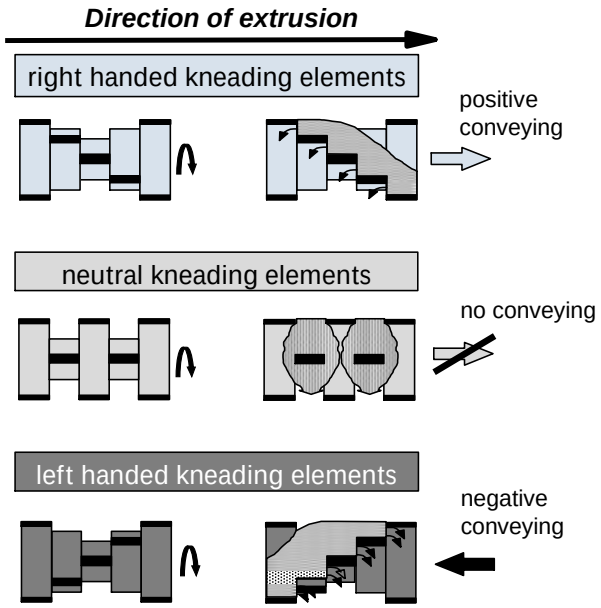
Material transport
same as
Process direction

No material transport

Material transport
contrary to
Process direction

Kneading elements

Product flow in kneading elements



- staggered in direction of flow

- neutral (90°) staggered kneading discs
- have to be **overrun**.

- staggered <u>contra</u> direction of flow have to be **overrun**.

Kneading elements

Working principle

Influence of the disk thickness **Influence of the staggering angle**

Type of Element	Mixing effect	Dispersion effect (shear)	Conveying effect	Type of Element	Mixing effect	Dispersion effect (shear)	Conveying effect
X°							
X°							

Mixing Elements

4

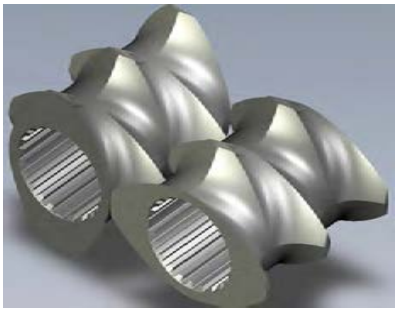


Types, forms and materials of screw elements

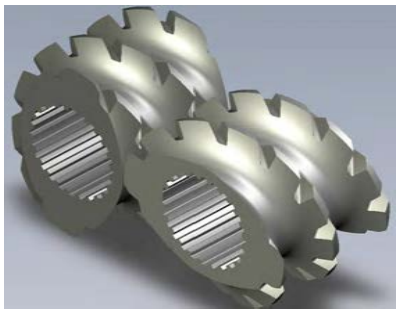
Mixing elements

Distributive mixing

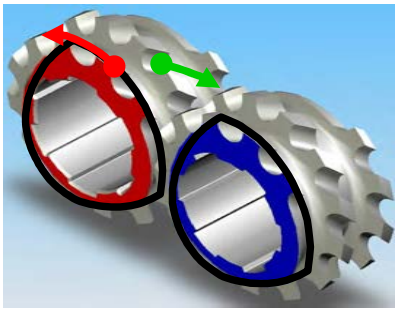
Igel



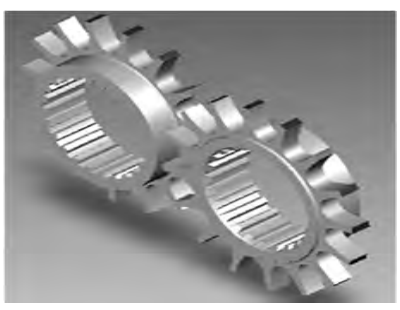
SME



ZME



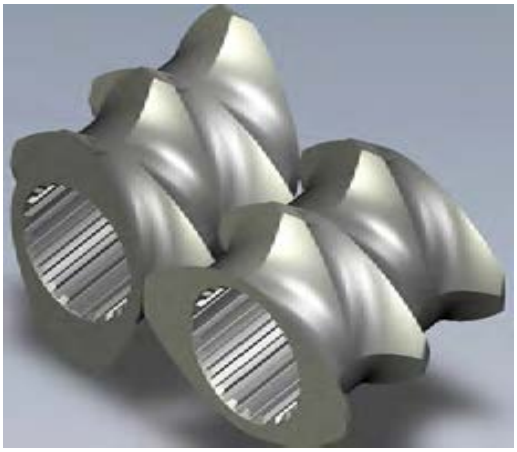
TME

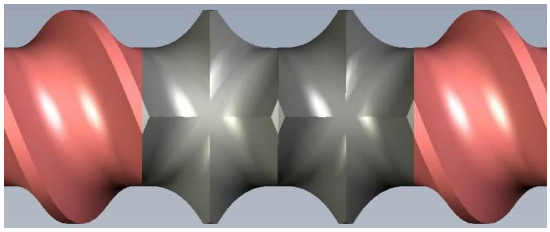


Mixing elements

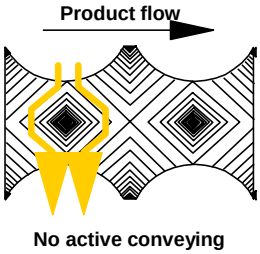
Igel

- Right-handed conveying profile and a superimposed left-handed profile





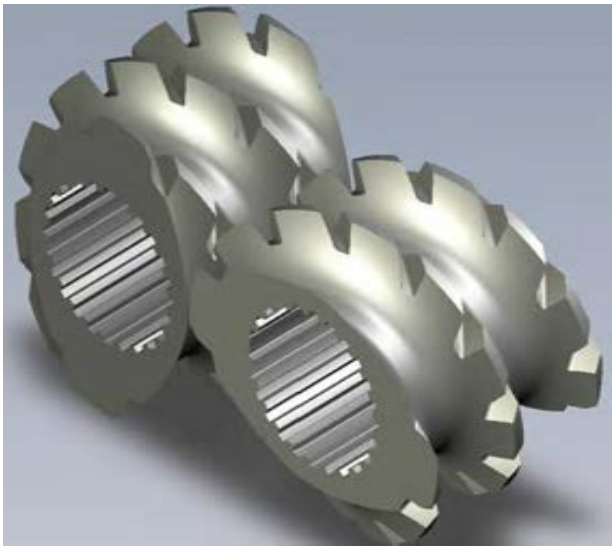
Upstream, in between and downstream:
no transition elements or spacer required .

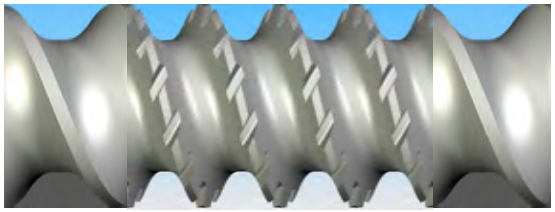


Mixing elements

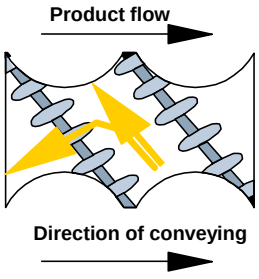
SME

- Right-handed profile and superimposed left handed profile with lower flight depth





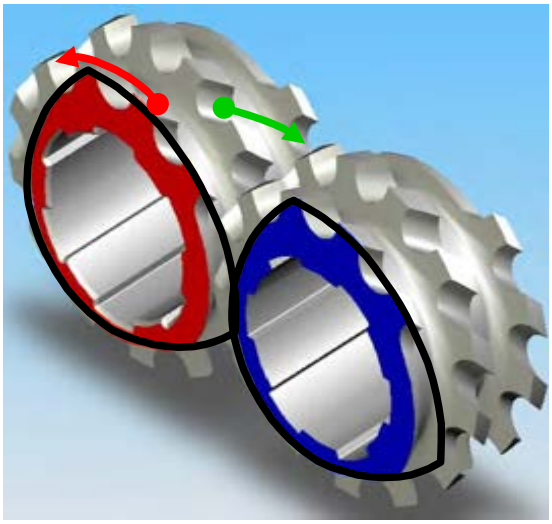
Upstream, in between and downstream: no transition elements or spacer required.

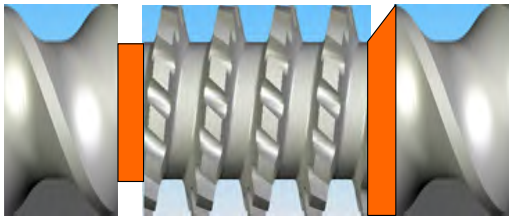


Mixing elements

ZME

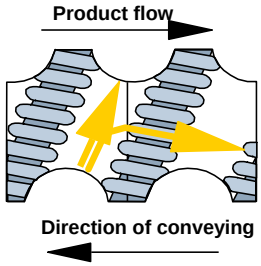
- Left-handed single-flighted conveying elements with superimposed right-handed multi-flighted profiles with low flight depth





Upstream and downstream: transition elements or spacer required.

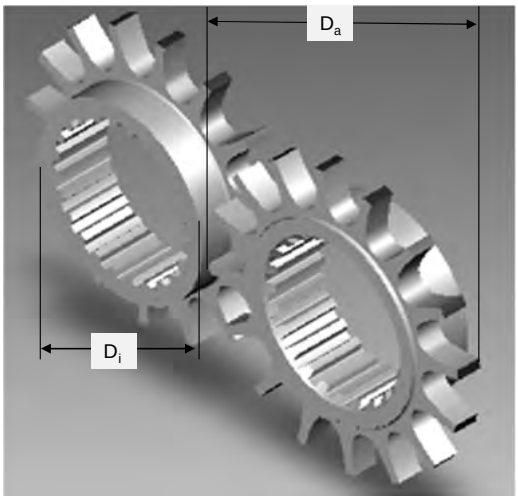
In between: no spacer required.

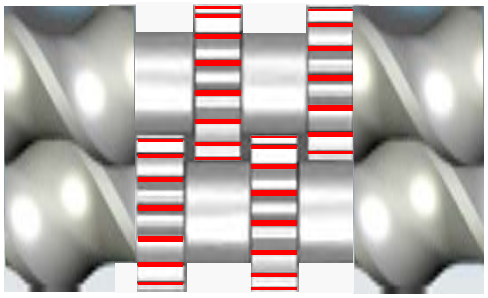


Mixing elements

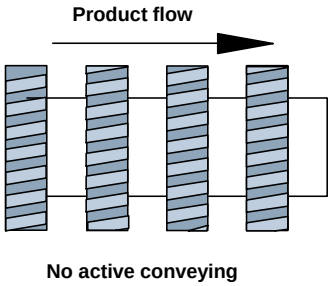
TME

- Neutral elements. Cylindrical ring (D_i) combined with a gear-wheel (D_a)
- Teeth can have a neutral-, left- or right-handed angle
- TME-elements are mounted asymmetrically



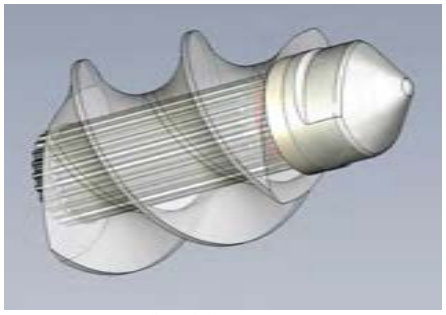


TME-elements have an integrated spacer on both sides
→ Correct transition between the elements is given
→ No additional transition elements required

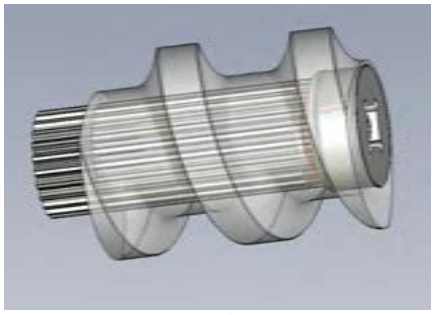


Mixing elements

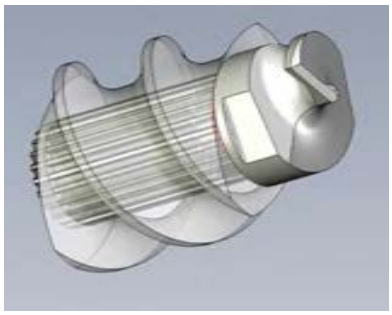
Special element: Screw tip



standard tip – 90°



recessed tip



mixing tip

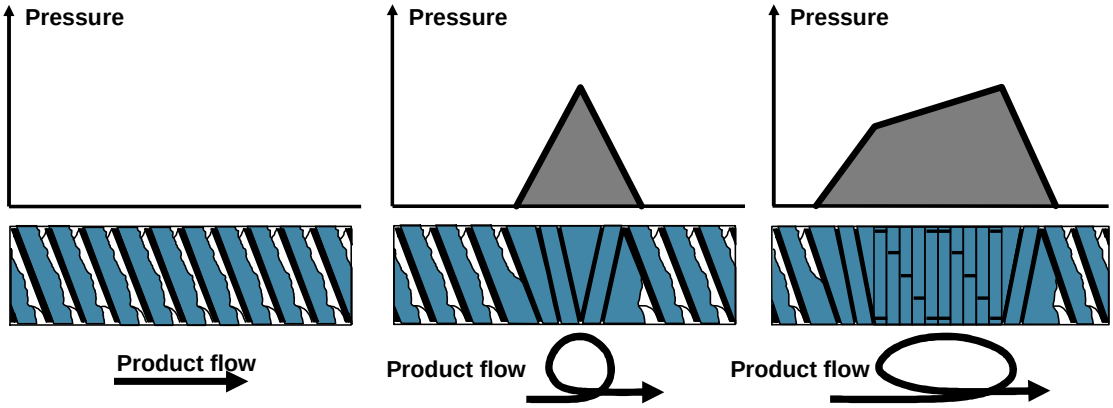
Combining effects

5



Combining effects

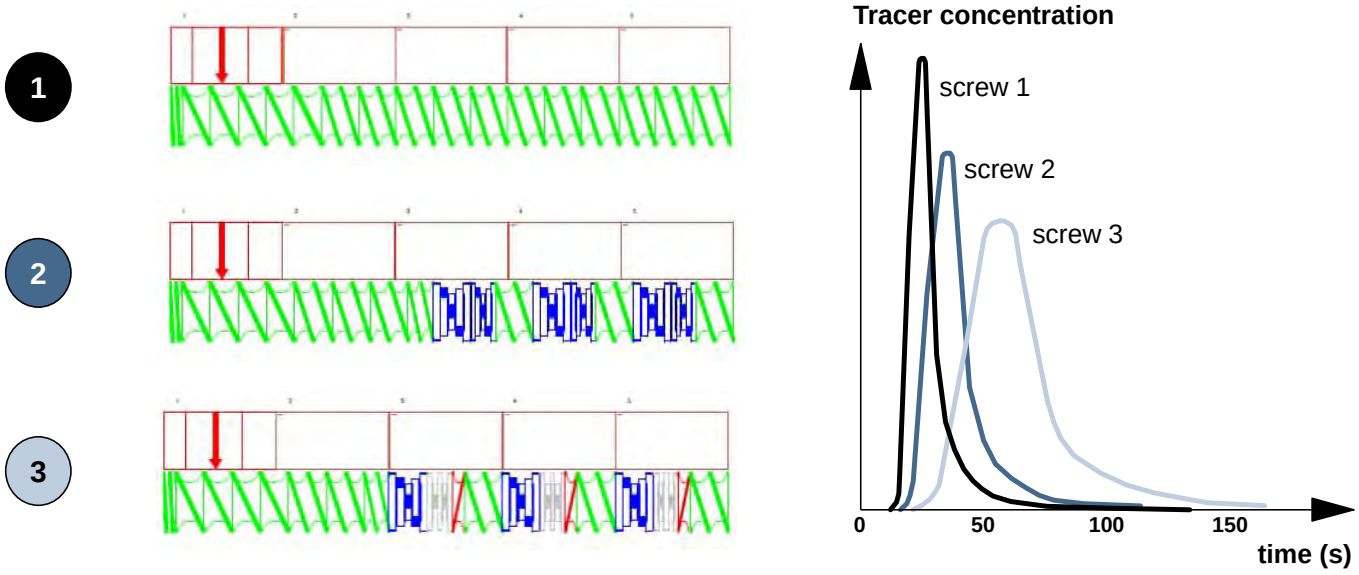
Influence of screw set up on pressure



Right handed elements are
Partly filled with product.
→ This section is pressureless.

Combining effects

Influence of screw set up on residence time



Material

6



Possible materials for screw elements

Material

Overview Coperion

8026 - 25 . 2 1 - 036 / 036 - 36

Screw diameter

Material of construction

00	Nitrated steel
05	Cr-steel
	Composite materials
15	Wear resistant
25	Corrosion resistant

Number of flights, direction

1	1-flighted, right
2	2-flighted, right
3	3-flighted, right
4	1-flighted, left
5	2-flighted, left
6	3-flighted, left
9	Special design

Length of element

Pitch of the conveying elements
(Kneading blocks or special design see below)

Profile

1	Self cleaning conveying element
2	Element without self cleaning profile
6	Kneading element

Kneading block: 4 0 5

Staggering angle

3	30°
4	45°
6	60°
9	90°

No. of disks

Special design: XXX

XXX	Element
373, 388 or 393	SME
369 or 397	ZME
521 / 522	KB 3lb-N
935 / 935, 978 / 988	SF-N

Connection screw shaft / element

00, 01, 02	Standard key (0°)
66, 67, 68	6-key
24, 34	multiple spline (Mv, Mc)
26, 36	multiple spline (Mv, Mc) 3.1

More numbers for special profiles are available



Assembly of Screw Elements

Food Extrusion Seminar Intense 2026

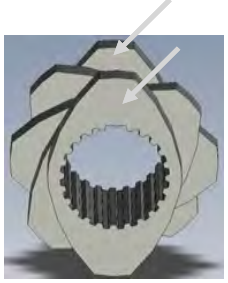
Tobias Angres, Process Engineer Food Extrusion

Screw Elements

Cross Section

ZSK Standard Elements

Cross section of both sides of the screw element in the same angle



Exceptions

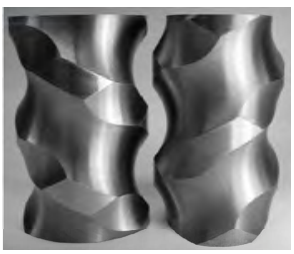
A-Kneading-blocks

Transition Elements

Special Elements



A-KB



Special Mixing Element

Screw Shafts

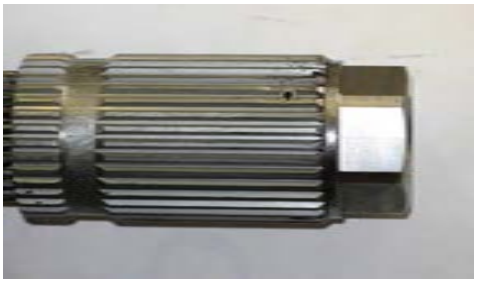
Evolute Spline with Marks

ZSK shaft with 24 teeth (ZSK 18: only 12 teeth)

- 0-Position marks on both ends of shafts
- Allow threading in correct position
- Allow positioning and fixing the screws into the screw shaft coupling in correct position



Screw shafts with 0-position (Die side)



Screw shaft with 0-position (Coupling side)

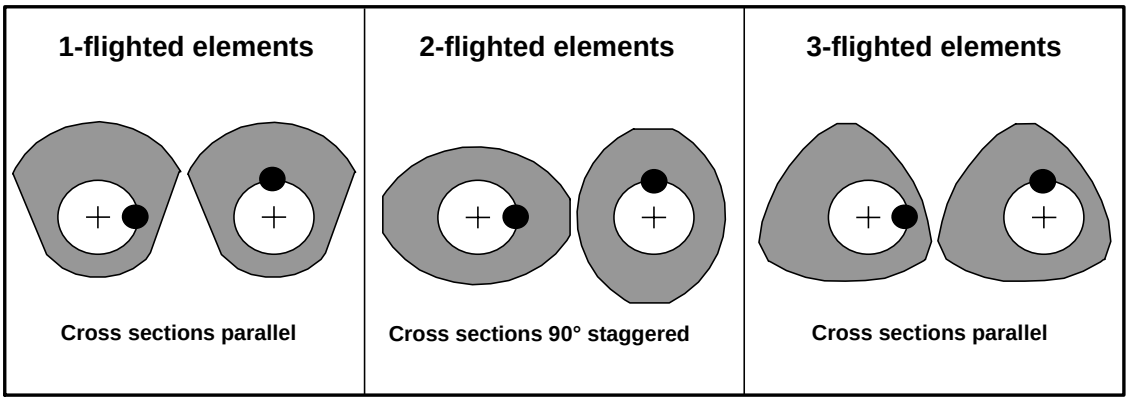


Lantern with Screw Shaft Coupling

Assembly of Screw Elements

Running Position of Screw Elements

Running Position

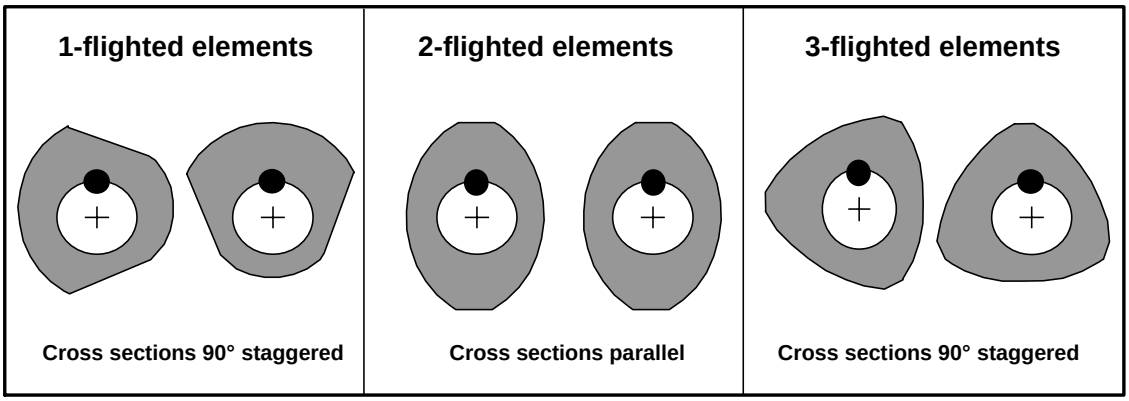


Assembly of Screw Elements

Running Position of Screw Elements

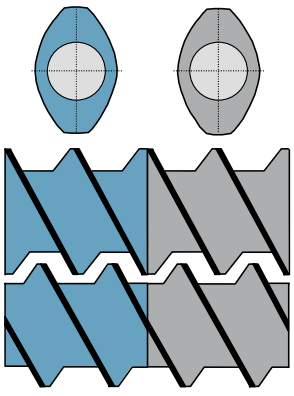
Assembly Position

Marks on both screw shafts positioned side by side



Installation of Screw Elements

Elements with Identical Cross Sections

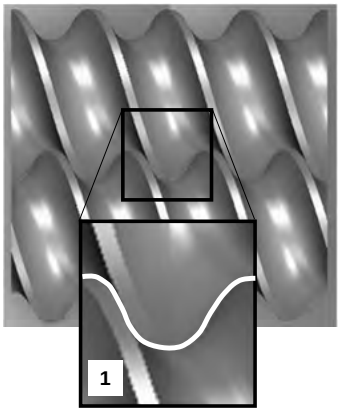


Screw elements with identical cross section are installed without any offset, regardless of the direction or the element type

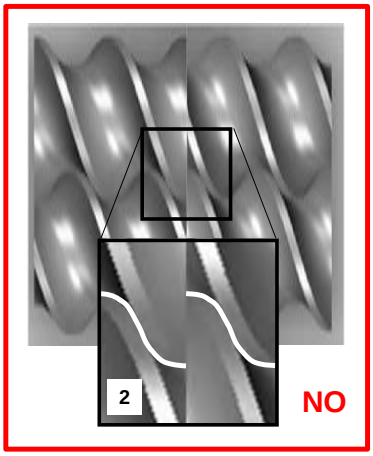
⇨ The transition is **continuous.**
⇨ There is sufficient **axial clearance.**

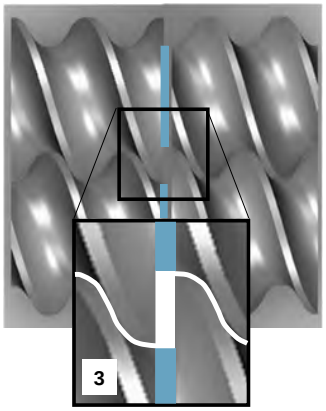
Installation of Screw Elements

Off-set Installation of Conveying Elements



Conveying elements, having the identical cross section, are installed without any off-set (1).



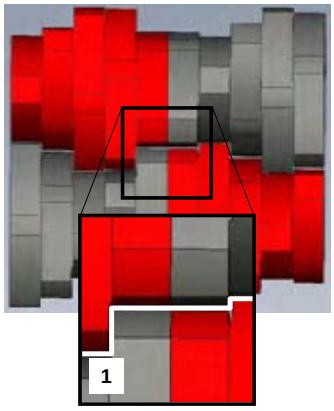


If these elements have to be installed in an off-set manner (2) due to any reason, a **spacer ring** has to be installed (3)

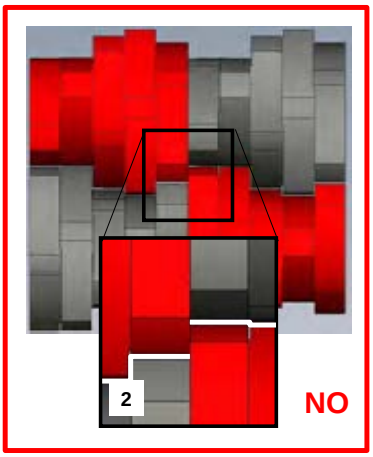
➡ The transition is **not continuous**, but the **axial clearance** is given by the spacer.

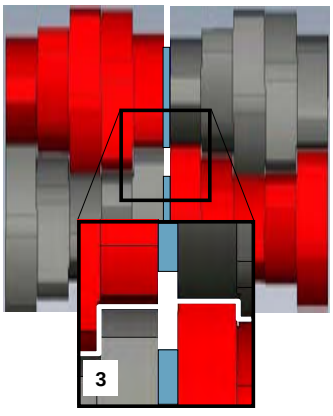
Installation of Screw Elements

Off-set Installation of Kneading Elements



Kneading elements, having the identical cross section, are installed without any off-set (1).



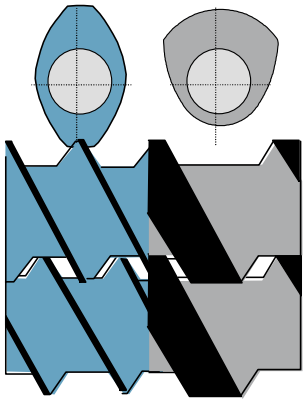


If these elements have to be installed in an off-set manner (2) due to any reason, a **spacer ring** has to be installed (3)

➡ The transition is **not continuous**, but the **axial clearance** is given by the spacer.

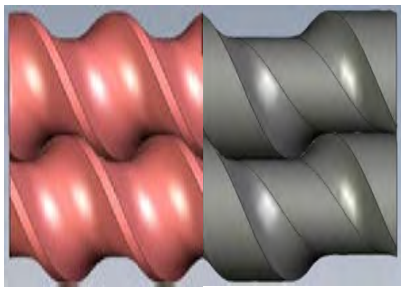
Installation of Screw Elements

Elements with Different Cross Sections



NO

There is **no axial clearance**

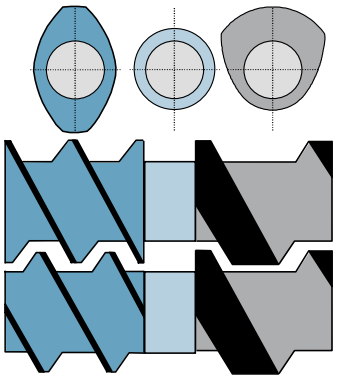


When elements with different cross sections have to be combined...

➡ The transition is **not continuous**. There is **no axial clearance**.
The screw will touch each other which will lead to mechanical damages.

Installation of Screw Elements

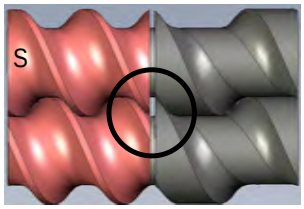
Elements with Different Cross Sections

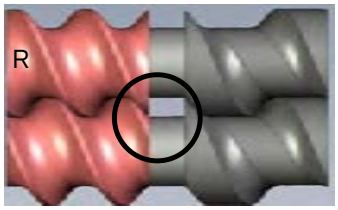


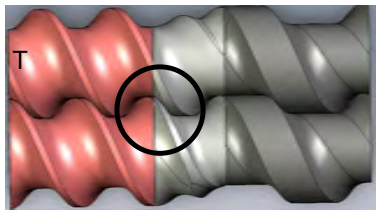
Axial clearance is existing

Between elements with different cross sections a **spacer (S)**, a **ring (R)** or a special **transition element (T)** has to be installed.

