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13th Food Extrusion Seminar

Oct 29/30, 2025 by Coperion · Stuttgart · Germany

Presentations

→ Agenda • Day 1 • Wednesday, Oct 29, 2025

08:45	Registration | HolidayInn Stuttgart, Conference Room
09:15	Welcome/Presentation Coperion + Organisation Stefan Gebhardt & Uta Kühnen, Coperion
09:45	Twin Screw Extruder Basics Uta Kühnen, Coperion
10:30	Types, Forms and Materials of Twin Screw Elements Tobias Gaiser, Coperion
11:15	Coffee Break
11:35	Practical Session: Assembly of Twin Screw Elements Tobias Gaiser & Team, Coperion
12:30	Lunch | Holiday Inn
13:30	Process Opportunities in Food Extrusion Fabian Specht, Coperion & Catherine Cooper, Baker Perkins
14:00	Feeding of Various Ingredients Beat Müller-Ranft, Coperion
14:45	Research Highlights in Food Extrusion Processing Verena Schmidt, Fraunhofer-Institut für Verfahrenstechnik u Verpackung Felix Ellwanger Karlsruher Institut für Technologie
15:00	Coffee Break
15:30	Extrusion of Meat Analogues: TVP and HMMA Tobias Gaiser, Coperion
16:15	Expansion & Die Design Christian Hüttner, Coperion & Tom Shipman, Baker Perkins
17:00	Preview Practical Sessions Coperion Test Lab and Plant Fabian Specht
17:10	End of Day 1
19:00	Dinner 'Ristorante Italiani', Ingersheimer Str. 12, 70499 Stuttgart (vis-á-vis the HolidayInn)

Subject to changes

→ Agenda • Day 2 • Thursday, Oct 30, 2025

08:15	Departure Shuttle | from HolidayInn to Coperion
08:55	*Safety Briefing*
09:00	Practical Session 1: Breakfast Cereals | Food Test Lab Christian Hüttner, Coperion & Tom Shipman, Baker Perkins
09:25	Practical Session 2: HMMA | Food Test Lab Tobias Gaiser, Coperion
09:50	Practical Session 3: Samples | Food Test Lab Uta Kühnen, Coperion
10:15	Practical Session 4: Forming Extrusion of Chewing Gum | Food Test Lab Patrick Gabler, Gabler
10:40	Practical Session 5: Selecting Dies for Breakfast Cereal Design | Food Test Lab Catherine Cooper, Baker Perkins
11:05	Practical Session 6: Factory Tour Coperion factory
11:30	Departure Shuttle | from Coperion to HolidayInn
12:15	Lunch | HolidayInn
13:00	Innovative Food Extrusion: Efficient Production of Plant-Based Alternatives at Vemiwa Michael Walk, Vemiwa
13:30	Process Design Uta Kühnen, Coperion
14:15	Recipe Ingredients in Food Extrusion Fabian Specht, Coperion
15:00	Coffee Break
15:20	Extrusion Processing of Breakfast Cereals and Its Ancillary Equipment Catherine Cooper & Tom Shipman, Baker Perkins
16:05	Get Your Settings Right – the Impact of Extruder Settings on the Product Properties Christian Hüttner, Coperion
16:50	Closing Remarks
17:00	End of Seminar Day 2

Subject to changes

Table of Content

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Twin Screw Extruder Basics

Fundamentals

Uta Kühnen, Head of Process Technology Food

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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

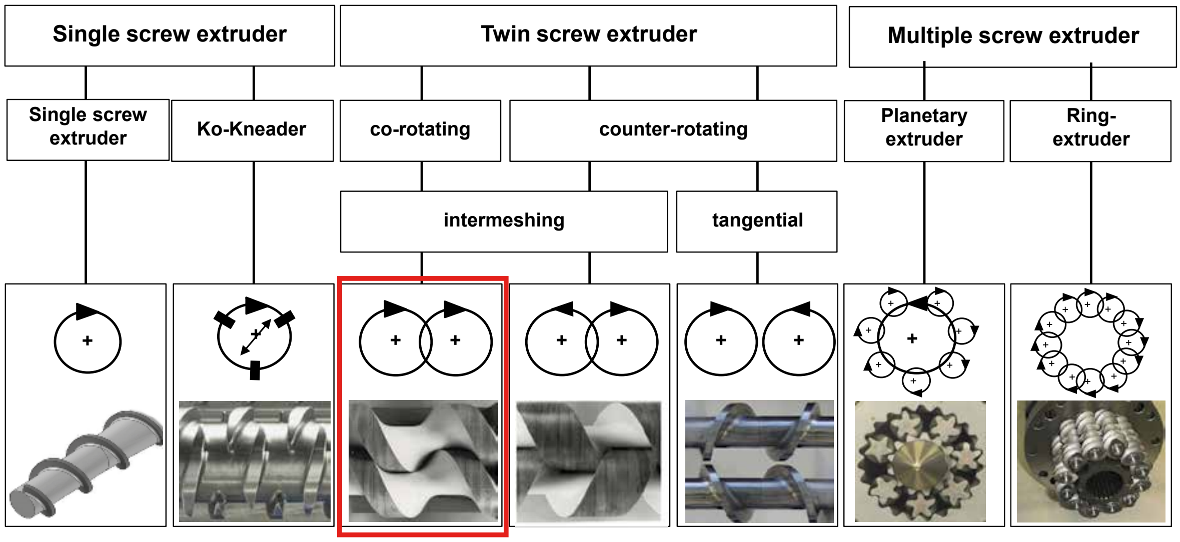
Extrusion basic mechanisms

2

General Working Principle of screw extrusion machines

Extrusion Systems

Different Concepts



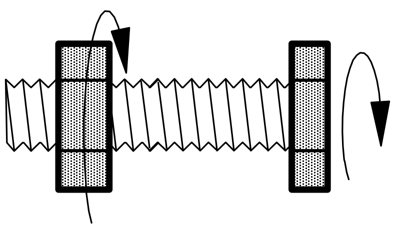
Basics Extrusion systems

Conveying mechanism I

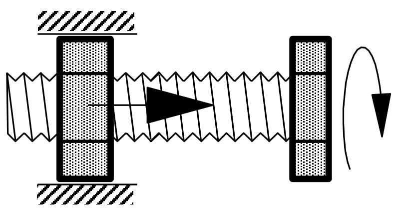
Principle of function

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.



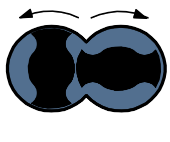
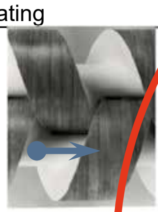
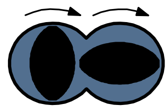
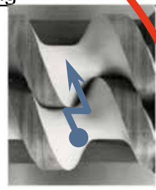
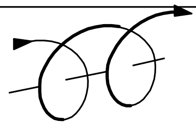
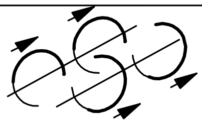
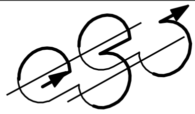
Good product transportation if product sticks to the barrel wall.

Conveying of product

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

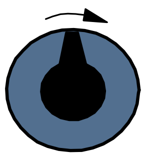
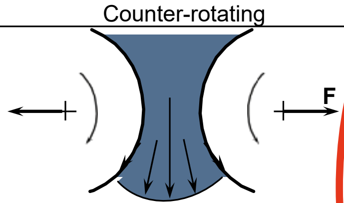
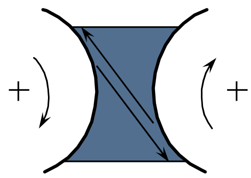
Basics Extrusion systems

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

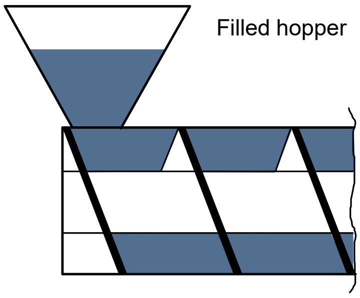
Self wiping (cleaning) effect

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

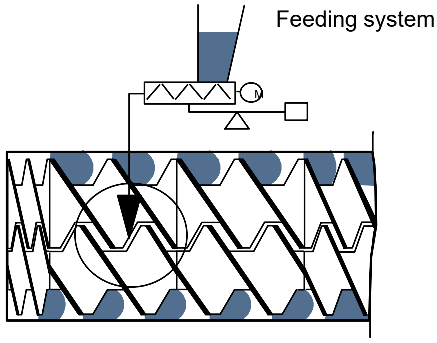
Throughput and Degree of Fill

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

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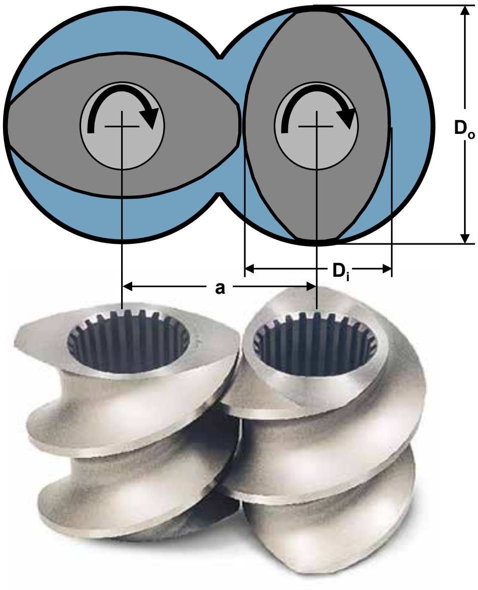
Design features of twin screw extruders

Characteristic dimensions



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

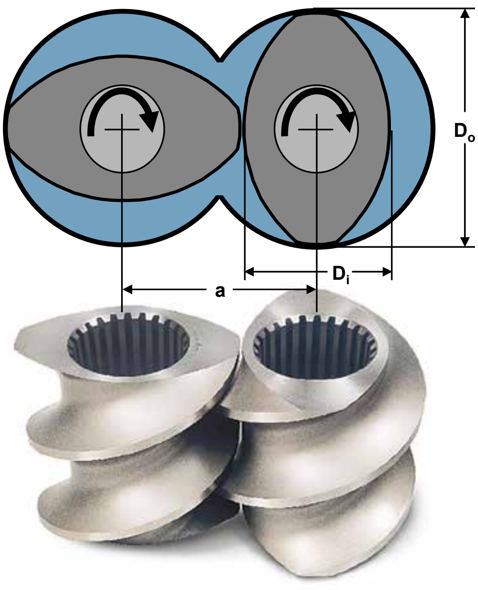
D_o / D_i = Diameter ratio
determines shear, degassing and powder intake

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/cm^3

n up to 1800 rpm

ZSK Mc

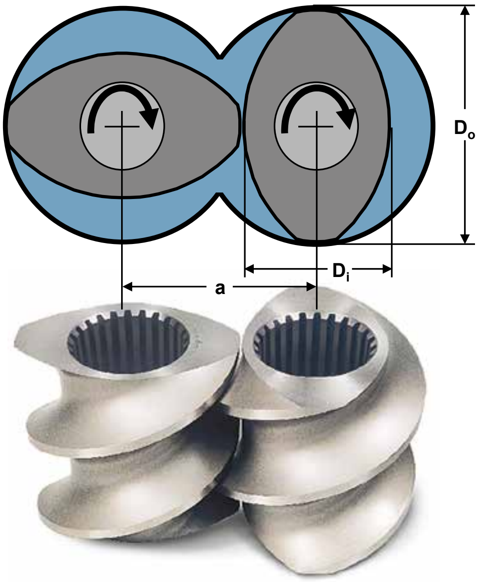
D_o / D_i = 1,55

M_d / a^3 up to 18 Nm/cm^3

n up to 1200 rpm

Design features of Baker Perkins Food Extruders

Food Extruders MPF and SBX Series



SBX – 'Solid Barrel X'

D_o / D_i = 1,76

M_d / a^3 up to 11 Nm/cm³ for SBX65-125

n up to 1700 rpm

Solid barrel

MPF – 'Multi Purpose Food'

D_o / D_i = 1,76

M_d / a^3 up to 11,0 Nm/cm³

n up to 1000 rpm

Clamshell barrel

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

Geometrically similar design of process section

of the Baker Perkins Food Extruders

SBX Food Extruder

Screw diameter
45 to 125 mm

MPF Lab Extruder

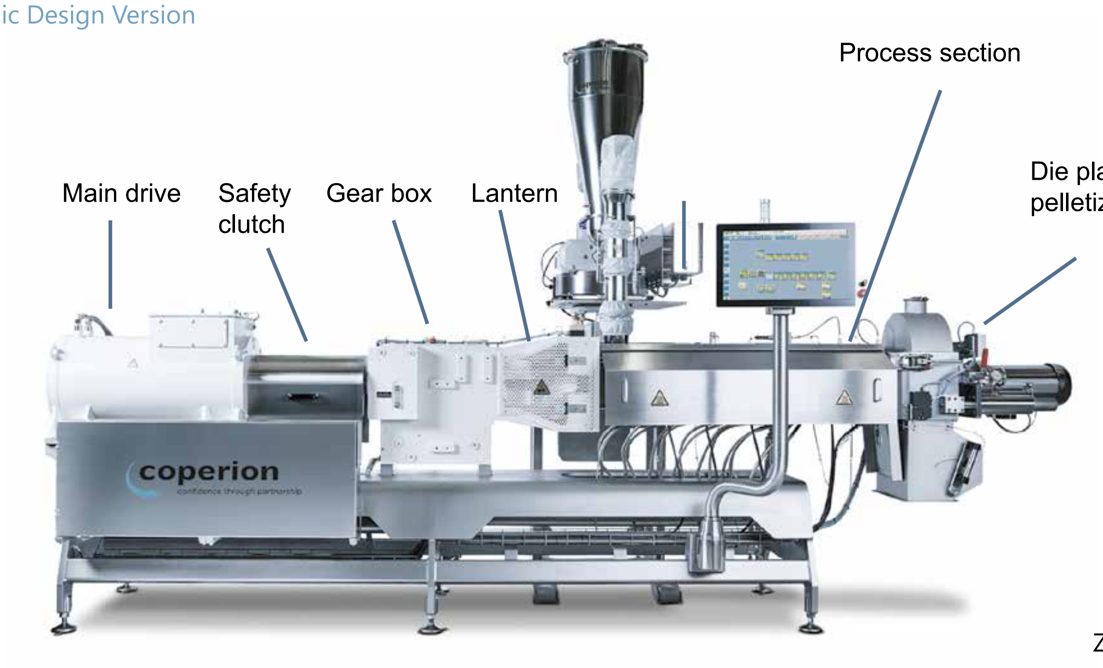
Screw diameter
19 and 24 mm

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

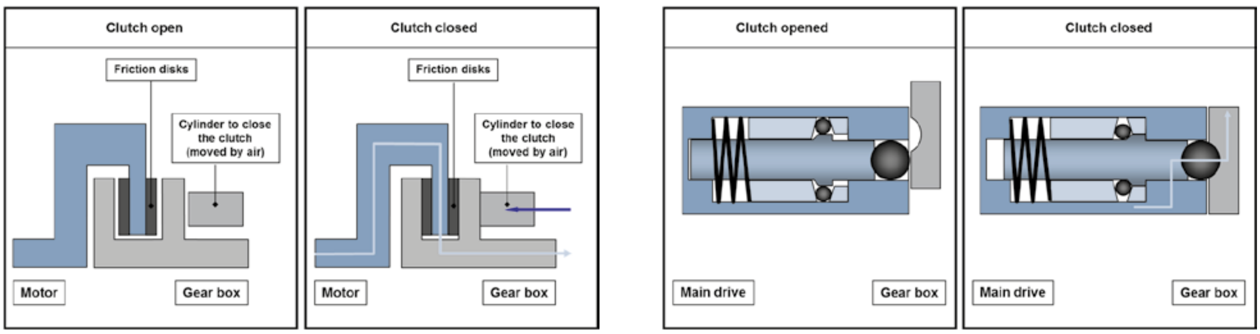
Driving side:
Main drive motor

Driven side:
Gearbox and
screw shafts

Safety clutch
Main safety element
limits the torque
disconnects the driving side
from the driven side

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

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

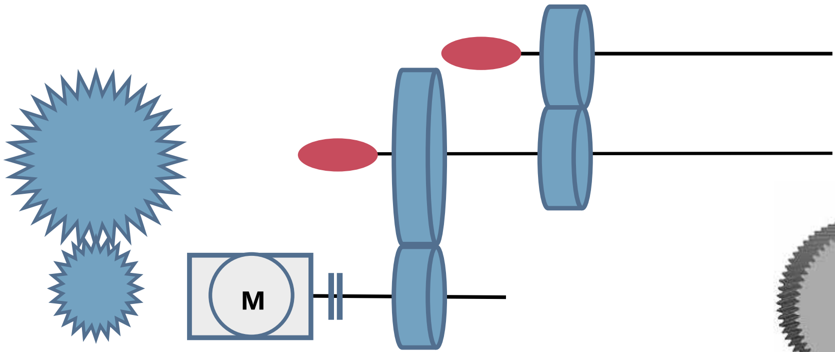
n1 > n2

Distribution gears

Distribution to two shafts

Trust bearing of screw shafts

Only one-sided bearing of screw shafts



Lantern

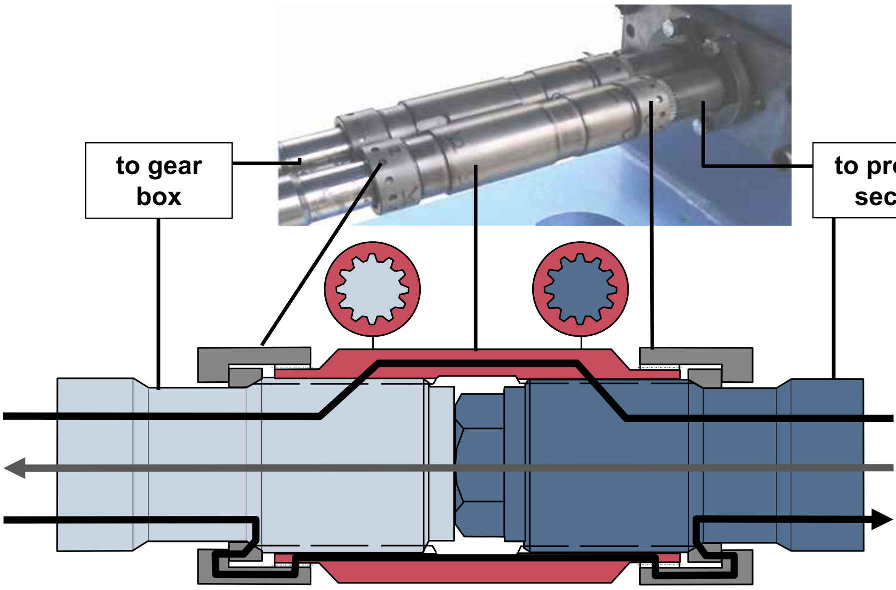
Coupling between gear shaft and screw shaft

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

5

The ZSK Megavolume extrusion system

Modular design and versatility

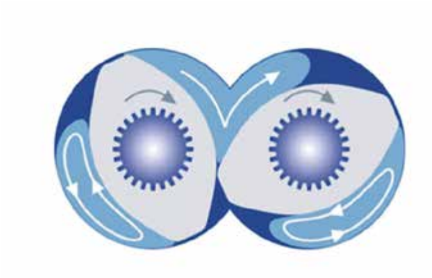
- **ZSK** = twin screw kneader
- Modular screws:
  single elements are threaded on a shaft
- Modular barrels:
  single barrels are coupled by flanges or held together by tie-rods
- Each barrel heated / cooled individually

Individual Design

Each extruder mounted with unique configuration of components and parts

Action of the screws

Lookout



Cross section of a ZSK

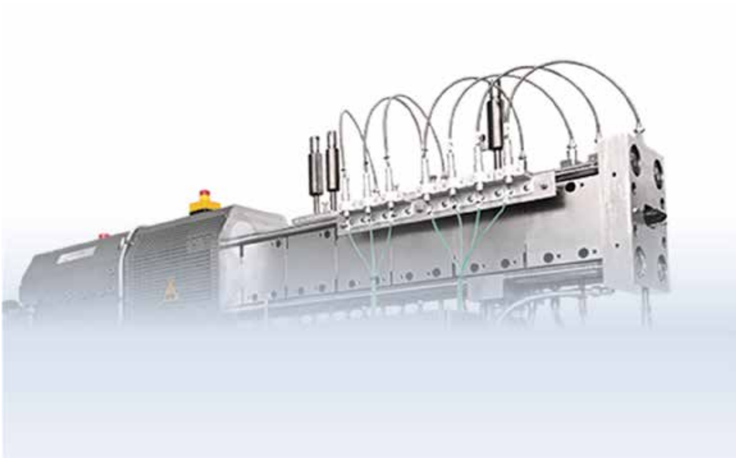
2 lobe system

Deeper insights

In the presentation on screw elements by Tobias Gaiser, Coperion

Modular design of ZSK process section

Example Extruder with tie rods



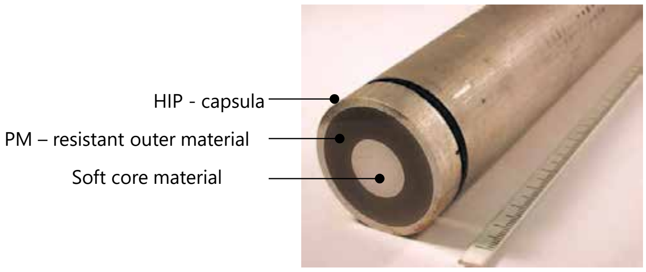
ZSK 43 barrels fixed with tie rods

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

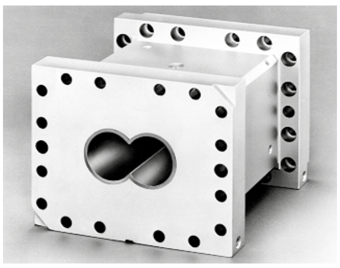
Protecion against corrosion and abrasion of Extruder barrels

- 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

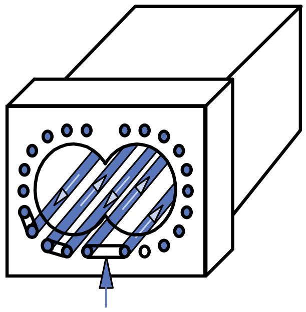
- Water (pressurized max. 200 °C)
- Steam (max. 250 °C)
- Oil (max. 350 °C)

➡ 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

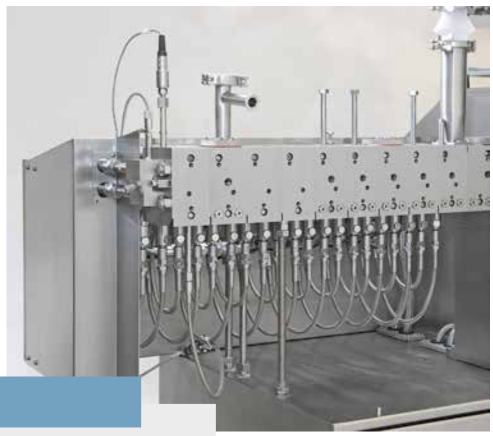
Barrel heating and cooling

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

Twin screw extruder basics

Feeder

Integral component of extrusion line

Ensure smooth, reliable, constant to sensure a consistant extusion process

One of the most important pieces of ancillary equipment

Details & Insights

See presentation on feeding by Beat Müller-Ranft, Coperion Ktron

ZSK 54Mv

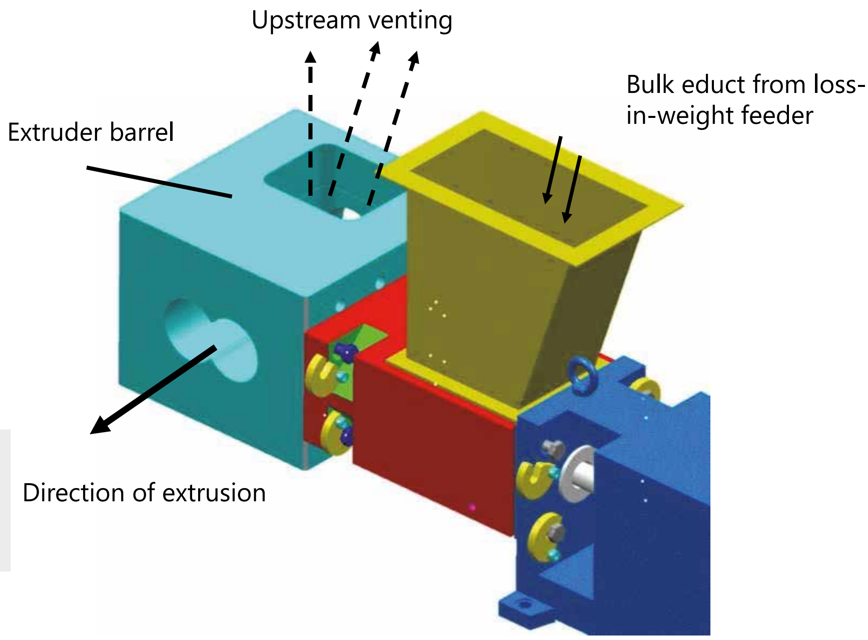
ZS-B twin screw sidefeeder

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

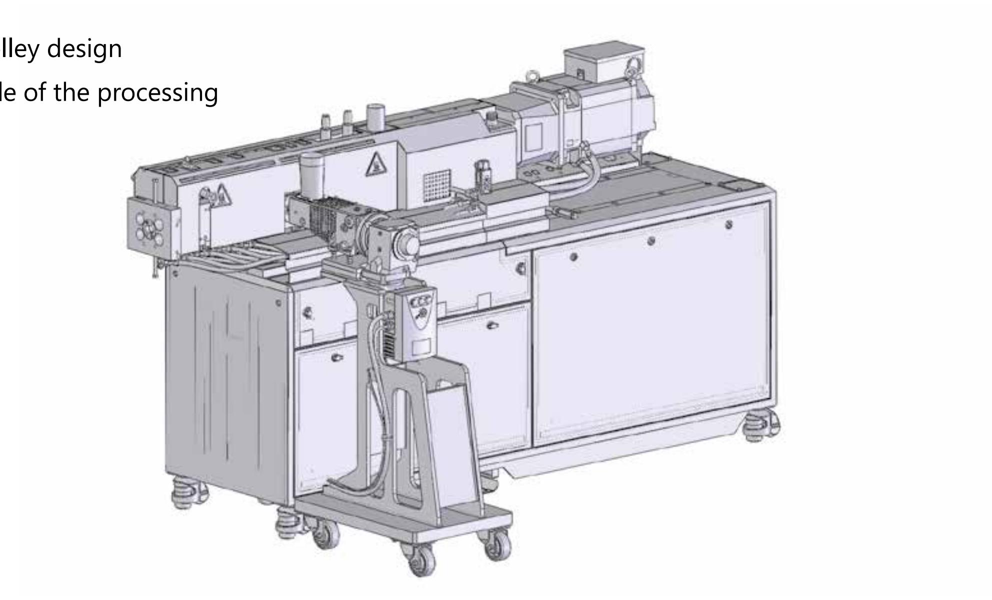


Lab Extruder ZSK 27Mv

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

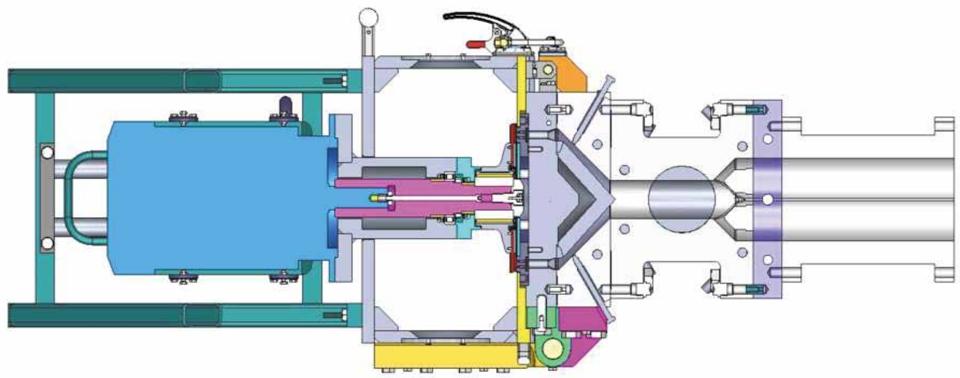
Pelletizer ZGF and Cutter cage SBX

Food pelletizer ZGF

General design

Hinged pelletizer for easy access

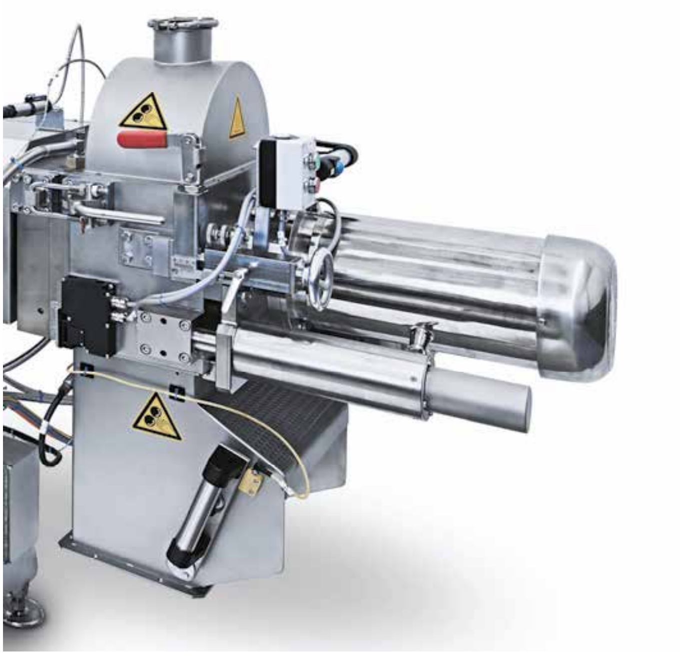
Cut view from top



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

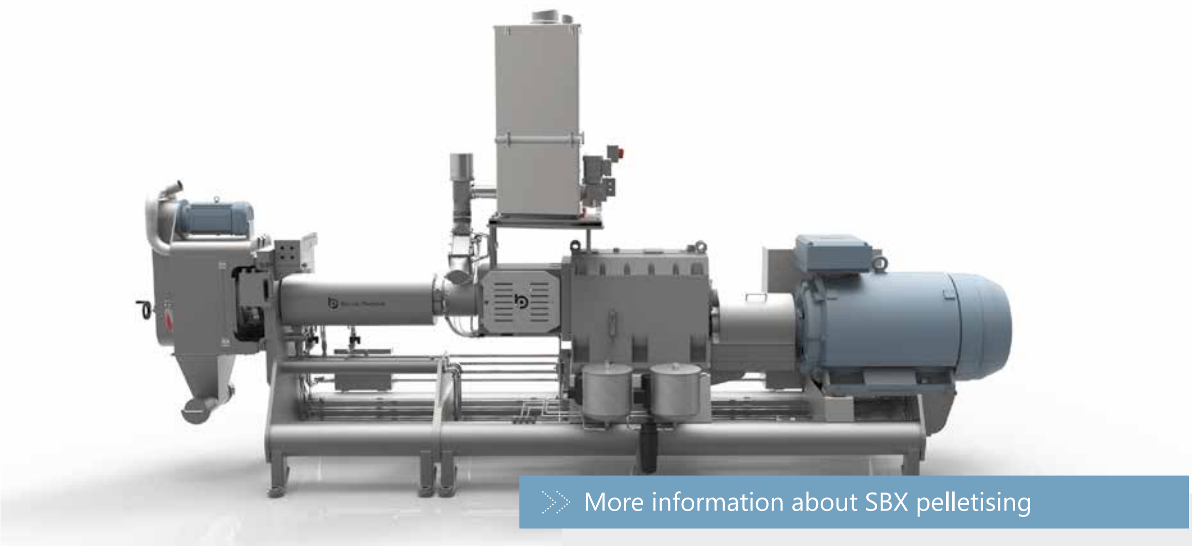
See presentation on expansion & die design by Christian Hüttner, Coperion & Tom Shipman, Baker Perkins

Pelletizer ZGF 125

Mounted onto ZSK 98

Production of breakfast cereals

SBX65 Extruder with Cutter Cage



More information about SBX pelletising

See presentation on cereal extrusion and ancillaries by Catherine Cooper and Tom Shipman, Baker Perkins

Process control system

8

Twin screw extruder basics

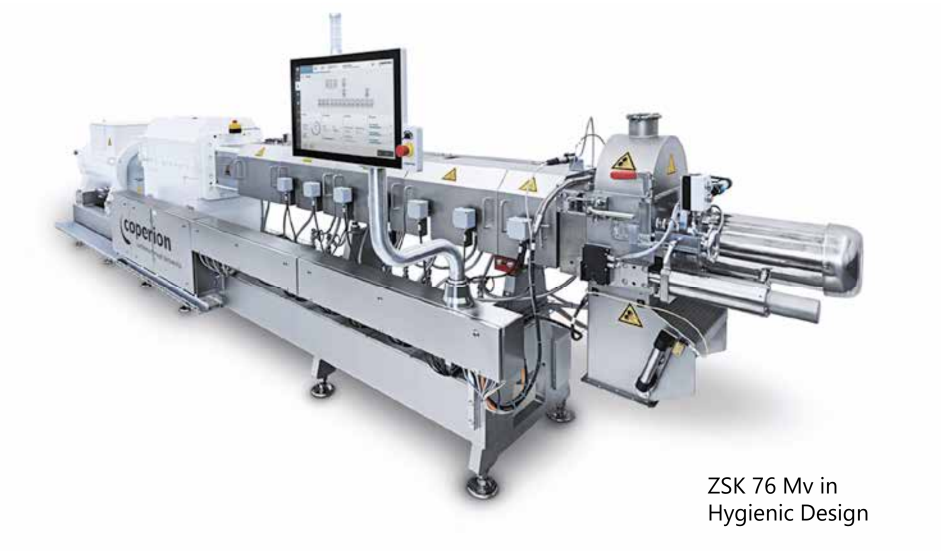
Control cabinet separate from extruder

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

Contact

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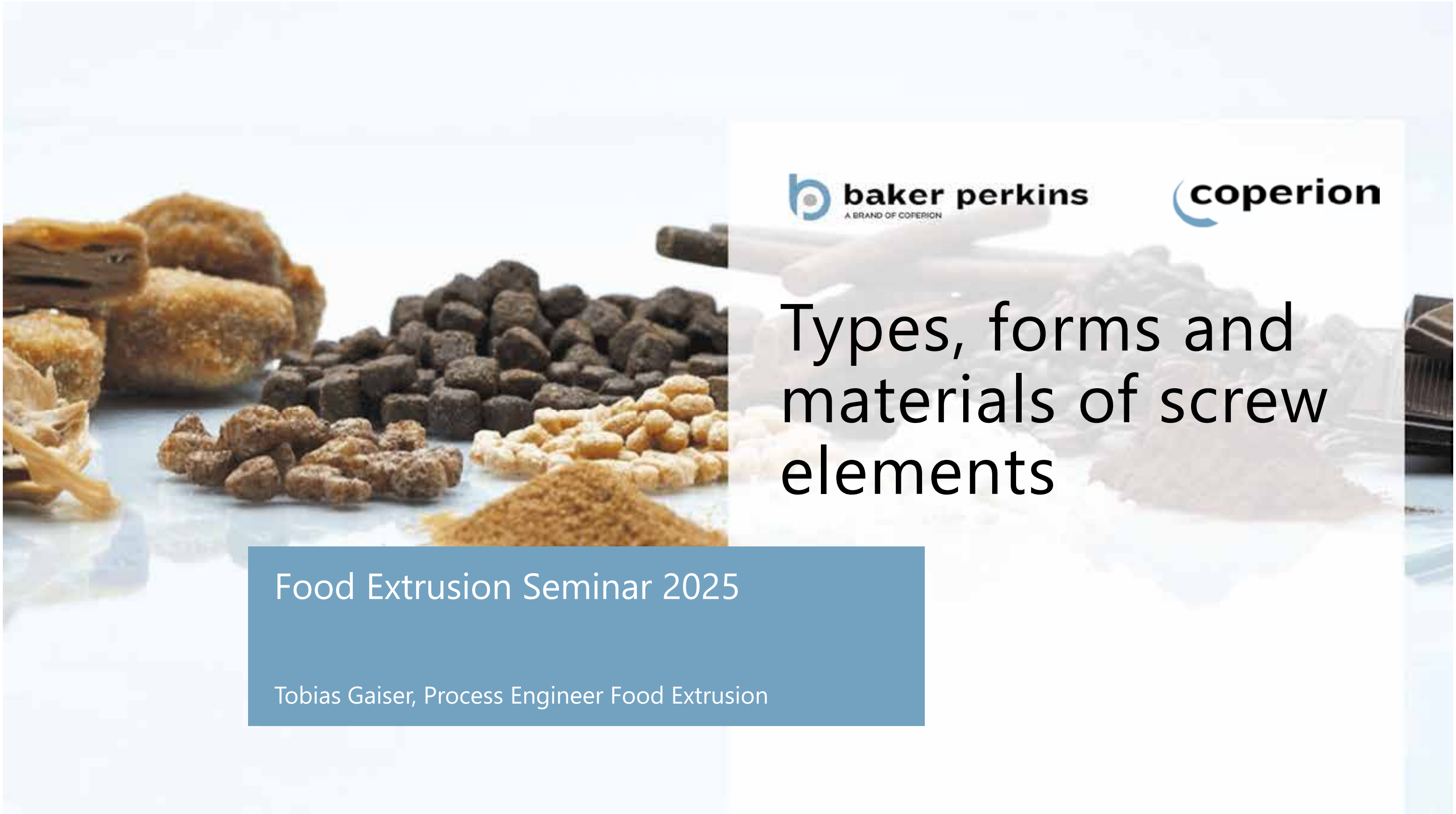