➡ The transition remains **not continuous**.
➡ Nevertheless it is sufficient **clearance** available





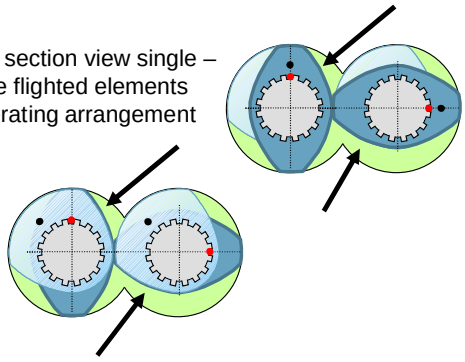


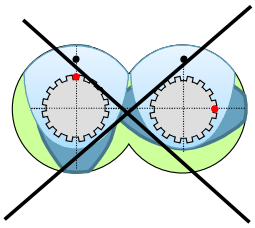
Transition of Different Cross Sections

From Single to Two-flighted Elements

Best solution with transition-element
If without: one flange should continue
45° stagger arrangement of elements (3 teeth of spline shaft - if shaft has 24 teeth)
Spacer ring required

Cross section view single – double flighted elements in operating arrangement

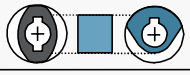
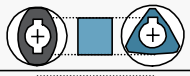
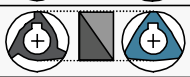
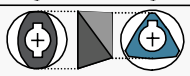
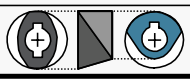




Mechanically correct arrangement
BUT Process vise not good

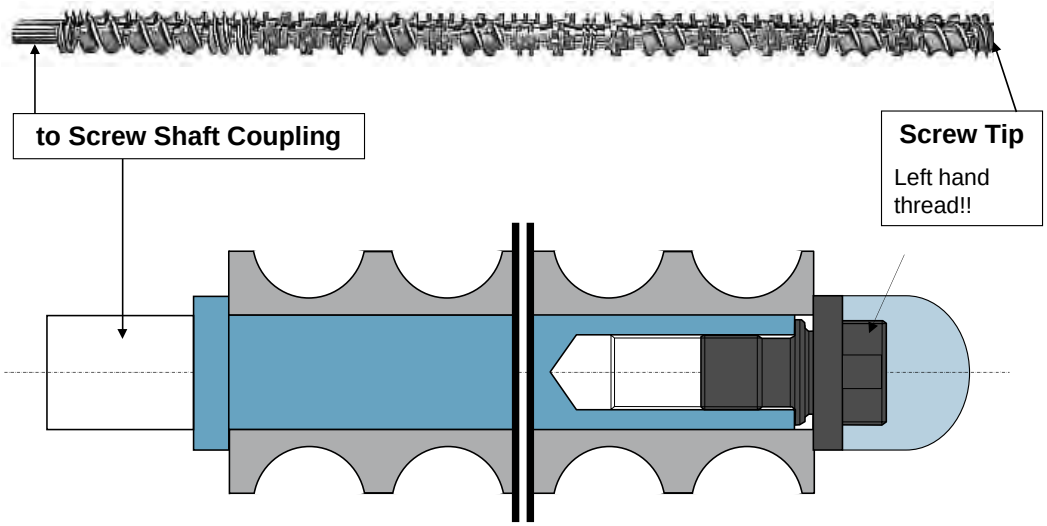
Overview Transitions of Screw Elements

Possibilities in Threading

Type of element	Self cleaning	Installation		Process function
		Position of cross section	Example	
Spacer (1 - 3 mm, depending on ZSK-size)	no		1-flighted <--> 2-flighted 1-flighted <--> 3-flighted	none
	no		Between kneading disks (part of kneading blocks)	none
Distance ring (15 - 60 mm, depending on ZSK-size)	no		2-flighted <--> 1-flighted 3-flighted <--> 2-flighted	Distribution of product flow
	no		2-flighted screw element to 3-flighted kneading block	Distribution of product flow
Transition element (continuous transition from one profile to the other)	partly		Undercut to standard (self-cleaning) profile	Continuous transition
	partly		First / last kneading disk of a 3-flighted kneading block.	none
	yes		2-flighted <--> 1-flighted 3-flighted <--> 2-flighted	Distribution of product flow

Assembly of Extruder Screw Shafts

Screw assembly, Screw Tip





Process Opportunities in Food Extrusion

Food Extrusion Seminar Intense 2026

Fabian Specht, Senior Process Engineer

1 Elements of the Process Section Twin Screw Food Extruders

2 Process Opportunities Mechanical

3 Process Opportunities Thermal

4 Process Examples and Applications

Elements of the Process Section

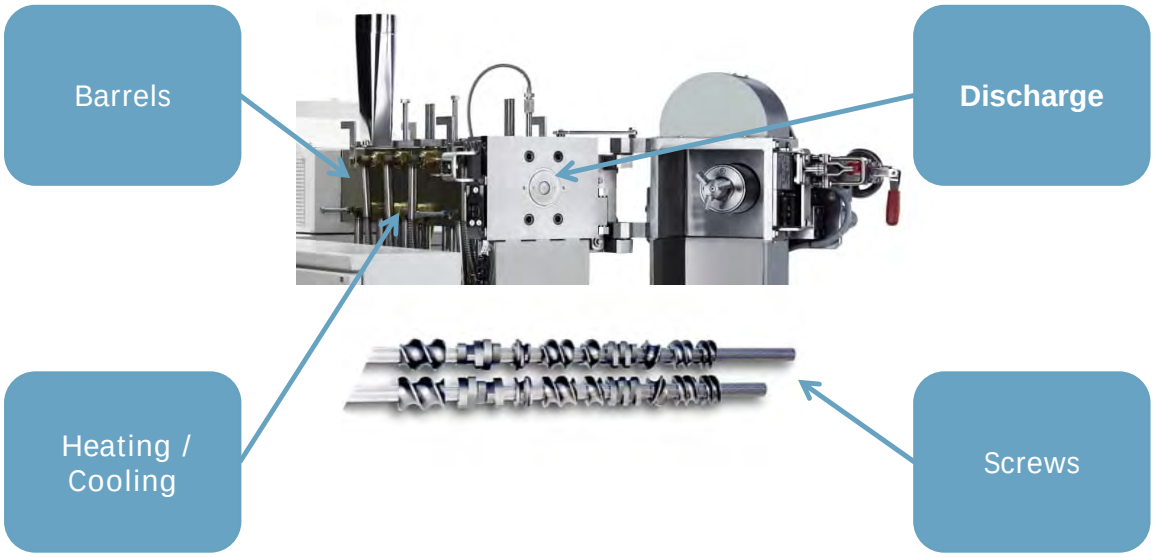
1



Twin Screw Food Extruders

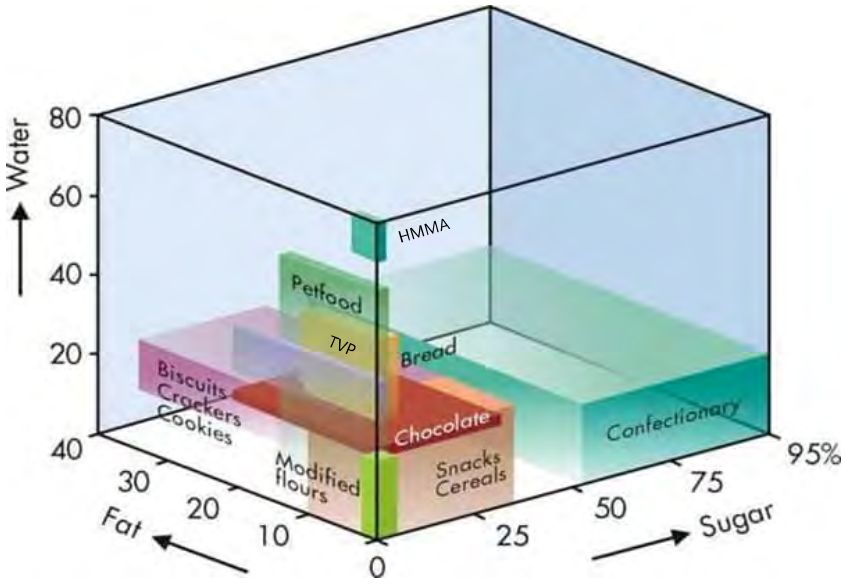
Twin Screw Food Extruders

High Flexibility due to Modular Design



Extruded Food Products

Extrusion Applications across all Recipe Categories



Process Opportunities

2



Mechanical

Mechanical Process Opportunities

Screws and Barrels

Rotating Screws Shafts with Screw Elements

- Conveying, Kneading, Mixing, Melting, Cooking
- Continuous Processing
- Processing of High Viscous Masses
- Mechanical Energy Input into Product



Barrels

- Defined Process Volume
- Kneading Under Pressure
- High Local Shear Rates



Mechanical Process Opportunities

Effects on Raw Materials

Change of Physical State

- Hydration when Water is Present
- Plasticizing
- Forming of a Dough or Melt



Mixing

- Distributive
- Dispersive

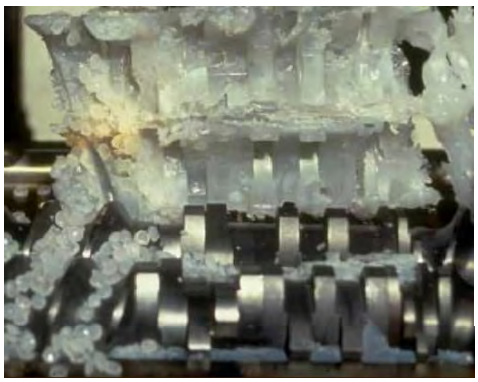
Molecular Degradation / Denaturation

- By Mechanical Forces
- By Dissipated Heat

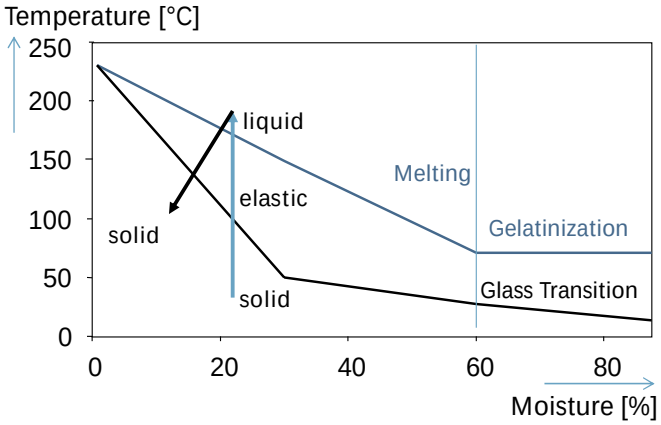


Mechanical Process Opportunities

Effects on Raw Materials



Plasticizing in Kneading Elements



Starch Melting During Extrusion

Diagram by Yaku

Mechanical Process Opportunities

Product Discharge

Flow Through a Resisting Die

- Pressure Build-up
- Mechanical Energy Input
- Basis for Product Expansion

Texturization

- Down-stream of the Screws
- Flow Characteristics Determine Texture
- Supported by Cooling

Forming Through Die Shape

Cutting



Process Opportunities

3



Thermal

Thermal Process Opportunities

Characteristics

Additional Thermal Energy Input is Possible

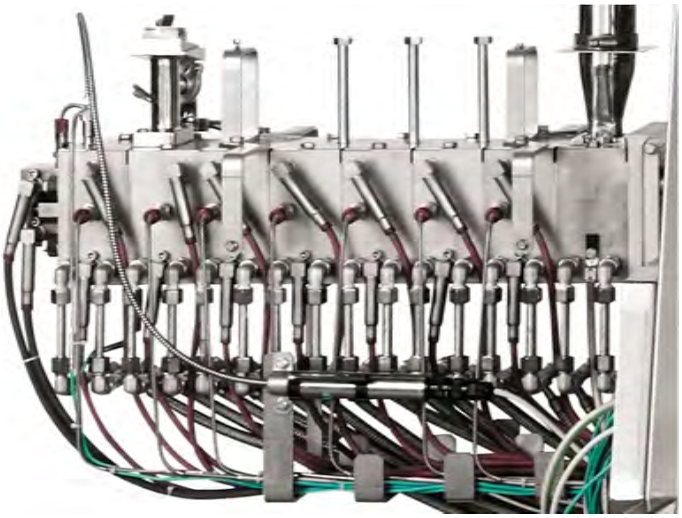
- Barrel Heating
- Direct Steam Injection
- Preconditioning

Cooling

- Barrel Cooling
- Die Cooling
- Screw Shaft Cooling

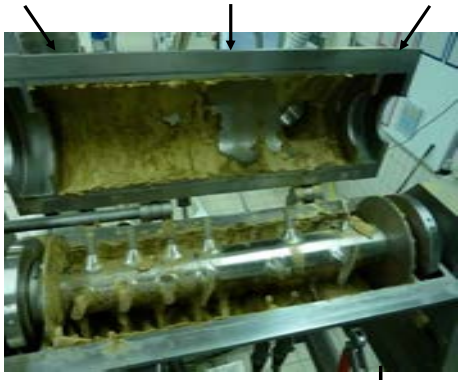
Degassing

- Removal of Water, Steam, Volatiles
- Removal of Thermal Energy



Thermal Process Opportunities

Preconditioning - Theory



Upstream introduction of heat and moisture

↓

Increased gelatinisation

↓

Less mechanical energy input in extrusion

Additional residence time

↓

Time limited processes possible

↓

e.g. coarse particle hydration

Thermal Process Opportunities

Preconditioning – is it required?

What is possible in the ZSK MEGAvolume?

- Direct steam injection of >10 % steam
  low shear, high thermal energy input
- Longer residence times 1-3 minutes possible
- Mixing of various ingredients



Two stage set-up for enzymatic reaction

ZSK Twin Screw is preferred to a Preconditioner

Different approach – but similar results
Less equipment
Less cleaning efforts

Process Examples and Applications

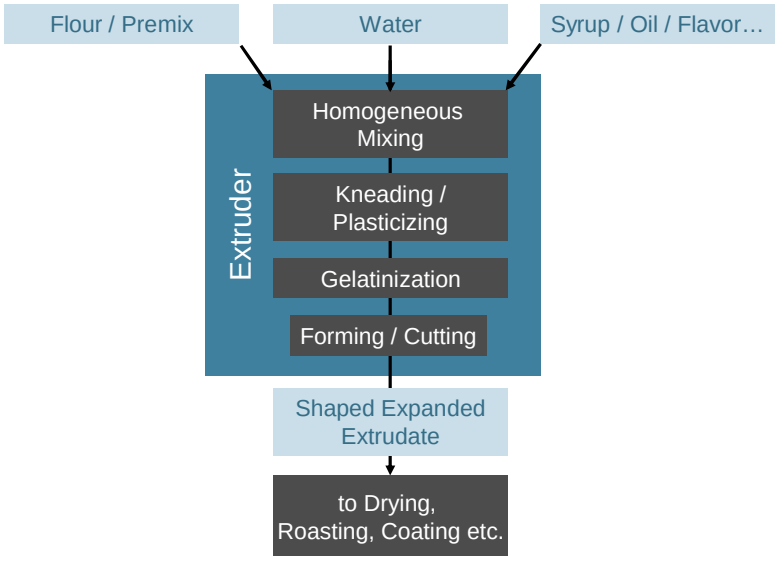
4



Intermediate and
End Product Examples

Direct Expanded Breakfast Cereals

Starch Based Extrusion

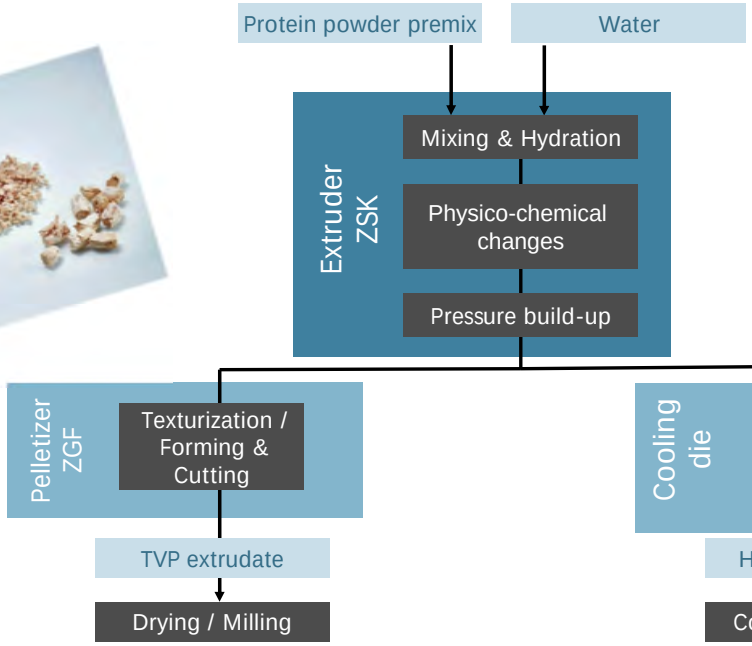




Texturized proteins

TVP & HMMA extrusion process

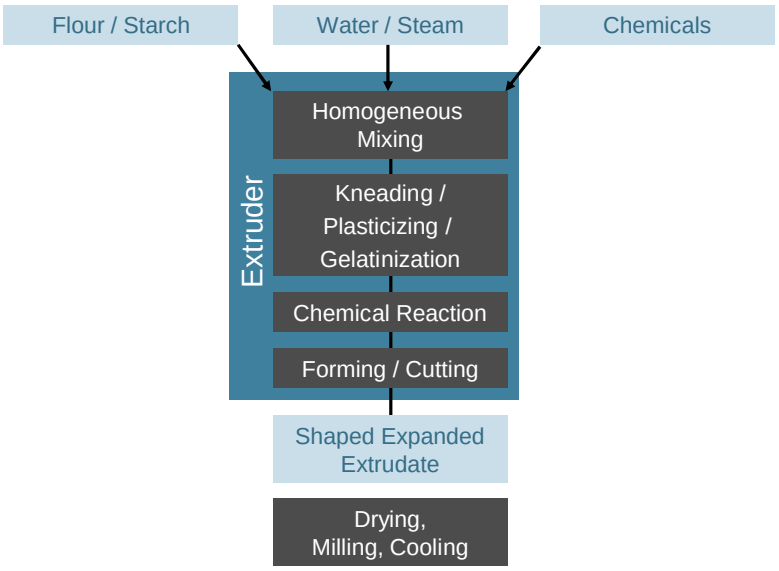






Starch Modification

Extrusion Cooking combined with a Chemical Reaction

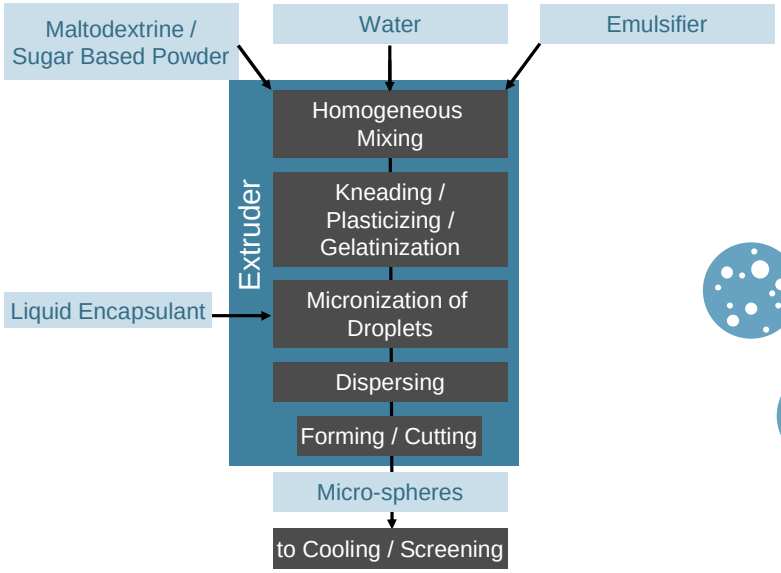


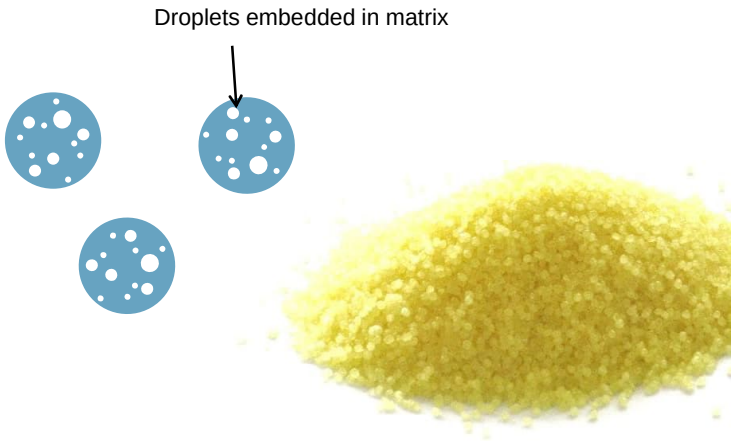




Flavor Encapsulation

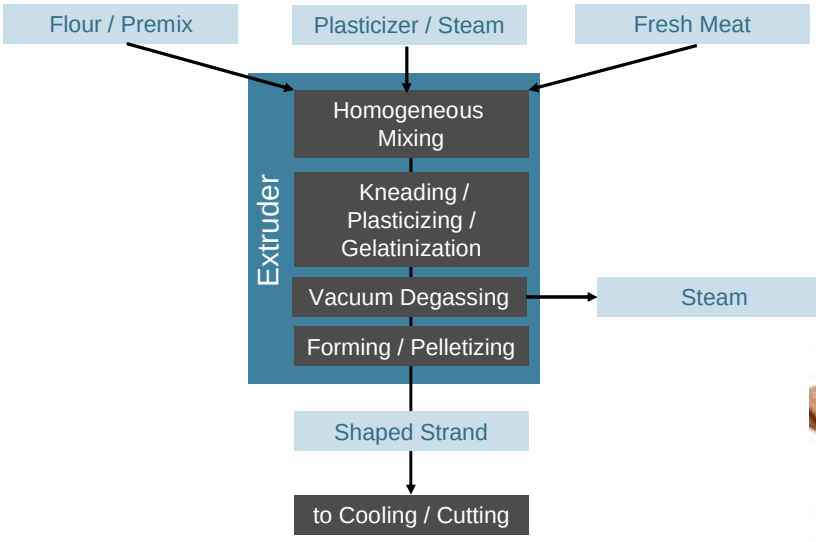
Dispersion / Emulsion of Flavor Droplets





Pet Treats

Process with Steam Injection and Degassing





Reaction Processes

Characteristics and Opportunities

- Adjustment of
  - Temperature
  - Moisture Content
  - Residence Time
- Addition of Reactants
  - In the Desired Ratio
  - At the Desired Process Section
- Intensive Mixing
- Continuous Reaction

Twin Screws are a Versatile Continuous Reactor

Physical and Chemical Reactions are Possible



Maillard Reaction

A Chemical Reaction Common in Almost any Food Product

Colour, Flavor Formation

- Cereals, Roasted malt, Cocoa Beans or Coffee Beans ...

Confectionary products

- Caramel Candy, Chocolate Crumb, Sugar Caramelization = *Pyrolytic Reaction!*

Roasted Flavors

- Onion, Garlic, Yeast ...

Instant Gravy Products

Extruded Flavours

- Tailor-made Reaction
  Different Meat Type Flavors
  Beef, Chicken, Pork ...



Cocoa crumb

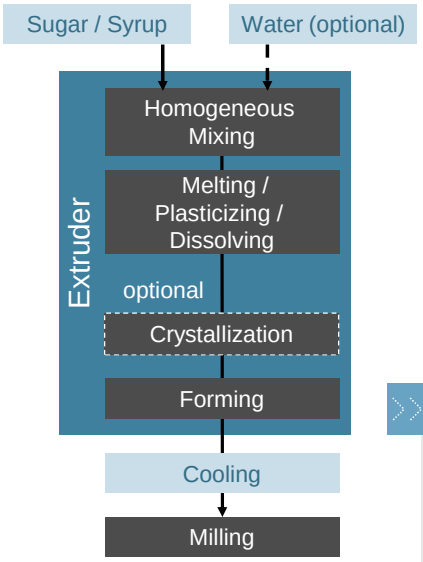


White crumb



Sugar Modification

A Physical Reaction to Achieve Tailor-Made Properties



Possibility to influence

- Particle size
- Molecular Order
- Solubility
- Hygroscopicity



Crystalline



Conclusion

Twin Screw Extrusion Offers lots of Process Opportunities

Modular Design
Highest Flexibility

Highly Customizable
For Your Process Task

Process Know-how
Process Support, Trials, Scale-up...

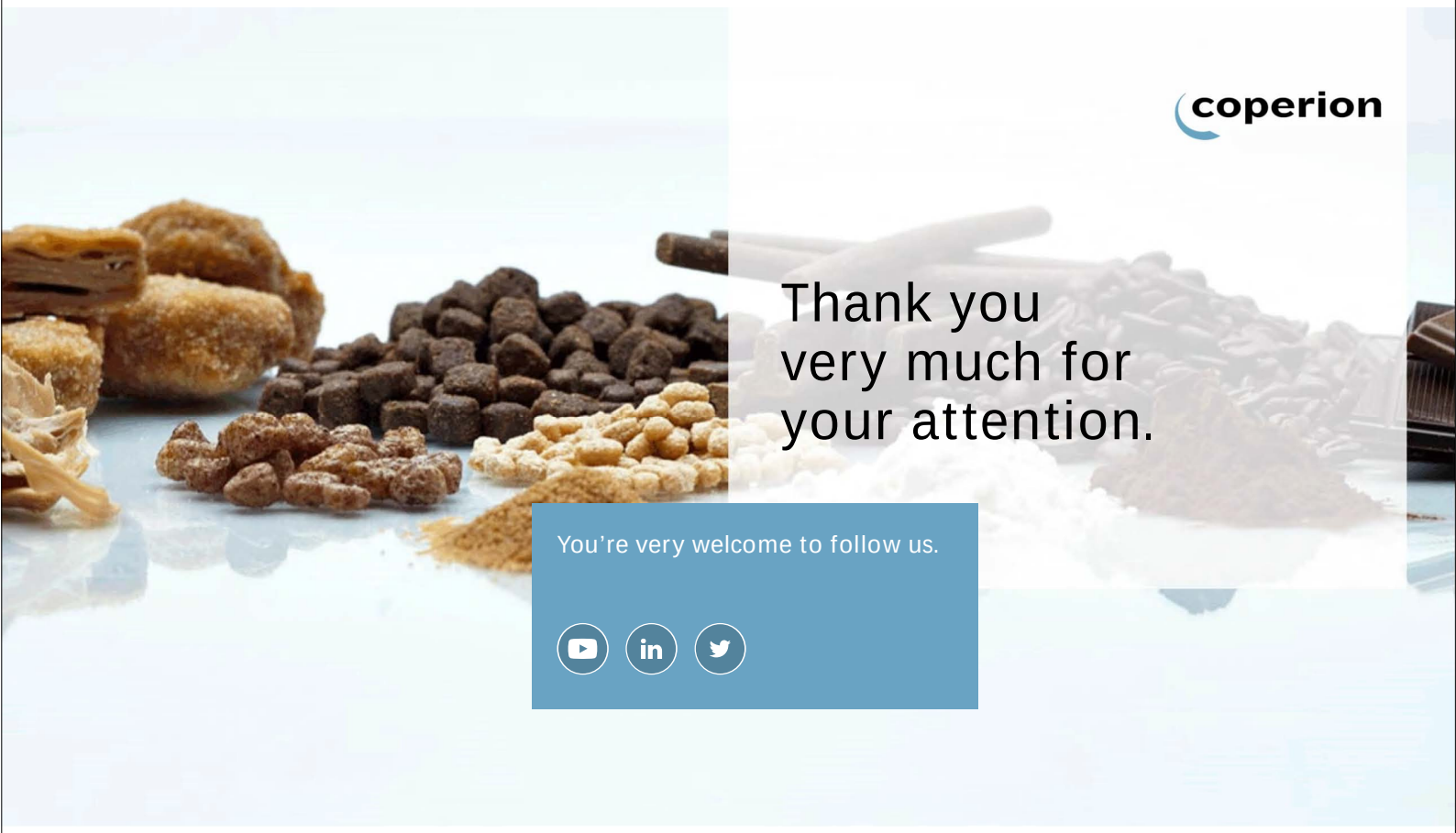






Explore the opportunities of extrusion for your processes

Contact us!



coperion

Thank you very much for your attention.

You're very welcome to follow us.



Expansion and die design

Food Extrusion Seminar Intense 2026

Christian Hüttner, Senior Process Engineer Food Extrusion

1 Introduction – die flow

2 Die basics and design features

3 Mechanism of expansion in food extrusion

4 Expansion indices

5 Types of expansion

6 Die calculations

7 Shaping the product

Introduction – die flow

1



Introduction

Die functions

- Shaping the product
- Structure formation
- Introduction of mechanical energy
- Providing resistance

↓

- Creating pressure

↓

- Expansion
- Seal against pressure inside the extruder





Introduction

Die flow

Flow through a resisting die is a function of pressure, product rheology and geometry of the die.

$$Q = k_d \frac{p}{\mu_\alpha}$$

Influence by

- extrusion process section parameters
  - throughput, screw configuration, rpm (degree of fill)
- transition between screws and die openings (dead space)
- orifice design
- die and pelletizer parameters
  - Die temperature, throughput per die hole, pelletizer (rpm, distance to die plate)
- recipe , water content, steam

Die basics and design features

2

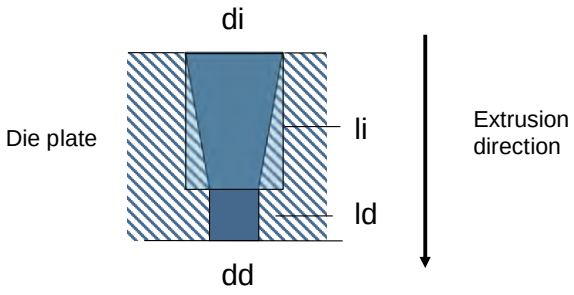


Die basics and design features

Die design parameters

Orifice characteristics

- Orifice shape (round)
- Size/ diameter d_d
- Land length l_d
- Inlet length l_i
- Inlet design (tapper, angle, d_i/counterbored)



Die plate characteristics

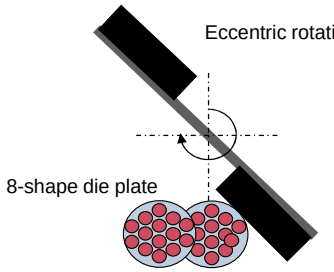
- Number of orifices in die plate
- Dead space and product flow path before die opening
- Material of construction of die plate/ inserts
- If concentric: diameter and count of orifice rows

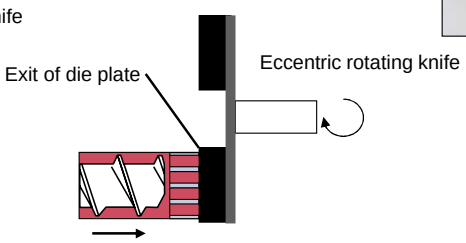
Die basics and design features

Transition screw to orifice

- Die holes only in prolongation of 8-shape
- If centric pelletizer, in center no die holes
- Eccentric pelletizer possible
- Very restricted surface for die holes
- Screws protruding into die plate
  – Use of recessed screw tips
- No inserts possible







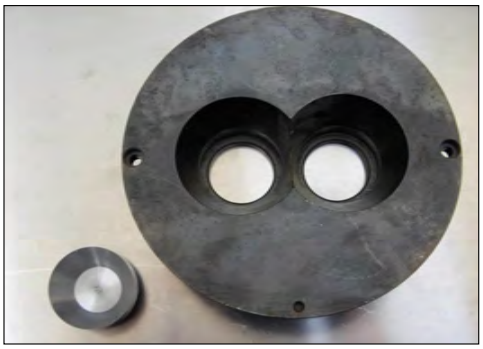
Die basics and design features

Best flow pattern situation

- Die holes in prolongation of screw tips
- Very restricted surface for orifices available
- Smooth transition
- Difficult situation for centric pelletizer
  – Short center distance
- Use of inserts possible







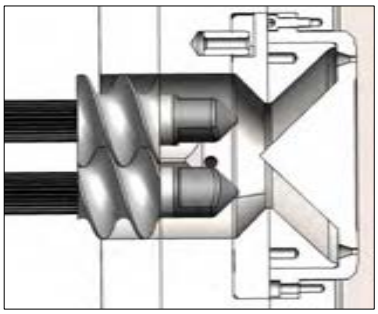
Die basics and design features

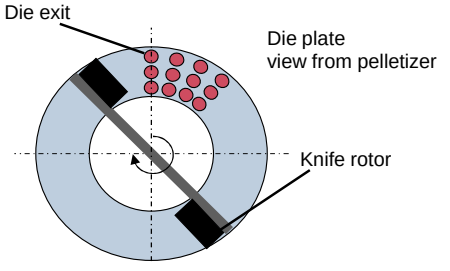
Large die plate surface situation

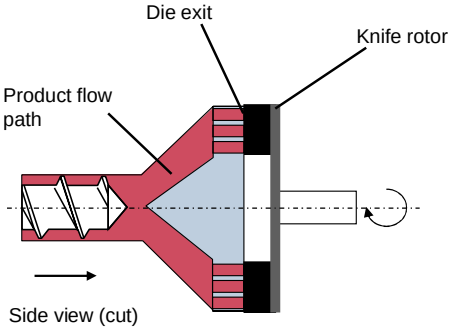
Central fed die

- For larger throughput rates
- Spreading of product flow to larger surface
- Longer flow path
- 8-0 transition before flow to die plate

Top view (cut)







Die basics and design features

Other discharge possibilities: strand die

For sticky or low viscous products

No direct cutting possible or desired

Die face sloped for smooth product flow

Often transition to conveyor belt





Die basics and design features

Other discharge possibilities: open discharge

Low pressure situation

For very low viscous/ liquid products

During trials for first shot of unknown material

Discharge downwards possible

- No dirty surface
- For some downstream processing better suited



Die basics and design features

Other discharge possibilities: special discharge

Special lateral die with natural breaking of particles

Orifices around the laying 8 shape

Product pushed out by the screws inside this special die



3 Mechanism of expansion in food extrusion

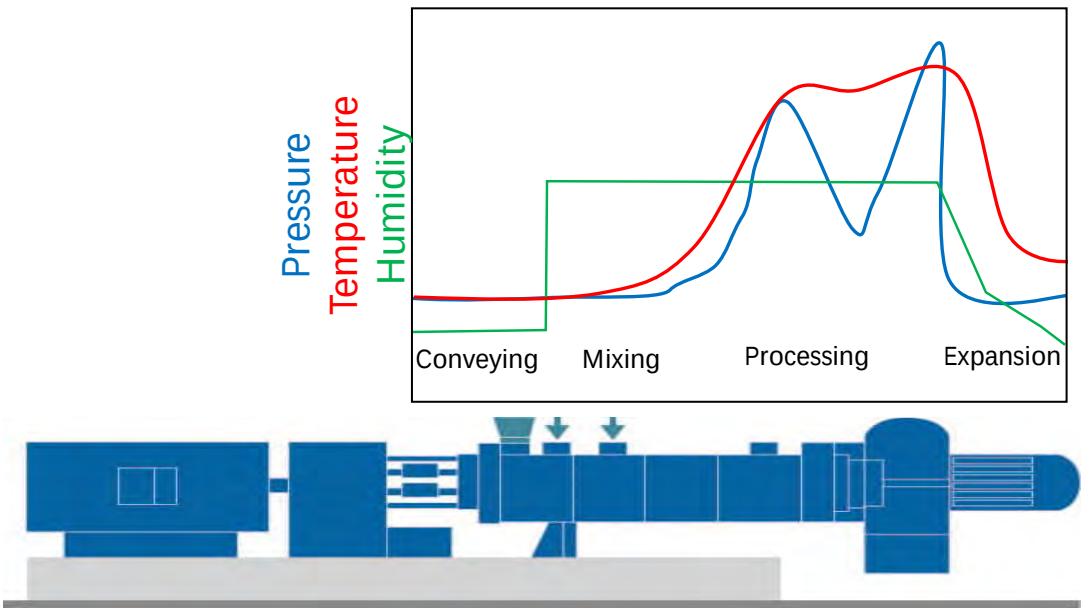


Mechanism of expansion in food extrusion



Mechanism of expansion in food extrusion

Pressure – Temperature – Humidity during Extrusion



Mechanism of expansion in food extrusion

Essential conditions for expansion at the die

- Free water available
- p/T conditions above evaporation conditions
- viscous material (possibility to build up pressure)
- Narrow orifice (possibility to build up pressure)
- Pressure drop after die

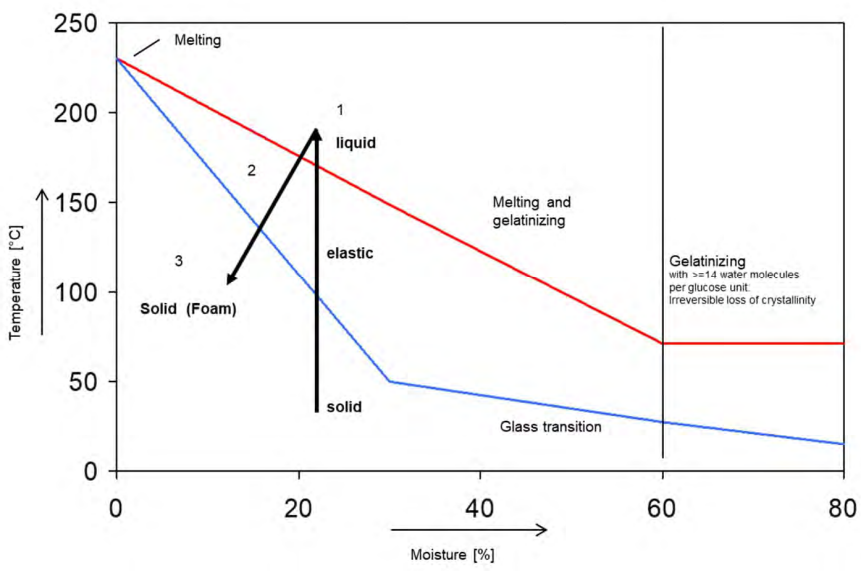
Sudden flash of water after exit of the die



- High molecular matrix with gas holding capacity
- Flowable viscous mass when exiting the die
- Solid product keeping its shape when cooled down

Mechanism of expansion in food extrusion

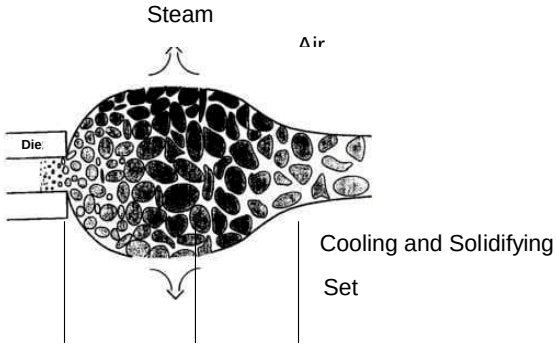
Simplified phase diagram



Mechanism of expansion in food extrusion

Essential conditions for expansion at the die

1 High viscous liquid inside the die, water in liquid state
2 Plastic when water flashing off, expanding
3 Solid when cooled down/ dried up



Too elastic – expands a little but shrinks afterwards
Needs too long time till solid – expands but shrinks afterwards
Low viscosity/ poor gas holding capacity – cannot keep the gasbubbles and collapses
Too hard/ poor gas holding capacity – surface tears off, ruptures to release the vapour. No/poor expansion

Expansion indices 4

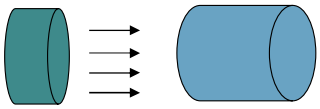


Expansion indices

Longitudinal expansion

Longitudinal expansion (LEI)

- Longer land length
- Higher rpm
- Higher temperature of barrel/ die



Keeps well the shape of the die design

Degree of expansion difficult to determine

Comparison of m/min of extrudate or rpm of pelletizer (daily life)

Longitudinal expansion index in literature

$$LEI = \frac{v_{extrudate}}{v_{in\ die}} = \left(\frac{\rho_{in\ die}}{\rho_{extrudate}} \right) \times \frac{A_{die}}{A_{extrudate}} \times \frac{1 - moist_{in\ die}}{1 - moist_{extrudate}} \quad [-]$$

$\rho_{in\ die}$ *density of product in the die* $[g/mm^3]$

$\rho_{extrudate}$ *density of extrudate* $[g/mm^3]$

$moist_{in\ die}$ *water content in extruder* $[\%]$

$moist_{extrudate}$ *water content after flash off* $[\%]$

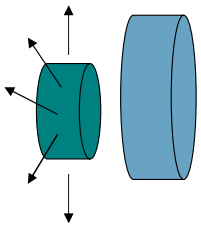
Expansion indices

Radial expansion and overall expansion

Radial expansion (SEI)

- Shorter land length (land length-diameter ratio)
- Lower rpm
- Lower temperature of barrel/ die

$$SEI = \left(\frac{d_{extrudate}}{d_{die}} \right)^2 \quad [-]$$



Product shape blurred compared to die design

Easy to determine $d_{extrudate}$ /d_{die} [%] (daily life)

Surface expansion index SEI (literature)

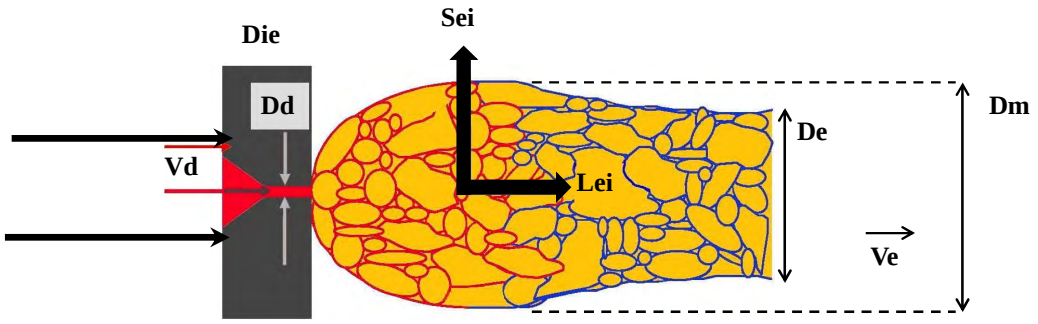
Overall Expansion (VEI)

- Expressed by product Density
- Volumetric expansion index VEI

$$VEI = SEI \times LEI \quad [-]$$

Expansion indices

Relation with input parameters



Operating conditions	VEI	SEI	LEI
Moisture content ↗	↘	↘	↘
Screw speed ↗	→	↘	↗
Throughput ↗	↗	↗	↗
Barrel temperature ↗	→	↘	↗

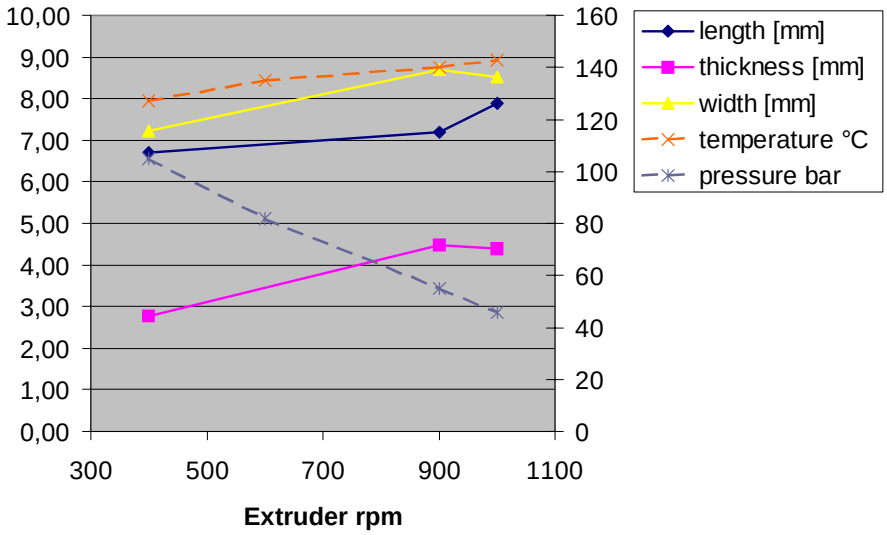
Expansion indices

Relation with input parameters

Water rate ↗	• Viscosity ↘ • Pressure ↘ • Expansion ↘	Bulk density & brittleness increase
Throughput rate ↗	• Viscosity ↗ • Pressure ↗ • Expansion ↗	total Expansion (VEI) increases
Screw speed ↗	• Viscosity ↘ • Pressure ↘ • Expansion ↗	Cell size decrease & softness increase. Structure in direction of flow
Barrel/ die temperature ↗	• Viscosity ↘ • Pressure ↘ • Expansion →	Surface roughness increases, cell size decreases

Expansion indices

Relation with input parameters





Expansion indices

Relation with input parameters



Types of expansion

5



Types of expansion

Bubble size and orientation

Small bubbles
- Very high rpm
- Low water content
- Recipe with more ingredients acting as nucleation points (bran/fibres, undissolved mineral or salt components)

➡ Product looks brighter (oriented bubbles)

Big bubbles
- Low rpm
- Higher water content

➡ Round bubbles

Same product density can be achieved by few big or many small bubbles





Types of expansion

Die influence

Roundish expansion

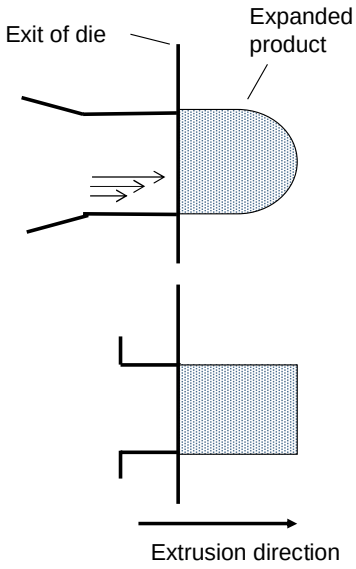
More laminar die-flow, more radial expansion, more friction in die

- Longer land length
- Tapered inlet
- Lower temperature of barrel/ die plate

Vessel-type expansion

More turbulent die-flow, more longitudinal expansion, more slip in die

- Higher rpm
- Sudden beginning of orifice (no smooth taper)
- Low friction material (insert)
- Higher temperature of barrel/ die plate

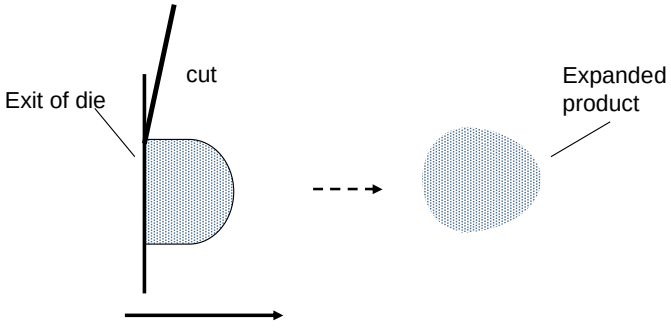


Types of expansion

Influence of cutting

Backward expansion

- Backward side expands after cut
- Expansion contrary to product flow direction
- Backward side of product expands similar to forward side
- Forward side more roundish than backward side





Die calculations

6



Die calculations

Designing die plates

For food products, merely rheological data available

difficult to calculate and simulate product flow by viscosity data

Calculation of restriction against the flow inside die

- Scale up calculations where
  - die plate thickness changes
  - Extrudate size changes
- Comparison of different die plates/ shapes

$$Q = k_d \frac{p}{\mu_\alpha}$$

Die constant k_d

Indicates restriction against flow of specific die

Only applicable for simple forms

Only compare the die (die plate) not the product.

only to be compared for one and the same product

Die calculations

Die constant (k value) I – restriction of the die

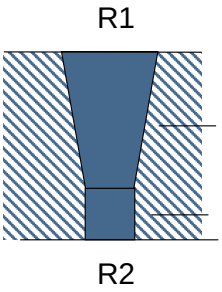
Die constant k_d in mm³ (smaller k_d value = more restriction)

All dimensions in mm

Circular die $$k_d = \frac{\pi \cdot R_d^4}{8 \cdot L_d}$$

Inlet taper $$k_i = \frac{3 \cdot \pi \cdot (R_1 - R_2)}{8 \cdot L_i \cdot \left[(1/R_2^3) - (1/R_1^3)\right]}$$

Circular die with taper $$k_t = \frac{1}{\left[(1/k_i) + (1/k_d)\right]}$$



L_d = length of straight section (land lenght)

R_d (R2) = die radius in straight section

L_i = length of inlet taper

R_1 = die radius of inlet taper

R_2 = die radius of outlet taper

Die calculations

Die constant (k value) II - restriction of the die

Thin slit die $$k_d = \frac{w \cdot h^3}{12 \cdot L_d}$$

Rectangular die $$k_d = \frac{\frac{w \cdot h^3}{L_d}}{12 + 16.6 \cdot \left(\frac{h}{w}\right)^{1.5}}$$

Thin annular die $$k_d = \frac{\pi}{12 \cdot L_d} \times (R_0 + R_i) \times (R_0 - R_i)^3$$



w = width of slit

h = thickness of slit

L_d = length of straight section

R_0 = outer radius of ring

R_i = inner radius of ring

Die calculations

Die constant (k value) III – restriction of the die

Die constant for total die plate $K_d = k_d \cdot n \quad [mm^3]$

n = count of orifices on die plate

Die constant for multiple die plates in series $\frac{1}{K_{total}} = \frac{1}{K1} + \frac{1}{K2} + \ldots + \frac{1}{Kn}$

n = number of restrictions in flow path

Throughput in relation to total die constant: specific throughput : $\overset{*}{m} = \frac{\dot{m}}{K_d} \quad \left[kg/h\,mm^3\right]$

ṁ = throughput in kg/h

→ keep $\overset{*}{m}$ constant

Die calculations

Example calculation

Lab extruder:

12 die holes

1,0 mm diameter orifice 1,5mm lendlength

Inlet taper 10,3 mm diameter (50°)

Full die plate thickness 11,5mm

Throughput 15 kg/h

Circular die kd =0,016 mm³

Inlet taper ki =0,069 mm³

die hole kt =0,013 mm³

Whole die plate Kd= 0,159 mm³

Specific mass flow m*= 94,581 kg/h mm³

given values in black, *calculated values in* red

Production extruder:

100 die holes

1,5 mm diameter orifice 1,8 mm lendlength

Inlet taper 12,36 mm diameter

Full die plate thickness 13,5mm

Throughput 500 kg/h

Circular die kd =0,067 mm³

Inlet taper ki =0,232 mm³

die hole kt =0,052 mm³

Whole die plate Kd= 5,286 mm³

Specific mass flow m*= 94,581 kg/h mm³

Play with parameters to find suitable die plate. Observe type of expansion if applicable when choosing parameters

Shaping the product

7



Expansion and die design

Shaping the product

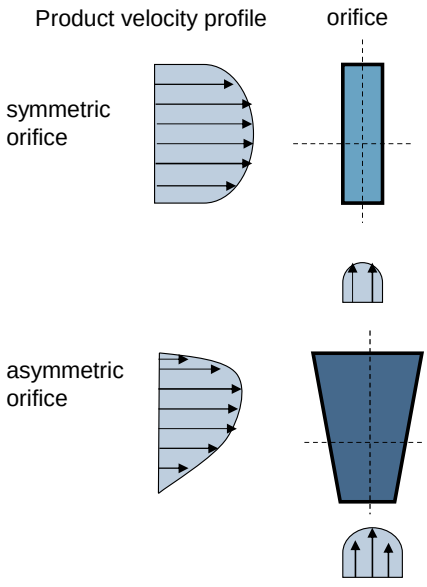
Velocity profile

Higher product velocity in thicker die areas

Non-uniform product flow

- Thicker/ more expanded parts; blurring of product shape
- Twisting product leading to 3D shaped product





Shaping the product

Velocity profile



Film:

Extrudate twisting when exiting the die and expanding

Shaping the product

Velocity profile

Bowl- shape formed by velocity difference in the flow



Shaping the product

Velocity profile

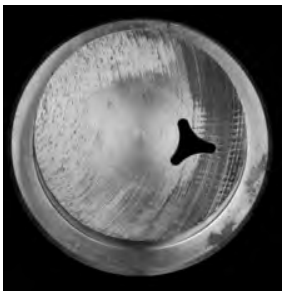
Faster flow in the thick centre

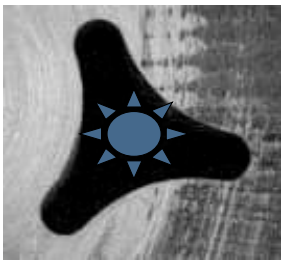
Thicker product in the centre

More (radial) expansion than in edges

Die shape different than resulting product shape!!



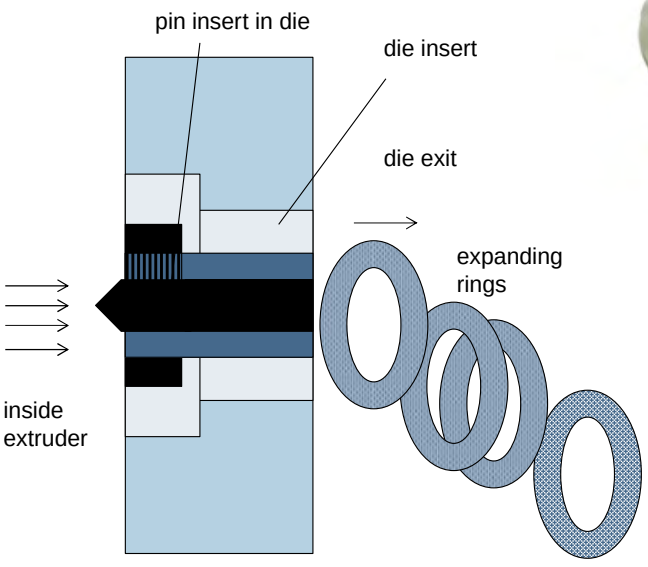






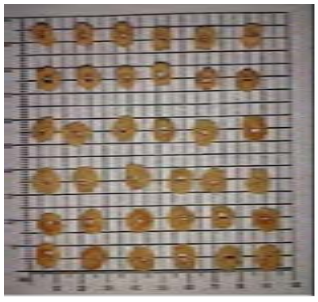
Shaping the product

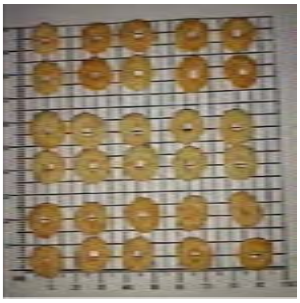
More complex figures with insert pin











Shaping the product

Coextrusion

„Filled ring extrusion“

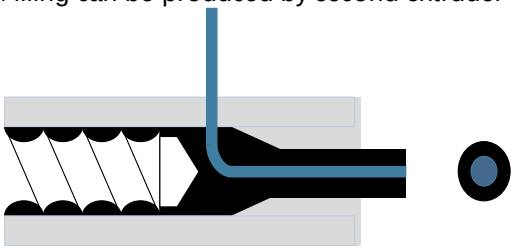
Postcut (filled tube) or crimped (pillow type) product

Filling mass

- Liquid for pumping, solid when cold
- Withstand high product temperature
- Low water activity

Filling can be produced by second extruder





Shaping the product

Coextrusion

„If working with particle-ingredients: no particle larger than 1/3 of die diameter!

→ Risk of blockage

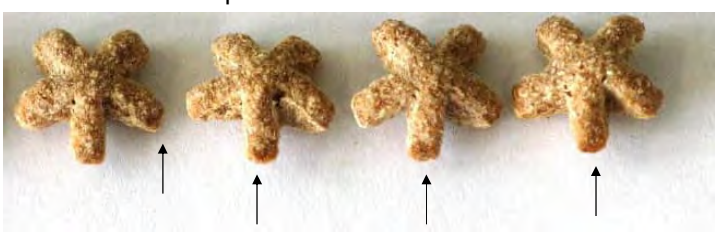
Avoid narrow corners in die shape design

→ Risk of burnt (darker) edges

Avoid die holes too far at outside area of die plate

→ Less/slower flow in outer area

stunded parts in extrudate





Shaping the product

Different flow velocities of orifices

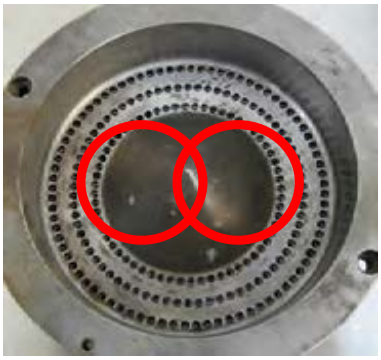
Multiple orifice dies have a tendency of different flow velocities

Concentric die plates have a superimposed difficulty

Inner rows flow faster

Faster flow in prolongation of screws





slow

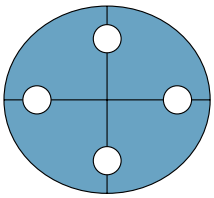
medium

fast/ main flow

Shaping the product

Different flow velocities of orifices

Caused by not suitable die plate design





Shaping the product

Adjustment of flow velocities in orifices

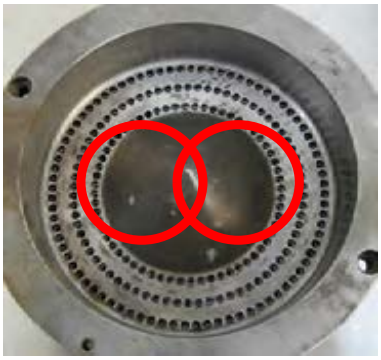
Strainer plate and distribution cone

Shorter land length where flow is slower (less restriction)

Less die holes (more distance) where flow is slower

By screw profile





slow

medium

fast/ main flow

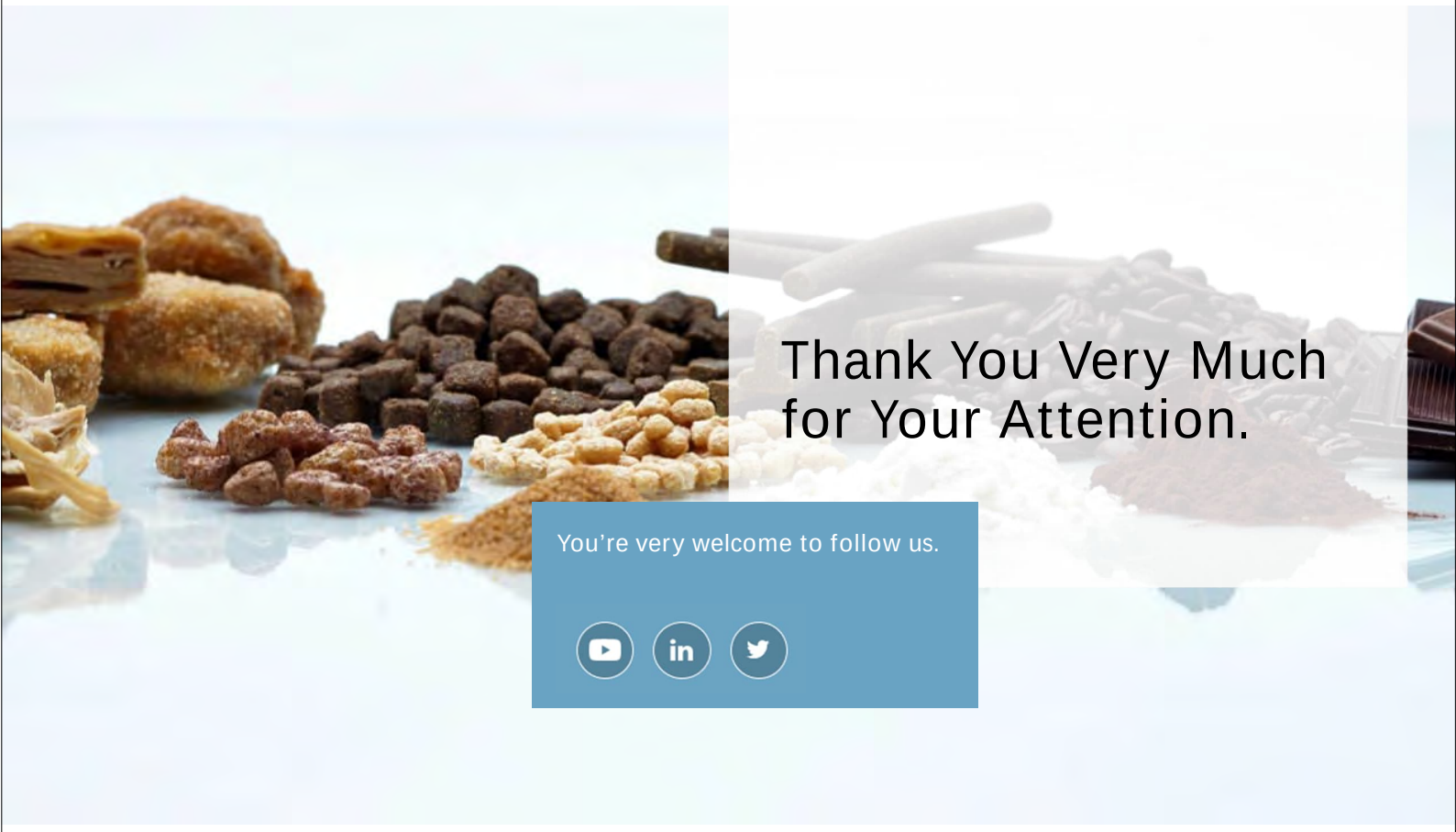
Shaping the product

Safety: prevention of steam blows

Die pressure considerably higher than steam pressure inside extruder

Consult steam table!

Steam table for saturated steam			
overpressure		temperature of saturated steam	enthalpy of water
bar	kPa	°C	kJ/kg
2,0	200	133,5	561
2,5	250	138,9	584
3,0	300	143,6	605
3,5	350	147,9	623
4,0	400	151,8	640
4,5	450	155,5	656
5,0	500	158,8	670
6,0	600	165,0	697



Thank You Very Much for Your Attention.

You're very welcome to follow us.



Feeding of Various Ingredients

Food Extrusion Seminar Intense 2026

Fabian Specht, Senior Process Engineer

BEST COMPONENTS & BETTER SYSTEMS

THE RECIPE FOR PERFECT FOOD

Index

Feeding, Conveying, Extrusion, where do I find what?

1. Importance of Feeding in continuous Processing
2. Weighing Technology
3. Material Characteristics & Feeder selection
4. Feeding for continues and batch Process
5. Batch Technology
6. Know-how & Technology
   I. EPC
   II. ActiFlow
   III. Refill Array
7. Refilling Guideline



1 Importance of Feeding in Continuous Processing



Why are Feeders Necessary?