Types, forms and materials of screw elements

Food Extrusion Seminar 2025

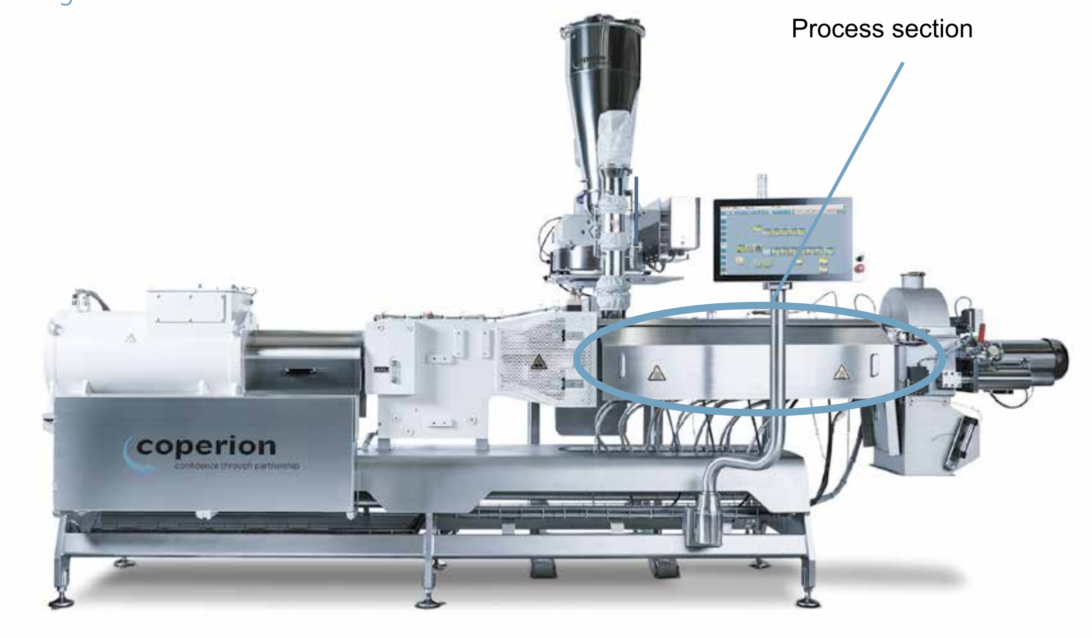
Tobias Gaiser, Process Engineer Food Extrusion

General layout of the process section

1

General layout of the process section

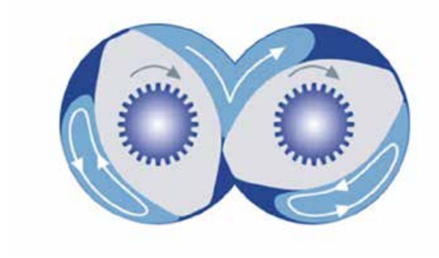
General design of the ZSK



General layout of the process section

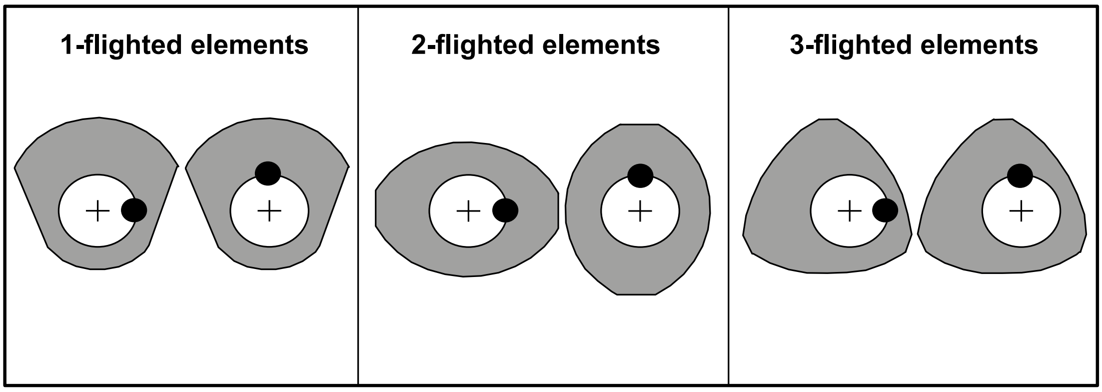
General design of the ZSK

- **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
- This allows **individual design of each extruder**



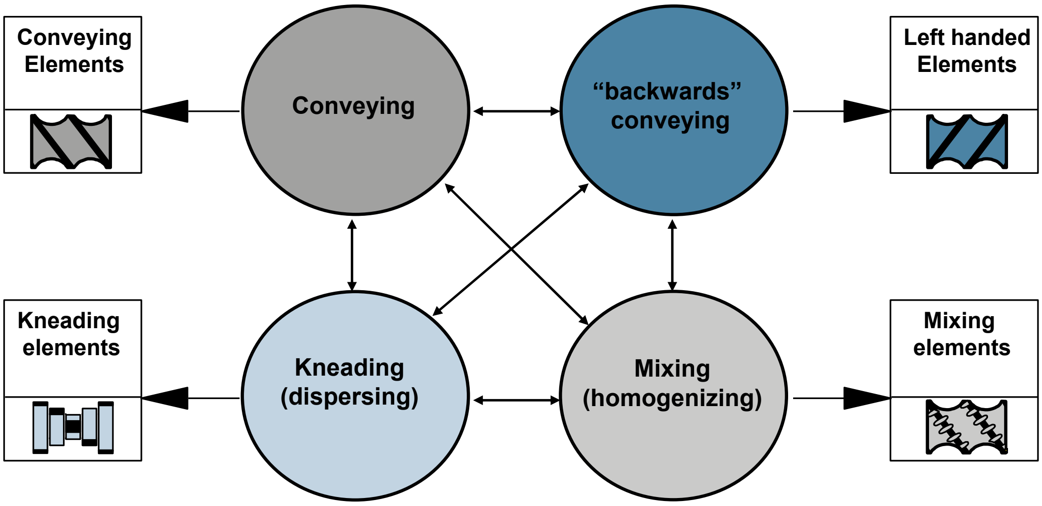
General layout of the process section

Element design



General layout of the process section

Basic effects of screw elements



Conveying elements

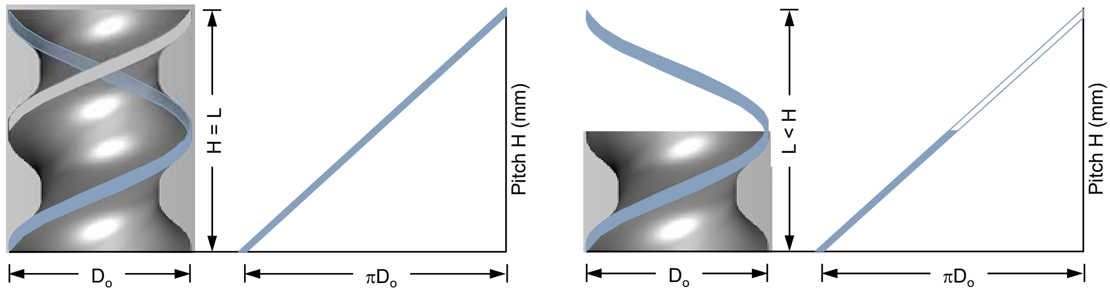
2

Conveying elements

Definition of pitch and length

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

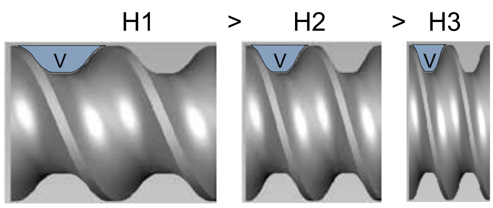
If L<H (e.g. half elements)
the helix has to be completed theoretically in order to get the value of the pitch.



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.



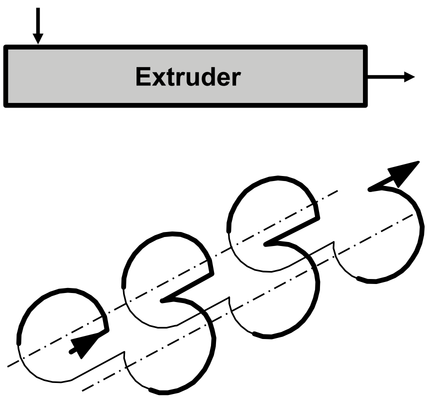
Conveying elements

Fill factor

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

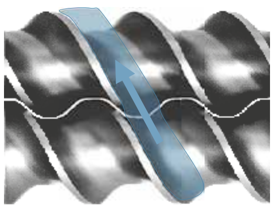
Conveying elements

Product flow



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

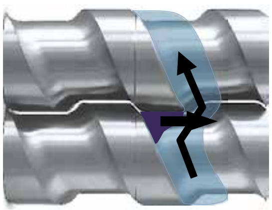
Two-flighted elements



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.

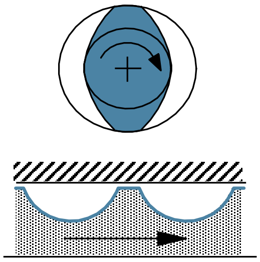
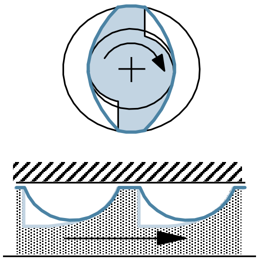
This means: improved transportation of the product in axial direction.

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.

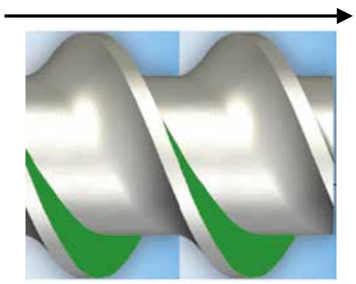
- With sticky products the self cleaning profile might be rebuilt by the product
- In the intermeshing area of the screws there is an open gap which reduces the conveying efficiency

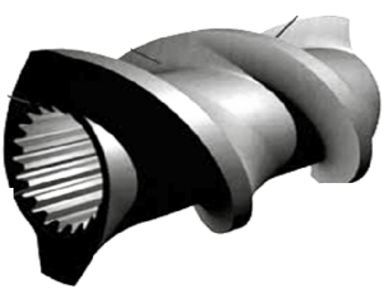
Self-cleaning profile	Undercut profile (SK)
	
Free cross section: 100%	Free cross section: approx. 115%

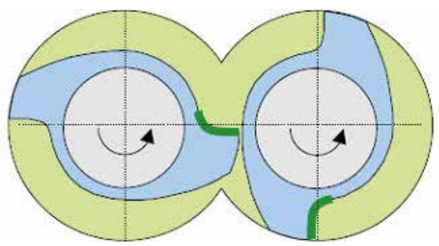
Conveying elements

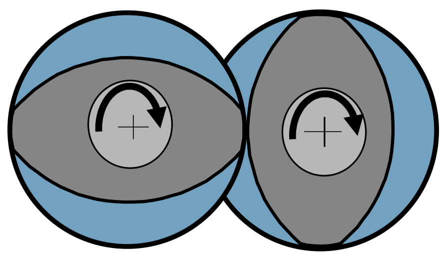
undercut conveying elements

Direction of flow



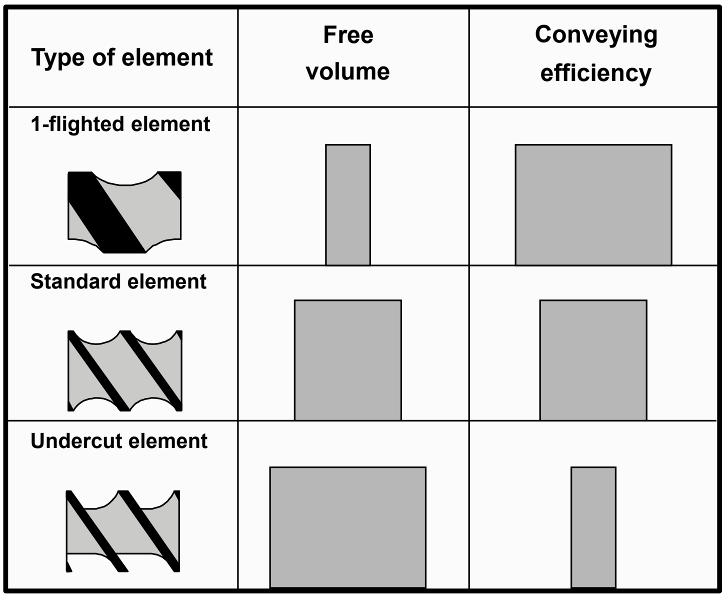






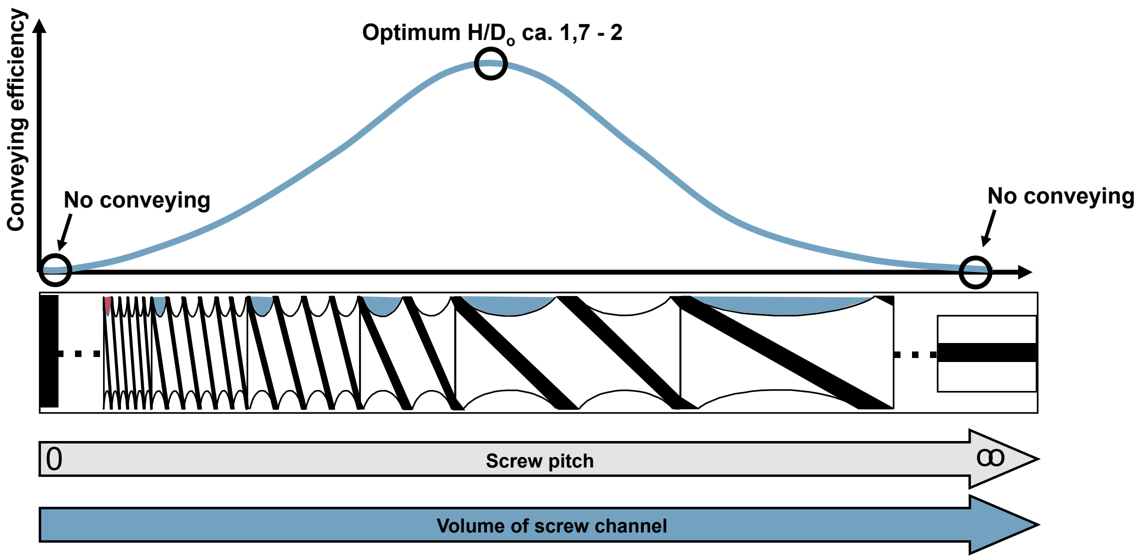
Conveying elements

Free volume and conveying efficiency



Conveying elements

Optimal screw pitch

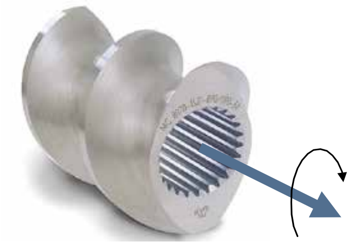


Conveying elements

Conveying direction

Extruder

Right handed elements	Left handed elements



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

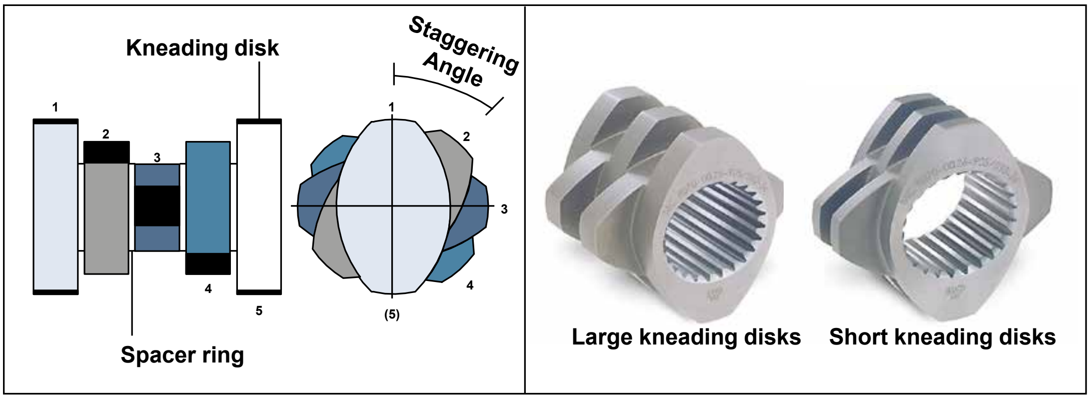
Conveying direction of the element
contrary to
the direction of product flow in the extruder

Kneading elements

3

Kneading elements

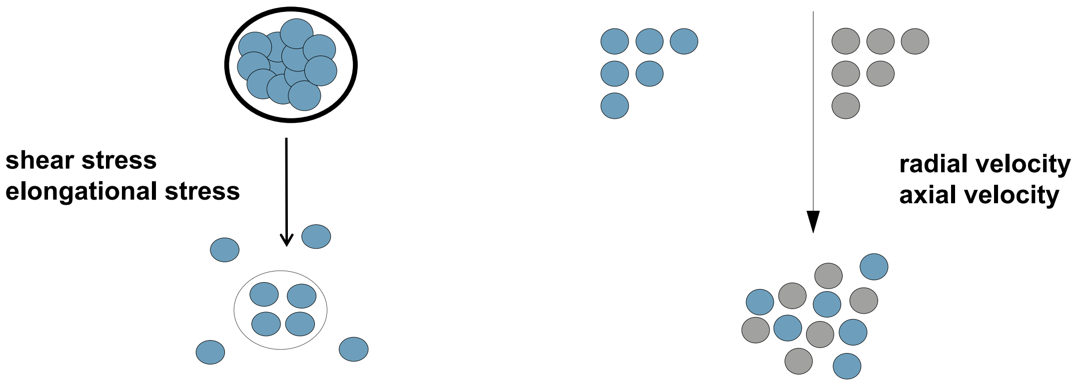
Overview



Kneading elements

Mixing mechanisms in twin screw extruders

Dispersive Mixing = Break up of agglomerates and aggregates	Distributive Mixing = Distribution of primary particles

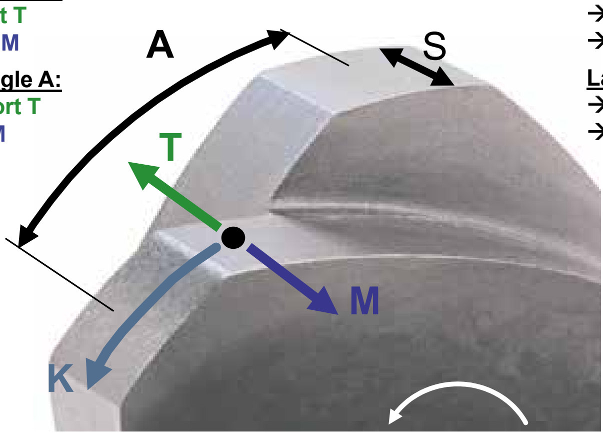


Kneading elements

Wokring 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

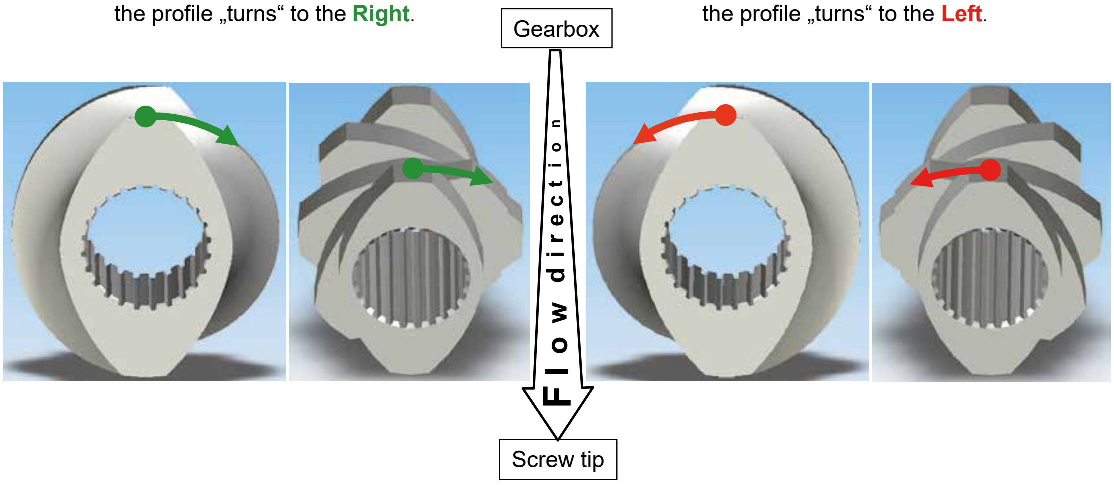
Direction of pitch

Right handed elements

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

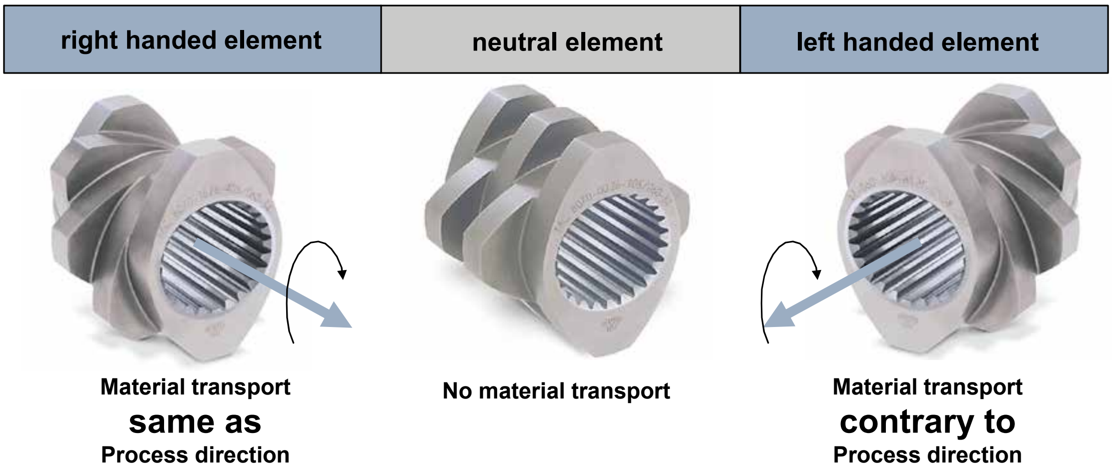
Left handed elements

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



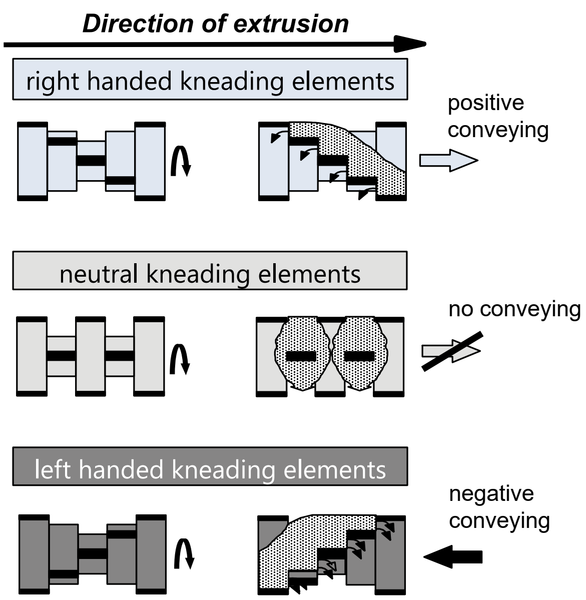
Kneading elements

Direction of product transportation



Kneading elements

Product flow in kneading elements



- staggered in direction of flow

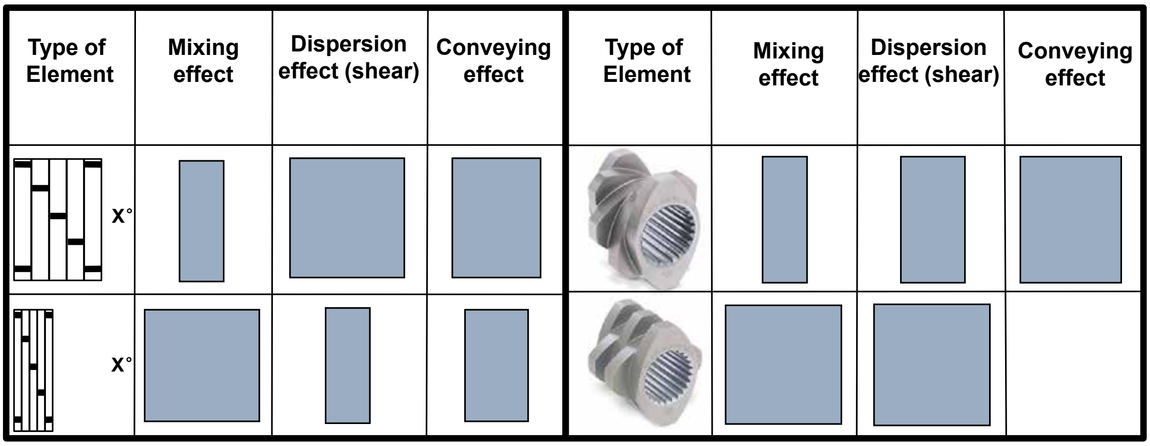
- neutral (90°) staggered kneading discs
- have to be **overrun.**

- staggered contra direction of flow have to be **overrun**.

Kneading elements

Working principle

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



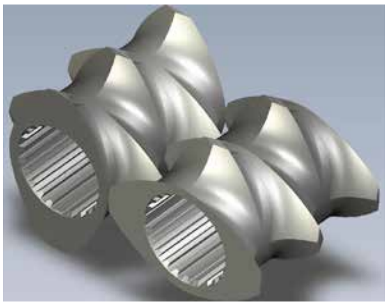
Mixing Elements

4

Mixing elements

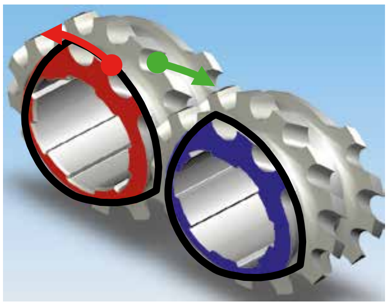
Distributive mixing

Igel

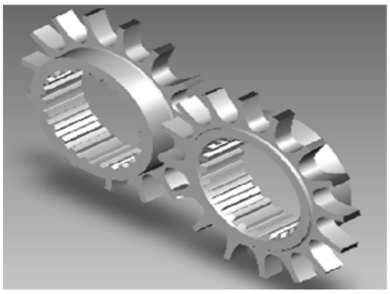


SME

ZME



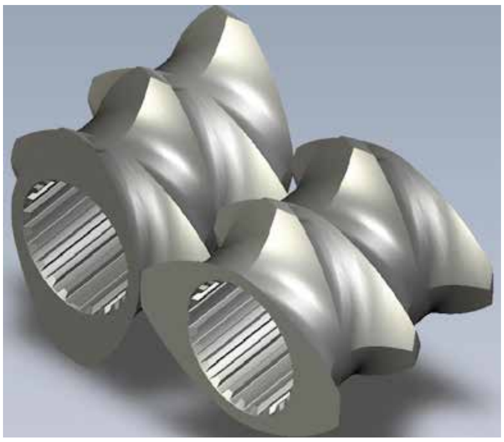
TME

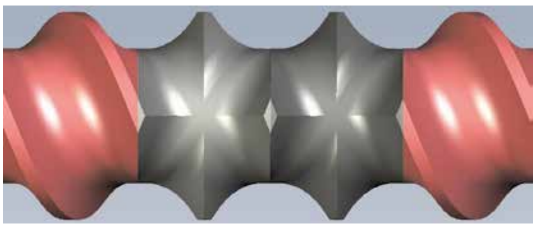


Mixing elements

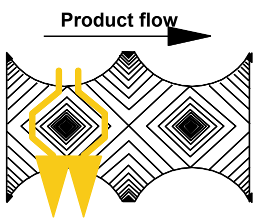
Igel

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





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

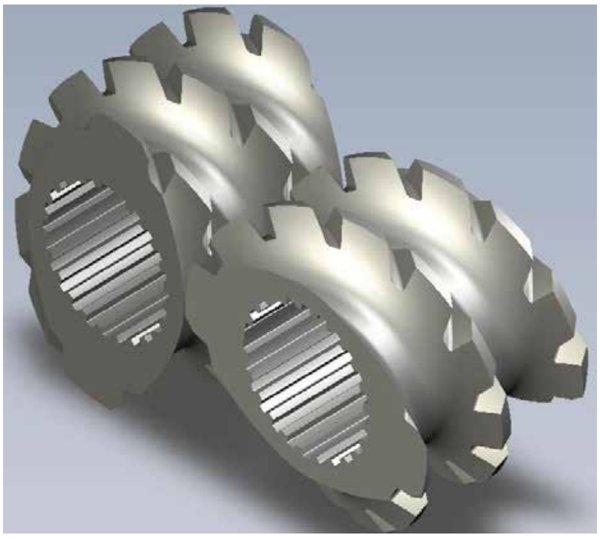


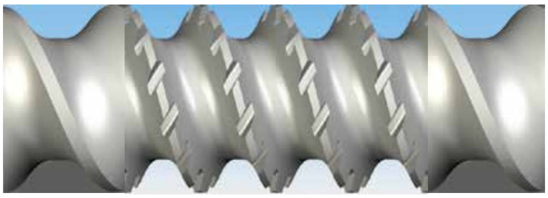
No active conveying

Mixing elements

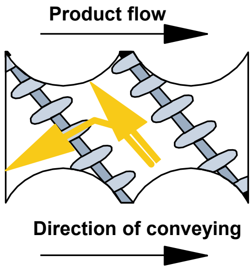
SME

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





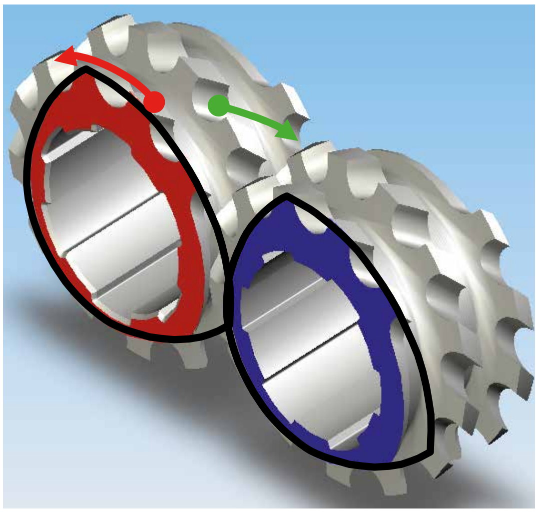
Upstream, in between and downstream: no transition elements or spacer required.

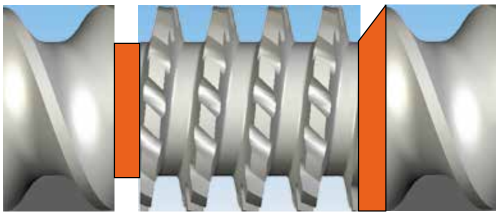


Mixing elements

ZME

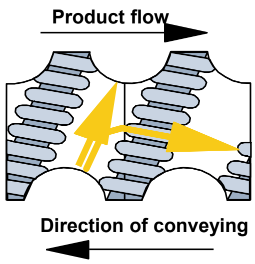
- Left-handed single-flighted conveying elements with superimposed right-handed multi-flighted profiles with low flight depth





Upstream and downstream: transition elements or spacer required.

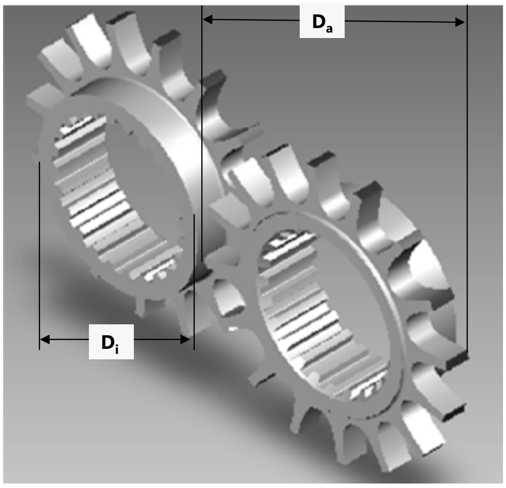
In between: no spacer required.