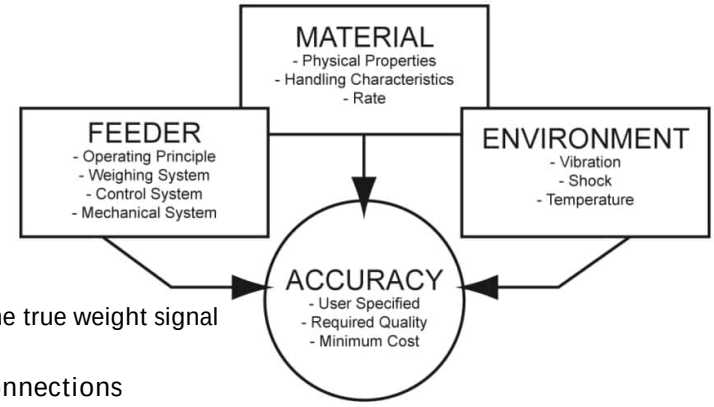
- To set the precise throughput to a downstream process - Accuracy
  - Feeders are used to set the flow rates of both liquids and bulk solids
- Allows for more efficient processing in continuous mode - Consistency
  - Continuous processes such as extrusion become “slaves” to the feeders
  - Discontinuous feeding can cause torque issues on the extruder
  - Torque issues could cause quality issues
  - Provide an accurate blend of bulk solids and liquids for a formulation
  - More accurate delivery of ingredients = greater control on ingredient costs
- Eliminate pre-mixing of solids/segregation
  - Premixing can lead to segregation
  - Premixing requires additional space and cleaning requirements – more labor intensive
- Provide an automated method of material handling
  - Eliminates waste as well as provides a safe method of transfer of ingredients to the process
  - Automation helps maintain overall safety





Considerations for feeders in a continuous process

- Feeder Type
  - Single screw vs. Twin screw
  - Screw configuration
  - Hopper configurations
  - Agitation vs. vibration
- Refill Method
- Controls and Weight Measurement
  - Load Cell Resolution
  - Reaction Time of Controller
  - Signal Clarity
  - Goal of filtering is to eliminate external noise that affects the true weight signal
- Environmental influences and upstream/downstream connections
  - Flexible Connections
  - Proper Venting
  - Drafts/Air currents
  - Excessive Plant Vibration



Feeding Principles

- There are two basic feeding principles:
  - Volumetric
  - Gravimetric
- Coperion K-Tron generally employs the following types of gravimetric feeding:
  - Loss-in-weight feeding
  - Weigh belt feeding
  - Flow metering



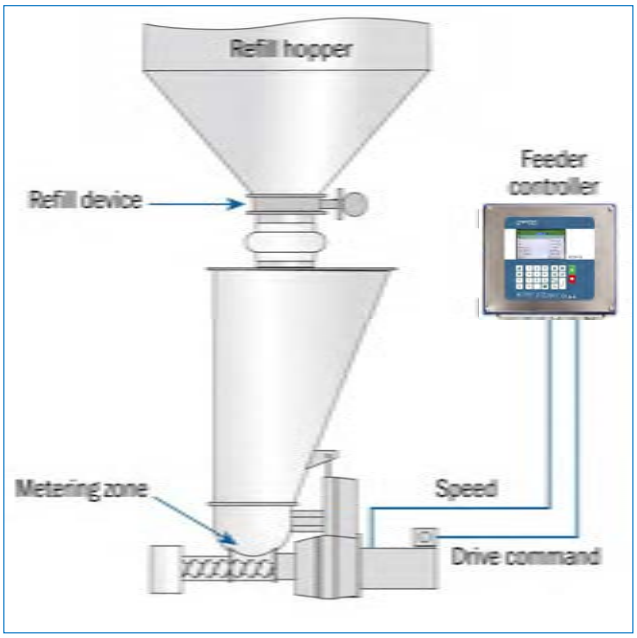






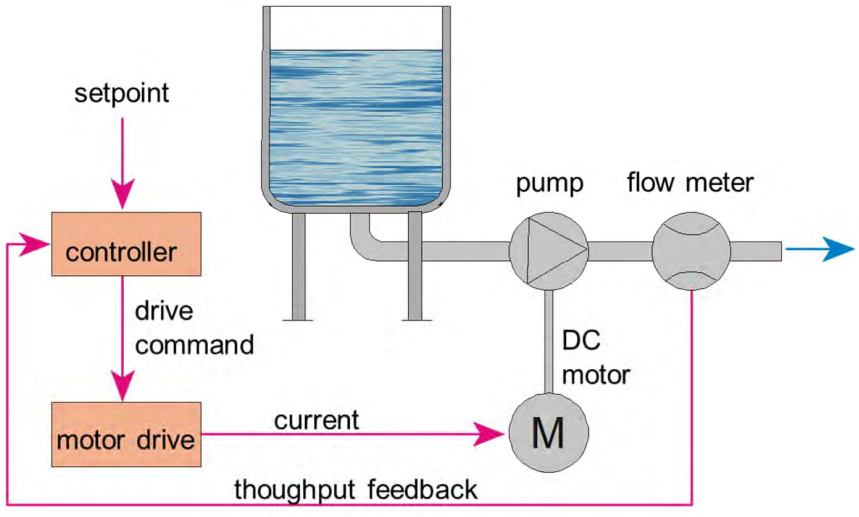
Volumetric Feeding I

Speed Regulated
Volumetric Feeding:



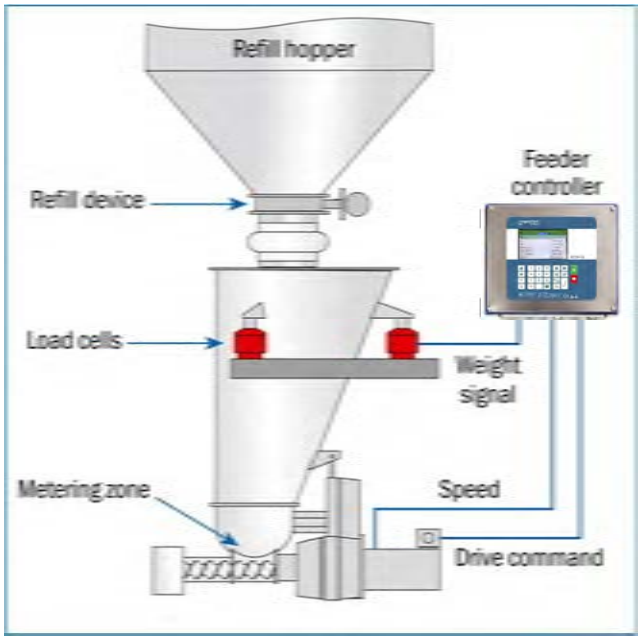
Volumetric Feeding II

Controlled Volumetric Feeding:



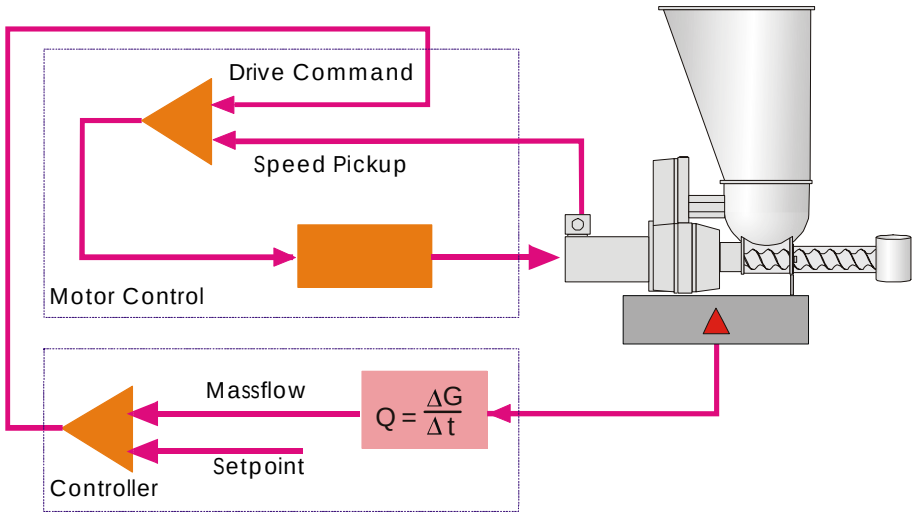
Gravimetric Control Principle

Weight Regulated
Gravimetric Feeding:



Loss-in-Weight Control Principle

For loss-in-weight screw and belt feeders



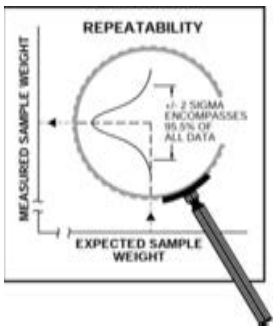
Weighing Technology

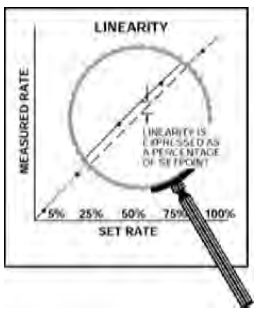
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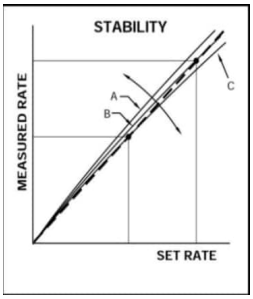


Validation of a Feeder's Performance

- Repeatability
  - Variance of multiple, sequential samples
  - Reports how consistent the feeder's discharge rate is at a given point
- Linearity
  - Accuracy deviation over a setpoint range
- Stability
  - Gauges performance drift over time





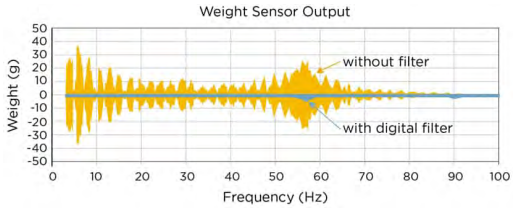


Choose Load Cell Technology

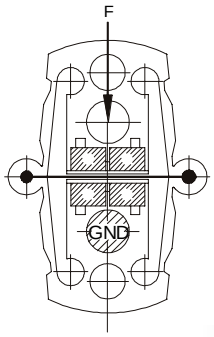
Filtering feeder noise and environmental vibrations

The Smart Force Transducer (SFT) offers ...

- Vibrating wire measurement technology
- Resolution – 1:8‘000‘000 in 20ms
- Built-in microprocessor
- One-time calibration at factory
- Noise-free signal transmission
- Fast sampling time (450 samples/sec.)
- High short-term accuracy in any conditions
- Not affected by vibrations



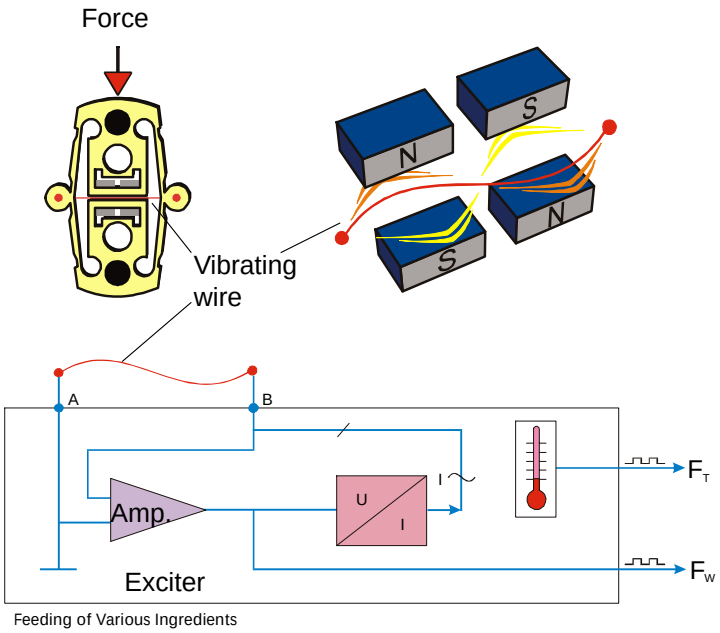


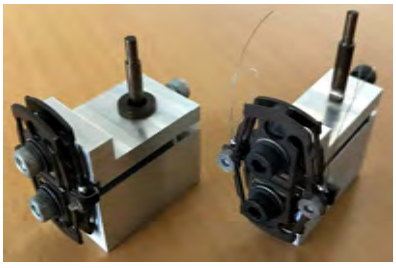


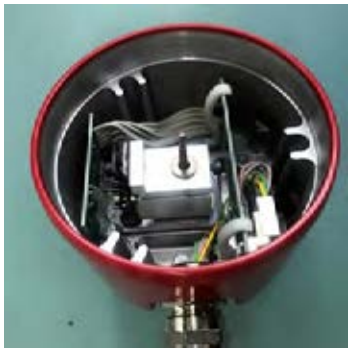


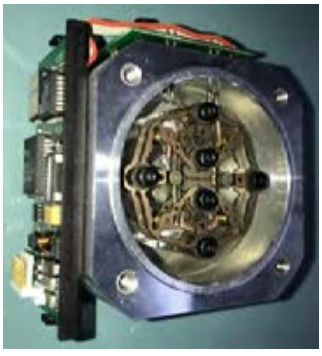


Vibrating Wire









Effect of Vibration: Dynamic Weighing



Material Characteristics & Feeder selection

3

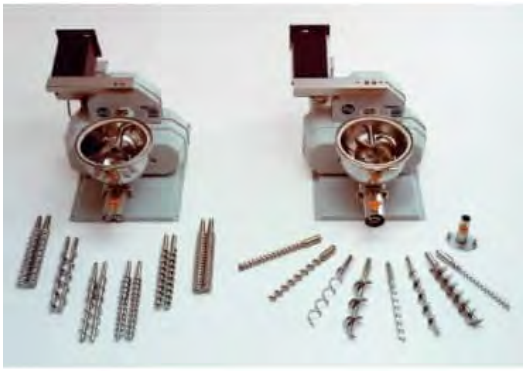


Material Characteristics I
Effect of Particle Properties on Flow

Property	Effects
Particle Shape	Discharge from hoppers
Particle Size & Distribution	Flowability & Compressibility
Particle Hardness	Abrasiveness on equipment & particle fragility
Bulk Density (L&C)	Storage vessels size & material's compressibility
Moisture Content	Cohesive strength & arching ability of bulk materials
Compressibility	Tendency to pack in a feeder hopper
Cohesiveness	Minimum outlet diameter for bins, hoppers, and outlets
Permeability	Tendency to flood



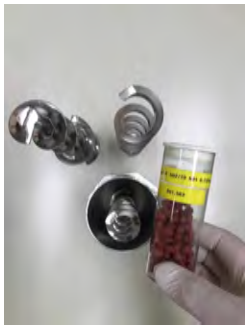
Feeder Selection
Screw Configurations





	Code	Feeding Screws
	TCC	Twin concave screws
	TCF	
	TAC	Twin auger screws
	TAF	
	TSC	Twin spiral screws
	TSF	
	DSC	Double spiral screws
	DSF	
	SAC	Auger screw
	SAF	
	SSC	Spiral screw
	SSF	





Material Characteristics II

Powder Material:

Free Flowing – Sticky - Floating





Twin Screw TCC or TAC



Single Screw SAC

Material Characteristics III

Granular Material:

Free Flowing





Single Screw SSC
Reduced Screw Size



Single Screw with and without overflight to avoid product in the bowl

Material Characteristics IV

Screw Selection depending on the Product:



Material Characteristics VI

Free flowing fragile Products:







Material Characteristics VII

Feeder flowing fragile Products to be fed with a Vibratory Feeder



Material Characteristics VIII

Liquids and Waxes, which sometimes must be heated or even melted before feeding







Material Characteristics IX

Liquids and Waxes, which sometimes must be heated or even melted before feeding will be fed with a liquid feeder



Feeding for continues and batch Process

4



Feeding for continues and batch Process I

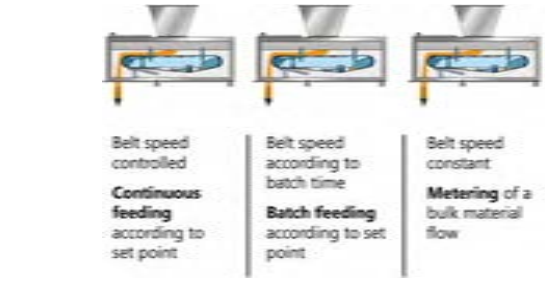
Screw Feeder

- Twin screw MT12 – T80 => 0.045 to 24'700 dm^3/h
- Single screw S60 – S500 => 0.140 to 45'300 dm^3/h
- Great flexibility with Quick-Change solution
- Stand allow or hanging system



Smart Weight Belt Feeder

- SWB-300-N/O => 10 to 40'000 dm^3/h
- SWG-600-N/O => 20 to 80'000 dm^3/h
- Smal hight, can be direct installed under the silo
- Chantel feeding for fragile products like potato chips
- Easy to clean with the slide out conveyor frame





Feeding for continues and batch Process II

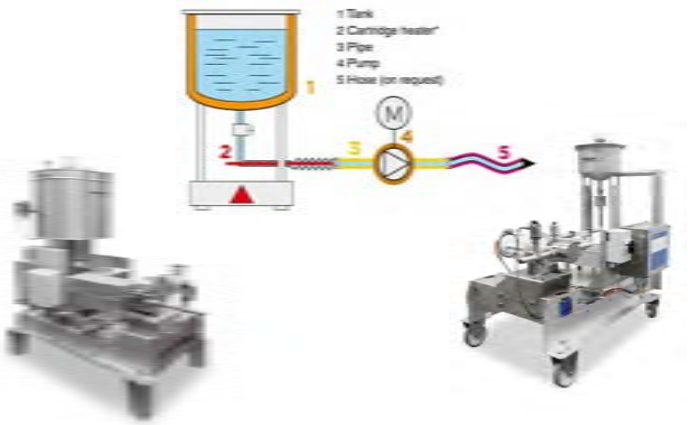
Vibratory Feeder

- V100 – V300 => 1 to 8'500 dm^3/h
- Various feeding tray options
- Minimal damage to the product
- Easy to clean
- Low power consumption



Liquide Feeder

- Modular Line for Liquids LLW => 0.5 to 1'500 dm^3/h
- Backpressure up to 40 bar
- Standard or with heating
- Pre-melting tank option
- Flexible to locate

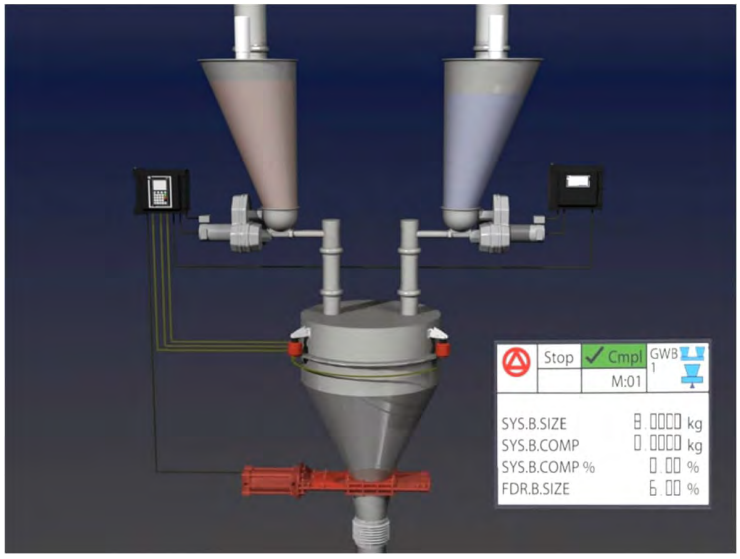


Batch Technology 5



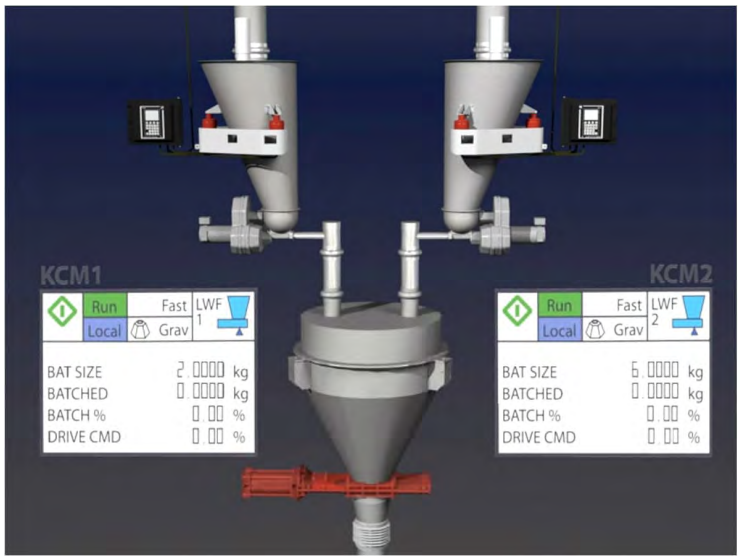
Gain-in-Weight Batch Principle

- Advantages
  - Only one scale device for load hopper
  - Cost effective since feeders are volumetric
  - Well suited to large batches
- Disadvantages
  - Total batch time is dependent upon the number of individual batch times necessary
  - Combination of large single batches and very small batches not as versatile (due to large taring values of the collection hopper)



Loss-in-Weight Batch Principle

- Advantages
  - Each ingredient is batched out in its own LIW feeder
  - Feeders can then operate simultaneously, making overall batching process shorter
  - Can also batch out variety of ingredients at different bulk densities and high variation in mix percentages with high accuracy
- Disadvantages
  - Higher initial investment for loss-in-weight feeders



6 Know-how & Technology



What Affects Loss in Weight Feeding Accuracy?

- Interface with Upstream / Downstream Equipment
  - Refill
  - Pressure Fluctuations
- External Influences:
  - Noise (Vibration) from other plant equipment
- Internal Influences:
  - Pressure Fluctuations

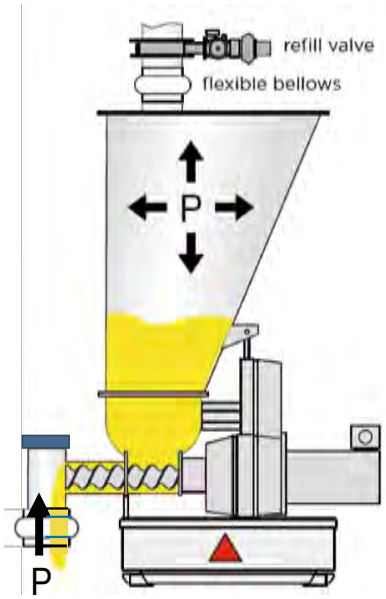


EPC

Effects of Pressure on Feeder Performance

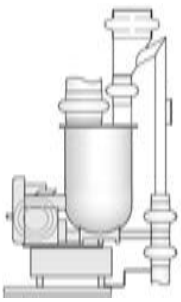
Pressure exerted externally or internally causes weigh scale errors

- Cause:
  - Poorly vented feeder hopper
  - Refill from vacuum receiver with fluidizing pads
  - N2 Blanket
- Effect:
  - DN 150 refill valve
  - 5 mbar over pressure
  - 0,883 kg weight difference



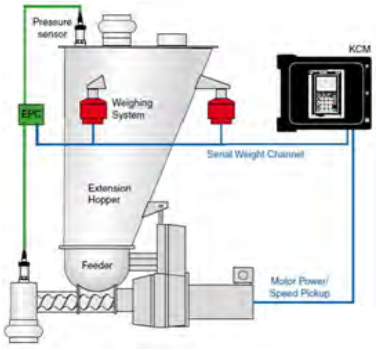
Pressure Compensation - Mechanical Solution / Electronic Solution

- Outlet:
  - Two identical bellows that compensate the weight in both directions simultaneously on one line.
  - Normally a good solution
  - Still requires maintenance
- Hopper solution:
  - Much more expensive,
  - Usually custom engineered,
  - Doesn't work as well





Instead of a mechanical compensation, we measure the pressure in the hopper and compensate the weight in software.



Advantages:

- Lower cost
- Easier installation
- More accurate
- More reliable
- Less error-prone
- Compensation is self-optimizing via software
- Identical dynamics as the SFT for best performance by using the same filter technique

ActiFlow II



Poor Flow in Hoppers = Poor consistent feeding

Difficult powders:

- May get compacted

- Form rat-holes & bridges

Result in operation:

- Production interruption

- Quality problems

Screw feeder accuracy is a function of consistent screw fill



Alternative Solutions for Improved Hopper Flow

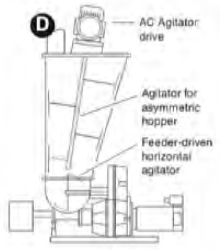






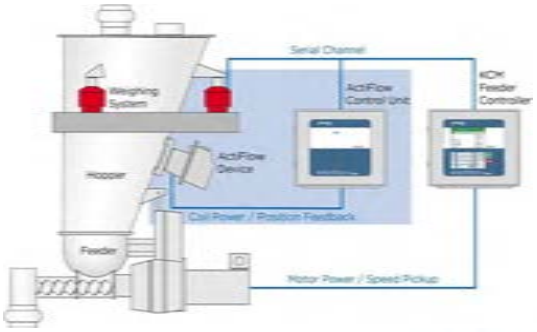
Design Options
Vertical Agitation
Flexible Elastomer Liners (e.g. FlexWall, Shear Hoppers)
Bin Vibrators
Air Injectors (e.g. Magic Mushrooms)
Elastomer Coatings





ActiFlow Design

- The ActiFlow Device is bolted to the outside of the hopper wall, with no product contact. It is ideal for applications which require a stainless-steel hopper.
- The special design ensures material activation has a minimal effect on the weighing system.
- Deteriorating material flow conditions in the hopper are detected by the KCM controls prior to a significant deviation of the feeder's desired mass flow.
- The ActiFlow activity is increased to get good mass flow in the hopper.
- ActiFlow just activates as much as necessary, not as much as possible

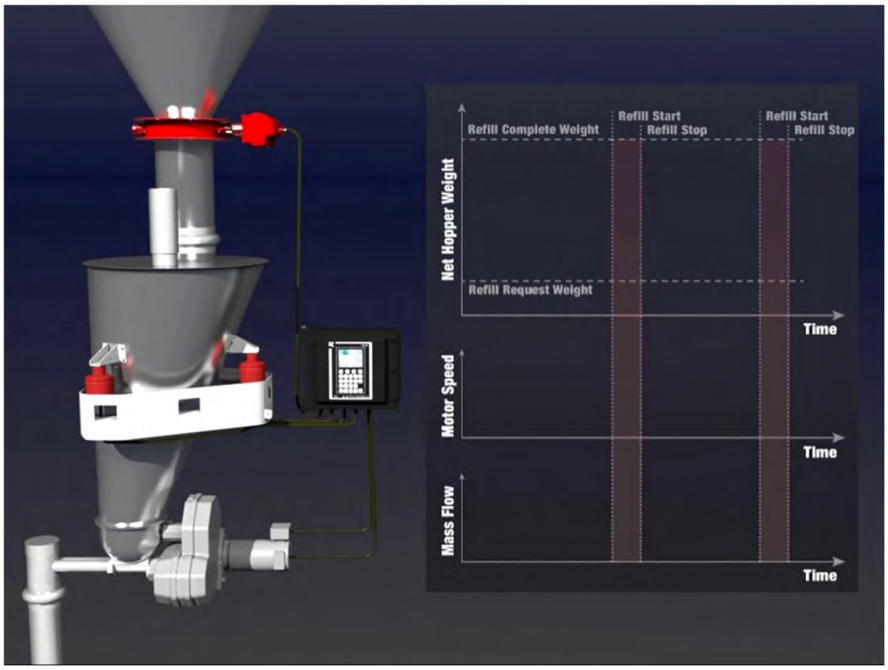




Refill Array

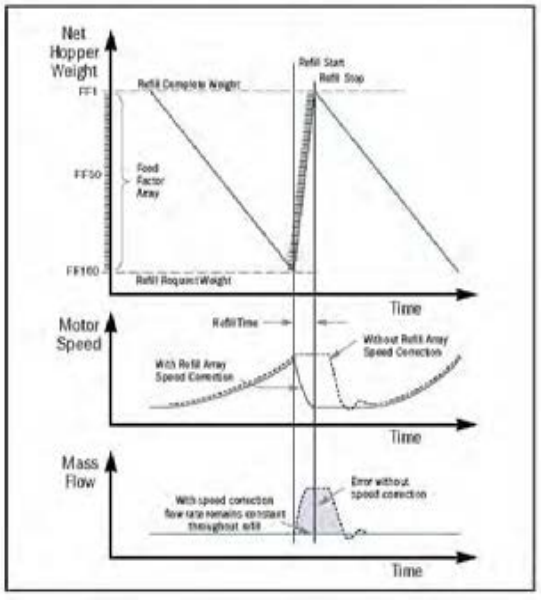
III

Continuous Loss-in-Weight Feeding

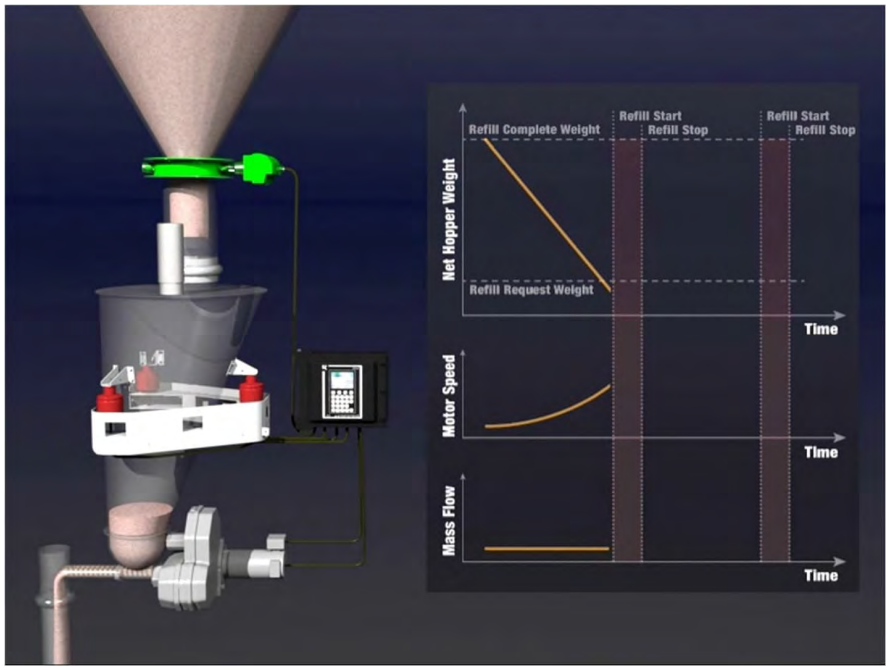


Refill Array and its Importance in the Continuous Process

- By trending the loss-in-weight intervals and corresponding speed of the screw, the same screw speed can be obtained during the gain in weight which occurs during refill
- Maintaining correlated screw speed = consistent and constant delivery of the ingredient to the process
- Refill devices can then be operated while the refill array is enabled to ensure that the process is never starved of material



Continuous Loss-in-Weight Feeding during Refill



Refilling Guideline

7



Additional Important Refill Considerations to Improve Feeder Accuracy

- Choosing the Proper Refill Device
  - Reaction time of the device
  - Device must be LEAK FREE
  - Material characteristics
- Choosing the Proper Hopper Size for Refill
- Choosing the Refill Times
  - Optimize the refill window
- Defining importance of accuracy during refill, particularly for low rate feeding



Loss in Weigh Feeder refill guideline

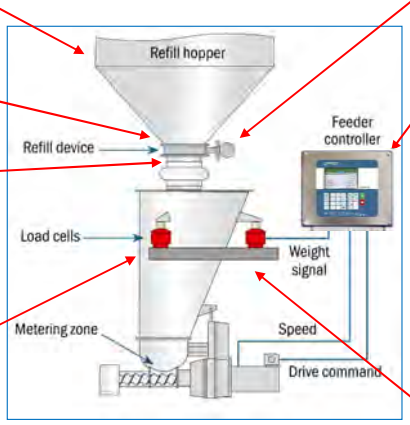
General Refill Rules

Refill rate has to be constant in order to achieve good feeder performance.

Thumb rule; refill rate = 8 to 10 times the maximum feed rate

Recommendation: keep falling height as short as possible and in any case
<1 m to reduce impact and material build-up in refill pipe.

Size weigh hopper as small as possible and as big as necessary.
As lower the load cell capacity as higher the absolute load cell resolution improving the feeding accuracy.



A refill should take < 30 seconds.
Typical refill time is 5 to 20 seconds.

Up to 25 refills/h are typical for 80% of CK LW-Feeder applications operating at max. feed rate.
Higher refill sequences causing no feeding performance issues as long as the general refill rules are considered. Wear issues of the refill valve have to be considered when operating at a higher refill rate than typical.

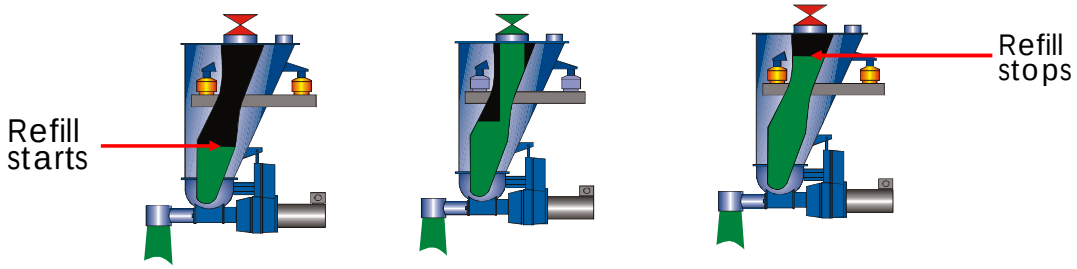
Up to 15% of the feeder operating time is foreseen for refill. During refill the Loss-in-Weight feeder switches to volumetric mode.

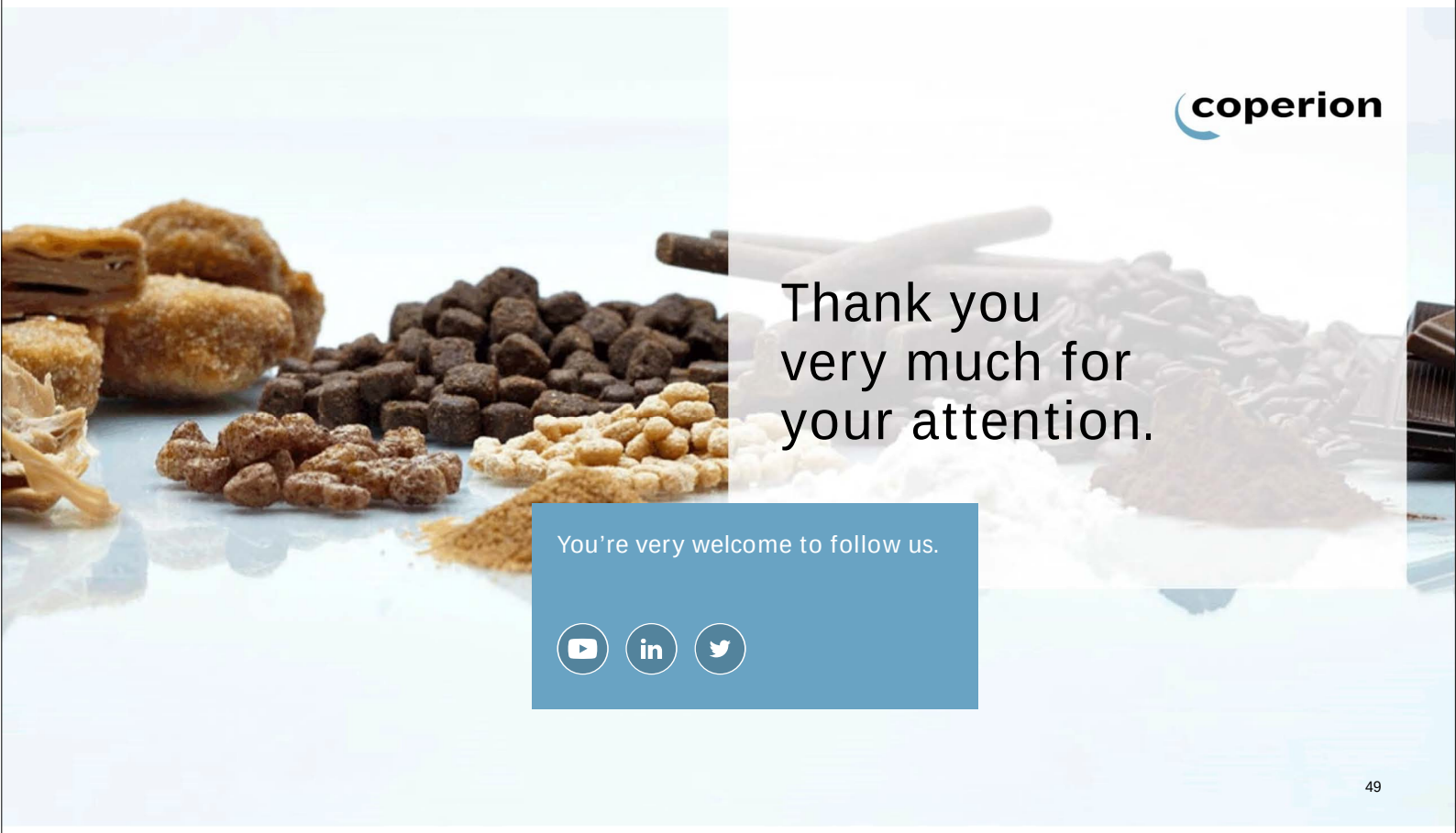
Loss in Weigh Feeder refill guideline

Guideline: Hopper volume used for refill:

- Crystalline free flowing materials like sugar or salt: Up to 70% of weigh hopper volume
- Coarse powders, low tendency for fluidization like milk powder: Up to 50% of weigh hopper volume
- Fine & easy to fluidize powders like starch: Up to 30 % of weigh hopper volume

Please note: The given values are general guidelines and might vary to actual refill settings. The individual setting is pending on material characteristics, height of refill pipe, material flow out of supply hopper, and open / close time of refill valve. Specific refill settings will be defined as part of a feeding accuracy test, or loss in weigh feeder start up.





coperion

Thank you very much for your attention.