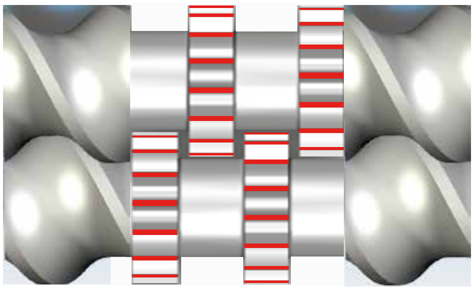


Mixing elements

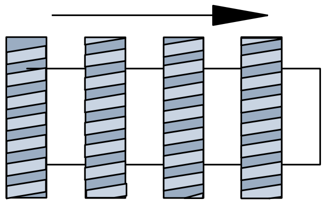
TME

- 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 unsymmetrically



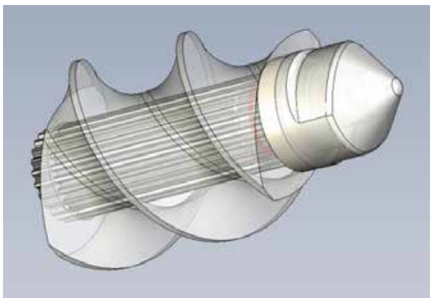


TME-elements have an integrated spacer on both sides
→ Correct transition between the elements is given
→ No additional transition elements required

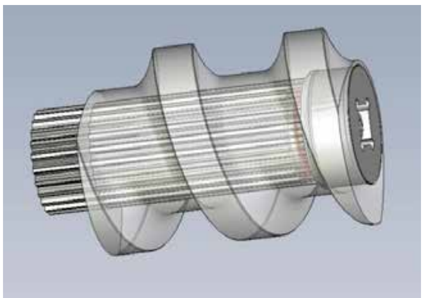


Mixing elements

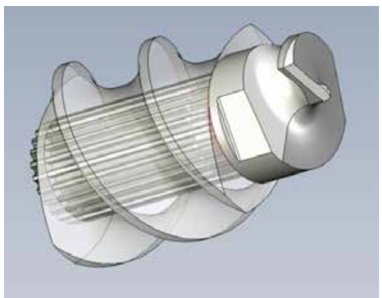
Special element: Screw tip



standard tip – 90°



recessed tip



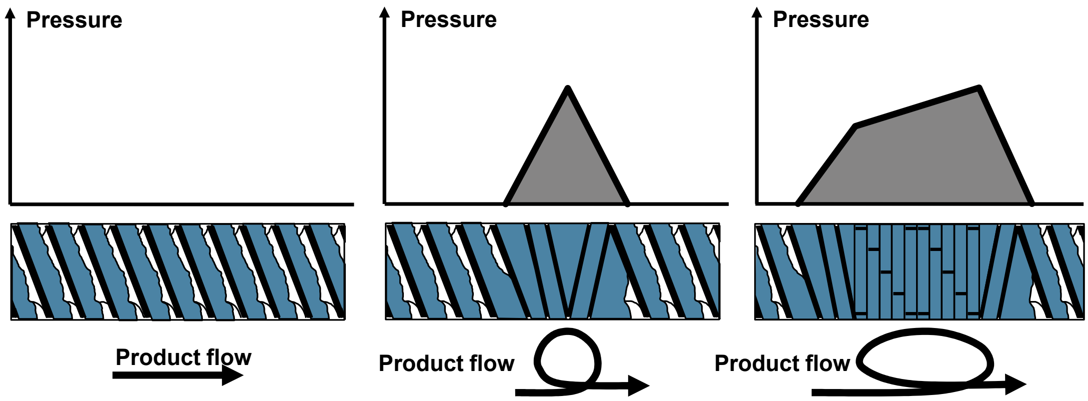
mixing tip

Combining effects

5

Combining effects

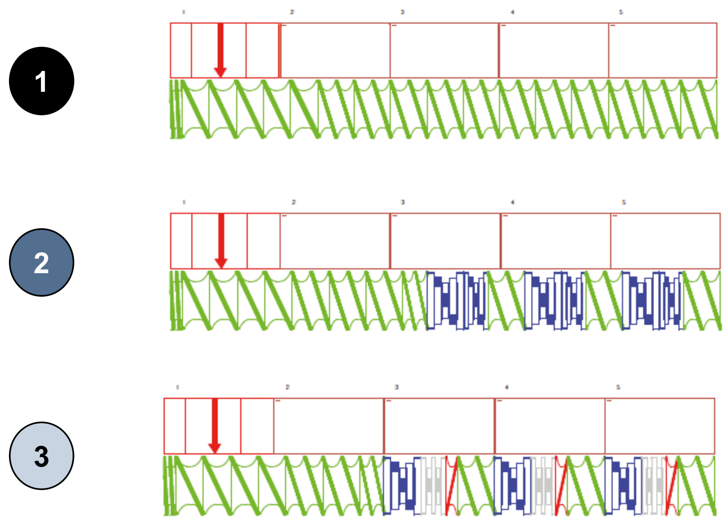
Influence of screw set up on pressure

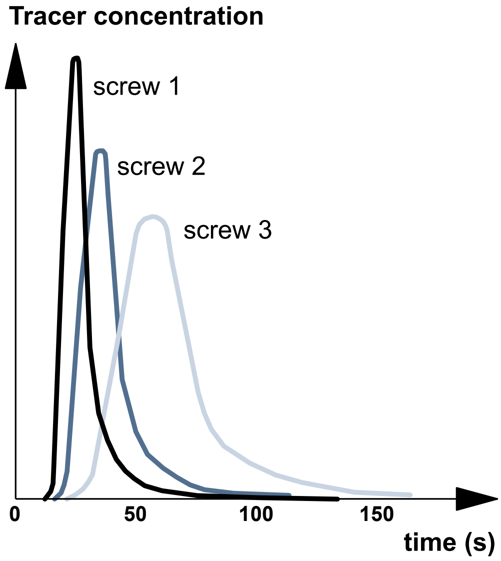


Right handed elements are
Partly filled with product.
→ This section is pressureless.

Combining effects

Influence of screw set up on residence time

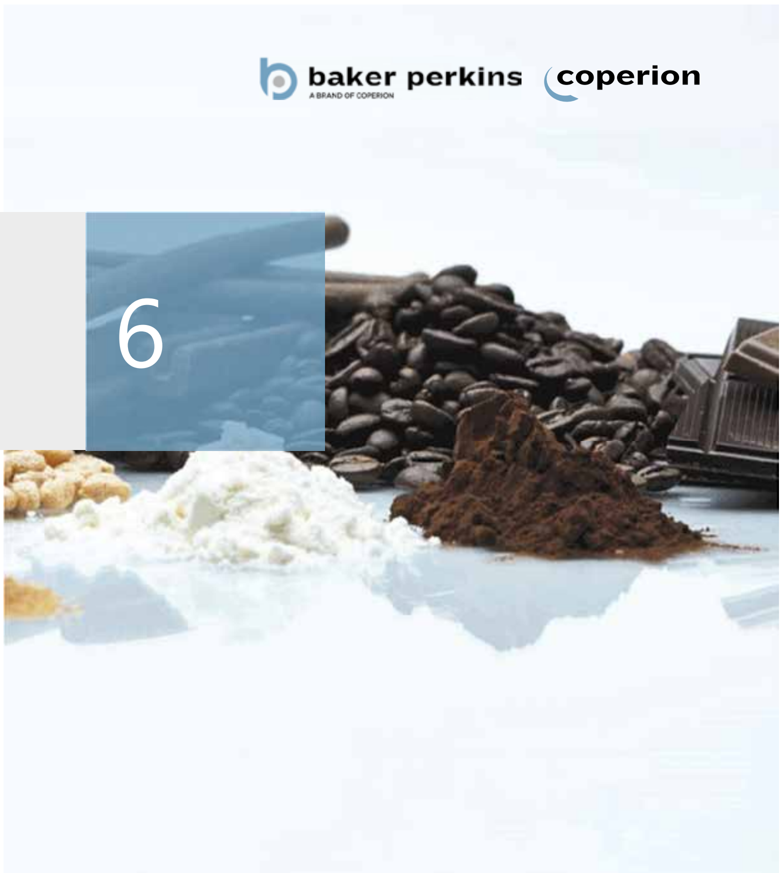




Material

6

Possible materials for screw elements



Material

Overview Coperion

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

Screw diameter

Length of element

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

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 05

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

Contact

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baker perkins
A BRAND OF COPERION
coperion

Assembly of Screw Elements

Food Extrusion Seminar 2025

Tobias Gaiser, Process Engineer Food Extrusion

Screw Elements

Cross Section

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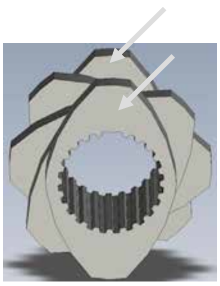
ZSK Standard Elements

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

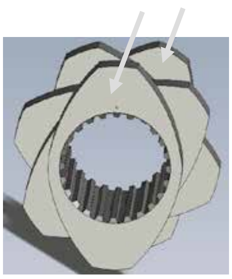


Exceptions

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)

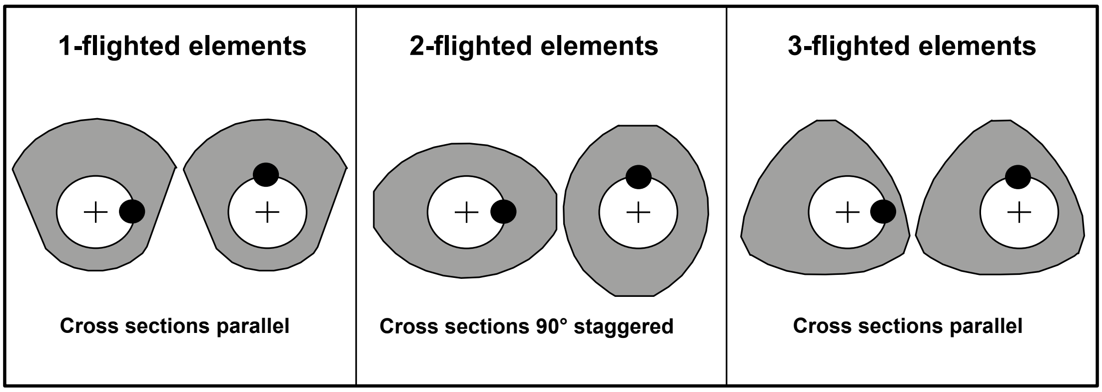
Screw shaft with 0-position (Coupling side)

Lantern with Screw Shaft Coupling

Assembly of Screw Elements

Running Position of Screw Elements

Running Position

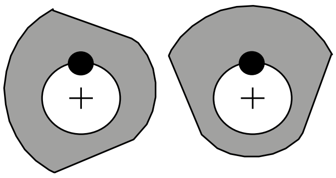
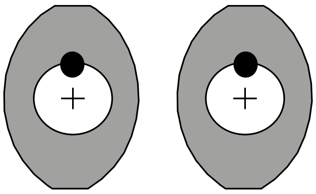
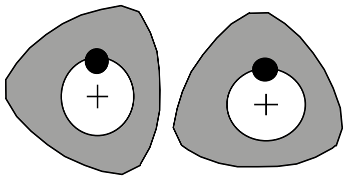


Assembly of Screw Elements

Running Position of Screw Elements

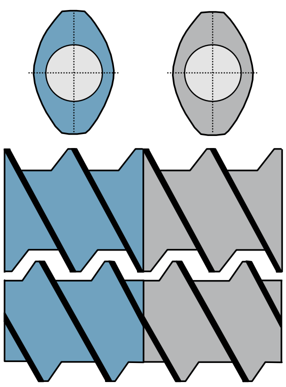
Assembly Position

Marks on both screw shafts positioned vertically

1-flighted elements	2-flighted elements	3-flighted elements
		
Cross sections 90° staggered	Cross sections parallel	Cross sections 90° staggered

Installation of Screw Elements

Elements with Identical Cross Sections

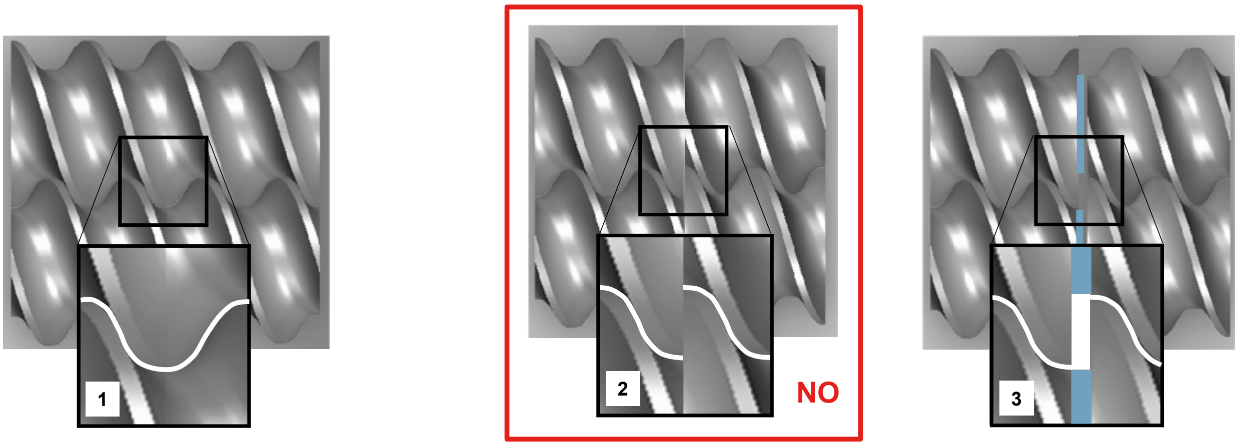


Screw elements with identical cross section are installed without any offset, regardless of the direction or the element type

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

Installation of Screw Elements

Off-set Installation of Conveying Elements



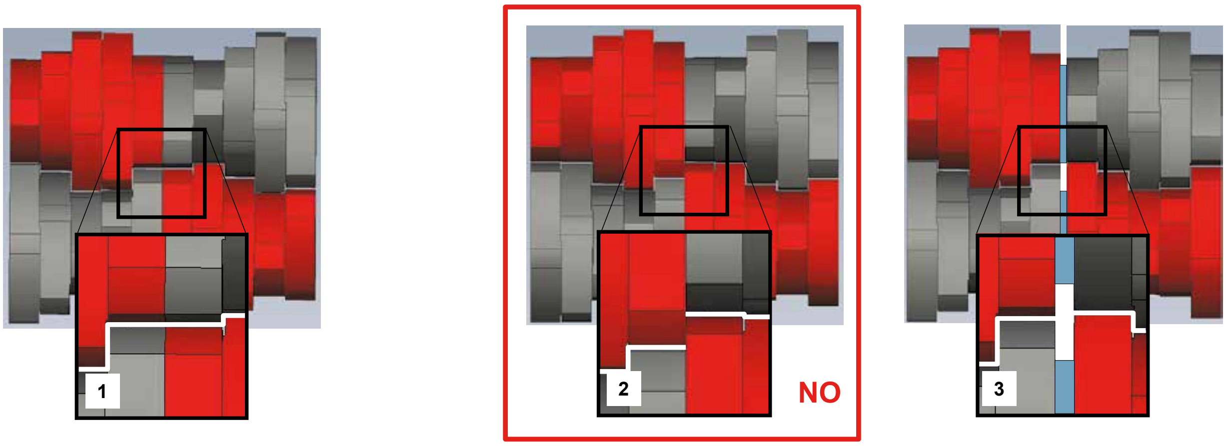
Conveying elements, having the identical cross section, are installed without any off-set (1).

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



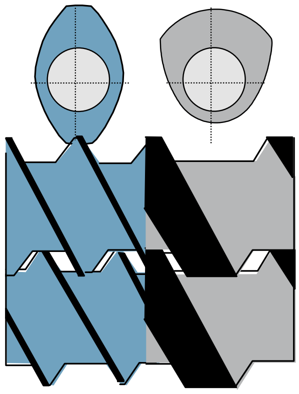
Kneading elements, having the identical cross section, are installed without any off-set (1).

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.

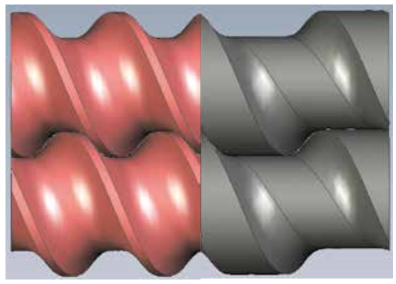
Installation of Screw Elements

Elements with Different Cross Sections



NO

There is **no axial clearance**

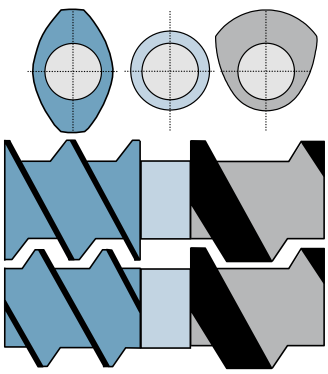


When elements with <u>different cross sections</u> have to be combined...

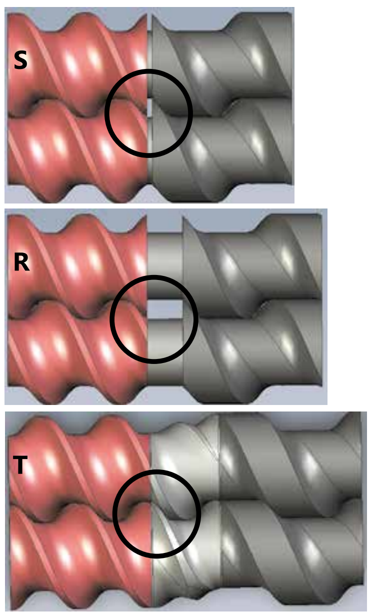
➡ The transition is **not continuous**. There is **no axial clearance**.
The screw will touch each other which will lead to mechanical damages.

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.

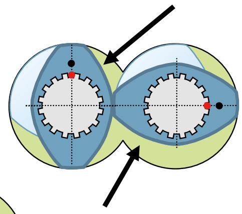
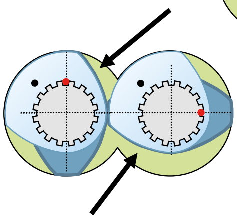
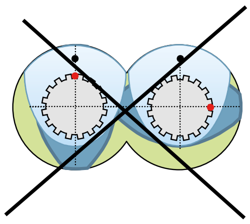
➡ The transition remains **not continuous**.
➡ Nevertheless it is sufficient **clearance** available

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

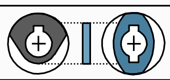
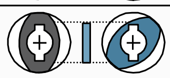
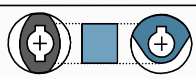
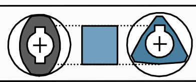
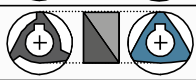
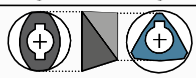
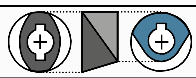
Cross section view single –
double flighted elements
in operating arrangement

Mechanically correct arrangement
BUT Process vise not good

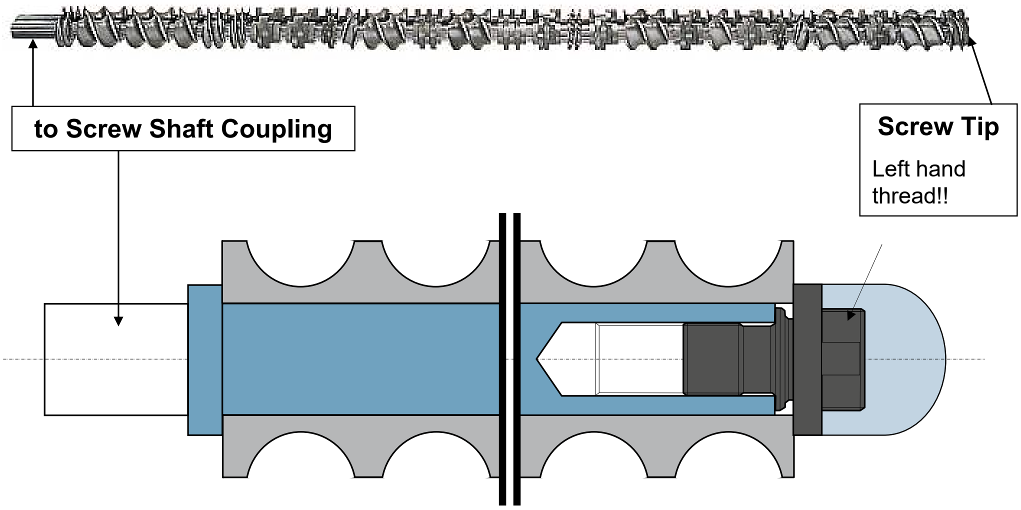
Overview Transitions of Screw Elements

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



Contact

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Process Opportunities in Food Extrusion

Catherine Cooper, Senior Food Technologist
Fabian Specht, Senior Process Engineer

Agenda long

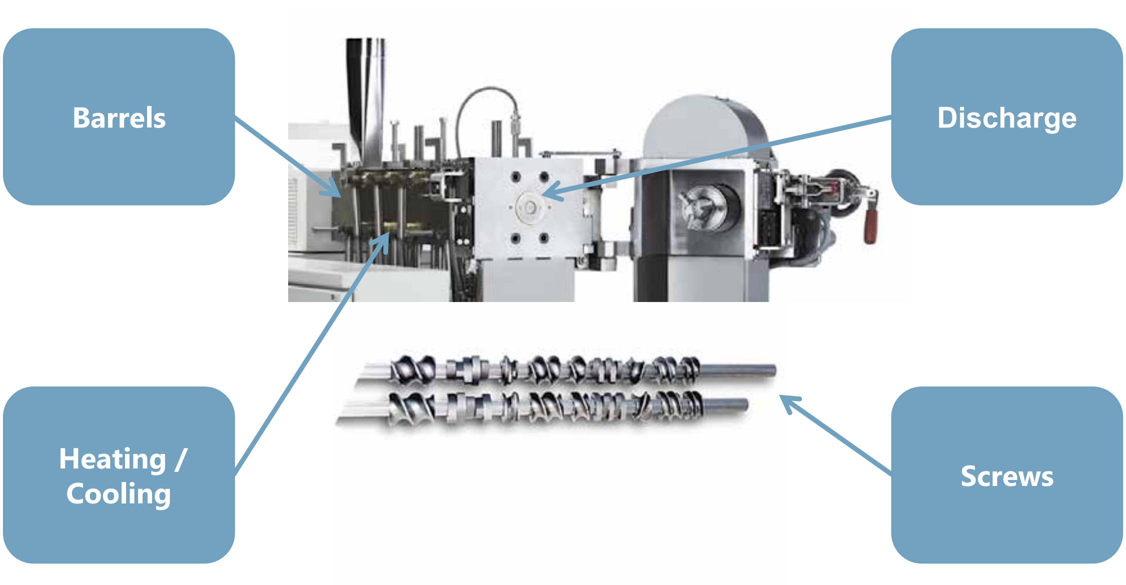
Elements of the Process Section

1

Twin Screw Food Extruders

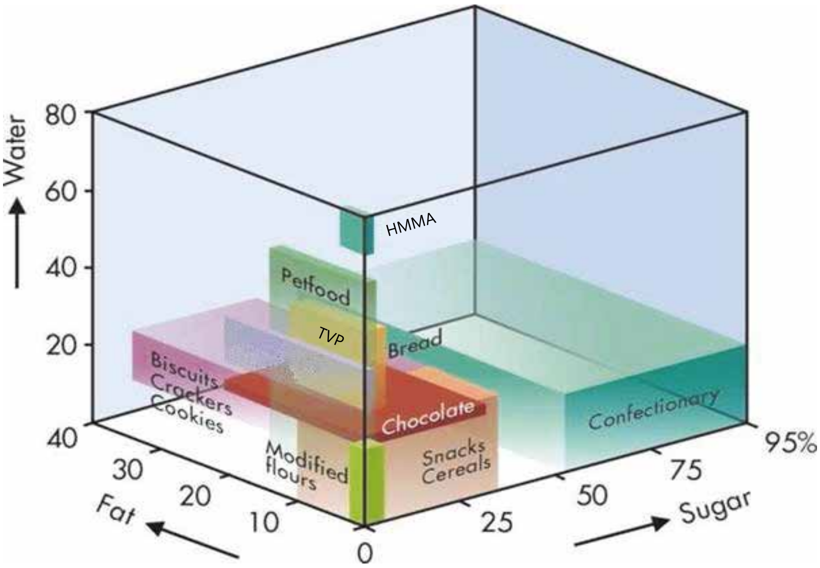
Twin Screw Food Extruders

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

Product Discharge

Flow Through a Resisting Die
- Pressure Build-up
- Mechanical Energy Input
- Basis for Product Expansion

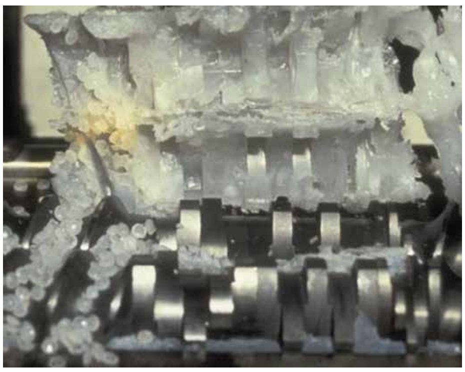
Texturization
- Down-stream of the Screws
- Flow Characteristics Determine Texture
- Supported by Cooling

Forming Through Die Shape

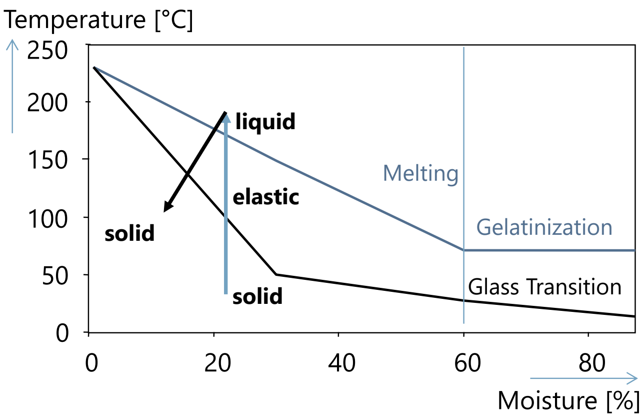
Cutting

Mechanical Process Opportunities

Effects on Raw Materials



Plasticizing in Kneading Elements



Starch Melting During Extrusion

Diagram by Yaku

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

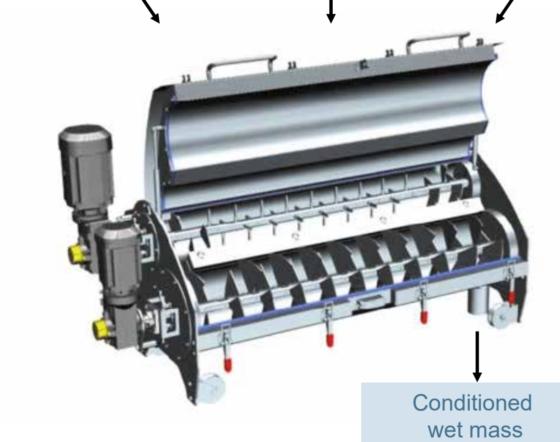
Thermal Process Opportunities

Preconditioning

Bulk materials

Water

Steam



Conditioned wet mass → Extrusion

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

Two Stage Preconditioner

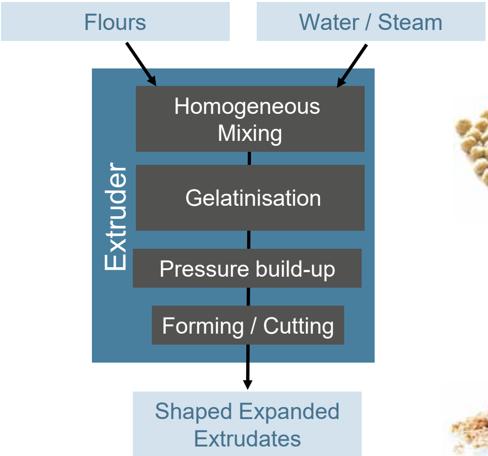
Process Examples and Applications

4

Intermediate and
End Product Examples

Extrusion Cooking

The Most Common Thermo-Mechanic Food Extrusion Process



Starch based recipes

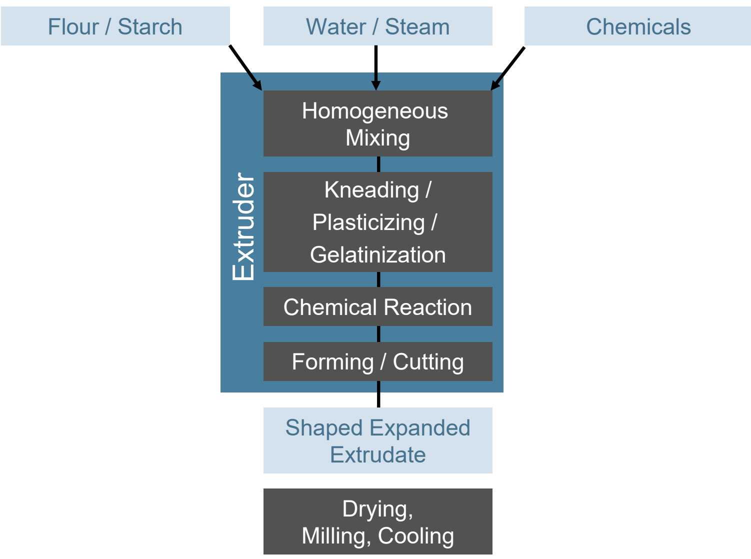
- Cereals, Snacks, Breadcrumbs, Pregelatinized Flours and Starches ...

Protein based recipes

- Texturized Vegetable Proteins, Pet Food, Aqua Feed ...

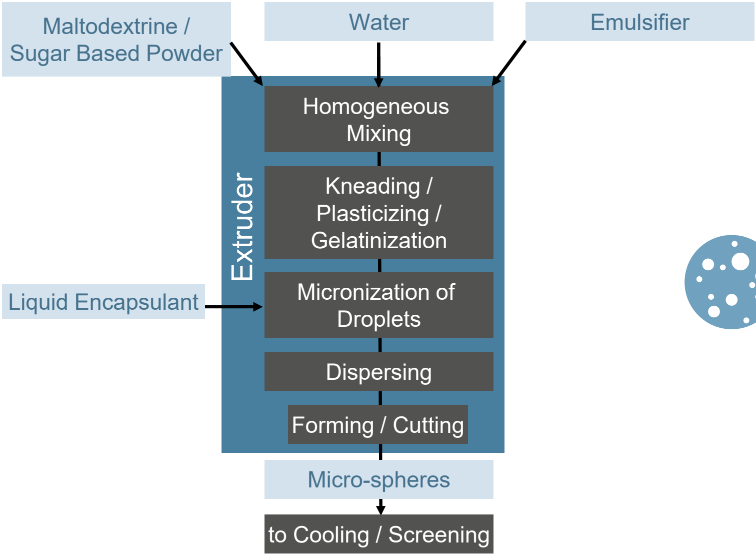
Starch Modification

Extrusion Cooking combined with a Chemical Reaction

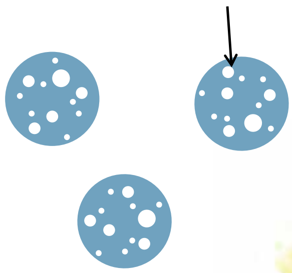


Flavor Encapsulation

Dispersion / Emulsion of Flavor Droplets

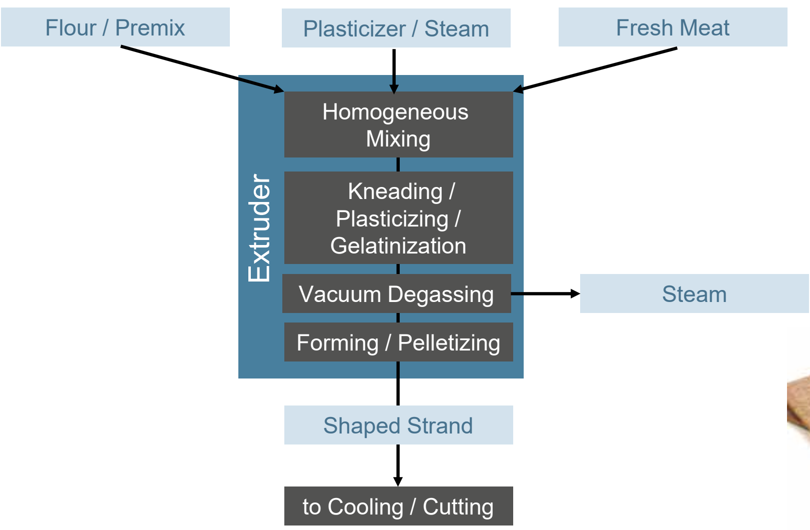


Droplets embedded in matrix



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

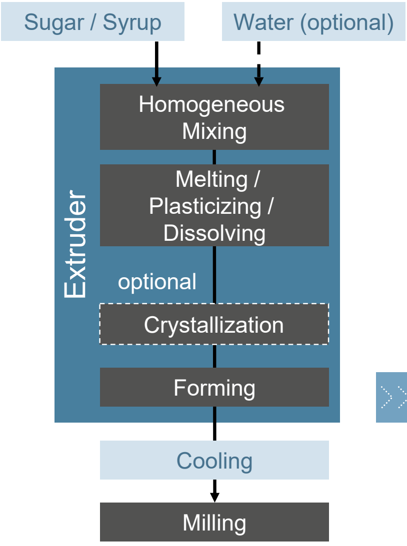
- Tailor-made Reaction
    Different Meat Type Flavors
    Beef, Chicken, Pork ...

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!