You're very welcome to follow us.



Process Design: From Unit Operations to Screw Profile

Food Extrusion Seminar Intense 2026

Uta Kühnen, Head of Process Technology Food

1 Unit operations

2 Feed zone

3 Injection of liquids and steam

4 Cooking / plastification / melting

5 Mixing zone

6 Degassing and venting

7 Pressure build up zone

8 Example screw configurations

Unit operations

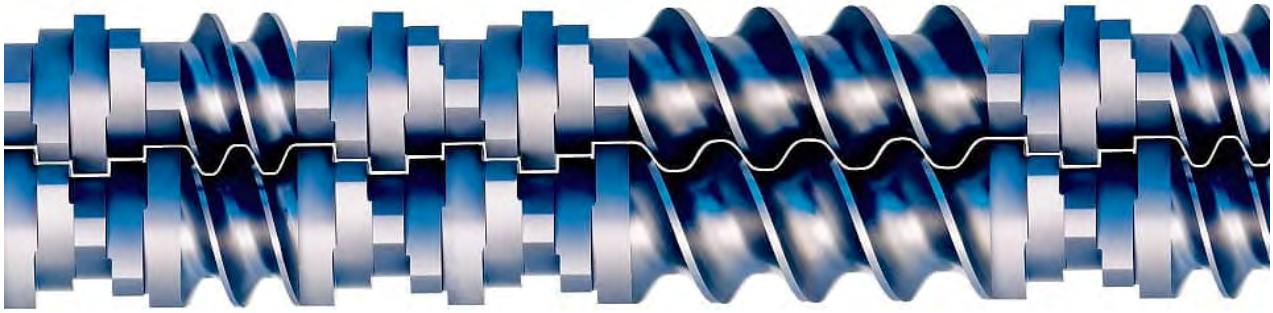
1



Working principle of a ZSK Extruder

- Various unit operations subsequently and/ or parallel within one machine
- Configuration: Type and order of single screw elements define the impact
- Introducing directed mechanical energy into the product

- Thermal energy transfer



From Production process to Screw configuration

"Translation" work

- Understand the process and its steps
- Break down the process to unit operations
- From batch to continuous
- Include extrusion specific unit operations where necessary

- For trials with unknown and complex process
  – Start with the first few steps, optimize if necessary, then add next steps

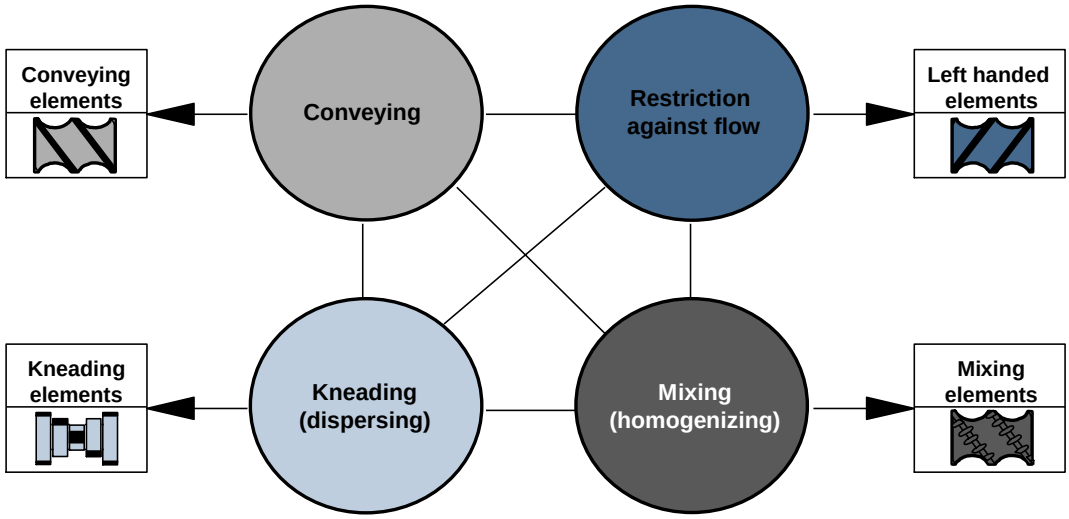
Unit operations

Examples for singular process tasks

- Intake
- Conveying
- Mixing
- Heating
- Cooling
- Residence time (keeping)
- Mechanical disruption/ destruction
- Melting
- Dissolving
- Kneading
- Cooking
- Plastification
- Denaturization
- Hydratation
- Emulsification
- Dispersion
- Devolatilization
- Degassing
- Chemical reaction
- Crystallization
- Thermal reaction
- Heat treatment (pasteurization)
- Texturization
- Pressure built up
- Forming
- Expansion
- ...

Process tasks

Realizing all required tasks with different types of elements



Feed zone

2

Intake and conveying of bulk material



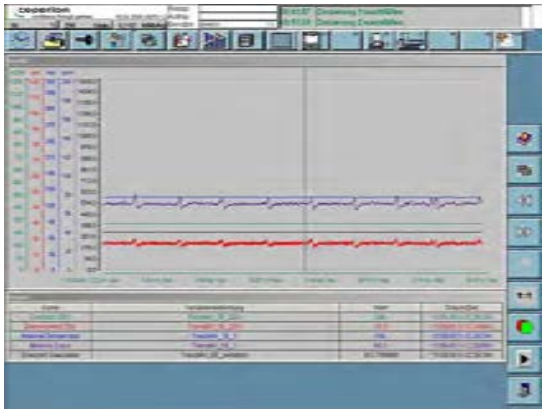
Feeding of bulk and other educts

feeders

Equal flow of feeders enables equal flow of extruder

Correct positioning in case of feed limited throughput very important

Good refilling procedure of feeder enables equal feeding // extruder flow



Process control panel

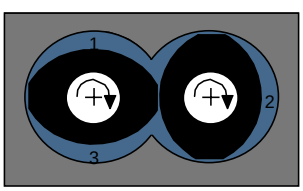
Torque in red

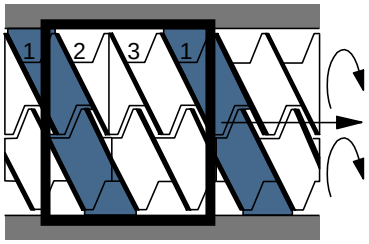
Pressure in violett

⇨ Feeder refill causing trouble

Intake of powder material

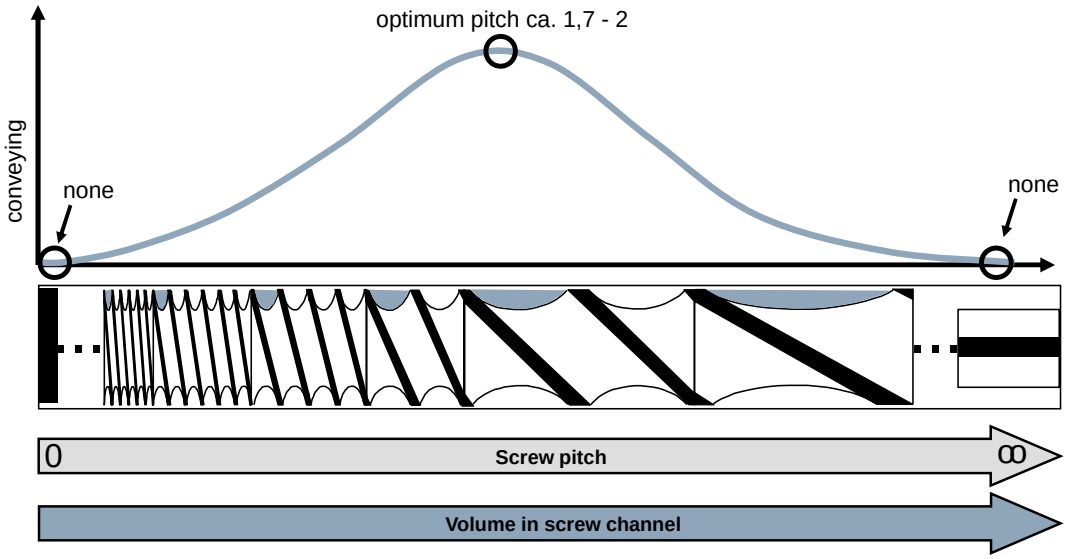
- Optimum pitch about 1,7D
- Barrel opening for three visible screw channels (2 Lobe)
- Powder should hit down turning (left) screw





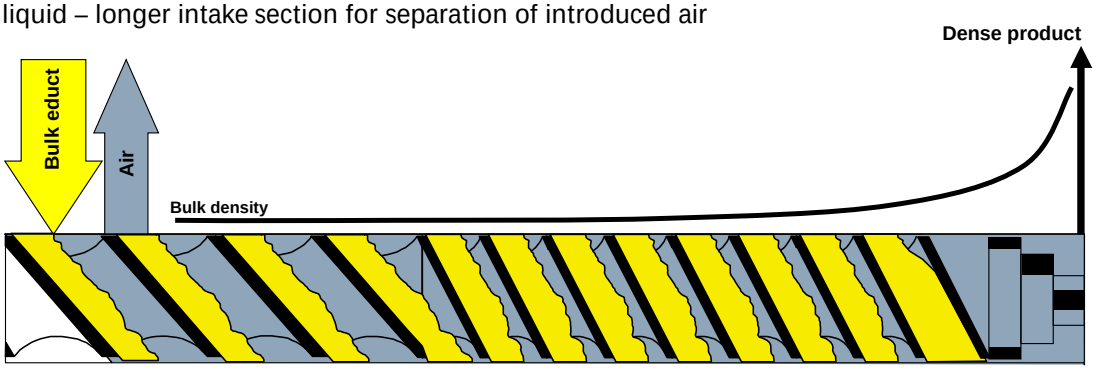
Feed zone

Optimal pitch



Feed section

- Take powder into the screw channels
- Transport away the powder
- Outlet for introduced air (between the particles of the powder)
- Air flows back through screw channels
- If without liquid – longer intake section for separation of introduced air



Problems in powder intake

Low bulk density powder
Fine particle size powder → more difficult
Without liquid addition



Consider:
Conveying efficiency
Available free volume (pitch of screw)

For difficult raw materials:

→ machine with large d_o/ d_i ratio (ZSK MEGA Volume for food products)
upstream venting
longer intake zone
side feeding unit ZS-B

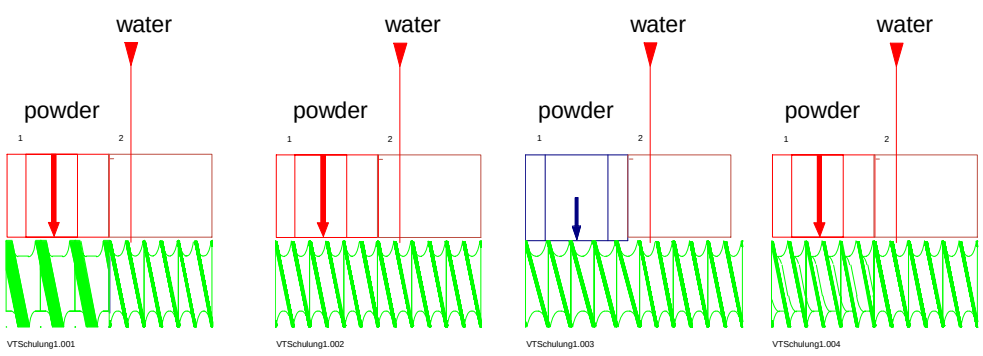
Lay out of feeding zone

Examples ZSK 43Mv

- 54/54 SF pitch 1,25
- 54/54 pitch 1,25
- 72/36 pitch 1,67 plus larger opening in barrel
- 54/54 SK (undercut)

Nondimensional pitch

Pitch [mm]/ do [mm]

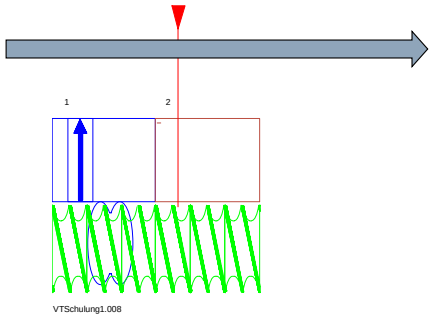


Feeding Zone with sidefeeder ZS-B

Twin screw side feeding device

Increased product intake by sidefeeder

- Screws with very large free volume do/ di = 2,0
- Sidefeeder screw speed independent from extruder screw speed
- Upstream opening in extruder barrel for venting of introduced air

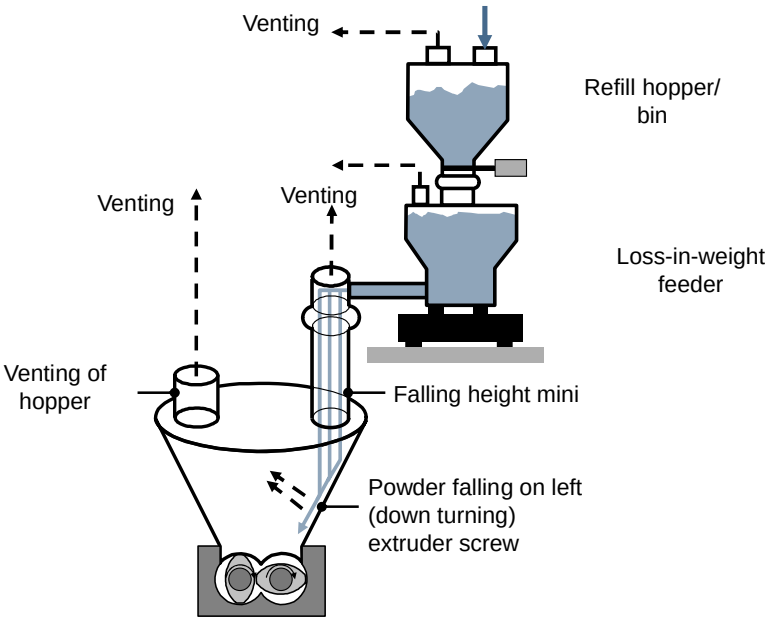




Correct installation of feeders

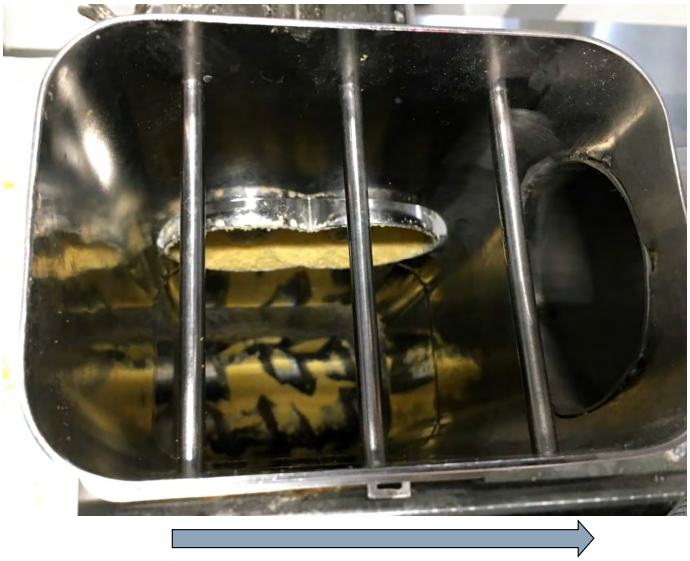
Decoupling of all aggregates (pressure and movement)

All vents either with filters or with exhaust sucction



Intake

Product falls from feeder onto left screw



open design feed hopper
With suction port (downstream side)

Minimized falling height from feeder to the extruder screws

Powder inlet

Venting: air stream coming out of inlet hopper



Extrusion Plant ZSK 43Mv

KT 35 Coperion Ktron powder feeder
Powder falling height minimized
Dust filter on inlet hopper
Loss-in-weight water feed pump



Injection of liquids and steam

3



Injection of liquids and water

As soon as possible after bulk product

Better conveying (stickier)

Higher density

Separation solids form air

Water injection: barrel temperature below 100°C





In partly filled zones pressure less possible

In more filled zones or zones with possible pressure or smearing of injection port

⇨ use WP-injection nozzle and pressure built up feeding pump

Versatile R&D lab extruder

ZSK 27Mv

Multiple openings for

- Liquid injection
- Side feeder
- Intake openenings

Openings, which are not in use, are plugged



Steam injection

Directly into the processing section

Process section has to be vapour proof (blocked by product inside the screw channels)

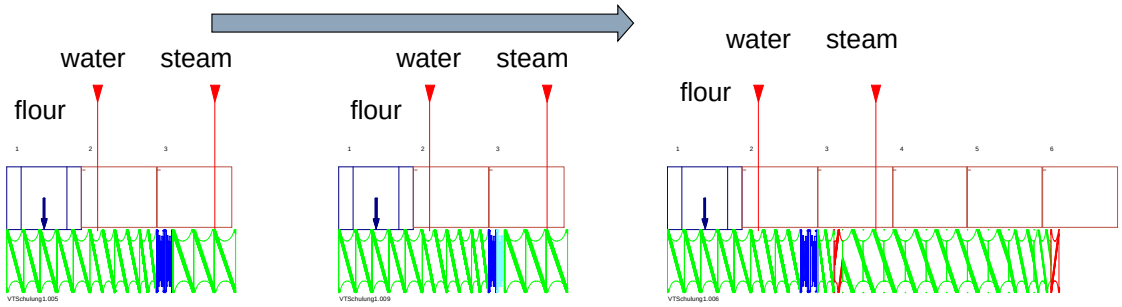
Prevent vapour from escaping via feed hopper to feeder

Seal the extruder with 100% filled screws

Adjust steam pressure

Low degree of fill in the extruder ⇨ More difficult to seal (small throughput/ high rpm)

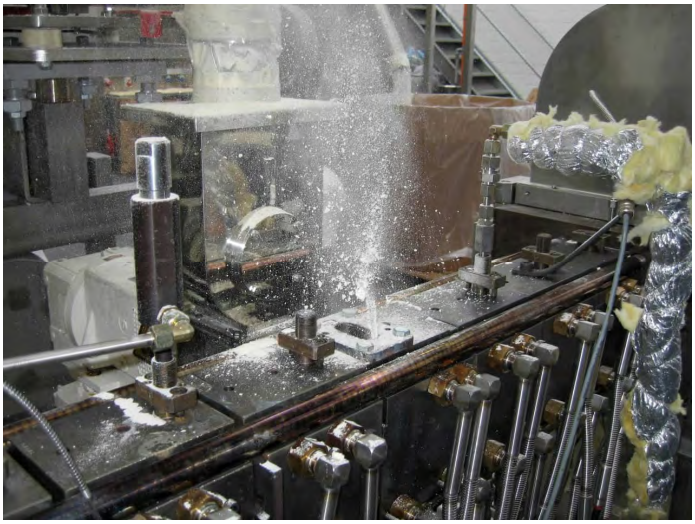
Allow vapour to condensate in large zone of low degree of fill



Steam injection

Extruder not sufficiently sealed

Upstream leakage: Sudden blow





Slow back flow

Cooking / plastification / melting zone

4



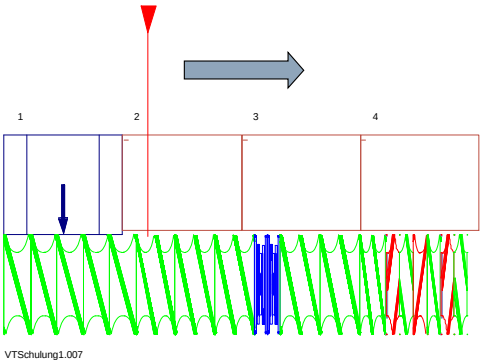
Standard cooking combination

Right-left combination

Mixing zone with small right-handed 45° kneading blocks

High shear left-handed conveying elements

90° stagger of left (reverse) elements to prevent from burnt material in recesses

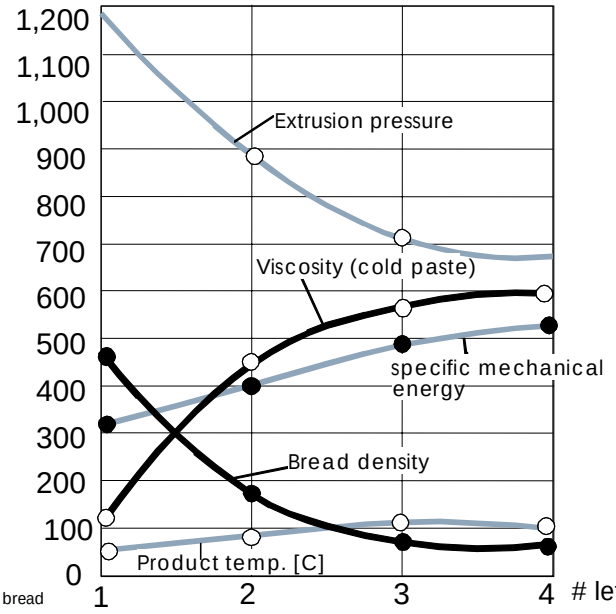


Variation of energy intake:

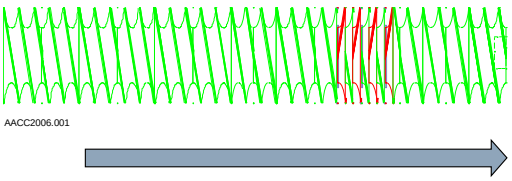
- Variation of count of left elements (max. 5)
- Longer distance between left elements (reduced shear)
- Kneading blocks upstream of left elements (increased shear)
- Two left elements consequently (much increased shear)

Impact of left-handed conveying elements

Effect of different screw configurations



Extruder	CONTINUA
Die	1 X 55 mm
Throughput	15 kg/h
Screw speed	190 RPM
Temp. set	150° C
Raw material	Wheat flour 550
Moisture	14.0%
Water addition	4.5%



Extrusion of flat bread

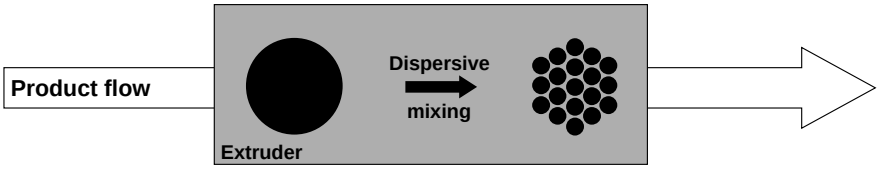
left elements (1/4 pitch length)

Working principle of screw elements

Dispersive mixing (= destroying of particles/ droplets)

Destroying of particles: big kneading blocks with thick crests; small stagger (prevent from flowing/slipping through)

Micronisation of droplets: see mixing



Conditioning of other matrices

By means of mechanical energy

e.g. melting of sugar matrices, „milling“ of particles, …

In general: shear by means of restriction against material flow

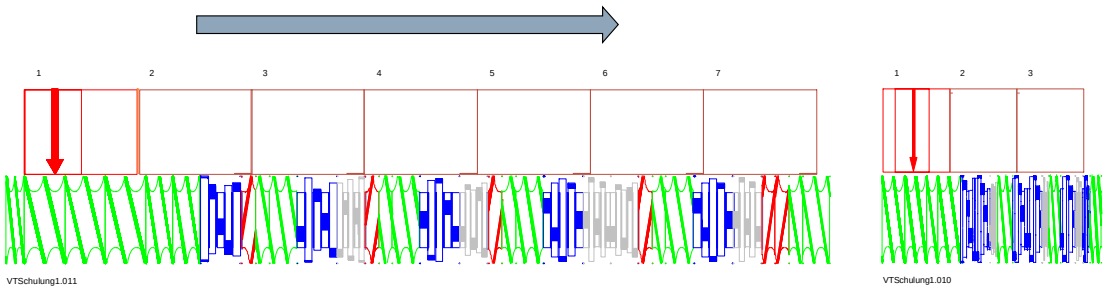
The more restriction the more shear

The bigger the crests of kneading blocks the more shear

The longer the residence time in the element the more shear

Typical element combinations

Right – left
Right – neutral – left
Right – neutral



5 Mixing zone



Working principle of screw elements

Distributive mixing (displacement of particles/ droplets)

Mixing length wise/axial

larger residence time and larger residence time distribution

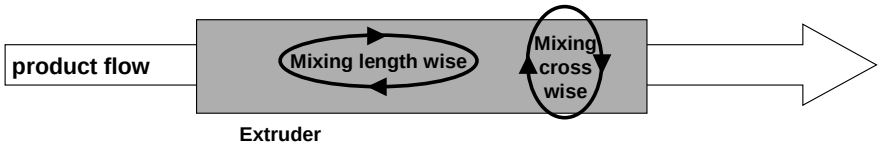
neutral kneading blocks, left handed kneading blocks, SME*, ZME, TME

Mixing cross wise/ radial

more narrow residence time distribution, shorter residence time

right handed kneading blocks (30°, 45°), sieve discs, TME (right hand turbine)

(to a lower degree all forward conveying elements)



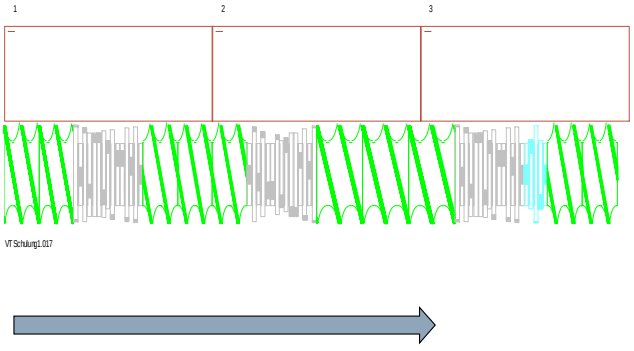
Mixing zone

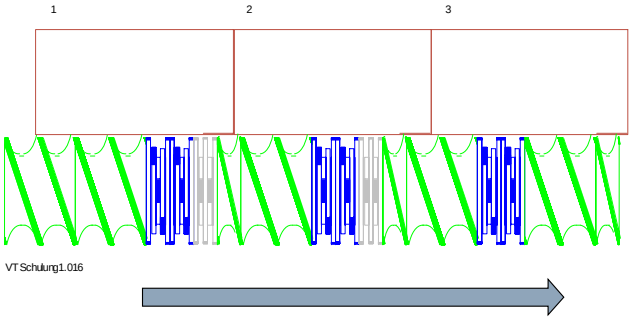
Intensive distributive for particles, dispersive for emulsions

Distributive mixing radial: kneading blocks with smaller stagger

Distributive mixing axial: neutral kneading blocks

e.g. building of new surfaces for reactive extrusion, emulsion forming...





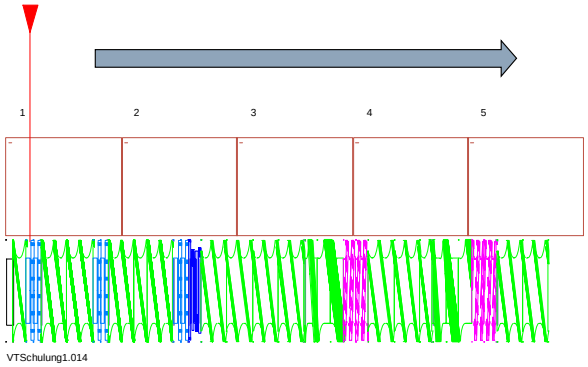
Mixing with non- self wiping elements

High shear dispersive and distributive mixing/ emulsion forming

Liquid injection into pressure zone possible

TME elements

ZME elements (single flighted left hand, cut crests)



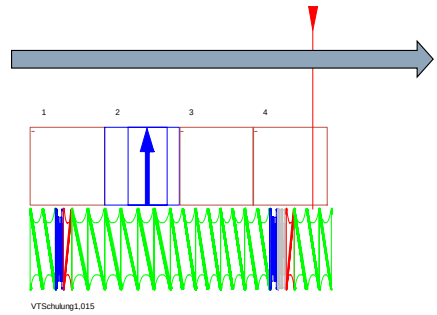
Degassing and venting

6



Degassing

- Getting rid of excess water as vapour or undesired volatiles
- Closing the screw by product dams for vacuum degassing
- “Pressure less” zone with low degree of fill in screws
  – (partial pressure of volatiles!)
- Atmospheric venting without dams possible



Remember:

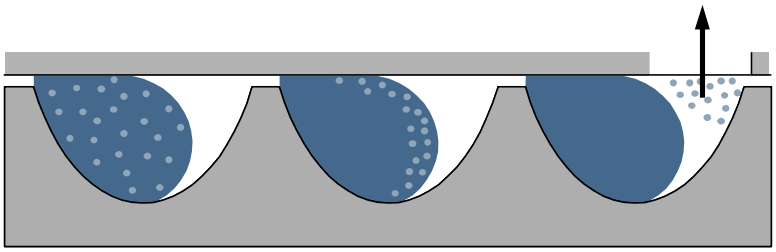
Gas volume increases with decreasing pressure (vacuum)

[gas volume to be transported away]

Partial gas pressure increases by decreasing pressure (vacuum)

[driving force]

Degassing principle



Separation of gas from plasticized product by diffusion

Gas has to come to the surface of the mass layer.

residence time
viscosity of mass
thickness of mass layer
renewal of mass surface
pressure difference

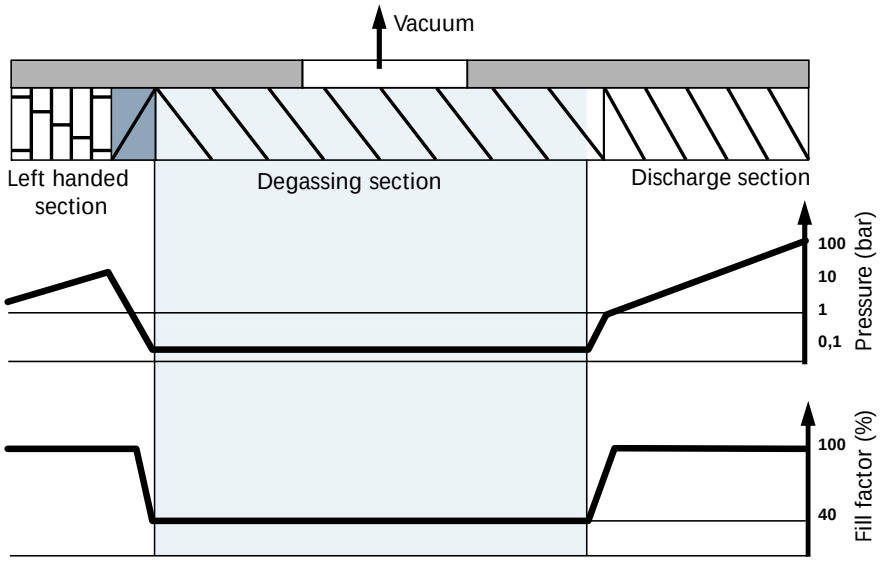
→

long degassing zone
low viscosity (= high temperature)
low fill factor of the screw (40%)
intensive mixing
vacuum

Atmospheric venting of water vapour



Degassing section

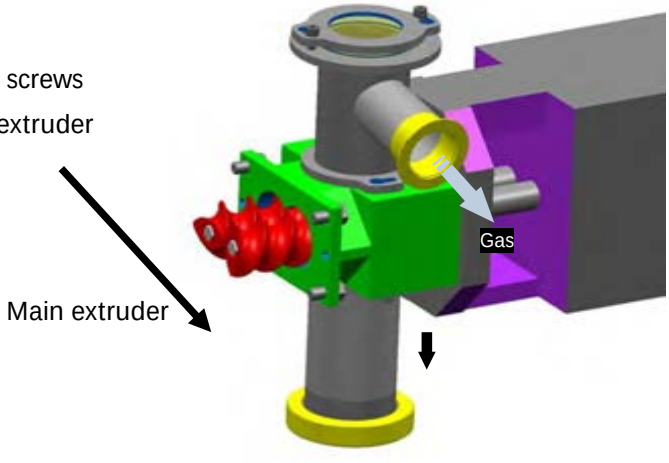


Good to know

Plastified mass also degassed in partly filled screw channels in closed barrel sections upstream and downstream of the vent opening

Degassing by twin screw side degassing

- ZS-EG
- Twin screw side degassing unit
- For difficult to handle products
- Mass stuffed back into main extruder by side screws
- No burnt particles can fall back down to the extruder

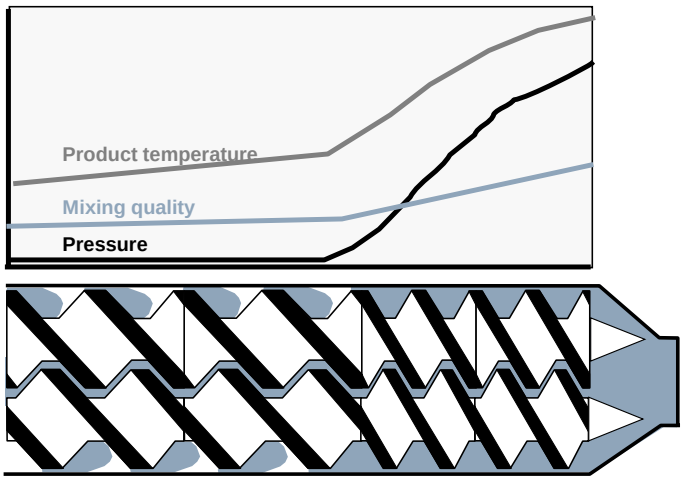


Pressure build up zone

7



Pressure build up zone



- Pressure build-up to pump mass through die plate / discharge
- Screws fully filled

Pressure build up zone

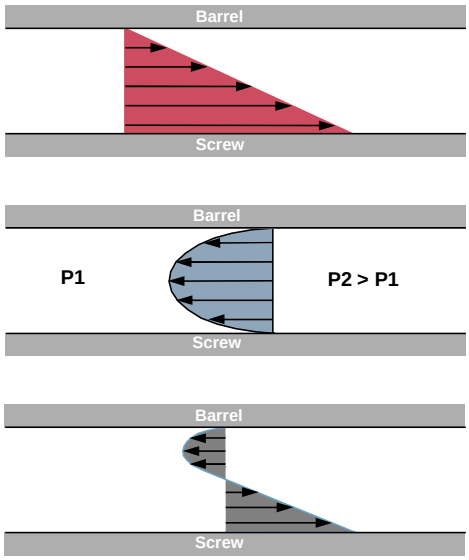
Drag flow

+

Pressure flow

↓

Combined flow



The extrudate flow is a combination of drag flow due to the rotation of the screws towards the screw tip and a pressure flow upstream

This results in a mixing effect

Flow pattern

Pressure build up zone

General layout information

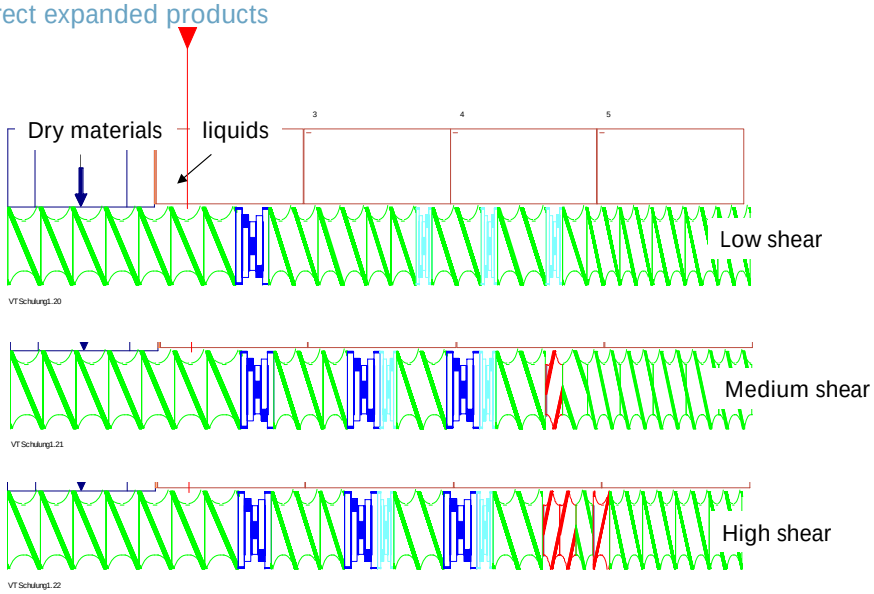
- Use elements with high conveying efficiency
- Small pitch for better pushing
- Caution with single-flighted and little dead space: pulsations possible
- Prevent filled length from unwillingly arriving cooking (shear) zone
- Dead space creates more pressure built up
- Dead space can reduce pulsations

8 Example screw configurations



Screw configuration examples

Direct expanded products

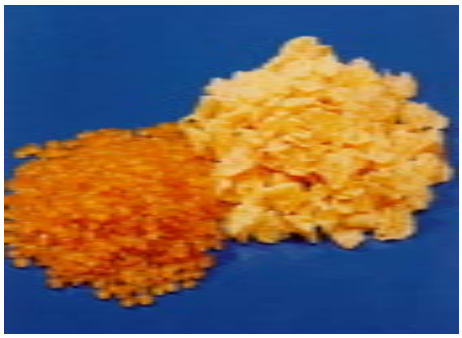


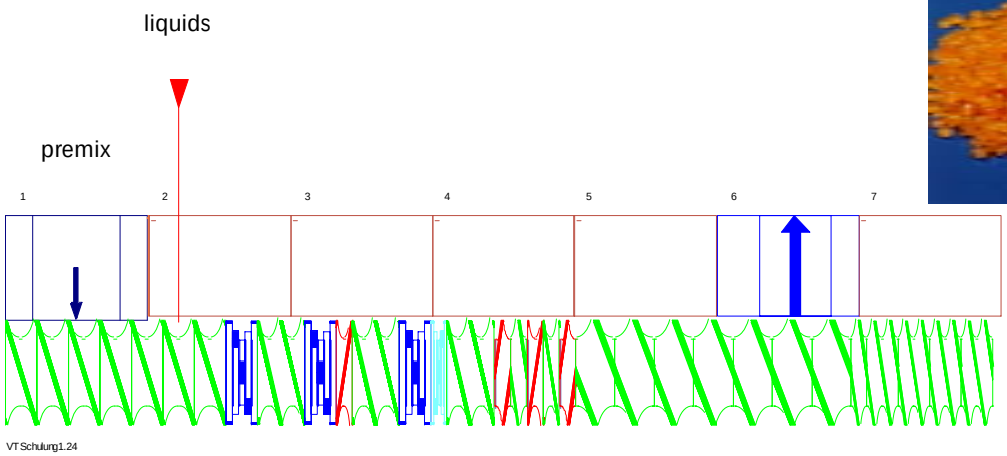


Feeding Mixing/Hydation/ Cooking/ Plastification Pressure build up

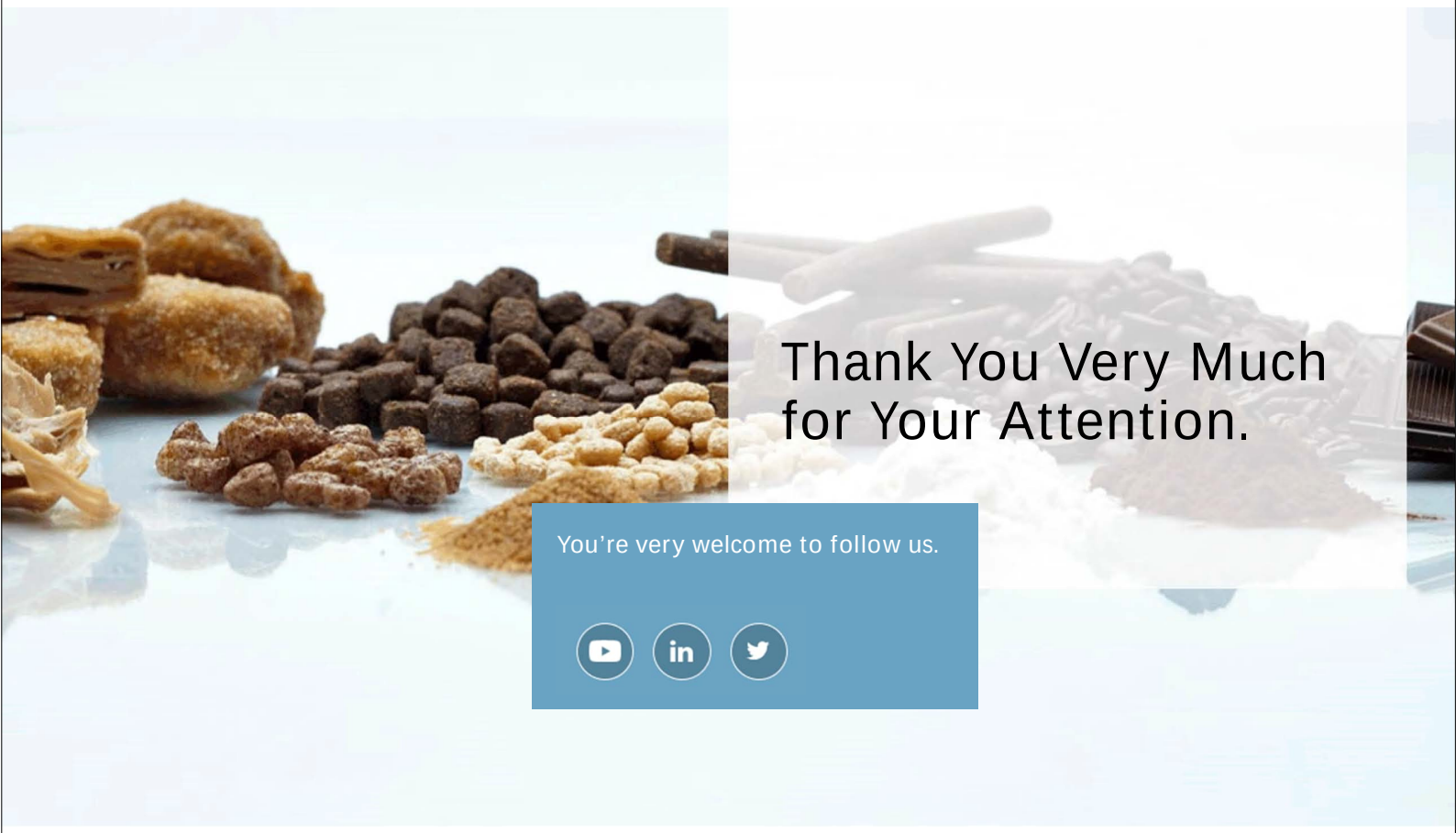
Screw configuration example for half products

Cold formed pellets





Feeding Mixing/Hydation/Cooking/ Plastification Degassing Pressure build up



Thank You Very Much for Your Attention.

You're very welcome to follow us.



Recipe Ingredients in Food Extrusion

Raw Materials and their Influence in Food Extrusion

Fabian Specht, Senior Process Engineer

1 Water

2 Starches

3 Proteins

4 Sugars

5 Fibers

6 Minor Ingredients

7 Basic Recipes

Ingredients Overview

Categorized based on their function

Major Ingredients

Matrix Forming Ingredients
- Starches and flours
- Proteins
- Sugars

Filling Ingredients
- Fibers
- Bran
- Some Proteins

Water
Steam

Minor Ingredients

Plasticizers
- Oil
- Emulsifiers
- Polyols (Glycerol…)

Coloring Ingredients
- Food coloring
- Reducing sugars
- Milk powder
- Cocoa

Flavoring Ingredients
- Spices
- Flavors
- Fruit concentrates
- Sugars
- Salts



1 Water

Essential for the majority of food extrusion processes

Water in Food Extrusion

Neither too little nor too much

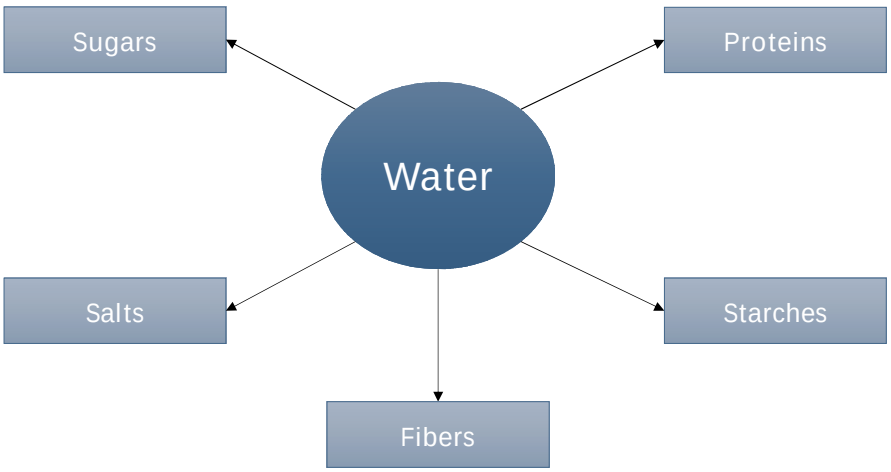
- Natural food polymers are not thermoplastic



- Almost all food extrusion processes need addition of water (otherwise burnt product)
  - an elastic mass or hydrated dough can be formed in the ZSK
  - water allows plasticizing the raw materials
  - water allows physicochemical reactions (gelatinization of starch, texturization, ...)
  - water is the basis for expanded extrudates (cereals, snacks, TVP, ...)
- Steam acts both as plasticizer and thermal energy input.
  when steam is added in addition to water, water addition must be reduced.

Water Availability

All ingredients interact with water!



Water binding influenced by

- Temperature
- Molecular structure
- Molecule affinity to water

Starches

2

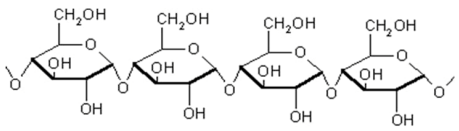


Molecular Structure

Polysaccharide with numerous glucose units joined by glycosidic bonds

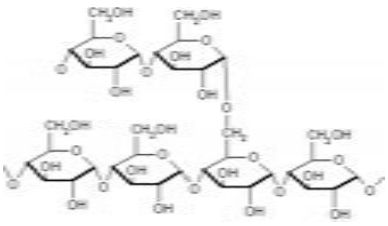
Amylose

Linear, low molecular weight biopolymer



Amylopectin

Branched, high molecular weight biopolymer



Recap from „Process Opportunities“

- Amylose and amylopectin are tightly packed in native starch granules
- They have a semi-crystalline form
- To exert functional properties and to interact with water and other molecules, they must be transferred to an amorphous state

Amylose vs. Amylopectine

Effects on extrusion and extrudate quality

High Amylose Content

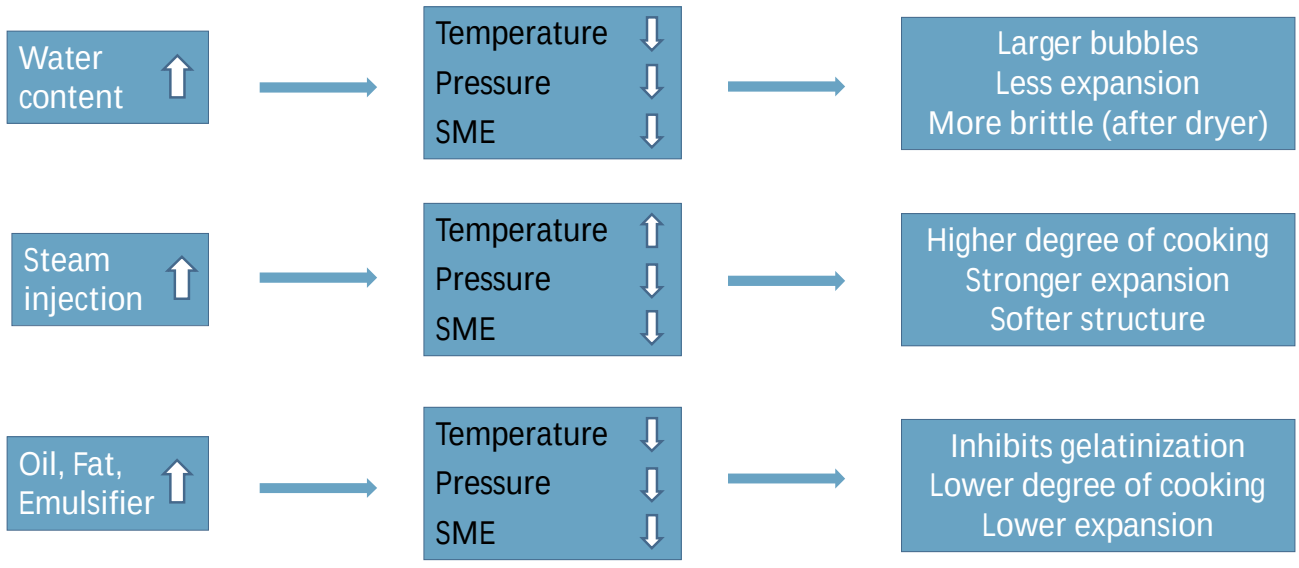
- Increased hardness
- Decreased expansion (compared to high amylopectine)
- More resistant to shear

Amylopectine

- Light, elastic but more brittle extrudates
- Increased expansion
- Higher cold paste viscosity in modified starches
- Branched molecules are easily degraded by mechanical shear stress

Starch Extrusion

Typical correlation of extrusion parameters and extrudate quality



Starch Extrusion

Same ingredients: which parameter(s) were changed?



Sample A



Sample B

Starch Extrusion

Different behaviour of flours at same processing parameters



Extruded rice flour

- Torn shape
- Crispy texture



Extruded wheat flour

- Keeps shape best
- No crispy texture



Extruded corn flour

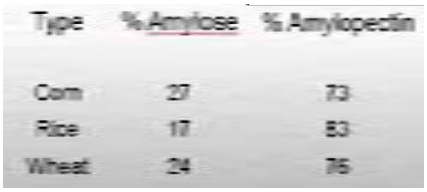
- More longitudinal expansion
- No crispy texture

Each raw material needs individual optimization of process parameters

Starch Extrusion

Different behaviour of flours at same processing parameters

Sample		rice	wheat	corn
screw speed	[min^{-1}]	350	350	350
torque	[%]	47	43	41
throughput	[kg/h]	109	109	109
S-mech	[kWh/kg]	0,103	0,094	0,090
T_{m1}	[°C]	160	159	153
p_1	[bar]	64	70	49
flour	[kg/h]	100	100	100
water	[kg/h]	9	9	9
summation	[kg/h]	109	109	109



Type	% Amylose	% Amylopectin
Corn	27	73
Rice	17	83
Wheat	24	76

Observation

- Both wheat and corn would need less water addition for crispy texture. They have less amylopectin than rice.
- Torque was highest for rice, which has most amylopectin.

Starch Extrusion

Influence of particle size

Wide particle size distribution

- Reduced expansion
- Increased bulk density of extrudate

Larger particles

- More time / higher temperature needed for hydration
  (starting to be relevant above 500 µm)
- Milling energy
  (for example, if pellets of several mm size are milled and crushed)
  - typically, there is no significant difference in SME
  - on very small extruders, pellets can result in torque peaks

Proteins

3



Protein Powders

Feeding to extruders

- Can have low bulk density
- Can have very small particle size
  ~ 3 µm (especially after dry fractioning process)
- Can stick to the hopper walls due to adhesive or electrostatic forces
- Can fluidize at high extruder screw speeds





- Advantage of high free screw volume of MEGAvolume extruders
- Feeding of protein powders as pellets is possible to extruders
- Mixtures of different proteins or proteins with coarser materials

Proteins

Effects in starch-based extrusion

Different effects, depending on protein type

- Corn flour extrusion: less protein content → increased expansion
- Wheat flour extrusion: addition of soy protein → increased expansion
- Wheat flour extrusion: addition of gluten → decreased expansion, more stable shape

Remember:



Extruded wheat flour

- Kept shape best

4 Sugars

or sugar-like ingredients



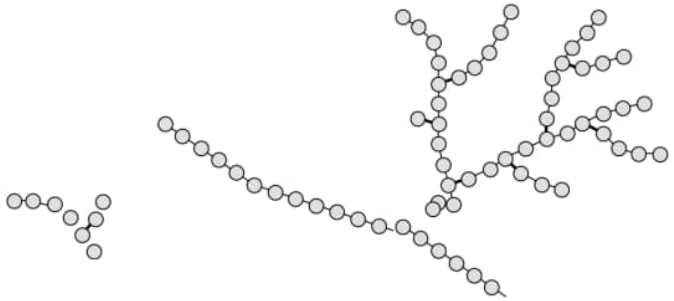
Extrusion of Sugar and Sugar-like Ingredients

- The typical unit operation is melting
  sometimes combined with dissolving and mixing
- SME might be estimated:
  Melting enthalpy + warming enthalpy (dominant)
  plus: energy for mixing + energy for pressure build-up
- Possible energy input by mechanical energy is limited
  (the melt is low viscous)
- Sugar particle size distribution should be very narrow
  (hence all particles melt at the same point of the screw)



Extrusion of Maltodextrin

- Maltodextrin: oligosaccharides obtained by partial hydrolysis of starch
- Classification by DE-value (dextrose equivalent)
  - low DE (3 - 10): long molecules, more starch like behavior
  - high DE (10 - 20): short molecules, more sugar like behavior
    - Lower glass transition temperature (of extrudate)
    - Cold water solubility
- Different maltodextrin types:
  => different behavior in the extrusion process
- Versatile application in the food industry.
  most common extrusion application:
  Encapsulation and confectionary extrusion



Maltodextrin Amylose Amylopectin

Sugars

Effects in non-sugar-based extrusion

- Addition < 10 %
  - minor influences on process
  - reduced expansion
  - more crispy bite of direct expanded cereals / snacks

  BUT:
  Reducing sugars result in browning (Maillard reaction)
  - glucose, lactose, maltose, fructose ...
  - desired effect: glucose added to extruded breadcrumbs
  - undesired effect: TVP browning > 160 °C



Baked | Extruded | Extruded + 5 % Glucose

- Addition > 10 %
  - dough / melt viscosity decreases significantly
  - mechanical energy input is reduced significantly
  - starch gelatinization is inhibited

5 Fibers



Fibers

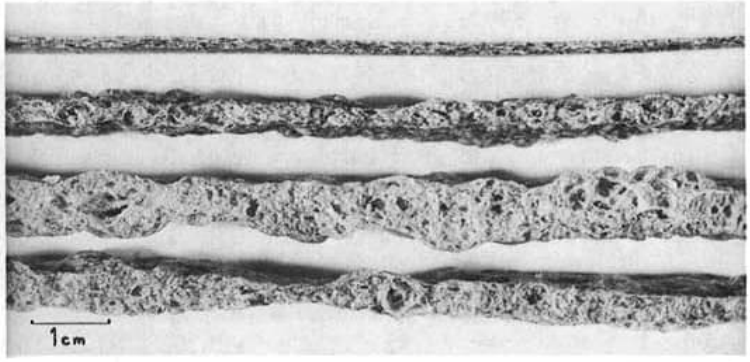
Definition and why are they interesting for food extrusion?

- Fibers in food extrusion are typically organic materials which are dispersed in the continuous phase (matrix)
  - insoluble fibers (carbohydrates in plant cell walls)
    - cellulose, hemicelluloses and lignin
  - soluble fibers
    - inulin oligofructose, beta-glucans, pectin, gums, dextrin,...
- Found in bran, hulls, seeds, stalks, leaves...
- Functional effect (water binding)
- Nutritional benefit of fibers
- Fibers as low-price fillers

Fibers

Effects in flat bread extrusion

	Ingredient, % (w/w)		
Formula	**Bran**	**Starch**	**Gluten**
I	50	40	10
II	30	60	10
III	10	80	10
IV	30	70	···



Y. ANDERSSON, B. HEDLUND, L. JONSSON, and S. SVENSSON, SIK—The Swedish Food Institute, S-400 23 Göteborg, Sweden

Fibers

Other effects

Expanded Extrudates:

- Act as nucleation agents for expansion bubbles (finer pore structure)
- Similar effects of insoluble proteins or resistant starches



2 %
Wheat fiber

Texturized Proteins:

- Promote fibrous textures (dispersion of insoluble fiber in the continuous phase)



6 %
Pea fiber

6 Minor Components



Plasticizers

Examples

- Decrease viscosity, glass transition temperature and tensile strength
  - mainly by weakening molecular interactions
  - or due to their lower melting point or viscosity
- Glycerol, sorbitol, oils, ...
- Can (partly) replace water
  - e.g., glycerol in pet treat formulations

- Emulsifiers also act as plasticizer, besides their emulsification function
  - monoglycerides of fatty acids, sodium stearoyl lactylate, lecithin

Plasticizers

Effects in food extrusion

- Addition < 0,5 %
  - minor influences on process
- Addition 0,5 - 5 %
  - dough / melt viscosity decreases
  - mechanical energy input is reduced
  - reduced expansion
  - reduced texturization but smoother surface, better die flow
- Addition 5 - 10 %
  - dough / melt viscosity decreases significantly
  - mechanical energy input is reduced significantly
  - starch gelatinization is inhibited
- Addition 10 – 20 %
  - very challenging for processes which need SME or starch gelatinization
  - partial help by use of emulsifiers


Extruded starch pellets


1 % oil addition

Minerals and Salts

- NaCl:
  addition of 1 - 1,5 % for flavoring. Mostly little influence on process.
- $CaCl_2$:
  - Ca-ions can form strong ionic bonding in food polymers
    result in more firm textures
  - alginate, pectin, proteins
- NaHCO3 or baking powder:
  - finer expansion pores and lighter color
- $CaCO_3$:
  - nucleation agent for direct expanded extrudates => finer expansion pores and lighter color
- pH value of process has influence on product quality
  - proteins have lowest charge at isoelectric point
  - limited flexibility in terms of using low or high pH in foodstuff
- Tap water quality:
  - demineralized versus Stuttgart tap water: no significant influence on HMMA quality

Coloring Ingredients

- All sorts of food colorings might be used in the extrusion process

Considerations:
- temperature or oxidation stability might be an issue
- Individual evaluation necessary, considering the short residence time in extrusion
- increased cleaning efforts
- extrudate can be used in less end products
  (compared to a basic HMMA which is marinated downstream)

Examples:
- $CaCO_3$: lighter color
- Oils or fats: lighter color
- Reducing sugars for Maillard browning (e.g., milk powder)



Encapsulated flavor with blue coloring



HMMA with curcuma powder

Flavoring Ingredients

Generally, minor effects due to minor addition

Considerations:

- temperature or oxidation stability or protein-flavor interactions
- increased cleaning efforts
- extrudate can be used in less end products

But:

- Flavors with fatty acids or oils can influence HMMA extrusion process for example
  - die flow, energy input, texture



Soy based HMMA



+ 1 % flavor

Basic Recipes

7



Basic Recipes

Extruded Snacks

Group	Ingredients	% by weight		
		Product A	Product B	Product C
Structure forming materials	Wheat flour	-	-	70.0
	Maize grits	85.0	50.0	-
	Potato granules	-	20.0	-
	Potato starch	-	5.0	-
Dispersed phase filling materials	Soya protein	-	-	5.0
	Wheat gluten	-	2.0	-
	Wheat bran	-	-	10.0
Plasticisers and lubricants	Oil (soya, palm,rape)	1.0	1.5	1.0
	Emulsifier	0.3	0.3	0.3
	water	18.0	18.0	16.0
Nucleating reagents	Sugar	-	-	5.0
	Maltodextrin	-	5.0	-
	Salt	1.0	1.0	1.5
	Flavourings	+	+	+
Flavouring agents	Baking powder	-	1.5	-
	Dicalcium phosphate	-	-	1.5
Colouring agents	Milk powder	1.0	2.0	2.5
	colour	+	-	-

FRAME N.D.: The technology of extrusion cooking, p.53, 1994

Product B:

- Gluten: nicer shape
- Baking powder: finer pores

Product C:

- Soy and bran for desired expansion

Basic Recipes

Extruded Breakfast Cereals

Group	Ingredients	% by weight		
		Product A	Product B	Product C
Structure forming materials	Wheat flour	15.0	-	20.0
	Rice flour	-	85.0	30.0
	Oat flour	-	-	35.0
Dispersed phase filling materials	Soya flour	2.0	-	-
	Wheat gluten	-	2.0	-
	Wheat bran	70.0	-	-
Plasticisers and lubricants	Oil (soya, palm,rape)	0.5	0.5	1.0
	Emulsifier	0.3	0.5	0.3
	water	18.0	18.0	16.0
Nucleating reagents	Sugar	10.0	5.0	10.0
	Maltodextrin	-	5.0	-
	Salt	1.0	1.0	1.2
Flavouring agents	Baking powder			1.5
Colouring agents	Milk powder	1.0	2.0	2.0

FRAME N.D.: The technology of extrusion cooking, p.54, 1994

Product A:

- High bran cereal
- Oil/emulsifier and soy for optimized shape

Product B:

- Crispy rice cereal

Product C:

- High sugar cereal
- Baking powder for better expansion

Basic Recipes

Extruded Breakfast Cereals

Rice crispy without sugar

Ingredient	%
Rice flour	81.0
Barley malt flour	17.8
Salt	1.2



Oat loop

Ingredient	%
Wholegrain oat flour	70.0
Corn flour	25.3
Sugar	4.0
Calcium Carbonate	0.5
Salt	0.2



Multigrain flake

Ingredient	%
Whole wheat flour	76.6
Whole rice flour	10.1
Polydextrose	9.0
Oat fibre	4.0
Salt	0.3
Sucralose	0.02



Basic Recipes

Texturized Proteins

Pea based HMMA

Dry Premix:

Ingredient	%
Pea protein isolate	87
Pea fiber	12
Salt	1

~55 % water addition on top into the extrusion process



Soy and wheat TVP

Dry Premix:

Ingredient	%
Soy protein isolate	72
Vital wheat gluten	18
Starch	10

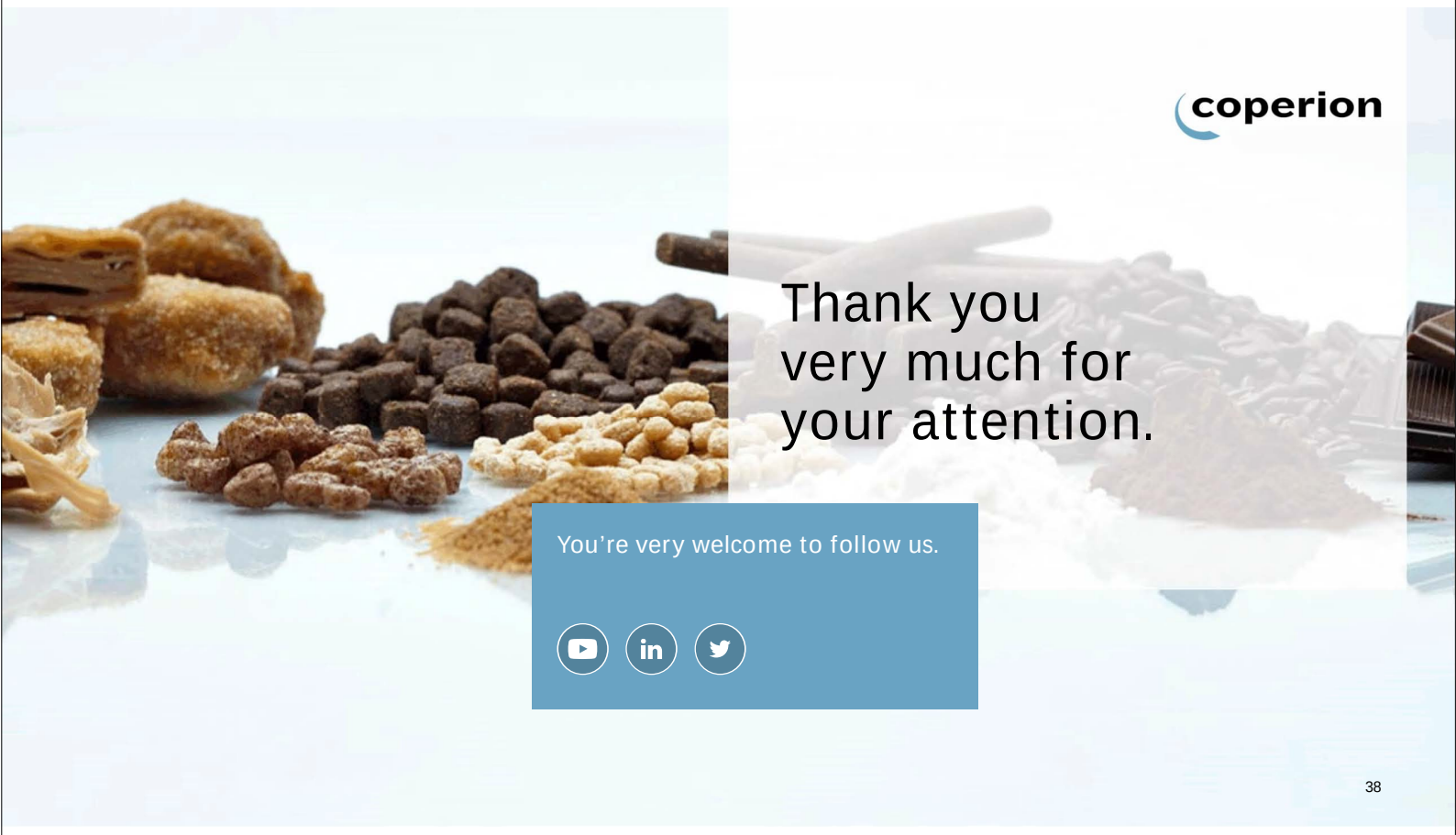
~30 % water addition on top into the extrusion process



Summary

Recipes and extrusion in a nutshell

- Define the basic recipe, first simple then complex
- Understand the properties and function of the ingredients in the extrusion process
- Design the process and its parameters accordingly
- Do trials and optimize based on the results
- Be aware of unpredictable interactions





Extrusion Process Examples

Food Extrusion Seminar Intense 2026

Uta Kühnen, Process Engineer Food Extrusion
Tobias Angres, Process Engineer Food Extrusion

1 Texturized proteins
2 Product examples - TVP
3 Post processing – TVP
4 Product examples - HMMA
5 Post processing - HMMA
6 Protein sources
7 Encapsulation of flavours and sensitive ingredients

Texturized proteins

1



Texturized proteins – TVP & HMMA

Texturized Vegetable Protein

(TVP)



High Moisture Meat Analogue

(HMMA)



Texturized proteins – TVP & HMMA

Comparison of characteristics

	TVP 	HMMA 
Water addition [%]	10 – 30	50 – 70
Extrudate exit temperature [°C]	120 - 170	70 – 100
Storage conditions	Dried, bulk product	Chilled or frozen
Texture	Expanded, fibrous	Dense, layered fibers
Application	Soaked in water prior to use	Ready to eat
Used for	Burger patties, minced meat, sausages	Meat like pieces, muscle meat-like products

Texturized proteins – TVP & HMMA

TVP & HMMA extrusion process





Texturized proteins – Hardware layout

One Hybrid-system – Two possible processes



pelletizer





cooling die



Product examples - TVP

2



Dry texturized vegetable protein (TVP)

Quality parameters – depending on application



- Water absorption capacity
- Duration and speed of hydration
- Fiber texture / length / strength
- Bulk density
- Shape
- Extrudate surface
- ...