Contact

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Importance of Feeding in Continuous Processing

13th Food Extrusion Seminar
29./30. October 2025

Beat Müller-Ranft / EMEA Sales Manager Food & Pharma

BEST COMPONENTS & BETTER SYSTEMS

THE RECIPE FOR PERFECT FOOD

Index

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

Importance of Feeding in Continuous Processing

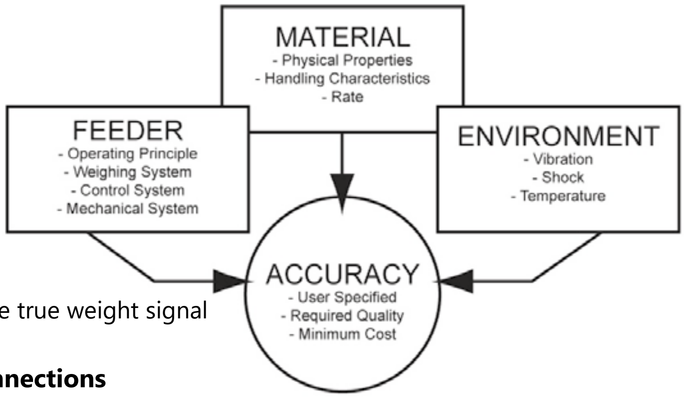
1

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



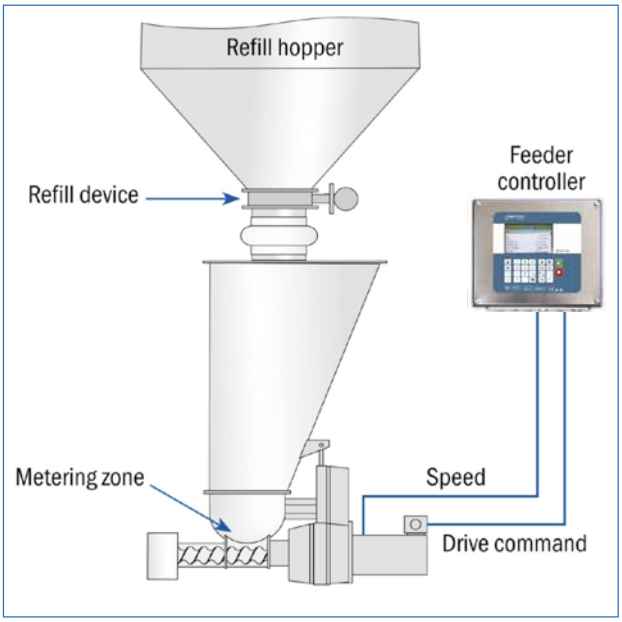
Feeding Principles

- **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

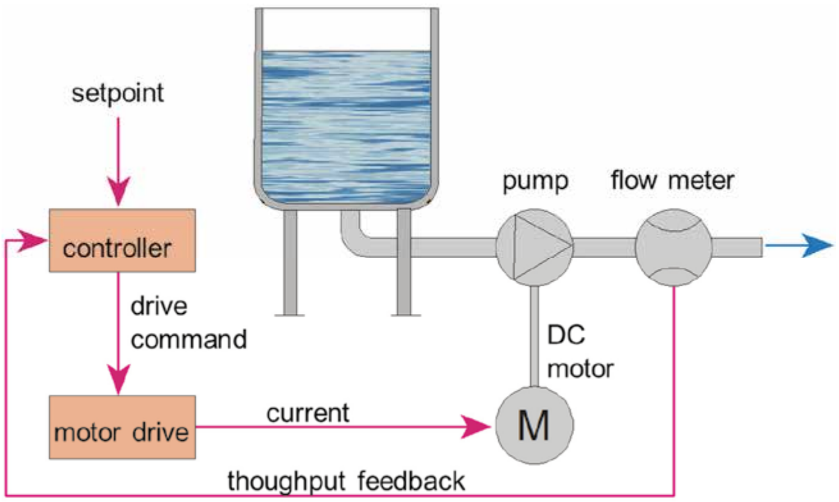
Speed Regulated
Volumetric Feeding:



Volumetric Feeding II

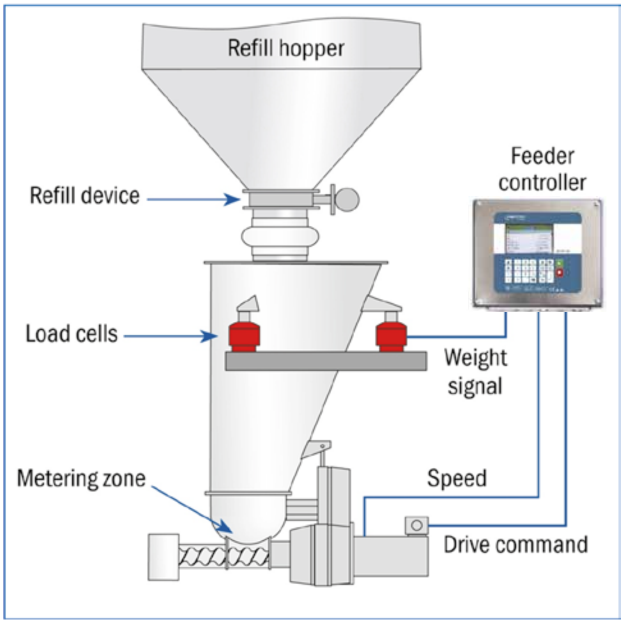
coperion coperion K-TRON

Controlled Volumetric Feeding:



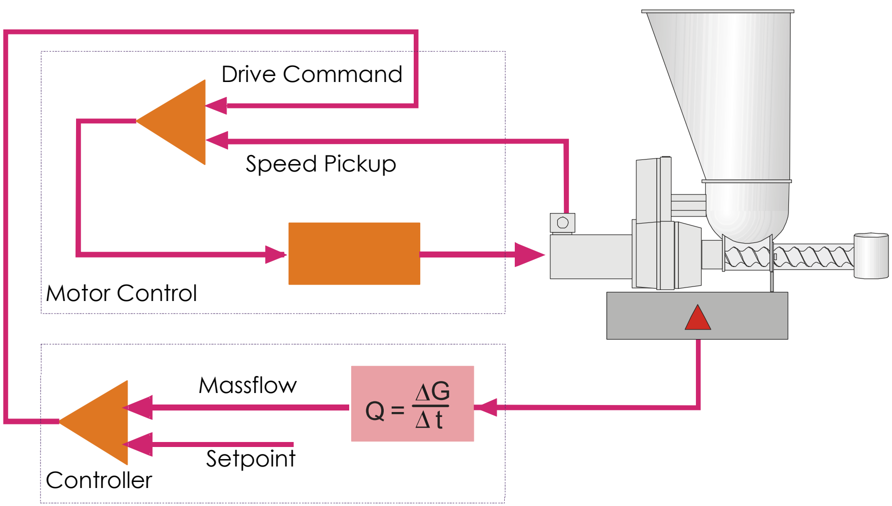
Gravimetric Control Principle

Weight Regulated
Gravimetric Feeding:



Loss-in-Weight Control Principle

For loss-in-weight screw and belt feeders



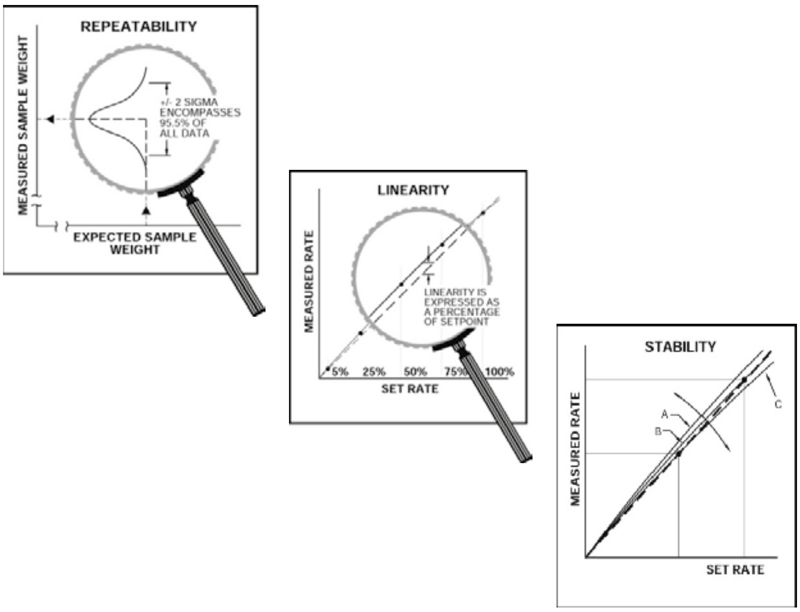
Weighing Technology

2

13th Food Extrusion Seminar / Feeding of Various Ingredients

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



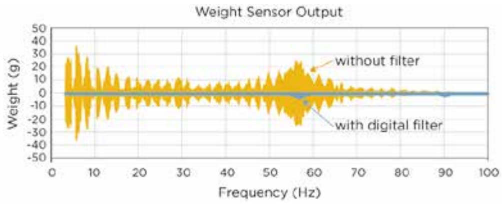
13th Food Extrusion Seminar / Feeding of Various Ingredients

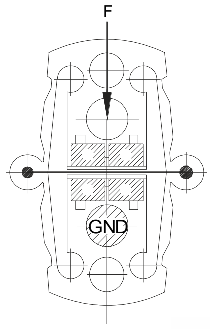
Choose Load Cell Technology

Filtering feeder noise and environmental vibrations

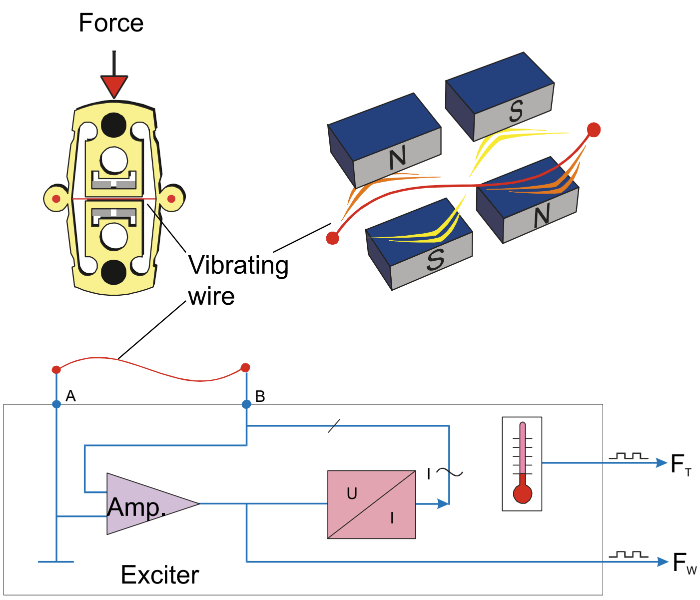
The Smart Force Transducer (SFT) offers ...

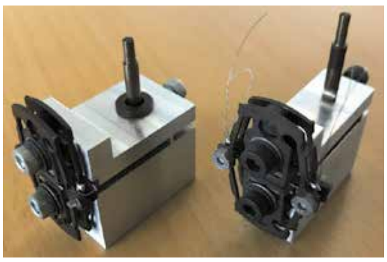
- Vibrating wire measurement technology
- Resolution – 1:8’000’000 in 20ms
- Built-in microprocessor
- One-time calibration at factory
- Noise-free signal transmission
- Fast sampling time (450 samples/sec.)
- High short-term accuracy in any conditions
- Not affected by vibrations

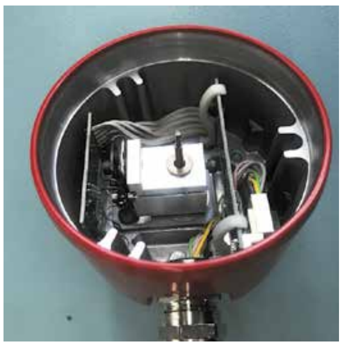


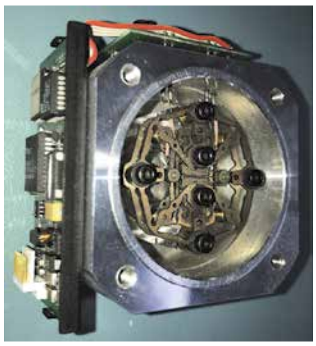


Vibrating Wire









Effect of Vibration: Dynamic Weighing

Material Characteristics & Feeder selection

3

Material Characteristics I

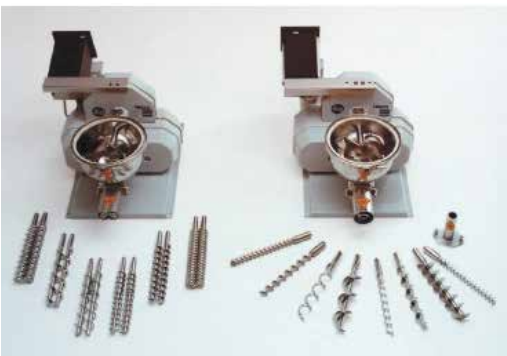
Effect of Particle Properties on Flow

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

13th Food Extrusion Seminar / Feeding of Various Ingredients

Feeder Selection

Screw Configurations



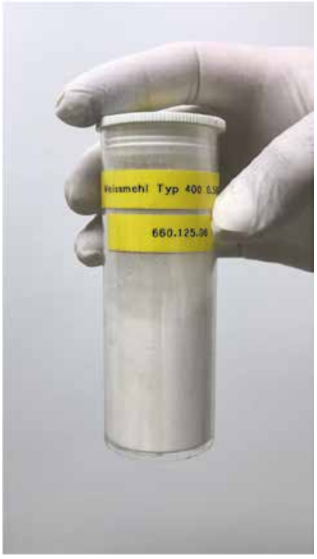
	Code	Feeding Screws
	TCC	Twin concave screws
	TCF	
	TAC	Twin auger screws
	TAF	
	TSC	Twin spiral screws
	TSF	
	DSC	Double spiral screws
	DSF	
	SAC	Auger screw
	SAF	
	SSC	Spiral screw
	SSF	

13th Food Extrusion Seminar / Feeding of Various Ingredients

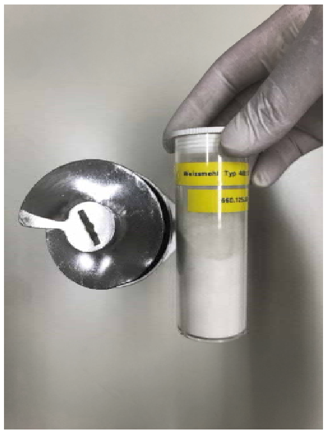
Material Characteristics II

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

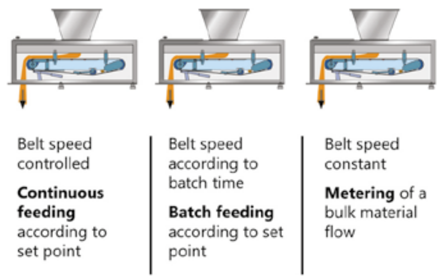
Feeding for continues and batch Process I

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



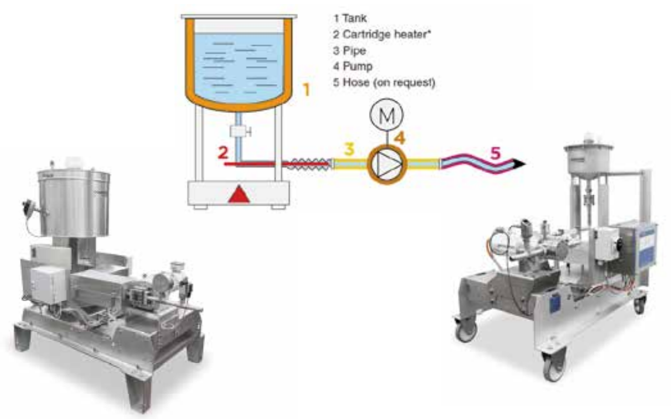
Feeding for continues and batch Process II

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



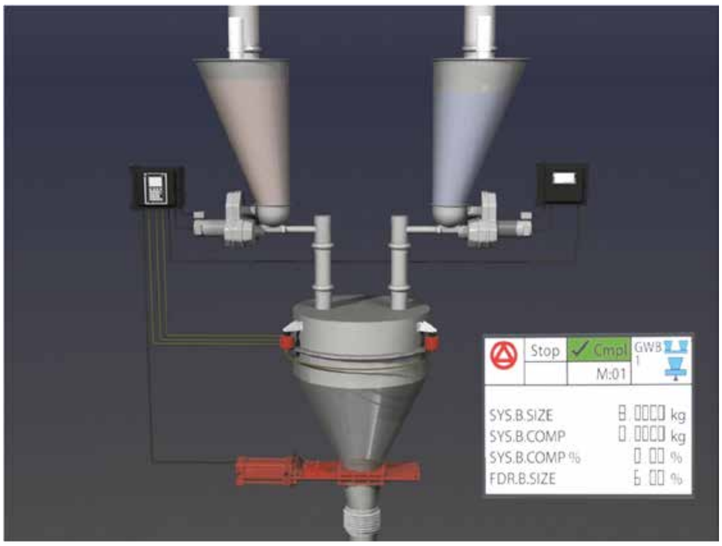
Batch Technology

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

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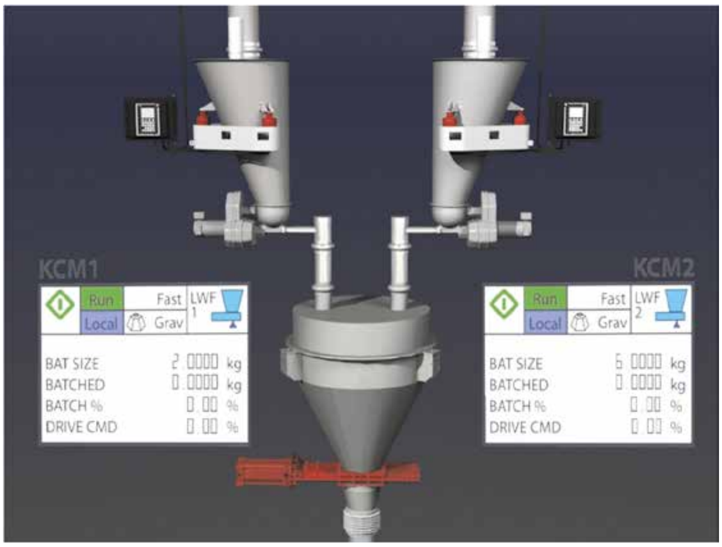
- **Advantages**
  - Each ingredient is batched out in its own LIW feeder
  - Feeders can then operate simultaneously, making overall batching process shorter
  - Can also batch out variety of ingredients at different bulk densities and high variation in mix percentages with high accuracy

- **Disadvantages**
  - Higher initial investment for loss-in-weight feeders



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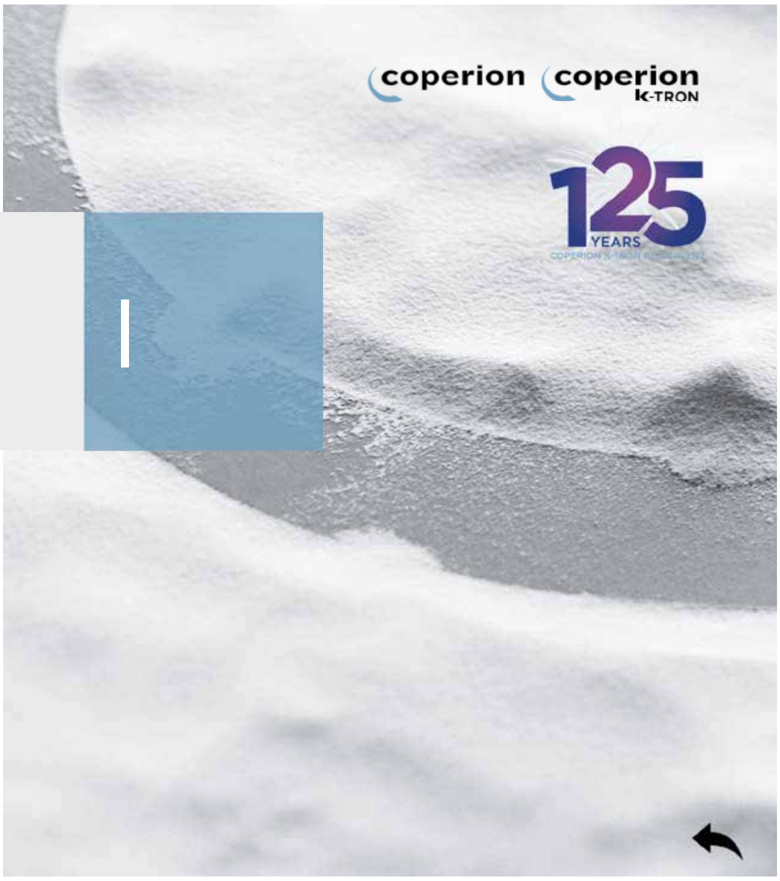
Know-how & Technology

6

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

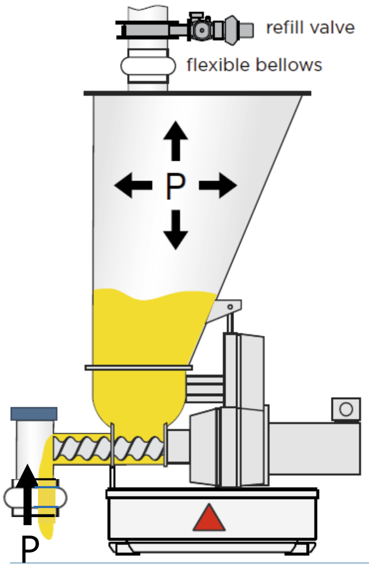
EPC



Effects of Pressure on Feeder Performance

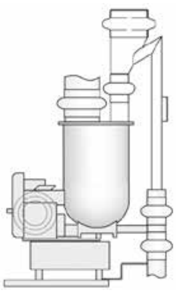
Pressure exerted externally or internally causes weigh scale errors

- **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

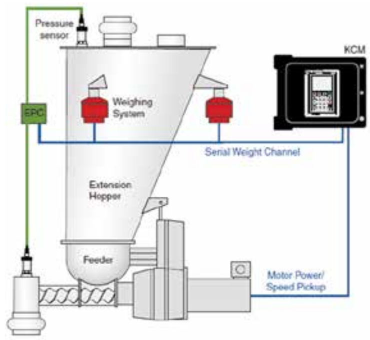


Pressure Compensation - Mechanical Solution / Electronic Solution

- **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.

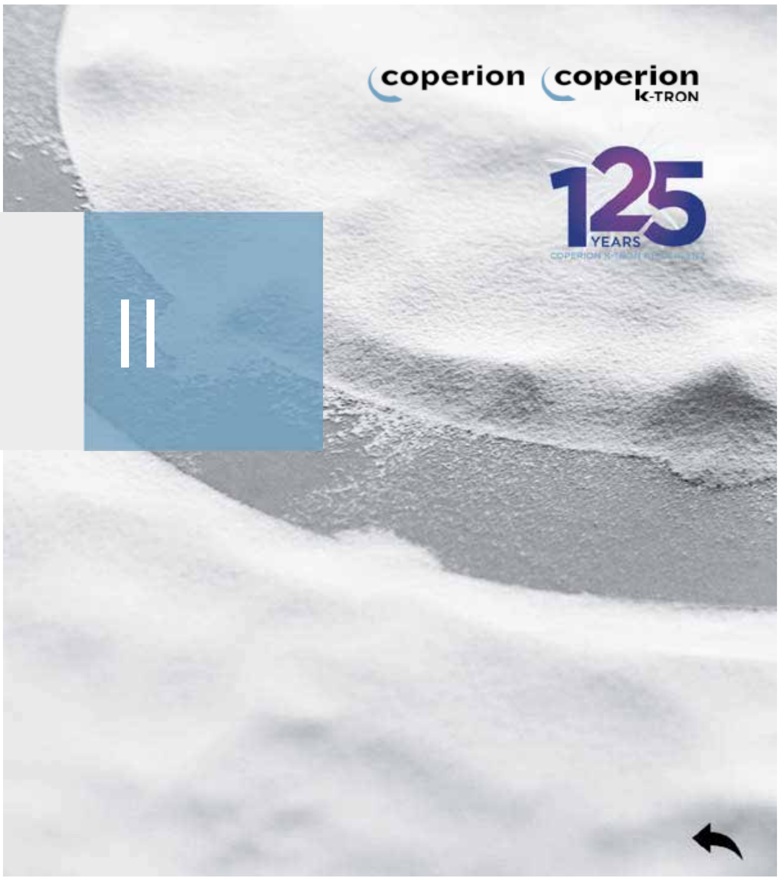


Advantages:

- 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



13th Food Extrusion Seminar / Feeding of Various Ingredients

Poor Flow in Hoppers = Poor consistent feeding

Difficult powders:

- May get compacted
- Form rat-holes & bridges

Result in operation:

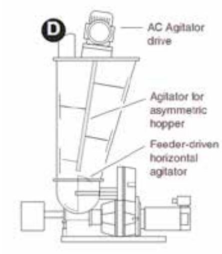
- Production interruption
- Quality problems

Screw feeder accuracy is a function of consistent screw fill

13th Food Extrusion Seminar / Feeding of Various Ingredients

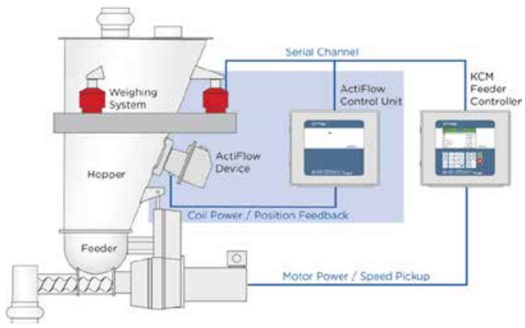
Alternative Solutions for Improved Hopper Flow

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



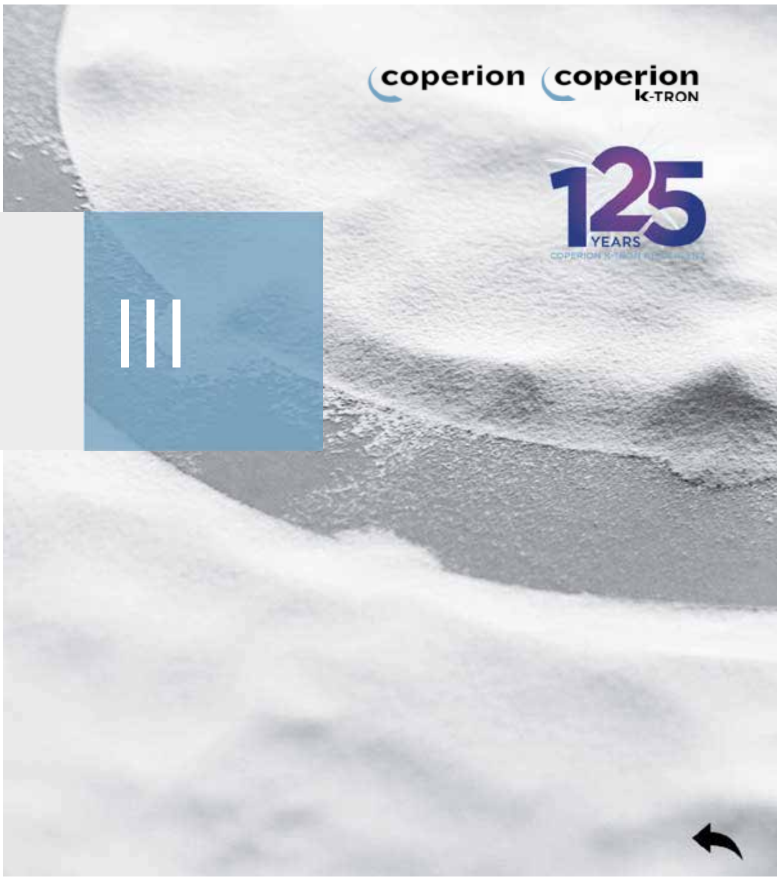
ActiFlow Design

- 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



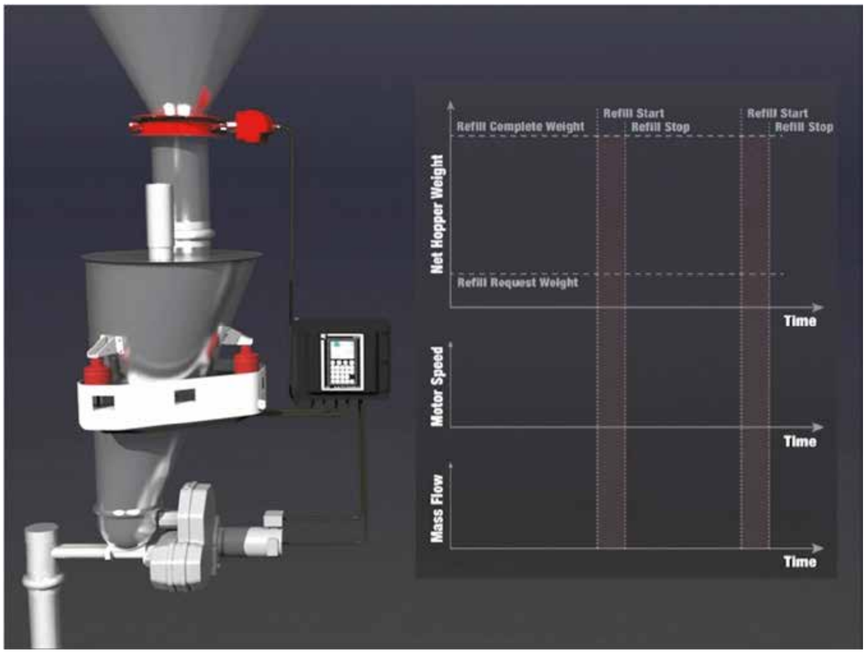
Refill Array

III



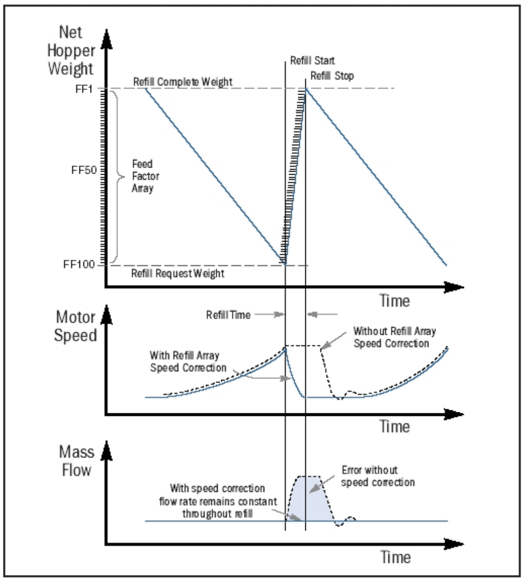
13th Food Extrusion Seminar / Feeding of Various Ingredients

Continuous Loss-in-Weight Feeding

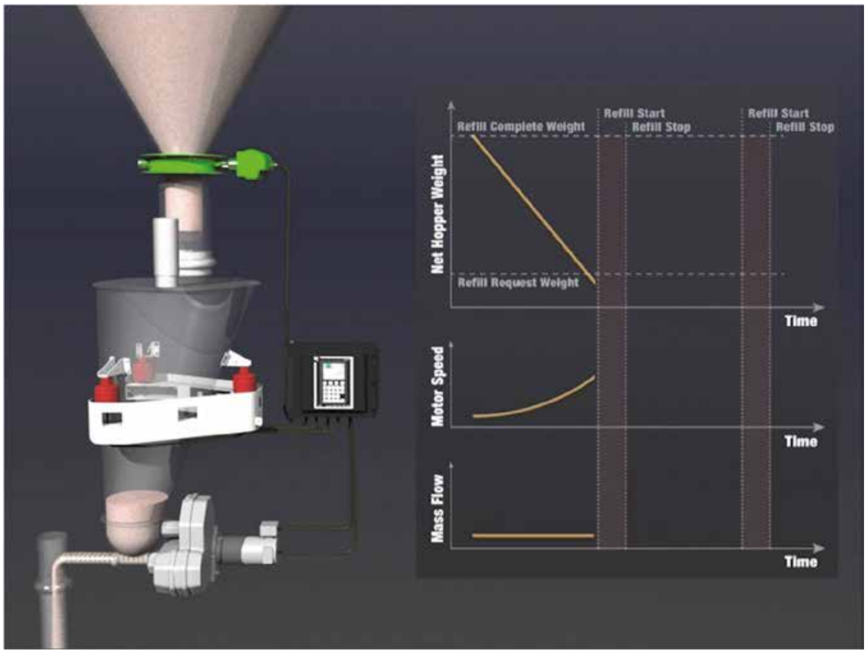


Refill Array and its Importance in the Continuous Process

- 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

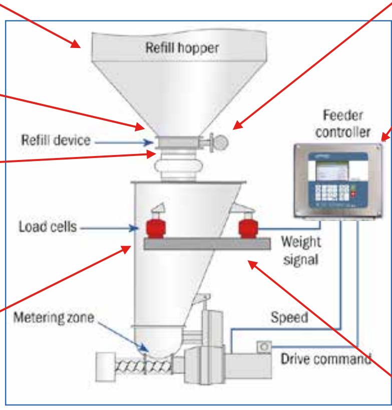
General Refill Rules

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.

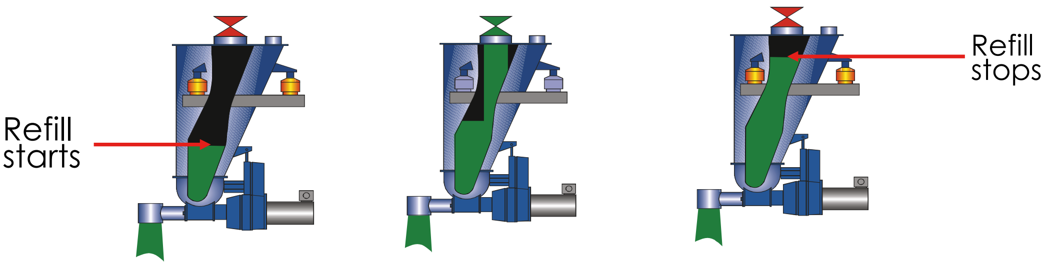
Up to 15% of the feeder operating time is foreseen for refill. During refill the Loss-in-Weight feeder switches to volumetric mode.

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.

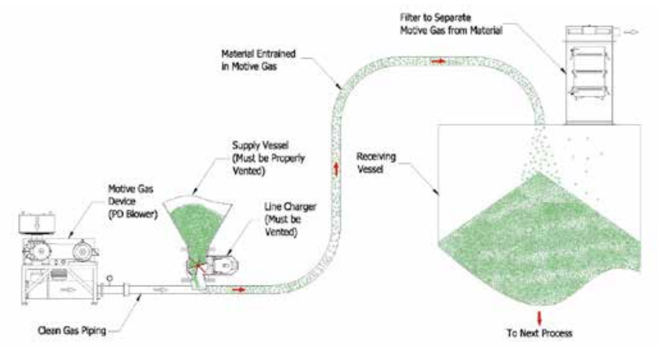


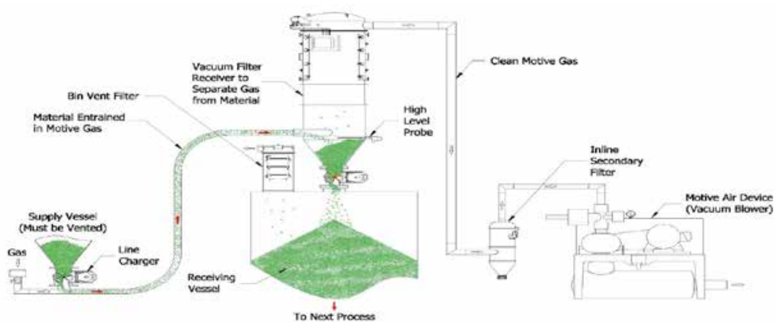
Conveying

8

Pneumatic Conveying – Dilute Phase

- Typical Pressure Dilute Phase System
- Typical Vacuum Dilute Phase System





Specialty Bag Dump Stations in Hygienic Design

Typical Feeders Used in Processing

Refill receiver for LWF feeder refill

Keep full receiver for day-hopper filling

GWB batch receiver for recipe conveying

Batch feeder-receiver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Development of a Textured Hemp Protein for use in Plant-Based Foods

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Fraunhofer IVV is involved in research and development projects focusing on texturing plant-based biopolymers, such as plant proteins, starch and fiber, using innovative processes. The focus is on structuring and functionalizing raw materials and food by-products for use in innovative foods such as meat substitutes and healthy snack alternatives. Hemp protein is one plant-based protein that has become increasingly important in recent years as part of the superfood trend. Despite its numerous nutritional, ecological, and functional advantages, there has been a lack of comprehensive research and development work on the texturization of hemp protein. The aim of the work was therefore to develop high-quality hemp-based texturates for use as a texturing component in meat alternatives and as a basis for healthy snacks.