Dry texturized vegetable protein (TVP)

Examples – pea based



Dry chunk



Chunk after soaking in water

Dry texturized vegetable protein (TVP)

Examples – Soy based



Dry chunk



Chunk after soaking in water

Dry texturized vegetable protein (TVP)

Examples – TVP-based end products



Hamburger patties



Fried minced meat

Dry texturized vegetable protein (TVP)

Examples – TVP-based end products



Sausages



Meat balls

Dry texturized vegetable protein (TVP)

Examples – TVP based end products



Fish fingers

- Considerations in application of dry texturized proteins:
  - Cutting / shredding
  - Rehydration
  - Seasoning
  - (Re-)Shaping

Dry texturized vegetable protein (TVP)

TVP-based dishes – Prepared and ready to serve



Fresh vegetable and TVP meals (Fava bean based)





Large TVP chunks - pan fried

Post processing - TVP

3



Granulation of TVP with die-face cutter

Different shapes and sizes achievable







Post-processing TVP: Further steps

Depend on the application in the end product.

Shredding:

- Increases open pore surface
- Can increase water uptake

Drying

- Consider different dryer types

Rehydrating

- Consider rehydrating with seasoned liquid

Reshaping

- Mix TVP with binders, seasonings, oil/fat to achieve cohesion and shape product (e.g., by filling in casings)

Packaging



Different end products require different post-processing.



Product examples - HMMA

4



HMMA (wet texturized proteins)

Quality parameters – depending on application



- Texture:
  - Toughness
  - Elasticity („Squeakyness“)
  - Fiber strength
  - Juiciness
- Colour
- Shape
- Extrudate surface
- ...

HMMA (wet texturized proteins)

Examples – intermediate product



Directly after extrusion



Shredded and marinated

HMMA is an intermediate product - further processing is necessary

HMMA (wet texturized proteins)

Examples – HMMA-based end product



Chicken chunks



Chicken nuggets

HMMA-based end product examples

HMMA (Wet Texturized Proteins)

End product examples



Chicken curry

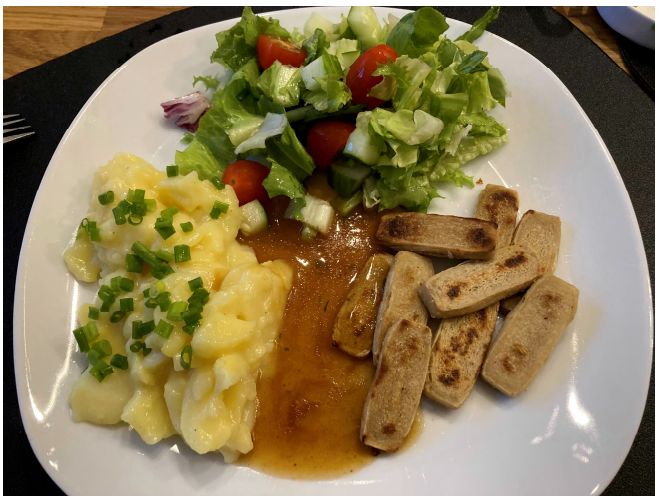
- Considerations in application of wet texturized proteins:
  - Cutting / shredding
  - Cooking
  - Marinating
  - Seasoning

HMMA (Wet Texturized Proteins)

HMMA-based dishes – Prepared and ready to serve



Chicken breast filet



„Maultaschen“ (swabian dumplings)

Post processing - HMMA

5



Post-processing HMMA: Cutting

Endless strand HMMA requires at least cutting after the extruder.







HMMA exits cooling die as an endless strand.

Post-extrusion cutting allows a vast variety of forms and shapes.

Considerations:

- Cut directly after extrusion
- Cut after freezing /thawing /cooking
- Cutting direction (along or across the fibers)
- Cutting type (clean cut or ripping/tearing)

Post-processing HMMA: Cutting

Different shapes and sizes possible.



Post-processing HMMA: Further steps

Possible further steps (depend on the application in the end product)

Blanching / Cooking:

- Water uptake up to 30 % possible

Marinating (wet seasoning)

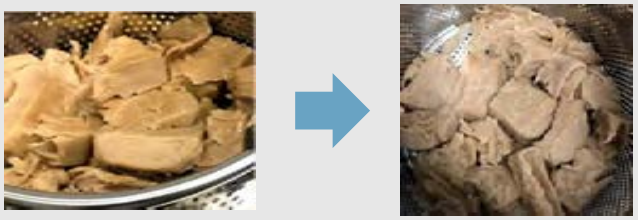
- Oil-based / Emulsion-based marinades can further increase product weight

Dry seasoning

Preservation

- Pasteurization
- Freezing/cooling
  - *Method of cooling has been shown to significantly influence HMMA structure and texture*

Blanching



Marinating



Possible ingredients

6



Protein sources for texturized proteins

Potential protein sources

- , Legumes & Pulses
  - Soy, Pea, Fava Bean, Chickpea Lentil, Lupin, ...
- Cereals & Tubers
  - Wheat, Corn, Rice, Potato, ...
- Seeds
  - Pumpkin, Sunflower, Rapeseed, ...
- Novel Sources
  - Algae, Fungus, Bacteria, ...
- Hybrid Products
  - Including Fish, Meat, Milk, Insects, ...



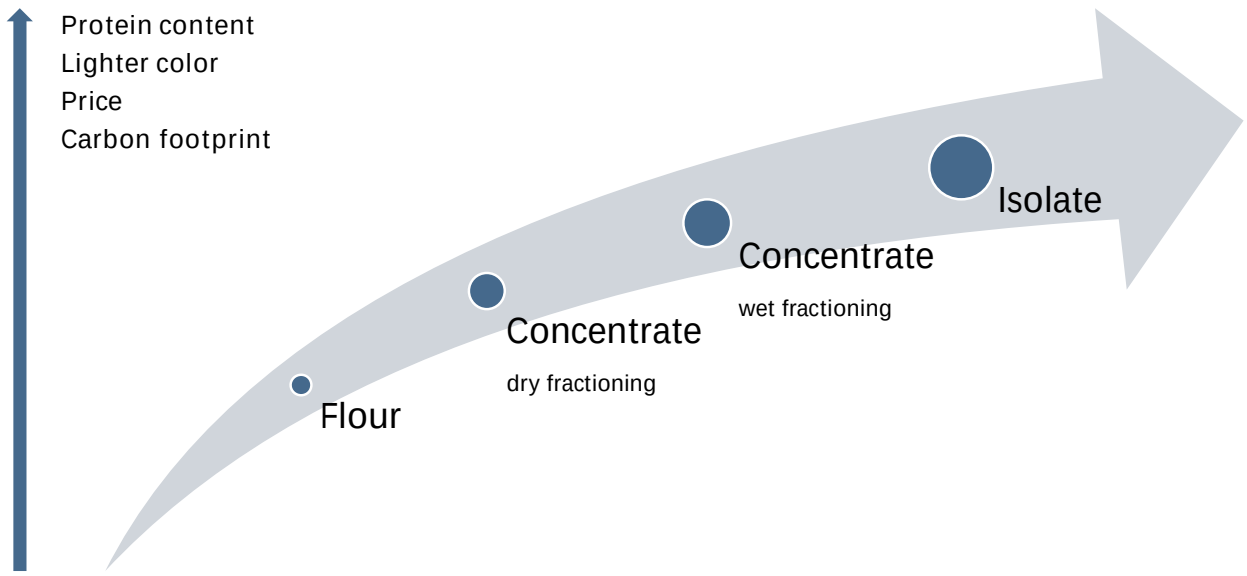
Comparison of different plant protein sources

Final product properties depend strongly on raw material characteristics

	Price	Availability	Fat content	Allergy potential	Color	Natural flavor	Fiber strength
Soy	+	++++	+++	+++	beige	++	+++
Pea	++	+++	+	+	brownish	+++	++
Wheat	+	++++	+	+++	beige	+	+++
Pumpkin	++++	+	+++	+	dark green	+++	++
Lupin	++	+	++	+++	yellowish	++	++
Potato	++++	++	+	+	dark brown	++++	+++
Fava bean	++	+++	+	+	beige	++	+++

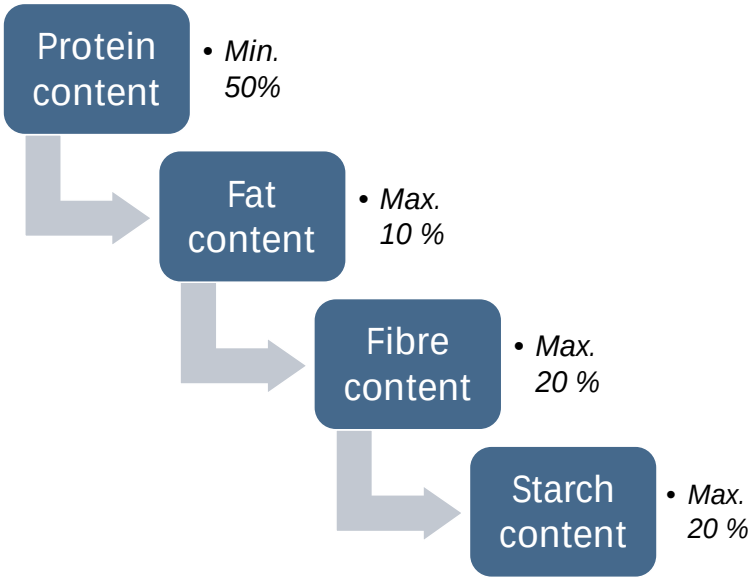
Comparison of protein product types

High protein contents require more intense processing steps



Raw material selection for texturized proteins

Certain requirements for protein raw material in texturized proteins



- Protein is the basis for network formation
  → *low protein content results in soft/weak texture*
- Fat can negatively influence processing in extruder
  → *must be limited*
- Fibres can negatively influence structure formation
  → *must be limited*
- Starches can negatively influence network formation
  → *high starch content results in doughy texture*

7 Flavours & sensitive ingredients



Reasons for microencapsulation

Sensitive ingredients

For encapsulation

- Aroma/ flavour
- Nutraceuticals
- Minerals
- Enzymes
- Vitamines
- Colours
- Microorganisms (dried)
- ...

Flavours in Food Formulations

General view

- Small amounts needed
- Volatile
- Low flash point / explosion protection issues
- Liquid
- Prone to degradation by oxigen and (sun)-light
- Expensive
- Value determing ingredient
- Difficult handling in processing of foodstuff
- Prone to degradation during processing of foodstuff

Reasons for Microencapsulation

In the Food Industry

- Transferring a liquid to powdered form for easy handling
- Avoiding explosion protection measures in application part/ at customer's site
- Prolonged shelf life protection against oxidation
- Controlled release of encapsulated substsance
  - During processing
  - During preparation
  - During consumption (flavour burst)
  - During digestion
- Adding nutritional value
- Adding sensoric effects
- Masking off-flavours
- Avoid reactions between ingredients (incompatibilities)
- Altering surface activity (i.e. from lipophilic to hydrophilic)

Embedding

If encapsulant and matrix are miscible

Avoid dust formation

Get in better dosage form

If there are incompatabilities

No strict distinction between embedding and encapsulation

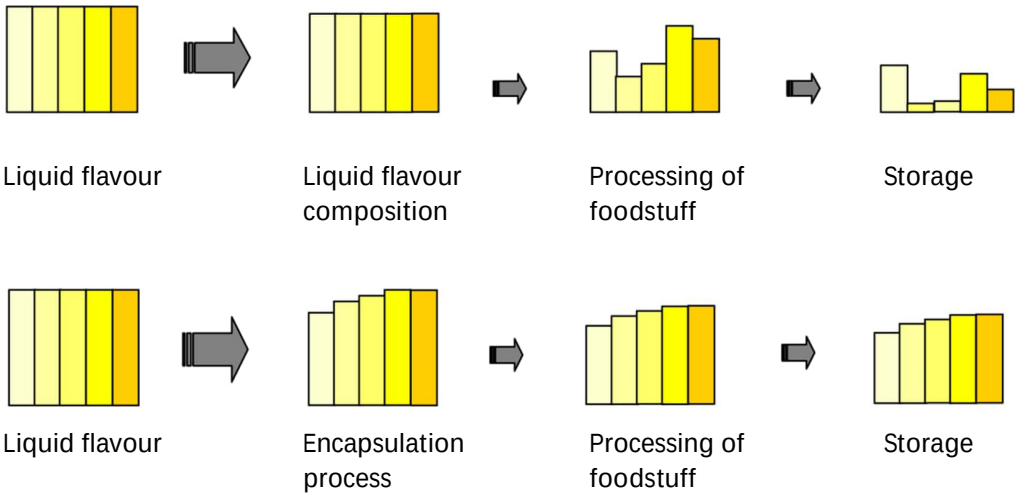
Smooth transition

Similar to encapsulation

Advantage of flavour encapsulation

Maintaining flavour profile during processing and storage

Extracted from Reinders, Symrise, FEI 2007

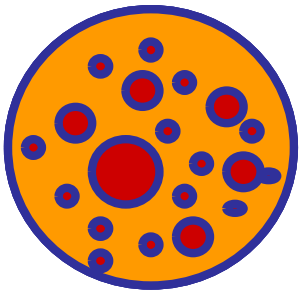


8 Encapsulation process by Extrusion



Matrix encapsulation

Differenciation to mononuclear capsul



Particle/ droplet
Embedded in a matrix

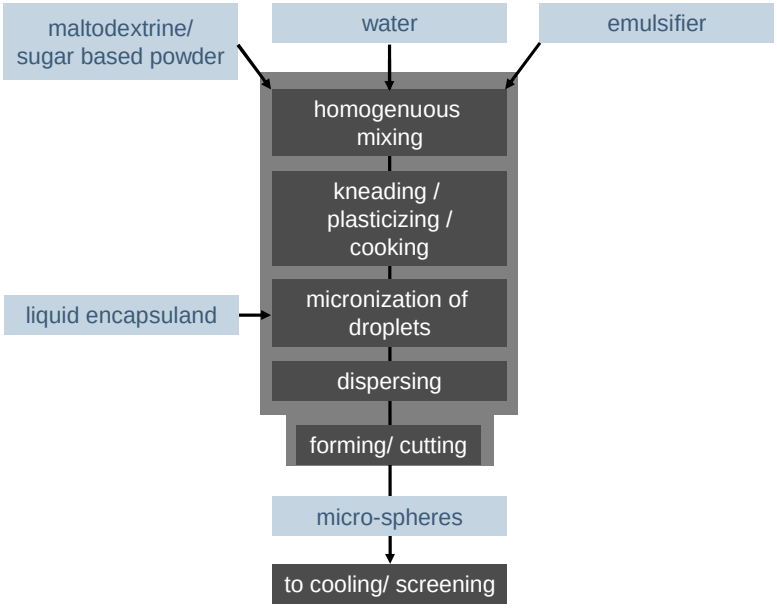
Optional:
core/ matrix encapsulated
or enrobed



Schematic image of an extruded pellet with encapsulated substance

Encapsulated Products

Flow chart





Encapsulation matrix

Continuous phase

Glassy when finished at ambient temperature

Viscosity during processing

Stickyness at die

Surface activity and emulsification capacity

Transition from liquid to solid

Water addition

Allow for low processing temperatures and soft treatment of the product inside the extruder

Compatibility of matrix with encapsulant

Comparison of encapsulation technologies

For flavour encapsulation

Technology	Flavor Loading	Shelf Life (years)	Particle/Capsule Size (mm)	Morphology	Solubility	Key Features
Spray Drying	10-40% (typ. 20-25%)	0.5-1	0.01-0.1	Fine powder	Good water solubility	Standard technology, cost-effective, very small particles.
Spray Bed Drying	2-40% (typ. 20-25%)	1.5	0.03-0.3	Agglomerated powder	Rapid dissolution, even in cold water	Suitable for alcohol encapsulation.
Fluid Bed Spray Granulation	20-25%	2	0.6-0.9 or larger	Spherical granules	Water-soluble	Hard, crunchy beads; suitable for alcohol encapsulation.
Compaction	5-20%	1.5	0.4-3.2	Irregular particles	Slow dissolution	Enables incorporation of flavors with fruit particles, additives, or functional ingredients.
Extrusion	4-8%	Up to 4	0.6-1.0	Spherical or rod-shaped or customized	Good water solubility	Longest shelf life; very hard glass-matrix particles.

Challenges in Product Development

For new clients

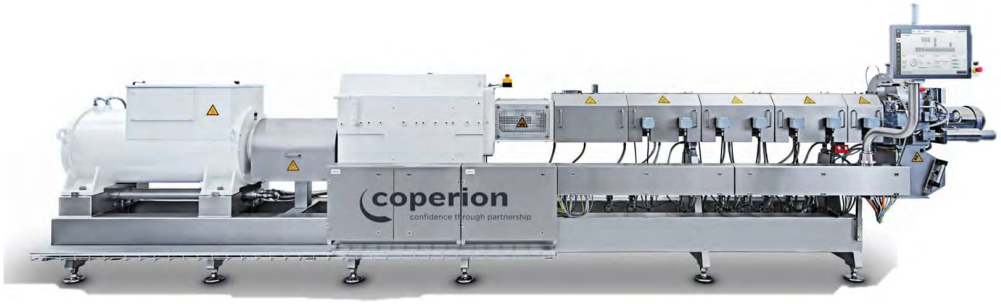
Extrusion completely different to other encapsulation techniques

Different recipes for matrix

Different flavour composition

Recipe & process development simulatniously needed

ZSK 76 MEGAvolume for flavour encapsulation



Challenges in flavour encapsulation

For process and equipment

Very precise feed rates -> difficult for small throughput rates

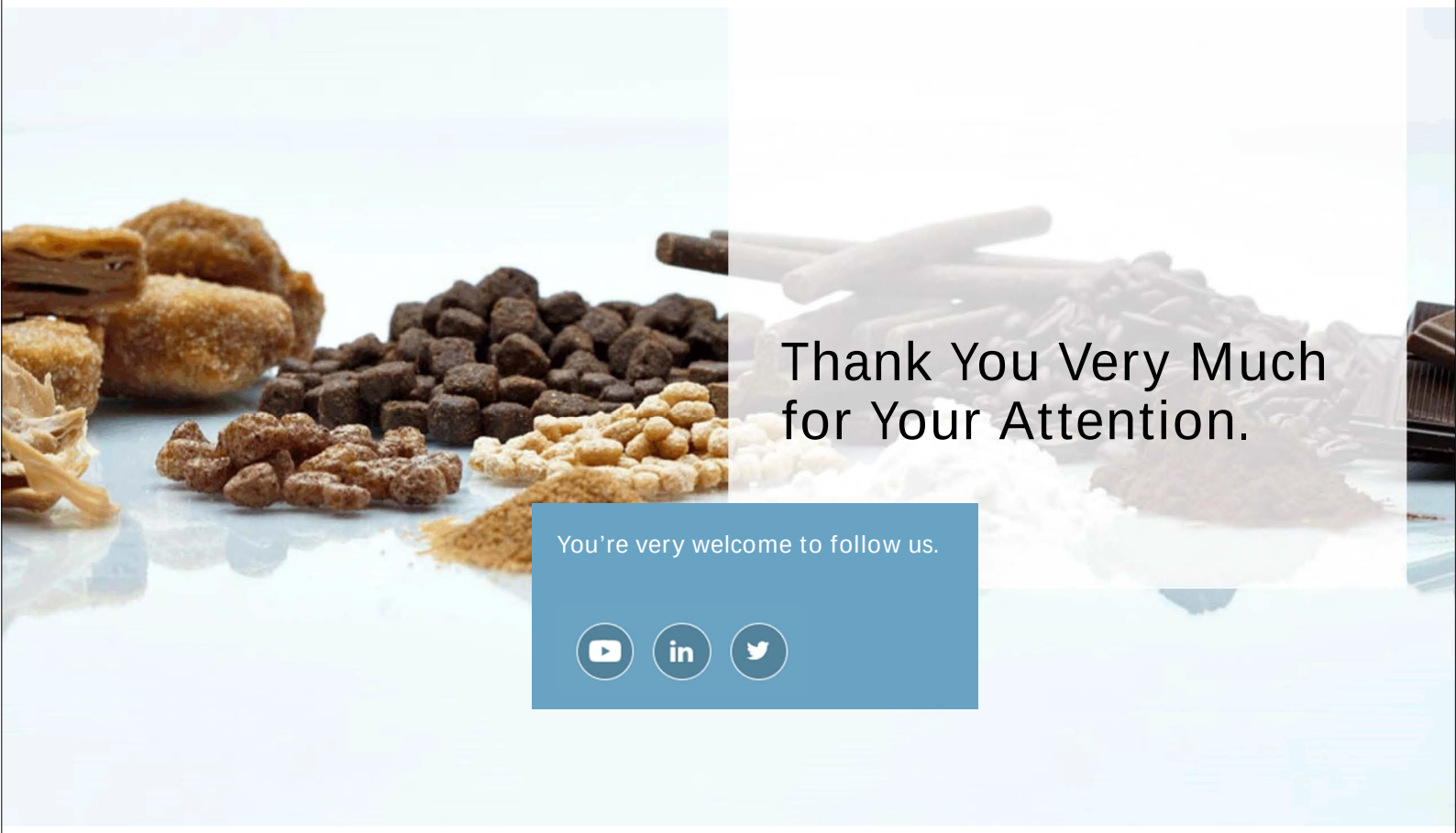
Small quantities of water & flavour to be injected

ATEX measures for extruder & ancillary equipment needed

Flavours very aggressive against plastics, rubbers (sealants)



Lab extruder ZSK 27 MEGAvolume for R&D in flavour encapsulation



Thank You Very Much for Your Attention.

You're very welcome to follow us.



Get your settings right – The impact of extruder settings on the product properties

Food Extrusion Seminar Intense 2026

Christian Hüttner, Senior Process Engineer Food Extrusion

1 From raw material to product

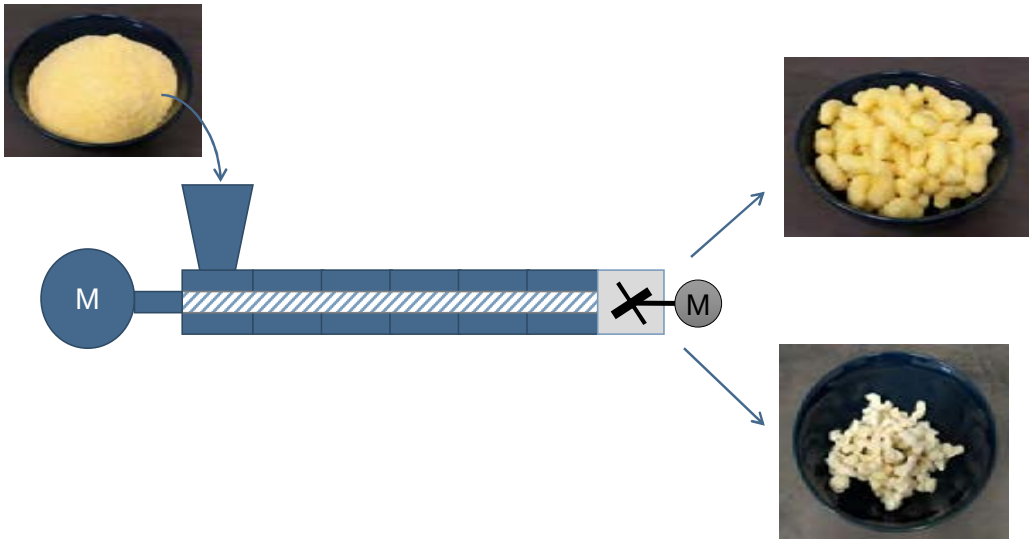
2 Inside the process section

3 Power - Torque - SEI

4 Problem? Solution!

5 Discussion

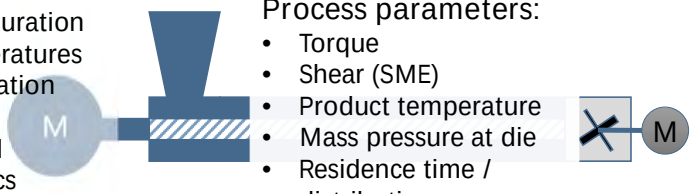
From raw material to the product



Raw material + thermal energy + mechanical energy = product

From raw material to the product

Process variables:
- Screw speed
- Throughput
- Water content
- Screw configuration
- Barrel temperatures
- Die configuration
- Recipe
- Raw material characteristics



Process parameters:
- Torque
- Shear (SME)
- Product temperature
- Mass pressure at die
- Residence time / distribution
- Degree of fill
- Viscosity of mass
- ...

Product properties:
- Flavor
- Color
- Texture
- Density
- Expansion
- Shape
- ...

From raw material to the product

Mutual dependencies in Extrusion

Extruder variables:
- Screw speed
- Throughput
- Water content
- Screw configuration
- Barrel temperatures
- Die configuration
- Recipe

Process parameters:
- Degree of fill
- Shear
- Torque
- Product temperature
- Mass pressure at die
- Residence time / distribution
- Viscosity of mass
- ...

Product properties:
- Flavor
- Color
- Texture
- Density
- Expansion
- Shape
- ...

Inside the process section

2



Degree of fill, residence time, pressure

Inside the process section

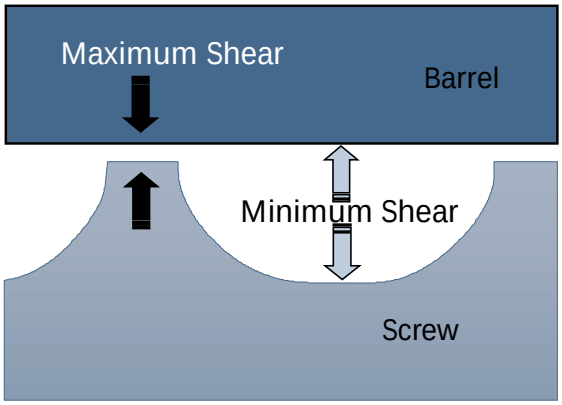
Degree of fill inside of the screw channels



Direction of flow

Inside the process section

Shear rate distribution



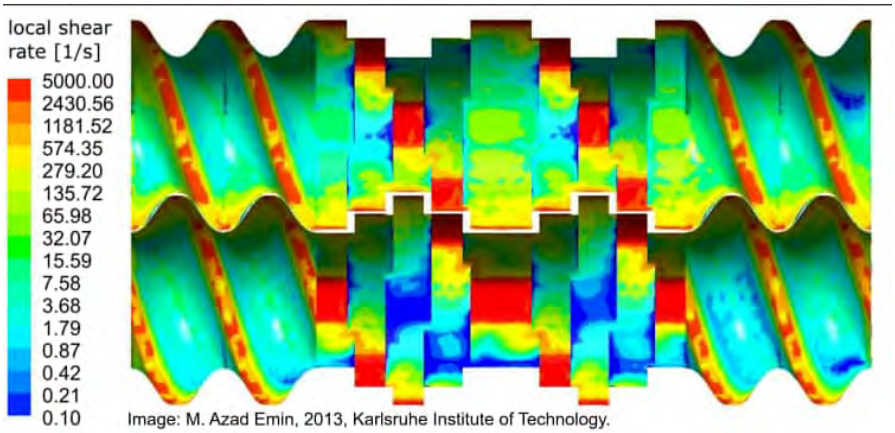
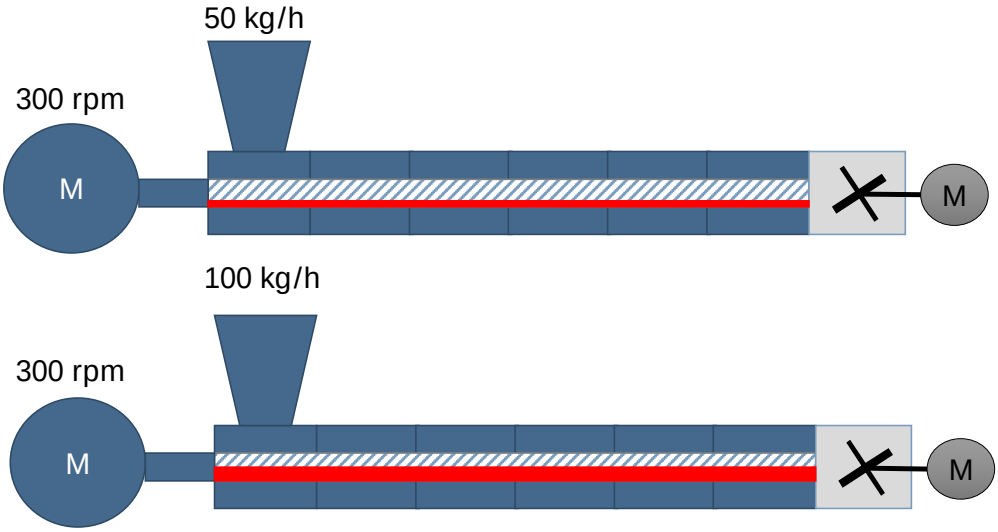


Image: M. Azad Emin, 2013, Karlsruhe Institute of Technology.

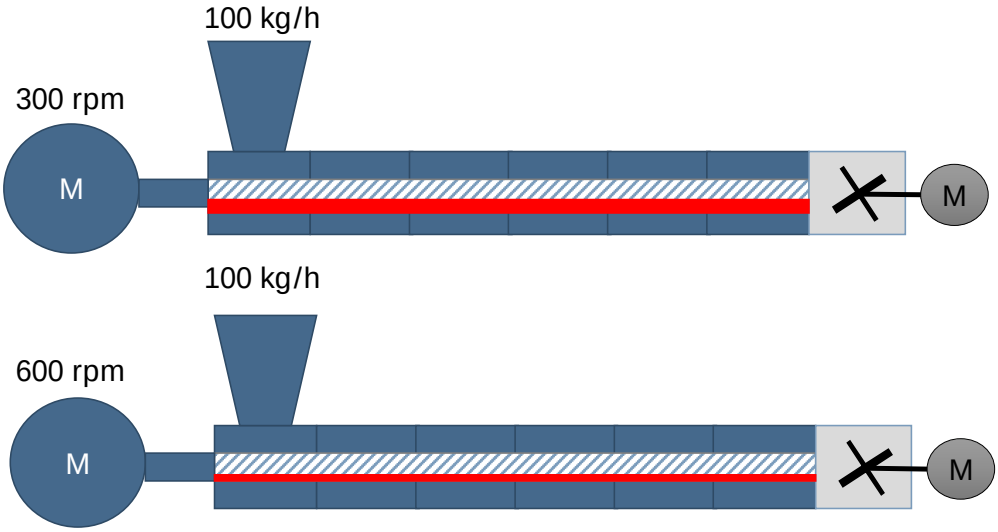
Inside the process section

Throughput -> Degree of fill



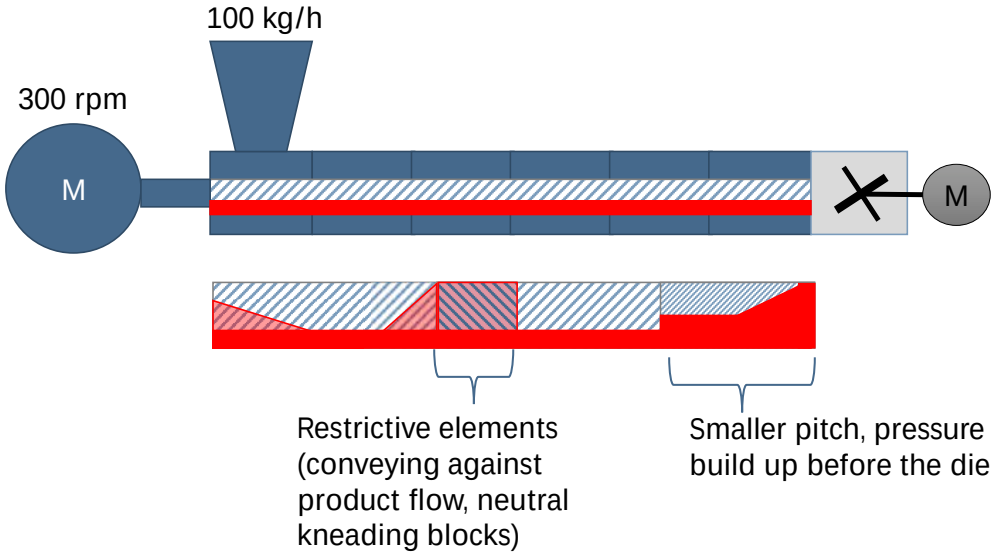
Inside the process section

Screw speed -> Degree of fill



Inside the process section

Screw configuration -> Degree of fill



Inside the process section

D_o/D_i of Extruder -> Degree of fill

ZSK Mv D_o/D_i = 1.8 ⟸ Same throughput ⟹ **ZSK Mc** D_o/D_i = 1.55



Advantages of higher D_o/D_i:

- Better intake
- Lower shear rate
- Lower product temperature
- Reduced product stress for sensitive products
- Improved devolatilization

Inside the process section

Local degree of fill depends on
- Throughput
- Screw speed
- Local screw element (i.e., pitch)
- Downstream restrictions
- D_o / D_i of extruder
- Length of upstream filled section of restrictions

...

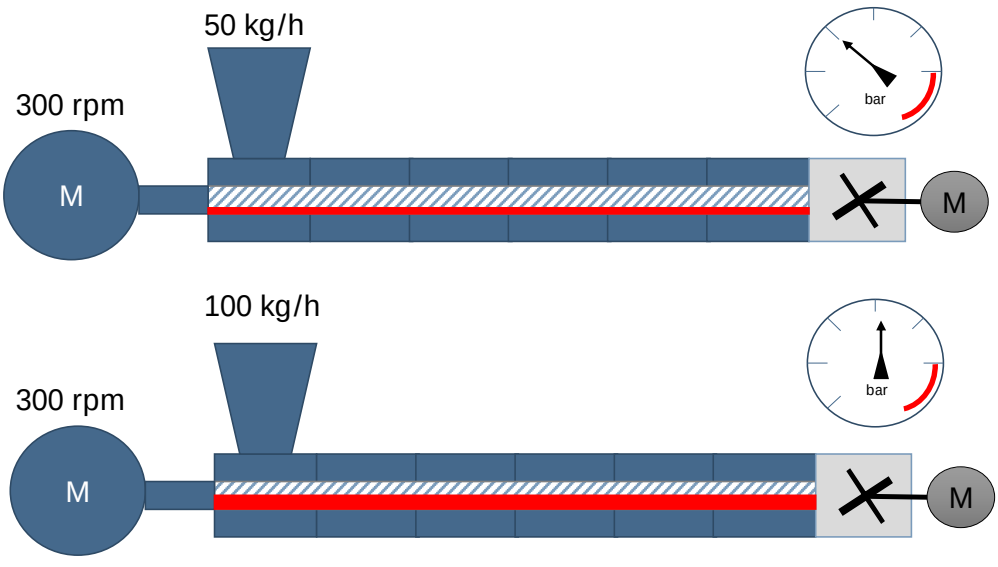
Degree of fill influences
- Heat transfer to barrel surface
- Residence time
- Degassing
- Shear and mixing capability

...



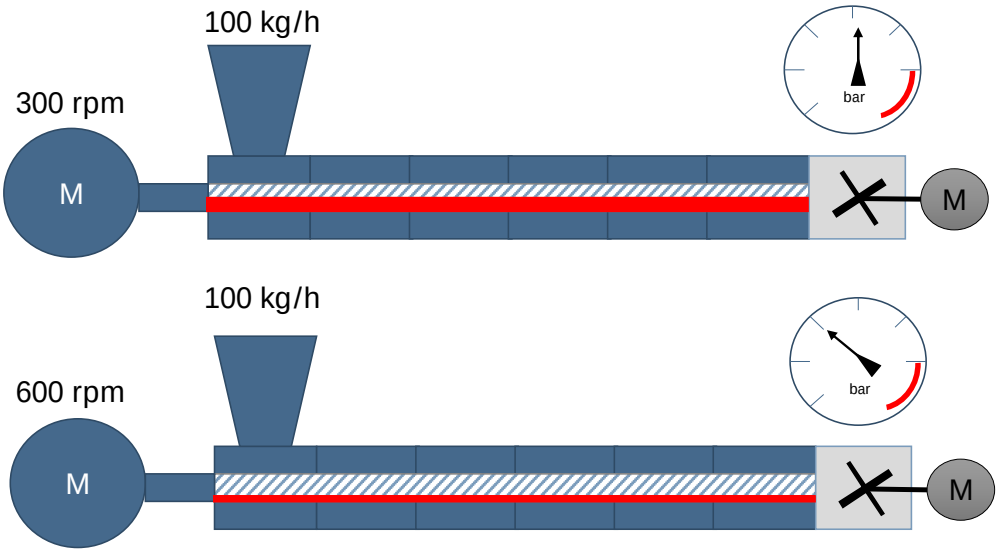
Inside the process section

Throughput -> melt pressure



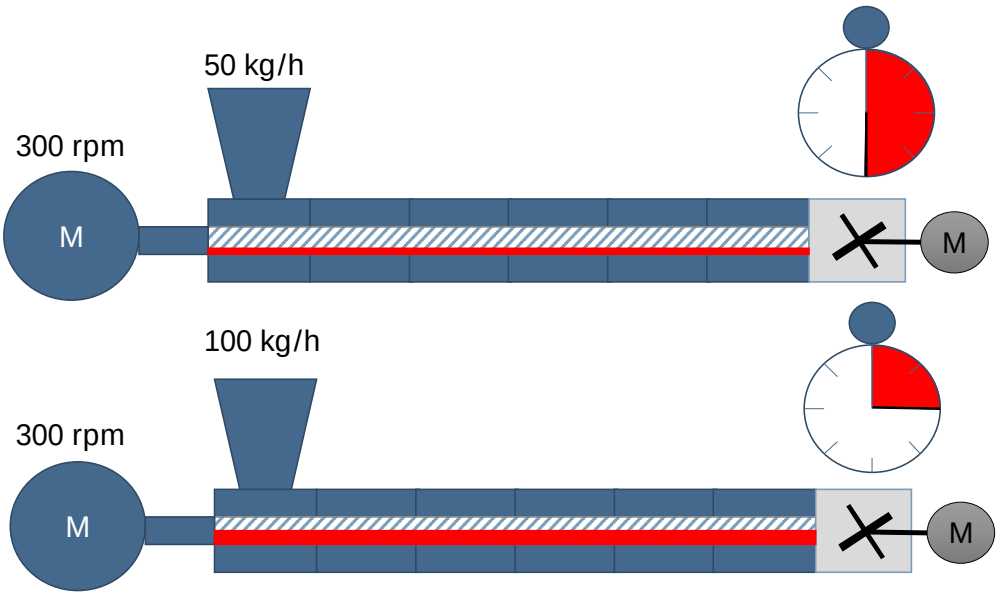
Inside the process section

Screw speed -> melt pressure



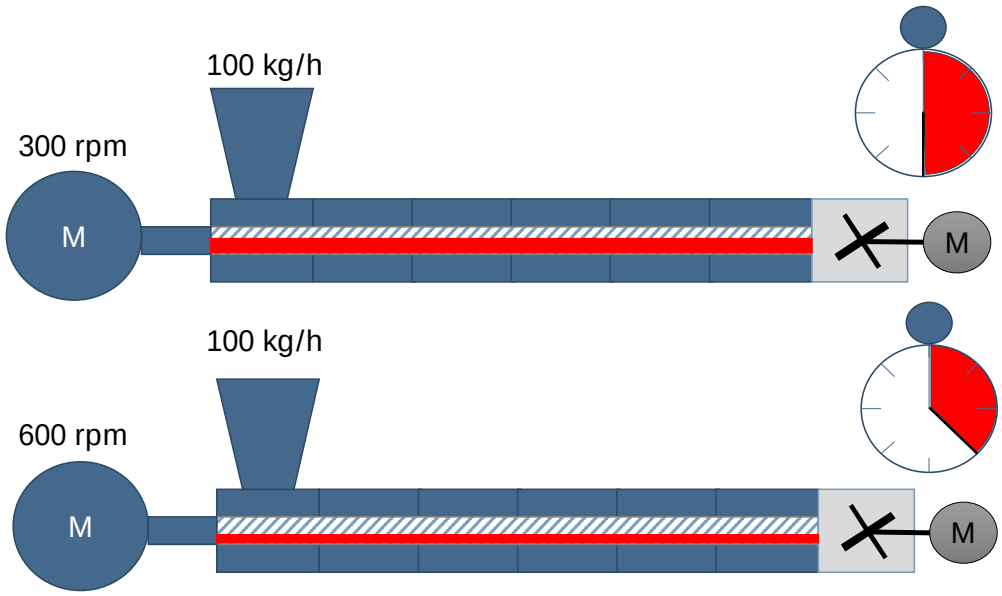
Inside the process section

Throughput -> Residence time



Inside the process section

Screw speed -> Residence time



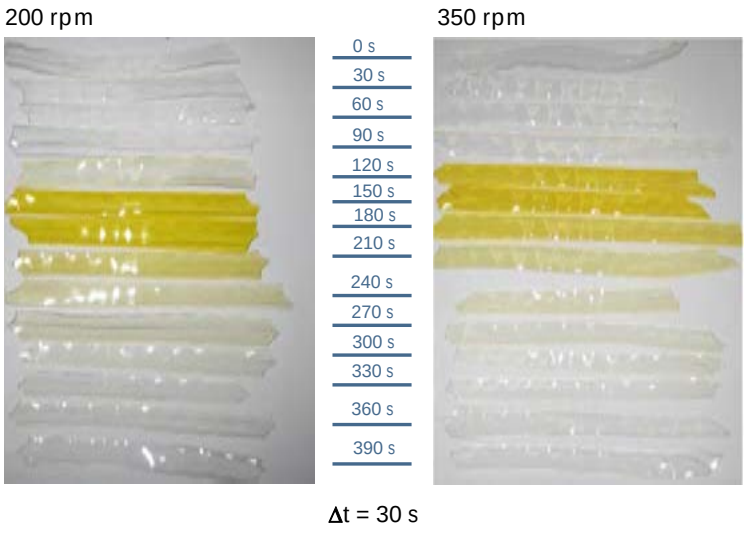
Inside the process section

Residence time distribution

Residence time distribution depends on:

- Throughput: biggest influence
- Screw speed: smaller influence
- Screw set up (type of elements):
  big influence on residence time distribution
- Downstream restrictions (die)
- D_o / D_i of extruder

...



Power - Torque - SEI

3



If you want to test an extruders character, give it power

Power – Torque – SEI

Power (electric motor)

given Extruder:

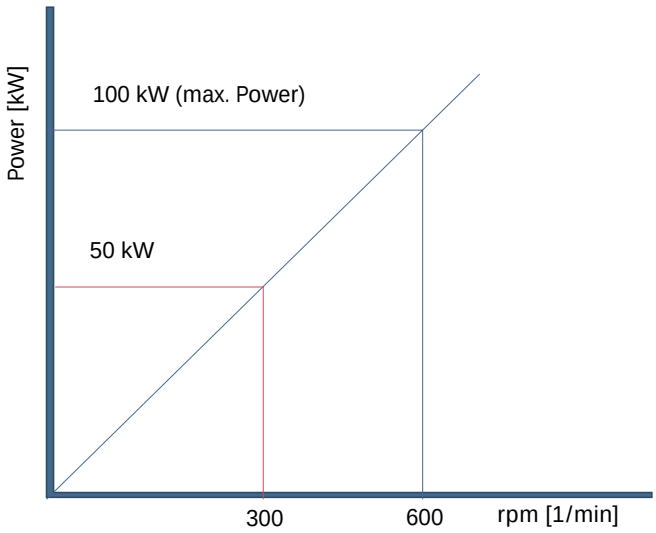
max rpm: 600 1/min

max power: 100 kW

Max power at 300 rpm: 50 kW

$$\max P_N = \max P_{mot} * \frac{N_{actual}}{N_{max}}$$

$$\max P_N = 100\ kW * \frac{300}{600} = 50\ kW$$



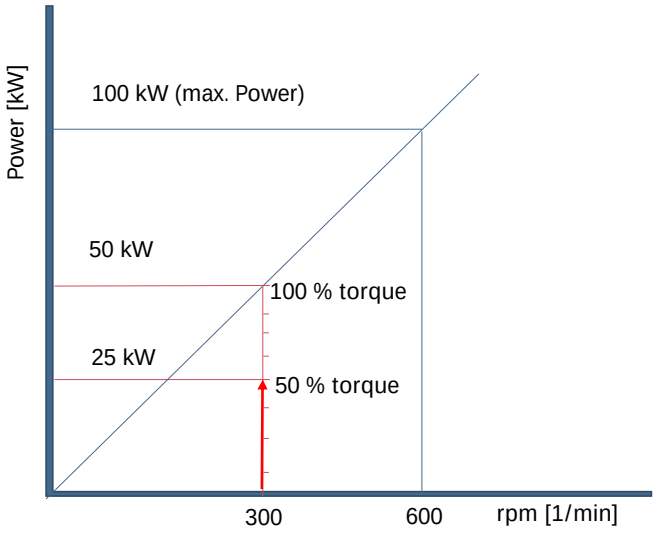
Power – Torque – SEI

Torque

given Extruder:
max rpm: 600 1/min
max power: 100 kW

Torque: a rotational force
Torque is displayed as % of
max. motor power at
the actual screw speed





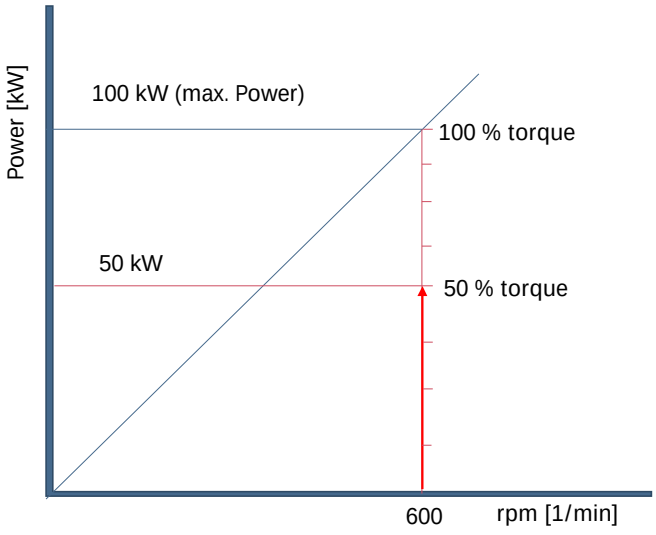
Power – Torque – SEI

Torque

given Extruder:
max rpm: 600 1/min
max power: 100 kW

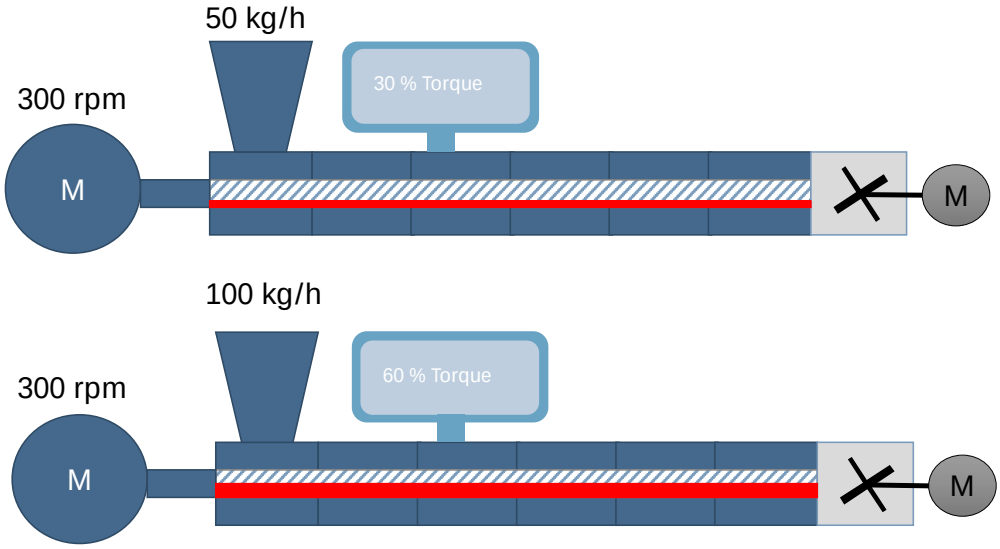
Torque: a rotational force
Torque is displayed as % of
max. motor power





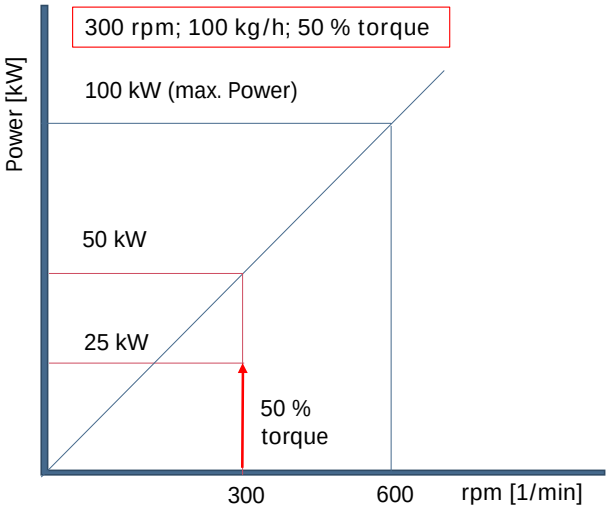
Power – Torque – SEI

Torque



Power – Torque – SEI

Specific mechanical energy (SME)



$$SME = \frac{\text{Used power}}{\text{Throughput}}$$

$$SME = \frac{25\ kW}{100\ kg/h}$$

$$SME = 0{,}25\ kWh/kg$$

$$SME = \frac{\left(\frac{300}{600}\ 1/s * \frac{50}{100}\right) * 100\ kW}{100\ kg/h} \left[\frac{kWh}{kg}\right] = 0{,}25\ kWh/kg$$

Power – Torque – SEI

Specific mechanical energy (SME)

Torque of the screws (not energy uptake from motor)

Used energy (from the motor) by screws

Coperion Extruders show torque as % of maximum

$$SME = \frac{\left(\frac{n_{act}}{n_{max}} * \frac{M_{act}}{100}\right) - \left(\frac{n_{act}}{n_{max}} * \frac{M_{empty}}{100}\right)}{\dot{m}} * Pmax \left[\frac{kWh}{kg}\right]$$

$$SME = \frac{Md_{act} - Md_{empty}}{\dot{m}} * 3{,}6 \left[\frac{kWh}{kg}\right]$$

n: Screw speed $[min^{-1}]$

M_{act}: actual Torque [%]

M_{empty}: Torque of empty machine [%]

P_{max}: max power proces section [kW]

$\dot{m}$: Throughput [Kg/h]

Md_{act}: [Nm]

Md_{empty}: [Nm]

$\dot{m}$: [Kg/h]

Power – Torque – SEI

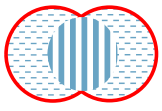
STE (Specific Thermal Energy (STE) and SEI (Specific Energy Intake)

STE: Thermal energy input from

- the barrels,
- thermal energy from steam or warm water

The heat exchanging capabilities of an extruder are limited

V > A



Ratio between volume / inner surface area gets bigger for bigger extruders

- less influence of heating/cooling
- be careful with settings on lab extruders if you want to scale up
- too hot barrels can lead to burned product

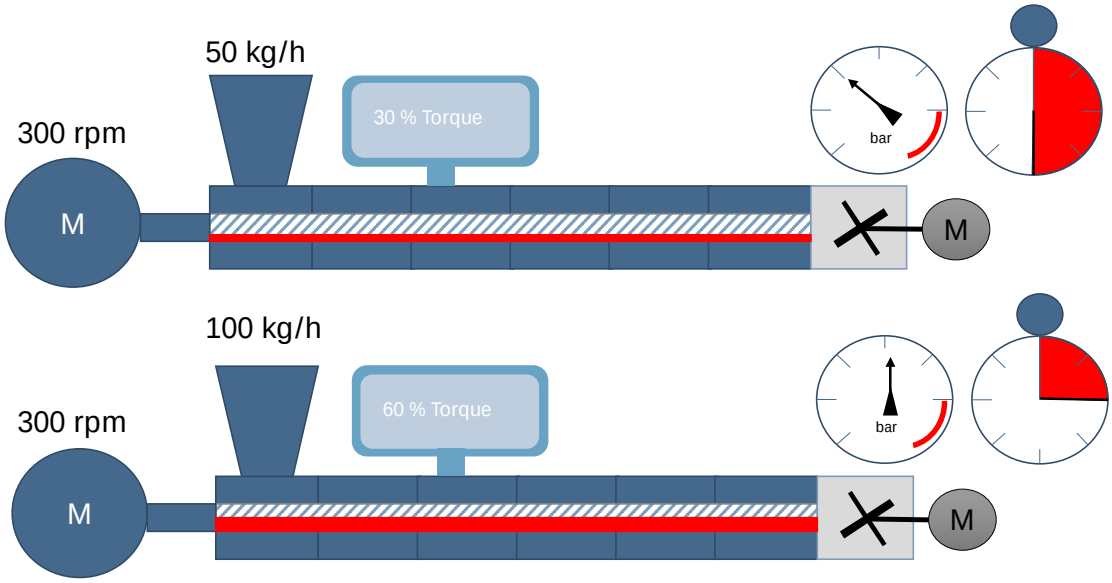
SEI = SME + STE

STE only important if strong heating or cooling is involved or if steam or hot water are used

For most processes only SME important

Power – Torque – SEI

Torque



Problem? Solution!

4

How to achieve the perfect product



Problem? Solution!

Start-up and Shut-down

Higher viscous material can always push lower viscous material through the extruder

Start-up: start lower viscosity (e.g., more water addition) and increase viscosity

Shut-down: reduce barrel temperatures below 100 °C (to prevent steam)

Slowly decrease throughput, viscosity and rpm until the pressure is low

Problem? Solution!

Understanding the Problem

Product doesn't fit to requirements

- Describe the deviations
- Know where you are coming from:
  (increasing rpm might help if the degree of cook is not sufficient, but it might lead to starch degradation and less expansion if it is already ok)
- Take your time:
  – Wait at least 4 times the residence time after each change
  – Only change one parameter at a time
- Practice makes perfect! Just try it! Check also the limits/ extremes of your process

Example: too less expansion

Pressure has the biggest impact on expansion:

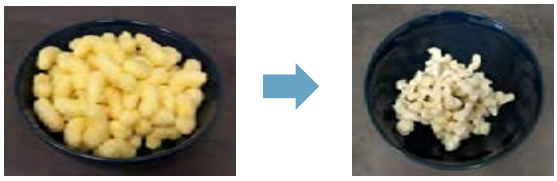
- Increase throughput
- Decrease rpm
- Increase viscosity (reduce water addition)
- Change die configuration (more restriction)

This only applies if the product is theoretically able to expand more

Problem? Solution!

Starch based products

How to achieve Popcorn?



Mechanical breakdown of the starch: high rpm, low moisture content, strong screw

How to achieve high cold paste viscosity?

Gentle process to protect the starch molecules:

- High moisture content
- low rpm (or low shear screw)
- Use thermal energy (barrels, steam)

Problem? Solution!

Starch based products

Real Life example:

Throughput goal reached!



How to achieve higher bulk density?

-
-
-
-
-
-
...

Problem? Solution!

Protein texturization / Reaction / Roasting

Too less texturized TVP:

- Increase the rpm for more shear (be aware of steam bursts and torn product due to higher temperatures and lower viscosity)
- Increase the barrel temperature (be aware of steam bursts and torn product or burned particles)
- Add steam to bring in thermal energy
- Change the screw for more shear at lower rpm
- Change the recipe to achieve a higher viscosity at the same process settings

Reaction process:

Create enough mixing (screw configuration, screw speed) and enough residence time (throughput)

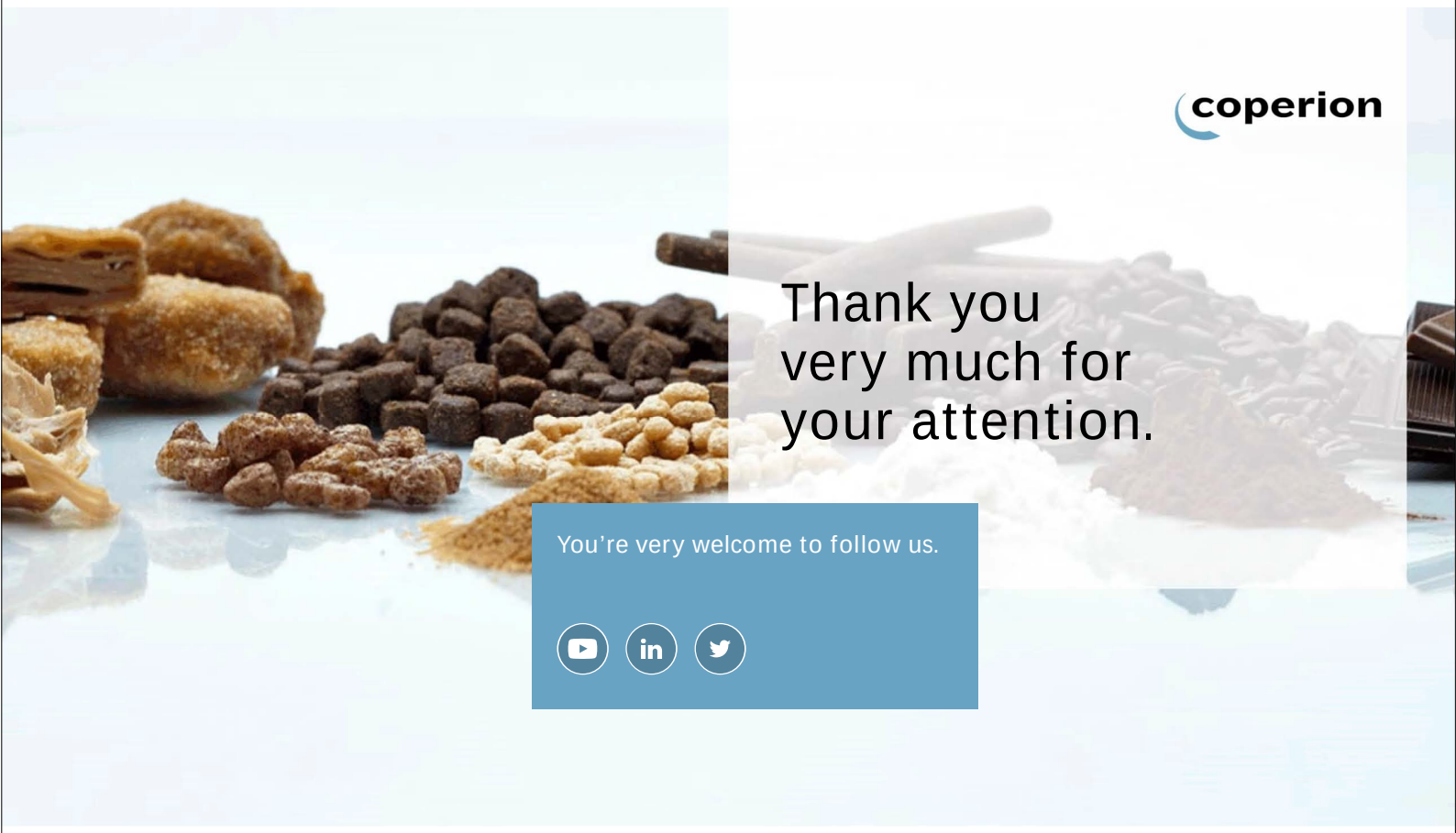
Roasting:

Low rpm and low throughput (creating residence time)

Discussion

5





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Thank you very much for your attention.

You're very welcome to follow us.

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Thank you very much for your attention.

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