First, various commercially available hemp proteins were identified, characterized, and evaluated in terms of their chemical composition and techno-functional properties, such as solubility, water-binding capacity, and rheological behavior. To produce protein- and starch-rich texturates, the selected protein ingredients were thermomechanical processed using a co-rotating twin-screw extruder at low water content, with the addition of selected legumes and polysaccharides in different recipe formulations. The influence of the recipe formulation and process parameters such as temperature, shear and water content on the texturate properties was analyzed. Expansion, color, hardness, rehydration behavior and sensory properties were evaluated. The process was then scaled up from the pilot scale to the industrial scale, and the suitability of the texturates was tested in applications such as burger patties and snack products.

The characterization and evaluation of plant-based protein ingredients derived from hemp revealed that those with a high protein content met the desired techno-functional requirements for texturizing. Promising protein- and starch-rich textures were produced using low moisture extrusion with a combination of hemp protein concentrate and pea protein isolate (PPI) and corn starch. By systematical varying recipe formulations and process parameters, functional relationships were identified between composition, processing and resulting texture properties. The results showed that adding PPI or corn starch to the recipe formulation, and preheating the plant proteins, optimized the texture and rehydration properties of the texturates. These results demonstrate the potential of hemp protein as a base for meat alternatives and snack products.

This work was carried out as part of the "hempTVP" project (FKZ: 16KN092724), which was founded by the BMWK as part of the ZIM innovation network InnoHemp.

A Toolbox of Methods to Advance the Mechanistic Understanding of Plant Protein Extrusion

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The demand for plant-based meat alternatives is steadily increasing, driven by consumer interest in more sustainable and health-conscious diets. Extrusion processing is the key technology for producing these products, with two main approaches: high-moisture extrusion to create fibrous meat-like structures and low-moisture extrusion to generate texturized vegetable proteins as functional intermediates. To better understand and optimize these processes, advanced characterization methods are required that can capture both material properties and structure formation under extrusion-relevant conditions.

At our institute, we present a methodological toolbox to investigate extrusion processes comprehensively. Extrusion trials can be performed at different processing scales, ranging from laboratory to pilot equipment, enabling direct transfer of findings to industrial conditions. The resulting extrudates can be characterized visually and mechanically to quantify structure formation and product quality. Rheological data under extrusion-like conditions can be obtained with a closed cavity rheometer, which allows the measurement of flow and deformation behavior at high temperature and shear. In addition, flow within the die and screw sections can be simulated to provide detailed insights into local stress and temperature distributions. From the combination of these methods, a mechanistic understanding of structure formation during the production of meat analogs is created, contributing to the development of innovative, high-quality, and sustainable plant-based products.

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Extrusion of meat analogues: TVP and HMMA

Food Extrusion Seminar 2025

Ing. Tobias Gaiser, Process Engineer Food Extrusion

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Agenda long

Texturization of proteins

1

The ZSK Twin Screw Extruder

What is happening inside

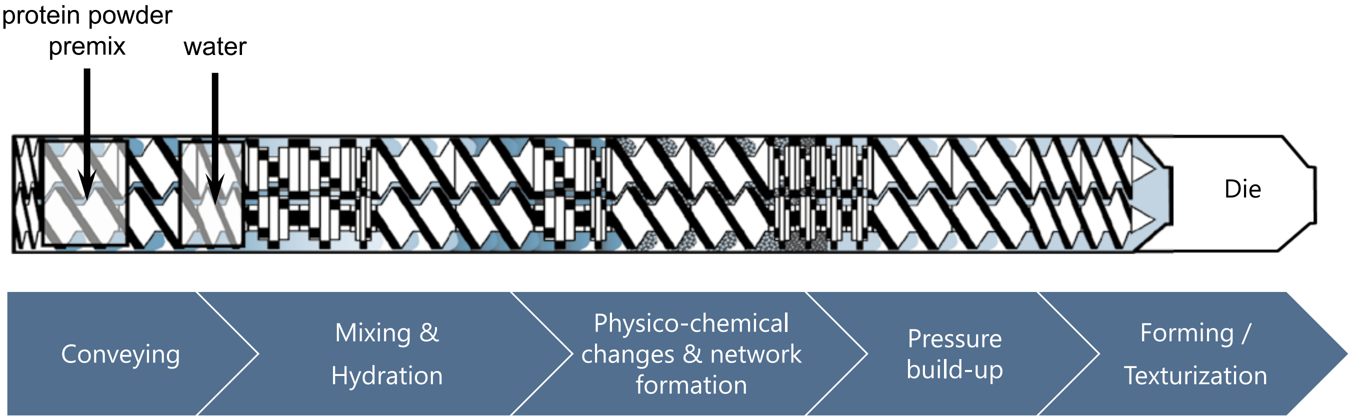
Mechanical / Physical processes

- Hydration, dispersion, dissolving
- Kneading, cooking, plastification
- Distributive & dispersive mixing (mechanical disruption, milling)
- Heating & cooling (over certain residence time)
- Melting & crystallization
- Physico-chemical reactions (denaturation, gelatinization)
- Thermal reaction, heat treatment (pasteurization)
- Devolatilization/ degassing (atmospheric / vacuum)
- **Texturization**
- Pressure built up, forming, expansion

texturized proteins

Texturization of proteins

Most food extrusion processes can be described by **“extrusion cooking”**. This refers to a **thermo-mechanical process** combining moisture, pressure, temperature and mechanical shear. Thermo-mechanical energy input is needed to form a continuous and cohesive matrix from the mixture of protein powder and water → **texturization**.



Texturized proteins – TVP and HMMA

2

Texturized proteins – TVP & HMMA

Texturized **V**egetable **P**rotein

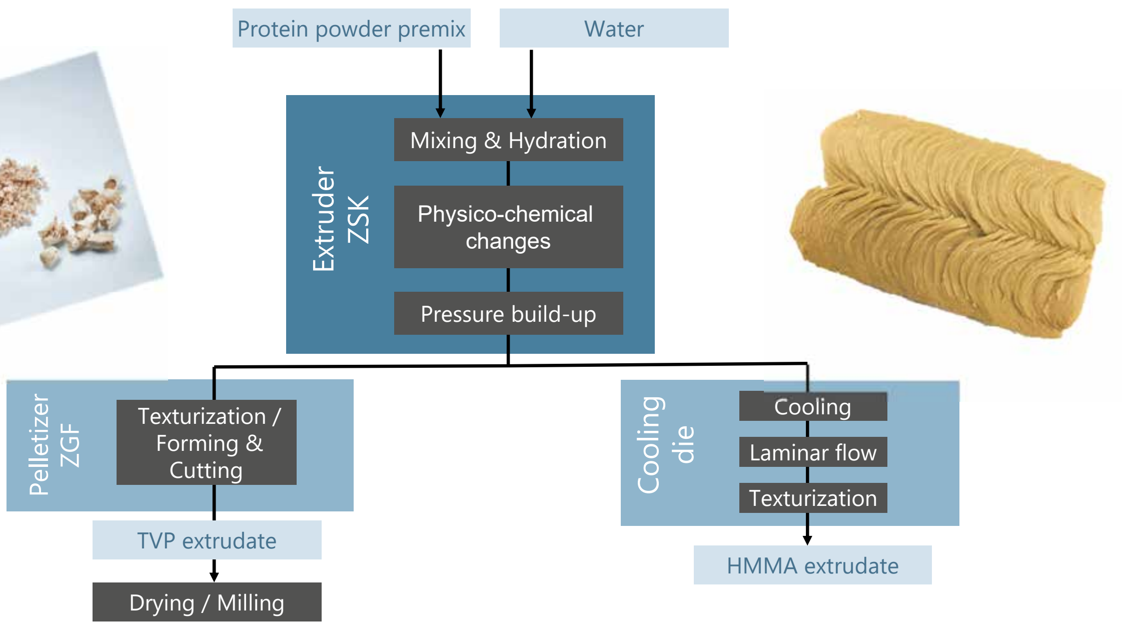
(TVP)

High **M**oisture **M**eat **A**nalogue

(HMMA)

Texturized proteins – TVP & HMMA

TVP & HMMA extrusion process



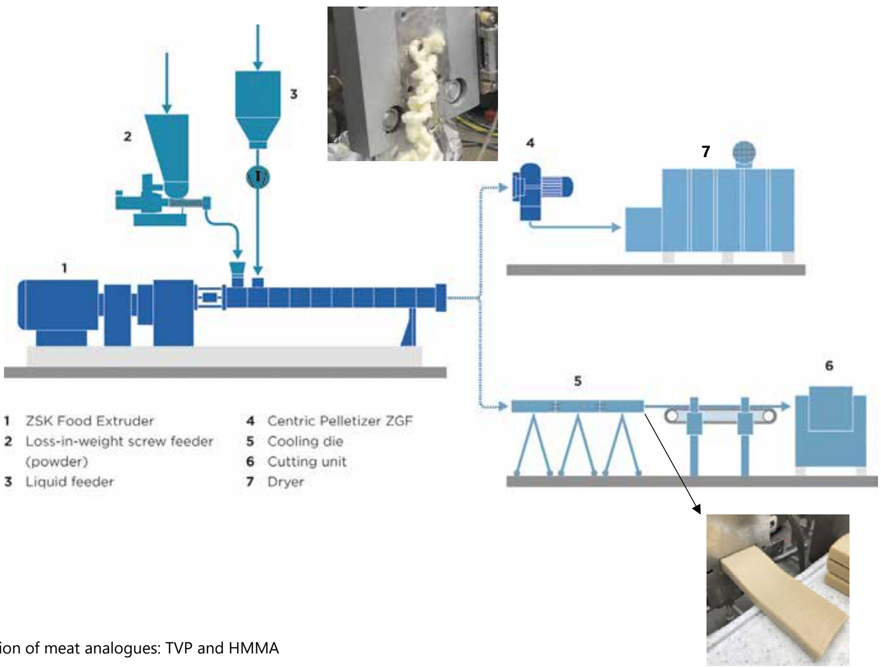
Texturized proteins – TVP & HMMA

Comparison of characteristics

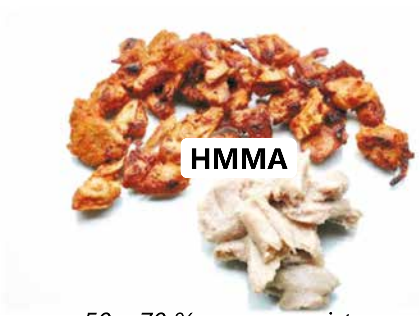
	TVP 	HMMA 
Water addition [%]	10 – 30	50 – 70
Extrudate exit temperature [°C]	120 - 170	70 – 100
Storage conditions	Dried, bulk product	Chilled or frozen
Texture	Expanded, fibrous	Dense, layered fibers
Application	Soaked in water prior to use	Ready to eat
Used for	Burger patties, minced meat, sausages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

Texturized proteins – Meat analogues

One Hybrid-system – Two possible processes



10 – 30 % process moisture



50 – 70 % process moisture

Texturized proteins – Hardware layout

One Hybrid-system – Two possible processes

Product examples - TVP

3

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

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)

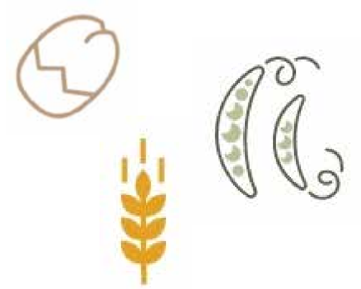
Recipe development

5

Recipe development 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, …



Influence of protein source

Structure, Color, Taste,…

Soy-based

Pea-based

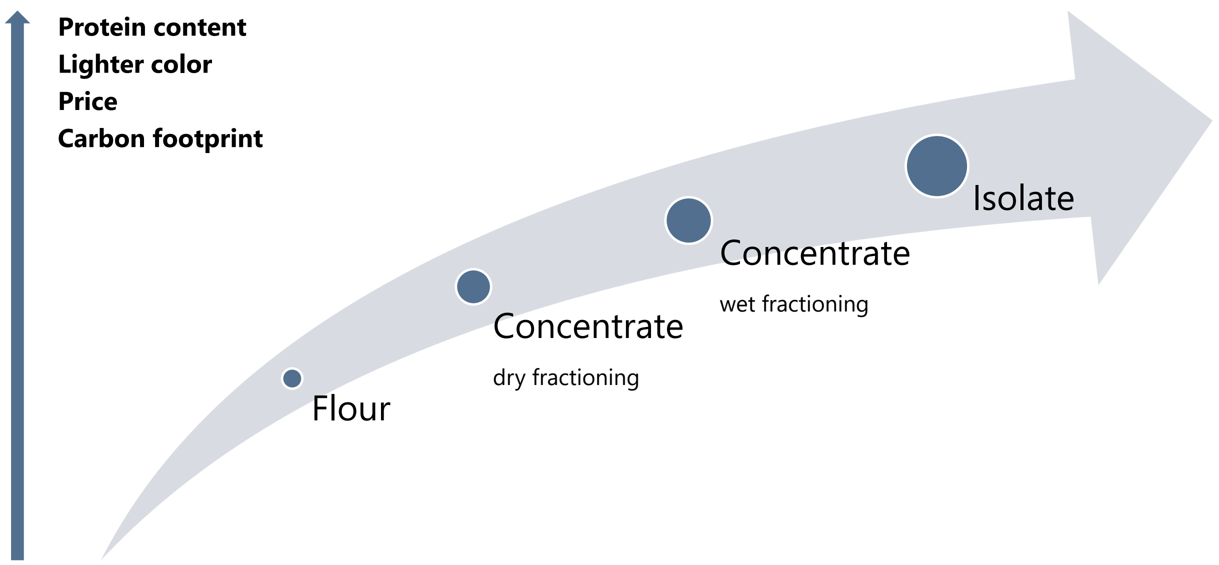
Comparison of different plant protein sources

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 content
- *Min. 50%*

Fat content
- *Max. 10 %*

Fibre content
- *Max. 20 %*

Starch content
- *Max. 20 %*

- **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*

Mixing components in recipe development

Influence of fibre type and source on pea-based HMMA recipe

Pea fibre 1

Appealing texture
Fibrous mouthfeel
Fine structures

Pea fibre 2

Rubber-like texture
No fibrous mouthfeel

Wheat fibre

Appealing texture
Fibrous mouthfeel
Coarse structures

Mixing components in recipe development

Changing Characteristics based on selected protein source

Wheat gluten

+ soy protein
+ pea protein

Pea protein

+ soy flour

Process development

6

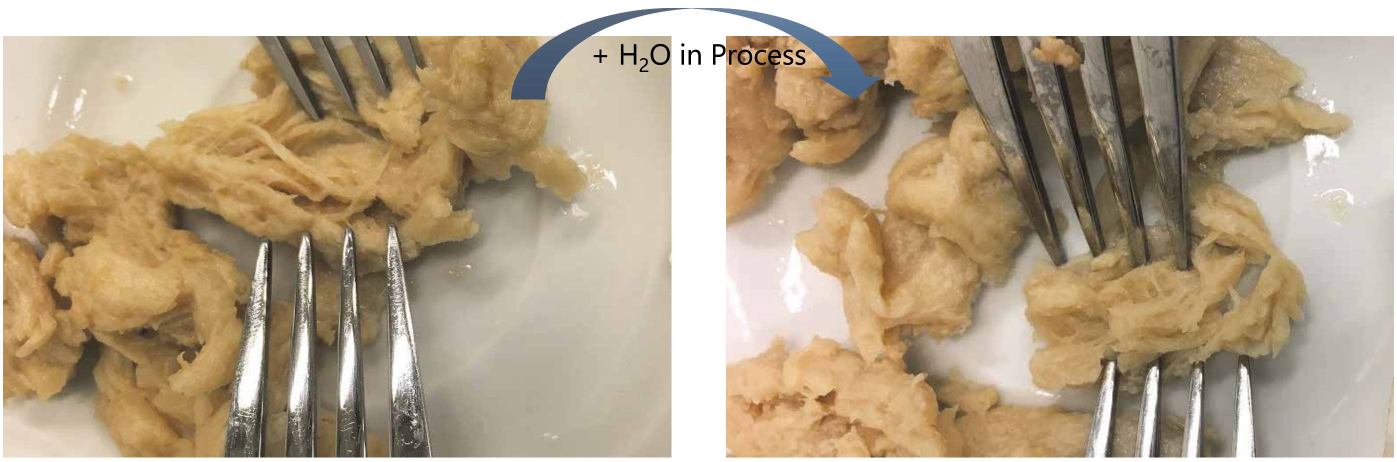
Influence of moisture on texturized proteins

Determination of process moisture after developing raw material recipe

Process moisture ↑ → **Energy input ↓ / Temperature ↓ / Pressure ↓** → **Softer texture / Less expansion / Lighter color**

Influence of process moisture on TVP

Higher process moisture leads to softer texture

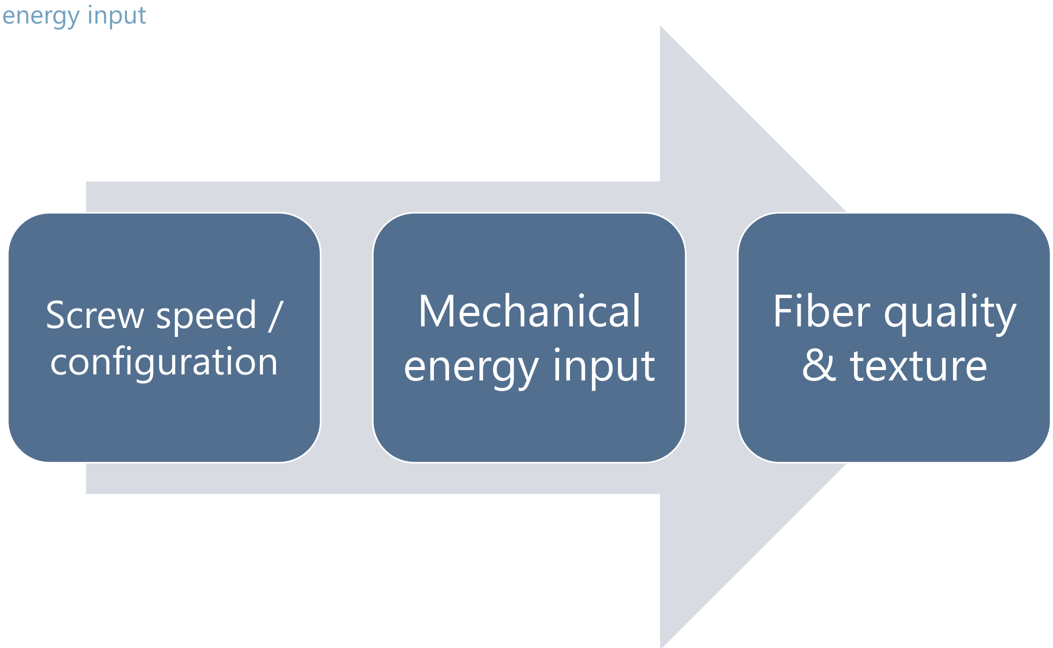


Firm texture
Visible fibers

Softer / mushy texture
Less visible fibers
Lighter color

HMMA product quality

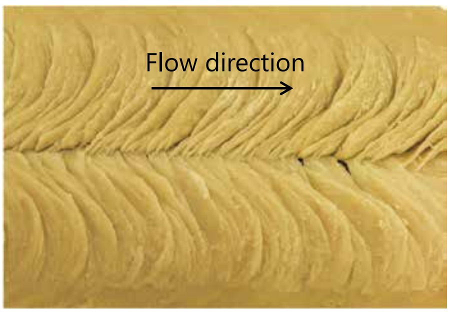
Influence of energy input



Influence of energy input on HMMA structure

Energy input through screw speed

low rpm



- Soft texture, dough-like, brittle
- fiber layers break easily

medium rpm

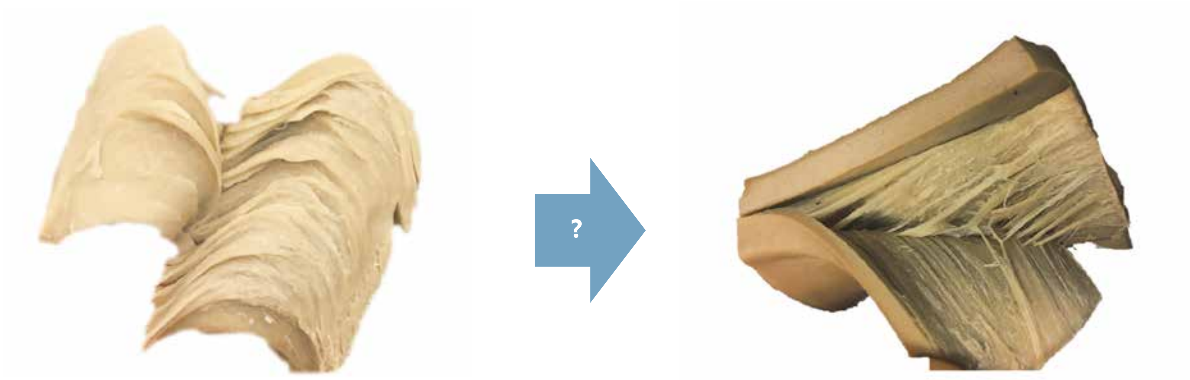
- Consistent texture
- fiber layers easy to separate

high rpm

- strong texture, gum-like
- fiber layers harder to separate

Process development for texturized proteins

Find a possible solution

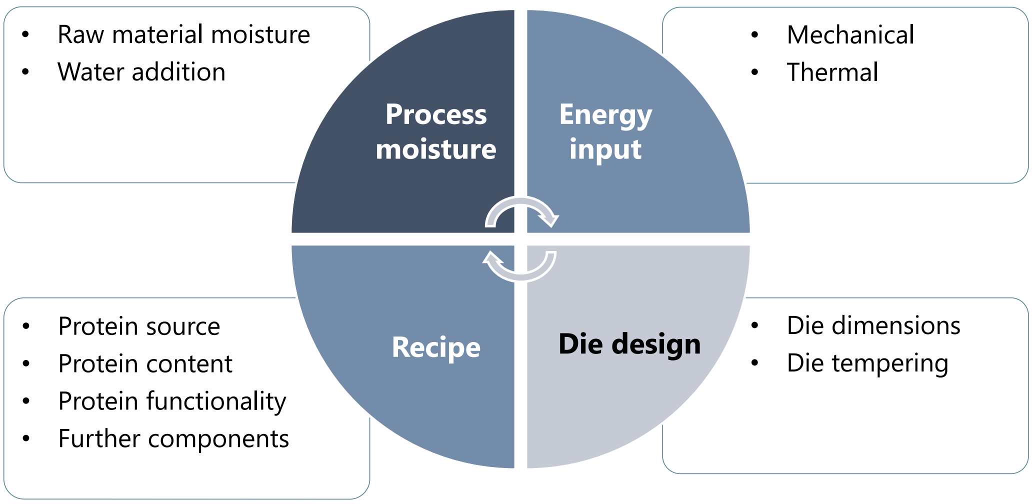


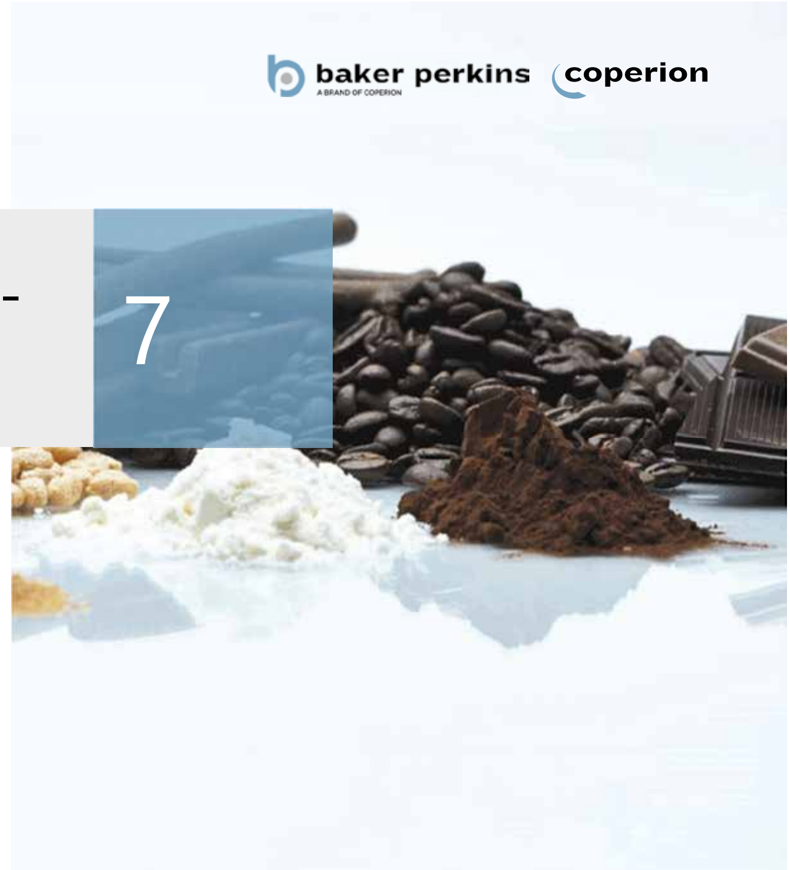
soft texture, bright color **strong texture, darker color**

How to achieve different product structures?

Product quality of texturized proteins

Key influencing parameters to consider





Post processing - TVP

7

Extrusion of meat analogues: TVP and HMMA

Granulation of TVP with die-face cutter

Different shapes and sizes achievable

Extrusion of meat analogues: TVP and HMMA

42

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.

Post processing - HMMA

8

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

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Expansion and die design

Food Extrusion Seminar 2025

Christian Hüttner, Senior Process Engineer Food Extrusion
Tom Shipman, Process Engineer Cereal and Food Extrusion

BEST COMPONENTS & BETTER SYSTEMS

THE RECIPE FOR PERFECT FOOD

Introduction – die flow

1

Title of Presentation

Introduction

Die functions

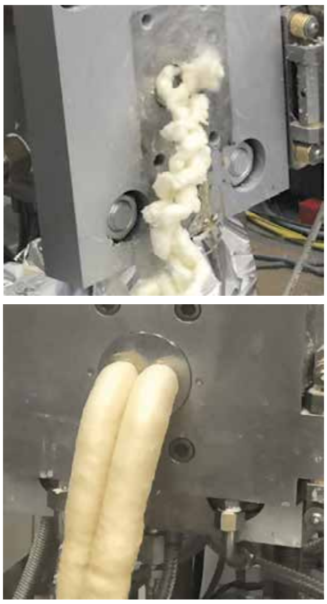
- Shaping the product
- Structure formation
- Introduction of mechanical energy
- Providing resistance

↓

- Creating pressure

↓

- Expansion
- Seal against pressure inside the extruder



Expansion and die design

4

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

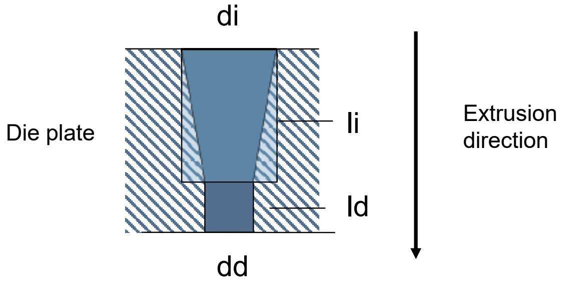
2

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)



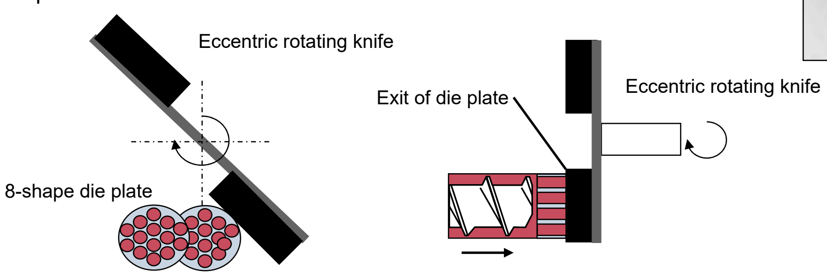
Die plate characteristics

- 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

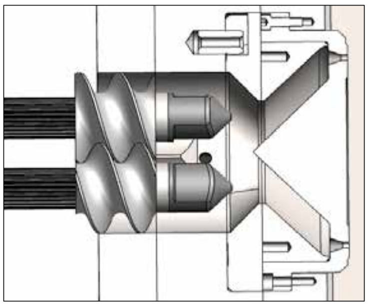
Die basics and design features

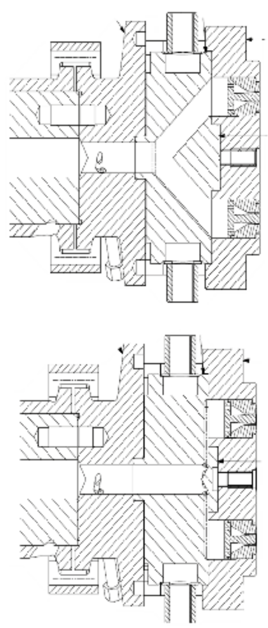
Large die plate surface situation

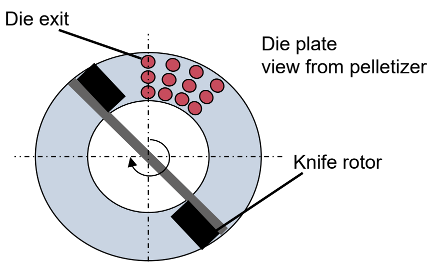
Central fed die

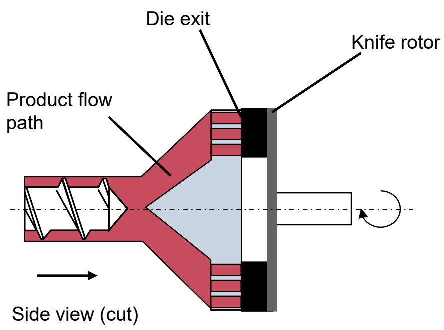
- For larger throughput rates
- Spreading of product flow to larger surface
- Longer flow path
- 8-0 transition before flow to die plate

Top view (cut)









Die basics and design features

Crispbread die

8 to 0

Distribution core

Flow control

Dies

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

Mechanism of expansion in food extrusion

3

Title of Presentation

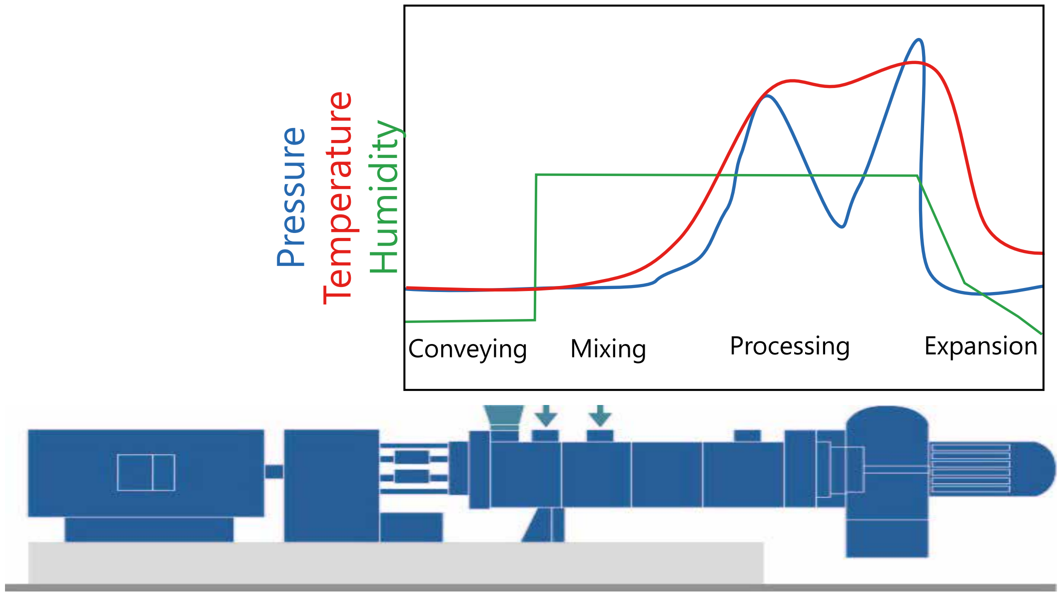
Mechanism of expansion in food extrusion

Expansion and die design

16

Mechanism of expansion in food extrusion

Pressure – Temperature – Humidity during Extrusion



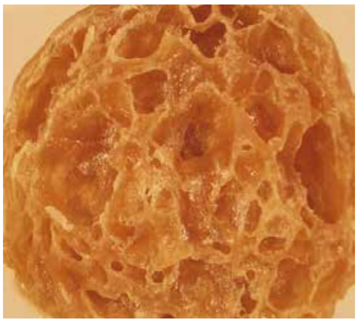
Mechanism of expansion in food extrusion

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

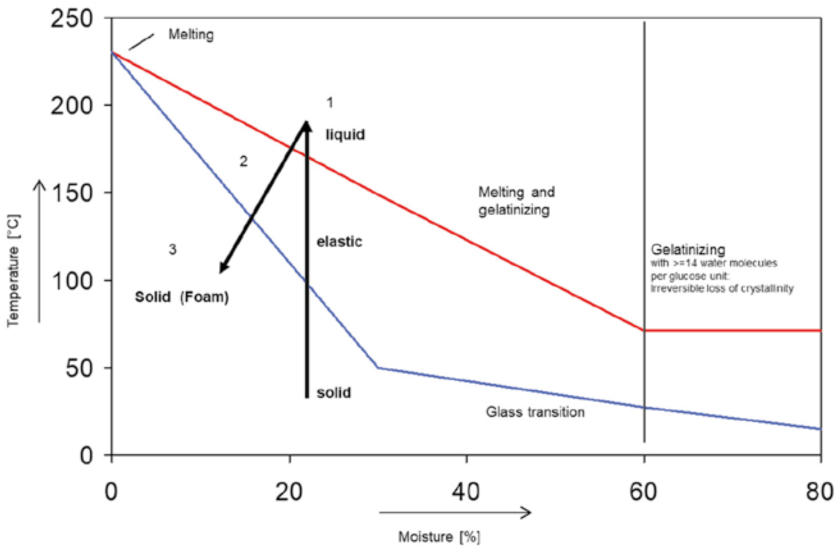
Sudden flash of water after exit of the die

- 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



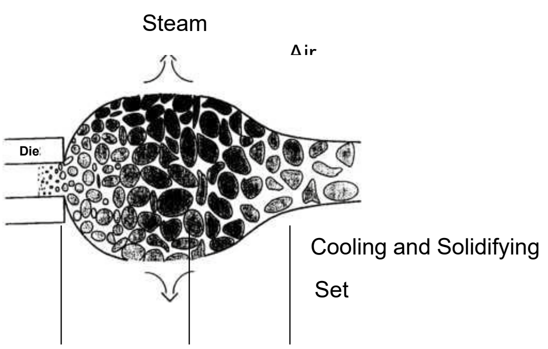
Mechanism of expansion in food extrusion

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

Title of Presentation

Expansion indices

Longitudinal expansion

Longitudinal expansion (LEI)

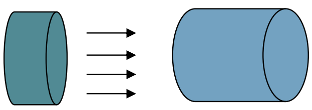
- Longer land length
- Higher rpm
- Higher temperature of barrel/ die

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)

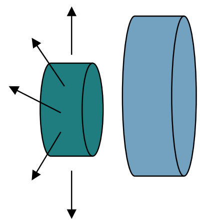
- Shorter land length (land length-diameter ratio)
- Lower rpm
- Lower temperature of barrel/ die

Product shape blurred compared to die design

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

Surface expansion index SEI (literature)

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



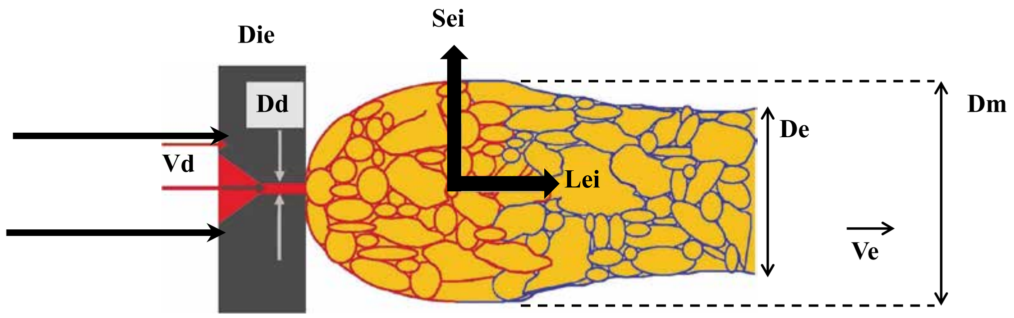
Overall Expansion (VEI)

- 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

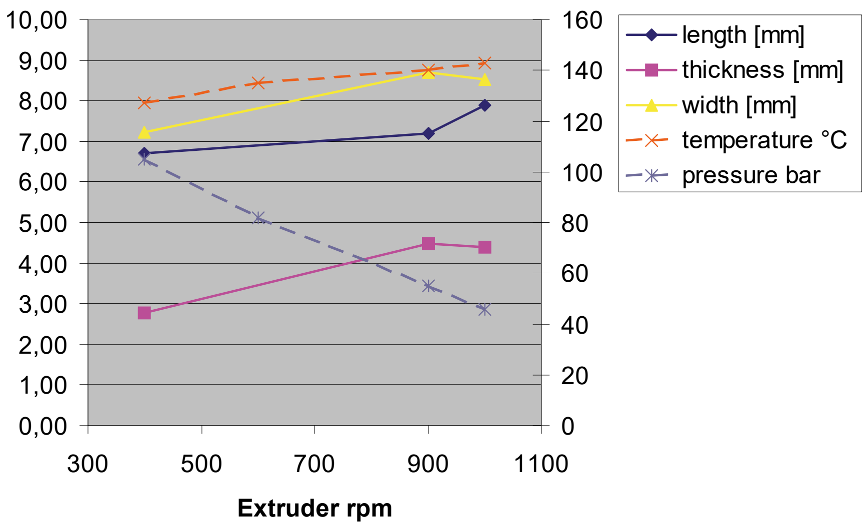
Throughput rate ↗ → • Viscosity ↗ • Pressure ↗ • Expansion ↗ → total Expansion (VEI) increases

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

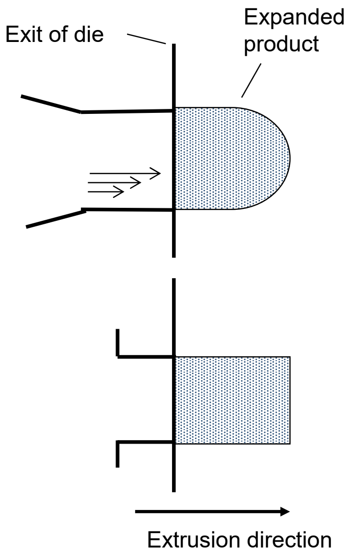
More laminar die-flow, more radial expansion, more friction in die

- 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

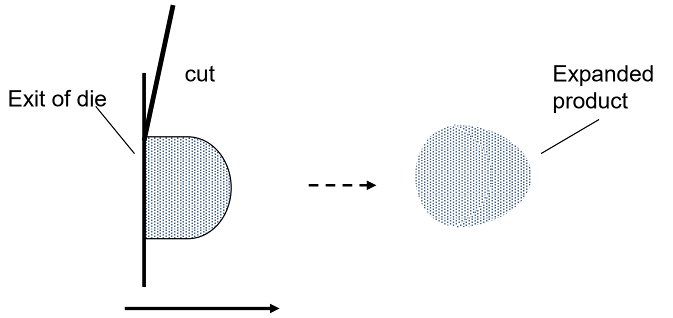


Types of expansion

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

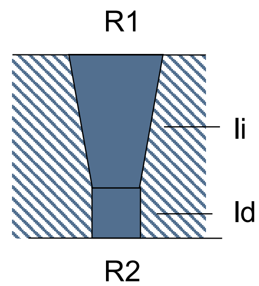
Die constant k_d in mm^3 (smaller k_d value = more restriction)

All dimensions in mm

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

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

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



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

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

w = width of slit

h = thickness of slit

L_d = length of straight section

Thin annular die

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

R_0 = outer radius of ring

R_i = inner radius of ring

Expansion and die design 35

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 :

$$\overset{*}{m} = \frac{\dot{m}}{K_d} \quad \left[\frac{kg}{h\, mm^3}\right]$$

ṁ = throughput in kg/h

keep $\overset{*}{m}$ constant

Expansion and die design 36

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

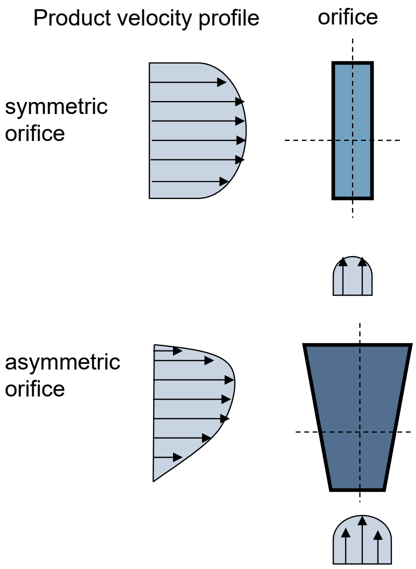
Shaping the product

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

Flow balancing

Using the same principles, we can promote flow into a sheet, or other linear formats

Shaping the product

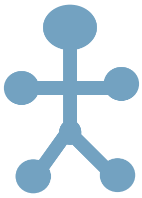
Velocity profile

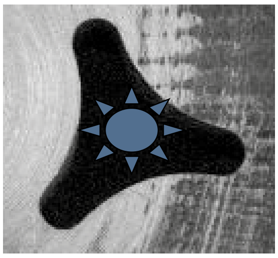
Faster flow in the thick centre

Thicker product in the centre

More (radial) expansion than in edges

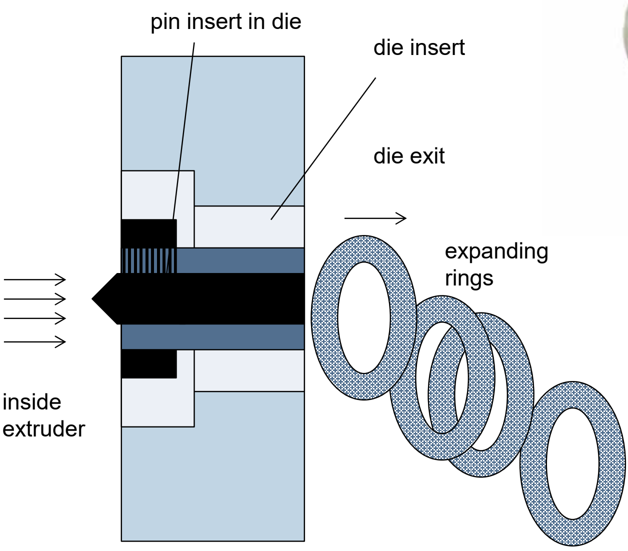
Die shape different than resulting product shape!!

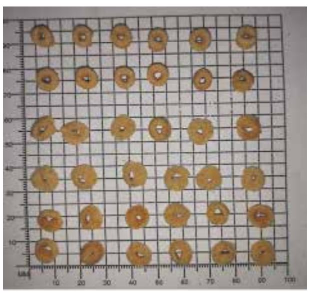


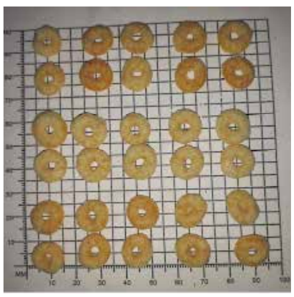


Shaping the product

More complex figures with insert pin







Shaping the product

Coextrusion

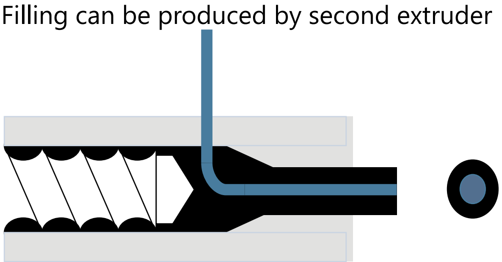
„Filled ring extrusion“

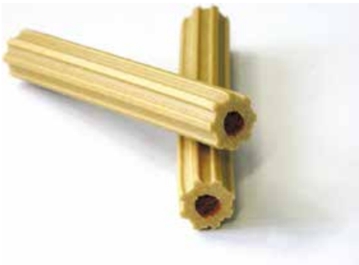
Postcut (filled tube) or crimped (pillow type) product

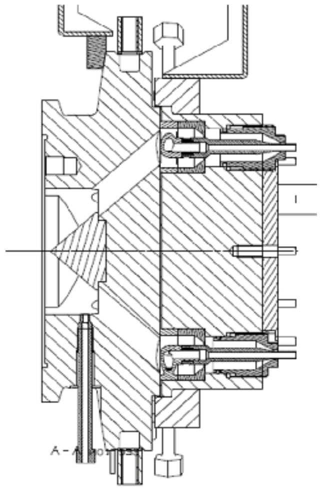
Filling mass

- 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

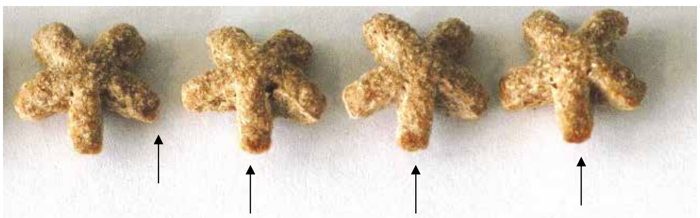
Avoid narrow corners in die shape design

→ 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

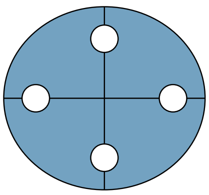
medium

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

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vemiwa

Rethink the way we eat!

Michael Walk

"We believe in challenging the status quo of plant-based food by making products that are delicious, clean and good for our planet"

vemiwa

Rethink the way we eat!

A background that polarizes...

Start-up: Metzgersohn entwickelt vegane Fleischalternative

Start-up: Metzgersohn entwickelt vegane Fleischalternative

Als mittelständischer Metzger hätte Michael Walk in die Fußstapfen des Vaters treten können. Doch der Junior investiert lieber in pflanzliche Fleischalternativen. Das Protein sollen Landwirte aus heimischen Erbsen oder Ackerbohnen liefern.

Von Susanne Wimmer

Merkur.de

„Der Metzger-Sohn, der auf vegan macht": Bekannte Fleischerei-Kette aus Bayern bald mit Alternativ-Produkten

Gerlach kostet pflanzliche Wiesn-Brotzeit

Ein veganer Leberkäs für die CSU-Ministerin

Focus: High Moisture Extrusion

Meat Alternatives

Cheese Alternatives

vemiwa

?

Product Development

Fish Alternatives

High Convenience

One-Stop-Extrusion-Shop

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One Mission, two companies

Foodservice

White Label Production

Technikum

IFS

vemiwa

BIO

Production & B2B

creativeaty

D2C & Retail

Basic HMMA Products

Convenience Products

Special Products

vemiwa

Production in Bavaria

Development & manufacture of out of the box products on mass market scale

Super clean meat alternatives

- Clean Label
- Allergen Free
- Only 5 Ingredients
- Different product categories: Chunks, Minced, Kebab, etc.

Plant-based Functional Food

- First Product in Europe with 5 plant-based proteins for amino acid optimization & 32g of Protein / 100g
- Co-Development with a German 1st tier football club (FC Augsburg)

HMMA Cheese

- First cheese-alternative in Europe produced on an Extruder
- Clean Label
- Pea-based
- 13g of protein / 100g

vemiwa

Rethink the way we eat!

Process Design: From Unit Operations to Screw Profile

Food Extrusion Seminar 2025

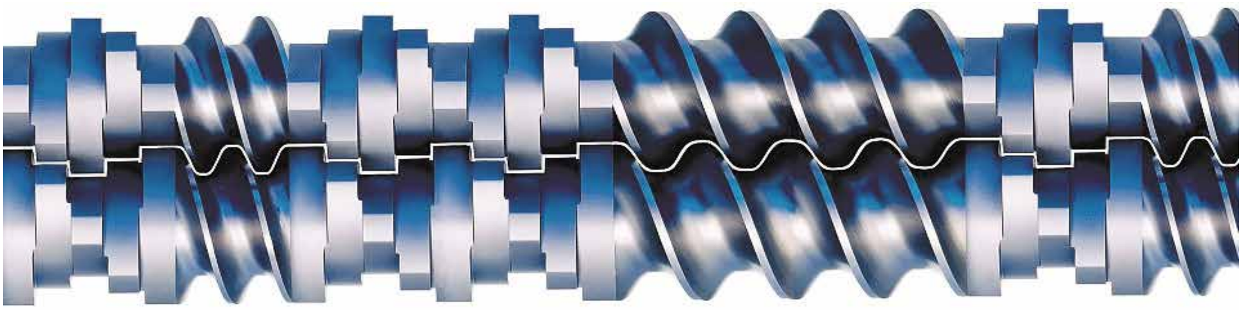
Uta Kühnen, Head of Process Technology Food

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

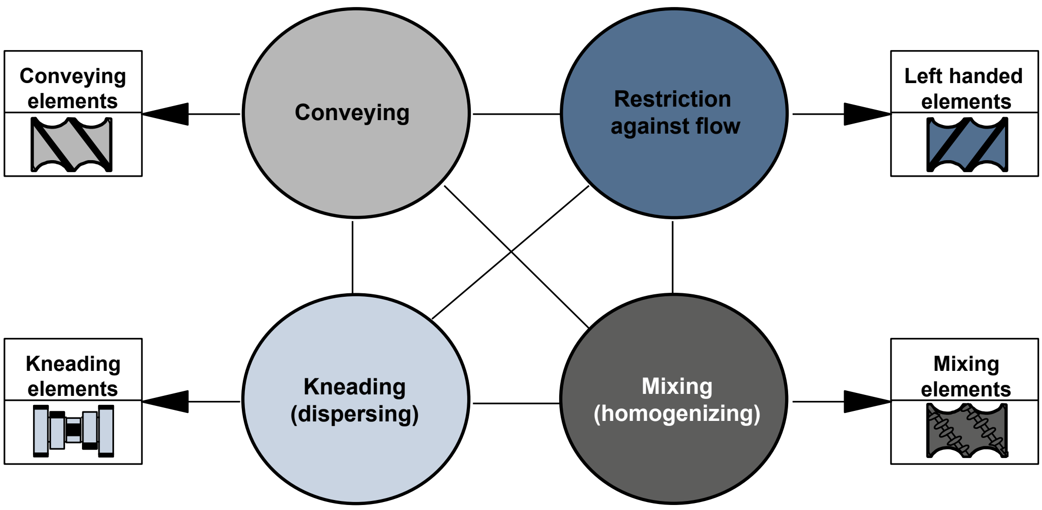
Unit operations

Examples for singular process tasks

- Intake
- Conveying
- Mixing
- Heating
- Cooling
- Residence time (keeping)
- Mechanical disruption/ destruction
- Melting
- Kneading
- Cooking
- Plastification
- Denaturization
- Hydratation
- 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

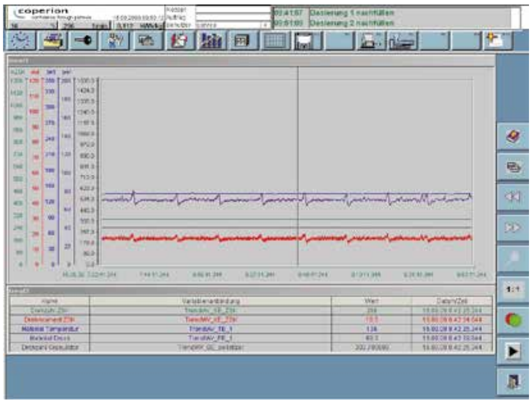
Feeding of bulk and other educts

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

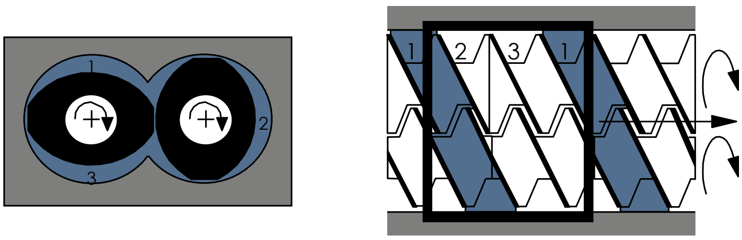
Torque in red

Pressure in violett

Feeder refill causing trouble

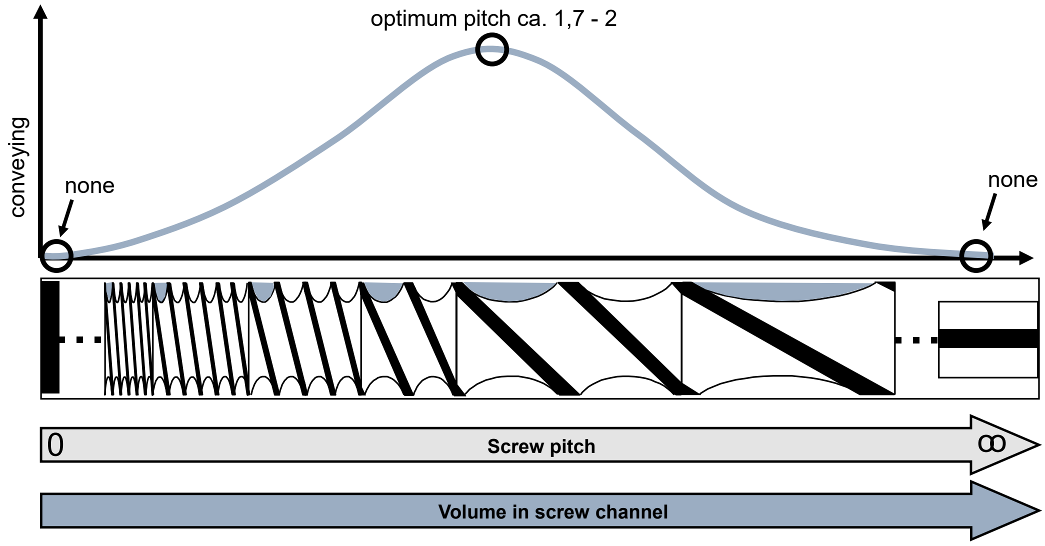
Intake of powder material

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



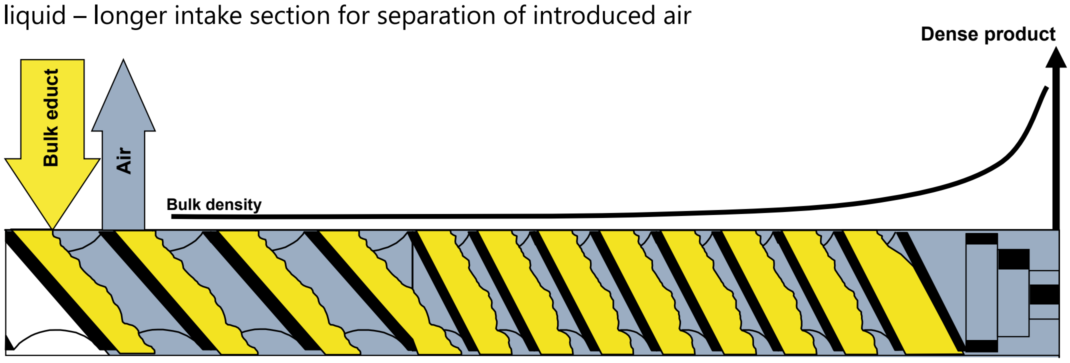
Feed zone

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

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Low bulk density powder
Fine particle size powder
Without liquid addition

more difficult

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

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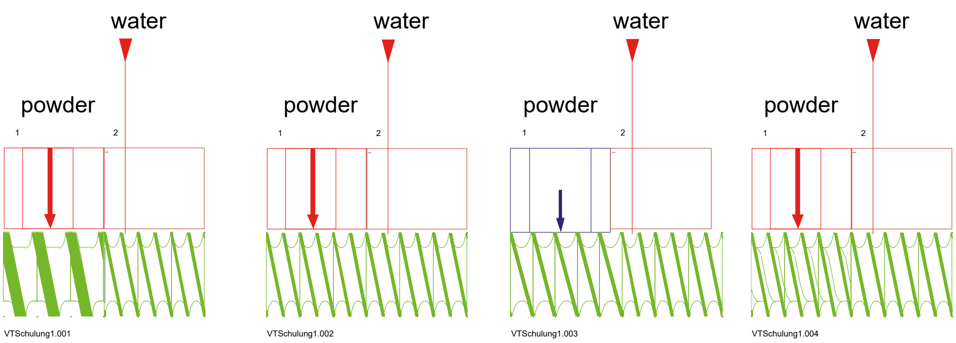
Examples ZSK 43Mv

- 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]

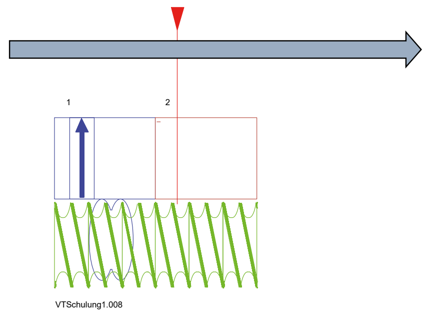


Feeding Zone with sidefeeder ZS-B

Twin screw side feeding device

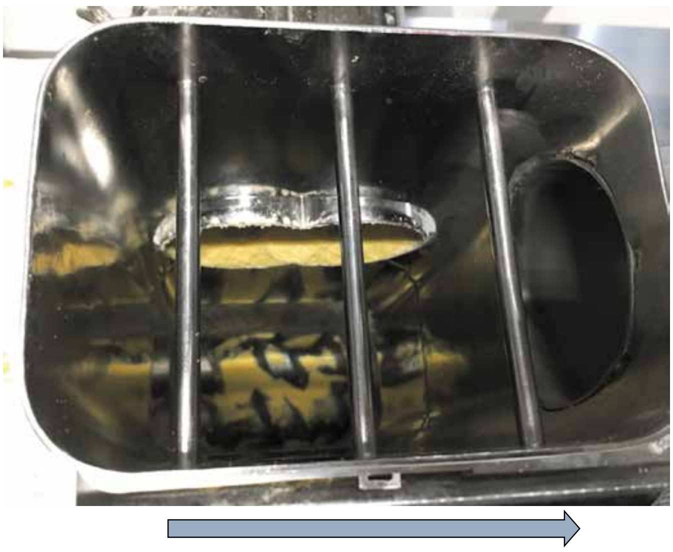
Increased product intake by sidefeeder

- 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



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)

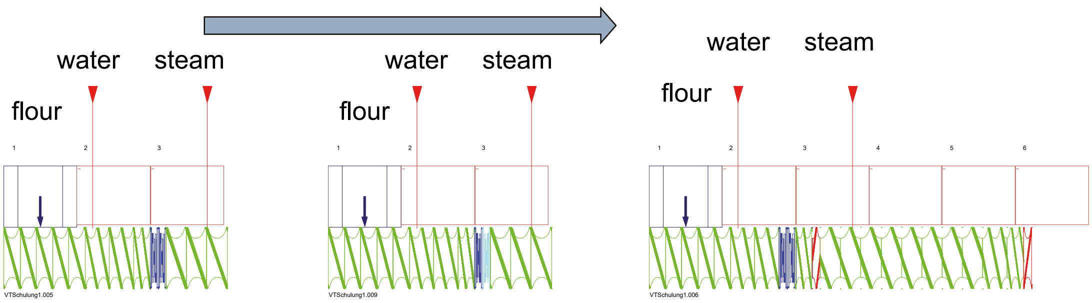
Prevent vapour from escaping via feed hopper to feeder

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

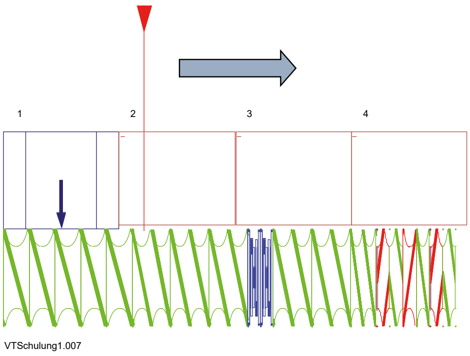
Standard cooking combination

Right-left combination

Mixing zone with small right kneading blocks

High shear left elements

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

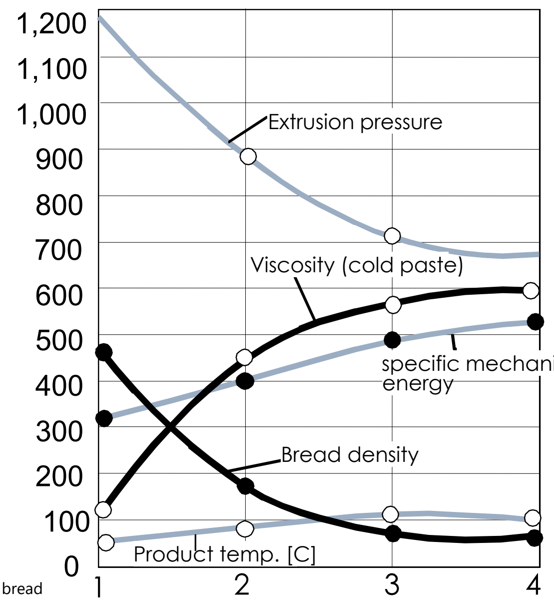


Variation of energy intake:

- 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)

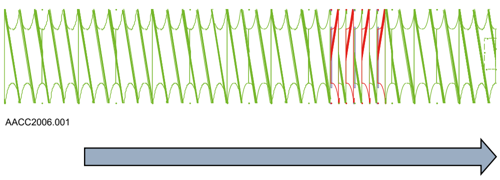
Impact of left handed elements

Effect of different screw configurations



Extrusion of flat bread

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%

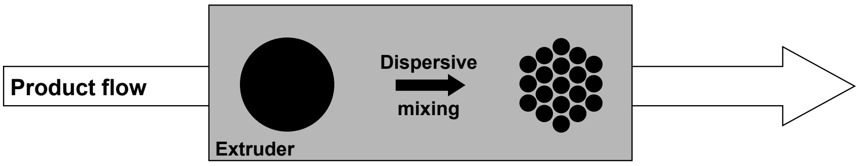


Working principle of screw elements

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**:



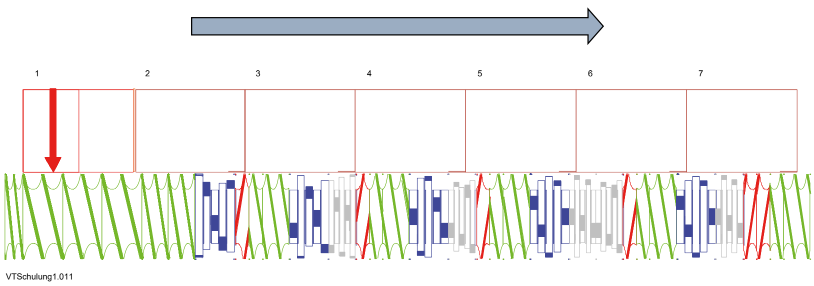
Conditioning of other matrices

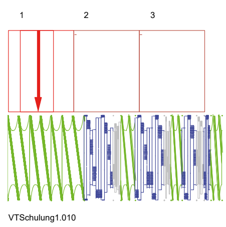
By means of kneading blocks

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





Mixing zone

5

Process Design: From Unit Operations to Screw Profile

Working principle of screw elements

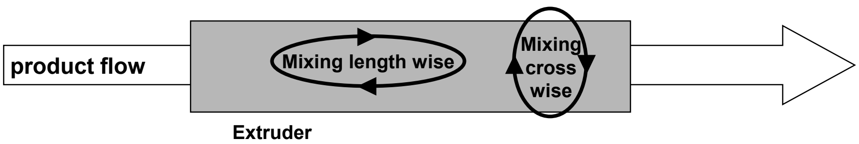
Distributive mixing (displacement of particles/ droplets)

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)



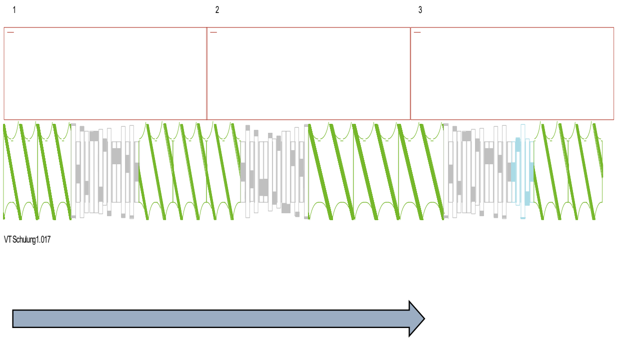
Mixing zone

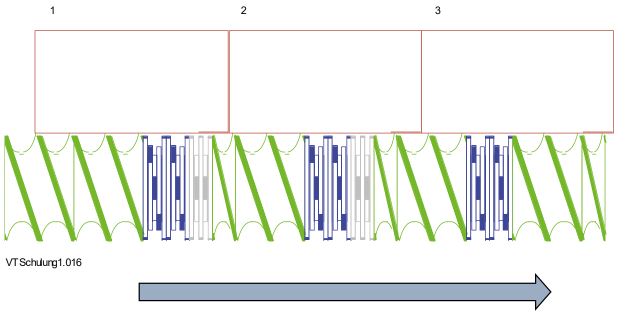
Intensive distributive for particles, dispersive for emulsions

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…





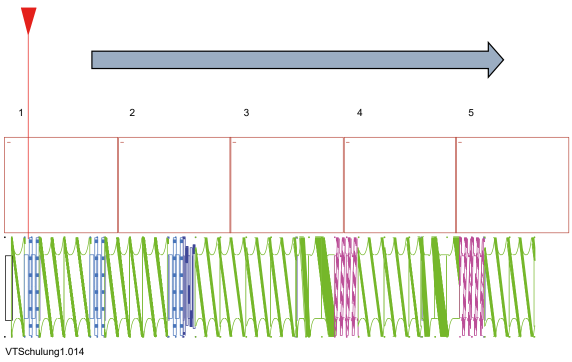
Mixing with non- self wiping elements

High shear dispersive and distributive mixing/ emulsion forming

Liquid injection into pressure zone possible

TME elements

ZME elements (single flighted left hand, cut crests)



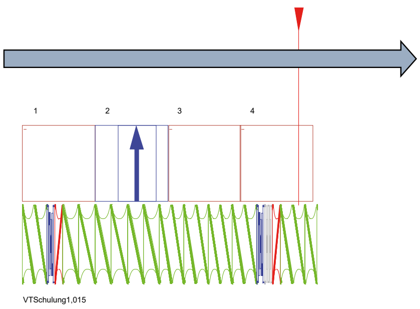
Degassing and venting

6

Process Design: From Unit Operations to Screw Profile

Degassing

- Getting rid of excess water 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]

Process Design: From Unit Operations to Screw Profile

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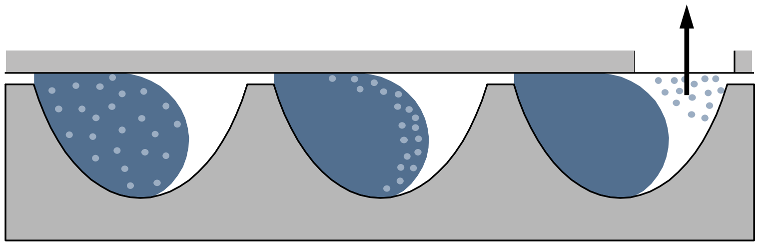
Degassing principle



Separation of gas from plasticized product by diffusion

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

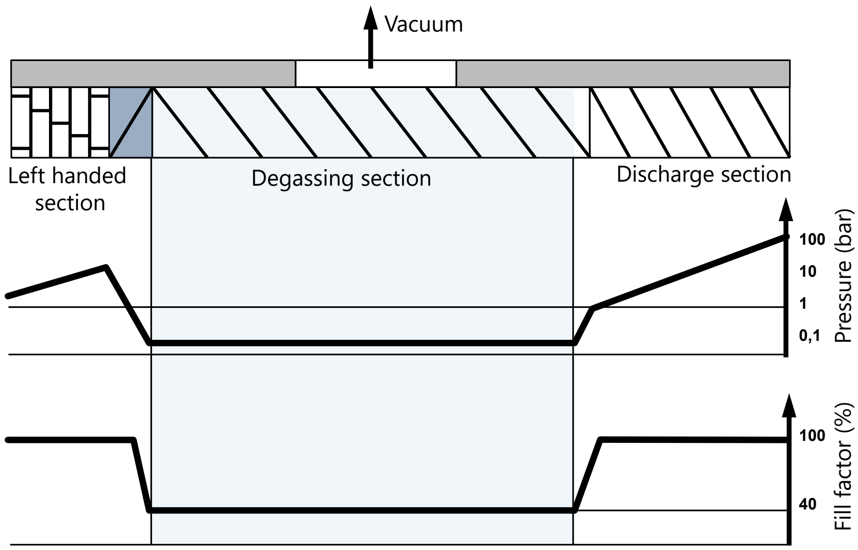
residence time
viscosity of mass
thickness of mass layer
renewal of mass surface
pressure difference

→

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

Atmospheric venting of water vapour

Degassing section

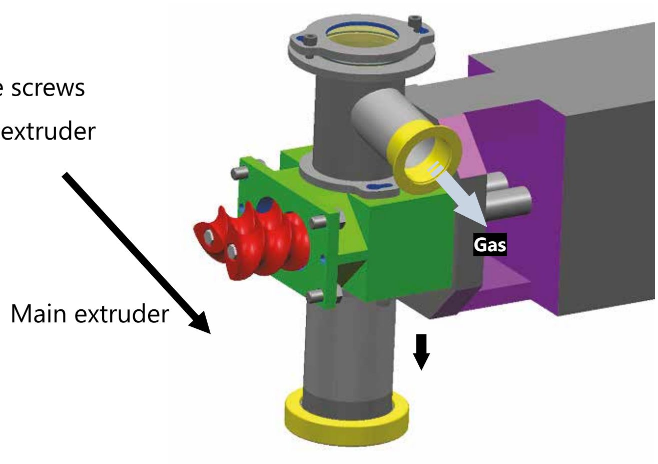


Good to know

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

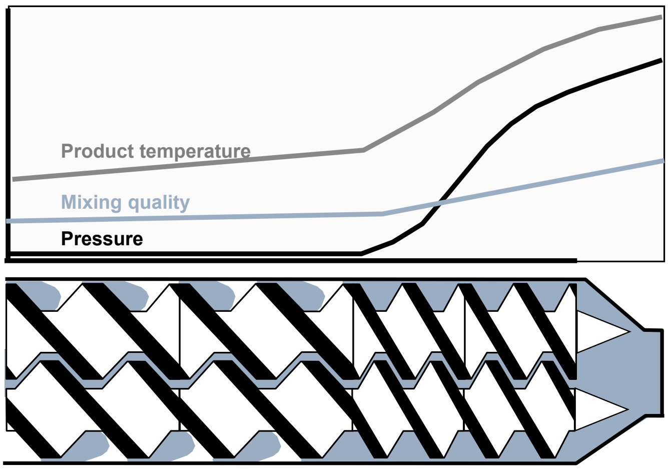
- ZS-EG
- Twin screw side degassing unit
- For difficult to handle products
- Mass stuffed back into main extruder by side screws
- No burnt particles can fall back down to the extruder



Pressure build up zone

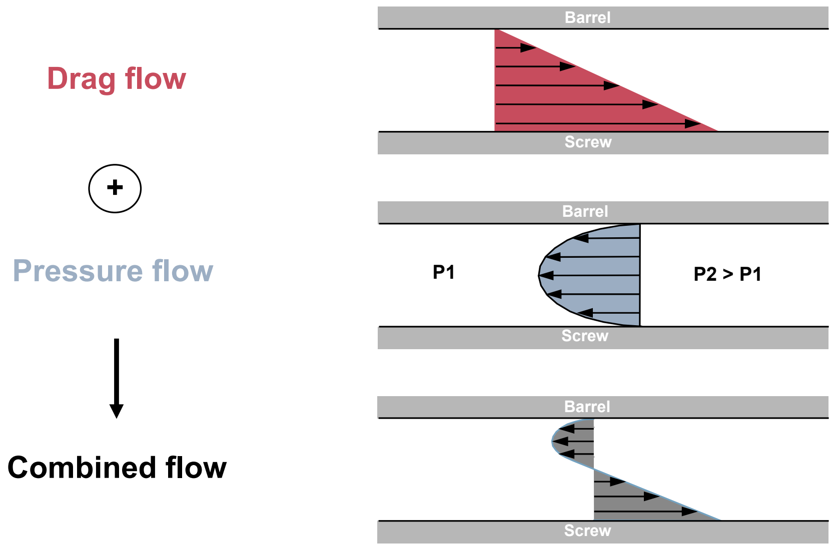
7

Pressure build up zone



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

Pressure build up zone



Flow pattern

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

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

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Example screw configurations

8

Screw configuration examples

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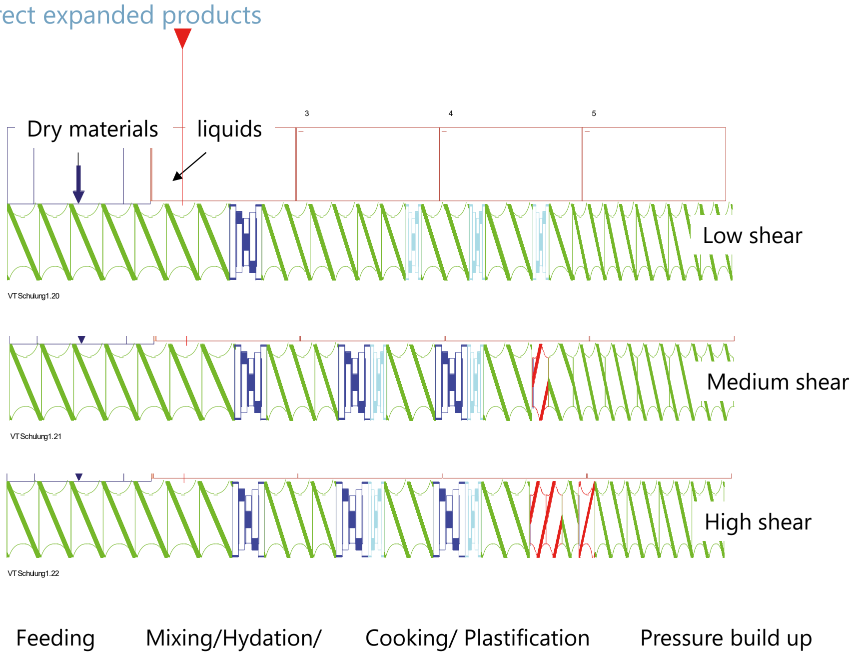
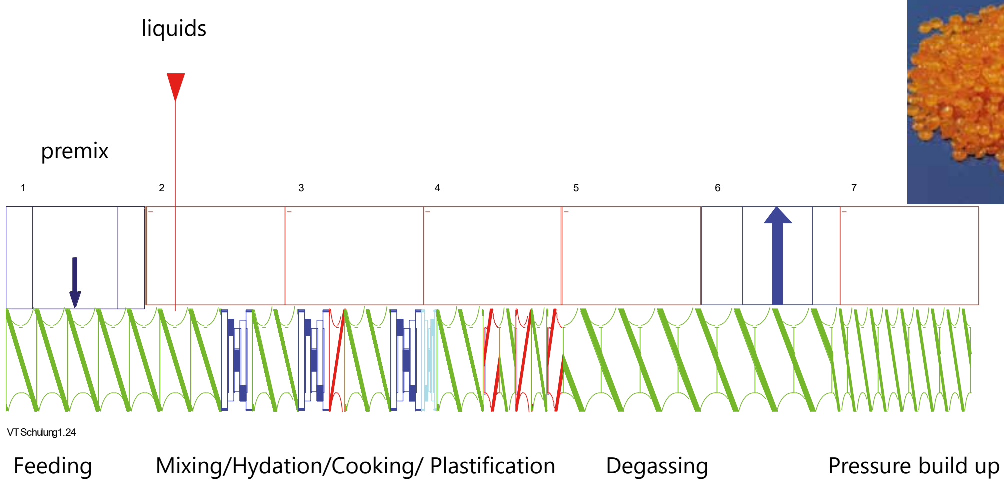
Direct expanded products



Screw configuration example for half products

Cold formed pellets



Contact

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Recipe Ingredients in Food Extrusion

Raw Materials and their Influence in Food Extrusion

Fabian Specht, Senior Process Engineer

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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

Water

1

Essential for the majority of food extrusion processes

Water in Food Extrusion

Neither too little nor too much

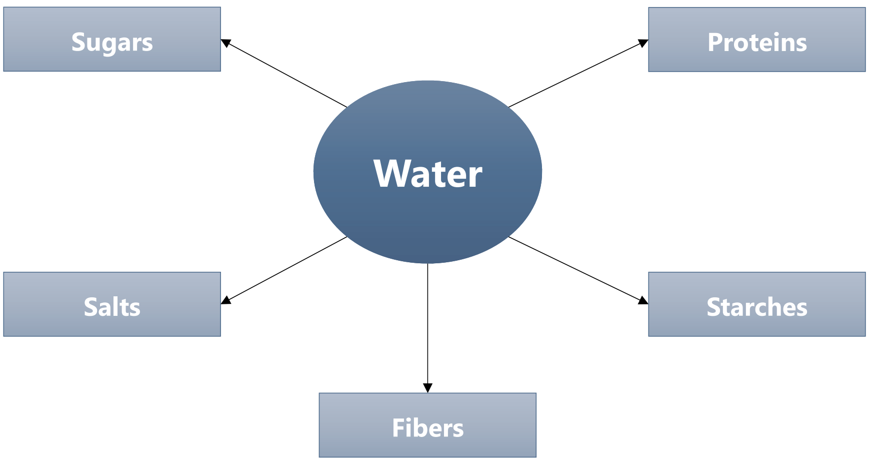
- Natural food polymers are not thermoplastic

- 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

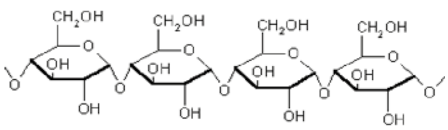
2

Molecular Structure

Polysaccharide with numerous glucose units joined by glycosidic bonds

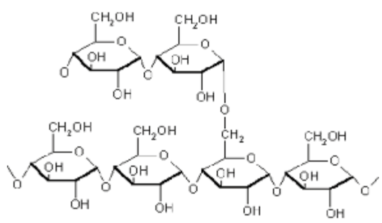
Amylose

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

Water content ↑ →	Temperature ↓ Pressure ↓ SME ↓ →	Larger bubbles Less expansion More brittle (after dryer)
Steam injection ↑ →	Temperature ↑ Pressure ↓ SME ↓ →	Higher degree of cooking Stronger expansion Softer structure
Oil, Fat, Emulsifier ↑ →	Temperature ↓ Pressure ↓ SME ↓ →	Inhibits gelatinization Lower degree of cooking Lower expansion

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

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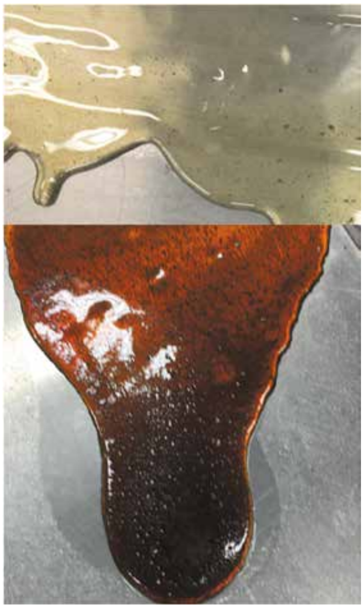
Sugars

4

or sugar-like ingredients

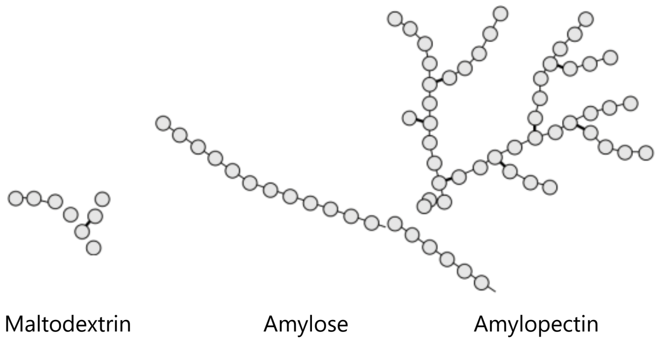
Extrusion of Sugar and Sugar-like Ingredients

- 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



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

Fibers

5

Fibers

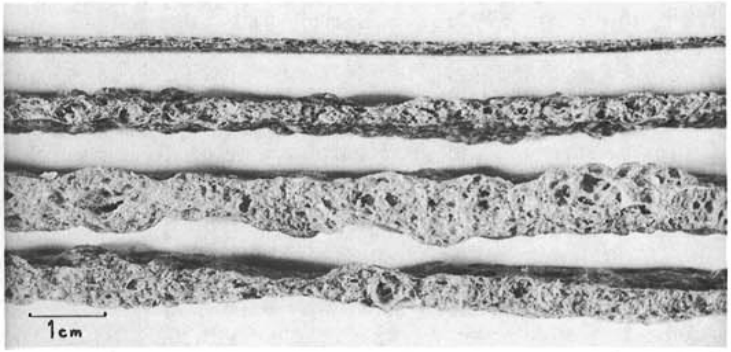
Definition and why are they interesting for food extrusion?

- 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

Minor Components

6

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

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

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Extrusion Processing of Breakfast Cereals and Ancillary Equipment

Catherine Cooper | Senior Food Technologist

Tom Shipman | Process Engineer

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Extrusion of Breakfast Cereals

1

Starch Cooking

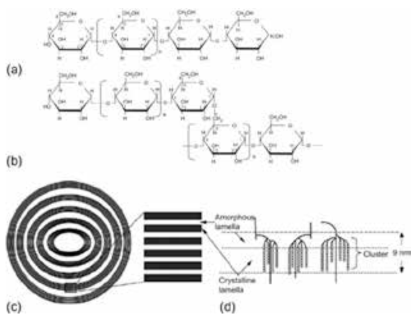
Starch Structure Recap

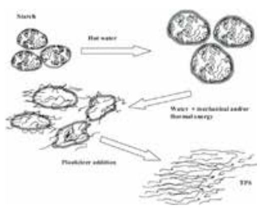
Transformation from Crystalline to Amorphous

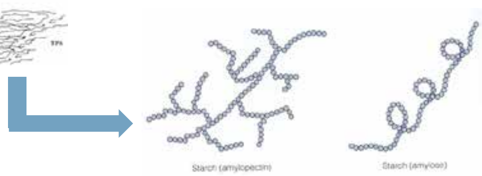
Native (raw) starch is in a crystalline form. It consists of tightly packed chains of amylose and amylopectin. Because they are tightly packed, digestive enzymes (e.g., amylase) cannot access the starch biopolymers, and so it cannot be digested effectively. It must first be cooked.

Gelatinisation: When starch is heated in an excess of water, the starch granules start to break apart and take on water. The water is able to bind in between the previously inaccessible strands.

The granules swell until they burst, and the starch chains leach out into the liquid, and viscosity increases as the biopolymers form a network, entrapping water.







Conclusion box

Starch requires heat and water to unlock its functionality and digestibility.

Starch Cooking in Extrusion

Finding a Balance Between Heat and Shear

- In the extruder, there is much higher shear, and lower water content than in traditional cooking.
- This leads to dextrinization, where granules are mechanically sheared, allowing faster water take up than in traditional cooking, providing an efficient starch cooking process. This also causes browning and the 'cooked flavour', along with Maillard browning.
- The breakdown of the starch chains acts as a bell curve when compared to expansion. Most processes promote expansion and a crisp product by shearing the chains, reducing the physical disentanglement that may prevent a light expanded product from being formed.
- The greater the shear a product is subjected to, the greater the 'friable' nature of the product ex-die. The starch chains can no longer form a strong structure, and aspects such as gel formation and glass transition temperatures are reduced.
- Gentle processing (reduced shear, increased water), or even pre-conditioning can help with troublesome materials.

Conclusion box

Extrusion promotes a light texture in breakfast cereals by providing shear energy during the cook. This allows some breakdown of the starches to allow for browning and a light texture. This must not be overdone, as the product will become soft and collapse easily. Processes can be controlled to find the correct balance.

Starch Cooking with a Preconditioner

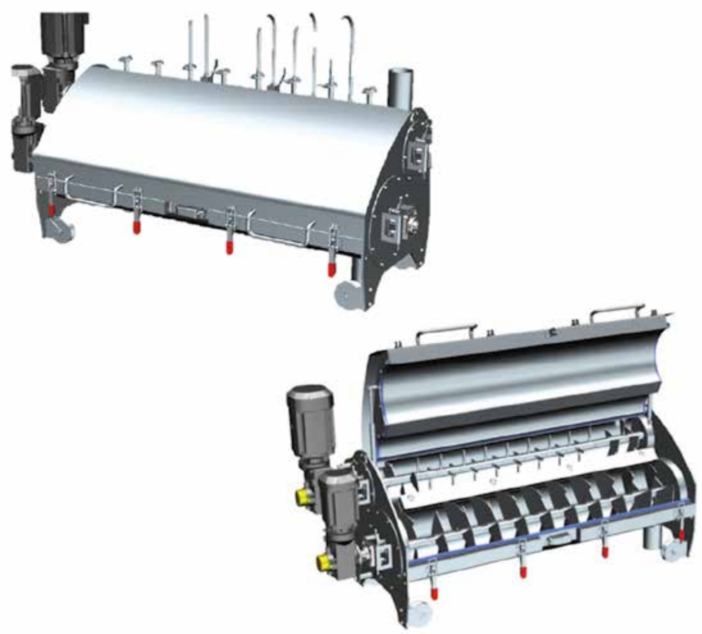
Specific Processes and Difficult Materials

Pre-conditioners help induce the cooking of starch by introducing heat to the system early. This can allow the material to be fed at a higher throughput.

This also helps replicate conventional gelatinisation. The starch has an opportunity for the granule to swell and burst with heat and water.

Pre-conditioners are useful for:

- Single-extruder cornflakes
  - Allows cook to start earlier
- Difficult materials such as oat
  - The higher fat content of oat can cause issues. If overworked, it can fractionate out and cause shearing issues in the barrel. A pre-cook helps with both feeding into the barrel and provides a gentler process to help this.
- Very high throughput requirements
  - Starting the cook earlier means a shorter residence time is possible.



Controlling Texture

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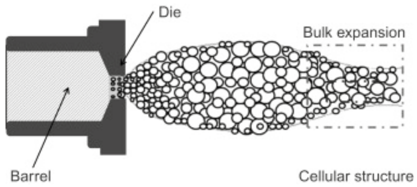
- By controlling the transformation of starch, the viscoelastic properties of the extrudate can be controlled.
- Key parameters include dry feed rate, water feed rate, screw speed, screw configuration, barrel temperature, and die aperture diameter/land length.
- E.g., increasing the water will typically lower the viscosity of the extrudate, leading to greater recoil following expansion, thus increasing the bulk density, creating a coarser cell structure and harder textures.
- Increasing the screw speed will lower the bulk density, as the increased shear causes more work in the barrel, which provides a more intense cook, promoting bubble formation and a lighter texture.
- The addition of calcium carbonate to the blend provides inorganic nucleation sites, promoting a lighter, finer structure.



Conclusion

Twin-screw extruders offer detailed process parameter control, which allows for the creation of a versatile portfolio of products.

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Pre-Extruder Ancillaries

2

Preconditioner

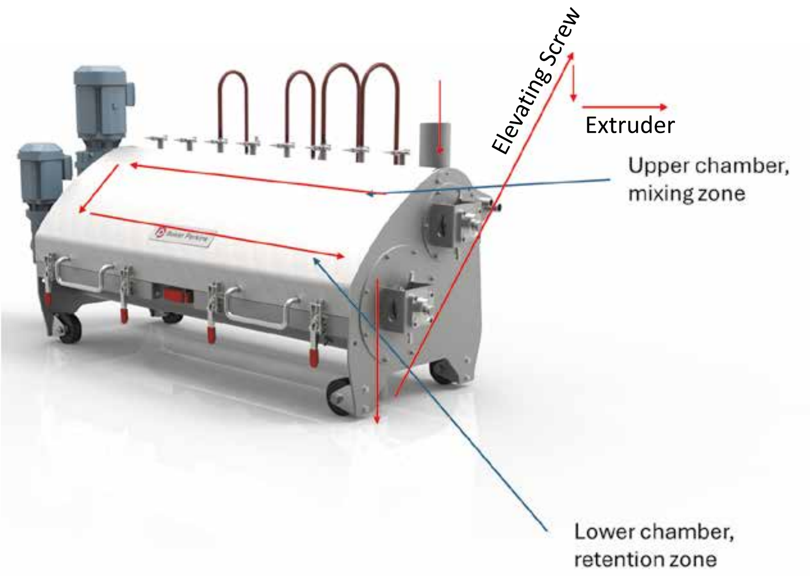
Cereal and other food extrusion products

Process Challenges

- Difficult materials
- Homogenous output
- Hygiene
- Stack height

Baker Perkins' Solution

- Floor mounted unit machines
  - o Accessible height
  - o Transport to wash down area
  - o Only used when needed

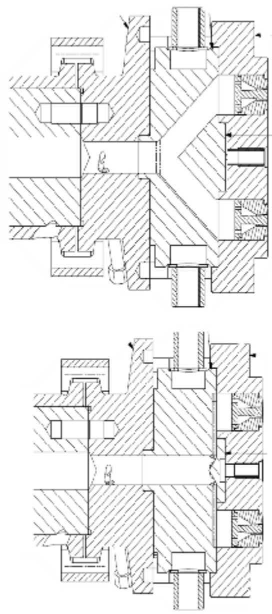


Spectrum Colour Change Skid

Cereal and other food extrusion products

Application technicalities

- Reduced volume die assembly
- Sequencing programme
- 3 primary colours, plus a 4th tertiary colour
- Easily retrofittable



Value can be added to products by injecting colours

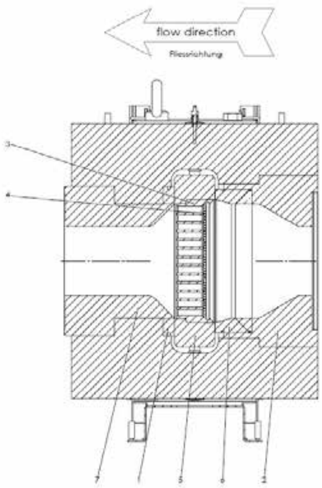
Any spectrum of colours can be programmed e.g. shades of brown

Post Extruder Ancillaries

3

Screen changing

Other food extrusion products



Process benefits

- Continuous processing of cooked grains
- Removes fibre / bran
- Mesh ¼ die size
- Pressure monitoring for screen change

Sheeting Die and Rotary Cutter

Other food extrusion products

Process Technology

- Rotary cutting is Biscuit technology – dough cutting
- Used for snack type products
- A cutting roll acts on a rubber covered anvil roll
- A separate embossing roll can also be integrated to add to the product form or ensure even cooking
- Rolls are easily removable for different products

Further processing required!

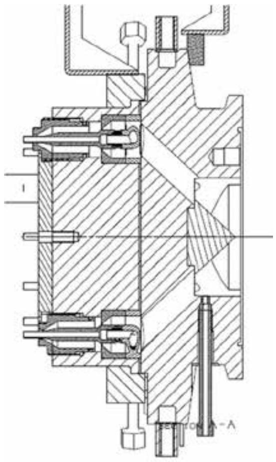
The dough leaves the die in an uncooked state, the extruder is performing a mixing and forming action only

Co-Extrusion

Cereal and other food extrusion products

Technical challenges & solutions

- Flow control & seam position
- Filling material viscosity and Water activity properties
- Crimping / cutting / forming
- Roll phasing & gap control
- Shapes are also possible



Other types of co-extrusion

It is even possible to couple two extruders together for specific co-extrusion applications!

Coating

Cereal and other food extrusion products

Purpose

- Protect heat/shear sensitive ingredients
- Flavour
- Visual appeal
- Improve Bowl life

Technical challenges

- Spray nozzles
- Challenging shapes
- Product temperature
- Retention time
- Product build-up

Types of Coating

Savoury

- Atomised oil & apply seasoning
- Electrostatic charge & apply seasoning (SAS)

Sweet

- Syrup preparation skid sugar/sugar free
- Glaze 72% Brix
- Frosting 82% Brix

Nutritional coating

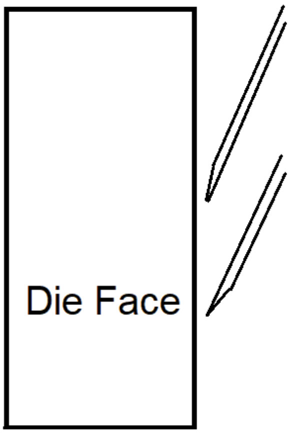
Vitamin sprays are also commonly used to fortify cereals

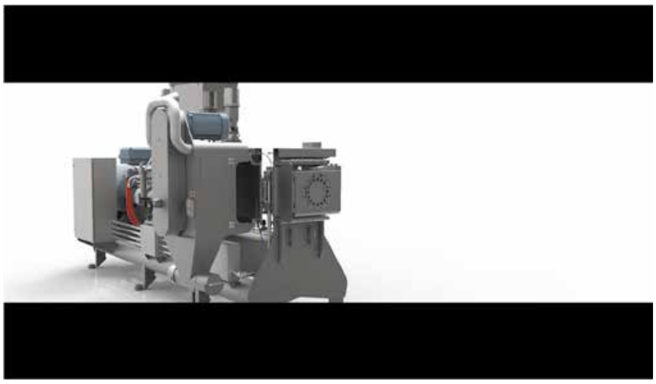
Product Cutters

Cereal and other food extrusion products

Die Face Extrudate Cutting

- Solid vs Flexible blades
- Changing the angle of attack
- Translating vs Fixed
- Off-centre axis
- Steam condensate management





Which blade should I use?

There are many factors to consider; blade life, material, design, product definition

Downstream Cutters

- Lawnmower / Helical
- Windmill

Flaking Mill

Cereal products

Process details

- The pellets are flaked between a set of rolls
- The gap is hydraulically controlled to maintain flake thickness
- The rolls are cooled to prevent sticking
- Vibratory or grooved roll feed to efficiently feed grits across the full roll width

Fun Fact

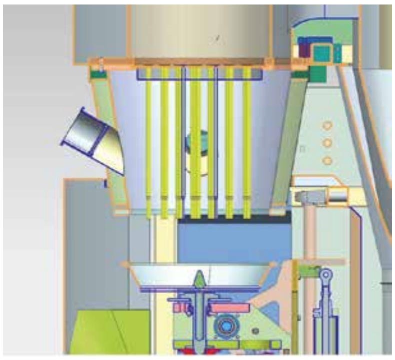
One corn grit requires the equivalent of 69 tonnes to be squashed into a flake!

Toasting

Cereal and other food extrusion products

Purpose

- A toaster serves multiple functions, in some types of flakes, trapped moisture may puff, causing a lighter texture, e.g. MultiGrain flakes.
- It also reduces the moisture to a point where it is shelf stable
- Once the moisture is at the correct level, the application of heat then also leads to glycation between reducing sugars and proteins, resulting in a lightly toasted flavour and colour



Process

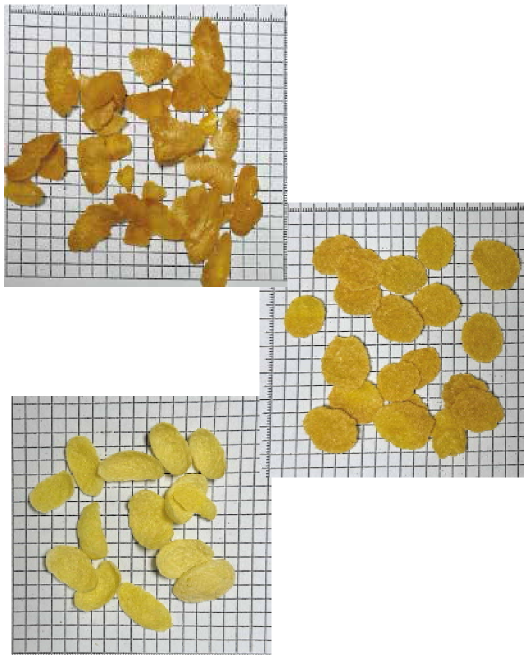
- 2 discreet zones
  - Z1 Higher Temperature – Blistering / Texture
  - Z2 Lower Temperature – Colour / Flavour / Moisture
- A vibratory conveyor helps to transport the product through the toaster and promotes a 'fluid bed' of material for even toasting

Breakfast Cereal Case Studies

4

Case Study: Cornflake Types and Process

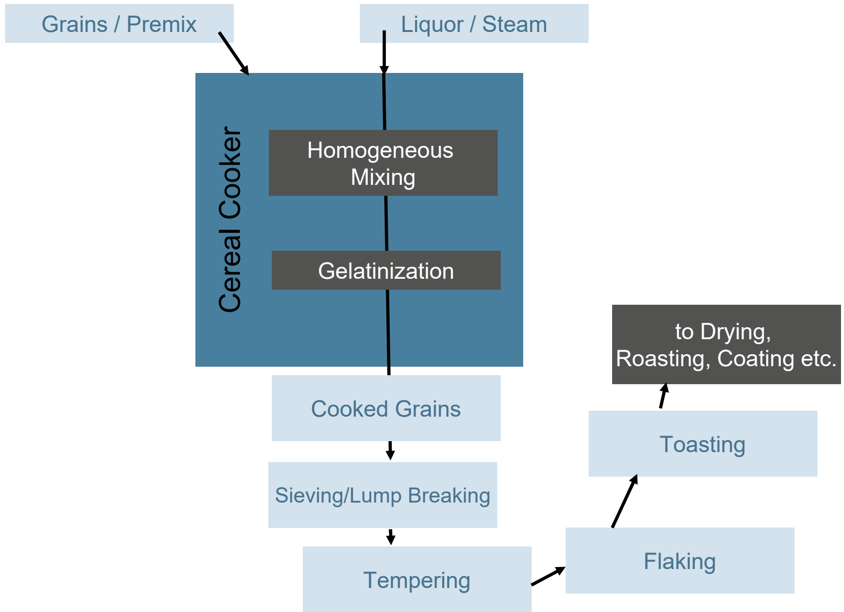
- Traditional cornflakes. Cooking, Drying & tempering, flaking, toasting
  - The highest quality cornflakes but requires a large amount of plant space and is time intensive. Highest capital expenditure.
- Pelletised cornflakes. Pellet extrusion, tempering, flaking, toasting
  - Slightly lower quality flakes, requires an extruder. Lower footprint and capital cost.
- Direct Expanded Cornflakes. Extruded, face cut.
  - Lowest capital expenditure and most simple process, but lowest quality product.

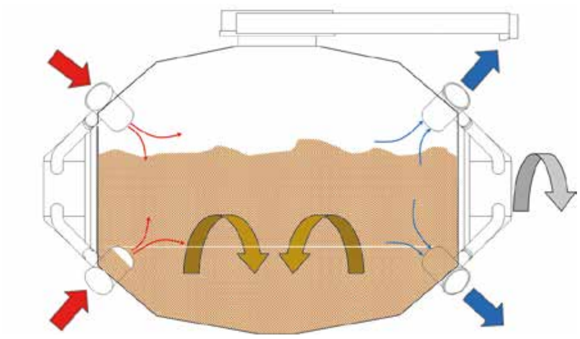


Conclusion

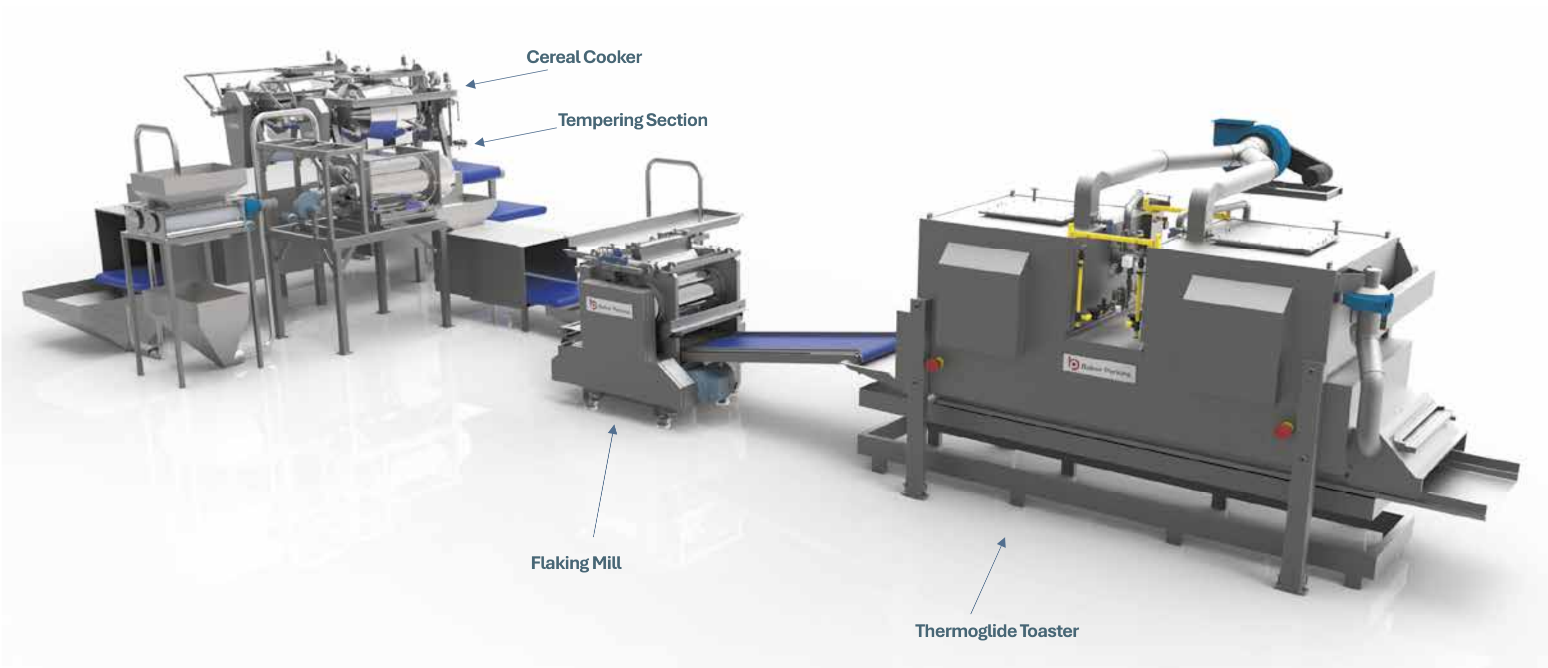
Three different cornflake production methods are possible. All have their pros and cons.

Process Diagram: Traditional Cornflakes

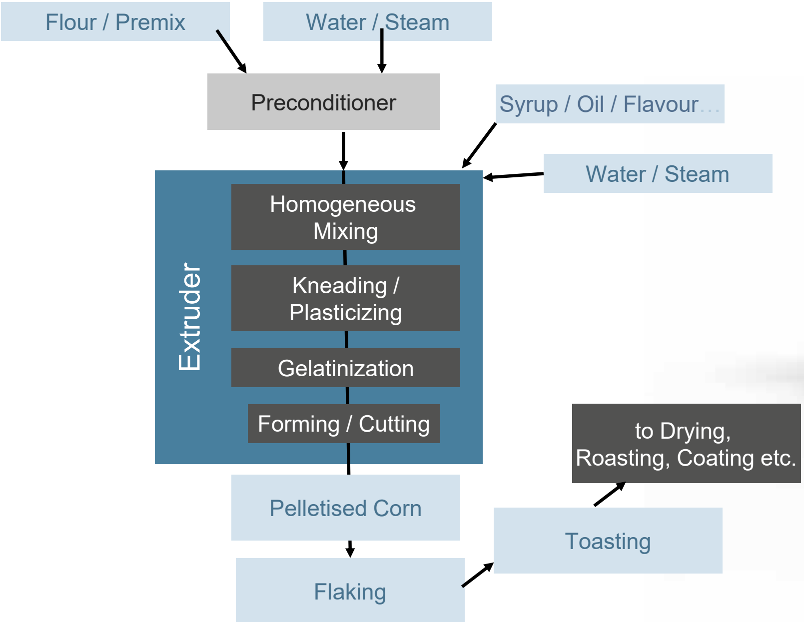




Traditional Cornflake Production



Process Diagram: Extruded Cornflakes



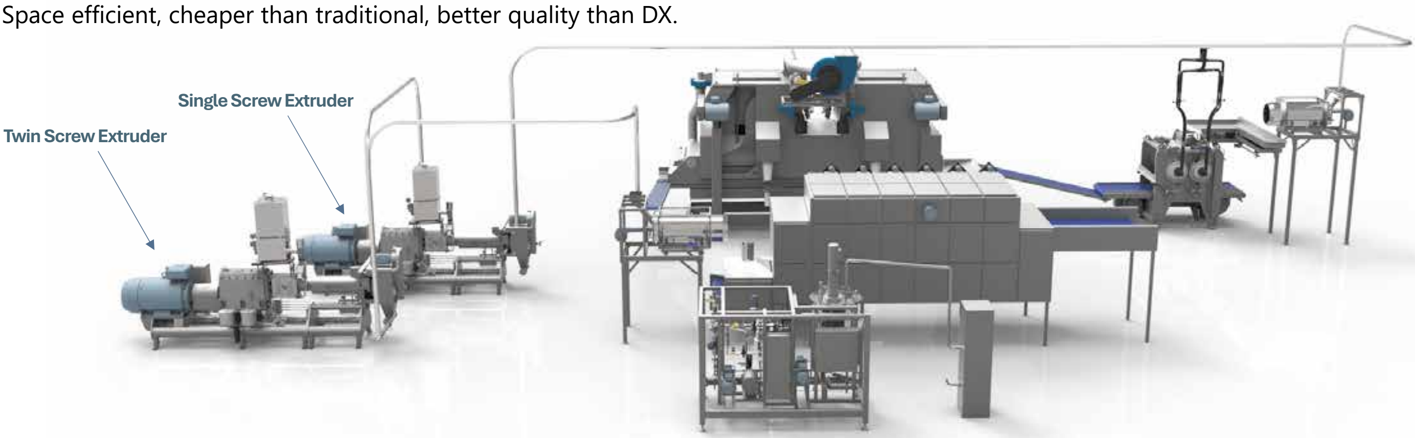
Two Extruder Method (Pelletised Cornflakes)

A twin-screw cooker-extruder is used to cook the material

It is then conveyed via pipe die (held under pressure) to a second, single screw forming extruder.

This gives time for heat escape the extrudate as it leaves the pipe die, and via cooling in the single screw extruder to prevent expansion of the pellet before flaking.

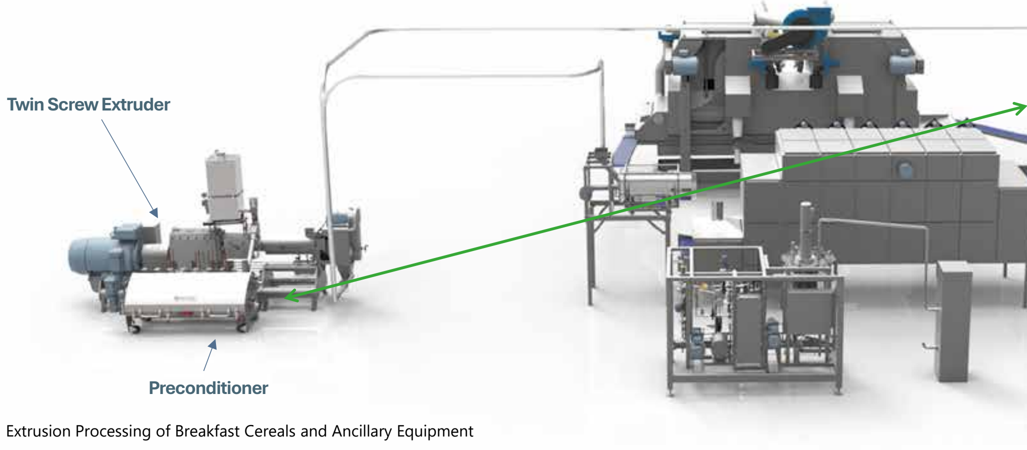
This is a good option for retrofitting to a system with an existing, shorter barrel twin screw extruder, with the addition of a single screw extruder
Space efficient, cheaper than traditional, better quality than DX.



Single Extruder Method (Pelletised Cornflakes)

By using a venting system to allow steam to escape, the product can be cooked and pelletised with the same extruder. A pre-conditioner helps to initiate the starch cooking, which is continued in the barrel of the extruder.

This method ensures full gelatinisation, while allowing latent heat energy and steam to escape, meaning that the product can be sufficiently cooled to allow atmospheric product release without puffing.



Process Diagram: Direct Expanded Cornflakes

Flour / Premix | Water / Steam | Syrup / Oil / Flavor…

Extruder:
- Homogeneous Mixing
- Kneading / Plasticizing
- Gelatinization
- Forming / Cutting

Shaped Expanded Extrudate

to Drying, Roasting, Coating etc.

Further possibilities with direct expansion in breakfast cereals:

Flexible DX Setup (DX Cornflakes)

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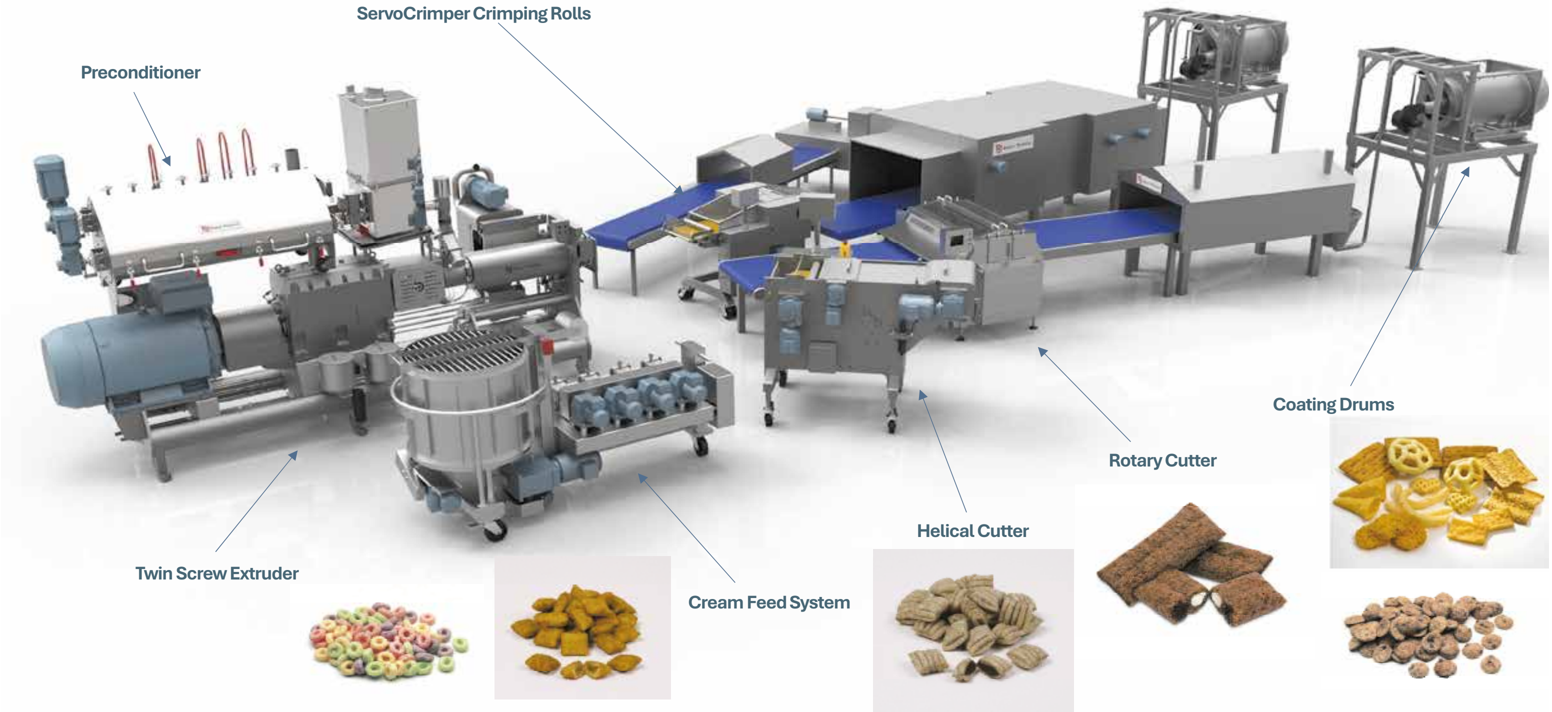

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Get your settings right – The impact of extruder settings on the product properties

Food Extrusion Seminar 2025

Christian Hüttner, Senior Process Engineer Food Extrusion

BEST COMPONENTS & BETTER SYSTEMS

THE RECIPE FOR PERFECT FOOD

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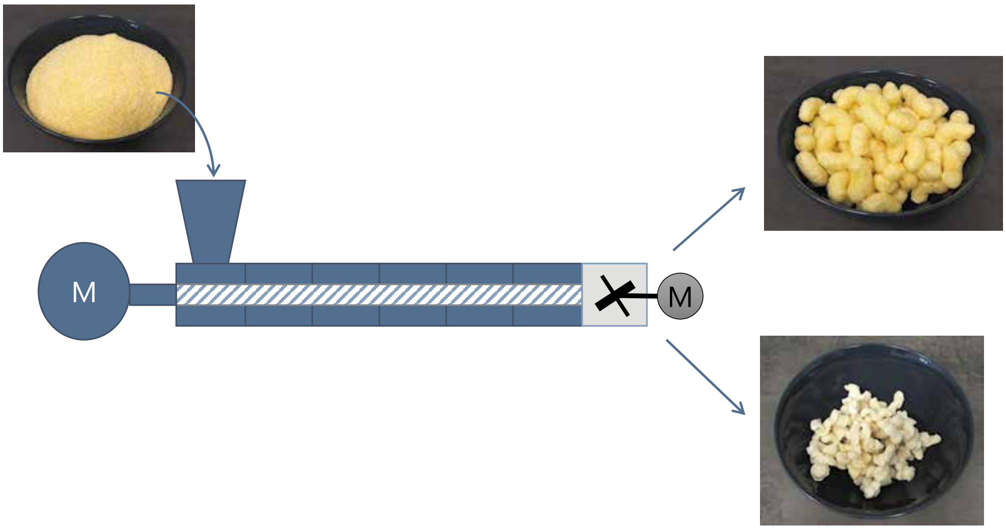
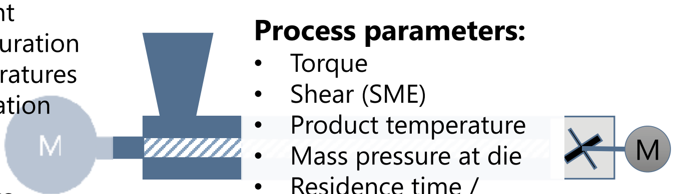
From raw material to the product



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

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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
- …

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Inside the process section

2

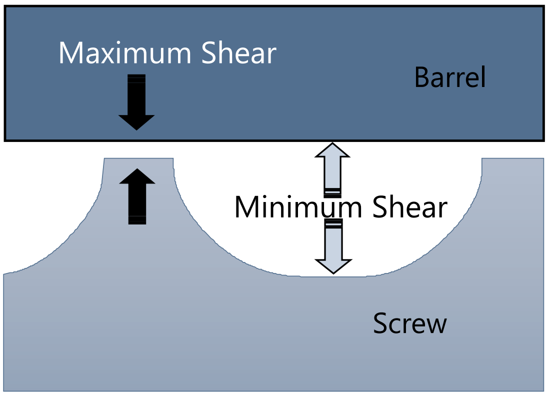
Degree of fill, residence time, pressure

Inside the process section

Degree of fill inside of the screw channels

Inside the process section

Shear rate distribution



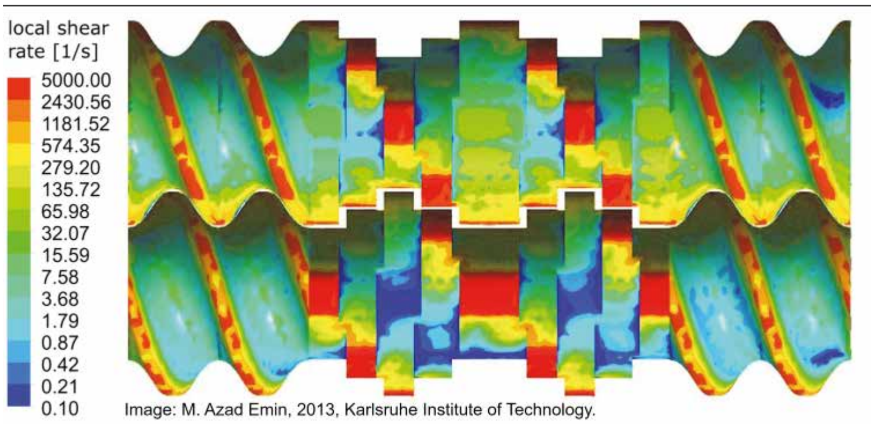
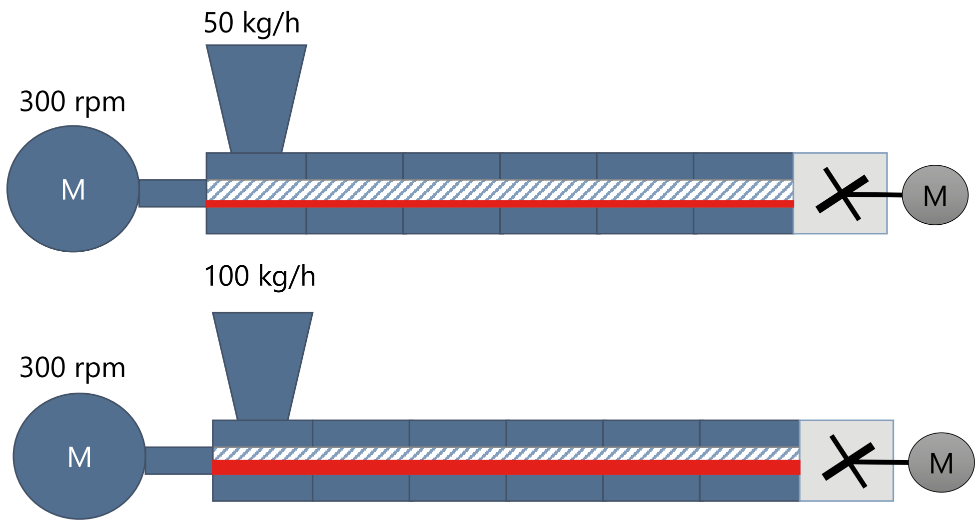


Image: M. Azad Emin, 2013, Karlsruhe Institute of Technology.

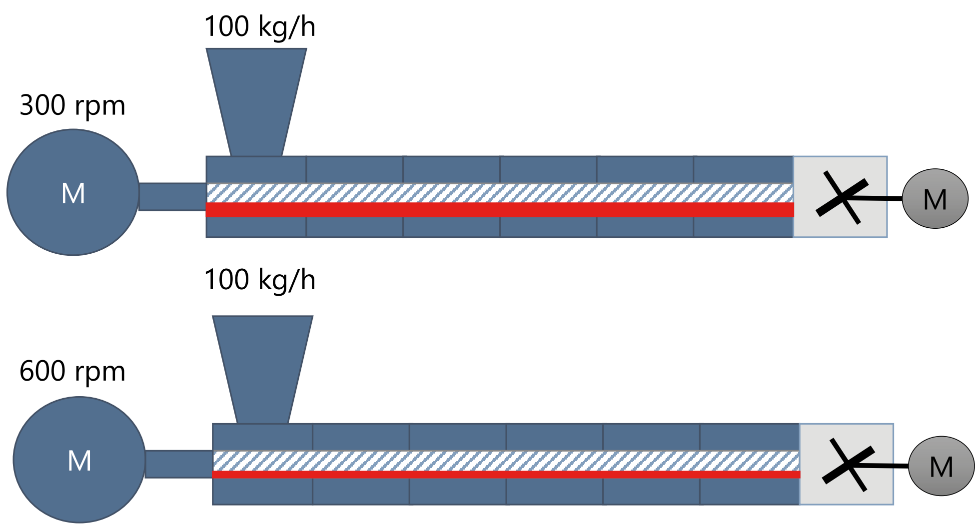
Inside the process section

Throughput -> Degree of fill



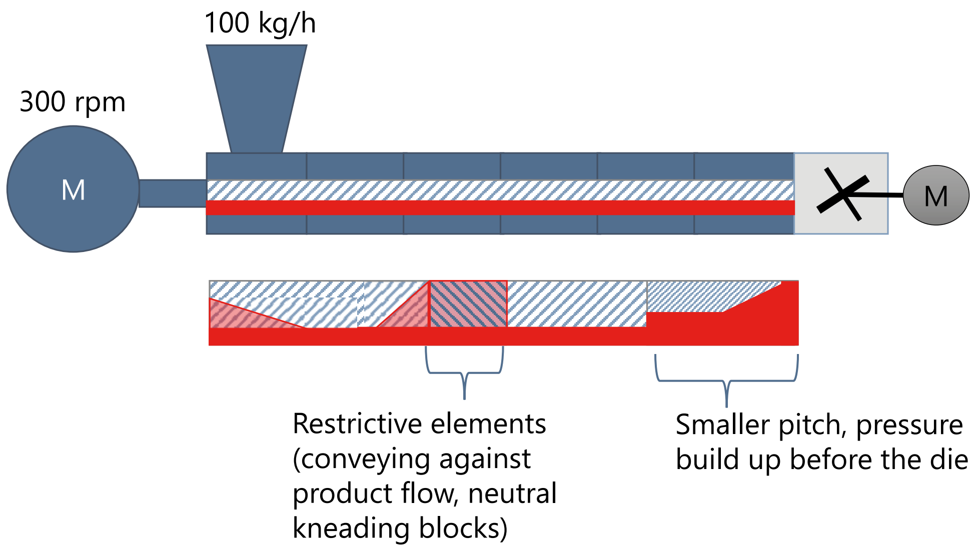
Inside the process section

Screw speed -> Degree of fill



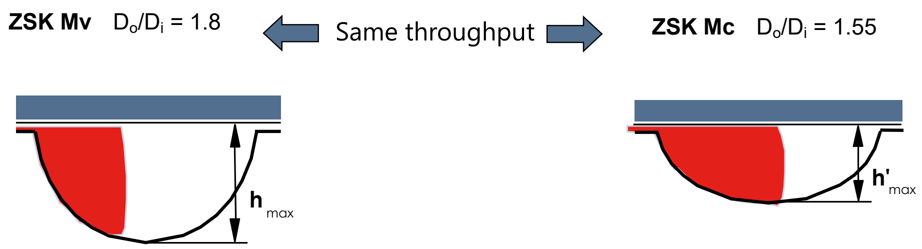
Inside the process section

Screw configuration -> Degree of fill



Inside the process section

D_o/D_i of Extruder -> Degree of fill



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

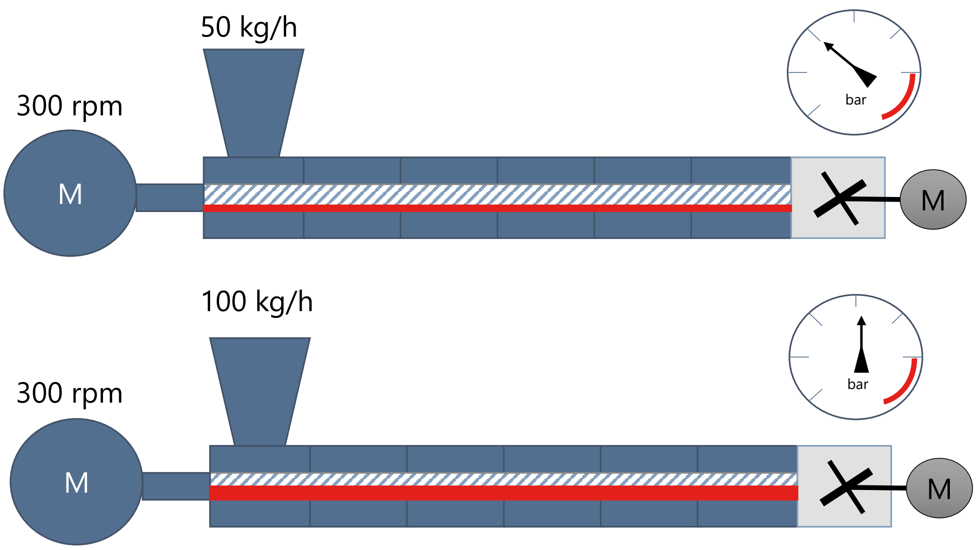
...

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

...

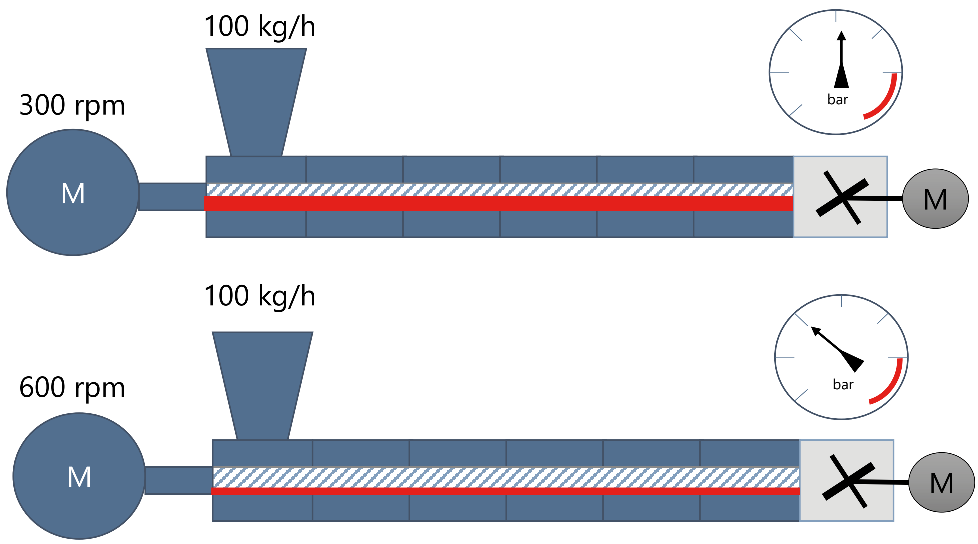
Inside the process section

Throughput -> melt pressure



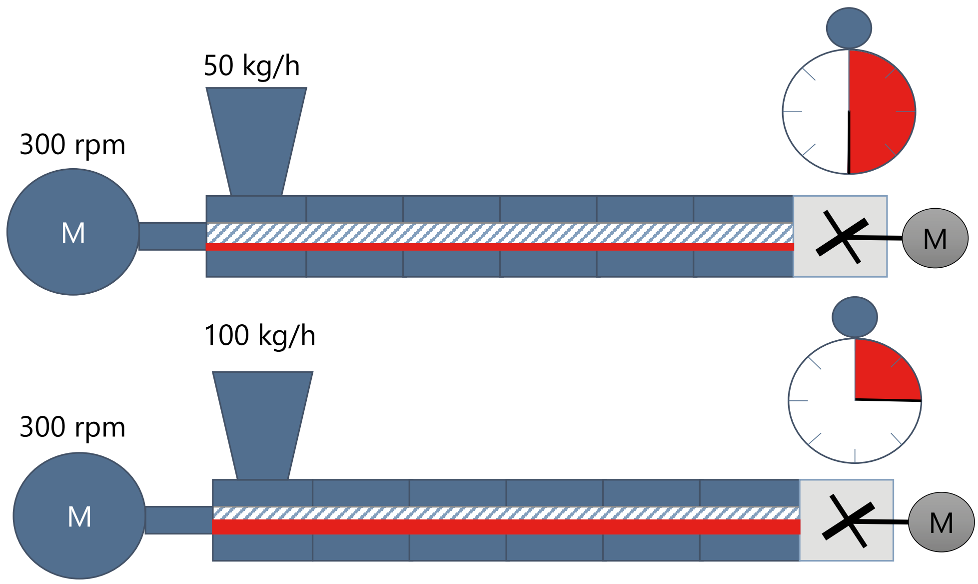
Inside the process section

Screw speed -> melt pressure



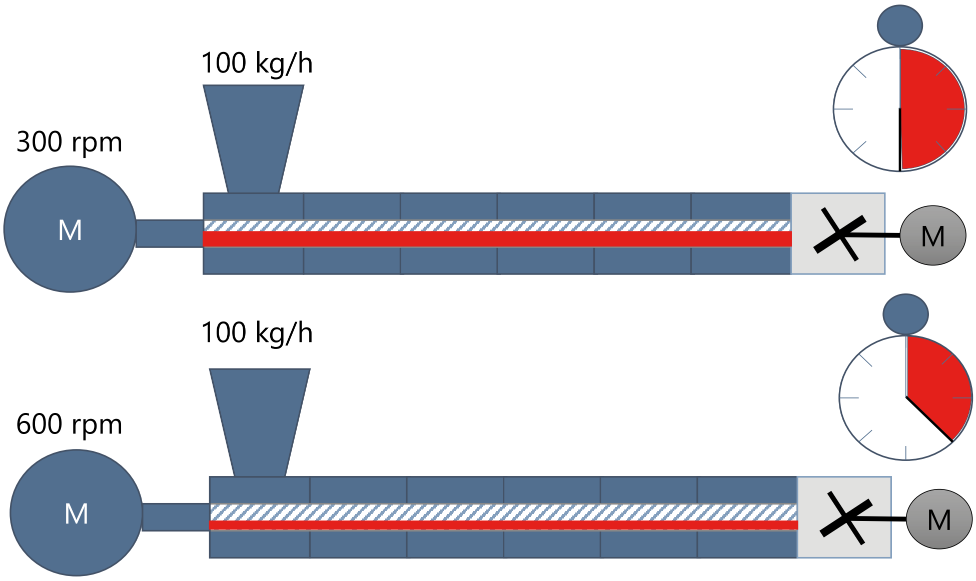
Inside the process section

Throughput -> Residence time



Inside the process section

Screw speed -> Residence time



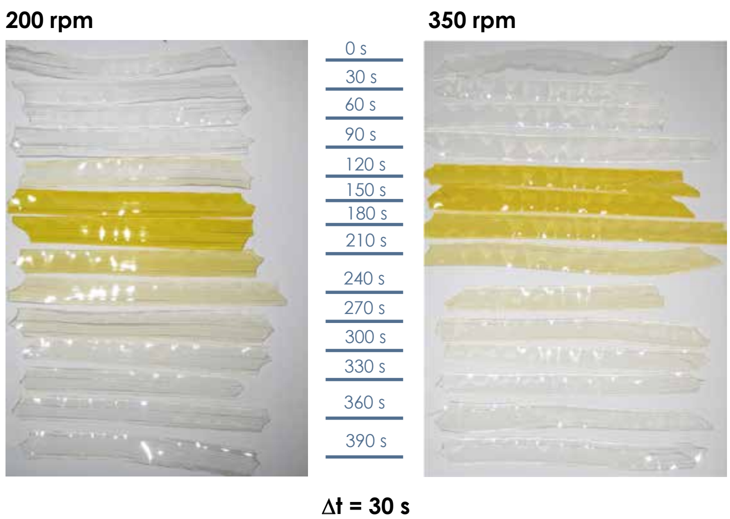
Inside the process section

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:

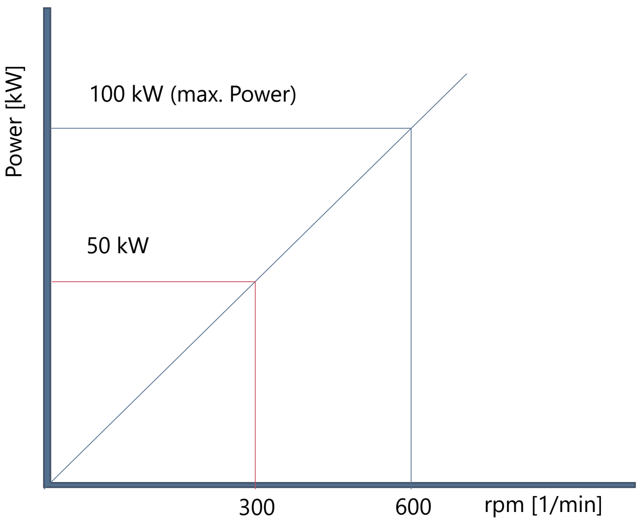
max rpm: 600 1/min

max power: 100 kW

Max power at 300 rpm: 50 kW

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

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

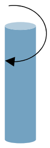


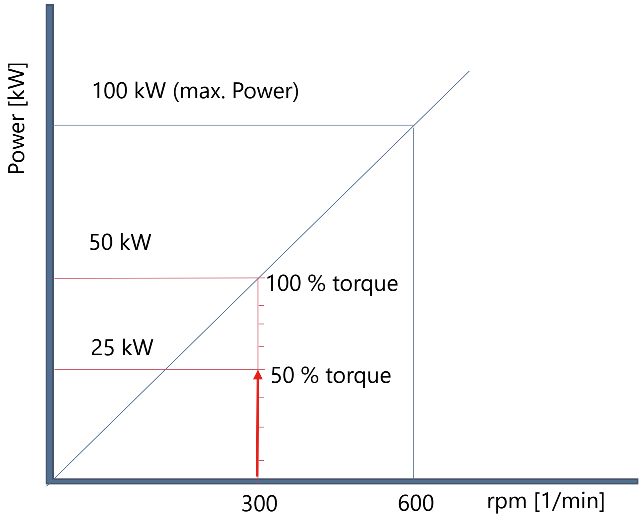
Power – Torque – SEI

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



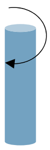


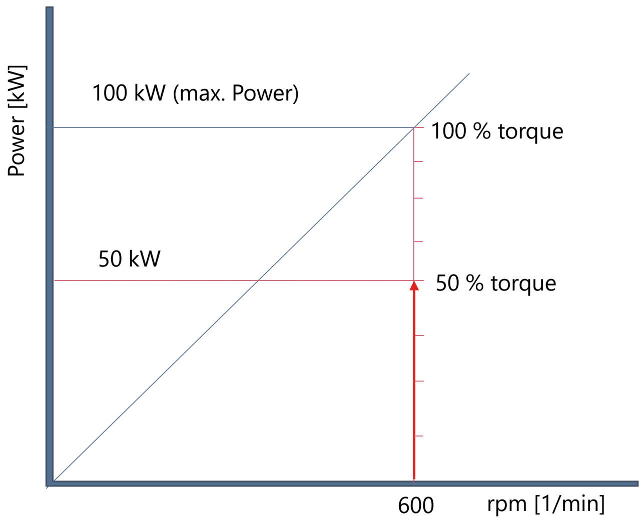
Power – Torque – SEI

Torque

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

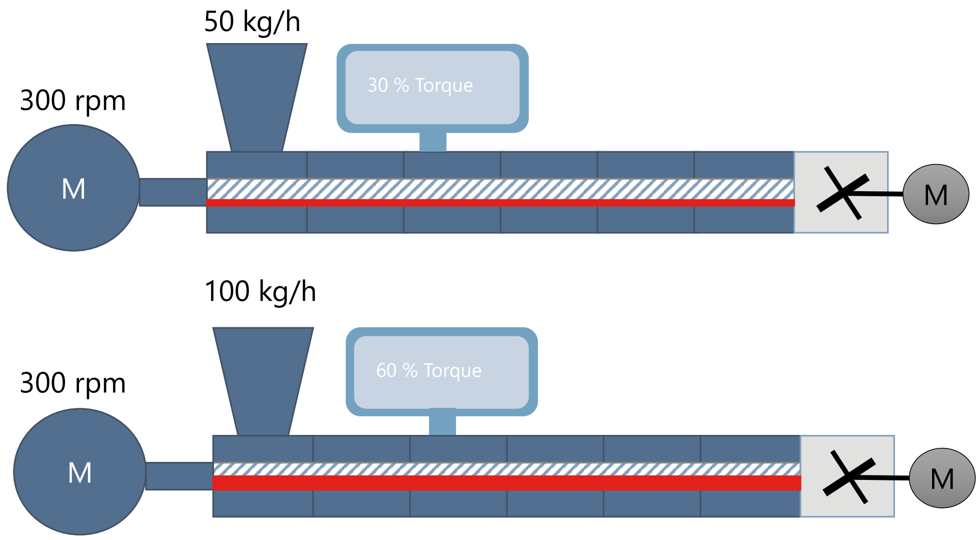
Torque: a rotational force
Torque is displayed as % of
max. motor power





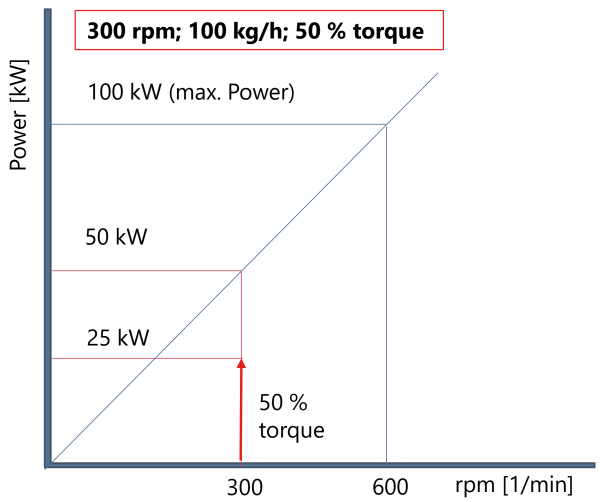
Power – Torque – SEI

Torque



Power – Torque – SEI

Specific mechanical energy (SME)



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

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

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

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

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

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

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

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

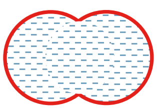
STE (Specific Thermal Energy (STE) and SEI (Specific Energy Intake)

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

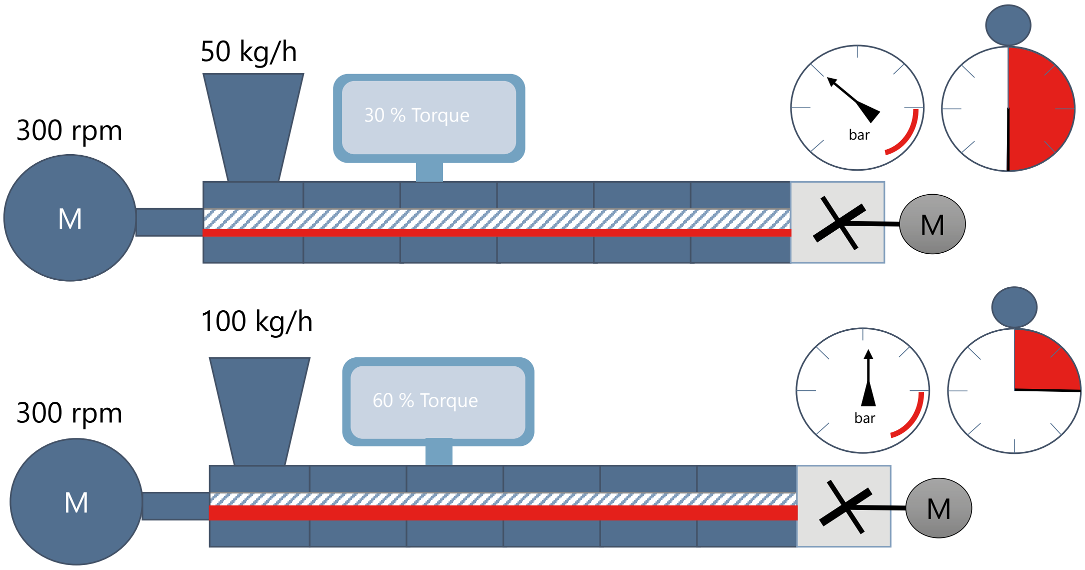
SEI = SME + STE

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!

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!

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

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

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